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**Federal Railroad
Administration**

Safety Testing of Intermodal Hazmat Configurations, Summary Report

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**Office of Research and Development
Washington, D.C. 20590**

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16. Abstract

This report presents summary results of a research program sponsored by the Department of Transportation, Federal Railroad Administration (FRA). The program was concerned with safety issues of flatcars and the transport of liquid hazardous materials (hazmat) in intermodal configurations. Primary attention of the program focused on vehicle dynamics and the effects of liquid lading slosh with the objective of providing the FRA a technical basis for recommendations on regulation for intermodal hazmat transport in the rail mode. Five series of tests were performed: vibration of several trailer on flatcar and container on flatcar (TOFC/COFC) configurations; lift and drop tests of a motor container (MC) cargo tank trailer; track tests of two TOFC configurations; yard impact tests of several TOFC/COFC configurations; and accident simulations of several TOFC/COFC configurations. Problem areas found are reviewed and recommendations for corrective action and for further investigations are made.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in²	square inches	6.5	square centimeters	cm²
ft²	square feet	0.09	square meters	m²
yd²	square yards	0.8	square meters	m²
mi²	square miles	2.6	square kilometers	km²
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft³	cubic feet	0.03	cubic meters	m³
yd³	cubic yards	0.76	cubic meters	m³
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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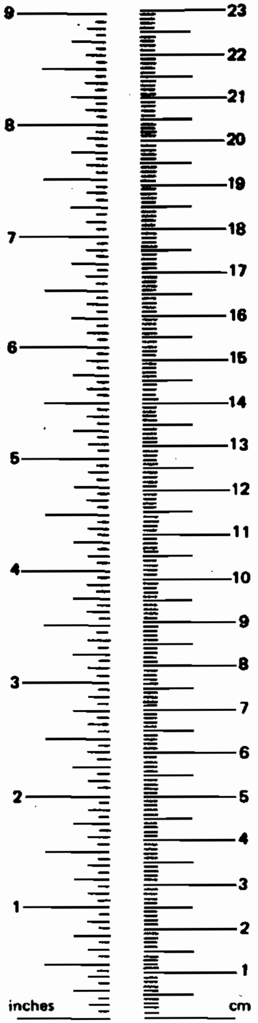
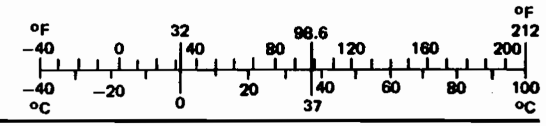
*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm²	square centimeters	0.16	square inches	in²
m²	square meters	1.2	square yards	yd²
km²	square kilometers	0.4	square miles	mi²
ha	hectares (10,000 m²)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m³	cubic meters	36	cubic feet	ft³
m³	cubic meters	1.3	cubic yards	yd³
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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This report summarizes the results of a test program sponsored by the Federal Railroad Administration (FRA) Office of Research and Development and under the direction of Claire L. Orth of that office. All tests were performed at the Transportation Test Center (TTC), Pueblo, Colorado by the Association of American Railroads (AAR). The key AAR people leading the test performances were Fridausi Irani in the VTU and Yard Impact tests, Curtis Urban in the Track Tests, and R. Lane Maxwell in the Accident Simulation tests. The MITRE Corporation assisted the FRA in the planning and monitoring of tests and was responsible for the analysis and reporting of test results. Diane E. Boone of The MITRE Corporation was responsible for the analysis and reporting of the Vibration Test Unit (VTU) test results and assisted in the Yard Impact and Accident Simulation tests. Dr. Milton R. Johnson of the Illinois Institute of Technology (IIT) Research Institute was responsible to the FRA for the planning, witnessing, and results reporting of the Lift/Drop and Yard Impact tests. Photographs taken by the AAR/TTC Photo Lab are identified with their photo number.

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EXECUTIVE SUMMARY

INTRODUCTION

Intermodal transportation of freight has grown rapidly in recent years placing increasing demands on the railroads for intermodal shipment of hazardous materials (hazmat). However, due to questions concerning the safety of carrying liquid hazmat, the current Code of Federal Regulations (CFR) does not allow hazmat transport by motor carrier (MC) cargo tank trailers or intermodal (IM) portable tank containers in the trailer on flatcar (TOFC) or container on flatcar (COFC) modes except under conditions approved by the Federal Railroad Administration (FRA). The shipment of regulated commodities by TOFC in interchange service is also prohibited by an Association of American Railroads (AAR) regulation. The FRA has granted a limited number of waivers in the past, allowing some hazardous materials to be transported in COFC modes in specified IM tanks.

With the growing interest in intermodal transportation, there has been an increasing number of requests for approval of IM tank TOFC/COFC hazmat transport and also for approval of hazmat transport with MC cargo tank trailers in the TOFC mode. These requests led to the issue of an Advanced Notice of Proposed Rulemaking (ANPRM) by the Office of Hazardous Materials Transportation (OHMT), an establishment of OHMT Docket Number HM-197, and a public hearing held on June 11, 1985 to receive comments for the docket. These requests have also led the FRA to sponsor a program of testing of tank TOFC/COFC with the purpose of providing information on which to base decisions regarding changes in the Federal Regulations. The FRA test program consisted of five series of tests which included:

- vibration,
- yard impact,
- lift and drop of an MC tank trailer,
- track, and
- accident simulation.

PROGRAM OVERVIEW

Vibration Tests were performed using the Vibration Test Unit (VTU) at the FRA's Transportation Test Center (TTC), Pueblo, Colorado, with two general objectives: (1) to determine the vibration modes of the various configurations tested (modal testing), and (2) to measure the response of the vehicle to several track condition simulations. The modal testing is of interest since these properties determine the dynamic behavior of the vehicle on the track. Track simulations using the VTU were performed so that the track conditions that may result in unsafe motion of the test vehicle could be determined. There were a total of 12 configurations tested with various combinations and liquid fill levels of MC cargo tank trailers and IM portable tanks in COFC and on highway trailer chassis. Water was used as the liquid lading for all tests.

Two conditions were identified as potential problem areas: (1) the harmonic roll response of an 89-foot flatcar with a single trailer on the B-end and (2) the bounce/pitch response of TOFC configurations at grade crossings. Slosh of the liquid lading had a dampening effect on most vehicle motions.

Yard Impact and Trailer Lift/Drop tests were conducted to determine the dynamic loads and responses of various TOFC/COFC arrangements with MC cargo tank trailers and intermodal portable tank containers. One hundred and six separate car coupling impact tests were made that included 10 different arrangements of MC cargo and IM portable tanks mounted on a flatcar. The tests revealed no tendency for the trailers and containers to become dislodged from the flatcar during the impact, although the design load on the container pedestal supports was exceeded on some of the higher speed tests. The trailer and container securement forces were significantly larger for impacts on the A end of the car than on the B end. Apparently the properties of end-of-car cushioning devices were different at each end of the car. The tests produced only minor apparent damage to the trailers and containers, which did not affect the structural integrity of the tanks. There was, however, some damage to vents and valves which allowed some release of liquid.

Eight drop tests were conducted on the tank trailers where the front landing gear support legs of the trailer were lifted off the ground and allowed to fall 3.5 inches in accordance with AAR test requirements. These tests caused significant damage to the support legs of the trailer. It would appear that an investigation should be made to determine if the test is more severe than necessary for this component of the trailer, or if the trailer support leg should be modified.

The Track Testing investigated performance in areas not covered by laboratory and yard impact testing. This consisted of the four conditions of hunting, curve entry, steady state curving, and harmonic roll on curved track. The test objectives were to measure the responses of the configurations tested and to identify unsafe conditions.

The track tests were performed with a consist made up of five cars: a locomotive, a buffer car, the test car, a second buffer car, and an instrumentation car. The buffer cars were both 89-foot flatcars each carrying two loaded van trailers. The test car was also an 89-foot flatcar configured with two MC cargo tank trailers in the two loading conditions of 95 percent and 80 percent full (by volume) and then with two IM portable tanks on chassis trailers in the two loading conditions of 92.5 percent and 80 percent.

The Accident Simulation tests were performed with two scenarios: broken rail and accordion. The broken rail tests simulated the typical action in this type of derailment where the derailed car continues to travel parallel to the rails but with its wheels running on the ties. Six broken rail simulations were performed with the speed at derailment ranging from 19.0 to 64.5 miles an hour and with several TOFC/COFC configurations.

The typical action of a derailed train is for the cars trailing the point of derailment to pile up into an accordion pattern. The accordion derailment test accomplished this with a five car consist by running the consist through a turnout switch and changing the position of this switch between the passing of the leading and trailing truck of each car. The consist had three test flatcars with a mix of TOFC and COFC. The test consist was running at 60.8 mph at the initiation of the derailment.

A Rollover Loads Analysis was performed to compare the relative merits of releasing and nonreleasing pedestals in a container on flatcar configuration. The study results showed that there was no difference in rollover probability between the two types of attachments. The analysis results showed that dynamic loads on the portable tank containers due to derailment and rollover will be less with releasing pedestals than they would be with nonreleasing pedestals for most trackside terrain.

CONCLUSIONS

Although there were a number of problem areas identified, the safety performance of both MC cargo tank trailers and IM portable tanks was encouraging. The following positive factors were identified.

- Slosh of liquid cargo had a dampening effect on harmonic roll response and roll motions were relatively small with the exception of one, single trailer TOFC configuration.
- Slosh of liquid cargo alleviated loads due to yard coupling impacts.
- The MC 307 cargo tank and all the IM portable tanks tested were able to survive severe damage without tank failure.

There were also a number of negative factors identified; these were as follows.

- A derailed intermodal flatcar, whether TOFC or COFC, will probably rollover and release its trailers and containers.

- Emergency vents,* valves, manhole covers and other tank accesses are likely to develop leaks in a derailment.
- Emergency vents* are likely to develop leaks due to the dynamic actions of the liquid lading caused by yard coupling impacts and over-the-road motions.
- Although the trackside terrain of the derailment test site is typical of a major portion of continental U.S. track, it does not represent worst case conditions that would include such things as steep embankments or obstructions such as bridge pylons.

The MC cargo and IM portable tanks sustained considerable damage without tank failure or leakage in the course of the seven derailment tests performed. This will be a positive factor in any assessment of the accident survivability of these tanks. There were, in addition, several suggestions that grew out of the testing that would further enhance accident survivability

Also based on the results of the testing of this report, there were a number of areas recommended for further investigation for accident avoidance as well as accident survival. These suggestions and recommendations are presented in Section 7 of this report.

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*That is, pressure and vacuum relief devices on IM portable tanks and vents and safety relief devices on MC cargo tanks.

1.0 INTRODUCTION

This report presents summary results of a research program sponsored by the Department of Transportation, Federal Railroad Administration (FRA). The program was concerned with safety issues of flatcars and the transport of hazmat in intermodal configurations. Primary attention of the program focused on vehicle dynamics with the objective of providing the FRA a technical basis for recommendations on regulations for intermodal hazmat transport in the rail mode.

1.1 Background Discussion

Intermodal transportation of freight has grown rapidly in recent years placing increasing demands on the railroads for intermodal shipment of hazardous materials (hazmat). However, due to questions concerning the safety of carrying liquid hazmat, the current Code of Federal Regulations (CFR 174.61 and 174.63) [1]* does not allow hazmat transport by motor carrier (MC) cargo tank trailers or intermodal (IM) portable tank containers in the trailer on flatcar (TOFC) or container on flatcar (COFC) modes except under conditions approved by the FRA. The shipment of regulated commodities by TOFC in interchange service is also prohibited by the Association of American Railroads (AAR) regulation AAR.600, [2]. The FRA has granted a limited number of exemptions in the past, allowing some hazardous materials to be transported in COFC modes in specified IM tanks.

With the growing interest in intermodal transportation, there has been an increasing number of requests for approval of IM tank TOFC/COFC hazmat transport and also for approval of hazmat transport with MC cargo tank trailers in the TOFC mode. These requests led to the issue of an Advanced Notice of Proposed Rulemaking (ANPRM) by the Office of Hazardous Materials Transportation (OHMT), establishment of OHMT Docket Number HM-197, and a public hearing held on June 11, 1985 to receive comments for the docket. These requests also led the FRA to sponsor a program of testing of tank TOFC/COFC with the purpose of providing information on which to base decisions regarding changes in the Federal Regulations. The FRA test program consisted of five series of tests which included:

- vibration,
- yard impact,
- lift and drop of an MC tank trailer,
- track, and
- accident simulation.

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* References, bracketed numbers, are listed in the Appendix.

1.2 Program Objectives

The test program had two general objectives. The first was to evaluate the safety performance of these configurations and to determine whether they are likely to be the cause of accidents. This objective was addressed in the laboratory, track, and yard tests, results of which are contained in References [3], [4], and [5].

The second general objective was to observe the behavior of these configurations under accident conditions and to assess their survivability. Two accident scenarios were simulated: broken rail derailments and accordion derailments. The preliminary results of these tests, six broken rail and one accordion, have been documented in References [6] through [12].

1.3 Report Format

Each series of tests are summarized in this report: the VTU tests in Section 2, the yard impact and lift/drop tests in Section 3, the track tests in Section 4 and the accident simulation tests in Section 5. Section 6 presents the results of an analytical study that compares the merits of releasing against non-releasing container-on-flatcar pedestals under derailment and rollover conditions. Findings and conclusions are presented within each section while recommendations are summarized in Section 7.

2.0 VIBRATION TESTS

The overall objective of the VTU testing was to assess safety issues involved in TOFC/COFC transport of hazardous materials in intermodal tank trailers and tank containers and to determine to what extent safety is affected by motions of the liquid lading.

VTU tests were performed with two general objectives: (1) to determine the vibration modes of the various configurations tested (modal testing), and (2) to measure the response of the vehicle to several track condition simulations. The modal testing is of interest since these properties determine the dynamic behavior of the vehicle on the track. For example, the vehicle motion driven by staggered rail is in the roll mode; consequently, the vehicle roll mode characteristics will determine the vehicle's performance on staggered rail track. In a similar fashion, the yaw mode relates to carbody hunting; the bounce and pitch modes relate to the negotiation of grade crossing and other track profile perturbations; and the carbody torsion influences curve entry and exit.

Track simulations using the VTU were performed so that the track conditions that may result in unsafe motion of the test vehicle could be determined. The VTU is capable of simulating many different track conditions and configuration changes are relatively easy to make, allowing a wide range of configuration and track conditions to be tested in a short period of time. VTU testing permits extensive data collection as well as automatic shut down of the shaker system when safety limits are exceeded because instrumentation is wired directly into the shaker control and data acquisition systems. Laboratory testing also permits visual observation of vehicle responses which aids in the understanding of the vehicle's behavior and the success of each test can be evaluated immediately with a revised test easily performed if needed.

2.1 Test Configurations

There were a total of twelve configurations of TOFC and COFC tested. Data on the components used are listed in Table 2-1 and each configuration is defined in Table 2-2. Configuration 0 was the empty flatcar and was tested to provide insight into the contributions of the flatcar to the motions of a loaded car. Configurations 1A, 1B, 1C, and 2 were with a single MC cargo tank trailer with different fill levels and at different positions on the flatcar. Configurations 3A and 3C had two MC tanks with different fill levels mounted on the flatcar. Configurations 4A and 4B had an MC tank in TOFC and an IM portable tank mounted in COFC. Configurations 5A and 5B were similar to 4A and 4B except that the IM tank was mounted on a chassis trailer in TOFC. Configuration 6 contained two IM tanks mounted on chassis trailers in TOFC.

TABLE 2-1
COMPONENT DATA

ITEM	I.D. NO.	EMPTY WEIGHT (lb.)	CAPACITY		MAXIMUM GROSS WEIGHT (lb.)	INSIDE DIMENSIONS	
			Weight (lb.)	Volume (gal.)		Length (in.)	Diameter (in.)
89-Foot Flatcar	TTWX 978174	70,900	149,000	(NA)	220,000	(NA)	(NA)
MC 307 SS Cargo Tank Trailer	MTLZ 6961	16,020	48,980	6,900	65,000	484	60 - 72.5
MC 307 SS Cargo Tank Trailer	MTLZ 6970	16,020	48,980	6,900	65,000	484	60 - 72.5
IM 102 Portable Tank	FR 2074	6,500	46,410	5,670	52,910	259	82
IM 102 Portable Tank	FR 2075	6,835	46,075	5,294	52,910	223	85
20-Foot Chassis	FLXZ 21928	6,200	51,330	(NA)	57,530	(NA)	(NA)
20-Foot Chassis	FLXZ 22199	6,850	45,150	(NA)	52,000	(NA)	(NA)

Additional Flatcar Data: Truck distance = 66', Axle distance = 5'8", 14" center plate, Barber S2 truck with: 7, D5 outer springs and 4, D5 inner springs in each nest, Stucki constant contact resilient side bearings, load variable friction snubbers with single side springs.

TABLE 2-2
INTERMODAL HAZMAT VTU TEST CONFIGURATIONS

NO.	A-END		B-END	
	Tank	% Full	Tank	% Full
0	(empty flatcar)			
1A	MC 307	50	none	-
1B	MC 307	75	none	-
1C	MC 307	95	none	-
2	none	-	MC 307	95
3A	MC 307	95	MC 307	95
3C	MC 307	75	MC 307	75
4A	IM 102 in COFC	92.6	MC 307	95
4B	IM 102 in COFC	80	MC 307	95
5A	IM 102 in TOFC	92.6	MC 307	95
5B	IM 102 in TOFC	80	MC 307	80
6	IM 102 in TOFC	80	IM 102 in TOFC	92.6

MC 307 and IM 102 data are given in Table 2-1 and 2-3.
% Full is by volume with water.

Weight and center of gravity (c.g.) data for the several components that make up each configuration are given in Table 2-3, and c.g. data for several TOFC configurations are given in Table 2-4.

One aspect of TOFC configurations that should be noted is the c.g. heights of the trailers. The c.g. heights of the total vehicle are lower than for high cube boxcars and covered hopper cars that have experienced problems related to c.g. height. However, trailers on flatcars are prone to roll on their own suspension systems so that the c.g. height of the trailer is of more relevance than that of the total vehicle. In view of this consideration, Table 2-4 presents a comparison of c.g. heights of vehicles and trailers for several configurations. Where vehicle c.g.'s are between 84 and 94 inches from top of rail, the trailer c.g.'s are between 120 and 129 inches from top of rail.

Water was used as lading in all tests because of safety requirements, because of its convenience, and also because it has a higher density than most hazardous materials and could be considered a worst case condition. The comparison shown in Table 2-5 of weights and c.g.'s for water and acetone is presented as a representative example. Water lading results in gross weights that are up to 12 percent greater than with acetone and vehicle c.g. heights up to 5 inches higher.

It should also be noted that the gross vehicle weight rating of 65,000 pounds (lbs) for the MC trailers was exceeded by 8.7% in the configurations using water at the 95% full level. Therefore, in order to carry a full load of hazardous material, the density would have to be lower than that of water. It should also be noted that the Code of Federal Regulations [1], paragraph 173.32C(j), requires that the IM tanks be filled to a minimum of 80%.

2.2 Test Procedures

The Vibration Test Unit is a computer controlled system of fourteen hydraulic actuators capable of supporting the full weight of a 100-ton rail vehicle while imposing pre-programmed vertical and lateral motions at each wheel and longitudinal motions at the couplers. The input motions can be input to the computer with mathematical expressions, sine and rectified sine are most commonly used, or with tape records of track geometry measurements. Time and phase sequencing of the motion at each wheel can be controlled to replicate desired track speeds and rail wave lengths.

Slosh modes were obtained in the modal testing by imposing a single haversine pulse of lateral motion simultaneously at each wheel and recording the decaying motions of liquid slosh.

TABLE 2-3
COMPONENT WEIGHTS AND CENTERS OF GRAVITY

COMPONENT	(FILL)	WEIGHT (lbs.)	ESTIMATED C. G. (in.)	
Flatcar	(empty)	70,900	30	
MC 307 Cargo Tank	(empty)	16,020	107	
Water in MC 307	(50%)	28,760	118.9	
	(75%)	43,145	125.8	
	(80%)	46,020	127.1	
	(95%)	54,650	131.4	
FLXZ 22199 Chassis Trailer	(empty)	6,850	78	
FLYZ 21928 Chassis Trailer	(empty)	6,200	78	
			(COFC)	(TOFC)
FR 2075 Portable Tank	(empty)	6,835	83.5	132.25
Water in FR 2075	(80%)	35,320	81.06	129.81
	(92.6%)	40,885	86.16	134.91
FR 2074 Portable Tank	(empty)	6,200	83.5	132.25
Water in FR 2074	(80%)	36,980	82.1	130.85
	(92.6%)	43,285	86.7	135.45

Notes:
- The two cargo tanks are identical.
- C. G. height is measured from top-of-rail.

TABLE 2-4
EXAMPLE C.G.'S FOR TANKS MOUNTED IN TOFC

COMPONENT AND FILL	ESTIMATED C.G. HEIGHT (inches)	
	Total Vehicle	Each Tank & Trailer
Flatcar with Two MC Cargo Tanks Filled to:		
75%	86.7	120.7
80%	88.5	121.9
95%	93.9	125.9
Flatcar with Two IM Portable Tanks on 20-Foot Chassis and each Tank Filled to:		
80%	85.1	124.4
92.6%	90.4	128.7

*C. G. Height measured from top of rail

TABLE 2-5
COMPARISON OF WEIGHTS AND C.G.'S FOR WATER AND ACETONE LADINGS

CONFIGURATION	WATER		ACETONE	
	Gross Wt. (lbs.)	C.G. (in.)	Gross Wt. (lbs.)	C.G. (in.)
0	70,900	30.00	70,900	30.00
1A	115,680	62.76	109,670	56.69
1B	130,065	71.26	121,050	67.20
1C	141,570	77.85	130,150	73.16
2	141,570	77.85	130,150	73.16
3A	212,240	93.84	189,400	89.31
3C	189,230	86.72	171,200	82.61
4A	189,290	79.85	169,325	76.06
4B	183,725	78.68	164,925	74.93
5A	195,490	91.70	175,525	86.67
5B	181,295	86.39	164,295	82.06
6	169,585	84.51	154,475	80.04

C.G. is measured from top of rail
Specific gravity of acetone = 0.791

Testing for the vehicle modes (such as roll, pitch, yaw, sway, bounce, bending and torsion) was accomplished by imposing sinusoidal motions at the wheel-rail interface with motions and frequencies intended to excite the vehicle resonant frequency of interest.

Track simulation tests were performed for three basic track conditions: staggered rail, grade crossing, and vehicle yaw and sway motions representative of body hunting conditions. The staggered rail was simulated with a rectified sine profile using rail lengths of 39 and 33 feet. Constant speed runs using 10 rail lengths of staggered rail were made, first finding the critical speed and then increasing the cross level amplitude of the staggered rail until an unsafe condition was reached. The staggered rail simulations were also performed with braking and accelerating runs through the critical speeds over a continuous series of staggered rail and were also performed with 2.0 inches of superelevation to represent staggered rail in a curve at below balance speeds.

Grade Crossing road beds will invariably be stiffer to vertical loading than at other points in the track. As a result, even when the track is new and laid with no unloaded profile variations, there will be an effective profile variation under load due to this stiffness difference. With time and traffic, this bump at the grade crossing will increase as the roadbed settles. There will also be additional profile waves impressed into the track due to the bounce motions of the passing trains. This profile variation can be as much as ± 2.0 inches and still be within federal regulations for class 4 (60 mph) track and ±1.25 inches for class 5 track (80 mph). For the purposes of the VTU testing in this test program, a series of four haversine constant amplitude waves was used to simulate a grade crossing. Although the number four is arbitrary, it represents a possible track profile condition and is felt to be more realistic than a single bump.

Two wavelengths were used with these four cycle haversine wave functions: 33 feet, to excite the bounce mode; and 44 feet, to excite the pitch mode. The 33-foot wavelength was used rather than 66 feet for the bounce mode in order to keep the critical speed within the normal track speeds.

The Yaw and Sway Tests were an attempt to simulate motions and loads that result from body hunting conditions. The tests consisted of imposing yaw and sway motions to the flatcar in frequency sweeps from 1.5 to 4.0 Hertz (up to 5.0 Hz for some testing), the typical hunting frequency range and corresponding to a range of approximately 30 to 80 mph. These tests were performed on the VTU to provide a more complete quantification of vehicle loads than could be obtained in the field from track testing.

Instrumentation to measure and record the VTU testing totaled 72 channels and included the following types of measurements:

- input displacements
- wheel rail forces, vertical and lateral
- roll motions of the flatcar body and trailers
- accelerations of the flatcar body and trailers
- displacements of the flatcar body relative to ground and trailer bodies and tandems relative to the flatcar
- liquid lading slosh

The liquid slosh measurement device (developed by Wayne Cooksey of the AAR/TTC) consisted of uninsulated nichrome wire, wound on long nylon rods which were mounted against the inner wall of the tank, one on each side running from the top down. The wires were connected as branches of Wheatstone bridges using the liquid lading to close the circuit. With this arrangement the wire resistance varied with its unwetted length giving a measure of liquid slosh motion. This slosh measurement device was mounted at both ends of the tank and the two sides recorded separately so that distinction could be made between side-to-side and fore-and-aft slosh.

Data measurements to be recorded for each test were selected from the 72 channels available: 40 channels were recorded for post test processing and analysis and 22 were displayed in real time on strip charts as time histories. Each of the 40 channels recorded was low pass filtered at 30 Hertz, converted from analog to digital and recorded on digital tape at 64 samples per second. The 22 channels of strip chart recording were for the most part duplicates of the 40 channels of tape recorded data.

2.3 Summary of VTU Test Results

The results of the VTU testing of intermodal hazmat configurations are summarized in this section. More detailed results can be found in Reference [3].

2.3.1 Modal Test Results

The Modal Frequencies identified in the Modal Testing are summarized in Figure 2-1 for slosh and Table 2-6 for all modes. The slosh mode frequency is seen to vary from 0.6 to above 0.9 Hertz as the tank fill level varies from 50% to 95%. The IM portable tank frequencies are slightly lower than the MC cargo tank because the IM has a larger diameter tank, and frequency and diameter are inversely related.

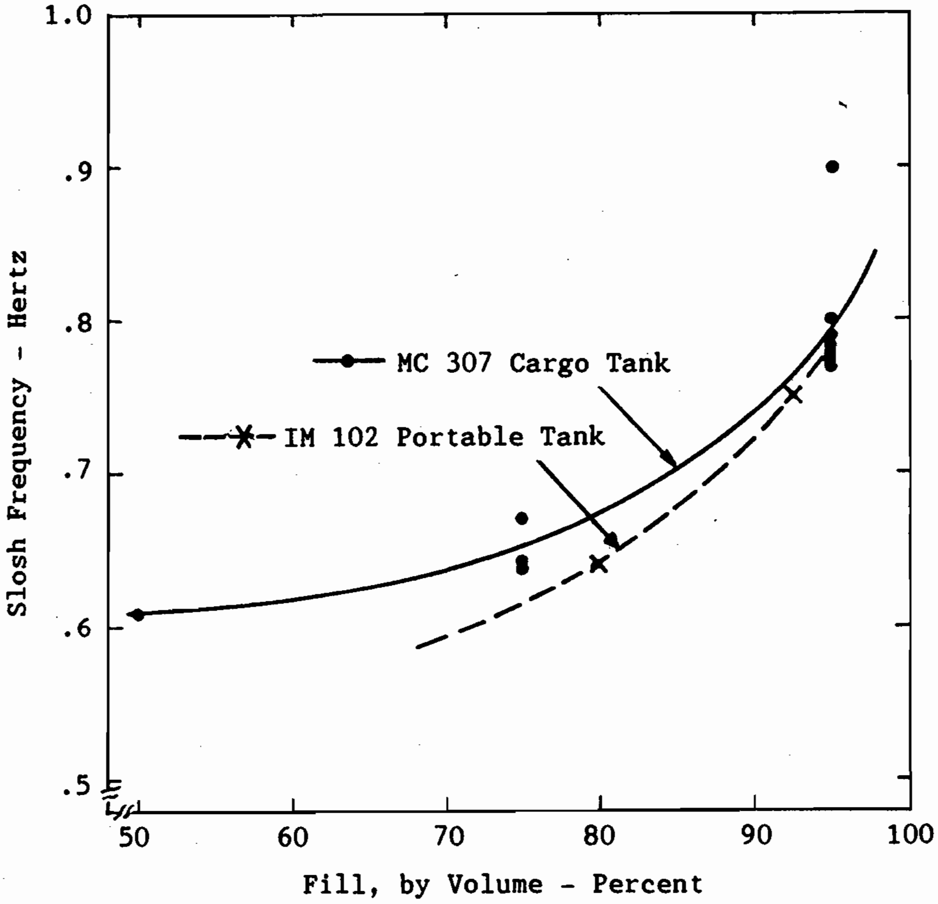

FIGURE 2-1
SLOSH FREQUENCIES FOR MC AND IM TANKS

TABLE 2-6
MODAL FREQUENCIES

MODE	FREQUENCY (Hz)
Slosh	0.6 - 0.9
First Roll	
Flatcar	0.4 - 0.7
Chassis Trailer with IM Tank	0.9 - 1.0
MC Trailer	1.1 - 1.2
Second Roll	0.8 - 1.5
Yaw	
First Yaw	0.5 - 1.9
Second Yaw	1.9 - 5.0 *
Bounce	1.8 - 5.0 *
Pitch	2.3 - 5.0 *
Flatcar Bending	2.4 - 3.0
Flatcar Torsion	8.7 - 12

* Because of the friction snubbers, the Yaw, Bounce, and Pitch modes are very amplitude dependent. The modal frequencies are low for large amplitudes of motion and increase as the amplitudes decrease. As each mode approaches 5.0 Hertz, the amplitudes become too small to cause the snubbers to slide and the mode disappears.

There was no slosh resonance found with the IM portable tanks on the 20-foot chassis trailers. This was attributed to the tilt of the tanks when on the 20-foot trailer, that is the hitch end was higher than the tandem end with a tilt angle of 2.25 degrees. The tilt caused a continuous variation of the height of the liquid, from front to back with a corresponding continuous variation of slosh resonance which resulted in no measurable slosh mode.

A summary of all the modes identified is presented in Table 2-6. It is a summary in the sense that a band of frequencies is given for each mode that includes variations due to configuration, loading, and amplitude.

The First Roll Mode is actually a composite of four resonances: the flatcar, 0.4 to 0.7 Hertz; the liquid in slosh, 0.6 to 0.9 Hertz; the IM portable tank on a 20-foot chassis trailer, 0.9 to 1.0 Hertz; and the MC cargo tank 1.1 to 1.2 Hertz. In each case the frequency of the mode varies with the liquid fill level and amplitude of motion. The net result is that the vehicle first roll mode is spread out over a broad frequency band and is not a strong resonance.

The liquid slosh also reduced the strength of the first roll resonance through an apparent dampening effect caused by splashing as larger amplitudes are reached. This was especially noticeable for the chassis trailer mode. That is, because the trailer mode was at a higher frequency than the slosh mode, the tank and trailer motions were out of phase with the slosh motions, and the liquid splashed at relatively small amplitudes.

The Second Roll Mode is distinguished from the first roll mode in that the resonant frequency is higher and the center of rotation of the roll motion is near the center of gravity of the vehicle. (The center of rotation of the first mode roll motion is near the track level.) The second roll mode is actually the sway mode of the vehicle coupled with the roll motion. Because the second roll mode frequencies were in the same range as the trailer first roll frequencies and because the motions were similar, it was difficult to separate the two modes. Generally if the trailer roll motion was predominant, the mode was called a trailer roll mode and if there was a significant amount of lateral motion of the flatcar body, it was identified as a second roll (sway) mode.

The Yaw Modes were also strongly coupled to trailer yaw and roll motions. In fact, the distinction between first and second yaw was based on the phasing of trailer and carbody motions: in first yaw the trailer and carbody at each end would be in-phase while in second yaw they would be out-of-phase.

The Yaw, Bounce, and Pitch modes were all very amplitude dependent because of the friction snubbers. That is, the modal frequencies were at the low end of the ranges shown in Table 2-6 for large amplitudes of input motion and would increase as the amplitudes decreased. There was a threshold amplitude below which the snubbers would not slide, at which point, generally between 4.0 and 5.0 Hertz, the mode would disappear.

2.3.2 Track Simulation Test Results

The results of the Staggered Rail Track Simulation are summarized in Tables 2-7, 2-8, and 2-9, for 39-foot rail and 33-foot rail with level and superelevated rail. The data presented are critical speeds, carbody and trailer roll angles, and carbody and trailer tandem displacements for the maximum cross level reached. The maximum cross level reached was that level where some potentially unsafe condition had been broached.

The best and worst performers over staggered rail were Configuration 1C and Configuration 2 respectively. Both of these configurations had one MC 312 cargo tank trailer loaded to 95% volume capacity: in Configuration 1C the cargo tank was at the A-end of the flatcar, in Configuration 2 the same cargo tank was at the B-end. The standard 89-foot flatcar configured for intermodal use has the hitch end of each trailer facing the B-end of the flatcar. Thus for Configuration 1C the trailer tandem was directly above the A-truck of the flatcar and for Configuration 2 the trailer tandem was near the center of the flatcar.

The roll response data from Tables 2-7, 2-8, and 2-9 are also presented in Table 2-10 with two changes: (1) the roll response values have been interpolated to a cross level input of 0.75 inches; and (2) the configurations have been listed in order of the average response of the level track test results, the largest response first. There are several aspects of the data shown in Table 2-10 that should be noted.

- Configuration 2 responses are significantly larger than for all other configurations tested.

- Configuration 1C responses are significantly smaller than the others.

- Responses were not significantly affected by changes in liquid fill levels between 75 and 95 percent.

- Responses with superelevated rail were slightly less than with level track.

TABLE 2-7
39-FOOT STAGGERED RAIL TEST - SUMMARY OF RESULTS

CONFIGURATION	MAXIMUM CROSS LEVEL(1) (in.)	CRITICAL SPEED (mph)	MAXIMUM CARBODY ROLL(2) (deg, P-P)	MAXIMUM TRAILER ROLL(2) (deg, P-P)	MAXIMUM CARBODY DISP (in.)	MAXIMUM TANDEM DISP(3) (in.)
1C	0.8 (D)	15.2-19&26.6	2.1	0.9	1.53	0.64
2	0.6 (D)	14.4-18	6.6	9.6	1.25	0.58
3A	0.7 (D)	14.4-18	3.0	3.8	1.56	0.45
3C	0.8 (D)	15.5	2.4	3.6	1.43	0.54
	0.9	12-14	3.5	4.5	1.96	0.54
4A	0.9	15-19	3.8	6.1	2.02	0.64
4B	0.9	14.5-19	3.5	5.6	1.97	0.52
5A	0.8	13-16	2.4	5.3	0.62	0.68
5B	0.7	13-15	2.4	4.0	1.11	0.49
6	0.8	13-15	2.9	5.0	1.31	0.57
	0.8 (B)	13-15	3.8	6.3	1.35	0.55
70 Ton Box	0.6 & 0.4	19 & 22	3.0 & 2.5			
100 Ton Hopper	1.0 & 0.6	15 & 17	6.5 & 3.0			

(1) Maximum amplitude of the rectified sine simulation at the critical speed.

(2) Problems were encountered with the roll gyros used to measure roll angles and data are of uncertain accuracy.

(3) Tandem vertical displacement measured relative to flatcar from outboard extension of rear axle.

(D) = Dwell test, all others sweep.

(B) = B-end leading, all others A-end leading.

TABLE 2-8
33-FOOT STAGGERED RAIL TEST
SUMMARY OF RESULTS

CONFIGURATION	MAXIMUM CROSS LEVEL(1) (in.)	CRITICAL SPEED (mph)	MAXIMUM CARBODY ROLL(2) (deg, P-P)	MAXIMUM TRAILER ROLL(2) (deg, P-P)	MAXIMUM CARBODY DISP (in.)	MAXIMUM TANDEM DISP(3) (in.)
1C	0.8 (D)	15.2	3.4	1.1	1.88	1.06
2	0.6 (D)	14.4-16	9.4	11.6	1.05	0.72
3A	0.7 (D)	14.4	3.0	3.7	1.55	0.66
3C	0.7 (D)	11.5-13	3.3	4.4	1.79	0.80
	0.7	11-12	3.1	4.1	1.82	0.77
4A	0.7	13-15	4.1	7.4	1.92	0.70
4B	0.6	12-16	3.5	7.1	1.8	0.71
5A	0.6	10.5-12	2.8	7.4	0.79	0.74
5B	0.7	10.5-12	4.1	8.2	1.73	0.80
6	0.7	10.5-11	3.5	6.4	1.5	0.68

(1) Maximum amplitude of the rectified sine simulation at the critical speed.
(2) Problems were encountered with roll gyros and roll data are of uncertain accuracy.
(3) Tandem vertical displacement measured relative to flatcar from outboard extension of rear axle.
(D) = Dwell test, all others sweep.

TABLE 2-9
SUPERELEVATED STAGGERED RAIL
SUMMARY OF RESULTS

CONFIGURATION	MAXIMUM CROSS LEVEL(1) (in.)	CRITICAL SPEED (mph)	MAXIMUM CARBODY ROLL(2) (deg, P-P)	MAXIMUM TRAILER ROLL(2) (deg, P-P)	MAXIMUM TANDEM DISP(3) (in, 0-P)
39-Foot Rail					
3A	0.6 (D)	15-18	2.14	2.89	0.55
4A	0.8	15-17	3.34	5.12	0.61
5A	0.7	14-16	3.04	4.92	0.76
6	0.8	13	3.02	4.78	0.68
	0.8 (B)	13-14	3.12	5.39	0.66
33-Foot Rail					
3A	0.4 (D)	13	2.02	2.73	0.53
4A	0.7	13-14.5	3.5	5.65	0.81
5A	0.6	12	3.01	4.18	0.88
6	0.6	11	3.11	5.79	0.60

(1) Maximum amplitude of the rectified sine simulation at the critical speed.
(2) Roll data accuracy uncertain.
(3) Tandem vertical displacement relative to flatcar deck from outboard extension of rear axle.
(D) = Dwell Test, all others sweep.
(B) = B-end leading, all others A-end leading.

TABLE 2-10
HARMONIC ROLL RESPONSE TO 0.75 INCH CROSS LEVEL STAGGERED RAIL

Config. (1)	ROLL RESPONSE - DEGREES, PEAK-TO-PEAK									
	Level Track					Superelevated Track				
	33-Foot Rail		39-Foot Rail		Avg. of 4	33-Foot Rail		39-Foot Rail		Avg. of 4
	Flat	Trailer	Flat	Trailer		Flat	Trailer	Flat	Trailer	
2	11.8	14.1	8.3	12.0	11.5	not tested				
4B	4.4	8.8	2.9	4.7	5.2	not tested				
4A	4.4	7.9	3.2	5.1	5.1	3.8	6.1	3.1	4.8	4.4
5B	4.4	8.7	2.5	4.3	5.0	not tested				
5A	3.6	9.2	2.2	4.9	5.0	3.8	5.2	3.3	5.3	4.4
6	3.8	6.8	2.7	4.7	4.5	3.9	7.2	2.8	4.5	4.6
3A	3.2	4.0	3.2	4.0	3.6	3.8	5.1	2.7	3.6	3.8
3C	3.6	4.7	2.2	3.4	3.5	not tested				
1C	3.2	1.1	2.0	0.9	1.8	not tested				

(1) Configurations are listed in order of average response for level track, largest response first.

Refer to Table 2 for definition of configurations.

With the objective of relating cause and effect for the differences in responses just presented, the following logic is proffered.

- The largest response to staggered rail occurs with an intermodal configuration of a single tank trailer on the B-end of the flatcar, the two, trailer and flatcar, apparently being in a strong synergistic mode.

- The addition of a second tank, at the A-end, disrupts the coupling between B-end trailer and carbody and results in a reduction of the harmonic roll response. A portable tank in COFC provides the smallest reduction; a portable tank on a chassis trailer results in more reductions; and a cargo tank trailer results in the most reduction.

The following conclusions and recommendations are made relative to harmonic roll response to staggered rail:

- The flatcar configuration of a single trailer on the B-end behaved so poorly in the staggered rail tests that additional testing is recommended in order to verify these results, to test variations of this configuration, and to determine the effects of direction of travel.

- An adjunct to this suggested testing would be to test an intermodal flatcar configured with both trailer hitches at the center of the car: so that the tandem of each trailer is at its end of the flatcar. If the logic presented above holds true, a flatcar with this configuration would have reduced harmonic roll response with either one or two trailers.

- All other configurations tested behaved well with 39-foot staggered rail. Behavior was marginal with 33-foot rail in that although carbody roll angles were less than 6.0 degrees peak-to-peak, trailer roll angles generally exceeded 6.0 degrees and were accompanied with wheel lift.* This does not apply to Configuration 1C which was very well behaved for all conditions.

The Bounce and Pitch Test Results are summarized in the tandem wheel displacements of Figures 2-2 and 2-3 and the flatcar vertical wheel loads of Figure 2-4. All of the configurations tested, i.e., 3A, 4A, 5A, and 6,

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*The 33-foot rail length was used for two reasons: (1) 33-foot rail was at one time a standard length and some of it remains in use on low speed, low traffic track; (2) and 33 feet would be a rail length of maximum response for the 66-foot truck spacing of 89-foot flatcars.

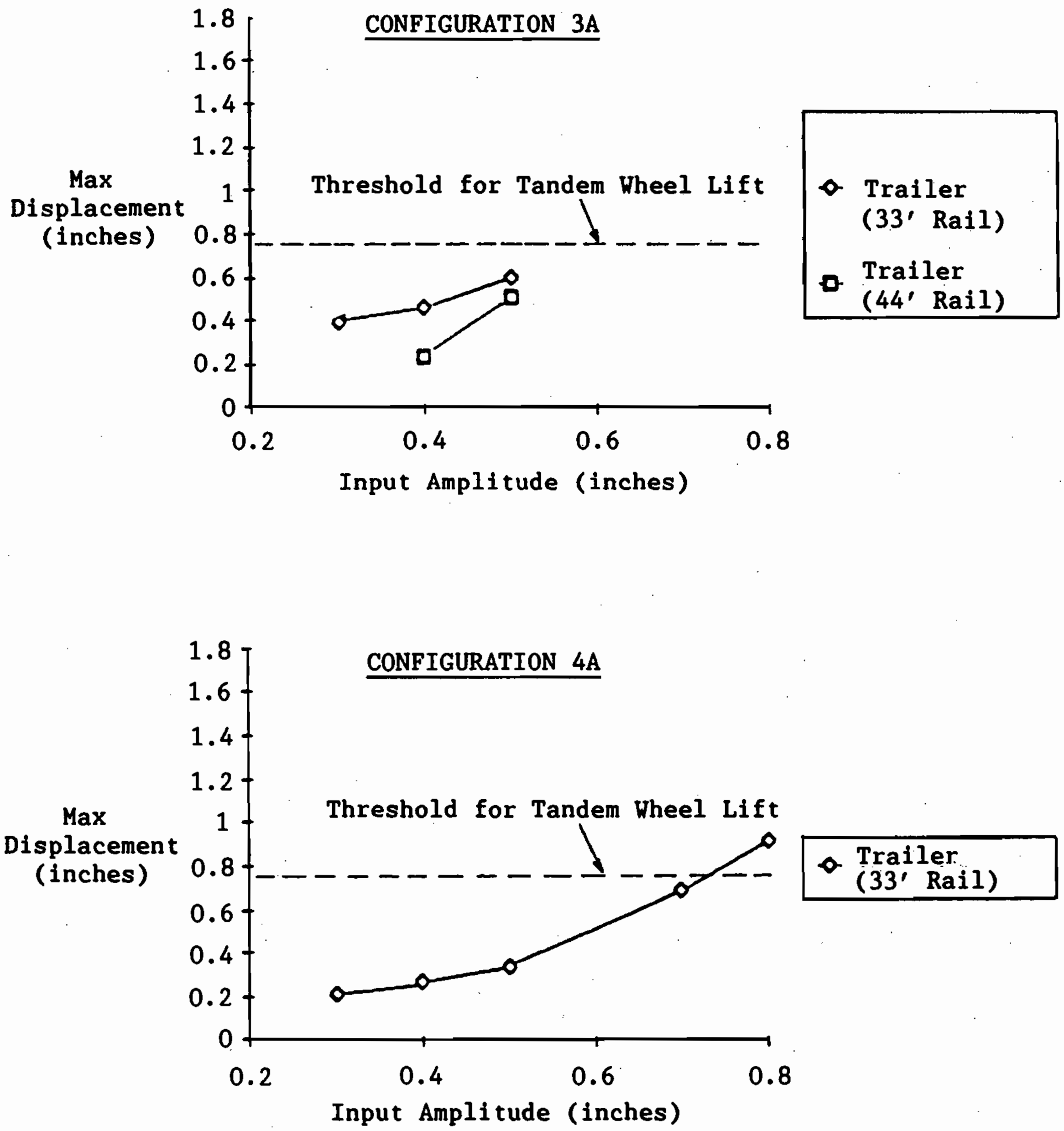


FIGURE 2-2
MAXIMUM TANDEM WHEEL DISPLACEMENTS RELATIVE TO FLATCAR DECK, CONFIGURATIONS 3A AND 4A, BOUNCE AND PITCH TESTS

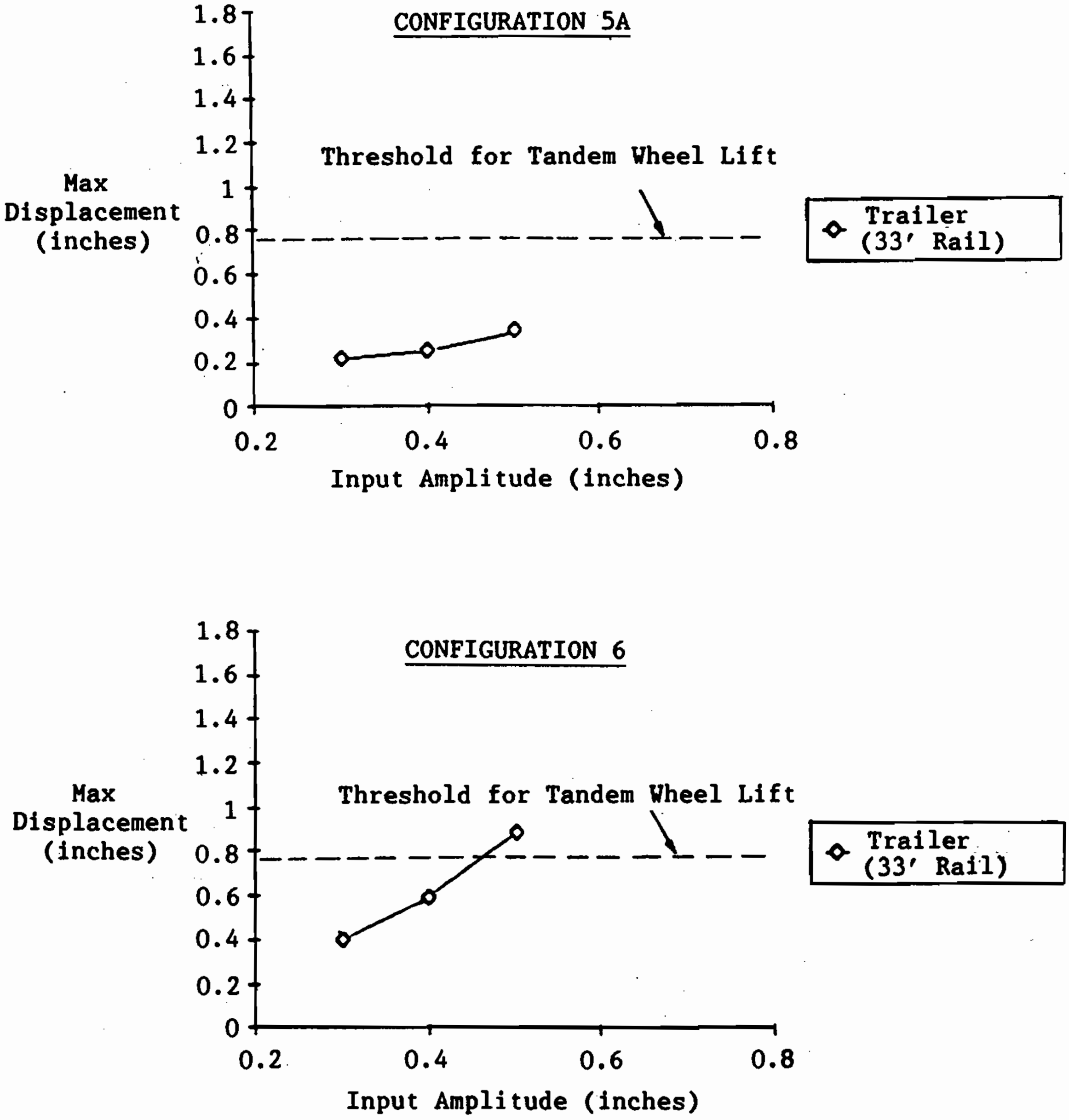


FIGURE 2-3
MAXIMUM TANDEM WHEEL DISPLACEMENT RELATIVE TO FLATCAR DECK, CONFIGURATIONS 5A AND 6, BOUNCE AND PITCH TESTS

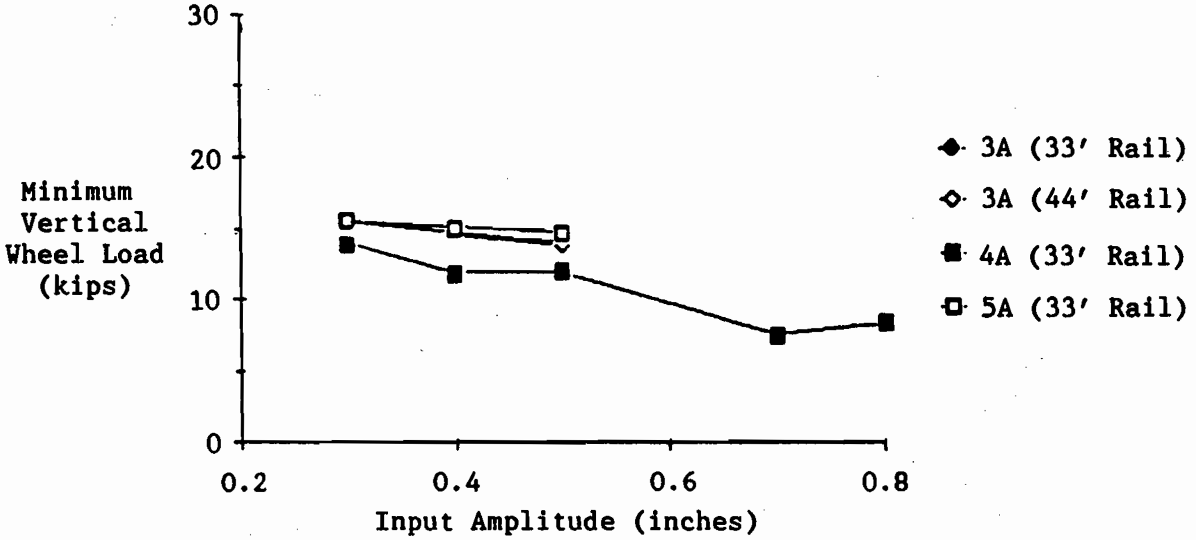


FIGURE 2-4
MINIMUM VERTICAL WHEEL LOADS FOR BOUNCE TESTING

had wheel lift of the tandems at bump heights of less than 0.8 inches: Configurations 4A and 5A were between 0.7 and 0.8 inches, Configuration 3A was between 0.5 and 0.6 inches, and Configuration 6 was between 0.4 and 0.5 inches. Vertical wheel loads for the flatcar reached a maximum unloading of about 70% (where wheel lift would be 100%). Critical speeds ranged from 45 to 75 mph.

Since Title 49 CFR, Section 213.63 permits profile variations of up to 2.0 inches for class 4 track (60 mph) and 1.25 inches for class 5 track (80 mph) these test results indicate that there can be severe bounce of the trailer tandems at grade crossings that could result in the tandem end of the trailer bouncing off the flatcar deck.

The Yaw and Sway Test Results are summarized in Table 2-11. These tests were performed in an exploratory attempt to replicate loading conditions due to hunting. Hunting, simply stated, is a dynamic instability of rail car trucks characterized by oscillation of the truck, within the gage clearance, in coupled yaw and lateral motions of the truck. The onset of hunting and frequency of the oscillation is dependent on track speed and a number of other factors which include: wheel profile; rail profile; yaw and warp (out of square) stiffness and damping of the truck; the unsprung mass of the truck; creepage factors; and the car weight acting on the truck. The hunting frequency generally runs from 1.0 to 2.5 Hertz. In general, both trucks of a freight car are nearly the same as to basic properties and wear conditions and have nearly the same critical hunting speed. As the critical hunting speed is approached, both trucks will independently experience bursts of the hunting oscillation. Frequently the leading truck motions will dominate and the resulting car motions are known as "nosing." However, when a car mode has motions that couple with the truck motions in hunting (usually yaw or sway), and when the frequencies coincide, for example truck hunting and carbody yaw are both at 2.0 Hertz, the condition is one of coupled motions of the car body and both trucks. This condition, known as body hunting, will always have larger motions and loads than with truck hunting.

The body hunting modes found in the VTU testing ranged from 2.8 to 4.5 Hertz and from 2.2 to 3.9 Hertz in the track hunting tests (refer to Table 2-2 and Figure 2-3). However, the frequency of the predominant hunting motion in the track tests was between 1.0 and 2.5 Hertz. This leads to the conclusion that the hunting experienced in the track tests was truck hunting with a minimal coupling with the body yaw and sway modes.

The lateral accelerations in the VTU tests were of higher g values than in the track testing. This again can be attributed to track tests being truck hunting at a lower frequency, while the VTU tests simulated body hunting conditions at the higher frequency.

TABLE 2-11
YAW AND SWAY TEST SUMMARY

CONFIGURATION	INPUT (in.)	CRITICAL FREQUENCY (Hz)	MAXIMUM LATERAL RESPONSES				MINIMUM VERTICAL WHEEL LOAD (kip)	L/V(1)
			Flatcar Body		Trailer Accel. (g)	Wheel Load (kip)		
			Displ. (in.)	Accel. (g)				
YAW (out of phase)								
1C	0.4	3.0-4.0	0.97	2.25	(no data)	6.45	5.8	1.1
2	0.6	3.0-4.5	1.50	4.37	(no data)	7.70	8.6	0.9
3A	0.6	3.5-4.0	0.80	2.54	3.42	3.82	14.8	0.3
6	0.6	3.8-4.3	0.86	1.65	0.85	3.17	15.3	0.2
SWAY (in phase)								
1C	0.6	2.8-4.0	1.41	2.76	(no data)	7.07	4.6	1.5
2	0.6	3.0-4.4	1.45	2.66	(no data)	5.55	5.0	1.1
3A	0.6	3.9-4.3	1.39	4.37	1.32	10.81	15.6	0.7
6	0.6	3.5-3.9	0.91	1.77	1.27	3.44	14.6	0.2

Note: All displacement (in.) and acceleration (g) amplitudes are peak-to-peak; wheel loads are zero-to-peak.

(1) Maximum lateral wheel load divided by minimum vertical wheel load regardless of times of occurrence.

Finally the lateral wheel loads measured in the VTU testing were high, with maximum lateral wheel forces divided by minimum vertical wheel forces (L/V) exceeding 1.0. However, time correlated values of lateral and vertical forces were not available and actual L/V values could not be obtained.

The objective of these yaw and sway tests was to show if hunting motions and resulting dynamic forces on the trucks and car body could be reproduced on the VTU. The VTU could then be used in place of, or in conjunction with, track tests to measure these forces without incurring the risk of derailment. Although the testing did not include sufficient measurement of motions and loads nor a sufficient variety of input motions to provide a complete evaluation, the tests did show enough correlation between VTU and track tests to encourage a continuation of this kind of test.

Other Results

Water was observed leaking from the MC cargo tank trailers and IM portable tank containers several times during the VTU testing, and at the time it was attributed to leakage from the slosh gage instrumentation ports. During yard impact testing, which was performed immediately following the VTU tests, the fusible vent on one of the cargo tank trailers was found to be broken. The failed vent could have been the source of leakage during VTU testing. The cause of failure is not known, although one explanation is that pressure surges or liquid impacting on the vent may have been the cause. A second vent also failed during the yard impact testing. The Department of Transportation is addressing the design of vents, valves, and other openings for cargo tanks in Docket Nos. HM-183 and 183A and the findings should be studied in relation to rail transportation regulations.

3.0 COUPLING IMPACT AND LIFT/DROP TESTS

This section presents a summary of results from the car coupling impact and lift/drop tests which were conducted during April 1985 at the Transportation Test Center (TTC), Pueblo, Colorado. The contents of this section are for the most part excerpted from the IIT Research Institute Report by Dr. Milton Johnson [5].

The scope of the car coupling impact tests included 106 separate test runs, which were subdivided into 10 separate test series. Each test series considered a different arrangement of cargo tank trailers and/or intermodal containers mounted on a flatcar.

The scope of the lift/drop tests included 9 separate lift tests to determine the deflection curve of a tank trailer under different loading conditions and 8 drop tests where the front landing gear support legs of the trailer were lifted off the ground and allowed to fall a short distance.

3.1 Objective of Coupling Impact and Lift/Drop Tests

The overall objective of the car coupling impact tests was to determine the dynamic loads and responses of various TOFC/COFC arrangements with cargo tank trailers and intermodal tank containers. The impacts which occur during car coupling switchyard operations are one of the most severe environments encountered in railroad service. The specific objectives included:

- Investigation of the tendency of a container or trailer to become dislodged from a flatcar under normal classification yard movements.
- Understanding of the structural dynamic phenomena associated with a high deceleration stop of the car so that calculations could be made of the expected results under more severe conditions.
- Determination of the forces at the points of attachment so that the adequacy of present requirements for securement devices could be assessed, and
- Development of acceptable instrumentation techniques for measuring the tendency of the container or trailer to become dislodged from the car so that these techniques would be available when derailment tests were conducted.

The overall objective of the lift/drop tests was to assess the potential for accumulating damage during the loading and unloading of cargo tank trailers. These tests were restricted to tank trailers.

3.2 Test Guidelines

3.2.1 Coupling Impact Tests

The test plan for the car coupling impact tests was developed after considering the requirements of existing AAR specifications which are summarized in this section. All but one of the test series conducted under this program followed the procedures outlined in AAR Specification M-928, which is used to demonstrate the effectiveness of flatcar or trailer hitch cushioning for limiting trailer hitch loads. The flatcar, containing a cargo tank trailer or portable tank container, was impacted into standing, loaded hopper cars at speeds of 4, 6, 8, and 10 mph. One set of tests was made following the AAR.600-15d procedures where a standing car on which the container is mounted was impacted by a loaded hopper car.

There are five AAR specifications which pertain to the structural integrity and securement of tank trailers and intermodal containers in the car coupling impact environment. These are summarized as follows:

AAR Specification M-928 covers the structural adequacy and testing of highway semi-trailer hitches which are used on freight cars. The intent of the specification is that the hitch structure at the trailer kingpin will not be subjected to a longitudinal force greater than 210 kips at a car impact of 10 mph. Tests are prescribed to demonstrate that the hitch can withstand, without damage, the loads from car impacts. The tests include a series of impact tests. The hitch is installed on a flatcar which is loaded with two 40-foot trailers. The car is impacted at speeds from 4 to 10 mph in both directions against loaded cars. The cushioning on the flatcar or within the hitch itself must limit the kingpin longitudinal force to 210 kips at a 10 mph impact speed.

AAR Specification M-931 pertains to the design of highway trailers used in TOFC service. The design criteria given for longitudinal shear load at the kingpin is 3.5 times the maximum gross weight of the trailer, in both directions. A static test is specified for demonstrating the ability to carry the load.

AAR Specification M-943 pertains to the design of container chassis for TOFC service. (Note that this specification states that the chassis covered by this specification are not suitable for transportation of hazardous materials in tank containers.) The design requirements concerning kingpin forces are similar to those of M-931. A maximum longitudinal load 3.5 times the maximum gross weight is specified. A static test is specified for demonstrating the ability to carry the load.

AAR Specification M-952 pertains to intermodal container support and securement systems for freight cars. Tests are prescribed to demonstrate the adequacy of the securement device. A static test is conducted to demonstrate that a corner support system can sustain a longitudinal load of 67,200 lbs in the direction from which the corner support structure would receive the container force during a switching impact. An impact test is prescribed to demonstrate that when the securement system is installed on a flatcar, the container total longitudinal restraining force shall not exceed 135,000 lbs. during a 10 mph impact. The test involves installing the securement system on a flatcar, loading the car with two 40-foot intermodal containers, and then impacting the car into standing cars at speeds from 4 to 10 mph.

The AAR Specifications for Tank Cars, Section AAR.600, pertains to the acceptability of portable tank containers used in COFC service. Section 15, paragraph d, of this specification describes an impact test for determining the structural adequacy of a tank container. The tank container is placed on a free-standing car and impacted by a loaded car at increasing speeds until a longitudinal load on the container is developed which is equal to 4 times its maximum gross weight. The tank container must give no evidence of visible damage under this test condition. Section 19, Paragraph b, of this specification states that each corner securement must be capable of sustaining a longitudinal load of 78,400 lbs. without incurring distortion that would render it unsatisfactory for normal operation.

3.2.2 Lift/Drop Tests

The potential for accumulating damage during loading and unloading of tank containers or trailers was assessed by performing tests which simulate the loads and shock motions which occur during these operations. The problem is likely to be more critical with tank trailers than with IM tank containers. The IM tank containers are fairly rigid structures because of their containment within a skid and framework structure, whereas the tank trailers tend to be long slender structures with lower fundamental frequencies.

To examine the potential problems with tank trailers, trailer lift/drop tests were performed. The purpose of the tests was to compare results from tests prescribed by the AAR for trailers used in TOFC services with the results from the vibration and car coupling impact tests. The data were to be reviewed to determine if the AAR specifications describe a severe enough condition for trailers which are intended to be used for hazardous material service. The tests were concerned with establishing the deflection curve of the trailer under different loading situations in order to gain an indication of the dynamic and static response of the structure. The tests were based, in part, on tests described in AAR M-931 for highway trailers used in TOFC service. The criterion for the successful completion of the M-931 tests is that the trailer should remain serviceable and should not show permanent deformation resulting in any abnormality which would make it unsuitable for use.

The Lift Test described in Section 6.4 of AAR M-931 requires that the tank trailer be supported equally on four lift shoes (or their equivalent), each having a bearing area of approximately 4 x 18 in. at the lifting pads. The trailer is then loaded to 1.7 times its gross weight and the load held for a period of at least 5 minutes.

The Drop Test procedures outlined in Section 6.7.2 of AAR M-931 require that the trailer be uniformly loaded to produce a load of 32,500 lbs. on the trailer support with the trailer support legs extended to position the kingpin support plate 46 to 48 in. above the test surface. The front end of trailer is elevated by a tractor until the support legs are 3 to 3-1/2 in. above the test surface. The tractor must not engage the kingpin and is to extend under the front of the trailer the minimum distance required to support the trailer in a static condition. The tractor is then accelerated abruptly permitting the trailer to drop. The trailer landing gear is to impact on an asphalt test surface which is to be level and smooth. The trailer must withstand 10 nominal 3 in. drops.

3.3 Test Procedures and Configurations

This section describes the test equipment, procedures, instrumentation and configurations for the car coupling impact tests.

3.3.1 Equipment

The freight car used in the tests was a TWIN 45 TTX car (No. 978174). It had an empty weight of 70,900 lbs. and a load limit of 149,000 lbs. The car was equipped with Freightmaster end-of-car cushioning units and was built in October 1974.

Two tank trailers supplied by Montgomery Tank Lines were used (Nos. MTLZ6961 and MTLZ6970). They were 6,900 gallon, MC307 trailers with an approximate empty weight of 14,000 lbs.

Three 20-foot intermodal tank containers were used. Two were supplied by EUROTAINER and one was owned by the DOT. The nameplate data on these containers are summarized in Table 3-1. Each of these containers had its own unique framework design.

TABLE 3-1
CONTAINER DATA
(FROM NAMEPLATES)

DATA ITEM	EUROTAINER		DOT
Number	SELS 716005 FR 2075	SELS 914064 FR 2074	BLSU 300019 US 2272
Designation	IM 102	IM 102 E7516	IM 102
Max Gross Weight	52,910 lbs	52,910 lbs	67,196 lbs
Tare Weight	6,835 lbs	6,395 lbs	6,437 lbs
Max Allowable Load	--	46,520 lbs	--
Liquid Capacity	20,600 l	19,800 l	21,000 l
Diameter	2,180 mm	2,100 mm	2,200 mm
Shell Thickness			
Actual	---------3 mm----------		3 mm
Equiv. Mild Steel	------"standard"-------		3.97 mm
Material	26 CNDT 17-12/316TI	26 CNDT 17-12/316TI	--
Built	1974	1974	Oct 1983
Manufacturer	--	--	BSL
Max Working Pressure	25 psi	25 psi	25.39 psig
Test Pressure	37 psi	37 psi	38.01 psig

3.3.2 Test Procedures

The procedures for conducting the car coupling impact tests generally followed those outlined in AAR Specifications M-952 and M-928. The trailer or container was loaded with water and installed on the TTX car which became the hammer car. The anvil cars included three hopper cars each loaded with dry sand to an approximate gross rail weight of 220,000 lbs. The hand brake was set on the third car. The impact tests were run at speeds, 4, 6, 8 and 10 mph in both directions.

3.3.3 Test Configurations

The car coupling impact test series were conducted under different test configurations which were designated as Configurations 2, 3A, 3B, 4A, 4B, 4C, 4D, 4E, 6 and 7. The conditions associated with Configurations 2 through 7 are summarized in Table 3-2.

TABLE 3-2
COUPLING IMPACT TEST CONFIGURATIONS

TEST CONFIGURATION (AND IMPACTING DIRECTIONS)	"A" END OF FLATCAR		"B" END OF FLATCAR	
	Tank Type	Water Load in Tank (volume filled, %)	Tank Type	Water Load in Tank (volume filled, %)
2 (A and B)	none	-	MC	94.2
3A (A and B)	MC	94.2	MC	94.2
3B (A and B)	MC	94.2	MC	80.0
4A (A and B)	IM in COFC	92.6	MC	80.0
4B (A and B)	IM in COFC	80.0	MC	80.0
4C (A-end)	none	-	IM in COFC	92.6
4C (B-end)	IM in COFC	92.6	none	-
4D (A-end)	none	-	IM in COFC	80.0
4D (B-end)	IM in COFC	80.0	none	-
4E (A-end)	none	-	IM in COFC	92.6
6 (A and B)	IM in TOFC	80.0	IM in TOFC	92.6
7 (A-end)	none	-	IM in COFC	92.6

The tests on Configurations 2 through 4D and 6 were conducted by impacting the flatcar on which the container or trailers were mounted into standing cars, in both directions, at nominal speeds of 4, 6, 8 and 10 mph. The Configuration 4E impact tests were made in only one direction and the Configuration 7 tests involved impacting the standing test car with a moving car.

3.4 Summary of Results

A summary of results from the coupling impact tests is given in Table 3-3 from which a number of observations are to be made. First, coupling impact on the A-end of the flatcar consistently resulted in higher coupling forces than the B-end coupling, the A-end impact loads being about twice the B-end impact loads. This was attributed to a malfunction of the end-of-car cushioning at the A-end. Second, the accelerations measured on the carbody for the 10 mph impacts were for the most part between 3 and 4 g's (after the high frequency vibration g's were filtered out). A third observation was that the hitch loads ranged from 52 to 160 kip, for the 10 mph impacts. These loads are well below the 210 kip limit defined in the AAR M-928 specification. Finally, the container restraint loads ranged from 78 to 209 kip, for the 10 mph impacts. Out of the nine tests wherein this measurement was made, six were above the M-952 specification limit of 135 kip and three were above the AAR 600 specification limit of 157 kip. Further discussion of these results and other observations are given below.

3.4.1 Securement of Trailers and Containers to Flatcar

One of the major objectives of the tests was to determine if there would be a tendency for the trailers and containers to become dislodged from the flatcar during car coupling impacts. The force and displacement measurements as well as the visual observations indicated that trailers and containers were secure at all impact speeds tested.

3.4.2 Trailer, Container and Chassis Damage

The car coupling impact tests did produce minor apparent damage on the trailers and containers used on the tests. The primary damage to the trailers was separation of the insulation cover jacket sheets at the seams. One of the intermodal tank containers received minor damage to the gusset plates connecting the partitions which support the tank to structural members of the framework. Also, several small tabs which connect vertical framework members to the tank were damaged.

A potentially more serious problem with both the tank trailers and containers is damage to the vents and valves under impact conditions. The fusible link vents on both tank trailers (which open under high temperature) failed during the tests and released water. The bottom outlet

TABLE 3-3
SUMMARY OF COUPLING IMPACT TEST RESULTS

Config.	Max Impact speed (mph)	Max Load Condition					
		Coupler/Carbody		Trailer Hitch (1)		Container (2)	
		(Kip)	(g's)	A (Kip)	B (Kip)	A (Kip)	B (Kip)
2	(A) 10.2	**	3.7	*	124	*	*
	(B) 9.7	239	2.8	*	108	*	*
3A	(A) 10.3	810	4.0	142	145	*	*
	(B) 10.0	350	3.4	111	103	*	*
3B	(A) 10.4	710	3.1	160	85	*	*
	(B) 10.1	340	3.0	109	55	*	*
4A	(A) 10.1	960	(ND)	*	155	**	*
	(B) 10.1	**	3.4	*	66	149	*
4B	(A) 10.0	770	4.0	*	144	**	*
	(B) 10.1	420	3.6	*	52	120	*
4C	(A) 10.0	860	4.2	*	*	*	209
	(B) 10.1	530	2.9	*	*	163	*
4D	(A) 10.0	860	4.0	*	*	*	114
	(B) 10.1	420	2.9	*	*	78	*
4E	(A) 10.2dry	290	2.7	*	*	*	*
	(B) 10.7lub	380	3.8	*	*	*	146
6	(A) 9.8	750	7.3	*	*	**	161
	(B) 10.0	410	3.1	*	*	**	**
7	(A) 11.2	910	3.8	*	*	*	152

* – not in this test configuration
** – no data due to measurement problems
(1) – Hitch load limit defined by AAR specification M-928 is 210 kip.
(2) – Container securement load limits defined by AAR specification are 135 kip from M-952 and 157 from AAR 600.19 (B)

valve on one of the portable tanks was damaged which allowed slight leakage to take place. The safety relief valve on another container also allowed liquid to come out during the liquid surge associated with the impact.

There was minor damage to one of the chassis trailers. A crack developed in a weld on a front diagonal member which reinforced the framework connecting the front part of the container support to the member which extended forward to the hitch connection.

3.4.3 Condition of End-of-Car Cushioning Units on TTX Car

The results of the tests revealed that the condition of the car carrying TOFC/COFC hazmat is an important factor. Specifically, the trailer and container securement forces were significantly larger for impacts on the A-end of the car than on the B-end. This showed that the properties of end-of-car cushioning devices were considerably different at each end of the car.

The differences in the performance of end-of-car cushioning devices raises a potential problem with securing trailers and containers on flatcars. The design criteria for the securement system is based on a properly functioning end-of-car cushioning device. If it is not working properly, the loads may be considerably higher under impact conditions and could cause failures in the securement system. End-of-car cushioning devices can have degraded properties even though there is no visible indication of damage. Although visual examinations are routinely performed to check for damage and cracks, performance checks are not made.

3.4.4 Liquid Sloshing Effects

A close study of the test results showed clearly that slosh of the liquid lading resulted in an alleviation of longitudinal forces on the container and container attachment. Further this alleviation increased with increase in outage. The obvious phenomenon is that the reaction forces of the sloshing mass of liquid reach their peak at a later time than the rest of the container body and liquid, resulting in the deceleration forces occurring over a longer period of time and hence with lower forces. With increased outage there is more space for the liquid to slosh and there is consequently a greater volume of liquid sloshing and greater stretch out, in time, of the deceleration forces. This seems to hold true within the limits of outage tested. It should be noted that even though the impact forces measured at the car coupler are reduced by liquid slosh, accelerations measured on the car body or tank structure can be expected to be higher.

However, there is a detrimental aspect of liquid slosh in that the back and forth movement causes surges of pressure and vacuum that can be severe. This could have caused some of the damage to vents and valves discussed in section 3.4.2.

3.4.5 AAR.600 Container Test

The impact tests conducted in accordance with Specification AAR.600-15 requires the test container to be mounted on a free standing test car which is to be impacted by a car of no less than 70 tons nominal capacity. Velocity of impact is to be increased until the impact force on the container is equal to four times the weight (mass) of the loaded container as measured through load cells at the corner castings. At 11 mph the container force was measured to be 152 Kip which is only 2.9 times the container weight. Higher speed impact was not attempted because of the danger of derailment.

The filtered accelerations measured on the flatcar deck were 3.8 g's for the 11 mph impact test. The difference in the 3.8 g's and the 2.9 factor on the container weight is due primarily to the load alleviation resulting from liquid slosh. There is also some question as to the accuracy and reliability of the load cell measurement.

Since the specification test condition of four times container weight was not attainable, it seems that some modification of the test specification may be needed, for example, changing the requirement to a speed at impact or to an acceleration measurement on the flatcar body. In either case this specification would need to be very specific about test cars, test car weights, draft gear, accelerometer types, signal conditioning and data processing.

3.4.6 Lift and Drop Tests

The lift tests were performed on the MC 307 cargo tank trailers with no problems encountered. Deflections of the tank and trailer body were very small.

The drop testing consisted of three 3.5 inch drops in each of the three tank fill conditions of empty, 3,450 gallons and 6,900 gallons of water. The landing feet sustained some damage during the empty tank tests. During the partial load series of tests there was further damage to the landing feet, the leg-to-foot connections were damaged, and the support leg assembly was bent.

Only two drop tests were performed of the planned three with the trailer fully loaded with 6,900 gallons of water. It was in these drop tests that the trailer body was damaged. Severe bending occurred at the top of the support legs where they connect to the trailer undercarriage. The outer shell of the tank in the same area was also damaged. After the second fully loaded drop test, the support leg crank could not be turned in either high or low gear range. The leg framework was bent, the leg to foot connection was severely damaged and the up/down adjustment gear was inoperable. The test was then terminated.

The fully loaded test was an overtest. The weight of 6,900 gallons of water was 57,500 lbs. whereas the maximum product load rating of the trailer was 48,980 lbs., a 17 percent overload. The M-931 test specification requires a 32,500 lb. load at the trailer support whereas the actual test condition was approximately 47,000 lbs., a 45 percent overtest.

Because of the extent of the damage and because damage was also sustained in the empty and partial load conditions, review of the test requirement should be performed to determine if this is indeed a reasonable representation of what can or does happen in service. If the 3.5 inch drop test is found to be reasonable, a modification of the landing gear that would include a cushioning device should be considered.

The fully loaded drop tests performed were, as noted, an overtest causing extensive damage to the landing gear and some damage to the trailer body and tank structure. It was a demonstration of the capability of the tank structure to withstand this load condition without fracture and spill. From a hazmat safety standpoint the performance of the MC 307 cargo tank trailer, in this test, did not cause loss of lading or tank failure.

3.5 Conclusions

From a Test Specification and Test Performance viewpoint, there were two problem areas encountered. First, in the drop tests of the MC cargo tank trailer there was extensive damage sustained by the trailer body and tank structure as well as the landing gear. Despite the fact that the trailer was overloaded for two of the eight drop tests performed, it was concluded that there was a need for action to verify that the 3.5 inch drop test is valid and the possible need for landing gear modification.

The second testing problem encountered was the inability to attain the car coupling impact test conditions required by the AAR 600-15(d) specification. This is a severe test made more difficult by the use of load cells to measure container loads, and by load alleviation provided by sloshing of the liquid lading. It was concluded that a change in the test specification may need to be made.

From a Structural Integrity viewpoint it was concluded that the MC 307 cargo tanks and the IM 102 portable tanks were shown to be adequate. Damage occurred to both the cargo tank and the portable tank during the coupling impact tests. The stainless steel skin used to cover the cargo tank insulation shifted longitudinally. There was some minor yielding and fracture of the container frame structure. There was extensive damage to the cargo tank trailer landing gear and yielding of the trailer body and tank shell resulting from the drop tests. However, the damage sustained did not result in loss of liquid cargo and did not result in structural weakening of the tanks. Damage to the landing gear was extensive and needs to be addressed. The over test in the drop tests did not cause tank failure and that speaks well for the survivability of the tank.

From a <u>Safety Relief Device</u> viewpoint it was concluded that there is a potential problem. Failure of the frangible temperature relief vents apparently occurred during both the VTU vibration testing and during the coupling impact testing. Probable cause of failure was attributed to pressure and vacuum surges caused by liquid slosh motion.

4.0 TRACK TESTS

The track testing investigated performance in areas not covered by laboratory and yard impact testing. This consisted of the four conditions of hunting, curve entry, steady state curving, and harmonic roll on curved track. The test objectives were to measure the responses of the configurations tested and to identify unsafe conditions.

4.1 Description of Configurations Tested

The track tests were performed with a consist made up of five cars: a locomotive, a buffer car, the test car, a second buffer car, and an instrumentation car. The buffer cars were both 89-foot flatcars each carrying two loaded van trailers. The test car was an 89-foot flatcar configured with two MC cargo tank trailers in the two loading conditions of 95 percent and 80 percent full (by volume) and then with two IM 102 portable tanks on chassis trailers in the two loading conditions of 92.5 percent and 80 percent. Photographs showing the test consist and the test car configurations are shown in Figure 4-1. Weight and center of gravity data are given in Table 4-1. Other dimensional data can be found in Reference [4].

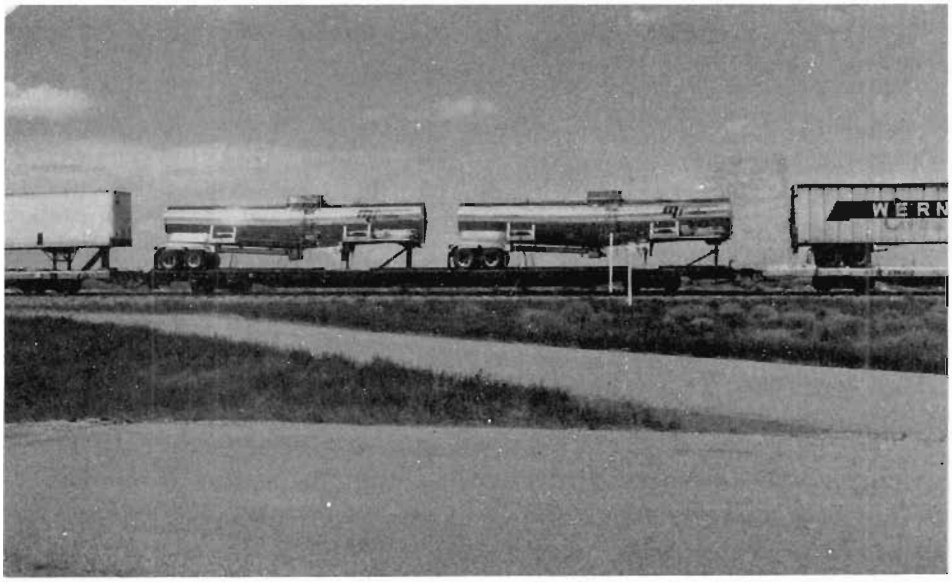
The test flatcar, number TTWX 978174, was a Twin 45, 89-foot flatcar. It had 33-inch wheels, 6 X 11 journals, D-5 springs with 7 outer and 4 inner springs in each nest, and load variable friction snubbers with single side springs.

The test flatcar configurations differed between the hunting and curving tests in two respects: 1) wheel profiles; and 2) side bearings. Canadian National Heumann profiled wheels were used in the hunting tests while 1:20 conicity profiles were used in the curving tests. Roller side bearings were used in the hunting tests and Stucki constant contact resilient side bearings were used in the curving tests. These differences were specifically chosen because poorer performance would result in each instance.

4.2 Test Procedures

The hunting tests were performed on the western leg of Railroad Test Track (RTT), which is located at the TTC as shown in Figure 4-2. This section of the RTT is Class 6 track consisting of 1.0 mile of tangent track with 50 minute curves at either end. The curves have 6 inch superelevation. The test procedure followed was to make constant speed runs over the test section, increasing the speed in 5 mph increments until a hunting condition was reached. Four runs were made at each speed: clockwise and counterclockwise with the A-end leading, and clockwise and counterclockwise with the B-end leading.

(a)



(b)

FIGURE 4-1
TRACK TEST CONSIST WITH (a) CONFIGURATION 6, AND (b) CONFIGURATION 3

TABLE 4-1
WEIGHT AND CENTER OF GRAVITY DATA

TEST	CONFIGURATION	% LOAD	GROSS WT.(3) (lbs)	C. G.(4) (in)
Hunting	3A(1)	95.7	210,100	95.0
	3C	75.9	187,300	87.9
	6(2)	92.5	174,460	84.3
	6	78.9	162,500	84.3
Curving	3A	94.8	209.050	94.5
	3C	79.7	191,650	89.0
	6	78.8	162,400	84.3

(1) Configuration 3 is two MC 307 cargo tank trailers on the 89-foot flatcar.
(2) Configuration 6 is two IM 102 portable tanks on 20-foot chassis trailers on the 89-foot flatcar.
(3) Weight data from measurement on scales.
(4) Height from top of rail.

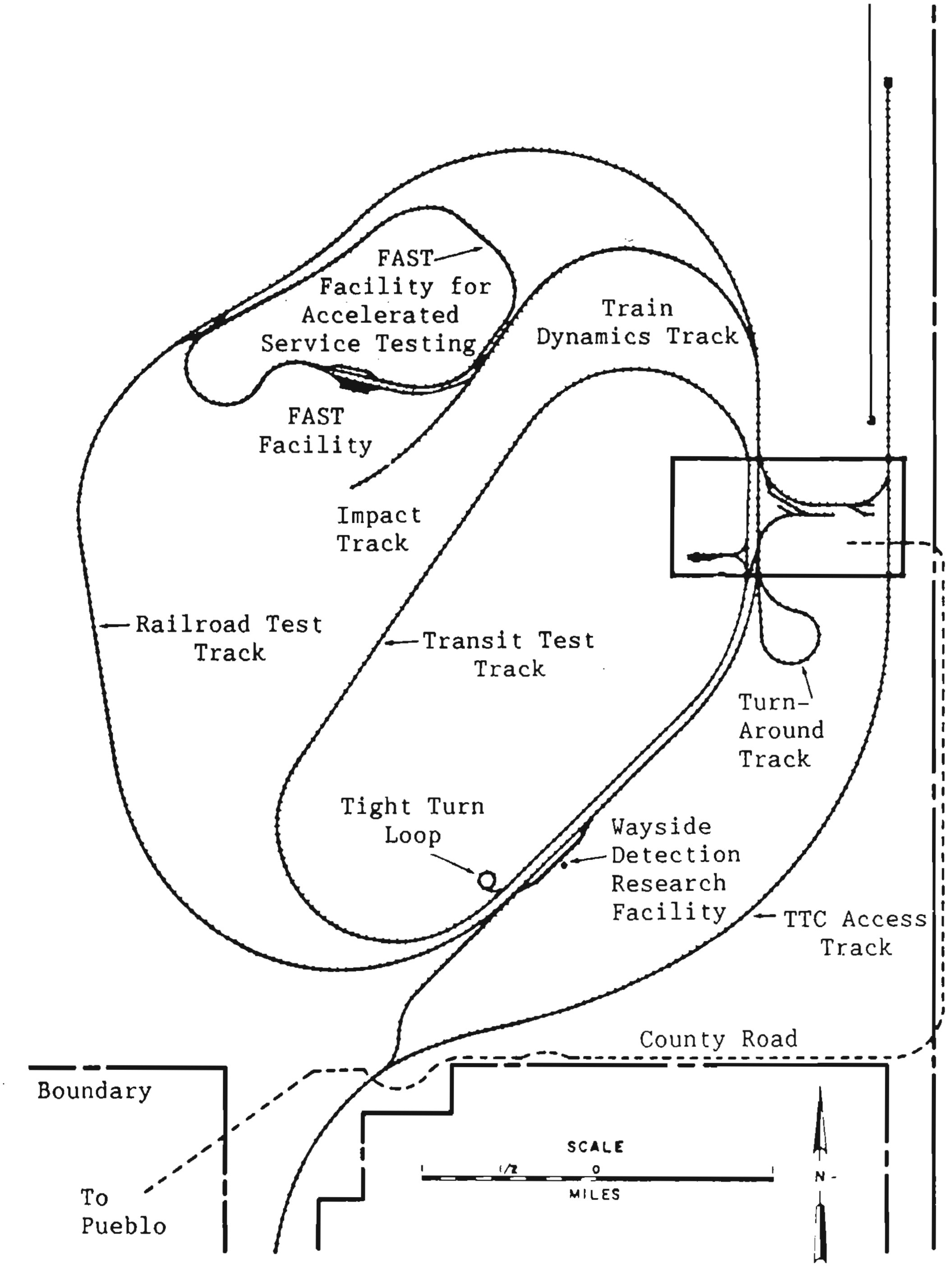


FIGURE 4-2
TEST TRACK LAYOUT AT THE TRANSPORTATION TEST CENTER

The curving and perturbed track (harmonic roll) testing was performed on the Turn-around Track shown in Figure 4-2 which is also known as the Balloon Loop or Balloon Track. The curving tests were performed in constant speed runs in 5 mph increments with a 40 mph safe speed limit. The four combinations were performed of A and B-ends leading for clockwise and counterclockwise travel around the loop.

The perturbed track testing was performed in conjunction with the curving tests by the addition of runs between 10 and 20 mph in 2 mile per hour increments. Intermediate speed runs were made to identify critical speeds more precisely.

The Balloon Loop has a bunched spiral entry, 7.5 degrees curvature with 4.5 inches superelevation. The reverse curve at the other end of the loop is 5 degrees with 3 inches superelevation.

Instrumentation installed on the test vehicles and buffer cars measured wheel forces, axle and carbody accelerations, and accelerations, displacements, and roll angles of the trailers. Selected measurements were displayed in real time on an eight channel strip chart recorder on the instrumentation car. All channels were digitized and recorded on digital tape for post test processing.

4.3 Track Test Results

The test results are presented and discussed in this section for the hunting, curve negotiation, and harmonic roll on curved track.

4.3.1 Hunting

The objective of the hunting tests was to show the effect that liquid lading has on TOFC hunting performance. In the absence of a baseline vehicle, this objective was accomplished by measuring vehicle response over a range of speeds and qualitatively assessing the influence of the liquid by the characteristics of its motions. Synergistic liquid motions would be considered harmful in that hunting speed is lowered or amplitudes of hunting motion are larger, or both.

A summary of the results from the hunting tests are presented in Table 4-2. The TOFC configurations with portable tanks on chassis trailers reached the hunting threshold at 65 mph when running with the A-end leading and 70 mph with the B-end leading. Results with MC cargo tank trailers were similar except that the hunting threshold appeared to be higher than 65 mph with the A-end leading. The empty flatcar hunting threshold was found to be at 45 mph. The buffer cars reached hunting thresholds at about 60 mph and seemed to be degrading as the test progressed. Because of concern for the buffer car hunting condition, not all tests were continued to the hunting threshold of the test car.

TABLE 4-2
HUNTING TEST RESULTS SUMMARY

CONFIGURATION	LEADING END	HUNTING THRESHOLD SPEED (mph)	DESCRIPTION
6 (92.5%)	B	70	At or near hunting critical speed
	A	65	At hunting speed
6 (78.9%)	A	65	Hunting in test (tangent track) section
	A	55	Hunting in curve section approaching test section
Empty Flatcar	A	45	Hunting
3A (94.8%)	A	65	Near hunting - lead buffer intermittent hunting 60-65
3C (75.9%)	A	65	Near hunting - lead buffer intermittent hunting
3C (75.9%)	B	70	Some hunting motion but relatively steady - lead buffer still intermittent hunting

There were three characteristic frequencies found in the accelerometer and wheel force data. These frequencies are shown in Figure 4-3 plotted against track speed. The lowest frequency was between 1.0 and 1.1 Hertz and corresponds to the first yaw mode for this configuration. The middle frequency ranged from 1.0 to 2.5 Hertz with corresponding speeds from 30 to 70 mph and was the predominant hunting motion of the vehicles. The third frequency ranged from 2.0 to 4.0 Hertz for the same speed range. It should be noted that hunting motions occur at all speeds but have relatively small amplitudes and damp out after a few cycles at speeds below hunting. As the hunting threshold is approached the amplitudes increase and continue for a greater number of cycles. In full hunting the amplitudes are limited by gage clearance and the motions continue indefinitely. The hunting motion was a coupled body yaw and second roll with a nosing tendency, that is the leading end was at a larger amplitude than the trailing end. The motion of the third frequency is believed to be an occasional burst of coupled yaw, second roll and body twist with both ends at about equal amplitude.

There was an unexpected result in that there appeared to be a tendency for the hunting threshold to be at lower speeds in the curved track just before the test section of tangent track. This was most noticeable with the 80 percent full portable tank on chassis trailer, where hunting was at 55 mph in the curve and 65 mph in the tangent track.

No explanation can be given with confidence for the lower hunting speed in the curve. The track is Class 6. Balance speed in the curve is 110 mph. Because of the long distance between truck centers (66 feet) and because of the poor steering properties of the truck, the lead axle will want to ride the high rail even at speeds below balance. It may be that there is a critical speed below balance where the gravity force pulling the truck to the low rail and the tendency for the truck to steer into the high rail interact in such a way as to result in a reduced hunting speed in the curve.

Lateral/vertical wheel force ratio, axle lateral accelerations, carbody and trailer lateral accelerations, all had significant increases in value at hunting speeds and are seen to be good indicators of hunting. Axle and carbody accelerometers are useful measurements not only in that they will indicate the onset of hunting but also they will facilitate distinction of truck hunting, nosing, and body hunting.

Trailer wheel vertical displacements were fairly constant at about 0.4 inches peak-to-peak, and the liquid slosh amplitudes were between 5 and 15 inches peak-to-peak without any consistent pattern. Neither seem to be affected by the onset of hunting. Lateral accelerations of the trailers on the buffer cars indicate that the hunting onset of these cars was between 55 and 60 mph.

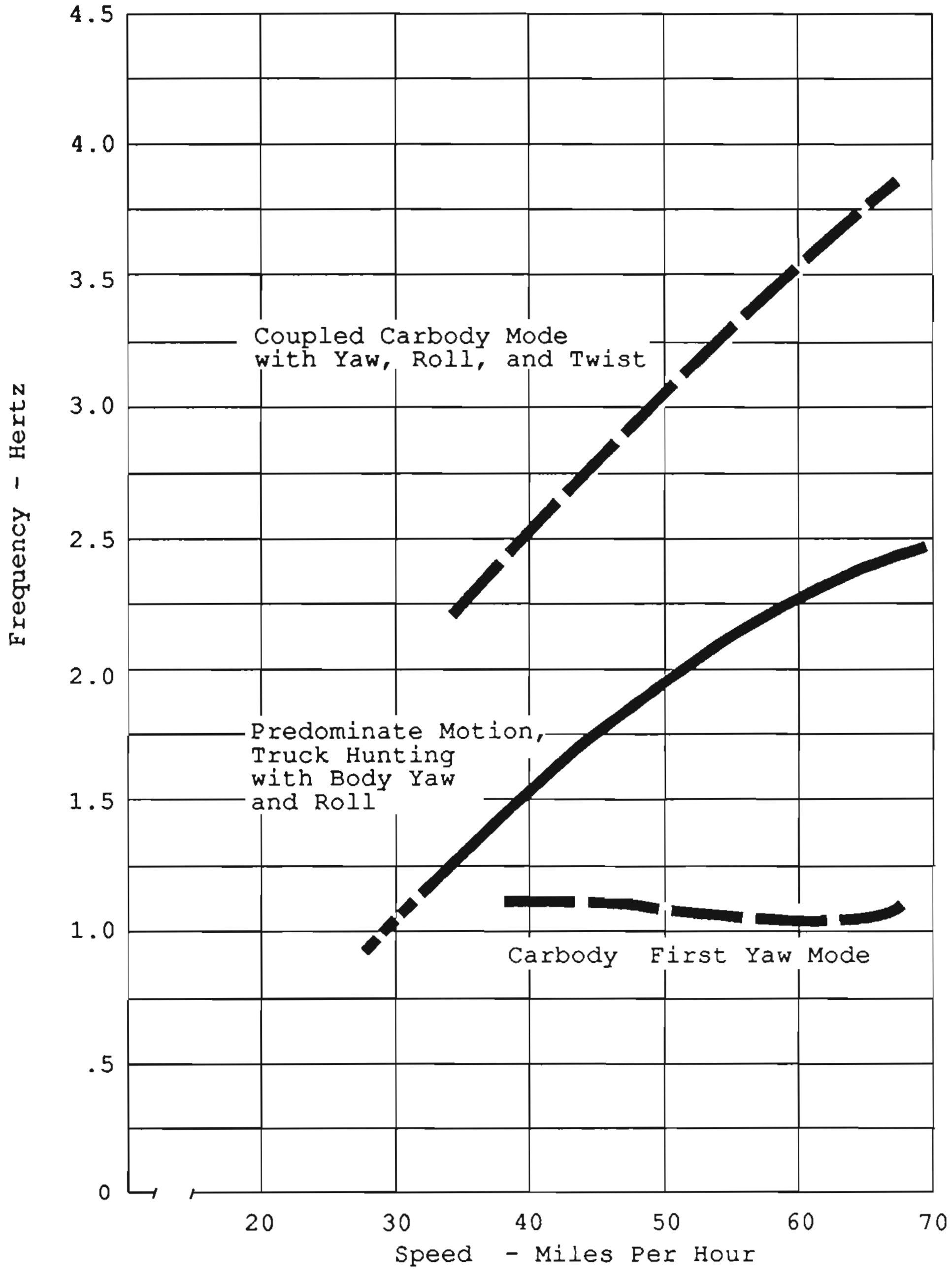


FIGURE 4-3
FREQUENCY CONTENT OF VEHICLE MOTIONS AT HUNTING SPEEDS, COMPOSITE OF ALL CONFIGURATIONS

The following observations are based on the hunting test results:

- The threshold of hunting for the intermodal configurations tested was no less than 65 mph on tangent track.
- The severity of the hunting motion appeared to increase rapidly when the speed was increased beyond the threshold.
- Hunting was experienced in the curved track leading into the test section at speeds as low as 55 mph. However, this curve hunting was not consistent.
- Although there were motions of the liquid lading (water), they were not large, had no consistent pattern, and did not seem to be affected by the hunting motions.

4.3.2 Curve Negotiation

The curve negotiation tests were performed with the objective of identifying unsafe conditions for intermodal hazmat on curved track. The tests were performed on the Turn-around track (Balloon Loop) shown in Figure 4-2 and Figure 4-4. Steady state curving, curve entry, curve exit, and bunched spiral were to be investigated. The data presented and discussed here are from accelerometer and instrumented wheel set measurements.

The Balloon Loop, diagramed in Figure 4-4, has a 7.5 degree curve with 4.5 inches superelevation in the main loop and 5 degrees in the reverse curve with 3 inches superelevation. The balance speed for both curved sections is 30 mph. In the standard spirals the curvature and superelevation changes were both accomplished in 300 feet. In the bunched spiral the curvature change was in 300 feet but superelevation was accomplished in the middle 100 feet of the spiral as a duplication of track conditions frequently found in service.

The loop was marked in 100 foot stations with station 0 at the start of the 7.5 degree curve. The stations marking the spiral points, going around the loop in a counter clockwise direction are given in Table 4-3.

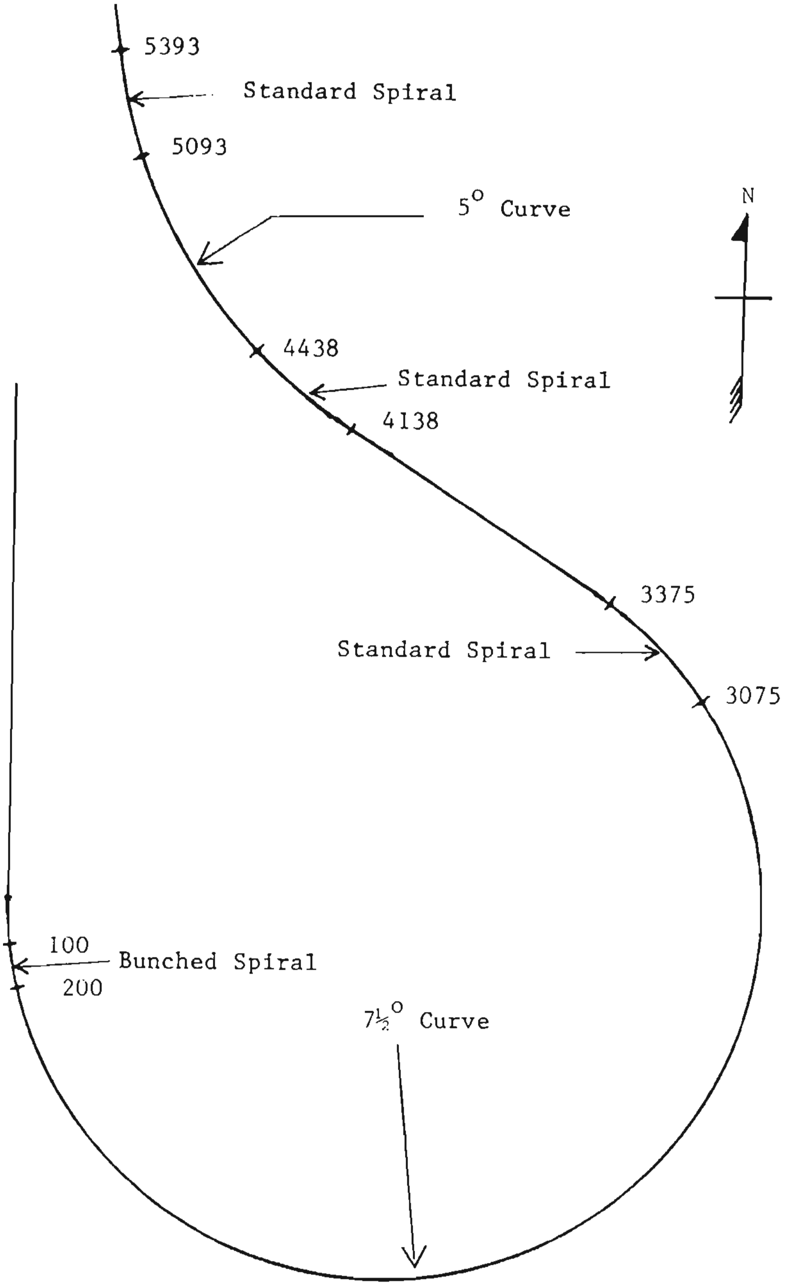


FIGURE 4-4
BALLOON LOOP SHOWING LOCATIONS OF SPIRAL TRACK

TABLE 4-3
LOCATION OF SPIRAL POINTS IN BALLOON LOOP

POINT	STATION (100 ft)
Point of Spiral - Tangent	0
Start Superelevation Change	1
End Superelevation Change	2
Point of Spiral - 7½° Curve	3
Point of Spiral - 7½° Curve	30.75
Point of Spiral - Tangent	33.75
Point of Spiral - Tangent	41.38
Point of Spiral - 5° Curve	44.38
Point of Spiral - 5° Curve	50.93
Point of Spiral - Tangent	53.93

The accelerometer and wheel loads data were 30 Hertz low pass filtered and were analyzed in samples that covered 200 feet of track length, with read-outs of maximums, minimums, max. minus min., mean, standard deviation, and root-mean-square values for each sample. The accelerometer data are also summarized in Figure 4-5. Based on this accelerometer data the following observations are made.

- The largest accelerations were experienced in the 5 degree curve entry and exit.
- There was little difference between bunched and standard spiral except that the highest lateral g values in the 7.5 degree curve were experienced in the standard spiral entry.
- Carbody and axle lateral accelerations were consistently at higher g values than trailer lateral accelerations.
- Carbody lateral accelerations were generally higher than for the wheel set.
- There were no significant differences in responses between configurations 3A and 6.

Two general conclusions are indicated by this accelerometer data: 1) since trailer response was less than carbody response, liquid lading seems to have a dampening effect on transient responses during curve entry and exit; and 2) bunched spirals do not worsen the lateral transient responses during curve entry and exit.

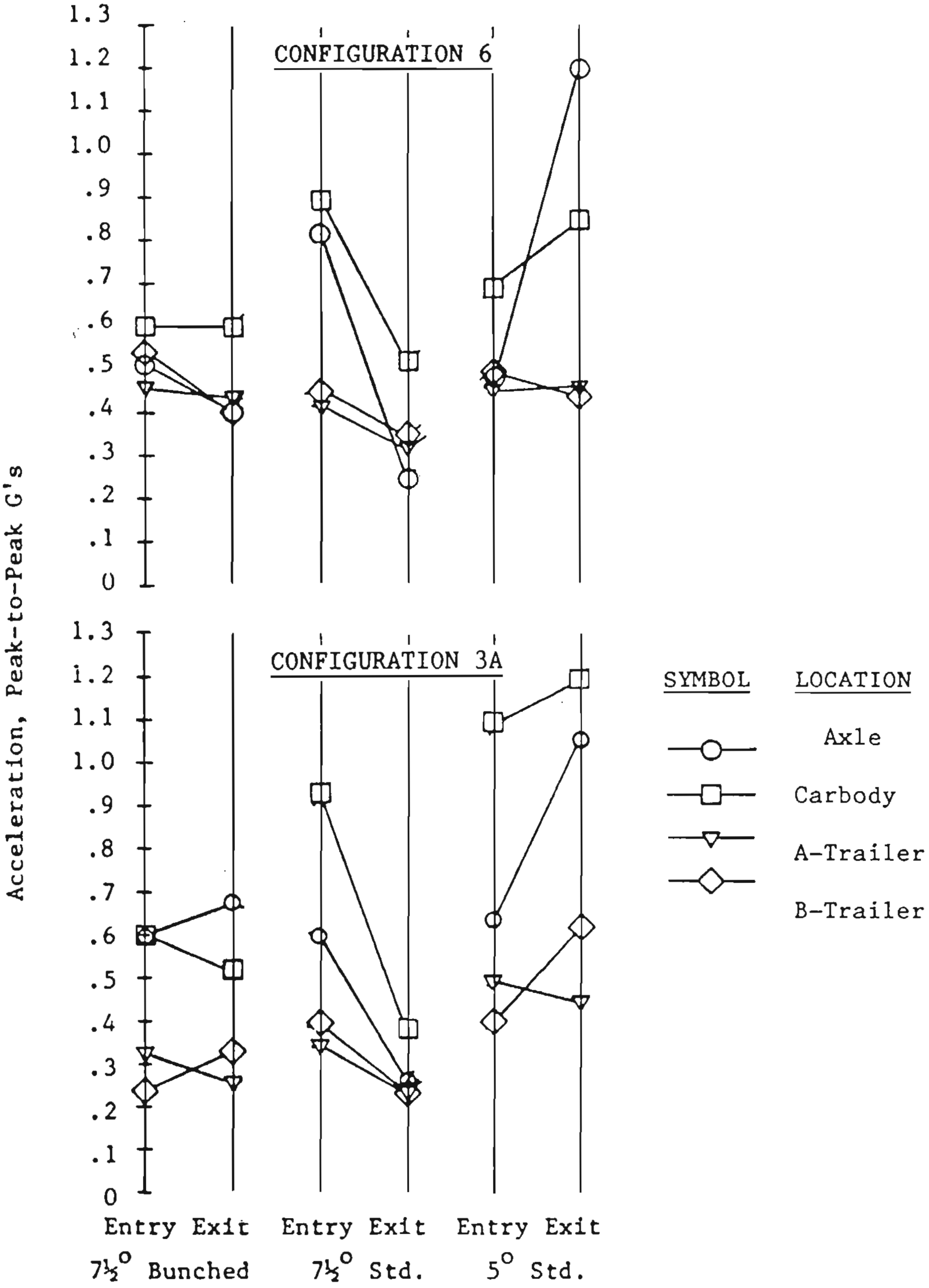


FIGURE 4-5
SUMMARY OF LATERAL ACCELERATION DATA FROM FOUR ACCELEROMETERS DURING CURVE ENTRY AND EXIT

In the investigation of steady state curving, the objective was to show if the liquid lading had any adverse effects. It had been envisioned that centrifugal forces would cause an outward shift of liquid above balance speeds and an inward shift below balance speeds. However, measurements of the liquid motions, acceleration forces, and wheel forces due to the centrifugal effects were all masked by larger transients from other causes. Consequently, there were no experimental data that could be used for steady state curving evaluation. A study that would analytically determine the change in vertical wheel forces due to shifting liquid and the effect of these changes on curving would be an appropriate approach to study the problem. Such an analytical study would also be a convenient way to show the effects of outage changes.

4.3.3 Harmonic Roll on Curved Track

The objective of this test was to show the influence of liquid lading on the harmonic roll performance of TOFC configurations on curved track and to identify unsafe conditions.

A description of the Balloon Loop perturbed track is presented in Figure 4-6. The perturbed section is roughly 400 feet long with 10 perturbations in each rail as shown in the figure. Track geometry measurements were made, using the T-6 vehicle to load the track, just prior to the test. The cross levels at the maximum perturbations were measured to be between 0.65 and 0.86 inches, with an average value of 0.73 inches.

The harmonic roll tests consisted of traversing the perturbed track test section in constant speed runs covering the speed range from 10 to 40 mph. Responses were measured and recorded. Figures 4-7 and 4-8 present representative results.

The data show that there were two critical speed ranges. The first one was in the usual range of 12 to 16 mph, corresponding to the first roll mode, and the other between 25 and 35 mph, apparently corresponding to the trailer roll modes.

The minimum vertical loads from the instrumented wheel set data show no significant unloading, indicating that wheel lift was not close.

The trailer roll angles, Figure 4-8, reached maximums of 4 degrees peak-to-peak in the first roll mode, and 3 degrees in the trailer roll mode. These are relatively mild responses for the perturbed track test.

The vertical displacement data for the trailer wheels reached values of 1.05 inches peak-to-peak in first roll and 1.22 inches peak-to-peak in trailer roll. These displacements are close to wheel lift conditions based on vibration tests in the Rail Dynamics Laboratory where it was estimated

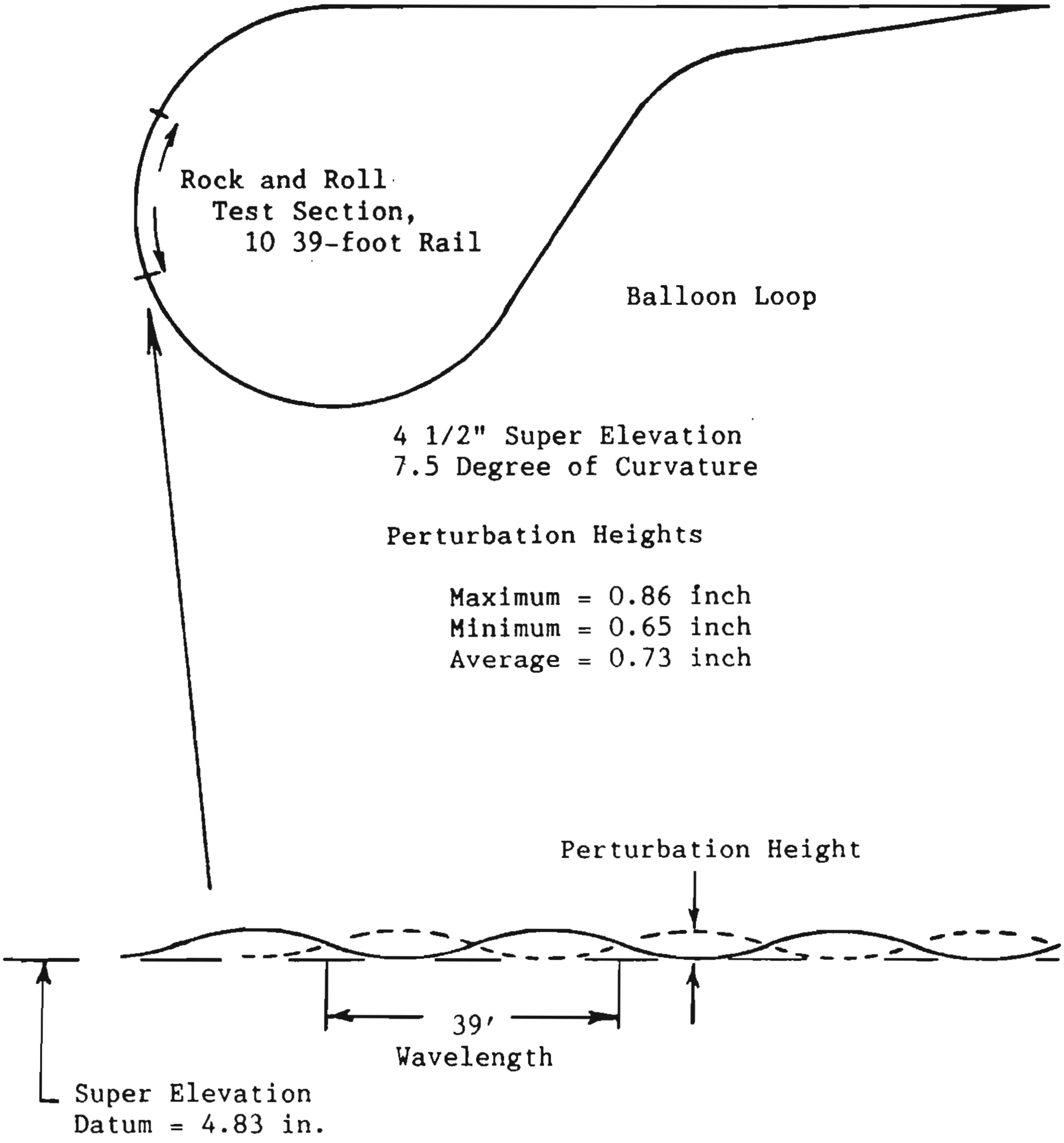


FIGURE 4-6
DESCRIPTION OF STAGGERED RAIL PERTURBED TRACK IN BALLOON LOOP

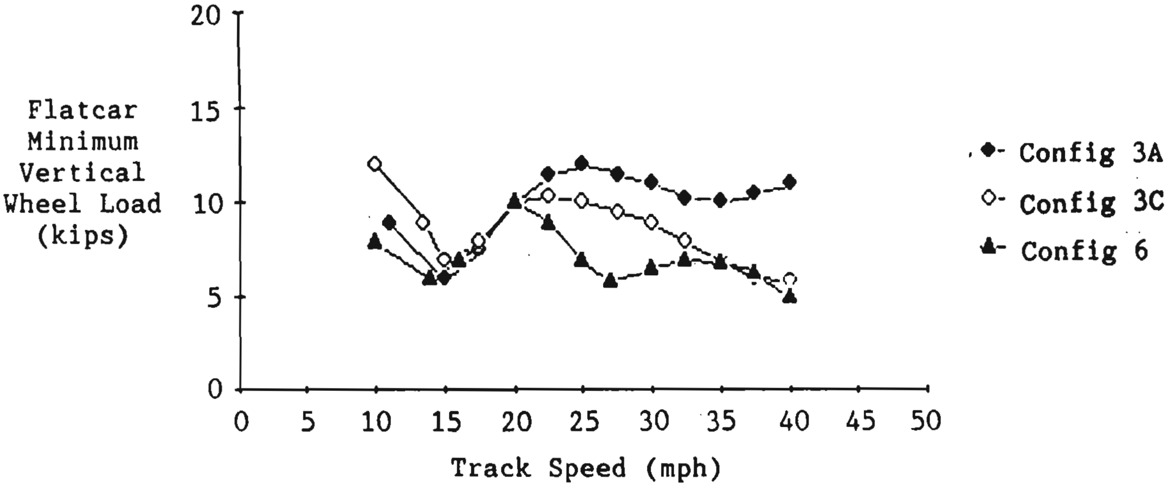


FIGURE 4-7
CONFIGURATIONS 3A, 3C, AND 6 BALLOON TRACK,
PERTURBED SECTION MINIMUM VERTICAL WHEEL-RAIL FORCES

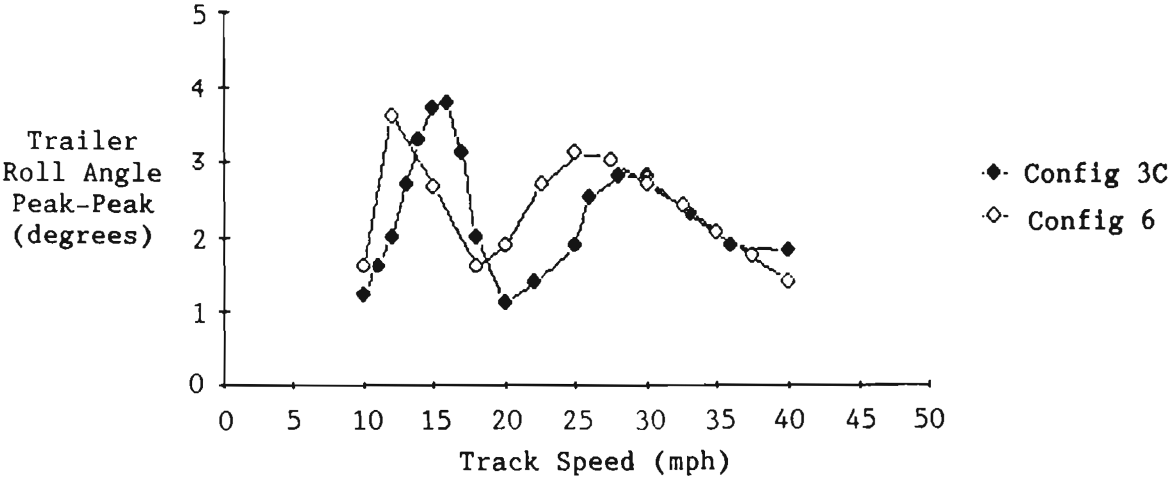


FIGURE 4-8
CONFIGURATIONS 3-C AND 6, BALLOON TRACK, PERTURBED SECTION
TRAILER ROLL ANGLES

that trailer wheel lift occurred between 1.2 and 1.4 inches peak-to-peak displacement measured at the axle.

4.4 Conclusions

The hunting tests revealed no unusual behavior of the TOFC configurations with liquid lading tested. Hunting tests made with the same flatcar but with van trailers and solid lading resulted in the same hunting threshold speeds, that is, between 65 and 70 miles per hour. Although there were motions of the liquid lading indicated by the slosh measurements, they were not large, they occurred at all speeds with no consistent patterns, and they did not seem to be affected by the hunting motions. This indicates that the liquid motions are not synergistic with the hunting motions and may actually have dampening effects.

The hunting motions that were experienced in the 50 minute curve leading into the hunting test section are of some concern. Although further investigation is desirable, this is not perceived as a problem peculiar to liquid lading.

The fact that trailer responses were less than carbody responses during curve entry and exit is viewed as an indicator that the liquid lading has a dampening affect. The data also indicated that bunched spiral do not worsen lateral transient responses during curve entry and exit.

The harmonic roll test performed on 7.5 degree curved track with 4.5 inches superelevation showed TOFC with liquid lading to be well behaved in comparison to other freight car configurations. That is, maximum roll angles were 3 degrees peak-to-peak for the carbody and 4 degrees for the trailers compared to the 6 degree maximum considered acceptable for the perturbed track test. Sloshing of the liquid apparently has a dampening effect. Two critical speeds were identified: 12-16 miles per hour where the motion was in the first roll mode; and 25-35 mile per hour where the motion was trailer roll. Although trailer roll angles were not large, reaching a maximum value of 4 degrees peak-to-peak, the vertical displacement of the tandem wheels were close to a wheel lift condition.

5.0 ACCIDENT SIMULATION

The second general objective of this research program was to observe the behavior of the intermodal hazmat configurations under accident conditions and to assess their survivability. This was accomplished through simulations, performed at the TTC in Pueblo, Colorado, of two accident scenarios: broken rail derailments and accordion derailments. The results of these tests, six broken rail and one accordion, have been documented in References [6] through [12] and are summarized in this section of this report. All tests were performed on a tangent section of the Precision Test Track (PTT) running from east-northeast to west-southwest on a slight downgrade.

Broken Rail Derailment is one of the more frequent derailment scenarios in the continental USA railroad experience. It is where a piece of rail, several feet in length, has broken out. Derailment occurs when a truck turns into the broken rail and ends up with the wheels on the broken rail side outside the rail and with all four wheels on the cross ties. Depending on a host of circumstances, the derailed car may stay in the train running on the ties, may be re-railed or may move away from the tracks pulling adjacent cars with it. The test objectives were to simulate this derailment scenario and to observe and measure behavior tendencies of several TOFC/COFC tank configurations over the speed range of 20 to 60 mph.

Accordion Derailment is a frequently occurring pattern of car pileup following a derailment. It occurs when derailment in the forward portion of a train results in an abrupt slow down and stop of the front, and pileup of the back of the train. Figure 5-1, from an actual derailment, [14], is typical of an accordion derailment.

5.1 Description of Derailment Tests

The procedure for these tests was for the locomotive pulling the test consist to accelerate to the desired speed on the approach to the derailing switch. At an appropriately safe distance from the point of derailment the locomotive released the test consist, and accelerated through the switch and away from the accident scene. The derailing switch was armed manually after the locomotive was safely beyond the test area and was activated automatically using trackside optical sensors and triggering reflectors mounted on the sides of the test cars.

The Broken Rail Derailment Test Consist had three buffer cars leading a single test flatcar. The derailing switch was thrown so that the last truck of the third buffer car and both trucks of the test flatcar were derailed. The effect of the derailing switch was to cause the right-hand wheels of the derailed trucks to switch from the inside to the outside of the right rail and for all wheels to drop to and run on the cross ties.

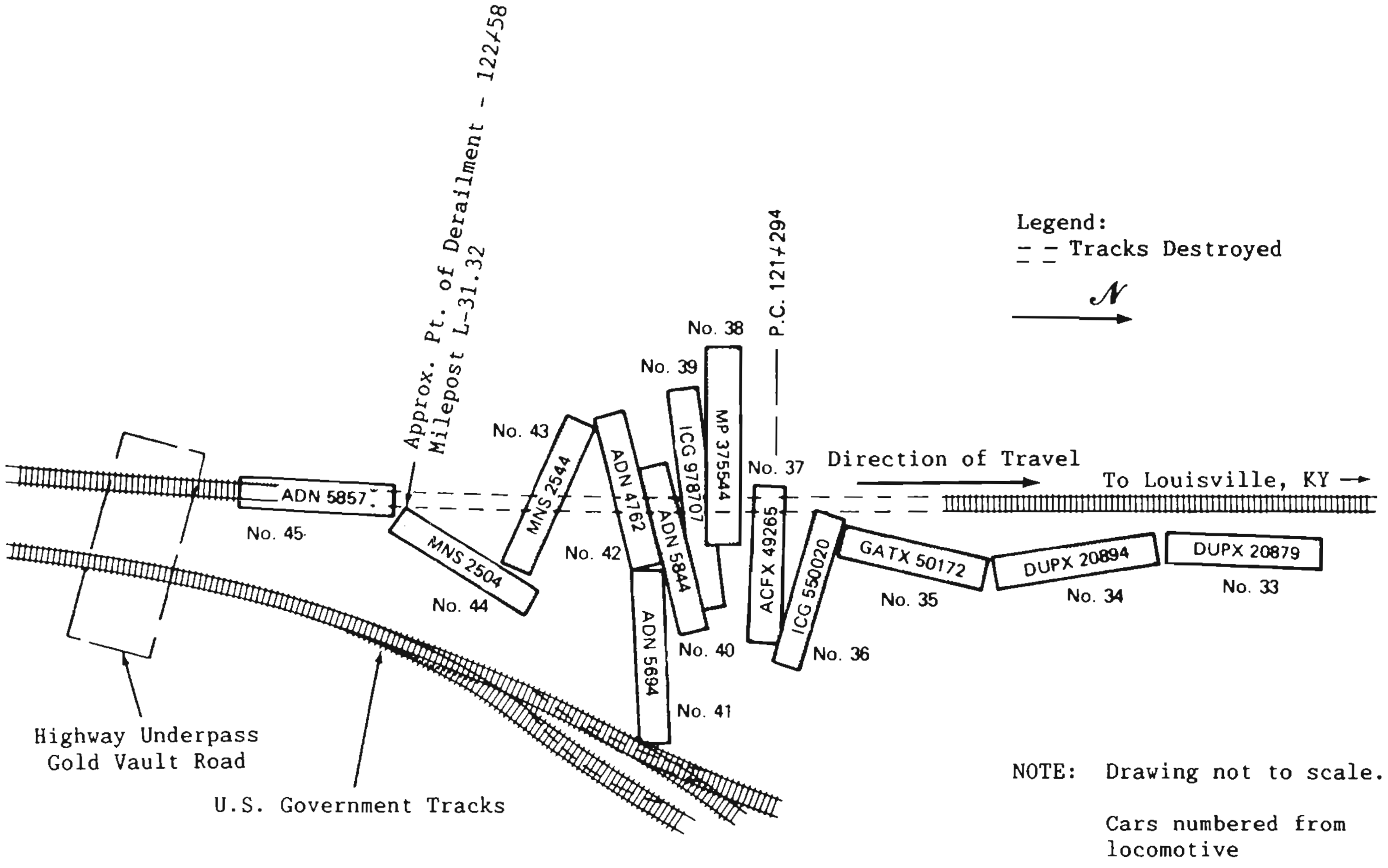


FIGURE 5-1
DERAILMENT OF ILLINOIS CENTRAL GULF FREIGHT TRAIN, LST NO. 64, AT FORT KNOX, KENTUCKY ON MARCH 22, 1983

The Accordion Derailment Test used a five car consist made up of three test flatcars with a leading and a trailing buffer car. The accordion derailment action was forced by automatic activation of the switch into a turnout between the leading and trailing trucks of each car. That is, the first truck went straight, the second and third trucks took the turnout, the fourth and fifth trucks went straight, the sixth and seventh trucks took the turnout and the eighth, ninth, and tenth trucks went straight. The turnout track ended at 245 feet from the point of switch with the net result that the accordion pattern was initiated and then derailment was forced.

Photographs of the derailing switch are shown in Figure 5-2 for broken rail derailment Test 3 and the accordion derailment test.

The Test Flatcar Configurations for the six broken rail derailment tests are shown in Figure 5-3. The track speed of the test consist at derailment is also listed. The chassis trailers used were for 20 foot containers. The test flatcar configurations for the accordion test are shown in Figure 5-4.

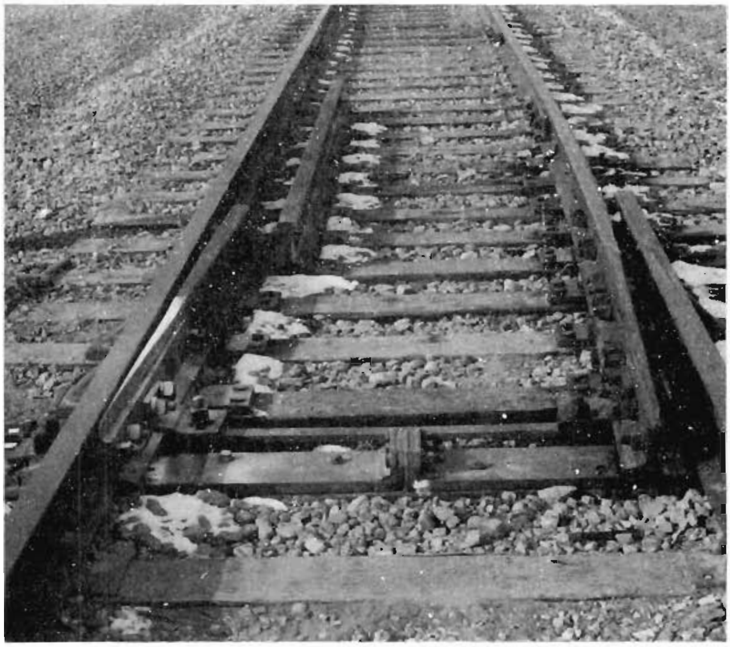
Instrumentation

The on board instrumentation for both the broken rail and accordion derailment tests consisted of axle mounted tachometers to measure car speed, accelerometers mounted on the test tanks as well as on the flatcar bodies, liquid slosh gages and displacement measuring string potentiometers to detect when the tanks separate from the flatcars. Signals from these measurements were filtered with 500 Hertz low pass filters, transmitted to the receiving station with multiplexed FM telemetry, digitized, and recorded on tape at 2400 samples per second.

In addition to the on board instrumentation a system of video and high speed movie cameras was used. The number of cameras used and their arrangement changed with each test; however, the one for broken rail Test 6 was typical and is shown in Figure 5-5. In Test 6, four video and three high speed movie cameras were used.

5.2 Sequence of Derailment Events, Car and Tank Behavior

A general description is given in this section of the sequence of derailment events and car and tank behavior for the broken rail and accordion derailments. Detailed descriptions can be found in References [6] through [12].


Broken Rail Derailment Test 3

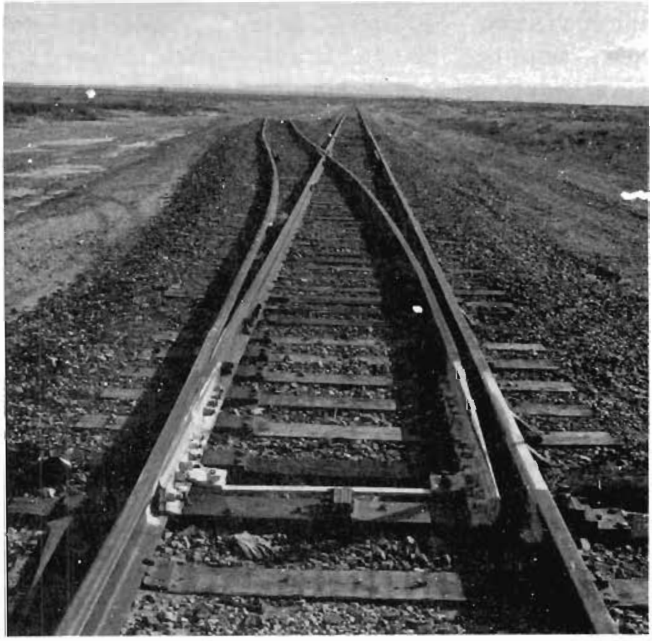

Accordian Derailment Test

FIGURE 5-2
DERAILING SWITCHES

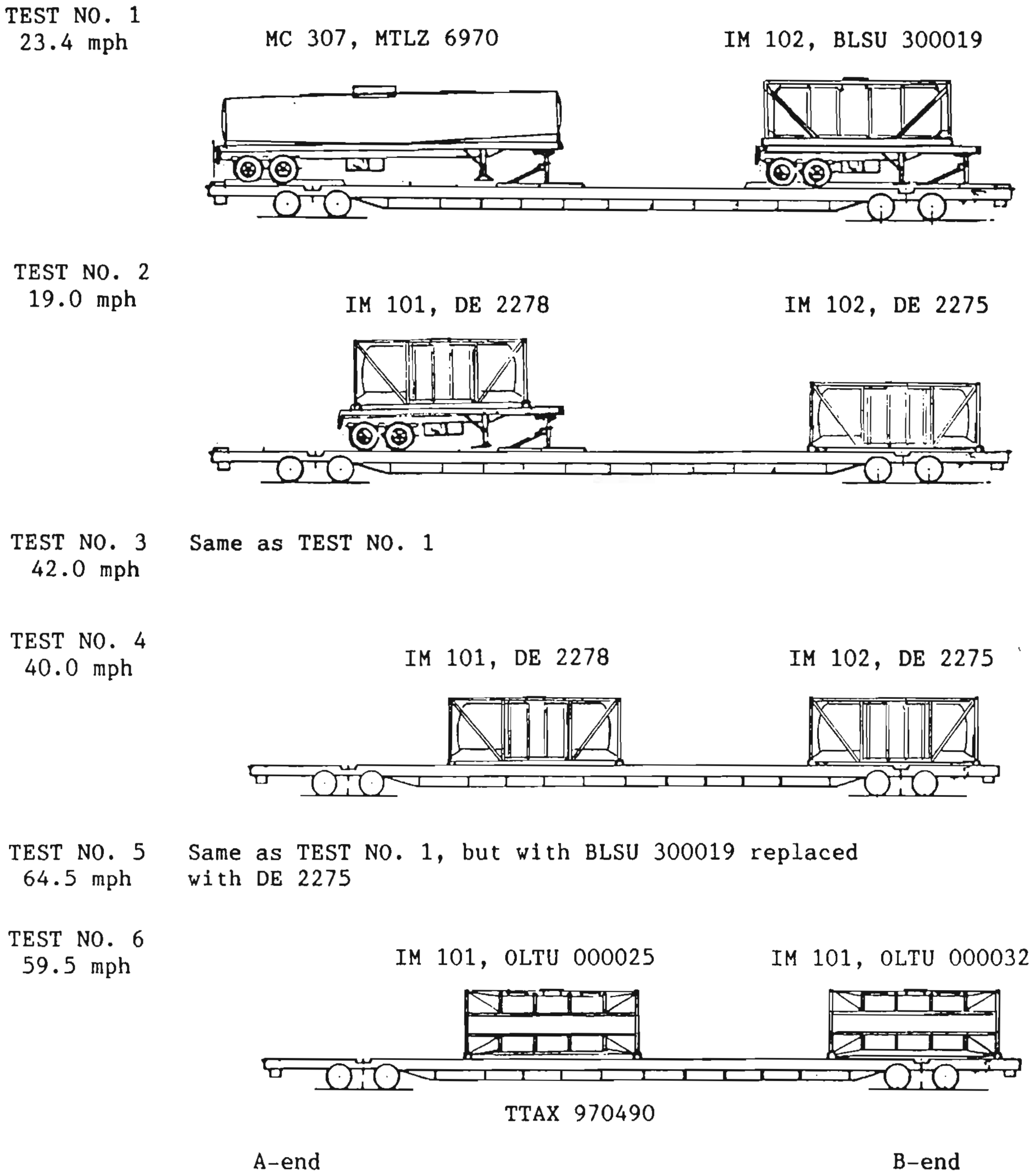
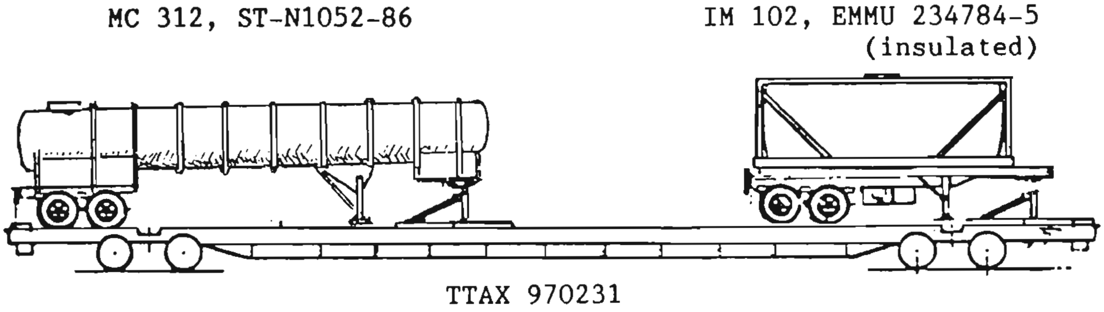
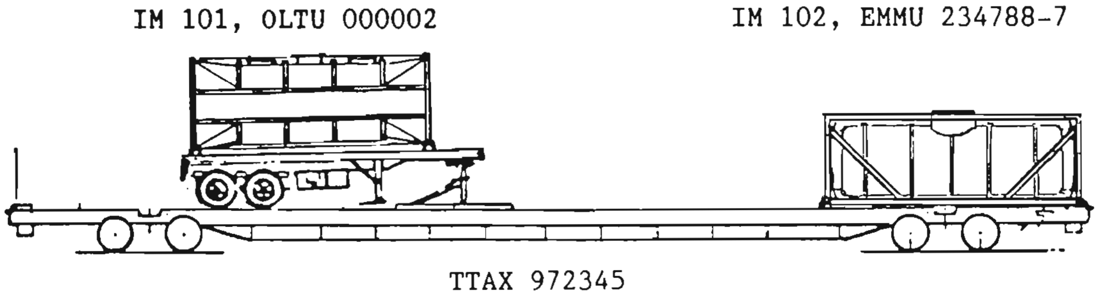


FIGURE 5-3
TEST FLATCAR CONFIGURATIONS, BROKEN RAIL DERAILMENTS

First Test Flatcar



Second Test Flatcar



Third Test Flatcar

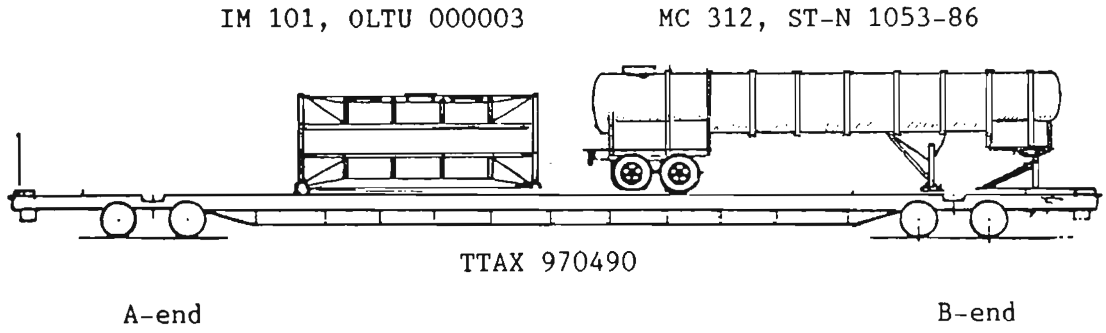


FIGURE 5-4
TEST CAR CONFIGURATIONS, ACCORDION TEST

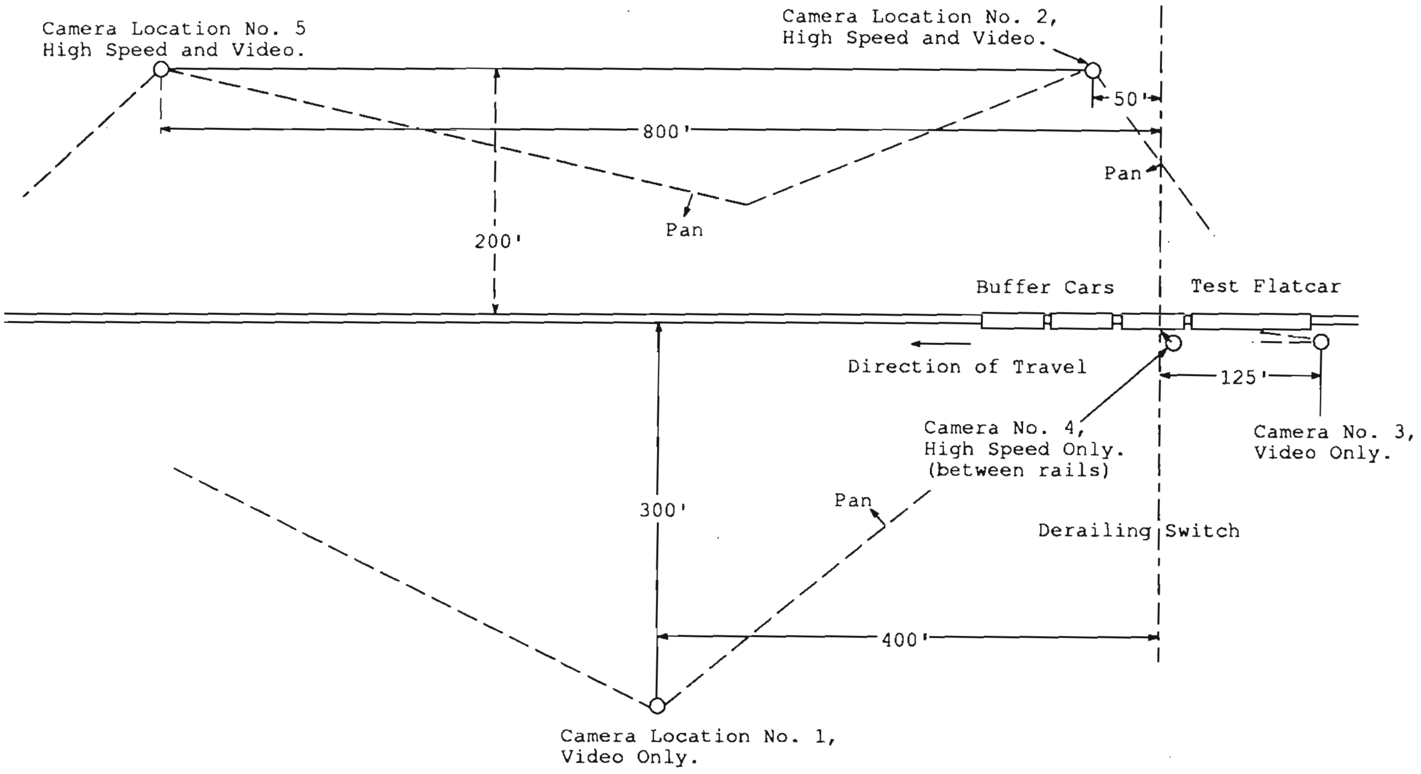


FIGURE 5-5
CAMERA LOCATIONS FOR DERAILMENT TEST NO. 6

In each Broken Rail Derailment, following the derailment, the test car moved to the right, running on the cross ties, until its right wheels ran off the ties and into the ballast, following which the test car tilted far enough to release the MC cargo and/or IM portable tanks. The time and distance from the switch point to the point where the tanks had first ground contact ranged from 3.2 to 8.3 seconds and 160 to 500 feet. The lower speed rollover generally took more time and less distance.

There were several test conditions that varied from test to test that had no significant influence on the derailment sequence of events. These variations are discussed below.

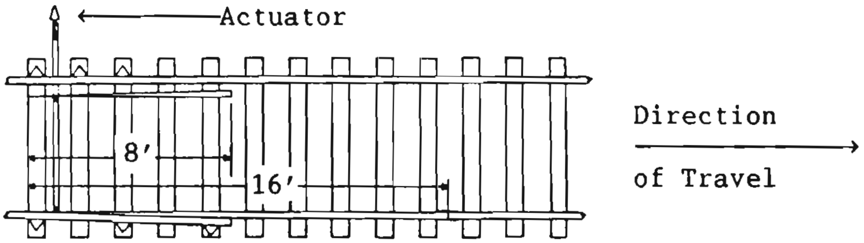
Shelf couplers were used in Tests 3 and 4 with no apparent influence on the post derailment behavior of the test flatcars: they all moved to the right, rolled over, and released the tanks. In Test 1 the test flatcar uncoupled as its A-truck was being derailed. Where shelf couplers were used, Tests 3 and 4, the flatcar did not uncouple. In the remaining three tests (2, 5, and 6) the flatcar uncoupled as it was in its rollover process of releasing the tanks.

There were three changes made to the derailing switch. For Test 3, a guard rail was placed on the gage side of the left rail in an attempt to cause the derailed car to run parallel to the rails rather than move to the right. In Test 4 the right switch point was shortened from 16 to 11 feet to shorten the switch response time. In Test 6, the left switch point (8-foot) was replaced with a 16-foot switch point because it was found in Test 5 that at 60 mph the wheels were climbing the left switch point. Also, a guard rail was added outside the right rail to help keep the derailed car from moving to the right. Diagrams of the derailing switch in its several configurations are shown in Figure 5-6.

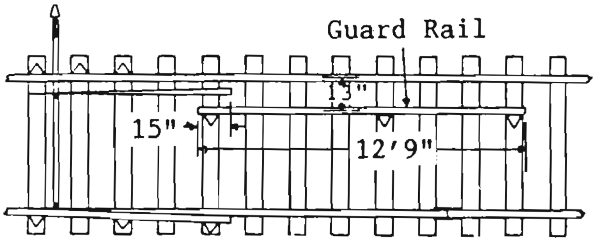
A 29,000 gallon tank car was used in Test 4 as the third buffer car, because its long wheel base would allow more time for derailing switch actuation. This car was in an overload condition of 30 percent above its maximum gross weight allowable. The tank car rolled over at the same time as the test flatcar. Because of the shelf couplers and because the tank car was nearly twice the gross weight as the test flatcar (313,900 compared to 160,650 lbs.) the tank car may have aided the flatcar in its rollover. In any case the tank car did not have the stabilizing influence that had been expected of it.

The Accordion Derailment proceeded as expected for the most part. The switch automatic operation was exactly as planned. In this derailment the leading buffer car rotated in yaw counterclockwise and each succeeding car alternately rotated clockwise and counterclockwise forming the desired accordion pattern. It had been anticipated that the leading buffer car would stop abruptly and help shorten the pile up of cars. However, the

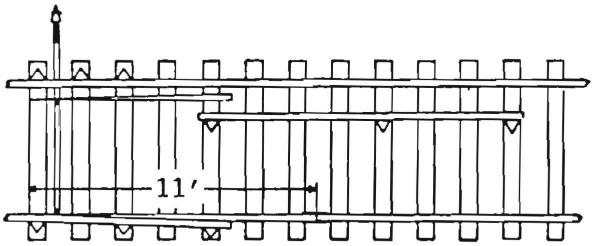
TESTS 1 and 2



TEST 3 Guard rail added inside left rail.



TESTS 4 and 5 Right switch point shortened to 11 feet.



TEST 6 Left switch point lengthened to 16 feet and guard rail added outside right rail.

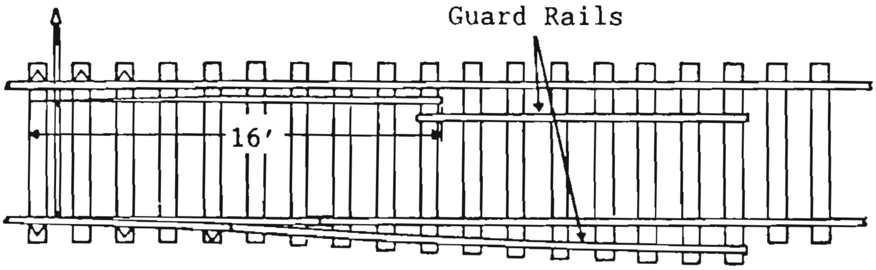


FIGURE 5-6
DERAILING SWITCH CONFIGURATIONS FOR THE BROKEN RAIL DERAILMENTS

leading tank car did not stop with the rest of the consist but uncoupled and continued down track for about 500 feet beyond the other cars.

Except for one 20-foot chassis trailer, all trailers were ejected from the test flatcars and all portable tanks broke free of their attachments to trailer and/or flatcar. The lateral, longitudinal, and rotational deceleration forces were large enough to cause failures to attachments.

The MC Cargo Tank Trailers, both the MC 307SS used in the three broken rail derailments and the two MC 312's used in the accordion derailments, were separated from the flatcars in every test. In the broken rail derailment, the separations were a result of the flatcar tilting and the cargo tank rolling off with failure of the hitch kingpin. In the accordion test the kingpin did not fail but remained secured to the hitch stantion. Instead, the welded assembly on both trailers, to which the kingpins attach, were torn away from the trailers.

The two MC 312 cargo trailers in the accordion derailment test were mounted on the leading end of the first flatcar (1A) and on the trailing end of the last flatcar (3B). Both the first and third test flatcar moved clockwise in the accordion scenario and rolled (tilted) to their left. Both cargo tanks rotated 270 degrees in the roll direction apparently the result of lateral deceleration forces. (The cargo tanks in the broken rail derailment rolled 90 degrees from their upright position on the flatcar to their final position on the ground.)

The IM Portable Tanks in COFC in every case came away from the flatcar. Where the forces on the pedestal connections were perpendicular and away from the flatcar deck (e.g., on the left side when rolling to the right), the separations were clean and with no failures. Where there were moments and shear forces applied to the pedestals (e.g., on the right side pedestals when rolling to the right and when ground contact was made with forward velocity while still connected) there was breakage of the pedestals and failures of the flatcar deck local to the pedestal attachment as well as damage to the corner castings of the portable tank frame structure.

IM Portable Tanks on 20-Foot Chassis Trailers were used in four of the broken rail derailment tests (1, 2, 3, and 5) and two were used in the accordion test. In Tests 1 and 2, the flatcar had stopped as it was rolling over and the tanks stayed attached to the chassis trailers as they fell to the ground. In the other cases the tanks and trailers had forward velocities of no less than 20 mph when the tanks made ground contact, whereupon the tanks broke away from the trailers. The attachment failure was generally of the pin in the twist lock with a few cases of failure of the chassis trailer fitting and its local structure.

The experience of the 20-Foot Chassis Trailers in the derailment testing varied. In Tests 1 and 2, when the flatcars tilted the trailer kingpin failed and the trailers fell to the ground. In Test 3, the chassis body broke in two, the result of the tandem end hitting first the ground and then the MC cargo tank: the hitch half staying with the flatcar and the tandem half flying through the air to a maximum height of about 20 feet and covering a distance of about 100 feet.

In derailment Test 5, the chassis trailer frame was severely twisted and bent but remained attached to the flatcar.

Of the two 20 foot chassis in the accordion derailment test, one remained attached to the flatcar while the other separated at the hitch. The frame of the one that remained attached was severely bent and twisted. The failure at the hitch of the chassis trailer that separated was of the welded assembly on the chassis that holds the kingpin. The kingpin and a portion of the welded assembly remained with the flatcar.

5.3 Description of Damage, Derailment Testing

A description is given in this section of damage sustained by each tank in the derailment testing with the underlying objective of assessing each tank design as to its ability to survive derailment without liquid cargo spillage.

5.3.1 Damage Sustained by MC Cargo Tanks

The MTLZ 6970 Cargo Tank Trailer was built to AAR specifications M-931 and also complies to DOT MC 307SS. It has a maximum capacity of 6900 U.S. gallons. Its cross section is circular, 72.5 inches inner diameter (ID) at the center and tapering to 60.0 inches ID at the ends. The overall length of the tank is 484 inches. The tank material is T-316LSS with thicknesses of 7 gage on the end domes and 8 gage on the shell. The tank is insulated with a fiberglass blanket covered with a stainless steel jacket. It should be noted that the minimum gage required to comply with MC 307SS is SG 13 for both head and shell. Nominal thickness for gages 7, 8, and 13 are 0.1838, 0.1685 and 0.0919 inches respectively.

MTLZ 6970 was used in broken rail derailments 1, 3, and 5 where speeds at derailment were 23.4, 42.0, and 64.5 mph respectively. The sequence of events in each of these three tests were essentially the same: the flatcar tilted to the right until the tandem started to slide off the flatcar deck, the kingpin failed, and the tank fell to the ground. Speeds of the cargo tanks at ground impact were 0, 25 and 40 mph for Tests 1, 3, and 5 respectively. Although most of the general damage to the tank was due to ground impact, the single, most damaging blow was inflicted by a chassis trailer in Test 3. In this test the MC 307 was mounted on the A-end of the test flatcar and an IM portable tank was on the B-end mounted on a 20-foot chassis trailer. In the sequence of events the portable tank and cargo tank trailer rolled off, but the chassis trailer continued with the flatcar. With the MC 307 lying on its side on the ground and the flatcar still moving at about 20 mph, the tandem end of the chassis trailer swung off the flatcar deck and struck a severe blow to the dome of the cargo tank. This impact was severe enough to cause one of the chassis axles to break off and for the chassis body to break in two. The flatcar was still coupled to the three buffer cars and all of the inertia of these four cars was behind the chassis trailer's blow to the MC cargo tank.

In addition to the three broken rail derailments, this tank was used in the yard impact, lift and drop tests reported in Section 3 of this report and was also involved in two minor unintentional accidents following Test 1. In the first of these unintentional accidents, the loaded tank was standing on its landing gear on soft ground when the ground gave away, the landing gear buckled, and the hitch end of the tank fell to the ground. In the second incident, the trailer was being moved at the TTC when the hitch end, with the broken kingpin, slipped off the tractor and fell to the ground.

Kingpin Failure was the same in all three derailment tests: pieces of the shoulder at the end of the pin were broken off allowing the pin to come out of the slot in the hitchplate. A photograph of each of these three failed kingpins is shown in Figure 5-7.

Damage to the cargo tank trailer in general was extensive, some of which can be seen in Figures 5-8 through 5-12. The tandem structure was twisted and fractured, the landing gear had collapsed, the thermal covering was in shreds, the tank reinforcing ring at the tandem end of the tank was bent and split at the weld (Figure 5-10) and the tank had dents and buckles local to this ring, the lifting pads and their structural attachments to the tank were bent and buckled and had split welds, and finally the tank itself had many dents and buckles as shown in the photographs of Figure 5-12.

Leak checks were made on the tank after each test and, despite the extensive damage sustained, the tank itself did not leak and had no apparent cracking of the shell. However, there were leaks following each derailment in which the MC 307 was used: in Test 1 a vacuum relief vent leaked at an estimated rate of between 10 and 15 gallons per minute; in Test 3 the manhole cover leaked and the cap on a cleanout leaked; and in Test 5 the manhole cover again leaked. These leaks may not have been caused by the derailment but may only have become evident after the test because the tank lay on its side at the end of each test.

Test No.

1

3

5

FIGURE 5-7
MC 307 FAILED KINGPINS

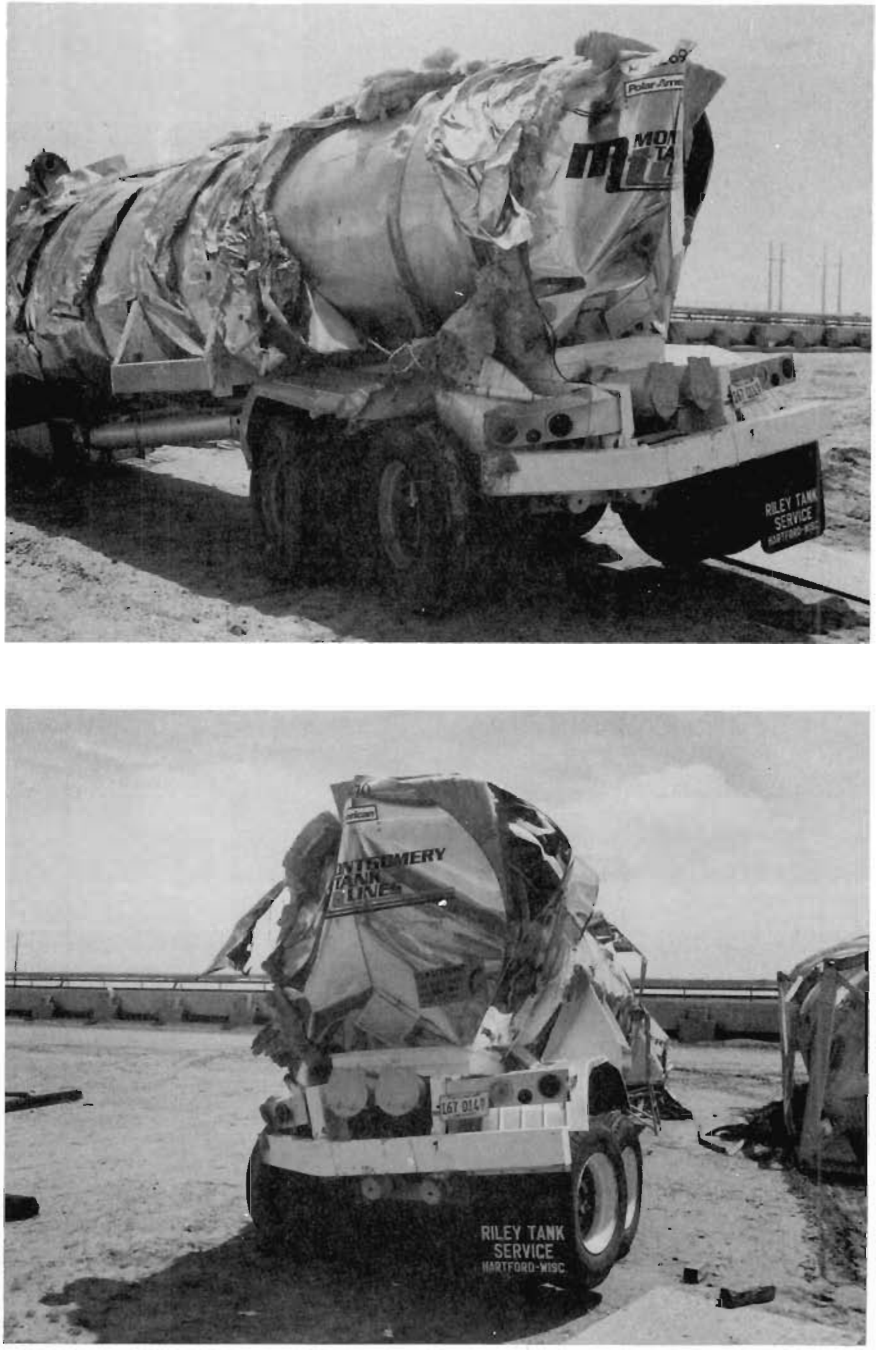


FIGURE 5-8
MC 307 MTLZ 6970 TANDEM END VIEWS OF DAMAGE AFTER THREE BROKEN RAIL DERAILMENT TESTS

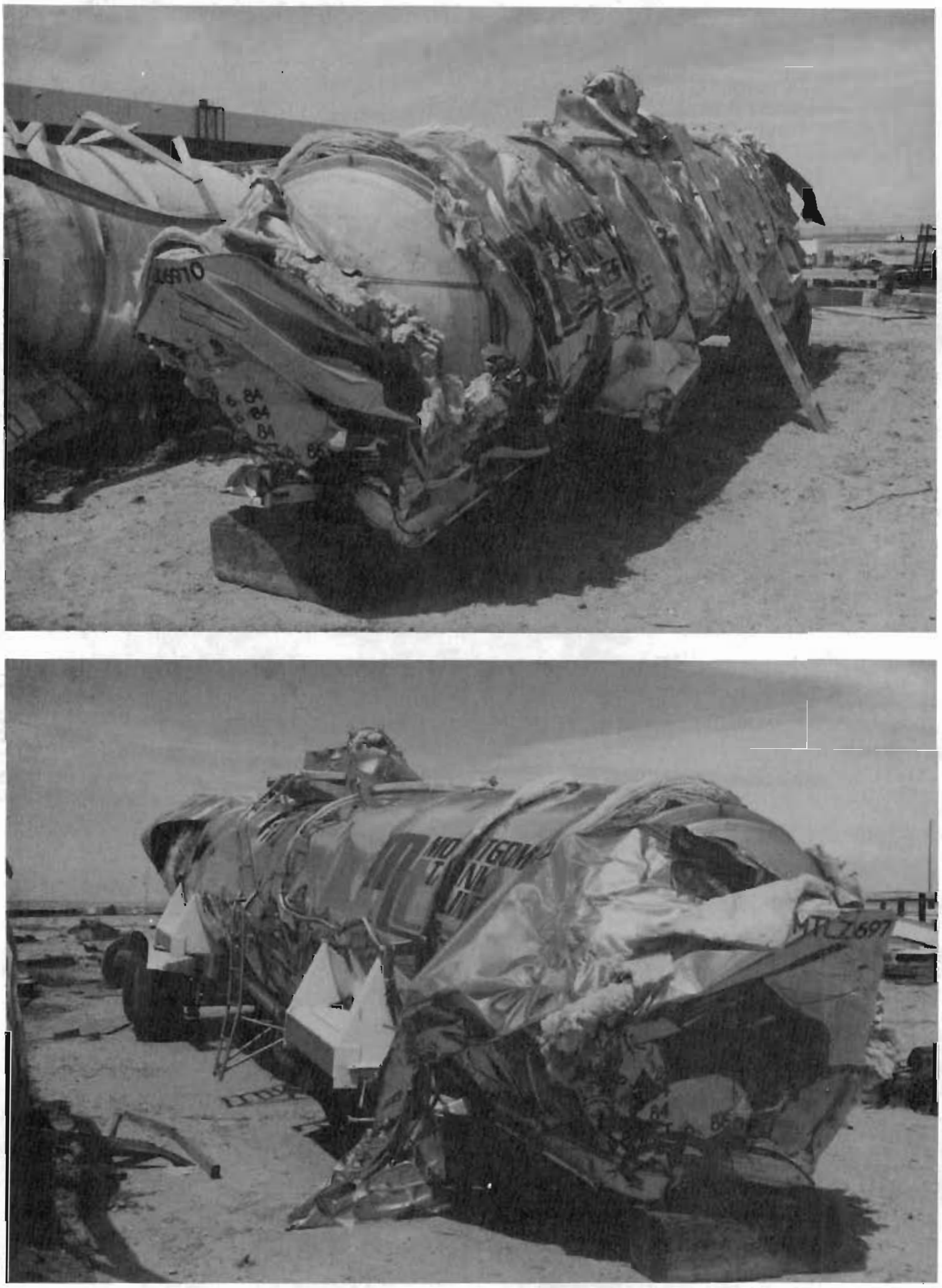


FIGURE 5-9
MC 307 MTLZ 6970 HITCH END VIEWS OF DAMAGE AFTER THREE BROKEN RAIL DERAILMENT TESTS

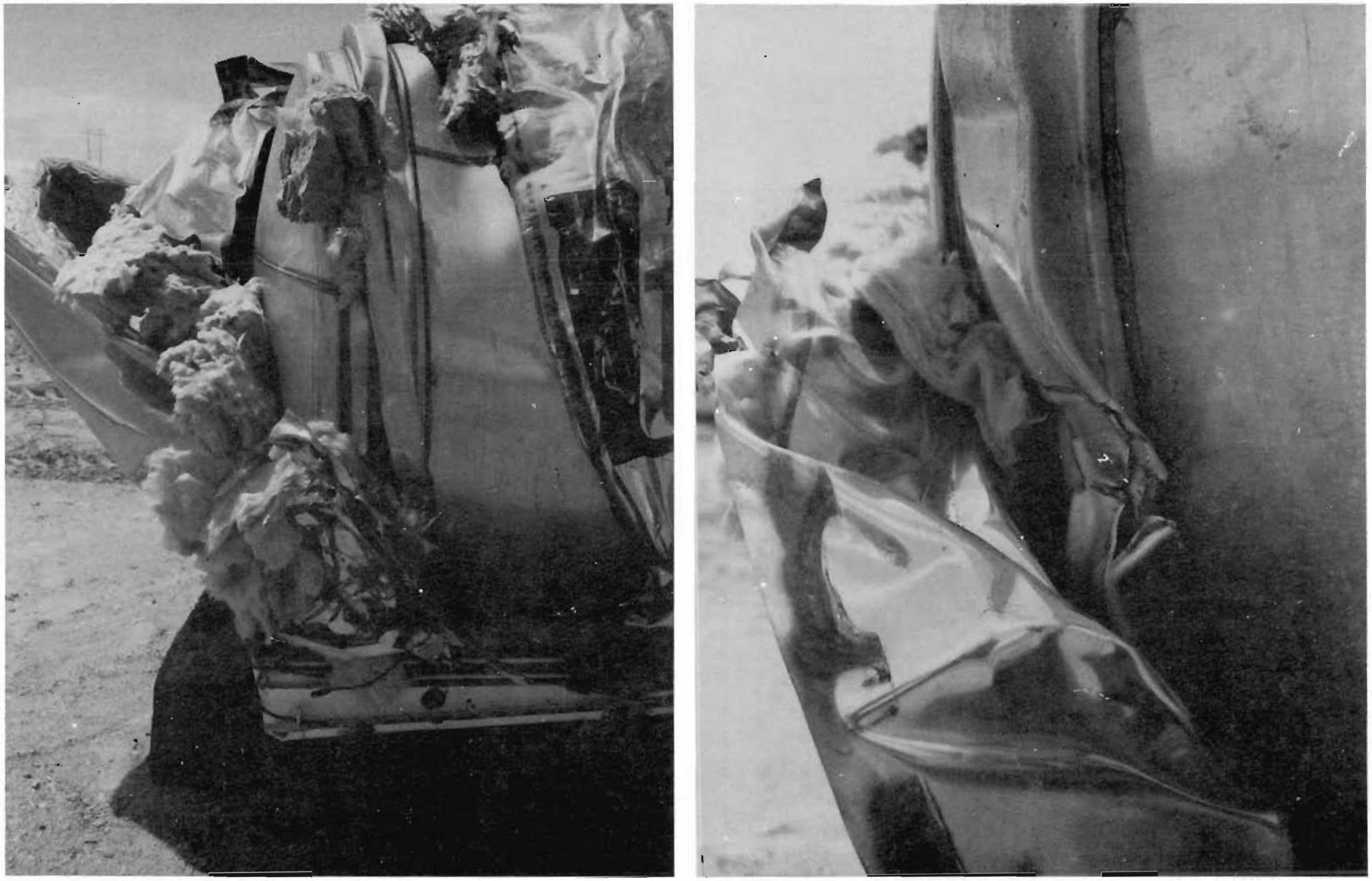


FIGURE 5-10
MC 307 MTLZ 6970 DAMAGE AT TANDEM END OF TANK AFTER
THREE BROKEN RAIL DERAILMENT TESTS

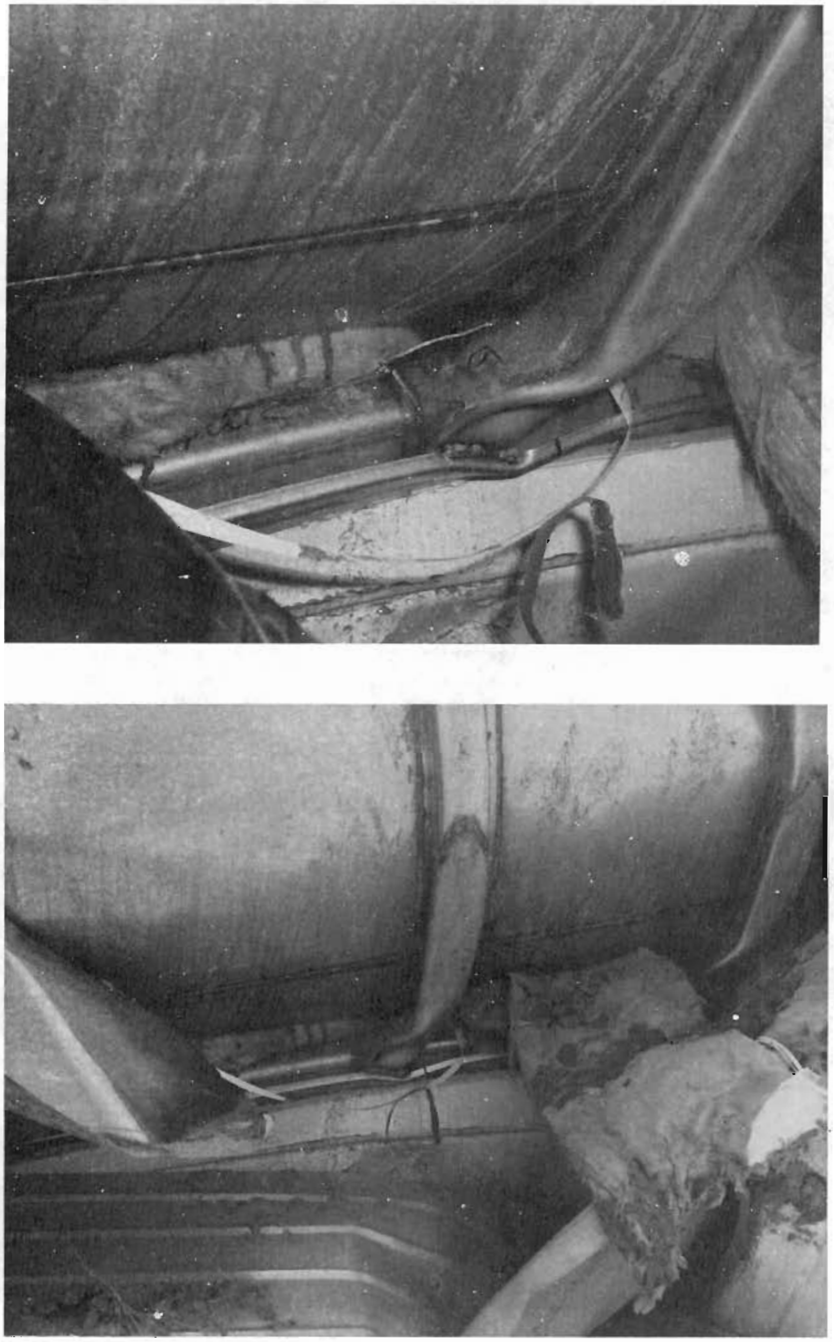


FIGURE 5-11
MC 307 MTLX 6970 DAMAGE IN LIFTING PAD AREA AFTER THREE BROKEN RAIL DERAILMENT TESTS

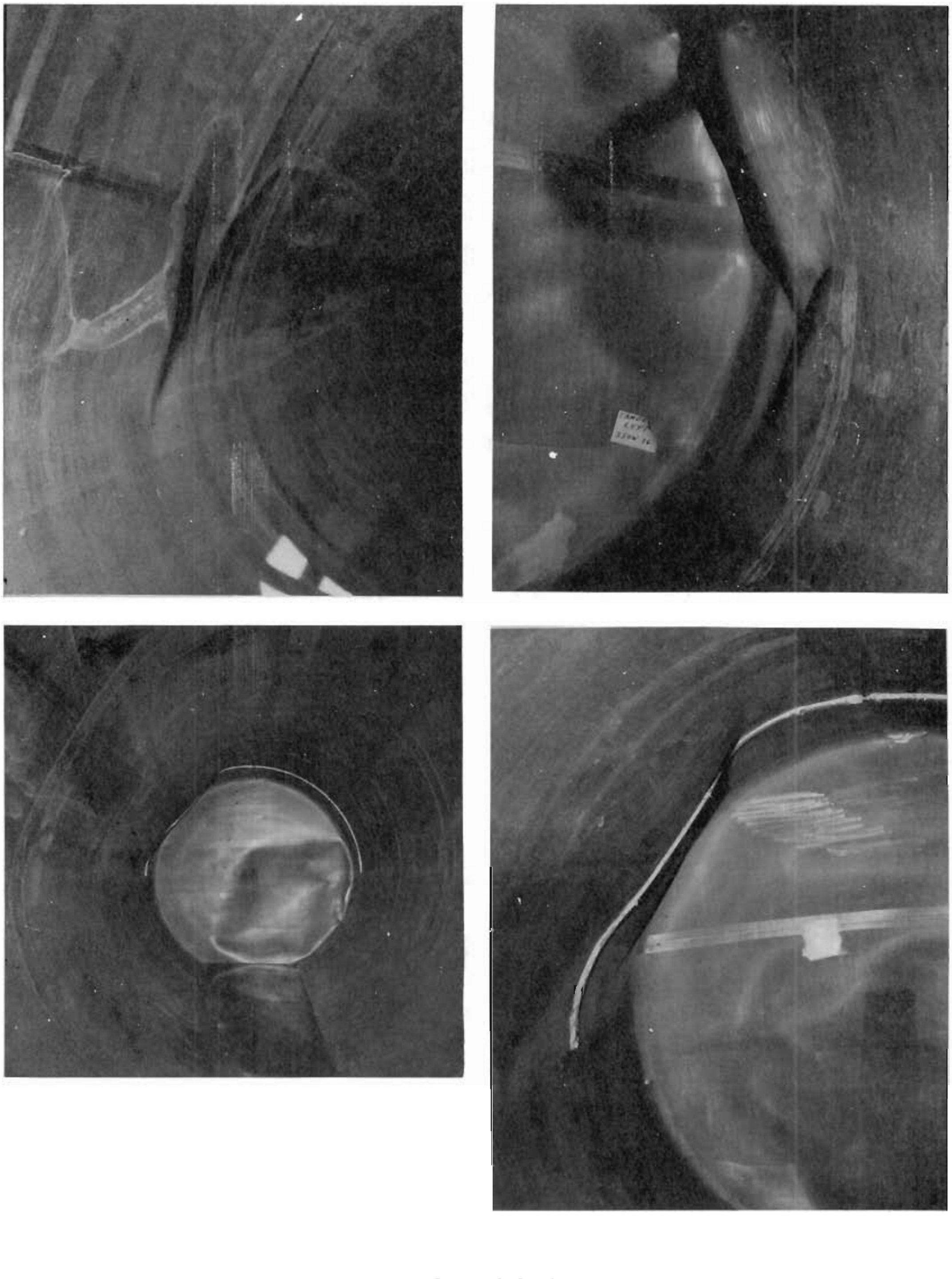


FIGURE 5-12
MC 307 MTLZ 6970 INTERNAL VIEW OF TANK DAMAGE AFTER
THREE BROKEN RAIL DERAILMENT TESTS

The vacuum relief vent has a teflon valve that is held in the closed position with a permanent magnet and a coil spring. Under normal operation a 2 inch Hg vacuum will overcome the magnetic and spring hold down forces and the valve will open. Upon relief of the vacuum the spring returns the teflon valve to its seated position and the full magnetic force is reinstated. However, after Test 1 the teflon valve was found at the bottom of the MC 307 cargo tank. This could have been caused by a vacuum greater than 2 inches of mercury sucking the valve through the valve seat. (Since the vent was not inspected prior to the derailment test it can only be assumed that it was properly assembled and in proper working condition.) Such a vacuum could have occurred in the derailment process by motion of the liquid surging to one end of the tank as the flatcar decelerated, with the liquid filling the manhole well with a wave action that would remove all or most of the air in the well, so that on the returning wave of liquid the weight of the liquid would pull a vacuum at the vent. The full height of water would be 81 inches and if it were all "hanging" would exert a vacuum of 6 inches of mercury. The dynamics of the fore and aft flow of the liquid would also tend to increase the vacuum. Although a cursory hypothesized analysis such as this can not be used in a valid determination of vacuum on the vent at derailment, it appears that the vacuum could have been 2 or 3 times the normal relief vacuum the vent was designed for and that the valve could have been sucked into the tank. Consequently a review of the vent design should be made.

The valve housing and valve are factory assembled and consequently the vent could not be used again. The opening was closed with a blank plate for Tests 3 and 5.

The manhole cover leaked in Test 3 due to the hold-down dogs not being tight. It is not known why they were not tight; they may have been loosened in the crash or they may not have been properly tightened before the test. One of the dogs was damaged in Test 3 and could not be tightened for Test 5. (There are a total of six hold-downs.) The manhole was damaged in Test 5 to the extent that it became unseated and leaked badly: at the estimated rate of 20 gallons per minute.

The cleanout leaked in Test 3 at the approximate rate of half pint per minute. The cause of the leak was that the cap was not tight.

Two MC 312 Cargo Tank Trailers were used in the Accordion Test, ST-N1052-86 was in the 1A position (the A-end of the first flatcar) and ST-N1053-86 was in the 3B position (the B-end of the third flatcar). Both trailers came away from their hitches, 1A by kingpin failure and 3B by tearing away the welded assembly on the trailer that houses the kingpins. Both tanks were punctured.

The tank in the 1A position ended under the first flatcar with four areas of major damage: the kingpin plate was torn out; the tandem separated from the trailer body and was in two pieces; there were two buckled areas on the top of the tank where the tank had landed on a wheel set; and the tank was buckled and had a rupture where the flatcar side sill and center sill had landed on the tank. Figure 5-13 shows two photographs of the tank and flatcar.

In the accordion pileup of the cars the third car yawed clockwise as planned. The MC 312 in the 3B position did not yaw with the flatcar but continued with its body oriented parallel to the track. When the flatcar stopped, the MC 312 tore away from the hitch, rolled, bounced on the tracks, collided with the IM portable tank that had been in the 3A position, and finally slid to a stop. The tank had numerous dents, buckles, and scrapes where it had bounced on the rails. The manhole cover had been forced open and the well had a large indentation of its side wall as can be seen in the lower photograph of Figure 5-14. The upper photograph in the same figure shows the dent and puncture in the tank head that is the result of impact with the IM portable tank. This puncture was at the head-to-shell joint, extending six inches on the head and two inches on the shell with a maximum gap of one and a half inches.

5.3.2 Damage Sustained by the IM Portable Tanks

There were a total of nine portable tanks used in the derailment testing, five were IM 101 and four were IM 102. One of the tanks, an IM 102, was insulated with a fiberglass blanket and metal jacket. In addition to these nine portable tanks, there were two IM 102 tanks that were used in the VTU, yard impact and track testing. Descriptions and photographs of the eleven tanks are presented in this section. Most of the photographs shown were taken after each derailment test to show the extent of damage sustained by the portable tanks.

This section also contains descriptions of the damage to each tank incurred in each derailment test. The general experience had four salient features:

1. The frame structures were severely damaged and consequently absorbed much of the impact energy and thus provided a cushioning for the tanks.

2. The tanks had dents and buckles of varying severity.

3. Leak tests were made after each test with no tank leaks being found. Visual inspections were also made after each test, internal as well as external to the tank, and no cracks were found in the tank material.

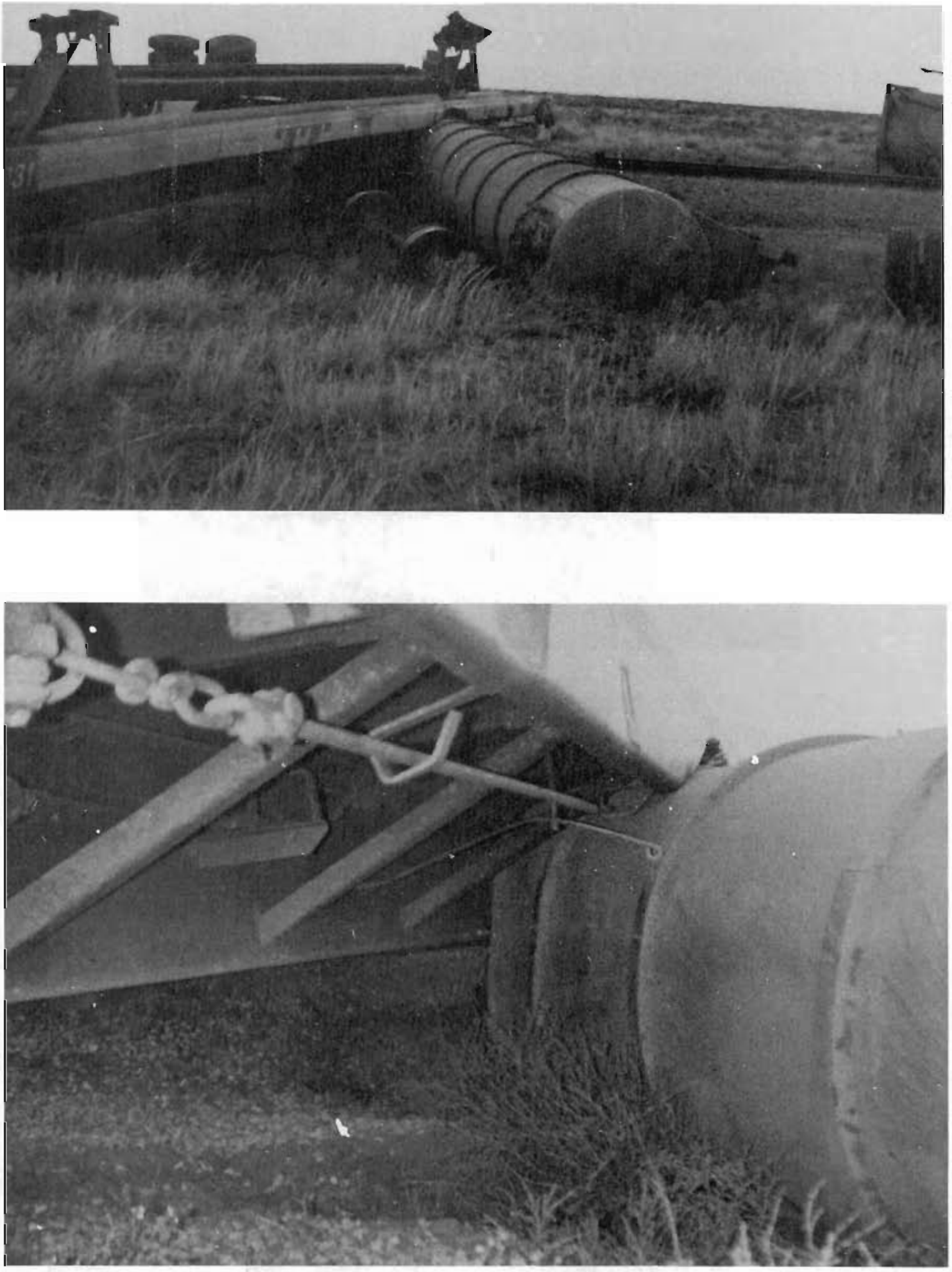


FIGURE 5-13
MC 312 TANK TRAILER FROM ACCORDION TEST
POSITION 1-A UNDER FLATCAR

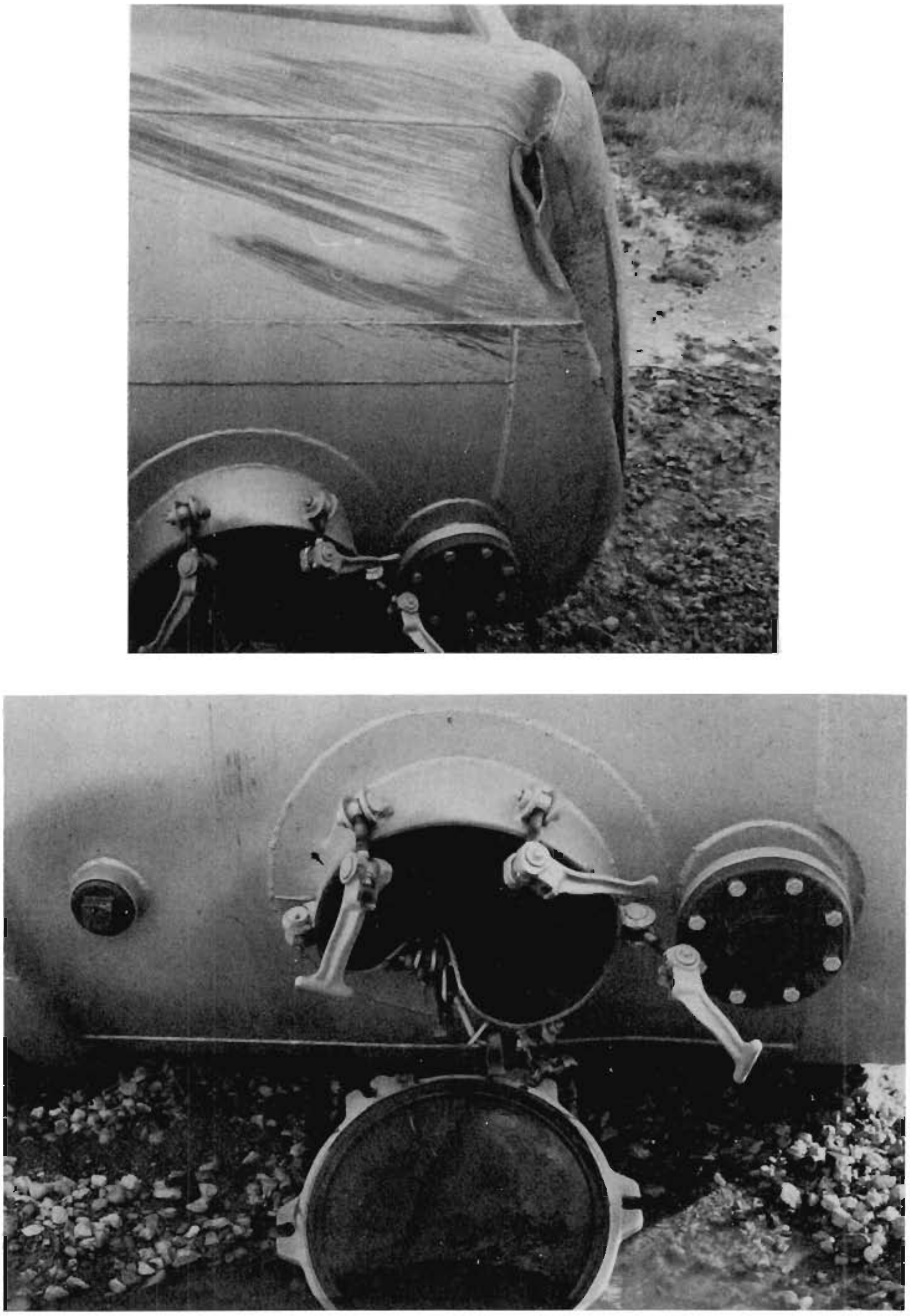


FIGURE 5-14
MC 312 FROM ACCORDION TEST POSITION 3B
SHOWING DAMAGE TO TANK AND MANHOLE

4. There were three safety relief vents that leaked: one each in broken rail derailment Tests 2 and 5, and one in the accordion derailment test.

The general conclusions reached as a result of the derailment testing were that survivability of the tanks are enhanced by the protection and crush-up cushioning provided by the frame structure and by the material properties and thickness that enable the tanks to undergo severe deformations without failure. Further, tank accesses such as emergency vents and manhole covers are vulnerable and have a higher than desirable probability of damage and leakage in a derailment.

Of the tanks tested, the ones with Type 4 structure, shown in Figure 5-15, generally had more damage to the structural framework and less damage to the tank itself. Four of this type were tested, two in Broken Rail Test 6 and two in the Accordion Test. The probable reason for their good performance is that the tank is supported on a full ring, four feet from the end of the frame structure: this provides distance for the frame structure to crush-up as well as distributing the loads into the tank. Types 1 and 5 frame structures resulted in the most damage to the tanks in the form of large buckles. Types 2 and 3 frame structures were not used in any derailment tests.

Of the five types of frame structure shown in Figure 5-15, Type 3 is concluded to provide the most protection to the tank in the derailment environment. Specifically, the tank is supported at two half rings and two full rings over the length of the tank, thus distributing loads into the tank; the tank support closest to the end of the frame is three feet from the end, thus allowing crush-up distance in the structural framework; and there are longitudinal and transverse structural members that completely surround the tank providing a measure of protection to the manhole cover and safety vents. The IM 102 portable tank FR 2075, shown in Figure 5-16, is the model for the Type 3 designation.

The eleven IM portable tanks used in this test program are listed in Table 5-1 with data on class, dimensions, type of frame, and test usage. Tank material and gages were not available on several of the tanks. Photographs of each representative tank are shown in Figures 5-16, 5-17, and 5-18.

A <u>Description of Tank Damage</u> will now be presented for each tank and each test.

<u>Broken Rail Derailment Test 1</u> had one portable tank, BLSU 300019, Type 1 frame, mounted on a 20-foot chassis trailer. In this 23.4 mph derailment, the flatcar tilted and the trailer and tank fell to the ground. Forward speed was zero when the trailer and tank made ground

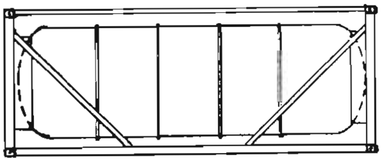
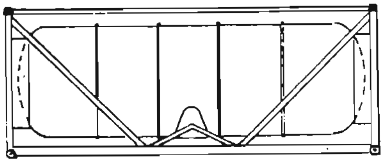
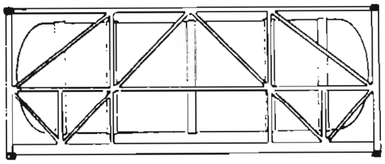
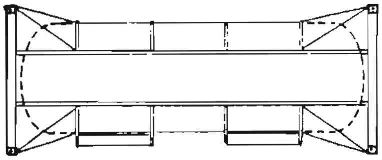
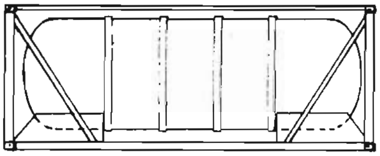
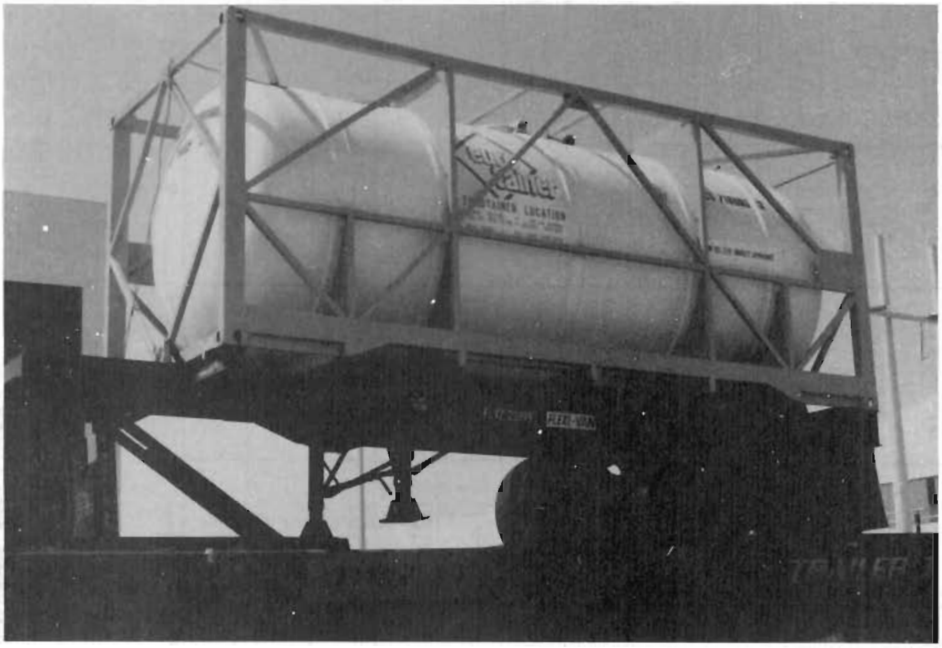
FRAME TYPE NUMBER		TANK SUPPORT DESCRIPTION
1.		Welded cylinder at each head.
2.		Welded cylinder at each head and saddle at bottom center
3.		Four ring frames, two have lower half only, two have upper quarter panels as well. (See Figure 5-16)
4.		Full circumferential at ends of cylinder and side beams full length of shell cylinder.
5.		Brackets at four bottom corners. Brackets bolted to flange which is welded to tank shell.

FIGURE 5-15
TYPES OF FRAME CONSTRUCTION FOR PORTABLE TANKS



IM 102 FR 2075

FIGURE 5-16
TYPE 3 FRAME STRUCTURE CONFIGURATION FOR IM PORTABLE TANKS

TABLE 5-1
IM PORTABLE TANK DATA

ID	CLASS	TANK INNER DIMENSION Length (in.)	Diameter (in.)	Volume (gal.)	TANK MATERIAL	TANK GAGE Head (in.)	Shell (in.)	TEST USAGE	FRAME TYPE
FR 2074	IM 102	259	82	5670	AISI 316TI	.118	.118	V,Y,T	3
FR 2075	IM 102	223	85	5294	AISI 316TI (1)	.118	.118	V,Y,T	2
BLSU 300019	IM 102	232	86	5548	NFA 36.209 (2)	.118	.118	Y,1,3	1
DE 2275	IM 102	235	86	5653	316TI (3)			2.4	5
DE 2278	IM 101	234	82	5125	316TI (3)	(5)	(5)	2,4,5	5
EMMU234784-5 (insulated)	IM 102	230	87	5020				A	1
EMMU234788-7	IM 102	230	87	5020				A	1
OLTU 000002	IM 101	211	78	3860	(4)	(5)	(5)	A	4
OLTU 000003	IM 101	211	78	3867	(4)	(5)	(5)	A	4
OLTU 000025	IM 101	211	78	4120	(4)	(5)	(5)	6	4
OLTU 000032	IM 101	211	78	4096	(4)	(5)	(5)	6	4

Notes: Test Usage: V = Vibration Test Unit   Y = Yard Impact
T = Track   A = Accordion Derailment
1-6 = Broken Rail Derailment Tests 1-6

Frame Type: See Figure 5-15

(1) Eurotainer drawing specifies French Specification Z28 CNDT 17 12 equiv. to SS320S17
(2) Equivalent French specification Z6CN18.09
(3) German specification equivalency 1.4571
(4) British Code 1501-151-28a
(5) Equivalent to 0.25 inch mild steel

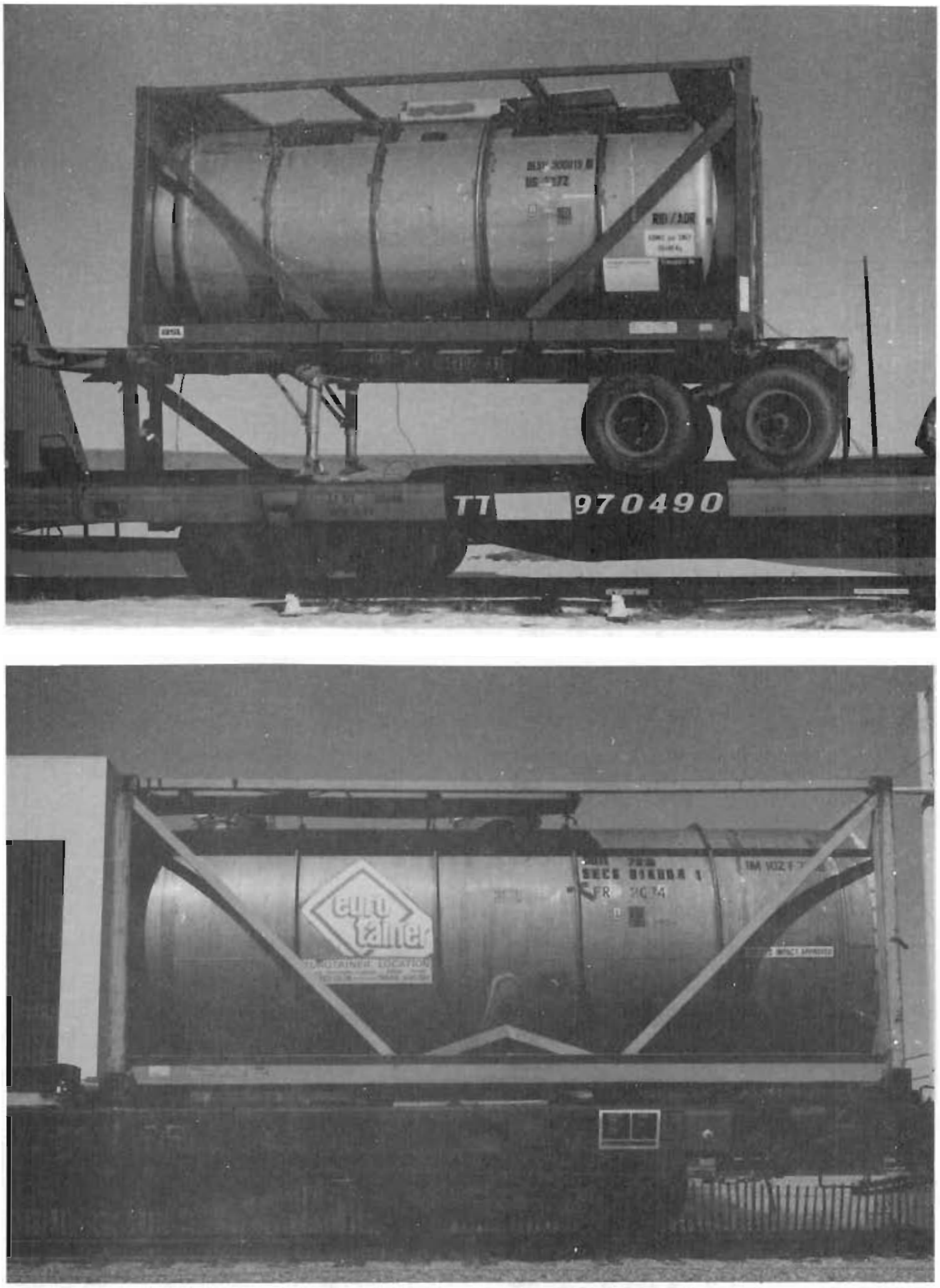


FIGURE 5-17
IM 102 PORTABLE TANKS BLSU 300019 AND FR 2074

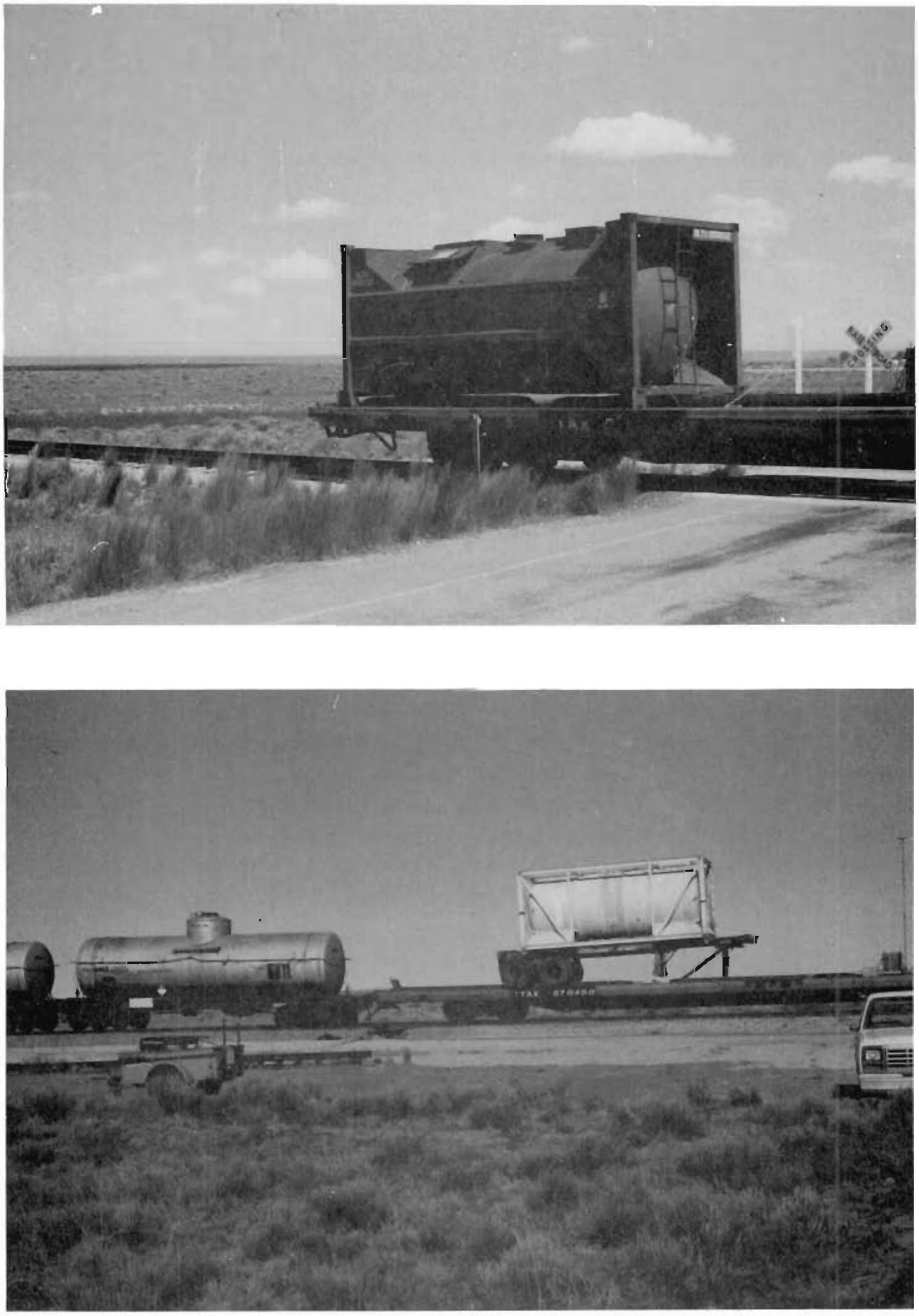


FIGURE 5-18
PORTABLE TANKS OLTU 000032 AND DE 2275

contact. The tank remained attached to the trailer. There was some bending of the frame structure but the most significant damage was deep buckling at one end of the tank shell. Two photographs of these buckles are shown in Figure 5-19. There were no leaks other than through an opening used for wiring to the slosh gages inside the tank.

Broken Rail Derailment Test 2 had two portable tanks: DE 2278, an IM 101, on a 20-foot chassis trailer and DE 2275, an IM 102, in COFC. Both tanks had Type 5 frames and were identical in appearance. The photographs in Figure 5-20 show the post test positions of each tank. Derailment was at 19.0 mph and, as in Test 1, the forward velocity was zero when the tanks fell to the ground. The tank on the 20-foot chassis received more damage than the tank in COFC. The two bracket attachments on the left side both failed completely on the TOFC tank, permitting the tank itself to fall to the ground. There were buckles in this tank where the failing brackets had pulled outward and a long buckle, on the opposite side, the length of the tank, caused by the ground impact of the tank.

The tank in COFC (DE 2275) had only one of the support brackets fail completely (see the lower photograph of Figure 5-20). It also had shell buckles at the bracket attachments.

The cover of a safety release valve on DE 2278 had been knocked off and the valve had a trickle leak (about 5 drops per second). The instrumentation wiring access hole leaked in DE 2275.

Broken Rail Derailment Test 3 was performed at 42.0 mph and used the same configuration as Test 1 which had the BLSU 300019 IM 102 on a 20-foot chassis trailer. The forward velocity of trailer and tank (still attached to the flatcar) was about 25 mph when the tank had ground impact. The force of ground impact caused failure of the tank-to-chassis twist lock attachments. The damage to the tank frame and tank is shown in the photographs of Figure 5-21. The frame is buckled and fractured and the tank shell and head have deep buckles. There were no leaks.

Broken Rail Derailment Test 4 was performed at 40.0 mph with a COFC/COFC configured flatcar. The portable tanks used were the same ones used in Test 2, DE 2278 (IM 101) and DE 2275 (IM 102), with repaired brackets and frames. Photographs of the tanks after Test 4 are shown in Figure 5-22.

There was less damage to the tank support brackets in this test than in Test 2 but there were greater deformation and fracture of the frame structure. There was some additional buckling of the tank shells. There was no leakage except through an instrumentation port in DE 2275.

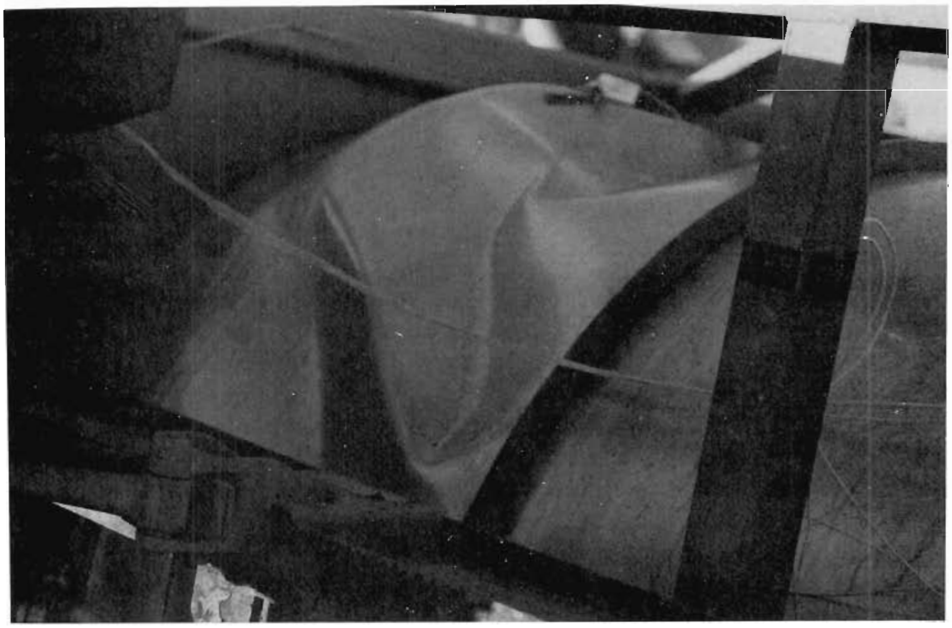


FIGURE 5-19
BLSU 300019 BUCKLED TANK, FROM BROKEN
RAIL DERAILMENT TEST 1 AT 23.4 MPH

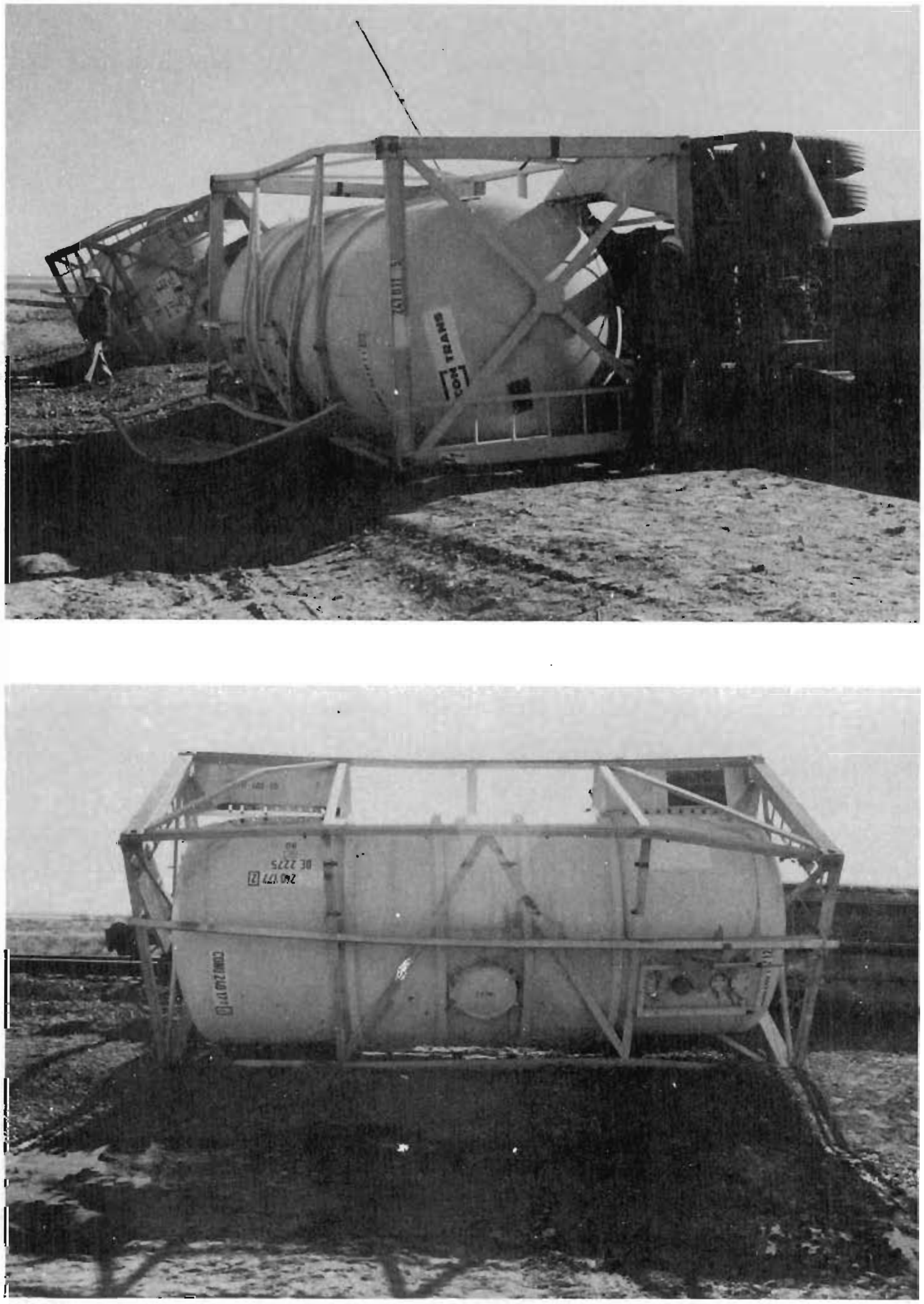
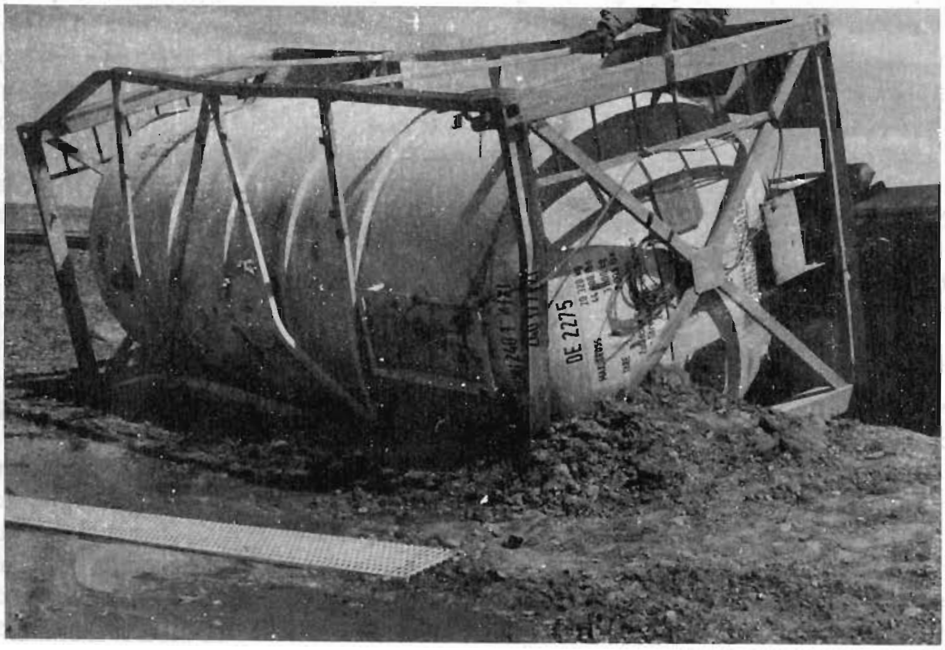


FIGURE 5-20
DAMAGE TO PORTABLE TANKS IN BROKEN RAIL DERAILMENT TEST 2 AT 19.0 MPH

FIGURE 5-21
DAMAGE TO BLSU 300019 AFTER BROKEN RAIL
DERAILMENT TEST 3 (ALSO USED IN TEST 1) AT 42.0 MPH



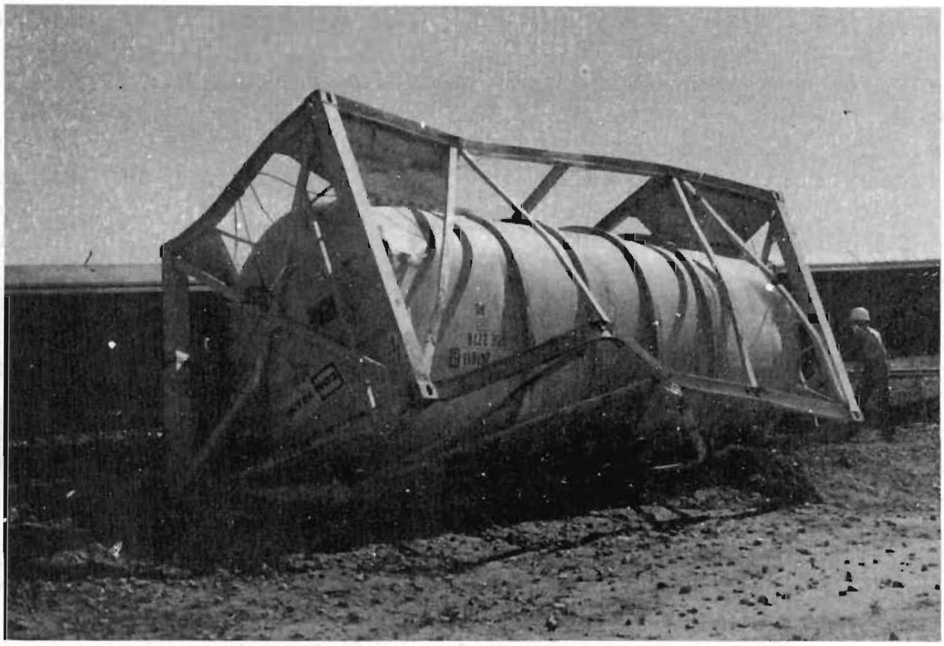


FIGURE 5-22
DAMAGE TO PORTABLE TANKS IN BROKEN RAIL
DERAILMENT TEST 4 AT 40.0 MPH

Broken Rail Derailment Test 5 was performed at 64.5 mph with DE 2275, an IM 102 portable tank, on a 20-foot chassis trailer. The damage to DE 2275 from Tests 2 and 4 had been repaired prior to Test 5, except that the tank buckles and some bends in the frames could not be removed. In this derailment the portable tank separated from the chassis trailer as the flatcar tilted. The forward velocity of the tank was about 50 mph at ground impact. The tank first contacted the ground on its top, right hand forward corner and continued to roll, bounce and slide. Major damage was done to the frame structure and tank on the first impact with the ground with bending and fracturing of the frame and large buckles in the head and shell of the tank. The photographs in Figure 5-23 show some of this damage. The bottom photograph also shows the water leak from the pressure relief valve.

Broken Rail Derailment Test 6 was a COFC/COFC configuration performed at 59.5 mph. In the derailment process both containers rolled off the flatcar as it tilted to the right, both containers made first contact with the ground on their top, forward right-side corner, and both containers did an end-over-end cartwheel landing topside up. Forward velocity of both containers was approximately 50 mph at first ground contact. The tank from the B-end of the flatcar landed on the tracks and there was damage to the frame structure at the rails. However the major damage on both containers was to the framework at the corner of first contact with the ground. This can be seen in the photographs of Figure 5-24. There was no apparent damage to either tank. There were no leaks in either tank.

The Accordion Derailment Test used two IM 101 and two IM 102 portable tanks with one of each in COFC and the other two on 20-foot chassis trailers. The IM 101 tanks, OLTU 000002 and OLTU 000003, were both of the Type 4 frame construction (refer to Figure 5-15). The IM 102 tanks were both of Type 1 construction but one, EMMU 234784-5, was insulated and the other, EMMU 234788-7, was not. Figures 5-25 through 5-30 present post test photographs of each tank showing some of the damage each received.

The track speed of the test consist was 60.8 mph at the initiation of the derailment. The speeds of the first, second and third flatcar as each derailed were approximately 60, 51, and 44 mph respectively. Forward velocity of each item at point of ground impact could not be estimated as planned, using the high speed movies, due to the dust cloud raised by the derailed consist.

The insulated IM 102 portable tank was on the B-end of the first flatcar on a 20-foot chassis. The chassis and tank were thrown off, landing on the left side of the track. The tank landed upside down and rolled upright traveling about 50 feet further down the track than the flatcar and 50 feet to the left of the tracks. Figure 5-25 shows two views of this tank in its post-derailment positions. Figure 5-26 has a photograph of the top of the tank and one of the inside of the tank.

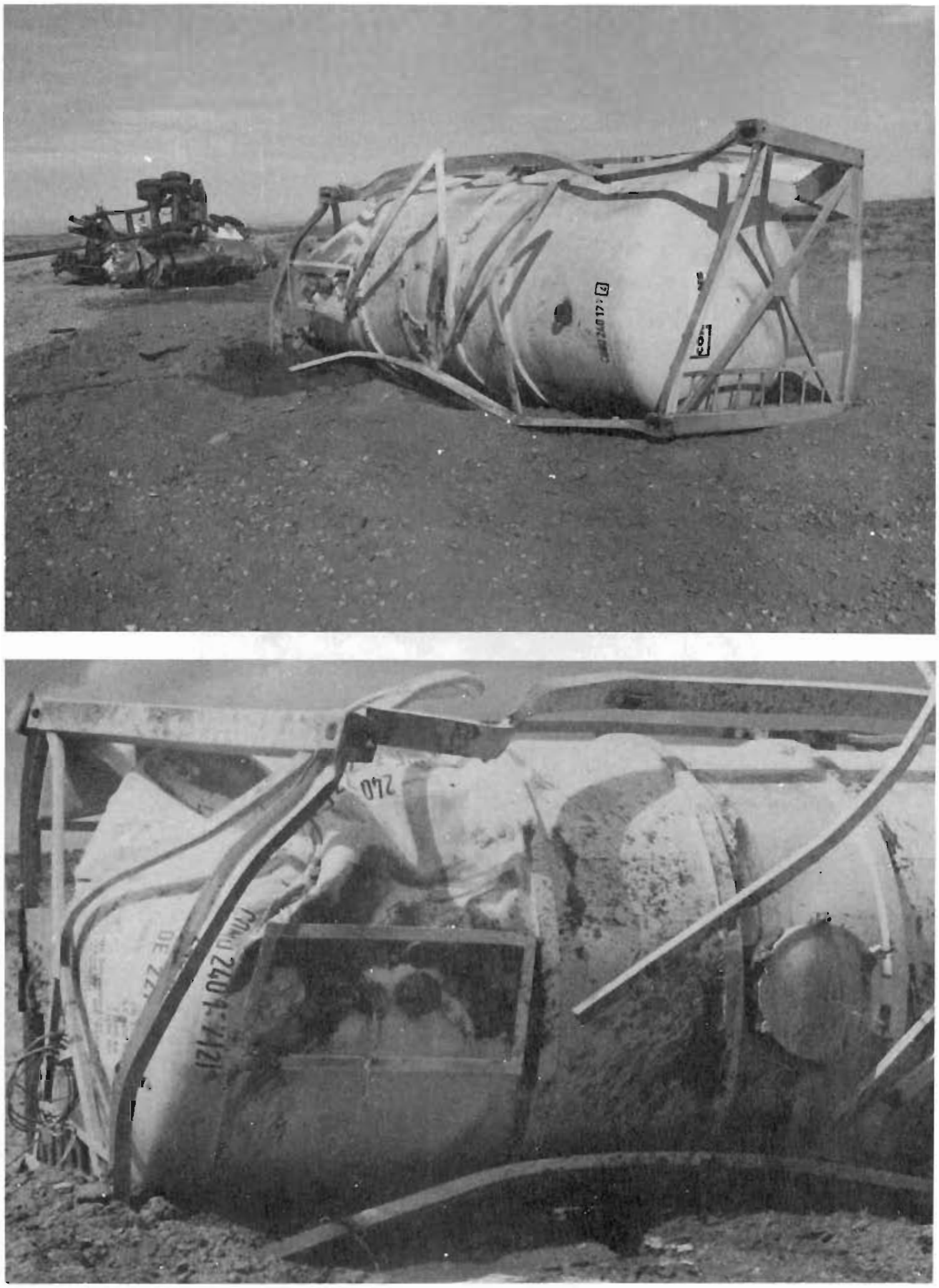


FIGURE 5-23
DAMAGE TO PORTABLE TANK IN BROKEN RAIL DERAILMENT TEST 5 AT 64.5 MPH

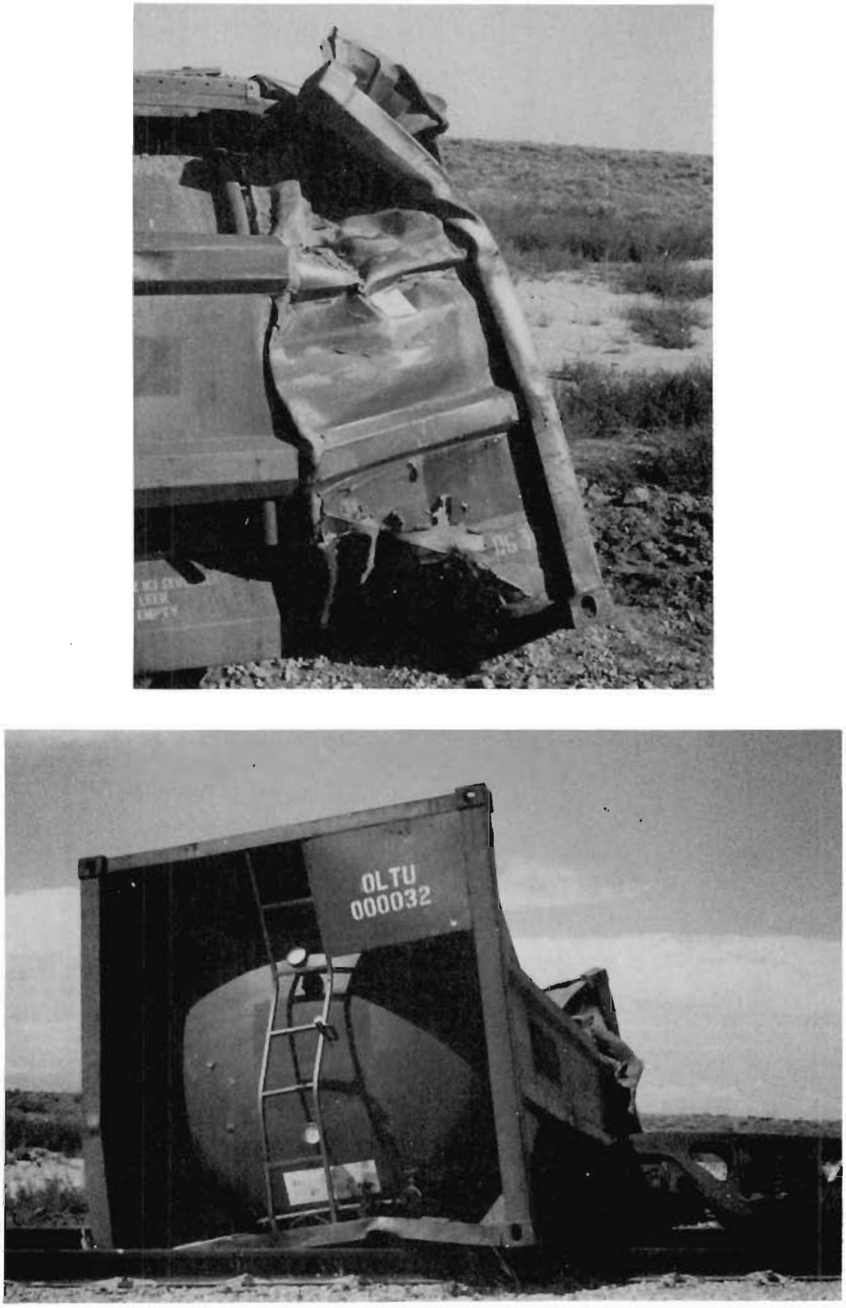


FIGURE 5-24
DAMAGE TO PORTABLE TANKS IN BROKEN RAIL DERAILMENT TEST 6 AT 59.5 MPH

FIGURE 5-25
DAMAGE TO INSULATED IM 102, EMMU 234784-5,
POSITION 1B (TOFC) ACCORDION TEST

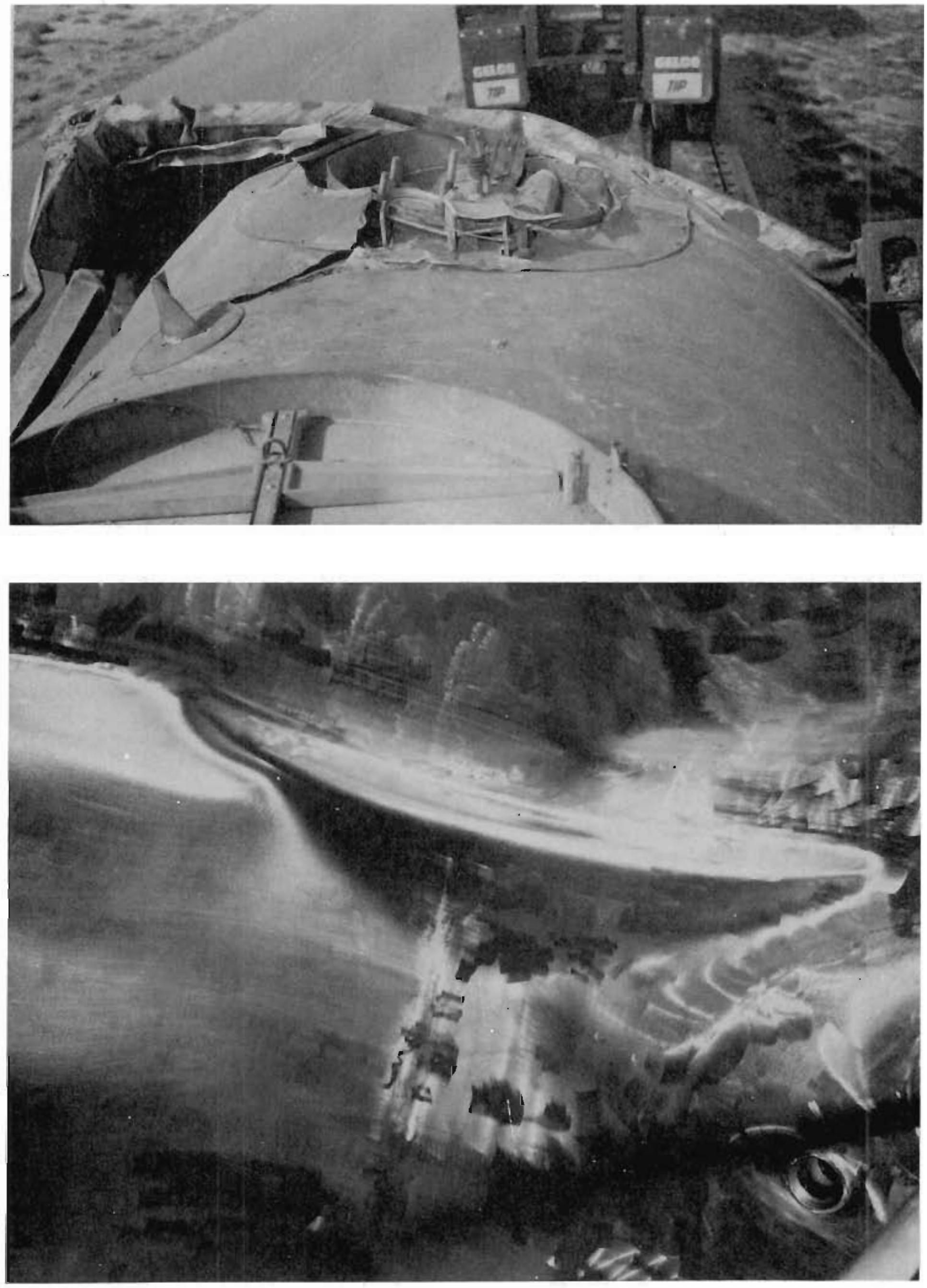


FIGURE 5-26
DAMAGE TO VENT COVER AND INSIDE TANK,
EMMU 234784-5, ACCORDION TEST

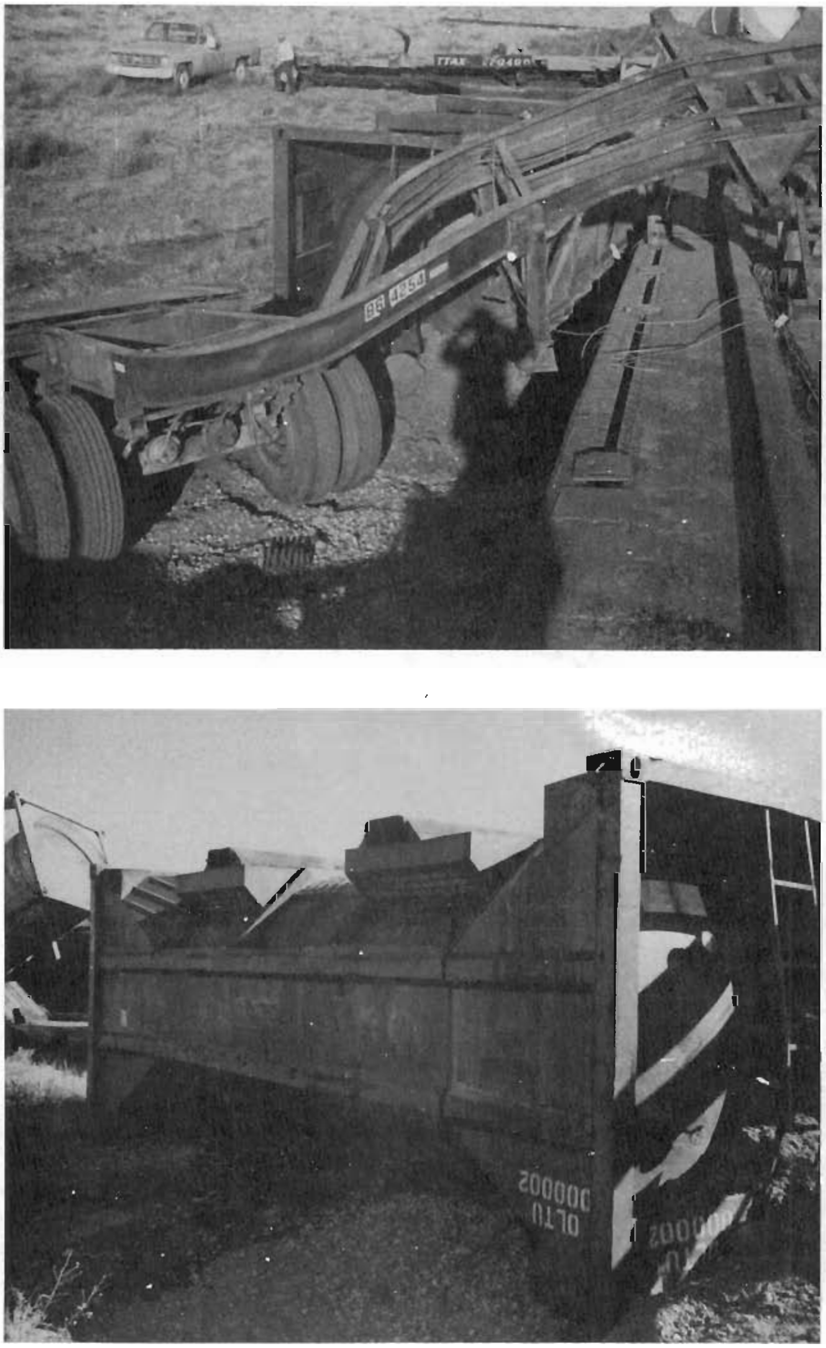


FIGURE 5-27
DAMAGE TO IM 101, OLTU 000002, POSITION 2A (TOFC), ACCORDION TEST

FIGURE 5-28
DAMAGE TO IM 102, EMMU 234788-7, LOCATION 2B (COFC),
ACCORDION TEST

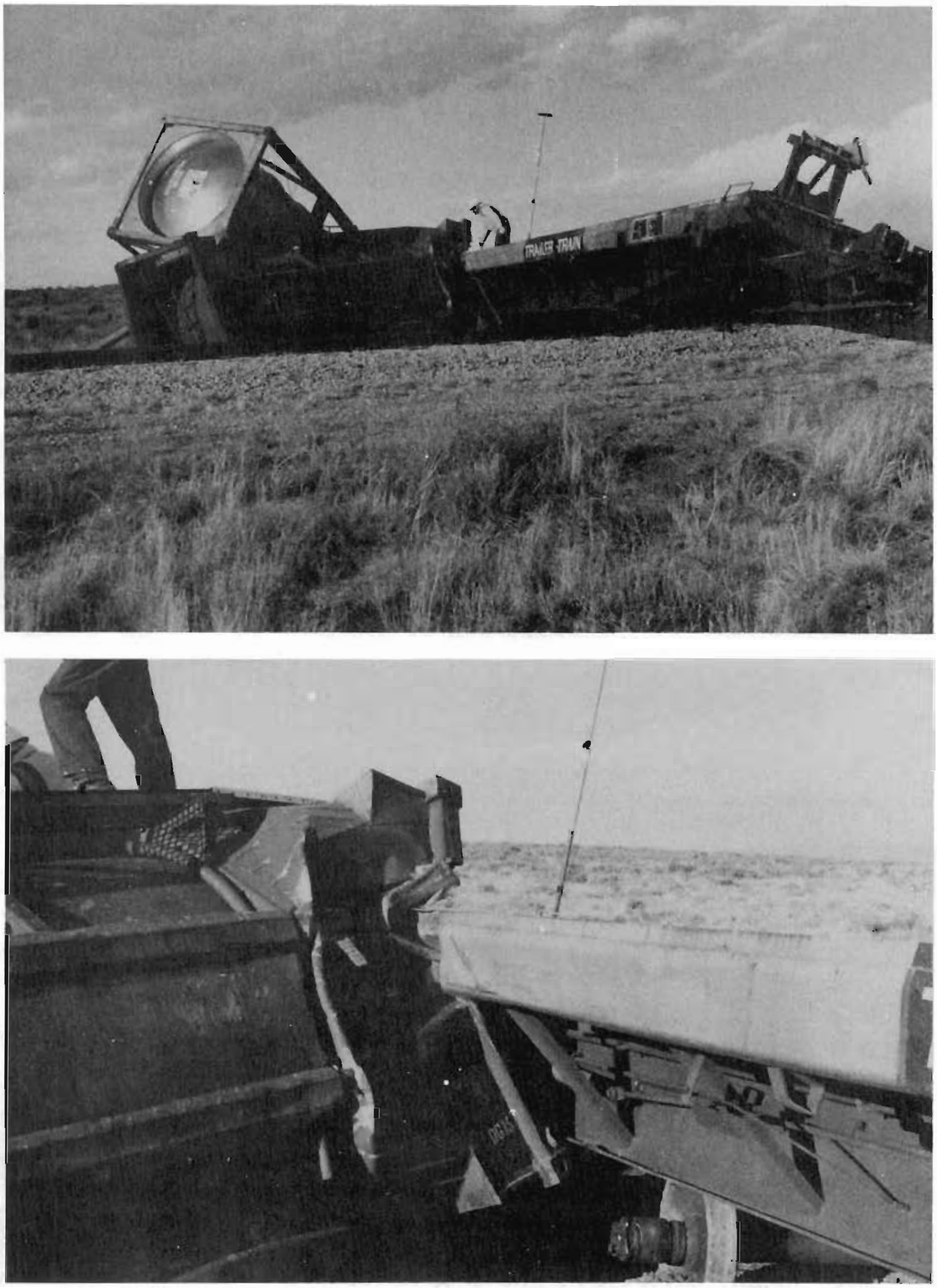


FIGURE 5-29
DAMAGE TO IM 101, OLTU 000003, POSITION 3A (COFC),
ACCORDION TEST

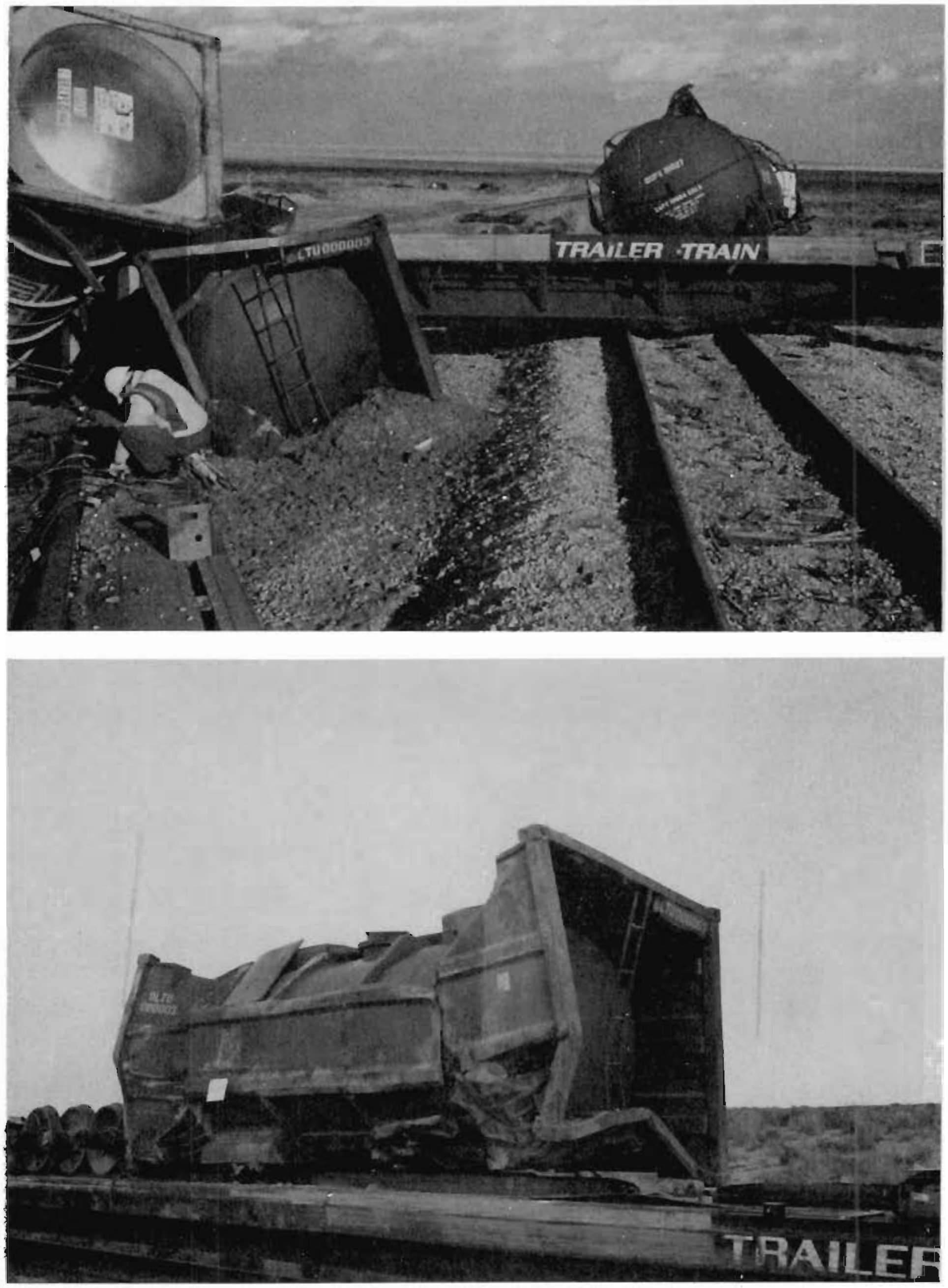


FIGURE 5-30
DAMAGE TO IM 101, OLTU 000003, ACCORDION TEST

Two things are worthy of note in the photographs of the insulated IM 102 shown in Figure 5-26: (1) the protective cover and frame structure have been wiped clear of the valves and safety vents that access the tank, indicating how vulnerable to damage they are; and (2) the tank itself will withstand severe dents and crimps without fracture because of the tank material and thicknesses.

As the second flatcar derailed, with a forward velocity of approximately 51 mph, it rotated counterclockwise and rolled to the right. In the process, the IM 101 portable tank on the A-end, OLTU 000002, rolled off landing upside down beside the flatcar. Figure 5-27 shows two views of the tank. The tank had been on the chassis trailer shown in the upper photograph. There was relatively little damage to this tank. There was leakage as evidenced by the wetness of the ground under the tank. The source of the leak was not found. The tank did not leak in a post test leak test.

The uninsulated IM 102, EMMU 234788-7, in COFC on the B-end of the second flatcar rolled off the flatcar, hit the ground at its leading end and did an end-over-end cartwheel. While the tank was still on end it was struck by the third flatcar and finally fell over, landing on the IM 101 tank from the A-end of the third flatcar. Figure 5-28 has two photographs of EMMU 234788-7 showing some of the damage the tank had sustained, one in its post test position and the other after it had been put on the ground. This tank leaked from an unidentified vent that was apparently not properly assembled.

The IM 101, OLTU 000003, COFC in position 3A, probably received the most damage of any of the portable tanks, as can be seen in the photographs of Figures 5-29 and 5-30. The sequence of events for this tank during the derailment were as follows:

- The portable tank was in the 3A position which is on the A-end (leading) of the third flatcar. The flatcar rotated clockwise (that is, A-end to the right and B-end to the left) in keeping with the planned accordion derailment scenario. An MC 312 cargo tank was on the B-end of this flatcar.

- The 3A portable tank was thrown off the flatcar. Its trailing end hit the ground and bounced, and then its leading end hit the ground and dug in, causing the tank to cartwheel.

- The 3A portable tank was then hit by the MC 312 that had been in the B-end position of the flatcar. The force of this impact was great enough to cause a large dent and puncture in the MC 312 head (see Figure 5-14).

- The 3A portable tank came to a stop and was hit by the side sill of the flatcar.

- The portable tank from position 2B finished a cartwheel landing on top of the portable tank from 3A (see Figure 5-29 and 5-30).

As the photographs show, the frame structure of OLTU 000003 was very badly damaged. Viewed from the inside of the tank, there was one larger dent in the shell (about 20 by 40 inches across and about 5 inches deep), and a smaller second dent. The tank did not have any leaks.

A summary of leaks experienced by the IM portable tanks in the derailment testing is given in Table 5-2. Of the 13 tank/test cases there were four leaks experienced (other than leaks caused by instrumentation wire access holes). Of these four, one was unidentified and one was due to a suspected improperly assembled vent. There were no leaks of the tanks.

5.4 Summary Comments, Derailment Tests

Six broken rail derailment tests have been performed at speeds varying from 19 to 64 mph with a similar pattern of results. That is, the derailed test car moved to the right, tilted, and eventually tilted far enough that the trailers and/or portable tanks were released.

Further, the tanks tested survived the derailment without tank failure. The only leakages experienced were from vents, manhole covers, and other tank openings. This survivability factor was emphasized by the fact that two of the IM portable tanks were used in three different derailment tests.

The accordion derailment test was the seventh and final test in this series of tests to investigate intermodal hazmat configurations. Judging from the damage inflicted on the track and test consist the accordion derailment was the most severe of the seven tests. This severity can be attributed to two factors: (1) because the cars were caused to rotate with the accordion pattern, deceleration forces were higher; and (2) there was more impacting between bodies.

There was generally more damage to the portable tank frame structure of the IM portable tanks in the accordion derailment than in the broken rail derailment. Despite this, there was only minor damage to the tank shells and no rupture or leakage of the shells. One vent on IM 102, EMMU 234788-7, leaked as if it were wide open.

The MC 312 cargo tank trailers were both ruptured in the accordion test, one by impact on its hitch end dome with the OLTU 000003 portable tank and the other by the flatcar falling on it. In comparing the general

TABLE 5-2

PORTABLE TANK LEAKS IN DERAILMENT TESTS

TEST	TANK	DESCRIPTION OF LEAK
1	BLSU 300019 (TOFC)	Trickle-instrumentation port
2	DE 2275 (COFC)	Instrumentation port
	DE 2278 (TOFC)	Safety release valve, trickle
3	BLSU 300019 (TOFC)	No leaks
4	DE 2275 (COFC) IM 102	Instrumentation port leaked
	DE 2278 (COFC) IM 101	No leaks
5	DE 2275 (TOFC)	Pressure relief valve (10 gal/min) instrumentation port
6	OLTU 000025 (COFC)	No leaks
	OLTU 000032 (COFC)	No leaks
A	EMMU-234784-5 (TOFC)	No leaks
	EMMU-234788-7 (COFC)	Open vent
	OLTU-000002 (TOFC)	Unidentified leak (ground wet under upside down tank)
	OLTU-000003 (COFC)	No leaks

damage to these MC 312's to the damage of the MC 307SS cargo tank used in Broken Rail Derailment Tests 1, 3, and 5, there was significantly more total damage to the MC 307 tank. And yet, the MC 307 tank had no ruptures. There are two factors that enabled the MC 307 to be more durable:

- the thermal insulation and outer stainless steel jacket act to cushion impacting forces and to dull the sharp edges of impacting bodies; and

- the MC 312 tested has a stiffer shell because of its smaller diameter and consequently does not buckle as easily as the MC 307 tested. Thus, if the same impacting conditions were imposed on both tanks, the forces generated on the MC 312 would be greater, and there would be more likelihood of penetration.

The six broken rail derailment configurations and the one accordion test included 13 portable tanks of which 6 were on chassis trailers and 7 were mounted directly on the flatcar. Except for two container-on-trailer cases, all containers separated at ground impact at their attachments to trailer or flatcar. In the two non-separating cases, forward velocity was zero at ground impact. The damage sustained at container separation varied greatly. Some of the COFC pedestals released with no damage. The other attachments released with various amounts of damage to the container, the pedestal, the flatar deck, the twist lock pin, and the chassis trailer structure.

The seven derailment tests involved a total of five MC cargo tank trailers; in every case there was a failure at the kingpin and the trailer was released from the flatcar. In four of the five, pieces of the kingpin shoulder sheared off and the kingpin pulled out of the hitch. In the fifth case, the plate supporting the kingpin tore away from the trailer body, with the trailer leaving the flatcar and the plate and kingpin staying on the hitch. If it is theorized that it would be better to keep the trailer on the flatcar in a derailment, it could only be done by auxiliary attachments at the tandem end of the trailer and a change in hitch end strength would probably not be required.

There were six 20-foot chassis trailers used in the derailment tests. A summary of the damage experience is as follows:

- There were two cases where the forward velocity of the chassis trailers and IM portable tanks was zero at ground impact and in both cases the IM tanks stayed with the chassis.

- In the other four cases velocity was not zero at ground impact, and the IM portable tanks separated by failure of the twist lock pin or failure of the fittings on the chassis.

- Three of the six chassis trailers separated from the trailer hitches with failures of the kingpins.

- In the fourth case, the chassis trailer also separated from the trailer hitch, but the failure was in the trailer structure supporting the kingpin: kingpin and its supporting structure tore away from the chassis and stayed with the hitch.

- The fifth chassis trailer broke in half, the hitch half staying on the flatcar and the tandem half flying off.

- The sixth chassis trailer stayed on the flatcar.

- In Broken Rail Tests 1 and 2, where the forward velocity was zero at ground impact, there was no apparent damage to the chassis trailers other than the kingpin failures.

- In the other four cases, the damage to the chassis trailers was extensive, to the point that the trailers were beyond repair.

The nature of freight train derailments is that no two are the same because of the many variables such as: cause of derailment, speed at derailment, consist make-up, car types, car load conditions, car state of repair, and trackside terrain. Trackside terrain is probably the most significant variable that needs to be addressed. Although the test site is representative of a large portion of the total continental U.S. trackside terrain, it is also one of the least hostile. In the final analysis consideration must be given to such things as bridge pylons, tunnel entrances, rocky outcropping, mountain side, and cars that may be standing still or moving in the opposite direction on sidings or adjacent track. There should, at the least, be an analytical study that would evaluate the probabilities of various terrains and scenarios as well as the probability of tank rupture and spill in each case.

5.5 Conclusions

Based on the results of the accident simulation testing the following conclusions are presented:

1. Derailment of intermodal configurations with liquid hazmat whether in TOFC or COFC have a high probability of rollover and ejection of the tanks.

2. MC 307SS cargo tank trailers and IM portable tanks in COFC or TOFC have been shown to have a high probability of surviving derailment without puncture and spill.

3. Thermal insulation covered with a stainless steel jacket acts to absorb impact energy and to blunt sharp edges of impacting bodies.

4. IM portable tanks that suffered the least damage of the tank itself in a derailment, had frame structure that supported the tank at several points along the shell and that could crush-up on impact for a relatively large distance before impacting the tank shell.

5. In a derailment the impacting forces on tanks, MC or IM, can be expected to be large enough to damage the tank. If the tank is able to buckle without being punctured it will itself act as an energy absorber and tend to reduce the impact forces. It follows that a tank designed for accident survival must be able to sustain severe buckles and crimps without puncture or failure.

6. Safety vents, valves, manhole covers, cleanouts and all similar tank accesses are vulnerable to damage and leakage in a derailment. Covers that are for protection from the elements are of no significant protection in a rollover.

6.0 ROLLOVER LOADS ANALYSIS

As the derailment tests of COFC configurations were being performed, it became apparent that there was a high probability of flatcar rollover and release of the IM portable tanks. The container pedestals were the type used in normal service which release with the application of an upward force. The question was raised as to whether a more positive tie down would be better for rollover survival of a portable tank. An analytical study was planned and performed in order to compare the relative merits of the releasing type pedestal presently in use in all COFC versus a positive tie down such as the twist lock used for attachment to chassis trailers and between containers. A static analysis was performed to show which case is more likely to result in a rollover. A dynamic analysis was performed to determine and compare forces acting on the IM portable tank in rollover.

6.1 Static Analysis

There is an angle of roll of COFC configurations that represents an equilibrium condition. That is, the body is at that neutral point where its center of gravity is directly above the pivot point of the roll motion, and it is consequently in a balanced condition between returning to an upright position and rolling over.

A critical element of the problem solution is the axis about which the roll motion takes place. For the large roll angle of a rollover, the pivot points are the side bearings for the carbody, and the pedestals for the portable tanks. Since the centers of gravity are on or near the center of the vehicle and since the side bearings are at a shorter radius than the pedestals, the equilibrium condition for roll about the side bearings will be at smaller roll angles than for roll about the pedestals. This means that once the side bearing critical roll angle has been exceeded, the vehicle will roll over whether the pedestals are of the releasing type or not.

From this perspective, performance of the static analysis was an academic exercise in generating the numbers representing critical roll angles for the carbody with portable and for portable tanks alone. The results are summarized below.

The configuration studied consisted of two 20-foot portable tank containers on an 89-foot flatcar. Each tank was assumed to have an inner diameter of 85 inches and a volume capacity of 5786 gallons. The method of analysis was to calculate the balance moments for a range of roll angles and to present these results in plots of balance moment versus roll angle. The calculations were performed for four fill conditions, for four different specific gravities of the liquid lading, and for the two cases of slosh and no slosh. Weight and configuration data used are presented in Table 6-1 and Figure 6-1.

Representative results of the static analysis are presented in Figure 6-2, a plot of critical roll angles for the range of percent of fill studied, for the specific gravity of 0.9. The plot shows that the critical roll angle is about 30 degrees. The analysis showed that with 95% fill the critical roll angle ranged from 29 degrees for specific gravity of 1.0 to 32 degrees for specific gravity of 0.70.

The following conclusions were drawn from this study:

1. The critical roll angle for rollover of a flatcar with liquid filled portable tanks is approximately 30 degrees.
2. The critical rollover angle is not changed by the use of nonreleasing pedestals for the portable tanks.
3. Liquid slosh causes the critical roll angle to be reduced.
4. The critical roll angle is constant with variations in percent fill because the effects of C. G. height and slosh are opposite and canceling.

6.2 Rollover Dynamic Analysis

The dynamic rollover analyses had two parts, one where the container had ground impact by itself and the other where the container and carbody were attached as they hit the ground. A computer program was prepared for each case wherein initial conditions were assumed and a numerical integration was performed to determine time variation of displacements, velocities, accelerations and forces.

The programs were both prepared in FORTRAN and run on an IBM AT personal computer. One of the critical elements of the analyses was the formulation of soil properties. The same algorithms and coefficients were used for both the container alone and container and carbody analyses.

One set of initial conditions was analyzed for the case of the releasing container and three sets of conditions were used for the nonreleasing container. The initial conditions for these analyses are listed in Table 6-2. In each analysis, runs were made for forward speeds from 0 to 60 mph in 10 mph steps. Additional runs were made at 30 mph for several initial roll angles in the nonreleasing container analysis.

TABLE 6-1
HYPOTHESIZED WEIGHT CONFIGURATIONS & C. G.'s

ITEM		SEPARATE		COMBINED	
		Wt. (k lb.)	C.G. (in.)	Wt. (k lb.)	C.G. (in.)
Flatcar Body		70.0	33.5		
Empty Container		9.0	95	88.0	46.1
Liquid Vol. - Sp. G.					
100%	1.0	48.3	100.0	184.6	74.3
95%	1.0	45.9	98.0	179.8	72.6
	.9	41.3	98.0	170.6	71.2
	.8	36.7	98.0	161.4	69.7
	.7	32.1	98.0	152.2	68.0
90%	1.0	43.5	96.2	175.0	71.0
	.9	39.1	96.2	166.2	69.7
	.8	34.8	96.2	157.6	68.2
	.7	30.5	96.2	149.0	66.6
85%	1.0	41.1	94.3	170.2	69.4
	.9	37.0	94.3	162.0	68.1
	.8	32.9	94.3	153.8	66.7
	.7	28.8	94.3	145.6	65.2
80%	1.0	38.6	92.6	165.2	67.8
	.9	34.7	92.6	157.4	66.6
	.8	30.9	92.6	149.8	65.3
	.7	27.0	92.6	142.0	63.8

Note: C. G. measured from top of rail.

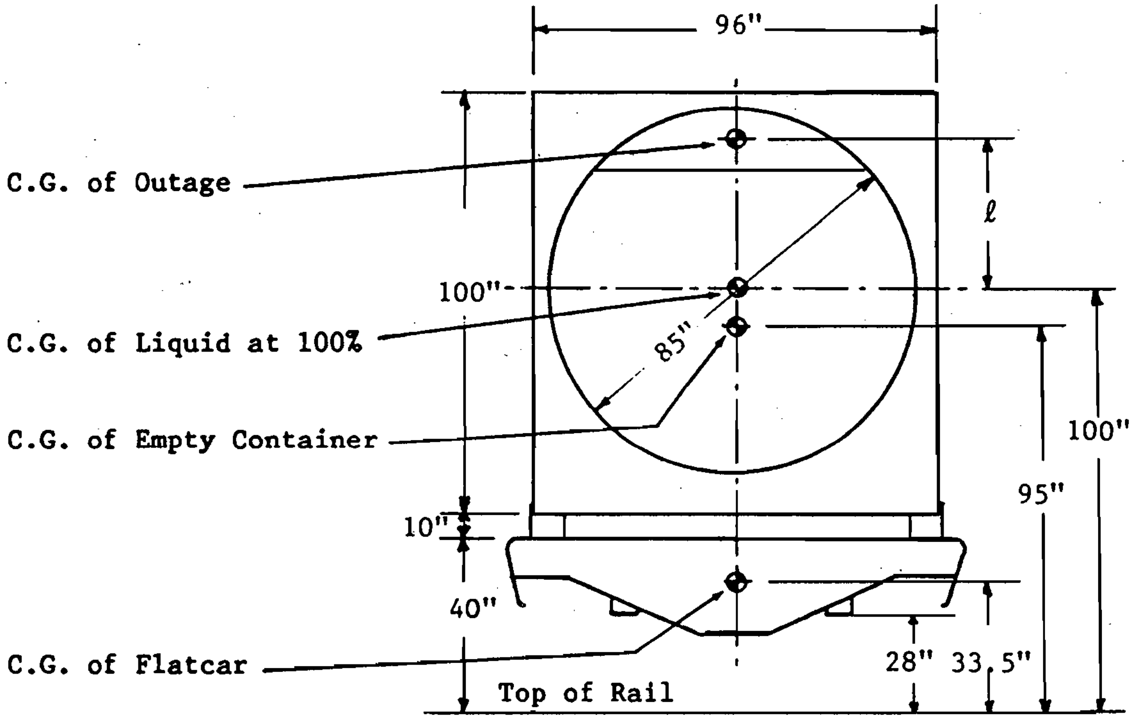


FIGURE 6-1
CONTAINER AND FLATCAR DIMENSIONS

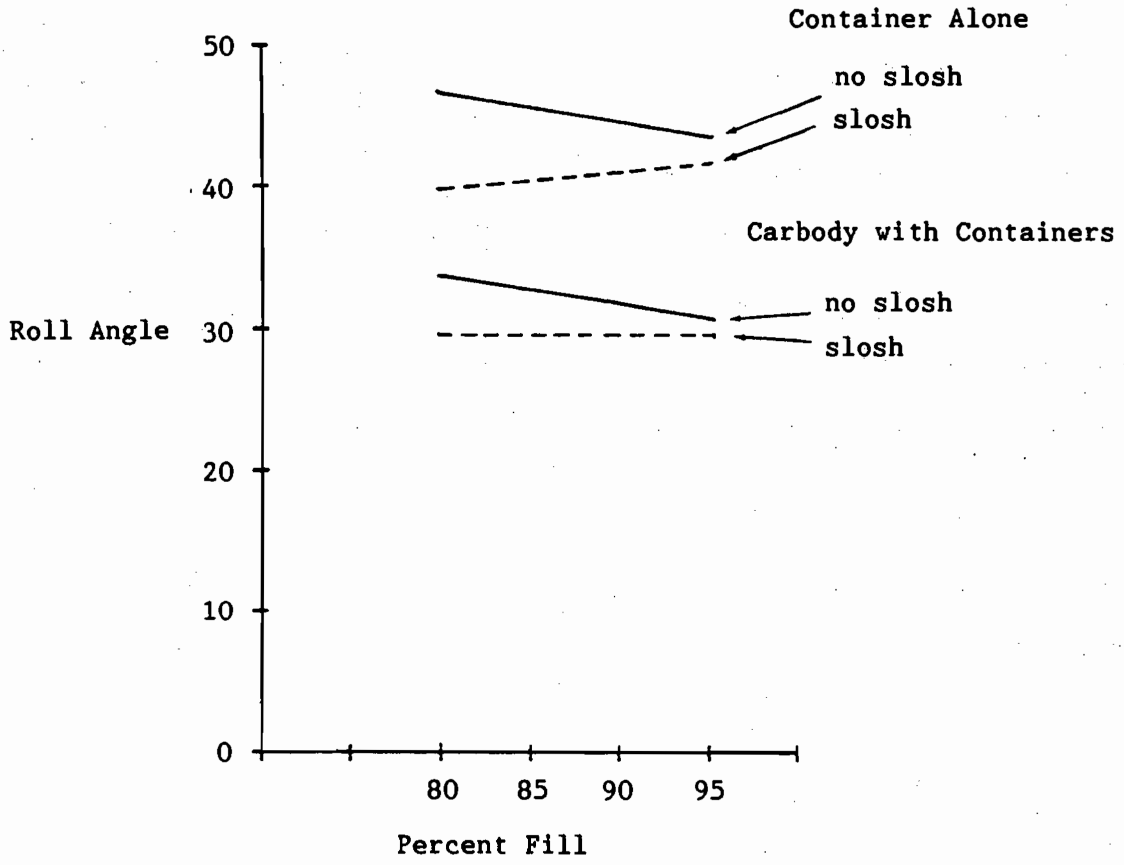


FIGURE 6-2
COMPARISON OF CRITICAL ROLL ANGLES,
SPECIFIC GRAVITY OF 0.9

TABLE 6-2
ANALYSIS INITIAL CONDITIONS

INITIAL CONDITIONS	CASE NO.			
	0	1	2	3
Container Vertical Velocity (in./sec.)	120	120	120	120
Roll Angle (both)* (deg.)	90	90	90	115.8
Roll Velocity (both) (deg./sec.)	0	34.4	96.3	96.3
Carbody Height Above Ground (in.)	-	0	20	20
Carbody Vertical Velocity (in./sec.)	-	43.2	0	0

* Both refers to both carbody and portable tank.

Case 0: Releasing pedestals

Cases 1-3: Nonreleasing pedestals

Case 0 was the analysis of the unrestrained portable tank by itself. The roll angle at ground impact was 90 degrees to the upright position and vertical velocity at the c.g. was 120 inches per second.

Cases 1, 2, and 3 were for the nonreleasing analyses. Case 1 corresponded to the same initial conditions as Case 0 with simultaneous ground contact of carbody and tank. In Case 2, the roll velocity at impact was increased over Case 1 and the tank had first ground contact. Case 3 was a variation on Case 2 wherein the roll attitude was increased from 90 to 115.8 degrees. In each case the forward velocity at ground impact was varied from 0 to 60 mph in 10 mph increments.

There were two additional variations made from Case 3 in that the roll attitude was assumed at 102 and 139 degrees for the forward velocity case of 30 mph.

Figures 6-3 and 6-4 compare the results of analyses with releasing and nonreleasing containers. These results show that the nonreleasing case can be more severe or less severe than the releasing case depending on the initial condition of roll angle at ground impact. In the analysis the roll angle of 90 degrees corresponds to the car and container on its side. For initial roll angles less than 110 degrees, loads on the container are greater for the releasing case. For initial roll angles greater than 110 degrees container loads are greater for the nonreleasing case.

The significance of roll angle at ground impact relates to trackside terrain. Typically the track will be on relatively flat ground and, in a rollover, the car and container will be on their sides (90 degrees roll angle) at initial ground impact. Where the track is on an embankment, the roll angle at impact will be greater than 90 degrees, the angle depending on the height of the embankment. In a cut, the angle would be less than 90 degrees.

The container c.g. acceleration is shown in Figure 6-5 plotted against initial roll angle. Below 110 degrees, the releasing container has the higher loading and above 110 degrees, the nonreleasing container has the higher loading.

It should be noted in Figures 6-3 and 6-4 that the highest loads occur at or below 10 mph. This can be attributed to the soil properties used in the formulation of the ground impact forces. Soil properties were adjusted to duplicate soil conditions of the derailment test. More specifically, ground penetration forces were found to decrease with increased forward velocity because of the plowing effect resulting from the forward motion.

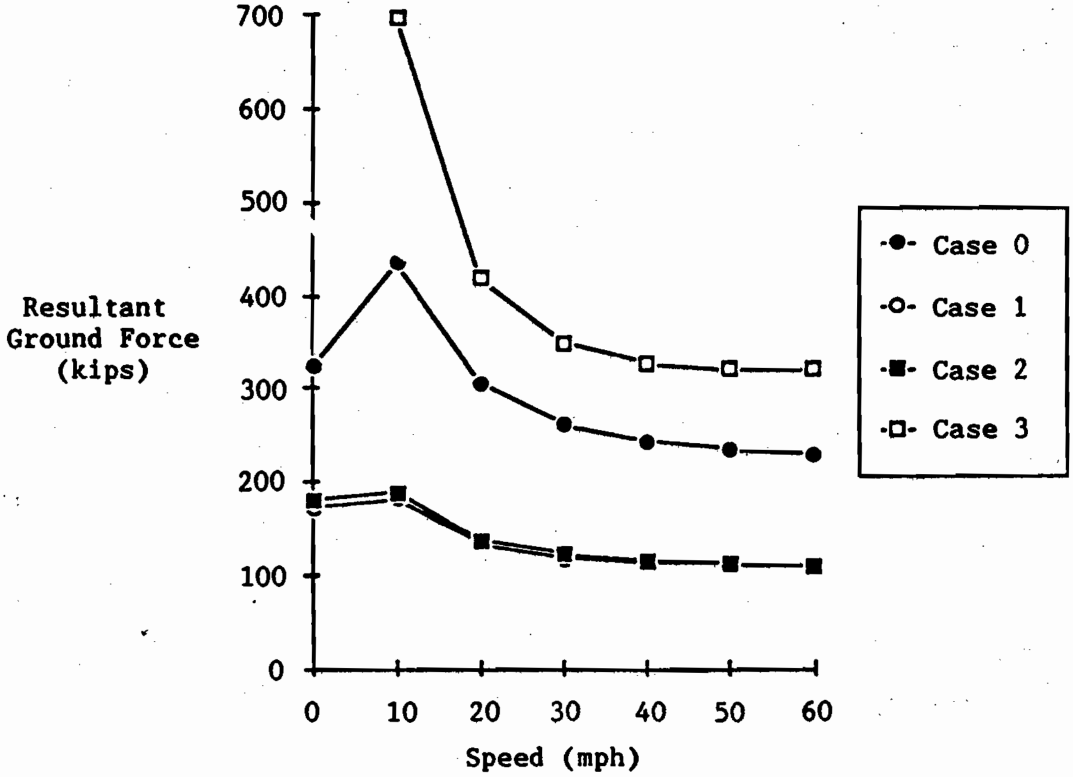


FIGURE 6-3
COMPARISON OF CONTAINER GROUND IMPACT FORCES

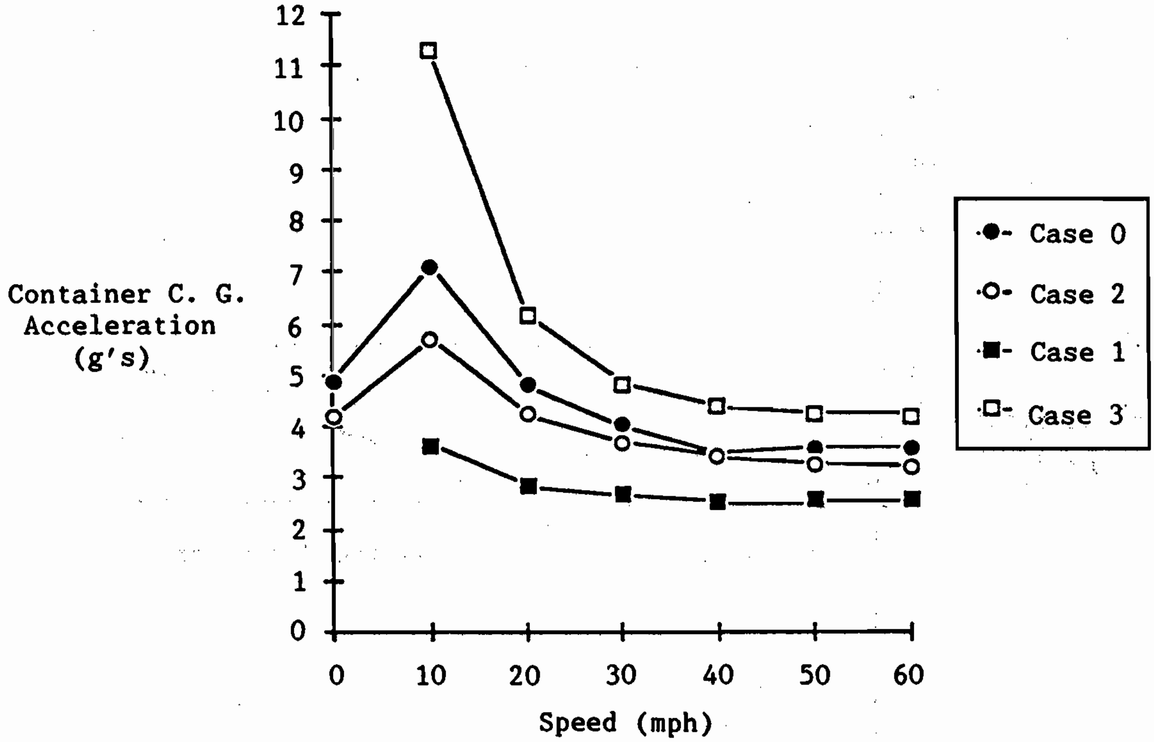


FIGURE 6-4
COMPARISON OF CONTAINER C.G. ACCELERATIONS

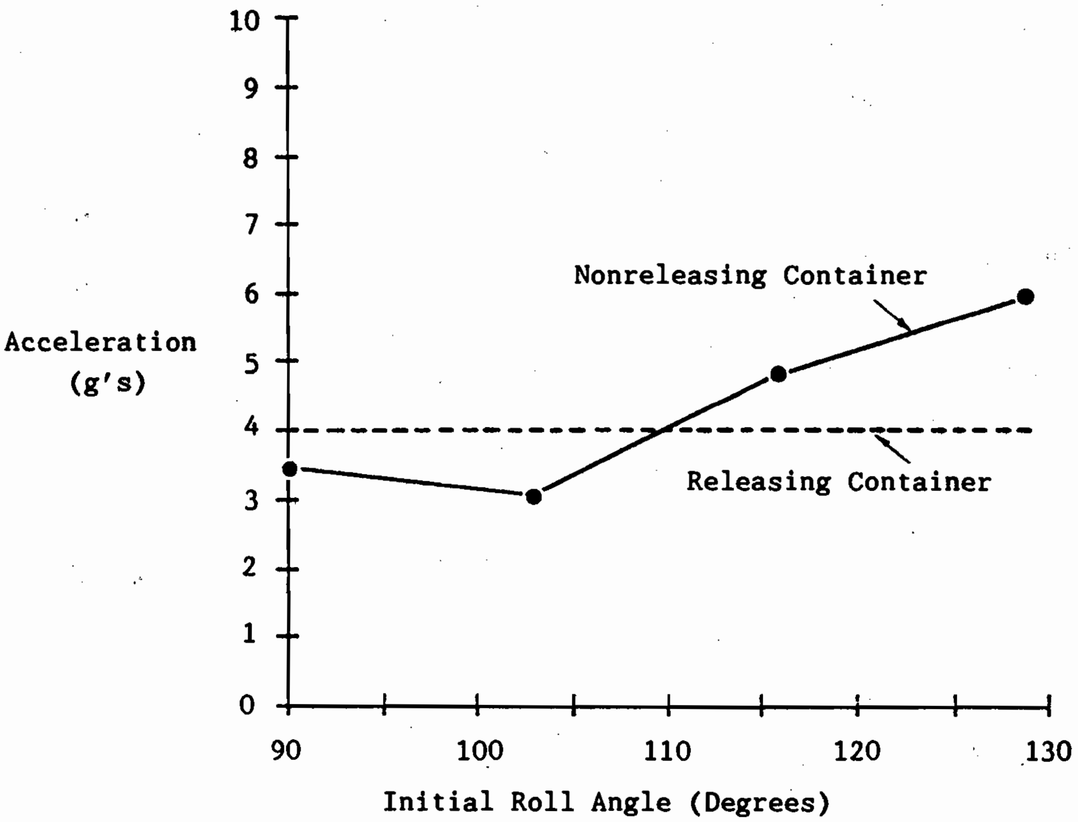


FIGURE 6-5
EFFECT OF ROLL ANGLE AT GROUND IMPACT ON CONTAINER RESULTANT ACCELERATION FOR A NONRELEASING ROLLOVER AT 30 MPH

6.3 Summary Discussion of Rollover Analysis Results

The static analysis results showed that the container attachment being of the releasing or non-releasing type had no effect on rollover probability. This is because once the flatcar rolls beyond its angle of neutral stability, rollover will take place whether the container releases or not. The only difference is that carbody and container will rollover together in the nonreleasing case, while the carbody and container will separate in the releasing case. In the latter case, the container will continue its rollover and the carbody will probably return to an upright position.

The results of the dynamic rollover analysis, summarized in Figures 6-3, 6-4, 6-5 indicate that the ground impact forces and acceleration forces on the container will probably be less with a nonreleasing tie down. However, loads are influenced by trackside terrain, and there will be some terrain where the nonreleasing tie down will result in higher loads on the portable tank than if the tank had been released.

An interesting result of the analysis is that maximum loads occur at low speeds. This is primarily a function of the soil properties used which were adjusted to duplicate soil conditions of the derailment test performed at the TTC. More specifically, ground penetration forces decrease with increased forward velocity because of the plowing effect resulting from the forward motion.

6.4 Conclusions from Rollover Analysis

The results of the analyses performed indicate that container deceleration and ground impact forces will probably be less for a nonreleasing container than for a releasing container. However, there are probabilistic variables that will influence container loads such that there will be cases where container loads will be greater for a nonreleasing container. Chief among these variables are the contours of the ground beside the track and the type of soil. A quantification of container load probabilities would require extension of the analysis to several contours and soils and determination of the probability of encountering each contour and soil condition.

Pedestal loads for the nonreleasing case were shown to be large (equivalent to acceleration forces of over 4 g's), and would probably require a strengthening of both the pedestal and flatcar deck.

Although nonreleasing container tie down shows an advantage over releasing tie down, the advantage can be reversed by trackside terrain.

7.0 RECOMMENDATIONS

There are a number of recommendations to be made based on the results of this investigative program. These are listed below.

1. A review of frangible/fusible vents is recommended. Specifically, these vents appear to be unable to withstand pressure and vacuum surges caused by liquid lading slosh. Further, the merits of a relief vent that would continue to discharge the hazmat once the vent is opened is highly questionable.

2. A review of vacuum relief vents is recommended. Specifically, the vent must reclose after the vacuum surge has passed. Test experience with the vent used in this program was that the valve was pulled out of the vent body leaving the vent wide open.

3. A mandatory check list should be prepared and its use enforced for verifying that all vents, valves, and other tank accesses such as manhole covers and fill caps are properly secured. The check should be completed at the time the covers are sealed, just prior to shipment.

4. The derailment testing of both MC cargo and IM portable tanks revealed that manholes, valves, vents, and other tank openings that protrude from the tank shell are susceptible to damage and subsequent leakage. Typical covers provide protection against the elements and provide very little mechanical protection in a rollover. The requirement in section 178.270-8 of Title 49 [1] that there "shall be adequate protection against mechanical damage" needs to be more definitive. For example, the strength of the cover might be required to be such that it can support the full weight of the tank, as in a rollover, at maximum gross weight (MGW) without any damage. Further, there should be space between the inside of the cover and the devices being protected so that there is room for crush-up of the cover. Still further, the design of the cover-to-tank attachment should be such that the tank can buckle or otherwise deform without tear or puncture.

   However, before these determinations can be made, additional study of the problem is recommended, together with the objective of formulating design guidelines for a protective cover for tank openings. Such a study should include experimental verification of any proposed guidelines suggested by the analytical study.

5. In the TOFC configurations tested on the VTU for harmonic roll response, the best performer was a single fully loaded trailer on the A-end of the flatcar and the worst performer was the same

loaded trailer on the B-end of the flatcar. In fact, the B-end trailer response was large enough to suggest that a single trailer TOFC should always have the trailer on the A-end. An analytical study should be performed that would confirm these results and would investigate a broader range of configurations and test conditions. For example, since these tests were performed only with the A-end of the flatcar leading, the performance with B-end leading should also be determined. The program objective would be to verify an apparently unsafe TOFC configuration and to identify optimally safe configurations.

6. It was found in the TOFC grade crossing tests that the threshold of profile variations resulting in trailer bounce varied from 0.5 to 0.8 inches, depending on the configuration. Critical speeds were at 45 and 70 mph. Dangerously large amplitudes of bounce can be anticipated if the grade crossing profile variations are at the Title 49 CFR limits of 2.0 inches for Class 4 (60 mph) and 1.25 inches for Class 5 (80 mph) track. Recommendation is made that this condition be analytically quantified.

7. In harmonic roll the critical response was found to be wheel lift of the trailer tandem. This would indicate that the most likely cause of an accident would be for the tandem end of the trailer to walk off the flatcar deck. Therefore, it is recommended that the feasibility and benefits of the addition of auxiliary restraints on the tandem of hazmat TOFC be investigated.

8. The curving tests were incomplete because the instrumentation was unable to provide the information needed to evaluate steady state curving. However, before additional tests are run, this issue should be first evaluated analytically. The need for further testing would depend on the findings of this analytical effort.

9. The occurrence of hunting motions in a curved section of track at speeds 10 mph below hunting threshold in tangent tracks was unexpected. Although this occurrence is not considered to be directly attributable to the influence of the liquid cargo, it is a phenomenon that should be investigated. It is recommended that a search be made of hunting test reports to determine if this is an isolated incident and to determine if further investigations should be performed.

10. The yard impact test results showed that slosh of the liquid lading resulted in a reduction of the impact forces compared to a solid lading. Consequently no structural problems are anticipated for intermodal liquid hazmat lading configurations in the yard impact environment that would be due to the liquid lading.

However, there were questions that came out of the yard impact tests that should be addressed. AAR specifications M-928 and M-952 define car coupling tests for demonstrating that the end-of-car cushioning limit forces into trailer kingpin and container attachments. In actual service there will be undetected deterioration of the end-of-car cushioning that will result in loads into trailer kingpins and container attachments that are greater than the design criteria.

The yard impact test defined in the AAR 600 specifications to demonstrate the structural adequacy of container tanks and their attachments in COFC applications differs from M-928 and M-952 in two major aspects: (1) in AAR 600, the test flatcar is a stand alone anvil while in M-928 and M-952, the flatcar is the hammer; and (2) AAR 600 specifies minimum loads that must be obtained in the impact tests as measured at the container attachment while M-928 and M-952 specify maximum loads that are not to be exceeded. During the tests carried out in this program, the minimum demonstration loads of AAR 600 were not reached while the maximum allowable loads of M-928 and M-952 were exceeded.

It is therefore recommended that the requirements for intermodal yard impact demonstration testing be reviewed and modified as appropriate to ensure that intended test results are achievable, accurate, and repeatable. It is recommended that accelerometers be used to measure the loading with specific requirements placed on accelerometer type and location, signal conditioning, data processing, and data display. The requirements should also be very specific on all aspects of the test set up. Finally the requirement should specify a maximum impact speed as well as a minimum g value.

11. The 3.5 inch drop test performed according to AAR M-931 resulted in severe damage to the MC 307 landing gear. It was concluded that either the test was an over-test or the landing gear needs to be redesigned. Further, it was concluded that should the landing gear need to be redesigned, the redesign should include shock absorbing features that would limit loads into the tank.

    The current procedures for loading and unloading trailers and containers on flatcars should be reviewed and a new drop test specification drafted for both trailers and containers that would account for both human error and handling equipment malfunction. The test requirements should be for two levels: one to cover normal handling environment which the trailer or container must survive without damage; and one for extreme, but possible, cases where the trailer or container may be damaged but must not have any spill or leak of liquid lading.

12. IM Portable Tank Design Recommendation

Based on the findings in this test program, there are four tentative recommendations for change or addition to the portable tank specifications in the Code of Federal Regulations, 49 CFR 178.0. These recommendations are limited to tanks to be used for intermodal transport of liquid hazardous materials and are for the purpose of improving accident survival without spill or leakage.

These portable tank design recommendations are given as tentative for several reasons. The derailment testing on which the recommendations are based is limited and formulation of the recommendations required the exercise of engineering judgment. The quantitative aspects of the recommendations are also influenced by engineering judgment and have consequently been given as examples rather than specific requirements. It is not practical to obtain an IM portable tank that will survive any and all accident conditions without leakage. In the final analysis the design will be a compromise between limiting costs and achieving maximum survivability.

a. In an accident environment, the framework structure that supports the portable tank also protects the tank against intrusion and provides an attenuation of impact forces. To do this the framework should meet three requirements.

   - The framework, including both longitudinal and transverse members, should completely surround the tank with adequate space between the frame envelope and the tank envelope for crush-up of the frame.

   - The framework should be of adequate strength. The AAR 600 specification [2] requires that the frame and tank supports must be designed so as not to exceed 80% of the yield strength for combined loadings of 2.0g vertical with 3.5g longitudinal, and 2.0g vertical with 1.5g transverse. Title 49 CFR [1] sections 178.270-4(b) and 178.270-6 require that the calculated stress of framework and tank supports must not exceed 80% of the specified minimum yield strength with loading conditions of 3g vertically downward and 1g vertically upward in combination with 1g lateral and 2g longitudinal. It is recommended that a review be made of the CFR design load factors in light of the findings of the accident simulation tests of this report and the AAR 600 requirements with the objective of revising the CFR requirements.

- The tank should be supported on full rings at several positions along its length. It was found in the accident testing of this report that portable tanks with this type of support resulted in the least amount of damage to the tank.

b. Buckling of the tank is an unavoidable part of the impact energy absorption systems. Consequently the tank material and its thickness must be such that it will withstand severe buckles without fracture. It is recommended that section 178.270-3 of Title 49 CFR be reviewed for possible incorporation of a new emphasis on the importance of tank material ductility, in particular, consideration of limiting tank materials to alloy steels and of increasing minimum elongation capability from 20% to 30%. The review should also consider that increased stiffness by increasing material thickness and decreasing tank diameter may not be of benefit. Buckling forces would be higher, and there would consequently be less buckling, but material stress would probably be higher, making tank rupture more likely. Such trade-offs deserve careful attention prior to revising Section 178.270-3.

c. Section 178.272-2(c) of 49 CFR states the following for IM 102 portable tanks:

"The following puncture protection systems are authorized:

(1) An overall external structural protection, such as a jacket, which is rigidly secured to the tank with a layer of cushioning material installed between the external structural protection and the tank; or

(2) A complete framework surrounding the tank including both longitudinal and transverse structural members."

The experience of the MC 307SS cargo tank in the accident testing is that its thermal insulation with stainless steel jacket did indeed provide puncture protection. Further, since thermal insulation is required on tank cars carrying certain hazmat the requirement may also be justifiable for cargo and portable tanks. A study should be performed that would determine the need for a thermal insulation and jacket requirement for cargo and portable tanks carrying certain hazmat.

d. The fourth recommendation addresses the provision of additional protection for manholes, valves, vents and other tank accesses. This has been covered in item 4 of this section.

13. Slosh of liquid lading was found to have a dampening effect which acted to reduce motions and loads during yard impact and harmonic roll. This dampening seemed to also reduce dynamic responses during curve entry and exit and during hunting. It is recommended that maximum fill requirements be reviewed with the objective of justifying a 95% fill requirement.

14. Although the trackside terrain of the derailment test site is typical of a major portion of continental U.S. track, it does not represent worst case conditions that would include such things as steep embankments or obstructions such as bridge pylons. It is recommended that a survey be made of trackside terrain in the United States, that a hypothetical grouping be made as to hostility of terrain, and that the total track mileage be divided into track miles for each grouping. The goal of this study would be to determine probability of accident in each grouping. An extension of the study would be to assign severity of accident for each terrain grouping and to assign probabilities of spill for each class of tank in each terrain grouping.

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