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### **METRIC CONVERSION FACTORS**

**Approximate Conversions to Metric Measures** 

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		VOLUME		
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### **Approximate Conversions from Metric Measures**

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		AREA				
cm² m² km² ha	square centim. square meters square kilom. hectares (10,000 m <sup>2</sup> )	0.16 1.20 0.40 2.50	square inches square yards square miles acres	in² yd² mi²		
	1	MASS (weig	iht)			
g kg t	grams kilograms tonnes (1000 k	0.035 2.2 g) 1.1	ounces pounds short tons	oz Ib		
		VOLUME				
ml l l m <sup>9</sup> m <sup>3</sup>	milliliters liters liters liters cubic meters cubic meters	0.03 2.10 1.06 0.26 36.00 1.30	fluid ounces pints quarts gallons cubic feet cubic yards	fi oz pt qt gai ft <sup>3</sup> yd <sup>3</sup>		
TEMPERATURE (exact)						
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\* 1 in. = 2.54 cm (exactly)

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# **Table of Contents**

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4

1.0 INTRODUCTION	1
2.0 OBJECTIVE	2
3.0 METHODOLOGY	2
3.1 TEST CAR	3
4.0 TEST MATRIX	5
4.1 TEST SERIES 1: TANK CAR IMPACTS WITH BLIND FLANGES INSTALLED ON SAFETY VENT NOZZLES	5
4.1.1 Car Preparation	5
4.1.2 Test Procedures	8
4.2 TEST SERIES 2: TANK CAR IMPACTS WITH SAFETY VENTS INSTALLED	8
4.2.1 Car Preparation	8
4.2.2 Test Procedures	8
4.3 TEST SERIES 3: TANK CAR IMPACTS WITH SURGE PRESSURE REDUCERS INSTALLED IN SAFETY VENT NOZZLES	11
4.3.1 Car Preparation	11
4.3.2 Test Procedures	13
4.4 TEST SERIES 4: TANK CAR IMPACTS WITH SURGE PRESSURE REDUCERS AND SAFETY VENTS INSTALLED	13
4.4.1 Car Preparation	13
4.4.2 Test Procedures	17
4.5 TEST MATRIX	17
5.0 MATERIALS	20
5.1 TEST VEHICLES	20
6.0 MEASUREMENTS AND INSTRUMENTATION	21

7.0	) RESULTS	23
	7.1 SAFETY VENT NOZZLE SURGE PRESSURE AND COUPLER	40
	FORCE	23
	7.2 SUMMARY PLOTS OF SURGE PRESSURES	23
	7.3 IMPACT CONDITIONS CAUSING DISC RUPTURE	23
	7.4 VENT SURGE PRESSURES BEFORE AND AFTER INSTALLA- TION OF SPR'S	23
	7.5 COUPLER FORCE VS IMPACT SPEED AND OUTAGE	23
	7.6 B-END TANK SHELL STRAIN VS COUPLER FORCE AND IMPACT SPEED	23
	7.7 VIDEO RECORDS	23
8.0	DISCUSSION	38
9.0	CONCLUSIONS	43
	APPENDIX A: SAFETY VENT NOZZLE AND SURGE PRESSURE REDUCER DIMENSIONS 4	15
,	APPENDIX B: IMPACT TEST DATA - SAFETY VENT NOZZLE SURGE PRESSURES AND COUPLER FORCES MEA- SURED DURING TEST SERIES 1A - 4F	3

APPENDIX C: VIDEO LOG - LIST OF VIDEO RECORDINGS SHOW-		
ING DISC KUPTURES	77	

.

# **Table of Figures**

Figure 1.	DOT 111A-100w2 Tank Car	4
Figure 2.	View of Instrumented Coupler	6
Figure 3.	View of Strain Gage Rosette (9' 3/8" from B-end)	6
Figure 4.	View of Strain Gage Rosette 2 (Location is on Middle Cross Section of Car)	7
Figure 5.	View of the Weighted Locomotive Used as Hammer Car	9
Figure 6.	View of Test Car and Three Backstop Cars	9
Figure 7.	Surge Chamber, Physical Test Setups	10
Figure 8.	View of Surge Pressure Reducers	12
Figure 9.	View of Safety Vent/Baffle Type SPR for 6 1/2" Safety Vent	14
Figure 10	. View of Safety Vent/Mesh Type SPR for 6 1/2" Safety Vent	15
Figure 11	. View of Safety Vent/Pipe Type SPR for 4 1/2" Safety Vent	16
Figure 12	. Instrumentation Layout	21
Figure 13.	Surge Pressure vs Distance From Struck End & Impact Speed 0% outage, B-end Impacted, Blind Flanges Installed	24
Figure 14.	Surge Pressure vs Distance From Struck End & Impact Speed 1% outage, B-end Impacted, Blind Flanges Installed	25
Figure 15.	Surge Pressure vs Distance From Struck End & Impact Speed 2% outage, B-end Impacted, Blind Flanges Installed	26
Figure 16.	Surge Pressure vs Distance From Struck End & Impact Speed 4% outage, B-end Impacted, Blind Flanges Installed	27
Figure 17.	Surge Pressure vs Distance From Struck End & Impact Speed 0% outage, A-end Impacted, Blind Flanges Installed	_, 28
Figure 18.	Surge Pressure vs Distance From Struck End & Impact Speed 2% outage, A-end Impacted, Blind Flanges Installed	29
Figure 19.	Surge Pressure in 2 1/2" Nozzle 0% outage. B-end Impacted	30
Figure 20.	Surge Pressure in 2 1/2" Nozzle 0% outage. A-end Impacted	30
Figure 21.	Surge Pressure in 4 1/2" Nozzle 0% outage, B-end Impacted	31
Figure 22.	Surge Pressure in 4 1/2" Nozzle 0% outage. A-end Impacted	31
Figure 23.	Surge Pressure in 6 1/2" Nozzle 0% outage. B-end Impacted	32
Figure 24.	Surge Pressure in 6 1/2" Nozzle 0% outage, A-end Impacted	32

Figure 25.	Surge Pressure in 2 1/2" Nozzle Without SPR, 0% outage, B-end Impacted at 5 mph	34
Figure 26.	Surge Pressure in 2 1/2" Nozzle With SPR, 0% outage, B-end Impacted at 5 mph	34
Figure 27.	Surge Pressure in 6 1/2" Nozzle Without SPR, 0% outage, A-end Impacted at 5 mph	35
Figure 28.	Surge Pressure in 6 1/2" Nozzle With SPR, 0% outage, A-end Impacted at 5 mph	35
Figure 29.	Coupler Force vs Impact Speed, 0% Outage, B-end Impacted	36
Figure 30.	Coupler Force vs Impact Speed, 0% Outage, A-end Impacted	36
Figure 31.	Longitudinal and Lateral Strains vs Coupler Force	37
Figure 32.	Longitudinal and Lateral Strains vs Impact Speed	37
Figure 33.	Percent Reduction in Surge Pressure For Three SPR Designs (0% Outage, 5 mph Impact Speed)	41

# Tables

Table 1.	General Test Matrix for Characterization of Impact Surge Pressures	18-10
Table 2	$T_{rest} O = 1^{1} C = 1^{1} C = 1^{1} C = 1^{1} C$	10-19
Table 2.	Test Conditions Which Resulted in the Rupture of 60 psi Discs	33
Table 3.	Test Conditions Which Resulted in the Rupture of 100 psi Discs	33
Table 4	Conditions Leading to Diag Durature	
таою т.	conditions Leading to Disc Kupture	39

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#### **1.0 INTRODUCTION**

Tank cars transporting corrosive liquids are often equipped with safety vents which employ frangible discs to protect the tank from over-pressurization during fires.

Premature failure of the frangible disc occasionally occurs during switching operations. The failure is caused by surge pressures resulting from liquid movement inside the tank car during switching speeds above 4 mph. These surge pressures can exceed the rated pressure of the disc, causing it to break. Once the disc is broken, product can repeatedly discharge through the safety vent during routine car handling. If railroad personnel are exposed to the discharged product, serious injury can result.

This study was funded by the Federal Railroad Administration (FRA) to determine the magnitude of surge pressures that the safety vent is exposed to at various speeds and to test devices that are designed to reduce these surge pressures. The effect of lading outage on surge pressure and the variation of surge pressures along the length of the car was also examined (outage is defined in the Code of Federal Regulations, Title 49 as "the amount by which a packaging falls short of being liquid full, usually expressed in percent by volume").

The study was performed under a research program entitled "Hazardous Materials Transportation Safety Research." Under the same program, the Association of American Railroads (AAR) had previously conducted a series of tests to evaluate the performance of various frangible disc designs under laboratory conditions. Tests were performed to determine the range of burst pressures for five types of discs by subjecting them to test pressures as specified by the AAR *Manual of Standards and Recommended Practices* (A5.03). The effect of temperature, creep, pressure surge, and exposure to corrosive materials on the burst pressures of frangible discs was also examined. <sup>1</sup>

<sup>1</sup> DiBrito, D. A. and B. R. Rajkumar. "Tank Car Frangible Disc Test," April 89 Final Report to FRA, AAR, 1989.

The present report documents results from a series of tests in which a weighted locomotive was coupled to a stationary DOT 111A100W2 tank car at different speeds. Pressure surge and coupler force data are presented for a matrix of test conditions which include impact speed, lading outage, and type of equipment installed on safety vent nozzles placed at three locations along the length of the car.

### 2.0 OBJECTIVE

The objective of these tests was to provide an understanding of coupler forces and internal pressures developed during controlled impacts with tank cars. It was projected that this information could be used for the future qualification of surge pressure reducer and vent spill trap devices.

### **3.0 METHODOLOGY**

Four types of tests were performed to investigate the influence of typical switch-yard type impacts on tank car surge pressure. The four types of tests were:

Series 1 -	Tank Car Impacts With Blind Flanges Installed On Safety Vent
	Nozzles
Series 2 -	Tank Car Impacts With Safety Vents Installed
Series 3 -	Tank Car Impacts With Surge Pressure Reducers Installed In Safety
	Vent Nozzles
Series 4 -	Tank Car Impacts With Surge Pressure Reducers And Safety Vents
	Installed

The objective of the Test Series 1 was to measure surge pressures inside safety vent nozzles. Since safety vent design could influence surge pressures at the safety vent nozzle, it was determined that this test series should be performed with the safety vent nozzle sealed with a blind flange to eliminate safety vent design as a test variable.

The objective of Test Series 2 was to measure surge pressures which occur inside safety vents with frangible discs installed. One type of safety vent design was used in the test series.

The objective of Test Series 3 and 4 was to measure the reduction in safety vent surge pressure produced by several prototype surge pressure reducers. In Test Series 3, the end of the surge pressure reducer was sealed off with a blind flange; in Test Series 4, the same safety vents used during test series 2 were installed outboard of each surge pressure reducer.

For each of the above test series, impact tests were conducted for lading outages of 0 percent, 1 percent, 2 percent and 4 percent and test speeds ranging from 3 to 8 mph. A fifth test series, tank car impacts with vent spill traps installed, was planned but could not be conducted since the required vent spill traps were not available during testing.

#### 3.1 TEST CAR

A DOT 111A100W2 tank car was used for the impact tests. The car was equipped with a 6 1/2 inch safety vent nozzle, a 4 1/2 inch sump nozzle on the manway, a 2 1/2 inch safety vent nozzle, and 2-inch pipe fittings on each end of the tank (Figure 1). The car, which was provided by Union Tank Car, had previously been used for transporting phosphoric acid. Prior to the test, a rubber lining was removed from the inside of the car and the acid residue was flushed out.



Figure 1. DOT 111A100W2 Tank Car

#### 4.0 TEST MATRIX

The controlled tank car impact test series were conducted to determine the magnitude of surge pressures that develop at various speeds and to test devices that were designed to reduce the surge pressure that the safety vent is exposed to. The effect of lading outage on surge pressures and the variation of surge pressures along the length of the car was also examined. The manner in which the test car was prepared and the test procedures that were used are described below for each of the test series.

# 4.1 TEST SERIES 1: TANK CAR IMPACTS WITH BLIND FLANGES INSTALLED ON SAFETY VENT NOZZLES

#### 4.1.1 Car Preparation

Pressure transducers were mounted on the side of both safety vent nozzle locations, on the side of the 4 1/2 inch sump nozzle on the manway, and on each end of the car on the top of the tank. The safety vents were replaced with blind flanges and a blind flange was mounted on the end of the 4 1/2 inch sump nozzle (the sump pipe assembly was removed and was not in place during Test Series 1 and following test series). An instrumented coupler (Figure 2) was installed to allow measurement of impact forces. An accelerometer was mounted 9 feet 3/8 inches from the B-end of the tank on the underside of the car on the center line. Two strain gages (Figures 3, 4) were also mounted on the underbelly of the car to allow the detection of possible structural yielding as a result of impacts sustained during the test series. The first gage was located on the tank shell 12 inches to the side of the accelerometer. The second gage was located in the middle of the car, on the underside, 8 inches to the side of the center line on the tank shell. The signals from the above instrumentation were recorded on data acquisition computers. Velocity was calculated based on timing measurements made with two automatic locating device reflectors on the impact car.



Figure 2. View of Instrumented Coupler



Figure 3. View of Strain Gage Rosette (9' 3/8" from B-end)



Figure 4. View of Strain Gage Rosette 2 (Location is on Middle Cross Section of Car)

### 4.1.2 Test Procedures

A weighted locomotive (Figure 5) was used to impact the stationary test car at various speeds to simulate yard switching. The speed of the locomotive at impact was controlled by placing the locomotive a predetermined distance uphill from the test car on a constant grade track. Three loaded hopper cars, placed downhill of the test car, were used as a backstop. Figure 6 shows the test car and three hopper cars. Impacts were initiated at 3 mph and increased in 1 mph increments until a 1,250 kip coupler force was achieved (at approximately 8 mph). Speed, coupler force, and pressure at each transducer location were recorded. Tests were conducted at outages of 0 percent, 1 percent, 2 percent, and 4 percent. Water level was checked periodically to assure that the outages were at the desired level. Surge chamber volumes and inlet areas were recorded for each safety vent nozzle (see Figure 7).

# 4.2 <u>TEST SERIES 2: TANK CAR IMPACTS WITH SAFETY VENTS INSTALLED</u> 4.2.1 <u>Car Preparation</u>

The same instrumentation was used as in Test Series 1. Safety vents were installed on the safety vent nozzles and fitted initially with 60 pounds per square inch (psi) pressure rating frangible discs. In the event of a disc rupture during an impact, the test was repeated with a 100 psi disc in place of the 60 psi frangible disc.

### 4.2.2 Test Procedures

Test procedures were the same as were used in Test Series 1 except that impacts were initiated at a speed 1 mph less than the minimum speed required to produce a disk rupture (based on Test Series 1 measurements) and increased in 1 mph increments until all three discs failed or until a 1,250 kip coupler force was achieved.



Figure 5. View of the Weighted Locomotive Used as Hammer Car







Figure 7. Display of the Four Set-ups Used in this Test

# 4.3 TEST SERIES 3: TANK CAR IMPACTS WITH SURGE PRESSURE REDUCERS INSTALLED IN SAFETY VENT NOZZLES

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#### 4.3.1 Car Preparation

The same instrumentation was used as in Test Series 1 except that the pressure transducer which was normally on the end of the tank car was moved to the side of one of the pipe-type surge pressure reducers (SPR's) on either the 21/2 inch nozzle or 41/2 inch nozzle. Candidate SPR's were placed in each safety vent. Drawings of each of the SPR's and their respective safety vents are given in Appendix A.

Three general types of SPR's were tested. The "baffle" type SPR incorporates an annular-shaped flow restriction and was designed for installation in a standard safety vent nozzle.

The "pipe" type SPR utilizes a pipe with a hole on the end that serves to restrict the flow. This type of SPR was designed for installation in either the manway sump nozzle or in a safety vent nozzle.

The "mesh" type SPR utilizes a steel mesh to create the desired flow restriction. The mesh type SPR was designed for use in a safety vent nozzle.

Each of the SPR prototypes was designed to reduce surge pressures impinging on a frangible disc while allowing adequate venting in circumstances where a sustained pressure exceeds the rated pressure of the installed disc.

Figure 8 shows three of the SPR's used during testing.



Figure 8. View of Surge Pressure Reducers (left to right): Baffle Type SPR for 2 1/2" Safety Vent, Pipe Type SPR for 4 1/2" Sump Nozzle, Baffle Type SPR for 6 1/2" Safety Vent

### 4.3.2 <u>Test Procedures</u>

Test procedures were the same as was used in Test Series 1 except that the impacts were initiated at the approximate speed which resulted in disc ruptures in Test Series 2. Tests were conducted with all candidate SPR's.

# 4.4 TEST SERIES 4: TANK CAR IMPACTS WITH SURGE PRESSURE REDUCERS AND SAFETY VENTS INSTALLED

## 4.4.1 Car Preparation

The same instrumentation was used as in Test Series 2. The surge pressure reducers were placed in each safety vent nozzle and the safety vents were installed. The three tested safety vent and SPR assemblies are shown in Figures 9, 10, and 11.



Figure 9. View of Safety Vent/Baffle Type SPR for 6 1/2" Safety Vent



Figure 10. View of Safety Vent/Mesh Type SPR for 6 1/2" Safety Vent



Figure 11. View of Safety Vent/Pipe Type SPR for 4 1/2" Safety Vent

## 4.4.2 Test Procedures

Test procedures were the same as were used in Test Series 3.

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# 4.5 TEST MATRIX

The general test matrix for the controlled tank car impact test series is given in Table 1.

## TABLE 1.

## GENERAL TEST MATRIX FOR CHARACTERIZATION OF IMPACT SURGE PRESSURES.

TEST SERIES	VENT NOZZLE	OUTAGE	IMPACT SPEED	COUPLER FORCE
1A	blind flange	0%	3 mph 4 mph 5 mph (speed increased until max. coupler force attained)	Up to 1250 kips
2A	60 psi or 100 psi frangible discs at all vent locations (depending on pressures measured in the previous test)	0%	1 mph below predicted initial rupture speed (determined from Series 1A) and increased in 1 mph increments until all 3 discs ruptured	Up to 1250 kips
3A	candidate Surge Pressure Reducers (SPR's) with blind flanges	0%	at the speed where discs ruptured in Series 2A and increased in 1 mph increments until max. coupler force attained	Up to 1250 kips
4A	candidate SPR's with safety vents	0%	at the speed where discs ruptured in Series 2A and increased until all 3 discs ruptured	Up to 1250 kips

### **B - END IMPACTS**

Series one through four repeated for the following outages:

1B, 2B, 3B, 4B	FOR 1% OUTAGE
1C, 2C, 3C, 4C	FOR 2% OUTAGE
1D, 2D, 3D, 4D	FOR 4% OUTAGE

### TABLE 1.

## GENERAL TEST MATRIX FOR CHARACTERIZATION OF IMPACT SURGE PRESSURES -- (continued)

TEST SERIES	VENT NOZZLE	OUTAGE	IMPACT SPEED	<b>COUPLER FORCE</b>
1E	blind flange	0%	3 mph 4 mph 5 mph (speed increased untill max. coupler force attained)	Up to 1250 kips
3E	candidate SPR's with blind flanges	0%	1 mph below predicted initial rupture speed (determined from Series 1E) and increased in 1 mph increments until max. coupler force attained	Up to 1250 kips
1F	blind flange	2%	3 mph 4 mph 5 mph (speed increased untill max. coupler force attained)	Up to 1250 kips
3F	candidate SPR's with blind flanges	2%	1 mph below predicted rupture speed (determined from Series 1F) and increased in 1 mph increments until max. coupler force attained	Up to 1250 kips

### A - END IMPACTS\*

\* The A-end Impact Test Series was added to the test matrix approved by FRA in the original Test Implementation Plan.

### 5.0 MATERIALS

### 5.1 TEST VEHICLES

The following cars were required for this program:

Hammer Car: Modified locomotive (weight: 237,050 lbs) used in puncture tests with MS 488 draft gear (nose assembly was removed)

- Freight Cars: Three loaded freight cars (total weight: 400,450 lbs) to backstop for the impacted tank car.
- Tank Car: 15,000 gallon non-coiled, non-insulated, 111A100W2 car. The car had provisions for mounting safety vents on two separate nozzles (one a 6 1/2 inch diameter and the other a 2 1/2 inch diameter nozzle on each side of the manway), and also on the top unload assembly (4 1/2 inch sump nozzle) located on the manway. The car was equipped with an instrumented coupler.

### 6.0 MEASUREMENTS AND INSTRUMENTATION

The instrumentation layout for the impact test series is shown below.



Figure 12. Instrumentation Layout

Two pressure transducers rated at 100 psi and three pressure transducers rated at 500 psi were used to measure the peak pressures at the five designated locations of the tank car during impact. The 100 psi transducers were installed at the two safety vent nozzles nearest to the impacted end of the car and the 500 psi transducers were installed at the other locations.

An instrumented coupler mounted on the tank car was used to measure the impact force.

A 0 - 100 g (1g equals 32.17 feet per second per second) accelerometer was used to measure the impact velocity. The accelerometer frequency response was 0.2 - 6 khz (1khz equals 1000 cycles per second).

Two strain gage rosettes were mounted on the tank car underbelly at the locations described in Section 4.3.1.

A Hewlett-Packard 9826 data acquisition system with a Bernoulli drive and a Gould DASA 9000 with a personal computer were used to acquire and store data.

A video camera was used to record splashes resulting from ruptured discs in Test Series 2.

### 7.0 RESULTS

Time history plots of pressure and coupler force test data were provided to the Transportation Systems Center (TSC). The test data was also converted to ASCII format on 3.5 inch floppy discs and shipped to TSC after the completion of the test series for detailed analysis. Following are highlights of the test results.

## 7.1 SAFETY VENT NOZZLE SURGE PRESSURE AND COUPLER FORCE

Safety vent nozzle surge pressures and coupler force for each of the impact tests are provided in Appendix B. The data is arranged by test series (1A through 4F).

### 7.2 SUMMARY PLOTS OF SURGE PRESSURES

Plots of safety vent nozzle surge pressures for different outages and test speeds are given in Figures 13 through 24.

During certain tests, the surge pressure exceeded the maximum range of the data collection system for one or more of the instrumentation channels. In those cases, the surge pressure for a given channel was taken to be equal to the maximum recorded pressure even though the true value could be assumed to be somewhat higher. The affected data points are denoted with an asterisk in Figures 13 through 24.

## 7.3 IMPACT CONDITIONS CAUSING DISC RUPTURE

Tables 2 and 3 list the test conditions that caused the installed frangible discs to fail.

# 7.4 VENT SURGE PRESSURES BEFORE AND AFTER INSTALLATION OF SPR'S

Figures 25-28 show time histories of safety vent nozzle surge pressures before and after installation of two baffle type SPR's.

# 7.5 COUPLER FORCE VS IMPACT SPEED AND OUTAGE

Coupler force is plotted for various impact speeds and outages in Figures 29 and 30.

# 7.6 B-END TANK SHELL STRAIN VS COUPLER FORCE AND IMPACT SPEED

B-end tank shell longitudinal and lateral strain data for impacts with 0 percent lading outage is plotted in Figures 31 and 32.

### 7.7 <u>VIDEO RECORDS</u>

A listing of video log times corresponding to disc ruptures is provided in Appendix C.



Figure 13. Surge Pressure vs Distance from Struck End & Impact Speed -- 0% Outage, B-end Impacted, Blind Flanges Installed



Figure 14. Surge Pressure vs Distance from Struck End & Impact Speed -- 1% Outage, B-end Impacted, Blind Flanges Installed



Figure 15. Surge Pressure vs Distance from Struck End & Impact Speed -- 2% Outage, B-end Impacted, Blind Flanges Installed



Figure 16. Surge Pressure vs Distance from Struck End & Impact Speed -- 4% Outage, B-end Impacted, Blind Flanges Installed



Figure 17. Surge Pressure vs Distance from Struck End & Impact Speed -- 0% Outage, A-end Impacted, Blind Flanges Installed


Figure 18. Surge Pressure vs Distance from Struck End & Impact Speed -- 2% Outage, A-end Impacted, Blind Flanges Installed



ure 19. Surge Pressure in 2 1/2" Nozzle 0% Outage, B-end Impacted



Figure 20. Surge Pressure in 2 1/2" Nozzle 0% Outage, A-end Impacted



Surge Pressure in 4 1/2" Nozzle 0% Outage, B-end Impacted



Figure 22. Surge Pressure in 4 1/2" Nozzle 0% Outage, A-end Impacted



Figure 23. Surge Pressure in 6 1/2" Nozzle 0% Outage, B-end Impacted



ure 24. Surge Pressure in 6 1/2" Nozzle 0% Outage, A-end Impacted

### TABLE 2.

## TEST CONDITIONS WHICH RESULTED IN THE RUPTURE OF 60 PSI DISCS.

OUTAGE (%)	IMPACTED END	RUN NO.	SPEED (mph)	COUPLER FORCE (kips)		RUPTURED DISCS	
					2 1/2" Nozzle	4 1/2" Nozzle	6 1/2" Nozzle
0	В	9	5.4	888	X	Х	
0	В	24	6.3	992	(Pipe SPR)	Х	Х
0	В	26	6.4	1047	Х	Х	Х
1	В	42	8.3	1174	Х		
4	В	63	8.2	1055	Х		
0	А	73	5.4	814		Х	Х
0	А	74	6.4	1167	Х	Х	Х
0	А	80	6.5	1206	(Baffle SPR)	X (Pipe SPR)	(Baffle SPR)
0	А	100	6.4	1037	(Blind Flange)	(Blind Flange)	X (Mesh SPR)

### TABLE 3.

### TEST CONDITIONS WHICH RESULTED IN THE RUPTURE OF 100 PSI DISCS.

OUTAGE (%)	IMPACTED END	RUN NO.	SPEED (mph)	COUPLER FORCE	RUPTURED DISCS						
			(	(kips)	(2 1/2" Nozzie)	(4 1/2" Nozzle)	(6 1/2" Nozzle)				
0	В	91	6.3			Х					
0	A	76	6.4	1143		Х	Х				

33



Figure 25. Surge Pressure in 2 1/2" Nozzle without SPR, 0% Outage, B-end Impacted at 5 mph



Figure 26. Surge Pressure in 2 1/2" Nozzle with SPR, 0% Outage, B-end Impacted at 5 mph







Figure 28. Surge Pressure in 6 1/2" Nozzle with SPR, 0% Outage, A-end Impacted at 5 mph



Figure 29. Coupler Force vs Impact Speed, 0% Outage, B-end Impacted



Figure 30. Coupler Force vs Impact Speed, 0% Outage, A-end Impacted

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Figure 31. Longitudinal and Lateral Strains vs Coupler Force



Figure 32. Longitudinal and Lateral Strains vs Impact Speed

#### 8.0 DISCUSSION

### EFFECT OF FILLING TANK CAR TO 0 PERCENT OUTAGE

The results confirm that over-filling a tank car will substantially increase safety vent nozzle surge pressures which occur during coupling impacts. Measurements of safety vent nozzle surge pressures and physical observation of frangible discs after coupling indicate that vent pressures caused by coupling exceed the design rating of 60 and 100 psi frangible discs when the test car was filled to a shell full condition. The coupler forces which ruptured the 60 and 100 psi discs were approximately 800 kips and 1100 kips respectively.

#### PRESSURE PROFILE WITHIN TANK CAR

During a given impact, the largest surge pressures (on the order of 300 psi) were measured at the impacted end; lower pressures were measured with increased distance from the impacted end. An important exception to this is noted for the 0 percent outage condition for which the pressure profile described above was augmented with a sharp increase in pressure at the end of the tank opposite from the impacted end. During Test Series 3A, run 11, a very short duration (approximately 3 milliseconds) pressure pulse of at least 1500 psi was produced in the pipe fitting located on the A-end of the tank. This pressure pulse was sufficient to damage a pressure transducer that was rated for pressures up to 3000 psi (previously, a pressure transducer that was rated for 500 psi was destroyed during run 4 at the same location). It may be noted that the design burst pressure of the test car was 500 psi. It would be worthwhile to conduct additional tests with higher capacity pressure transducers to confirm this measurement.

Subsequent to test run 11, a second 3000 psi transducer (with a resolution of approximately 15 psi) was used to measure pressure surges occurring in the opposite end of the tank from the struck end for outages of 1 percent, 2 percent and 4 percent. For these conditions, no response was measured, indicating that the pressures were no greater than 15 psi.

38

#### CONDITIONS LEADING TO DISC RUPTURE

The minimum coupler forces and impact speeds which produced ruptured discs are summarized in Table 4.

Outage	Speed (mph)	Coupler Force (kips)
0%	5.4	814
1%	8.3	1174
2%	No Rupture Observed	
4%	8.2	1055

TABLE 4.
CONDITIONS LEADING TO DISC RUPTURE.

Test results show that approximately 50 percent higher coupler forces are required to rupture the frangible discs at a lading outage of 1 percent as compared to 0 percent; a coupler force of 1174 kips is needed to rupture the frangible disc at a lading outage of 1 percent. It may be noted that, in six cases where discs were ruptured, the measured vent pressure was less than the design burst pressure (60 psi) of the affected discs. It is thought that there was a pressure differential between the pressure transducer location (on the side of the 2 1/2 inch and 6 1/2 inch safety vent nozzles) and the location of the frangible disc (on top of the safety vent, which is attached to the top of the safety vent nozzle). Since the pressure pulse (assumed to be along the length of the vent), the measured pressure may have been lower than the pressure developed at the face of the frangible disc (which was oriented perpendicular to the direction of the pressure pulse). A complicating factor is that the safety vent itself contains an orifice which would tend to produce a pressure drop between the safety vent and the frangible disc. For these reasons, it would be desirable in future tests to construct a fixture

to hold the pressure transducer diaphragm flush with the surface where the frangible disc would normally be placed. This would ensure that the measured pressure pulse is the pulse which actually impinges on the frangible disc.

#### EFFECTIVENESS OF INSTALLED SPR'S

Examination of Figures 25 - 28 and Appendix B reveals that installation of the baffle type SPR'S in the 2 1/2 inch and 6 1/2 inch safety vent nozzles effectively lowered the safety vent surge pressures and prevented disc ruptures during coupling impacts. The pipe type SPR (installed in the 2 1/2 inch safety vent nozzle) and the mesh type SPR (installed in the 6 1/2inch safety vent nozzle) also lowered peak vent pressures, albeit to a lesser extent. Figure 33 shows the percentage reduction in nozzle surge pressure which was measured after installation of the above four SPR's. The values shown are for a test condition of 0 percent outage and 5 mph impact speed. Values shown for the 21/2 inch safety vent nozzle were measured during tests in which the B-end (the end closest to the nozzle) was impacted; values shown for the 6 1/2 inch safety vent nozzle were measured during tests in which the A-end was impacted. Although the 2 1/2 inch pipe type SPR and the 6 1/2 inch mesh type SPR produced less of a reduction in surge pressure than the two baffle type SPR's, the former two designs were still effective in that they prevented the rupture of 60 psi composite discs for test conditions of 0 percent and 5 mph impact speed (see Appendix B, Test Series 2A, 4A, 2E, and 4E). In addition, although the 4 1/2 inch pipe type SPR did not appear to reduce measured surge pressures, it did prevent the rupture of 100 psi discs for those same test conditions. By adjusting the dimensions of the mesh and pipe type SPR's, it should be possible to achieve a larger reduction in surge pressures. Thus, any of the general SPR types could be used to prevent the rupture of 60 psi discs during coupling impacts.



Figure 33. Percent Reduction in Surge Pressure For Four SPR Designs (0% Outage, 5 mph Impact Speed)

#### COUPLER FORCE VS SPEED

Examination of Figures 29 and 30 reveals that, for impact speeds between 5 and 7 mph, substantially higher coupler forces were developed for a lading outage of 0 percent as compared to coupler forces developed for outages of 1 percent, 2 percent, and 4 percent. Furthermore, there was little difference between coupler forces for outages of 1 percent, 2 percent, and 4 percent, 2 percent, and 4 percent. It is also seen that, for lower impact speeds (3 mph) and higher impact speeds (8 mph), the coupler forces for different outages converge to the same value.

### ROSETTE STRAIN VS COUPLER FORCE AND IMPACT SPEED

Longitudinal and lateral strains measured on the tank shell near the B-end of the test car (rosette #1) were approximately proportional to coupler force and impact speed (see Figures 31 and 32). A coupler force of 1100 kips produced a longitudinal strain of  $-700 \times 10^{-6}$ . This is close to the value of  $-748 \times 10^{-6}$  computed from strength of materials for a beam subjected to a combined end load and bending.

41

#### 9.0 CONCLUSIONS

A series of impact tests were performed to characterize the internal pressures which occur in a filled, non-pressure tank car during a coupling impact.

Analysis of the test data leads to the following conclusions:

- When loaded to a shell-full condition, a tank car of the design tested will develop safety vent nozzle surge pressures sufficient to rupture 60 and 100 psi frangible discs during impacts which produce coupler forces of 800 kips and 1100 kips, respectively.
- For outages of 1 percent and higher, the highest measured impact surge pressure (approximately 300 psi) occurs at the top of the tank at the struck end of the car.
- For an outage of 0 percent, the highest measured impact surge pressure (approximately 1500 psi) occurs at the opposite end of the tank from the struck end of the car.
- A large decrease in safety vent surge pressures results when outage is changed from 0 percent to 1 percent.
- For impact speeds between 5 and 7 mph, substantially higher coupler forces are developed for a tank car loaded to a shell-full condition as compared to a 1 percent outage condition.
- When installed, two baffle-type safety vent nozzle SPR's effectively reduced surge pressures acting on frangible discs installed in 2 1/2 inch and 6 1/2 inch diameter nozzle safety vents. The SPR's prevented the discs from rupturing during coupling impacts involving forces up to 1200 kips.

- Each of the SPR designs tested provided some degree of protection from disc rupture. It is likely that, once suitable alterations are made to the dimensions of each design, any of the general designs could be successfully used to prevent frangible discs from rupturing during coupling impacts. ۰.

## APPENDIX A

## SAFETY VENT NOZZLE AND SURGE PRESSURE REDUCER DIMENSIONS

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### DIMENSIONS OF 2 1/2" SAFETY VENT NOZZLE WITH BAFFLE TYPE SURGE PRESSURE REDUCER



# DIMENSIONS OF 2 1/2" SAFETY VENT NOZZLE WITH PIPE TYPE SURGE PRESSURE REDUCER



DIMENSIONS OF 4 1/2" SAFETY VENT NOZZLE WITH PIPE TYPE SURGE PRESSURE REDUCER



## DIMENSIONS OF 6 1/2" SAFETY VENT NOZZLE WITH BAFFLE TYPE SURGE PRESSURE REDUCER



## DIMENSIONS OF 6 1/2" SAFETY VENT NOZZLE WITH MESH TYPE SURGE PRESSURE REDUCER

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## APPENDIX B

IMPACT TEST DATA SAFETY VENT NOZZLE SURGE PRESSURES AND COUPLER FORCES MEASURED DURING TEST SERIES 1A - 4F •

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TEST SERIES: 1A OUTAGE: 0% IMPACTED END: B-END

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TEST	IMPACT	COUPLER	2" B-END	<b>&lt;</b>	***************	PEAK SURGE P	RESSURE (psi)			-> 20 A-END
#	SPEED	FORCE	PIPE	2 1	/2" NOZZLE	4 1	/2" NOZZLE	6 1/2	N0771 F	DIDE
	(mph)	(kips)	FITTING	SIDE	ТОР	SIDE	, TOP	SIDE	TOP	FITTING
1	3.7	433	29.5	4.8	• • • • • • • • • • • • • • • • • • •	1.6		4.0		70.4
2	3.7	381	19.3	4.6		2.0		3.1		67.1
3	3.8	363	21.9	7.1		1.0		4.0		187.2
4	6.8	1103	159.2	109.1		114.1		35.4		>500
5	4.5	450	25.0	20.0		10.0		11.0		4
6	4.5	450	40.0	16.0		8.0		8.0		
7	5.4	833	94.8	65.4		54.7		24.4		<b>4</b>
8	5.4	888	127.9	75.6		65.7		37.3		
(	Test Car	Coupled t	to Backup Ca	rs Before Run #	8 Impact)					•
27	5.3	699	106.7	46.3		18.7		18.1		
28	5.4	751	108.6	39.5		18.7		18.2		
29	5.4	751	104.5	41.3		18.2		14.9		
30	5.4	750	100.0	52.0		19.0		12.0		
31	5.4	706	98.6	41.5		20.4		12.6		

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TEST SERII	ES: 2A	OUTAGE:	0% IMPAC	TED END: B-END	DISK TYPE/ PHYSICAL C A60 - Stainless Steel B100 - Composite Disk R - Indicates Disc Ru	CONDITION L Rated for 60 p k Rated for 100 p uptured During Te	3 i osi est	
TEST #	IMPACT SPEED (mph)	COUPLER FORCE (kips)	2" B-END PIPE Fitting	<2 1/2" NOZZLE SIDE	PEAK SURGE PRESS 4 1/2" TOP SIDE	SURE (psi) NOZZLE   TOP	6 1/2" NOZZLE SIDE   TOP	-> 2" A-END PIPE FITTING
9	5.4	888	99.9	45.8 (A60)(R)	60.6 (A60)(	R)	33.5 (A60)	
10	5.5	843	100.3	70.5 (Open Vent)	46.1 (Open	Vent)	10.9 (A60)	
25	5.4	810	100.0	60.0 (B60)	50.0 (B60)		10.0 (B60)	
26	6.4	1047	297.6	88.0 (B60)(R)	113.6 (B60)(	R)	25.3 (B60)(R)	
90	5.3	÷ =	110.4	24.6 (B100)	97.6 (B100)		69.3 (B100)	••
91	6.3		136.5	34.6 (B100)	115.5 (B100)	(R)	59.4 (B100)	
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	TEST	IMPACT				PEAK SURGE	PRESSURE (psi)		•••••••••••••	->
	#	SPEED	FORCE	PIPE	2 1/2" NOZZI F	4	1/28 NO771 E		SH No.	2" A-END
		(mph)	(kips)	FITTING SIDE	i to	P SIDE		SIDE	Z" NOZZLE	PIPE FITTING
	11	5 5	077					************	* *	
			660	(Baffle SPR)		106.5 (Pipe SPR)	89.6 (E	4.5 Maffle SPR)		1500 <b>.0</b>
	12	6.4	1134	26.0		(22.0				
				(Baffle SPR)		422.9 (Pipe SPR)	114.1 (B	6.5 affle SPR)		2700.0
	13	3.4	300	4.0		0.0	0.0	11.0		
				(Baffle SPR)		(Pipe SPR)	(8	affle SPR)		
57	14	3.6	331	4.7		0.0	0.0	4.6		
				(Baffle SPR)		(Pipe SPR)	(B	affle SPR)		
	15	4.4	463	7.8		0.0	2.8	0.6		
				(Battle SPR)		(Pipe SPR)	(8	affle SPR)		
	21	5.4	705	45.4 (Pice SPP)	45.9	18.8		9.7		
	22	5.3	760	48.8 (Pine SPR)	41.0	20.6		15.7		

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TEST	SERIE	S: 4A	OUTAGE:	OX IMF	ACTED END: B	-END		DISK TYPE A60 - Sta B100 - Co R - Indic	E/ PHY minles mposi ates	SICAL S Stee te Dis Disc R	CONDITION l Rated for k Rated for uptured Dur	r 60 psi r 100 psi ring Test				
	TEST	IMPACT	COUPLER	2" B-END	<b>~</b> ••••••			PEAK	SURG	E PRES	SURE (psi)-	•••••				> 2" A-END
	#	SPEED	FORCE	PIPE	<b>61</b> 0	2 1/2"	NOZZLE			4 1/2"	NOZZLE		(	6 1/2"	NOZZLE	PIPE
	••••••		(Kips)		51D		1 TOP		SIDE		Г ТОР		SIDE		TOI	° FITTING
	16	3.6	415	45.4	9.9 (Baffle SPR)	<b>(8</b> 60)		(Pipe	15.3 SPR)	(B60)		(Baffle	75.8 SPR)	(860)		
	17	4.4	ALL DATA	AFFECTED	BY NOISE											
	18	5.3	751	90.6	30.5 (Baffle SPR)	(860)		(Pipe	20.0 SPR)	(860)		(Baffle	3.4 SPR)	(860)		
	19	6.3	993	268.8	31.5 (Baffle SPR)	(860)		(Pipe	79.5 SPR)	(860)		(Baffle	4.0 SPR)	(B60)		
	20	7.2	1179	460.7	44.1 (Baffle SPR)	(860)		(Pipe	>114 SPR)	(860)		(Baffle	4.8 SPR)	(860)		
	23	5.3	751	93.5	54.5 (Pipe SPR)	(860)			17.1	(860)			9.3	(860)		
	24	6.3	992	320.1	103.1 (Pipe SPR)	(860)			98.9	(860)(	R)		35.2	(B60)	(R)	

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TEST #	IMPACT SPEED (mph)	COUPLER FORCE (kips)	2" B-END Pipe Fitting	<2 1 Side	/2" NOZZLE   TOP	-PEAK SURGE PF 4 1/ SIDE	RESSURE (psi) /2" NOZZŁE j. TOP	6 1/2 SIDE	" NOZZLE	> 2" A-END PIPE FITTING
		********								
32	3.6	309	103.3	7.4		4.9		8.9		
33	4.5	334	103.8	12.1		7.9		12.5		
34	5.4	404	73.2	27.6		14.0	-	22.9		
35	5.4	396	96.7	23.2		13.3		19.0		
36	5.4	404	92.3	23.4		13.1		20.4		
37	6.3	653	148.2	54.2		19.6		24.3		
38	7.6	914	318.6	47.2		29.2		43.5		
39	8.2	1162	310.3	63.6		38.8		46.5		

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TEST SERIES: 18 OUTAGE: 1% IMPACTED END: B-END

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TEST SERI	ES: 2B	OUTAGE:	1% IMPACTE	D END: B-END	DISK TYPE/ PHYSICAL CONDITION A60 - Stainless Steel Rated f B100 - Composite Disk Rated f R - Indicates Disc Ruptured D	 or 60 psi or 100 psi uring Test
TEST #	IMPACT SPEED (mph)	COUPLER FORCE (kips)	2" B-END PIPE Fitting	< 2 1/2" NOZZLE SIDE   T(	PEAK SURGE PRESSURE (psf 4 1/2" NOZZLE XP SIDE   TO	)> 2" A-END 6 1/2" NOZZLE PIPE P SIDE   TOP FITTING
40	6.4	751	131.8	36.9 (B60)	20.5 (860)	33.6 (860)
41	7.3	1033	242.9	46.9 (B60)	27.8 (B60)	<b>39.8 (B</b> 60)
42	8.3	1174	370.6	40.0 (B60)(R)	40.4 (B60)	40.0 (B60)
92	8.3		315.7	40.5 (B100)	39.8 (B100)	103.4 (B100)

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TECT	INDACT			••••••	•••••		PEAK	SURGE P	RESSURE (psi)					->
#	SPEED	FORCE	2" B-END PIPE	2	1/211 NO	771 8								2" A-EN
	(moh)	(kine)	FITTING	610F	176" HU	2215		4 1	/2" NOZZLE		6 1/	2" NOZZ	LE	PIPE
				51DE	ا 	TOP		SIDE 	. TOP		SIDE		TOP	FITTING
43	5.4	368		16 6				• • •						
			(Deff)	17.7				10.0	14.1		18.4			
			(barrie	: SPK)			(Pipe	SPR)		(Baffle	SPR)			
44	6.3	762		20.0				24.2	21.0		24.6			
			(Baffle	SPR)			(Pipe	SPR)		(Baffle	SPR)			
45	7.4	965		24.0				<b>7</b> 0 9	20.7					
			(Raffla	SDDI			(Dine	50.0	29.3		28.3			
			(burrie	JINJ			Pipe	SPRJ		(Baffle	SPR)			
46	8.3	1179		40.0				46.6	40.7		28.0			
			(Baffle	SPR)			(Pipe	SPR)		(Baffle	SPR)			
47	8.2	1209		161.1		48.0		42.3			10 8			
			(Pipe	SPR)			(Pipe	SPR)		(Baffle	SPR)			
48	7.2	858	1	122:8		36 6		20.0			-			
			(Pine	CODY		54.0	(01	6710			50.0			
			tripe	Jrn)			tribe	5PK J		(Baffle	SPR)			

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TEST SERIES: 38 OUTAGE: 1% IMPACTED END: R-FN

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TEST	SERIE	S: 4B	OUTAGE:	1% IMP/	ACTED END:	B-END			DISK TYPE A60 - Ste B100 - Co R - Indic	/ PHN inles mposi ates	SICAL S Stee te Dis Disc R	CONDI I Rat k Rat uptur	ition ted for ted for ted for	 60 psi 100 psi ing Test				
1	EST #	IMPACT SPEED (mph)	COUPLER FORCE (kips)	2" B-END PIPE Fitting	< S	2 1, IDE	/2" NC	DZZLE TOP	PEAK	SURG	E PRES 4 1/2"	SURE NOZZ	(psi) LE TOP		6 1, SIDE	  /2" NOZZ 	LE TOP	> 2" A-END PIPE FITTING
	93	8.3		228.3	2( (Baffle SF	).8 (Ad PR)	50)		(Pipe	42.8 SPR)	(A60)	•••••		(Baffle	56.1 (Ad SPR)	60)		

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TEST SERIES: 1C OUTAGE: 2% IMPACTED END: B-END

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	IMPACT SPEED (mph)	COUPLER FORCE (kips)		<deak (<="" descript="" since="" th=""></deak>							
TEST #			2" B-END PIPE Fitting	2 1 Side	/2" NOZZLE	4 1/ SIDE	2" NOZZLE	6 1/2 Side	2" NOZZLE	> 2" A-EN PIPE Fittin	
49	3.6	272	44.2	11.2		5.6		5.2			
50	4.4	326	63.5	22.6		9.5		18.2			
51	5.3	355	65.9	24.0		15.8		13.0			
52	6.3	724	155.5	19.0		20.8		22.4			
53	7.3	854	227.8	68.0		32.1		29.8			
54	8.2	441	22.4	3.5		16.8					
55	8.2	1124	282.2	39.9		24.2		16.0			
56	7.2	801	163.3	37.1		34.2		25.8			

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TEST SERI	ES: 2C	OUTAGE:	2% IMPACTE	D END: B-END		DISK TYPE/ PHYSICA A60 - Stainless St B100 - Composite D R - Indicates Disc	L CONDITION eel Rated for 60 isk Rated for 100 Ruptured During	psi Dpsi Test		
TEST #	IMPACT SPEED (mph)	COUPLER FORCE (kips)	2" B-END PIPE Fitting	2 1/2"   SIDE	NOZZLE	PEAK SURGE PRI 4 1/3 SIDE	ESSURE (psi) 2" NOZZLE   TOP	6 1/2 SIDE	2" NOZZLE   TOP	> 2" A-END PIPE FITTING
57	7.3	825	190.0	40.0 (B60)		32.0 (B60	))	29.0 (B60	))	
58	8.2	1111	260.5	55.6 (B60)		<b>39.4 (B6</b> 0	))	26.0 (B60	))	

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TEST SERI	ES: 1D	OUTAGE:	4% IMPACT	ED END: B-END						
TEST #	IMPACT SPEED (mph)	COUPLER FORCE (kips)	2" B-END PIPE FITTING	< 2 1/2" N SIDE	IOZZLE TOP	PEAK SURGE PRESSU 4 1/2" NO SIDE	RE (psi) DZZLE TOP	6 1/2 SIDE	2" NOZZLE   TOP	-> 2" A-END PIPE FITTING
59	3.6	339	45.9	7.6		4.8	••••••	1 5		•••••
60	4.4	379	62.0	13.5		15.2		5.5		
61	7.3	859	154.0	50.1		20.0		15.0		
62	8.2	1059	184.1	60.3		27.0		19.8		

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TEST	SERIES	5: 2D	OUTAGE:	1% IMP/	ACTED END:	8-END		D I A6 B1 R	SK TYPE/ PHYSICAL 0 - Stainless Ste 00 - Composite Dis - Indicates Disc I	CONDITION el Rated for 60 sk Rated for 100 Ruptured During	psi psi Test		
I	IEST #	IMPACT SPEED (mph)	COUPLER FORCE (kips)	2" B-END PIPE FITTING	<	2 1/2 IDE	:" NOZ	ZLE TOP	PEAK SURGE PRES 4 1/2' SIDE	SSURE (psi) " NOZZLE   TOP	6 1/2 SIDE	2" NOZZLE	> 2" A-END PIPE FITTING
	63	8.2	1055	183.4	5	1.8 (860	)(R)		55.9 (Blir	nd Flange)	20.8 (BL	ind Flange)	

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20.8 (Blind Flange)

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TEST SERI	ES: 3D	OUTAGE:	4% IMP/	CTED END: B-EN	D						
TEST #	IMPACT SPEED (mph)	COUPLER FORCE (kips)	2" B-END PIPE FITTING	<2 SIDE	1/2" NOZZI	LE TOP	PEAK SURGE PR 4 1/ SIDE	RESSURE (psi) /2" NOZZLE   TOP	6 1, SIDE	/2" NOZZLE	> 2" A-END PIPE
95	8.3			5.0 (Baffle SPR)			(Pipe SPR)	35.0	10.0 (Baffle SPP)	1	

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TEST	SERIE	S: 4D	OUTAGE:	4% IMP	ACTED END:	B-EN	D		D1: A6( B1( R -	SK TYPE D - Sta DO - Co - Indic	/ PHN inles mposi ates	(SICA) BS Sto ite Di Disc	L COND eel Ra isk Ra Ruptu	ITION - ted for ted for red Dur	60 psi 100 psi ing Test					
T	EST #	IMPACT SPEED (mph)	COUPLER FORCE (kips)	2" B-END Pipe Fitting	< \$	2 1 IDE	1/2"	NOZZLE	 	PEAK	SURG SIDE	E PRE	SSURE NOZI	(psi)- LE TOP	51	  DE	5 1/2"	NOZZ	LE TOP	> 2" A-END PIPE Fitting
	94	8.3		145.0	(Baffle Si	3.5 (A PR)	A60)			(Pipe	49.7 SPR)	' <b>(A</b> 60	)		8 (Baffle SP	.7 R)	(A60)			

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TEST SE	RIES: 1E	OUTAGE :	OX IMPACTE	D END: A-END						
•••••			**********		•••••					
166	T INDACI		24 B-EMD	<b>4</b>	* * * * * * * * * * * * * * * * * * * *	PEAK SURGE PR	ESSURE (psi)	••••••	,	•>
IEa	I INFACI	LUOFLER	E. B.END							Z" A-END
	# SPEED	FORCE	PIPE	2 1/2	NOZZLE	4 1/	Z" NOZZLE	6 1/2	I NOZZLE	PIPE
	(mph)	(kips)	FITTING	SIDE	I TOP	\$1DE	TOP	SIDE	10P	FITTING
				• •						
6	4 3.6	310		5.0		1.3		10.0		17.4
*6	5 4.4	375		5.0		2.0		25.0		25.0
64	5 5.3	780		21.9		79.4		113.4		107.7
				2007						
67	6.3	1075		47.8		135.7		>200		173.6
68	3.6	405		8.7		4.7		8.2		17.3
	(Test Car	Coupled	to Backup Cars	Before Run #68	Impact)					
69	4.4	542		18.7		5.5		25.4		69.1
	(Test Car	Coupled	to Backup Cars	Before Run #69	impact)					
70	5.4	863	·	30.6	•	87.9		112.6		185.1
• -	(Test Car	Coupled	to Backup Cars	Before Run #70	(mpact)					
71	6.2	1217		68.8		135.6		>200		236.1
	(Test Car	Coupled	to Backup Care	Refore Run #71	(mpact)					
	1									

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 Run 65 data was read from strip charts instead of being recorded from Hewlett-Packard data acquisition equipment

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		********			R - Indicates Disc Ruptured During	gTest	
TEST	IMPACT				PEAK SURGE PRESSURE (psi)	•••••••••••••••••••••••••••••••••••••••	->
#	SPEED (mph)	FORCE (kips)	PIPE FITTING	2 1/2" NOZZLE SIDE   1	4 1/2" NOZZLE OP SIDE   TOP	6 1/2" NOZZLE SIDE   TOP	2" A-END PIPE Fitting
73					•••••••••••••••••••••••••••••••••••••••		
12	4.4	459		8.2 (A60)	6.6 (A60)	27.5 (A60)	35.9
73	5.4	814		16.5 (A60)	76.5 (A60)(R)	115.2 (A60)(R)	106.7
74	6.4	1167		51.0 (A60)(R)	135.8 (A60)(R)	>200 (A60)(R)	185.6
75	5.4	818		27.3 (B100)	61.7 (B100)	177.9 (B100)	132.3
76	6.4	1143		38.8 (B100)	135.9 (B100)(R)	>200 (B100)(R)	186.3

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				<b>&lt;</b>				PEAK SURGE F	PRESSURE (psi)			>
IESI #	SPEED	COUPLER	2" B-END									2" A-END
•	(moh)	/kine)	FIFE		2 1/2 -	WUZZ	LE	4 1	/2" NOZZLE	6	1/2" NOZZLE	PIPE
	(mpn)	(Kips)	FIIIING	SID	E 	 	TOP	\$IDE	TOP	SIDE	Тор	FITTING
77	5.4	825		2				45.7	70.0			
				(Reffie CDD)					/8.8	21.1		
				(ballie Srk,	•			(Pipe SPK)		(Baffle SPR)		
78	6.4	1170		2.!				228.3	135.7	147.2		
				(Baffle SPR)	I			(Pipe SPR)		(Baffle SPR)		
96	5.3	766		27.7	,			3.3		57 5	50 0	
										(Mesh SPR)	37.7	
97	6.4	1082		63.3				75.9		138.7	150.0	
										(Mesh SPR)		
98	6.4	1023		60.1				81.2		140 0	154 +	
										147.7	120.1	

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TEST SERI	ES: 4E	OUTAGE:	OX IMPACTED END:	<b>A</b> -	END			DISK TYP A60 - St B100 - C R - India	E/ PH ainle ompos cates	YSICA SS St ite D Disc	L COND eel Ra isk Ra Ruptu	ITION ted for ted for red Dur	r 60 psi r 100 psi ring Test					
			<					PEA	C SUR	GE PRE	SSURE	(psi)-	• • • • • • • • • • •				·····>	
TEST	IMPACT	COUPLER	2" B-END														;	2" A-END
#	SPEED	FURCE	PIPE		2 1/2"	NOZZ	<u>'LE</u>			4 1/2	" NOZ	ZLE			6 1/2" 1	NOZZLE		PIPE
*******	(mpn)	(K1ps)	FITTING S	IDE			TOP		SIDE			TOP		SIDE		TC	)P	FITTING
70		<b>6</b> 50																
17	3.3	020		2.5	(A60)				76.0	(A60	)			15.0	(860)			117.9
			(Battle SP	'R )				(Pipe	SPR)	I			(Baffle	SPR)				
80	6.5	1206	2	2.5	(A60)				135 8	1460	1781			70 0				
			(Baffle SP	R)				(Pipe	SPR				(Raffla	50.0	(NOU)			100.0
				-				1					(bailte	JF N J				
81	6.4	1198	2	.5	(A60)				135.8	(810	0)			35.9	(A60)			208.0
			(Baffle SP	R)				(Pipe	SPR)				(Baffle	SPR)				20010
82	6.4	1205	5	.0	(A60)				136.0	(810	0)			26.3	(A60)			293.7
			(Baffle SP	R)				(Pipe	SPR)				(Baffle	SPR)				
99	5.4	747	21	.0	(Biind	ELa	nae)		10 0	7813	nd Ela	546)		40 7				
				•••			.ge/		10.0	(011	nu rta	iger	(Mesh	SPP1	(AOU)			
													(near)	JENJ				
100	6.4	1037	73.	.1	(Blind	Flar	nge)		74.0	(Bli	nd Fla	nge)	4	136.6	(A60)(R	)		
												• •	(Mesh	SPR)	(	•		
101	6.3	975	54.	.4	(Blind	Flar	nge)		60.0	(Blin	nd Fļa	nge)	1	27.7	(B60)			
													(Mesh	SPR)				

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TEST SERI	IES: 1F	OUTAGE:	2% IMPACTE	D END: A-END						
TEST #	IMPACT SPEED (mph)	COUPLER FORCE (kips)	2" B-END PIPE FITTING	<2 1/ SIDE	2" NOZZLE   TOP	PEAK SURGE P 4 1, Side	RESSURE (psi) /2" NOZZLE	6 1/ SIDE	2" NOZZLE   TOP	-> 2" A-END PIPE FITTING
83	4.4	316		3.1		10.4		44.6		80.3
84	5.4	346		10.1		15.5		44.7		78.9
85	6.3	652		13.0		17.3		52.1		111.3
86	7.3	1009		16.3		19.0		53.5		208.0
87	8.3	1164		10.0		36.1		>200		263.7

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TEST SERI	ES: 2F	OUTAGE:	2X IMPACTED E	ND: A-END	DISK A60 - B100 R - II	TYPE/ PHYSIC Stainless S - Composite ndicates Dis	CAL CONDITI Steel Rated Disk Rated SC Ruptured	ION d for 60 psi d for 100 psi d During Test			
TEST #	IMPACT SPEED	COUPLER FORCE	<- 2" B-END PIPE	2 1/2"	NOZZLE	PEAK SURGE P	RESSURE (p	si)			-> 2" A-END
	(mph)	(kips)	FITTING	SIDE	TOP	SIDE			SIDE	1 TOP	FITTING
88	7.2	916		11.1 (A60)		32.7 (Ad	60)		48.3 (A6(	))	231.5
89	8.3	1130		13.7 (A60)		31.7 (Ad	60)	1	155.7 (A60	))	316.7

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TEST SERI	ES: 4F	OUTAGE:	2% IMPACTED	END: A-END	DISK A60 - B100 R - I	TYPE/ PHYSICAL Stainless Stee - Composite Dis ndicates Disc F	CONDITION el Rated for 6 ek Rated for 1 euptured Durin	0 psi 00 psi g Test	( ;		
TEST #	IMPACT SPEED (mph)	COUPLER FORCE (kips)	2" B-END PIPE FITTING	<2 1/2" SIDE	NOZZLE	PEAK SURGE PRES 4 1/2" SIDE	SURE (psi) NOZZLE	6 1, Side	/2" NOZZL 	E	> 2" A-END PIPE FITTING
102	5.4	407		29.9 (Blin	d Flange)	3.0 (Blin	d flange)	48.8 (A4 (Mesh SPR)	50)		
103	6.4	713		33.6 (Blin	d Flange)	3.0 (Blin	d Flange)	47.5 (Ad (Mesh SPR)	50)		
104	8.3	1204		35.0 (Blin	f Flange)	3.0 (Blin	d flange)	85.8 (Ad (Mesh SPR)	50)		
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## APPENDIX C

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## VIDEO LOG (LIST OF VIDEO RECORDINGS SHOWING RUPTURES)

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Run Number	Date	Video Time (min)	Test Series	Outage (%)	Actual Speed (mph)	Coupler Force (kips)	2-1/2"	4-1/2"	6-1/2"
26	8/4/89	15:39:45.87	2A	0	5.4	888	x	x	x
42	8/10/89	13:27:37.51	2B	1	8.3	-1200	x		
63	8/11/89	15:34:17.83	2D	4	8.2	-1050	x		
73	8/15/89	12:54:49.65	2E	0	5.4	-800		x	x
74	8/15/89	13:12:00.83	2E	0	6.4	-1200	x	x	x
76	8/15/89	13:41:13.63	2E	0	6.4	-1200		x	x