REPORT NO. FRA/ORD-76/303,II

TRAIN-TO-TRAIN REAR END IMPACT TESTS
Volume II - Impact Test Summaries

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MARCH 1977

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Research and Development
Washington DC 20590

Train-to-
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Vol. II

Technical Report Documentation Page

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16. Abstract

Nine train-to-train rear end impact tests were performed by the Dynamic Science Division of Ultrasystems, Inc., at DOT's Transportation Test Center under contract with the Transportation Test Center undercontract with the Transportation Systems Center which is conducting the program for the Federal Railroad Administration.

This final report documents these nine tests.

Volume I, Pre-Impact Determination of Vehicle Properties, summarizes the vehicle properities obtained prior to the impact tests. These vehicle properties were used in computer simulation of the impact tests and included weights, pitch moments of inertia, force deflection characteristics, vertical center of gravity location, and linear dimensions.

Volume II, Impact Test Summaries, describes the impact tests. The impact tests were remotely controlled with impact speeds ranging from 3 to 30 mph. An array of approximately 20 high-speed cameras and 50 channels of data, including accelerations, strains, and displacement, documented the impacts.

Volume III, Impact Test Summaries Appendix, is an appendix to Volume II. It contains the original data of the impact test.

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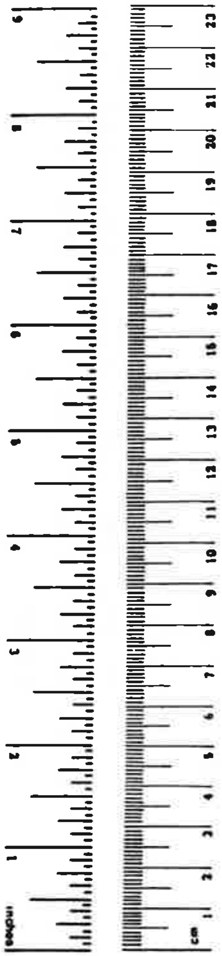
METRIC CONVERSION FACTORS

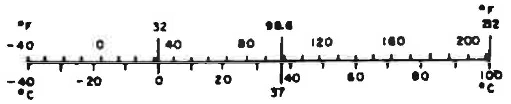
Approximate Conversions to Metric Measures

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		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	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
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



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		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	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
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF ILLUSTRATIONS (CONTD)

1. INTRODUCTION

BACKGROUND

As part of the effort to decrease the loss of life, the injury rate, and the extent of property damage due to train collisions, derailments, and other accidents, the Federal Railroad Administration (FRA) is pursuing a program to study the crashworthiness of rail vehicles and techniques for occupant injury minimization. In support of this effort, the DOT/Transportation Systems Center (TSC) provided assistance in the organization, conduct, and analysis of train-to-train impact tests relative to locomotive cabs, directed toward minimizing occupant fatalities and injuries during rear-end collisions. These tests were performed by the Dynamic Science Division of Ultrasystems, Inc., under Contract DOT-TSC-840. Major contributions to the test program were made by the Association of American Railroads, Washington University, the Brotherhood of Locomotive Engineers, and the United Transportation Union.

In the eight-year period from 1966 to 1973, there were 332 reported rear-end collisions. Seventy-two of these were responsible for 51 fatalities and 112 injuries to locomotive cab occupants. The FRA safety effort in this area is focused on determining why, in many instances, the impacted car, usually a caboose, overrides and crushes the locomotive cab during its post-impact trajectory while sustaining limited or no damage itself. This work is also aimed at determining the crushing forces exerted on the cab and the manner in which it fails, so that appropriate structural improvements may be developed.

The objective of the test series was to generate data which provide basic information on train-to-train dynamic interaction. These data include information on:

a) Locomotive frontal deformation

b) Force levels on the locomotive, caboose, and car in front of the caboose

c) Locomotive and caboose dynamics (trajectories, derailment)

d) Locomotive and caboose interaction (intrusion, buckling, crushing)

e) Possible injury modes of locomotive occupants

f) Fire hazards.

The data from these tests also provided the basis for refinement of mathematical computer models which will establish the capability of predicting the dynamic behavior of the two trains under other test conditions. From a study of the train-to-train interactions, the basic test data acquired, along with the results of computer simulations, will be applied to modify and delethalize the impacting vehicles and will be utilized in the planning of future crash energy management efforts.

The program consisted of 9 impact tests, ranging from 3 mph to 30 mph. Each test included high-speed photography and instrumentation to obtain data on the above areas of interest.

Volume II of this report summarizes the nine impact tests.

2. COMPUTER ANALYSIS

Computer analysis was conducted independently by TSC and Washington University.

The analytical and testing efforts were complementary, providing mutual benefits. The analytical results obtained with the computer model provided a means of predicting the dynamic response of the railcars to be tested. These predictions contributed to the technical design activity that preceded each test. Each test provided a means of evaluating the accuracy of the analytical effort, leading to refinements in the computer model, as well as providing the technical data that were sought and which helped determine the configurations for subsequent tests.

A detailed description of the computer modeling effort is beyond the scope of this report. The TSC model, however, did employ the modular formulation* developed at TSC. This method of formulation includes three-dimensional beam elements, various spring elements, rigid body elements, and modal elements. Figure 1 is an example of a schematic for the caboose model used in the simulation for the train-to-train impacts.

For the computer, the cars are idealized and replaced by somewhat simplified elements and interconnections that can be conveniently described by mathematical expressions. The mass, inertial, and stiffness characteristics of each of these elements and interconnections must then be defined for the mathematical model to be used. For instance, the force deflection curve of the track and ground that is idealized by spring A, shown in Figure 1. The underframe and draft gear force deflection characteristics are idealized by springs B and C. The mathematical description of the idealized cars then provides the basis for the computer analysis.

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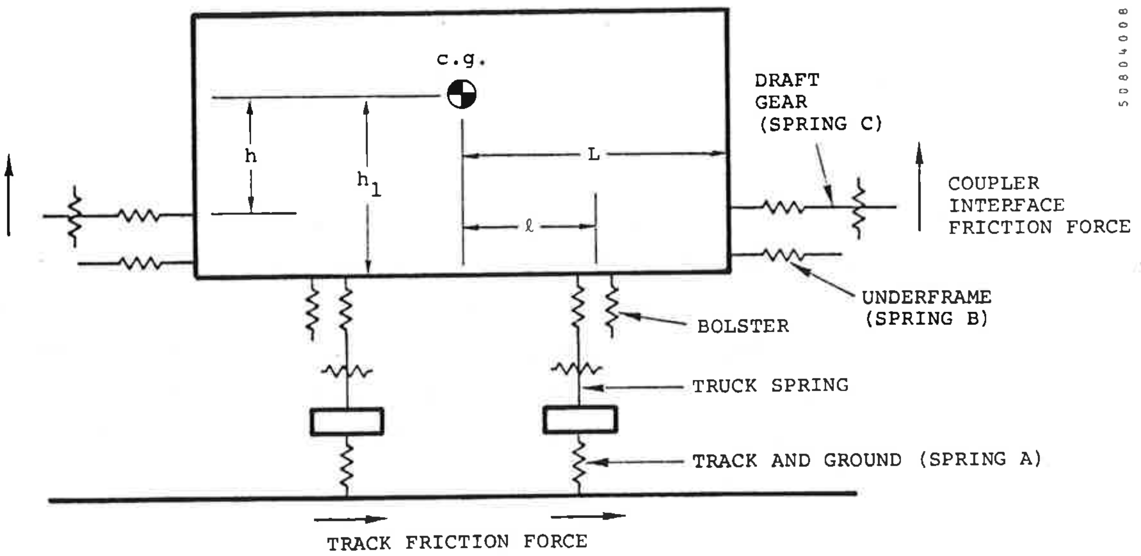
*Tong, Pin, and Tossettos, J. H., "Modular Approach to Structural Simulation for Vehicle Crashworthiness Prediction," DOT Report No. DOT-TSC-NHTSA-74-7, March 1975.



*SPRING LETERS ARE FOR TEXT REFERENCE.

FIGURE 1. MATHEMATICAL MODEL OF A CAR.

PROPERTY MEASUREMENTS

The test train consisted of three different types of vehicles: locomotive, caboose, and hopper car. The parameters for each car were obtained in a series of tests called pre-test measurements and include such things as weights, moments of inertia, dimensions, force deflection characteristics, etc. These measurements and tests are discussed along with the results in the Volume I Final Report.* Each measurement and test was aimed at filling out the required information for the computer analysis.

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*Anderson, R. L., and Cramer, P. L., "Train-to-Train Rear End Impact Tests, Final Report, Volume I - Vehicle Property Measurements."

3. IMPACT TEST CONDITIONS

The test matrix for the nine train-to-train impact tests is shown in Figures 2 through 5.

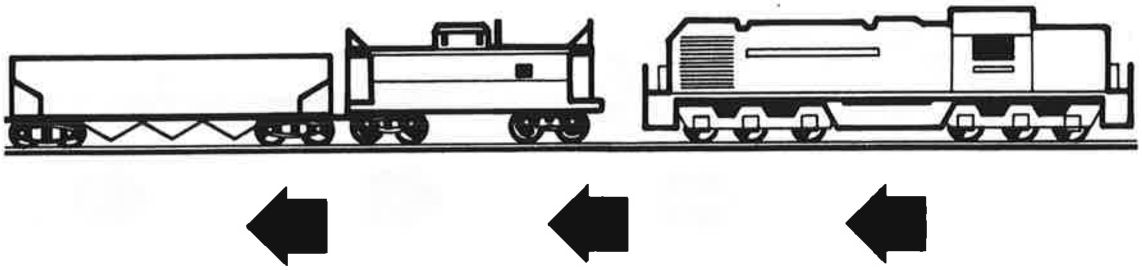

FIGURE 2. TEST MATRIX - TESTS 1 AND 2 (3 AND 5 MPH)

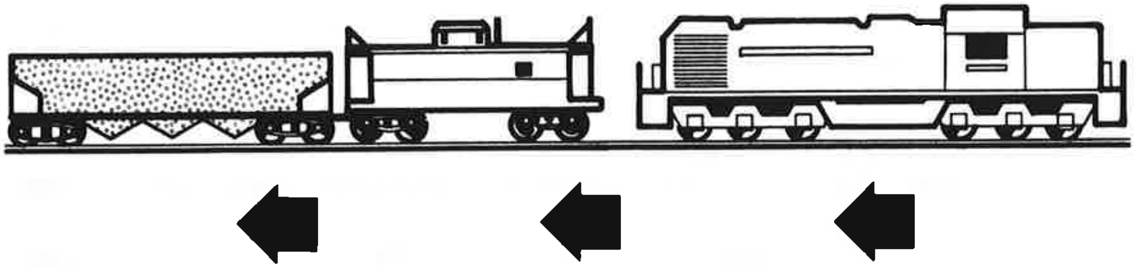

FIGURE 3. TEST MATRIX - TESTS 3 AND 4 (3 AND 5 MPH)

The low-speed tests 1 through 7 were used to verify the experimental configuration (testing procedures, location, and type of instrumentation, camera fields of view, etc.), as well as the computer model, and obtain data without destroying the test vehicles. The first two tests involved a caboose and empty hopper impacted by a single locomotive. The two impact velocities were 3 mph and 5 mph. These two tests were run on the same day.

Tests 3 and 4 were performed the following day using a loaded hopper in front of the caboose instead of an empty hopper car. These test speeds were 3 mph and 5 mph; thus giving a comparison between the dynamic reaction of the caboose coupled to

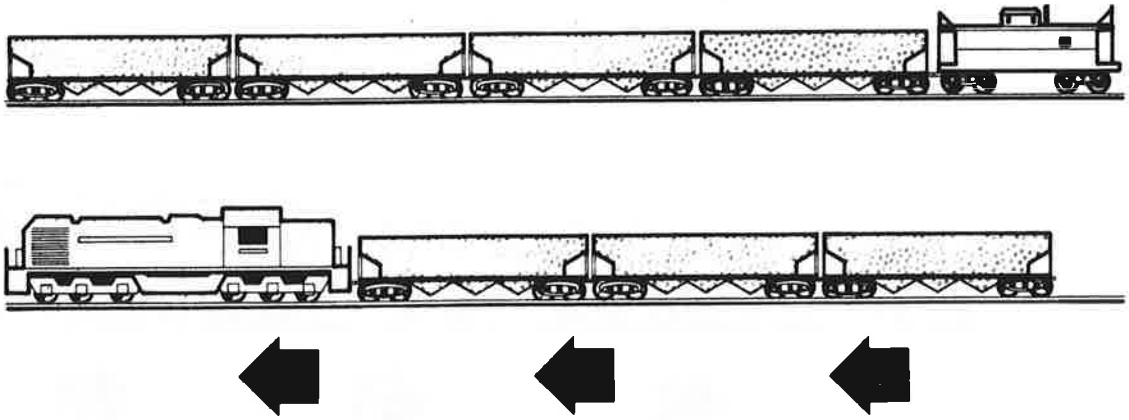

FIGURE 4. TEST MATRIX - TESTS 5 THROUGH 8
(5, 5, 8, AND 18 MPH)

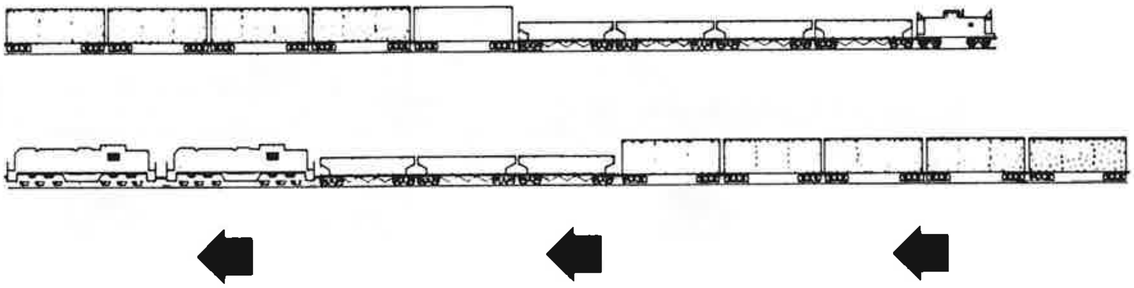

FIGURE 5. TEST MATRIX - TEST 9 (30 MPH)

an empty car or a loaded car. The two impact velocities also aided in checking the repeatability of this type of test.

Tests 5 and 6 were performed using longer trains. The struck train consisted of a caboose coupled to four loaded hopper cars. The striking train consisted of one locomotive and three loaded hopper cars. The impact speed for both tests was 5 mph. The only difference between the tests was that in Test 5 the cars of the standing train had their draft gears stretched out ("in draft") and in Test 6 the cars of the standing train had their draft gears compressed ("in buff").

Test 7 utilized the same train configuration as Test 6 with an impact velocity of 8 mph. Some minor changes were made in the caboose test configuration and are discussed in the section on test summaries.

The objectives of the high-speed tests 8 and 9 were to provide data during high-energy destructive tests and further refine and upgrade computer predictions.

Test 8 employed the same consists as in Tests 5 through 7. The standing train was in buff except that coupling between the caboose and hopper was in draft. The test speed was 18 mph. Test 8 was originally planned to be conducted at 15 mph, but the computer analysis indicated that 18 mph would tend to show more caboose override characteristics.

Test 9 (see Figure 5) employed the longest trains of the impact test series. Additional boxcars were added to simulate more closely typical long trains. An additional five loaded boxcars and one locomotive were added to the striking train, making a total of ten vehicles. The struck train had one empty boxcar and four loaded boxcars added to make a total of ten vehicles. Additional instrumentation was added to the second locomotive, but the boxcars were not instrumented.

During the test preparation for Test 9, minor changes were made to improve the dynamic action of caboose override. The changes included adjusting the relative heights of the couplers between the caboose and adjacent car as well as between the caboose and impacting locomotive. In addition, spacers already existing in the caboose suspension system were rearranged to give the caboose a preferred attitude for override prior to impact. Since a caboose and hopper were destroyed in Test 8, similar cars were substituted for the damaged ones. The test speed for Test 9 was 30 mph.

4. FACILITIES, DATA ACQUISITION, AND TEST PREPARATION

4.1 FACILITIES

Two facilities were utilized during the program.

All instrument calibration, train controller buildup, and data reduction was performed in Phoenix, Arizona, at the facilities of Ultrasystems, Inc., the Dynamic Science Division. The facilities utilized included office space, model shop, instrument calibration laboratory, machine shop, remote Univac 1108 terminal, data reduction laboratory, and photo laboratory.

The Federal Railroad Administration's Transportation Test Center (TTC) in Pueblo, Colorado, was the actual impact site. The facilities utilized at TTC included the train dynamics track and impact track, and the Project Management Building (PMB), the Rail Dynamics Laboratory (RDL), and the Storage and Maintenance Building (SMB). The impact site was remote from any buildings or utilities. An office building, portable shop, and electrical generators were acquired and installed at the impact site by Ultrasystems, Inc. Figure 6 is a schematic of the entire facility and Figure 7 is a picture of the operations area.

4.2 DATA ACQUISITION SYSTEM

4.2.1 <u>Photography</u>

All tests were conducted with an array of high-speed and real-time cameras photographing the impact. The movie coverage was complemented with still photography both before and after the test. The use of flashbulbs provided impact time correlation between cameras.

A timing generator with an accuracy of better than one percent triggered a lamp inside the high-speed cameras to provide a reference time base for establishing a precise sequence of events. The high-speed cameras were activated by a breakwire trap triggered by a mechanical arm attached to the locomotive. Camera activation occurred approximately 1.5 seconds prior to impact in

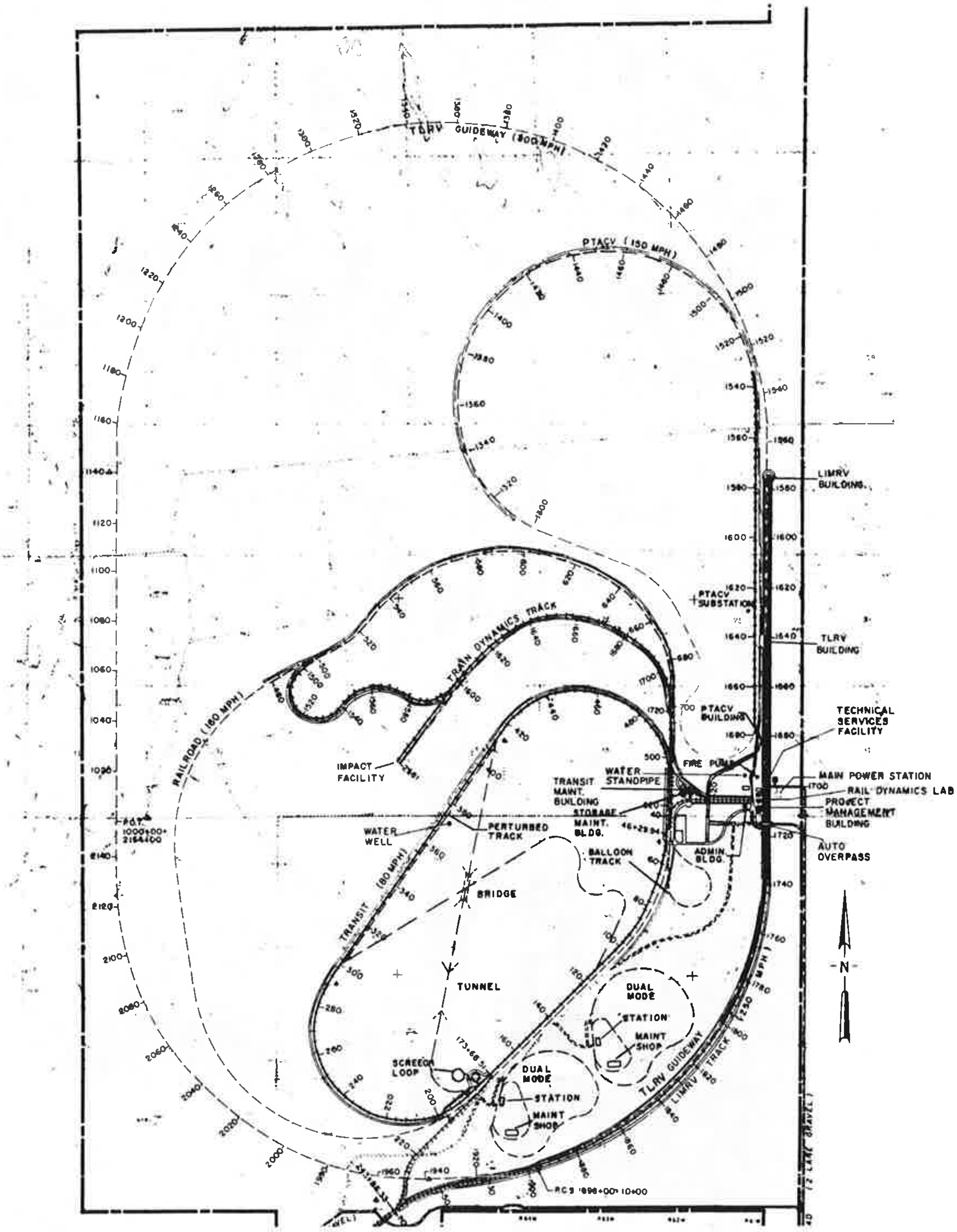

FIGURE 6. TRANSPORTATION TEST CENTER

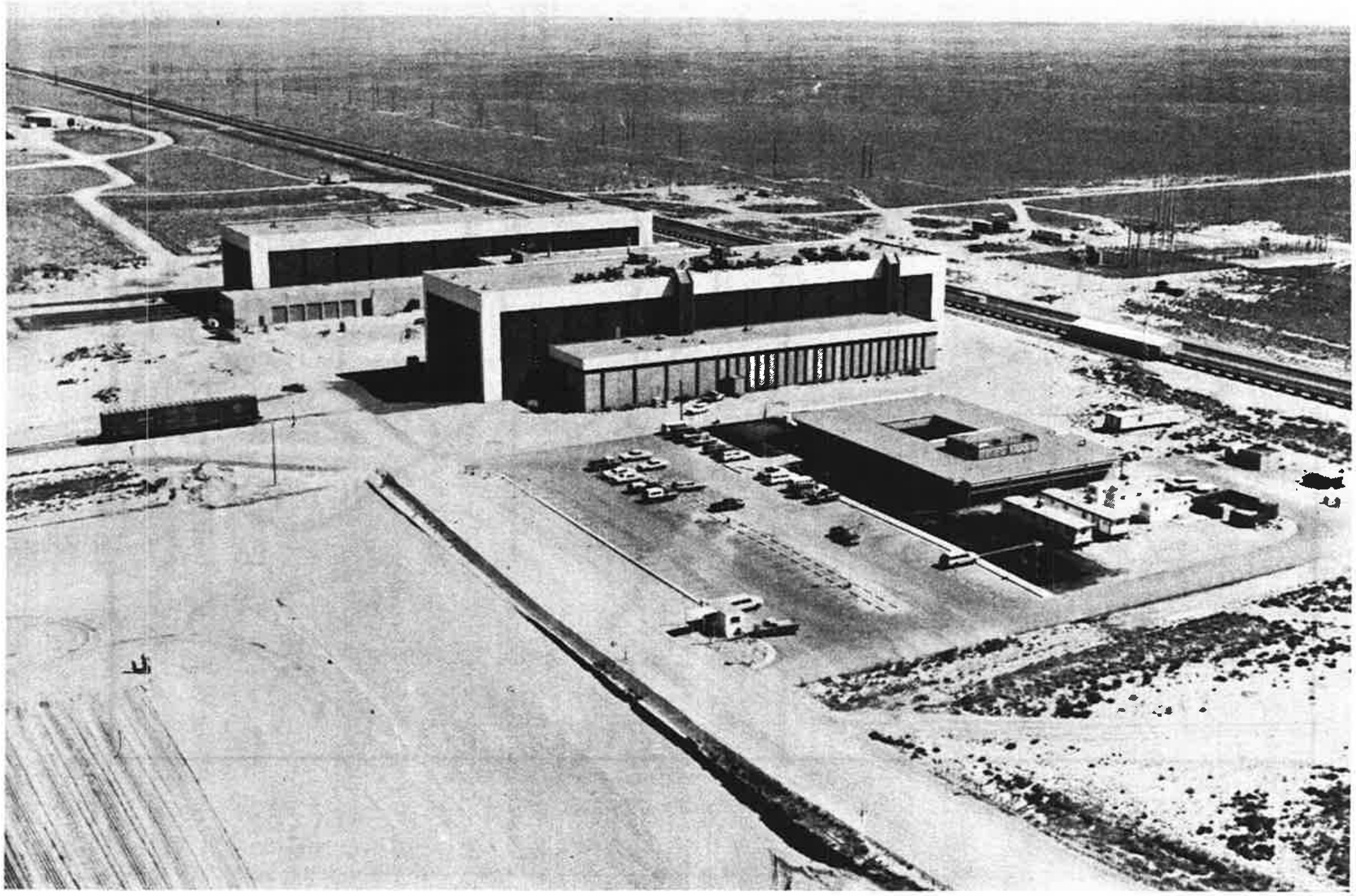

FIGURE 7. TRANSPORTATION TEST CENTER'S OPERATIONS AREA

order to allow the cameras to reach their steady-state speed. A control unit also deactivated the cameras after a predetermined time to prevent breaking up of the film after a reel had been exposed. Figure 8 is a schematic showing typical fields of view for the ground-based cameras.

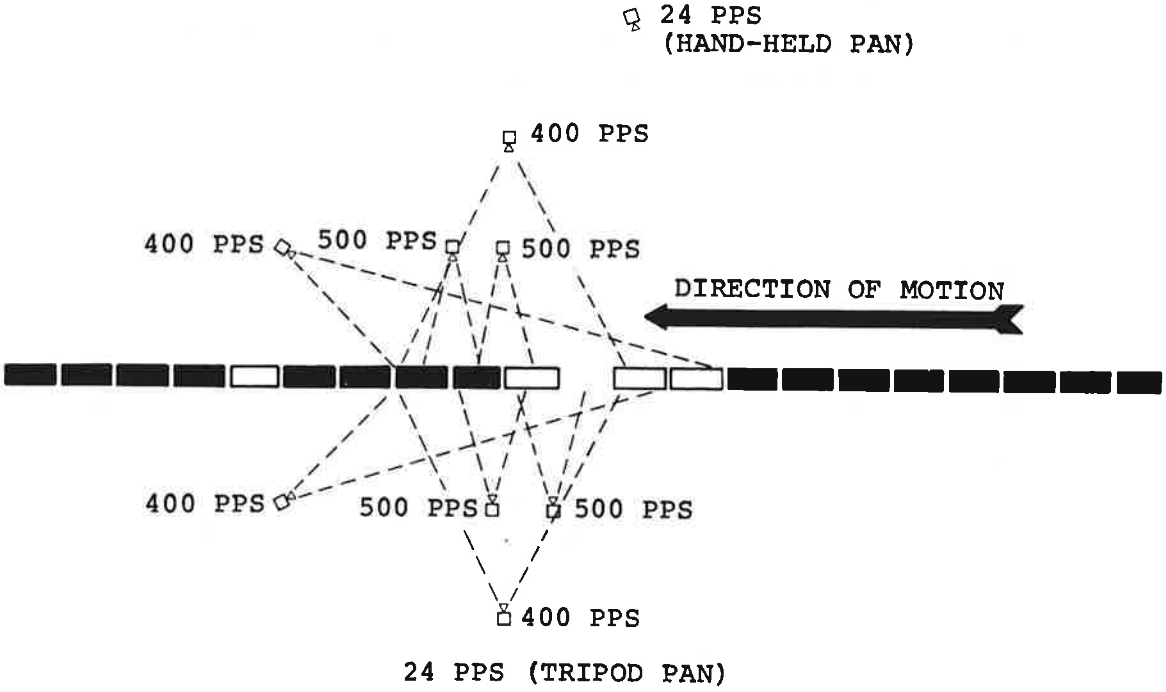

FIGURE 8. FIELD OF VIEW OF GROUND-BASED CAMERAS

The on-board cameras for the caboose consisted of two high-speed cameras (1,000 pictures per second (pps)) mounted directly over the couplers on each end. A third high-speed camera (1,000 pps) was mounted on the underside of the caboose to observe center sill deformation and separation of the rear center plate from the truck bolster. To obtain complete coverage of the rear truck, an additional high-speed camera (1,000 pps) was mounted on the railroad tie directly under the caboose. Lighting for these cameras was supplemented by long-duration flashbulbs that were triggered prior to impact to allow the bulbs to reach their full intensity prior to actual impact.

On-board cameras for the locomotive, consisting of one high-speed camera (1,000 pps) and one real-time camera (run at 24 pps), were used to observe the dummies in the cab. Additional lighting was also required inside the cab. A high-speed camera (1,000 pps) was mounted outside the cab window to view the lateral motion of the caboose. For Test 9 only, an additional high-speed camera was mounted on top of the impacting locomotive, focusing on the top of the struck train and viewing lateral motion of the cars in front of the caboose.

4.2.2 Impact Speed

All tests required an accurate measurement of the impact speed. The measurement was taken with a breakwire speed trap mounted on the cross ties. The trap was triggered by a rigid mechanical arm attached to the locomotive such that the measurement was obtained just prior to impact. The signals from each of the breakwires were recorded on an oscillograph along with a 1000-Hz timing signal. Since the distance between the wires was accurately known, the impact speed could be calculated to within 0.3 percent.

4.2.3 Transducer Data

The data obtained throughout the test series utilized three basic instruments: strain gauges, accelerometers, and linear potentiometers or "string-pots." A schematic drawing of the train illustrating the location of the instruments is presented along with the data for each test in the Appendix. The total number of instruments for a test ranged from 37 in Test 1 to 54 instruments for Test 9. This quantity of instruments provided some redundancy and reflected what happened at different sections of the train at various times.

Signals from all instruments, including a contact closure switch and a speed trap, were fed into a Remote Signal Conditioning Module (RSCM). The RSCM amplified, FM modulated, and multiplexed the signals for transmission to the tape recorder. The data from the moving train were transmitted along with the feedback information from the controller via telemetry to the tape deck. Data from the standing train were transmitted through an 800-foot-long umbilical cord. The umbilical cord was long enough to allow the struck train to move 400 feet before being disconnected at a special connector. The data, along with pre- and post-calibrations (if possible), were recorded on magnetic tape which was read directly into a computer system in Phoenix.

4.3 DATA REDUCTION TECHNIQUES

The data reduction techniques and analysis employed depended upon the type of data recorded. Basically, three types of data (transduced, film, and supplementary) were collected.

4.3.1 Transduced Data

Transduced data were recorded continuously as a function of time on an FM/FM magnetic tape recorder. These data consisted of accelerometer-versus-time records and force-versus-time records.

The data were reproduced in two forms: "quick-look" and digitized.

The "quick-look" data were obtained by demodulating the FM data tape and displaying it on an oscillograph strip chart as a quick check on the completeness and general nature of the data.

In order to do a complete engineering analysis of the data, the data tape was then digitized for further computations on a digital computer. A copy of the tape of digitized data was forwarded to TSC to be used with the computer model. The computer is programmed to write a plot tape to drive an automatic plotter.

4.3.2 Film Data

Film data consisted primarily of high-speed film which was analyzed with a Vanguard Film Analyzer. This process made it possible to order events in the crash sequence and establish vehicle kinematics. From this, the chronology of events during the crash sequence was constructed which, when correlated with the transduced data, added significantly to the interpretation of the dynamic response of the test vehicles.

4.3.3 Supplementary Data

Supplementary data consisted of all data that did not require continuous recording. This included pre- and post-test measurements, still photographs, observations, and measurements of various other parameters that were necessary to establish the test conditions and analyze the overall test.

4.4 TEST PREPARATION

Prior to field testing, work was required in the following areas:

Locomotive preparation
Controller modification and checkout
Caboose preparation
Equipment preparation
Facility preparation

4.4.1 Locomotive Preparation

Two locomotives were utilized throughout the program. The 130-ton Alco Locomotive #8031, built about 1940, was used as the "pusher" for the moving train. Preparation included installation of the automatic controller system which consisted of two servomotors which operated the brake levers, the main control unit, throttle relays, the on-board control panel, and miscellaneous air control valves.

Another 130-ton Alco Locomotive #8003, also built in the early 1940's, was used as the impacting locomotive for the entire test program (see Figure 9). A third 130-ton Alco Locomotive #8670 was added to the moving train for Test 9.

FIGURE 9. IMPACTING LOCOMOTIVE

Accelerometers were mounted in five locations on the impacting locomotive: two in the cab and three on the frame. Strain gauges were applied to the forward locomotive coupler. Three camera mounts were fabricated and installed; two in the control compartment and one outside the locomotive operator's window.

A fourth camera mount was added on top of the locomotive for Test 9.

As originally designed, the forward draft gear assembly was attached to the frame rail with rivets. A low-speed impact test (about 10 mph) performed by TTC showed that these rivets fail at a relatively low force level. Therefore, the impact end draft gear assembly was reinforced by welding and the addition of gusset plates. For Test 9, this reinforcing procedure was applied to the other end of Locomotive #8003 and to both ends of Locomotive #8670. Targets were applied to the sides of the locomotive in equal intervals to provide a reference and scale for measurement of deflections, displacements, and other motions during the analysis of the high-speed films.

4.4.2 Controller Preparation

The remote controller used to control the "Pusher" Locomotive #8031 was designed and built by Ultrasystems, Inc., for the FRA-sponsored locomotive-to-automobile baseline crash tests, Contract No. DOT-TSC-700.* For the train-to-train impact tests, the system was modified to include additional automatic brake controls, the decouple subsystem, and the distance counter for measuring the point of decouple.

The modifications were made in the Ultrasystems, Inc. laboratory at Phoenix, and final adjustments and checkouts were performed at the test site. The automatic brake valve mechanism was removed from the locomotive, sent to Phoenix for fabrication of mounting brackets and attachments, and returned to Pueblo for installation and checkout.

Section 5.0 includes a description of the features of the remote control system.

4.4.3 Caboose Preparation

The two cabooses used for the test program were identical and the instrumentation was applied to each in the same locations (see Figure 10). Three accelerometers were mounted on the center sill; one triaxial type at each end and one longitudinal type in the middle. The couplers were removed and sent to the National Castings Division, Midland-Ross Corporation, in Cleveland, Ohio, where strain gauges were applied and the couplers were calibrated in terms of force versus strain. The swinghangers were also removed and sent to Ultrasystems, Inc. in

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*Anderson, R. L., "Locomotive-to-Automotive Baseline Crash Tests," Final Report, Report No. FRA-OR&D-76-03, August 1975.

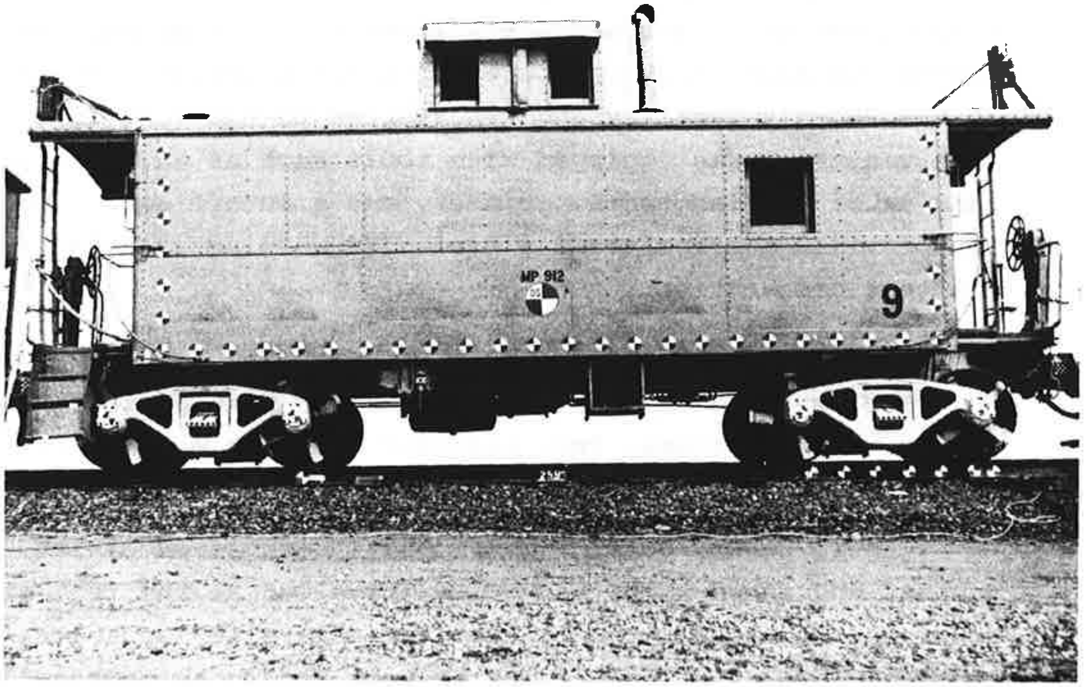

FIGURE 10. IMPACTED CABOOSE

Phoenix to have strain gauges installed and to be calibrated. Four linear potentiometers were installed between the sides of the caboose and the truck side frame (essentially ground) to measure vertical deflection.

Camera coverage was obtained by installing a fixture on top of the caboose at each end to view coupler actions. Another fixture was mounted on the underside to view the interaction between the truck and car. To improve photo coverage of the couplers, the steps were removed on one side of each end. Paint and reference tape were used to enhance photography. Five-inch targets were placed in one-foot intervals to measure deformation and deflection when analyzing the high-speed films.

4.4.4 Equipment Preparation

To complement the support facilities at the impact site, shop equipment, instrumentation laboratory equipment, and a comprehensive assortment of spare parts and material were gathered at the Phoenix facility and transported to the test site. A 24-foot van truck was equipped with tools such as an MIG welder, band saws, cutting torch, grinder, and a cutoff saw. The shop van provided the tools and a protected working area for facility and test preparation.

4.4.5 Facility Preparation

The impact track was provided by the Transportation Test Center. Ultrasystems, Inc. provided a portable field office and test control center and portable generators for electrical energy.

Camera power, control lines, instrumentation cables, antennas, and speed traps had to be installed at the test site and connected to the instrumentation and controller apparatus in the control center. All lines and systems had to be thoroughly checked prior to conducting the tests.

4.5 TEST PROCEDURES

As a test was being prepared, each system was tested and problems were assessed and resolved.

Two hours prior to test, after the basic test preparation was complete, the countdown, according to the checklist shown in Figure 11, was initiated. The checklist assured that a track conditioning run had been accomplished, security was in force, the remote controller was functioning properly, the camera systems were in readiness, and the instrumentation systems were in readiness for test.

OPERATIONAL TEST PROCEDURE
FOR
REMOTELY OPERATED
TRAIN-TO-TRAIN IMPACT TESTS, PHASE I

EFFECTIVE DATE
27 March 1975

APPROVED BY:

Ross T. Gill, Test Controller, TTC

Robert Anderson, Program Manager
Dynamic Science

Harry P. Smith, Hazards Evaluation
Officer, TTC

FIGURE 11. COUNTDOWN CHECKLIST

TRAIN-TO-TRAIN PRE-TEST CHECKLIST

TEST: ______________________ DATE: ______________

ITEM	FUNCTION	TIME	BY
1.	Pre-test meeting conducted by Dynamic Science Chief Test Engineer.		
2.	Test Controller post security guard stations. Test Controller verifies area is secure.		
3.	Test Controller request custody of test dynamic track and impact track from Operations Control Center.		
4.	Test Controller reports to Test Conductor track status.		
5.	Test Controller verifies fire support and first aid are supporting on-call status.		
6.	Test Controller reports Operations Control Center on program status.		
7.	Verification that all Dynamic Science Test Personnel are on station and ready for countdown.		
8.	Request permission from Chief Test Engineer to start pre-test countdown.		
9.	a. Power up all RSCMs and verify impact correlation reset.		
	b. Verify reception from all RSCMs set record levels.		
	c. Make announcement for radio silence.		
	d. Run pre-cals and stop tape deck upon completion.		

FIGURE 11 (CONTD). COUNTDOWN CHECKLIST

TRAIN-TO-TRAIN PRE-TEST CHECKLIST

TEST: ______________________________ DATE: __________________

ITEM	FUNCTION	TIME	BY
10.	Request permission from Test Controller for clearance to start the countdown and move the train for test.	________	________
11.	Move train manually to decouple point.	________	________
12.	Verify remote controller counter reset.	________	________
13.	Move train to start position.	________	________
14.	Verify train is at designated start point assigned by the Chief Test Engineer.	________	________
15.	All stations stand by for remote and local controller checkout sequence test.	________	________
16.	Verify 8031 ________________		
	a. Reverser is in neutral.	________	________
	b. Manual throttle is in idle position.	________	________
17.	Ensure the remote controller manual brake is in slow.	________	________
18.	Turn on local controller main power.	________	________
19.	Verify local receiver-transmitter power on.	________	________
20.	Place local-remote switch to remote.	________	________
21.	Make verification checks of remote control throttle switches.	________	________

FIGURE 11 (CONTD). COUNTDOWN CHECKLIST

TRAIN-TO-TRAIN PRE-TEST CHECKLIST

TEST: ______________________________ DATE: __________________

ITEM	FUNCTION	TIME	BY
22.	Make verification checks of remote control brake application.	________	________
23.	Stand by for fail-safe checks:		
	a. Verify throttle position 4.	________	________
	b. Verify brakes to run position.	________	________
	c. Turn off remote receiver and transmitter and verify throttle goes to idle and brakes to emergency aboard Locomotive 8031.	________	________
24.	a. Verify remote and local controller back to normal.	________	________
	b. Verify decouple mechanism is in proper position.	________	________
25.	Verification of all personnel ready for test.	________	________
	a. Struck train.		
	b. 8003.		
	c. 8031.		
	d. Locomotive Engineers.		
	e. Photo 1.		
	f. Photo 2.		
	g. Test Controller.		
	h. Instrumentation.	________	________
26.	Request permission from Test Controller to pick up final countdown at T-15 minutes.	________	________

FIGURE 11 (CONTD). COUNTDOWN CHECKLIST

TRAIN-TO-TRAIN PRE-TEST CHECKLIST

TEST: ______________________ DATE: ______________

ITEM	FUNCTION	TIME	BY
27.	Announce T-15.		
	T-15 Minutes		
	a. Verify all breakwires.		
	b. Verify all correlation bulbs installed on caboose and 8031.		
	c. Verify speed trap leads are installed.		
	d. Verify photo breakwires are installed.	______	______
28.	T-10 Minutes		
	Verify all personnel have left both trains except necessary Instrumentation Technicians.	______	______
	T-5 Minutes		
	a. Verify locomotive engineers ready for test and all personnel have left both trains.	______	______
	b. Verify camera timing on.	______	______
	T-3 Minutes		
	Make final checks of record levels.	______	______
	T-2 Minutes		
	Verify oscillograph set 2 in./sec. Timing at 1000 Hz.	______	______
	T-1 Minute		
	Reconfirm Test Controller ready for test.	______	______
	T-30 Seconds		
	Locomotive Engineer stand by for T-5 second rollout.	______	______

FIGURE 11 (CONTD). COUNTDOWN CHECKLIST

TRAIN-TO-TRAIN PRE-TEST CHECKLIST

TEST: ____________________ DATE: ____________________

ITEM	FUNCTION	TIME	BY
	T-5 Seconds		
	Five (5) second countdown - rollout.	________	________
29.	Remote Controller Operations:		
	a. Accelerate locomotive up to Vc mph.		
	b. Hold locomotive at constant speed.		
	c. At distance = 0, decouple.		
	d. When the decouple light goes steady, the train is committed.		
	e. Push slow brake on independent, bringing 8670 to complete stop.		
	Impact.	________	________
	Post-Cal.	________	________
30.	Turn track over to Test Controller and announce completion of test.	________	________

FIGURE 11 (CONTD). COUNTDOWN CHECKLIST

5. LOCOMOTIVE CONTROLLER

The locomotive was remotely controlled during the impact. The controller consisted of a control box, throttle relays, brake lever servomotors on the locomotive, and a control console inside the test control center near the impact site. The locomotive was manually started and positioned at the initial start point by a locomotive operating crew.

The controller was required to control the brakes, decouple, and throttle functions as well as operate the horn, bell, and forward/reverse function. The throttle has eight discrete positions in addition to idle. The controller utilizes a series of relays that parallel the switches inside the control panel of the locomotive itself.

The independent brake lever, which is used to apply brakes on the locomotive only, has five positions as follows:

a) Fast brake - applies brake pressure at a rapid rate.

b) Slow brake - applies brake pressure at a slow rate.

c) Lap - holds the brake pressure at the level in existence when lever is placed into this position.

d) Run - slowly releases brake pressure.

e) Release - rapidly releases brake pressure.

The automatic train brake lever enables the operator to control the brakes on the entire train as well as the locomotive. The six positions are:

a) Emergency - applies brake pressure at a rapid rate.

b) Service - applies brake pressure at a slow rate.

c) Lap - holds the existing brake pressure.

d) Holding - keeps brake pressure applied to the locomotive brakes while the train brake pressure system is being recharged.

e) Run - slowly releases brake pressure.

f) Release - rapidly releases brake pressure.

Servomotors physically position the brake levers on the locomotive brake valves in one of the brake positions.

The operator at the remote console receives the required confirmation of throttle position, locomotive speed, and brake line pressures by way of lights and gauges on the console.

The locomotive speed was determined by attaching an optical target of alternating black-and-white strips on the inside of a drive wheel and observing the frequency of pulses generated by a photo cell sensor attached to the locomotive frame. The pulse frequency was converted to an analog signal that was scaled as velocity. This signal was also used to generate a display for the distance counter, indicating the distance between the locomotive and the decouple point.

The brake line pressures were obtained by installing pressure transducers in the brake lines.

Two radio frequencies were required for the controller system:

416.6 MHz for the command link

219.0 MHz for the feedback link

The on-board control unit is shown in Figure 12. The onboard unit contains the control electronics and also has the capability to control the locomotive in a local mode directly using the controls of the on-board unit, bypassing the radio link to the remote control unit. The series of five buttons in the upper left corner are for selecting the brake setting when the brake is to be controlled from on board the locomotive in the local mode via the brake servomotor (eliminating the radio link). The series of nine buttons on the upper right corner of the console are for on-board local control of the throttle using the relays. The series of buttons in the center of the front panel turn on various subsystems of the unit.

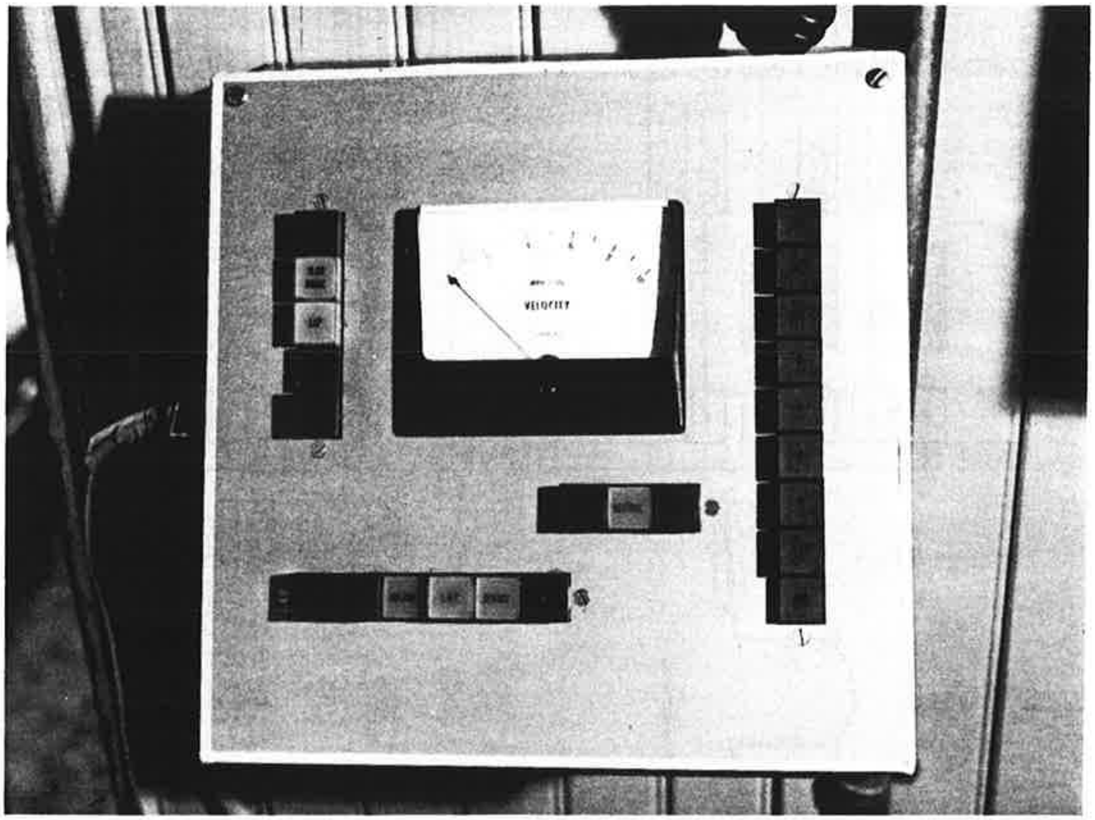

FIGURE 12. AUTOMATIC TRAIN CONTROLLER SYSTEM - LOCAL CONTROL

Figure 13 is a block diagram of the remote controller system. The right-hand side of the figure represents the on-board control unit. The upper series of blocks follows the signal from the receiver through the discriminators, represented by boxes labeled 1A through 8A, on to the controlling functions. The locomotive can be controlled in a local mode on board via the control switches or using the discriminated telemetry signal from the remote console. The lower series of blocks traces the feedback from the sensors through the signal conditioning and into the transmitter for input to the remote unit.

Figure 14 is a photo of the remote control console. The buttons duplicate the buttons required for local control on the on-board unit. The right-hand meter displays velocity and the

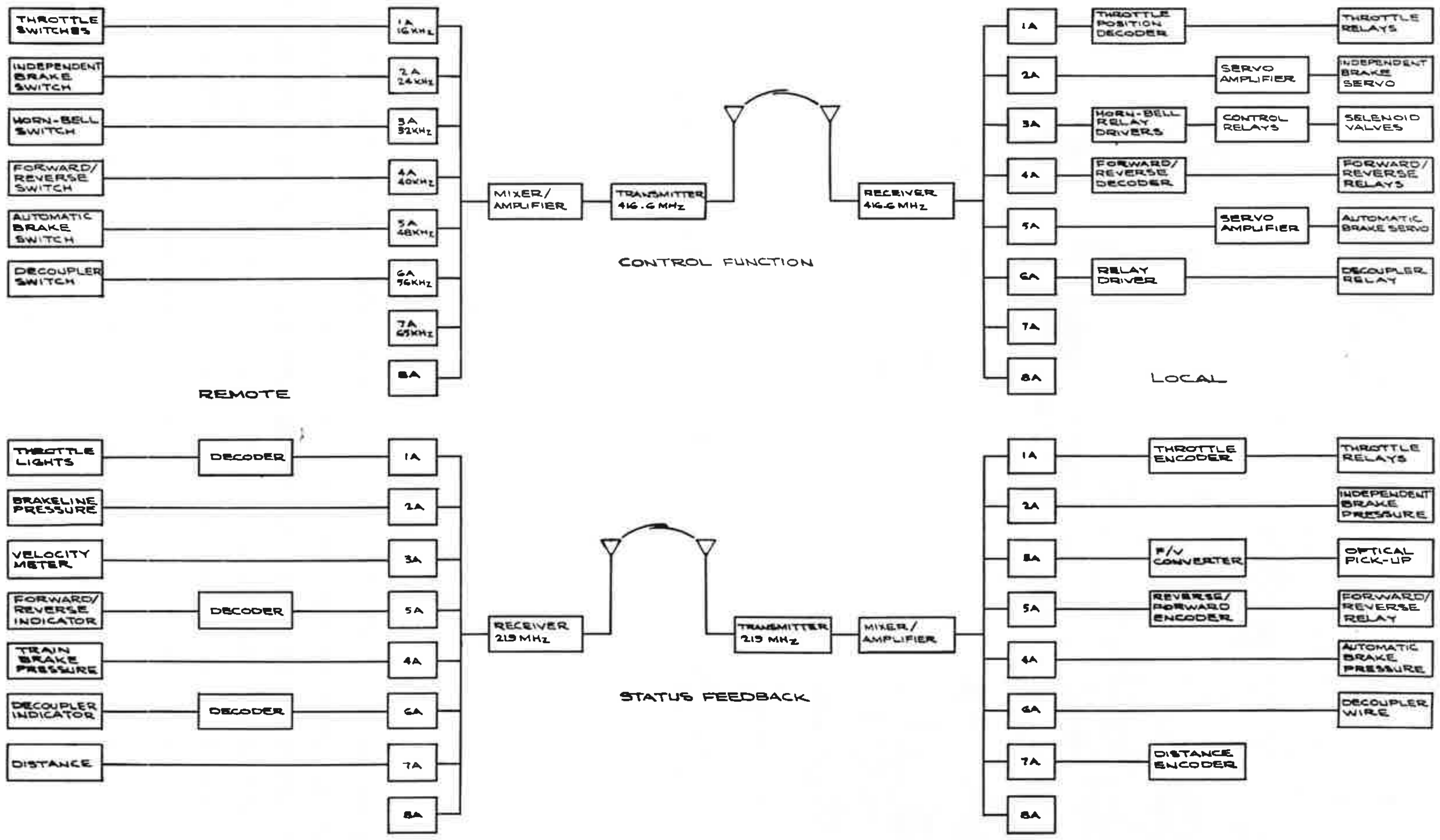

FIGURE 13. ULTRASYSTEM'S AUTOMATIC TRAIN CONTROLLER SYSTEM BLOCK DIAGRAM

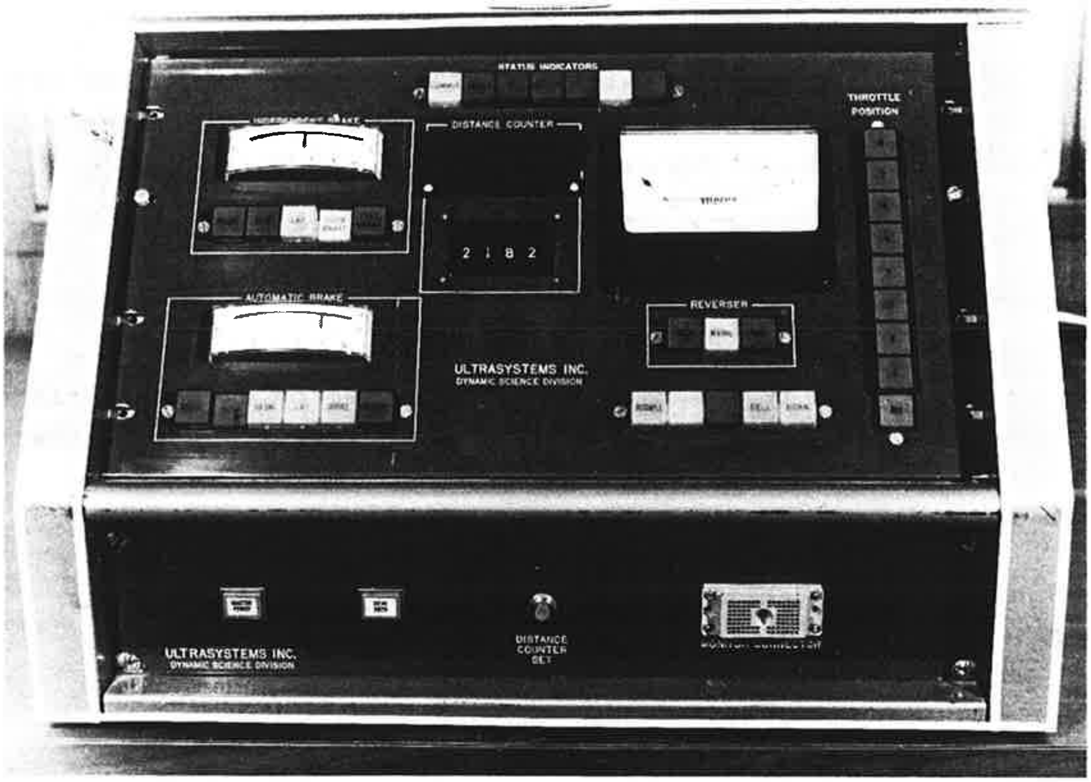

FIGURE 14. AUTOMATIC TRAIN CONTROLLER SYSTEM - REMOTE CONTROL UNIT

two left-hand meters display independent and automatic brake pressures. Lights internal to the throttle switches and brake position switches indicate the position of the controls.

Buttons under the meters turn on various subsystems of the control units, and the termination above the switches provides checkpoints for checkout of the system.

The left-hand side of Figure 13 represents the remote control console.

The upper set of blocks traces the command link from the switches through the signal conditioning and to the transmitter for transmission to the on-board controller. The lower set of blocks illustrate the feedback information from the on-board unit through the discriminators and into the displays.

6. TEST SUMMARIES

A total of nine train-to-train impact tests was performed during the program; with only the last two being destructive. The test summaries are presented in three groups:

Tests 1 through 7, Section 6.1

Test 8, Section 6.2

Test 9, Section 6.3

These test summaries are followed by data comparisons and data evaluations related to all nine tests which consist of the following considerations:

Coupler forces

Vehicle accelerations

Swinghanger forces

Caboose displacement measurements

Finally, the Appendix contains a complete set of computer plots of data obtained along with the train configuration, instrument location for each test, and instrument calibration information.

6.1 IMPACT TESTS 1 THROUGH 7

The first seven train-to-train impact tests were conducted as follows:

Test No.	Test Date	Impact Speed (mph)	No. Vehicles Stationary Train	No. Vehicles Moving Train
1	March 5, 1975	3.4	2	1
2	March 5, 1975	5.2	2	1
3	March 6, 1975	3.3	2	1
4	March 6, 1975	8.8	2	1
5	March 14, 1975	4.7	5	4
6	March 14, 1975	4.9	5	4
7	March 20, 1975	7.8	5	4

When the cars of the consist are compressed together as tightly as possible, the train is in buff. When the cars of the consist are separated or stretched out as much as possible, the train is in draft. The maximum difference between buff and draft for a car was 6 inches. The impact train configuration before and after impact was:

Test No.	Prior to Impact	After Impact
1	Draft	Draft
2	Draft	Draft
3	Draft	Draft
4	Draft	Draft
5	Draft	Draft
6	Buff	Draft
7	Buff	-----

During impact, the train was alternately in buff and draft as the locomotive stopped (coupled to the caboose) and the impacted train stretched out.

The method of performing the impact tests was to push the impacting train with a remotely controlled, operating "pusher" locomotive and automatically decouple the "pusher" from the moving train prior to impact. The "pusher" was then stopped at a safe distance from the impact and the moving train allowed to coast unassisted into impact. The brakes on the impacting train were activated just prior to impact with the use of a trip-wire system and electrically operated air solenoids. When the air system of the train's brakes experience this sudden change in pressure, the brakes are applied at a maximum rate similar to that experienced by an emergency application of brakes. This was done to simulate an operating locomotive engineer recognizing the impending accident and applying the brakes at the maximum rate. The air brakes have a delay of about 3 seconds from time of application until the brakes begin to decelerate the train. The brake activation was timed so that the moving train did not begin deceleration due to the brakes until shortly after impact. Thus, the brakes did not influence the initial impact dynamics but did aid in limiting destructive forces.

To attain the desired impact speeds, trial runs were performed prior to each test to determine "pusher" speed and location at the instant of decoupling. For the trial runs, the stationary train was moved safely away from the impact site and the brake trip-wire system was used to stop the moving train. The approximate stopping distance of the moving train was:

Test Speed (mph)	Stopping Distance (ft)
3	30
5	40
8	100
18	350

The stationary train had the hand brakes applied during the entire test sequence. The combination of having all brakes applied and of the momentum exchange upon impact, caused the trains to stop quickly. For Tests 1 through 6, the trains coupled together and the distance traveled after impact was as follows:

Test No.	Impacting Train Speed (mph)	Coupled Train Stopping Distance (ft)
1	3.4	6
2	5.2	12
3	3.3	5
4	8.8	22
5	4.7	10
6	4.9	9

During Test 7 at 7.8 mph, the trains did not couple. The stationary train moved 144 feet from impact while the moving train stopped only 18 feet from impact.

In Tests 1 through 6, the couplers of all cars were centered by wooden wedges. Figure 15 is a post-test photograph of the locomotive impacting coupler with the wedge jarred loose. For Test 7, the locomotive impacting coupler was blocked with steel wedges welded to the buffer casting and blocks were removed on all other couplers on both trains.

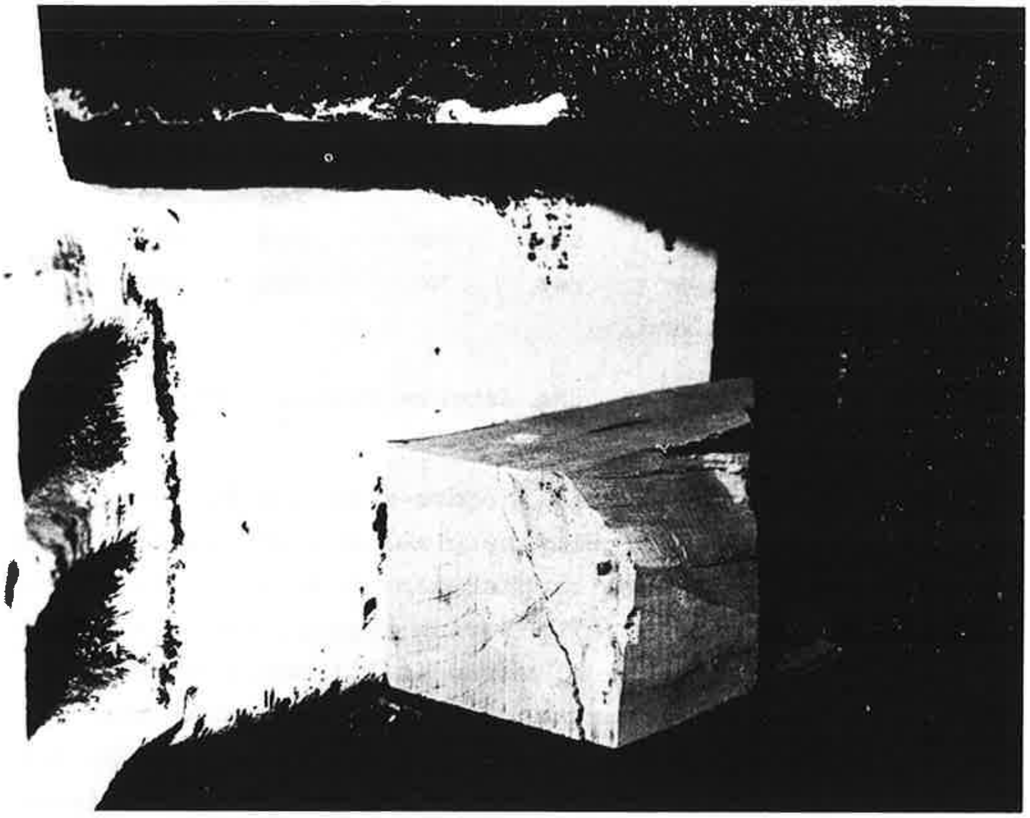

FIGURE 15. LOCOMOTIVE IMPACT END COUPLER WITH WOODEN WEDGE JARRED LOOSE

In addition to blocking, spacers were placed behind the coupler shanks on Tests 5 through 7. The spacers were 3/4-inch steel plates which increased the effective length of the coupler, and helped prevent the coupler horn from hitting the buffer casting. The objective was to direct impact forces through the coupler shank where strain gauges were applied. Figure 16 shows an example of the hopper rear coupler horn after impacting the buffer casting. Couplers which hit buffer castings during impact are shown below.

		Caboose		Hopper		Locomotive
Test No.	Impact Velocity	Rear(1)	Front	Rear(1)	Front	Rear(1)
1	3.4	No	No	No	No	No
2	5.2	Yes	No	No	No	No
3	3.3	No	No	No	No	No
4	8.8	Yes	No	Yes	No	Yes
5	4.7	Yes	No	Yes	No	No
6	4.9	Yes	No	Yes	No	No
7	7.8	Yes	No	Yes	No	Yes

(1) Impact end.

Prior to each test, the caboose couplers were centered with the knuckles open.

In all tests, the caboose rear (or impact) coupler height was adjusted vertically by placing steel spacers under the coupler (initially, the coupler sloped down with about one inch difference between ends). During impact, the coupler rotated to the right (south side) where it hit small steel blocks installed to protect strain gauges. The spacer plate behind the coupler shank on the caboose did not prevent coupler horn contact with the buffer casting during the tests with higher impact speeds.

Figure 17 is a photograph of the "short train" used for Tests 1 through 4. The hopper car was loaded with ballast for Tests 3 and 4, and during impact, the ballast shifted toward the caboose. The most significant movement of ballast occurred during Test 4 (8.8 mph). Tests 5 through 7 showed little indication of additional ballast shift.

The addition of extra loaded hopper cars (see Figure 18) did not have any major influences on the initial dynamics of the caboose during impact. The "long train" stopped in a shorter

FIGURE 16. CRUSHED TAPE ON HOPPER REAR COUPLER HORN WHICH INDICATES CONTACT WITH BUFFER CASTING DURING IMPACT.

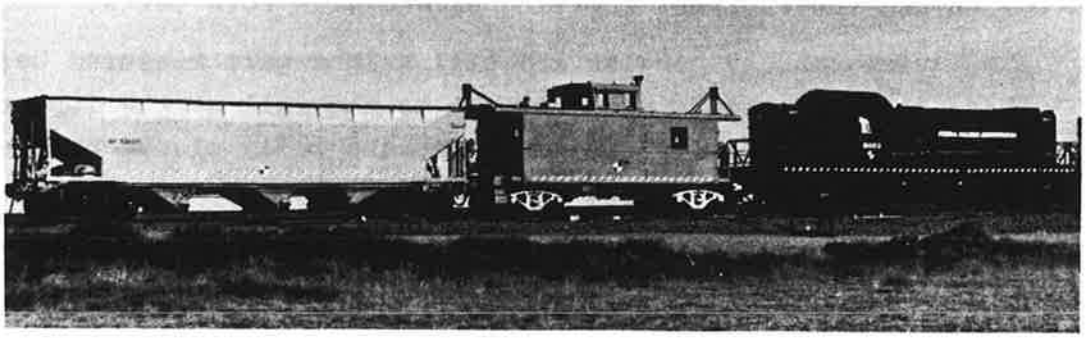

FIGURE 17. "SHORT TRAIN" USED FOR TESTS 1 THROUGH 4.

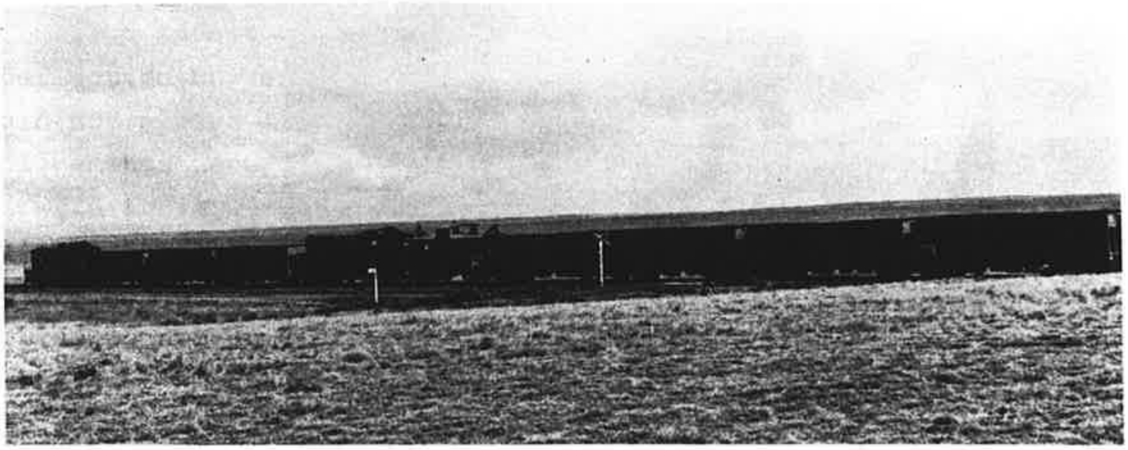

FIGURE 18. "LONGER TRAIN" USED FOR TESTS 5 THROUGH 8.

distance after impact and the ballast in the hopper next to the caboose did not shift as much as with the "short train."

Test 4 (8.8 mph) and Test 7 (7.8 mph) caused some minor damage in the caboose: wooden doors were ripped off of their hinges.

Ninety-fifth percentile (215-pound) anthropomorphic dummies were placed in the impacting locomotive to simulate a brakeman and an operating engineer (see Figure 19). In Test 4, the brakeman slid forward on the bench and hit a rear window, breaking the glass. Test 7 produced a similar occurrence with the brakeman and the engineer shifting slightly in both tests.

The caboose coupler and sill height were measured before and after the tests with respect to the rail at the impact site using a steel bar perpendicular to the rail, placed on the rails directly below the point of measurement.

The average measurements for Tests 1 through 7 are:

	Coupler Height Above Rail	Sill Height Above Rail
Rear End(1)	31.75 in.	27.25 in.
Front End	33.63 in.	29.75 in.

(1) Impact end.

FIGURE 19. ANTHROPOMORPHIC 95TH PERCENTILE MALE DUMMY PLACED IN THE LOCOMOTIVE OPERATORS SEATING POSITION.

These dimensions changed very little except for a slight settling after Test 2.

6.2 IMPACT TEST NO. 8

Test 8 was performed with the "longer train" as follows:

Test Date: April 9, 1975
Impact Velocity: 18.1 mph
No. Vehicles in Stationary Train: 5
No. Vehicles in Moving Train: 4
Standing Train Positioning: Draft

The test trains were the same as those used in Tests 5 through 7 except for the following major changes:

1. The coupler and sill heights of the caboose were revised.
2. 1,400 gallons of water were put in the fuel tanks of the impacting locomotive.
3. The draft gear assembly of the locomotive was reinforced.
4. Air brakes were applied to the stationary train.

In order to increase the possibility of overriding the locomotive, the caboose coupler heights were revised to make the impact end higher than the end opposite to the impact. This was accomplished by changing steel shims in the leaf springs of the caboose trucks, thus lowering the sill on one end and raising it on the other. In addition, a 3/8-inch spacer plate was installed under the impact coupler. The final measurements were:

	Coupler Height Above Rail	Sill Height Above Rail
Rear End (1)	34.5 in.	29.9 in.
Front End	31.5 in.	27.25 in.

(1) Impact end.

The coupler height of the hopper adjacent to the caboose was 32.25 inches, giving a .75-inch offset above the caboose coupler. The locomotive coupler was 32.4 inches high, making the caboose impact coupler 2.1 inches higher than the locomotive.

The fuel tanks of the impacting locomotive were loaded with 1,400 gallons of dyed water (11,676 pounds) to simulate fuel and aid in detecting leaks after destructive impacts.

Prior to Test 8, the FRA performed additional low-speed impact tests at TTC. It was discovered that the forces incurred during a 10-mph impact were severe enough to shear the rivets of the draft gear assembly of the type of locomotive being used for these impact tests. Figures 20, 21, and 22 show the locomotive draft gear, the caboose crushed end platform, and the sheared rivets from the locomotive. To avoid this problem in Test 8, the draft gear assembly on the impacting locomotive was reinforced by welding thick plates from the frame rails to the draft gear. This reinforcement brought the draft gear strength to a higher level that is more representative of modern locomotives.

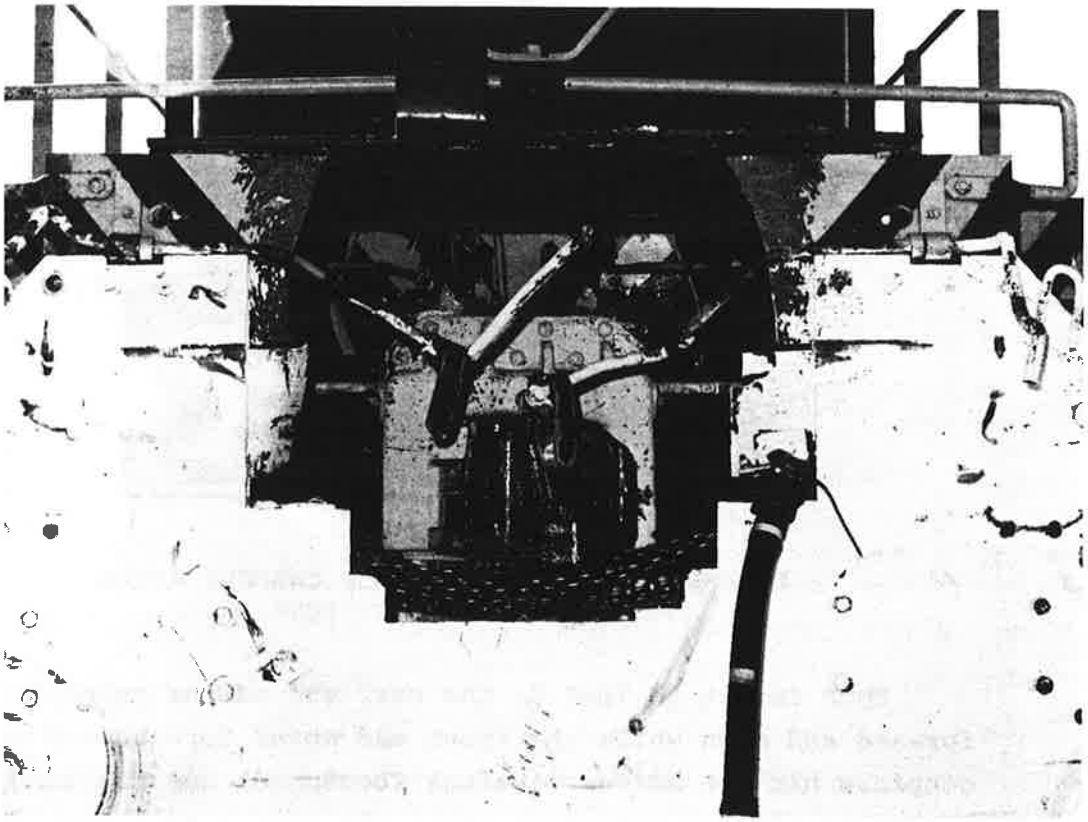

FIGURE 20. SHEARED DRAFT GEAR AFTER 10-MPH IMPACT TEST.

A three-mile-per-hour impact test was performed prior to Test 8 to verify instrumentation, camera operation, and the remote controller system.

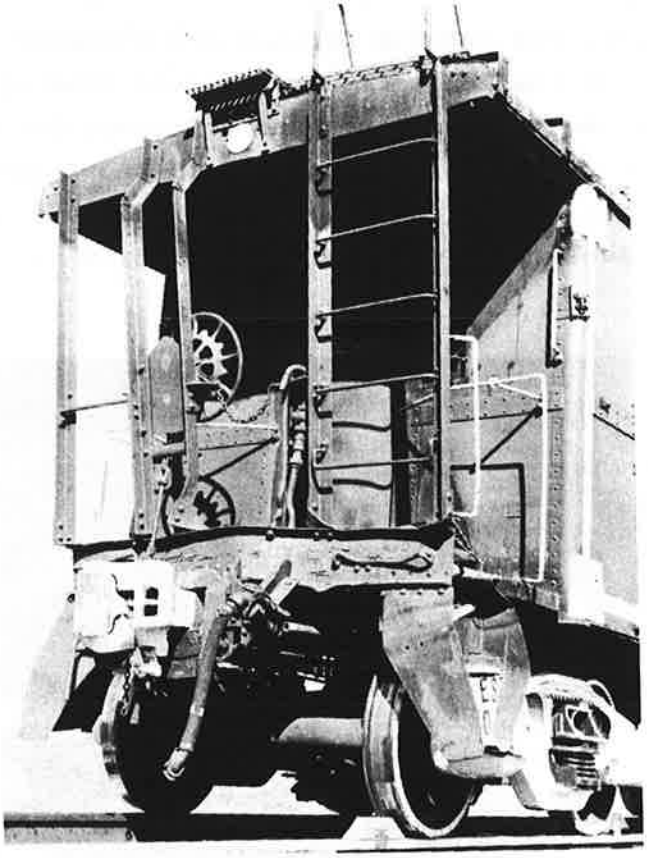

FIGURE 21. CRUSHED END OF CABOOSE AFTER 10-MPH IMPACT TEST.

Upon impact in Test 8, the rear end of the caboose moved forward and down while the front end moved forward and up. The couplers hit the buffer castings (bottomed) and the longitudinal compression force increased until the center sill buckled where it was perforated to permit the passage of an air brake pipe. The front end coupler slipped up out of the hopper rear coupler and intruded into the end section of the hopper. The sides of the hopper bent outward and forward as the caboose came to rest partially overriding the hopper.

The caboose front truck was derailed under the caboose, but suffered no permanent damage.

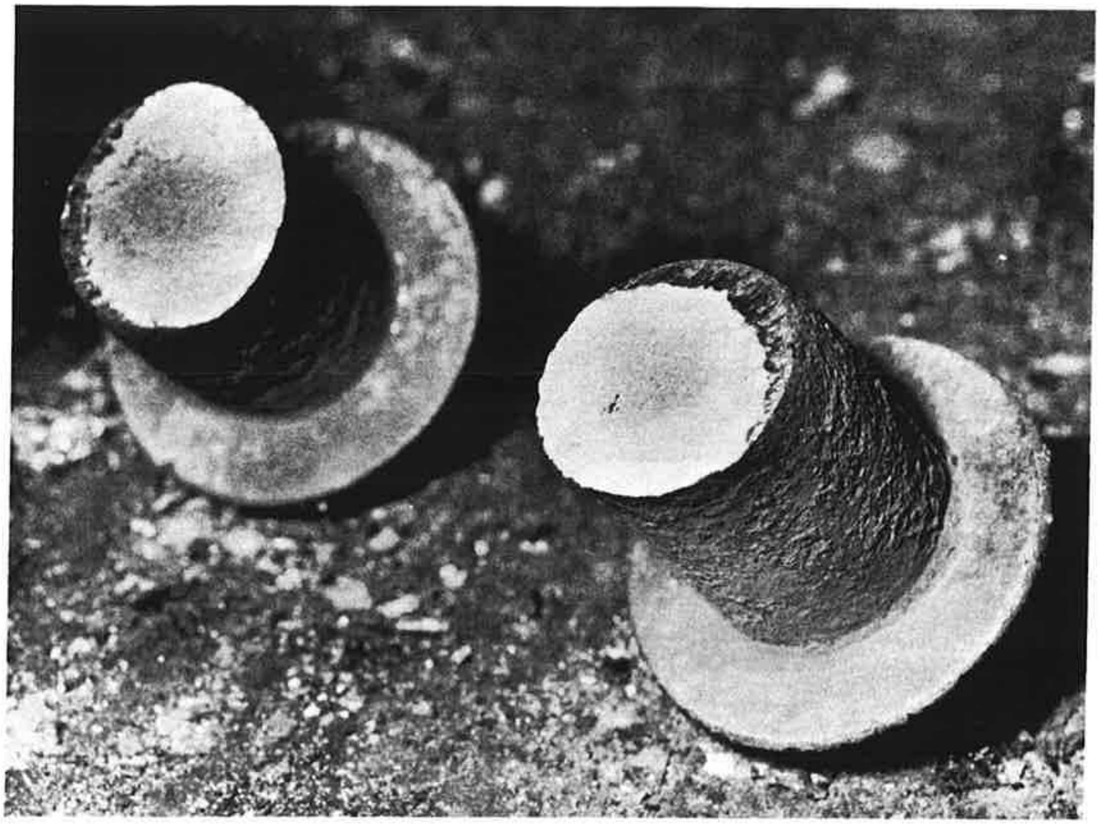

FIGURE 22. SHEARED DRAFT GEAR ASSEMBLY RIVETS AFTER 10-MPH IMPACT TEST.

The sill of the hopper in front of the caboose was buckled in several places, with the rear end section bent up about 3 inches. Figures 23 and 24 illustrate the buckles in the center sills of the caboose and hopper, respectively.

The time at which these buckles occurred and the magnitude of the buckle are important in determining the subsequent course of events. For Test 8, the caboose had time to rotate until the couplers between the caboose and hopper were beginning to disengage vertically, before the forces built up enough to buckle the sills. The speed was slow enough that the couplers bent and completely disengaged before the sill buckles could progress further. As will be seen in the higher speed impact (Test 9), the caboose did not have time to rotate before forces built up

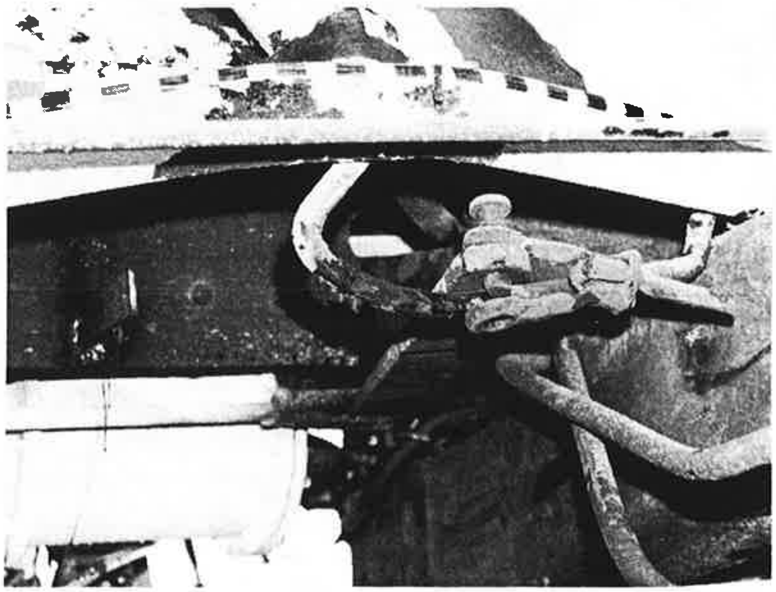

FIGURE 23. POST-TEST BUCKLE OF CABOOSE CENTER SILL - TEST 3.

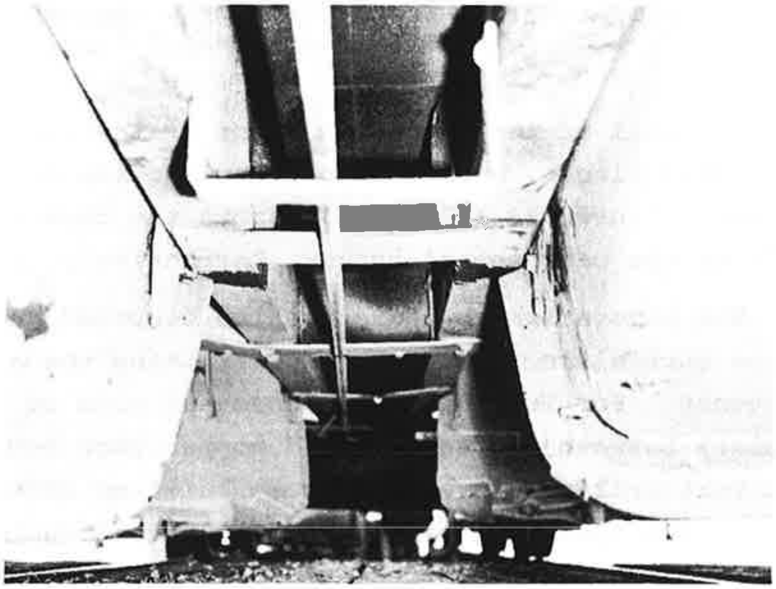

FIGURE 24. POST-TEST BUCKLE OF HOPPER CENTER SILL - TEST 3.

in the sill, causing much more severe buckling. For Test 9, the added energy due to both increased mass and speed caused more extensive damage.

Table 1 is a list of the sequence of significant events that occurred during the first 2 seconds of the impact for Test 8. The time, shown in the table in milliseconds, was obtained from an analysis of high-speed photography using a Vanguard Motion Analyzer. The terms "rear end" and "front end" will be defined for this report as:

> Rear End - on all cars, the rear end was the end facing the impact. The caboose is generally on the rear end of a train and the impacting locomotive was facing backward to the direction of motion (on older locomotives, the long hood or engine end is considered the front end).
>
> Front End - end opposite impact on all cars.

The 18.1-mph impact caused extensive damage to a caboose and one hopper. Table 2 is a list of the significant damage observed after the test. Also associated with the damage is a list (Table 3) of debris near the track as a result of the impact. All measurements were taken laterally from the south rail. Note that anything to the north and less than 4 feet 8 inches was between the rails.

Figure 25 is an overall view of the train configuration prior to impact. The locomotive on the far left is the "pusher" locomotive. Figures 26, 27, and 28 show the train configuration after test, with two close-up side views of the caboose. Figure 29 is a picture of the caboose intrusion into the hopper taken from inside the hopper body. Figure 30 shows the interior of the caboose. The debris on the inside consists mostly of wood from the walls. Note that no major damage occurred inside the caboose. The volume on the interior of the caboose is adequate for an occupant to survive. Figure 31 shows the caboose front end truck after impact; the bolster was thrown up onto the hopper's end section of its sill. Figure 32 is a view of the rail

TABLE 1. SEQUENCE OF EVENTS - TEST 8

Time (msec)	Description
0	Impact.
1	Caboose rear coupler starts to move forward.
10	Caboose rear coupler hits buffer casting.
17	Locomotive rear coupler hits buffer casting.
22	Caboose rear truck bolster begins to roll, allowing the center plate to translate forward.
30	Caboose front draft gear compressed.
31	Caboose front begins to lift.
35	Locomotive door swings open.
39	Hopper rear draft gear compressed.
42	Caboose front coupler begins to lift out of hopper rear coupler.
45	Hopper front truck springs begin to compress.
46	Hopper rear coupler hits buffer casting.
48	Caboose front coupler hits buffer casting.
50	Caboose sill begins to buckle.
75	Hopper front truck compresses to its maximum.
82	Caboose rear coupler deflects laterally to a maximum.
92	Locomotive engineer's left hand catches in window frame.
97	Caboose sill buckle reaches a maximum.
97	Caboose front coupler lifts free of hopper rear coupler.

TABLE 1. SEQUENCE OF EVENTS - TEST 8 (CONTD)

Time (msec)	Description
102	Caboose rear coupler slides down from locomotive coupler.
127	Caboose rear coupler separates from buffer casting.
139	Locomotive rear coupler separates from buffer casting.
144	Locomotive engineer's right knee hits door sill.
174	Caboose rear center plate clears bolster.
208	Separation of locomotive and caboose couplers reaches a maximum.
224	Caboose rear coupler hits buffer casting (2nd force).
247	Caboose front coupler starts penetration of hopper end plate.
264	Forward motion of locomotive engineer's head reaches a maximum.
269	Locomotive rear coupler hits buffer casting (2nd force).
314	Caboose rear truck brake arm is broken.
323	Second impact force, locomotive to caboose, reaches an apparent maximum.
619	Caboose front truck hits hopper rear truck.
715	Hopper rear sill end bends up.
1005	Hopper rear truck wheel lifts off rail 3 inches.
1737	Locomotive rear coupler within 2 inches of overriding caboose coupler.
1991	Caboose rear truck hits locomotive rear step.

TABLE 2. SIGNIFICANT DAMAGE OBSERVED AFTER TEST 8

Struck train stopped 68 feet from impact point, with 3 feet between caboose and locomotive.

No significant damage to locomotive.

Track was bent to south about 4 inches at an average distance of 34 feet from impact.

CABOOSE MP918

Rear End:

Steps distorted approximately 6 inches on bottom.

Sill and floor - no damage.

Coupler hit buffer casting - no distortion in buffer casting.

Side of caboose (where steps were removed) hit inside of wheel.

Very slight indication of sill pushing into caboose at first cross-member.

Front End:

Coupler closed - shank bent (more than coupler on impact end) - bottom of buffer casting broken.

Grate, steps, and ladder crushed back and in toward sill.

Roof buckled (pulled down by ladder and crushed side).

Sill buckled at point where air pipe passes through perforations (holes about 2 inches x 6 inches).

Bottom of sill buckled 26 inches wide maximum (normally 12-1/2 inches).

Rear End Truck:

Truck had slight twist, but did not take a permanent set.

Brake rod broken at truck.

Center pin bent into "S" shape, but not sheared completely off.

Wheels hit rear steps of locomotive.

Front End Truck:

Derailed 54 feet from impact, ended up about 2 feet from rail to north.

Bolster lifted up off truck and thrown up on hopper sill.

Leaf springs separated but not damaged.

Center pin bent into "S" shape, but not sheared completely off.

Brake rod broken at center of caboose.

NOTE: No permanent damage to either truck.

HOPPER 536843

Impact end coupler intact.

Upright supports at end of sill severely damaged.

End plate of car split open and peeled back (about 6 feet on north side).

Three locations of center sill buckling; each at a point where a hopper end passes around the sill.

TABLE 3. LOCATION OF DEBRIS FOLLOWING TEST 8

Description(1)	Distance From Impact	Distance From South Rail	Direction
Leaf spring from truck	20 ft 5 in.	3 ft 9 in.	North
Side bearing	27 ft 6 in.	8 ft 2 in.	North
Bolster shim	29 ft 1 in.	3 ft 8 in.	North
Draft gear support plate bolt	33 ft 1 in.	3 ft 3 in.	North
Eliptical spring end casting	38 ft 4 in.	7 ft 2 in.	North
Side bearing	39 ft 7 in.	2 ft 8 in.	North
Center pin	40 ft 5 in.	3 ft 3 in.	North
Side bearing shim	45 ft 0 in.	0 ft 10 in.	North
Angle cock handle	45 ft 5 in.	4 ft 4 in.	North
Cotter key from coupler	50 ft 8 in.	0 ft 6 in.	South
Body rivet - hopper	50 ft 10 in.	3 ft 7 in.	North
Stove pipe cap	51 ft 1 in.	9 ft 5 in.	South
Piece of air tank	51 ft 6 in.	19 ft 8 in.	North
Brake valve cap	54 ft 2 in.	2 ft 10 in.	North
Piece of air tank	56 ft 6 in.	5 ft 0 in.	North
Body rivet - hopper	60 ft 4 in.	2 ft 3 in.	North
Board from caboose interior wall	61 ft 7 in.	7 ft 1 in.	North
9-1/2" x 4" x 1" steel plate	64 ft 2 in.	0 ft 8 in.	North
Board from caboose interior wall	68 ft 4 in.	10 ft 0 in.	North
Piece of air tank	70 ft 9 in.	12 ft 9 in.	North
Piece of air tank	72 ft 11 in.	3 ft 4 in.	North
Piece of air tank (on hopper truck side frame)	93 ft 4 in.	4 ft 6 in.	North

(1) All parts are from the caboose unless otherwise noted.

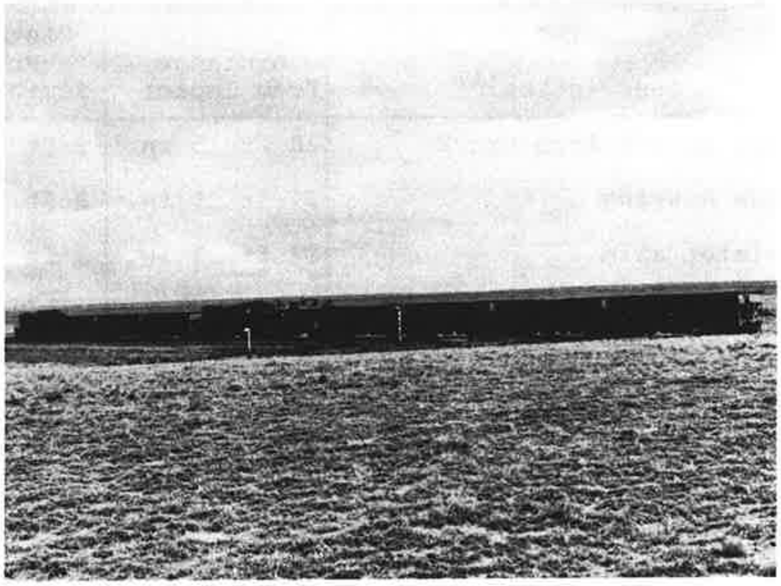

FIGURE 25. PRE-TEST TRAIN CONFIGURATION - TEST 8.

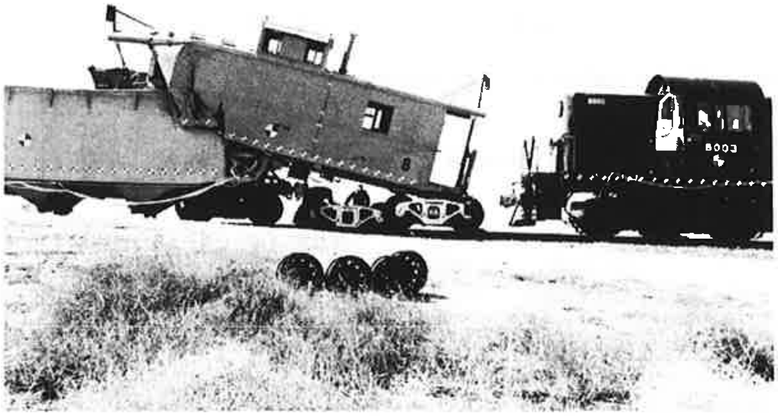

FIGURE 26. POST-TEST CABOOSE AND HOPPER - TEST 8.

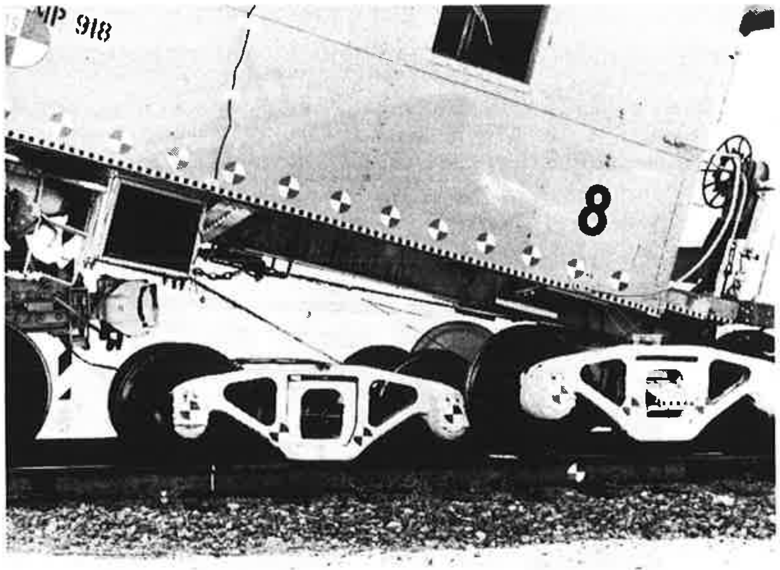

FIGURE 27. POST-TEST REAR END OF CABOOSE - TEST 8.

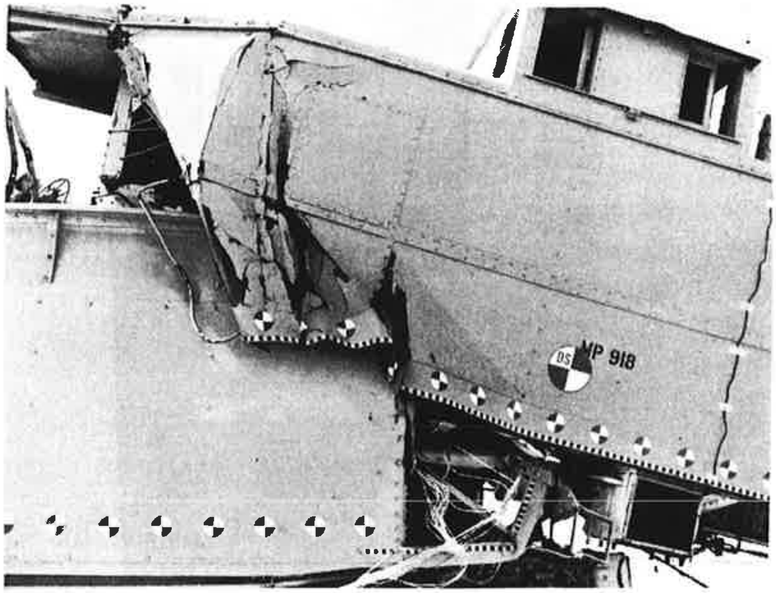

FIGURE 28. POST-TEST FRONT END OF CABOOSE - TEST 8.

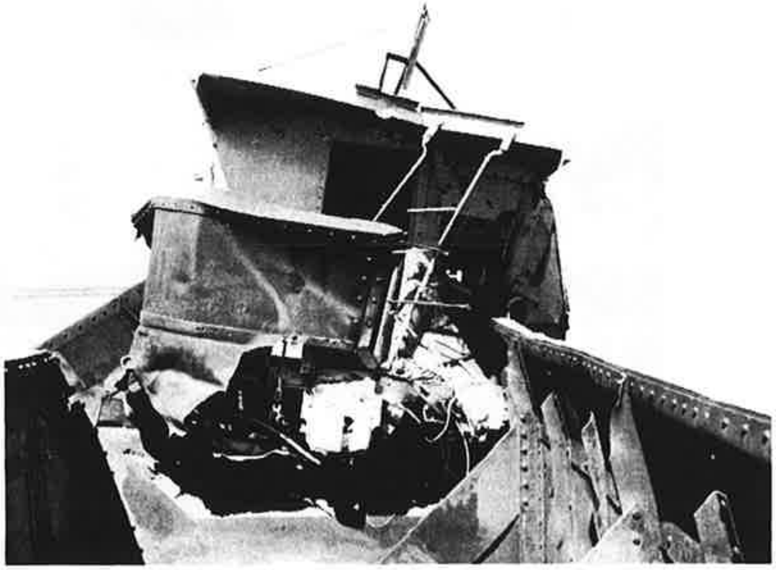

FIGURE 29. POST-TEST CABOOSE INSTRUSION INTO HOPPER - TEST 8.

FIGURE 30. POST-TEST CABOOSE INTERIOR - TEST 8.

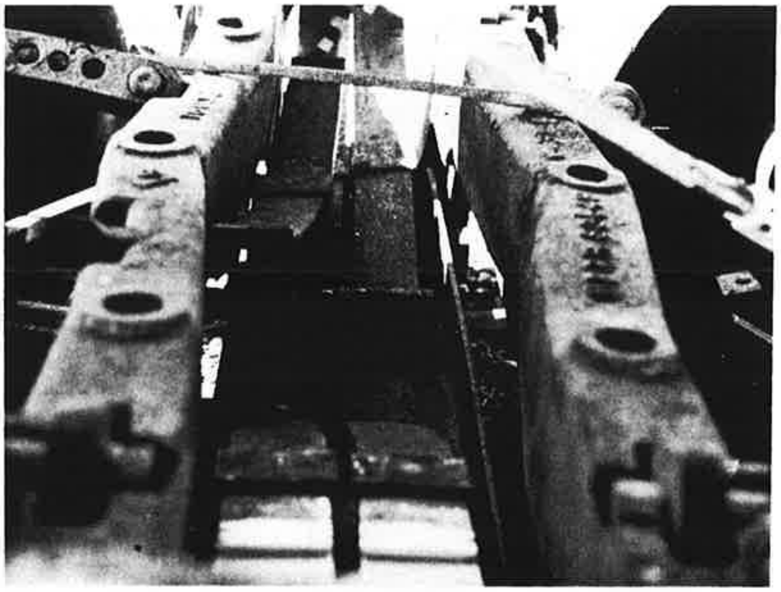

FIGURE 31. POST-TEST CABOOSE FRONT TRUCK - TEST 8.

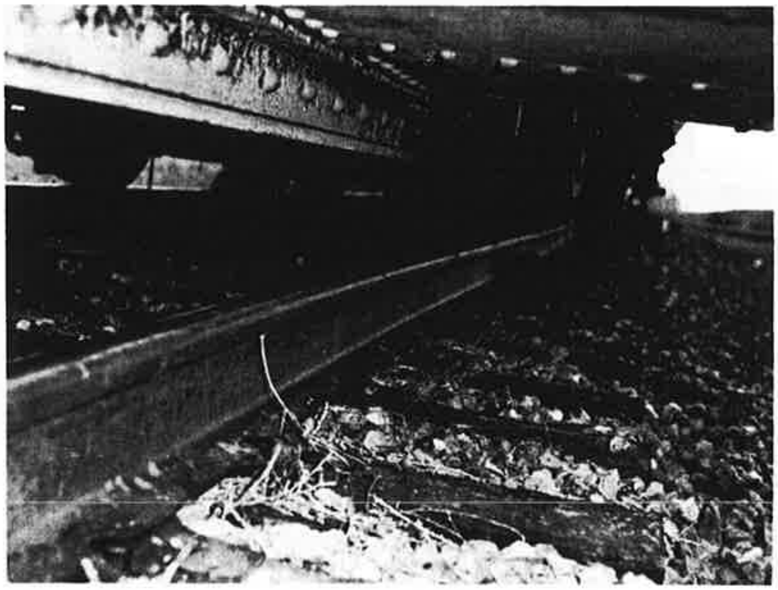

FIGURE 32. POST-TEST LATERAL RAIL DEFLECTION - TEST 8.

sill also was instrumented and calibrated to measure the force in the end section. Before the coupler bottomed out, the coupler applied the force to the center sill inside the strain gauge so that the sill did not register the compressive force until the coupler bottomed out. In fact, the end portion of the sill accelerated the structure of the end of the caboose and had a small tension force. Figure 36 is a superposition of the caboose coupler and center sill force. Note how the coupler force level was dropping as the center sill rose. This happened as the caboose began to move and rotate. The total force on the caboose at about 80 msec was approximately the sum of these two and was estimated to be approximately 600,000 pounds. One coupler between each car was instrumented with a strain gauge for measuring force. Figures 37 and 38 superpose the coupler force curves for the stationary and moving trains, respectively. These curves illustrate how the force propagated through the train. The front caboose coupler force was relatively low as the coupler between the caboose and hopper was decoupled by the rotation of the caboose before large forces could be realized.

The longitudinal and vertical accelerations of the caboose are shown in Figures 39 and 40.

The accelerometer data had high frequencies of structural vibrations superposed upon the rigid body motion-type acceleration.

The caboose rotation as taken from an analysis of the film is shown in Figure 41. The angular velocity at about 100 msec was approximately 17 deg/sec. Between about 100 and 300 msec the caboose had an average angular acceleration, α, of 155 deg/sec^2. This is approximately 2.7 radians/sec^2. The caboose had a c.g. height, x, of 24 inches and a mass moment of inertia, I, of 754,643 in.-lb-sec^2. This means a force applied through the center of the coupler can be found from the relation.

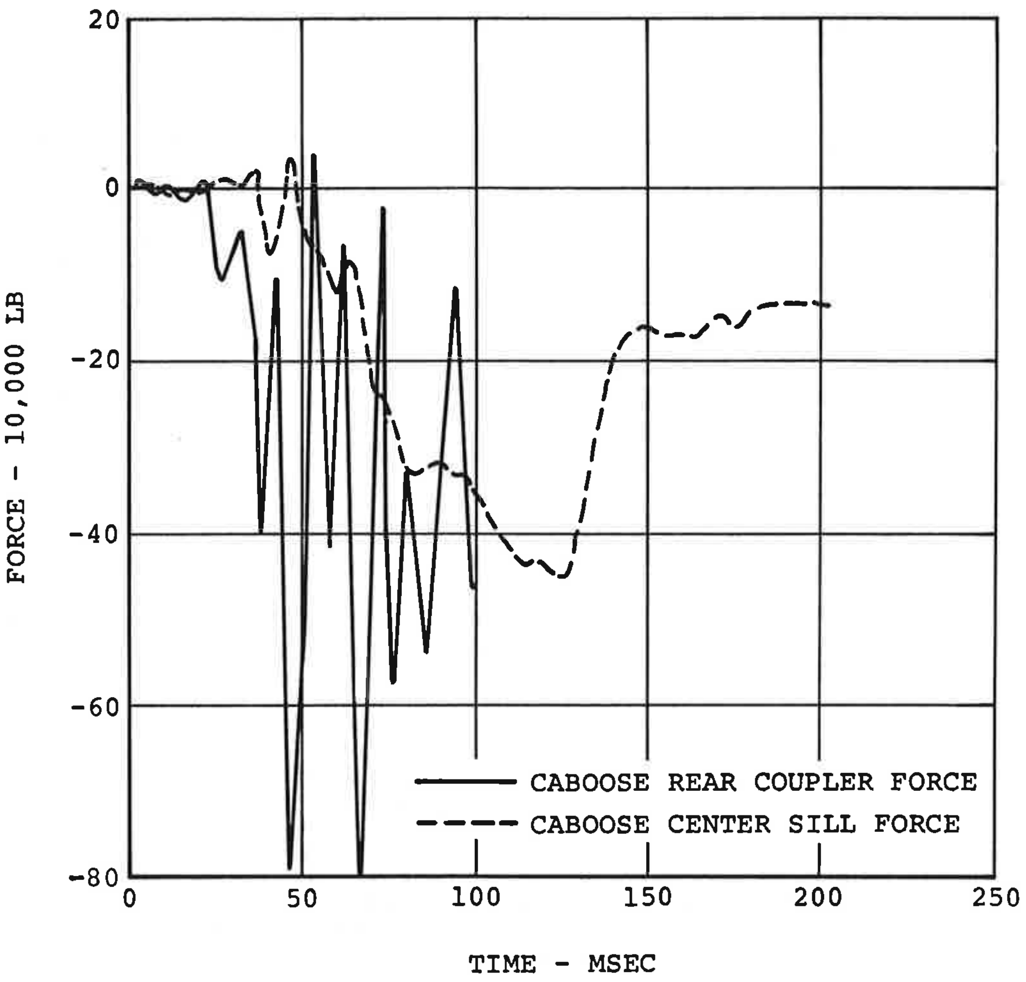

FIGURE 36. CABOOSE COUPLER FORCE AND CENTER SILL FORCE - TEST 8.

$$Fx = I\alpha$$

$$F \approx 85{,}000 \text{ lb}$$

This force is approximately that required to simply rotate the caboose acting between about 100 and 300 msec. The entire set of data from the instruments onboard the train are presented in Appendix A and discussions of trends and tabulation of characteristics of filtered curves are discussed in Section C.4.

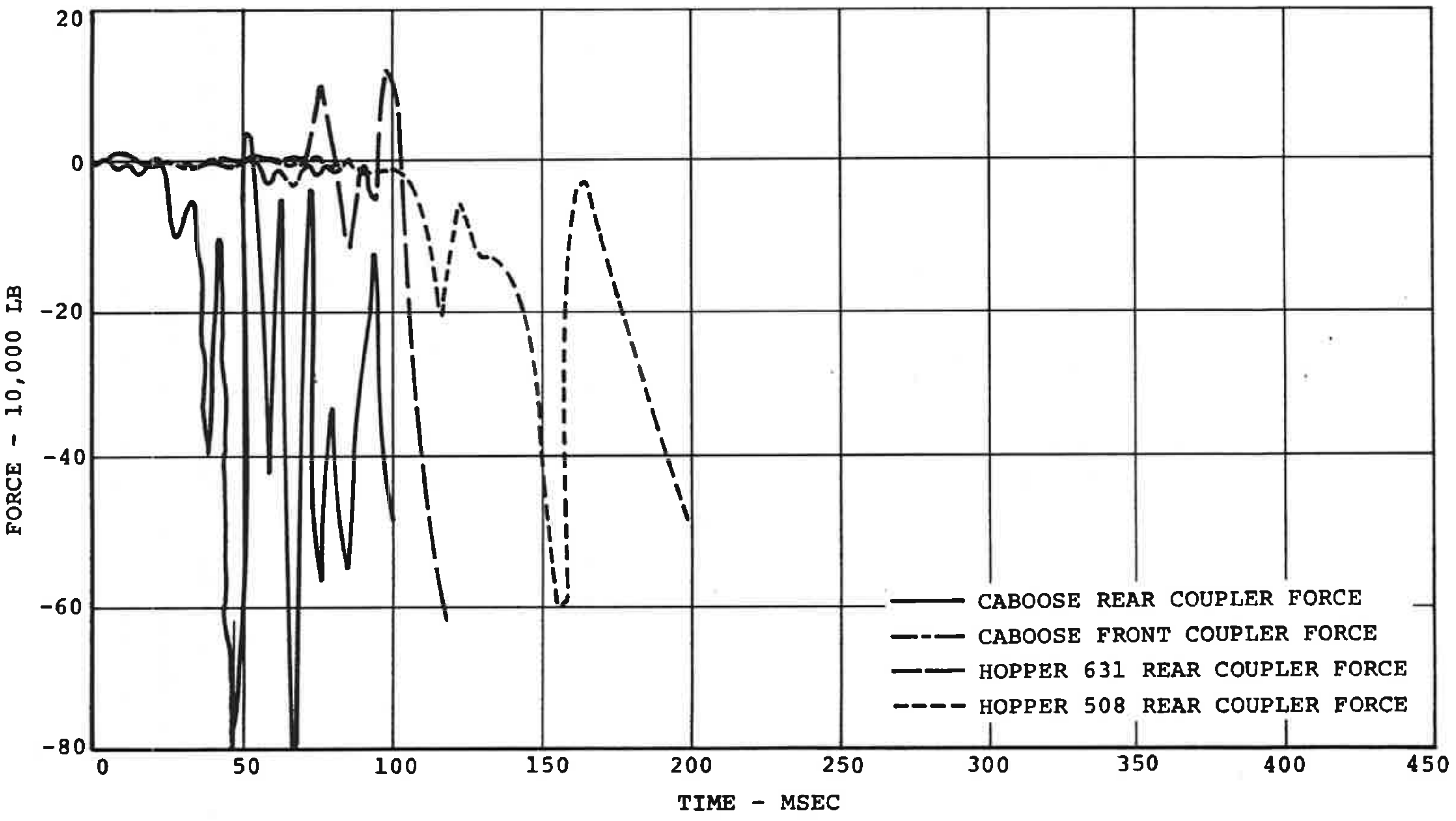

FIGURE 37. STATIONARY TRAIN COUPLER FORCES.

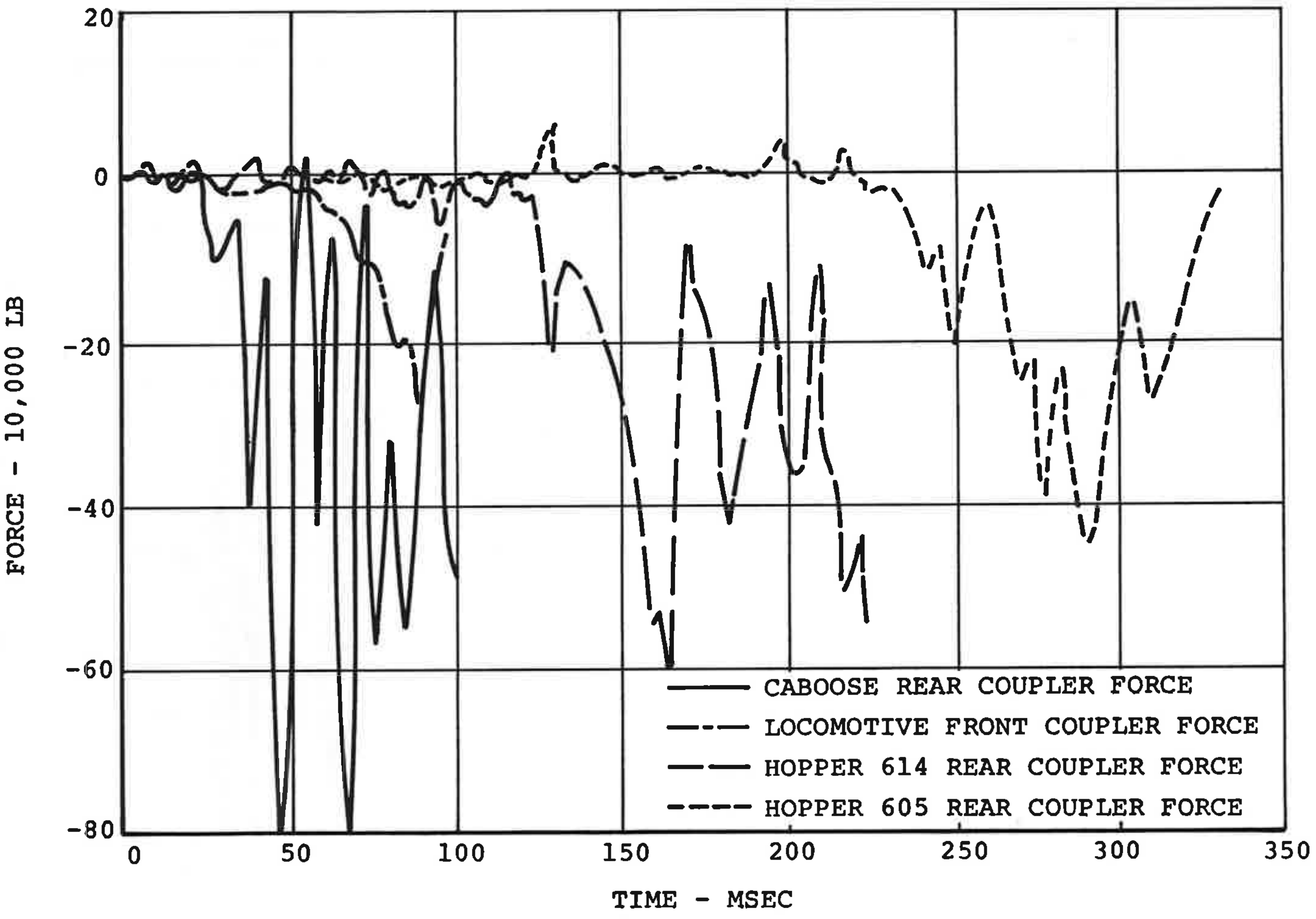

FIGURE 38. COUPLER FORCE IN MOVING TRAIN.

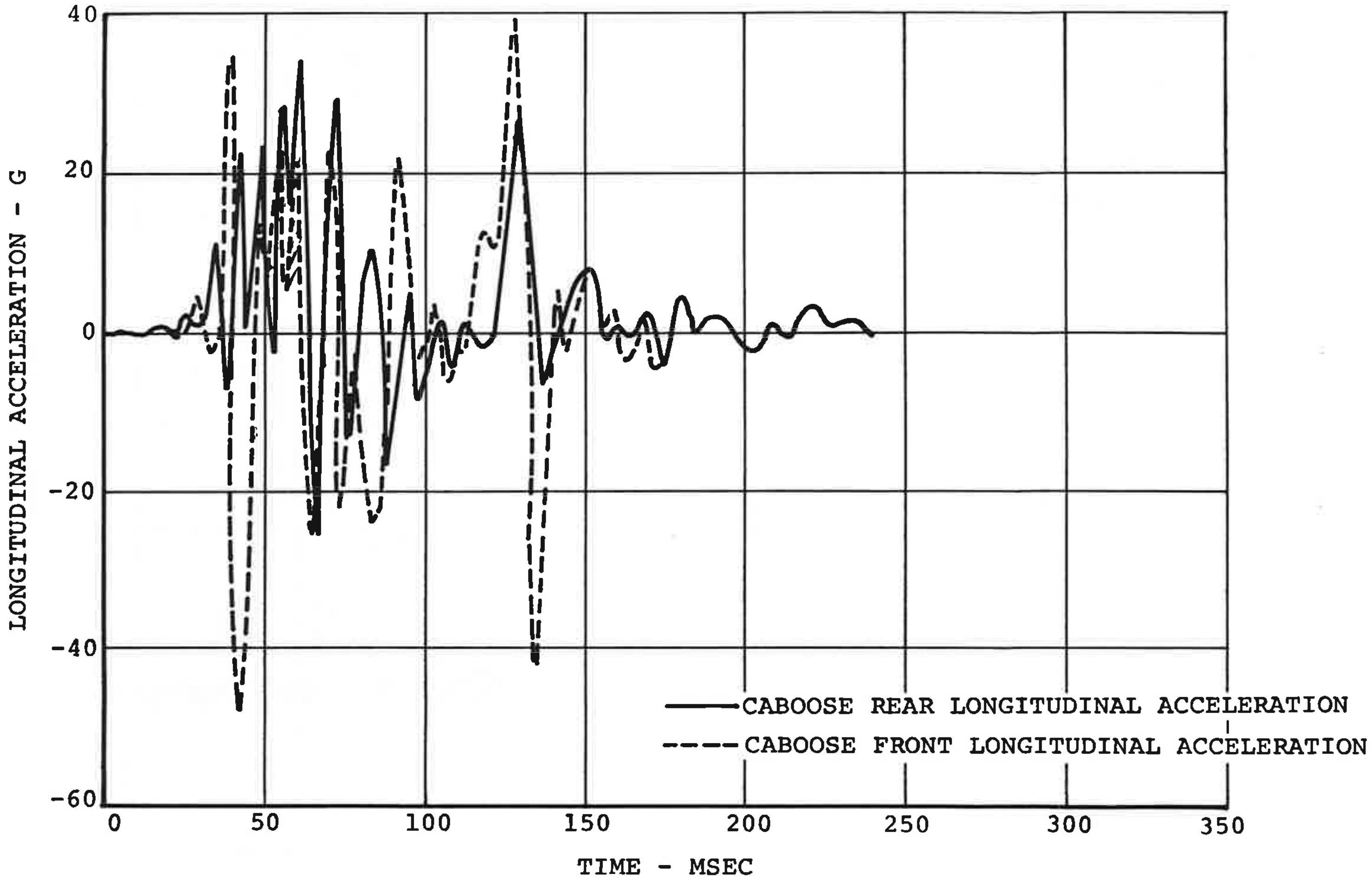

FIGURE 39. CABOOSE LONGITUDINAL ACCELERATION - TEST 8.

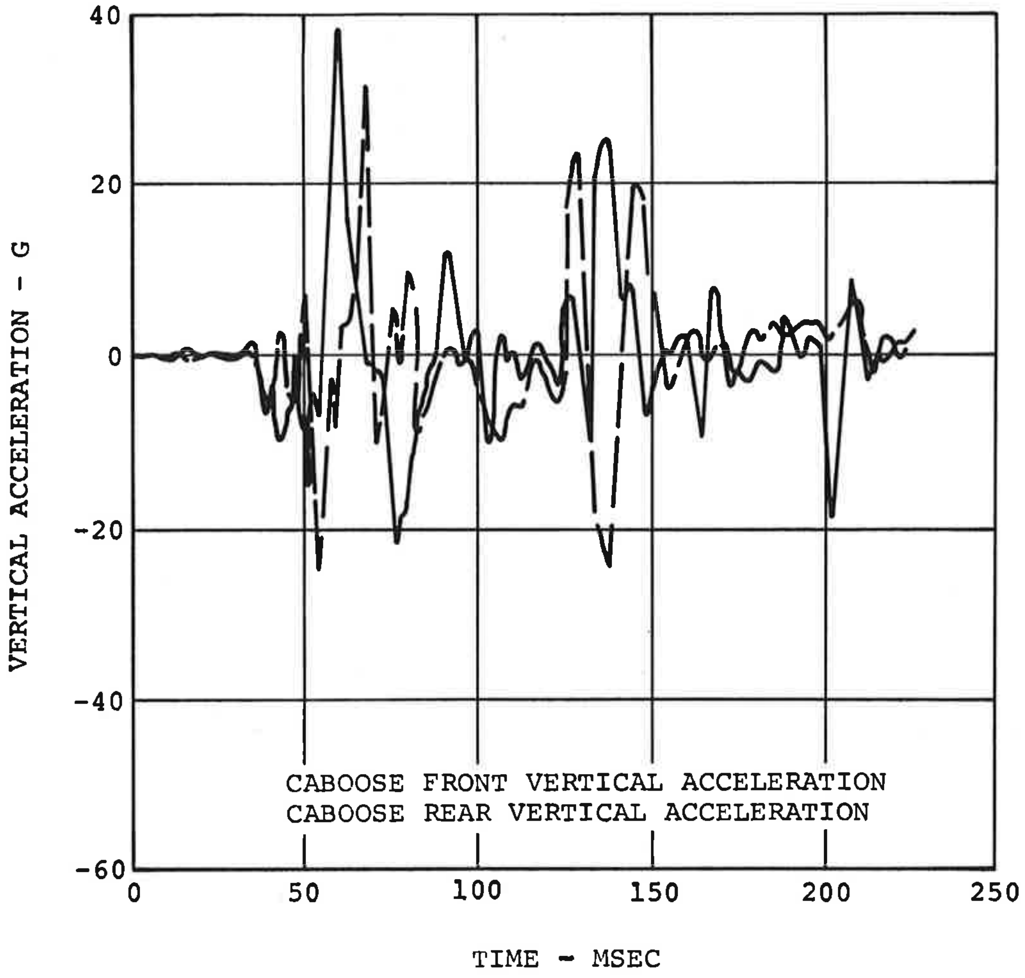

FIGURE 40. CABOOSE VERTICAL ACCELERATION - TEST 8.

6.3 IMPACT TEST NO. 9

Test 9 was performed as follows:

Test Date: May 30, 1975
Impact Velocity: 30.3 mph

No. Vehicles in Stationary Train: 10

No. Vehicles in Moving Train: 10

Standing Train Positioning: Draft

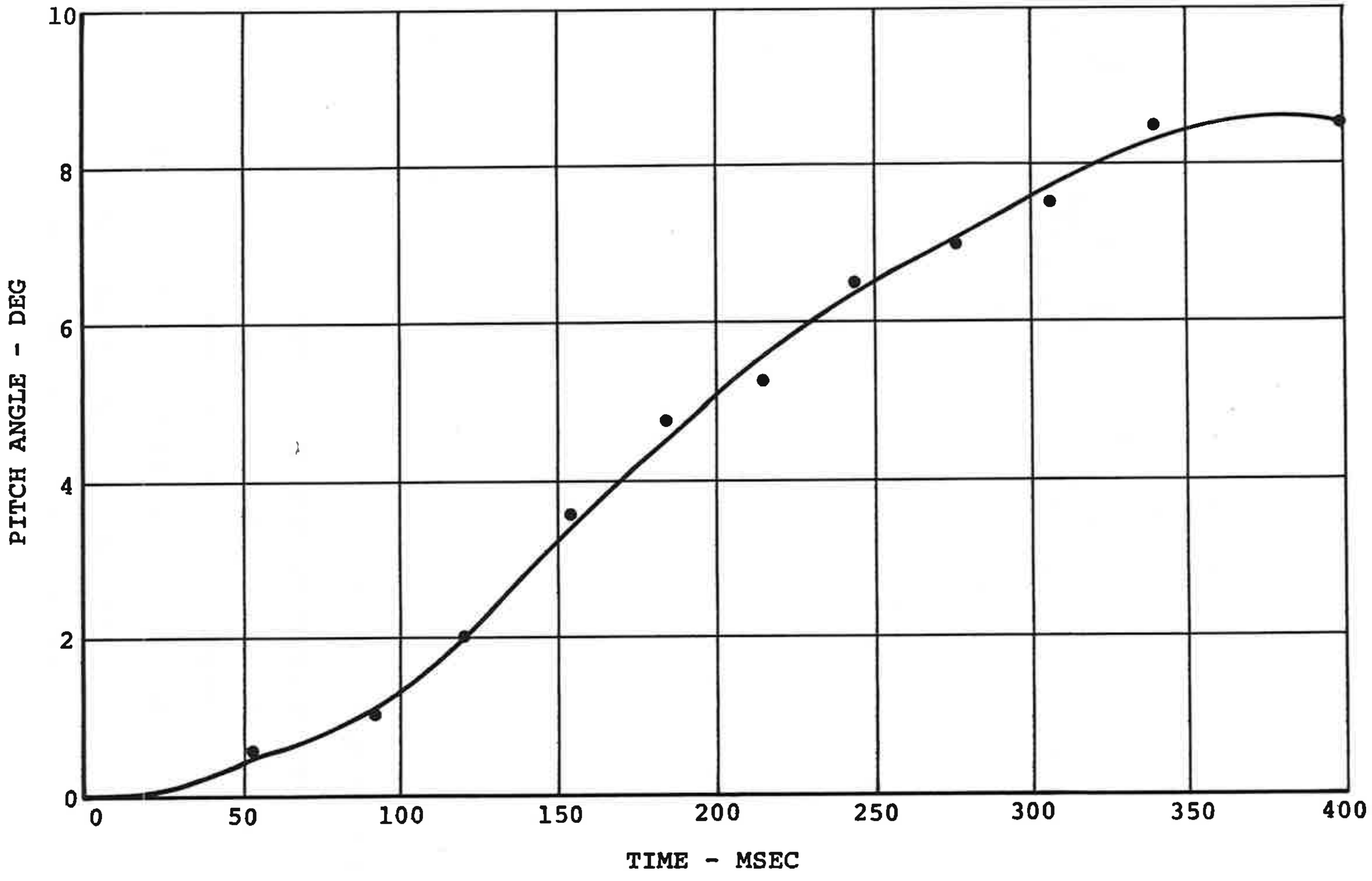

FIGURE 41. CABOOSE PITCH - TEST 8.

The test trains were increased in mass and length by the addition of 10 boxcars and one locomotive. The stationary train consisted of 1 caboose, 4 loaded hoppers, 1 empty boxcar, and 4 loaded boxcars. The impacting train consisted of 2 locomotives, 3 loaded hoppers, and 5 loaded boxcars. The total increase in mass was 1.76 million pounds. Additional changes were made to the trains prior to test as follows:

a) The draft gear assembly was reinforced on the front end of Locomotive 8670.

b) The bolsters of the front and rear caboose trucks were shimmed to minimize the longitudinal motion between the bolster and centerplate. Also, the centerpin holes in the bolsters were filled in to reduce centerpin motion. Figures 42 and 43 show the condition of the bolsters before and after this reworking

c) Since the draft gear of Caboose MP918 was measured for longitudinal stiffness prior to Test 8, the draft gear in MP912 was removed and MP918 units were installed.

d) The spacers attached to the end of the coupler shanks on the front of the caboose and the rear of the first hopper were removed

e) 1,400 gallons of water were put in the fuel tanks of the second locomotive

f) The struck train had its air brakes and manual brakes applied on all cars except the caboose and first hopper.

Coupler heights were measured prior to the test. The caboose rear coupler was found to be 2 inches higher than the locomotive rear coupler while the hopper rear coupler was 1-1/8 inches higher than the caboose front coupler.

A 3-mph impact test was performed prior to Test 9 to verify instrumentation, camera operation, and the remote controller system.

During the 30-mph test, the rear end of the caboose moved forward and down. The rear end of the locomotive moved down 3.4 inches. The rear end of the caboose moved down only 2.6 inches. The front end of the caboose moved forward and up, bending the

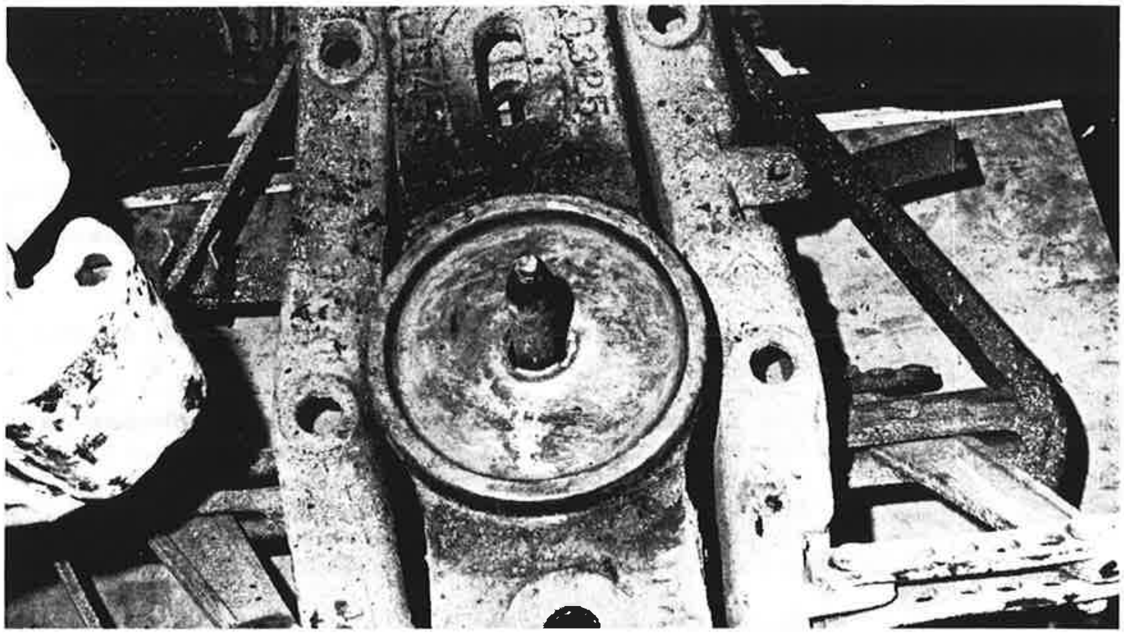

FIGURE 42. CABOOSE TRUCK BOLSTER PRIOR TO SHIMMING.

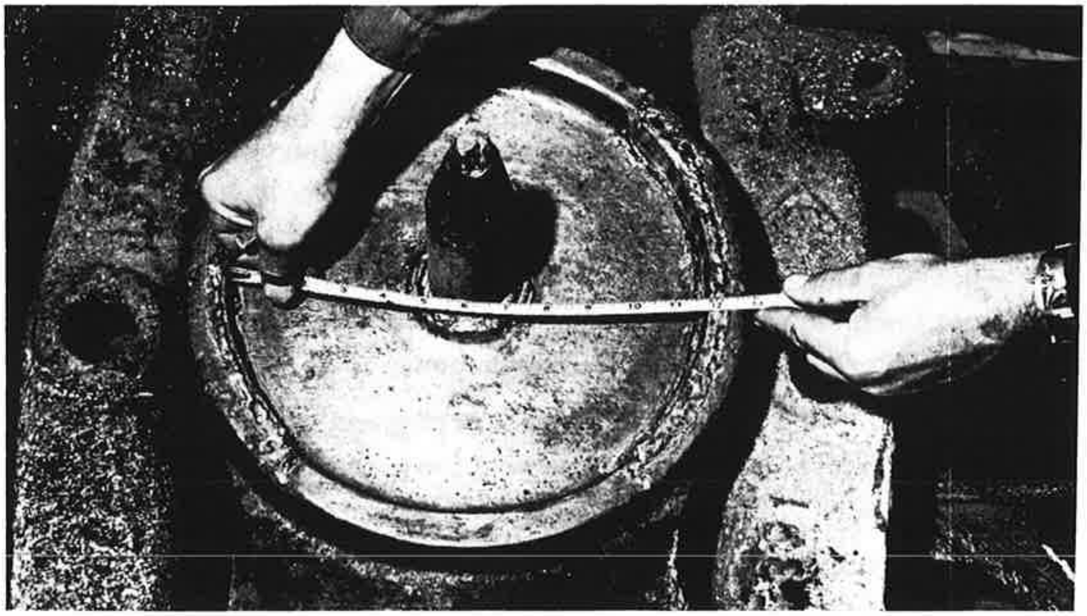

FIGURE 43. CABOOSE TRUCK BOLSTER AFTER SHIMMING.

shanks of the mating couplers of the caboose and the hopper. The couplers did not have time to vertically disengage as occurred during Test 8 before the buckle formed in the caboose center sill. When the center sill buckled, the caboose body began to crush between the hopper and locomotive. The locomotive continued to crush the caboose until its body was completely folded in half. The crushed body was squeezed out to the south and pulled the first hopper over on its side. The locomotive made little contact with the first hopper. With the first hopper derailed, the locomotive continued on to impact the second hopper, crushing a caboose truck and a hopper truck between them. Finally, the locomotive derailed to the south, pushing a hopper truck under its rear draft gear. The front end of the first locomotive derailed to the north, derailing the rear end of the second locomotive. The remainder of the impacted train continued to move an additional 330 feet away from its impact position. Two hoppers and one caboose suffered extensive damage. The battery compartment (short hood) and one side of the locomotive cab was also damaged. Table 4 is a list of the sequence of significant events that occurred during impact.

Table 5 is a list of significant damage observed after Test 9.

Table 6 is a list of debris found around the track after impact. Small items, such as rivets, pieces of bolts, pieces of wood, etc., were too numerous to include in the table.

Figure 44 is an overall view of both trains prior to impact. The locomotive on the far right is the "pusher" which was decoupled from the moving train and stopped about 1,000 feet short of the impact point. Figure 45 shows the impact end truck bolster and center plate of the caboose. This is the view as seen by the high-speed ground camera under the caboose. Figure 46 is a post-test view of the impacting train. Note that the impacting locomotive came to rest over 100 feet past the crushed caboose and derailed hopper.

TABLE 4. SEQUENCE OF EVENTS - TEST 9

Time (msec)	Description
0	Impact
11	Caboose rear coupler hits buffer casting
16	Locomotive rear coupler hits buffer casting
20	Caboose begins forward motion
22	Caboose rear truck bolster begins to roll, allowing forward translation of the caboose relative to the truck
29	Caboose front end coupler is compressed
30	Caboose rear truck begins to slide forward
35	Hopper rear end coupler is compressed
37	Caboose front and hopper rear couplers hit buffer casting
42	Roll of bolster reaches a maximum
53	Locomotive rear end dive reaches a maximum
66	Caboose rear truck wheel begins to rotate
67	Caboose rear end dive reaches a maximum
144	Caboose rear truck hits locomotive
168	Top of caboose hits hopper
214	Side of caboose begins to buckle
384	Top of caboose hits locomotive
834	Caboose completely crushed
1134	Locomotive hits first hopper
2019	Side of first hopper hits the ground
3594	Locomotive hits second hopper
4127	Second locomotive is derailed

TABLE 5. SIGNIFICANT DAMAGE OBSERVED AFTER TEST 9

CABOOSE MP912

Body completely crushed

Sill bent into a "U" shape with the bend abut 8 inches from the center (toward the impact end)

The two couplers were 4 feet, 6 inches apart

The c.g. of the caboose ended up approximately 20 feet from the south rail and 56-1/2 feet from impact

Both coupler shanks bent in the vertical direction (downward)

The strain gauged area of the sill had no bends or buckles

CABOOSE TRUCKS

Rear end - one axle and side frame up in crushed caboose near the sill

Bolster on ground near caboose

The other axle on the ground partially under the caboose

Front end - one axle 96-1/2 feet from impact, 4 feet south of the south rail

The other axle was suspended on the coupler of the second hopper

The side frames and bolster were broken under the caboose

HOPPER CAR 538021 (FIRST HOPPER ADJACENT TO THE CABOOSE)

The sill broke between the first and second hopper dump

The c.g. of the car was approximately 12 feet south of the south rail and 86-1/2 feet from impact

The sill had a small buckle on top, 10 inches from the buffer casting on the end opposite of impact

Both couplers were bent at the shank

Rear end truck - upside down, 16 feet from the south rail and 161-1/2 feet from the impact point (or 90 feet from point where the truck was before impact)

TABLE 5. SIGNIFICANT DAMAGE OBSERVED AFTER TEST 9 (CONTD)

LOCOMOTIVE 8003

The battery compartment was smashed; mostly by the caboose, with some slight damage by first hopper of stationary train.

The caboose ripped open one corner (engineer's side, rear end) of the cab

A hopper truck from the first hopper of the stationary train turned 90 degrees to the track and was buried under the draft gear of the locomotive (rear end); no major damage to the truck or locomotive

The impact coupler was 21 feet south of the south rail and 205 feet from impact

The front coupler was 4 feet north of the north rail (front wheel 3-1/2 feet north of north rail)

The longitudinal axis of the locomotive had a 33.4-degree angle to the rail and the locomotive had a zero post-test roll angle

The fuel tank was in contact with the south rail but not damaged

LOCOMOTIVE 8670 (SECOND LOCOMOTIVE)

No significant damage to the locomotive

The rear end of the locomotive was derailed to the north with its longitudinal axis at a 7-degree angle to the rail

The locomotive post-test roll angle was approximately 20 degrees

The rear end coupler was 4 feet, 3 inches from the north rail; the front end was in the center of the track

HOPPER 537119 (SECOND HOPPER FROM REAR OF STATIONARY TRAIN)

The hopper, with rear end smashed by locomotive 8003, stopped on rail 410 feet from impact (332.5 feet from original position)

The front truck was at a 45-degree angle to the rail

The sill was buckled at the rearmost hopper dump, with small buckles at the second and third hopper dumps

TABLE 5. SIGNIFICANT DAMAGE OBSERVED AFTER TEST 9 (CONTD)

HOPPER 537508 (THIRD HOPPER FROM REAR OF STATIONARY TRAIN)

Still connected to Hopper 119; in buff

Two buckles in the sill, on either side of hopper dump nearest impact

HOPPER 536631 (FOURTH HOPPER FROM REAR END OF STANDING TRAIN

Still connected to Hopper 508, in buff

The sill had a very small buckle at the center of the hopper dump toward impact

HOPPER 536506 (HOPPER ADJACENT TO LOCOMOTIVE IN MOVING TRAIN)

Hopper still connected to locomotive 8670

Sill had 3 buckles; one on each side of the hopper dump toward impact and one in the center of the middle hopper dump

The truck toward impact was derailed, with the north side wheels on the folded over rail

RAILS

The north rail was twisted, starting 33 feet, 4 inches from impact up to the grade crossing (103 feet); vertical through the crossing (140 feet) and twisted clockwise looking in the direction of motion of the impacting train from the crossing to about 300 feet from impact

Several anchors were broken and one rail joint had broken bolts

One tie (at the grade crossing) was partially broken

Very little lateral shift occurred in the rail

Figures 47, 48, and 49 show the damage incurred by the impacting locomotive. The intrusion into the side of the cab was caused as the crushed caboose was pushed off to one side.

Figure 50 is a view of the second locomotive in its derailed position. All other cars of the moving train remained on the rails. Figure 51 shows the top of the crushed caboose and

TABLE 6. LOCATION OF DEBRIS FOLLOWING TEST 9			
Description	Distance From Impact	Distance From South Rail	Direction
Battery box lead bushing	25 ft 0 in.	5 ft 0 in.	South
Battery box lead bushing	28 ft 4 in.	4 ft 0 in.	South
Brake arm bar	41 ft 6 in.	3 ft 1 in.	North
Air pipe cap	41 ft 8 in.	7 ft 6 in.	South
Brake rod support bar	46 ft 8 in.	9 ft 11 in.	South
Battery box	55 ft 0 in.	15 ft 9 in.	South
Journal wedge	56 ft 8 in.	17 ft 2 in.	South
Center of caboose	57 ft 0 in.	20 ft 0 in.	South
Battery box bracket	56 ft 10 in.	15 ft 9 in.	South
Journal brass	61 ft 7 in.	10 ft 11 in.	South
Side bearing	61 ft 7 in.	17 ft 9 in.	North
Piece of brake beam	61 ft 8 in.	7 ft 6 in.	South
Journal wedge	61 ft 8 in.	4 ft 6 in.	South
Swinghanger pin	63 ft 4 in.	9 ft 1 in.	South
Elliptical spring end casting	63 ft 4 in.	13 ft 10 in.	South
Stove top panel	65 ft 1 in.	14 ft 5 in.	South
Truck spring shim	65 ft 2 in.	14 ft 9 in.	South
Elliptical spring end casting	65 ft 2 in.	13 ft 9 in.	South
Coupler lock lifter	65 ft 3 in.	13 ft 6 in.	South
Coupler carrier	66 ft 1 in.	16 ft 2 in.	South
Journal brass	66 ft 1 in.	4 ft 0 in.	South
Elliptical springs (2)	66 ft 3 in.	13 ft 3 in.	South
All parts are from the caboose unless otherwise noted.			

TABLE 6. LOCATION OF DEBRIS FOLLOWING TEST 9 (CONTD)

Description	Distance From Impact	Distance From South Rail	Direction
Journal brass	68 ft 4 in.	10 ft 10 in.	South
Sheared center pin	70 ft 0 in.	7 ft 2 in.	South
Side bearing	70 ft 2 in.	13 ft 11 in.	South
Spring plank saddle	71 ft 8 in.	10 ft 1 in.	South
Brake pin	71 ft 8 in.	11 ft 10 in.	South
Journal brass	71 ft 10 in.	12 ft 1 in.	South
Elliptical spring	71 ft 11 in.	14 ft 2 in.	South
Side frame	73 ft 5 in.	13 ft 6 in.	South
Brake shoe	73 ft 5 in.	0 ft 6 in.	South
Elliptical spring	74 ft 0 in.	8 ft 1 in.	South
Piece of locomotive headlight	75 ft 2 in.	4 ft 4 in.	South
Truck bolster	75 ft 2 in.	10 ft 1 in.	South
Spring plank	75 ft 6 in.	9 ft 6 in.	South
Truck inner frame	75 ft 8 in.	7 ft 11 in.	South
Rail joint bolt	76 ft 8 in.	0 ft 2 in.	North
Swinghanger pin	78 ft 2 in.	15 ft 5 in.	North
Elliptical springs (3)	78 ft 4 in.	8 ft 7 in.	South
Rail joint bolt	78 ft 4 in.	0 ft 6 in.	South
Swinghanger and pin	80 ft 1 in.	7 ft 1 in.	South
Truck spring shim	81 ft 7 in.	6 ft 10 in.	South
Piece of hopper coil spring	81 ft 7 in.	0 ft 6 in.	South
Piece of hopper coil spring	81 ft 8 in.	1 ft 0 in.	North

TABLE 6. LOCATION OF DEBRIS FOLLOWING TEST 9 (CONTD)

Description	Distance From Impact	Distance From South Rail	Direction
Broken rail anchor	81 ft 8 in.	0 ft 8 in.	North
Coupler carrier	83 ft 5 in.	6 ft 2 in.	South
Center of Hopper 021	86 ft 6 in.	10 ft 0 in.	South
Elliptical spring (in hopper)	86 ft 9 in.	11 ft 8 in.	South
Side bearing	86 ft 9 in.	0 ft 11 in.	North
Elliptical spring end casting	90 ft 2 in.	2 ft 3 in.	North
Brake wheel	93 ft 4 in.	8 ft 4 in.	South
Hopper journal wedge	93 ft 4 in.	7 ft 1 in.	South
Hopper brake shoe	95 ft 1 in.	3 ft 2 in.	South
Hopper center pin	100 ft 0 in.	6 ft 10 in.	South
Journal cover	105 ft 5 in.	4 ft 4 in.	South
Hopper side bearing	108 ft 3 in.	8 ft 2 in.	South
Hopper journal cover	111 ft 8 in.	5 ft 0 in.	South
Hopper journal wedge	111 ft 8 in.	6 ft 0 in.	North
Hopper journal wedge	111 ft 8 in.	9 ft 4 in.	South
Caboose journal wedge	130 ft 4 in.	5 ft 11 in.	North
Hopper bolster shim	133 ft 4 in.	10 ft 1 in.	South
Hopper bolster shim	133 ft 4 in.	19 ft 10 in.	South
Numerous hopper coil springs	133 ft to 176 ft	17 ft South to 2 ft North	
Hopper brake shoe	145 ft 3 in.	10 ft 3 in.	South
Center of hopper truck	162 ft 0 in.	16 ft 0 in.	South
Hopper journal cover	162 ft 5 in.	11 in.	North

TABLE 6. LOCATION OF DEBRIS FOLLOWING TEST 9 (CONTD)			
Description	Distance From Impact	Distance From South Rail	Direction
Side bearing	166 ft 8 in.	0 ft 6 in.	North
Side bearing	171 ft 5 in.	16 ft 2 in.	South
Handle from locomotive	173 ft 4 in.	6 ft 6 in.	South
Hopper journal wedge	191 ft 8 in.	30 ft 2 in.	South
Journal wedge (on locomotive rear landing)	200 ft 4 in.	16 ft 7 in.	South

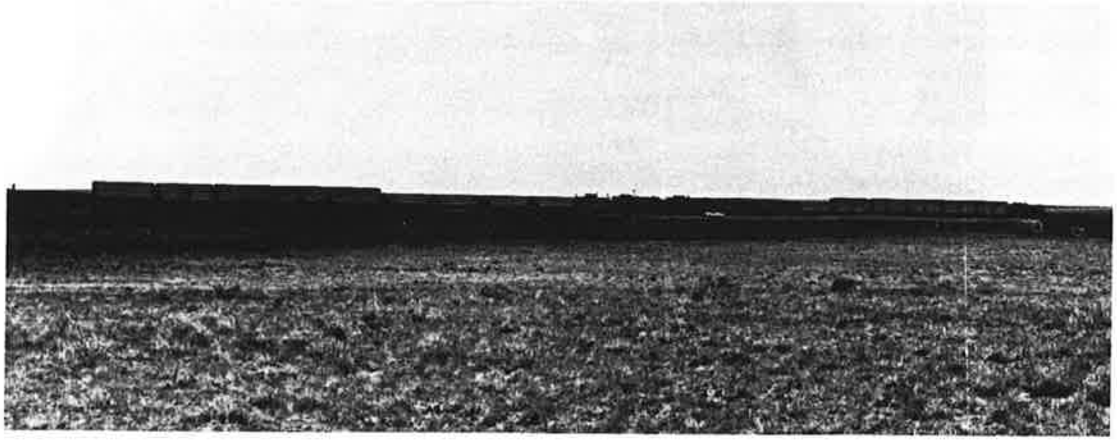

FIGURE 44. PRE-TEST TRAIN CONFIGURATION - TEST 9.

Figure 52 the bottom, showing the "U" shaped center sill. Figure 53 depicts the impact coupler of the caboose with its shank bent down. Figures 54 and 55 show the top and bottom of the first hopper. Only the rear end section of the hopper sill was crushed. Figure 56, taken from on top of the impacting locomotive, shows how far the struck train continued before coming to rest.

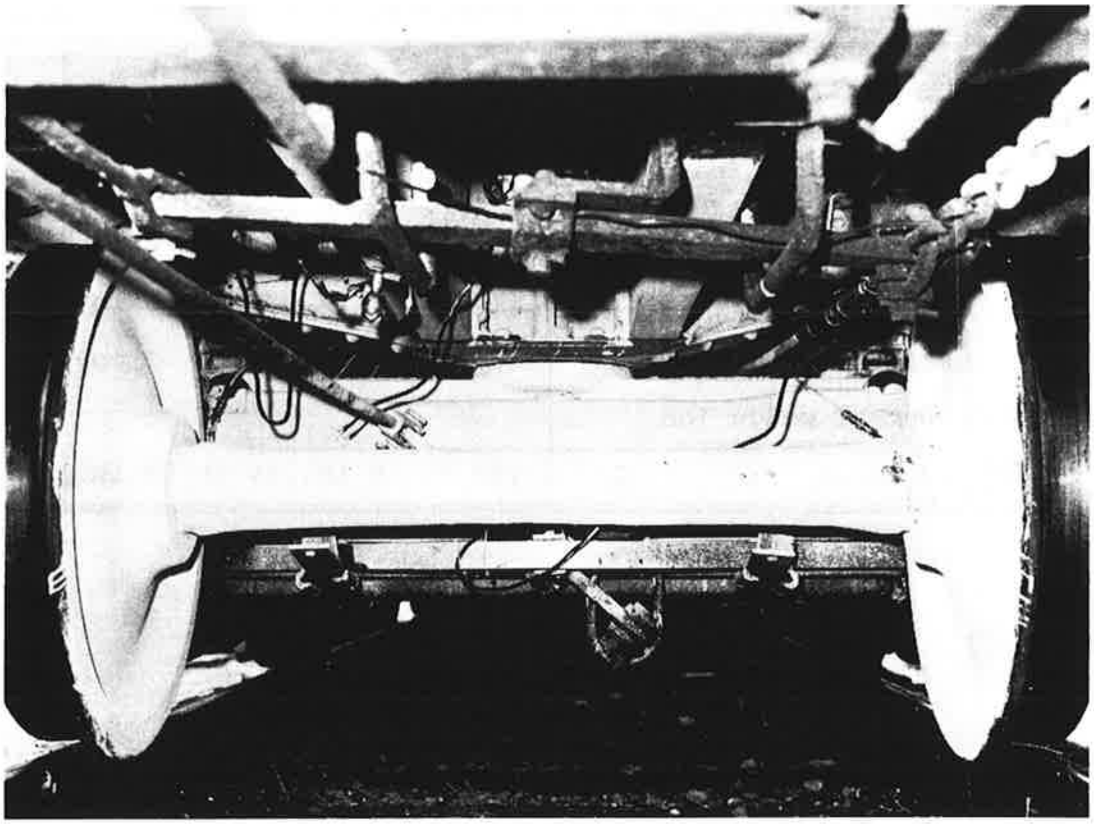

FIGURE 45. PRE-TEST CABOOSE REAR TRUCK - TEST 9.

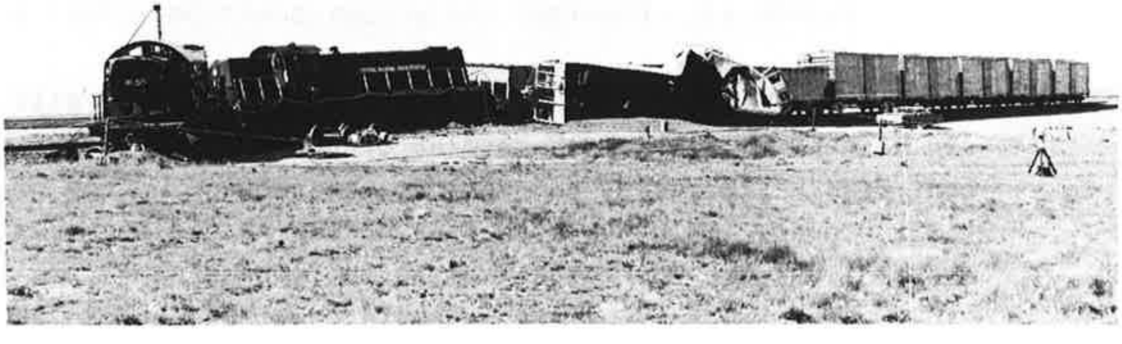

FIGURE 46. POST-TEST STRIKING TRAIN - TEST 9.

FIGURE 47. POST-TEST IMPACTING LOCOMOTIVE SOUTH SIDE - TEST 9.

FIGURE 48. POST-TEST IMPACTING LOCOMOTIVE REAR END - TEST 9.

FIGURE 49. POST-TEST IMPACTING LOCOMOTIVE CAB - TEST 9.

FIGURE 50. POST-TEST SECOND LOCOMOTIVE - TEST 9.

FIGURE 51. POST-TEST CABOOSE - TEST 9.

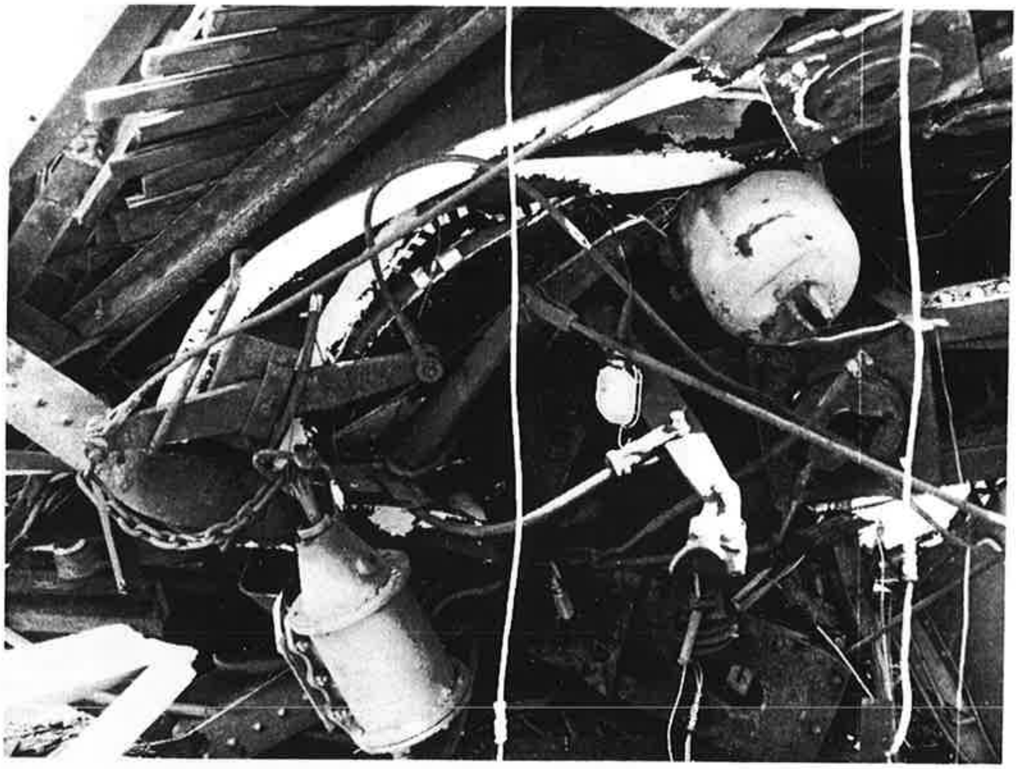

FIGURE 52. POST-TEST CABOOSE CENTER SILL - TEST 9.

FIGURE 53. POST-TEST CABOOSE REAR COUPLER - TEST 9.

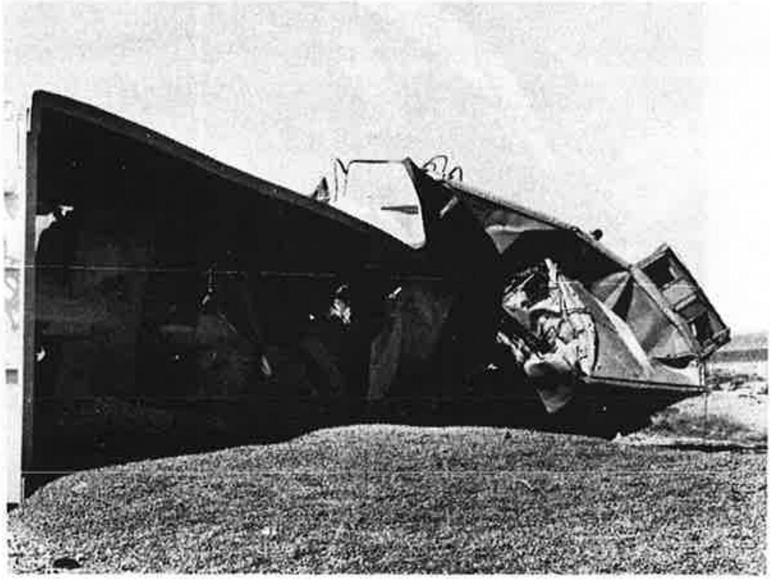

FIGURE 54. POST-TEST HOPPER AND CABOOSE - TEST 9.

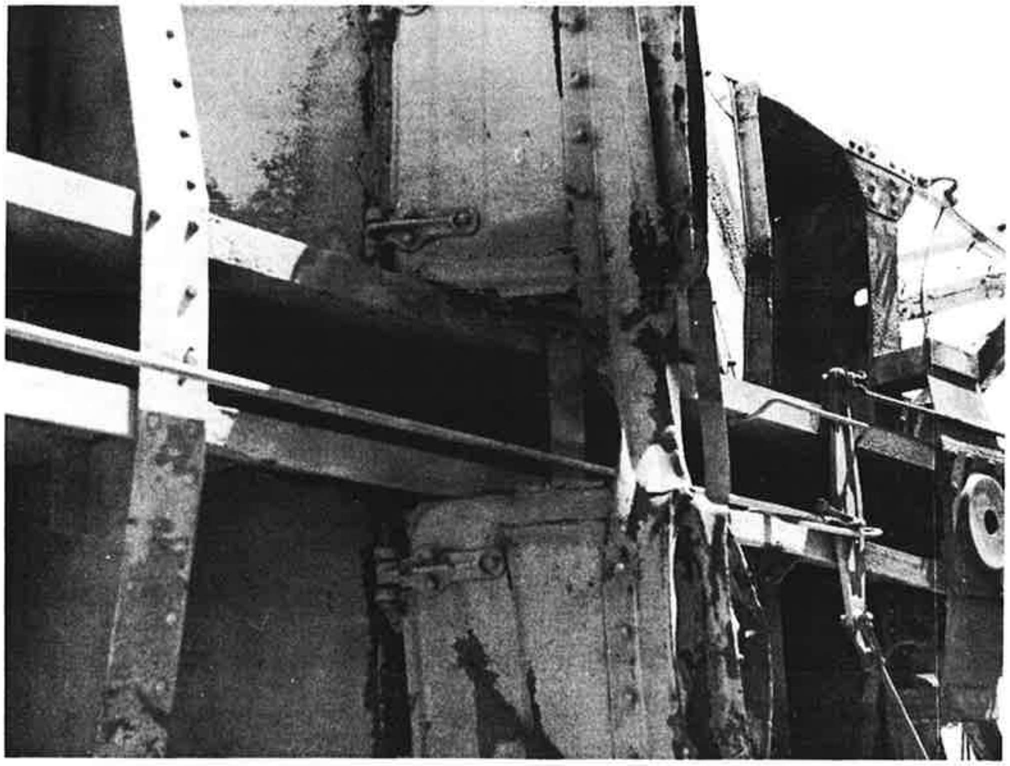

FIGURE 55. POST-TEST HOPPER CENTER SILL - TEST 9.

Figure 57 is a view of the second hopper with a caboose axle across its coupler.

Some of the more important parameters for Test 9 are the forces and accelerations experienced during the initial portion of the impact. The force on the caboose initially was transmitted through the rear coupler, which was instrumented with strain gauges which were calibrated in terms of force. After the coupler completely compressed its draft gear, the coupler horn contacted the center sill. The center sill also was instrumented and calibrated to measure the force in the end section. Before the coupler bottomed out, the coupler applied the force into the center sill inside of the strain gauges so that the sill did not register the compressive force until the coupler

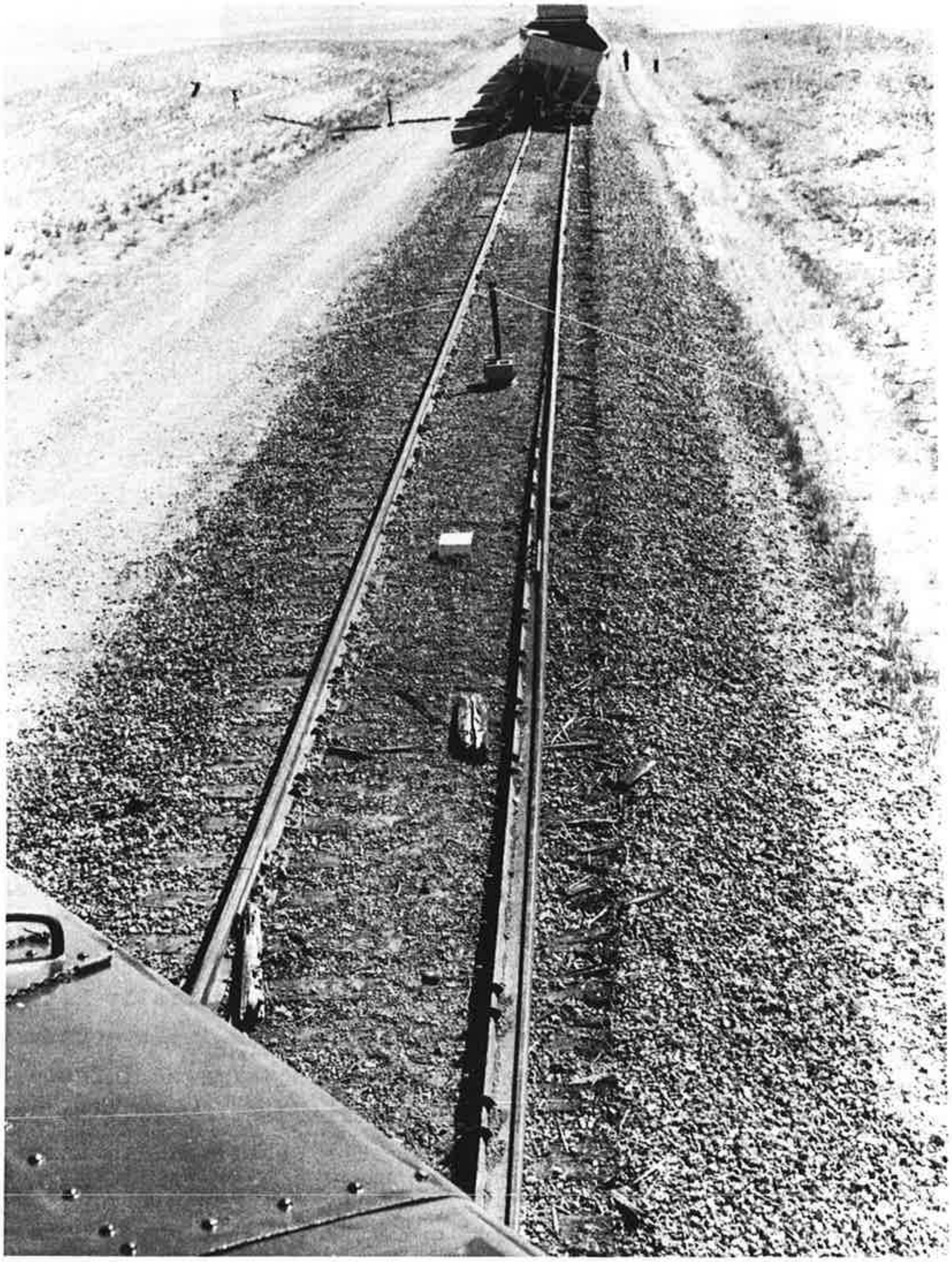

FIGURE 56. POST-TEST BENT RAIL AND SECOND HOPPER - TEST 9.

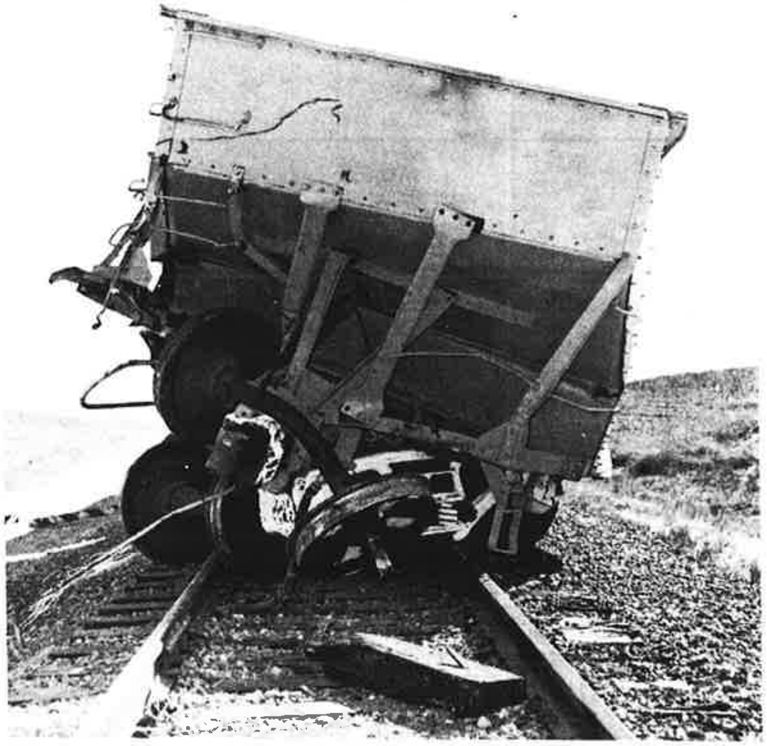

FIGURE 57. POST-TEST SECOND HOPPER - TEST 9.

bottomed out. In fact, the end portion of the sill was actually in compression as the sill accelerated the structure of the end of the caboose and had a small tension force. Figure 58 is a superposition of the caboose rear coupler force and the force measured by the center sill strain gauges. Note how the sill force begins to rise as the coupler force lowers. This occurred in time shortly after the coupler was observed to contact the buffer casting and as the caboose began to move forward. The total force on the caboose at about 50 msec is estimated to be approximately 500,000 pounds.

One of the couplers between each car was instrumented with a strain gauge. Figures 59 and 60 superpose the coupler forces as measured by these couplers for the stationary train and moving train, respectively. These curves illustrate how the force wave

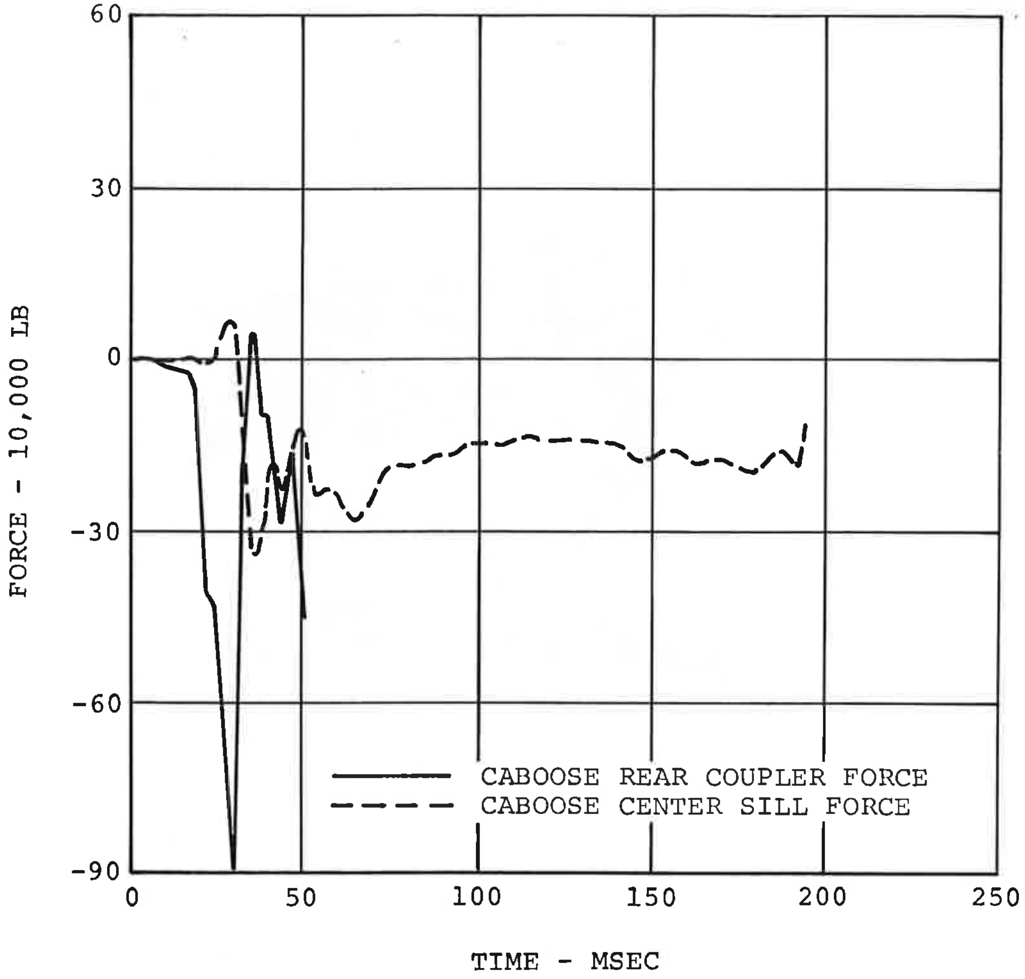

FIGURE 58. CABOOSE COUPLER FORCE AND CENTER SILL FORCE TESTING.

traveled down each train. The time between the initial peak for each successive car increased as the distance the cars were from impact increased, particularly for the stationary train.

The accelerometers on the caboose for this impact exhibited a lot of high frequency vibrational "spikes". Figures 61 and 62 superpose the longitudinal and vertical accelerations from each end of the caboose.

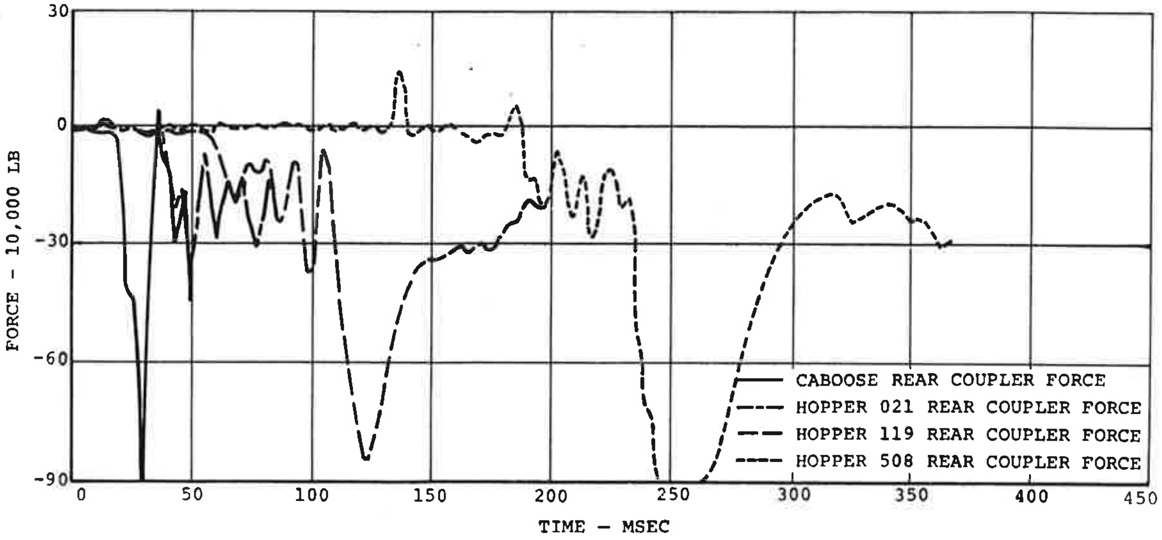

FIGURE 59. COUPLER FORCE PROPAGATION THROUGH STANDING TRAIN - TEST 9.

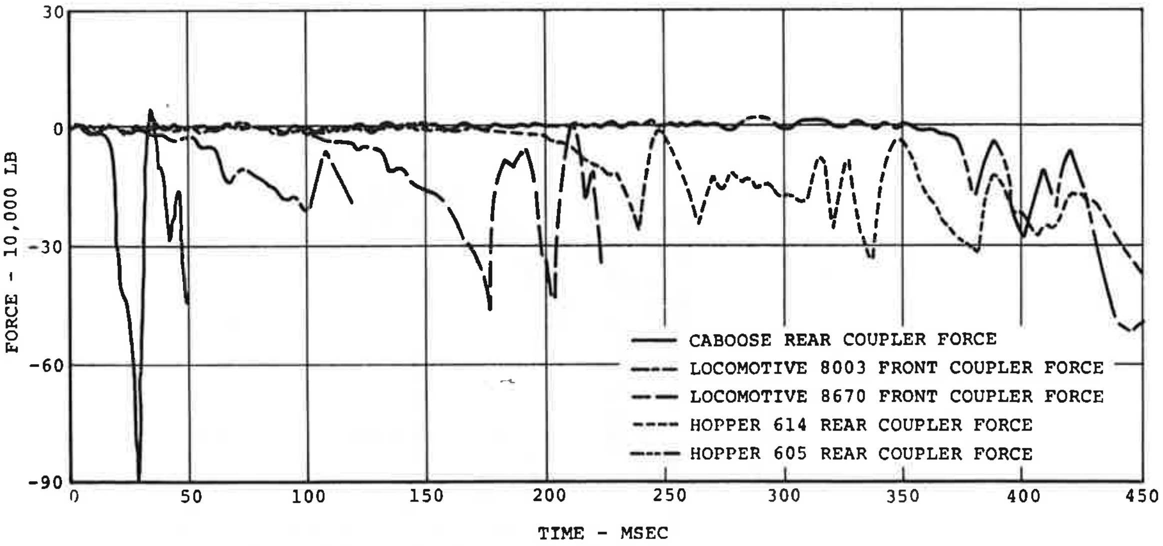

FIGURE 60. COUPLER FORCE PROPAGATION THROUGH MOVING TRAIN - TEST 9.

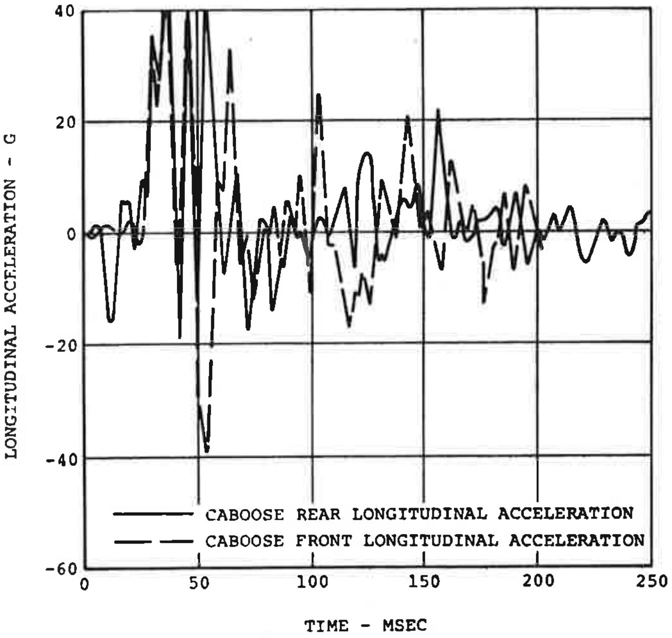

FIGURE 61. CABOOSE LONGITUDINAL ACCELERATION - TEST 9.

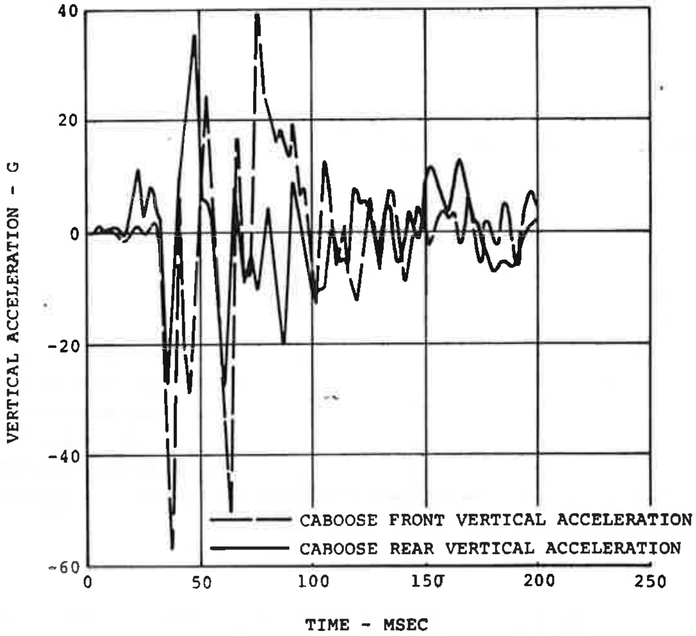

FIGURE 62. CABOOSE VERTICAL ACCELERATION - TEST 9.

If the caboose weight is taken as 30,000 pounds, and the average longitudinal force was 500,000 near 50 msec, then the average acceleration near 50 msec should be about 17G.

The entire set of data from the instruments on board the train are presented in Appendix A and discussions of trends and tabulation of characteristics of filtered curves are discussed in Section 6.4.

6.4 DATA EVALUATION - TESTS 1 THROUGH 9

Data from the digital plots shown in the Appendix are tabulated here for the more important instruments in order to show relationships, trends, and unusual occurrences. The values shown in the tables were obtained from filtered or smoothed curves. The curves were smoothed as required to eliminate local vibrational effects. In many cases, the data displayed a high-frequency ringing noise superposed on the lower frequency data that represent rigid body-type motion of the train or train components. This high-frequency part of the data is in the form of spikes of short duration. The physical gross motion of the instrument is difficult to determine without smoothing. This is true, particularly of accelerometers and strain gauges. An example of this smoothing of an acceleration curve which shows high acceleration peaks is shown in Figure 63.

The columns of the tables marked "START" indicate the time in milliseconds at which the plot deviated from "0", indicating the beginning of the acceleration, force, etc. The column marked "TIME" is the time in milliseconds at which the peak value recorded by the instrument occurred.

Tables 7 and 8 are tabulations of peak forces obtained from the strain gauges mounted on the couplers and center sills. The caboose rear coupler (SS1) generally experienced a small initial force peak due to the coupler shank contacting the draft gear assembly. The first major peak occurred when the draft gear was completely compressed. The caboose moved forward

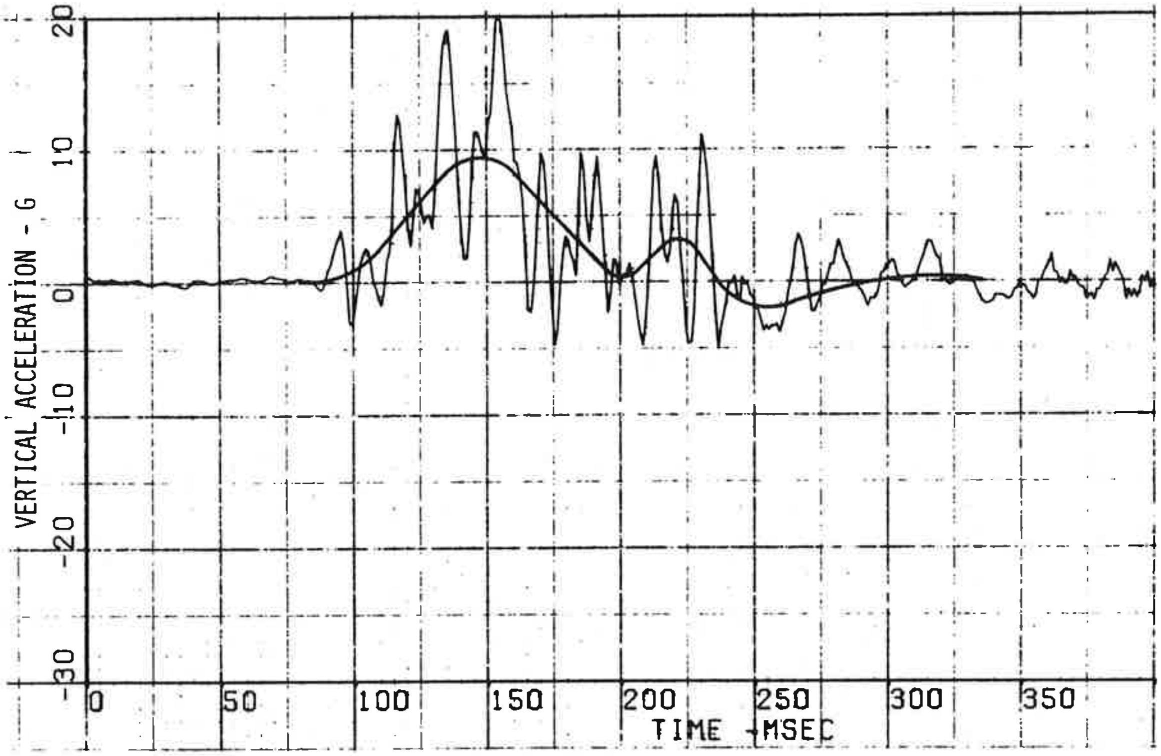

FIGURE 63. EXAMPLE OF CURVE SMOOTHING OF ACCELEROMETER DATA.

slightly and the coupler hit the buffer casting, producing the second major peak. Unfortunately, the strain gauges failed shortly after impact in Tests 8 and 9 and did not indicate the drop in force due to the caboose rebounding away from the locomotive. For example, at about 215 msec, the locomotive-caboose couplers were outstretched and a second series of force peaks occurred at about 300 msec. The same thing occurred in the low-speed tests at a later time interval; Test 5 had a second series of peaks at about 525 msec.

The strain gauges on the center sill experienced a change in sign of their readings due to the location of the gauges between the buffer casting on the end of the sill and the draft gear mount position. Initially, the impact force was transmitted through the coupler and draft gear into the sill (about 3 feet toward center from the end of the sill), which put the end

TABLE 7. LONGITUDINAL FORCE - STATIONARY TRAIN

Test No.	Location	Start	1st Peak		2nd Peak	
			Time	Klb	Time	Klb
1	SS1	125	210	-150	320	-110
	SS2	-	-	-	-	-
	SS3	200	260	-70	300	-90
	SS5	240	275	+14	335	+14
2	SS1	90	185	-165	290	-160
	SS2	160	185	+60	275	+50
	SS3	160	240	-160	285	-100
	SS5	175	245	+25	290	+14
3	SS1	60	135	-160	300	-240
	SS2	-	-	-	-	-
	SS3	180	255	-220	315	-180
	SS5	200	260	+30	320	+30
4	SS1	25	85	-480	175	-680
	SS2	45	80	+300	170	+450
	SS3	85	125	-60	165	-100
	SS5	115	-	-	-	-
5	SS1	75	160	-210	320	-260
	SS2	300	350	+130	-	-
	SS3	180	280	-370	340	-380
	SS5	200	295	+37	360	+25
	SS6	390	-	-	-	-
	SS7	580	675	-285	-	-

TABLE 7. LONGITUDINAL FORCE - STATIONARY TRAIN (CONTD)

Test No.	Location	Start	1st Peak		2nd Peak	
			Time	Klb	Time	Klb
6	SS1	75	245	-330	325	-270
	SS2	210	250	+180	330	+158
	SS3	110	265	-500	325	-400
	SS5	210	245	+30	285	+29
	SS6	215	310	-500	485	-280
	SS7	285	425	-350	490	-240
7	SS1	45	120	-440	170	-600
	SS2	-	-	-	-	-
	SS3	90	160	-850	-	-
	SS5	140	175	-100	275	-80
	SS6	-	-	-	-	-
	SS7	210	310	-600	400	-500
8	SS1	25	45	-650	70	-650
	SS2	40	45	+50	125	-400
	SS3	50	60	-250	65	-500
	SS5	60	85	-600	110	-480
	SS6	75	95	-1,200	200	-330
	SS7	85	155	-600	200	-520
9	SS1	15	30	-900	50	-
	SS2	25	30	+70	35	-360
	SS3	-	-	-	-	-
	SS4	25	47	-400	75	-300
	SS5	45	47	+40	53	-300
	SS6	55	120	-800	-	-
	SS7	175	250	-1,100	400	-700

TABLE 8. LONGITUDINAL FORCE - MOVING TRAIN

Test No.	Location	Start	1st Peak		2nd Peak	
			Time	Klb	Time	Klb
5	MS1	140	180	-80	375	-160
6	MS1	100	175	-80	310	-280
7	MS1	115	180	-200	220	-200
	MS3	190	240	-150	320	-400
	MS4	325	375	-500	-	-
8	MS1	50	85	-275	-	-
	MS3	90	150	-260	250	-380
	MS4	210	250	-200	285	-400
9	MS1	25	100	-200	-	-
	MS2	75	175	-400	200	-350
	MS3	175	240	-250	265	-340

section of the sill in tension. Next, the coupler horn hit the buffer casting (on high impact velocity tests) and some of the force was transmitted directly into the sill, putting the end section of the sill in compression. Thus, the total force transmitted was greater than the sill force for high-speed tests.

It must be pointed out that the stress-strain curve for steel is nonlinear near the plastic range where the strain continues to increase even though the stress tends to remain constant with increasing strain. When force is measured from a strain gauge, the assumption is that there is a linear relation between stress and strain. Near the plastic range this is invalid. The actual forces are lower than those indicated from the strain measurements. Also, when the steel begins to deform plastically, the gauge may give an incorrect reading due to partial loss of bonding and potential reorientation of the gauged location.

There were several notable trends to be obtained from the longitudinal acceleration data shown in Table 9. For example, the four accelerometers on the locomotive did not start to record deceleration at the same time even though the locomotive was a very stiff massive structure. The accelerometers on the front generally started later than the rear. In Tests 5 through 8, the locomotive had some positive acceleration due to the hopper in front of the locomotive impacting it after the locomotive slowed due to the initial impact. The time lag between the first locomotive deceleration peak and the positive acceleration peak is the time required to compress the draft gear of both the locomotive and its adjacent hopper car.

The impact velocity of Tests 5 and 6 was too low to cause noticeable locomotive acceleration by the hopper. Table 10 lists values of longitudinal acceleration of the standing train. The low impact speed tests (less than 10 mph) showed two positive peaks followed by a negative peak, but the two positive peaks merged into one on higher speed tests. The negative peak was a result of a car rebounding off the car in front of it. With the longer trains, the peaks induced by impacts from the hopper cars often complicated the wave form of the caboose data.

Tables 11 and 12 list the peaks of the vertical acceleration for the caboose and locomotive, respectively. Several trends are common between the caboose and locomotive: the impact or rear end goes down while the front end goes up. The caboose rotated about a point near the center of gravity which is close to the geometric center where the center vertical accelerometer was mounted. This causes low values of vertical acceleration for the low-speed tests. For Tests 8 and 9, the center vertical accelerometer data appear similar to the front accelerometer, implying the caboose was rotating about a point between the rear coupler and the center. The locomotive rear coupler had a negative or upward acceleration for its first peak. This was probably due to the location of the accelerometer which was mounted on the rear of the draft gear assembly. Upon initial

TABLE 9. LONGITUDINAL ACCELERATION - MOVING TRAIN

Test No.	Location	Start	1st Peak		2nd Peak		3rd Peak		4th Peak	
			Time	G's	Time	G's	Time	G's	Time	G's
1	MA1	115	130	-1.0	-	-	-	-	-	-
	MA2	135	165	-1.0	210	-1.0	-	-	-	-
	MA3	115	135	-1.5	180	-1.5	-	-	-	-
	MA5	135	160	-0.8	205	-0.6	-	-	-	-
2	MA1	105	125	-2.2	170	-5.0	-	-	-	-
	MA2	100	130	-1.0	180	-1.0	-	-	-	-
	MA3	100	130	-1.0	185	-0.5	-	-	-	-
	MA5	105	135	-1.0	185	-1.0	-	-	-	-
3	MA1	60	75	-0.8	120	-1.0	290	-1.0	-	-
	MA2	60	80	-1.0	135	-1.0	270	-1.5	320	-1.5
	MA3	50	80	-1.0	130	-1.5	275	-2.0	325	-2.0
	MA5	65	85	-0.5	135	-0.5	275	-1.0	325	-1.0
4	MA1	25	35	-2.0	75	-2.5	160	-2.0	210	-1.0
	MA2	40	75	-1.5	115	-1.5	165	-2.5	215	-2.5
	MA3	50	75	-2.0	120	-1.5	170	-3.0	215	-2.0
	MA5	50	75	-2.0	120	-0.5	165	-3.0	200	-1.5
5	MA1	75	110	-0.6	150	-0.5	315	-0.5	-	-
	MA2	100	135	-0.8	200	-0.5	325	-0.5	-	-
	MA3	100	135	-1.2	200	-0.3	325	-0.5	-	-
	MA5	75	105	-0.8	145	-0.8	335	-1.0	-	-
6	MA1	80	105	-0.8	160	-2.5	235	-2.0	325	-1.5
	MA2	80	115	-1.0	170	-1.0	240	-1.3	330	-1.5
	MA3	75	115	-1.5	175	-1.0	240	-1.5	335	-1.5
	MA5	80	110	-1.0	175	-0.5	245	-1.5	325	-1.5

TABLE 10. LONGITUDINAL ACCELERATION - STATIONARY TRAIN (CONTD)

Test No.	Location	Start	1st Peak		2nd Peak		3rd Peak		4th Peak	
			Time	G's	Time	G's	Time	G's	Time	G's
7	SA1	60	90	5.0	155	-5.0	225	-3.0	-	-
	SA3	60	75	4.0	120	5.0	140	-3.0	175	3.0
	SA5	100	120	2.0	185	5.0	225	-4.0	260	2.0
	SA7	175	190	2.0	225	-2.0	260	2.0	-	-
	SA8	220	250	3.0	280	-2.0	330	4.0	-	-
	SA9	225	270	2.5	310	4.0	-	-	-	-
8	SA1	25	60	20.0	90	-4.0	135	4.0	285	-3.0
	SA3	25	60	10.0	75	-10.0	125	8.0	285	-4.0
	SA5	50	85	7.5	100	-7.5	190	-2.5	-	-
	SA7	75	115	4.0	140	-3.0	-	-	-	-
	SA8	110	125	3.0	165	3.5	245	-1.5	-	-
	SA9	165	220	1.0	-	-	-	-	-	-
9	SA1	5	40	25.0	85	-7.5	150	6.0	-	-
	SA3	15	45	24.0	75	-4.0	100	6.0	120	-11.0
	SA5	30	50	10.0	115	-9.0	150	3.0	255	-3.0
	SA7	50	110	8.0	235	-5.0	-	-	-	-
	SA8	180	235	7.0	320	-2.0	365	-5.0	-	-
	SA9	300	365	5.0	-	-	-	-	-	-

impact, the coupler was pushed back and down, causing the rear of the draft gear assembly to accelerate up for a short period of time; after which the entire locomotive rear end accelerated downward. A time lag between the start of the rear end motion and the start of the front end motion indicated some elastic bending in the locomotive frame structure. Also, in Tests 5 through 9, the impacts of the hopper cars in front of the

TABLE 11. VERTICAL ACCELERATION - CABOOSE

Test No.	Location	Start	1st Peak		2nd Peak		3rd Peak		4th Peak	
			Time	G's	Time	G's	Time	G's	Time	G's
1	SA1	120	125	-1.0	175	2.0	-	-	-	-
	SA2	125	190	-1.5	230	1.0	260	-1.5	-	-
	SA3	140	175	-1.0	270	3.0	-	-	-	-
2	SA1	100	110	-1.0	125	2.0	160	-2.5	240	-1.0
	SA2	110	125	-1.0	160	-1.0	-	-	-	-
	SA3	120	130	-1.0	185	-2.0	250	2.5	-	-
3	SA1	70	75	1.0	85	-1.0	105	0.5	125	-0.5
	SA2	65	75	-0.5	110	0.5	125	-1.0	160	1.0
	SA3	75	125	-1.0	150	1.0	225	1.0	300	-1.0
4	SA1	25	35	-2.0	50	2.0	80	-4.0	150	-4.0
	SA2	30	35	-1.0	50	1.0	-	-	-	-
	SA3	30	40	-1.5	60	0.5	75	-2.5	120	4.0
5	SA1	100	115	1.0	160	-0.5	175	0.5	250	-1.0
	SA2	110	125	0.5	140	-0.5	175	0.5	260	-1.0
	SA3	125	135	-0.5	200	-2.0	250	1.5	275	-2.0
6	SA1	80	90	2.0	110	-2.0	130	3.0	165	-3.0
	SA2	85	105	1.0	110	-2.0	130	1.0	145	-1.5
	SA3	90	95	-2.0	155	0.5	170	-3.5	185	5.0
7	SA1	60	75	3.0	85	-2.0	120	4.0	155	-3.0
	SA2	65	70	1.0	85	-2.0	100	1.0	170	-5.0
	SA3	70	110	2.0	135	-5.0	160	5.0	175	-4.0
8	SA1	25	35	1.5	40	-7.0	65	5.0	80	-5.0
	SA2	35	60	-5.0	80	6.0	-	-	-	-
	SA3	35	55	-5.0	65	6.0	85	-5.0	110	-8.0
9	SA1	15	25	6.0	35	-4.0	45	8.0	95	-10.0
	SA2	10	15	4.0	35	-15.0	-	-	-	-
	SA3	20	30	2.0	45	-8.0	65	18.0	115	-5.0

TABLE 12. VERTICAL ACCELERATION - LOCOMOTIVE

Test No.	Location	Start	1st Peak		2nd Peak		3rd Peak		4th Peak	
			Time	G's	Time	G's	Time	G's	Time	G's
1	MA1	65	115	1.0	150	1.0	185	-1.5	300	-1.0
	MA4	100	135	-1.0	160	1.0	185	-0.5	200	1.0
	MA5	110	135	0.5	185	0.5	-	-	-	-
2	MA1	85	120	-1.0	175	1.0	200	-2.0	225	1.5
	MA4	125	150	0.5	190	-0.5	225	0.3	275	-0.3
	MA5	135	150	0.5	205	0.5	235	-1.0	265	1.5
3	MA1	60	85	-2.0	115	2.0	280	1.5	-	-
	MA4	75	95	0.5	120	-0.5	160	0.5	-	-
	MA5	90	110	0.5	-	-	-	-	-	-
4	MA1	20	35	-2.0	70	6.0	110	-5.0	165	5.0
	MA4	50	80	-1.5	110	1.5	125	-2.0	125	1.5
	MA5	60	75	-1.5	105	0.5	130	-2.5	165	3.0
5	MA1	75	110	-2.5	145	1.0	175	-2.0	225	1.0
	MA4	120	130	1.0	-	-	-	-	-	-
	MA5	110	135	-0.5	175	0.5	200	-1.0	235	1.0
6	MA1	85	115	-2.5	165	6.0	230	4.0	265	-1.5
	MA4	100	130	-1.0	170	1.0	240	-1.0	-	-
	MA5	100	120	-0.5	170	0.5	230	1.0	255	-1.0
7	MA1	75	95	-2.0	115	5.0	140	-4.0	190	-4.0
	MA4	100	125	-1.0	150	1.5	205	1.5	240	-1.0
	MA5	150	175	-2.0	190	8.0	220	-3.0	-	-
8	MA1	25	50	-8.0	75	4.0	140	-8.0	175	4.0
	MA4	40	55	-4.0	100	2.0	140	3.0	165	-4.0
	MA5	40	55	-4.0	75	6.0	120	-6.0	150	12.0
9	MA1	5	40	-2.0	-	-	-	-	-	-
	MA4	25	40	-6.0	75	3.0	135	-4.0	-	-
	MA5	25	35	-1.0	65	3.0	110	-8.0	130	15.0

locomotive made the front accelerometer data erratic; that is, not exactly opposite to the rear end motion, as would be the case for unencumbered rotational acceleration.

Table 13 is a summary of the caboose vertical displacement transducers. The up and down motion is verified by the vertical accelerometers: the rear end translated down for a short duration while the front end displaced upward only. The caboose pitched slightly about its center of gravity, then the whole car raised fairly uniformly. In three cases the front end began its upward motion ("start" time) before the impact end started downward motion. The caboose rolled to the left in every case. Tests 5 and 6 indicated that the caboose jumps higher when in draft than in buff. Tests 8 and 9 were not included in the table because the caboose had a large amount of longitudinal motion combined with the vertical motion while separating from the trucks, so the transducers were pulled out at a large angle and gave misleading measurements. The vertical displacements increased as impact velocity increased.

Table 14 summarizes the peak resultant swinghanger forces for both caboose trucks. A positive number is downward compressive force (more tension in the swinghangers) and a negative number is lifting of the caboose (less tension in the swinghangers). Again, the rear end of the caboose went down and then up while the front end only went up. The downward force increased with increased impact velocity (see Figure 64) up to 18 mph, but at 30 mph, the longitudinal motion was larger than the downward motion. For this test, the caboose center plate passed beyond the rim of the bolster before the end of the caboose reached its maximum downward motion.

TABLE 13. CABOOSE VERTICAL DEFLECTION MEASUREMENTS						
Test No.	Location	Start	Maximum Down		Maximum Up	
			Time	In.	Time	In.
1	SD1	-	-	-	-	-
	SD2	-	-	-	-	-
	SD3	125	0	0	325	1.25
	SD4	135	0	0	350	1.65
2	SD1	125	220	.45	315	.50
	SD2	125	180	.45	320	.95
	SD3	120	0	0	325	1.70
	SD4	125	0	0	260	2.10
3	SD1	115	185	.30	260	.35
	SD2	100	150	.15	350	.95
	SD3	80	0	0	390	1.55
	SD4	80	0	0	390	2.95
4	SD1	55	100	.60	-	-
	SD2	-	-	-	-	-
	SD3	60	0	0	175	3.10
	SD4	60	0	0	175	3.20
5	SD1	125	210	.30	310	.90
	SD2	150	200	.10	325	1.20
	SD3	115	0	0	310	1.90
	SD4	110	0	0	255	2.50
6	SD1	100	155	.45	275	.55
	SD2	-	-	-	-	-
	SD3	110	0	0	220	1.35
	SD4	90	0	0	215	2.30
7	SD1	100	145	.55	260	1.95
	SD2	100	140	.45	250	2.10
	SD3	75	0	0	250	2.10
	SD4	80	0	0	-	-

TABLE 14. CABOOSE SWINGHANGER FORCE

Test No.	Location	Start	1st Peak		2nd Peak	
			Time	Klb	Time	Klb
1	SH1	135	200	3.5	335	-2.5
	SH2	-	-	-	-	-
2	SH1	125	185	5.0	285	-5.0
	SH2	175	275	-9.0	410	-5.0
3	SH1	-	-	-	-	-
	SH2	110	225	-4.5	340	-5.0
4	SH1	55	115	+8.0	200	-10.0
	SH2	70	-	-	-	-
5	SH1	100	180	3.0	310	-7.0
	SH2	100	240	-11.0	370	-11.0
6	SH1	80	160	3.0	275	-6.0
	SH2	75	225	-10.0	450	-7.0
7	SH1	75	140	5.5	225	-10.0
	SH2	100	250	-12.0	-	-
8	SH1	30	110	+12.0	325	-13.0
	SH2	-	-	-	-	-
9	SH1	25	70	+10.0	150	-11.0
	SH2	25	60	+11.9	150	-11.0

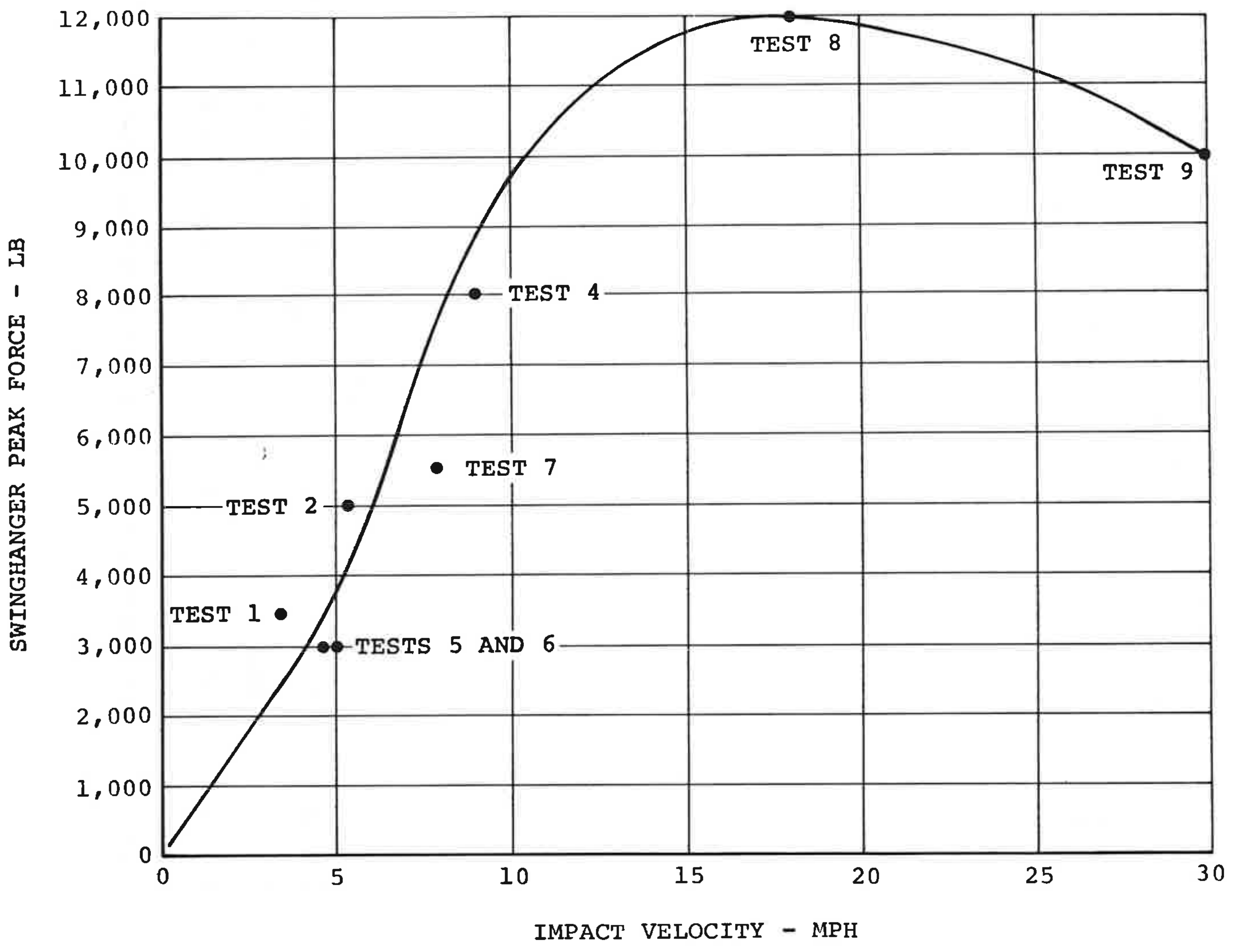

FIGURE 64. CABOOSE REAR END DOWNWARD FORCE

7. CONCLUSIONS AND RECOMMENDATIONS

The objective of this effort was to establish the data, through the remotely-controlled train impacts, required to study the dynamics of train rear end collision accidents. These data can now be used as a base to establish and improve locomotive and caboose energy management under operational conditions, and has provided data that form a basis for upgrading mathematical computer models. These models will provide the capability of performing parametric studies and analytically estimating initial impact dynamic behavior under other test conditions.

7.1 CONCLUSIONS

7.1.1 Repeatability of Tests

An important concern for any experiment is the ability to obtain repeatable results from a series of tests. Although the tests had differences, several specific trends were observed and supported by data output and high-speed photography. The tests, ranging from impact speeds of 3 mph to 30 mph, were consistent with respect to initial vehicle dynamics.

1. The impact end of the locomotive moved downward upon impact.
2. The rear end of the caboose went down upon impact, then moved upward.
3. The front end of the caboose never translated downward, always upward.
4. Multiple impacts between the locomotive and caboose were observed. The high initial longitudinal impact forces from the impacting locomotive pushed the caboose away from the locomotive with the forces acting on the rear end reducing to essentially zero. The moving locomotive impacted the caboose a second time somewhat later.
5. The caboose rolled to the left in all cases, but probably not enough to change the basic crush dynamics that would have been experienced without the roll.

In Tests 8 and 9, the caboose center sill buckled (due to column loading) in the same area. The upward motion of the front end of the caboose caused override onto the hopper in front of it for Test 8 which relaxed the compressive force on the caboose center sill. The difference in timing between Tests 8 and 9 when rotation and large axial caboose forces reached large magnitudes, governed the outcome of the tests. Both the caboose and hopper were destroyed with minimal damage to the locomotive.

All of these points indicate that the tests were consistent and that future tests performed with similar conditions would produce similar results.

7.1.2 Occupant Safety

The problem of occupant safety is always a major factor in any type of collision environment. There are four categories which can define most injury modes:

Survivable Space

Intrusion

Acceleration

Occupant Impact

These areas will be discussed for Tests 8 and 9 only since Tests 1 through 7 were of such low impact velocity that injury probability was extremely low.

7.1.2.1 Survivable Space

When a vehicle involved in a collision is crushed, it is possible that occupants fatally injured by the crush could have survived acceleration, intrusion, and impacts. The loss or retention of survivable space is very easily determined by observing the post-test results. Test 8 did not crush the caboose or locomotive to any great extent; survivable space was available in both vehicles. The caboose in Test 9 was crushed to the point that no occupant could have survived the impact. There was no space large enough for a human body. The locomotive had part of the cab crushed, but the survivable space was more than sufficient for several occupants.

7.1.2.2 Intrusion

Intrusion represents a hazard to occupants when a portion of a vehicle is pushed into the passenger or crew compartment. Test 8 did not have intrusion into the locomotive cab, but the caboose suffered some intrusion from split hardwood boards from the floor and wall. Figure 30 is a post-test photograph of the caboose interior, showing broken boards on the floor. Test 9 produced the same type of caboose intrusion as Test 8, although the caboose was so completely crushed that injury from intrusion was insignificant. The locomotive in Test 9 is a good example of intrusion; the caboose smashed the rear left corner of the cab causing hardwood boards and sharp steel sheet metal to protrude into the occupant compartment. This intrusion could have caused a fatality in the locomotive cab.

7.1.2.3 Acceleration

The human body has a limited acceleration tolerance. High accelerations can cause injury or fatalities. Even if the impact between the occupant and his compartment is minimal and no sharp objects are encountered, high acceleration of the occupant, as measured by compartment structure acceleration (i.e., locomotive cab), can cause injuries and fatalities.

Many studies have been performed in attempts to define the level of human tolerance to forces and accelerations. Injury criteria have been developed which correlate these forces and acceleration, as measured during an impact from instrumentation in anthropomorphic dummies to the level of injury. Calculations of injury criteria and thresholds are possible from the dummy instrumentation. For the train-to-train impact tests, the dummies were not instrumented so these calculations cannot be made. However, an estimate of the level of severity can be obtained from looking at the locomotive cab acceleration. The simplest form of injury criteria specifies the maximum acceleration, acceleration rate, and length of time above the specified threshold that can be tolerated. For instance, the maximum survivable head acceleration and acceleration rate are as follows.*

1. A maximum deceleration of 50G, provided the deceleration rate did not exceed 500G/sec.
2. A maximum deceleration of 40G, provided deceleration rates do not exceed 1500G/sec.

Experimental evidence suggests that human tolerance limits depend on the duration as well as the magnitude of deceleration (Figure 65).

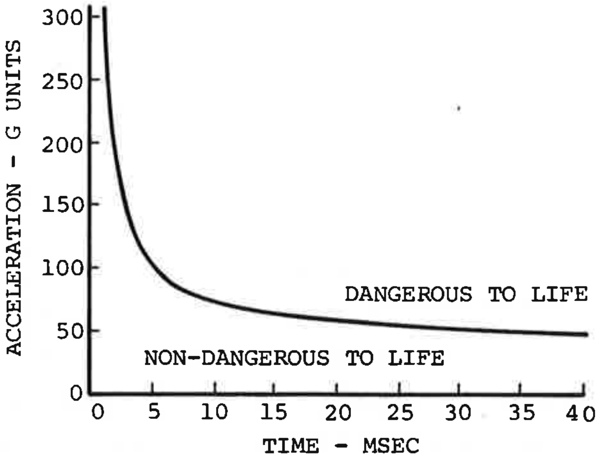

FIGURE 65. HEAD ACCELERATION VERSUS TIME FOR HUMAN SURVIVAL.

Both Tests 8 and 9 had very low values (less than 20G) of maximum deceleration in the locomotive cab (Location MA2) and the caboose (Location SA1). It can be inferred, then, that the acceleration levels were not high enough to cause significant injury. This does not eliminate possibilities of injuries due to contacting sharp interior surfaces, intrusion, whiplash, etc.

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*Girrad, W. L., "Crashworthiness for High-Capacity Personal Rapid Transit Vehicles", Minnesota University, 1974.

7.1.2.4 Occupant Impact

A fourth type of injury mode occurs when an occupant contacts the interior of the decelerating or accelerating occupant compartment. Injury not only occurs from high acceleration, but from contact with sharp or protruding surfaces. A graphic example of this is the motion of the anthropomorphic engineer dummy in Test 8. The dummy's body fell rearward and the head impacted a sharp corner of the control console. Since the dummies for this test were not instrumented, it is difficult to estimate the extent of injury from this impact, however, it could have caused severe injury or perhaps even a fatality. In Test 9, the engineer dummy fell to the floor and did not impact any sharp objects. Occupants in the caboose might have incurred similar impacts, depending on such factors as seating arrangement, sharp objects around the seating area, etc.

In summary, the most severe conditions occurred in Test 9 with the elimination of survivable space.

7.1.3 Post-Crash Fire Safety

Post-crash evaluations were conducted following Tests 8 and 9 to assess the degree of fire hazard resulting from the crashes. The following sections describe the fuel system and possible ignition sources and present the results of the post-test evaluations.

7.1.3.1 Locomotive Fuel System

The fuel system contains two fuel tanks - one located beneath the cab floor and one mounted below the underframe of the locomotive. The lower tank holds approximately 750 gallons of fuel while the upper tank holds 850 gallons, giving a total capacity of approximately 1,600 gallons of fuel.

A fuel booster pump draws fuel from the lower tank and distributes it throughout the system. The suction side of the system, between the tank and the booster pump, contains an emergency fuel cutoff valve and a fuel strainer. The pressure side of the system is between the booster pump and the pressure regulating valve which discharges excess fuel back to the tank. As the fuel is discharged from the pump, the pressure is regulated by the valve which is set to maintain 35 to 40 psi. The fuel from the pump first passes by a pressure relief valve set at 75 psi, then through a filter assembly to the fuel inlet manifold where the individual injection pumps deliver the fuel to the injection nozzles.

Filling is accomplished through filler connections located in the top tank near sight gauge glasses which permit observation of the fuel level during filling (see Figure 66). Fuel from the top tank is gravity fed to the lower tank through the equalizing pipe on the right side of the locomotive which is shown in Figure 67. The fuel feed and return lines, shown in Figure 68, exit the lower tank from the front left corner of the tank.

7.1.3.2 Potential Ignition Sources

The two most probable ignition sources during a crash are electrical sparks and friction sparks. Eight 8-volt batteries are normally installed in the battery compartment. Although the batteries had been removed from the striking locomotive during the tests for safety reasons, Figure 69 shows the typical battery installation for this type of locomotive. The battery compartment is located directly rearward of the cab and is subject to severe damage during high-speed crashes or if the locomotive is overridden by the caboose. High energy electrical sparks would be generated if the wires leading from the batteries were broken and shorted to the locomotive structure. Sparks would also be generated if any displaced structure were to come in contact with the exposed positive battery terminals.

Friction sparks could be generated by structure sliding along the rails or roadbed in the event of a derailment. Friction sparks might also be generated by the wheels sliding on the rails if the brakes were locked up prior to impact.

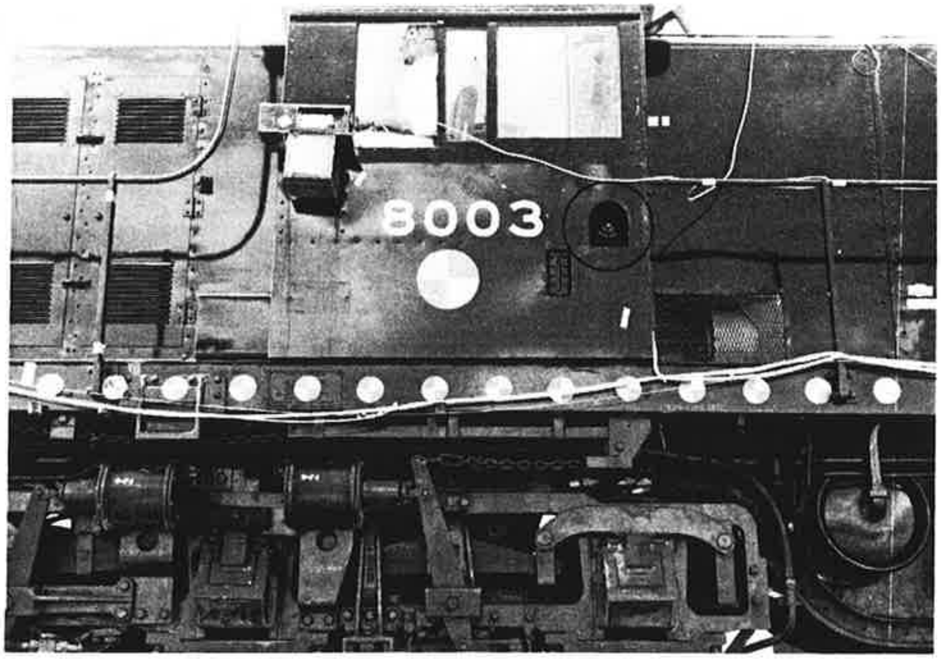

FIGURE 66. LOCOMOTIVE FUEL FILLER.

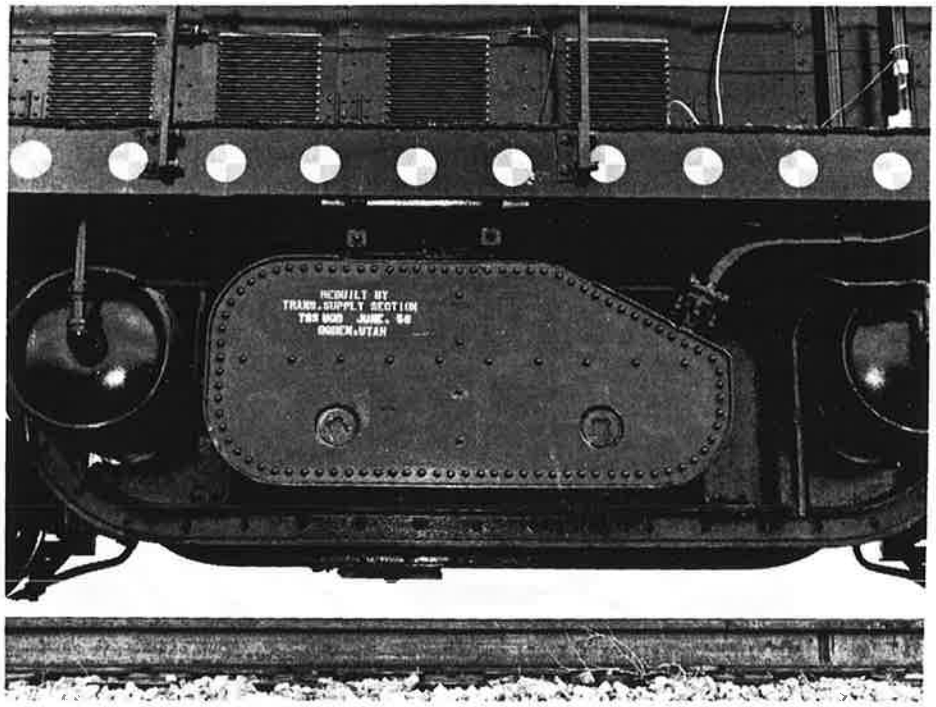

FIGURE 67. LOCOMOTIVE LOWER FUEL TANK.

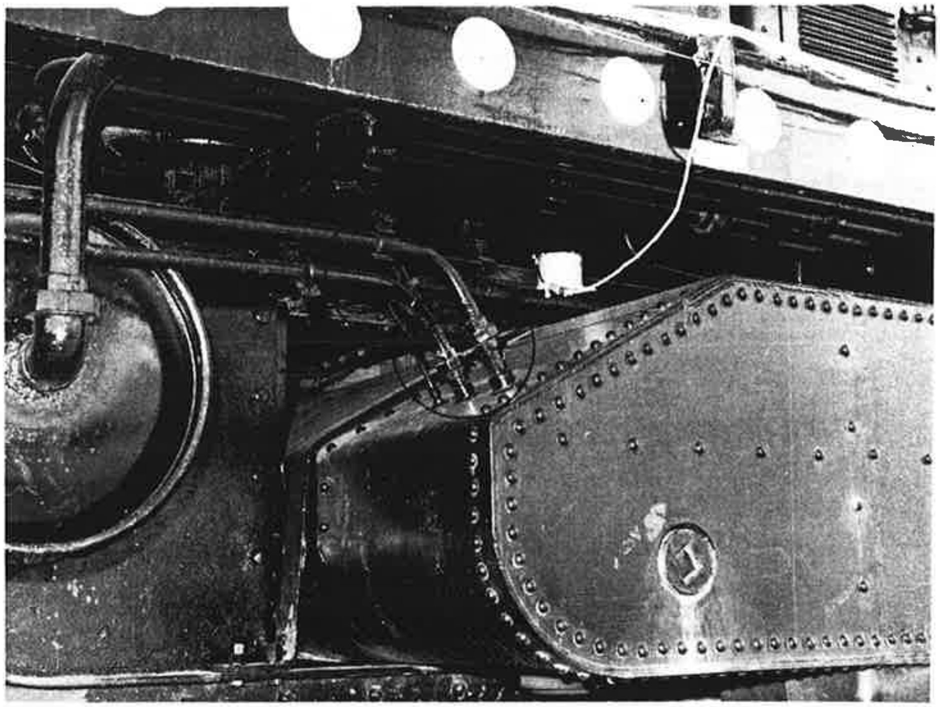

FIGURE 68. LOCOMOTIVE FUEL FEED AND RETURN LINES.

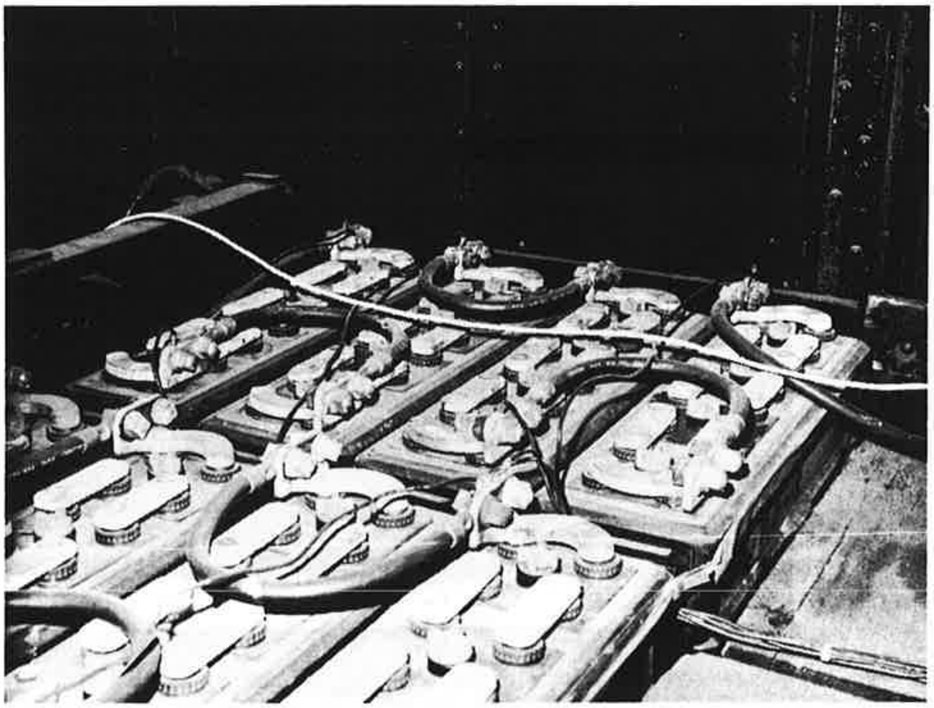

FIGURE 69. LOCOMOTIVE BATTERY COMPARTMENT - REAR END.

Both types of ignition sources are readily capable of igniting spilled gasoline from another vehicle. However, in the case of a train-to-train impact, where diesel fuel oil is the only fuel present, the probability of igniting a crash fire is greatly reduced because of the higher flash point of the diesel fuel. Diesel fuel oil has a minimum flash point of 100°F to 125°F, depending on the type of fuel oil used. This is the minimum temperature at which the fuel gives off sufficient vapor to form an ignitable fuel/air mixture near the fuel surface. Thus, the fuel oil must be moderately heated before ignition will occur. The probability of this happening during most crashes must be considered quite small.

If the fuel system is damaged during a crash, resulting in fuel oil spillage, a post-crash fire may be ignited by an external ignition source. A flare or open flame from any source could ignite any spilled fuel. The pooled fuel would continue to burn until fuel depletion or fire extinguishment.

7.1.3.3 Test Number 8

Prior to the test, the fuel tanks were drained of all fuel oil and filled with 1,400 gallons of dyed water. The test was conducted at an impact velocity of 18.18 mph. Damage to the striking locomotive was minor as the caboose overrode the hopper car ahead of it instead of overriding the locomotive.

The fuel system was not damaged although the lower fuel tank had shifted forward slightly during the impact. However, there was some minor fuel leakage which occurred around the union of the fuel feed line into the tank fitting as shown in Figure 70. This spillage measured approximately 1-1/2 oz/min. Since there was no damage to the battery compartment and fuel spillage was minor, it must be concluded that the crash fire hazard in respect to the locomotive was minimal.

There could have been a fire hazard in connection with the caboose, however. Although the fuel oil heater in the rear of the caboose did not tear loose, it had been bent rearward on its

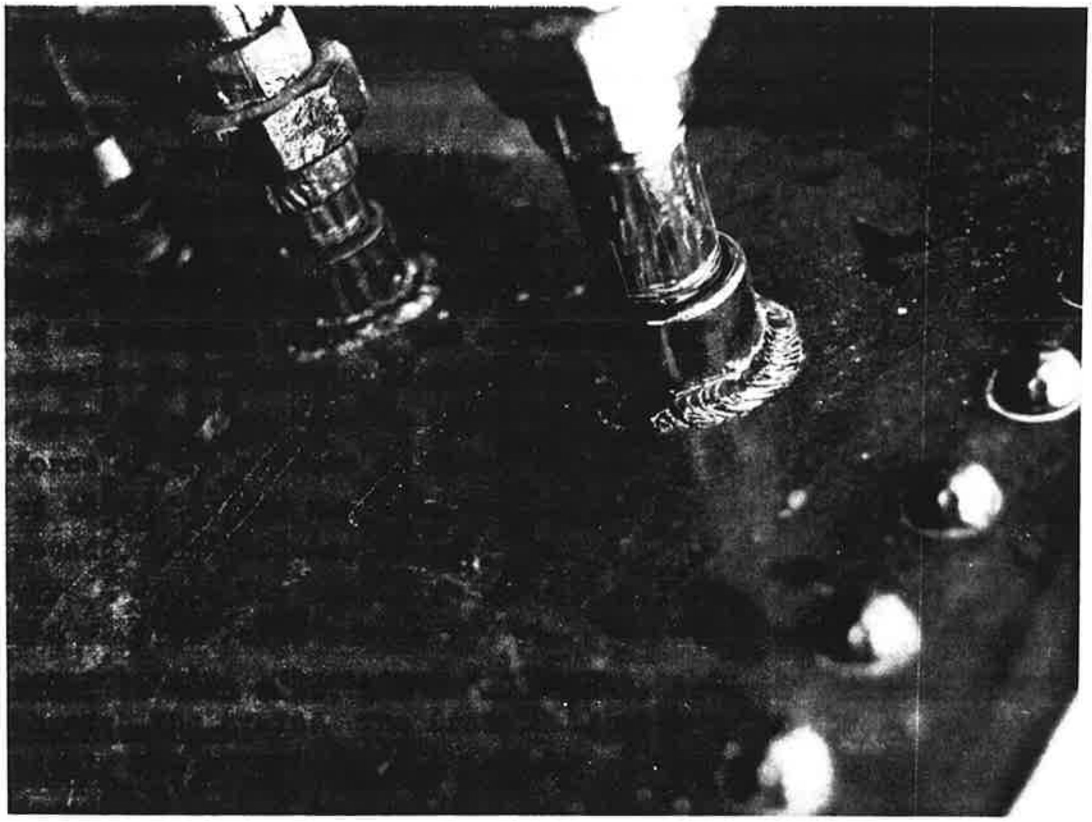

FIGURE 70. LOCOMOTIVE FUEL TANK LEAK - TEST 8.

mounting by the impact. In addition, the oil line feeding the heater was pulled loose from the heater connection. This, in conjunction with the tilt of the stove and caboose, allowed some residual oil to spill onto the floor as shown in Figure 71. Had the heater been burning at the time of impact, burning oil could have spilled onto the wooden floor and ignited it.

7.1.3.4 Test Number 9

As in the previous test, the fuel oil had been removed from both locomotives and the tanks of each locomotive filled with approximately 1,400 gallons of water before the test. The test was conducted at an impact velocity of 30.3 mph.

Both locomotives were derailed during the impact. The battery compartment of the lead locomotive was heavily damaged.

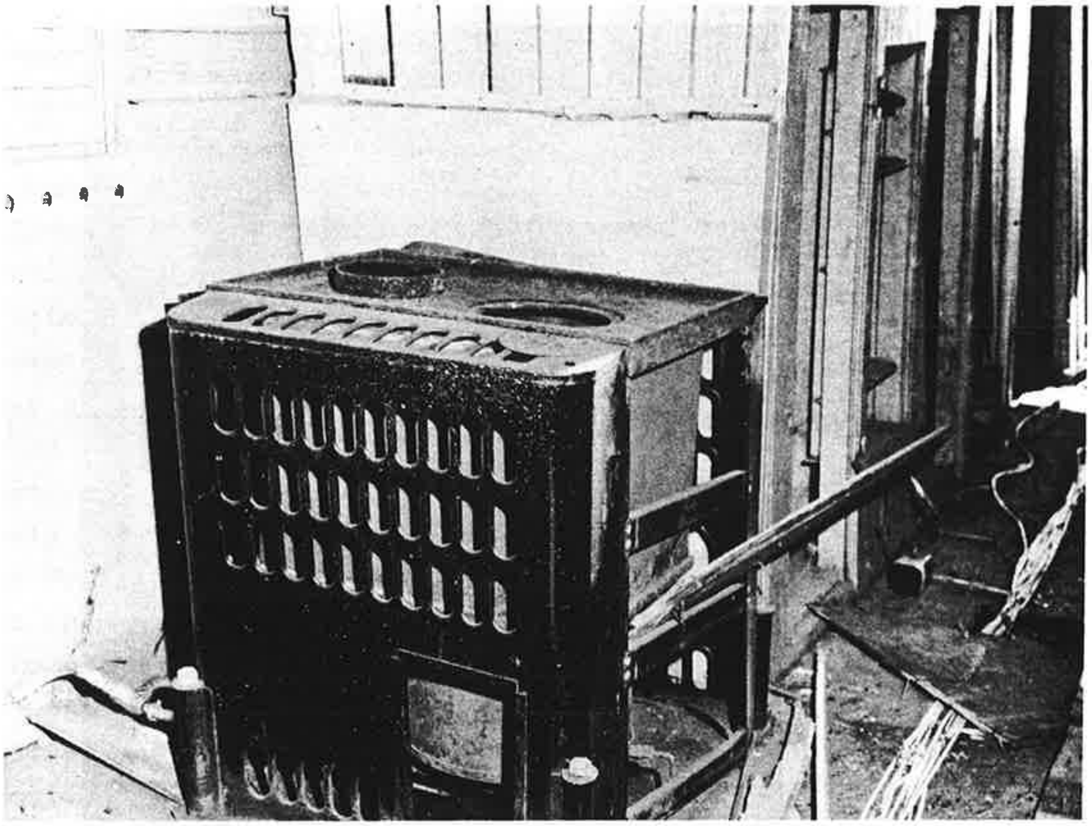

FIGURE 71. POST-TEST VIEW OF CABOOSE HEATER - TEST 8.

Although the left side of the cab was damaged, there was no noticeable damage to the underfloor fuel tank. The rest of the fuel system was also intact, although fuel leakage did occur from the union of the fuel feed line into the lower tank, as happened in the previous test. The amount of spillage was considerably more than in the first test, as may be seen in Figure 72, measuring approximately 5 ounces per minute. There was no damage to the second locomotive.

The probability of a crash fire occurring in the front locomotive must be considered minor because of the physical separation of the fuel spillage from the electrical ignition sources. Although friction sparks were probably generated during the derailment, the high flash point of the diesel fuel would make

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