UNITED STATES GOVERNMENT

Memorandum

PAP 325

TO : Memorandum
Head, Hydraulics Research Section

Denver, Colorado
DATE: August 13, 1975

FROM : J. Charles Givens

SUBJECT: Test of Clayton Automatic Valve 50G-01 20 to 200 lb/in^2 for Water-hammer Relief Applications - Open and Closed Conduit Systems Program

Introduction

This particular relief valve was proposed for application to water-hammer problems of an irrigation district. The water-hammer could occur when fire fighting equipment is connected to the irrigation system. The fire fighters use quick closing valves on lines straight off the system to a valve at the nozzle, or through a pumper that has the ability to come on the line in a short time. The relief valve was tested to see if it would react quickly enough to a pressure surge to prevent damage to a pipeline. The results were compared to a dead ended line, and to a line with a standpipe.

The main component of the test valve is referred to as the relief valve. The pressure control valve which is referred to as the control valve is used to adjust the relief pressures.

Test Facility

The High Head Pump Facility in the Hydraulics Branch was used to produce the required test pressures. These pressures included the calibration of the relief valve through the manufacturer's range of operation of 20 to 200 lb/in^2, and the waterhammer tests at 90 lb/in^2.

The system for the testing was set up on the end of a 1-inch line on the facility downstream from a venturi, but upstream of a multijet sleeve valve and chamber. This arrangement allowed the operator to set the line pressure from the control board. A 1-1/2-inch tee was installed at the end of the 5-foot-long 1-inch line. The relief valve was in line with the 1-inch line and a quick closing valve was placed 90° to the 1-inch line (see figures 1 and 2). Modifications included replacing the relief valve with a plug (see figure 1, detail A, and figure 3). A standpipe was placed between the tee and the quick-closing valve (see figure 1, detail B, and figure 4). The standpipe included a 1-1/2-inch-diameter pipe with a gage glass for determining the length of the air column in the pipe. An external air supply was connected to the standpipe to adjust the length of the air column.

The pressure in the line was adjusted at the control board. The pressure for the water-hammer system was measured in the 1-inch line 1 inch

upstream from the tee. The pressure transducer was connected to a Sanborn series 350 chart recorder. A Kistler transducer (0 to 200 lb/in^2) was used to calibrate the control valve on the relief valve. When the first tests were made the Kistler's range was not adequate. A Pace (0 to 500-lb/in^2 range) transducer was substituted and used throughout the water hammer tests.

Test Procedure

The Clayton Automatic Valve was calibrated in the range 20 to 200 lb/in^2. The relief valve was set to zero by backing out the adjustment bolt on the control valve until the bolt could be turned by hand. The bolt was then screwed in until it touched the spring. The pressure was brought up to 30 lb/in^2. The bolt was tightened until the leaking stopped, then it was loosened until leaking started. The line pressure was increased at 10-lb/in^2 increments using the same procedure for determining relief pressure versus number of turns from zero (see table 1 and figure 5).

For the water hammer tests, the line pressure was set at 90 lb/in^2. The relief valve was set to relieve at line plus 10 percent or 99 lb/in^2. The quick-closing valve was opened to let water flow freely to the atmosphere for 10 to 15 seconds, then slammed shut. The same procedure of setting line pressure and operation of the quick-closing valve was used for the relief valve, the plug, and the standpipe.

Results

With quick closure of the valve:

a. The pressure surged to 445 lb/in^2 with the relief valve in place (see figure 6 for pressure recordings).

b. The pressure surged to 450 lb/in^2 with the relief valve replaced by a plug (see figure 7 for pressure recordings). Note that secondary pressure surges occurred at values approximately at half of the maximum peak.

c. The pressure surged to 150 lb/in^2 with the standpipe in place (see figure 8 for pressure recordings). During the free flow condition the length of the air column was adjusted at 24 to 26 inches in the 36-inch standpipe.

d. Calculations show that a peak of 450 lb/in^2 was possible. The 450 lb/in^2 maximum depends on the method or location

of study. A range of 420 to 2,609 lb/in^2 was calculated (see appendix for calculations).

e. For comparison a test was made with the standpipe installed and the quick closing valve was closed over a longer period of time (3.6 s). The pressure surged to maximum of 104 lb/in^2. This maximum was 15.6 percent over the line pressure of 90 lb/in^2 (see figure 9 for pressure recordings).

Conclusions

The relief valve does not react quickly enough to handle the waterhammer that occurs from rapidly closing a valve. The standpipe appears to be a solution. The size of the pipe and method of keeping a specified amount of air in the standpipe should be determined by the design group involved.

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PROCEDURE: The High Head Pump Facility was used because of the high pressures involved. The pressure was increased in 10-lb/in^2 increments. The valve was adjusted until leaking stopped, then the bolt was loosened until leaking started. The amount that was leaking was continuous and carried out 2 to 3 inches horizontally before dropping. The zero point for adjustment was determined by completely adjusting the bolt out until it could be turned by hand. The bolt was then tightened by hand until it touched the spring.

NOTE: A test was made to check 100-lb/in^2 factory setting. The valve began leaking at 90 lb/in^2 and was full open at 100 lb/in^2.

Table 1

RECORD NUMBER OF TURNS VERSUS PRESSURE

Trial 1		Trial 2		Trial 3	
Pressure lb/in^2	Number of turns	Pressure lb/in^2	Number of turns	Pressure lb/in^2	Number of turns
30*	11/12	30	1	30	1
40	1-1/3	40	1-1/4	40	1-1/3
50	1-3/4	50	1-3/4	50	1-3/4
60	2-1/12	60	2-1/6	60	2-1/6
70	2-1/2	70	2-1/2	70	2-1/2
80	2-11/12	80	2-5/6	80	2-11/12
90	3-1/4	90	3-1/4	90	3-1/4
100	3-2/3	100	3-2/3	100	3-2/3
110	4	110	4	110	4
120	4-5/12	120	4-5/12	120	4-5/12
130	4-5/6	130	4-5/6	130	4-3/4
140	5-1/3	140	5-1/6	140	5-1/6
150	5-1/2	150	5-1/2	150	5-1/2
160	5-11/12	160		160	
170	6-1/6	170		170	
180	6-7/12	180		180	
190	6-1/4	190		190	
200	7-1/4	200		200	

*NOTE: 26 lb/in^2 was lowest pressure available so testing began at 30 lb/in^2.

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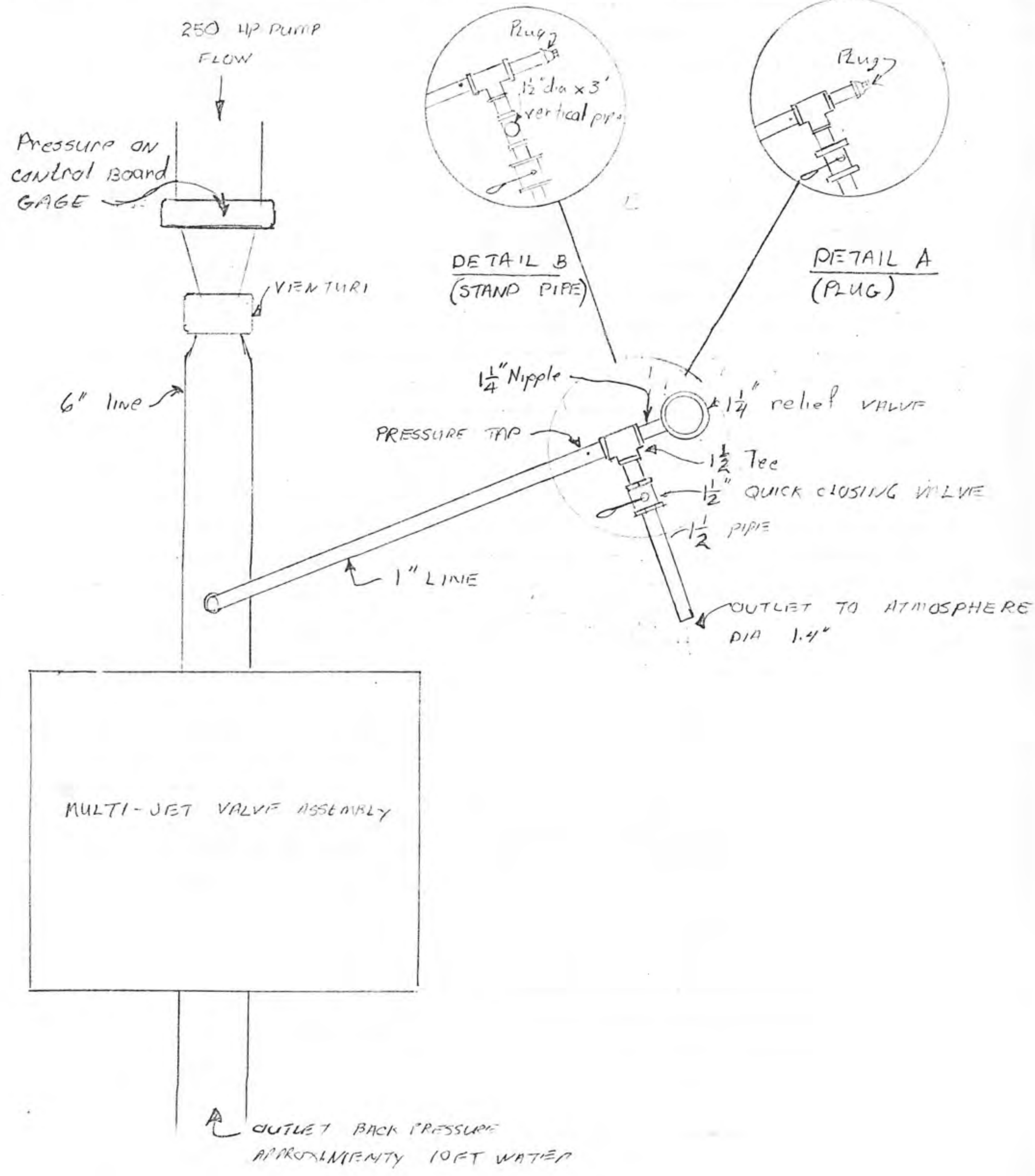
COMPUTATION SHEET

Fig. 1

BY	DATE	PROJECT Open Closed Conduit Study	SHEET 5 OF
CHKD BY	DATE	FEATURE General Layout of Test Facility	
DETAILS			



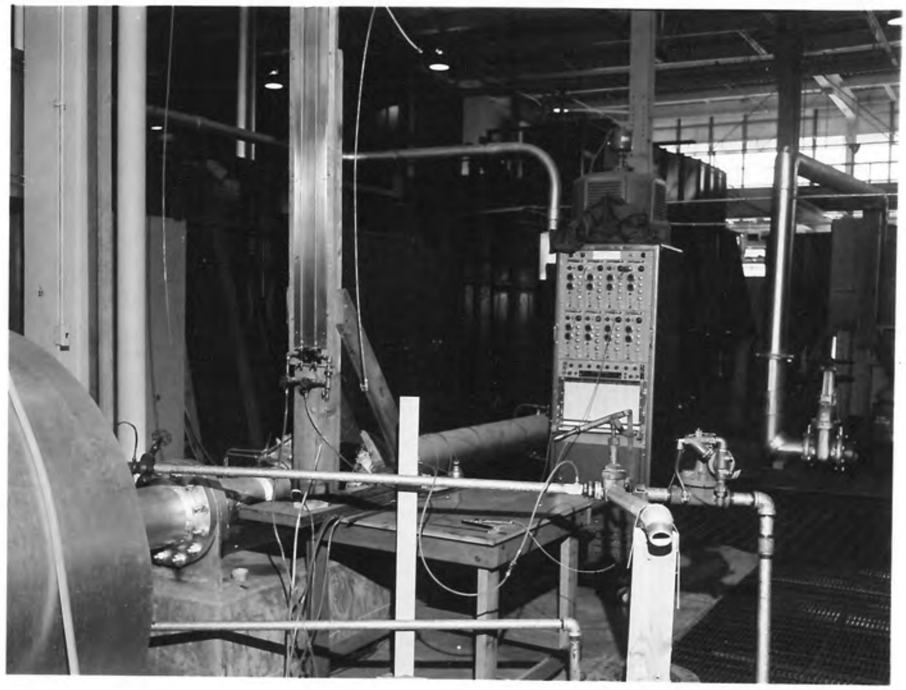


Figure 2. - Test setup with relief valve installed. Photo H-1762-2

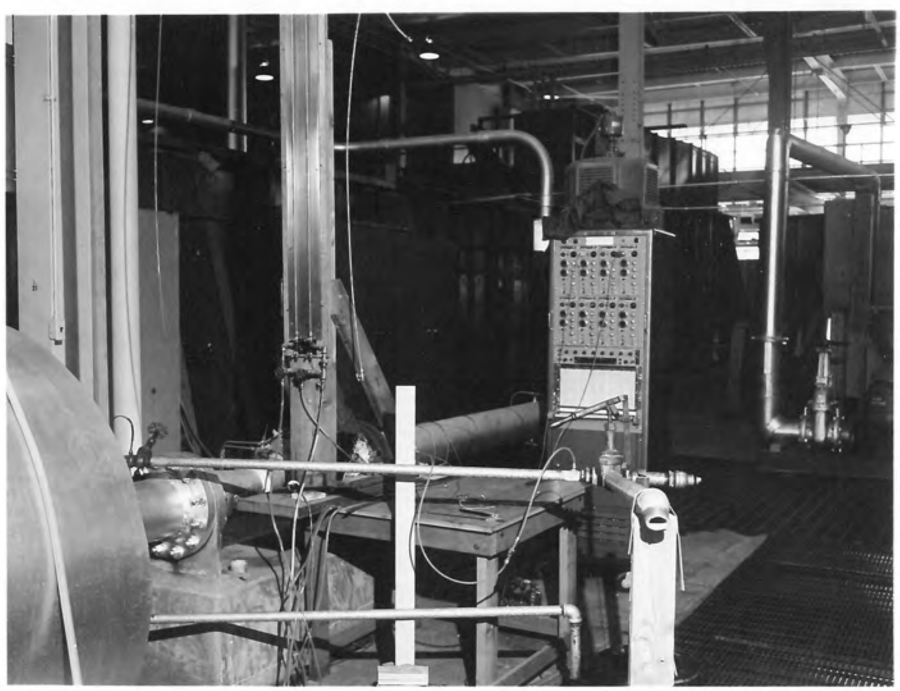


Figure 3. - Test setup with relief valve replaced by a plug. Photo H-1762-3

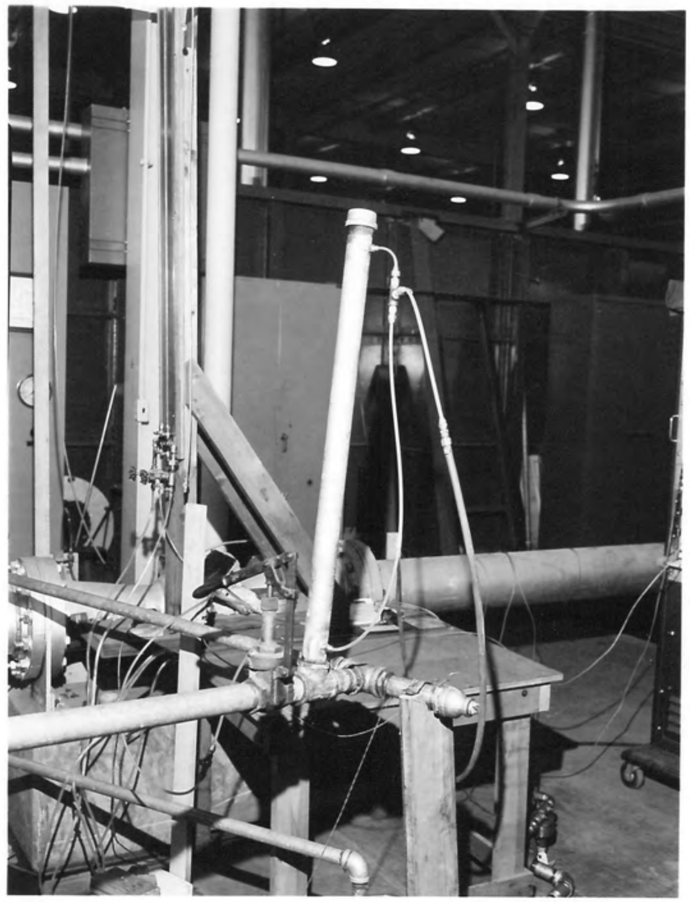


Figure 4. - Test setup with a standpipe installed upstream of the quick-closing valve. Photo H-1762-4

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COMPUTATION SHEET

FIG 5

BY	DATE	PROJECT	SHEET 8 OF
J. Givens	4-29-75	Open - Closed Conduit Study	
CHKD BY	**DATE**	**FEATURE**	
		Calibrate Clayton Automatic Valve 50G-01 20-200	

DETAILS Zero setting on spring was determined by touch - the [illegible] first touched the spring. Relief [illegible] determined by a [illegible] [illegible] dropping

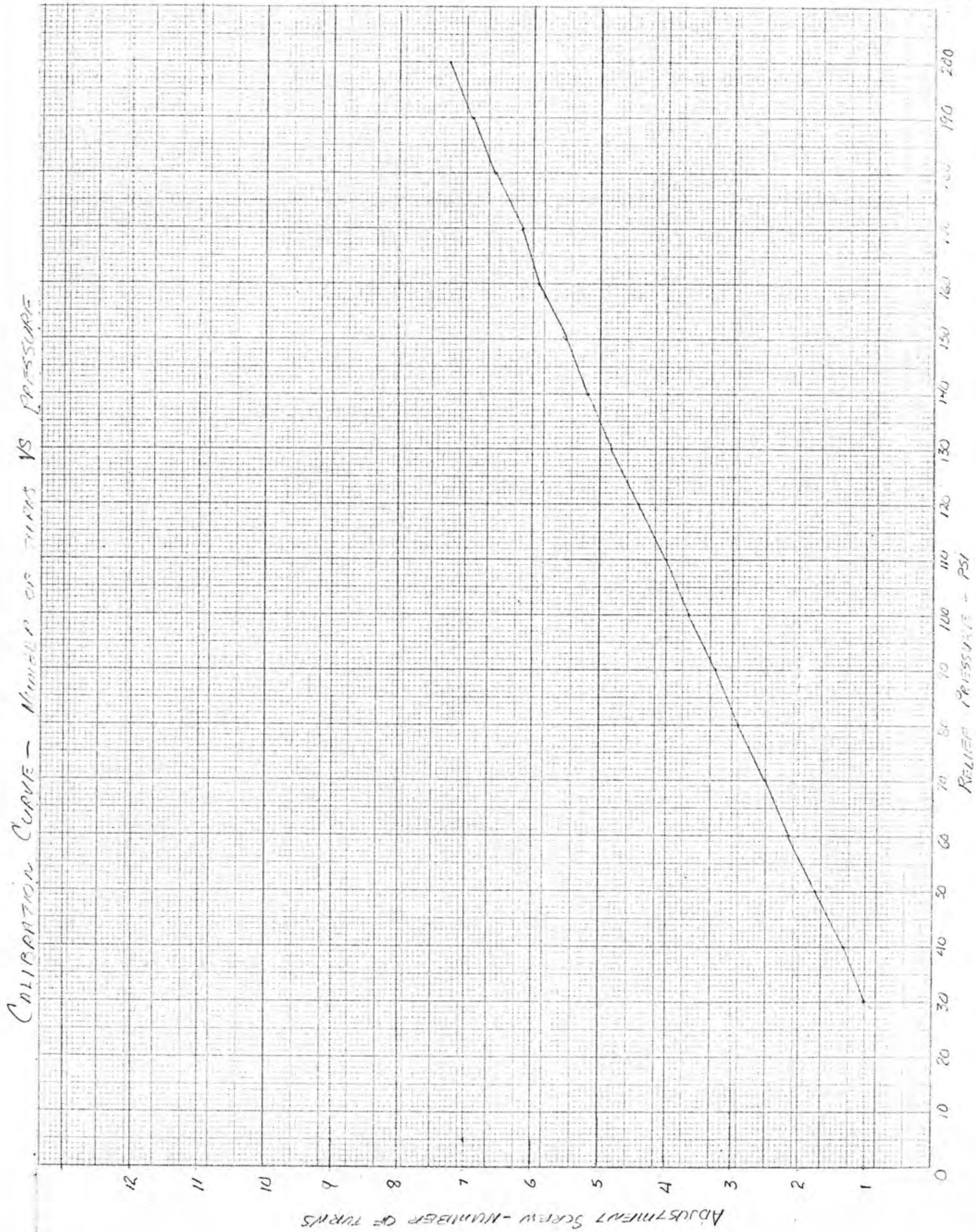

FIG. 5

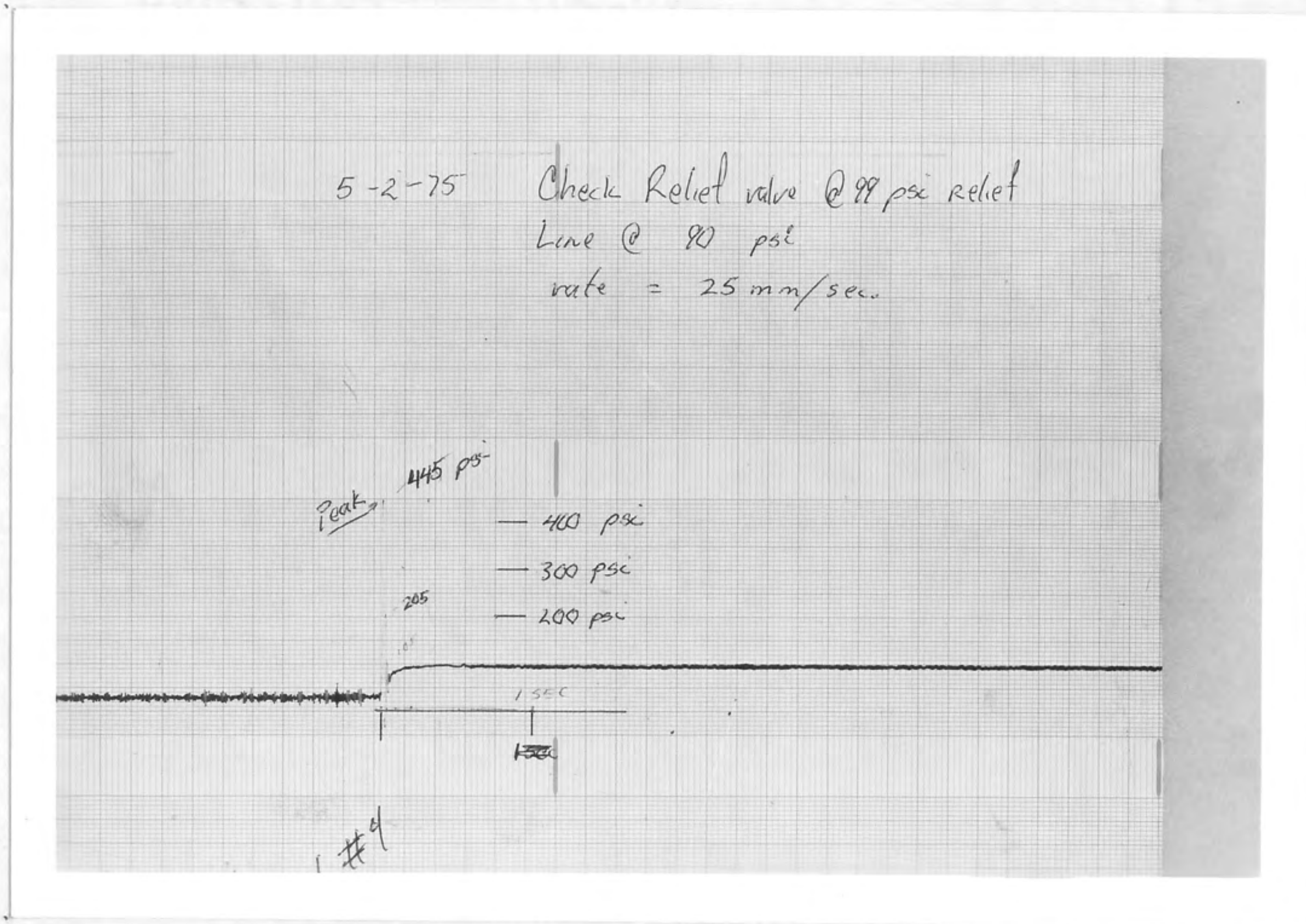

Figure 6. - Pressure rise for quick closure with pressure relief setting of 99 lb/in^2.

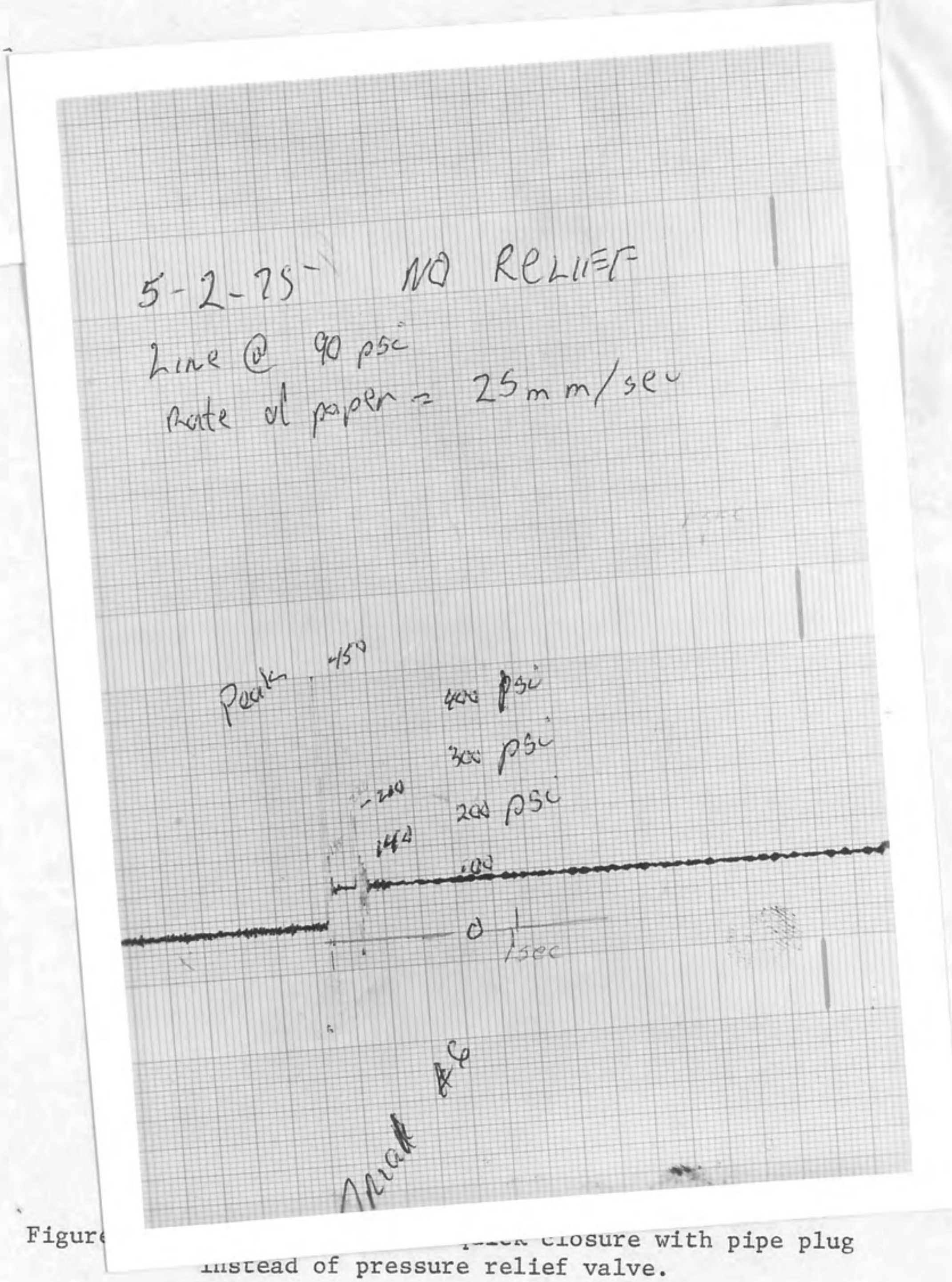

Figure ... ick closure with pipe plug instead of pressure relief valve.

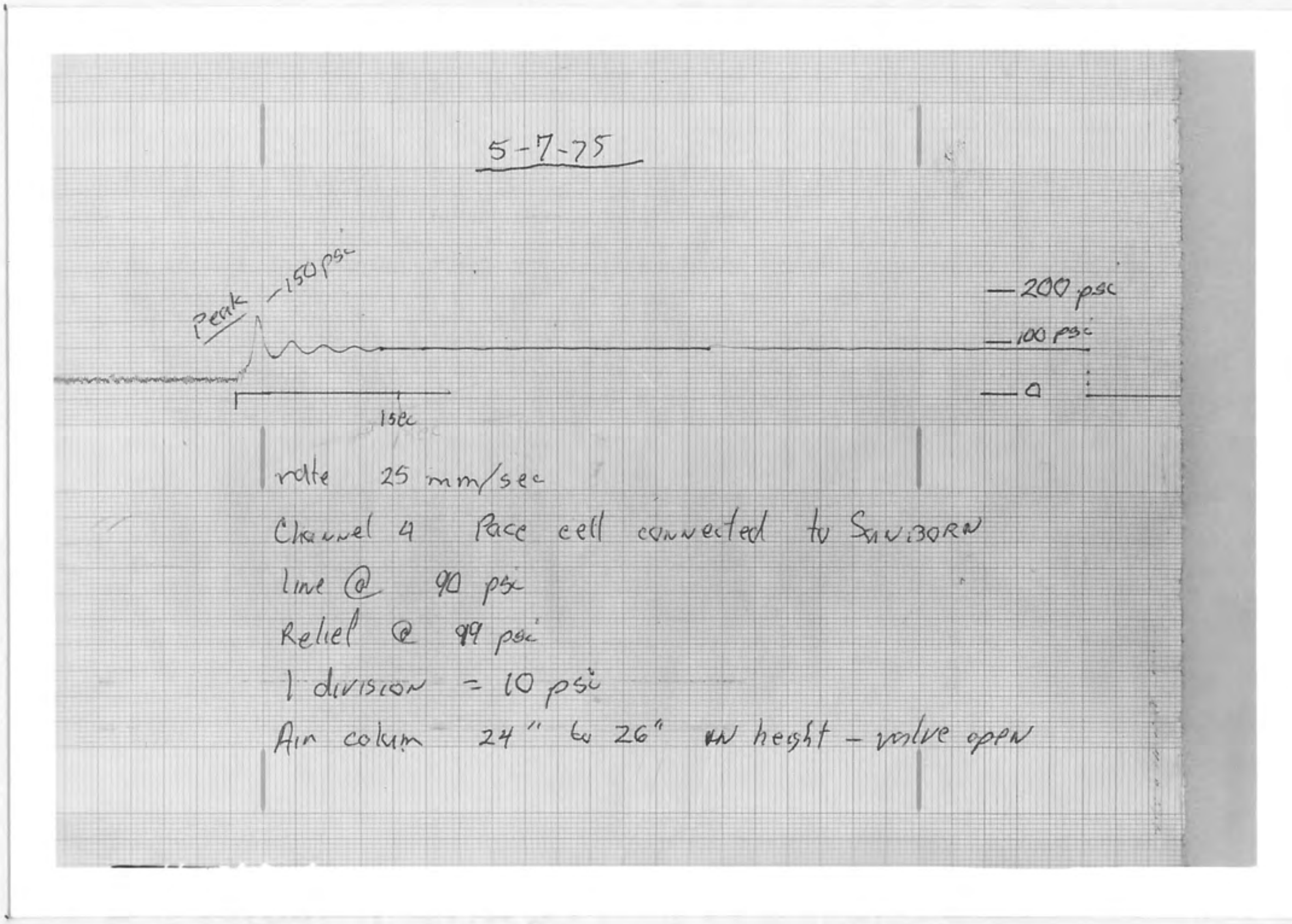

Figure 8. - Pressure rise for air column standpipe in place of pressure relief valve.

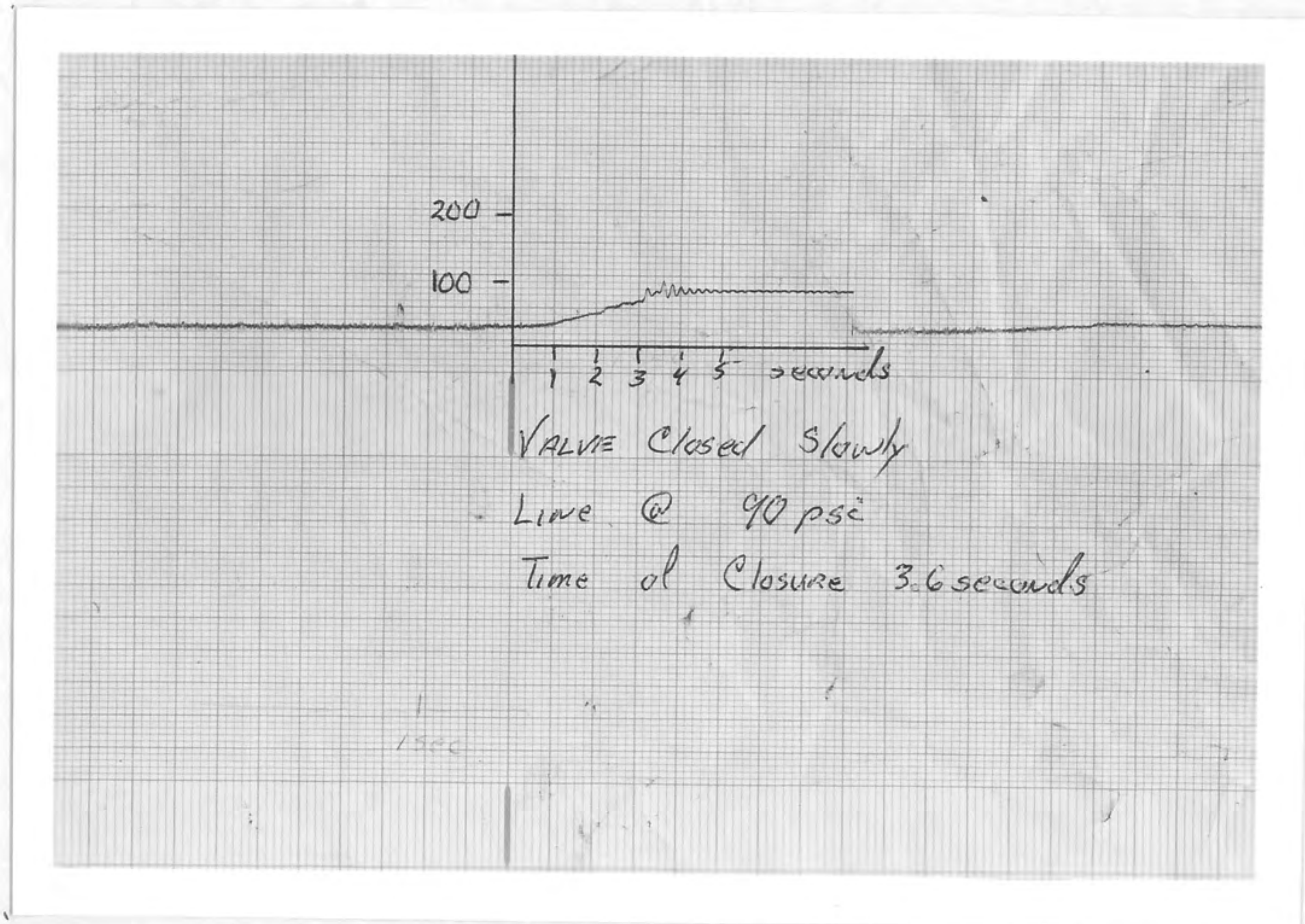

Figure 9. - Pressure rise for slow valve closure with standpipe.

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COMPUTATION SHEET

BY	DATE	PROJECT	SHEET ____ OF ____
CHKD BY	DATE	FEATURE	
DETAILS			

APPENDIX ....

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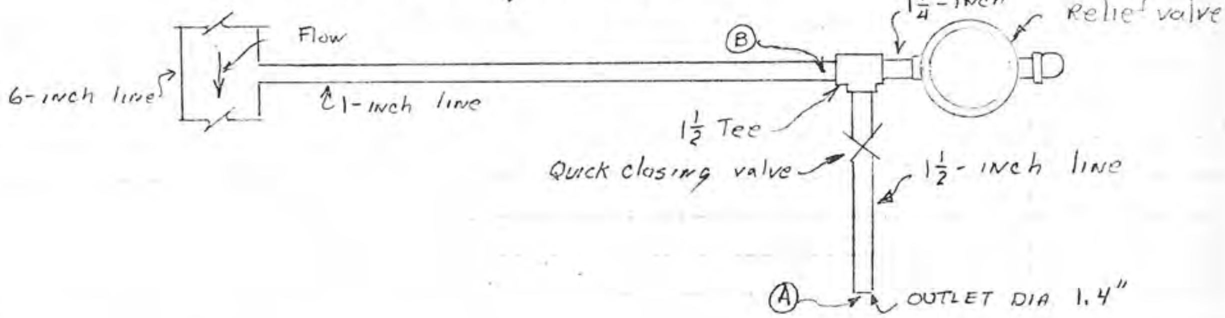
COMPUTATION SHEET

BY	DATE -	PROJECT Open-Closed Conduit Study	SHEET A-1 OF
CHKD BY	DATE	FEATURE Water hammer - measured flow	
DETAILS Measure the flow and calculate water hammer.			

Given: The discharge of the system was determined by measuring the weight of water during an elasped time.

Determine: Water hammer by calculating a velocity for the measured flow. The velocity of the pressure wave in water a, is equal to 4500 fps for no air entrainment and 1100 fps for an air entrainment of .04%. 1/



EQUATIONS

$Q = \frac{W_2 - W_1}{\rho} \; t$

W_1 = initial wt of tare
W_2 = final wt
t = time elasped
ρ = 62.4 lb/ft³

$V_A = Q/A_A$

$V_B = Q/A_B$

$H = k\frac{aV}{g}$

V_A, V_B velocity of water @ A & B. fps
A_A, A_B Area of pipe @ A & B ft²
k conversion feet of water to psi 14.7/34.0
H maximum pressure
a velocity of wave in water
g gravitational constant 32.2 ft/sec²

TEST TRIAL	W_2 lb.	W_1 lb.	ΔW lb	t sec	Q ft³/sec	V_A ft/sec	V_B ft/sec	Water hammer H, psi a= 4500 fps H_A	H_B	a = 1100 fps H_A	H_B
1	351	52	299	15	.3194	29.88	58.56	1805.41	3538.31	441.32	864.92
2	391	93	288	15	.3077	28.78	56.41	1738.95	3408.40	425.08	833.17
3	394	66	328	17	.3092	28.92	56.68	1747.40	3424.72	427.14	837.15
avg						29.33	57.22	1772.18	3457.35	433.20	845.13

1 "Hydraulic Transients" Streeter and Wylie pg. 8 FIG 1.5

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COMPUTATION SHEET

BY	DATE	PROJECT Open-closed Conduit Study	SHEET A-2 OF
CHKD BY	DATE	FEATURE Water hammer caused by Velocity under free flow	
DETAILS			

GIVEN: Line pressure at 90 psi under static conditions and a line pressure of 25 psi under free flow conditions. (see Fig 6)

Determine: Water Hammer at points A and B where the water velocity, $V = \sqrt{2gH}$ and $H = aV/g$ where $a = 1100$ & 4500 fps.

$$V_B = \sqrt{2gh}$$

$$= \left[2(32.2)\,25\left(\frac{34}{14.7}\right)\right]^{\frac{1}{2}}$$

$$V_B = 61.66 \text{ ft/sec}$$

$$V_A = \frac{V_A A_A}{A_B}$$

$$V_A = (61.66)\,\frac{\frac{\pi}{4}(1)^2}{\frac{\pi}{4}(1.4)^2}$$

$$V_A = 31.45 \text{ ft/sec}$$

$$H_A = \frac{a\,V_A}{g}\left(\frac{14.7}{34}\right)$$

$a = 1100$ fps, $H_A = \frac{(1100)(31.45)(14.7)}{(32.2)(34.0)} = 464.51$

$a = 4500$ fps, $H_A = \frac{4500(31.45)(14.7)}{32.2\ (34.0)} = 1900.27$

$a = 1100$ fps, $H_B = \frac{1100(61.66)(14.7)}{32.2\ (34.0)} = 917.71$

$a = 4500$ fps, $H_B = \frac{4500(61.66)(14.7)}{(32.2)\ (34.0)} = 3725.62$

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COMPUTATION SHEET

BY	DATE	PROJECT Open Closed Conduit Study	SHEET A-3 OF
CHKD BY	DATE	FEATURE Impulse Momentum balance	
DETAILS			

Given: L = 5-FEET TO QUICK-CLOSING VALVE. The conditions AT B AT FREE FLOW P = 25 psi, and for an estimated closing time of .0275 seconds the peak pressure is 445 psi (see Fig 6)

Discussion: The water hammer pressure relationship, H = aV/g applies only up to the time that a wave is reflected back.[2] The time it takes for the wave to return is determined by the period, 2L/a. For a wave velocity a = 4500 the time is .002 sec. For a wave velocity a = 1000 the time is .01 seconds. The operator of the test estimated the valve closing time of .5 seconds. The test charts showed a peak occuring at a time of .0275 seconds (see Fig 6) The wave has been reflected before the valve has closed and before the pressure surge has had time to build to its theoretical maximum of 3500 psi. (see calc. sheet A-1) This reflected wave counteracts the initial surge and stops it at 445 psi (see Fig 6). If the relationship of H = aV/g does not apply the change in momentum caused by decreasing the velocity to zero should be equal to the impulse of Force over the time it takes to decrease the velocity to zero. This force F is determined by the area under the curve from time equals zero to the peak pressure. The impulse is equal F×t where force = $\frac{1}{3}$ pressure times the end area of the pipe. (see Fig 6)

EQUATIONS:

Mass $M = W/g$ W = weight of water = Volume × 62.4

$V = \sqrt{2gH}$

Momentum $= M \times V$

Impulse $= F \times t$

2 "Hydraulic Transients" Streeter and Wylie pg 5 equation 1.2.19

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DETAILS			

IMPULSE MOMENTUM CONTINUED

$$W = \left[\left(\frac{\pi}{4}\right)(1)^2 \frac{(60)}{1728}\right] \cdot 62.4 \frac{lb}{ft^3}$$

Area = .7854 in^2

$W = 1.702$ lb

$V = \sqrt{2gH}$

$= \sqrt{2(32.2)\ 25 \left(\frac{34}{14.7}\right)}$

$V_B = 61.02$ fps

time t = .0275 sec

Peak = 445 psi

$M \times V = F \times t$

$$\frac{1.702}{32.2} \times 61.02 = \frac{1}{3}(445)\left(\frac{\pi}{4}(1)^2\right)(.0275)$$

3.26 lb-sec = 3.20 lb-sec agrees

CONCLUSIONS:

The results of the three methods of calculation support the measured test results. The pressure surge does not attain its theoretical maximum because a combination of a factors. The factors include the possibility of air, friction losses, and the short length of pipe for the test facility.

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(12-61)
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INFORMATIONAL ROUTING

Memorandum
Head, Hydraulics Research Section
J. Charles Givens

Denver, Colorado
August 13, 1975

Test of Clayton Automatic Valve 50G-01, 20 to 200 lb/in^2 for Water-hammer Relief Applications - Open and Closed Conduit Systems Program

Introduction

This particular relief valve was proposed for application to water-hammer problems of an irrigation district. The water-hammer could occur when fire fighting equipment is connected to the irrigation system. The fire fighters use quick closing valves on lines straight off the system to a valve at the nozzle, or through a pumper that has the ability to come on the line in a short time. The relief valve was tested to see if it would react quickly enough to a pressure surge to prevent damage to a pipeline. The results were compared to a dead ended line, and to a line with a standpipe.

The main component of the test valve is referred to as the relief valve. The pressure control valve which is referred to as the control valve is used to adjust the relief pressures.

Test Facility

The High Head Pump Facility in the Hydraulics Branch was used to produce the required test pressures. These pressures included the calibration of the relief valve through the manufacturer's range of operation of 20 to 200 lb/in^2, and the waterhammer tests at 90 lb/in^2.

The system for the testing was set up on the end of a 1-inch line on the facility downstream from a venturi, but upstream of a multijet sleeve valve and chamber. This arrangement allowed the operator to set the line pressure from the control board. A 1-1/2-inch tee was installed at the end of the 5-foot-long 1-inch line. The relief valve was in line with the 1-inch line and a quick closing valve was placed 90° to the 1-inch line (see figures 1 and 2). Modifications included replacing the relief valve with a plug (see figure 1, detail A, and figure 3). A standpipe was placed between the tee and the quick-closing valve (see figure 1, detail B, and figure 4). The standpipe included a 1-1/2-inch-diameter pipe with a gage glass for determining the length of the air column in the pipe. An external air supply was connected to the standpipe to adjust the length of the air column.

The pressure in the line was adjusted at the control board. The pressure for the water-hammer system was measured in the 1-inch line 1 inch

upstream from the tee. The pressure transducer was connected to a Sanborn series 350 chart recorder. A Kistler transducer (0 to 200 lb/in^2) was used to calibrate the control valve on the relief valve. When the first tests were made the Kistler's range was not adequate. A Pace (0 to 500-lb/in^2 range) transducer was substituted and used throughout the water hammer tests.

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For the water hammer tests, the line pressure was set at 90 lb/in^2. The relief valve was set to relieve at line plus 10 percent or 99 lb/in^2. The quick-closing valve was opened to let water flow freely to the atmosphere for 10 to 15 seconds, then slammed shut. The same procedure of setting line pressure and operation of the quick-closing valve was used for the relief valve, the plugs, and the standpipe.

Results

With quick closure of the valve:

a. The pressure surged to 445 lb/in^2 with the relief valve in place (see figure 6 for pressure recordings).

b. The pressure surged to 450 lb/in^2 with the relief valve replaced by a plug (see figure 7 for pressure recordings). Note that secondary pressure surges occurred at values approximately at half of the maximum peak.

c. The pressure surged to 150 lb/in^2 with the standpipe in place (see figure 8 for pressure recordings). During the free flow condition the length of the air column was adjusted at 24 to 26 inches in the 36-inch standpipe.

d. Calculations show that a peak of 450 lb/in^2 was possible. The 450 lb/in^2 maximum depends on the method or location

of study. A range of 420 to 2,609 lb/in^2 was calculated (see appendix for calculations).

e. For comparison a test was made with the standpipe installed and the quick closing valve was closed over a longer period of time (3.6 s). The pressure surged to maximum of 104 lb/in^2. This maximum was 15.6 percent over the line pressure of 90 lb/in^2 (see figure 9 for pressure recordings).

Conclusions

The relief valve does not react quickly enough to handle the water-hammer that occurs from rapidly closing a valve. The standpipe appears to be a solution. The size of the pipe and method of keeping a specified amount of air in the standpipe should be determined by the design group involved.

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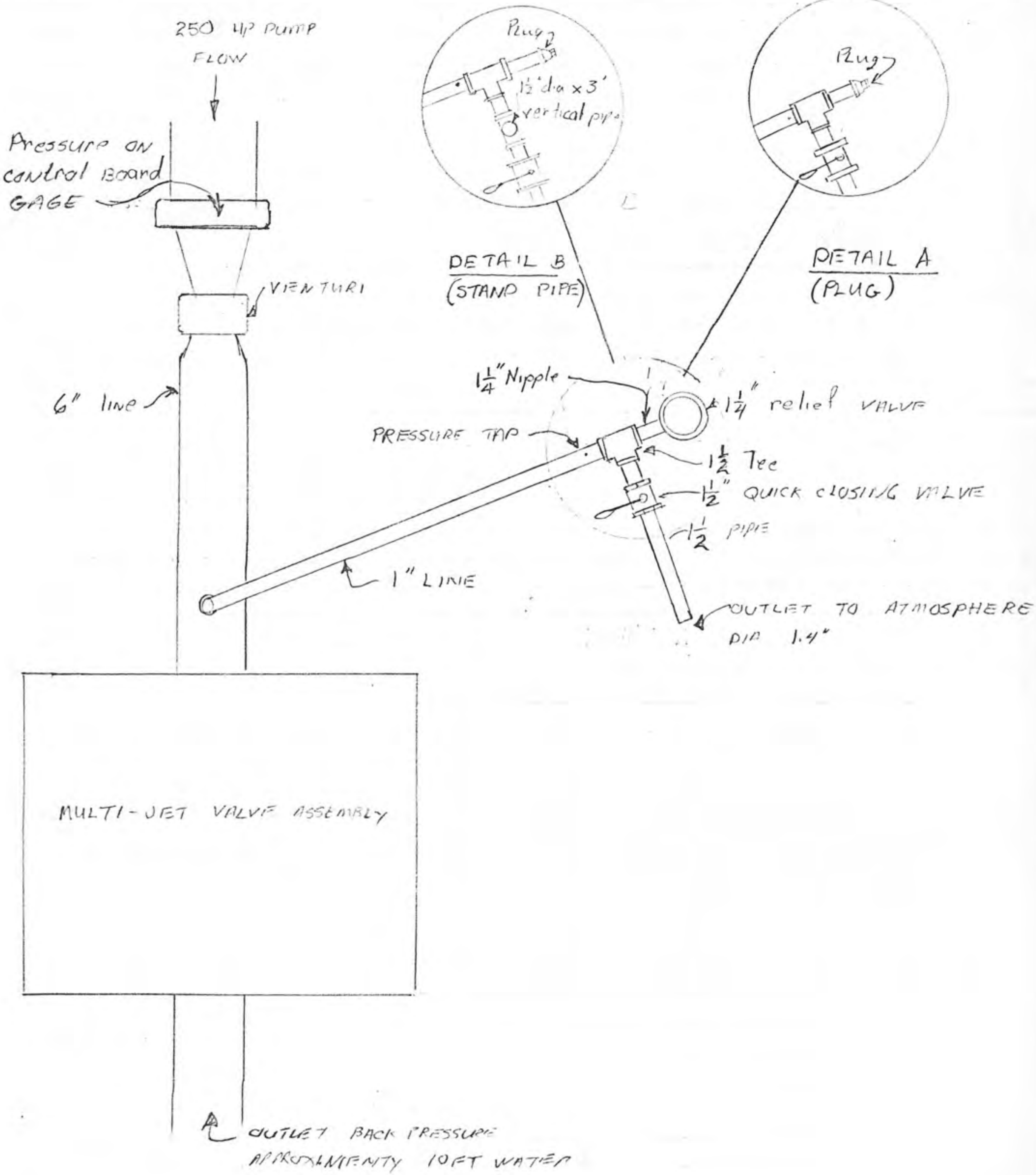
COMPUTATION SHEET

Fig. 1

BY	DATE	PROJECT Open Closed Conduit Study	SHEET 5 OF
CHKD BY	DATE	FEATURE General Layout of Test Facility	
DETAILS			



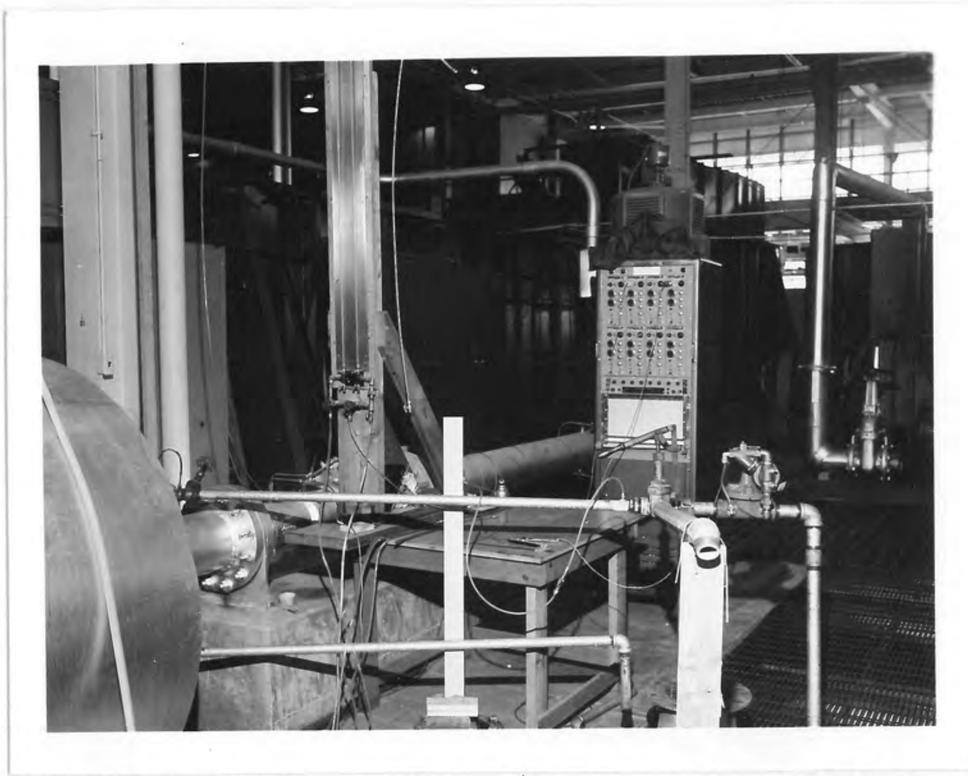


Figure 2. - Test setup with relief valve installed.
Photo H-1762-2

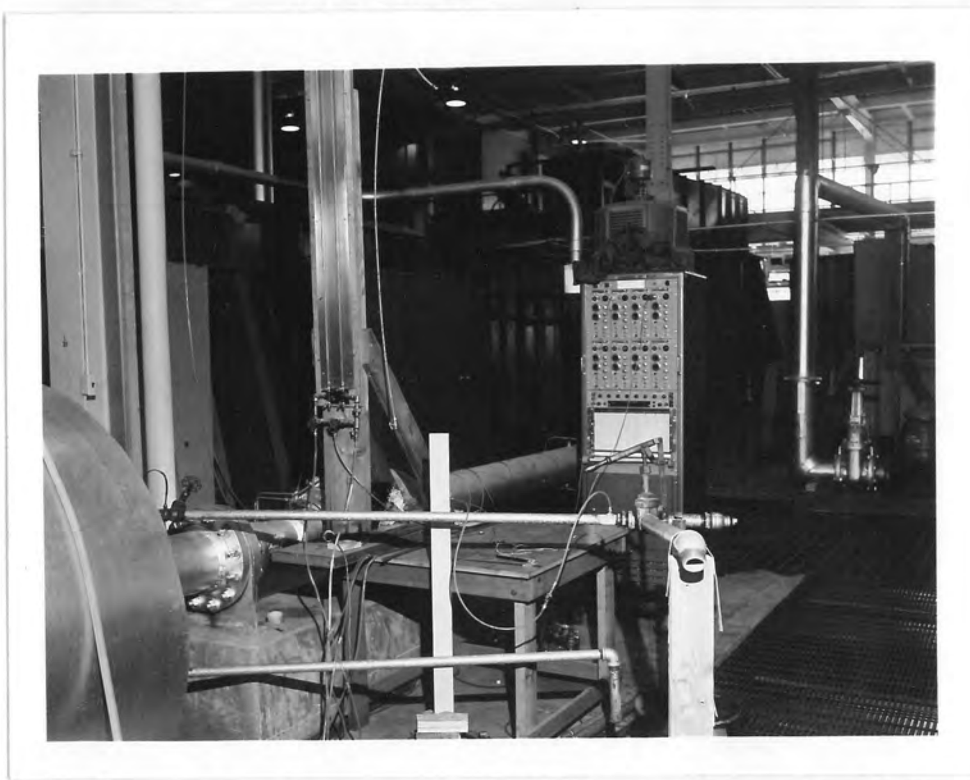


Figure 3. - Test setup with relief valve replaced by a plug. Photo H-1762-3

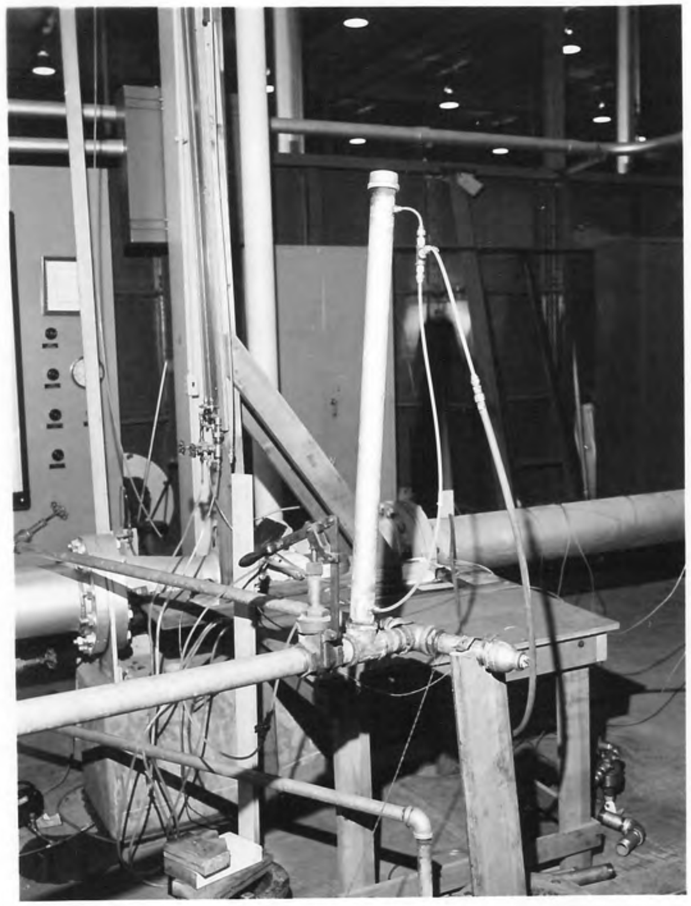


Figure 4. - Test setup with a standpipe installed upstream of the quick-closing valve.
Photo H-1762-4

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COMPUTATION SHEET

FIG 5

BY	DATE	PROJECT	SHEET 8 OF
J. Givens	[illegible] 4-29-75	OPEN-CLOSED CONDUIT STUDY	
CHKD BY	**DATE**	**FEATURE**	
		CALIBRATE CLAYTON AUTOMATIC VALVE 50G-01 20-200	

DETAILS ZERO SETTING ON SPRING WAS DETERMINED BY TOUCH-THE [illegible] FIRST TOUCHED THE SPRING
RELIEF [illegible] DETERMINED BY [illegible] DROPPING

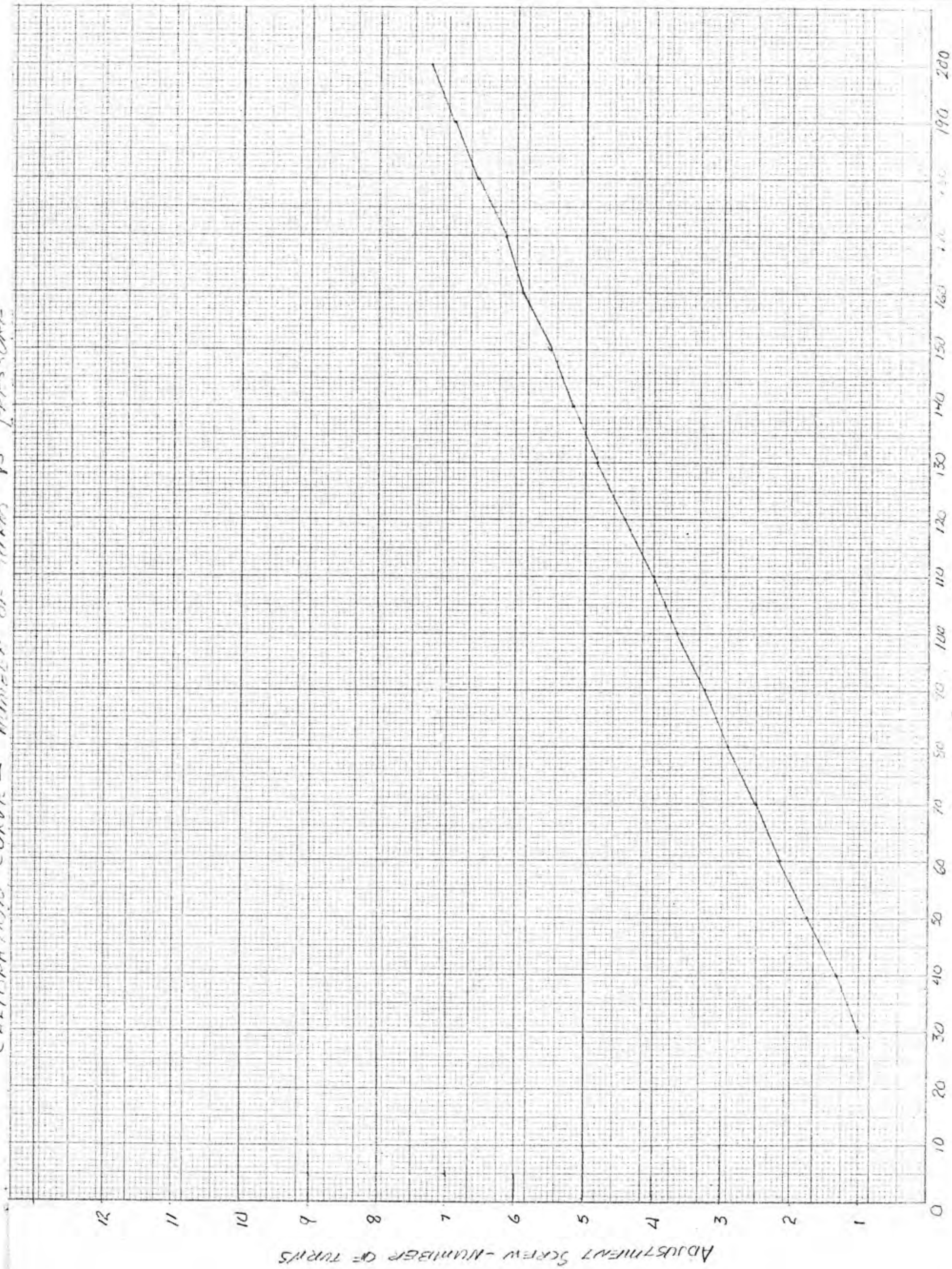

FIG. 5

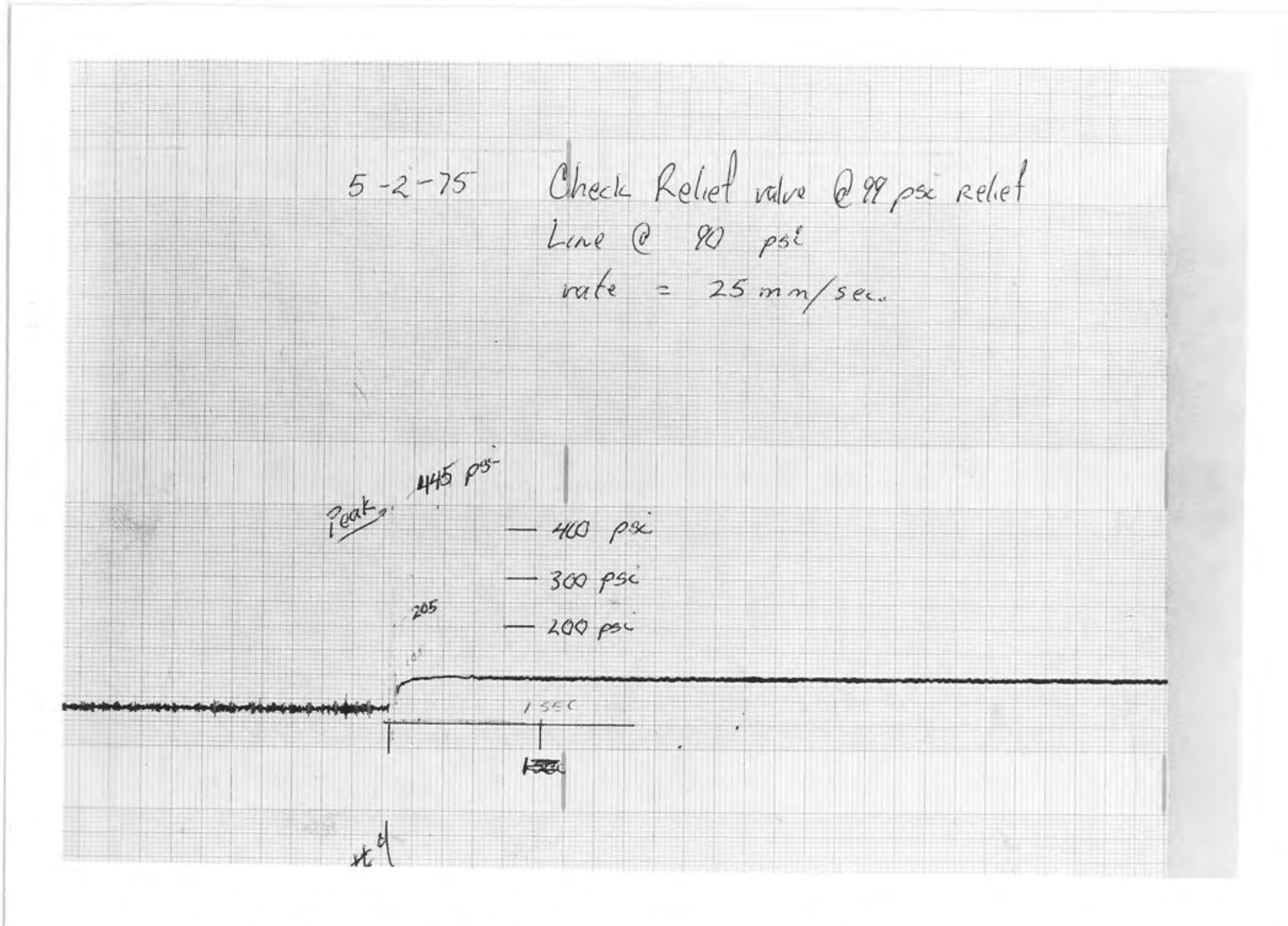

Figure 6. - Pressure rise for quick closure with pressure relief setting of 99 lb/in^2.

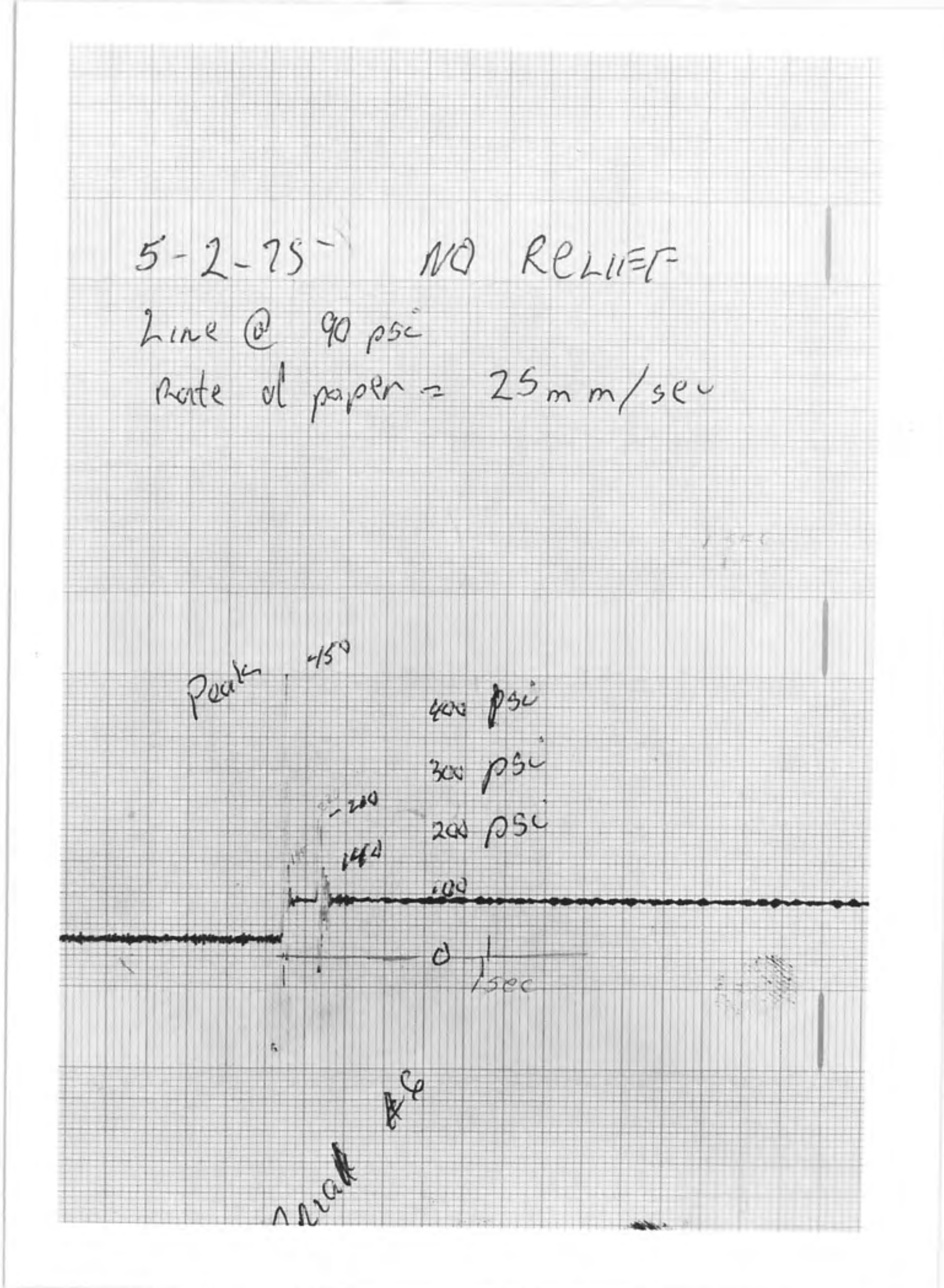

Figure 7. - Pressure rise for quick closure with pipe plug instead of pressure relief valve.

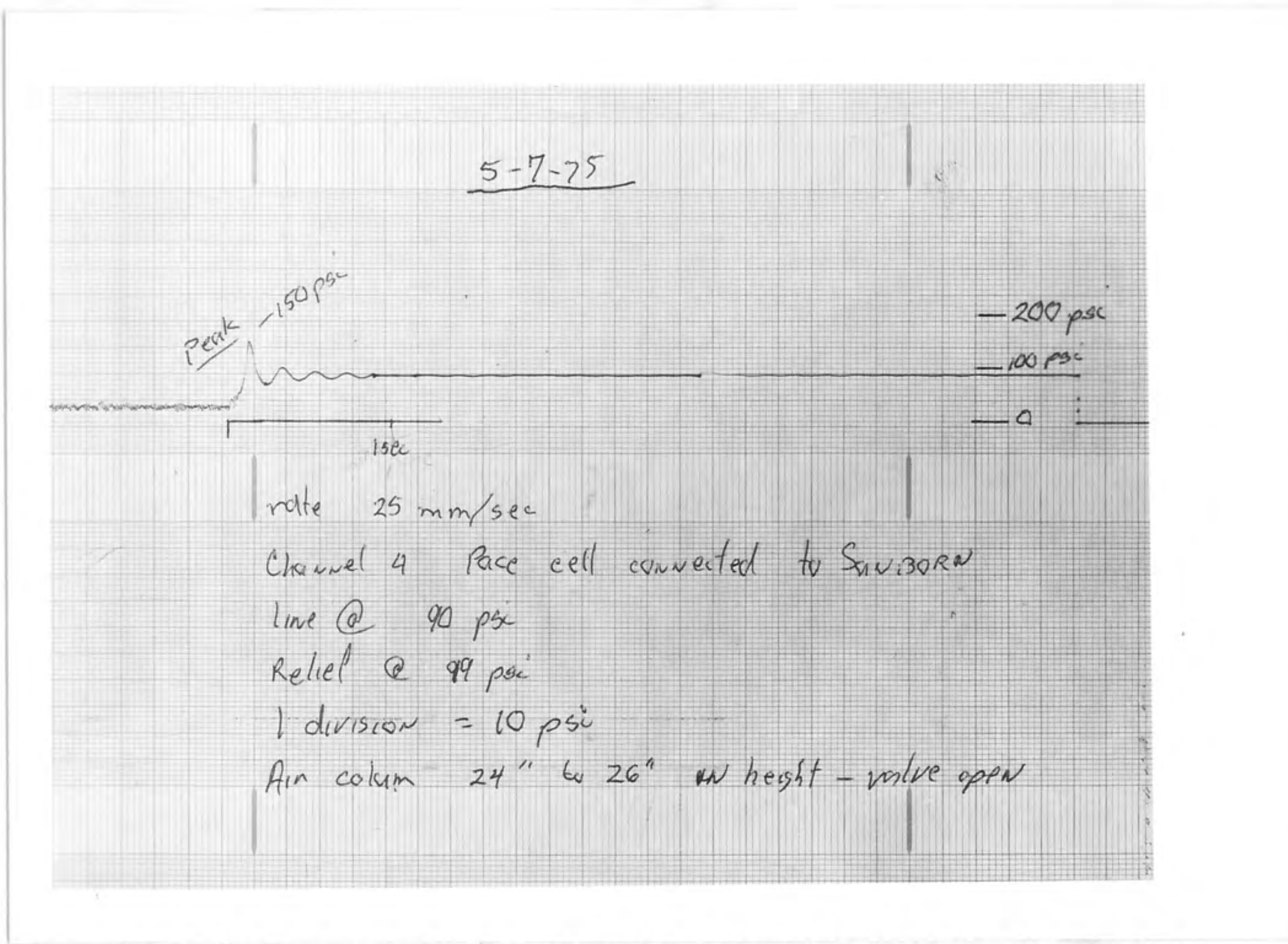

Figure 8.-Pressure rise for air column standpipe in place of pressure relief valve

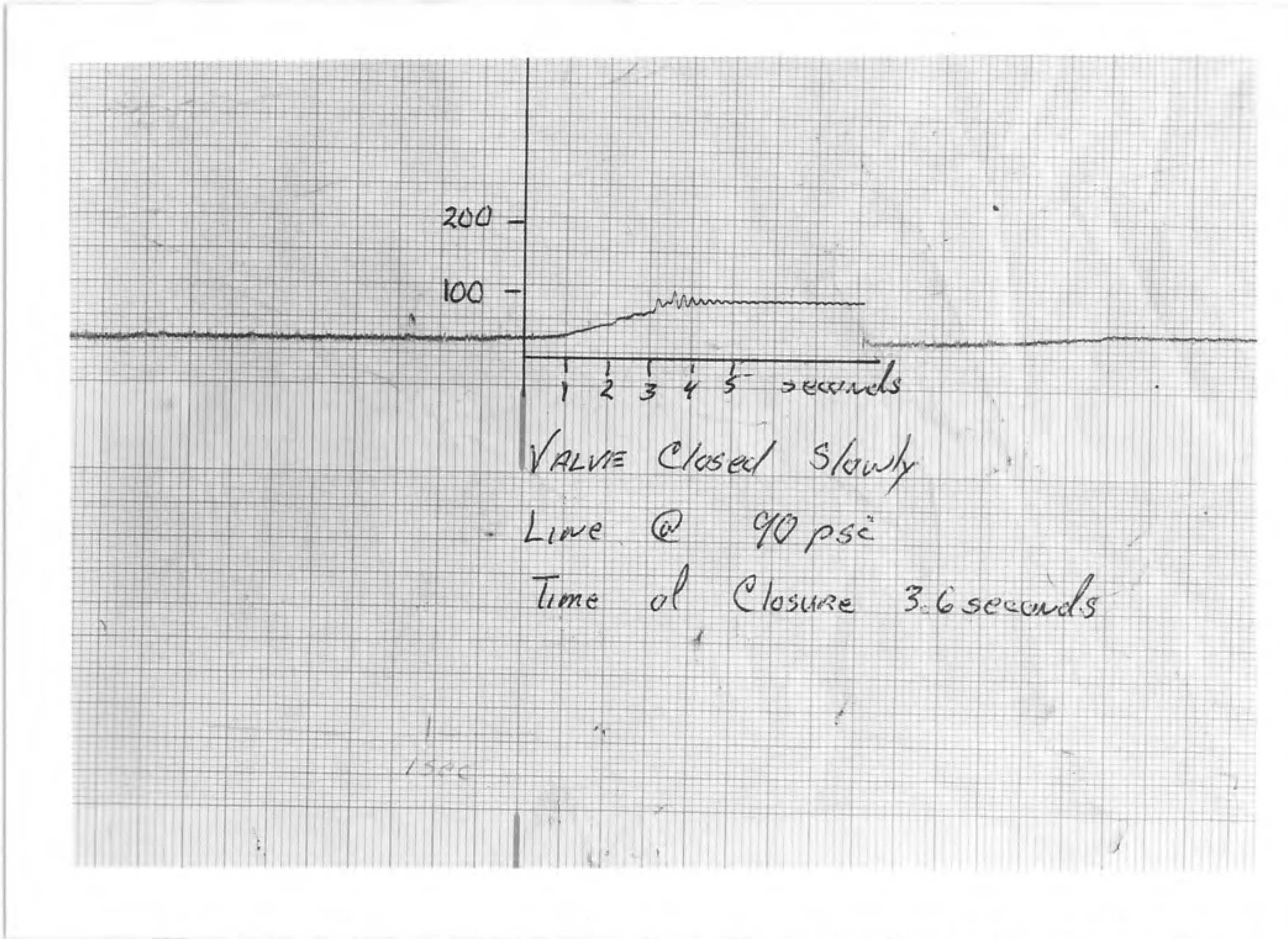

Figure 9. - Pressure rise for slow valve closure with standpipe.

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BY	DATE	PROJECT	SHEET ___ OF ___
CHKD BY	DATE	FEATURE	
DETAILS			

APPENDIX ....

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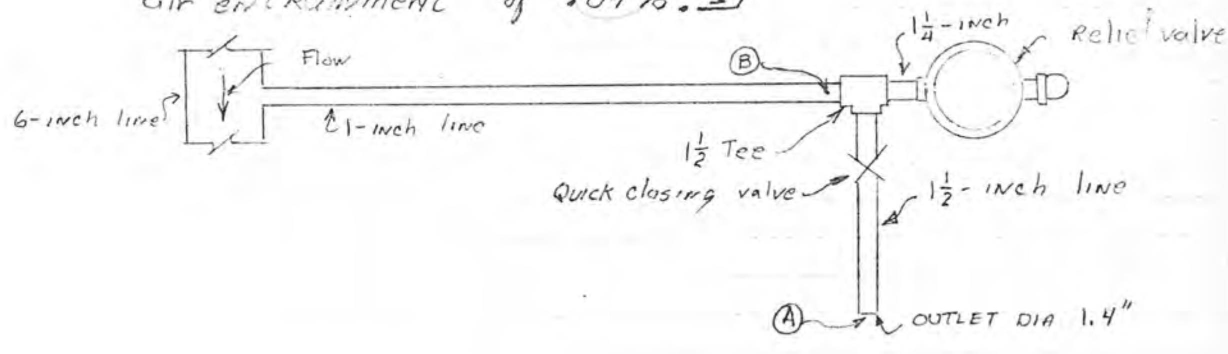
COMPUTATION SHEET

BY	DATE	PROJECT	SHEET A-1 OF
	-	Open-Closed Conduit Study	
CHKD BY	DATE	FEATURE	
		Water hammer - measured flow	
DETAILS			
Measure the flow and calculate water hammer.			

Given: The discharge of the system was determined by measuring the weight of water during an elasped time.

Determine: Water hammer by calculating a velocity for the measured flow. The velocity of the pressure wave in water a, is equal to 4500 fps for no air entrainment and 1100 fps for an air entrainment of .04%. 1/



EQUATIONS

$Q = \frac{W_2 - W_1}{\rho}\ t$

W_1 = initial wt of tare
W_2 = final wt
t = time elasped
ρ = 62.4 lb/ft³

$V_A = Q/A_A$

$V_B = Q/A_B$

$H = k\frac{aV}{g}$

V_A, V_B velocity of water @ A & B fps
A_A, A_B Area of pipe @ A & B ft²
k conversion feet of water to psi 14.7/34.0
H maximum pressure
a velocity of wave in water
g gravitational constant 32.2 ft/sec²

TEST TRIAL	W_2 lb.	W_1 lb.	ΔW lb	t sec	Q ft³/sec	V_A ft/sec	V_B ft/sec	Water hammer H, psi a = 4500 fps H_A	H_B	a = 1100 fps H_A	H_B
1	351	52	299	15	.3194	29.88	58.56	1805.41	3538.31	441.32	864.92
2	391	93	288	15	.3077	28.78	56.41	1738.95	3408.40	425.08	833.17
3	394	66	328	17	.3092	28.92	56.68	1747.40	3424.72	427.14	837.15
avg						29.33	57.22	1772.18	3457.35	433.20	845.13

1 "Hydraulic Transients" Streeter and Wylie pg. 8 FIG 1.5

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COMPUTATION SHEET

BY	DATE	PROJECT: Open-closed Conduit Study	SHEET A-2 OF
CHKD BY	DATE	FEATURE: Water hammer caused by Velocity under free flow	
DETAILS			

GIVEN: Line pressure at 90 psi under static conditions and a line pressure of 25 psi under free flow conditions. (see Fig 6)

Determine: Water Hammer at points A and B where the water velocity, $V = \sqrt{2gH}$ and $H = aV/g$ where $a = 1100$ & 4500 fps.

$$V_B = \sqrt{2gh}$$

$$= \left[2(32.2)\,25\left(\frac{34}{14.7}\right)\right]^{\frac{1}{2}}$$

$$V_B = 61.66 \text{ ft/sec}$$

$$V_A = \frac{V_B A_B}{A_A}$$

$$V_A = (61.66)\,\frac{\frac{\pi}{4}(1)^2}{\frac{\pi}{4}(1.4)^2}$$

$$V_A = 31.45 \text{ ft/sec}$$

$$H_A = \frac{a\,V_A}{g}\left(\frac{14.7}{34}\right)$$

$a = 1100$ fps, $H_A = \frac{(1100)(31.45)(14.7)}{(32.2)\;(34.0)} = 464.51$ $\left(\frac{sec^2}{ft}\,\frac{ft}{sec}\,\frac{ft}{sec}\,\frac{psi}{ft}\right)$

$a = 4500$ fps, $H_A = \frac{4500(31.45)(14.7)}{32.2\;(34.0)} = 1900.27$

$a = 1100$ fps, $H_B = \frac{1100(61.66)(14.7)}{32.2\;(34.0)} = 917.71$

$a = 4500$ fps, $H_B = \frac{4500(61.66)(14.7)}{(32.2)\;(34.0)} = 3725.62$

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COMPUTATION SHEET

BY	DATE	PROJECT Open Closed Conduit Study	SHEET A-3 OF
CHKD BY	DATE	FEATURE Impulse Momentum balance	
DETAILS			

GIVEN: L = 5-FEET TO QUICK-CLOSING VALVE. The CONDITIONS AT B AT FREE FLOW P = 25 psi, and for an estimated closing time of .0275 seconds the peak pressure is 445 psi (see Fig 6)

DISCUSSION: The water hammer pressure relationship, $H = aV/g$ applies only up to the time that a wave is reflected back.[2] The time it takes for the wave to return is determined by the period, $2L/a$. For a wave velocity a = 4500 the time is .002 sec. For a wave velocity a = 1000 the time is .01 seconds. The operator of the test estimated the valve closing time of .5 seconds. The test charts showed a peak occuring at a time of .0275 seconds (see Fig 6) The wave has been reflected before the valve has closed and before the pressure surge has had time to build to its theoretical maximum of 3500 psi. (see calc. sheet A-1) This reflected wave counteracts the initial surge and stops it at 445 psi (see Fig 6). If the relationship of $H = aV/g$ does not apply the change in momentum caused by decreasing the velocity to zero should be equal to the impulse of Force over the time it takes to decrease the velocity to zero. This force F is determined by the area under the curve from time equals zero to the peak pressure. The impulse is equal $F \times t$ where force = $\frac{1}{3}$ pressure times the end area of the pipe. (see Fig 6)

EQUATIONS:

Mass $M = W/g$ W = weight of water = Volume × 62.4

$V = \sqrt{2gH}$

Momentum $= M \times V$

Impulse $= F \times t$

2 "Hydraulic Transients" Streeter and Wylie pg 5 equation 1.2.19

IMPULSE MOMENTUM CONTINUED

$$W = \left[\left(\frac{\pi}{4}\right)(1)^2\frac{(60)}{1728}\right] 62.4 \frac{lb}{ft^3} \qquad Area = .7854\ in^2$$

$$W = 1.702\ lb$$

$$V = \sqrt{2gH}$$

$$= \sqrt{2(32.2)\ 25\left(\frac{34}{14.7}\right)}$$

$$V_B = 61.02\ fps$$

time $t = .0275$ sec

Peak = 445 psi

$$M \times V = F \times t$$

$$\frac{1.702}{32.2} \times 61.02 = \frac{1}{3}(445)\left(\frac{\pi}{4}(1)^2\right)(.0275)$$

$$3.26\ lb\text{-}sec = 3.20\ lb\text{-}sec \qquad \text{agrees}$$

CONCLUSIONS:

The results of the three methods of calculation support the measured test results. The pressure surge does not attain its theoretical maximum because a combination of a factors. The factors include the possibility of air, friction losses, and the short length of pipe for the test facility.

Form DFC-11
(12-61)
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INFORMATIONAL ROUTING

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Memorandum
Head, Hydraulics Research Section JCS
J. Charles Givens

Denver, Colorado
August 13, 1975

Test of Clayton Automatic Valve 50G-01 20 to 200 lb/in^2 for Water-hammer Relief Applications - Open and Closed Conduit Systems Program

Introduction

This particular relief valve was proposed for application to water-hammer problems of an irrigation district. The water-hammer could occur when fire fighting equipment is connected to the irrigation system. The fire fighters use quick closing valves on lines straight off the system to a valve at the nozzle, or through a pumper that has the ability to come on the line in a short time. The relief valve was tested to see if it would react quickly enough to a pressure surge to prevent damage to a pipeline. The results were compared to a dead ended line, and to a line with a standpipe.

The main component of the test valve is referred to as the relief valve. The pressure control valve which is referred to as the control valve is used to adjust the relief pressures.

Test Facility

The High Head Pump Facility in the Hydraulics Branch was used to produce the required test pressures. These pressures included the calibration of the relief valve through the manufacturer's range of operation of 20 to 200 lb/in^2, and the waterhammer tests at 90 lb/in^2.

The system for the testing was set up on the end of a 1-inch line on the facility downstream from a venturi, but upstream of a multijet sleeve valve and chamber. This arrangement allowed the operator to set the line pressure from the control board. A 1-1/2-inch tee was installed at the end of the 5-foot-long 1-inch line. The relief valve was in line with the 1-inch line and a quick closing valve was placed 90° to the 1-inch line (see figures 1 and 2). Modifications included replacing the relief valve with a plug (see figure 1, detail A, and figure 3). A standpipe was placed between the tee and the quick-closing valve (see figure 1, detail B, and figure 4). The standpipe included a 1-1/2-inch-diameter pipe with a gage glass for determining the length of the air column in the pipe. An external air supply was connected to the standpipe to adjust the length of the air column.

The pressure in the line was adjusted at the control board. The pressure for the water-hammer system was measured in the 1-inch line 1 inch

upstream from the tee. The pressure transducer was connected to a Sanborn series 350 chart recorder. A Kistler transducer (0 to 200 lb/in^2) was used to calibrate the control valve on the relief valve. When the first tests were made the Kistler's range was not adequate. A Pace (0 to 500-lb/in^2 range) transducer was substituted and used throughout the water hammer tests.

Test Procedure

The Clayton Automatic Valve was calibrated in the range 20 to 200 lb/in^2. The relief valve was set to zero by backing out the adjustment bolt on the control valve until the bolt could be turned by hand. The bolt was then screwed in until it touched the spring. The pressure was brought up to 30 lb/in^2. The bolt was tightened until the leaking stopped, then it was loosened until leaking started. The line pressure was increased at 10-lb/in^2 increments using the same procedure for determining relief pressure versus number of turns from zero (see table 1 and figure 5).

For the water hammer tests, the line pressure was set at 90 lb/in^2. The relief valve was set to relieve at line plus 10 percent or 99 lb/in^2. The quick-closing valve was opened to let water flow freely to the atmosphere for 10 to 15 seconds, then slammed shut. The same procedure of setting line pressure and operation of the quick-closing valve was used for the relief valve, the plug, and the standpipe.

Results

With quick closure of the valve:

a. The pressure surged to 445 lb/in^2 with the relief valve in place (see figure 6 for pressure recordings).

b. The pressure surged to 450 lb/in^2 with the relief valve replaced by a plug (see figure 7 for pressure recordings). Note that secondary pressure surges occurred at values approximately at half of the maximum peak.

c. The pressure surged to 150 lb/in^2 with the standpipe in place (see figure 8 for pressure recordings). During the free flow condition the length of the air column was adjusted at 24 to 26 inches in the 36-inch standpipe.

d. Calculations show that a peak of 450 lb/in^2 was possible. The 450 lb/in^2 maximum depends on the method or location

of study. A range of 420 to 2,609 lb/in^2 was calculated (see appendix for calculations).

e. For comparison a test was made with the standpipe installed and the quick closing valve was closed over a longer period of time (3.6 s). The pressure surged to maximum of 104 lb/in^2. This maximum was 15.6 percent over the line pressure of 90 lb/in^2 (see figure 9 for pressure recordings).

Conclusions

The relief valve does not react quickly enough to handle the waterhammer that occurs from rapidly closing a valve. The standpipe appears to be a solution. The size of the pipe and method of keeping a specified amount of air in the standpipe should be determined by the design group involved.

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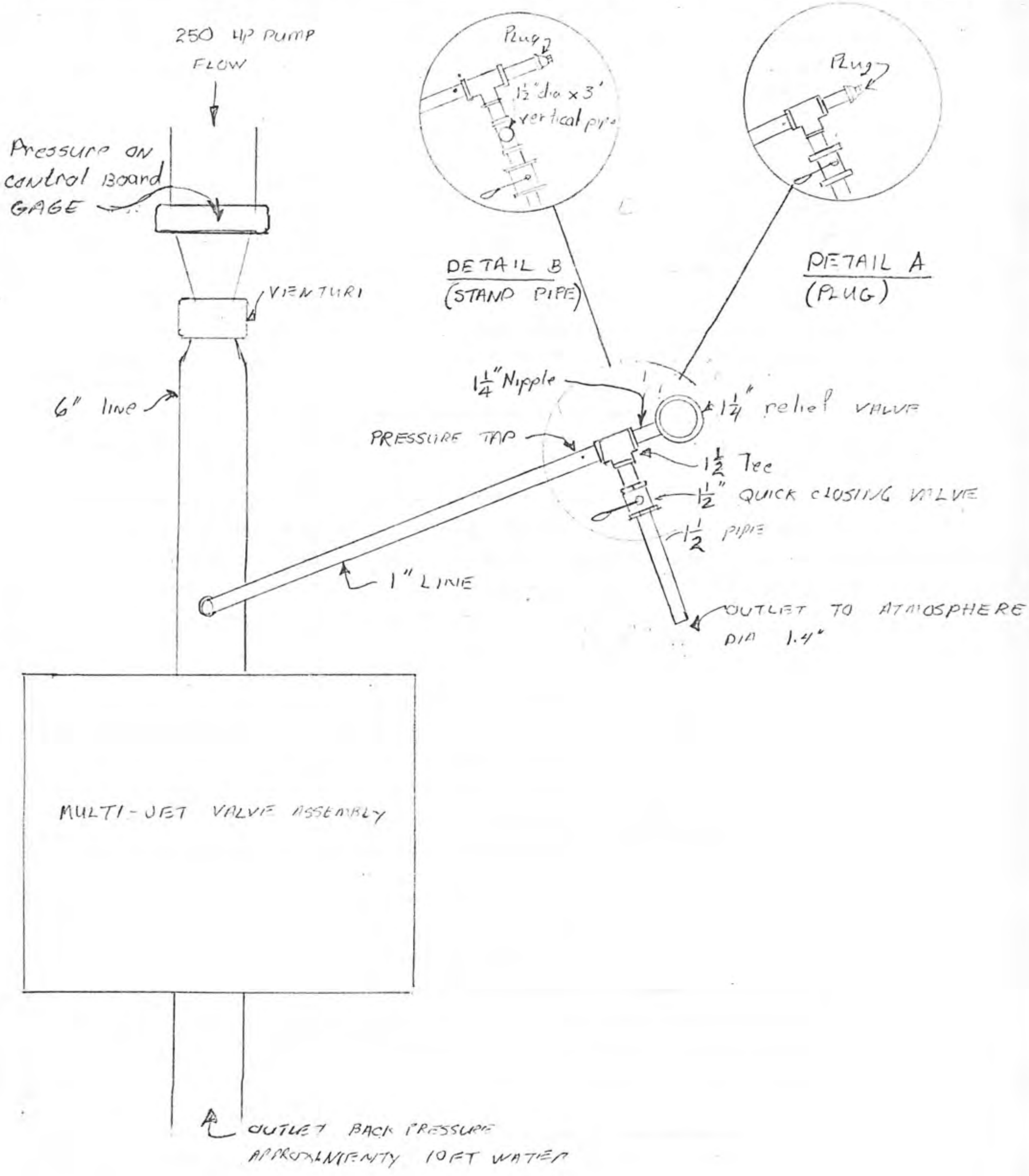
7-1654 (7-73)
Bureau of Reclamation

COMPUTATION SHEET

Fig. 1

BY	DATE	PROJECT Open Closed Conduit Study	SHEET 5 OF
CHKD BY	DATE	FEATURE General Layout of Test [illegible]	
DETAILS			



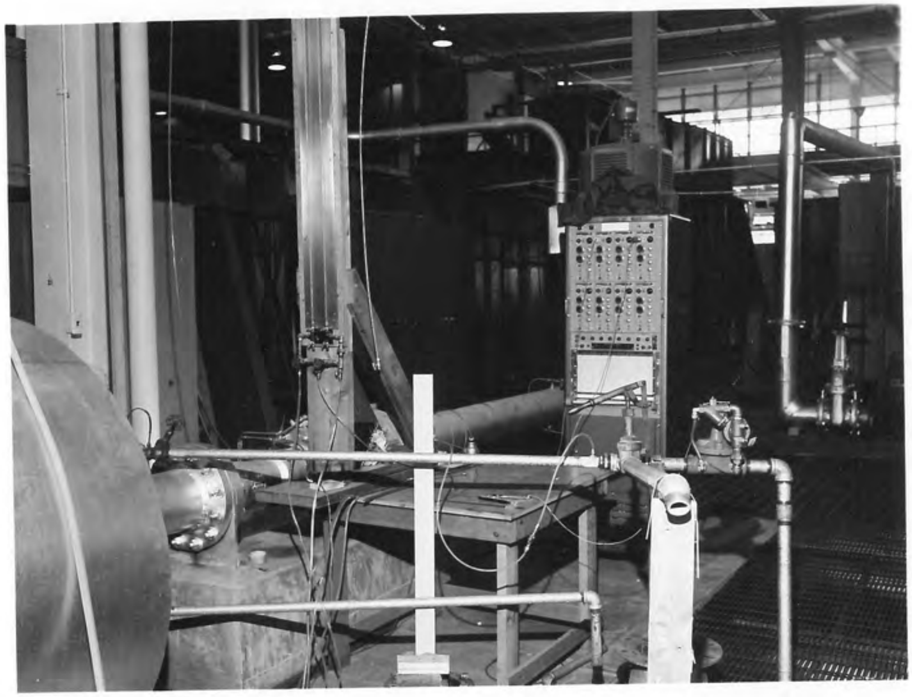


Figure 2. - Test setup with relief valve installed. Photo H-1762-2

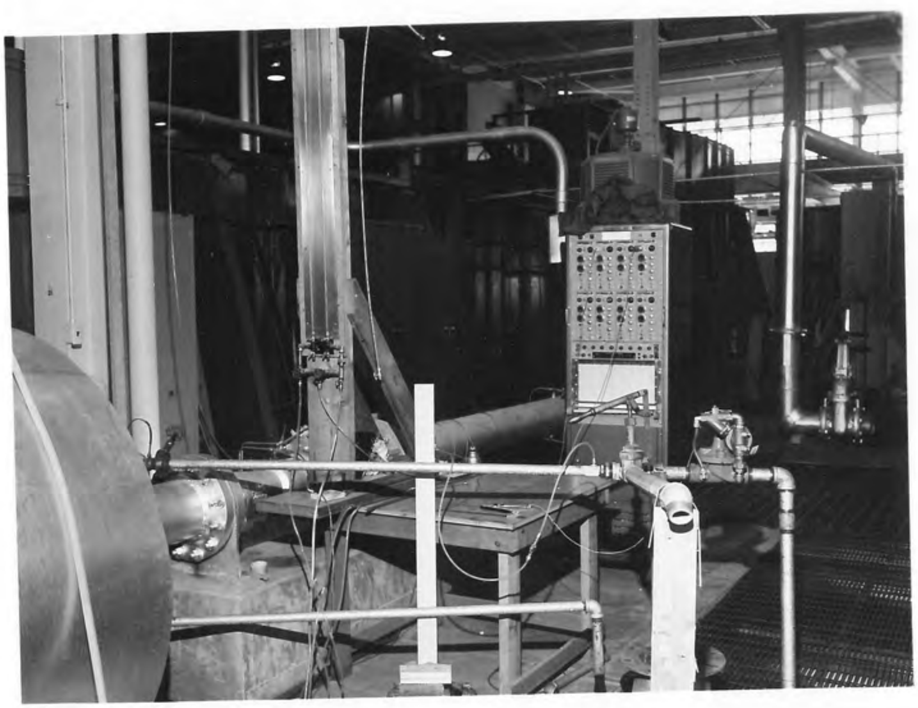


Figure 3. - Test setup with relief valve replaced by a plug. Photo H-1762-3

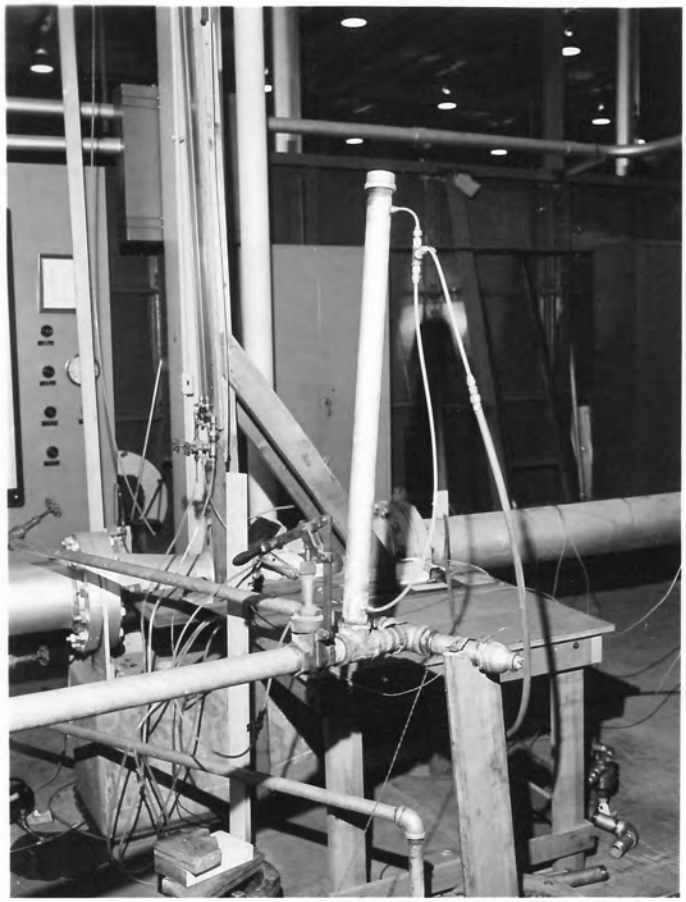


Figure 4. - Test setup with a standpipe installed upstream of the quick-closing valve.
Photo H-1762-4

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COMPUTATION SHEET

FIG 5

BY	DATE	PROJECT	SHEET
J. GIVENS	4-29-75	OPEN - CLOSED CONDUIT STUDY	SHEET 8 OF
CHKD BY	**DATE**	**FEATURE**	
		CALIBRATE CLAYTON AUTOMATIC VALVE 506-01 20-200	

DETAILS ZERO SETTING ON SPRING WAS DETERMINED BY TOUCH - THE [illegible] BOLT FIRST TOUCHED THE SPRING
RELIEF [illegible] DETERMINED BY A [illegible] LEAK - [illegible] DROPPING

CALIBRATION CURVE - NUMBER OF TURNS VS PRESSURE

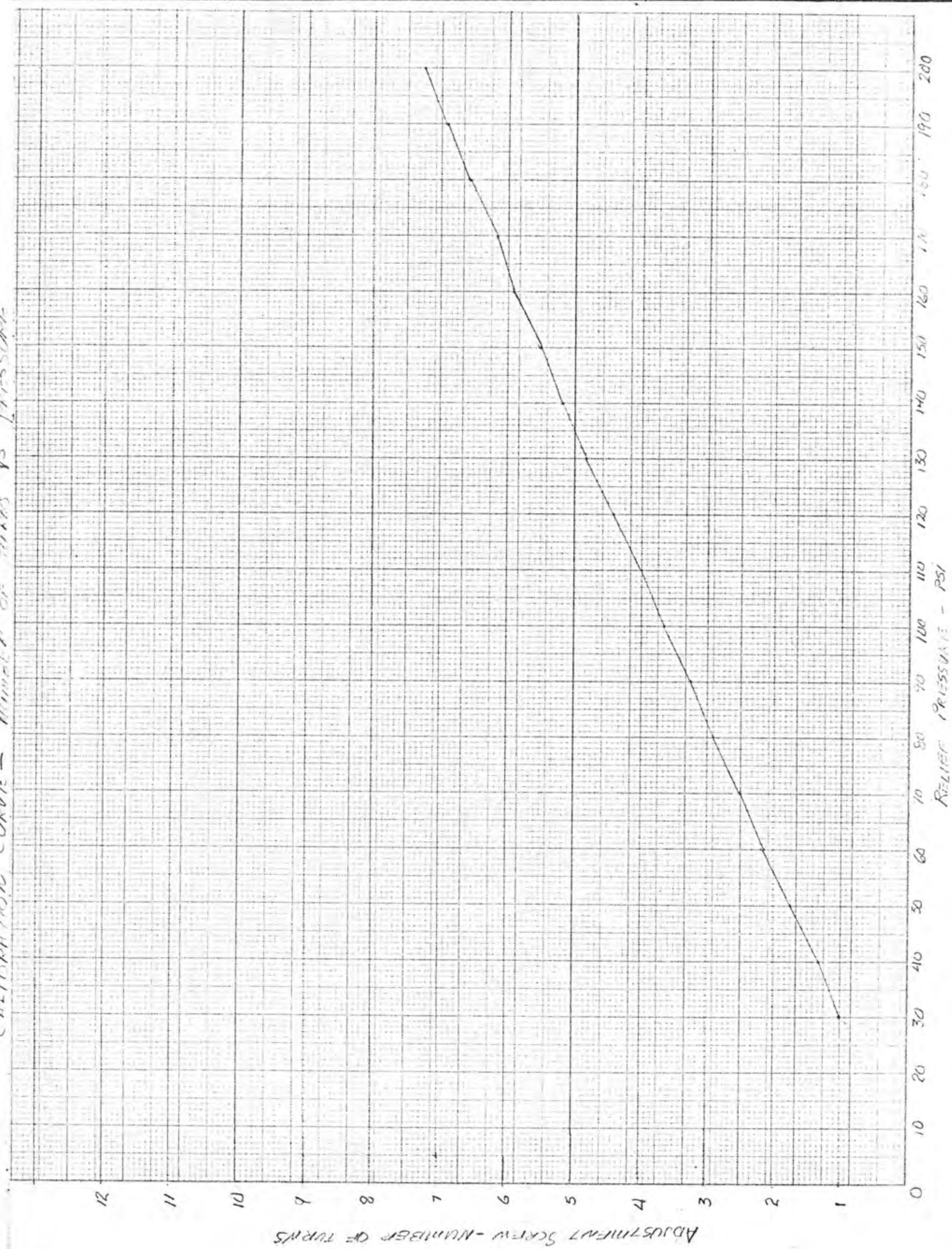

FIG. 5

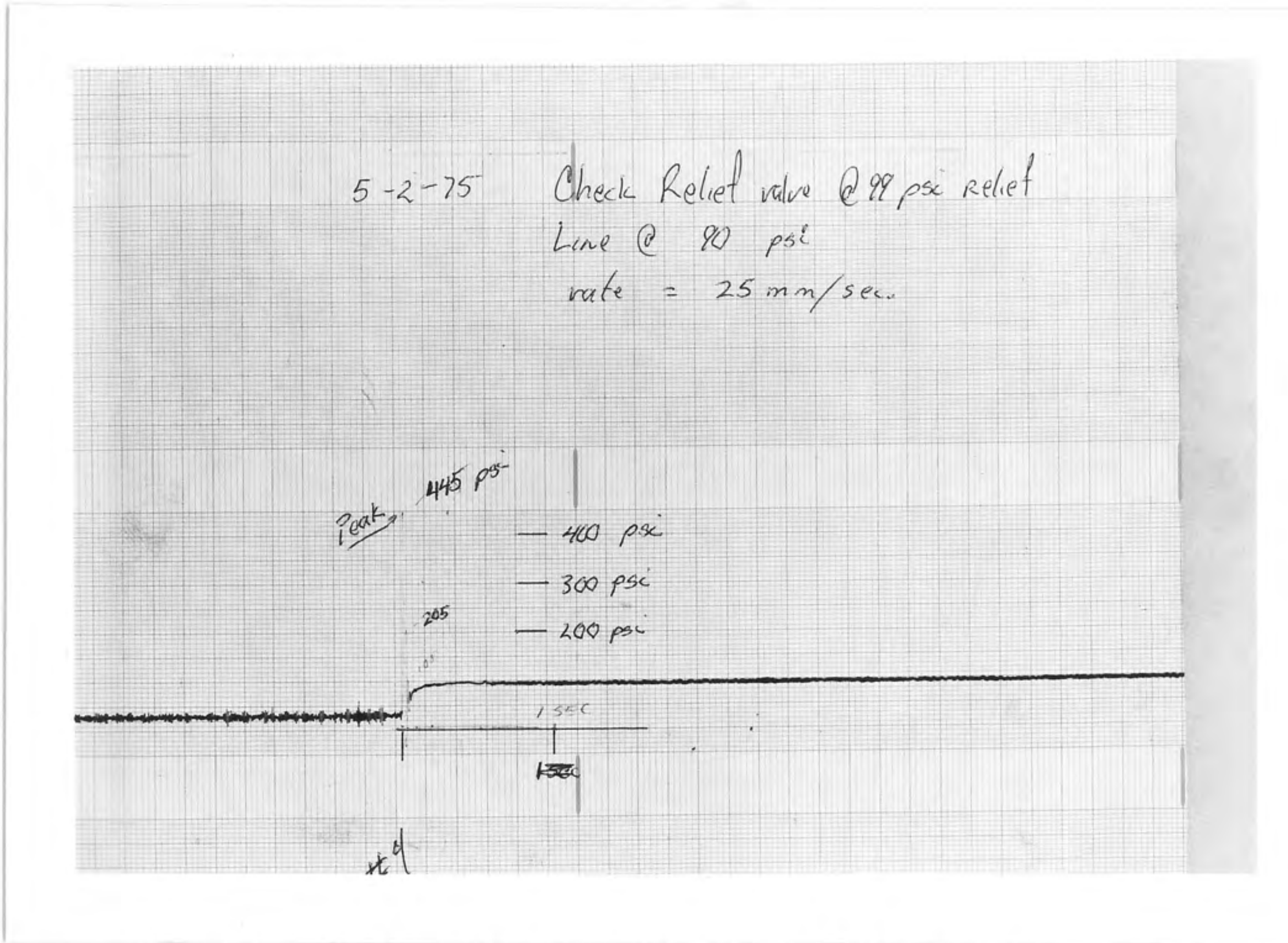

Figure 6. - Pressure rise for quick closure with pressure relief setting of 99 lb/in^2.

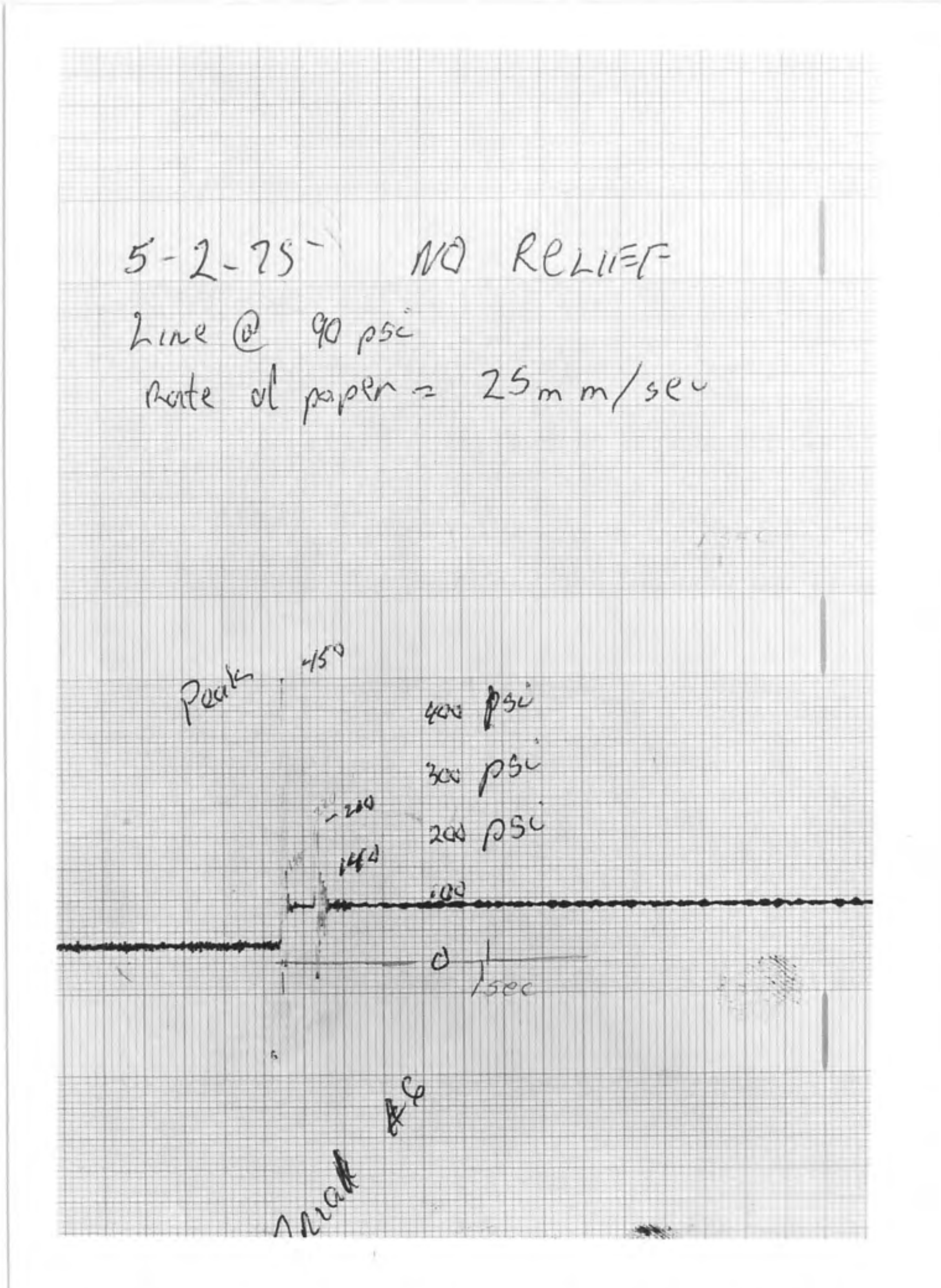

Figure 7. - Pressure rise for quick closure with pipe plug instead of pressure relief valve.

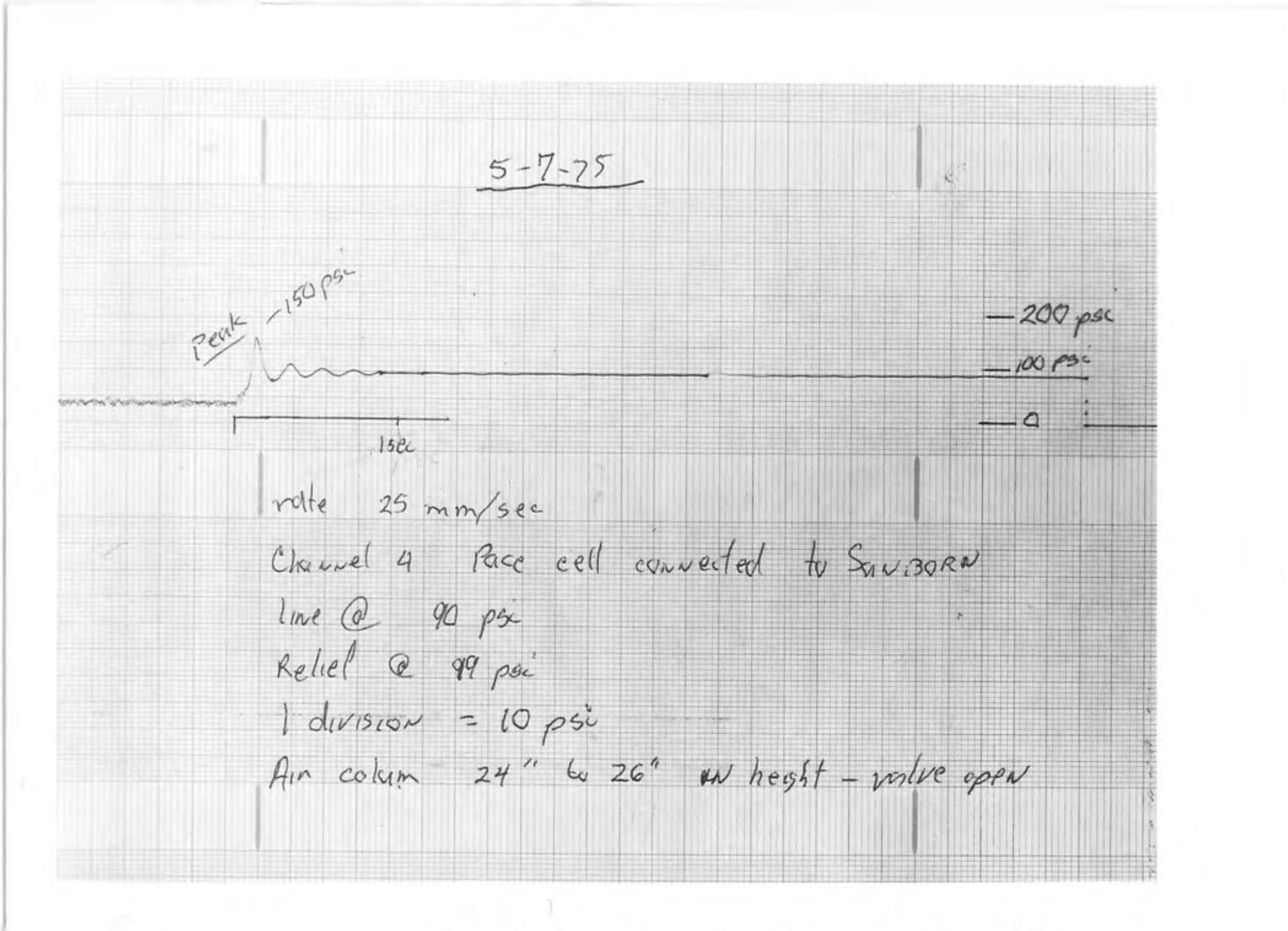

Figure 8.-Pressure rise for air column standpipe in place of pressure relief valve

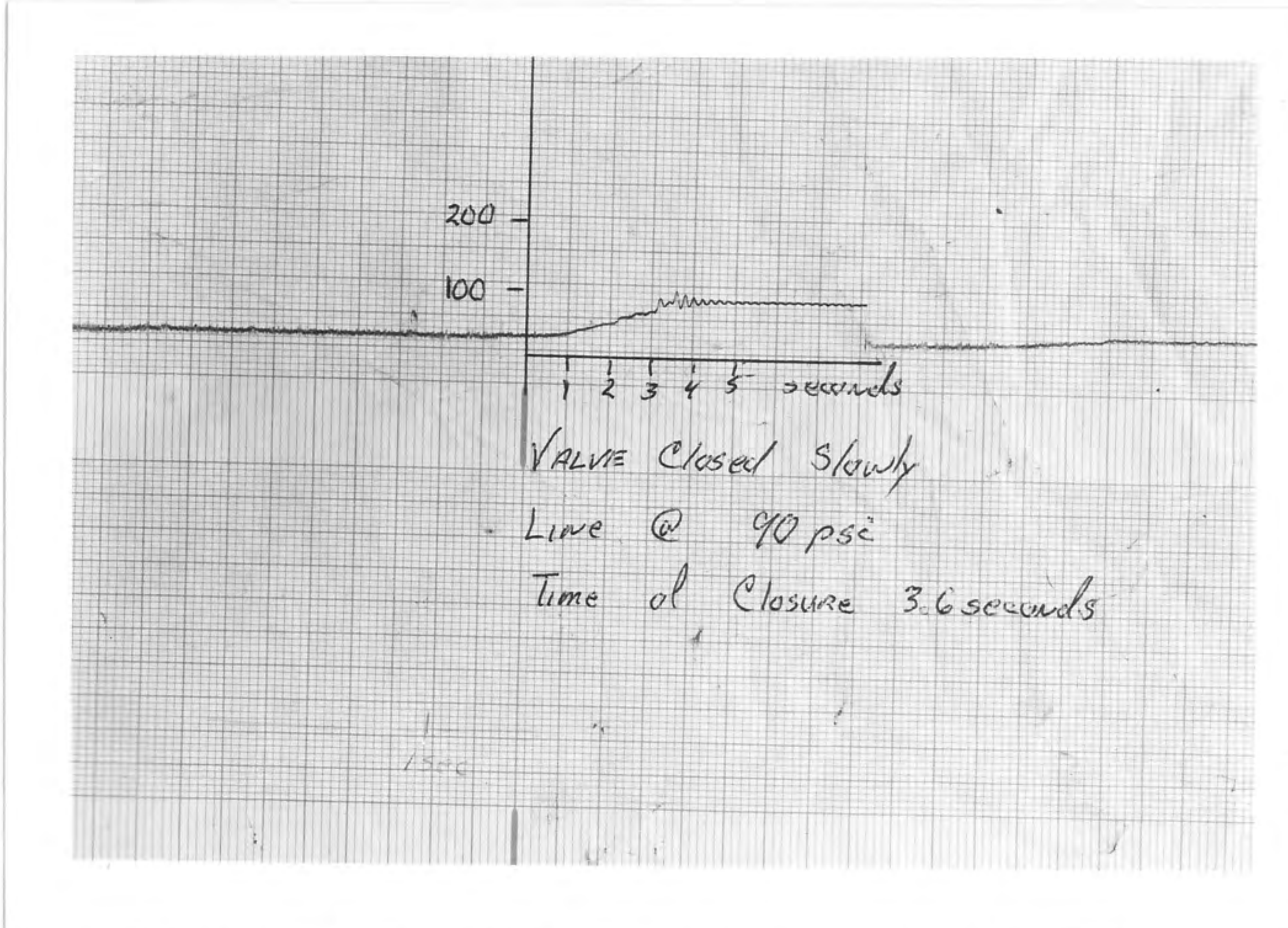

Figure 9. - Pressure rise for slow valve closure with standpipe.

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COMPUTATION SHEET

BY	DATE	PROJECT	SHEET ____ OF ____
CHKD BY	DATE	FEATURE	
DETAILS			

APPENDIX . . . .

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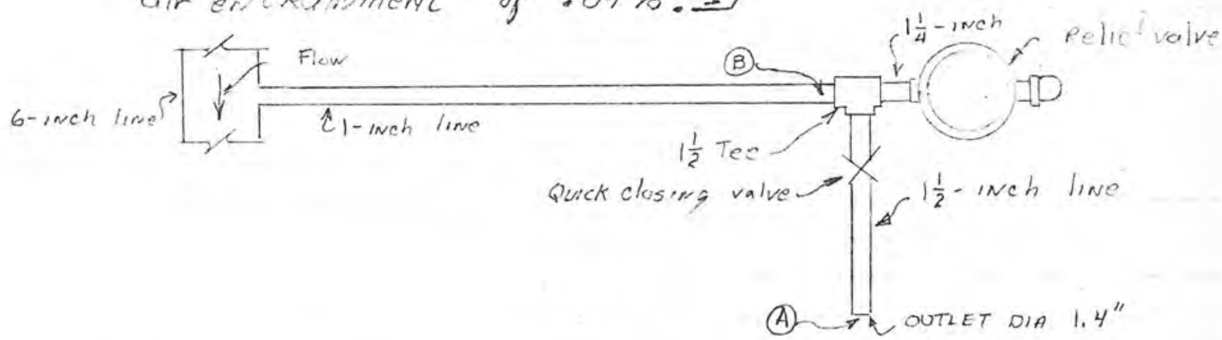
COMPUTATION SHEET

BY	DATE	PROJECT	SHEET
	-	Open-Closed Conduit Study	A-1 OF
CHKD BY	DATE	FEATURE	
		Water hammer - measured flow	

DETAILS
Measure the flow and calculate water hammer.

Given: The discharge of the system was determined by measuring the weight of water during an elasped time.

Determine: Water hammer by calculating a velocity for the measured flow. The velocity of the pressure wave in water a, is equal to 4500 fps for no air entrainment and 1100 fps for an air entrainment of .04%. 1/



EQUATIONS

$Q = \frac{W_2 - W_1}{\rho}\ t$

W_1 = initial wt of tare
W_2 = final wt
t = time elasped
ρ = 62.4 lb/ft^3

$V_A = Q/A_A$

$V_B = Q/A_B$

$H = k\frac{aV}{g}$

V_A, V_B velocity of water @ A & B fps
A_A, A_B Area of pipe @ A & B ft^2
k conversion feet of water to psi 14.7/34.0
H maximum pressure
a velocity of wave in water
g gravitational constant 32.2 ft/sec^2

TEST TRIAL	W_2 lb.	W_1 lb.	ΔW lb	t sec	Q ft^3/sec	V_A ft/sec	V_B ft/sec	Water hammer H, psi: a = 4500 fps, H_A	a = 4500 fps, H_B	a = 1100 fps, H_A	a = 1100 fps, H_B
1	351	52	299	15	.3194	29.88	58.56	1805.41	3538.31	441.32	864.92
2	391	93	288	15	.3077	28.78	56.41	1738.95	3408.40	425.08	833.17
3	394	66	328	17	.3092	28.92	56.68	1747.40	3424.72	427.14	837.15
avg						29.33	57.22	1772.18	3457.35	433.20	845.13

1 "Hydraulic Transients" Streeter and Wylie pg. 8 Fig 1.5

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COMPUTATION SHEET

BY	DATE	PROJECT Open-Closed Conduit Study	SHEET A-2 OF
CHKD BY	DATE	FEATURE Water hammer caused by Velocity under free flow	
DETAILS			

Given: Line pressure at 90 psi under static conditions and a line pressure of 25 psi under free flow conditions. (see Fig 6)

Determine: Water Hammer at points A and B where the water velocity, $V = \sqrt{2gH}$ and $H = aV/g$ where a = 1100 & 4500 fps.

$$V_B = \sqrt{2gh}$$

$$= \left[2(32.2)\ 25\left(\frac{34}{14.7}\right)\right]^{\frac{1}{2}}$$

$$V_B = 61.66 \text{ ft/sec}$$

$$V_A = \frac{V_A A_A}{A_B}$$

$$V_A = (61.66)\ \frac{\frac{\pi}{4}(1)^2}{\frac{\pi}{4}(1.4)^2}$$

$$V_A = 31.45 \text{ ft/sec}$$

$$H_A = \frac{a\,V_A}{g}\left(\frac{14.7}{34}\right)$$

a = 1100 fps, $H_A = \frac{(1100)(31.45)(14.7)}{(32.2)(34.0)} = 464.51$

a = 4500 fps, $H_A = \frac{4500(31.45)(14.7)}{32.2\ (34.0)} = 1900.27$

a = 1100 fps, $H_B = \frac{1100(61.66)(14.7)}{32.2\ (34.0)} = 917.71$

a = 4500 fps, $H_B = \frac{4500(61.66)(14.7)}{(32.2)\ (34.0)} = 3725.62$

BY	DATE	PROJECT Open Closed Conduit Study	SHEET A-3 OF
CHKD BY	DATE	FEATURE Impulse Momentum balance	
DETAILS			

GIVEN: L = 5-FEET TO QUICK-CLOSING VALVE. The CONDITIONS AT B AT FREE FLOW P = 25 psi, and for an estimated closing time of .0275 seconds the peak pressure is 445 psi (see Fig 6)

DISCUSSION: The water hammer pressure relationship, $H = aV/g$ applies only up to the time that a wave is reflected back.[2] The time it takes for the wave to return is determined by the period, $2L/a$. For a wave velocity a = 4500 the time is .002 sec. For a wave velocity a = 1000 the time is .01 seconds. The operator of the test estimated the valve closing time of .5 seconds. The test charts showed a peak occurring at a time of .0275 seconds (see FIG 6) The wave has been reflected before the valve has closed and before the pressure surge has had time to build to its theoretical maximum OF 3500 psi. (see CALC. SHEET A-1) This reflected wave counteracts the initial surge and stops it at 445 psi (see FIG 6). If the relationship of $H = aV/g$ does not apply the change in momentum caused by decreasing the velocity to zero should be equal to the impulse of Force over the time it takes to decrease the velocity to zero This force F is determined by the area under the curve from time equals zero to the peak pressure. The impulse is equal F x t where force = $\frac{1}{3}$ pressure times the end area of the pipe. (see FIG 6)

EQUATIONS:

Mass $M = W/g$ W = weight of water = Volume × 62.4

$V = \sqrt{2gH}$

Momentum = $M \times V$

Impulse = $F \times t$

2 "HYDRAULIC TRANSIENTS" Streeter and Wylie pg 5 equation 1.2.19

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COMPUTATION SHEET

BY	DATE	PROJECT	SHEET A-4 OF
CHKD BY	DATE	FEATURE	
DETAILS			

IMPULSE MOMENTUM CONTINUED

$$W = \left[\left(\frac{\pi}{4}\right)(1)^2 \frac{(60)}{1728}\right] 62.4 \frac{lb}{ft^3} \qquad Area = .7854\ in^2$$

$$W = 1.702\ lb$$

$$V = \sqrt{2gH}$$

$$= \sqrt{2(32.2)\ 25 \left(\frac{34}{14.7}\right)}$$

$$V_B = 61.02\ fps$$

time $t = .0275$ sec

Peak = 445 psi

$$M \times V = F \times t$$

$$\frac{1.702}{32.2} \times 61.02 = \frac{1}{3}(445)\left(\frac{\pi}{4}(1)^2\right)(.0275)$$

3.26 lb-sec = 3.20 lb-sec agrees

CONCLUSIONS:

The results of the three methods of calculation support the measured test results. The pressure surge does not attain its theoretical maximum because a combination of a factors. The factors include the possibility of air, friction losses, and the short length of pipe for the test facility.