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SHOCK-WAVE ATTENUATION PROPERTIES OF A BUBBLE SCREEN (U)

TECHNICAL REPORT NO. 2-564

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U. S. Army Engineer Waterways Experiment Station
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PREFACE

(U) The study reported herein was accomplished for the Panel on Ship Protection, Mine Advisory Committee, National Academy of Sciences, National Research Council, under the sponsorship of the Office of Naval Research (ONR), Code 463. Authority for conducting the study was contained in MIPR-11-58-ONR, dated 11 November 1957. Additional funds for enlarging the scope of the program were made available during fiscal year 1959 by the Chief of Engineers, Department of the Army, as Task 1.2 under Research and Development Subproject 8-12-95-420. (U)

(U) The investigation was conducted during the period 1 April 1958 to 15 June 1959 by personnel of the Hydraulics Division of the U. S. Army Engineer Waterways Experiment Station under the general supervision of Messrs. E. P. Fortson, Jr., and F. R. Brown. Mr. G. L. Arbuthnot, Jr., Chief of the Special Investigations Section, was directly in charge of the study and was assisted by Mr. J. N. Strange. This report was prepared by Messrs. J. N. Strange and Louis Miller. Mr. Miller was also in charge of design and construction of the test facilities, and data reduction. Mr. B. E. Boggan assisted with the data reduction. Field operations were supervised by Mr. S. E. Bartlett. Instrumentation equipment was provided and operated by the Waterways Experiment Station Instrumentation Branch, under the supervision of Mr. E. H. Woodman, assisted by Messrs. F. P. Hanes and E. W. Flowers. (U)

(U) The cooperation, advice, and liaison activities of Mr. H. A. Strothers, ONR, are gratefully acknowledged. Appreciation is also extended to Dr. A. B. Arons, Amherst College, and Dr. H. G. Snay, Naval Ordnance Laboratory, for their periodic review of results and suggestions as to the most meaningful methods of analysis. (U)

(U) Directors of the Waterways Experiment Station during the

accomplishment of this program were Col. A. P. Rollins, Jr., CE, and Col. Edmund H. Lang, CE. Technical Director was Mr. J. B. Tiffany. (U)

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ABBREVIATIONS AND SYMBOLS

A Screen air content, per cent of air by volume, dimensionless

A_c Screen air content ($ft^3/sec/ft^2$), ft/sec

A_ℓ Screen air flow ($ft^3/sec/ft$), ft^2/sec

e_1 Reduced energy at point of reference (first gage behind screen), $in.\text{-}lb/in.^2/lb^{1/3}$

$(e_{fw})_1$ WES reduced free-water energy at point of reference (first gage behind screen), $in.\text{-}lb/in.^2/lb^{1/3}$

i' Reduced positive impulse, $lb\text{-}ms/in.^2/lb^{1/3}$

L_s Shock-wave length

ms Milliseconds

n_e Characteristic slope of the energy versus reduced distance plots

n_p Characteristic slope of the pressure versus reduced distance plots

p Peak pressure, $lb/in.^2$

p_1 Peak pressure at point of reference (first gage behind screen), $lb/in.^2$

$(p_{fw})_1$ WES free-water peak pressure at point of reference (first gage behind screen), $lb/in.^2$

R_o Stand-off distance, ft

T_s Screen thickness, ft

Z_g Gage depth, ft

λ Reduced distance, $ft/lb^{1/3}$

λ_{so} Reduced stand-off distance (charge to near face of screen), $ft/lb^{1/3}$

ν Kinematic viscosity of water at 68 F (1.1×10^{-5}), ft^2/sec

σ Standard deviation of a single observation

σ_m Standard deviation of the mean

θ Time constant of the shock wave, ms

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SUMMARY

(C) Tests were made to determine the attenuation of various water-shock parameters resulting from the passage of explosion-generated water-shock waves through various bubble screens. The tests were conducted in a rectangular basin 130 ft long, 100 ft wide, and 22 ft deep. The bubble generator was submerged to a depth of 18 ft and, when supplied with compressed air, produced a bubble screen 20 ft long. The generator was so constructed that the screen thickness could be varied from 0.5 to 3.0 ft. One hundred and seventeen 8-lb TNT spherical charges positioned 9 ft below the water surface were fired in making the tests. Two stand-off distances, three screen thicknesses, and five screen air contents were tested, and measurements of the peak pressure, impulse, energy, duration, and arrival times were obtained at three gage levels within the water layer. Test results indicated that reductions in peak pressure and reduced energy parameters varied with the amount of air furnished the screen. Pressure reductions, ranging from 10 to 95% of the normal free-water pressure, were obtained with air flows ranging from 0.04 to 0.10 cfs per linear foot of screen. Similarly, energy reductions ranged from 20 to 95% with the same air flows. Empirical equations were derived for computing the pressure and energy of the shock wave immediately behind a bubble screen. A procedure for evaluating the propagation of that portion of the shock wave penetrating the screen to distances behind the screen is recommended. (C)

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SHOCK-WAVE ATTENUATION PROPERTIES OF A BUBBLE SCREEN (U)

PART I: INTRODUCTION

Background

(U) 1. The use of a screen of air bubbles to reduce the damaging effects of an underwater explosion is not a new idea. In 1944, the Navy Department conducted an investigation of the effect of an air-bubble screen on pressures resulting from an underwater explosion.[1*] This investigation, consisting of a series of small-scale tests, indicated that the peak pressure and the total shock-wave energy were substantially decreased as the wave passed through the bubble screen. In 1954, the Hydro-Electric Power Commission of Ontario, Canada, used a screen of air bubbles to protect certain structures from the effects of an underwater explosion, and in so doing achieved a 70:1 reduction in pressure from that which would have normally been expected.[2] (U)

(U) 2. At the request of the Mine Advisory Committee, National Research Council, the possibility of conducting a study of the effectiveness of a bubble screen in attenuating water shock was first discussed with Waterways Experiment Station (WES) personnel by Dr. A. B. Arons in March 1956. Dr. Arons, at that time a member of the Panel on Ship Protection, Mine Advisory Committee, was and still is a consultant to the WES. (U)

(U) 3. As a result of that and subsequent discussions, an exploratory study of the effect of a bubble screen on water shock was conducted during November-December 1956 by WES for the Panel on Ship Protection. This experimental study was sponsored by the Office of Naval Research (ONR), Code 463. A report of the findings of this pilot investigation was published in October 1958 as WES Miscellaneous Paper No. 2-285.[4] (U)

(U) 4. This rather preliminary study revealed that considerable reductions in peak pressure could be achieved. Because of these rather promising results, the Panel on Ship Protection suggested that additional

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* Raised numbers refer to similarly numbered items in the List of References.

research be made to evaluate more completely the shock-attenuation properties of a bubble screen. Consequently, the study described herein was authorized by ONR. (U)

Purpose

(U) 5. The purpose of the study was to determine the effect of a screen of bubbles on explosion-generated, water-shock waves. Of major interest was the attenuation of peak pressure, impulse, and shock-wave energy which would result from passage of the shock wave through various bubble screens. (U)

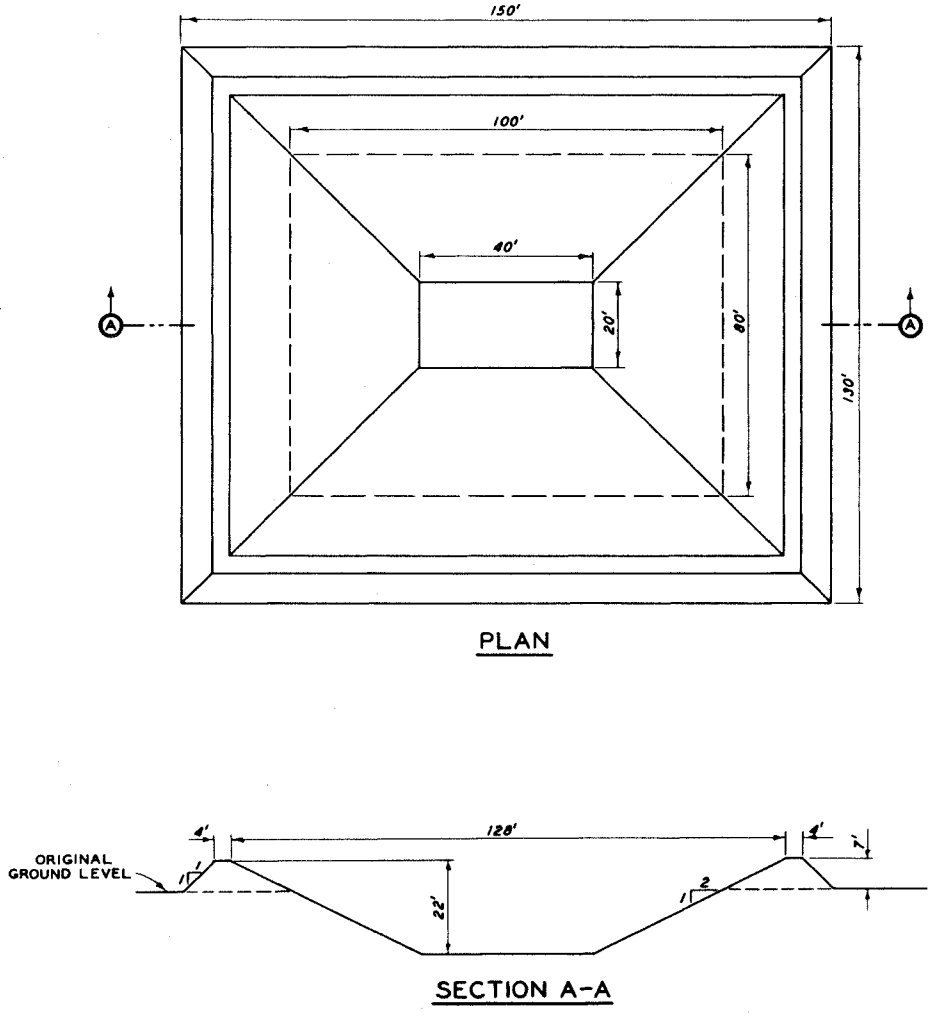
Scope

(U) 6. The test program consisted of firing 117 TNT charges positioned at two stand-off distances from the bubble screen. Three screen thicknesses and five screen air contents were used during the tests. Measurements of the principal shock-wave parameters, i.e. peak pressure, impulse, energy, duration, and arrival time, were obtained at three gage levels within the water layer. (U)

PART II: EXPERIMENTAL PROCEDURES

Test Site

(U) 7. All tests were conducted in an existing rectangular basin at the WES Big Black test site (BBTS). This basin is approximately 130 ft long, 100 ft wide, and 22 ft deep (fig. 1). During the tests, the depth



(U) Fig. 1. Plan and section of deep-water basin

of water in the deepest portion of the basin, where the bubble generator was located, was about 18 ft. (U)

Bubble Generator

(U) 8. The bubble generator was designed to produce a bubble screen

20 ft long and 3 ft thick with the provision that it could be readily adjusted to produce screens 1.5 and 0.5 ft thick. The generator consisted of two 21-ft-long manifolds, made of 2-1/2-in.-ID galvanized iron pipe, which were attached to opposite sides of a wood frame that was reinforced with steel bracing (figs. 2 and 3). Each manifold was equipped with two intake ports (symmetrically spaced) and 80 exhaust ports spaced 3 in. apart. Opposing exhaust ports of the two manifolds were connected by means of 3.5-ft-long sections of 3/4-in.-ID plastic tubing perforated along its length with diametrically opposed rows of holes approximately 0.5 mm in diameter and spaced at 1/8-in. intervals. Air was supplied by a mobile air compressor having a capacity of 130 cu ft per min. (U)

Bubble Screen Air Content

(U) 9. One of the major objectives of this study was to establish the shock-wave attenuation properties of a bubble screen when its air content is varied. To make this determination, five screen air contents were selected for use in the testing program: 0.3, 1, 3, 6, and 12% of air by volume. The determination of these percentages was made as follows:

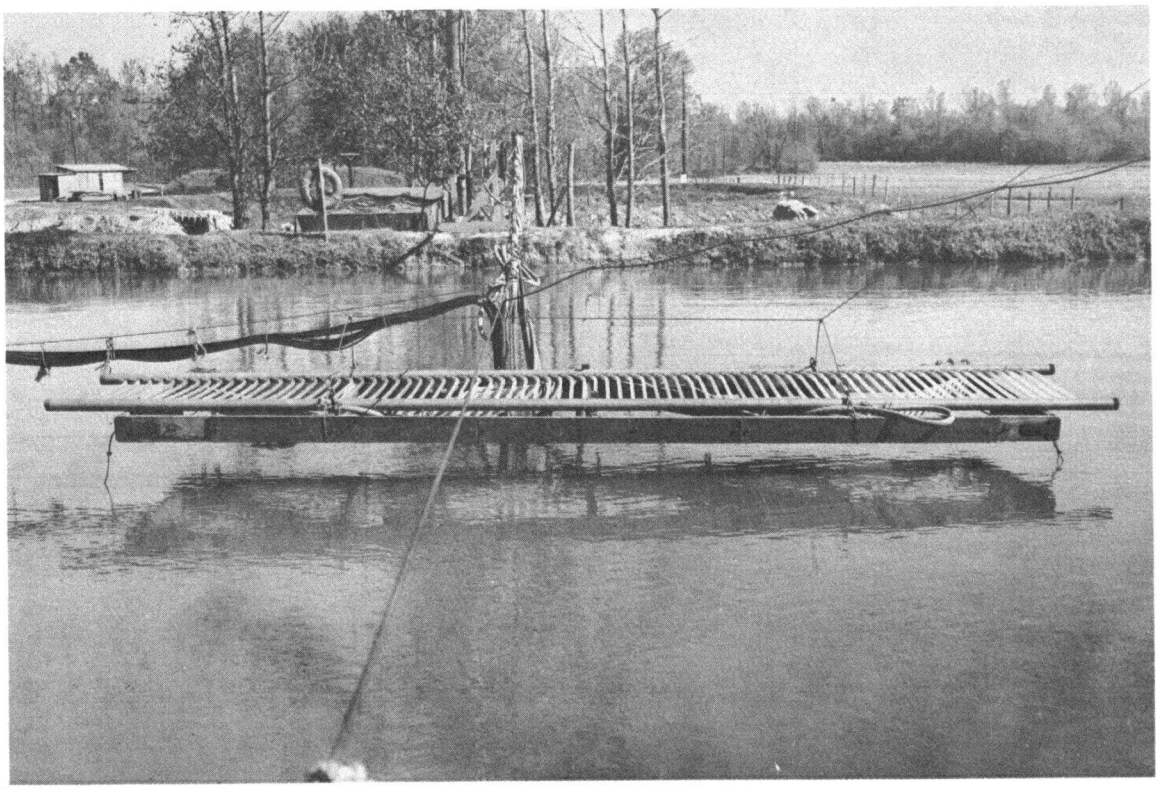
a. The air supplied to the screen was maintained at a constant pressure of 40 psi; the quantity supplied was measured by means of a rotameter in units of cubic feet per minute.

b. Numerous volumetric samples of the air-water mixture were taken at various locations within the screen volume for various rotameter settings. The samples were taken with a cylindrical sampling device equipped with spring-actuated trap doors on each end. The sampling device was lowered in the water to the desired position and the doors were triggered by the operator in a boat.

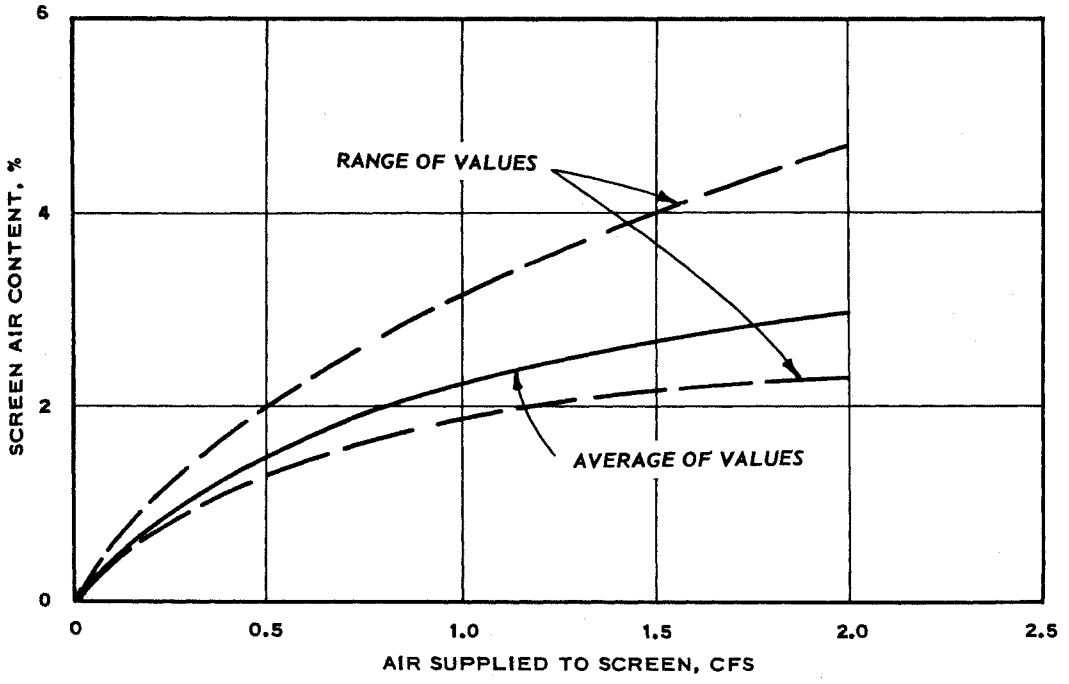
c. On the basis of the values obtained with the sampling device, a curve was plotted showing the percentage of air by volume in the bubble screen versus the amount of air supplied to the screen (fig. 4). Thus the selection of any air percentage, within the range of values sampled, could be accomplished by setting the desired reading on the rotameter. (U)

(U) 10. The above procedure was used to determine the rotameter settings for all tests made during the study; however, due to the wide

(U) Fig. 2. End view of bubble generator



(U) Fig. 3. Side view of bubble generator



(U) Fig. 4. Variation of the screen air content with quantity of air supplied to the 3-ft-thick screen

scatter obtained in the values of the air-water samples, some uncertainty exists as to the exact air content of the screen when expressed as a per cent of air by volume. Therefore, the screen air contents are also expressed as cubic feet of air per second per square foot of screen (A_c) (screen was always positioned in a horizontal plane), and as cubic feet of air per second per linear foot of screen (A_ℓ). The tabulation on the following page presents the various air contents in each of these units of measure along with other pertinent data. (U)

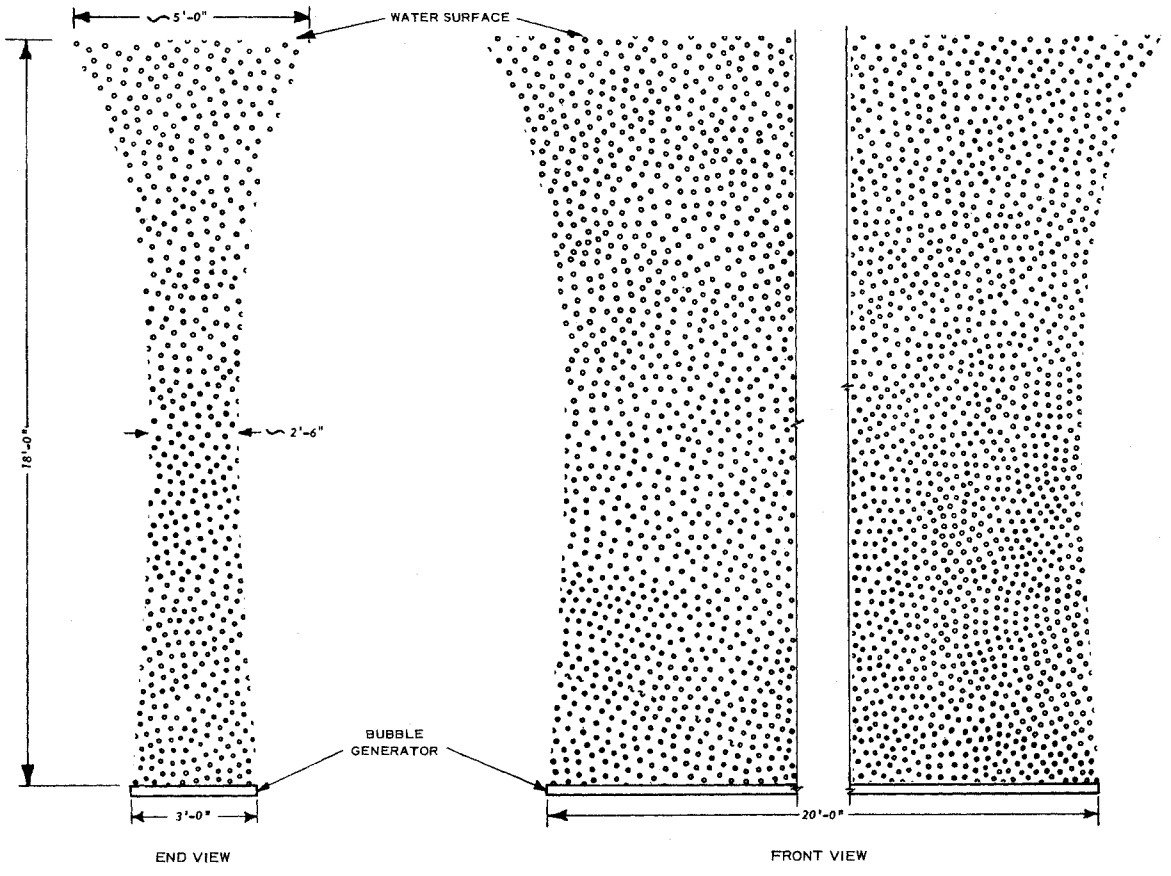
Description of the Bubble Screen

(U) 11. From tests conducted previously in a Plexiglas tank,[4] it was known that operation of a bubble screen would cause considerable turbulence in the water mass within a confined basin. It was also known that the screen would tend to be hourglass-shaped in that it would be pinched in near its midheight and bell out as it approached the surface (fig. 5). In the operation of the screen used in these tests, the turbulent water

(U) Tests and Test Conditions

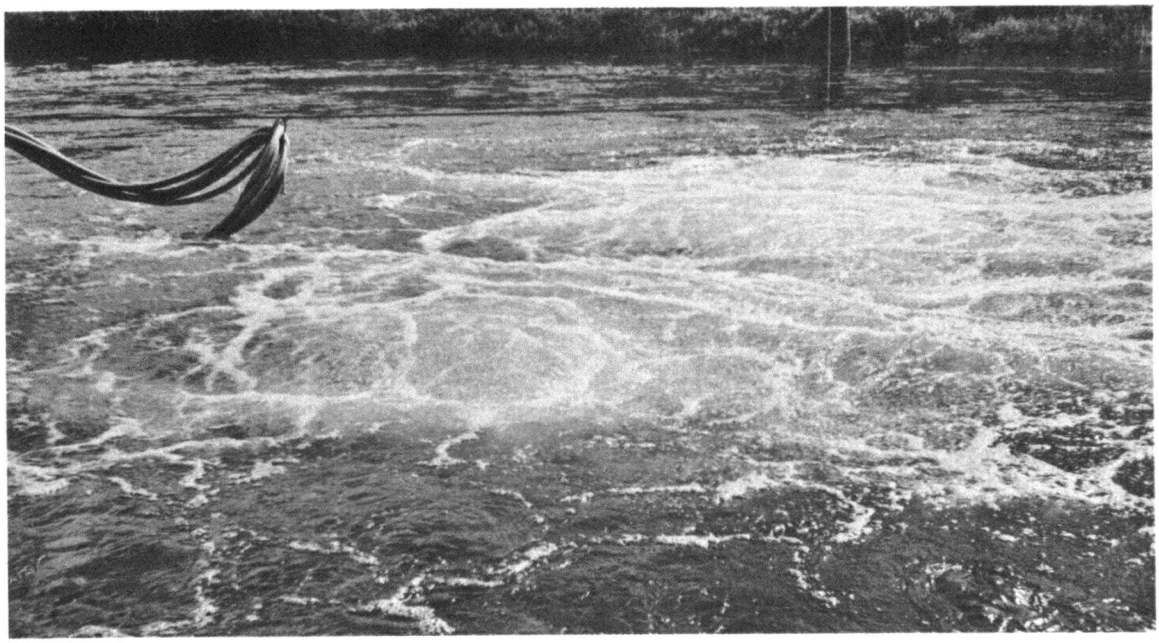
No. of Shots	Gage Array Depth ft (Z_g)	Stand-Off Distance ft (R_o)	Screen Thickness ft (T_s)	% of Air by Volume (A)	cfs of Air per sq ft of Screen (A_c)	cfs of Air per lin ft of Screen (A_ℓ)
3	9.0	6.0	Free water*			
2	4.5	6.0	Free water*			
2	0.25	6.0	Free field*			
2	9.0	12.0	Free water*			
2	4.5	12.0	Free water*			
3	0.25	12.0	Free field*			
4	9.0	6.0	3.0	0.3	0.0014	0.0042
6	9.0	6.0	3.0	1.0	0.0044	0.0133
7	9.0	6.0	3.0	3.0	0.0347	0.1042
4	9.0	12.0	3.0	0.3	0.0014	0.0042
4	9.0	12.0	3.0	1.0	0.0044	0.0133
8	9.0	12.0	3.0	3.0	0.0347	0.1042
3	4.5	6.0	3.0	0.3	0.0014	0.0042
3	4.5	6.0	3.0	1.0	0.0044	0.0133
4	4.5	6.0	3.0	3.0	0.0347	0.1042
3	4.5	12.0	3.0	0.3	0.0014	0.0042
3	4.5	12.0	3.0	1.0	0.0044	0.0133
3	4.5	12.0	3.0	3.0	0.0347	0.1042
2	0.25	6.0	3.0	0.3	0.0014	0.0042
2	0.25	6.0	3.0	1.0	0.0044	0.0133
2	0.25	6.0	3.0	3.0	0.0347	0.1042
4	0.25	12.0	3.0	0.3	0.0014	0.0042
2	0.25	12.0	3.0	1.0	0.0044	0.0133
7	0.25	12.0	3.0	3.0	0.0347	0.1042
2	9.0	6.0	1.5	0.3	0.0028	0.0042
2	9.0	6.0	1.5	1.0	0.0044	0.0066
2	9.0	6.0	1.5	3.0	0.0347	0.0521
2	9.0	6.0	1.5	6.0	0.0694	0.1042
2	9.0	12.0	1.5	0.3	0.0028	0.0042
2	9.0	12.0	1.5	1.0	0.0044	0.0066
3	9.0	12.0	1.5	3.0	0.0347	0.0521
2	9.0	12.0	1.5	6.0	0.0694	0.1042
3	0.25	6.0	1.5	0.3	0.0028	0.0042
2	0.25	6.0	1.5	1.0	0.0044	0.0066
2	0.25	6.0	1.5	3.0	0.0347	0.0521
2	9.0	6.0	0.5	0.3	0.0083	0.0042
2	9.0	6.0	0.5	3.0	0.0350	0.0175
2	9.0	6.0	0.5	6.0	0.0700	0.0350
2	9.0	6.0	0.5	12.0	0.1400	0.0700

* Bubble screen not in operation.



(U) Fig. 5. Approximate shape of bubble screen

flow also caused the screen to weave from side to side as the bubbles rose to the surface. This action made it extremely difficult to determine exactly where the boundaries of the screen were in relation to the charge and gages at any given instant. The dimensions shown in fig. 5 were estimated visually by making repeated dives into the basin while the screen was in operation. Similar estimates of screen boundaries for the 1.5- and 0.5-ft screens were not obtained. Because of the variations in screen dimensions, the screen thickness is stated throughout this report as the thickness of the bubble screen generator itself. The size of the bubbles generated was estimated to vary from roughly 1/8 to as much as 3/8 in. in diameter; the average size was estimated to lie between 3/16 and 1/4 in. It is believed that the weaving action of the screen was one of the principal reasons for the wide variation in readings obtained with the sampling device referred to in paragraph 9. The action of the bubbles in breaking through the surface also caused a maximum rise of 9 in. in the water

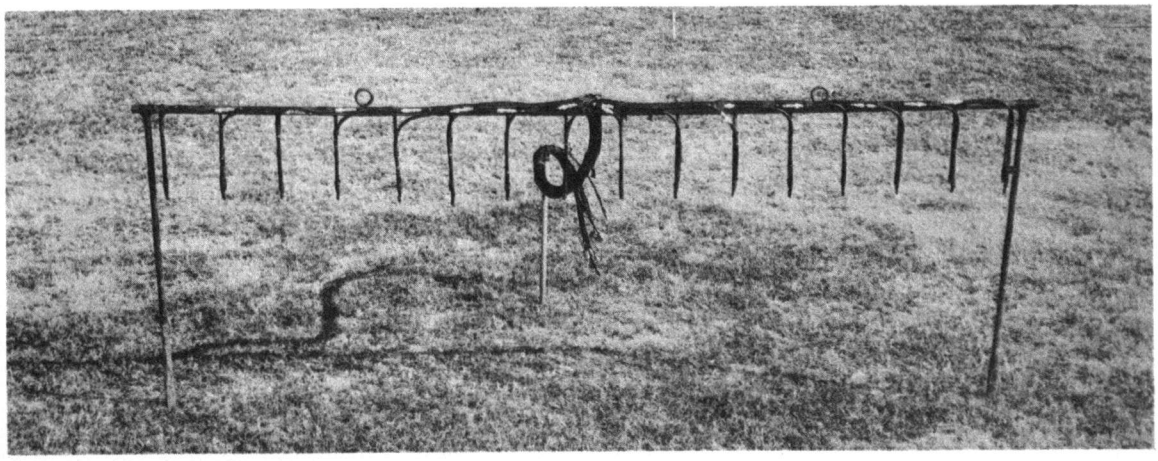


(U) Fig. 6. Turbulence at the water surface caused by an air flow of 0.0374 cfs per square foot of screen

surface directly over the generator during the maximum air flows (see fig. 6). (U)

Instrumentation

(U) 12. Sixteen tourmaline, piezoelectric gages connected to Dumont dual-beam, cathode-ray oscilloscopes were used to measure the water shock. The 16 gages, spaced 0.75 ft apart, were attached to a steel bracket to hold them in a horizontal line (fig. 7). The gages were 1/4 and 1/2 in.



(U) Fig. 7. Gage rack with water-shock gages attached

in diameter; they were located in front of, in, and behind the bubble screen, as shown in plate 1. The gage signals were recorded by rotating-drum cameras on 10-in., 35mm filmstrips. Sixteen channels of recording equipment were used throughout the test program. (U)

Explosive

(U) 13. Eight-pound charges of TNT were used as the energy source throughout these tests. These charges were spherically shaped and were 0.54 ft in diameter. The charge center of gravity was used as the reference point for positioning the charges. All charges were centrally initiated with Corps of Engineers special electric blasting caps. (U)

Test Procedures

(U) 14. The bubble generator was attached to a system of cables and pulleys so that it could be suspended above the basin when not in use, lowered into position for each test, then raised after completion of the test. Air flows sufficient to overcome the hydrostatic water pressure were maintained in the generator during its entire period of submergence to prevent foreign particles from entering the system and plugging the small orifices from which the air was emitted. For each test the generator was lowered into position and securely cradled in a framework on the bottom of the basin. This procedure made certain that the screen was positioned identically for all tests. The gage rack, with its attached gages, was lowered to the desired position, and the charge was suspended at middepth at the required stand-off distance in front of and on the center line of the bubble screen. The required air flow was then supplied to the generator and the shot was fired. (U)

PART III: TESTS AND TEST RESULTS

Test Program

(U) 15. The test program consisted of 117 shots fired with various combinations of test conditions. Three screen thicknesses, five bubble screen air contents, three gage depths, and two stand-off distances were used during the investigation. Test geometries and gage arrays used during the tests are shown in plate 1. To facilitate the analysis of test data and for convenience in preparing this report, the test program has been divided into four parts, namely, the free-water/free-field tests and tests with the 3-ft-, 1.5-ft-, and 0.5-ft-thick bubble screens. A summary of the tests and test conditions is presented in the tabulation on page 7. (U)

Presentation of Results

(U) 16. The results of all water-shock measurements obtained during the course of the study are presented in tables 1-36. The peak pressure and reduced positive impulse data are also presented graphically in plates 2-37. (U)

Record Interpretation and Analysis Procedures

(U) 17. The pressure-time records obtained in the free-water/free-field tests were typically shaped records for the respective environments. The impulse and energy values obtained from these records were computed by integrating the positive phase of the pressure-time trace to 6.7θ, where θ is the time constant associated with the decay rate of the records. Similarly, the duration values were measured to 6.7θ. The records obtained from gages located in front of the bubble screen and in a free-water region, for those tests in which the screen was in operation, were also treated as free-water records. The impulse and energy values obtained from all records affected by the bubble screen (gages located within and behind the screen) represent the integration of the total

positive phase of the recorded shock wave. Similarly, the duration values are the scaled lengths of the positive phase of the shock wave. At the suggestion of Dr. A. B. Arons, efforts were made to limit the integration of the pressure-time record obtained from gages within the screen to four reflections of the shock wave off the front and rear faces of the screen. This proved to be impracticable with any degree of reliability, as the action of the bubbles greatly distorted the shape of the shock wave as it passed through the screen making it impossible to delineate the perturbations caused by reflection. (U)

(U) 18. The working procedure used in analyzing the data was as follows: First, the parameters of the shock wave were determined for the scaled distance equivalent to the location of the first gage immediately behind the bubble screen. The observed parameters were then compared with similar parameters for the free-water case (gages at corresponding depths) and the per cent reduction computed. Second, the attenuation rate of the particular shock-wave parameter was then evaluated for those measurements obtained with the remaining gages situated behind the screen. Establishing the attenuation rate for each parameter makes possible the calculation of the parameter over the distance from the rear face of the screen to the gage location farthest from the charge. (U)

Free-Water/Free-Field Tests

(U) 19. The free-water/free-field tests were made for the purpose of evaluating any possible effects which boundaries of the test basin or the free surface might superimpose on the shock-wave records as well as to furnish basic data with which the results of similar tests, made with the bubble screen in operation, could be compared. The free-water/free-field tests showed that boundaries of the test basin had no influence on record shape for the geometries tested. The same geometries and gage arrays were used with the various screens in operation so that a direct comparison of the free-water/free-field results with the screen-on results shows quantitatively the effectiveness of the bubble screen in attenuating the shock wave. The free-water/free-field tests also revealed that the gage mount and support were sufficiently free of ringing and vibration not to

introduce spurious signals onto the pressure-time traces. The free-water/free-field test results are presented in tables 1-3 and in plates 2-4. (U)

Tests with a 3-ft-Thick Screen

(U) 20. In this series of tests a wide range of test conditions was employed. The shock phenomena were measured at three gage depths, namely, middepth, one-quarter depth, and 0.25 ft below the water surface. Three air flows were used ranging from the minimum to the maximum possible with the equipment available (0.3, 1, and 3% of air by volume). Two stand-off distances were also used so that the effects of the screen on shock waves of different intensities could be observed. The results of the tests made with the 3-ft-thick bubble screen are presented in tables 4-21 and plates 5-22. (U)

Tests with a 1.5-ft-Thick Screen

(U) 21. Fewer tests were made with the 1.5-ft-thick screen than with the 3-ft screen. Only two gage depths were used (middepth and 0.25 ft below surface); likewise only two stand-off distances were used in the middepth tests, and one (6.0 ft) in the 0.25-ft-depth tests. However, due to the reduction in the thickness of the screen, a fourth air flow was available and was used (0.3, 1, 3, and 6% of air by volume) in the mid-depth tests; three were used in the 0.25-ft-depth tests. The results of this series of tests are presented in tables 22-32 and plates 23-33. (U)

Tests with a 0.5-ft-Thick Screen

(U) 22. This series consisted of only four tests with four air flows, namely, 0.3, 3, 6, and 12% of air by volume. Only one stand-off distance (6 ft) and only one gage depth (middepth) were used in this group of tests. The results of the 0.5-ft-thick screen tests are presented in tables 33-36 and in plates 34-37. (U)

PART IV: DISCUSSION OF RESULTS

Reliability of Test Results

(U) 23. The tabulated results (tables 1-36) include values of the standard deviation of the mean where three or more measurements were obtained. Although the significance of statistical inference from such small samples is limited, the measures obtained indicated that the results are reproducible to a satisfactory degree. The measurements of peak pressure show less variation than do the measurements of impulse and energy. For the free-water/free-field tests, the over-all average values of the standard deviation of the mean in per cent (σ_m%) for peak pressure, reduced impulse, and reduced energy were 4.4, 6.0, and 11.2, respectively. Values of σ_m% for similar tests with the screen in operation were 10.6, 11.4, and 17.3. The average values of the deviations of a single observation for the free-water/free-field tests were 8.2, 10.9, and 21.0, respectively, for peak pressure, reduced impulse, and reduced energy; similar values for the bubble screen tests were 20.2, 21.9, and 33.0. Although a minimum amount of data was obtained in a number of the tests, the data are generally felt to be sufficiently reliable to permit a definitive analysis. (U)

Free-Water/Free-Field Tests

(C) 24. The peak pressure and reduced positive impulse results for the free-water/free-field tests are presented graphically in plates 2-4. For comparison purposes, the generally accepted free-water curves[5] for peak pressure and reduced positive impulse are also shown in the plates. The slopes of the plotted lines in plates 2, 3, and 4 indicate that in these tests the peak pressure, on the average, varies inversely as $\lambda^{1.09}$ for the middepth gage position, and inversely as $\lambda^{1.16}$ for both the one-quarter depth gage position and for gages positioned 0.25 ft below the water surface. The attenuation rate for peak pressure in free water varies inversely as $\lambda^{1.13}$. As shown, the WES peak pressure results agree very well with the generally accepted free-water values. The results also

show that the depth of the gage array below the water surface, in the geometries tested, has very little effect on peak pressure. (C)

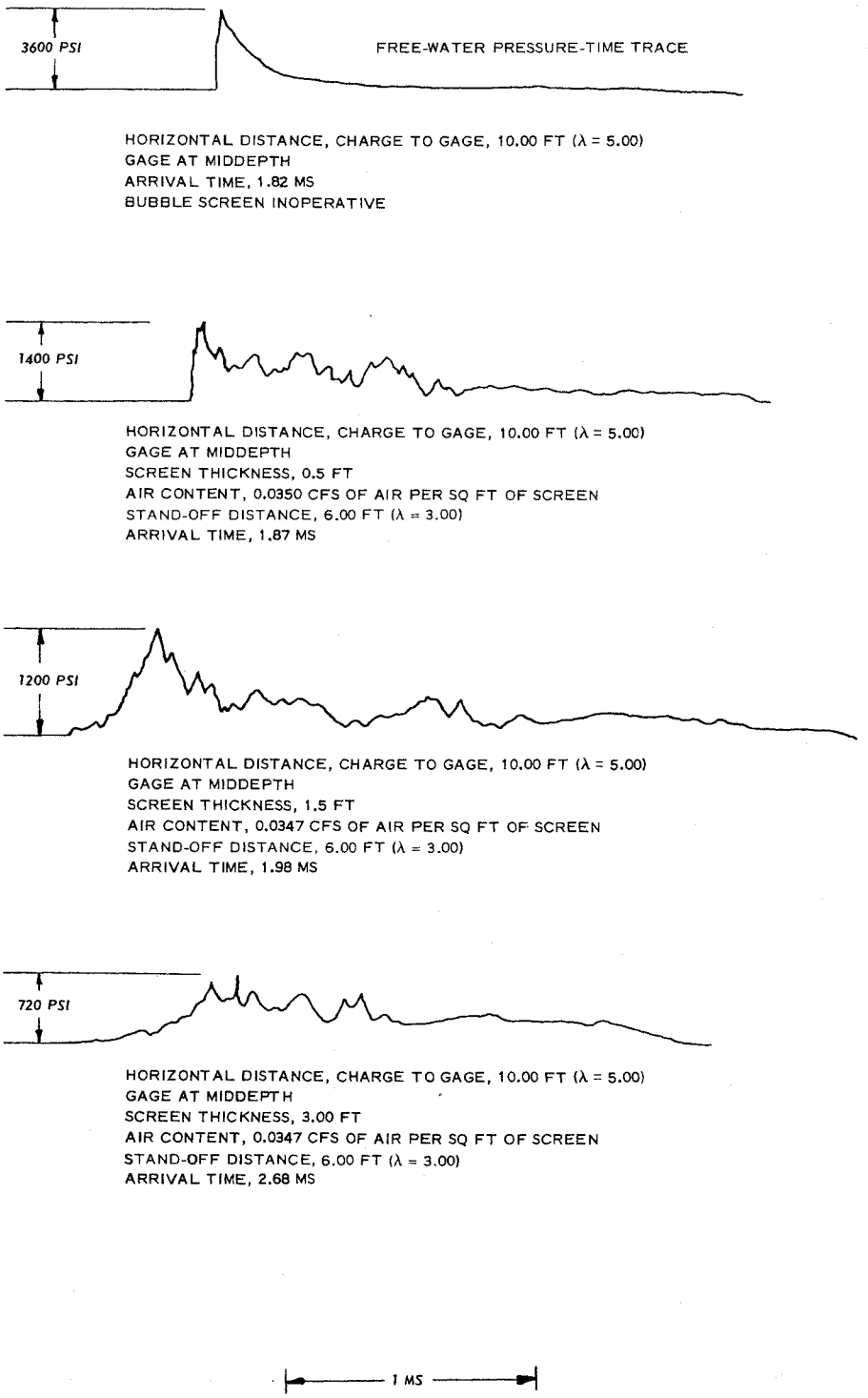
(C) 25. Reduced positive impulse on an average varies inversely as $\lambda^{0.92}$ for the middepth gage position, inversely as $\lambda^{0.97}$ for the one-quarter depth position, and inversely as $\lambda^{2.07}$ for the gages positioned 0.25 ft below the water surface. The attenuation rate for reduced positive impulse in free water varies inversely as $\lambda^{0.89}$. From the above comparison, it is obvious that the WES reduced positive impulse results, obtained with the gages positioned at middepth and one-quarter depth, agree very well with the generally accepted free-water values. For the tests made with the gages 0.25 ft below the water surface, reduced positive impulse fell considerably below the free-water value, particularly as distance from the charge increased. This reduction in impulse is due to surface cutoff (reflection of the incident wave from the water-air interface as a rarefaction) which is common to such shot geometries. (C)

(C) 26. Reduced energy, not shown graphically, has an attenuation rate in free water that varies inversely as $\lambda^{2.04}$. The free-water/free-field tests verified this experimental axiom for the middepth gage position, and showed the energy to vary inversely as $\lambda^{2.22}$ for the one-quarter depth gage position, and inversely as $\lambda^{3.29}$ for the gages just below the water surface. The reduced energy results generally exhibited the same trends as the reduced positive impulse results. The values obtained with gages positioned at middepth and one-quarter depth agree very well with the free-water values, while the values obtained with the gages positioned near the water surface fell, as expected, progressively below the free-water values as distance from the charge increased. As was the case with reduced impulse, this reduction in energy was due to the surface-cutoff effect. (C)

General Effect of a Bubble Screen on a Water-Shock Wave

(C) 27. In general, a water-shock wave passing through a screen of bubbles is greatly modified from its usual steep-fronted peak and exponential decay characteristics. The amount of modification experienced is dependent on the air content of the screen, the screen thickness, and the

magnitude of the shock-wave incident upon the screen. As may be seen in fig. 8, the steep-fronted peak is altered in each case, and the pressure



(C) Fig. 8. Modification of the pressure-time trace caused by a shock wave passing through bubble screens of various thicknesses

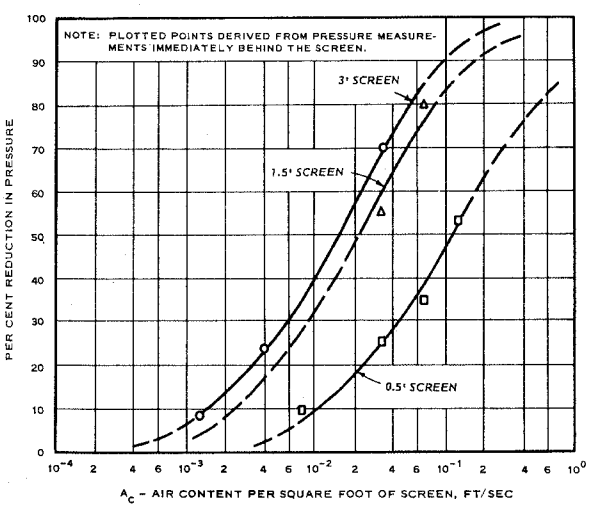
[redacted]

is greatly reduced while the length of the pulse is increased. It will be noted that even though the time of arrival of the shock wave at a particular gage may remain unchanged, the rise time from ambient pressure to the observed peak pressure is considerably increased over what the rise time would be in the classical free-water case. (C)

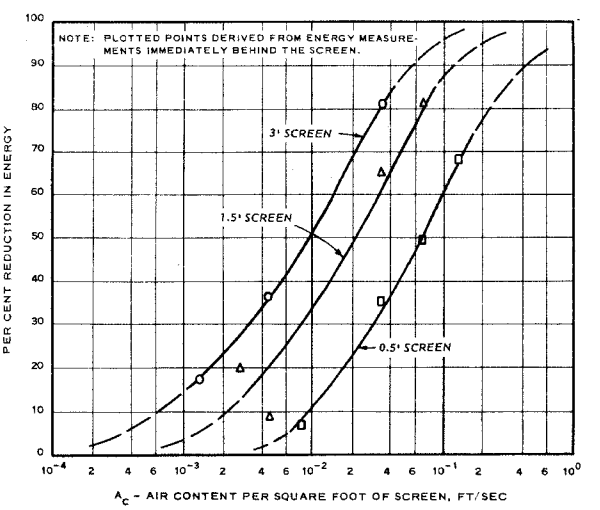
Effect of Screen Thickness

Gages at middepth

(C) 28. The effects of screen thickness on the peak pressure and energy parameters are shown in figs. 9 and 10, respectively, where the per cent reduction of these two parameters is plotted versus the air content



(C) Fig. 9. Variation of pressure reduction with air content for various screen thicknesses (Z_g = 9.0, R_o = 6.0)



(C) Fig. 10. Variation of energy reduction with air content for various screen thicknesses (Z_g = 9.0, R_o = 6.0)

of the screen (cubic feet per second per square foot of screen) for the various screen thicknesses tested. The per cent reduction values were computed by dividing the difference between the WES free-water/free-field value and the value obtained behind the screen by the WES free-water value, or algebraically,

$$\text{Per cent reduction for pressure} = \frac{\left[(p_{fw})_1 - p_1\right]}{(p_{fw})_1}$$

[redacted]

$$\text{Per cent reduction for energy} = \frac{\left[(e_{fw})_1 - e_1\right]}{(e_{fw})_1}$$

The value obtained at the first gage behind the screen and the value obtained from the WES free-water curve at the same reduced distance were the actual values used in the above equations. Fig. 9 shows that the 1.5-ft- and 3-ft-thick bubble screens were more effective in reducing the pressure than was the 0.5-ft-thick screen by factors of two and three, respectively. Fig. 10 shows that in reducing energy the 1.5- and 3-ft screens were more effective than the 0.5-ft-thick screen by factors of three and five, respectively. Although figs. 9 and 10 illustrate results obtained only at the 6-ft stand-off distance for the middepth gages, similar plots of results obtained at the 12-ft stand-off distance follow the same general pattern and show that the screen is slightly more effective at the greater stand-off distance. By averaging the per cent reduction in pressure obtained at all gages in and behind the bubble screen, average reductions at the 6-ft stand-off distance with 0.0347 cfs of air per square foot of screen were: 3-ft screen, 66%; 1.5-ft screen, 56%; and 0.5-ft screen, 44%. A similar analysis of energy data shows reductions of 77, 63, and 55% for the 3-, 1.5-, and 0.5-ft screens, respectively. At the 12-ft stand-off distance, the average reductions in pressure obtained at all gages in and behind the bubble screens with 0.0347 cfs of air per square foot of screen area were 69% with the 3-ft screen and 64% with the 1.5-ft screen. Similarly, energy reductions were 78 and 73% with 3- and 1.5-ft screens, respectively. (C)

(C) 29. The effect of the bubble screen on impulse was not as apparent as was the case with the pressure and energy of the shock wave. An examination of the tabulated results (tables 1-36) reveals that in numerous instances the reduced impulse behind the screen was as great or greater than the free-water value for the same location. It is believed that this is due, in large part, to the methods used in analyzing the water-shock records. As mentioned previously in paragraph 17, the pressure-time records were integrated to 6.7θ for the free-water records, which is the generally accepted practice; the records obtained from gages positioned in and behind the bubble screen were integrated through the entire positive

phase of the pressure-time history rather than 6.7θ or some other arbitrary time. As the pressure pulse was greatly attenuated in passing through the screen, the shock-wave duration, established from the records, far exceeded the limit of 6.7θ, thus accounting for the apparent increase in impulse behind the screen when compared to the free-water value. If a realistic and meaningful integration time limit could be arrived at, the impulse parameter might be reduced by the effect of the bubble screen. The integration times of impulse and energy were the same; however, the decrease in pressure more than compensated for the increase in duration, so that the net result as regards the energy parameter was a very marked reduction from the equivalent free-water value. (C)

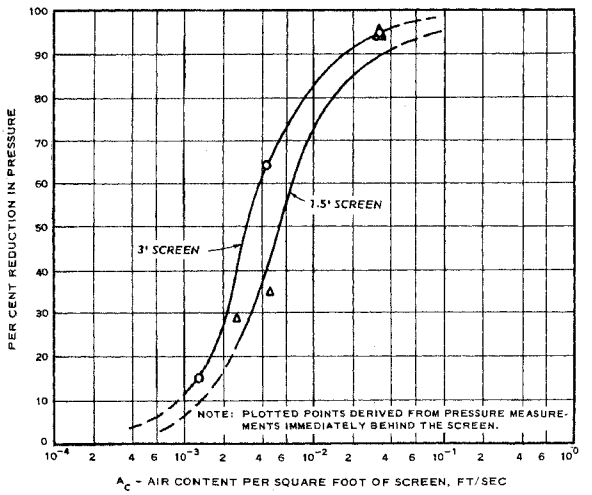
(C) 30. The changes in reduced positive impulse, as indicated by averaging the results obtained at all gages in and behind the bubble screen at the 6-ft stand-off distance with 0.0347 cfs of air per square foot of screen area, were reductions of 22 and 4% with the 3- and 0.5-ft screens, while the 1.5-ft screen showed an increase of 6%. At the 12-ft stand-off distance, the average changes in reduced positive impulse as obtained by gages in and behind the bubble screens with 0.0347 cfs of air per square foot of screen area were reductions of 36 and 14% with the 3- and 1.5-ft screens, respectively. (C)

Gages at one-quarter depth

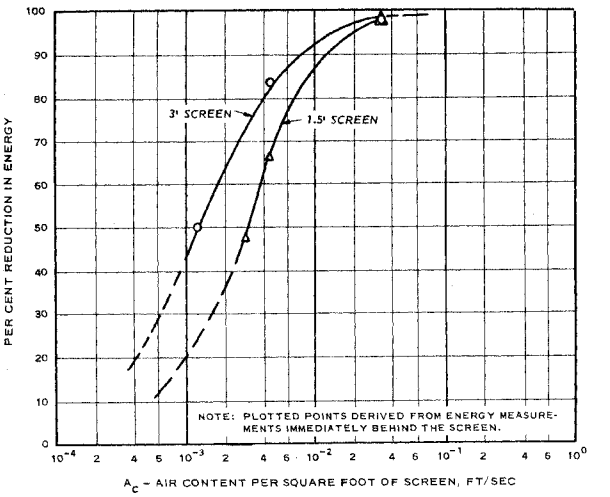
(U) 31. The results of the free-water/free-field tests showed little difference between tests made with the gages positioned at middepth and one-quarter depth. On the basis of the free-water/free-field results, the bubble screen tests with the gages positioned at one-quarter depth were limited to a single screen thickness, namely, 3 ft; therefore, no direct comparison of the screen thickness effect is possible. (U)

Gages 0.25 ft below the water surface

(C) 32. The effect of screen thickness on the gages positioned 0.25 ft below the water surface at the 6-ft stand-off distance is shown in figs. 11 and 12 where pressure and energy reductions in per cent are plotted versus screen air content (cubic feet per second per square foot of screen). Fig. 11 indicates that the 3-ft screen was slightly more effective than the 1.5-ft screen in reducing pressure. Fig. 12 indicates that at the lower air flows the 3-ft screen was approximately 30% more



(C) Fig. 11. Variation of pressure reduction with air content for various screen thicknesses (Z_g = 0.25, R_o = 6.0)



(C) Fig. 12. Variation of energy reduction with air content for various screen thicknesses (Z_g = 0.25, R_o = 6.0)

effective in reducing energy than the 1.5-ft screen. However, as the air flows increased, the difference between the two screens decreased, so that at the highest air flow tested, no apparent difference existed and the energy reductions achieved were very close to 100%. Tables 18 and 21 indicate that the records obtained from gages positioned beyond a reduced distance of $\lambda = 5.84$ for the 6-ft stand-off distance and beyond a reduced distance of $\lambda = 8.79$ for the 12-ft stand-off distance were too small to evaluate when the maximum air flows were used. (C)

(C) 33. Impulse reductions for the gages positioned 0.25 ft below the water surface, as indicated by averaging the values obtained at each gage in and behind the screen, were appreciable for each screen thickness and air flow tested. At the 6-ft stand-off distance with an air flow of 0.0347 cfs per square foot of screen, the 3-ft screen had an average reduction of 76% while the 1.5-ft screen had an average reduction of 68%. (C)

Effect of Screen Air Flow

Gages at middepth

(C) 34. The effects of air flow, or the quantity of air in the

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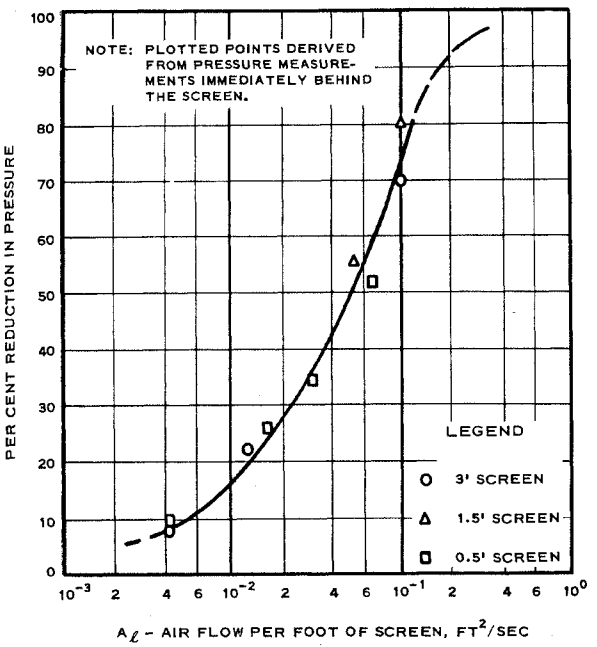
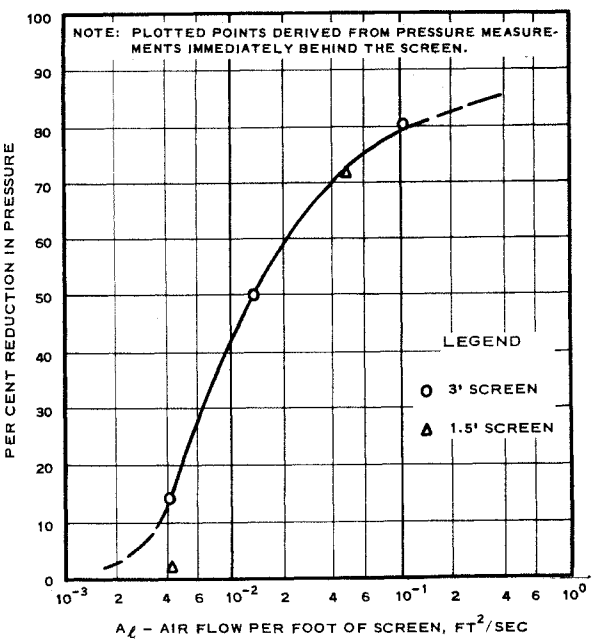
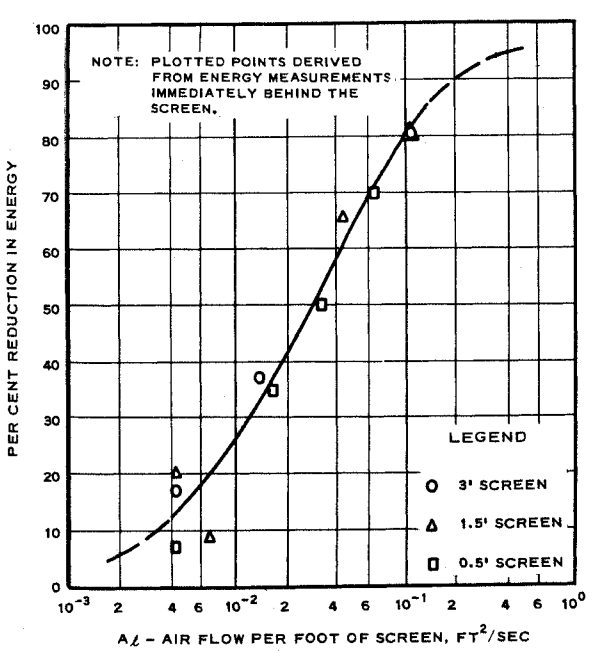
bubble screen, on the pressure and energy parameters at two stand-off distances are shown in figs. 13-16. The air flow in these plots is expressed



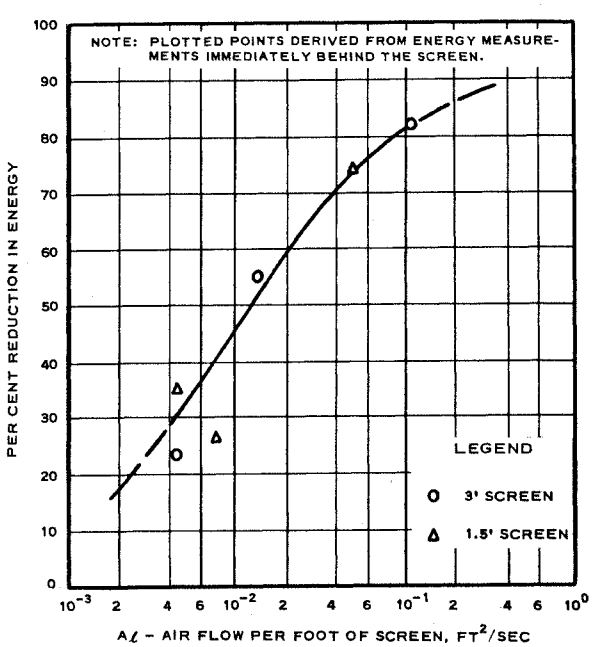
(C) Fig. 13. Variation of pressure reduction with air flow (Z_g = 9.0, R_o = 6.0)



(C) Fig. 14. Variation of pressure reduction with air flow (Z_g = 9.0, R_o = 12.0)



(C) Fig. 15. Variation of energy reduction with air flow (Z_g = 9.0, R_o = 6.0)



(C) Fig. 16. Variation of energy reduction with air flow (Z_g = 9.0, R_o = 12.0)

[redacted]

in cubic feet per second per linear foot of screen. Figs. 13 and 14 indicate that pressure reductions of approximately 10 to 75% were obtained with air flows ranging from 0.004 to 0.10 cfs per linear foot of screen. Similarly, figs. 15 and 16 show that energy reductions of approximately 20 to 80% were obtained with the same air flows. (C)

(C) 35. A comparison of fig. 9 with figs. 13 and 14 reveals what appears to be a contradiction. Fig. 9 shows that when the air in the screen is reckoned as a unit volume per unit area of screen, pressure reduction varies with screen thickness. Figs. 13 and 14, however, indicate that screen thickness is not significant when the air in the screen is expressed in units of volume per screen length. It should be remembered that the length of the bubble screen was 20 ft and the horizontal areas of the 0.5-ft-, 1.5-ft-, and 3-ft-thick screens were 10.0, 30.0, and 60.0 sq ft, respectively. Thus the amount of air furnished the 0.5-ft-thick screen must be multiplied by six in order to maintain the same unit volume per square foot ratio in the 3-ft-thick screen. Therefore, figs. 9, 13, and 14 all indicate that, within the range of air flows tested, pressure reduction varies with the total amount of air furnished the screen and is almost unaffected by the screen thickness. A similar comparison of fig. 10 with figs. 15 and 16 indicates that the same general relation applies to the energy parameter also. (C)

Gages at one-quarter depth

(C) 36. The effects of the various bubble screen air flows on the pressure and energy parameters are not shown graphically for the gages positioned at one-quarter depth because of the sparsity of data. However, an examination of the data indicates that comparable air flows effected reductions approximately 10% greater at the one-quarter depth than at the middepth gages. As previously mentioned, this difference is probably due to test geometry configuration, i.e. the shock traverses a greater distance in reaching a comparable gage. (C)

Gages 0.25 ft below the water surface

(C) 37. The effects of the screen air flow on the pressure and energy parameters are shown in figs. 17 and 18. For the gages positioned 0.25 ft below the water surface, pressure reductions varied from approximately 20 to 95% with air flows ranging from 0.004 to 0.10 cfs per linear

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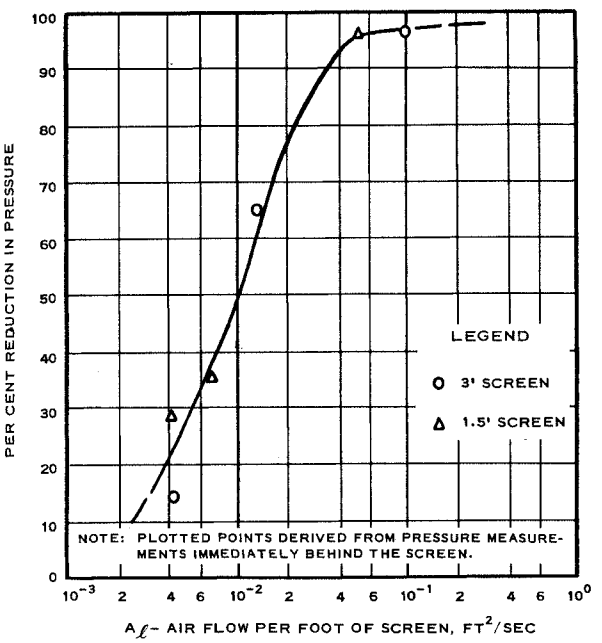
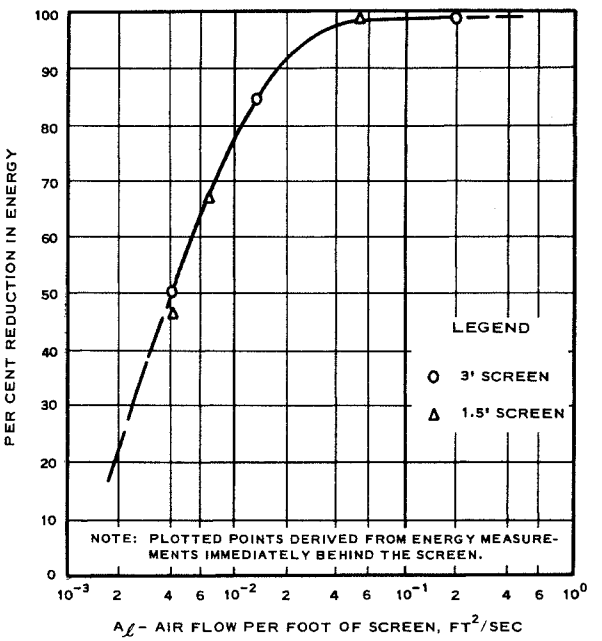


(C) Fig. 17. Variation of pressure reduction with air flow (Z_g = 0.25, R_o = 6.0)

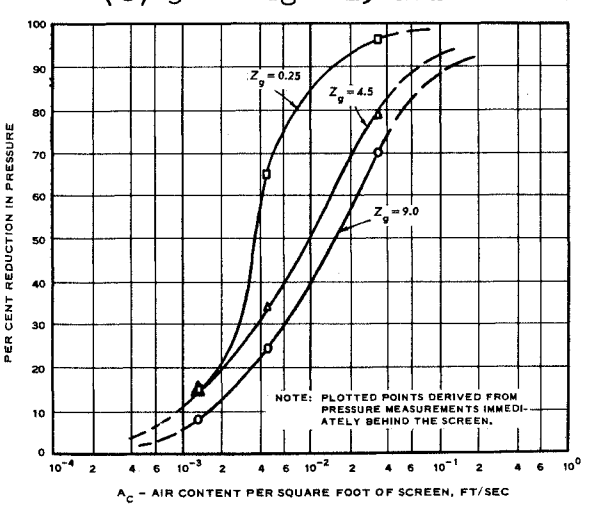


(C) Fig. 18. Variation of energy reduction with air flow (Z_g = 0.25, R_o = 6.0)

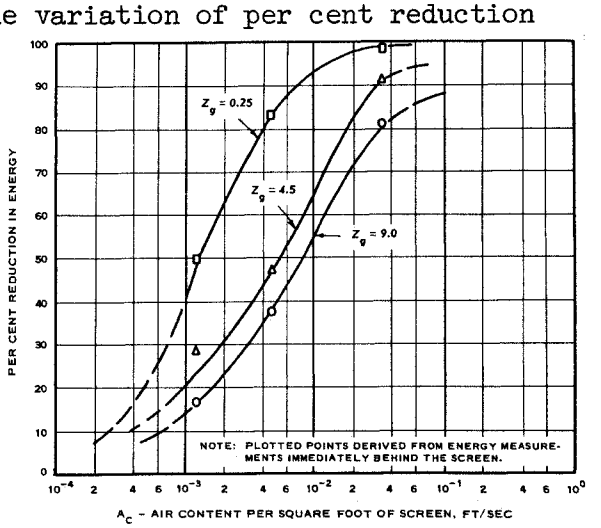
foot of screen. Energy reductions with the same range of air flows varied from approximately 50 to 98%. (C)

Variation of Bubble Screen Effects with Gage Depth

(C) 38. Figs. 19 and 20 show the variation of per cent reduction



(C) Fig. 19. Variation of pressure reduction with air content for various gage depths (T_s = 3.0, R_o = 6.0)



(C) Fig. 20. Variation of energy reduction with air content for various gage depths (T_s = 3.0, R_o = 6.0)

[redacted]

in the pressure and energy parameters common to the three gage depths. The 3-ft screen at the 6-ft stand-off distance is the only test condition for which all three gage depths were investigated. The values obtained at the first gage behind the screen at each gage depth were selected for comparison purposes. Figs. 19 and 20 both indicate that the gages positioned at the one-quarter depth experienced reductions approximately 10% greater than the gages positioned at middepth. This is not believed to be significant, since the first gage behind the screen at the one-quarter depth position was actually 1.04 ft farther from the charge than the comparable gage at the middepth position. To reach the gages behind the screen at the one-quarter depth position, the shock wave was forced to pass through a somewhat thicker screen than was the case when the gages were at middepth (see plate 1). The gages positioned 0.25 ft below the water surface experienced reductions considerably greater than the gages positioned at middepth. Again, the major reason for this difference was the distance from the charge to the first gage behind the 3-ft screen at each gage depth. These distances were 9.24 ft at middepth, 10.29 ft at one-quarter depth, and 13.29 ft at 0.25 ft below the water surface. Naturally the shock experienced near the water surface and at the one-quarter depth was weaker than that experienced at middepth due to the greater distances traversed by the shock wave. Another reason for the difference in pressure and energy reductions is the fact that at each gage depth the bubble screen thickness traversed by the shock wave in reaching the first gage behind the screen was different. These thicknesses were 3 ft at middepth, 3.4 ft at one-quarter depth, and 4.1 ft at 0.25 ft below the water surface. (C)

(C) 39. Figs. 21 and 22 are plots of the pressure and energy reductions achieved at the 6-ft stand-off distance versus air flow (cubic feet per second per linear foot of screen). Fig. 21 indicates that pressure reductions averaged 10% greater at the one-quarter depth gage position than at middepth, and 30% greater near the surface than at middepth. Fig. 22 shows that energy reductions averaged 15% greater at the one-quarter depth than at middepth and 45% greater at the gages near the surface than at middepth. Figs. 19-22 all show that

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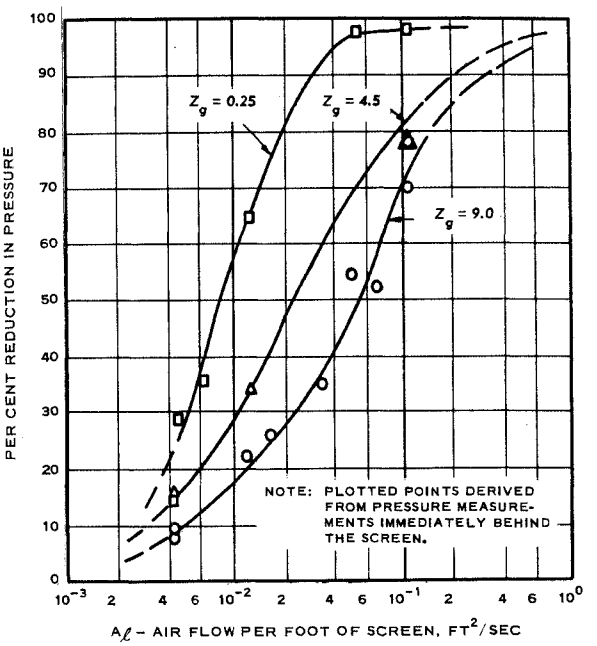
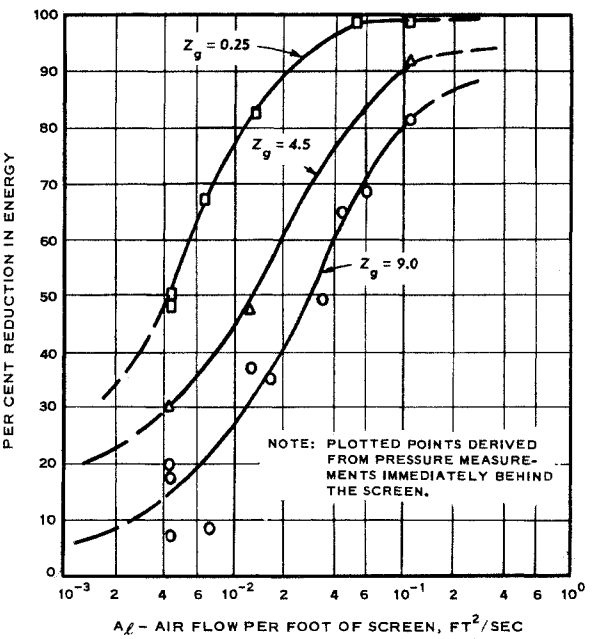


(C) Fig. 21. Variation of pressure reduction with air flow for various gage depths (T_s = 3.0, R_o = 6.0)



(C) Fig. 22. Variation of energy reduction with air flow for various gage depths (T_s = 3.0, R_o = 6.0)

at the maximum air flow tested, pressure and energy reductions realized were approaching 100%. (C)

Effect of Stand-off Distance

(C) 40. Two stand-off distances, 6 and 12 ft, were used during the tests so that the effectiveness of the bubble screen could be determined at different shock-wave intensities. Results obtained at all three gage depths with the 3-ft-thick screen indicated that larger pressure reductions, ranging from 1 to 25% greater, were achieved for the 12-ft stand-off distance than for the 6-ft stand-off distance. Similarly, average energy reductions ranged from 1 to 21% greater for the 12-ft stand-off distance than for the 6-ft stand-off distance. For comparison purposes, when the charge was positioned at the 6-ft stand-off distance the incident pressures at the front of the screen were 30 to 50% greater than when the charge was positioned at the 12-ft stand-off distance. For those tests in which maximum air flows were involved, the stand-off distance effect on the screen's ability to cause reductions in the shock wave was almost

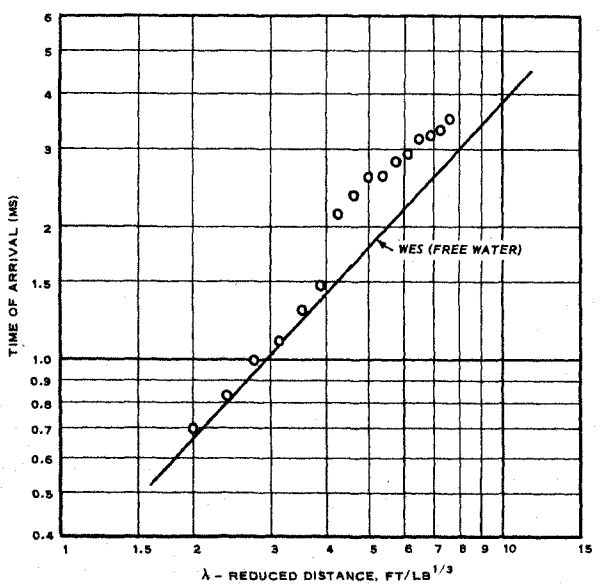
[redacted]

negligible. Where low air flows were involved, the effect was appreciable. (C)

(C) 41. With the 1.5-ft-thick screen, average pressure reductions at the 12-ft stand-off distance exceeded the reductions obtained at the 6-ft stand-off distance by approximately 5%. Similarly, average energy reductions at the 12-ft stand-off distance were approximately 12% greater than at the 6-ft stand-off distance. Since only one gage position (mid-depth) was used with the 1.5-ft-thick screen at the 12-ft stand-off distance, the data obtained from these tests are not as conclusive as those obtained in tests of the 3-ft-thick screen. (C)

Effect of the Bubble Screen on Arrival Time

(C) 42. Plots of arrival time versus reduced distance (λ) for each of the bubble screen tests are not presented in this report, because the great majority agreed very closely with the free-water results. There was, however, one exception to this general agreement that occurred repeatedly. Fig. 23 is a plot of the time of arrival of the shock wave versus reduced distance (λ) for the 3-ft-thick screen and the 6-ft stand-off distance. The gages were at middepth and the screen air content was 0.0347 cfs per square foot of screen (see table 6). Fig. 23 shows that the arrival time closely approximates that obtained in free water until the shock wave approaches the back side of the screen at approximately gage 7 (λ = 4.25). For the shock wave to travel the 0.75 ft between gages 6 and 7 required approximately 0.6 ms, whereas the average time required for it to travel the 0.75-ft distance between each preceding gage was 0.15 ms. This apparent change in the shock-wave velocity occurred only when the maximum air flows were used, and it occurred each time



(C) Fig. 23. Variation of arrival time with reduced distance (T_s = 3.0, R_o = 6.0, Z_g = 9.0, A_c = 0.0347)

these flows were used regardless of screen thickness, gage depth, or stand-off distance. With the 3-ft- and 1.5-ft-thick screens, this change occurred each time the air flow was 0.1042 cfs per linear foot of screen. With the 0.5-ft-thick screen, this phenomenon occurred only when the air flow was 0.07 cfs per linear foot, which was the maximum flow used for this screen. The change in the time of travel always occurred near the back of the screen, usually between the last gage in the screen and the first gage outside the screen. A study of the pressure data obtained with the maximum air flows reveals that the largest pressure reductions usually occurred between the same two gages (see plates 7, 10, 13, 16, 19, 22, 26, 30, and 37). A hypothesis to explain this phenomenon has not been formulated. It should be noted that reductions in peak pressure and energy were attained without the occurrence of this phenomenon; however, the largest reductions were achieved when the phenomenon was noted. (C)

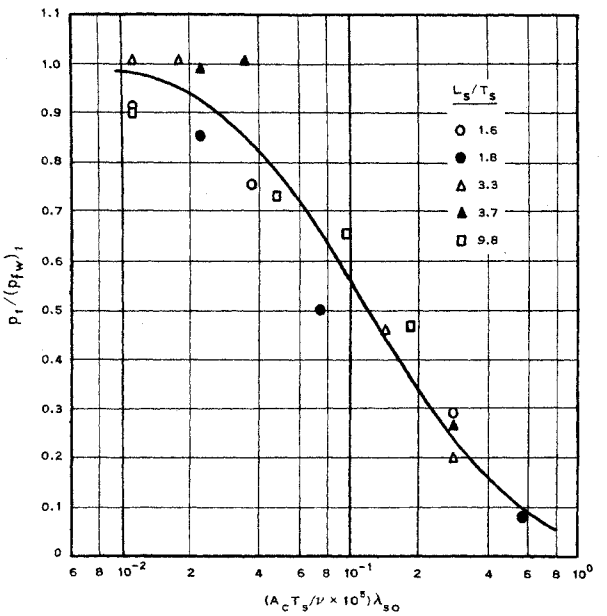
Effect of the Bubble Screen on Shock-Wave Duration

(C) 43. As mentioned previously in paragraph 27, the shock wave was lengthened considerably as it passed through the bubble screen. No analysis of the duration data was made to ascertain the magnitude of this increase in comparison with the free-water values; however, numerous instances were noted in the data tabulations where the shock-wave duration was increased by a factor of as much as three. (C)

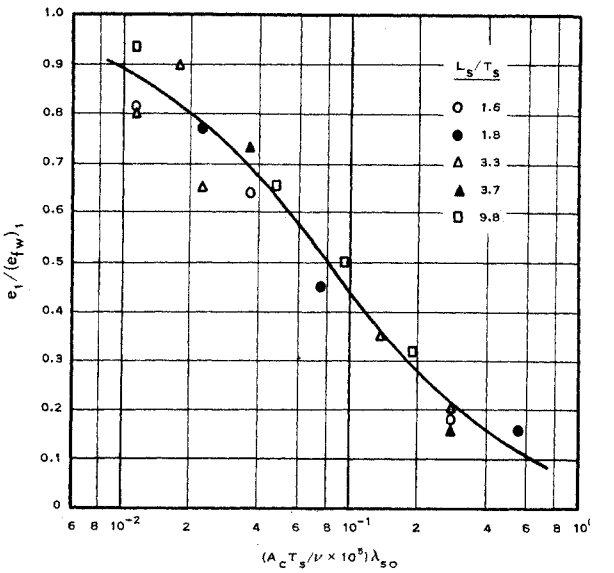
General Solution to Determine Effectiveness of a Bubble Screen

(C) 44. Considerable effort was devoted to developing a generalized solution of the bubble screen problem, one that would permit quantitative assessment of the screen's effectiveness. A dimensional analysis was accomplished, and from it the plots shown in figs. 24 and 25 were developed; these plots represent as near a general solution as can presently be determined. The following equations, determined by the method of approximation, fit the data sufficiently well to represent a general solution.

[redacted]



(C) Fig. 24. Dimensionless plot of pressure versus air content



(C) Fig. 25. Dimensionless plot of energy versus air content

For pressure,

$$\frac{p_1}{(p_{fw})_1} = 1 - \frac{A_c T_s \lambda_{so}}{\nu \times 10^5} \left(\frac{1}{\frac{A_c T_s \lambda_{so}}{\nu \times 10^5} + 0.14} \right) \tag{1}$$

and for energy,

$$\frac{e_1}{(e_{fw})_1} = 1 - \frac{A_c T_s \lambda_{so}}{\nu \times 10^5} \left(\frac{1}{\frac{A_c T_s \lambda_{so}}{\nu \times 10^5} + 0.07} \right) \tag{2}$$

In the above equations $\nu \times 10^5$ is the kinematic viscosity of water at 68 F (prevailing temperature), and its units are ft^2/sec. As is the case with all equations arrived at by empirical means, certain limitations must be imposed; these are that:

$$R_o/W^{1/3} > 3$$

$$0 < L_s/T_s \lesssim 12$$

$$0.01 < \frac{A_c T_s \lambda_{so}}{\nu \times 10^5} < 1.0$$

Similar efforts to rationalize the impulse results were not attempted, primarily because of the scatter associated with these data. (C)

[redacted]

Behavior of the Shock Wave Behind the Screen

(C) 45. In order to predict either the peak pressure or energy at locations behind the screen, the attenuation of each parameter with distance must be determined. The attenuation of peak pressure with distance behind the screen was determined by superimposing or overlaying a slope chart onto the pressure-distance plots in plates 5-37. The attenuation of energy with distance was evaluated in a similar manner from pencil plots of the energy versus distance (λ). Results of these determinations are presented in the tabulation on the following page. A similar effort to predict impulse was not attempted because of the scatter associated with these measurements. (C)

(C) 46. Efforts were made to correlate attenuation rates (characteristic slope of the plotted points) with air content; with a dimensionless parameter, $\frac{R_oA}{T_s}$; and with the product of the air content and screen thickness. These correlations were attempted both with and without regard to the depth of the gage array, but were not successful. The plots indicated that although there were considerable variations in the values of n_p and n_e, they seem to hover about a mean regardless of other factors. This implies that the attenuation rates behind the screen are not affected by parameters of the bubble screen. (C)

(C) 47. It was therefore decided to compute averages for the attenuation rates and to use these averages in establishing the pressure or energy magnitude behind the screen. (The pressure and energy immediately behind the screen may be computed from equations 1 and 2, respectively.) The average attenuation rate for pressure was calculated to be -3.1. By statistical methods it can be inferred that a single attenuation rate will lie between -1 and -5 with a confidence level of 95%. Similarly, the average of the energy attenuation rate was -4.7, and its standard deviation infers that a single attenuation rate will lie between -1 and -8. Therefore, the procedure for determining the shock-wave parameter immediately behind the screen and at other distances behind the screen is:

a. Compute the shock-wave parameter immediately behind the screen using equations 1 and/or 2.

b. On log-log paper, lay off the slope of -3.1 or -4.7

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(C) Approximate Attenuation Rates of Pressure and Energy Behind the Screen

Z_g	T_s	A_c	A_c%	R_o	n_p	n_e
9.0	3.0	0.0014	0.3	6.0	2.0	2.9
9.0	3.0	0.0044	1.0	6.0	2.5	2.9
9.0	3.0	0.0347	3.0	6.0	2.9	4.0
9.0	3.0	0.0014	0.3	12.0	3.3	3.7
9.0	3.0	0.0044	1.0	12.0	3.3	5.0
9.0	3.0	0.0347	3.0	12.0	3.3	6.5
4.5	3.0	0.0014	0.3	6.0	1.8	3.3
4.5	3.0	0.0044	1.0	6.0	2.2	3.3
4.5	3.0	0.0347	3.0	6.0	3.3	6.5
4.5	3.0	0.0014	0.3	12.0	2.9	4.0
4.5	3.0	0.0044	1.0	12.0	4.0	5.0
4.5	3.0	0.0347	3.0	12.0	4.0	7.5
0.25	3.0	0.0014	0.3	6.0	3.3	6.5
0.25	3.0	0.0044	1.0	6.0	3.3	6.5
0.25	3.0	0.0347	3.0	6.0	10.0*	7.5*
0.25	3.0	0.0014	0.3	12.0	6.7	8.0
0.25	3.0	0.0044	1.0	12.0	5.0	10.0
0.25	3.0	0.0347	3.0	12.0	10.0*	10.0*
9.0	1.25	0.0028	0.3	6.0	2.1	2.9
9.0	1.5	0.0044	1.0	6.0	2.0	2.9
9.0	1.5	0.0347	3.0	6.0	1.9	2.9
9.0	1.5	0.0694	6.0	6.0	3.3	3.5
9.0	1.5	0.0028	0.3	12.0	3.0	3.5
9.0	1.5	0.0044	1.0	12.0	3.0	3.5
9.0	1.5	0.0347	3.0	12.0	3.0	4.5
9.0	1.5	0.0694	6.0	12.0	5.0	6.5
0.25	1.5	0.0028	0.3	6.0	2.3	4.0
0.25	1.5	0.0044	1.0	6.0	3.0	6.5
0.25	1.5	0.0347	3.0	6.0	5.0	6.5
9.0	0.5	0.0083	0.3	6.0	1.7	3.0
9.0	0.5	0.0350	3.0	6.0	2.2	3.0
9.0	0.5	0.0700	6.0	6.0	3.0	3.0
9.0	0.5	0.1400	12.0	6.0	3.0	4.0

* Unreliable measurements. Omitted from average values shown in text.

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(depending on whether the graph is for pressure or energy) through the value of the pressure or energy computed in step a. The lines thus drawn determine the level of pressure and energy out to as great a distance as $\lambda = 15$. (C)

(C) 48. Although the average values of n_p and n_e are recommended in the above procedure, the statistical implications of the attenuation rates varying from -1 to -5 for pressure and -1 to -8 for energy should not be overlooked. Depending on the use of these data, it may be desirable to use the -1 value defensively and the higher rates for offensive planning. (C)

Damage Mechanism and How It Is Affected by Pressure, Impulse, and Energy

(U) 49. For some time, extensive efforts have been put forth to discern the interrelation between the explosion forces and the structural response of any given target. Quantitatively, the manner in which these forces (pressure, impulse, and energy) damage a given target cannot be assessed independently of the nature, mass, and strength of the target structure. Qualitatively, if the duration of a shock wave is assumed to be somewhat longer than the natural period of the structure, it will respond as though the loading were a static load and damage will depend directly on the pressure applied. If the pressure is sufficiently great to produce collapse of a structural frame, or to rupture outer shells, damage will result. If, however, the loading duration is short compared to the structure's natural period, the damage criteria will depend on the impulse and/or energy of the shock wave. Here again the critical level of impulse and energy depends upon the nature, mass, and strength of the structure as well as upon its elastic properties. (U)

(U) 50. Generally, impulse is the important consideration in determining damage to large, rigid underwater structures, whereas energy appears to be the better criteria for determining damage to underwater structures that can accept relatively large plastic deformations. Although these seem to be general trends, it must be emphasized that a clear separation of the roles of impulse and energy in the damage mechanism has

not been formulated, although in recent months the energy of the shock wave has been considered with greater emphasis for targets typical of an underwater environment (mainly ship hulls). For this reason the bubble screen gains considerable stature as a means of mitigating the effectiveness of underwater shock in that it reduces significantly both the peak pressure and energy of a given shock wave. (U)

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PART V: CONCLUSIONS AND RECOMMENDATION

Conclusions

(C) 51. The conclusions reached as a result of this study are summarized below:

a. Reproducibility of results. Considering the possible causes of scatter in the measurement of water-shock parameters, the uncertainty of the bubble screen boundaries at the instant of charge detonation, and that a minimum of data was obtained and evaluated for a number of the tests, the data are believed to be generally reproducible. For the free-water/free-field tests the water-shock measurements on an average basis showed that the standard deviation of the mean was approximately 4% of the observed average peak pressure, 6% of the observed average reduced impulse, and 11% of the observed average reduced energy. The standard deviation of a single observation amounted to approximately 8% of the average peak pressure, 11% of the average reduced positive impulse, and 21% of the average reduced energy. For the tests made with the bubble screen in operation, the standard deviation of the mean was approximately 11% of the observed average peak pressure and reduced impulse, and 17% of the observed average reduced energy. The standard deviation of a single observation for the bubble screen tests was 20% for peak pressure, 22% for reduced positive impulse, and 33% for reduced energy.

b. Effect of test basin boundary conditions. For the test geometries used, the results of the free-water/free-field tests indicated that no reflections or other significant irregularities, due to the boundaries of the basin, affected the test results. Reflections and perturbations from the basin boundaries were noted at times too late to influence the signature of the incident shock waves.

c. Effect of bubble screen thickness. In evaluating the relative effectiveness of bubble screens of various thicknesses, it is also necessary to consider the air content of the screens or the volume of air supplied to the screens. These properties of the bubble screen are interrelated in such a way that one cannot be considered without the other. The results of this study indicate that, for the screen thicknesses tested and air quantities used, varying the bubble screen thickness had no significant effect on the water-shock parameters

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measured provided the volume of air (cubic feet per second per linear foot of screen) remained unchanged. It was also noted that when the ratio of the physical length of the shock wave to the screen thickness (L_s/T_s) varied between 1.6 and 9.8, screen effectiveness in producing reductions in the pressure and energy was unhampered.

d. Effect of bubble screen air flows. Reductions in the peak pressure and reduced energy parameters varied directly with the bubble screen air flows. The magnitude of the pressure reductions ranged approximately from 10 to 75% of the free-water values with air flows ranging from 0.04 to 0.10 cfs per linear foot of screen for the gages positioned at middepth, while the gages positioned near the water surface experienced reductions varying from 20 to 95% with the same air flows. Energy reductions ranged approximately from 20 to 80% of the free-water values with air flows ranging from 0.04 to 0.10 cfs per linear foot of screen for the gages positioned at middepth, while reductions ranging from 50 to 95% were noted by the gages positioned near the water surface with the same air flows. It is significant to note that the bubble screen manifests its greatest effectiveness in attenuating both pressure and energy when

$$0.01 < \frac{A_c T_s \lambda_{so}}{\nu \times 10^5} < 1.0$$

The impulse parameter was also affected by the various air flows; however, the extent of the reductions achieved could not be stated in such generalities.

e. Effect of stand-off distance. Two stand-off distances, 6 and 12 ft, were used during the tests, with the majority of tests made with the screen at the 6-ft stand-off distance. Results indicated that the screen was approximately 15% more effective at the 12-ft stand-off distance than at the 6-ft distance. This difference was more apparent at the lower air flows used, and the difference gradually diminished as the air flow increased so that at the higher air flows very little difference was noted. Qualitatively, this indicates that a given bubble screen will be more efficient in effecting reductions in pressure and energy when the shock wave behaves more nearly as a sonic wave.

f. Variation of effects with gage depth. Slightly larger reductions (10 to 15%) in peak pressure and reduced energy were obtained at the one-quarter depth gages than at the gages positioned at middepth. Peak pressure reductions 30% larger and reduced energy reductions

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45% larger were obtained at the gages 0.25 ft below the water surface than were obtained at the middepth gages. The differences in effects between the middepth and one-quarter depth gages were attributed to differences in test geometry. The differences in effects between the middepth gages and the gages positioned 0.25 ft below the water surface were attributed to the surface-cutoff effects and differences in test geometry which combined with the bubble screen effects to cause much larger reductions in peak pressure and reduced energy near the surface than at middepth.

g. General solution. The following empirical equations can be utilized to determine the peak pressure and shock-wave energy immediately behind a bubble screen:

$$\frac{p_1}{(p_{fw})_1} = 1 - \frac{A_c T_s \lambda_{so}}{\nu \times 10^5} \left(\frac{1}{\frac{A_c T_s \lambda_{so}}{\nu \times 10^5} + 0.14} \right) \qquad (1)$$

$$\frac{e_1}{(e_{fw})_1} = 1 - \frac{A_c T_s \lambda_{so}}{\nu \times 10^5} \left(\frac{1}{\frac{A_c T_s \lambda_{so}}{\nu \times 10^5} + 0.07} \right) \qquad (2)$$

In order for the above equations to be meaningful, the following limitations are imposed:

$$R_o/W^{1/3} > 3$$

$$0 < L_s/T_s \lesssim 12$$

$$0.01 < \frac{A_c T_s \lambda_{so}}{\nu \times 10^5} < 1.0$$

h. The attenuation of pressure and energy behind the screen varies inversely as $\lambda^{3.1}$ and $\lambda^{4.7}$, respectively. The ranges of the respective exponents are discussed in paragraph 47.

i. Comparison of WES results with other work. All available reports[1,2,3] concerning similar bubble screen work were reviewed, and efforts were made to compare the published results with the results of this study. Although each of the referenced studies indicated that significant reductions in peak pressure could be achieved, the geometries of the tests, charge sizes, and air flows used were such that no direct comparisons were possible. (C)

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Recommendation

(U) 52. It is recommended that investigations be made to determine the shock-attenuation properties of aerated materials. Solids of an air-cellular structure such as plastic foam, sponge rubber, etc., would be of primary interest. Such materials could be used to form a "fixed screen," thereby eliminating the ancillary equipment needed to keep a bubble screen in operation. These materials would also lend themselves to flexibility in screen geometry and an accurate determination of the air content per unit volume. (U)

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4. U. S. Army Engineer Waterways Experiment Station, CE, An Exploratory Study of the Effect of a Bubble Screen on Water Shock (U). Miscellaneous Paper No. 2-285 (CONFIDENTIAL report), Vicksburg, Miss., October 1958.

5. U. S. Naval Ordnance Laboratory, Explosion Effects Data Sheets (U). NAVORD Report 2986 (CONFIDENTIAL report), White Oak, Md., June 1955.

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Table 1

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Results of Water-Shock Measurements

Free Water Condition

Water Depth - 18 ft Gages at Middepth

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$*	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$*	Reduced Positive Duration ms/lb$^{1/3}$**	Time of Arrival ms
			Distance, Charge to Gage, 4.00 ft (λ = 2.00)			
	2	9800	660	580	0.37	0.68
	3	9000	800	720	0.58	0.65
Average		9400	730	650	0.48	0.66
			Distance, Charge to Gage, 4.75 ft (λ = 2.38)			
	2	8800	700	620	0.43	0.80
	3	8100	730	650	0.53	0.78
	4	8400	640	420	0.41	0.77
Average		8400	690	560	0.46	0.78
σ_m		200	26	72	0.037	0.009
σ_m%		2.4	3.8	13	8.0	1.2
σ		350	46	120	0.064	0.015
σ%		4.2	6.6	21	14	2.0
			Distance, Charge to Gage, 5.50 ft (λ = 2.75)			
	2	7400	590	420	0.48	0.95
	3	7200	650	430	0.52	0.93
	4	7100	620	390	0.50	0.89
Average		7200	620	410	0.50	0.92
σ_m		91	17	12	0.036	0.018
σ_m%		1.3	2.8	2.9	7.2	1.9
σ		160	30	21	0.062	0.031
σ%		2.2	4.8	5.1	12	3.4
			Distance, Charge to Gage, 6.25 ft (λ = 3.12)			
	3	4900	480	230	0.58	1.09
	4	5600	530	270	0.53	1.06
Average		5200	500	250	0.56	1.08
			Distance, Charge to Gage, 7.00 ft (λ = 3.50)			
	2	5000	460	240	0.53	1.32
	3	4500	470	220	0.58	1.20
	4	4800	460	200	0.49	1.23
Average		4800	460	220	0.53	1.25
σ_m		150	4.1	12	0.026	0.036
σ_m%		3.1	0.9	5.4	4.9	2.9
σ		260	7.1	21	0.045	0.062
σ%		5.3	1.5	9.5	8.5	5.0
			Distance, Charge to Gage, 7.75 ft (λ = 3.88)			
	2	4600	470	230	0.62	1.45
	3	4700	400	180	0.43	1.38
	4	4500	380	160	0.45	1.40
Average		4600	420	190	0.50	1.41
σ_m		58	27	21	0.060	0.021
σ_m%		1.2	6.5	11	12	1.5
σ		100	47	36	0.10	0.036
σ%		2.2	11	19	21	2.6

(Continued)

* Integrated to 6.7θ, where θ is the time constant associated with the decay rate of the shock wave.
** Measured to 6.7θ.

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Table 1 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 8.50 ft (λ = 4.25)			
	2	3600	370	140	0.60	1.60
	3	4600	400	140	0.44	1.54
	4	4800	400	170	0.51	1.53
Average		4300	390	150	0.52	1.56
σ		370	10	10	0.046	0.022
σ_m%		8.6	2.6	6.7	8.8	1.4
σ_m		640	17	17	0.080	0.038
σ%		15	4.4	11	15	2.4
			Distance, Charge to Gage, 9.25 ft (λ = 4.62)			
	2	3600	340	100	0.54	1.67
	3	3600	300	85	0.46	1.67
	4	3600	420	130	0.58	1.66
Average		3600	350	100	0.53	1.67
σ			35	14	0.035	0.004
σ_m%			10	14	6.7	0.3
σ_m			61	24	0.061	0.008
σ%			17	24	12	0.5
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)			
	2	3200	300	80	0.68	1.79
	3	3900	300	90	0.37	1.80
	4	3600	280	90	0.45	1.57
	13	3600	350	120	0.58	1.82
	14	3400	350	90	0.57	1.80
Average		3500	320	94	0.53	1.76
σ		120	14	6.8	0.054	0.047
σ_m%		3.4	4.5	7.2	10	2.6
σ_m		260	32	15	0.12	0.10
σ%		7.6	10	16	23	5.9
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	2	3300	330	85	0.53	1.94
	3	2800	250	65	0.58	1.94
	4	3300	260	70	0.44	1.75
	13	3300	320	75	0.54	1.99
	14	2900	340	100	0.57	1.96
Average		3100	300	79	0.53	1.92
σ		110	19	6.2	0.025	0.043
σ_m%		3.6	6.2	7.8	4.7	2.2
σ_m		250	42	14	0.056	0.095
σ%		8.1	14	18	10	5.0
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)			
	2	3200	320	100	0.53	2.12
	3	2700	280	75	0.62	2.06
	4	2900	260	65	0.52	2.08
	13	3200	320	90	0.58	2.14
	14	2600	300	70	0.62	
Average		2900	300	80	0.57	2.10
σ		120	12	6.5	0.022	0.018
σ_m%		4.3	3.9	8.1	3.8	0.9
σ_m		280	26	14	0.048	0.036
σ%		9.6	8.8	18	8.4	1.7

(Continued)

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Table 1 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	2	2900	300	95	0.60	2.23
	3	2900	250	70	0.58	2.23
	4	2600	260	55	0.58	2.17
Average		2800	270	73	0.59	2.21
σ		100	15	12	0.007	0.020
σ^m%		3.6	5.6	16	1.2	0.9
σ^m		170	26	21	0.012	0.035
σ%		6.2	9.8	28	2.1	1.6
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	2	2600	260	55	0.56	2.37
	3	2600	260	60	0.60	2.40
	4	2700	280	70	0.59	2.43
	13	2100	190	50	0.60	2.44
	14	2300	300	49	0.66	2.41
Average		2500	260	57	0.60	2.41
σ		110	18	3.8	0.016	0.039
σ^m%		4.6	7.1	6.7	2.7	1.6
σ^m		250	41	8.5	0.036	0.087
σ%		10	16	15	6.0	3.6
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	2	2500	260	60	0.60	2.46
	3	2500	260	55	0.58	2.55
	4	2400	220	43	0.56	2.57
	13	2600	320	85	0.75	2.59
	14	2400	260	60	0.62	2.51
Average		2500	260	61	0.62	2.54
σ		39	16	6.8	0.034	0.023
σ^m%		1.5	6.2	11	5.4	0.9
σ^m		87	36	15	0.075	0.052
σ%		3.5	14	25	12	2.0
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	2	2200	220	49	0.60	2.76
	3	2000	160	27	0.45	2.72
	4	2200	220	40	0.52	2.70
	13	2600	300	43	0.53	2.73
	14	2400	300	70	0.66	2.72
Average		2300	240	46	0.55	2.73
σ		100	27	7.0	0.036	0.010
σ^m%		4.4	11	15	6.6	0.4
σ^m		230	60	16	0.081	0.022
σ%		10	25	34	15	0.8
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	2	2100	220	44	0.64	2.88
	3	2200	240	45	0.53	2.82
	4	2100	220	40	0.56	2.85
	13	2200	240	48	0.62	2.87
	14	1700	220	38	0.68	2.93
Average		2100	230	43	0.61	2.87
σ		95	5.0	1.8	0.027	0.018
σ^m%		4.5	2.2	4.2	4.5	0.6
σ^m		210	11	4.0	0.061	0.041
σ%		10	4.9	9.3	10	1.4

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Table 1 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 16.00 ft (λ = 8.00)			
	13	1900	140	27	0.44	3.03
	14	2100	200	37	0.57	2.99
Average		2000	170	32	0.50	3.01
			Distance, Charge to Gage, 16.75 ft (λ = 8.38)			
	13	2000	220	33	0.57	3.17
			Distance, Charge to Gage, 17.50 ft (λ = 8.75)			
	13	1700	190	24	0.52	3.33
	14	2000	220	41	0.63	
Average		1800	200	32	0.58	3.33
			Distance, Charge to Gage, 19.00 ft (λ = 9.50)			
	13	1700	180	25	0.52	3.62
			Distance, Charge to Gage, 19.75 ft (λ = 9.88)			
	13	1600	160	22	0.58	3.74
	14	1600	200	36	0.68	3.73
Average		1600	180	29	0.63	3.74
			Distance, Charge to Gage, 20.50 ft (λ = 10.25)			
	13	1900	180	23	0.52	3.92
	14	1700	200	40	0.66	4.07
Average		1800	190	32	0.59	4.00
			Distance, Charge to Gage, 21.25 ft (λ = 10.62)			
	13	1600	160	20	0.52	4.08
	14	1500	180	25	0.60	4.13
Average		1600	170	22	0.56	4.10

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Table 2

[redacted]

Results of Water-Shock Measurements

Free Water Condition

Water Depth - 18 ft Gages at One-Quarter Depth

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$*	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$*	Reduced Positive Duration ms/lb$^{1/3}$**	Time of Arrival ms
			Distance, Charge to Gage, 6.02 ft (λ = 3.01)			
	5	6200	590	330	0.57	0.95
	6	6500	600	390	0.54	1.01
Average		6400	600	360	0.56	0.98
			Distance, Charge to Gage, 6.54 ft (λ = 3.27)			
	5	6000	540	280	0.53	1.08
	6	6100	570	330	0.52	0.97
Average		6000	560	300	0.52	1.02
			Distance, Charge to Gage, 7.11 ft (λ = 3.56)			
	5	5300	500	250	0.53	1.22
	6	4200	420	120	0.52	1.26
Average		4800	460	180	0.52	1.24
			Distance, Charge to Gage, 7.70 ft (λ = 3.85)			
	5	5200	440	260	0.55	1.35
	6	4300	440	200	0.63	1.34
Average		4800	440	230	0.59	1.34
			Distance, Charge to Gage, 8.32 ft (λ = 4.16)			
	5	3700	400	140	0.58	1.42
	6	3800	450	180	0.62	1.52
Average		3800	420	160	0.60	1.47
			Distance, Charge to Gage, 8.96 ft (λ = 4.48)			
	5	4000	350	120	0.50	1.58
	6	4000	370	130	0.54	1.58
Average		4000	360	120	0.52	1.58
			Distance, Charge to Gage, 9.62 ft (λ = 4.81)			
	5	3700	360	140	0.57	1.71
	6	3200	380	110	0.60	1.74
Average		3400	370	120	0.58	1.72
			Distance, Charge to Gage, 10.29 ft (λ = 5.14)			
	5	3500	390	130	0.66	1.86
	6	3100	340	100	0.62	1.85
Average		3300	360	120	0.64	1.86

(Continued)

* Integrated to 6.7θ, where θ is the time constant associated with the decay rate of the shock wave.
** Measured to 6.7θ.

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Table 2 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.97 ft (λ = 5.48)			
	5	2900	270	70	0.52	1.97
	6	3500	340	70	0.49	1.98
	11	3300	300	85	0.56	1.85
	12	3200	320	130	0.56	2.01
Average		3200	310	89	0.53	1.95
σ		130	15	14	0.017	0.035
σ^m%		3.9	4.8	16	3.2	1.8
σ^m		250	30	28	0.034	0.070
σ%		7.9	9.7	32	6.4	3.6
			Distance, Charge to Gage, 11.65 ft (λ = 5.82)			
	5	2900	280	75	0.52	2.10
	6	3200	290	90	0.52	2.11
	11	2700	290	75	0.62	1.86
	12	3000	310	80	0.62	2.13
Average		3000	290	80	0.57	2.05
σ		110	6.5	3.5	0.029	0.064
σ^m%		3.6	2.2	4.4	5.0	3.1
σ^m		220	13	7.0	0.058	0.127
σ%		7.2	4.5	8.8	10	6.2
			Distance, Charge to Gage, 12.35 ft (λ = 6.18)			
	5	2500	300	55	0.63	2.23
	6	2900	340	120	0.61	2.25
	11	2700	300	55	0.57	2.21
	12	3000	290	80	0.58	2.31
Average		2800	310	78	0.60	2.25
σ		110	11	12	0.014	0.022
σ^m%		4.0	3.6	15	2.3	1.0
σ^m		220	22	24	0.028	0.043
σ%		8.0	7.2	31	4.6	1.9
			Distance, Charge to Gage, 13.05 ft (λ = 6.52)			
	5	2800	260	55	0.45	2.37
	6	2300	220	55	0.60	2.39
	11	2400	260	36	0.62	2.38
Average		2500	250	49	0.56	2.38
σ		150	13	6.3	0.054	0.001
σ^m%		6.1	5.4	13	9.6	0.3
σ^m		260	23	11	0.093	0.001
σ%		10	9.4	22	17	0.4
			Distance, Charge to Gage, 13.76 ft (λ = 6.88)			
	5	2400	240	39	0.50	2.51
	6	2900	260	70	0.52	2.58
	11	2100	300	50	0.76	2.48
	12	2100	280	60	0.80	2.57
Average		2400	270	55	0.64	2.54
σ		190	13	6.6	0.079	0.024
σ^m%		7.9	4.8	12	12	0.9
σ^m		380	26	13	0.157	0.048
σ%		16	9.6	24	24	1.9

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Table 2 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 14.47 ft (λ = 7.24)			
	5	2200	240	36	0.54	2.63
	6	2000	240	55	0.72	2.68
	11	2200	260	46	0.61	2.65
	12	2300	260	55	0.61	2.67
Average		2200	250	48	0.62	2.66
σ		64	5.8	4.5	0.037	0.011
σ_m%		2.9	2.3	9.4	6.0	0.4
σ_m		130	11	9.0	0.074	0.022
σ%		5.9	4.6	19	12	0.8
			Distance, Charge to Gage, 15.18 ft (λ = 7.59)			
	5	2500	240	34	0.50	2.82
	6	2000	230	55	0.68	2.76
	11	1700	210	34	0.64	2.83
Average		2100	230	41	0.61	2.80
σ		230	9.1	7.0	0.055	0.022
σ_m%		11	4.0	17	9.0	0.8
σ_m		410	16	12	0.095	0.038
σ%		19	6.9	30	16	1.4
			Distance, Charge to Gage, 15.90 ft (λ = 7.95)			
	5	1800	220	39	0.64	2.94
	6	2000	250	43	0.72	2.92
	11	2200	200	48	0.52	2.93
	12	2100	240	40	0.64	3.03
Average		2000	230	42	0.63	2.96
σ		87	11	2.0	0.041	0.026
σ_m%		4.3	4.9	4.8	6.6	0.9
σ_m		170	22	4.0	0.083	0.051
σ%		8.7	9.7	9.5	13	1.7
			Distance, Charge to Gage, 16.62 ft (λ = 8.31)			
	11	2400	210	33	0.57	2.92
	12	1700	140	32	0.44	3.12
Average		2000	180	32	0.50	3.02
			Distance, Charge to Gage, 17.34 ft (λ = 8.67)			
	12	1800	260	40	0.74	3.29
			Distance, Charge to Gage, 18.07 ft (λ = 9.04)			
	11	1800	220	29	0.71	3.40
	12	1600	180	21	0.62	3.44
Average		1700	200	25	0.66	3.42
			Distance, Charge to Gage, 18.80 ft (λ = 9.40)			
	11	1500	160	17	0.68	3.54
	12	1600	200	28	0.74	3.55
Average		1600	180	22	0.71	3.54

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Table 2 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse $lb\text{-}ms/in.^2/lb^{1/3}$	Reduced Energy $in.\text{-}lb/in.^2/lb^{1/3}$	Reduced Positive Duration $ms/lb^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 19.53 ft (λ = 9.76)			
	12	1500	160	22	0.61	3.72
			Distance, Charge to Gage, 20.26 ft (λ = 10.13)			
	12	1500	180	24	0.74	3.82
			Distance, Charge to Gage, 21.72 ft (λ = 10.86)			
	11	1400	180	30	0.66	4.12
	12	1600	170	22	0.59	4.17
Average		1500	180	26	0.62	4.14

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Table 3

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Results of Water-Shock Measurements

Free Field Condition*

Water Depth - 18 ft Gages 0.25 ft Below Water Surface

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse $lb\text{-}ms/in.^2/lb^{1/3}$	Reduced Energy $in.\text{-}lb/in.^2/lb^{1/3}$	Reduced Positive Duration $ms/lb^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 9.62 ft (λ = 4.81)			
	7	4200	120	90	0.054	1.70
	8	3200	150	75	0.073	1.55
Average		3700	140	82	0.064	1.62
			Distance, Charge to Gage, 9.96 ft (λ = 4.98)			
	7	3800	120	80	0.050	1.77
	8	3700	160	120	0.070	1.47
Average		3800	140	100	0.060	1.62
			Distance, Charge to Gage, 10.34 ft (λ = 5.17)			
	7	3200	100	55	0.047	1.82
	8	4100	180	110	0.064	1.78
Average		3600	140	82	0.056	1.80
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	7	3100	80	32	0.044	1.91
	8	3800	140	85	0.062	1.86
Average		3400	110	58	0.053	1.88
			Distance, Charge to Gage, 11.21 ft (λ = 5.60)			
	7	3000	80	48	0.046	2.02
	8	2500	85	30	0.059	1.90
Average		2800	82	39	0.052	1.96
			Distance, Charge to Gage, 11.69 ft (λ = 5.84)			
	7	3000	85	39	0.046	2.09
	8	3200	110	60	0.056	2.17
Average		3100	98	50	0.051	2.13
			Distance, Charge to Gage, 12.20 ft (λ = 6.10)			
	7	2800	80	55	0.045	2.26
	8	3100	110	70	0.062	2.18
Average		3000	95	62	0.054	2.22
			Distance, Charge to Gage, 12.73 ft (λ = 6.36)			
	7	2500	55	22	0.048	2.34
	8	3000	100	55	0.052	2.24
Average		2800	78	38	0.050	2.29

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* "Free field" denotes the fact that boundary conditions affected the water-shock measurements obtained at the stated depth.

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Table 3 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 13.29 ft (λ = 6.64)			
	7	3100	85	38	0.040	2.41
	8	2800	60	18	0.044	2.27
	9	2700	75	30	0.042	2.44
	10	2900	75	47	0.042	2.45
Average		2900	74	33	0.042	2.39
σ		87	5.2	6.2	0.0008	0.042
σ_m%		3.0	7.0	19	1.9	1.4
σ^m		170	10	12	0.0016	0.066
σ%		6.0	14	38	3.8	2.7
			Distance, Charge to Gage, 13.86 ft (λ = 6.93)			
	7	3300	85	40	0.044	2.52
	8	2800	80	34	0.044	2.42
	9	2600	80	34	0.042	2.55
	10	2700	55	22	0.034	2.57
Average		2800	75	32	0.041	2.52
σ		160	6.8	3.8	0.0024	0.033
σ_m%		5.6	9.0	12	5.8	1.3
σ^m		320	14	7.6	0.0048	0.067
σ%		11	18	24	12	2.6
			Distance, Charge to Gage, 14.45 ft (λ = 7.22)			
	7	2700	60	28	0.037	2.56
	8	2300	75	32	0.045	2.53
	9	2300	55	23	0.044	2.66
	10	2600	45	16	0.037	2.66
	86	2400	70	27	0.044	2.77
Average		2500	61	25	0.041	2.64
σ		84	5.3	2.7	0.0018	0.042
σ_m%		3.4	8.8	11	4.4	1.6
σ^m		190	12	6.0	0.0041	0.094
σ%		7.5	20	24	9.9	3.6
			Distance, Charge to Gage, 15.05 ft (λ = 7.52)			
	7	2100	49	17	0.034	2.68
	8	2200	60	33	0.044	2.73
	9	2300	55	20	0.040	2.78
	10	2300	48	16	0.032	2.82
	86	2300	70	26	0.054	2.88
Average		2200	56	22	0.041	2.78
σ		45	4.0	3.2	0.0039	0.035
σ_m%		2.0	7.2	14	9.6	1.3
σ^m		100	8.9	7.2	0.0088	0.078
σ%		4.6	16	33	21	2.8
			Distance, Charge to Gage, 15.67 ft (λ = 7.84)			
	7	2300	50	19	0.040	2.89
	8	2100	50	10	0.052	2.88
	9	1800	42	19	0.043	2.93
	10	1800	40	12	0.042	2.91
	86	1900	55	16	0.044	3.00
Average		2000	47	15	0.044	2.92
σ		97	2.8	1.8	0.0020	0.021
σ_m%		4.9	5.9	12	4.6	0.7
σ^m		220	6.2	4.0	0.0046	0.047
σ%		11	13	27	10	1.6

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Table 3 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 16.30 ft (λ = 8.15)			
	7	2100	48	20	0.042	3.03
	8	1800	50	17	0.050	3.09
	9	2200	46	20	0.036	3.06
	10	2100	46	14	0.039	3.00
	86	2500	55	19	0.042	3.10
Average		2100	49	18	0.042	3.06
σ		110	1.7	1.1	0.0023	0.019
σ_m%		5.4	3.4	6.1	5.6	0.6
σ_m		250	3.7	2.4	0.0052	0.042
σ%		12	7.6	13	12	1.4
			Distance, Charge to Gage, 16.94 ft (λ = 8.47)			
	7	1900	50	22	0.036	3.22
	8	1900	50	18	0.040	3.14
	9	1900	43	13	0.043	3.22
	10	1900	42	14	0.041	3.16
	86	1900	40	12	0.036	3.27
Average		1900	45	16	0.039	3.20
σ			2.1	1.9	0.0014	0.023
σ_m%			4.7	12	3.6	0.7
σ_m			4.7	4.2	0.0031	0.052
σ%			10	26	8.0	1.6
			Distance, Charge to Gage, 17.58 ft (λ = 8.79)			
	7	1800	35	10	0.028	3.35
	8	2100	48	13	0.042	3.34
	9	2100	47	11	0.044	3.30
	10	2000	34	8.0	0.034	3.47
	86	1900	42	11	0.038	3.36
Average		2000	41	11	0.037	3.36
σ		59	2.9	0.8	0.0029	0.028
σ_m%		3.0	7.1	7.3	7.8	0.8
σ_m		130	6.5	1.9	0.0064	0.064
σ%		6.6	16	17	17	1.9
			Distance, Charge to Gage, 18.24 ft (λ = 9.12)			
	9	1800	35	13	0.029	3.57
	10	2000	38	14	0.032	3.43
Average		1900	36	14	0.030	3.50
			Distance, Charge to Gage, 18.90 ft (λ = 9.45)			
	9	2000	40	18	0.042	3.59
	10	1900	38	14	0.036	3.57
Average		2000	39	16	0.039	3.58
			Distance, Charge to Gage, 19.56 ft (λ = 9.78)			
	9	1700	24	8.0	0.042	3.68
	10	1800	44	14	0.038	3.67
	86	1600	29	7.5	0.038	3.78
Average		1700	32	9.8	0.039	3.71
σ		58	6.0	2.1	0.0014	0.035
σ_m%		3.4	19	21	3.5	0.9
σ_m		100	10	3.6	0.0023	0.061
σ%		5.8	32	37	6.0	1.6

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Table 3 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 20.24 ft (λ = 10.12)			
	9	1400	27	9.0	0.038	3.80
	10	1600	32	8.5	0.034	3.84
	86	1800	27	8.5	0.026	3.92
Average		1600	29	8.7	0.033	3.85
σ		120	1.7	0.2	0.0035	0.035
σ^m%		7.2	5.8	2.0	11	0.9
σ^m		200	2.9	0.3	0.0061	0.061
σ%		12.5	10	3.4	19	1.6
			Distance, Charge to Gage, 20.92 ft (λ = 10.46)			
	9	1500	26	5.5	0.053	4.09
	10	1700	28	7.0	0.042	3.99
	86	1400	26	6.5	0.046	4.08
Average		1500	27	6.3	0.047	4.05
σ		91	0.7	0.4	0.0032	0.031
σ^m%		6.1	2.6	7.0	6.8	0.8
σ^m		160	1.2	0.8	0.0056	0.053
σ%		10	4.5	12	12	1.3
			Distance, Charge to Gage, 21.60 ft (λ = 10.80)			
	9	1600	27	5.5	0.039	4.08
	10	1800	26	8.0	0.039	4.06
	86	1200	24	6.0	0.049	4.19
Average		1500	26	6.5	0.042	4.11
σ		180	1.0	0.8	0.0033	0.040
σ^m%		12	3.8	12	8.0	1.0
σ^m		310	1.7	1.3	0.0058	0.070
σ%		20	6.7	20	14	1.7
			Distance, Charge to Gage, 22.29 ft (λ = 11.14)			
	9	1400	28	5.0	0.040	4.27
	10	1500	36	6.5	0.054	4.22
	86	1200	16	2.0	0.032	4.40
Average		1400	27	4.5	0.042	4.30
σ		91	5.8	1.3	0.0064	0.054
σ^m%		6.5	22	29	15	1.2
σ^m		160	10	2.3	0.0111	0.093
σ%		11	37	51	26	2.2
			Distance, Charge to Gage, 22.98 ft (λ = 11.49)			
	9	1600	23	3.5	0.036	4.36
	10	1300	27	7.0	0.036	4.27
Average		1400	25	5.2	0.036	4.32

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Table 4

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft

Air Content of Screen, 0.0014 cfs of Air per sq ft of Screen

Gages at Middepth

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 4.00 ft (λ = 2.00)*			
	20	10,000	750	610	0.44	0.69
	31	8,500	750	540	0.48	0.65
	52	11,000	850	940	0.49	0.66
Average		9,800	780	700	0.47	0.67
σ_m		730	33	390	0.015	0.012
σ_m%		7.4	4.3	56	3.2	1.8
σ		1,300	58	680	0.026	0.021
σ%		13	7.4	97	5.6	3.2
			Distance, Charge to Gage, 4.75 ft (λ = 2.38)*			
	20	9,500	700	580	0.44	0.78
	27	8,200	800	440	0.59	0.78
	31	7,100	700	270	0.52	0.82
	52	10,000	700	660	0.52	0.79
Average		8,700	720	490	0.52	0.79
σ_m		650	25	86	0.031	0.010
σ_m%		7.5	3.5	18	5.9	1.2
σ		1,300	50	170	0.061	0.019
σ%		15	7.0	35	12	2.4
			Distance, Charge to Gage, 5.50 ft (λ = 2.75)*			
	20	6,300	600	180	0.46	0.94
	27	7,500	700	520	0.49	0.93
	31	7,700	650	450	0.50	0.95
	52	9,300	800	640	0.51	0.94
Average		7,700	690	450	0.49	0.94
σ_m		610	43	97	0.011	0.004
σ_m%		8.0	6.2	22	2.2	0.4
σ		1,200	85	190	0.022	0.008
σ%		16	12	43	4.4	0.9
			Distance, Charge to Gage, 6.25 ft (λ = 3.12)			
	20	6,700	440	240	0.350	1.10
	27	6,500	480	260	0.450	1.08
	31	6,100	550	280	0.419	1.10
	52	8,200	750	510	0.479	1.10
Average		6,900	560	320	0.424	1.10
σ_m		460	69	63	0.0277	0.005
σ_m%		6.6	12	20	6.5	0.5
σ		900	140	130	0.0554	0.012
σ%		13	25	39	13	1.0
			Distance, Charge to Gage, 7.00 ft (λ = 3.50)			
	20	4,800	380	240	0.362	1.25
	31	5,400	470	160	0.570	1.26
	52	8,100	750	510	0.455	1.22
Average		6,100	530	300	0.462	1.24
σ_m		1,000	110	110	0.0601	0.012
σ_m%		17	21	35	13	1.0
σ		1,800	190	180	0.1041	0.021
σ%		29	36	61	22	1.7

(Continued)

* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 4 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 7.75 ft (λ = 3.88)			
	20	4,000	300	100	0.307	1.37
	27	3,600	---	---	---	1.38
	31	4,200	420	140	0.496	1.42
	52	5,600	600	290	0.540	1.36
Average		4,400	440	180	0.448	1.38
σ_m		440	87	58	0.0715	0.013
σ_m%		9.9	20	32	16	1.0
σ		870	150	100	0.1238	0.026
σ%		20	34	56	28	1.9
			Distance, Charge to Gage, 8.50 ft (λ = 4.25)			
	20	3,400	410	120	0.498	1.56
	27	4,200	600	180	0.938	1.51
	31	3,700	550	120	0.859	1.58
Average		3,800	520	140	0.765	1.55
σ_m		240	57	20	0.1354	0.021
σ_m%		6.2	11	14	18	1.3
σ		410	98	35	0.2345	0.036
σ%		11	19	25	31	2.3
			Distance, Charge to Gage, 9.25 ft (λ = 4.62)			
	20	3,200	300	84	0.410	1.68
	27	3,800	430	93	0.764	1.66
	31	3,100	450	90	0.708	1.72
	52	3,900	440	130	0.530	1.69
Average		3,500	400	99	0.603	1.69
σ_m		200	35	10	0.0814	0.013
σ_m%		5.8	8.8	10	14	0.7
σ		410	71	20	0.1628	0.025
σ%		12	18	20	27	1.5
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)			
	20	3,900	420	110	0.602	1.82
	27	3,300	320	69	0.614	1.83
	31	2,100	390	75	0.588	1.91
	52	3,300	310	67	0.478	1.84
Average		3,200	360	80	0.570	1.85
σ_m		380	27	10	0.0313	0.020
σ_m%		12	7.4	12	5.5	1.1
σ		760	54	20	0.0626	0.041
σ%		24	15	25	11	2.2
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	27	3,100	300	66	0.596	1.98
	31	2,100	420	74	0.802	2.04
	52	2,600	260	51	0.548	2.03
Average		2,600	330	64	0.649	2.02
σ_m		290	48	6.7	0.0779	0.019
σ_m%		11	15	10	12	0.9
σ		500	83	12	0.1349	0.032
σ%		19	25	18	21	1.6

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Table 4 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)			
	20	2,900	390	84	0.675	2.12
	27	2,600	320	56	0.904	2.12
	52	3,300	370	85	0.680	2.17
Average		2,900	360	75	0.753	2.14
σ		200	21	9.5	0.0755	0.017
σ_m%		7.0	5.8	13	10	0.8
σ_m		350	36	16	0.1308	0.029
σ%		12	10	22	17	1.4
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	27	2,600	460	72	0.922	2.29
	31	1,800	500	53	1.110	2.37
	52	2,700	280	52	0.637	2.38
Average		2,400	410	59	0.890	2.35
σ		290	68	6.5	0.1375	0.029
σ_m%		12	16	11	15	1.2
σ_m		500	120	11	0.2382	0.050
σ%		21	29	19	27	2.1
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	20	2,300	340	66	0.498	2.42
	27	2,200	400	43	1.186	2.42
	31	980	300	44	1.053	2.51
	52	2,400	250	47	0.602	2.48
Average		2,000	320	50	0.835	2.46
σ		330	32	5.4	0.1680	0.022
σ_m%		17	9.9	11	20	0.9
σ_m		660	64	11	0.3360	0.045
σ%		33	20	22	40	1.8
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	20	2,000	280	50	0.428	2.52
	27	1,500	280	28	0.887	2.60
	31	1,300	430	48	1.004	2.64
	52	2,300	320	50	0.859	2.63
Average		1,800	330	44	0.794	2.60
σ		230	35	5.4	0.1261	0.027
σ_m%		13	11	12	16	1.0
σ_m		460	71	11	0.2522	0.054
σ%		25	22	24	32	2.1
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	27	1,400	330	26	0.994	2.77
	31	1,200	330	29	0.992	2.80
	52	2,200	270	34	0.824	2.78
Average		1,600	310	30	0.937	2.78
σ		310	20	2.4	0.0563	0.009
σ_m%		19	6.4	7.8	6.0	0.3
σ_m		530	35	4.1	0.0975	0.016
σ%		33	11	14	10	0.6

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Table 4 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	20	1,500	200	27	0.589	2.88
	31	660	120	7.0	0.838	2.98
	52	1,600	160	26	0.458	2.92
Average		1,200	160	20	0.628	2.93
σ		300	23	6.5	0.1114	0.029
σ^m%		25	14	32	18	1.0
σ^m		520	40	11	0.1930	0.051
σ%		43	25	56	31	1.7

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Table 5

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft

Air Content of Screen, 0.0044 cfs of Air per sq ft of Screen

Gages at Middepth

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 4.00 ft (λ = 2.00)*			
	15	9,900	800	720	0.47	0.66
	16	9,500	800	550	0.45	0.70
	25	10,000	800	480	0.51	0.62
	32	8,600	700	410	0.44	0.78
	53	9,300	550	500	0.48	0.71
Average		9,500	730	530	0.47	0.69
σ		790	49	52	0.012	0.027
σ_m%		8.4	6.7	9.8	2.6	3.9
σ_m		1,800	110	120	0.028	0.060
σ%		19	15	22	5.8	8.7
			Distance, Charge to Gage, 4.75 ft (λ = 2.38)*			
	15	7,700	700	430	0.49	0.80
	16	7,800	700	520	0.53	--
	25	7,800	800	220	0.50	0.75
	32	7,300	550	310	0.48	0.82
	53	7,700	600	310	0.52	0.86
Average		7,700	670	360	0.50	0.81
σ		95	44	52	0.010	0.023
σ_m%		1.2	6.5	14	2.0	2.8
σ_m		210	97	120	0.021	0.046
σ%		2.8	14	32	4.2	5.6
			Distance, Charge to Gage, 5.50 ft (λ = 2.75)*			
	15	5,200	500	230	0.53	0.95
	16	6,300	460	280	0.44	0.99
	25	7,400	700	420	0.52	0.89
	32	6,900	550	340	0.55	0.93
	53	6,800	550	340	0.60	1.01
Average		6,500	550	320	0.53	0.95
σ		370	41	32	0.026	0.022
σ_m%		5.7	7.4	10	4.9	2.3
σ_m		830	91	72	0.058	0.048
σ%		13	16	22	11	5.1
			Distance, Charge to Gage, 6.25 ft (λ = 3.12)			
	16	4,200	430	150	0.474	0.97
	25	6,600	550	270	0.416	1.03
	32	6,000	480	300	0.326	1.10
	53	6,100	500	280	0.322	1.16
Average		5,700	490	250	0.384	1.06
σ		520	25	34	0.0369	0.042
σ_m%		9.2	5.1	14	9.6	3.9
σ_m		1,000	50	68	0.0738	0.083
σ%		18	10	27	19	7.8

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 5 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 7.00 ft (λ = 3.50)			
	15	4,400	400	170	0.396	1.20
	16	4,600	400	160	0.386	1.22
	25	5,300	440	200	0.450	1.18
	32	5,100	410	180	0.386	1.20
	53	3,800	440	170	0.556	1.28
Average		4,600	420	180	0.435	1.22
σ		270	9.2	7.1	0.0326	0.017
σ^m%		5.8	2.2	3.9	7.5	1.4
σ^m		600	21	16	0.0729	0.039
σ%		13	4.9	8.8	17	3.2
			Distance, Charge to Gage, 7.75 ft (λ = 3.88)			
	15	4,200	340	120	0.500	1.34
	16	4,100	420	130	0.648	1.37
	25	4,900	380	140	0.537	1.37
	32	3,400	470	97	0.896	1.42
	53	5,100	460	170	0.614	1.42
Average		4,300	410	130	0.639	1.38
σ		300	24	12	0.0695	0.016
σ^m%		7.1	6.0	9.2	11	1.1
σ^m		680	55	27	0.1554	0.035
σ%		16	13	21	24	2.6
			Distance, Charge to Gage, 8.50 ft (λ = 4.25)			
	15	2,900	340	71	0.750	1.54
	16	3,400	360	81	0.682	1.57
	25	3,200	500	100	1.032	1.53
	32	2,700	490	74	0.952	1.62
	53	3,900	500	120	0.790	1.65
Average		3,200	440	89	0.841	1.58
σ		210	36	9.2	0.0652	0.023
σ^m%		6.5	8.2	10	7.8	1.5
σ^m		460	81	21	0.1458	0.052
σ%		14	18	23	17	3.3
			Distance, Charge to Gage, 9.25 ft (λ = 4.62)			
	15	2,600	230	38	0.644	1.68
	16	2,300	260	38	0.546	1.69
	25	3,500	600	120	1.021	1.71
	32	2,600	420	74	0.723	1.73
	53	3,400	490	110	0.752	1.78
Average		2,900	400	76	0.737	1.72
σ		240	70	17	0.0794	0.018
σ^m%		8.3	17	22	11	1.0
σ^m		540	160	38	0.1775	0.040
σ%		18	39	50	24	2.3
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)			
	15	2,500	400	74	0.662	1.92
	16	2,800	340	68	0.580	1.85
	25	1,800	430	54	0.959	1.89
	32	2,300	390	52	0.887	1.97
Average		2,400	390	62	0.772	1.91
σ		210	19	5.4	0.0900	0.025
σ^m%		8.8	4.8	8.7	12	1.3
σ^m		420	37	11	0.1800	0.051
σ%		18	9.6	17	23	2.6

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Table 5 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	25	1,600	380	45	0.792	2.03
	32	2,500	320	47	0.832	2.15
	53	1,900	320	48	0.566	2.14
Average		2,000	340	47	0.730	2.11
σ		260	20	0.9	0.0828	0.038
σ_m%		13	5.9	1.9	11	1.8
σ_m		460	35	1.6	0.1434	0.067
σ%		23	10	3.4	20	3.2
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)			
	15	1,600	280	36	0.592	2.18
	16	1,800	220	38	0.653	2.18
	25	1,400	340	44	0.609	2.21
	53	1,900	320	52	0.518	2.27
Average		1,700	290	42	0.593	2.21
σ		110	26	3.6	0.0281	0.021
σ_m%		6.6	9.1	8.6	4.7	1.0
σ_m		220	53	7.2	0.0562	0.042
σ%		13	18	17	9.5	1.9
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	15	1,400	200	32	0.484	2.37
	16	1,500	220	21	0.589	2.38
	25	1,200	320	44	0.681	2.36
	32	2,000	260	34	0.918	2.44
	53	1,600	280	38	0.687	2.45
Average		1,500	260	34	0.672	2.40
σ		130	21	3.8	0.0718	0.019
σ_m%		8.9	8.2	11	11	0.8
σ_m		300	48	8.5	0.1606	0.042
σ%		20	18	25	24	1.7
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	16	1,500	210	24	0.578	2.41
	25	1,100	250	29	0.669	2.49
	32	1,400	410	29	1.111	2.54
	53	1,200	230	26	0.682	2.52
Average		1,300	280	27	0.760	2.49
σ		91	46	1.2	0.1192	0.029
σ_m%		7.0	16	4.4	16	1.1
σ_m		180	92	2.4	0.2384	0.057
σ%		14	33	8.9	31	2.3
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	15	1,200	180	20	0.632	2.56
	16	1,500	240	26	0.628	2.53
	25	990	260	19	1.270	2.61
	32	1,100	360	28	1.120	2.68
	53	1,400	260	32	0.782	2.69
Average		1,200	260	25	0.886	2.61
σ		96	29	2.4	0.1312	0.032
σ_m%		8.0	11	9.6	15	1.2
σ_m		220	65	5.4	0.2934	0.071
σ%		18	25	22	33	2.7

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Table 5 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	15	680				2.69
	16	1,100				2.69
	32	1,100	260	17	1.084	2.84
Average		960	260	17	1.084	2.74
σ		140				0.050
σ^m%		15				1.8
σ^m		240				0.087
σ%		25				3.2
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	15	550	140	7.0	0.719	2.82
	16	1,400	180	17	0.613	2.80
	32	630	90	3.5	0.800	2.96
Average		860	140	9.2	0.711	2.86
σ		270	26	4.0	0.1712	0.050
σ^m%		32	19	44	24	1.8
σ^m		470	45	6.9	0.2965	0.087
σ%		55	32	75	42	3.0

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Table 6

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft — Gages at Middepth

Air Content of Screen, 0.035 cfs of Air per sq ft of Screen — Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 4.00 ft (λ = 2.00)*			
	19	8900	700	540	0.46	0.69
	26	9200	850	700	0.56	0.69
	36	8600	650	440	0.42	0.74
	64	9800	750	500	0.45	0.69
Average		9100	740	540	0.47	0.70
σ		260	43	56	0.030	0.013
σ^m%		2.8	5.8	10	6.5	1.8
σ^m		510	85	110	0.061	0.025
σ%		5.6	12	21	13	3.6
			Distance, Charge to Gage, 4.75 ft (λ = 2.38)*			
	19	8800	850	540	0.49	0.80
	26	8900	900	660	0.64	0.82
	36	8500	600	350	0.44	0.87
	54	8400	600	380	0.44	0.82
	64	7500	650	240	0.54	0.84
Average		8400	720	430	0.51	0.83
σ		250	64	74	0.037	0.012
σ^m%		3.0	8.9	17	7.3	1.4
σ^m		550	140	160	0.084	0.026
σ%		6.6	20	38	16	3.2
			Distance, Charge to Gage, 5.50 ft (λ = 2.75)*			
	19	7500	600	360	0.48	0.92
	26	6800	600	310	0.53	0.91
	36	6200	480	210	0.46	1.16
	54	6800	600	280	0.47	0.98
	64	6900	480	300	0.50	1.04
Average		6800	550	290	0.49	1.00
σ		210	29	24	0.012	0.046
σ^m%		3.0	5.3	8.3	2.6	4.6
σ^m		460	66	54	0.028	0.102
σ%		6.8	12	18	5.7	10
			Distance, Charge to Gage, 6.25 ft (λ = 3.12)			
	19	5900	380	190	0.340	1.06
	26	6500	360	230	0.233	1.13
	36	6700	500	260	0.298	1.04
	54	6800	550	300	0.319	1.13
	64	6000	360	190	0.354	1.12
Average		6400	430	230	0.309	1.10
σ		180	40	21	0.0212	0.019
σ^m%		2.9	9.2	9.1	6.9	1.8
σ^m		410	89	47	0.0474	0.043
σ%		6.4	21	20	15	3.9

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 6 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 7.00 ft (λ = 3.50)			
	19	4600	280	150	0.150	1.22
	26	5100	260	99	0.360	1.28
	36	5400	270	140	0.292	1.33
	54	4900	260	110	0.198	1.28
	64	2100	240	32	0.526	1.37
Average		4400	260	110	0.305	1.30
σ		590	6.7	21	0.0662	0.026
σ^m%		14	2.6	19	22	2.0
σ^m		1300	15	47	0.1480	0.057
σ%		30	5.8	43	48	4.4
			Distance, Charge to Gage, 7.75 ft (λ = 3.88)			
	19	3600	200	47	0.375	1.38
	36	1500	420	38	1.250	1.58
	54	3300	190	43	0.390	1.44
Average		2800	270	43	0.672	1.47
σ		660	75	2.6	0.2892	0.059
σ^m%		23	28	6.0	43	4.0
σ^m		1100	130	4.5	0.5009	0.102
σ%		41	48	10	74	7.0
			Distance, Charge to Gage, 8.50 ft (λ = 4.25)			
	19	460	180	11	0.912	1.69
	24	680	---	--	---	2.27
	26	830	460	28	1.496	2.09
	36	770	250	20	0.877	2.14
	64	2500	420	29	1.349	2.50
Average		1000	330	22	1.158	2.14
σ		370	67	4.2	0.1555	0.133
σ^m%		37	20	19	13	6.2
σ^m		820	130	8.4	0.3110	0.296
σ%		82	41	38	27	14
			Distance, Charge to Gage, 9.25 ft (λ = 4.62)			
	26	840	360	22	1.384	2.34
	36	760	240	14	0.816	2.28
	54	1000	300	27	0.914	2.31
	64	1800	280	26	1.253	2.55
Average		1100	300	22	1.092	2.37
σ		240	25	3.0	0.1351	0.061
σ^m%		22	8.4	13	12	2.6
σ^m		480	50	5.9	0.2702	0.123
σ%		43	17	27	25	5.2
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)			
	19	1500	200	18	0.768	2.54
	24	410	100	5.0	0.751	2.60
	26	550	210	13	0.884	2.54
	64	720	150	10	0.940	2.68
Average		800	160	12	0.836	2.59
σ		240	26	2.7	0.0457	0.033
σ^m%		30	16	22	5.5	1.3
σ^m		490	51	5.4	0.0914	0.066
σ%		61	32	45	11	2.6

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Table 6 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	26	530	370	22	1.506	2.62
	36	500	320	18	1.446	2.59
	54	550	180	9.5	0.894	2.63
Average		530	290	16	1.282	2.61
σ		15	57	3.7	0.1947	0.012
σ^m%		2.8	20	23	15	0.5
σ^m		26	98	6.4	0.3372	0.021
σ%		4.8	34	40	26	0.8
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)			
	19	650	140	9.5	0.654	2.72
	24	400	85	2.0	0.660	2.90
	26	470	180	8.0	0.918	2.79
	36	380	290	12	1.582	2.77
	54	640	200	12	0.801	2.74
	64	520	360	16	1.938	2.92
Average		510	210	9.9	1.092	2.81
σ		47	41	1.9	0.2200	0.034
σ^m%		9.3	20	19	20	1.2
σ^m		120	100	4.6	0.5389	0.084
σ%		23	48	47	49	3.0
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	26	560	200	7.5	1.093	2.91
	36	420	350	16	1.609	2.90
	54	680	160	9.5	0.756	2.92
	64	470	360	13	1.913	2.98
Average		530	270	12	1.343	2.93
σ		57	51	1.9	0.2586	0.018
σ^m%		11	19	16	19	0.6
σ^m		110	100	3.8	0.5172	0.036
σ%		22	38	32	38	1.2
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	19	530	80	3.5	0.574	2.74
	24	310	47	1.0	0.565	3.22
	26	320	150	8.0	1.246	3.60
	54	540	200	16	2.208	3.05
	64	460	400	16	2.137	3.20
Average		430	180	8.9	1.346	3.16
σ		50	47	3.1	0.3595	0.139
σ^m%		12	26	35.0	27	4.4
σ^m		110	100	6.9	0.8038	0.311
σ%		26	58	78	60	9.8
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	19	440	120	4.5	0.800	3.26
	36	350	290	8.5	2.182	3.19
	54	470	260	10	1.640	3.15
	64	390	280	8.5	2.145	3.23
Average		410	240	7.9	1.692	3.21
σ		84	40	1.2	0.3219	0.024
σ^m%		20	16	15	19	0.7
σ^m		170	79	2.4	0.6438	0.048
σ%		41	33	30	38	1.5

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Table 6 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	19	250	65	1.5	0.604	3.32
	26	260	150	9.5	1.229	3.30
	36	260	290	6.5	2.148	3.25
	54	370	260	9.0	2.055	3.39
Average		280	190	6.6	1.509	3.32
σ		29	52	1.8	0.3655	0.030
σ_m%		10	27	28	24	0.9
σ_m		57	100	3.7	0.7310	0.059
σ%		20	54	55	48	1.8
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	19	270	90	2.5	0.634	3.37
	24	170	44	0.5	0.600	3.62
	36	95	30	0.5	0.744	3.42
	54	320	180	3.0	1.978	3.51
	64	360	300	9.5	2.137	3.64
Average		240	130	3.2	1.219	3.51
σ		49	50	1.7	0.3442	0.069
σ_m%		20	39	52	28	2.0
σ_m		110	110	3.7	0.7696	0.154
σ%		46	86	120	63	4.4

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Table 7

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft

Air Content of Screen, 0.0014 cfs of Air per sq ft of Screen

Gages at Middepth

Stand-Off Distance, 12 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)*			
	21	3200	320	80	0.57	1.80
	33	3100	300	78	0.49	1.86
	48	2600	200	36	0.39	1.90
Average		3000	270	65	0.48	1.85
σ		190	37	14	0.052	0.029
σ^m%		6.2	14	22	11	1.6
σ^m		320	64	24	0.090	0.050
σ%		11	24	37	19	2.7
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)*			
	21	3400	340	94	0.60	1.94
	29	3200	440	150	0.75	1.98
	33	3400	370	84	0.67	2.00
	48	3100	340	94	0.66	2.16
Average		3300	370	110	0.67	2.02
σ		76	24	15	0.031	0.048
σ^m%		2.3	6.4	14	4.6	2.4
σ^m		150	47	30	0.062	0.097
σ%		4.6	13	27	9.2	4.8
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)*			
	21	2800	240	42	0.46	1.94
	29	2900	380	66	0.74	2.16
	33	3200	360	110	0.62	2.14
	48	3100	340	85	0.66	2.30
Average		3000	330	76	0.62	2.14
σ		91	31	14	0.059	0.074
σ^m%		3.0	9.4	18	9.5	3.5
σ^m		180	62	28	0.118	0.148
σ%		6.1	19	37	19	6.9
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	29	2800	290	70	0.342	2.29
	33	2900	260	62	0.428	2.28
	48	3100	320	86	0.422	2.41
Average		2900	290	73	0.397	2.33
σ		91	17	7.1	0.0278	0.042
σ^m%		3.1	6.0	9.7	7.0	1.8
σ^m		160	30	12	0.0482	0.072
σ%		5.4	10	17	12	3.1
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	21	2300	180	25	0.377	2.22
	29	2700	260	53	0.520	2.43
	33	2700	260	64	0.356	2.38
	48	2300	260	48	0.438	2.60
Average		2500	240	48	0.423	2.41
σ		120	20	8.2	0.0367	0.078
σ^m%		4.6	8.3	17	8.7	3.2
σ^m		230	40	16	0.0734	0.157
σ%		9.2	17	34	17	6.5

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 7 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	21	2300	200	38	0.478	2.44
	29	2100	300	34	0.825	2.58
	33	2700	360	96	0.676	2.52
	48	2500	350	58	0.769	2.74
Average		2400	300	56	0.687	2.57
σ		130	37	14	0.0762	0.063
σ^m%		5.4	12	25	11	2.5
σ^m		260	73	28	0.1524	0.127
σ%		11	24	50	22	4.9
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	21	1800	220	22	0.632	2.73
	29	1800	270	26	0.921	2.72
	33	2400	240	38	0.618	2.68
Average		2000	240	29	0.724	2.71
σ		200	15	4.8	0.0987	0.015
σ^m%		10	6.1	17	14	0.6
σ^m		350	26	8.3	0.1710	0.026
σ%		17	11	29	24	1.0
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	21	1700	170	21	0.513	2.69
	29	1500	290	22	0.906	2.89
	33	2100	260	46	0.656	2.84
	48	2300	290	46	0.688	3.01
Average		1900	250	34	0.691	2.86
σ		180	28	7.1	0.0812	0.066
σ^m%		9.6	11	21	12	2.3
σ^m		360	57	14	0.1624	0.133
σ%		19	23	42	24	4.6
			Distance, Charge to Gage, 16.00 ft (λ = 8.00)			
	21	1700	240	27	0.555	2.83
	29	1300	240	26	0.665	3.10
	48	1400	240	31	0.654	3.18
Average		1500	240	28	0.625	3.04
σ		120		1.5	0.0349	0.106
σ^m%		8.2		5.4	5.6	3.5
σ^m		210		2.6	0.0605	0.183
σ%		14		9.4	9.7	6.0
			Distance, Charge to Gage, 16.75 ft (λ = 8.38)			
	29	1200	310	26	0.640	3.24
	33	2000	200	34	0.468	3.22
	48	1500	200	20	0.580	3.37
Average		1600	240	27	0.563	3.28
σ		230	37	4.1	0.0504	0.047
σ^m%		15	15	15	9.0	1.4
σ^m		410	64	7.0	0.0873	0.081
σ%		25	26	26	16	2.5

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Table 7 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 17.50 ft (λ = 8.75)			
	21	1200	220	28	0.651	3.04
	29	880	240	18	1.158	3.40
	33	1600	170	27	0.433	3.34
	48	1200	180	23	0.457	3.60
Average		1200	200	24	0.675	3.34
σ		150	17	2.3	0.1683	0.116
σ_m%		12	8.3	9.4	25	3.5
σ^m		300	33	4.5	0.3366	0.231
σ%		25	17	19	50	6.9
			Distance, Charge to Gage, 18.25 ft (λ = 9.12)			
	29	980	180	11	0.532	3.57
	33	1500	180	23	0.536	3.55
	48	1100	220	12	0.809	3.70
Average		1200	190	15	0.626	3.61
σ_m		160	14	3.8	0.0916	0.047
σ_m%		13	7.1	26	15	1.3
σ^m		270	23	6.7	0.1588	0.081
σ%		23	12	44	25	2.2
			Distance, Charge to Gage, 19.00 ft (λ = 9.50)			
	21	1100	160	16	0.414	3.57
	29	500	200	7.5	1.032	3.73
	48	880	220	21	0.840	3.90
Average		830	190	15	0.762	3.73
σ		180	18	3.9	0.1826	0.095
σ_m%		21	9.4	26	24	2.6
σ^m		300	31	6.8	0.3163	0.165
σ%		37	16	46	42	4.4
			Distance, Charge to Gage, 19.75 ft (λ = 9.88)			
	21	960	160	10	0.400	3.76
	29	460	210	10	1.456	3.89
	33	1100	130	6.5	0.462	3.83
	48	940	180	14	0.446	4.05
Average		860	170	10	0.691	3.88
σ		140	17	1.5	0.2552	0.062
σ_m%		16	9.9	15	37	1.6
σ^m		280	34	3.1	0.5104	0.124
σ%		32	20	31	74	3.2
			Distance, Charge to Gage, 20.50 ft (λ = 10.25)			
	29	520	150	8.0	0.614	4.03
	48	830	200	13	0.784	4.21
Average		680	180	10	0.699	4.12
			Distance, Charge to Gage, 21.25 ft (λ = 10.62)			
	21	690	70	4.0	0.366	3.88
	29	500	160	6.0	1.658	4.16
	33	560	60	3.0	0.408	4.10
	48	650	120	9.0	0.538	4.36
Average		600	100	5.5	0.742	4.12
σ		43	23	1.3	0.3074	0.099
σ_m%		7.2	23	24	41	2.4
σ^m		86	47	2.6	0.6147	0.198
σ%		14	47	48	83	4.8

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Table 8

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft — Gages at Middepth

Air Content of Screen, 0.0044 cfs of Air per sq ft of Screen — Stand-Off Distance, 12 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)*			
	17	3400	340	75	0.54	1.87
	34	2900	270	64	0.52	1.89
Average		3200	300	70	0.53	1.88
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)*			
	17	3100	270	64	0.50	1.99
	28	3600	440	220	0.62	1.93
	34	3200	340	100	0.61	2.01
	49	3100	400	100	0.68	2.13
Average		3200	360	120	0.60	2.02
σ		120	37	34	0.037	0.042
σ^m%		3.8	10	28	6.2	2.1
σ^m		240	74	68	0.075	0.084
σ%		7.6	21	57	12	4.2
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)*			
	17	2800	260	58	0.58	2.10
	28	3700	320	81	0.50	2.12
	34	2900	360	90	0.62	2.16
	49	2800	320	75	0.66	2.26
Average		3000	320	76	0.59	2.16
σ		220	21	6.8	0.035	0.036
σ^m%		7.3	6.5	8.9	5.9	1.6
σ^m		440	42	14	0.069	0.071
σ%		15	13	18	12	3.3
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	17	2900	200	48	0.243	2.25
	28	2600	190	80	0.234	2.30
	34	2900	250	66	0.384	2.30
	49	2900	340	91	0.422	2.40
Average		2800	240	71	0.321	2.31
σ		76	34	9.3	0.0482	0.032
σ^m%		2.7	14	13	15	1.4
σ^m		150	69	19	0.0964	0.063
σ%		5.4	29	26	30	2.7
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	17	2200	140	29	0.300	2.45
	34	2400	220	56	0.473	2.46
	49	2600	240	62	0.255	2.56
Average		2400	200	49	0.343	2.49
σ		120	31	10	0.0665	0.035
σ^m%		4.8	15	11	19	1.4
σ^m		200	53	18	0.1152	0.061
σ%		8.3	26	36	34	2.4

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 8 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	17	1700	100	16	0.258	2.59
	34	1900	220	36	0.500	2.62
	49	2300	220	46	0.332	2.68
Average		2000	180	33	0.363	2.63
σ		180	40	8.8	0.0716	0.026
σ_m%		8.9	22	27	20	1.0
σ^m		310	69	15	0.1240	0.046
σ%		15	38	46	34	1.7
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	28	1200	280	30	0.687	2.75
	34	1300	120	14	0.432	2.87
	49	1700	260	34	0.792	2.82
Average		1400	220	26	0.637	2.81
σ		150	50	6.1	0.1069	0.035
σ_m%		11	23	24	17	1.2
σ^m		260	87	10	0.1852	0.060
σ%		19	40	41	29	2.1
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	28	940	180	16	0.514	2.90
	34	1000	240	22	0.782	3.04
	49	1500	220	23	0.744	3.01
Average		1100	210	20	0.680	2.98
σ		180	18	2.2	0.0837	0.030
σ_m%		16	8.5	11	12	1.0
σ^m		310	31	3.8	0.1450	0.060
σ%		28	15	19	21	2.0
			Distance, Charge to Gage, 16.00 ft (λ = 8.00)			
	17	680	160	7.5	0.625	3.13
	28	880	190	14	0.571	3.18
	49	820	180	12	0.554	3.36
Average		790	180	11	0.583	3.22
σ		59	9.1	1.9	0.0214	0.070
σ_m%		7.5	5.0	18	3.7	2.2
σ^m		100	16	3.3	0.0371	0.121
σ%		13	8.8	30	6.4	3.8
			Distance, Charge to Gage, 16.75 ft (λ = 8.38)			
	28	810	140	12	0.506	3.32
	34	900	160	14	0.510	3.33
	49	920	140	13	0.406	3.58
Average		880	150	13	0.474	3.41
σ		34	7.1	0.6	0.0340	0.085
σ_m%		3.8	4.7	4.4	7.2	2.5
σ^m		59	12	1.0	0.0589	0.147
σ%		6.7	8.2	7.7	12	4.3

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Table 8 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 17.50 ft (λ = 8.75)			
	17	410	120	7.0	0.472	3.41
	28	930	130	10	0.446	3.45
	34	790	140	12	0.494	3.47
	49	990	120	12	0.370	3.71
Average		780	130	10	0.446	3.51
σ		130	5.0	1.2	0.0270	0.068
σ_m%		17	3.8	12	6.0	1.9
σ_m		260	10	2.4	0.0540	0.136
σ%		33	7.7	24	12	3.9
			Distance, Charge to Gage, 18.25 ft (λ = 9.12)			
	28	950	120	8.5	0.756	3.60
	34	680	120	11	0.488	3.66
	49	660	140	10	0.684	3.79
Average		760	130	9.8	0.643	3.68
σ		94	7.1	0.7	0.0800	0.056
σ_m%		12	5.5	7.4	12	1.5
σ_m		160	12	1.3	0.1386	0.097
σ%		21	9.4	13	22	2.6
			Distance, Charge to Gage, 19.00 ft (λ = 9.50)			
	17	450	110	7.0	0.397	3.78
	28	710	100	5.0	0.483	3.74
	49	690	180	11	1.226	3.95
Average		620	130	7.7	0.702	3.82
σ		84	25	1.8	0.2633	0.064
σ_m%		14	19	23	38	1.7
σ_m		140	44	3.1	0.4561	0.112
σ%		23	34	40	65	2.9
			Distance, Charge to Gage, 19.75 ft (λ = 9.88)			
	17	450	90	5.0	0.370	3.91
	28	490	80	2.5	0.517	3.90
	34	530	140	5.5	0.498	3.91
	49	650	180	8.0	1.193	4.10
verage		530	120	5.2	0.644	3.96
		43	27	1.1	0.1857	0.048
$_m$%		8.2	23	22	29	1.2
$_m$		86	55	2.3	0.3714	0.097
%		16	46	44	58	2.4
			Distance, Charge to Gage, 20.50 ft (λ = 10.25)			
	28	510	100	3.0	0.673	4.07
	49	600	130	8.5	0.750	4.26
erage		560	120	5.8	0.712	4.16
			Distance, Charge to Gage, 21.25 ft (λ = 10.62)			
	34	300	37	1.5	0.327	4.27
	49	470	95	3.5	0.775	4.45
erage		380	66	2.5	0.551	4.36

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Table 9

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft — Gages at Middepth

Air Content of Screen, 0.035 cfs of Air per sq ft of Screen — Stand-Off Distance, 12 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)*			
	18	4900	220	80	0.56	1.80
	23	3400	380	100	1.15	1.74
	35	2700	330	65	1.25	1.85
	37	2800	260	50	0.99	1.96
	50	3000	380	98	1.24	1.91
	51	3500	420	120	1.36	1.96
	91	2600	320	72	1.30	2.05
Average		3300	330	84	1.12	1.90
σ		300	27	9.0	0.104	0.040
σ_m%		9.0	8.1	11	9.3	2.1
σ^m		790	71	24	0.275	0.106
σ%		24	22	28	24	5.6
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)*			
	18	4100	200	62	0.53	1.89
	23	3700	360	110	0.71	1.99
	30	3200	390	120	1.20	2.04
	35	2900	330	70	1.20	1.92
	37	3300	320	78	1.15	2.00
	50	3000	330	74	1.30	1.99
	51	3100	320	74	1.19	2.07
Average		3300	320	84	1.04	1.98
σ		160	22	8.3	0.111	0.024
σ_m%		4.9	7.0	9.9	11	1.2
σ^m		430	59	22	0.295	0.063
σ%		13	18	26	28	3.2
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)*			
	23	3400	300	75	0.97	2.12
	30	2800	300	72	1.23	2.18
	35	2800	350	77	1.41	2.29
	37	2800	300	72	1.35	2.27
	50	2900	300	72	1.01	2.35
	51	2900	300	76	1.26	2.28
Average		2900	310	74	1.20	2.25
σ		97	8.4	0.8	0.073	0.034
σ_m%		3.3	2.7	1.1	6.1	1.5
σ^m		240	20	1.9	0.178	0.083
σ%		8.2	6.6	2.6	15	3.7
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	30	2600	180	46	0.184	2.34
	35	2700	200	52	0.288	2.37
	37	2600	140	35	0.184	2.39
	50	2500	200	64	0.276	2.37
	51	2800	300	76	0.344	2.40
Average		2600	200	55	0.255	2.37
σ		55	26	7.1	0.0313	0.010
σ_m%		2.1	13	13	12	0.4
σ^m		120	30	16	0.0700	0.023
σ%		4.7	15	29	27	1.0

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 9 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	23	1600	95	12	0.299	2.42
	35	2100	100	29	0.134	2.64
	50	1500	120	14	0.330	2.61
	51	2600	240	62	0.294	2.56
	91	2700	200	57	0.180	2.68
	91	2100	160	38	0.192	2.66
Average		2100	150	35	0.238	2.60
σ		200	24	8.6	0.0324	0.039
σ^m%		9.6	16	25	14	1.5
σ^m		490	58	21	0.0794	0.096
σ%		24	39	60	33	3.7
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	51	2200	160	21	0.465	2.71
	91	2300	90	22	0.152	2.77
	91	2800	90	25	0.152	2.78
Average		2400	110	23	0.256	2.75
σ		190	23	1.2	0.1044	0.022
σ^m%		7.8	21	5.3	41	0.8
σ^m		320	40	13	0.1808	0.038
σ%		14	37	9.3	71	1.4
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	23	800	60	3.0	0.545	3.45
	30	240	---	---	---	3.57
	35	290	150	4.0	1.241	3.38
	37	320	170	6.0	1.208	4.26
	50	380	150	6.0	0.924	3.85
	83	160	140	4.0	1.592	3.72
	84	160	100	2.0	1.180	3.77
	91	130	21	0.5	0.348	3.22
	91	410	48	1.5	0.607	3.37
	91	250	65	2.0	0.720	3.30
Average		310	100	3.2	0.929	3.59
σ		62	18	0.6	0.1349	0.100
σ^m%		20	18	20	14	2.8
σ^m		190	54	1.9	0.4047	0.316
σ%		63	54	61	44	8.8
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	30	340	200	7.0	1.686	3.97
	35	730	90	4.0	0.785	4.38
	37	660	130	7.5	0.716	4.83
	83	310	220	11	1.552	4.20
	84	440	300	15	1.572	4.30
	91	230	170	4.5	1.664	3.94
	91	220	180	5.0	1.620	3.96
	91	200	150	3.0	1.445	3.46
Average		390	180	7.1	1.380	4.13
σ		72	22	1.4	0.0443	0.142
σ^m%		18	12	20	3.2	3.4
σ^m		200	63	4.1	0.1252	0.401
σ%		52	35	57	9.1	9.7

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Table 9 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 16.00 ft (λ = 8.00)			
	50	400	100	3.5	0.758	4.25
	51	280	150	4.0	1.502	4.18
	91	480	260	5.0	1.700	4.30
	91	220	80	1.5	1.551	4.30
	91	300	120	3.0	1.580	4.28
Average		340	140	3.4	1.418	4.26
σ		46	32	0.6	0.1682	0.022
σ_m%		14	23	17	12	0.5
σ_m		100	50	1.3	0.3759	0.050
σ%		30	36	38	26	1.2
			Distance, Charge to Gage, 16.75 ft (λ = 8.38)			
	30	340	--	2.5	---	4.48
	35	330	90	2.0	0.827	4.48
	37	340	85	2.5	0.886	4.39
	50	300	80	3.0	0.832	4.31
	51	280	120		1.256	4.43
Average		320	94	2.5	0.950	4.42
σ		12	9.0	0.2	0.1028	0.032
σ_m%		3.8	9.6	8.2	11	0.7
σ_m		27	18	0.4	0.2056	0.071
σ%		8.4	19	16	22	1.6
			Distance, Charge to Gage, 17.50 ft (λ = 8.75)			
	30	560	--	---	---	4.55
	35	220	50	1.5	0.641	4.63
	37	290	140	3.0	1.439	4.48
	50	320	80	2.0	0.742	4.47
	51	260	170	4.5	1.638	4.65
Average		330	110	2.8	1.115	4.56
σ		60	27	0.7	0.2487	0.037
σ_m%		18	25	24	22	0.8
σ_m		130	55	1.3	0.4974	0.083
σ%		40	50	47	45	1.8
			Distance, Charge to Gage, 18.25 ft (λ = 9.12)			
	30	200	--	1.0	---	4.68
	35	180	80	2.0	1.033	4.83
	37	250	110	2.5	1.202	4.59
	50	260	100	4.0	1.172	4.64
	51	210	140		1.470	4.72
Average		220	110	2.4	1.219	4.69
σ		15	13	0.6	0.1000	0.041
σ_m%		6.9	11	26	8.2	0.9
σ_m		34	25	1.2	0.2000	0.091
σ%		15	23	52	16	1.9
			Distance, Charge to Gage, 19.00 ft (λ = 9.50)			
	30	180	---	---	---	4.94
	37	230	150	3.0	1.818	4.74
	51	170	140	2.5	1.994	4.75
Average		190	140	2.8	1.906	4.81
σ		19				0.065
σ_m%		10				1.4
σ_m		32				0.113
σ%		17				2.3

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Table 9 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 19.75 ft (λ = 9.88)			
	30	170	---	---	---	5.08
	51	200	200	4.5	2.220	4.91
Average		180	200	4.5	2.220	5.00
			Distance, Charge to Gage, 20.50 ft (λ = 10.25)			
	37	210	130	2.5	1.874	5.18
	51	180	120	2.0	1.941	5.07
Average		200	120	2.2	1.908	5.12
			Distance, Charge to Gage, 21.25 ft (λ = 10.62)			
	37	98	40	4.0	1.103	5.52
	51	140	90	1.0	1.674	5.27
Average		120	65	2.5	1.388	5.40

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Table 10

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft — Gages at One-Quarter Depth

Air Content of Screen, 0.0014 cfs of Air per sq ft of Screen — Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 6.02 ft (λ = 3.01)*			
	40	5000	490	200	0.48	0.96
	47	5400	360	120	0.46	1.09
	60	6200	650	350	0.56	1.05
Average		5500	500	220	0.50	1.03
σ		350	84	67	0.030	0.038
σ^m%		6.4	17	30	6.1	3.7
σ^m		610	140	120	0.053	0.067
σ%		11	29	53	11	6.5
			Distance, Charge to Gage, 6.54 ft (λ = 3.27)*			
	40	5100	550	220	0.55	1.20
	47	6000	650	280	0.62	1.19
	60	5500	500	270	0.54	1.16
Average		5500	570	260	0.57	1.18
σ		260	44	19	0.025	0.012
σ^m%		4.8	7.8	7.2	4.4	1.0
σ^m		450	77	32	0.043	0.021
σ%		8.2	13	12	7.6	1.8
			Distance, Charge to Gage, 7.11 ft (λ = 3.56)*			
	47	5400	550	220	0.54	1.33
			Distance, Charge to Gage, 7.70 ft (λ = 3.85)			
	40	4800	460	170	0.388	1.32
	47	5900	600	260	0.474	1.42
	60	4700	500	220	0.391	1.38
Average		5100	520	220	0.418	1.37
σ		380	42	26	0.0281	0.029
σ^m%		7.6	8.0	12	6.7	2.1
σ^m		670	72	45	0.0487	0.050
σ%		13	14	20	12	3.7
			Distance, Charge to Gage, 8.32 ft (λ = 4.16)			
	40	4000	410	150	0.394	1.54
	47	4400	360	140	0.320	1.56
	60	4300	410	140	0.348	1.51
Average		4200	390	140	0.354	1.54
σ		120	17	4.1	0.0215	0.015
σ^m%		2.9	4.3	2.9	6.1	1.0
σ^m		210	29	7.1	0.0373	0.026
σ%		5.1	7.5	5.1	10	1.7

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 10 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 8.96 ft (λ = 4.48)			
	40	4000	500	140	0.730	1.66
	47	4000	440	140	0.539	1.69
	60	3900	350	110	0.430	1.64
Average		4000	430	130	0.566	1.66
σ		40	44	10	0.0877	0.015
σ_m%		1.0	10	7.7	16	0.9
σ_m		70	76	17	0.1519	0.026
σ%		1.8	18	13	27	1.5
			Distance, Charge to Gage, 9.62 ft (λ = 4.81)			
	40	3000	360	76	0.665	1.78
	47	3600	440	110	0.674	1.82
Average		3300	400	93	0.670	1.80
			Distance, Charge to Gage, 10.29 ft (λ = 5.14)			
	40	2500	460	67	0.742	1.94
	47	2600	420	74	0.700	1.97
	60	3300	360	80	0.513	1.86
Average		2800	410	74	0.652	1.92
σ		250	29	3.8	0.0704	0.033
σ_m%		9.0	7.1	5.1	11	1.7
σ_m		440	51	6.5	0.1219	0.057
σ%		16	12	8.8	19	3.0
			Distance, Charge to Gage, 10.97 ft (λ = 5.48)			
	47	2600	360	68	0.741	2.18
	60	2200	280	49	0.569	2.05
Average		2400	320	58	0.655	2.12
			Distance, Charge to Gage, 11.65 ft (λ = 5.82)			
	40	2900	320	80	0.550	2.24
	47	2600	370	71	0.626	2.30
	60	1800	270	54	0.536	2.19
Average		2400	320	68	0.571	2.24
σ		330	29	7.6	0.0884	0.032
σ_m%		14	9.0	11	15	1.4
σ_m		570	50	13	0.1532	0.055
σ%		24	16	19	27	2.5
			Distance, Charge to Gage, 12.35 ft (λ = 6.18)			
	40	2800	380	76	0.572	2.44
	47	2300	320	59	0.541	2.48
	60	1600	320	53	0.466	2.38
Average		2200	340	63	0.526	2.43
σ		350	20	6.9	0.0315	0.029
σ_m%		16	5.9	11	6.0	1.2
σ_m		600	35	12	0.0545	0.051
σ%		27	10	19	10	2.1

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Table 10 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 13.05 ft (λ = 6.52)			
	40	2200	310	44	0.495	2.56
	47	2000	230	36	0.482	2.62
	60	1600	280	43	0.496	2.53
Average		1900	270	41	0.491	2.57
σ		180	24	2.5	0.0045	0.026
σ^m%		9.4	8.7	6.1	0.9	1.0
σ^m		310	41	4.4	0.0078	0.046
σ%		16	15	11	1.6	1.8
			Distance, Charge to Gage, 13.76 ft (λ = 6.88)			
	47	1800	280	41	0.694	2.79
	60	1600	360	60	0.673	2.70
Average		1700	320	50	0.683	2.74
			Distance, Charge to Gage, 14.47 ft (λ = 7.24)			
	40	1600	240	34	0.472	2.90
	47	1900	310	36	0.866	2.93
	60	1500	270	46	0.603	2.82
Average		1700	270	39	0.647	2.88
σ		120	20	3.7	0.0883	0.033
σ^m%		7.2	7.6	9.5	14	1.1
σ^m		210	35	6.4	0.1529	0.057
σ%		12	13	16	24	2.0
			Distance, Charge to Gage, 15.18 ft (λ = 7.59)			
	40	1600	260	32	0.726	3.10
	47	1700	260	25	0.796	3.11
Average		1600	260	28	0.761	3.10
			Distance, Charge to Gage, 15.90 ft (λ = 7.95)			
	47	1500	150	17	0.481	3.23

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Table 11

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft — Gages at One-Quarter Depth

Air Content of Screen, 0.0044 cfs of Air per sq ft of Screen — Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse $lb\text{-}ms/in.^2/lb^{1/3}$	Reduced Energy $in.\text{-}lb/in.^2/lb^{1/3}$	Reduced Positive Duration $ms/lb^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 6.02 ft (λ = 3.01)*			
	39	5400	480	220	0.52	1.08
	59	6000	650	280	0.56	1.07
Average		5700	560	250	0.54	1.08
			Distance, Charge to Gage, 6.54 ft (λ = 3.27)*			
	39	5400	650	240	0.62	1.13
	55	5800	600	280	0.64	1.18
	59	5800	600	290	0.64	1.16
Average		5700	620	270	0.63	1.16
σ		140	17	15	0.007	0.015
σ_m%		2.4	2.7	5.7	1.1	1.3
σ^m		230	29	26	0.012	0.026
σ%		4.1	4.7	9.8	1.9	2.2
			Distance, Charge to Gage, 7.11 ft (λ = 3.56)*			
	55	5400	480	200	0.56	1.26
	59	5500	470	200	0.53	1.26
Average		5400	480	200	0.54	1.26
			Distance, Charge to Gage, 7.70 ft (λ = 3.85)			
	39	5300	500	190	0.434	1.41
	55	4800	440	160	0.346	1.41
	59	5200	460	200	0.426	1.41
Average		5100	470	180	0.402	1.41
σ		150	18	12	0.0281	
σ_m%		3.0	3.8	6.8	7.0	
σ^m		260	31	21	0.0487	
σ%		5.2	6.6	12	12	
			Distance, Charge to Gage, 8.32 ft (λ = 4.16)			
	39	3900	450	140	0.566	1.55
	55	4200	490	150	0.642	1.55
	59	4000	340	120	0.328	1.54
Average		4000	430	140	0.512	1.55
σ		91	45	9.1	0.0946	0.004
σ_m%		2.3	10	6.5	18	0.3
σ^m		160	78	16	0.1638	0.007
σ%		4.0	18	11	32	0.5
			Distance, Charge to Gage, 8.96 ft (λ = 4.48)			
	39	3800	350	100	0.490	1.68
	55	2900	360	100	0.453	1.71
	59	4100	350	130	0.410	1.65
Average		3600	350	110	0.451	1.68
σ		360	4.1	10	0.0230	0.017
σ_m%		10	1.2	9.1	5.1	1.0
σ^m		620	7.1	17	0.0399	0.030
σ%		17	2.0	16	8.8	1.8

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 11 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 9.62 ft (λ = 4.81)			
	39	2100	240	47	0.382	1.81
			Distance, Charge to Gage, 10.29 ft (λ = 5.14)			
	39	1900	220	45	0.376	1.95
	55	2600	300	66	0.398	1.97
Average		2200	260	56	0.387	1.96
			Distance, Charge to Gage, 10.97 ft (λ = 5.48)			
	55	1900	240	40	0.449	2.11
	59	1700	170	17	0.477	2.13
Average		1800	200	28	0.463	2.12
			Distance, Charge to Gage, 11.65 ft (λ = 5.82)			
	39	1600	320	40	0.820	2.36
	55	1900	220	45	0.383	2.24
	59	2100	260	36	0.494	2.34
Average		1900	270	40	0.566	2.31
σ		150	29	2.6	0.1312	0.037
σ_m%		7.7	11	6.5	23	1.6
σ_m		260	51	4.5	0.2272	0.064
σ%		13	19	11	40	2.8
			Distance, Charge to Gage, 12.35 ft (λ = 6.18)			
	39	1100	230	24	0.594	2.59
	55	2000	220	40	0.438	2.40
	59	1900	260	38	0.443	2.43
Average		1700	240	34	0.492	2.47
σ		280	12	5.0	0.0512	0.059
σ_m%		17	5.1	15	10	2.4
σ_m		500	21	8.7	0.0887	0.102
σ%		29	8.8	26	18	4.1
			Distance, Charge to Gage, 13.05 ft (λ = 6.52)			
	39	1200	200	24	0.428	2.73
	55	2100	260	47	0.550	2.59
	59	1900	250	41	0.407	2.60
Average		1700	240	37	0.462	2.64
σ		270	19	6.9	0.0446	0.045
σ_m%		16	7.8	19	9.6	1.7
σ_m		470	32	12	0.0773	0.078
σ%		28	14	32	17	3.0
			Distance, Charge to Gage, 13.76 ft (λ = 6.88)			
	55	1900	160	30	0.304	2.77
	59	1500	210	30	0.366	2.70
Average		1700	180	30	0.335	2.74

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Table 11 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 14.47 ft (λ = 7.24)			
	39	820	210	18	0.878	2.91
	55	2100	220	38	0.472	2.91
	59	1300	200	30	0.389	2.84
Average		1400	210	29	0.580	2.89
σ		370	5.8	5.8	0.1511	0.023
σ^m%		27	2.8	20	26	0.8
σ^m		650	10	10	0.2617	0.041
σ%		46	4.8	35	45	1.4
			Distance, Charge to Gage, 15.18 ft (λ = 7.59)			
	39	940	210	16	0.890	3.09
	55	1900	170	30	0.366	3.08
	59	1300	180	25	0.386	3.04
Average		1400	190	24	0.547	3.07
σ		280	12	4.1	0.1714	0.015
σ^m%		20	6.4	17	31	0.5
σ^m		480	21	7.1	0.2970	0.026
σ%		35	11	30	54	0.9

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Table 12

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft

Air Content of Screen, 0.035 cfs of Air per sq ft of Screen

Gages at One-Quarter Depth

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 6.02 ft (λ = 3.01)*			
	38	5900	600	330	0.59	1.12
	57	5900	600	250	0.55	1.02
	58	5700	550	260	0.56	1.14
Average		5800	580	280	0.57	1.09
σ		71	17	25	0.012	0.037
σ^m%		1.2	2.9	9.0	2.1	3.4
σ^m		120	29	44	0.021	0.064
σ%		2.1	5.0	16	3.7	5.9
			Distance, Charge to Gage, 6.54 ft (λ = 3.27)*			
	38	6100	650	420	0.60	1.19
	56	5300	490	210	0.56	1.21
	57	5500	550	220	0.56	1.14
	58	5500	550	220	0.56	1.24
Average		5600	560	270	0.57	1.20
σ		170	33	51	0.010	0.021
σ^m%		3.1	5.9	19	1.8	1.8
σ^m		350	66	100	0.020	0.042
σ%		6.2	12	38	3.5	3.5
			Distance, Charge to Gage, 7.11 ft (λ = 3.56)*			
	38	5300	500	270	0.56	1.33
	56	5200	480	180	0.54	1.31
	57	5500	460	180	0.53	1.26
	58	5200	480	190	0.58	1.35
Average		5300	480	200	0.55	1.31
σ		71	8.2	22	0.011	0.019
σ^m%		1.3	1.7	11	2.0	1.5
σ^m		140	16	44	0.022	0.039
σ%		2.7	3.4	22	4.1	3.0
			Distance, Charge to Gage, 7.70 ft (λ = 3.85)			
	38	4600	380	210	0.216	1.47
	56	5500	290	170	0.206	1.46
	57	5000	380	160	0.232	1.40
	58	5000	440	190	0.312	1.48
Average		5000	370	180	0.242	1.45
σ		180	31	11	0.0241	0.018
σ^m%		3.7	8.4	6.2	10	1.2
σ^m		370	62	22	0.0482	0.036
σ%		7.4	17	12	20	2.5
			Distance, Charge to Gage, 8.32 ft (λ = 4.16)			
	38	3500	260	89	0.320	1.57
	56	2800	140	32	0.332	1.58
	57	3900	260	98	0.238	1.58
	58	4300	220	92	0.212	1.62
Average		3600	220	78	0.276	1.59
σ		320	28	15	0.0297	0.011
σ^m%		8.9	13	20	11	0.7
σ^m		640	57	31	0.0593	0.022
σ%		18	26	40	22	1.4

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 12 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 8.96 ft (λ = 4.48)			
	38	3700	200	56	0.302	1.72
	57	2400	180	43	0.225	1.77
	58	1900	180	26	0.363	1.74
Average		2700	190	42	0.297	1.74
σ		540	7.1	8.7	0.0400	0.015
σ_m%		20	3.7	21	13	0.8
σ_m		930	12	15	0.0691	0.026
σ%		34	6.5	36	23	1.5
			Distance, Charge to Gage, 9.62 ft (λ = 4.81)			
	38	1100	100	5.0	0.428	1.97
	56	1900	850	95	1.492	2.25
Average		1500	480	50	0.960	2.11
			Distance, Charge to Gage, 10.29 ft (λ = 5.14)			
	38	430	280	14	1.505	2.42
	56	1100	170	6.0	0.621	3.05
	57	400	120	3.0	0.734	2.44
	58	800	170	10	0.622	2.74
Average		680	180	8.2	0.870	2.66
σ		170	34	2.4	0.2132	0.148
σ_m%		24	19	29	24	5.6
σ_m		330	68	4.8	0.4264	0.297
σ%		49	38	58	49	11
			Distance, Charge to Gage, 10.97 ft (λ = 5.48)			
	56	630	100	5.0	0.597	3.29
	57	800	85	4.5	0.508	3.24
	58	800	100	5.5	0.654	3.23
Average		740	95	5.0	0.586	3.25
σ		57	5.0	0.3	0.0424	0.019
σ_m%		7.7	5.3	5.8	7.2	0.6
σ_m		98	8.7	0.5	0.0735	0.032
σ%		13	9.1	10	13	1.0
			Distance, Charge to Gage, 11.65 ft (λ = 5.82)			
	38	610	200	8.5	1.081	3.08
	56	580	130	6.0	0.664	3.38
	57	530	80	2.0	0.468	3.31
	58	800	100	6.5	0.460	3.32
Average		630	130	5.8	0.668	3.27
σ		59	26	1.4	0.1454	0.060
σ_m%		9.4	20	23	22	1.8
σ_m		120	53	2.7	0.2908	0.119
σ%		19	40	47	44	3.6
			Distance, Charge to Gage, 12.35 ft (λ = 6.18)			
	38	540	150	7.0	0.974	3.20
	56	750	180	11	0.762	3.24
	57	650	140	6.5	0.968	3.39
	58	790	160	12	0.737	3.32
Average		680	160	9.1	0.860	3.29
σ		56	8.7	1.4	0.0642	0.042
σ_m%		8.2	5.4	15	7.5	1.3
σ_m		110	17	2.8	0.1284	0.085
σ%		16	11	30	15	2.6

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Table 12 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 13.05 ft (λ = 6.52)			
	38	540	110	5.5	0.718	3.34
	56	620	120	6.5	0.636	3.41
	57	420	80	2.5	0.902	3.45
	58	780	160	10	0.638	3.46
Average		590	120	6.1	0.724	3.42
σ		76	17	1.6	0.0625	0.028
σ_m%		13	14	25	8.6	0.8
σ_m		150	33	3.1	0.1250	0.056
σ%		26	28	51	17	1.6
			Distance, Charge to Gage, 13.76 ft (λ = 6.88)			
	38	500	120	5.0	0.755	
	56	510	100	4.0	0.640	3.48
	57	310	170	3.5	1.500	3.50
	58	550	120	6.0	0.698	3.50
Average		470	130	4.6	0.898	3.49
σ		54	15	0.6	0.2020	0.007
σ_m%		11	12	12	22	0.2
σ_m		110	30	1.1	0.4039	0.012
σ%		23	23	24	45	0.4
			Distance, Charge to Gage, 14.47 ft (λ = 7.24)			
	56	410	100	4.5	0.640	3.54
	57	200	150	3.5	1.456	3.59
	58	450	120	5.0	0.719	3.57
Average		350	120	4.3	0.938	3.57
σ		78	22	0.4	0.2598	0.015
σ_m%		22	18	10	28	0.4
σ_m		130	38	0.8	0.4500	0.026
σ%		38	32	18	48	0.7
			Distance, Charge to Gage, 15.18 ft (λ = 7.59)			
	38	410	100	4.0	0.704	3.66
	56	320	100	2.5	0.722	3.63
	57	240	110	2.5	1.306	3.71
	58	460	220	7.0	1.812	3.71
Average		360	130	4.0	1.136	3.68
σ		49	29	1.1	0.2658	0.020
σ_m%		14	22	26	23	0.5
σ_m		97	59	2.1	0.5316	0.040
σ%		27	45	53	47	1.1
			Distance, Charge to Gage, 15.90 ft (λ = 7.95)			
	57	240	150	1.5	1.368	3.80

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Table 13

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft — Gages at One-Quarter Depth

Air Content of Screen, 0.0014 cfs of Air per sq ft of Screen — Stand-Off Distance, 12 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.97 ft (λ = 5.48)*			
	41	2300	240	40	0.51	1.99
	44	2500	150	25	0.32	2.08
	61	3100	380	88	0.65	1.99
Average		2600	260	51	0.49	2.02
σ		240	67	19	0.096	0.030
σ_m%		9.3	26	37	20	1.5
σ^m		420	120	33	0.166	0.052
σ%		16	45	64	34	2.6
			Distance, Charge to Gage, 11.65 ft (λ = 5.82)*			
	41	2500	280	56	0.69	2.11
	44	3000	310	66	0.63	2.21
	61	3000	330	97	0.68	2.14
Average		2800	310	73	0.67	2.15
σ		170	15	12	0.019	0.030
σ_m%		6.0	4.7	17	2.8	1.4
σ^m		290	26	21	0.032	0.051
σ%		10	8.2	29	4.8	2.4
			Distance, Charge to Gage, 12.35 ft (λ = 6.18)*			
	44	2600	300	65	0.70	2.32
	61	2700	290	72	0.64	2.36
Average		2600	300	68	0.67	2.34
			Distance, Charge to Gage, 13.05 ft (λ = 6.52)			
	41	2600	290	62	0.406	2.37
	44	2800	200	55	0.187	2.45
	61	2600	270	56	0.435	2.49
Average		2700	250	58	0.343	2.44
σ		71	27	2.2	0.0783	0.035
σ_m%		2.6	11	3.8	23	1.4
σ^m		120	48	3.8	0.1356	0.061
σ%		4.5	19	6.6	40	2.5
			Distance, Charge to Gage, 13.76 ft (λ = 6.88)			
	41	2100	260	45	0.493	2.67
	44	2400	180	38	0.402	2.59
	61	2800	280	52	0.607	2.62
Average		2400	240	45	0.501	2.63
σ		200	30	4.0	0.0593	0.023
σ_m%		8.5	13	9.0	12	0.9
σ^m		350	53	7.0	0.1028	0.041
σ%		15	22	16	20	1.5

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 13 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 14.47 ft (λ = 7.24)			
	41	2100	260	48	0.622	2.80
	44	1300	230	22	0.684	2.73
	61	2900	240	45	0.425	2.82
Average		2100	240	38	0.577	2.78
σ		460	9.1	8.2	0.0781	0.027
σ^m%		22	3.8	22	14	1.0
σ^m		800	16	14	0.1353	0.047
σ%		38	6.6	37	23	1.7
			Distance, Charge to Gage, 15.18 ft (λ = 7.59)			
	41	2100	200	21	0.600	3.01
	44	1500	300	28	0.632	2.99
Average		1800	250	24	0.616	3.00
			Distance, Charge to Gage, 15.90 ft (λ = 7.95)			
	41	1900	280	30	0.690	3.16
	61	2400	220	42	0.488	3.13
Average		2200	250	36	0.589	3.14
			Distance, Charge to Gage, 16.62 ft (λ = 8.31)			
	44	1100	260	28	0.682	3.36
	61	1600	160	18	0.468	3.30
Average		1400	210	23	0.575	3.33
			Distance, Charge to Gage, 17.34 ft (λ = 8.67)			
	41	1500	160	20	0.486	3.49
	44	1100	160	18	0.514	3.46
	61	1500	150	22	0.392	3.45
Average		1400	160	20	0.464	3.47
σ		140	4.1	1.2	0.0369	0.012
σ^m%		9.7	2.6	5.8	7.9	0.4
σ^m		230	7.1	2.0	0.0639	0.021
σ%		17	4.4	10	14	0.6
			Distance, Charge to Gage, 18.07 ft (λ = 9.04)			
	41	1100	180	15	0.472	3.62
	44	1500	170	22	0.380	3.67
	61	1500	180	25	0.342	3.59
Average		1400	180	21	0.398	3.63
σ		140	4.1	3.0	0.0386	0.023
σ^m%		9.7	2.3	14	9.7	0.6
σ^m		230	7.1	5.1	0.0669	0.041
σ%		17	3.9	24	17	1.1
			Distance, Charge to Gage, 18.80 ft (λ = 9.40)			
	41	950	180	16	0.438	3.76
	44	1500	170	23	0.344	3.81
	61	1200	140	12	0.480	3.76
Average		1200	160	17	0.421	3.78
σ		160	12	3.2	0.0402	0.017
σ^m%		13	7.6	19	9.6	0.4
σ^m		280	21	5.6	0.0697	0.029
σ%		23	13	33	17	0.8

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Table 13 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 19.53 ft (λ = 9.76)			
	44	1200	160	16	0.500	3.98
	61	1300	140	17	0.549	3.93
Average		1200	150	16	0.524	3.96
			Distance, Charge to Gage, 20.26 ft (λ = 10.13)			
	41	940	160	17	0.442	4.08
	61	1300	140	16	0.540	4.09
Average		1100	150	16	0.491	4.08
			Distance, Charge to Gage, 20.99 ft (λ = 10.50)			
	41	740	140	9.0	0.525	4.26
	44	1200	140	12	0.493	4.24
Average		970	140	10	0.509	4.25
			Distance, Charge to Gage, 21.72 ft (λ = 10.86)			
	44	970	95	6.0	0.607	4.33

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Table 14

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft — Gages at One-Quarter Depth

Air Content of Screen, 0.0044 cfs of Air per sq ft of Screen — Stand-Off Distance, 12 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.97 ft (λ = 5.48)*			
	42	3200	300	73	0.53	2.02
	62	3300	380	110	0.66	2.08
Average		3200	340	92	0.60	2.05
			Distance, Charge to Gage, 11.65 ft (λ = 5.82)*			
	42	3700	360	100	0.60	2.15
	45	3000	320	83	0.66	2.24
	62	2900	320	75	0.62	2.19
Average		3200	330	86	0.63	2.19
σ		250	14	7.4	0.018	0.026
σ_m%		7.9	4.1	8.6	2.8	1.2
σ_m		440	23	13	0.031	0.045
σ%		14	7.1	15	4.9	2.1
			Distance, Charge to Gage, 12.35 ft (λ = 6.18)*			
	45	2600	310	69	0.73	2.38
	62	2400	270	60	0.60	2.38
Average		2500	290	64	0.66	2.38
			Distance, Charge to Gage, 13.05 ft (λ = 6.52)			
	42	3000	330	100	0.360	2.42
	62	2400	220	50	0.348	2.52
Average		2700	280	75	0.354	2.47
			Distance, Charge to Gage, 13.76 ft (λ = 6.88)			
	42	2500	160	36	0.218	2.59
	45	2400	220	52	0.239	2.66
	62	1800	180	36	0.356	2.64
Average		2200	190	41	0.271	2.63
σ		220	18	5.3	0.0429	0.021
σ_m%		10	9.4	13	16	0.8
σ_m		380	31	9.2	0.0743	0.036
σ%		17	16	23	27	1.4
			Distance, Charge to Gage, 14.47 ft (λ = 7.24)			
	45	2500	160	35	0.156	2.80
	62	1600	140	22	0.351	2.82
Average		2000	150	28	0.254	2.81
			Distance, Charge to Gage, 15.18 ft (λ = 7.59)			
	45	2300	120	28	0.220	2.93
	62	1800	200	18	0.706	3.04
Average		2000	160	23	0.463	2.98

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 14 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 15.90 ft (λ = 7.95)			
	42	880	160	15	0.458	3.45
	62	540	140	9.0	0.731	3.17
Average		710	150	12	0.594	3.31
			Distance, Charge to Gage, 16.62 ft (λ = 8.31)			
	45	1200	130	12	0.421	3.58
	62	570	150	9.0	0.570	3.29
Average		880	140	10	0.496	3.44
			Distance, Charge to Gage, 17.34 ft (λ = 8.67)			
	42	900	230	20	0.640	3.75
	45	710	110	6.5	0.464	3.64
	62	560	140	3.5	0.572	3.43
Average		720	160	10	0.559	3.61
σ		98	36	5.1	0.0513	0.094
σ_m%		14	23	51	9.2	2.6
σ^m		170	62	8.8	0.0888	0.163
σ%		24	39	88	16	4.5
			Distance, Charge to Gage, 18.07 ft (λ = 9.04)			
	42	900	140	11	0.532	3.85
	45	680	100	4.0	0.562	3.76
	62	660	160	13	0.578	3.58
Average		750	130	9.3	0.557	3.73
σ		77	18	2.7	0.0134	0.054
σ_m%		10	14	29	2.4	1.5
σ^m		130	31	4.7	0.0232	0.094
σ%		18	24	51	4.2	2.5
			Distance, Charge to Gage, 18.80 ft (λ = 9.40)			
	42	800	120	8.5	0.470	3.96
	45	610	130	7.5	0.535	3.86
	62	610	120	9.5	0.516	3.71
Average		670	120	8.5	0.507	3.84
σ		63	4.1	0.6	0.0192	0.073
σ_m%		9.5	3.4	6.8	3.8	1.9
σ^m		110	7.1	1.0	0.0333	0.126
σ%		16	5.9	12	6.6	3.3
			Distance, Charge to Gage, 19.53 ft (λ = 9.76)			
	45	580	130	4.5	0.696	
	62	560	110	9.0	0.436	3.90
Average		570	120	6.8	0.566	3.90

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Table 14 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 20.26 ft (λ = 10.13)			
	42	690	140	10	0.486	4.25
	45	440	130	3.0	0.716	
	62	540	120	7.5	0.654	4.04
Average		560	130	6.8	0.619	4.14
σ		73	5.8	2.0	0.0687	
σ_m%		13	4.5	30	11	
σ_m		130	10	3.6	0.1190	
σ%		23	7.7	52	19	
			Distance, Charge to Gage, 20.99 ft (λ = 10.50)			
	42	520	110	6.0	0.470	
	45	560	120	3.5	0.626	
Average		540	120	4.8	0.548	

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Table 15

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft

Air Content of Screen, 0.035 cfs of Air per sq ft of Screen

Gages at One-Quarter Depth

Stand-Off Distance, 12 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.97 ft (λ = 5.48)*			
	43	2400	260	42	0.53	2.07
	63	3200	360	96	0.65	2.15
Average		2800	310	69	0.59	2.11
			Distance, Charge to Gage, 11.65 ft (λ = 5.82)*			
	43	2800	340	67	0.60	2.23
	46	3000	290	68	0.62	2.29
	63	3000	300	86	0.55	2.29
Average		2900	310	74	0.59	2.27
σ		71	15	6.2	0.021	0.020
σ_m%		2.4	4.9	8.4	3.5	0.9
σ_m		120	26	11	0.036	0.035
σ%		4.2	8.5	14	6.1	1.5
			Distance, Charge to Gage, 12.35 ft (λ = 6.18)*			
	43	2800	280	72	0.67	2.39
	46	2500	220	53	0.62	2.46
	63	1400	120	10	0.42	2.46
Average		2200	210	45	0.57	2.44
σ		430	47	18	0.076	0.023
σ_m%		19	22	41	13	1.0
σ_m		740	81	32	0.132	0.041
σ%		34	38	71	23	1.7
			Distance, Charge to Gage, 13.76 ft (λ = 6.88)			
	43	1900	100	27	0.105	2.68
	46	2400	120	33	0.114	2.74
Average		2200	110	30	0.110	2.71
			Distance, Charge to Gage, 14.47 ft (λ = 7.24)			
	43	1800	43	14	0.062	2.83
	46	1300	55	9.0	0.158	2.89
Average		1600	49	12	0.110	2.86
			Distance, Charge to Gage, 15.18 ft (λ = 7.59)			
	46	240	38	1.0	0.470	3.47
	63	460	120	4.0	1.054	3.94
Average		350	79	2.5	0.762	3.70
			Distance, Charge to Gage, 15.90 ft (λ = 7.95)			
	43	170	75	1.0	0.867	4.49
	63	380	110	3.0	1.343	4.00
Average		280	92	2.0	1.105	4.24

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 15 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 16.62 ft (λ = 8.31)			
	63	170	32	0.5	0.641	4.48
			Distance, Charge to Gage, 17.34 ft (λ = 8.67)			
	43	320	120	3.0	1.300	5.03
	46	210	65	1.5	0.618	4.88
	63	190	100	2.0	1.344	4.61
Average		240	95	2.2	1.087	4.84
σ		40	16	0.4	0.2349	0.123
σ_m%		17	17	20	22	2.5
σ_m		70	28	0.8	0.4069	0.2129
σ%		29	29	35	37	4.4
			Distance, Charge to Gage, 18.07 ft (λ = 9.04)			
	43	240	120	2.5	1.575	5.10
	46	210	95	2.0	1.200	5.42
	63	150	70	1.0	1.272	5.16
Average		200	95	1.8	1.349	5.23
σ		26	14	0.4	0.1149	0.098
σ_m%		13	15	25	8.5	1.9
σ_m		46	25	0.8	0.1990	0.170
σ%		23	26	42	15	3.3
			Distance, Charge to Gage, 18.80 ft (λ = 9.40)			
	43	210	80	1.0	1.188	5.37
	46	180	70	1.0	1.078	5.50
	63	160	75	1.5	1.220	5.51
Average		180	75	1.2	1.162	5.46
σ		15	2.9	0.2	0.0430	0.045
σ_m%		8.2	3.9	14	3.7	0.8
σ_m		26	5.0	0.3	0.0745	0.078
σ%		14	6.7	24	6.4	1.4
			Distance, Charge to Gage, 19.53 ft (λ = 9.76)			
	46	220	150	2.5	2.210	5.55
	63	150	49	1.0	0.828	5.59
Average		180	100	1.8	1.519	5.57
			Distance, Charge to Gage, 20.26 ft (λ = 10.13)			
	43	170	85	1.5	1.196	5.47
	63	140	50	0.5	0.834	5.80
Average		160	68	1.0	1.015	5.64
			Distance, Charge to Gage, 20.99 ft (λ = 10.50)			
	43	160	90	1.5	1.442	5.64
	46	170	85	1.0	1.614	5.30
Average		160	88	1.2	1.528	5.47
			Distance, Charge to Gage, 21.72 ft (λ = 10.86)			
	46	110	50	0.5	1.207	5.63
	63	260	160	5.5	1.462	5.40
Average		180	100	3.0	1.334	5.52

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Table 16

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft

Air Content of Screen, 0.0014 cfs of Air per sq ft of Screen

Gages, 0.25 ft Below Water Surface

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 9.62 ft (λ = 4.81)			
	92	3800	100	92	0.045	1.75
	93	2900	100	55	0.053	1.76
Average		3400	100	74	0.049	1.76
			Distance, Charge to Gage, 9.96 ft (λ = 4.98)			
	92	3100	90	61	0.044	1.82
	93	3100	80	49	0.045	1.81
Average		3100	85	55	0.044	1.82
			Distance, Charge to Gage, 10.34 ft (λ = 5.17)			
	92	4700	90	64	0.065	1.91
	93	3600	110	63	0.052	2.03
Average		4200	100	64	0.058	1.97
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	92	2600	65	31	0.065	2.04
	93	3200	100	52	0.046	2.10
Average		2900	82	42	0.056	2.07
			Distance, Charge to Gage, 11.21 ft (λ = 5.60)			
	92	2700	48	20	0.083	2.14
	93	3000	90	34	0.048	2.14
Average		2800	69	27	0.066	2.14
			Distance, Charge to Gage, 11.69 ft (λ = 5.84)			
	92	2400	45	18	0.070	2.24
	93	2800	80	30	0.048	2.23
Average		2600	62	24	0.059	2.24
			Distance, Charge to Gage, 12.20 ft (λ = 6.10)			
	92	1900	65	24	0.063	2.36
	93	2500	90	34	0.054	2.37
Average		2200	78	29	0.058	2.36
			Distance, Charge to Gage, 12.73 ft (λ = 6.36)			
	92	2000	50	17	0.062	2.46
	93	2700	60	21	0.050	2.44
Average		2400	55	19	0.056	2.45

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Table 16 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 13.29 ft (λ = 6.64)			
	92	1500	55	14	0.065	2.58
			Distance, Charge to Gage, 13.86 ft (λ = 6.93)			
	92	1400	44	10	0.070	2.63
	93	1200	55	10	0.139	2.66
Average		1300	50	10	0.104	2.64
			Distance, Charge to Gage, 14.45 ft (λ = 7.22)			
	92	1500	43	11	0.076	2.76
	93	1300	34	4.0	0.139	2.79
Average		1400	38	7.5	0.108	2.78
			Distance, Charge to Gage, 15.05 ft (λ = 7.52)			
	92	1200	35	9.5	0.082	2.88
	93	1500	43	7.5	0.084	2.98
Average		1400	39	8.5	0.083	2.93
			Distance, Charge to Gage, 15.67 ft (λ = 7.84)			
	92	1400	46	9.5	0.090	3.06
	93	1400	50	8.5	0.098	3.06
Average		1400	48	9.0	0.094	3.06
			Distance, Charge to Gage, 16.30 ft (λ = 8.15)			
	92	1000	36	8.5	0.068	3.17
	93	1500	50	8.5	0.080	3.17
Average		1200	43	8.5	0.074	3.17
			Distance, Charge to Gage, 16.94 ft (λ = 8.47)			
	92	1000	33	7.5	0.059	3.31
			Distance, Charge to Gage, 17.58 ft (λ = 8.79)			
	92	710	26	5.0	0.064	3.42
	93	830	22	2.0	0.090	3.36
Average		770	24	3.5	0.077	3.39

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Table 17

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft

Air Content of Screen, 0.0044 cfs of Air per sq ft of screen

Gages, 0.25 ft Below Water Surface

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 9.62 ft (λ = 4.81)			
	95	3400	120	86	0.080	1.74
			Distance, Charge to Gage, 9.96 ft (λ = 4.98)			
	94	2600	75	36	0.088	1.89
	95	3200	130	64	0.080	1.82
Average		2900	100	50	0.084	1.86
			Distance, Charge to Gage, 10.34 ft (λ = 5.17)			
	94	1700	70	19	0.079	1.96
	95	3700	140	56	0.074	1.89
Average		2700	100	38	0.076	1.92
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	94	1900	47	16	0.068	2.12
	95	3500	120	50	0.067	1.97
Average		2700	84	33	0.068	2.04
			Distance, Charge to Gage, 11.21 ft (λ = 5.60)			
	95	1900	75	24	0.080	2.10
			Distance, Charge to Gage, 11.69 ft (λ = 5.84)			
	94	1700	55	15	0.072	2.30
	95	2400	50	14	0.080	2.20
Average		2000	52	14	0.076	2.25
			Distance, Charge to Gage, 12.20 ft (λ = 6.10)			
	94	1700	60	14	0.078	2.33
	95	1100	34	4.0	0.155	2.38
Average		1400	47	9.0	0.116	2.36
			Distance, Charge to Gage, 12.73 ft (λ = 6.36)			
	94	1300	50	10	0.072	2.53
	95	810	24	3.0	0.086	2.59
Average		1000	37	6.5	0.079	2.56
			Distance, Charge to Gage, 13.29 ft (λ = 6.64)			
	94	890	41	7.5	0.077	2.62
	95	680	29	3.5	0.120	2.63
Average		780	35	5.5	0.098	2.62

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Table 17 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 13.86 ft (λ = 6.93)			
	94	950	42	7.5	0.078	2.80
	95	570	38	3.5	0.214	2.67
Average		760	40	5.5	0.146	2.74
			Distance, Charge to Gage, 14.45 ft (λ = 7.22)			
	94	910	36	4.0	0.080	2.81
	95	570	38	2.5	0.210	2.79
Average		740	37	3.2	0.145	2.80
			Distance, Charge to Gage, 15.05 ft (λ = 7.52)			
	94	1300	36	6.0	0.081	2.94
	95	510	46	2.5	0.190	2.90
Average		900	41	4.2	0.136	2.92
			Distance, Charge to Gage, 15.67 ft (λ = 7.84)			
	94	1000	29	4.0	0.087	3.02
	95	510	30	2.0	0.142	3.02
Average		760	30	3.0	0.114	3.02
			Distance, Charge to Gage, 16.30 ft (λ = 8.15)			
	94	1100	32	5.0	0.108	3.12
	95	660	32	3.0	0.112	3.16
Average		880	32	4.0	0.110	3.14
			Distance, Charge to Gage, 16.94 ft (λ = 8.47)			
	94	990	23	3.0	0.050	3.32
	95	670	30	2.5	0.116	3.34
Average		830	26	2.8	0.083	3.33
			Distance, Charge to Gage, 17.58 ft (λ = 8.79)			
	94	620	14	1.5	0.044	3.44
	95	360	18	1.0	0.092	3.46
Average		490	16	1.2	0.068	3.45

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Table 18

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft

Air Content of Screen, 0.035 cfs of Air per sq ft of Screen

Gages, 0.25 ft Below Water Surface

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 9.62 ft (λ = 4.81)			
	96	1600	55	15	0.119	1.81
	97	2000	60	10	0.118	1.88
Average		1800	58	12	0.118	1.84
			Distance, Charge to Gage, 9.96 ft (λ = 4.98)			
	96	1400	55	15	0.176	1.95
	97	1200	42	3.5	0.166	1.93
Average		1300	48	9.2	0.171	1.94
			Distance, Charge to Gage, 10.34 ft (λ = 5.17)			
	96	1300	55	10	0.174	2.16
	97	1900	160	19	0.536	2.12
Average		1600	110	14	0.355	2.14
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	96	510	18	3.0	0.092	2.40
	97	140	31	0.5	0.401	2.52
Average		320	24	1.8	0.246	2.46
			Distance, Charge to Gage, 11.21 ft (λ = 5.60)			
	96	120	12	0.5	0.233	2.48
	97	38	16	0.1	0.722	2.82
Average		79	14	0.3	0.478	2.65
			Distance, Charge to Gage, 11.69 ft (λ = 5.84)			
	96	99	14	5.5	0.296	2.82
	97	84	60	0.5	1.622	3.99
Average		92	37	3.0	0.959	3.40

Note: The records obtained from the remaining gages in this test configuration were too small and erratic to evaluate.

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Table 19

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft

Air Content of Screen, 0.0014 cfs of Air per sq ft of Screen

Gages, 0.25 ft Below Water Surface

Stand-Off Distance, 12 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 13.29 ft (λ = 6.64)			
	87	2600	75	28	0.044	2.58
	88	2500	65	28	0.039	2.54
	98	2100	65	27	0.053	2.49
	99	1900	70	32	0.058	2.48
Average		2300	69	29	0.048	2.52
σ_m		170	2.4	1.1	0.041	0.023
σ_m%		7.2	3.5	3.9	8.6	0.9
σ		330	4.8	2.2	0.0082	0.046
σ%		14	7.0	7.7	17	1.8
			Distance, Charge to Gage, 13.86 ft (λ = 6.93)			
	87	2600	65	31	0.048	2.69
	88	2500	55	20	0.039	2.66
	98	2300	70	30	0.056	2.55
	99	2300	70	28	0.058	2.57
Average		2400	65	27	0.050	2.62
σ_m		76	3.5	2.5	0.0044	0.034
σ_m%		3.2	5.4	9.2	8.7	1.3
σ		150	7.0	5.0	0.0087	0.068
σ%		6.4	11	18	17	2.6
			Distance, Charge to Gage, 14.45 ft (λ = 7.22)			
	87	2700	65	26	0.040	2.81
	88	2400	55	20	0.033	2.79
	99	2400	75	28	0.048	2.69
Average		2500	65	25	0.040	2.76
σ_m		100	5.8	2.4	0.0044	0.037
σ_m%		4.0	8.9	9.6	11	1.3
σ		170	10	4.2	0.0076	0.064
σ%		6.9	15	17	19	2.3
			Distance, Charge to Gage, 15.05 ft (λ = 7.52)			
	87	2300	65	26	0.047	2.92
	88	2600	50	20	0.040	2.92
	98	2600	65	26	0.042	2.79
	99	2500	75	30	0.050	2.79
Average		2500	64	26	0.045	2.86
σ_m		71	5.2	2.1	0.0022	0.038
σ_m%		2.8	8.1	8.0	5.0	1.3
σ		140	10	4.2	0.0045	0.075
σ%		5.7	16	16	10	2.6

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Table 19 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 15.67 ft (λ = 7.84)			
	87	1200	40	12	0.103	2.98
	88	1500	31	5.5	0.041	2.98
	98	2000	55	16	0.043	2.91
	99	2000	50	16	0.057	2.88
Average		1700	44	12	0.061	2.94
σ_m		200	5.3	2.5	0.0145	0.025
σ_m%		12	12	21	24	0.9
σ		400	11	5.0	0.0290	0.051
σ%		23	24	42	48	1.7
			Distance, Charge to Gage, 16.30 ft (λ = 8.15)			
	87	940	18	6.5	0.068	3.16
	88	1200	32	5.5	0.094	3.13
	98	2000	48	14	0.050	3.04
	99	1100	32	8.0	0.078	3.01
Average		1300	32	8.5	0.072	3.08
σ_m		240	6.1	1.9	0.0092	0.036
σ_m%		18	19	22	13	1.2
σ		470	12	3.8	0.0184	0.072
σ%		36	38	45	26	2.3
			Distance, Charge to Gage, 16.94 ft (λ = 8.47)			
	87	650	45	5.5	0.185	3.38
	88	990	32	4.0	0.074	3.28
	98	1100	34	7.5	0.101	3.19
	99	770	22	3.0	0.138	3.19
Average		880	33	5.0	0.124	3.26
σ_m		100	4.7	1.0	0.0241	0.045
σ_m%		12	14	20	19	1.4
σ		200	9.4	2.0	0.0482	0.091
σ%		23	28	39	39	2.8
			Distance, Charge to Gage, 17.58 ft (λ = 8.79)			
	87	490	22	7.0	0.112	3.50
	88	930	27	4.0	0.078	3.40
	98	520	27	3.5	0.094	3.37
	99	390	16	2.0	0.114	3.33
Average		580	23	4.1	0.100	3.40
σ_m		120	2.6	1.0	0.0085	0.036
σ_m%		20	11	26	8.5	1.1
σ		240	5.2	2.1	0.0170	0.073
σ%		41	23	51	17	2.1

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Table 19 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 18.24 ft (λ = 9.12)			
	88	730	16	2.0	0.084	3.58
	98	620	20	2.0	0.068	3.47
	99	320	18	2.5	0.222	3.54
Average		560	18	2.2	0.125	3.53
σ		120	1.2	0.2	0.0489	0.032
σ_m%		22	6.7	7.6	39	0.9
σ_m		210	2.1	0.3	0.0847	0.056
σ%		38	12	13	68	1.6
			Distance, Charge to Gage, 18.90 ft (λ = 9.45)			
	87	540	18	3.0	0.128	3.69
	88	740	18	2.0	0.068	3.71
	98	590	16	2.0	0.062	3.68
	99	370	10	1.0	0.081	3.74
Average		560	16	2.0	0.085	3.70
σ		76	1.9	0.4	0.0148	0.014
σ_m%		14	12	20	17	0.4
σ_m		150	3.8	0.8	0.0300	0.027
σ%		27	24	41	35	0.7
			Distance, Charge to Gage, 19.56 ft (λ = 9.78)			
	87	530	12	3.0	0.082	3.85
	88	510	13	1.0	0.058	3.80
	98	420	17	2.0	0.163	3.81
	99	430	21	1.5	0.172	3.98
Average		470	16	1.9	0.119	3.86
σ		28	2.1	0.4	0.0286	0.041
σ_m%		5.9	13	22	24	1.1
σ_m		56	4.2	0.8	0.0573	0.083
σ%		12	26	45	48	2.1
			Distance, Charge to Gage, 20.24 ft (λ = 10.12)			
	87	550	12	2.0	0.072	3.95
	88	440	12	2.5	0.065	3.98
	98	410	22	2.0	0.192	4.00
	99	570	24	2.5	0.106	4.06
Average		490	18	2.2	0.109	4.00
σ		40	3.2	0.1	0.0292	0.023
σ_m%		8.1	18	6.7	27	0.6
σ_m		79	6.4	0.3	0.0583	0.046
σ%		16	36	13	54	1.2

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Table 19 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure No.	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 20.92 ft (λ = 10.46)			
	87	380	8.0	1.0	0.066	4.11
	98	340	19	1.0	0.170	4.16
	99	480	21	2.0	0.112	4.16
Average		400	16	1.3	0.116	4.14
σ_m		42	4.0	0.3	0.0301	0.017
σ_m%		10	25	26	26	0.4
σ		72	6.9	0.6	0.0521	0.029
σ%		18	43	44	45	0.7
			Distance, Charge to Gage, 21.60 ft (λ = 10.80)			
	87	430	8.5	1.0	0.074	4.23
	88	310	8.0	0.5	0.068	4.24
	98	360	21	1.0	0.143	4.23
	99	450	17	1.0	0.091	4.29
Average		390	14	0.9	0.094	4.25
σ_m		32	3.2	0.1	0.0170	0.014
σ_m%		8.3	23	14	18	0.3
σ		65	6.4	0.2	0.0341	0.029
σ%		17	46	28	36	0.7
			Distance, Charge to Gage, 22.29 ft (λ = 11.14)			
	87	360	8.5	0.5	0.069	4.45
	88	270	7.5	0.5	0.059	4.40
	98	300	20	1.0	0.116	4.44
	99	550	14	1.0	0.092	4.39
Average		370	12	0.8	0.084	4.42
σ_m		63	2.9	0.1	0.0127	0.015
σ_m%		17	24	18	15	0.3
σ		120	5.8	0.3	0.0255	0.029
σ%		34	48	37	30	0.7
			Distance, Charge to Gage, 22.98 ft (λ = 11.49)			
	87	420	10	1.5	0.069	4.53
	88	360	14	0.5	0.074	4.53
	98	260	12	0.5	0.109	4.56
	99	230	8.0	0.5	0.082	4.50
Average		320	11	0.8	0.084	4.53
σ_m		44	1.3	0.2	0.0095	0.012
σ_m%		14	12	32	11	0.3
σ		88	2.6	0.5	0.0189	0.024
σ%		28	24	63	22	0.5

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Table 20

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft

Air Content of Screen, 0.0044 cfs of Air per sq ft of Screen

Gages, 0.25 ft Below Water Surface

Stand-Off Distance, 12 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 13.29 ft (λ = 6.64)			
	100	2600	95	45	0.062	2.50
	101	2400	100	42	0.066	2.50
Average		2500	98	44	0.064	2.50
			Distance, Charge to Gage, 13.86 ft (λ = 6.93)			
	100	2400	70	34	0.057	2.60
	101	2500	75	38	0.062	2.62
Average		2400	72	36	0.060	2.61
			Distance, Charge to Gage, 14.45 ft (λ = 7.22)			
	100	2100	75	26	0.057	2.67
	101	2400	70	22	0.078	2.71
Average		2200	72	24	0.068	2.69
			Distance, Charge to Gage, 15.05 ft (λ = 7.52)			
	100	2800	70	27	0.083	2.80
	101	1300	44	8.0	0.103	2.86
Average		2000	57	18	0.093	2.83
			Distance, Charge to Gage, 15.67 ft (λ = 7.84)			
	100	1500	33	7.0	0.078	2.93
	101	460	20	2.0	0.138	3.04
Average		980	26	4.5	0.108	2.98
			Distance, Charge to Gage, 16.30 ft (λ = 8.15)			
	100	490	8.5	1.0	0.072	3.05
	101	210	9.5	2.0	0.123	3.24
Average		350	9.0	1.5	0.098	3.14
			Distance, Charge to Gage, 16.94 ft (λ = 8.47)			
	100	330	26	2.0	0.215	3.48
	101	310	36	1.5	0.370	3.34
Average		320	31	1.8	0.292	3.41
			Distance, Charge to Gage, 17.58 ft (λ = 8.79)			
	100	380	24	2.0	0.166	3.69
	101	450	32	2.0	0.296	3.45
Average		420	28	2.0	0.231	3.57

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Table 20 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 18.24 ft (λ = 9.12)			
	101	430	28	2.0	0.248	3.63
			Distance, Charge to Gage, 18.90 ft (λ = 9.45)			
	100	330	16	1.5	0.115	3.83
	101	560	30	2.5	0.160	3.81
Average		440	23	2.0	0.138	3.82
			Distance, Charge to Gage, 19.56 ft (λ = 9.78)			
	100	270	14	0.5	0.166	3.85
	101	480	26	2.0	0.148	3.89
Average		380	20	1.2	0.157	3.87
			Distance, Charge to Gage, 20.24 ft (λ = 10.12)			
	100	320	17	1.0	0.208	3.97
	101	640	28	2.5	0.131	4.04
Average		480	22	1.8	0.170	4.00
			Distance, Charge to Gage, 20.92 ft (λ = 10.46)			
	100	280	13	0.5	0.196	4.10
	101	510	20	1.5	0.123	4.20
Average		400	16	1.0	0.160	4.15
			Distance, Charge to Gage, 21.60 ft (λ = 10.80)			
	100	300	14	0.5	0.174	4.24
	101	530	20	1.0	0.140	4.37
Average		420	17	0.8	0.157	4.30
			Distance, Charge to Gage, 22.29 ft (λ = 11.14)			
	100	270	14	0.5	0.160	4.36
	101	480	16	0.5	0.118	4.45
Average		380	15	0.5	0.139	4.40
			Distance, Charge to Gage, 22.98 ft (λ = 11.49)			
	100	160	6.5	0.2	0.146	4.51
	101	200	9.0	0.2	0.098	4.63
Average		180	7.8	0.2	0.122	4.57

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Table 21

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Results of Water-Shock Measurements

Bubble Screen Thickness, 3 ft

Air Content of Screen, 0.035 cfs of Air per sq ft of Screen

Gages, 0.25 ft Below Water Surface

Stand-Off Distance, 12 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 13.29 ft (λ = 6.64)			
	84	900	30	4.5	0.132	2.78
	89	1700	55	22	0.140	2.68
	90	1800	80	18	0.110	2.04
	103	1200	32	3.5	0.176	2.49
Average		1400	49	12	0.140	2.50
σ		210	12	4.7	0.0137	0.164
σ_m%		15	24	39	9.8	6.6
σ_m		420	23	9.4	0.0274	0.328
σ%		30	48	78	20	13
			Distance, Charge to Gage, 13.86 ft (λ = 6.93)			
	89	1400	36	13	0.114	2.78
	103	920	34	2.5	0.244	2.65
Average		1200	35	7.8	0.179	2.72
			Distance, Charge to Gage, 14.45 ft (λ = 7.22)			
	84	480	30	4.0	0.216	3.00
	89	760	30	8.5	0.150	2.89
	103	280	32	1.0	0.554	2.96
Average		510	31	4.5	0.307	2.95
σ		140	0.7	2.2	0.1251	0.032
σ_m%		27	2.3	48	41	1.1
σ_m		240	1.2	3.8	0.2167	0.056
σ%		47	4.0	84	71	1.9
			Distance, Charge to Gage, 15.05 ft (λ = 7.52)			
	84	240	19	1.5	0.184	3.30
	89	350	60	10	0.353	3.11
	103	200	30	0.5	0.570	3.60
Average		260	36	4.0	0.369	3.34
σ		45	12	3.0	0.1117	0.143
σ_m%		17	33	75	30	4.3
σ_m		78	21	5.2	0.1935	0.247
σ%		30	59	130	52	7.4
			Distance, Charge to Gage, 15.67 ft (λ = 7.84)			
	103	50	16	0.1	0.684	4.16
			Distance, Charge to Gage, 16.30 ft (λ = 8.15)			
	103	24	19	0.1	0.980	4.92
			Distance, Charge to Gage, 16.94 ft (λ = 8.47)			
	103	44	26	0.2	1.252	5.75
			Distance, Charge to Gage, 17.58 ft (λ = 8.79)			
	103	59	20	0.1	0.902	7.08

Note: The records obtained from the remaining gages in this test configuration were too small and erratic to evaluate.

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Table 22

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Results of Water-Shock Measurements

Bubble Screen Thickness, 1.5 ft

Air Content of Screen, 0.0028 cfs of Air per sq ft of Screen

Gages at Middepth

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb/-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 4.00 ft (λ = 2.00)*			
	72	8800	700	560	0.44	0.67
	77	9900	800	600	0.49	0.65
Average		9400	750	580	0.46	0.66
			Distance, Charge to Gage, 4.75 ft (λ = 2.38)*			
	72	8400	750	530	0.52	0.80
	77	8500	650	520	0.47	0.82
Average		8400	700	520	0.50	0.81
			Distance, Charge to Gage, 5.50 ft (λ = 2.75)*			
	72	6600	600	320	0.51	0.97
	77	7200	550	330	0.44	0.96
Average		6900	580	320	0.48	0.96
			Distance, Charge to Gage, 6.25 ft (λ = 3.12)			
	72	6000	500	270	0.378	1.10
	77	6500	550	310	0.356	1.11
Average		6200	520	290	0.367	1.10
			Distance, Charge to Gage, 7.00 ft (λ = 3.50)			
	72	5600	550	240	0.540	1.21
	77	5700	460	240	0.374	1.26
Average		5600	500	240	0.457	1.24
			Distance, Charge to Gage, 7.75 ft (λ = 3.88)			
	72	4800	460	170	0.490	1.36
	77	5000	260	110	0.250	1.40
Average		4900	360	140	0.370	1.38
			Distance, Charge to Gage, 8.50 ft (λ = 4.25)			
	72	3600	460	170	0.362	1.46
	77	5000	550	200	0.539	1.58
Average		4300	500	180	0.450	1.52

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 22 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 9.25 ft (λ = 4.62)			
	72	3400	310	120	0.261	1.62
	77	4000	460	140	0.454	1.73
Average		3700	380	130	0.358	1.68
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)			
	72	2900	420	98	0.815	1.90
	77	3400	300	96	0.320	1.91
Average		3200	360	97	0.568	1.90
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	72	2400	260	52	0.405	2.05
	77	2700	260	84	0.298	2.06
Average		2600	260	68	0.352	2.06
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)			
	72	2500	340	78	0.608	2.21
	77	2500	300	64	0.562	2.20
Average		2500	320	71	0.585	2.20
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	72	2300	240	40	0.640	2.34
	77	2200	320	52	0.608	2.36
Average		2200	280	46	0.624	2.35
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	72	2100	360	42	0.953	2.64
	77	1800	330	51	0.728	2.65
Average		2000	340	46	0.840	2.64
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	72	1800	340	37	0.927	2.80
	77	1700	300	39	0.829	2.80
Average		1800	320	38	0.878	2.80
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	72	1600	280	30	0.883	2.94
	77	1400	320	30	0.959	2.95
Average		1500	300	30	0.921	2.94

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Table 23

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Results of Water-Shock Measurements

Bubble Screen Thickness, 1.5 ft — Gages at Middepth

Air Content of Screen, 0.0044 cfs of Air per sq ft of Screen — Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 4.00 ft (λ = 2.00)*			
	73	9100	750	530	0.46	0.67
	75	8800	700	550	0.46	0.69
Average		9000	720	540	0.46	0.68
			Distance, Charge to Gage, 4.75 ft (λ = 2.38)*			
	73	8500	750	510	0.50	0.82
	75	8200	700	470	0.47	0.83
Average		8400	720	490	0.48	0.82
			Distance, Charge to Gage, 5.50 ft (λ = 2.75)*			
	73	6500	600	320	0.58	0.98
	75	7100	600	410	0.55	0.97
Average		6800	600	360	0.56	0.98
			Distance, Charge to Gage, 6.25 ft (λ = 3.12)			
	73	6200	480	320	0.318	1.09
	75	7100	500	340	0.321	1.11
Average		6600	490	330	0.320	1.10
			Distance, Charge to Gage, 7.00 ft (λ = 3.50)			
	73	5800	500	200	0.556	1.31
	75	5700	450	200	0.460	1.24
Average		5800	480	200	0.508	1.28
			Distance, Charge to Gage, 7.75 ft (λ = 3.88)			
	73	5100	460	180	0.580	1.44
	75	4400	420	140	0.474	1.39
Average		4800	440	160	0.527	1.42
			Distance, Charge to Gage, 8.50 ft (λ = 4.25)			
	73	4500	420	150	0.460	1.62
	75	3500	420	140	0.364	1.60
Average		4000	420	140	0.412	1.61
			Distance, Charge to Gage, 9.25 ft (λ = 4.62)			
	73	3800	360	130	0.446	1.70
	75	3400	330	110	0.274	1.75
Average		3600	340	120	0.360	1.72

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 23 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)			
	73	2900	310	88	0.318	1.92
	75	2700	380	90	0.708	1.90
Average		2800	340	89	0.513	1.91
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	73	2700	280	67	0.456	2.09
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)			
	73	2500	440	72	1.312	2.17
	75	2500	370	70	0.897	2.20
Average		2500	400	71	1.104	2.18
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	73	2300	340	46	1.174	2.33
	75	2400	340	62	0.879	2.37
Average		2400	340	54	1.026	2.35
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	73	2200	460	56	1.112	2.63
	75	2400	440	74	1.073	2.66
Average		2300	450	65	1.092	2.64
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	73	1700	330	35	1.012	2.79
	75	1700	310	36	1.004	2.78
Average		1700	320	36	1.008	2.78
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	73	1500	330	36	0.966	2.93
	75	1700	270	28	0.963	2.94
Average		1600	300	32	0.964	2.94

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Table 24

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Results of Water-Shock Measurements

Bubble Screen Thickness, 1.5 ft

Air Content of Screen, 0.035 cfs of Air per sq ft of Screen

Gages at Middepth

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 4.00 ft (λ = 2.00)*			
	74	8800	700	540	0.48	0.67
	76	8000	550	420	0.40	0.68
Average		8400	620	480	0.44	0.68
			Distance, Charge to Gage, 4.75 ft (λ = 2.38)*			
	74	8000	750	430	0.52	0.81
	76	8100	600	380	0.44	0.83
Average		8000	680	400	0.48	0.82
			Distance, Charge to Gage, 5.50 ft (λ = 2.75)*			
	74	7000	500	280	0.45	0.96
	76	7000	400	230	0.32	0.99
Average		7000	450	260	0.38	0.98
			Distance, Charge to Gage, 6.25 ft (λ = 3.12)			
	74	6400	340	280	0.172	1.08
	76	3900	180	98	0.120	1.12
Average		5200	260	190	0.146	1.10
			Distance, Charge to Gage, 7.00 ft (λ = 3.50)			
	74	4200	440	96	0.760	1.27
	76	1700	400	80	0.572	1.28
Average		3000	420	88	0.666	1.28
			Distance, Charge to Gage, 7.75 ft (λ = 3.88)			
	74	2400	470	78	0.882	1.52
	76	1800	280	44	0.627	1.59
Average		2100	380	61	0.754	1.56
			Distance, Charge to Gage, 8.50 ft (λ = 4.25)			
	74	1800	420	58	0.814	1.68
	76	2000	500	64	1.222	1.61
Average		1900	460	61	1.018	1.64
			Distance, Charge to Gage, 9.25 ft (λ = 4.62)			
	74	1900	380	52	0.742	1.84
	76	1600	380	40	1.188	1.76
Average		1800	380	46	0.965	1.80

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 24 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)			
	74	1300	390	38	1.254	1.95
	76	1200	420	45	1.282	1.98
Average		1200	400	42	1.268	1.96
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	74	1300	260	24	0.860	2.14
	76	1100	210	22	0.756	2.15
Average		1200	240	23	0.808	2.14
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)			
	74	1000	270	23	0.868	2.28
	76	1000	260	21	1.044	2.26
Average		1000	260	22	0.956	2.27
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	74	1100	280	23	1.047	2.44
	76	1000	280	22	1.054	2.44
Average		1000	280	22	1.050	2.44
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	74	1000	320	20	1.688	2.74
	76	780	430	23	2.303	2.80
Average		890	380	22	1.996	2.77
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	74	790	240	13	1.654	2.86
	76	650	300	14	1.832	2.93
Average		720	270	14	1.743	2.90
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	74	720	300	14	1.704	3.04
	76	550	220	8.0	1.764	3.18
Average		640	260	11	1.734	3.11

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Table 25

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Results of Water-Shock Measurements

Bubble Screen Thickness, 1.5 ft — Gages at Middepth

Air Content of Screen, 0.069 cfs of Air per sq ft of Screen — Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 4.00 ft (λ = 2.00)*			
	80	7500	600	420	0.44	0.69
	81	8800	700	550	0.46	0.72
Average		8200	650	480	0.45	0.70
			Distance, Charge to Gage, 4.75 ft (λ = 2.38)*			
	80	6900	650	470	0.50	0.82
	81	8400	600	510	0.45	0.85
Average		7600	620	490	0.48	0.84
			Distance, Charge to Gage, 5.50 ft (λ = 2.75)*			
	80	7700	440	290	0.38	0.99
	81	5900	440	230	0.50	1.02
Average		6800	440	260	0.44	1.00
			Distance, Charge to Gage, 6.25 ft (λ = 3.12)			
	80	6500	340	260	0.132	1.12
	81	4000	180	120	0.104	1.14
Average		5200	260	190	0.118	1.13
			Distance, Charge to Gage, 7.00 ft (λ = 3.50)			
	80	3000	150	55	0.225	1.26
	81	1400	550	56	1.215	1.43
Average		2200	350	56	0.720	1.34
			Distance, Charge to Gage, 7.75 ft (λ = 3.88)			
	80	690	300	24	1.137	1.67
	81	1100	360	40	0.970	1.97
Average		900	330	32	1.053	1.82
			Distance, Charge to Gage, 8.50 ft (λ = 4.25)			
	80	1000	320	32	0.785	2.12
			Distance, Charge to Gage, 9.25 ft (λ = 4.62)			
	80	810	300	28	0.776	2.33
	81	1800	280	43	0.687	2.48
Average		1300	290	36	0.732	2.40

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 25 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)			
	80	740	260	21	0.735	2.42
	81	1800	450	40	1.894	2.56
Average		1300	360	30	1.314	2.49
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	80	480	120	7.0	0.747	2.63
	81	1700	340	24	1.958	2.68
Average		1100	230	16	1.352	2.66
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)			
	80	730	190	16	0.616	2.72
	81	1600	420	30	1.993	2.73
Average		1200	300	23	1.304	2.72
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	80	510	110	6.5	0.462	2.88
	81	1300	290	16	1.895	2.88
Average		900	200	11	1.178	2.88
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	80	460	300	14	1.832	2.81
	81	940	270	12	1.830	2.98
Average		700	280	13	1.831	2.90
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	80	460	300	13	1.716	3.17
	81	910	280	15	1.734	3.18
Average		680	290	14	1.725	3.18
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	80	360	220	9.0	1.673	3.39
	81	710	280	13	1.723	3.33
Average		540	250	11	1.698	3.36
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	80	310	160	5.0	1.599	3.50
	81	530	240	9.0	1.918	3.44
Average		420	200	7.0	1.758	3.47

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Table 26

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Results of Water-Shock Measurements

Bubble Screen Thickness, 1.5 ft — Gages at Middepth

Air Content of Screen, 0.0028 cfs of Air per sq ft of Screen — Stand-Off Distance, 12 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)*			
	65	3200	380	100	0.68	1.90
	70	3300	340	88	0.56	1.91
Average		3200	360	94	0.62	1.90
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)*			
	65	3500	380	100	0.58	2.02
	70	3300	390	100	0.64	2.06
Average		3400	380	100	0.61	2.04
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)*			
	65	2900	300	78	0.58	2.20
	70	3100	330	83	0.59	2.23
Average		3000	320	80	0.58	2.22
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	65	2800	280	78	0.354	2.36
	70	3200	280	89	0.257	2.37
Average		3000	280	84	0.306	2.36
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	65	2800	230	66	0.260	2.50
	70	2800	270	62	0.523	2.52
Average		2800	250	64	0.392	2.51
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	65	2100	220	42	0.482	2.66
	70	2600	200	28	0.488	2.68
Average		2400	210	35	0.485	2.67
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	65	2700	220	25	0.402	2.82
	70	2300	260	52	0.441	2.85
Average		2500	240	38	0.422	2.84
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	65	2000	200	34	0.328	2.98
	70	1800	200	33	0.341	3.01
Average		1900	200	34	0.334	3.00

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 26 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 16.00 ft (λ = 8.00)			
	65	1600	190	34	0.323	3.09
	70	1600	220	30	0.562	3.18
Average		1600	200	32	0.442	3.14
			Distance, Charge to Gage, 16.75 ft (λ = 8.38)			
	65	1400	160	27	0.286	3.27
	70	1300	170	21	0.480	3.36
Average		1400	160	24	0.383	3.32
			Distance, Charge to Gage, 17.50 ft (λ = 8.75)			
	70	1500	160	24	0.413	3.49
			Distance, Charge to Gage, 18.25 ft (λ = 9.12)			
	70	1300	140	17	0.411	3.64
			Distance, Charge to Gage, 19.75 ft (λ = 9.88)			
	65	1400	140	20	0.352	3.92
	70	1300	170	16	0.549	3.92
Average		1400	160	18	0.450	3.92
			Distance, Charge to Gage, 20.50 ft (λ = 10.25)			
	65	1300	180	18	0.838	4.07
	70	1100	180	16	0.685	4.09
Average		1200	180	17	0.762	4.08
			Distance, Charge to Gage, 21.25 ft (λ = 10.62)			
	65	1000	220	14	0.896	4.22
	70	910	150	9.0	0.669	4.25
Average		960	180	12	0.782	4.24

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Table 27

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Results of Water-Shock Measurements

Bubble Screen Thickness, 1.5 ft

Air Content of Screen, 0.0044 cfs of Air per sq ft of Screen

Gages at Middepth

Stand-Off Distance, 12 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)*			
	66	2900	340	83	0.62	1.99
	71	3300	360	92	0.58	1.91
Average		3100	350	88	0.60	1.95
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)*			
	66	2800	320	83	0.64	2.12
	71	3200	370	92	0.57	2.06
Average		3000	340	88	0.60	2.09
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)*			
	66	2800	300	65	0.62	2.28
	71	2900	290	80	0.55	2.23
Average		2800	300	72	0.58	2.26
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	66	2500	260	63	0.353	2.31
	71	2800	300	70	0.401	2.38
Average		2600	280	66	0.377	2.34
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	66	2400	280	56	0.614	2.54
	71	2700	300	68	0.496	2.52
Average		2600	290	62	0.555	2.53
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	66	2400	180	24	0.538	2.68
	71	2600	280	56	0.547	2.66
Average		2500	230	40	0.542	2.67
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	66	2000	200	28	0.446	2.90
	71	2000	280	50	0.398	2.85
Average		2000	240	39	0.422	2.88
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	66	1800	210	26	0.548	3.04
	71	1700	260	44	0.537	2.99
Average		1800	240	35	0.542	3.02

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 27 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 16.00 ft (λ = 8.00)			
	66	1200	180	20	0.510	3.18
	71	1600	390	44	1.203	3.16
Average		1400	280	32	0.856	3.17
			Distance, Charge to Gage, 16.75 ft (λ = 8.38)			
	66	990	240	19	0.984	3.35
	71	1200	140	23	0.485	3.34
Average		1100	190	21	0.734	3.34
			Distance, Charge to Gage, 17.50 ft (λ = 8.75)			
	66	1200	240	19	0.925	3.48
	71	1300	160	18	0.442	3.45
Average		1200	200	18	0.684	3.46
			Distance, Charge to Gage, 18.25 ft (λ = 9.12)			
	71	1300	150	18	0.467	3.62
			Distance, Charge to Gage, 19.75 ft (λ = 9.88)			
	66	1000	200	14	0.934	3.93
			Distance, Charge to Gage, 20.50 ft (λ = 10.25)			
	66	1000	180	13	0.869	4.06
	71	1100	260	21	1.138	4.03
Average		1000	220	17	1.004	4.04
			Distance, Charge to Gage, 21.25 ft (λ = 10.62)			
	66	800	180	10	1.036	4.23
	71	720	140	9.0	0.824	4.19
Average		760	160	9.5	0.930	4.21

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Table 28

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Results of Water-Shock Measurements

Bubble Screen Thickness, 1.5 ft

Air Content of Screen, 0.035 cfs of Air per sq ft of Screen

Gages at Middepth

Stand-Off Distance, 12 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)*			
	68	3000	330	87	0.68	1.92
	69	3200	320	88	0.66	1.93
Average		3100	320	88	0.67	1.92
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)*			
	68	3100	320	80	0.63	2.08
	69	3200	320	92	0.62	2.07
Average		3200	320	86	0.62	2.08
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)*			
	68	3000	260	62	0.39	2.24
	69	2900	280	62	0.54	2.23
Average		3000	270	62	0.46	2.24
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	68	3000	180	46	0.177	2.38
	69	2700	160	50	0.247	2.36
Average		2800	170	48	0.212	2.37
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	68	1800	85	16	0.202	2.50
	69	960	250	19	1.085	2.51
Average		1400	170	18	0.644	2.50
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	68	580	200	14	0.924	2.91
	69	690	200	15	0.796	3.21
Average		640	200	14	0.860	3.06
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	68	840	220	4.5	1.291	3.22
	69	1100	220	20	0.816	3.52
Average		970	220	12	1.054	3.37
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	68	760	150	9.0	0.760	3.43
	69	1000	180	13	0.869	3.52
Average		880	160	11	0.814	3.48

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 28 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 16.00 ft (λ = 8.00)			
	68	510	140	7.0	0.615	3.50
	69	670	260	12	2.008	3.67
Average		590	200	9.5	1.312	3.58
			Distance, Charge to Gage, 16.75 ft (λ = 8.38)			
	68	410	100	5.0	0.530	3.66
	69	540	200	8.0	1.526	3.83
Average		480	150	6.5	1.028	3.74
			Distance, Charge to Gage, 17.50 ft (λ = 8.75)			
	69	580	210	8.0	1.484	3.89
			Distance, Charge to Gage, 19.00 ft (λ = 9.50)			
	69	350	160	5.0	1.430	4.23
			Distance, Charge to Gage, 19.75 ft (λ = 9.88)			
	69	430	190	6.0	1.761	4.39
			Distance, Charge to Gage, 20.50 ft (λ = 10.25)			
	69	350	160	5.0	1.394	4.50
			Distance, Charge to Gage, 21.25 ft (λ = 10.62)			
	69	270	140	3.5	1.349	4.64

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Table 29

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Results of Water-Shock Measurements

Bubble Screen Thickness, 1.5 ft

Air Content of Screen, 0.069 cfs of Air per sq ft of Screen

Gages at Middepth

Stand-Off Distance, 12 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)*			
	78	3200	360	90	0.58	1.88
	79	2900	320	76	0.60	1.85
Average		3000	340	83	0.59	1.86
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)*			
	78	3200	270	65	0.47	2.03
	79	3300	280	87	0.54	2.01
Average		3200	280	76	0.50	2.02
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)*			
	78	2600	230	39	0.60	2.19
	79	2600	260	60	0.58	2.16
Average		2600	240	50	0.59	2.18
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	78	2600	100	26	0.204	2.40
	79	2700	140	46	0.131	2.28
Average		2600	120	36	0.168	2.34
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	79	1400	60	6.0	0.346	2.48
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	78	710	300	8.5	0.800	3.55
	79	1240	210	21	1.055	3.57
Average		980	260	15	0.928	3.56
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	78	620	210	8.5	1.342	3.69
	79	880	160	10	1.110	3.70
Average		750	180	9.2	1.221	3.70
			Distance, Charge to Gage, 16.00 ft (λ = 8.00)			
	78	350	160	4.5	1.720	3.80
	79	610	180	6.0	1.833	3.78
Average		480	170	5.2	1.776	3.79

(Continued)

* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 29 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 16.75 ft (λ = 8.38)			
	78	200	210	7.0	1.772	3.96
	79	340	160	4.5	1.710	3.98
Average		270	180	5.8	1.741	3.97
			Distance, Charge to Gage, 17.50 ft (λ = 8.75)			
	78	220	160	3.0	1.978	3.94
	79	300	180	4.5	1.906	4.09
Average		260	170	3.8	1.942	4.02
			Distance, Charge to Gage, 18.25 ft (λ = 9.12)			
	78	220	170	3.5	2.002	4.08
	79	250	140	2.5	1.866	4.24
Average		240	160	3.0	1.934	4.16
			Distance, Charge to Gage, 19.00 ft (λ = 9.50)			
	78	170	160	3.0	2.139	4.19
	79	200	180	3.0	2.942	4.16
Average		180	170	3.0	2.540	4.18
			Distance, Charge to Gage, 19.75 ft (λ = 9.88)			
	78	190	160	3.0	2.140	4.30
	79	190	150	3.0	2.173	4.50
Average		190	160	3.0	2.156	4.40
			Distance, Charge to Gage, 20.50 ft (λ = 10.25)			
	78	210	140	2.5	2.030	4.46
	79	200	140	3.0	1.876	4.58
Average		200	140	2.8	1.953	4.52
			Distance, Charge to Gage, 21.25 ft (λ = 10.62)			
	78	140	85	1.0	1.653	4.58
	79	150	130	2.0	2.484	4.74
Average		140	110	1.5	2.068	4.66

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Table 30

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Results of Water-Shock Measurements

Bubble Screen Thickness, 1.5 ft

Air Content of Screen, 0.0028 cfs of Air per sq ft of Screen

Gages, 0.25 ft Below Water Surface

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 9.62 ft (λ = 4.81)			
	82	3100	140	54	0.089	1.82
	105	3200	100	46	0.050	1.73
Average		3200	120	50	0.070	1.78
			Distance, Charge to Gage, 9.96 ft (λ = 4.98)			
	82	3800	190	90	0.089	1.88
	105	3400	90	48	0.048	1.83
Average		3600	140	69	0.068	1.86
			Distance, Charge to Gage, 10.34 ft (λ = 5.17)			
	82	3500	170	81	0.082	1.97
	104	3400	110	50	0.048	1.90
	105	3200	80	30	0.078	1.86
Average		3400	120	54	0.069	1.91
σ_m		91	26	15	0.0107	0.032
σ_m%		2.7	22	28	16	1.7
σ		160	46	26	0.0186	0.056
σ%		4.6	38	48	27	2.9
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	82	3300	160	76	0.079	2.03
	104	3300	100	45	0.048	1.99
	105	3300	70	48	0.064	1.98
Average		3300	110	56	0.064	2.00
σ_m			26	9.9	0.0090	0.015
σ_m%			24	18	14	0.8
σ			46	17	0.0155	0.026
σ%			42	30	24	1.3
			Distance, Charge to Gage, 11.21 ft (λ = 5.60)			
	82	3000	120	47	0.086	2.13
	104	2800	85	36	0.046	2.08
	105	3000	80	30	0.046	2.04
Average		2900	95	38	0.059	2.08
σ_m		71	13	5.0	0.0133	0.026
σ_m%		2.4	13	13	23	1.2
σ		120	22	8.6	0.0231	0.045
σ%		4.2	23	23	39	2.2
			Distance, Charge to Gage, 11.69 ft (λ = 5.84)			
	82	2200	75	26	0.086	2.26
	104	2500	75	31	0.049	2.18
	105	2000	60	24	0.061	2.13
Average		2200	70	27	0.065	2.19
σ_m		150	5.0	2.1	0.0109	0.038
σ_m%		6.7	7.1	7.7	17	1.7
σ		250	8.7	3.6	0.0189	0.066
σ%		12	12	13	29	3.0

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Table 30 (Continued)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 12.20 ft (λ = 6.10)			
	82	2500	110	43	0.092	2.35
	104	3200	75	32	0.053	2.36
	105	2300	70	28	0.054	2.22
Average		2700	85	34	0.066	2.31
σ		270	12	4.5	0.0128	0.045
σ_m%		10	15	13	19	2.0
σ_m		470	22	7.8	0.0223	0.078
σ%		18	26	23	34	3.4
			Distance, Charge to Gage, 12.73 ft (λ = 6.36)			
	82	3100	95	44	0.072	2.48
	104	2100	50	14	0.077	2.48
	105	2500	65	24	0.045	2.33
Average		2600	70	27	0.065	2.43
σ		290	13	8.8	0.0100	0.050
σ_m%		11	19	33	15	2.0
σ_m		500	23	15	0.0173	0.087
σ%		19	33	57	27	3.6
			Distance, Charge to Gage, 13.29 ft (λ = 6.64)			
	82	2800	95	32	0.079	2.51
	104	1500	55	11	0.082	2.49
	105	2200	50	16	0.046	2.45
Average		2200	67	20	0.069	2.48
σ		380	14	6.3	0.0115	0.018
σ_m%		17	21	32	17	0.7
σ_m		650	25	11	0.0200	0.031
σ%		30	37	55	29	1.2
			Distance, Charge to Gage, 13.86 ft (λ = 6.93)			
	82	2300	75	24	0.067	2.61
	104	1800	50	13	0.066	2.62
	105	2000	55	14	0.038	2.51
Average		2000	60	17	0.057	2.58
σ		150	7.6	3.5	0.0030	0.035
σ_m%		7.4	13	21	5.3	1.4
σ_m		250	13	6.1	0.0052	0.061
σ%		13	22	36	9.1	2.4
			Distance, Charge to Gage, 14.45 ft (λ = 7.22)			
	82	2100	65	18	0.056	2.80
	104	2100	60	15	0.063	2.71
	105	2500	60	22	0.040	2.66
Average		2200	62	18	0.053	2.72
σ		140	1.7	2.0	0.0068	0.041
σ_m%		6.2	2.7	11	13	1.5
σ_m		230	2.9	3.5	0.0118	0.071
σ%		11	4.7	20	22	2.6

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Table 30 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 15.05 ft (λ = 7.52)			
	82	2200	48	12	0.054	2.93
	104	1600	48	9.5	0.050	2.82
	105	2200	50	19	0.034	2.78
Average		2000	49	14	0.046	2.84
σ_m		200	0.7	2.9	0.0061	0.045
σ_m%		10	1.4	20	13	1.6
σ		350	1.2	5.0	0.0106	0.078
σ%		17	2.5	36	23	2.7
			Distance, Charge to Gage, 15.67 ft (λ = 7.84)			
	104	1200	32	5.5	0.050	2.98
	105	2700	48	16	0.034	2.92
Average		2000	40	11	0.042	2.95
			Distance, Charge to Gage, 16.30 ft (λ = 8.15)			
	82	1800	55	16	0.061	3.20
	104	1200	38	6.0	0.131	3.10
	105	2000	50	14	0.046	3.04
Average		1700	48	12	0.079	3.11
σ_m		240	5.0	3.0	0.0262	0.047
σ_m%		14	10	25	33	1.5
σ		420	8.8	5.3	0.0454	0.081
σ%		25	18	44	57	2.6
			Distance, Charge to Gage, 16.94 ft (λ = 8.47)			
	82	1500	50	12	0.054	3.29
	104	920	31	3.5	0.114	3.21
	105	2000	43	12	0.038	3.16
Average		1500	41	9.2	0.069	3.22
σ_m		310	5.6	2.8	0.0231	0.038
σ_m%		21	13	31	34	1.2
σ		540	9.6	4.9	0.0400	0.066
σ%		36	23	53	58	2.0
			Distance, Charge to Gage, 17.58 ft (λ = 8.79)			
	82	1400	36	7.5	0.056	3.39
	105	1200	32	4.5	0.044	3.28
Average		1300	34	6.0	0.050	3.34

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Table 31

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Results of Water-Shock Measurements

Bubble Screen Thickness, 1.5 ft

Air Content of Screen, 0.0044 cfs of Air per sq ft of Screen

Gages, 0.25 ft Below Water Surface

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 9.62 ft (λ = 4.81)			
	106	2800	75	35	0.041	1.74
	107	2900	80	34	0.045	1.76
Average		2800	78	34	0.043	1.75
			Distance, Charge to Gage, 9.96 ft (λ = 4.98)			
	106	3200	90	43	0.048	1.82
	107	3200	90	43	0.054	1.77
Average		3200	90	43	0.051	1.80
			Distance, Charge to Gage, 10.34 ft (λ = 5.17)			
	106	3600	100	50	0.044	1.87
	107	3400	100	48	0.050	1.86
Average		3500	100	49	0.047	1.86
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	106	3800	65	34	0.037	2.01
	107	3500	70	35	0.044	1.94
Average		3600	68	34	0.040	1.98
			Distance, Charge to Gage, 11.21 ft (λ = 5.60)			
	106	2800	75	33	0.036	2.05
	107	2500	50	15	0.068	2.06
Average		2600	62	24	0.052	2.06
			Distance, Charge to Gage, 11.69 ft (λ = 5.84)			
	106	2300	65	24	0.052	2.15
	107	1800	46	10	0.103	2.16
Average		2000	56	17	0.078	2.16
			Distance, Charge to Gage, 12.20 ft (λ = 6.10)			
	107	1500	48	6.0	0.114	2.23
			Distance, Charge to Gage, 12.73 ft (λ = 6.36)			
	107	870	21	4.0	0.085	2.37

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Table 31 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 13.29 ft (λ = 6.64)			
	106	1200	65	10	0.151	2.55
	107	780	34	3.5	0.106	2.52
Average		990	50	6.8	0.128	2.54
			Distance, Charge to Gage, 13.86 ft (λ = 6.93)			
	106	1100	34	3.5	0.152	2.72
	107	940	30	4.0	0.096	2.58
Average		1000	32	3.8	0.124	2.65
			Distance, Charge to Gage, 14.45 ft (λ = 7.22)			
	106	1200	55	7.0	0.112	2.73
	107	1000	38	4.5	0.146	2.77
Average		1100	46	5.8	0.129	2.75
			Distance, Charge to Gage, 15.05 ft (λ = 7.52)			
	106	1200	46	5.5	0.098	2.84
	107	1300	34	4.5	0.077	2.86
Average		1200	40	5.0	0.088	2.85
			Distance, Charge to Gage, 15.67 ft (λ = 7.84)			
	106	1200	33	4.0	0.092	2.97
	107	970	27	3.0	0.066	2.97
Average		1100	30	3.5	0.079	2.97
			Distance, Charge to Gage, 16.30 ft (λ = 8.15)			
	106	910	33	3.0	0.094	3.10
	107	1100	30	4.5	0.079	3.10
Average		1000	32	3.8	0.086	3.10
			Distance, Charge to Gage, 16.94 ft (λ = 8.47)			
	106	960	23	2.0	0.078	3.28
	107	940	23	2.5	0.067	3.25
Average		950	23	2.2	0.072	3.26
			Distance, Charge to Gage, 17.58 ft (λ = 8.79)			
	106	820	20	2.0	0.075	3.40
	107	630	12	1.0	0.056	3.39
Average		720	16	1.5	0.066	3.40

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Table 32

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Results of Water-Shock Measurements

Bubble Screen Thickness, 1.5 ft

Air Content of Screen, 0.035 cfs of Air per sq ft of Screen

Gages, 0.25 ft Below Water Surface

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse $lb\text{-}ms/in.^2/lb^{1/3}$	Reduced Energy $in.\text{-}lb/in.^2/lb^{1/3}$	Reduced Positive Duration $ms/lb^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 9.62 ft (λ = 4.81)			
	109	3400	60	21	0.058	1.84
			Distance, Charge to Gage, 9.96 ft (λ = 4.98)			
	108	1600	50	7.5	0.146	1.91
	109	1200	50	7.5	0.170	1.92
Average		1400	50	7.5	0.158	1.92
			Distance, Charge to Gage, 10.34 ft (λ = 5.17)			
	108	820	38	3.0	0.172	2.01
	109	810	39	3.0	0.220	2.01
Average		820	38	3.0	0.196	2.01
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	108	600	38	2.5	0.237	2.23
	109	210	36	0.5	0.460	2.21
Average		400	37	1.5	0.348	2.22
			Distance, Charge to Gage, 11.21 ft (λ = 5.60)			
	108	160	18	0.3	0.238	2.56
	109	97	32	0.3	0.974	2.64
Average		130	25	0.3	0.606	2.60
			Distance, Charge to Gage, 11.69 ft (λ = 5.84)			
	108	88	36	0.3	1.205	2.79
	109	140	28	0.3	0.794	2.95
Average		110	32	0.3	1.000	2.87
			Distance, Charge to Gage, 12.20 ft (λ = 6.10)			
	109	540	46	1.5	0.434	3.00
			Distance, Charge to Gage, 12.73 ft (λ = 6.36)			
	108	210	24	0.4	0.668	3.22
	109	430	32	1.0	0.546	3.20
Average		320	28	0.7	0.607	3.21

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Table 32 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 13.29 ft (λ = 6.64)			
	108	97	25	0.3	0.628	3.33
	109	220	24	0.4	0.634	3.30
Average		160	24	0.4	0.631	3.32
			Distance, Charge to Gage, 13.86 ft (λ = 6.93)			
	108	100	20	0.2	0.576	3.38
	109	140	20	0.3	0.492	3.35
Average		120	20	0.2	0.534	3.36
			Distance, Charge to Gage, 14.45 ft (λ = 7.22)			
	108	150	20	0.3	0.836	3.39
	109	230	22	0.3	0.518	3.39
Average		190	21	0.3	0.677	3.39
			Distance, Charge to Gage, 15.05 ft (λ = 7.52)			
	108	130	16	0.2	0.660	3.47
	109	340	24	0.5	0.612	3.43
Average		240	20	0.4	0.636	3.45
			Distance, Charge to Gage, 15.67 ft (λ = 7.84)			
	108	150	14	0.1	0.718	3.57
	109	150	20	0.3	0.451	3.46
Average		150	17	0.2	0.584	3.52
			Distance, Charge to Gage, 16.30 ft (λ = 8.15)			
	108	240	12	0.2	0.386	3.60
	109	260	19	0.4	0.416	3.58
Average		250	16	0.3	0.401	3.59
			Distance, Charge to Gage, 16.94 ft (λ = 8.47)			
	108	180	12	0.2	0.365	3.58
	109	140	19	0.3	0.420	3.82
Average		160	16	0.2	0.392	3.70
			Distance, Charge to Gage, 17.58 ft (λ = 8.79)			
	108	86	3.9	<0.1	0.316	3.82
	109	46	4.7	<0.1	0.399	3.85
Average		66	4.3	<0.1	0.358	3.84

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Table 33

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Results of Water-Shock Measurements

ubble Screen Thickness, 0.5 ft

ir Content of Screen, 0.0083 cfs of Air per sq ft of Screen

Gages at Middepth

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 4.00 ft (λ = 2.00)*			
	110	7900	700	560	0.46	0.67
	111	8500	650	450	0.48	0.68
verage		8200	680	500	0.47	0.68
			Distance, Charge to Gage, 5.50 ft (λ = 2.75)*			
	110	5900	440	230	0.47	0.97
	111	6300	650	300	0.56	0.95
verage		6100	540	260	0.52	0.96
			Distance, Charge to Gage, 6.25 ft (λ = 3.12)			
	110	5500	470	200	0.469	1.11
	111	5300	480	190	0.430	1.10
verage		5400	480	200	0.450	1.10
			Distance, Charge to Gage, 7.00 ft (λ = 3.50)			
	110	4300	550	190	0.583	1.26
	111	4900	460	200	0.449	1.23
verage		4600	500	200	0.516	1.24
			Distance, Charge to Gage, 7.75 ft (λ = 3.88)			
	110	3800	460	130	0.718	1.41
	111	4200	360	120	0.497	1.38
verage		4000	410	120	0.608	1.40
			Distance, Charge to Gage, 8.50 ft (λ = 4.25)			
	110	3600	480	110	0.762	1.58
	111	3800	360	88	0.578	1.52
Average		3700	420	99	0.670	1.55
			Distance, Charge to Gage, 9.25 ft (λ = 4.62)			
	110	3200	400	93	0.670	1.63
	111	2500	340	60	0.596	1.67
Average		2800	370	76	0.633	1.65
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)			
	111	2600	320	68	0.521	1.76

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* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

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Table 33 (Concluded)

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Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	111	2500	360	70	0.556	1.97
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)			
	110	2300	300	41	0.954	2.14
	111	2800	320	65	0.545	2.12
Average		2600	310	53	0.750	2.13
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	110	2000	240	32	0.723	2.30
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	110	2600	310	55	0.602	2.48
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	110	2300	300	52	0.582	2.62
	111	2200	260	47	0.528	2.56
Average		2200	280	50	0.555	2.59
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	110	1500	200	28	0.422	2.73
	111	1800	180	30	0.334	2.76
Average		1600	190	29	0.378	2.74
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	110	1200	220	18	0.958	2.86
	111	1200	160	12	0.742	2.87
Average		1200	190	15	0.850	2.86

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Table 34

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Results of Water-Shock Measurements

Bubble Screen Thickness, 0.5 ft

Air Content of Screen, 0.035 cfs of Air per sq ft of Screen

Gages at Middepth

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 4.00 ft (λ = 2.00)*			
	112	8400	800	570	0.48	0.67
	113	8100	750	530	0.45	0.68
Average		8200	780	550	0.46	0.68
			Distance, Charge to Gage, 4.75 ft (λ = 2.38)*			
	112	8300	800	500	0.45	0.78
	113	7800	550	410	0.44	0.78
Average		8000	680	460	0.44	0.78
			Distance, Charge to Gage, 5.50 ft (λ = 2.75)*			
	112	6600	460	270	0.46	0.94
	113	6600	550	300	0.42	0.93
Average		6600	500	280	0.44	0.94
			Distance, Charge to Gage, 6.25 ft (λ = 3.12)			
	112	6400	500	280	0.650	1.08
	113	4600	470	210	0.506	1.07
Average		5500	480	240	0.578	1.08
			Distance, Charge to Gage, 7.00 ft (λ = 3.50)			
	112	3700	550	150	0.741	1.25
	113	3800	500	130	0.746	1.22
Average		3800	520	140	0.744	1.24
			Distance, Charge to Gage, 7.75 ft (λ = 3.88)			
	112	3400	380	84	0.759	1.41
	113	3300	380	100	0.549	1.44
Average		3400	380	92	0.654	1.42
			Distance, Charge to Gage, 8.50 ft (λ = 4.25)			
	112	2000	390	66	0.690	1.58
	113	2800	430	79	0.703	1.57
Average		2400	410	72	0.696	1.58
			Distance, Charge to Gage, 9.25 ft (λ = 4.62)			
	112	1600	350	52	0.718	1.73
	113	2600	440	76	0.750	1.72
Average		2100	400	64	0.734	1.72

(Continued)

* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.70.

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Table 34 (Concluded)

[redacted]

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)			
	112	1400	330	44	0.673	1.87
	113	1500	320	37	0.920	1.87
Average		1400	320	40	0.796	1.87
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	112	1400	320	44	0.628	2.04
	113	1500	360	44	0.918	2.01
Average		1400	340	44	0.773	2.02
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)			
	112	1500	280	14	0.910	2.13
	113	1200	310	32	0.832	2.15
Average		1400	300	23	0.871	2.14
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	112	1600	200	22	0.654	2.26
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	112	1500	250	8.5	0.518	2.46
	113	1100	230	20	0.654	2.45
Average		1300	240	14	0.586	2.46
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	112	1500	230	30	0.469	2.58
	113	1100	260	27	0.925	2.60
Average		1300	240	28	0.697	2.59
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	112	1300	170	18	0.498	2.74
	113	1000	180	18	0.530	2.75
Average		1200	180	18	0.514	2.74
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	112	960	150	8.5	0.856	2.88
	113	560	140	7.0	0.886	2.88
Average		760	140	7.8	0.871	2.88

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Table 35

[redacted]

Results of Water-Shock Measurements

Bubble Screen Thickness, 0.5 ft

Air Content of Screen, 0.07 cfs of Air per sq ft of Screen

Gages at Middepth

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse $lb\text{-}ms/in.^2/lb^{1/3}$	Reduced Energy $in.\text{-}lb/in.^2/lb^{1/3}$	Reduced Positive Duration $ms/lb^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 4.00 ft (λ = 2.00)*			
	114	7000	800	470	0.60	0.74
	115	7400	800	510	0.60	0.72
Average		7200	800	490	0.60	0.73
			Distance, Charge to Gage, 4.75 ft (λ = 2.38)*			
	114	8100	650	380	0.48	0.84
	115	8100	700	410	0.48	0.83
Average		8100	680	400	0.48	0.84
			Distance, Charge to Gage, 5.50 ft (λ = 2.75)*			
	114	6200	600	300	0.58	1.00
	115	6500	500	270	0.55	0.99
Average		6400	550	280	0.56	1.00
			Distance, Charge to Gage, 6.25 ft (λ = 3.12)			
	114	6000	340	200	0.152	1.14
			Distance, Charge to Gage, 7.00 ft (λ = 3.50)			
	114	4000	460	150	0.865	1.28
	115	2600	320	62	0.592	1.34
Average		3300	390	110	0.728	1.31
			Distance, Charge to Gage, 7.75 ft (λ = 3.88)			
	114	2200	340	42	0.853	1.40
	115	2000	210	22	0.700	1.57
Average		2100	280	32	0.776	1.48
			Distance, Charge to Gage, 8.50 ft (λ = 4.25)			
	114	1700	490	42	1.634	1.74
	115	1600	430	50	0.996	1.69
Average		1600	460	46	1.315	1.72
			Distance, Charge to Gage, 9.25 ft (λ = 4.62)			
	114	1400	200	20	0.630	1.96
	115	1100	280	28	0.950	1.85
Average		1200	240	24	0.790	1.90

(Continued)

* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

[redacted]

[redacted]

Table 35 (Concluded)

[redacted]

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)			
	114	1200	320	28	1.048	2.02
	115	1000	330	33	0.982	1.97
Average		1100	320	30	1.015	2.00
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	114	1200	350	30	1.068	2.14
	115	990	360	38	0.955	2.12
Average		1100	360	34	1.012	2.13
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)			
	114	700	200	12	0.976	2.31
	115	870	260	21	0.911	2.26
Average		780	230	16	0.944	2.28
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	114	870	210	18	0.620	2.56
	115	700	210	16	0.729	2.55
Average		780	210	17	0.674	2.56
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	114	740	210	14	0.970	2.71
	115	650	200	15	0.831	2.64
Average		700	200	14	0.900	2.68
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	114	740	160	10	0.806	2.86
	115	660	170	12	0.784	2.87
Average		700	160	11	0.795	2.86
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	114	480	120	6.0	0.914	3.01
	115	430	140	6.0	1.120	2.98
Average		460	130	6.0	1.017	3.00

[redacted]

[redacted]

Table 36

[redacted]

Results of Water-Shock Measurements

Bubble Screen Thickness, 0.5 ft

Air Content of Screen, 0.14 cfs of Air per sq ft of Screen

Gages at Middepth

Stand-Off Distance, 6 ft

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse lb-ms/in.^{2}/lb$^{1/3}$	Reduced Energy in.-lb/in.^{2}/lb$^{1/3}$	Reduced Positive Duration ms/lb$^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 4.00 ft (λ = 2.00)*			
	116	6500	550	320	0.48	0.77
	117	6900	500	330	0.41	0.76
Average		6700	520	320	0.44	0.76
			Distance, Charge to Gage, 4.75 ft (λ = 2.38)*			
	116	7500	600	370	0.44	0.90
	117	7800	420	320	0.31	0.90
Average		7600	510	340	0.38	0.90
			Distance, Charge to Gage, 5.50 ft (λ = 2.75)*			
	116	6500	500	300	0.46	1.06
			Distance, Charge to Gage, 6.25 ft (λ = 3.12)			
	116	5800	320	230	0.154	1.19
	117	3400	460	100	1.176	1.43
Average		4600	390	160	0.665	1.31
			Distance, Charge to Gage, 7.00 ft (λ = 3.50)			
	116	2900	360	62	0.859	1.31
	117	1900	550	74	1.485	1.47
Average		2400	460	68	1.172	1.39
			Distance, Charge to Gage, 7.75 ft (λ = 3.88)			
	116	1700	320	40	0.813	1.93
			Distance, Charge to Gage, 8.50 ft (λ = 4.25)			
	116	1800	460	49	1.481	2.18
	117	1100	330	23	1.333	1.81
Average		1400	400	36	1.407	2.00
			Distance, Charge to Gage, 9.25 ft (λ = 4.62)			
	116	1500	420	39	1.428	2.29
	117	1400	300	24	1.220	2.30
Average		1400	360	32	1.324	2.30
			Distance, Charge to Gage, 10.00 ft (λ = 5.00)			
	117	1100	300	22	1.254	2.04

(Continued)

* Gages were located in front of bubble screen; impulse, energy, and duration values shown at these locations were integrated to 6.7θ.

[redacted]

[redacted]

Table 36 (Concluded)

[redacted]

Averages and Deviations	Shot No.	Peak Pressure psi	Reduced Positive Impulse $lb\text{-}ms/in.^2/lb^{1/3}$	Reduced Energy $in.\text{-}lb/in.^2/lb^{1/3}$	Reduced Positive Duration $ms/lb^{1/3}$	Time of Arrival ms
			Distance, Charge to Gage, 10.75 ft (λ = 5.38)			
	117	1000	280	20	1.184	2.20
			Distance, Charge to Gage, 11.50 ft (λ = 5.75)			
	116	480	260	11	1.528	2.52
	117	860	200	12	1.034	2.30
Average		670	230	12	1.281	2.41
			Distance, Charge to Gage, 12.25 ft (λ = 6.12)			
	116	700	300	18	1.414	2.77
	117	920	200	12	1.077	2.46
Average		810	250	15	1.246	2.62
			Distance, Charge to Gage, 13.00 ft (λ = 6.50)			
	116	640	260	13	1.513	2.87
	117	820	240	15	1.082	2.54
Average		730	250	14	1.298	2.70
			Distance, Charge to Gage, 13.75 ft (λ = 6.88)			
	116	630	230	12	1.200	3.02
	117	860	150	10	0.773	2.69
Average		740	190	11	0.986	2.86
			Distance, Charge to Gage, 14.50 ft (λ = 7.25)			
	116	580	200	9.0	1.242	3.18
	117	660	170	8.5	1.020	2.84
Average		620	180	8.8	1.131	3.01
			Distance, Charge to Gage, 15.25 ft (λ = 7.62)			
	116	310	100	3.0	1.144	3.40
	117	430	80	2.5	0.919	3.09
Average		370	90	2.8	1.032	3.24

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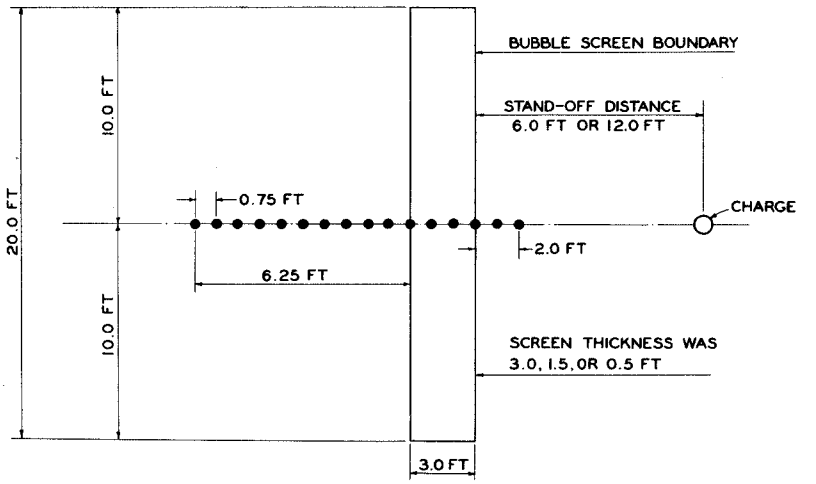
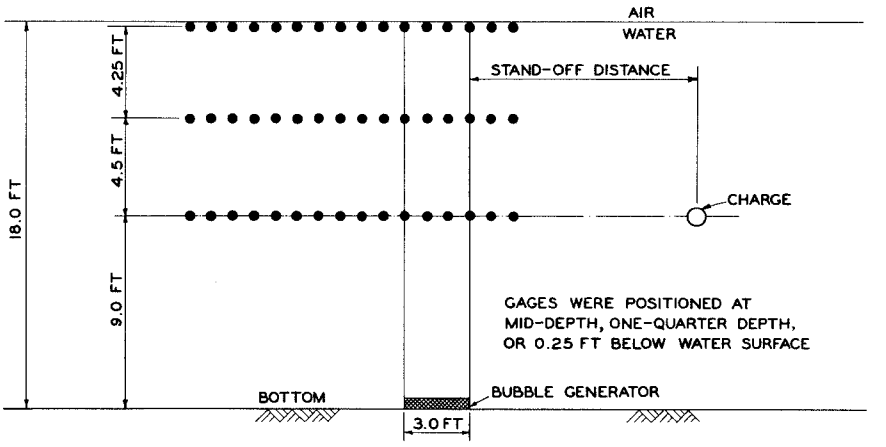


PLAN



ELEVATION

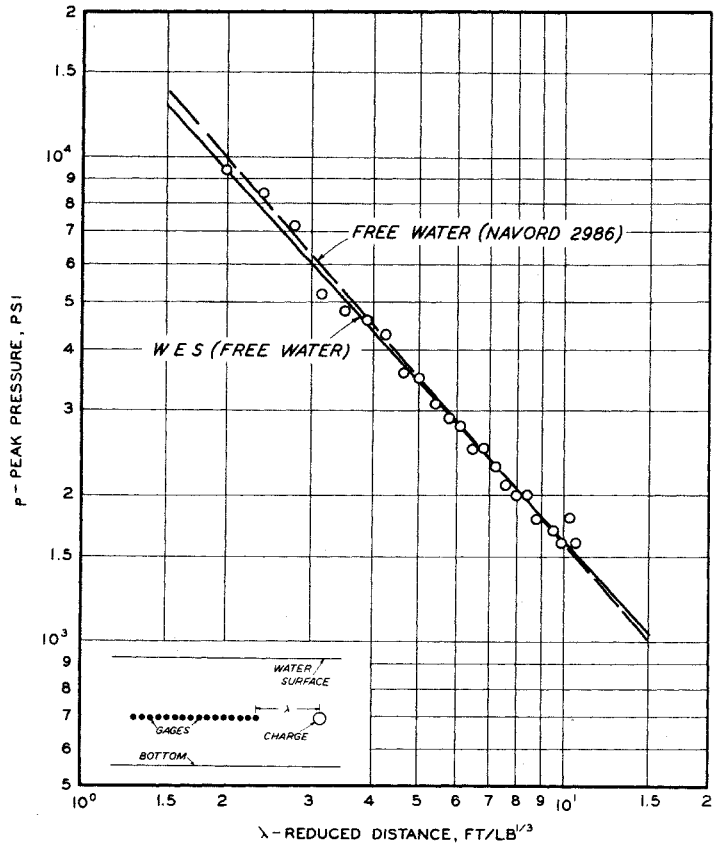
● - PRESSURE GAGE

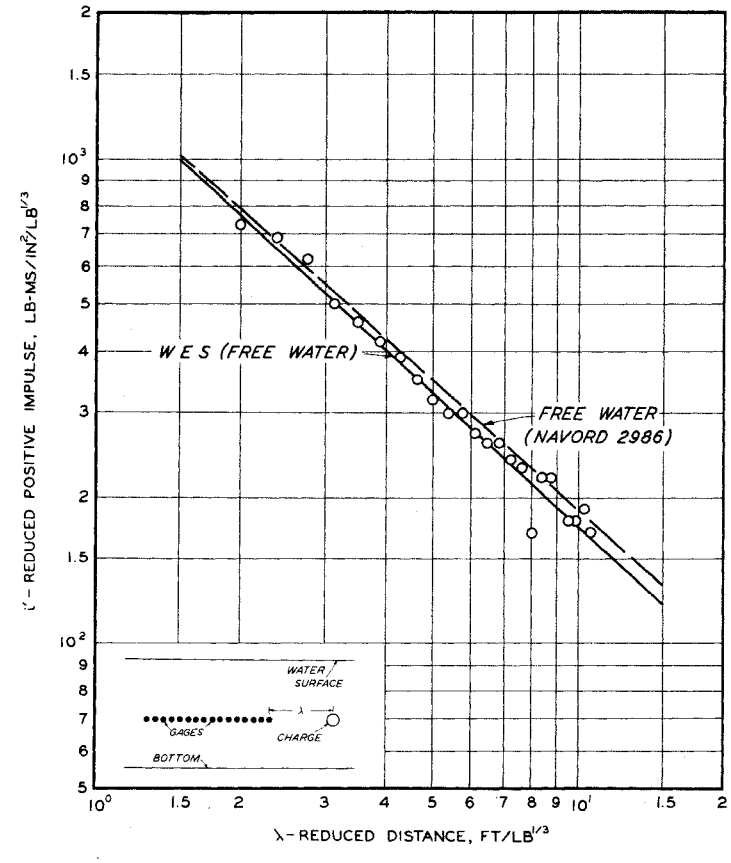
BUBBLE SCREEN GEOMETRY AND GAGE ARRAY

PLATE 1

[redacted]

PLATE 2



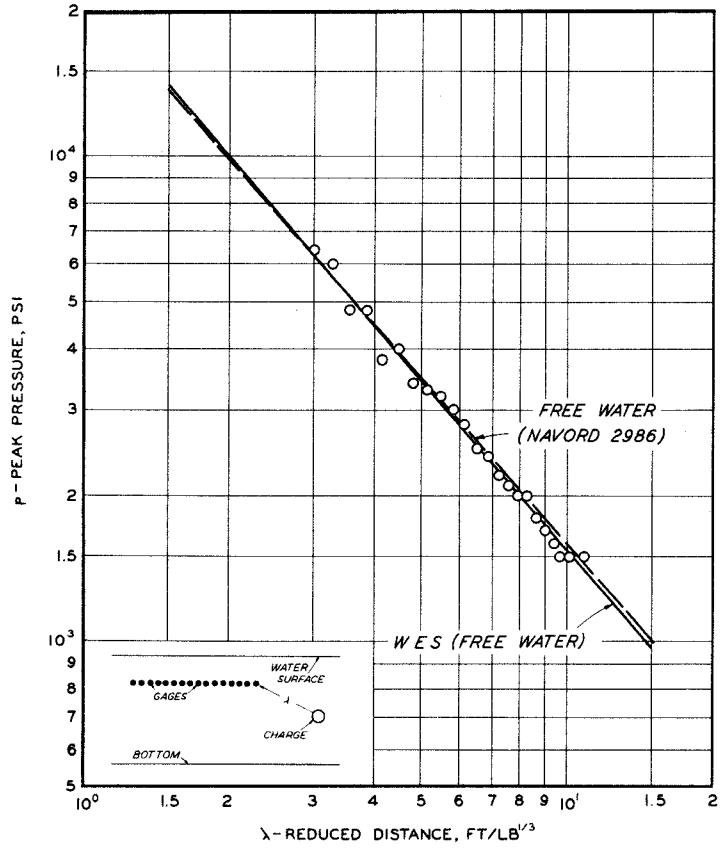


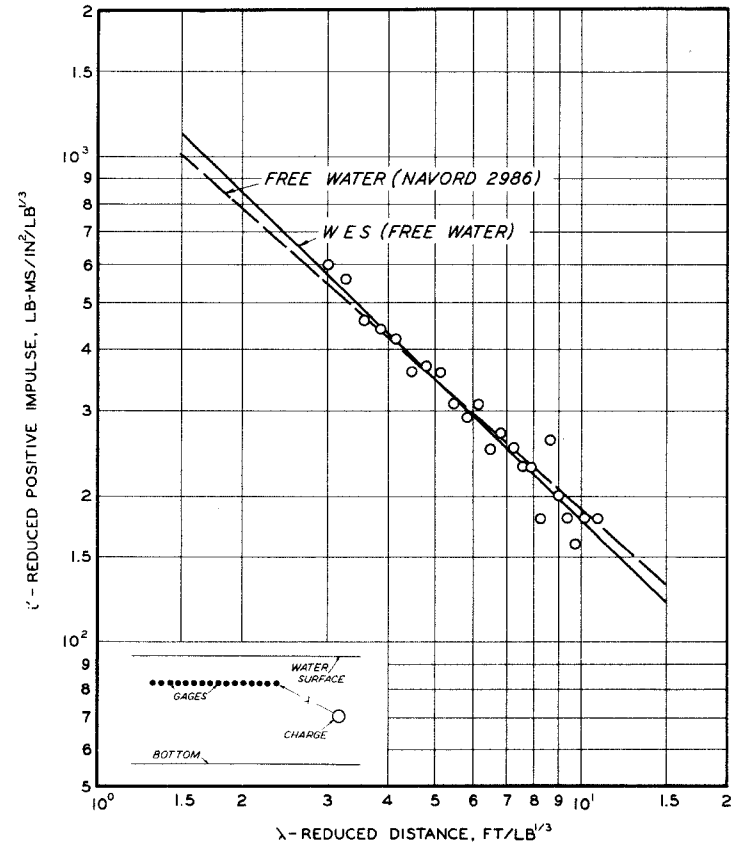
O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLE I

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

FREE WATER MEASUREMENTS

$Z_g = 9.0$



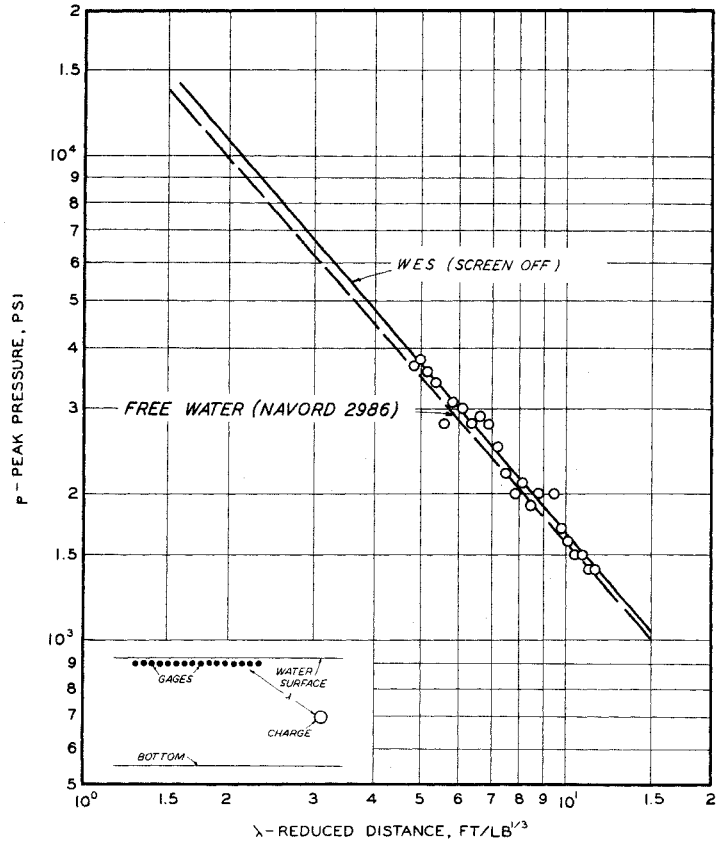


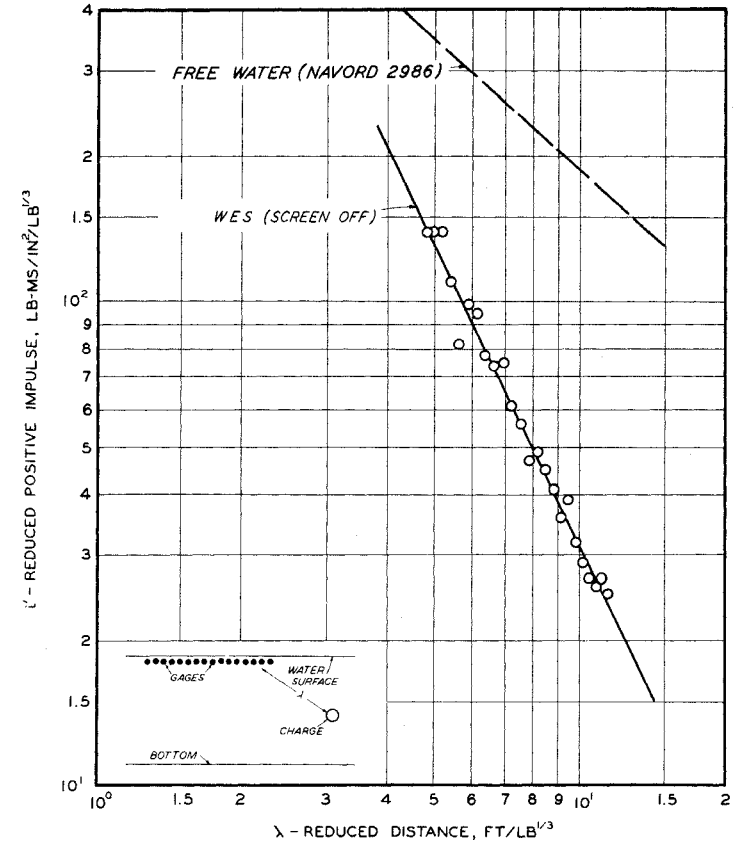
O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLE 2

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

FREE WATER MEASUREMENTS
$Z_g = 4.5$

PLATE 3

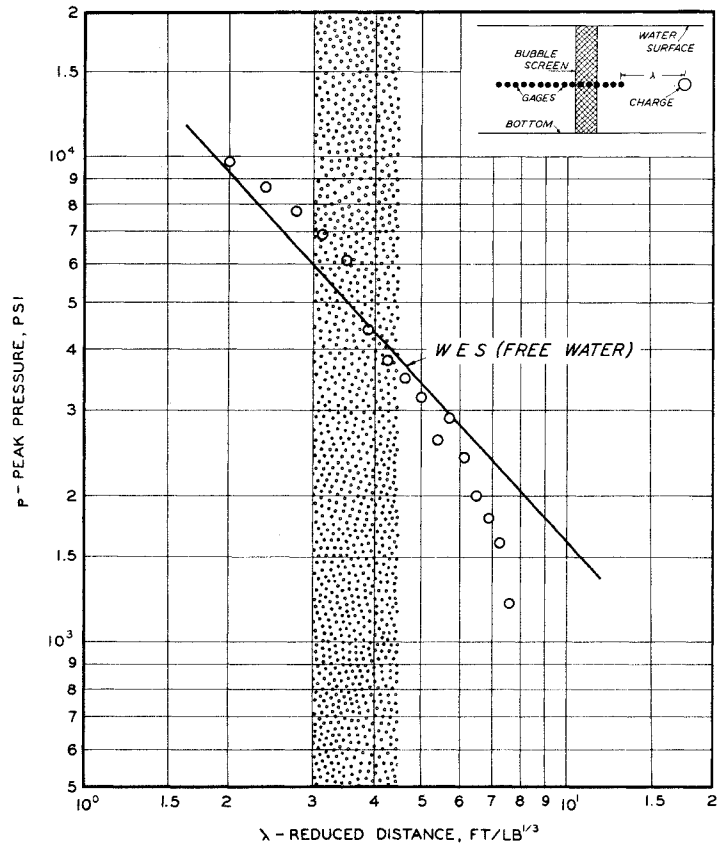


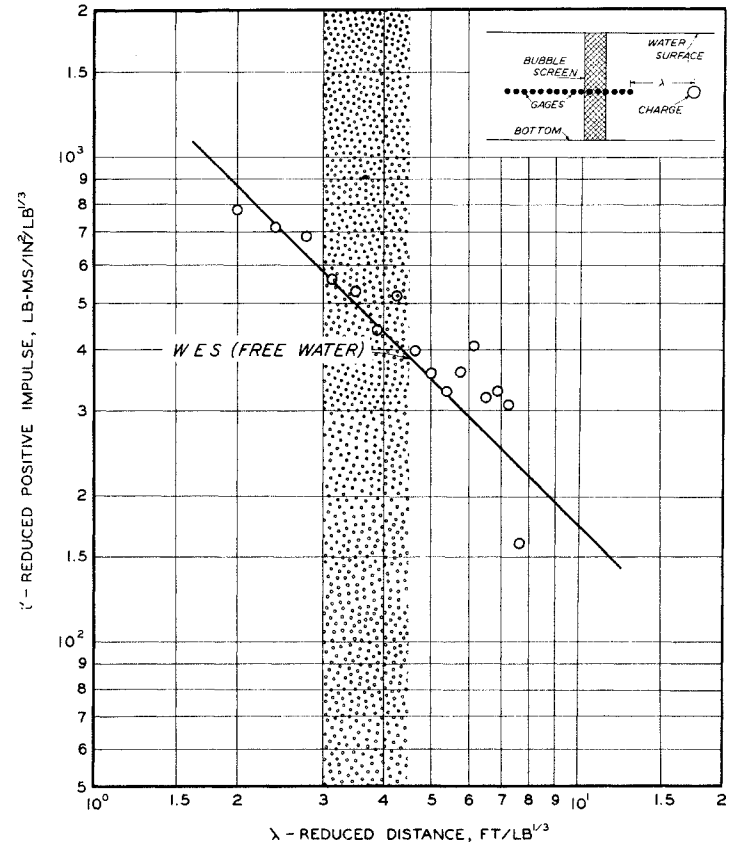


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLE 3

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 0.25$





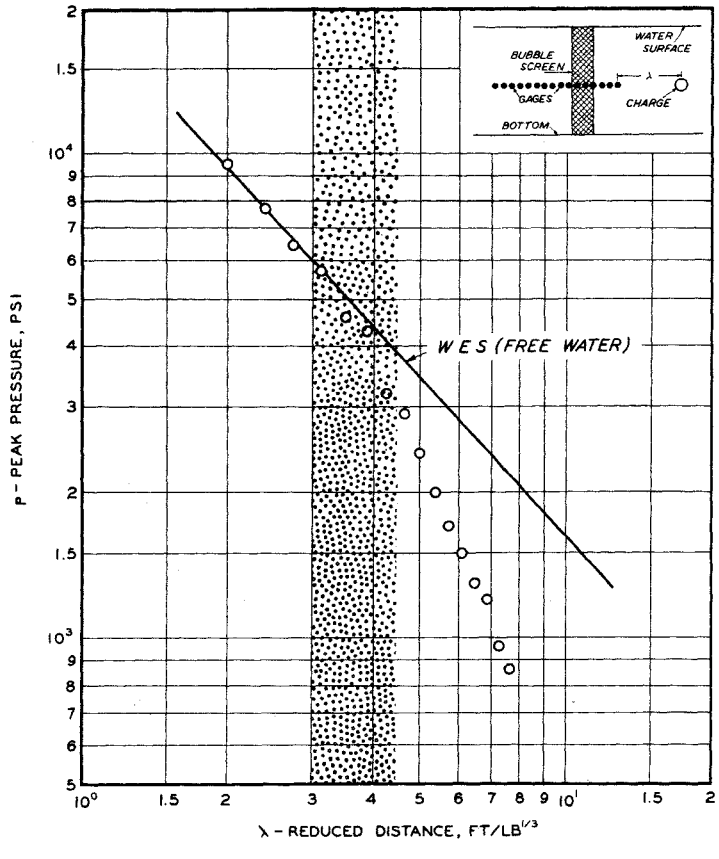
O - W.E.S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 4

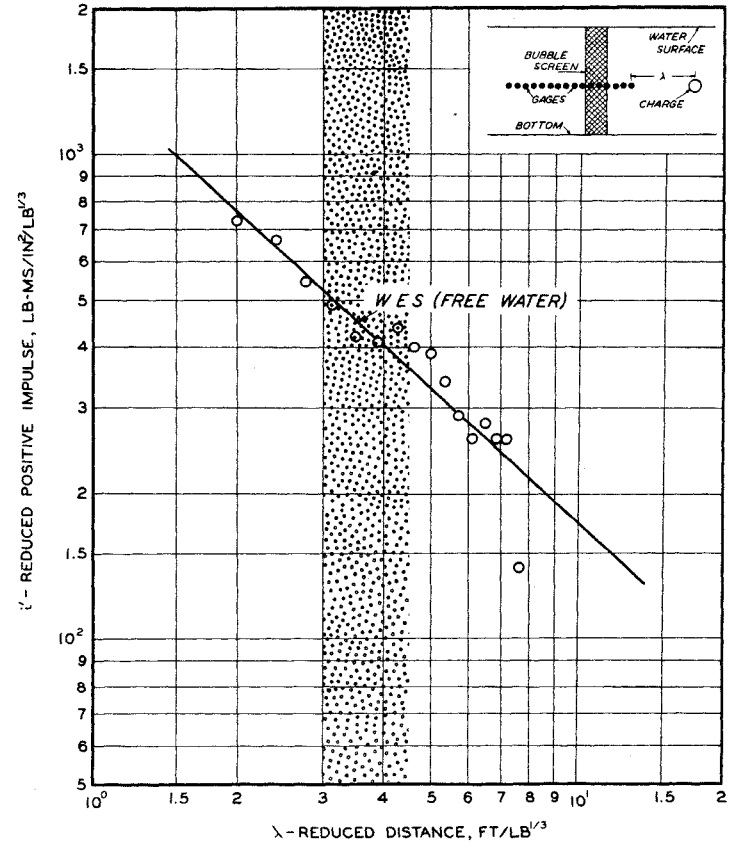
VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 3.0$, $A_c = 0.0014$ ($\sim 0.3\%$), $R_o = 6.0$

PLATE 5

PLATE 6

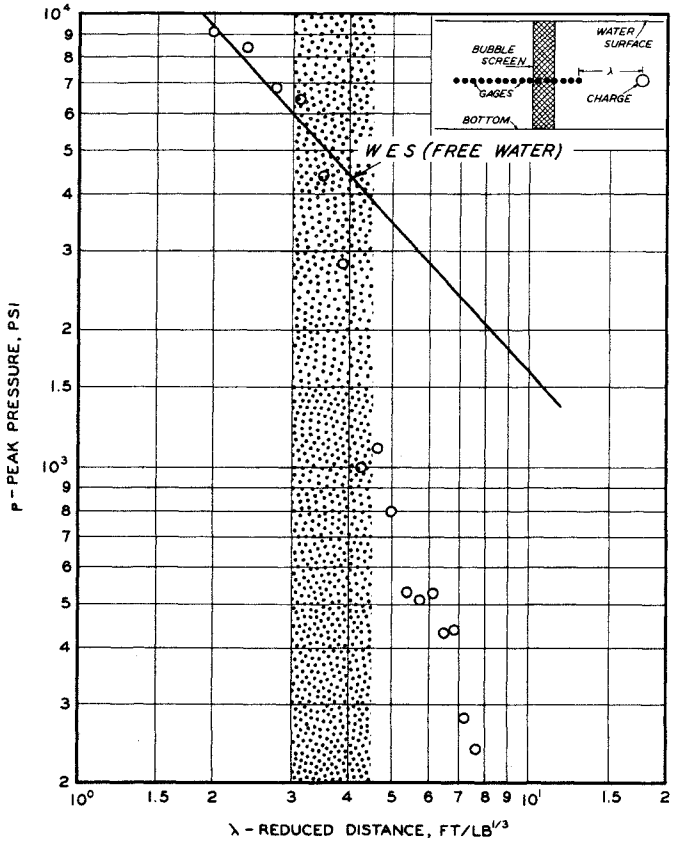


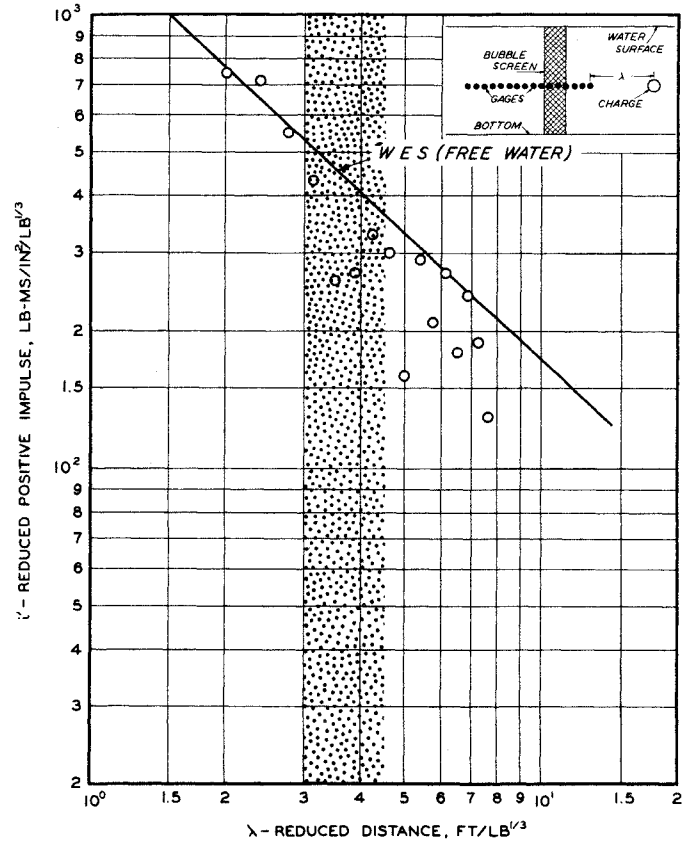


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 5

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 3.0$, $A_c = 0.0044 (\sim 1.0\%)$, $R_o = 6.0$



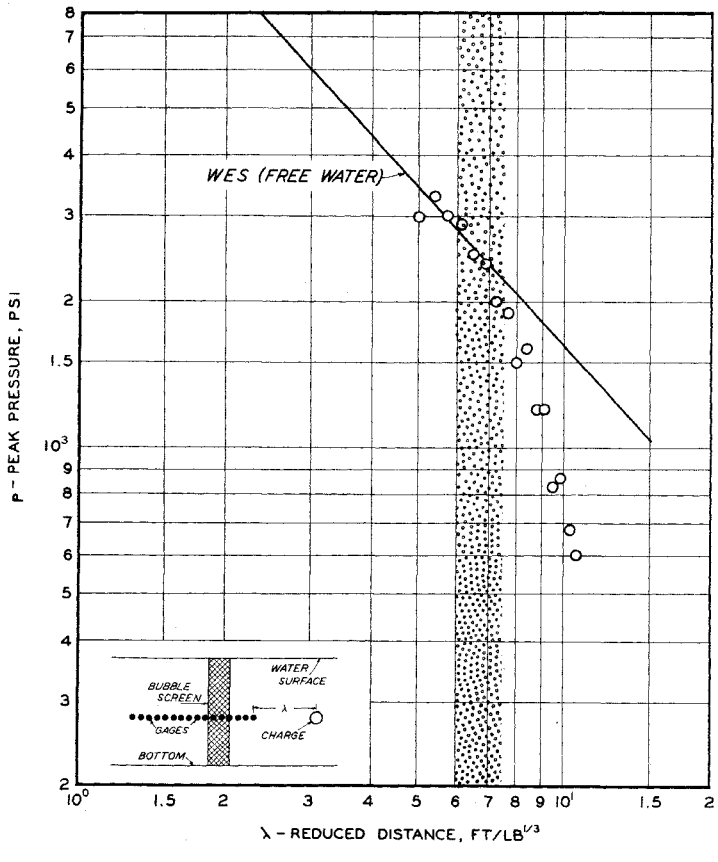


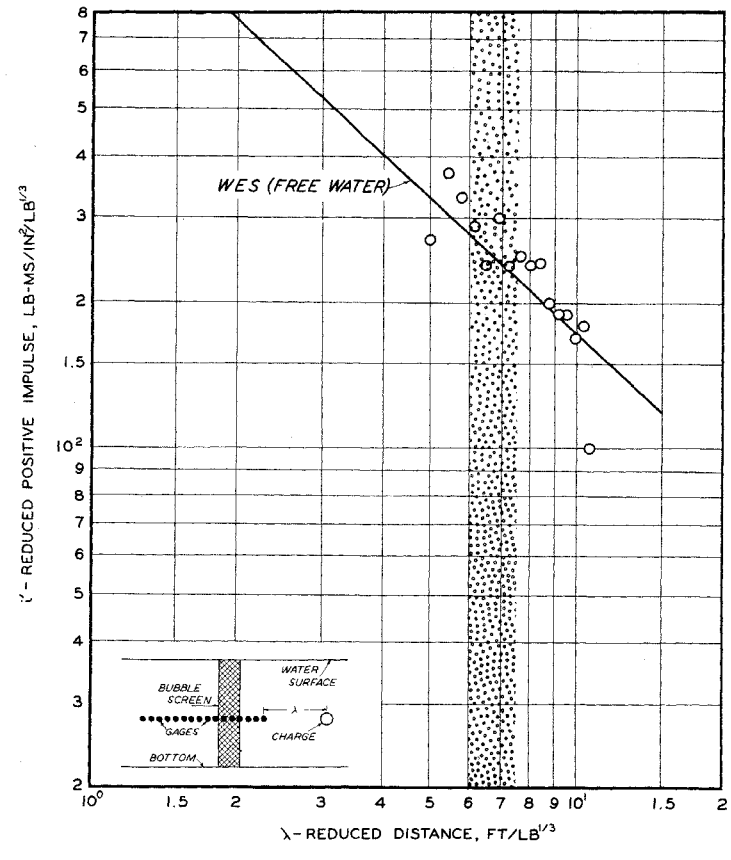
O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 6

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 3.0$, $A_c = 0.0347$ (~ 3.0%), $R_o = 6.0$

PLATE 7

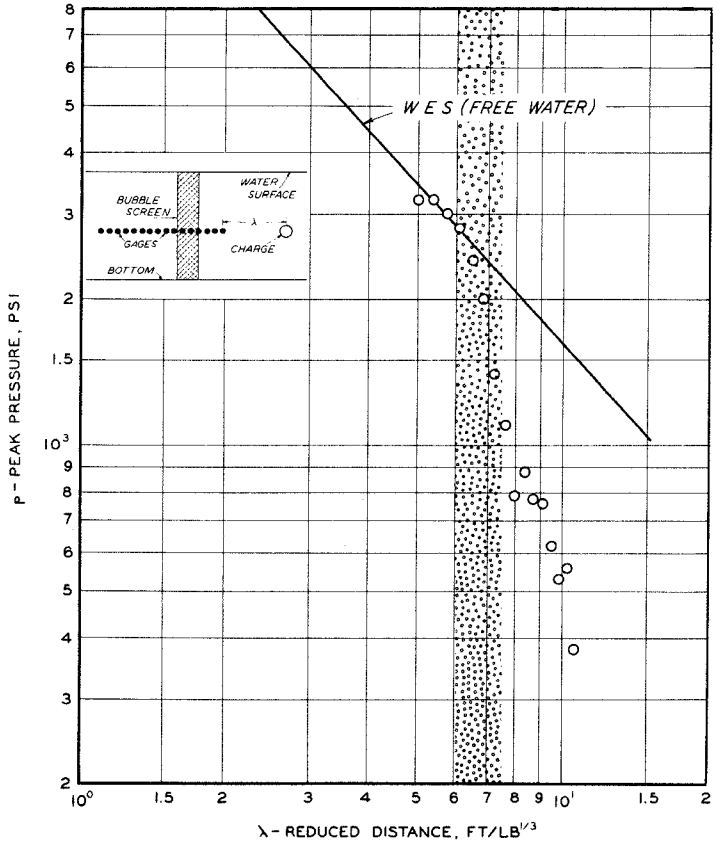


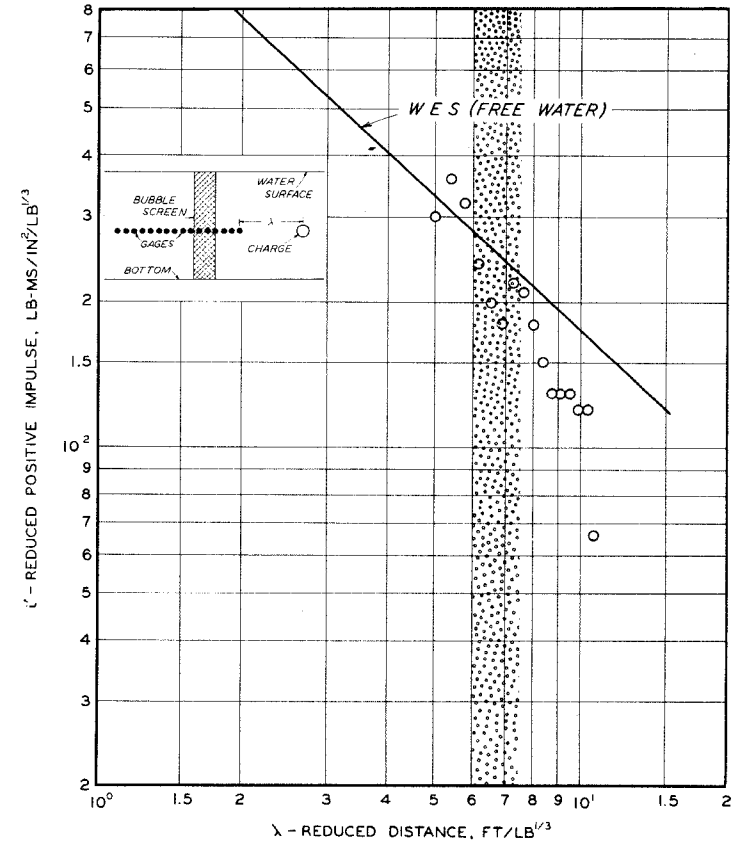


O - W.E.S. EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 7

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 3.0$, $A_c = 0.0014$ (~0.3%), $R_o = 12.0$



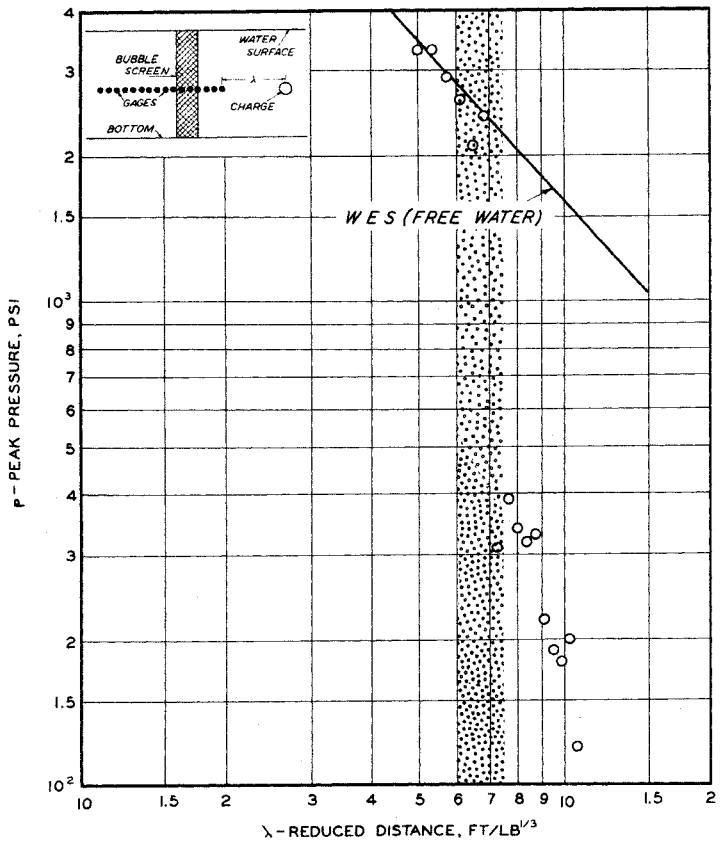


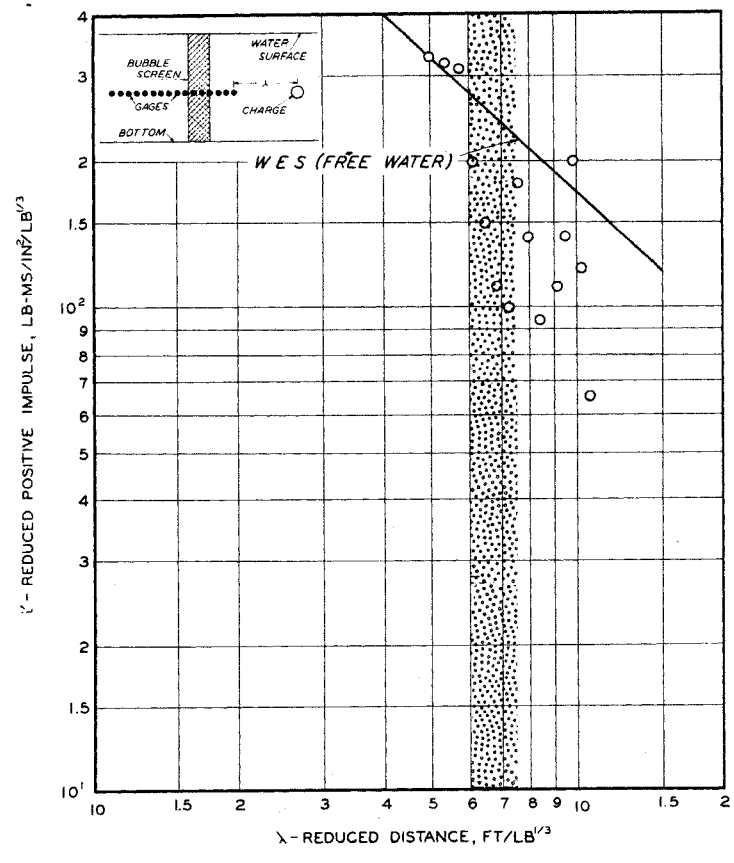
O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 8

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 3.0$, $A_c = 0.0044$ ($\sim$ 1.0%), $R_o = 12.0$

PLATE 9

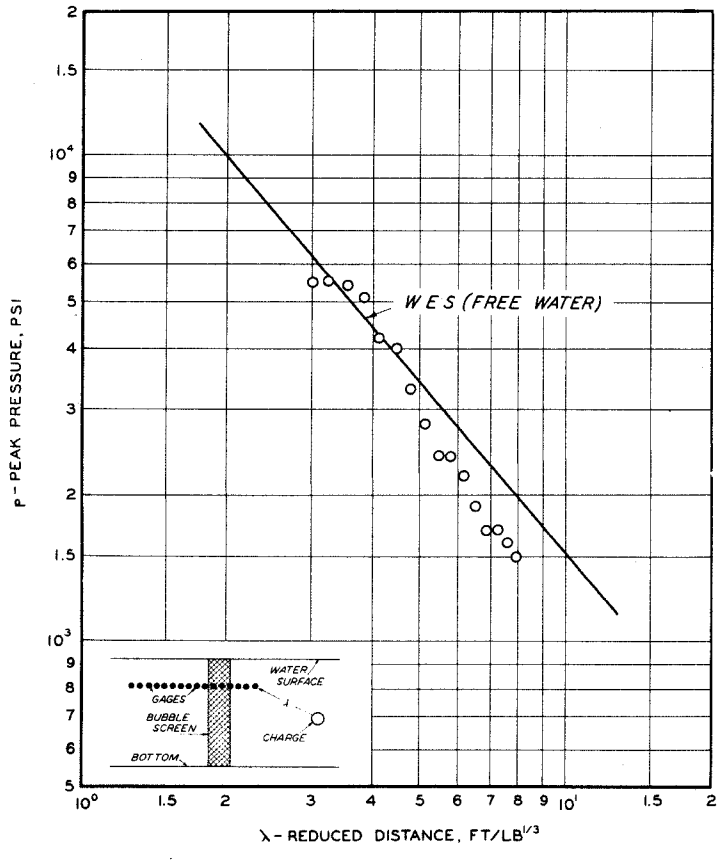


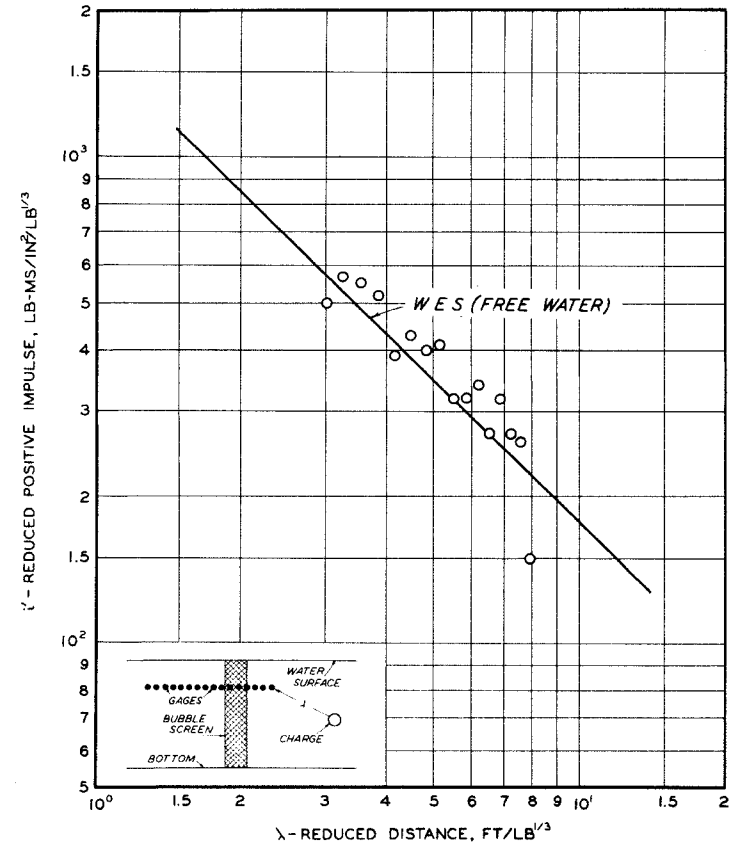


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 9

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 3.0$, $A_c = 0.0347$ ($\sim$ 3.0%), $R_o = 12.0$





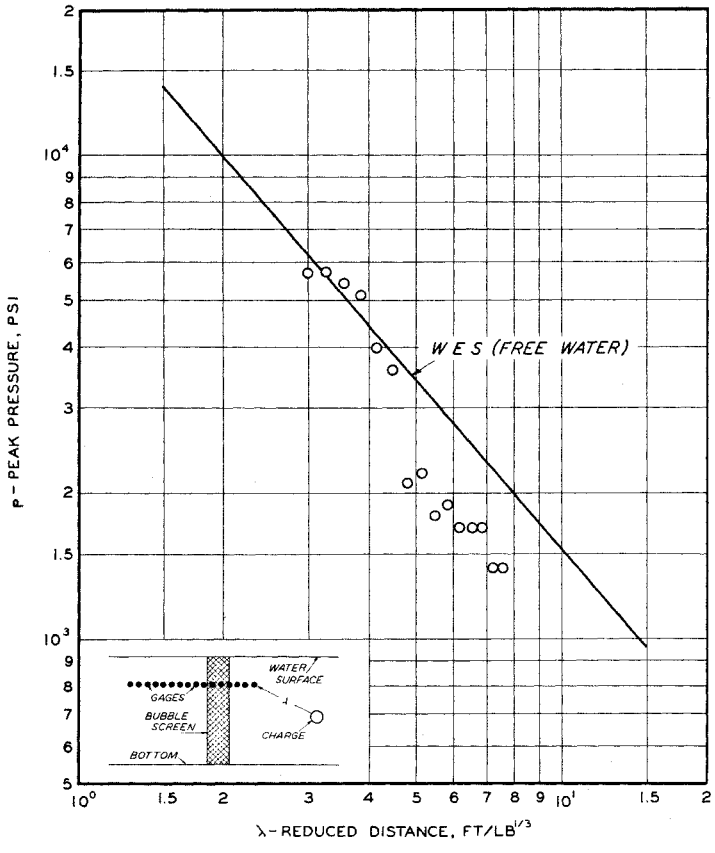
O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 2 AND 10

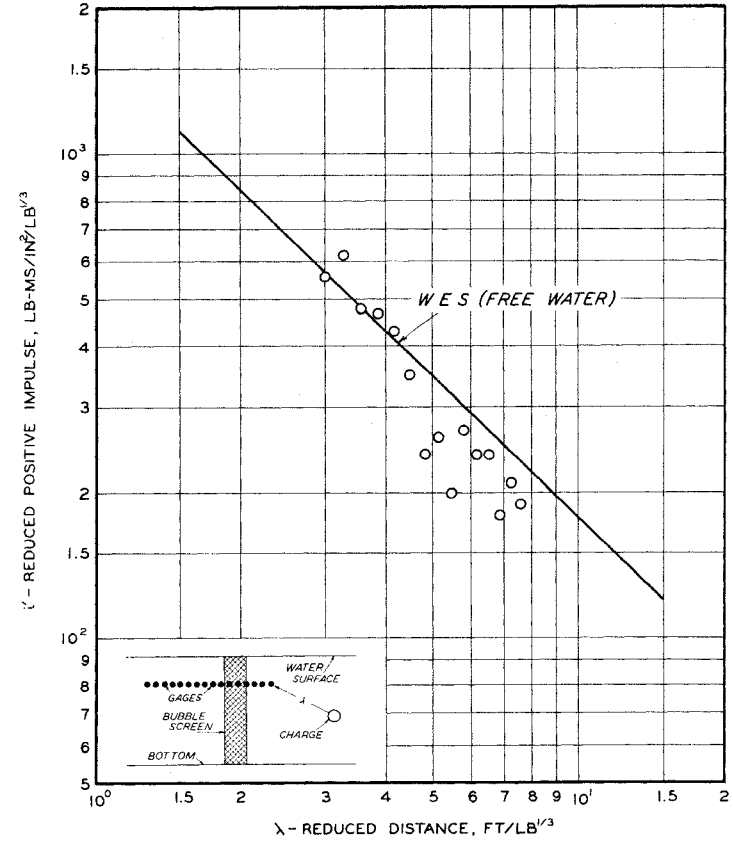
VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 4.5$, $T_s = 3.0$, $A_c = 0.0014$ ($\sim 0.3\%$), $R_o = 6.0$

PLATE 11

PLATE 12

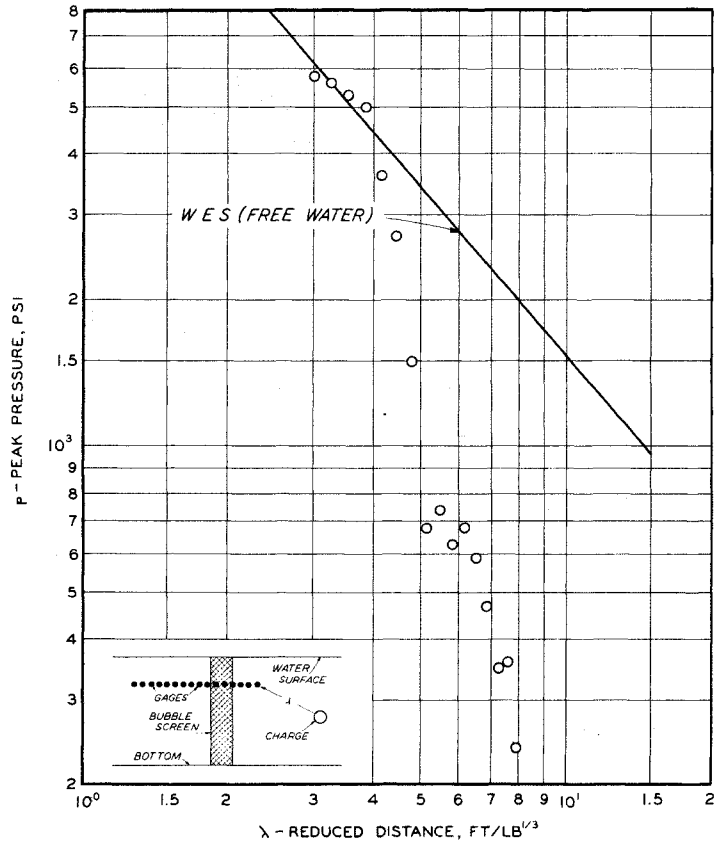


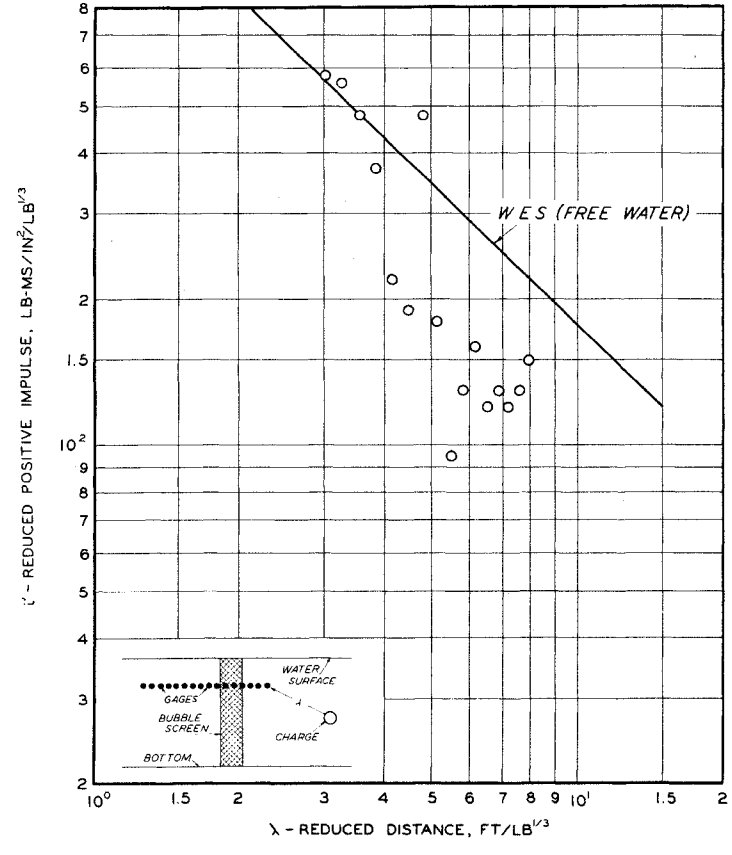


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 2 AND 11

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 4.5$, $T_s = 3.0$, $A_c = 0.0044$ (~ 1.0%), $R_o = 6.0$

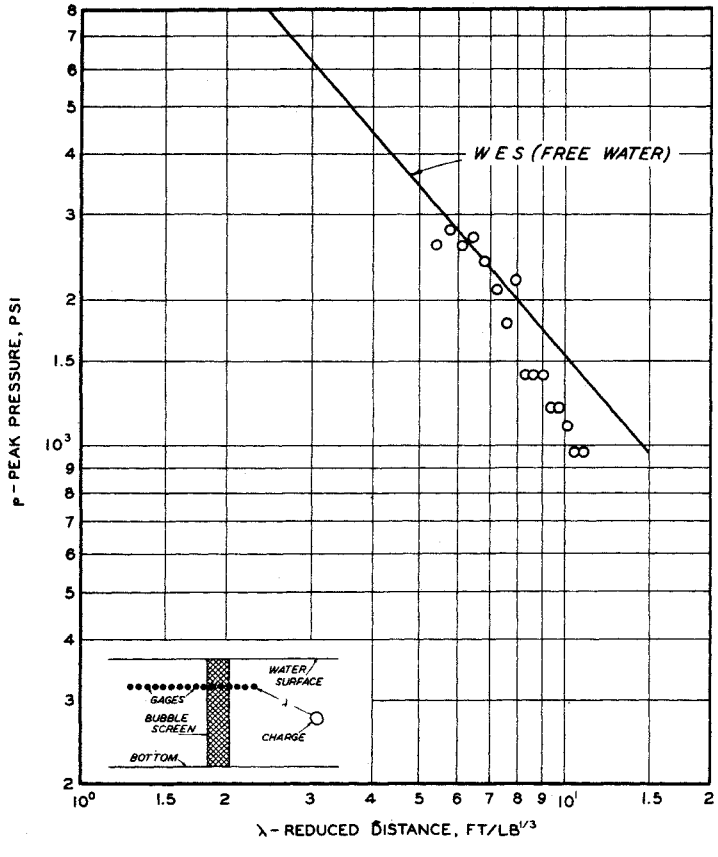


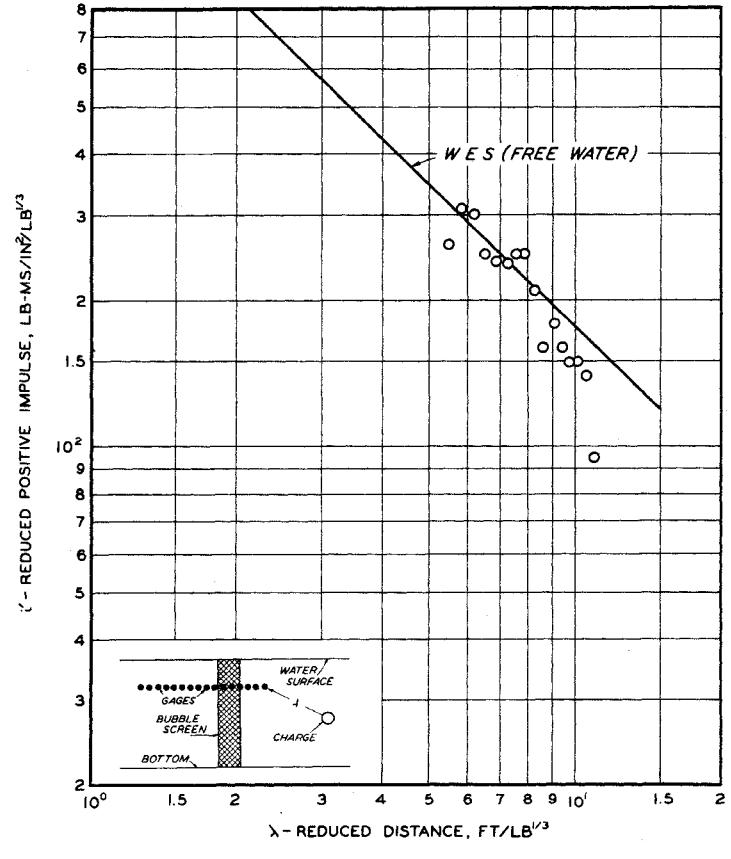


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 2 AND 12

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 4.5$, $T_s = 3.0$, $A_c = 0.0347$ (~ 3.0%), $R_o = 6.0$

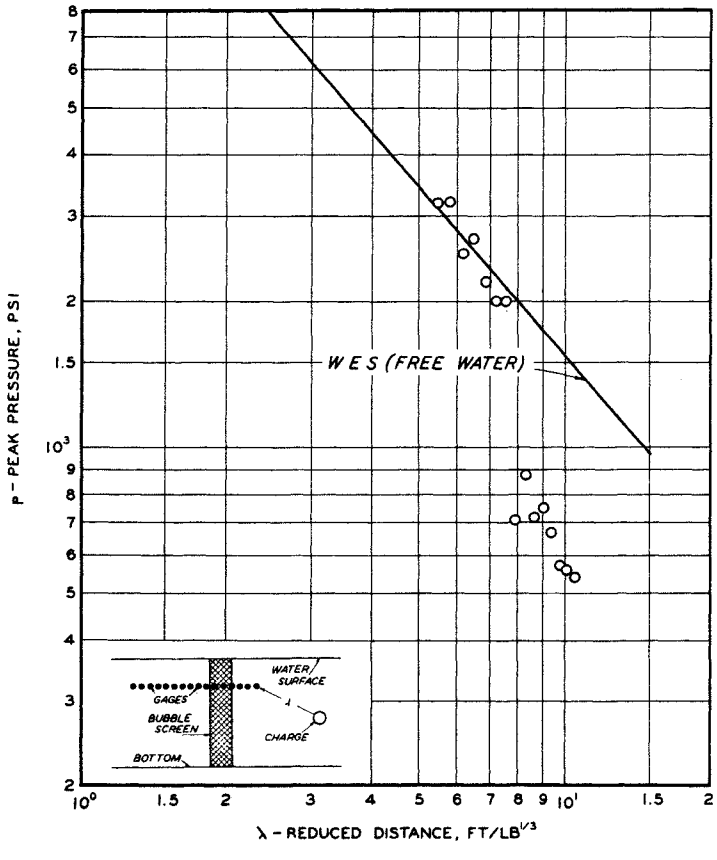


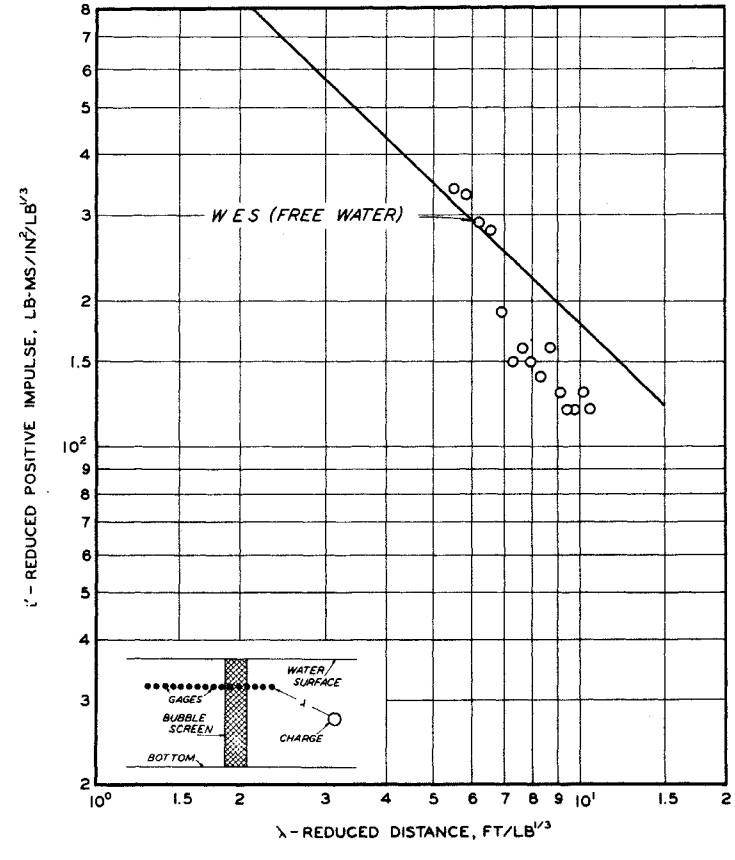


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 2 AND 13

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_\ell = 4.5$, $T_s = 3.0$, $A_c = 0.0014$ ($\sim$ 0.3%), $R_o = 12.0$



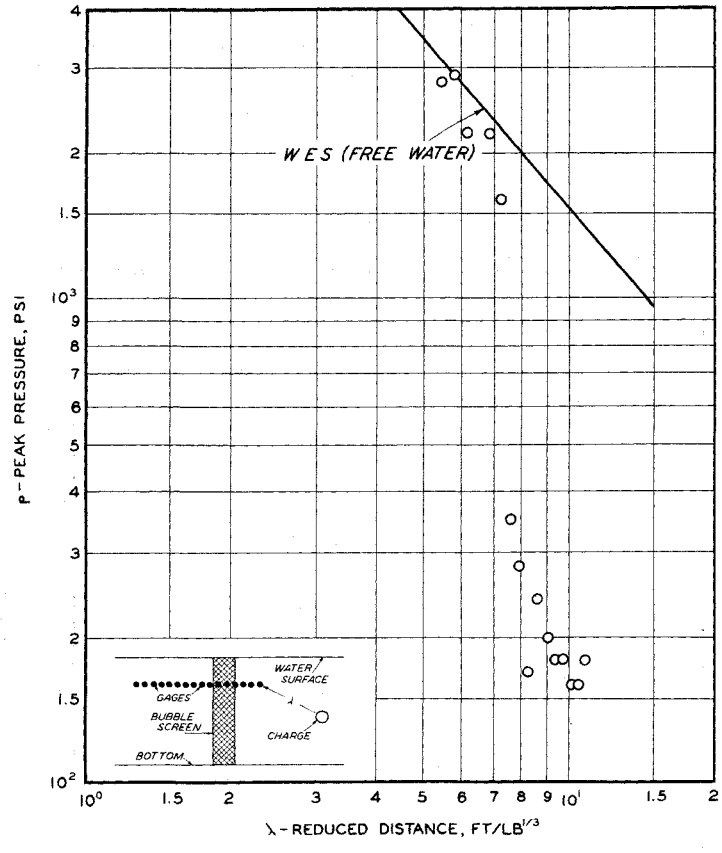


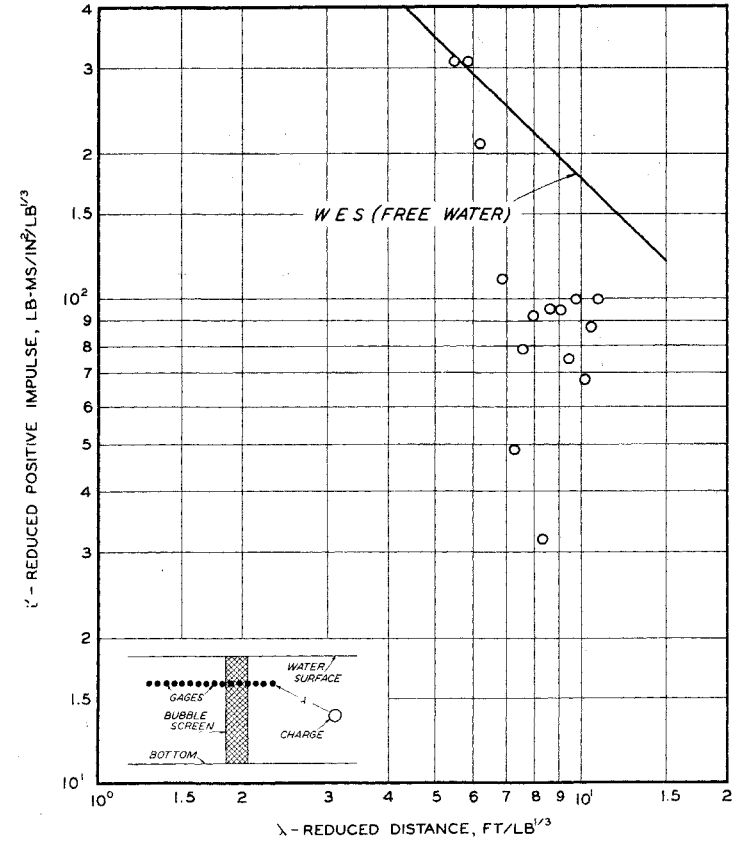
O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 2 AND 14

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 4.5$, $T_s = 3.0$, $A_c = 0.0044$ (~ 1.0 %), $R_o = 12.0$

PLATE 15

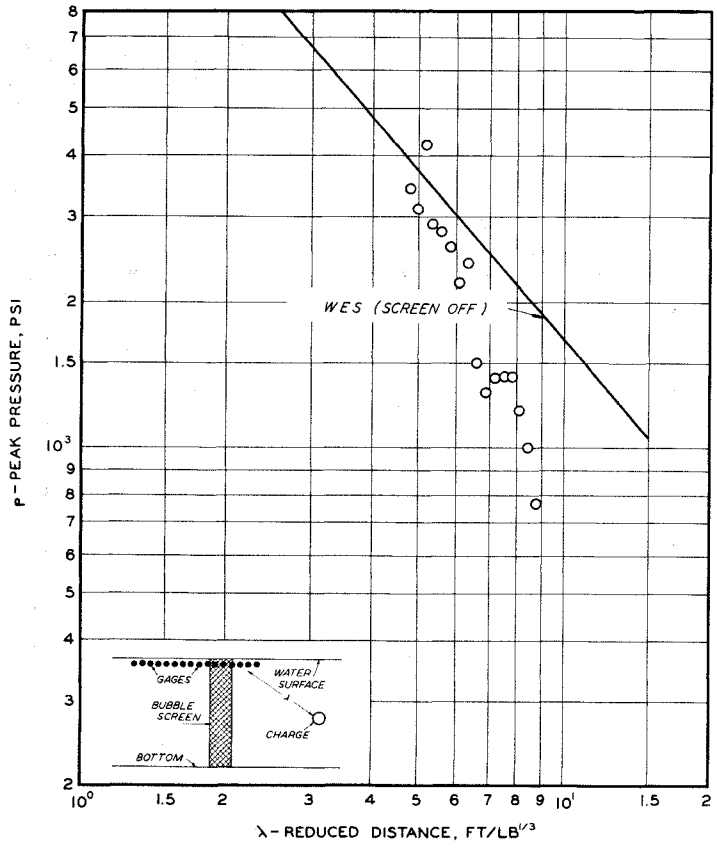


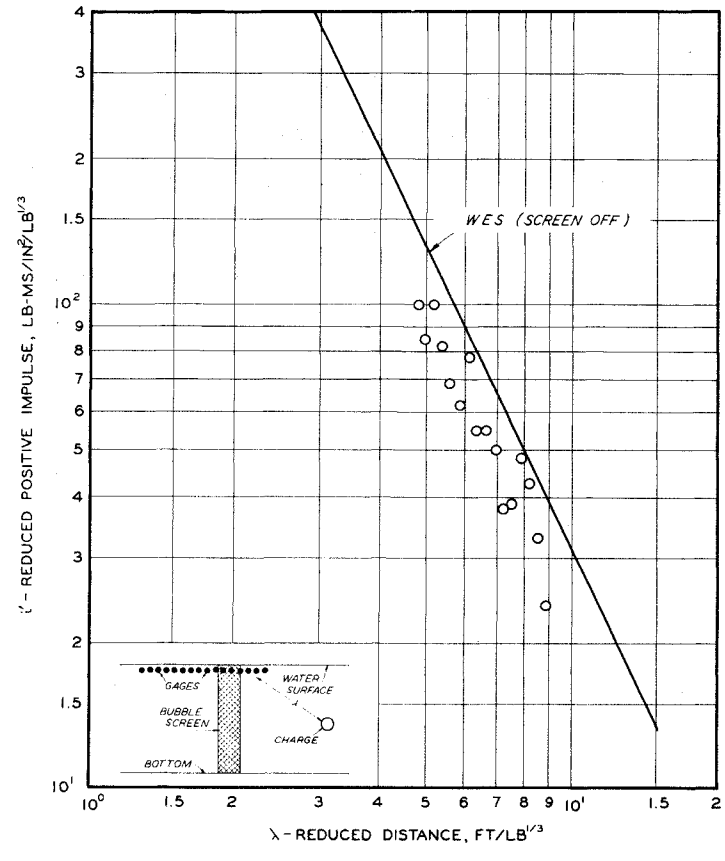


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 2 AND 15

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 4.5$, $T_s = 3.0$, $A_c = 0.0347$ (~ 3.0%), $R_o = 12.0$

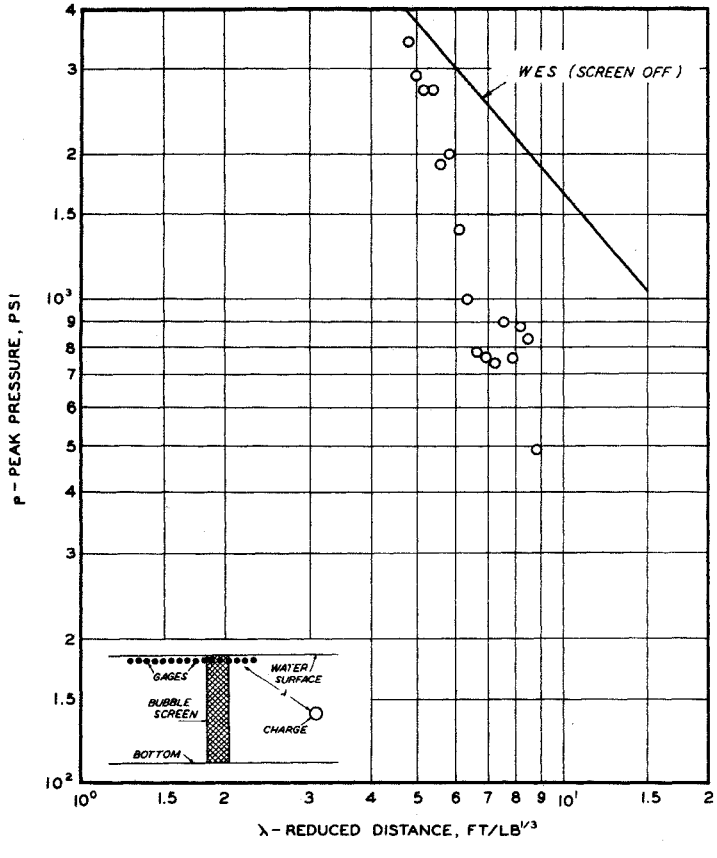


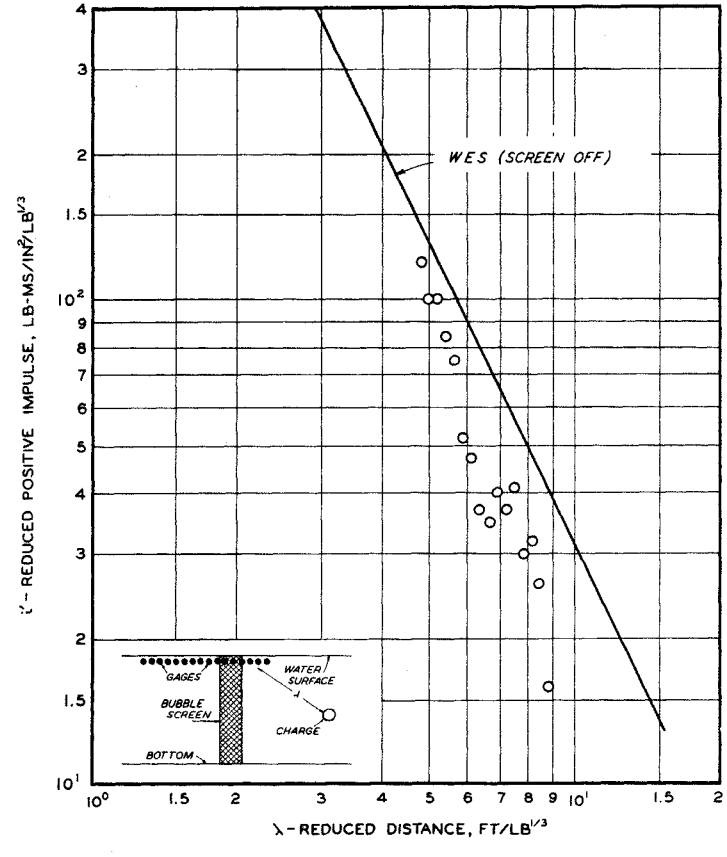


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 3 AND 16

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 0.25$, $T_s = 3.0$, $A_c = 0.0014$ ($\sim 0.3\%$), $R_o = 6.0$

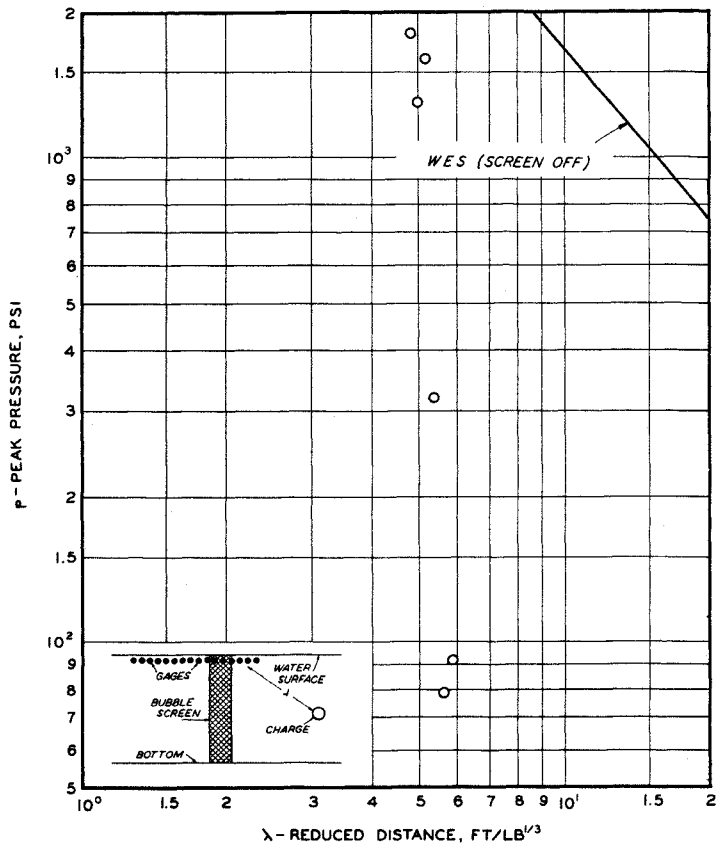


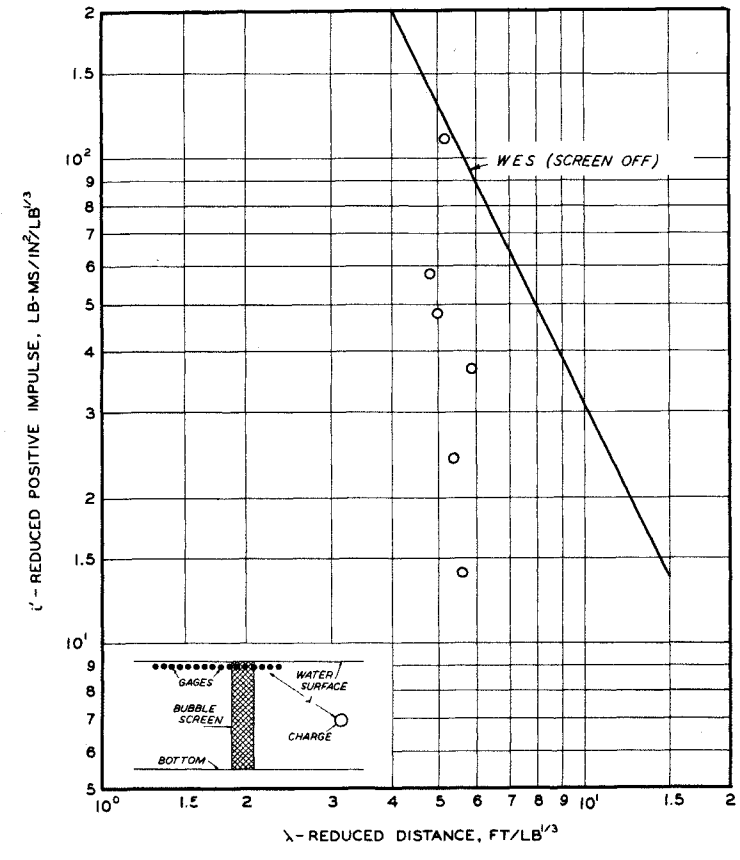


O - WES EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 3 AND 17

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 0.25$, $T_s = 3.0$, $A_c = 0.0044$ (~ 1.0%), $R_o = 6.0$



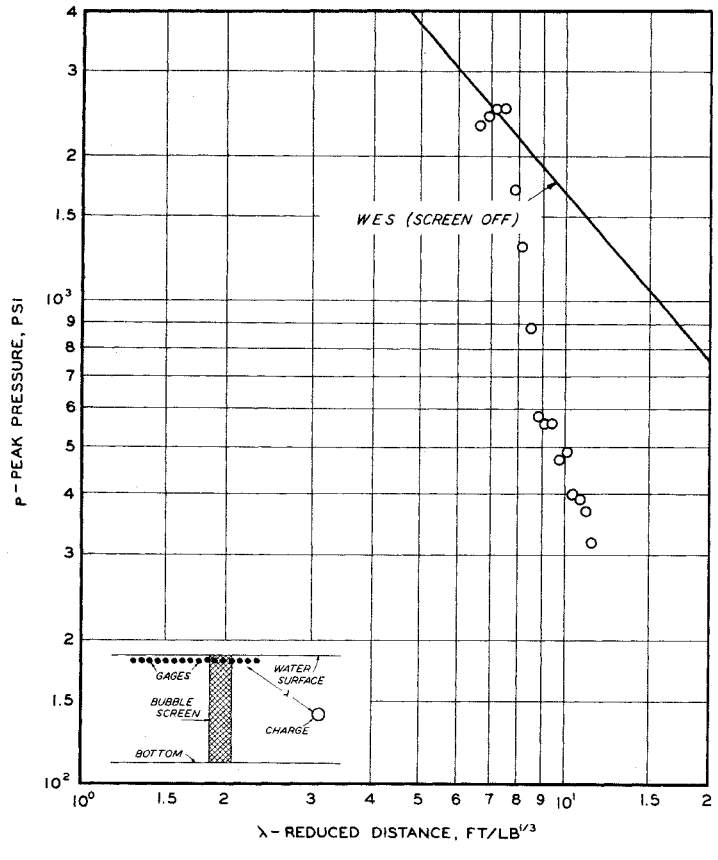


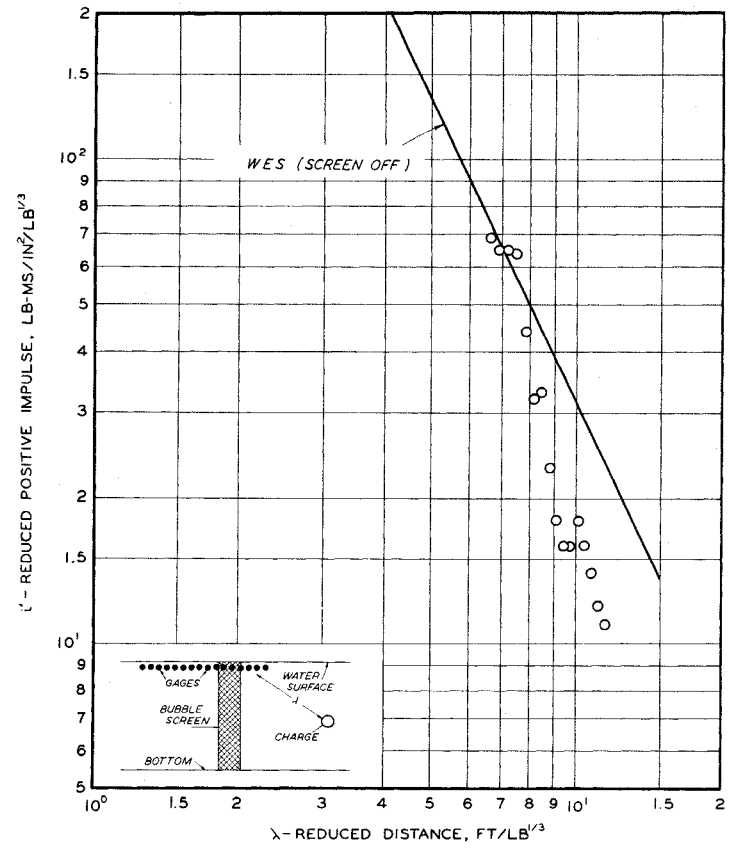
O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 3 AND 18

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 0.25$, $T_s = 3.0$, $A_c = 0.0347 (\sim 3.0\%)$, $R_o = 6.0$

PLATE 19.

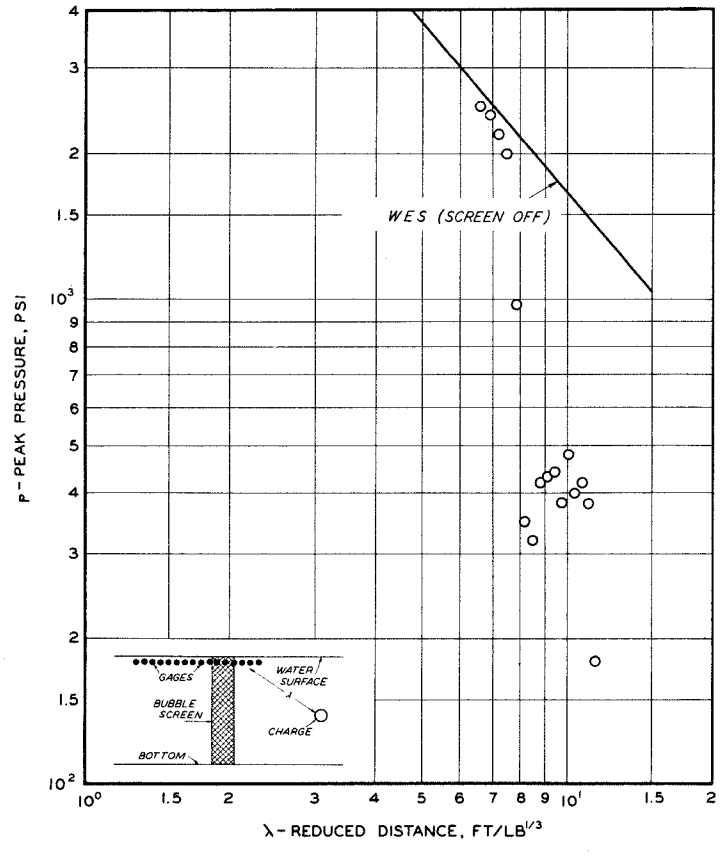


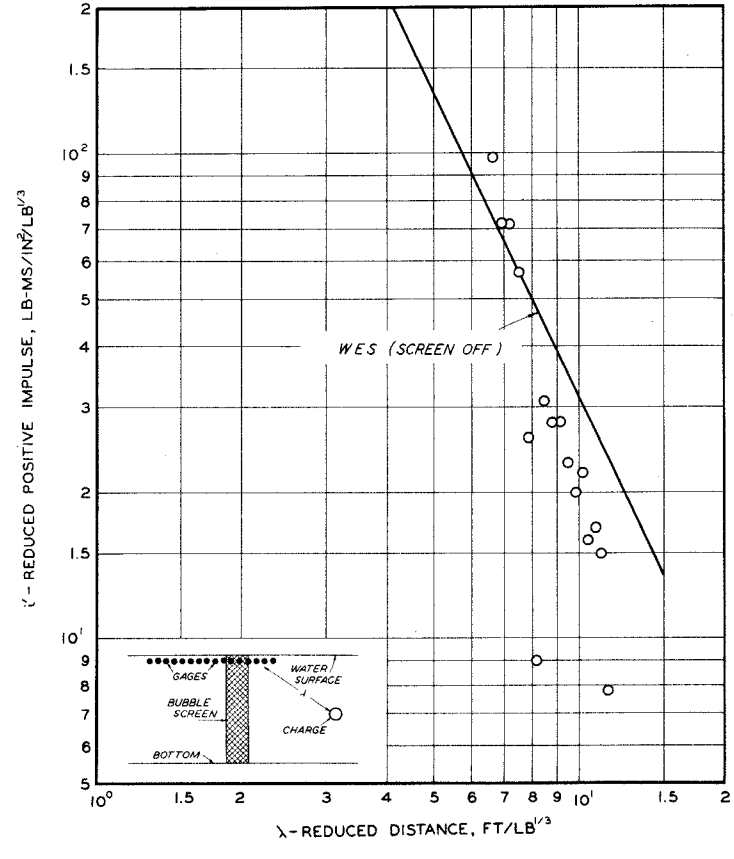


O - WES EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 3 AND 19

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 0.25$, $T_s = 3.0$, $A_c = 0.0014$ ($\sim 0.3\%$), $R_o = 12.0$

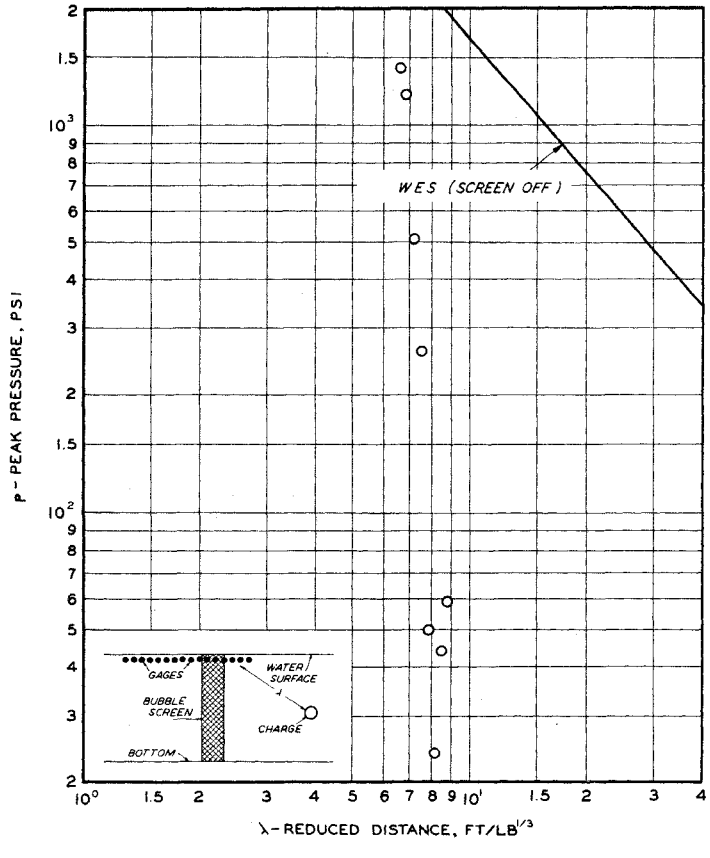


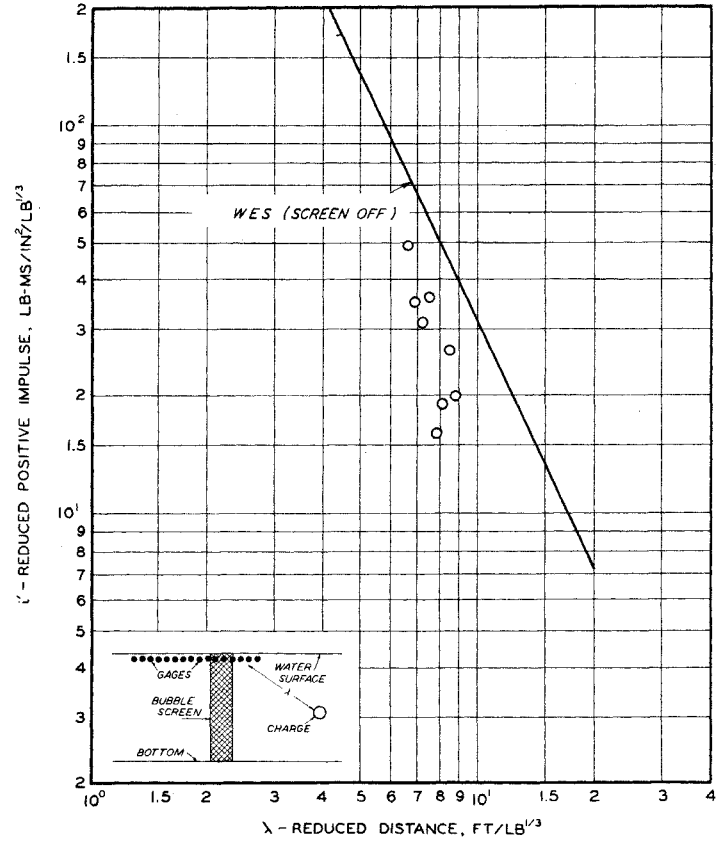


O - WES EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 3 AND 20

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 0.25$, $T_s = 3.0$, $A_c = 0.0044$ (~ 1.0 %), $R_o = 12.0$

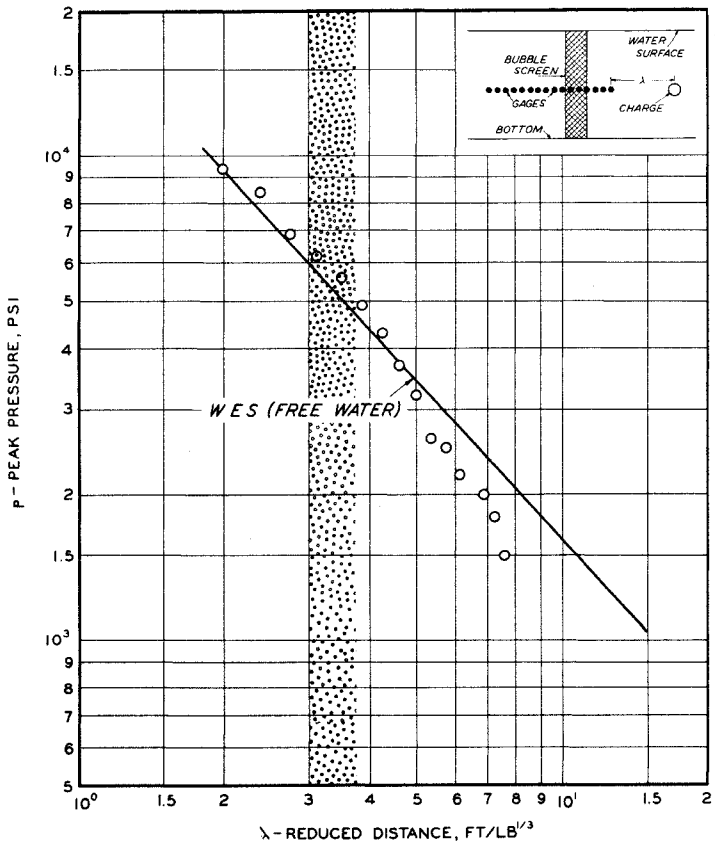


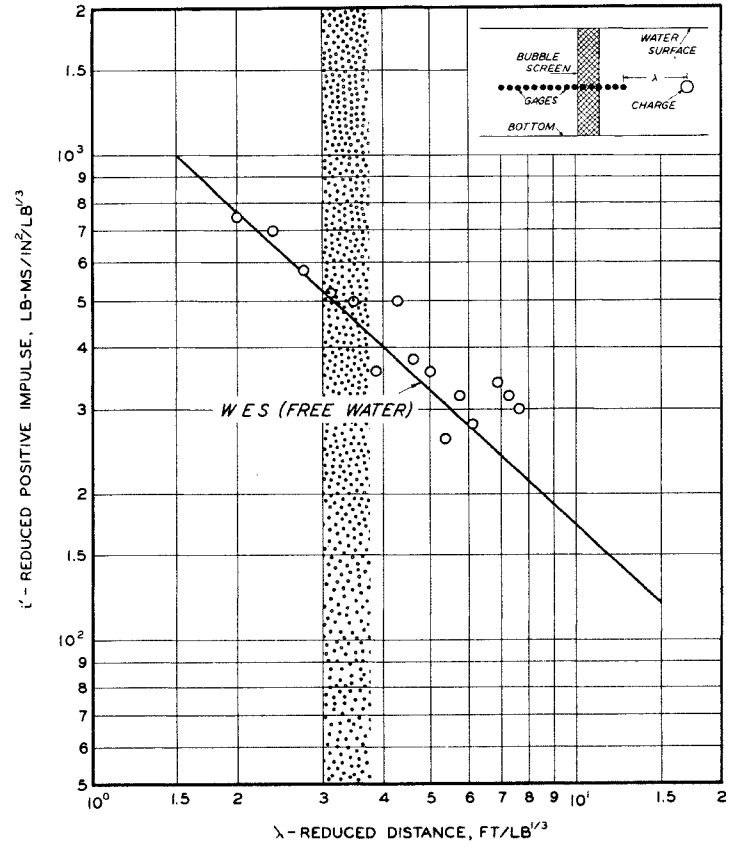


O - WES EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 3 AND 21

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 0.25$, $T_s = 3.0$, $A_c = 0.0347$ (~ 3.0%), $R_o = 12.0$

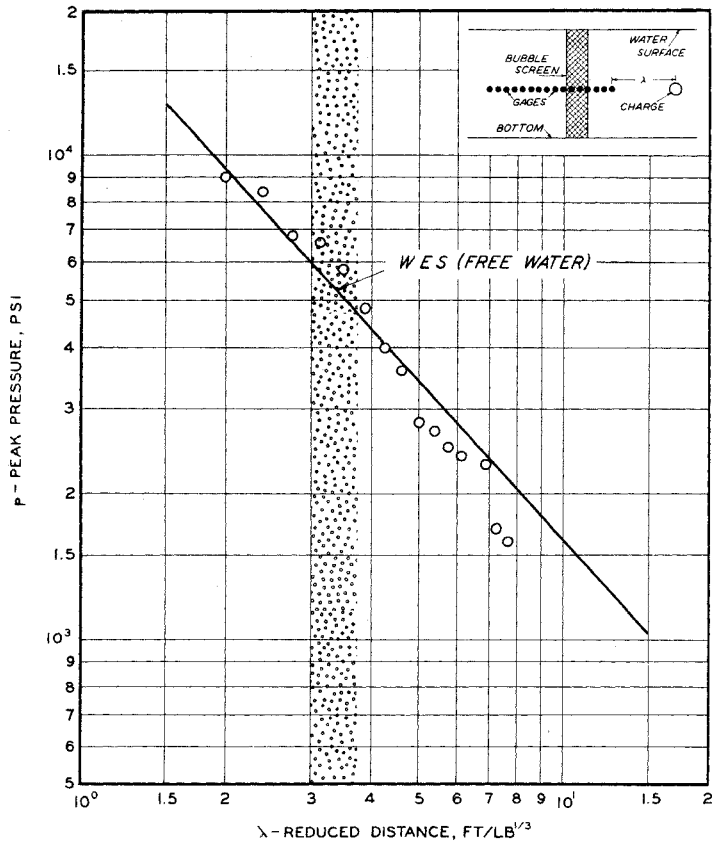


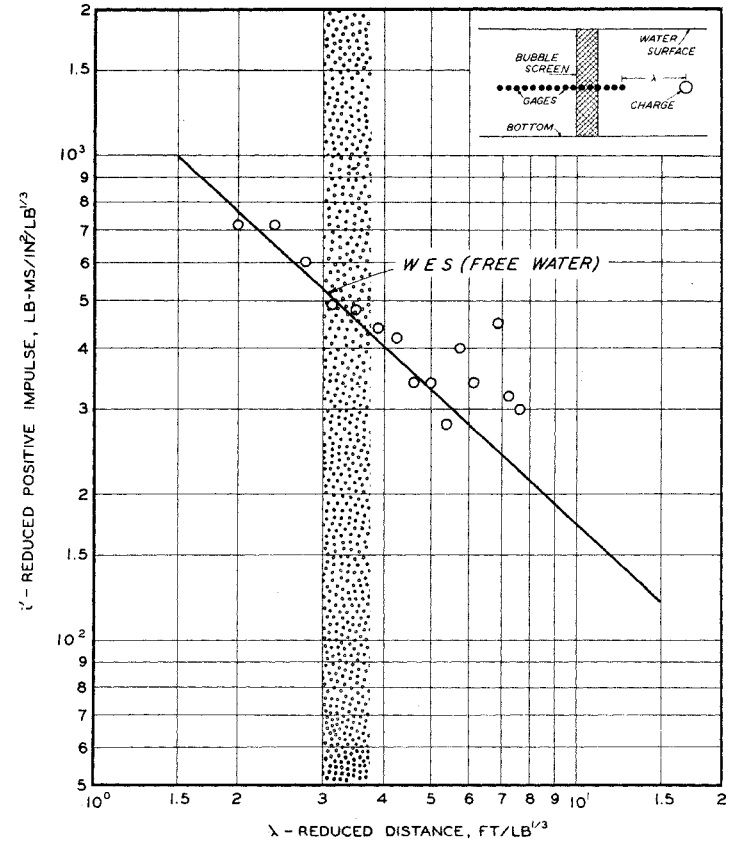


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 22

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 1.5$, $A_c = 0.0028 (\sim 0.3\%)$, $R_o = 6.0$

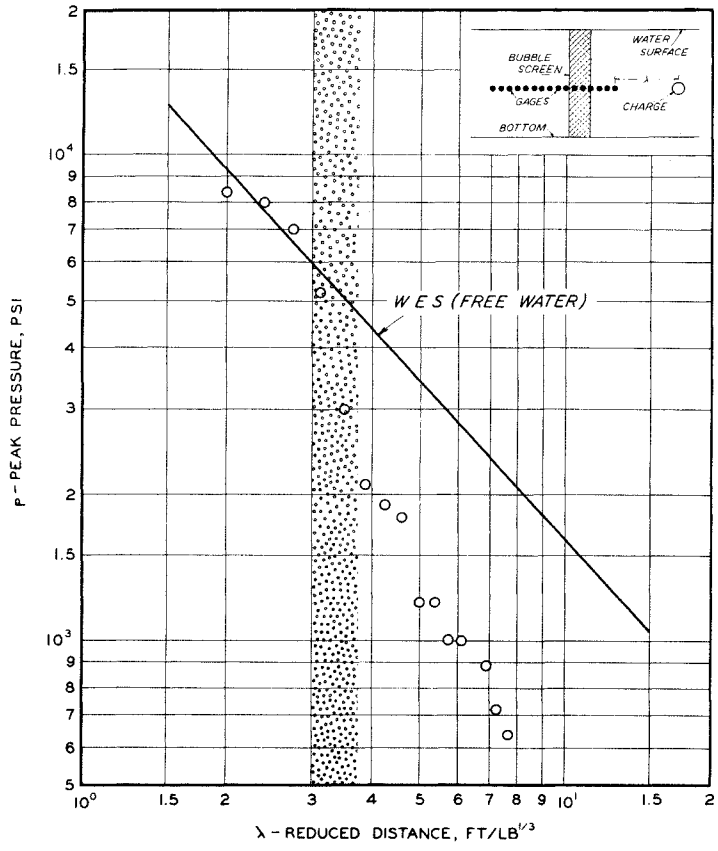


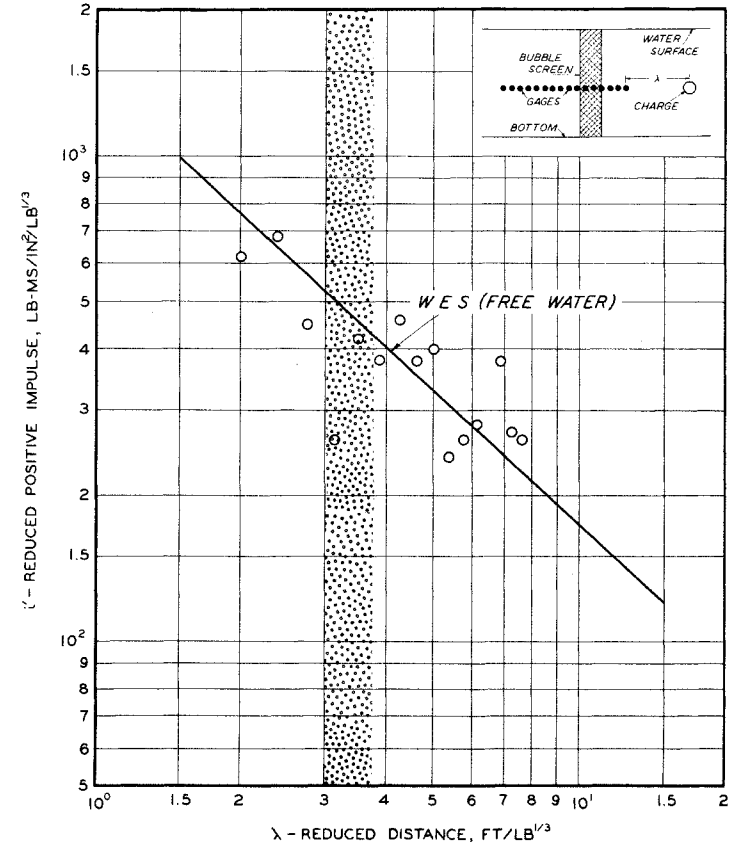


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 23

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 1.5$, $A_c = 0.0044$ (~ 1.0 %), $R_o = 6.0$

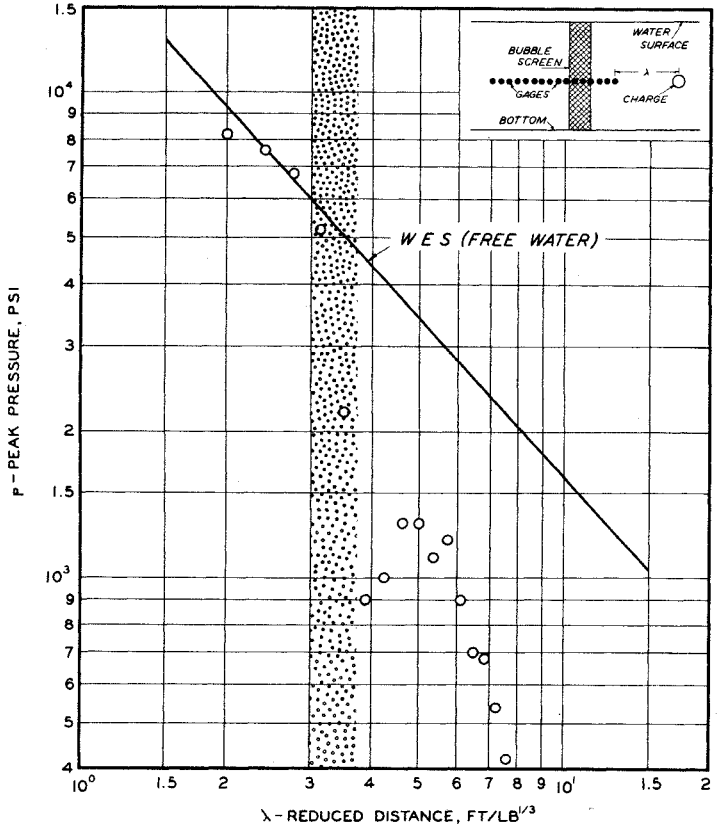


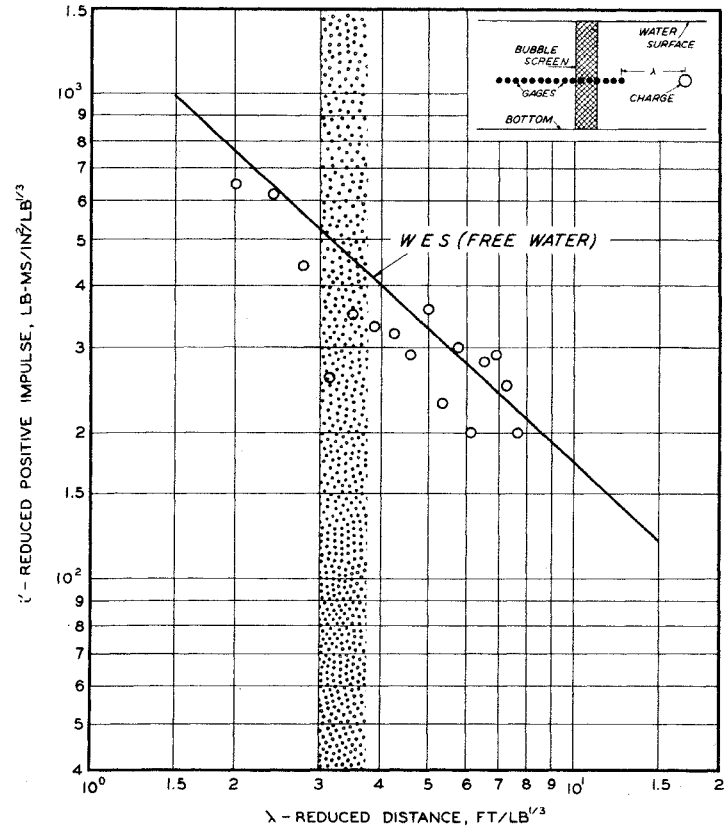


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 24

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 1.5$, $A_c = 0.0347 (\sim 3.0\%)$, $R_o = 6.0$

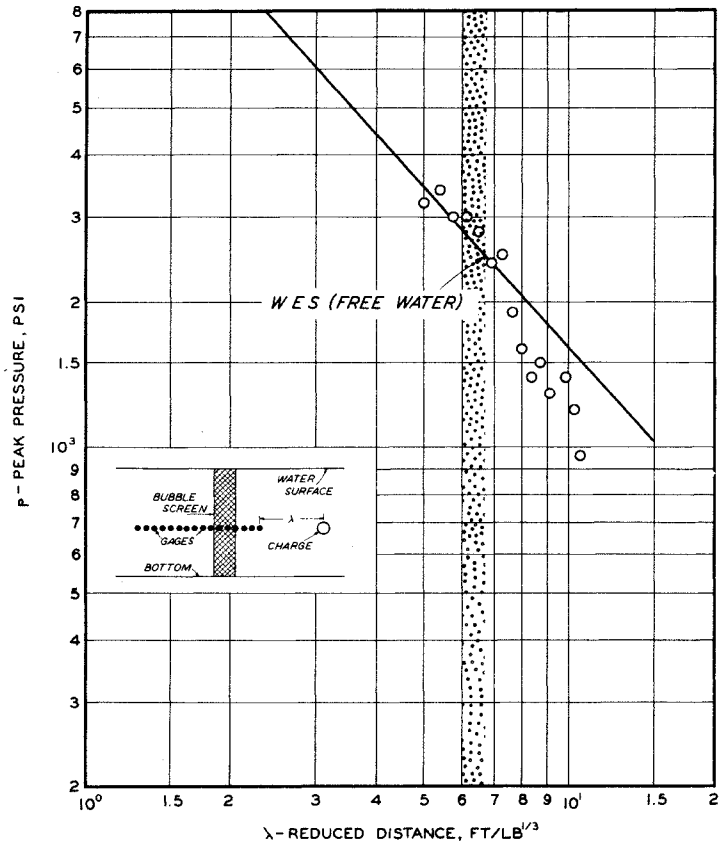


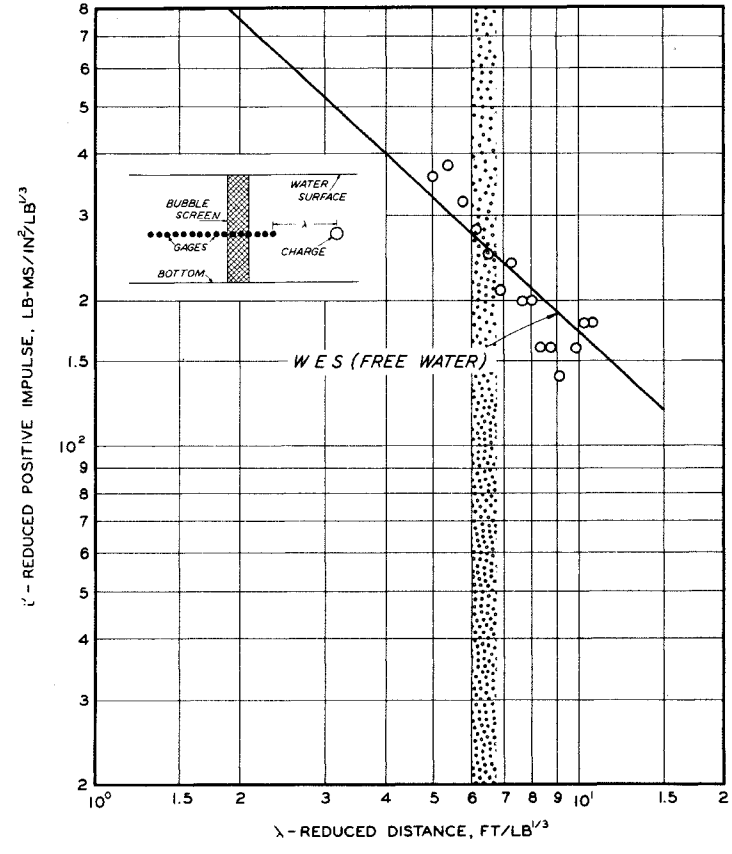


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 25

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_f = 9.0$, $T_s = 1.5$, $A_c = 0.0694$ (~ 6.0%), $R_o = 6.0$



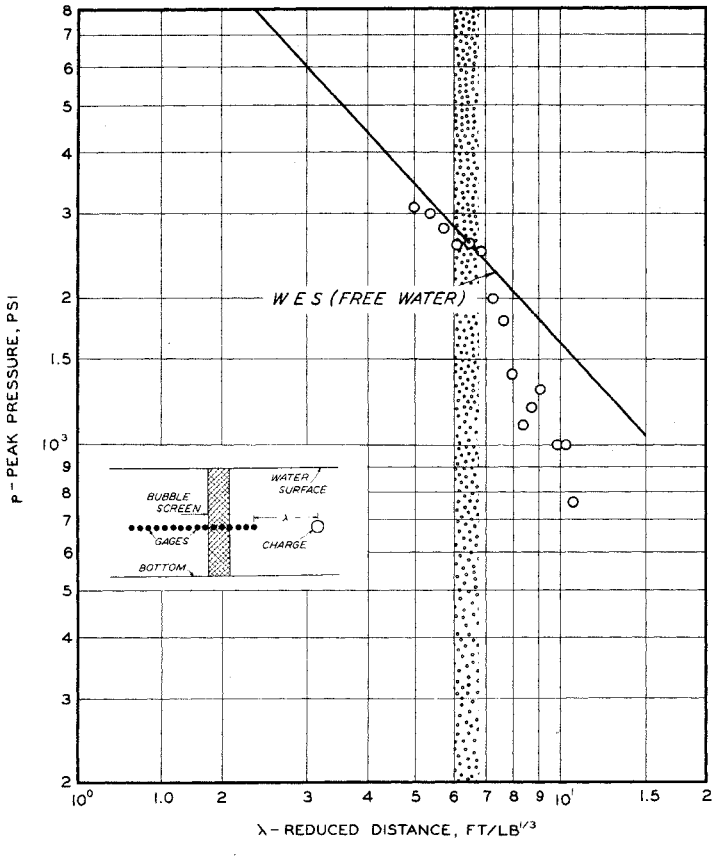


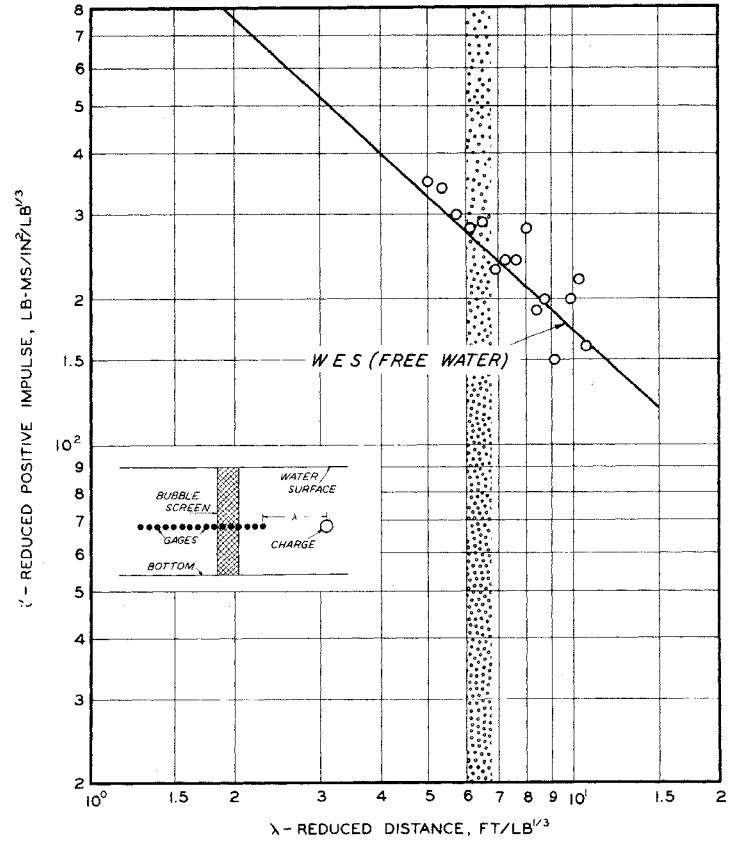
O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 26

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 1.5$, $A_c = 0.0028$ (~ 0.3%), $R_o = 12.0$

PLATE 27

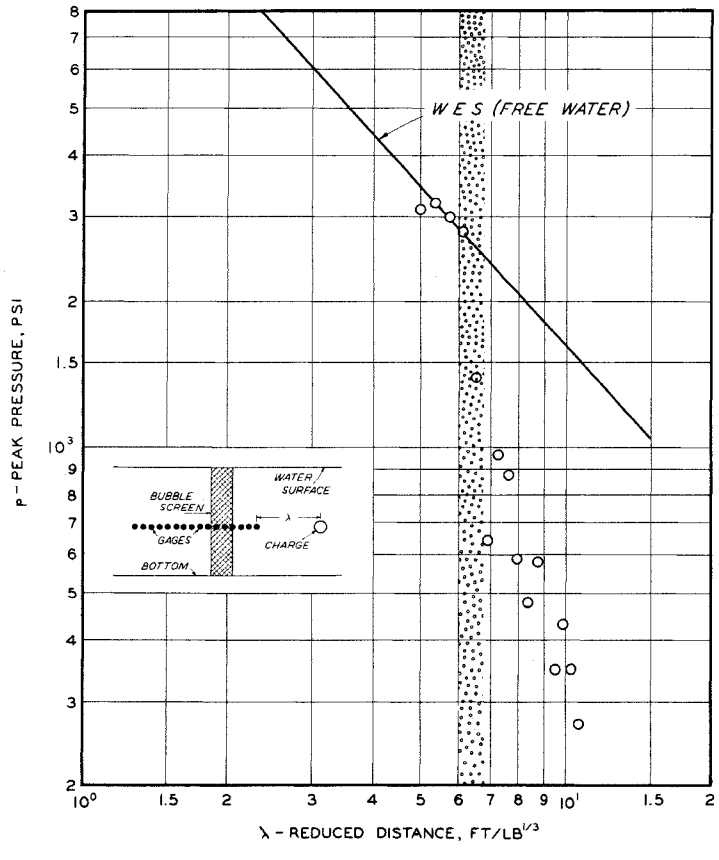


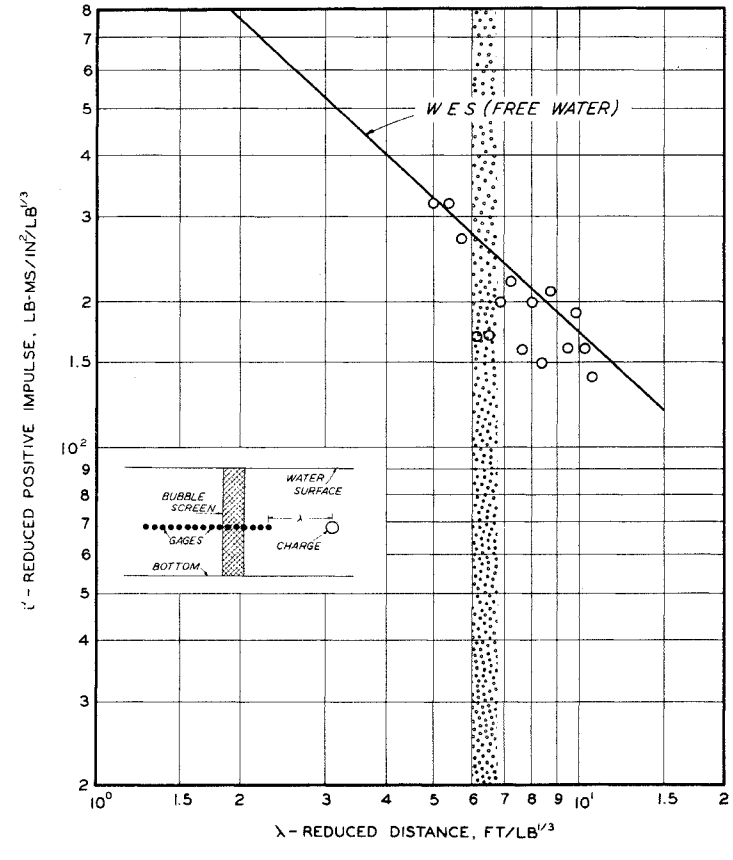


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 27

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 1.5$, $A_c = 0.0044 (\sim 1.0\,\%)$, $R_o = 12.0$

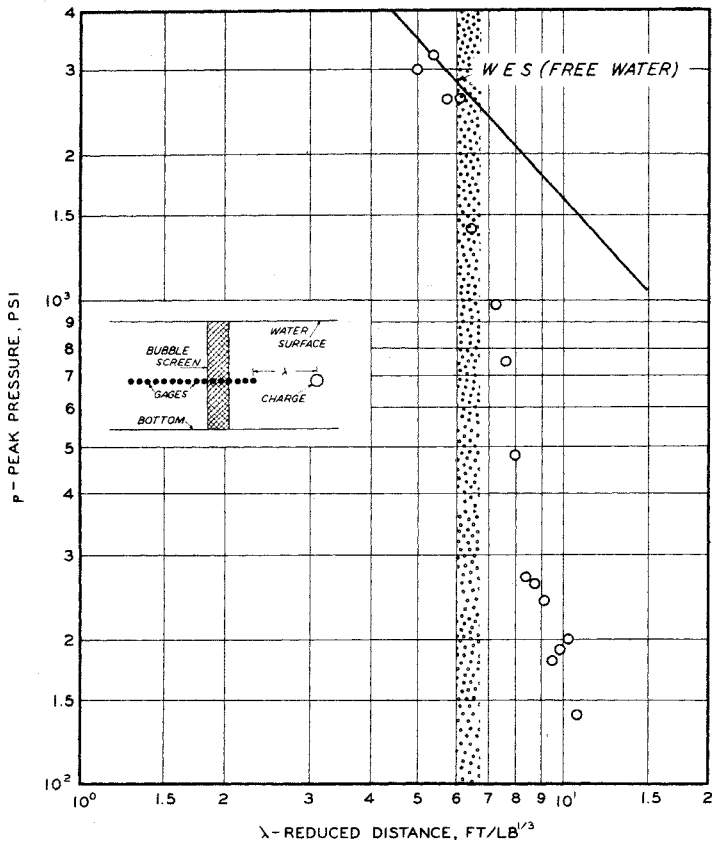


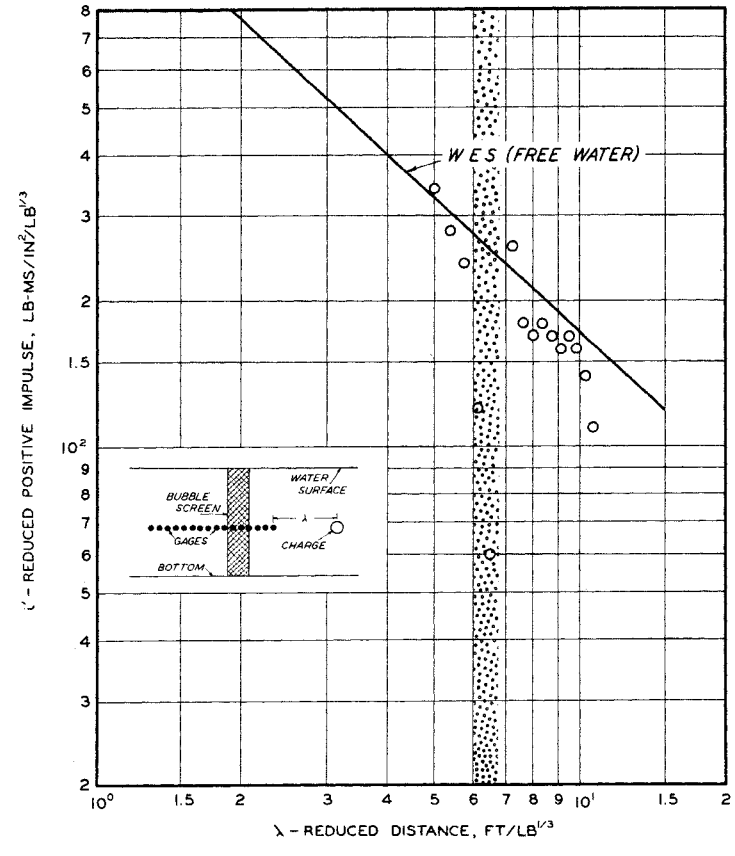


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES I AND 28

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 1.5$, $A_c = 0.0347$ (~ 3.0%), $R_o = 12.0$

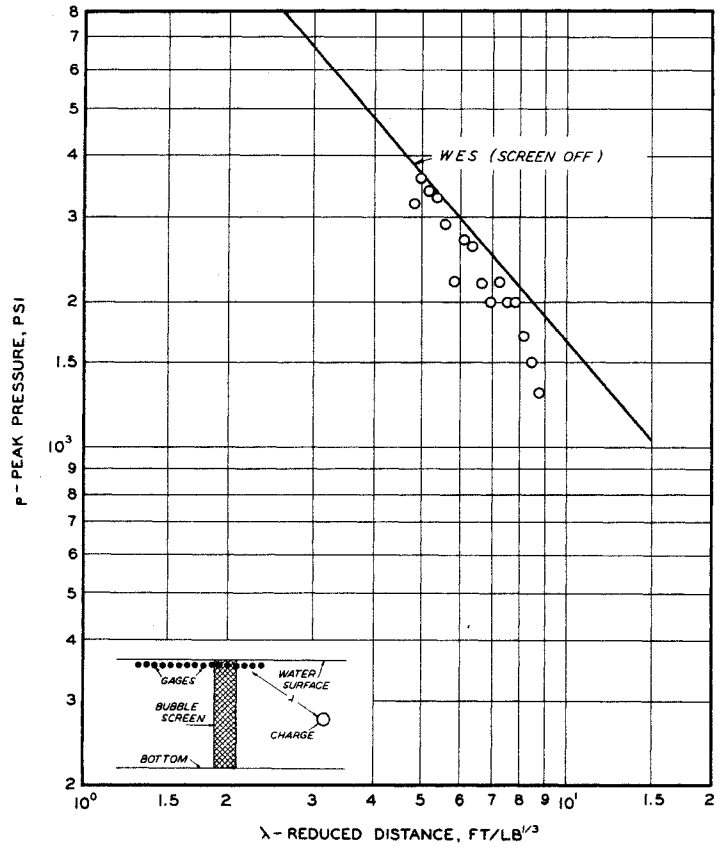


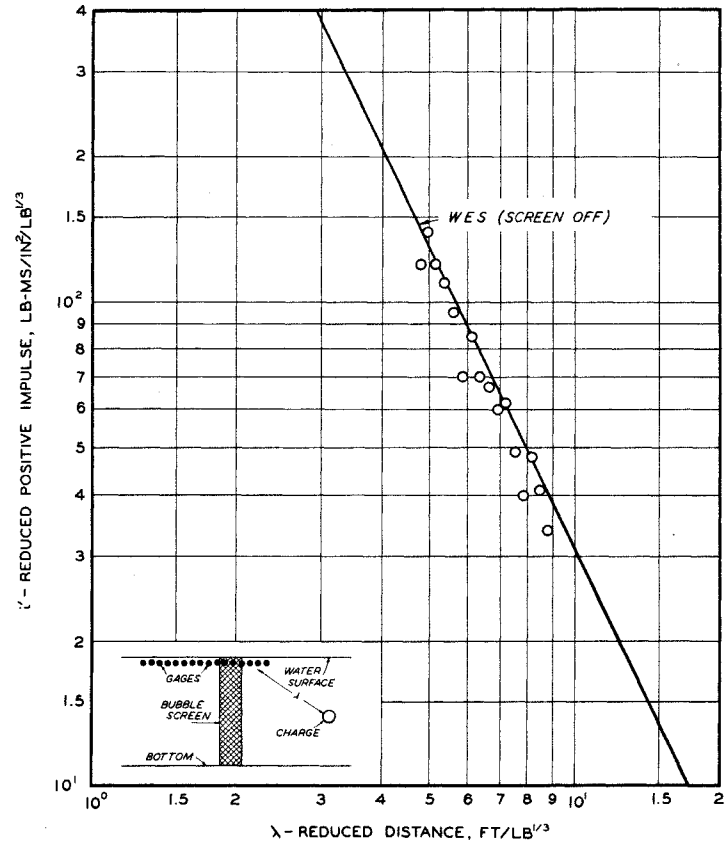


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES I AND 29

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 1.5$, $A_c = 0.0694$ (~ 6.0%), $R_o = 12.0$

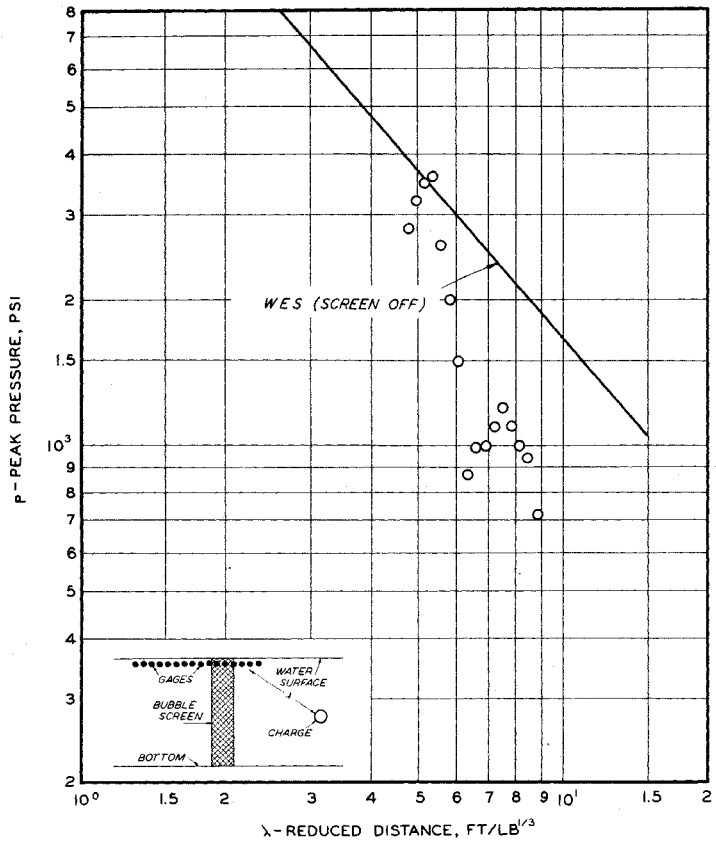


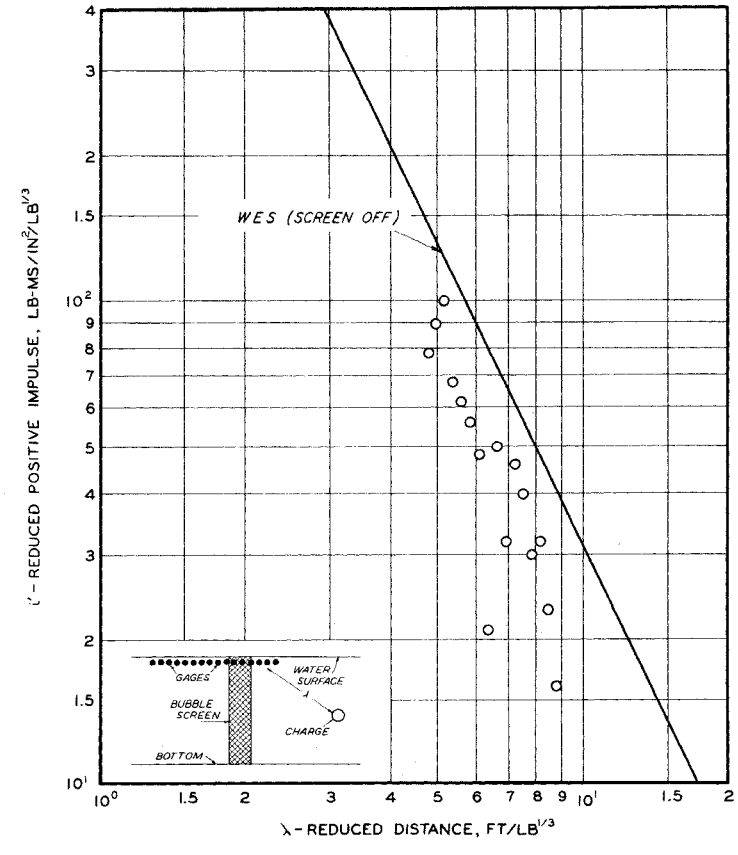


O - WES EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 3 AND 30

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 0.25$, $T_s = 1.5$, $A_c = 0.0028$ (~ 0.3%), $R_o = 6.0$

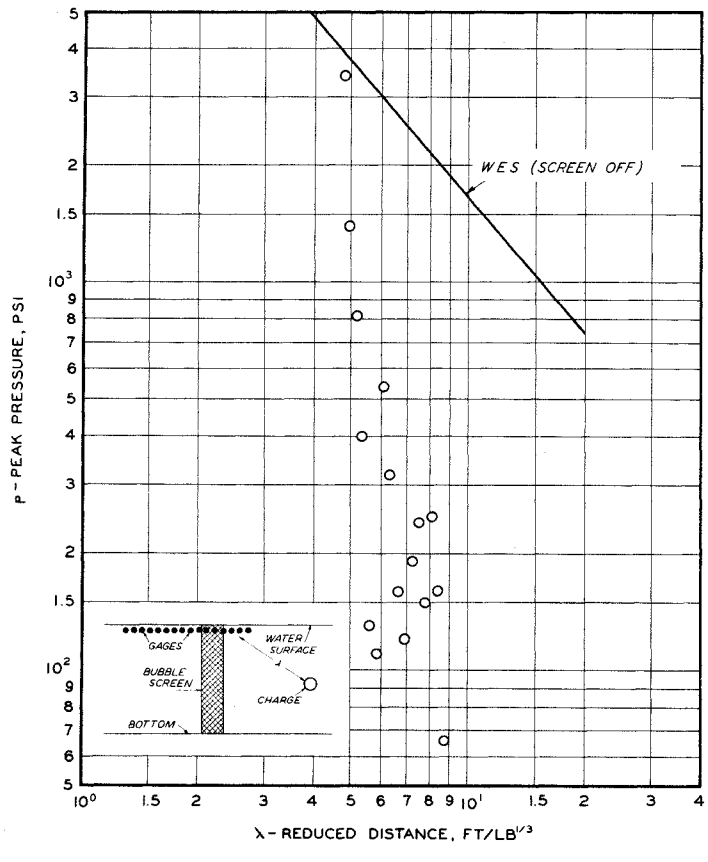


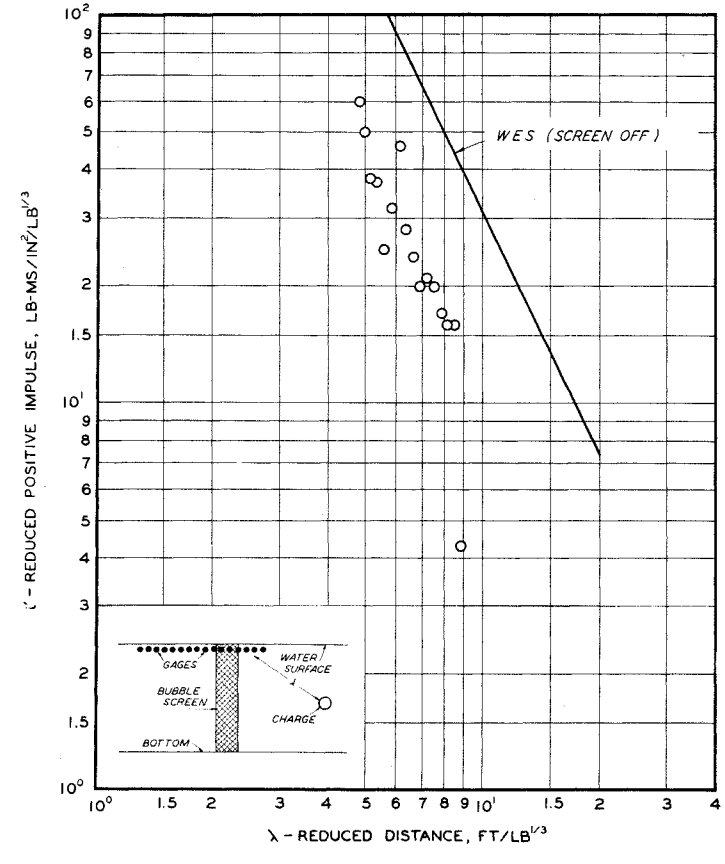


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 3 AND 31

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 0.25$, $T_s = 1.5$, $A_c = 0.0044$ (~ 1.0 %), $R_o = 6.0$



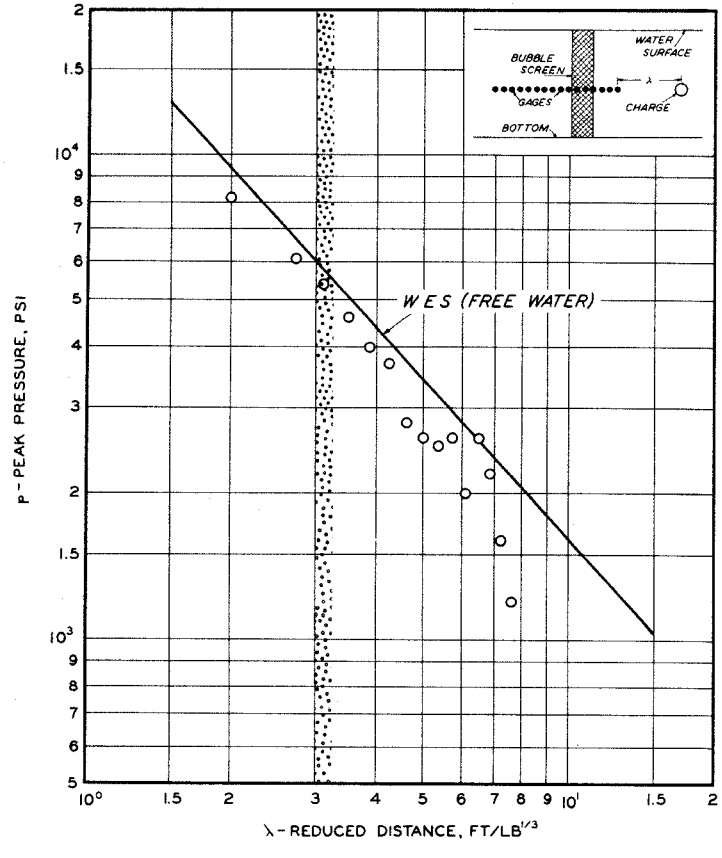


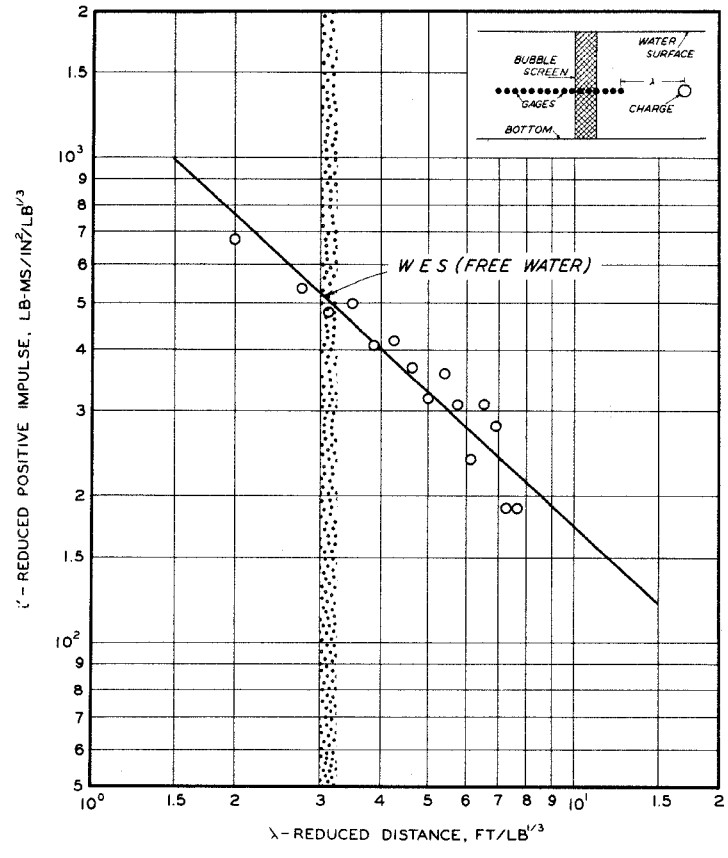
O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 3 AND 32

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 0.25$, $T_s = 1.5$, $A_c = 0.0347$ (~ 3.0%), $R_o = 6.0$

PLATE 33

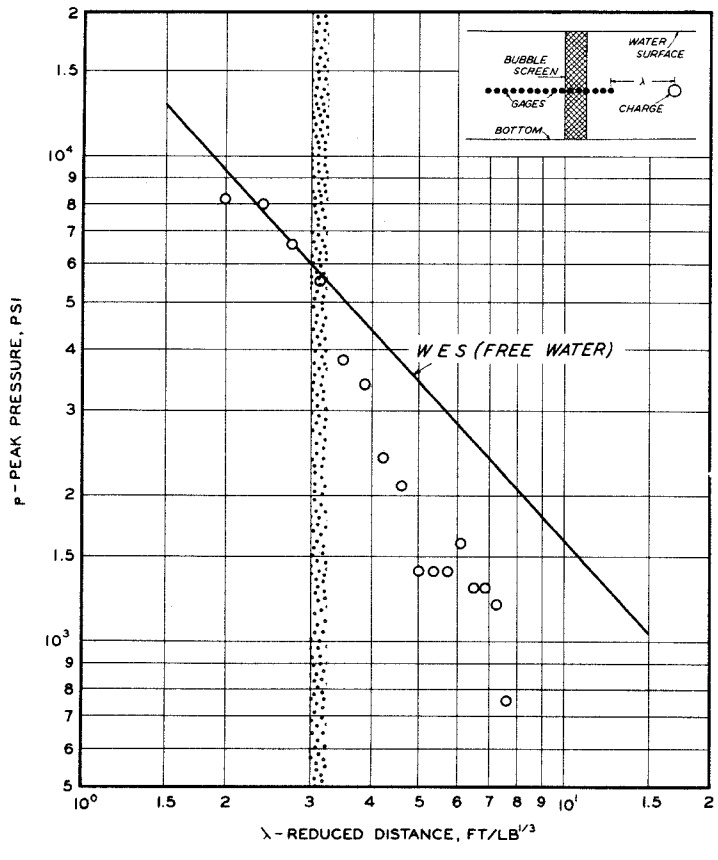


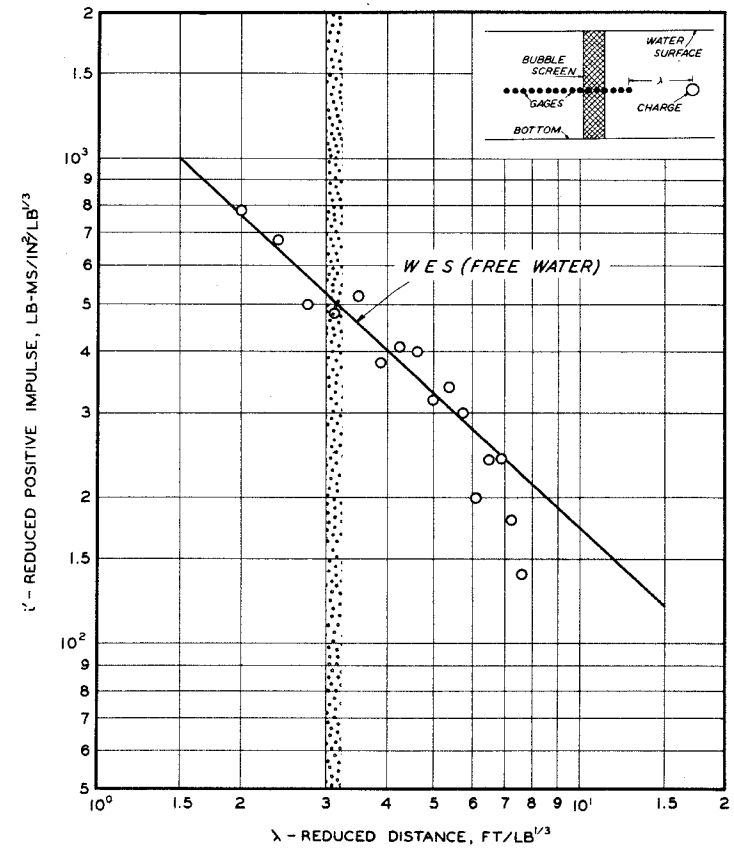


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 33

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 0.5$, $A_c = 0.0083$ (~ 0.3%), $R_o = 6.0$

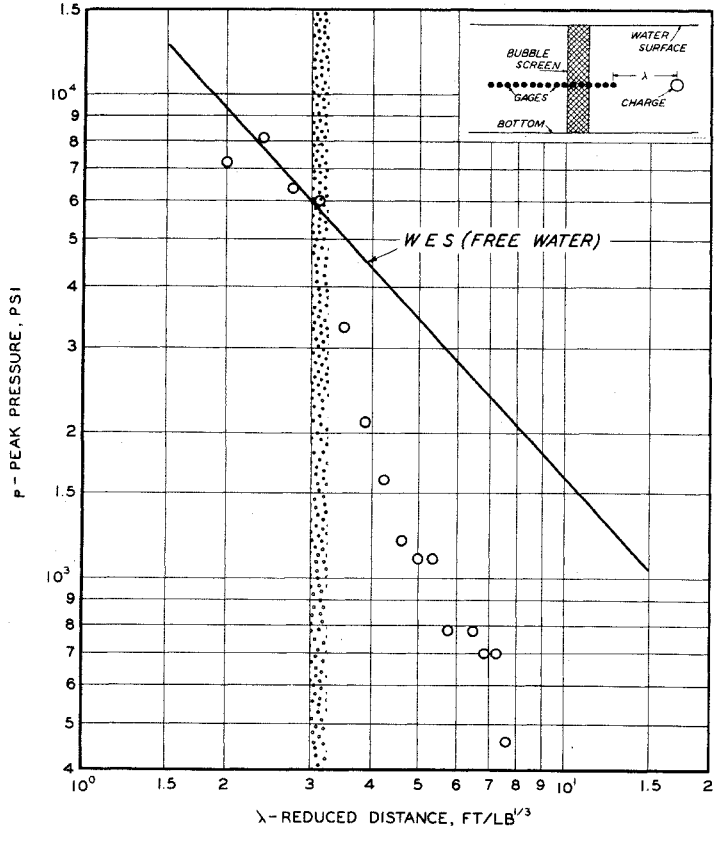


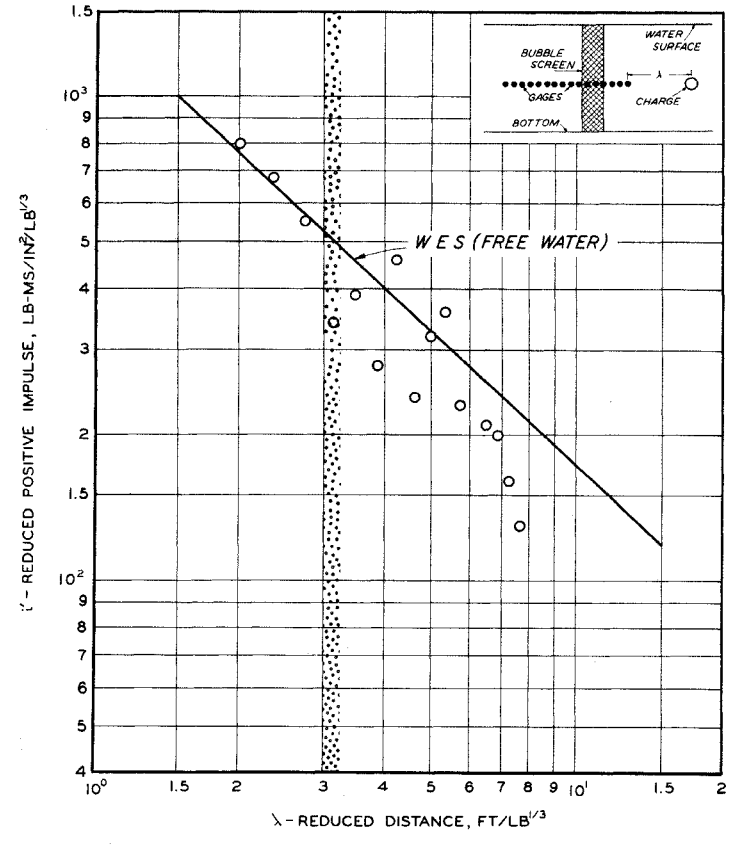


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 34

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 0.5$, $A_c = 0.035$ (~ 3.0%), $R_o = 6.0$

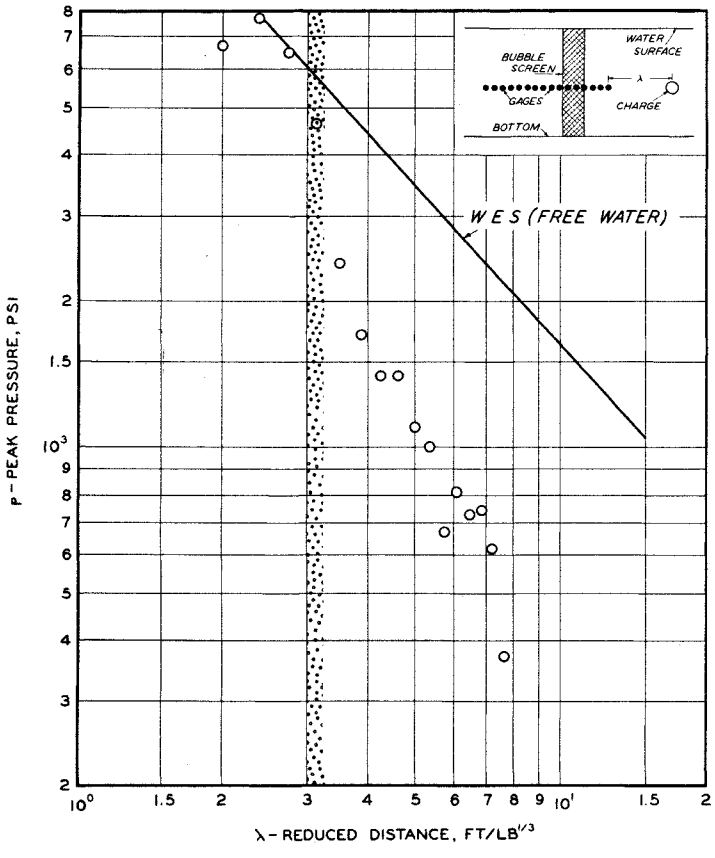


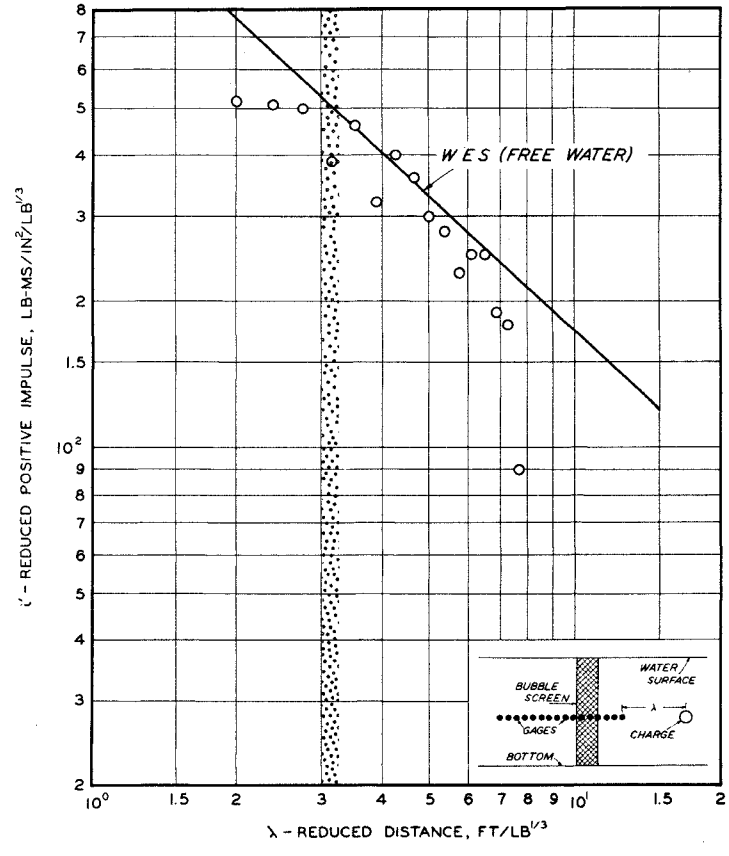


O - W E S EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES I AND 35

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 0.5$, $A_c = 0.070 (\sim 6.0\%)$, $R_o = 6.0$





O - WES EXPERIMENTAL DATA
DATA FOR THESE PLOTS WERE OBTAINED FROM TABLES 1 AND 36

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

$Z_g = 9.0$, $T_s = 0.5$, $A_c = 0.140$ (~ 12.0%), $R_o = 6.0$

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