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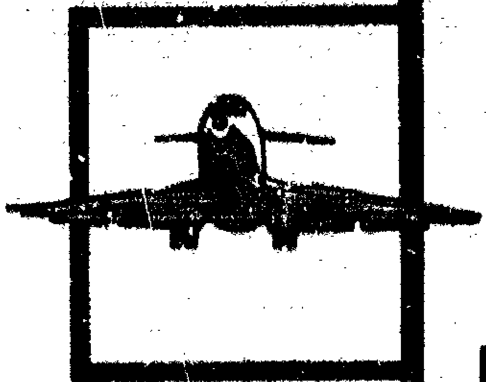
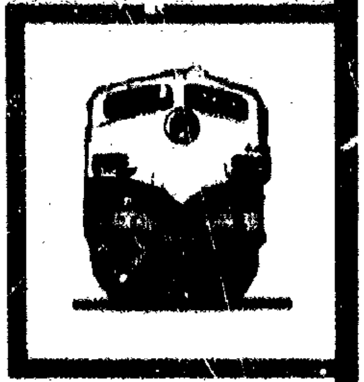
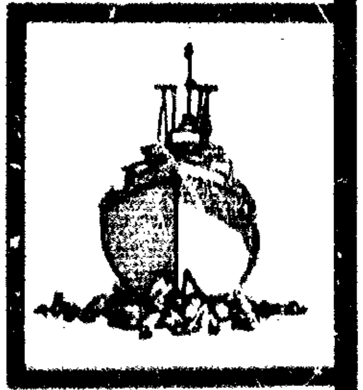


NATIONAL TRANSPORTATION SAFETY BOARD

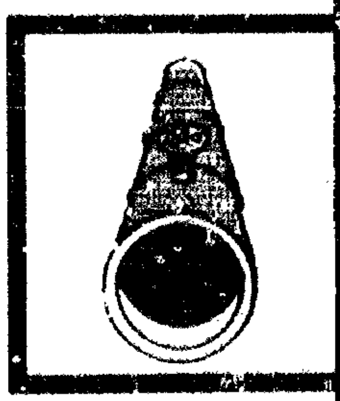


WASHINGTON, D.C. 20594

RAILROAD ACCIDENT REPORT



LOUISVILLE & NASHVILLE RAILROAD COMPANY FREIGHT TRAIN DERAILMENT AND PUNCTURE OF ANHYDROUS AMMONIA TANK CARS AT PENSACOLA, FLORIDA NOVEMBER 9, 1977



REPORT NUMBER: NTSB-RAR-78-4

UNITED STATES GOVERNMENT

41

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. NTSB-RAR-78-4	2. Government Accession No.	3. Recipient's Catalog No. PB284335

4. Title and Subtitle Railroad Accident Report -- Louisville & Nashville Railroad Company Freight Train Derailment and Puncture of Anhydrous Ammonia Tank Cars at Pensacola, Florida, November 9, 1977

5. Report Date July 20, 1978

6. Performing Organization Code

7. Author(s)

8. Performing Organization Report No.

9. Performing Organization Name and Address

National Transportation Safety Board
Bureau of Accident Investigation
Washington, D.C. 20594

10. Work Unit No. 2235A

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

NATIONAL TRANSPORTATION SAFETY BOARD
Washington, D. C. 20594

13. Type of Report and Period Covered

Railroad Accident Report
November 9, 1977

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

About 6:06 p.m., on November 9, 1977, 2 SD-45 locomotive units and 35 cars of Louisville & Nashville freight train No. 407 derailed when entering a 6°04' curve at Pensacola, Florida. The adjacent tank heads of the 18th and 19th cars were punctured during the derailment by a loose wheel and axle assembly; this released anhydrous ammonia into the atmosphere. Two persons died and 46 were injured as a result of the derailment, release of anhydrous ammonia, and evacuation of about 1,000 persons. Property damage was estimated to be $724,000.

The National Transportation Safety Board determines that the probable cause of this accident was the overturning of the high rail in the 6°04' curve which caused track gage to widen. The high rail tipped because it was not able to withstand the lateral forces generated by the 6-axle locomotive units because of the tight gage of the track, and the forces generated because of the placement of a lightly loaded long car and an empty short car directly behind the locomotive with large trailing tonnage. The cause of the fatalities and injuries was the release of anhydrous ammonia through punctures in the tank cars; head shields would have prevented such punctures.

17. Key Words

Railroad accident; derailment; freight trains; tank head puncture; evacuation; anhydrous ammonia; hazardous materials; track gage; track train dynamics; rail overturn.

18. Distribution Statement

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	47	MF A01 PC A03

NTSB Form 1765.2 (Rev. 9/74)

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NATIONAL TRANSPORTATION SAFETY BOARD
Washington, D.C. 20594

RAILROAD ACCIDENT REPORT

Adopted: July 20, 1978

LOUISVILLE & NASHVILLE RAILROAD COMPANY FREIGHT TRAIN DERAILMENT AT PENSACOLA, FLORIDA NOVEMBER 9, 1977

SYNOPSIS

About 6:06 p.m., on November 9, 1977, 2 SD-45 locomotive units and 35 cars of Louisville & Nashville freight train No. 407 derailed when entering a 6°04' curve at Pensacola, Florida. The adjacent tank heads of the 18th and 19th cars were punctured during the derailment by a loose wheel and axle assembly; this released anhydrous ammonia into the atmosphere. Two persons died and 46 were injured as a result of the derailment, release of anhydrous ammonia, and evacuation of about 1,000 persons. Property damage was estimated to be $724,000.

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INVESTIGATION

The Accident

About 5:31 p.m., on November 9, 1977, Louisville & Nashville Railroad Company (L&N) freight train No. 407 departed Goulding Yard, Pensacola, Florida, southbound for Chattahoochee, Florida. The train consisted of 3 SD-45 locomotive units and 127 cars, including 16 tank cars carrying anhydrous ammonia. A predeparture inspection and airbrake test at Goulding Yard disclosed no defects. The train had originated in New Orleans, Louisiana, earlier in the day.

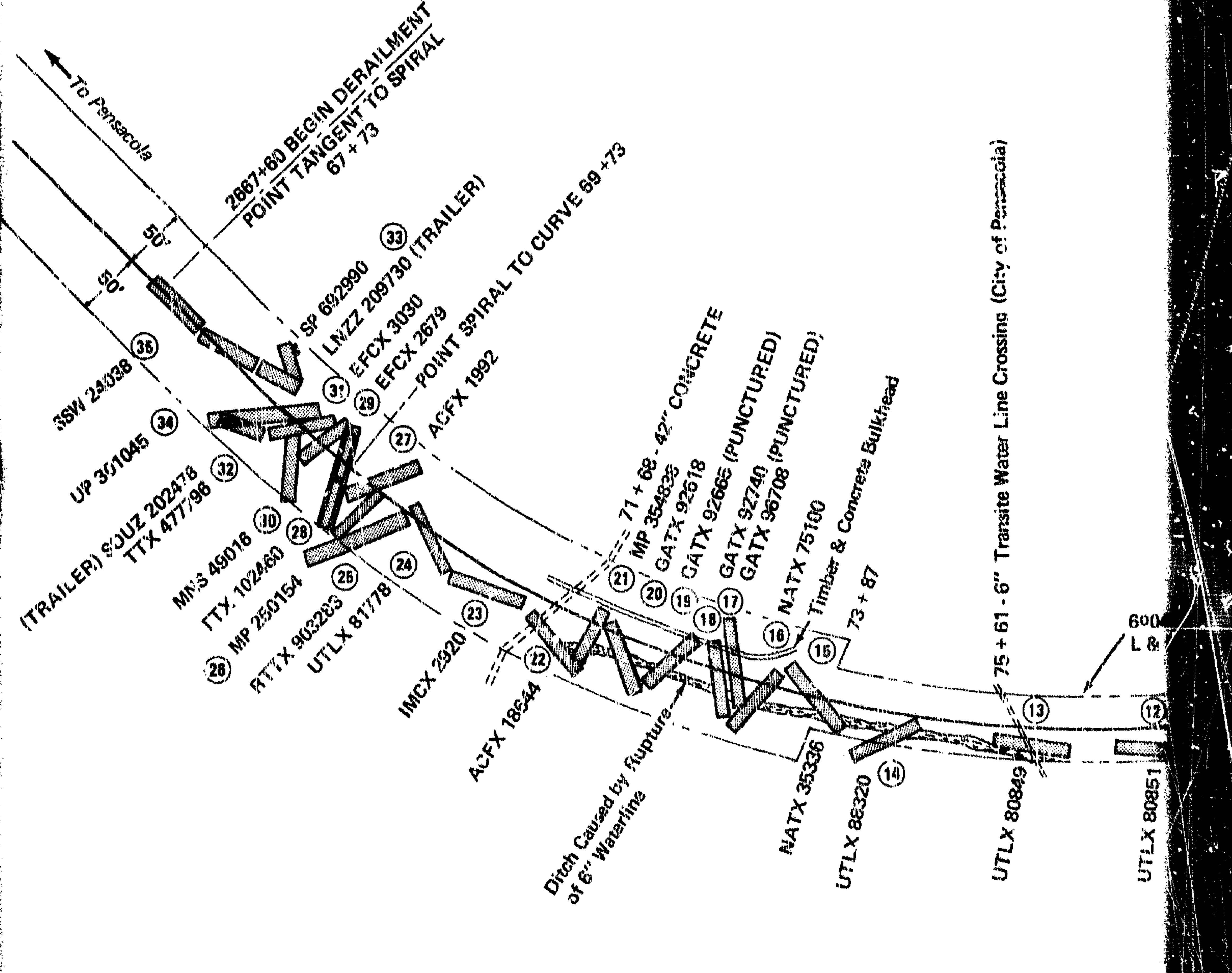
When the train was 9.5 miles south of Goulding Yard and moving at 35 mph, it entered a 6°04' curve at Gull Point, Pensacola. The engineer did not observe any defects in the track or any drainage problems as the locomotive entered and moved through the curve. However, the brakeman and reserve engineer sitting on the left side of the locomotive cab looked to the rear to visually inspect the train and saw sparks coming from under the rear locomotive units and the following seven cars just as the locomotive reached a road crossing beyond the middle of the curve. They could not see the remaining portion of the train because of a wooded area along the curve. The rear truck of the second locomotive unit, the third unit, and the following 35 cars derailed.

The engineer stated that he felt an unexpected emergency braking and reached for the brake valve, but the brakes were already in the emergency mode as a result of the derailment. The throttle was in the second power position and the ammeter was registering about 100 amperes before the derailment. However, the engineer stated that he had reduced the throttle in greater than 10-second intervals from the eighth to the second position during the 1.4 miles before entering the curve. This reduced the speed of the train from 40 mph to the required 35 mph through the curve. The brakes had not been applied on the train or locomotive since leaving Goulding Yard. The three crewmembers in the locomotive stated they did not hear or feel any unusual motions in the locomotive before the derailment.

The locomotive and cars traveled 800 feet before stopping after the emergency brake application. The conductor and flagman, who were in the caboose at the rear of the train, stated that as the train stopped they noted no slack, jerking, or buff forces in the caboose. The conductor called the engineer on the radio when the train stopped at 6:06 p.m. and was told that the train had derailed. The first two cars, a long flat car loaded with one truck trailer and an empty covered hopper car, remained upright and coupled to the locomotive. The next 11 cars were tipped but remained in line along the following 900 feet of track. The 14th through 35th cars jack-knifed and piled up within the next 700 feet. (See figure 1.)

The conductor inspected the 92 remaining cars and found no defects or derailments. The head brakeman and reserve engineer, who were inspecting the derailed portion of the train, detected the smell of ammonia and noticed a vapor cloud developing when they arrived at the 10th car; they informed the engineer by radio. The engineer radioed the Goulding yardmaster that the train was derailed and that ammonia was leaking. The lead locomotive unit was uncoupled and moved about 1/2 mile east to escape the enlarging vapor cloud. None of the crewmembers were injured in the accident.

The track roadbed follows the western shoreline of Escambia Bay in the accident area and is adjacent to Pensacola's eastern residential area. The water-level route has minimal gradients and its curvature conforms to the shoreline. At Gull Point the track curves inland through a wooded area and separates six beachside homes from the homes fronting


To Pensacola
2867+60 BEGIN DERAILMENT
POINT TANGENT TO SPIRAL
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UP 301045
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(TRAILER) SOUZ 202478
TTX 477796
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MNS 49016
28
TTX 102460
26
MP 250154
25
RTTX 903283
24
UTLX 81778
23
IMCX 2920
22
ACFX 18644
Ditch Caused by Rupture of 6" Waterline
71 + 68 - 42" CONCRETE
21
MP 354835
20
GATX 92618
19
GATX 92665 (PUNCTURED)
18
17
GATX 92740 (PUNCTURED)
GATX 36708
16
NATX 75100
Timber & Concrete Bulkhead
15
73 + 87
NATX 35336
14
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75 + 61 - 6" Transite Water Line Crossing (City of Pensacola)
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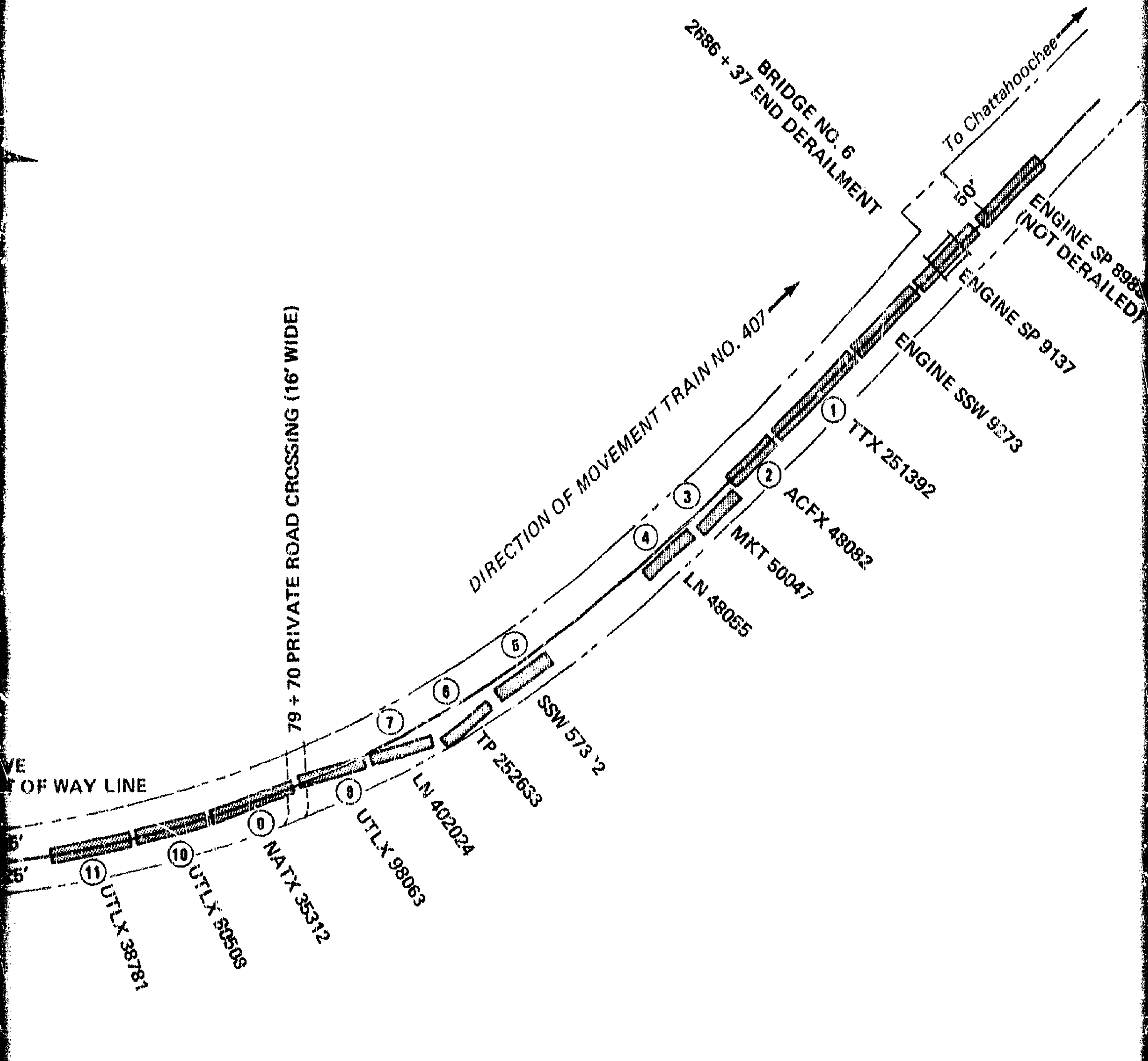
Figure 1. Pl



Accident Site

on Scenic Highway just west of the track. An extension of Creighton Road provides access to the Gull Point homes and crosses the track near the center of the curve. The ammonia vapor cloud enveloped the area. Two persons died from ammonia inhalation and 46 others were injured.

Injuries to Persons

Injuries	Crewmembers	Passengers	Other
Fatal	0	0	2 1/
Nonfatal	0	0	46
None	5	0	

Damage

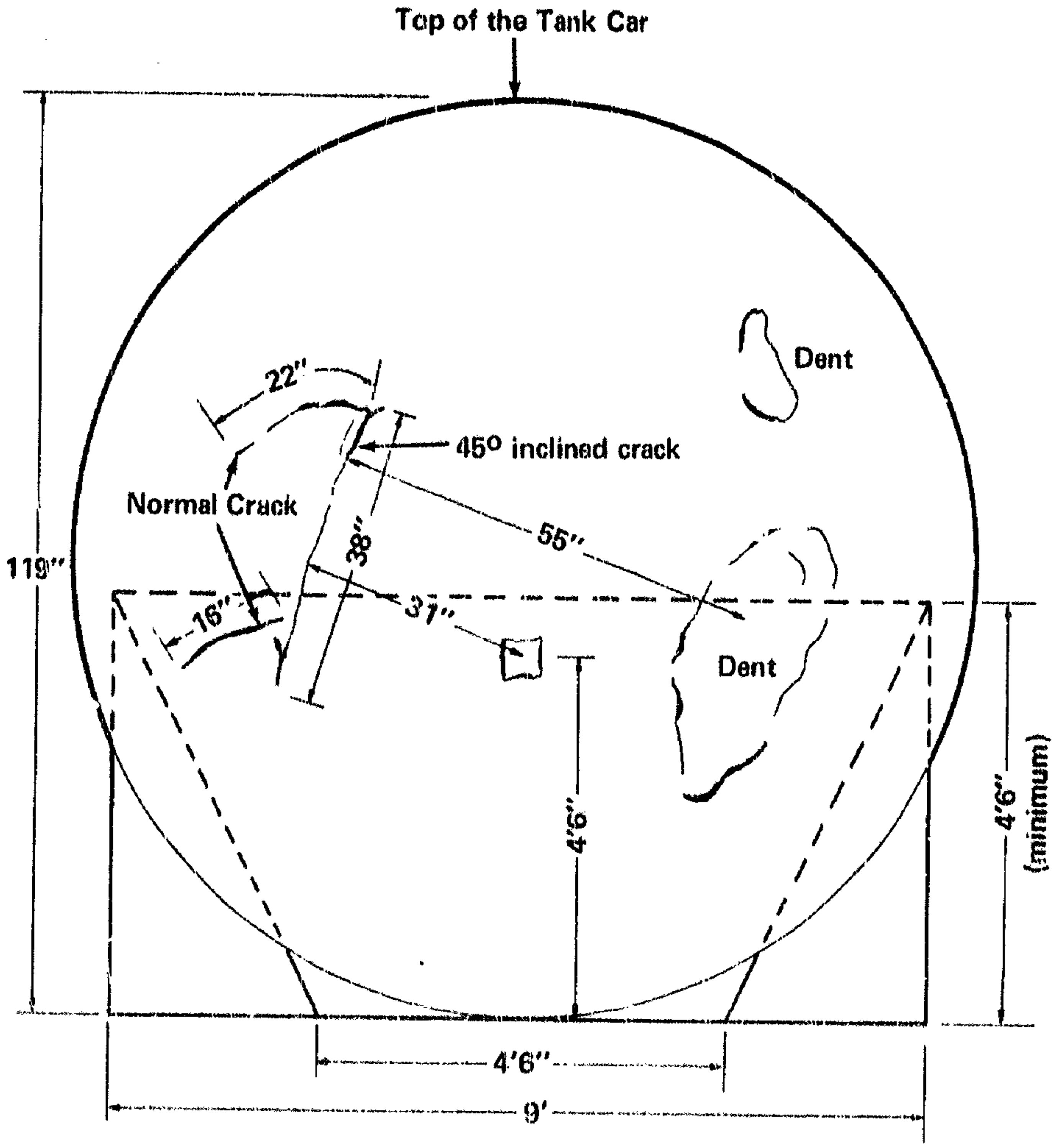
Sixteen of the 17 derailed tank cars contained anhydrous ammonia and were located between the 7th and the 28th cars. The 17th tank car contained solvent and was leaking slightly at a valve. The other derailed cars contained commodities such as feed, lumber, and automobiles. Twelve of the 35 derailed cars were destroyed and the others were heavily damaged. The 18th car was punctured on the right side near the junction of the head and shell of the tank. The puncture consisted of three parallel, 1/4-inch-wide, vertical cracks, about 6 inches apart, and located near the 4-o'clock position from the top of the tank. One 19-inch-long crack was adjacent to the weld of the head and shell. The other two cracks were 19 inches and 9 inches long respectively. The puncture of the 19th car was a 3-inch-wide by 38-inch-long tear in the leading tank head. It was located near the 10 o'clock position from the top and about 31 inches to the left of the vertical centerline. (See figure 2.)

The high rail throughout the curve was initially tipped outward within its tie plates. The low rail was initially tipped inward on its tie plates from 200 feet into the curve up to the point where the locomotive stopped. The total track structure in the first 800 feet of the curve was destroyed by the derailed cars. About 1,000 feet of the remaining track in the curve was damaged.

All trees and ground vegetation east of Scenic Highway and within 1,000 feet of the punctured tank cars were discolored and leaves withered by the ammonia vapor cloud. Birds and small wildlife were found dead within the 1,000-foot area.

Creighton Road access to the Gull Point area east of the accident site was blocked by the derailed cars. A water main crossing under the track, which provided service to the easterly Gull Point residents, was broken in the derailment.

1/ One person died 2 months after the accident as a result of her injuries.



The dashed lines show (approximately) the region which must be covered by the head shield being phased under current FRA regulations.

Figure 2. Tank car GATX 92665 head damage.

Cost of damages were estimated to be:

Equipment	$434,500
Track	30,000
Wreckage removal	24,500
Lading	235,000
Total	$724,000

Train Information

The 16 tank cars loaded with anhydrous ammonia had a capacity of about 33,500 gallons each and complied with U.S. Department of Transportation (DOT) specifications for DOT-112A340W. Twelve of the tank cars, including the two punctured cars, were provided with E-type couplers, two tank cars were provided with F-type couplers, and two cars had T&B shelf-type couplers.

When the rear block of cars in the train consist was switched at Pensacola, seven freight cars were located between the locomotive and the 16 tank cars; this arrangement complied with Federal regulations. However L&N special rules require that trains should not be assembled with empty or lightly loaded cars at or near the head end of heavy tonnage trains, and that care should be taken to prevent cars 80 feet or longer in length at the head end of heavy trains (generally more than 7,000 tons), whether loaded or empty. The L&N special rules also require that blocks of empty cars should not be assembled ahead of blocks of loaded cars anywhere in the train. However L&N management stated these special rules are only guidelines and are not enforced. (See appendix A.) These instructions also are recommended by the Association of American Railroads (AAR) under its Track Train Dynamics (TTD) program. (See appendix B.)

When train No. 407 departed Goulding Yard it did not comply with the L&N special rules or the AAR recommendations because it had a lightly loaded, 89 foot 1 inch-long flat car and an empty 50 foot 5 inch-long, covered hopper car coupled to the locomotive with a train that weighed 9,644 tons.

The locomotive consisted of three units with the following specifications:

Type	Type Truck	Truck Centers	Outside Length	Weight (pounds)
SD-45	3-axle Flexi-Coil	43 feet 6 inches	68 feet 10 inches	394,200
SD-45	3-axle Flexi-Coil	43 feet 6 inches	68 feet 10 inches	396,060
SD-45-2T	3-axle HTC	45 feet 5 inches	70 feet 8 inches	396, 160

The locomotive units were equipped with dynamic brakes, No. 26 airbrake systems, wheel slip-slide detectors, speed indicators, and radio with which the locomotive crewmembers could communicate with crewmembers on the caboose, on other trains, and with the train dispatcher or yardmaster. The locomotive units were not equipped with speed-recording or event-recording equipment.

Track Information

The track was constructed of used 132-pound rail that was manufactured from 1967 to 1973, recovered from other track locations, and shop-welded into 1,404-foot lengths. The 1,404-foot lengths were then field-welded into a continuous rail when laid in January 1975. The rail was anchored on each side of alternate crossties. The rail rested on 7 3/4-inch by 14-inch double-shoulder tie plates which were laid on 7-inch by 9-inch by 8 1/2-foot treated hardwood crossties spaced about 21 inches on centers. Four hundred and twenty of the 1,207 crossties in the accident area were replaced in 1973. The rail through the 6°04' curve was secured by two gage-side and one field-side 5/8-inch by 6-inch track spikes per tie plate. Each tie plate also was secured with an additional hold-down track spike. The track was ballasted with slag to a depth of about 10 inches under the crossties and was last surfaced and lined in 1975. The track rested upon the sandy soil subbase comprising the shoreline of Escambia Bay.

The grade of the track leading to the derailment site was level with minimal undulating grades except in the 6°04' curve where the grade became about 0.9 percent ascending for 2,000 feet before the road crossing beyond the center of the curve. The curve was designed to have a superelevation of 3 1/2 inches for an equilibrium speed of about 30 mph.

The track was maintained to meet or exceed Federal Track Safety Standards for Class 3. These standards require the railroad to inspect the track twice weekly with at least 1 calendar day interval between inspections. One of these inspections is done by the roadmaster who is responsible for the track, and the other by a subordinate employee. The inspection is performed by riding over the track at 15 to 20 mph in a hy-rail, 3/4-ton pickup truck. The inspection through the derailment area usually was made as a portion of an overall inspection of about 90 miles of main track east of Pensacola. This inspection normally took about 1 day to complete.

The track in the derailment area is part of a 50-mile section maintained by a foreman and five laborers. No work had been done on the track in the derailment area since a system gang worked on the track in 1975. Crossties in the area had not been thoroughly inspected since 1973.

In June 1977, the L&N track geometry bus was used to inspect the track, and it was determined that the track in the derailment area met Federal Class 3 geometry standards. However, the inspection did indicate that the track gage was 1/2 inch less than the standard gage of 4 feet 8 1/2 inches approaching the curve. (See appendix D.) The track also had been ultrasonically inspected for rail defects in July 1977, and no defects were noted in the derailment area. An inspection of the track had been made on the day before the derailment by representatives of the L&N and the Federal Railroad Administration (FRA); they took no exceptions to the track or right-of-way. A more intensive FRA track inspection, however, made after the derailment by walking the 4 miles of track leading to the derailment site, disclosed 16 locations with defective crosstie conditions, two defective rail conditions, and four defective drainage conditions.

Method of Operation

Trains are operated in this territory by timetable, train orders, and special instructions. The maximum authorized speed is 40 mph. The 6°04' curve at the point of derailment is restricted to 35 mph. Normal daily traffic consists of four freight trains in each direction. No passenger trains operate over this line. Traffic density over the track increased from 4.4 million gross tons per year in 1970 to 11.4 million gross tons in 1976. Length and tonnage of trains subsequently increased along with an increase in the number of cars containing hazardous materials. Anhydrous ammonia shipments to the Jacksonville, Florida, area constituted a majority of the shipments of hazardous material cars in the trains.

Six-axle locomotive units had not been used through the derailment area before May 1977.

Meteorological Information

At the time of the accident, it was dark, visibility was about 5 miles, and the temperature was about 68° F. The sky was overcast with broken clouds at 1,700 feet, and a light rain was falling. The wind was from the southwest at 3 1/2 mph, and in the following 6 hours changed to southeasterly at about 12 mph.

Medical and Pathological Information

Most of the injured persons were treated for ammonia inhalation and then released from hospitals. However, eight persons were hospitalized. When inhaled, ammonia vapor produces chemical injury to the linings of the respiratory tract. Depending on the concentration of gas in the atmosphere and the length of exposure, injury will range from irritation of the eyes, nose, and throat to blindness or death due to laryngeal or bronchial spasm and/or severe pulmonary edema.

The fatal injuries indicated an exposure to high concentrations of ammonia vapor. One man died within several hours from severe pulmonary edema, and his wife died from lung damage 2 months after the accident. Both exhibited second-degree chemical burns on exposed and unexposed portions of their bodies. Their two children recovered from their injuries and were released from the hospital within a month following the accident.

Anhydrous Ammonia Leakage

Anhydrous ammonia is a liquid which at atmospheric pressure boils at -28° F. The ammonia will remain in a liquid state when the temperature is above the boiling point if it is contained under pressure. If the pressure is removed when the temperature is above the boiling point, the liquid will be converted rapidly into a gas. When vaporized, one part by volume of the liquid becomes 877 parts by volume of gas. To conserve space, the commodity is loaded in tank cars as a liquid under pressure. If, after the ammonia is loaded, the temperature rises, some of the liquid will be converted to a gas which will increase the pressure within the tank and maintain the remainder of the commodity in the liquid state. When the ambient temperature reaches 68° F, as it was on the day of the accident, the pressure necessary to retain the anhydrous ammonia as a liquid in the tank is about 90 pounds psi.

When the two tank cars were punctured, the pressure within each tank caused the anhydrous ammonia to vent and vaporize. Within 10 minutes, about 50 percent of the contents of the 19th car quickly vaporized into the atmosphere. The contents of the 18th car slowly vaporized during the following 12 hours.

Survival Aspects

Because of the position of the puncture in the head of the 19th car, the escaping vapor was directed toward a nearby house on the west side of the track. The vapor cloud which quickly formed soon extended west to the Scenic Highway and north to Creighton Road. The concentrated cloud of ammonia vapor was held near the ground by the canopy created by trees in the surrounding woods, the light rain, and a light wind blowing from the southwest. Consequently, the cloud enlarged to the east or bay side of the track and engulfed six homes on Gull Point; 15 persons were in the homes.

A resident notified the Pensacola Police Department (PPD) of the derailment about 6:07 p.m. Members of the police and fire departments arrived at the scene about 6:13 p.m. The rescue personnel proceeded immediately toward the wreckage with breathing apparatus to locate the conductor and waybills. After finding the conductor with the waybills, they quickly ascertained the number and location of the anhydrous ammonia cars in the train. The Pensacola Pre-Fire Plan for Railroad Disasters which had been adopted following three other hazardous material accidents was put into effect at 6:30 p.m. The firechief subsequently ordered the evacuation of about 500 persons within a 3,500-foot radius, following information given in the DOT Emergency Action Spill guidelines. The Escambia County and Santa Rosa County civil defense officers were also advised of the cloud's movement and subsequently evacuated about 500 more persons living within the cloud's path. The firechief also requested the assistance of Air Products and Chemicals, Inc., located in Pensacola. A seven-man emergency team equipped with protective equipment was dispatched by the company and arrived at 6:45 p.m. They provided technical assistance.

The escaping vapor was restrained by spraying the punctured areas of the two tank cars with a fog-type water spray. This spray reduced the vapor cloud's size by about 30 percent. Water was then cautiously pumped through the dome of the 18th car to dilute the ammonia. It was continued until the following morning when only a 30-percent solution remained in the car with minimal escaping vapors.

The air traffic controller at the Pensacola Airport first observed the ammonia cloud formation on radar about 6:10 p.m. It appeared to be about 1 mile in diameter and about 125 feet high in the vicinity of Gull Point. He continued to observe the cloud as it moved in a northeast direction over Escambia Bay and into Santa Rosa County. The cloud traveled almost 15 miles and was seen on radar for about 1 hour before it faded. (See figure 3.) The controller detoured aircraft traffic away from the cloud and kept the Pensacola civil defense command post apprised of its progress.

The occupants of a nearby home on the west side of the track apparently tried to escape in a truck when their home was engulfed by the ammonia cloud. Firemen found the four persons lying in their front yard, critically injured. The ignition switch of the truck was found in the on position.

One motorist driving north on Scenic Highway observed the white fog across the road. He thought the cloud was from a brush fire or fog from Escambia Bay and attempted to drive through. However, poor visibility within the dense cloud caused him to drive off the road. He ran from his car when he smelled the ammonia and was rescued by a following motorist who took him to a nearby hospital for emergency treatment.

The Gull Point residents on the east side of the track saw the dense fog seeping into their homes through open windows. They took various protective measures such as closing windows, placing towels in door and window cracks, and remained inside, breathing through wet towels until help arrived. These residents, some reluctantly, were evacuated after 45 minutes by either helicopter or emergency rescue personnel. The rescue personnel shared their breathing equipment with the residents during the evacuation. This resulted in minor injuries to rescue personnel and the residents when the insufficient air supply was exhausted.

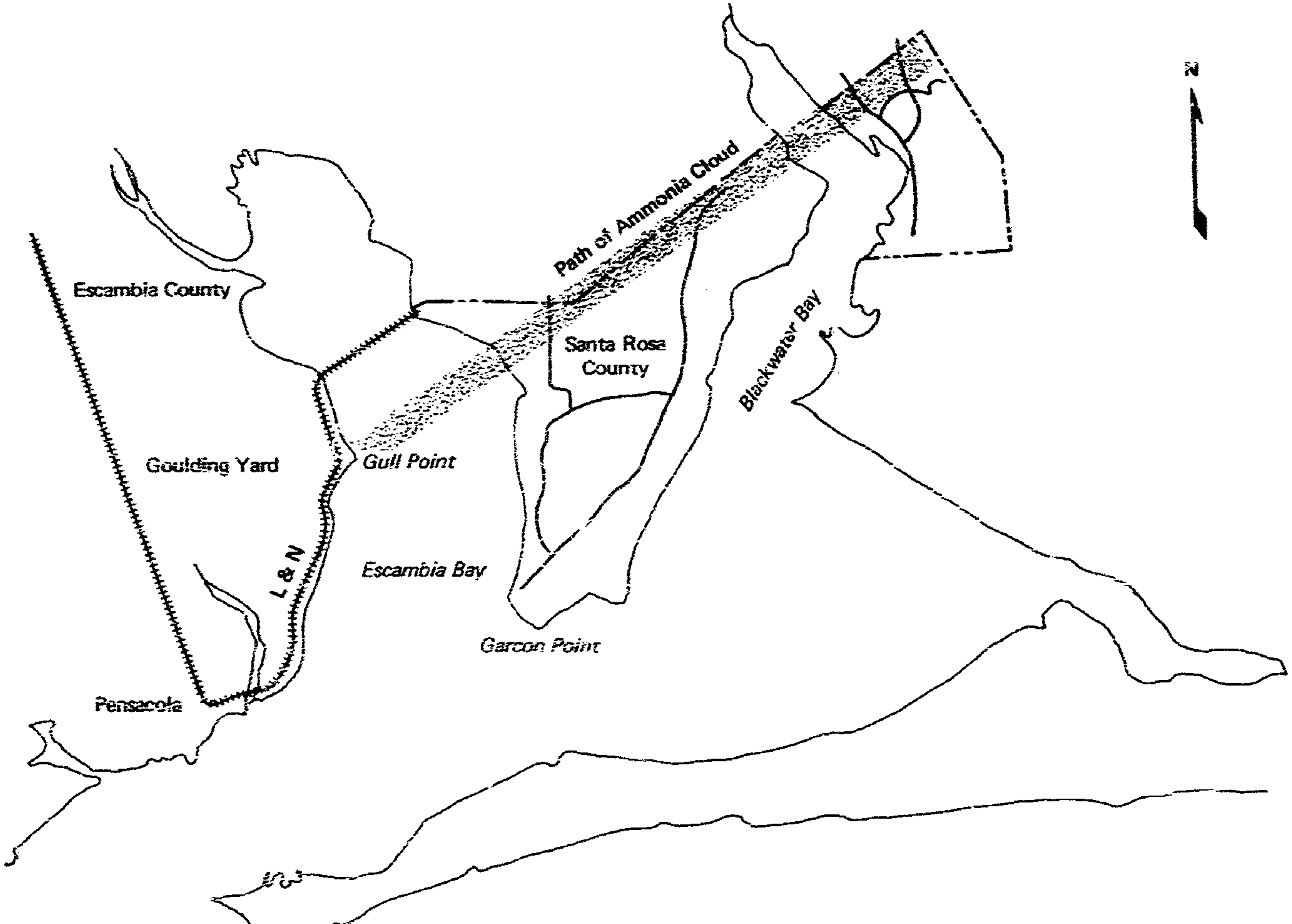


Figure 3. PATH OF AMMONIA CLOUD

A rescue helicopter was dispatched from a Pensacola hospital. The pilot stated that he had no communication with the command post or rescue personnel but only by radio telephone with the hospital dispatcher. He observed people on the beach at Gull Point as the cloud moved northeasterly over the bay. He made four trips to evacuate them.

During the afternoon of November 10, 1977, evacuees who lived west of Scenic Highway and more than 1,000 feet from the derailment site were allowed to return to their homes. On November 12, 1977, these persons were again evacuated because of possible puncture or rupture of the tank cars while they were being rerailed. All evacuees were allowed to return to their homes on November 13, 1977.

Tests and Research

A mechanical inspection and airbrake test of train No. 407's 92 remaining cars made immediately after the accident and later at Goulding Yard disclosed no defects. An inspection of the 35 derailed cars disclosed no defects that would have contributed to the derailment.

The three locomotive units were inspected shortly after the accident and later at the railroad's shop in Louisville, Kentucky. The speedometer in the lead unit was tested and found to be working properly. All locomotive measurements were within design specifications and tolerances, and no defective conditions that contributed to the accident were found. The first unit and the front truck of the second unit did not have signs of derailment. The rear truck of the second unit and both trucks of the third unit contained numerous indications of derailment. The back-to-back measurements of the Nos. 4-, 5-, and 6-wheel sets of the derailed truck of the second unit were 53 3/8 inches, the maximum allowed, and the total uncontrolled lateral motion varied from 1/2 inch to 29/32 inch. This was less than the 1-inch maximum allowed by Federal Standard 49 CFR 230.220. (See appendix C.) Both trucks of the third unit had derailed similarly to the rear truck of the second unit. Both snowplow-type pilots on the third unit and the similar rear pilot of the second unit had railhead-size indentations.

Measurements of 300 feet of the track structure on each side of the destroyed track disclosed that the gage varied from 1/2 inch less to 1/8 inch less than standard approaching and entering the curve. The gage varied from 1/8 inch less to 3/8 inch more than standard in the curve beyond the destroyed track. One inch of the 3 3/4-inch average elevation of the high rail in the curve was run off on the approaching tangent track. Consequently, cross level of the south rail on tangent track increased from zero to about 1-inch high for 100 feet ending at the beginning of the spiral to the curve. (See appendix D.) L&N Maintenance of Way rule 171 states, "In no case will it be permissible to run the elevation out on the tangent." (See appendix A.) Federal Track Safety Standard 49 CFR 213.59(b), however, permits runoff on the tangent. (See appendix C.)

An inspection of the undestroyed crossties did not disclose any defective conditions, nor did they exhibit any evidence of lateral tie plate movement. The condition of the destroyed crossties before the derailment could not be determined. Rail tipping occurred within the tie plate shoulders. All broken rails, including a piece of 131-pound rail which contained a longitudinal fracture about 15 feet 5 inches through the web, were found to have broken under stress from the derailment and no internal defects were evident. Wheel flange marks were evident on the lower gage corner and inside web of the high rail in the spiral of the curve. Locomotive truck side scrape marks began on the low rail about 200 feet into the curve.

An examination of the subgrade and ballast was complicated by the saturation of the roadbed with water from the broken water main and water sprayed on the leaking tank cars. However, no lateral displacement of the roadbed or of the crossties within the ballast was noted. Inspection of the culvert under the track in the derailment area, along with an inspection of drainage in the area, did not disclose any adverse effects.

Other Information

The L&N stated that about November 30, 1977, it had implemented a computer program which showed hazardous material information on its train consist sheets and waybills. This program provides train crewmembers with information on the hazardous materials in their trains, and also makes the information available to emergency personnel responding to an accident.

ANALYSIS

Derailment

The removal and addition of cars to the rear of train No. 407 at Goulding Yard was a continuation of the same type of train makeup done earlier at New Orleans known as "destination blocking." Railroad yards switch together cars, regardless of whether they are loaded or empty, that are destined for a particular delivery point. When a train is made up, these groups of cars are coupled together in blocks. This blocking of cars facilitates their removal when the train arrives at stations en route. One major problem confronting this type of train makeup is potentially the undesirable distribution of weight or the undesirable placement of long and short cars.

Since the L&N's special rules covering train handling are considered only as guidelines provided to train crewmembers and are not enforced by L&N supervisors, the train, when assembled in New Orleans and later switched in Pensacola, was not required to be assembled according to recent AAR and L&N guidelines. These "you may or may not" company procedures circumvent and render useless the special rules and pertinent AAR recommendations.

Assuming the engineer handled the train as he recollected after leaving Goulding Yard, when he reduced its speed from 40 to 35 mph for the speed restriction through the 6°04' curve at Gull Point, the slack in the train would have been stretched on the locomotive and the lead 5 to 10 cars when the head portion of the train ascended the 0.9-percent grade. The 17 tank cars would have undergone slack adjustments as the locomotive entered the curve. The remaining cars would have drifted with slack adjustments occurring commensurate with the undulating terrain over which they were traveling. However, in order to verify the engineer's testimony and to determine the actions actually taking place within the train, an "events recorder" on the locomotive is necesary. The Safety Board pointed out to the FRA the need for event recorders in its report on the Derailment of Illinois Central Railroad Company Train Second . , at Glendora, Mississippi, on September 11, 1969, (NTSB-RAR-70-2) and in its Special Study, "Train Accidents Attributed to the 'Negiligence of Employees,'" (NTSB-RSS-72-1). In response, the FRA advised that a study would be conducted at the Transportation Test Center to develop the needed information. A Federal requirement for event recorders has not yet been established, however.

As the train entered the curve, a lateral force would have been applied constantly against the high rail. This centrifugal force was due to the train moving at 35 mph, about 5 mph over equilibrium speed for the 3 3/4-inch superelevation of the curve.

In curve negotiation the lead wheel of the truck bears against the outside rail and the trailing wheels are restrained by the inside rail. The wheel and axle assemblies can shift relative to one another because of the lateral freedom of motion built into equipment trucks. The lateral freedom of each axle on train No. 407's locomotive was less than the 1-inch maximum tolerance allowed per Federal standard 49 CFR 230.220. However, the Federal standard is directed to only trucks in general and makes no mention of multiple-axle trucks. In addition, the railroad industry and suppliers have not developed corresponding maximum curvature figures for multiple-axle trucks when the gage of track in curves is reduced 1/2 inch less than standard as allowed by Federal standards and which was found in the 6°04' curve at Gull Point. This indicates that the locomotive trucks of train No. 407 would have been applying excessive lateral flange and frictional forces (binding) on both rails as it moved around the 6°04' curve.

The measurements of the locomotive wheels indicated that there would have been reduced free play between rail and wheels by about 15/16 inch at locations of 1/2 inch less than standard track gage and would have required the wheels to ride progressively higher on the fillet curve of their flanges. The area of contact thereby would have been increased, resulting in a higher value of curve resistance.

The forces generated by trains in moving around curves are transmitted from the wheel to the rail and can be divided into lateral and vertical components. The vertical (V) forces tend to hold the wheel over the rail while the lateral (L) forces tend to shove the wheel over the rail or move the rail laterally. The relationship of these two forces is referred to as the "L/V ratio."

As the wheels of the locomotive of train No. 407 moved toward the outside rail of the 6°04' curve, the fillet curve of each flange bore on the gage corner of the worn rail. As the wheels moved into the 1/2-inch, tight gage location, there was little or no space between the wheel flange and rail. Consequently, the wheel lifted slightly off the rail and began bearing at the gage corner. This would have caused the lateral and vertical forces to act as a single angular force on the rail. With the lateral forces increasing because of truck binding and rail wheel climb, the angular force would be directed beyond the outside edge of the rail base creating rail tipping.

As the long flat car and shorter empty hopper car began to enter the curve, their wheels and trucks would have reacted to the tight track gage as the wheels and trucks of the locomotive did. However, since these cars were being pulled by the locomotive and restrained by the following cars, their trucks were forced against the low rail with their drawbars in a stretched position. With the flat car already against the low rail, the lead wheels of each truck would have exerted an angle of attack force because of binding against the high rail with very little vertical force. The duration of this binding force would have become constant as the flat car entered the curve, and would have remained until the trailing tonnage caused a buff condition, or track gage adequately widened. Any slowing of the locomotive because of throttle reduction, increase in grade of the track, and increase in track curvature such as encountered at Gull Point would have created a buff condition on the flat car and hopper car. This buff condition would have changed the coupler angles on the flat car which would have transmitted an increase in lateral force to the high rail while the car was exerting very little vertical force. This additional lateral force behind the locomotive would have further increased rail tipping and turnover.

The tipping of the high rail widened the track gage and the locomotive and flat car wheels dropped off the low rail inside of gage. As the locomotive wheels dropped off the low rail, the truck side frame and bolts caught the field side of the low rail and caused it to tip inward. The wheel flange marks found on the gage corner and web of the high rail in the spiral and the bolt scraping marks found on the field side of the low rail beginning about 200 feet into the curve, indicate these were the initial areas of rail tipping and derailment. As the following cars derailed at this location and their wheel flanges began riding on the web of the outward tipped high rail, sparks developed which were seen by the crewmembers when the locomotive reached the road crossing beyond the center of the curve.

The FRA track inspection after the derailment enabled the inspectors to find the tight-gage track conditions, which apparently were not detectable from a moving hy-rail inspection vehicle. Consequently, the L&N track inspectors also were not able to determine the defective track conditions found during the intensive track inspection after the derailment by only using a hy-rail vehicle through the derailment area. The L&N geometry bus inspection in June 1977 indicated track gage and cross level conditions that did not conform with L&N track standards. However, apparently no action was taken following these inspections to determine if the gage conditions could become critical. These inspections and conditions indicate that the track was not maintained in all areas to Federal Class 3 standards. With the operation of 6-axle locomotive units, any deteriorated track conditions through a location with both tight gage and possibly poor crossties would have created a potential derailment situation.

Hazardous Materials

All of the serious injuries and most of the damage resulted from the abrupt release of the ammonia from the punctured head of the 19th tank car. A lethal cloud engulfed the Gull Point area within minutes and before the residents could evacuate their homes. Rescue personnel did not know the condition, number, and location of the Gull Point residents until search teams swept the area covered by fog and darkness. Because no one present was aware of the ability of the dwellings to protect the occupants, all victims, when found, were escorted on foot a distance of 200 to 1,000 feet through the ammonia cloud and out of the affected area. Accounts by rescue personnel indicate that a breathable and survivable atmosphere (i.e., a low concentration of ammonia vapors) was maintained in the six homes by the 15 Gull Point residents. This was most likely due to the residents securing the interiors of their homes by closing doors and windows and stuffing towels in openings under doors and around windows.

Some of the residents were reluctant to leave their homes when rescue personnel arrived and be exposed to the toxic atmosphere outside. The minor injuries sustained by these residents were due in part to their prolonged exposure to the ammonia vapor after they were taken outside by rescue personnel into the ammonia cloud without sufficient breathing equipment. Since the evacuation of the residents began at least 30 minutes after the initial cloud formation, lower concentrations of ammonia were present because of vapor cloud dispersion and a reduction in vapor production from the tank cars.

Survivability was enhanced by those individuals exposed to the ammonia vapors who breathed through a damp cloth. The damp cloth filtered out the aerosolized particles in the air. The anhydrous ammonia's attraction to water further diluted the concentrations reaching the sensitive tissues of eyes, nose, throat, and lungs.

Following the impact of the unprotected tank head of the 19th car with a wheel flange, about half of the tank's pressure vented through a 3-inch-wide puncture until the liquid level dropped below the breach. A head shield would have prevented or reduced the size of the head puncture because a shield would have retarded the puncturing wheel. A smaller puncture would have reduced the release rate of the escaping ammonia and the size of the danger zone. If the cars had been equipped with top and bottom shelf couplers, the cars might have stayed in line, reducing the probability of puncture, particularly from the loose wheel and axle assembly.

The developing heavy dense ammonia fog deposited ammonium hydroxide particulates on exposed surfaces as the wind carried this fog over Escambia Bay. This cloud migrated as a single puff of fine ammonium hydroxide droplets with the prevailing wind speed across the bay, reaching landfall 4 miles eastward in Santa Rosa County, a sparsely populated area. The ammonium hydroxide in this cloud enabled the airport radar to track the migration across the bay; otherwise, ammonia could not have been observed on the radar screen. Within 60 minutes the cloud of ammonium hydroxide traveled 4 miles over the bay and 5 miles over land in Santa Rosa County, before dissipating. The wind direction kept the number of injuries low; an eastern wind would have blown the lethal cloud through a heavily populated urban area of Pensacola.

After the escaping ammonia from two tank cars was brought under control by the fire department, with aid from the private emergency team, the danger of potential puncture of the 15 other hazardous material tank cars remained. The derailed tank cars were stressed, and the threat of additional breaching of tanks and release of anhydrous ammonia existed during the entire rerailing operation. If the flammable liquid tank car which was found to be leaking slightly had ignited accidentally during the rescue, the nature of the emergency would have changed completely.

The local public safety personnel reacted promptly and effectively to the emergency because of their development of an emergency plan and their experience with similar accidents. However, several developments during this emergency indicate a need for emergency response personnel in Pensacola to review their Pre-Fire Plan for Railroad Disasters. The plan should consider ways to inform threatened residents of the most effective means to protect themselves; ways to enable rescue personnel in aircraft ov r a derailment site to communicate directly with emergency ground personnel; and ways to determine the size of the evacuation area without relying solely on the suggested area in the DOT Emergency Action Spill guide, since the potential danger zone in this accident eventually covered 9 miles, considerably beyond the DOT guideline's prediction of less than a mile.

CONCLUSIONS

Findings

1. Since the locomotive was not equipped with an "event recorder," the determination of train actions and forces as it approached the derailment point was limited to the recollection of the locomotive engineer.

2. The placement of the empty and lightly loaded cars at the head end of the heavy tonnage train did not comply with L&N special rules governing train handling or AAR Track Train Dynamic recommendations.

3. The tight gage and elevation run-off on tangent track entering the curve preceding the derailment point were acceptable by the Federal Track Safety Standards but not L&N track maintenance rules.

4. Consistent hy-rail vehicle inspection of the track through the derailment area without recent interim walking inspections precluded the inspectors' determining any adverse track effects because of the recent use of 6-axle locomotive units.

5. Postaccident inspection of train No. 407's locomotive and cars did not reveal any mechanical defects that contributed to the cause of the derailment.

6. The broken rails found at the derailment site were a result of the derailment.

7. Defective track conditions found during postaccident inspections of the track leading to the derailment site indicate that the track was not maintained in all areas to Federal Class 3 standards.

8. Locomotive truck side bolt marks found on the field side of the low railhead about 200 feet into the curve, and wheel flange marks on the lower gage corner of the high rail in the spiral indicates an initial high rail tipping in the spiral and a derailment point 200 feet into the curve.

9. The tight gage in the track caused an increase in the L/V ratio and rail tipping because of greater than normal wheel to rail lateral forces as the 6-axle locomotive units entered the 6°04' curve.

10. The large trailing tonnage caused an additional increase in the L/V ratio and rail turnover because of the placement of the long, lightly loaded flat car and empty hopper car directly behind the locomotive.

11. If the punctured tank cars had been equipped with head shields and T&B shelf couplers the punctures may have been averted and the severity of the accident reduced.

12. The local public safety personnel reacted promptly and effectively to the anhydrous ammonia emergency because of their development of an emergency plan and prior accident experiences.

13. Current DOT hazardous material guidelines for handling an emergency lack adequate information on how to determine the potential danger zone of exposure to the released hazardous materials.

Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the overturning of the high rail in the 6°04' curve which caused track gage to widen. The high rail tipped because it was not able to withstand the lateral forces generated by the 6-axle locomotive units because of the tight gage of the track, and the forces generated because of the placement of a lightly loaded long car and an empty short car directly behind the locomotive with large trailing tonnage. The cause of the fatalities and injuries was the release of anhydrous ammonia through punctures in the tank cars; head shields would have prevented such punctures.

RECOMMENDATIONS

As a result of its investigation of this accident, the National Transportation Safety Board recommended that the Federal Railroad Administration:

"Include in its review of the current FRA track safety standards, investigation and testing to determine if the 4-foot 8-inch minimum gage allowed in curved track according to 49 CFR 213.53 is appropriate for 6-axle locomotive units and cars. (Class II, Priority Action) (R-78-43)

"Promulgate regulations to require locomotives used in trains on main tracks outside of yard limits to be equipped with operating event recorders. (Class II, Priority Action) (R-78-44)

"Investigate and test to determine the adequacy of the total uncontrolled lateral motion allowed in 49 CFR 230.220 when related to lateral forces developed on rails by 6-axle locomotive units or by 6-axle cars in curves of more than 2°. (Class II, Priority Action) (R-78-45)

"Promulgate regulations to require railroads to limit the length and tonnage of trains carrying hazardous materials to train makeup principles developed under the track train dynamic program. (Class II, Priority Action) (R-78-46)

"Promulgate regulations to require railroads to provide pertinent hazardous materials emergency information on waybills and to make this information available to public emergency personnel. (Class II, Priority Action) (R-76-47)"

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JAMES B. KING
Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ PHILIP A. HOGUE
Member

/s/ ELWOOD T. DRIVER
Member

July 20, 1978

APPENDIX A

Excerpts from Louisville & Nashville
Special Rules and Rules and Instructions

Louisville and Nashville Railroad Company

SPECIAL RULES

Governing Train Handling, Air Brakes And Dynamic Brakes

LOUISVILLE AND NASHVILLE
RAILROAD COMPANY

RULES AND REGULATIONS

Governing Train Handling, Air Brake and Dynamic Brake.

Effective April 1, 1975

Approved
C. N. Wiggins, Vice-President, Operations

The rules and instructions set forth in this manual govern employees of the Louisville and Nashville Railroad Co. whose duties require they be familiar with train handling, air brakes, dynamic brake, and their related operation.

This manual must not be defaced in any manner and must be kept up to date as replacement instructions are issued. This manual must be readily accessible while on duty.

W. A. Rice,
System General Road Foreman of Engines

x x x x x

9. PRECAUTIONS:

(a) Know your railroad.

(b) Know your equipment.

(c) Know where your train is on the railroad.

(d) Know where the TRAIN SLACK is and ADJUST ACCORDINGLY.

(e) APPLY DYNAMIC BRAKE GENTLY AND SMOOTHLY.

(f) Watch the load METER (Amperage Gauge).

(g) Use good judgment and apply dynamic brake gradually and do not use high retardation amperage as it will cause a lightly loaded or empty car to be lifted off its trucks.

(h) Trains should not be assembled with empty or lightly loaded cars at or near the head-end of heavy tonnage trains.

(i) Care should be taken to prevent cars 80 feet or longer at the head-end of heavy trains whether loaded or empty; or blocks of empty cars assembled ahead of blocks of loaded cars anywhere in the train.

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APPENDIX A

L&N

RULES and INSTRUCTIONS

of the

MAINTENANCE OF WAY DEPARTMENT

Effective July 1, 1967
Revised February 1, 1974
Revised March 1, 1975
Revised August 1, 1977

158. Spiral Curves—The curvature of a spiral curve begins at nothing at the tangent and increases gradually until it connects with the regular curve. The ending points of regular curve shall be indicated by a marker with the full elevation shown thereon. Where practical, spiral length shall be provided on the basis of not less than 78 feet for each inch of elevation

Gage of Track

160. Standard Gage—The gage of track is the distance between the heads of the rails, measured at right angles thereto, at a point five-eighths (⅝) inch below the top of the rail.

The standard gage of track is 4 feet 8½ inches. Straight track must be put to standard gage.

The gage will be restored, when it varies from standard by one-half (½) inch.

170. **Maximum Elevation**–No curve shall be elevated more than four (4) inches.

171. **Run-Off**–The elevation specified for a curve will be used throughout the simple curve between the ends of spirals, and should be run off, as gradually as possible, starting with full elevation at the end of the simple curve (where full curvature exists) and decreasing uniformly until zero elevation is reached (at zero curvature). Where possible, without decreasing the elevation at a rate greater than 1" in 78', the rate of runoff should be so that zero elevation is reached where zero curvature is reached. If the spiral is too short to run the entire elevation off on it at the rate of not more than 1" in 78', the runoff rate may be increased to as much as 1" in 62'. In no case will it be permissible to run the elevation out on the tangent. If local conditions will not permit a runoff to comply with the above provisions, the Division Engineer must be notified so that he may revise the length of spiral or specified elecvation, which may require a change in authorized speed.

APPENDIX B

Excerpts from Association of American Railroad Track Train Dynamics Program and Report

3.2.4 LONG CAR - SHORT CAR COMBINATIONS

Figure 12 illustrates the geometry of a long car - short car combination. Note the coupler angularity of the long car. It also illustrates the lateral forces produced by a 100,000 lb. drawbar force. When the coupler angle of the short car is 7 degrees the lateral force is 12,190 lbs. When the coupler angle is 13°28' the lateral force is 23,150 lbs.

High lateral forces may cause derailments when track shift, rail turnover, wheel climb, or wheel lift occurs. Research indicates that when the theoretical ratio of lateral force (L) to vertical force (V), the 'L/V Ratio', reaches certain critical limits, there is the danger of an impending derailment. These values are:

1. 0.64 (unrestrained rail may overturn)
2. 0.75 (flange may climb worn rail)
3. 0.82 (wheel may lift disengaging flange)
4. 1.29 (flange may climb new rail)

Note: All the above values are time dependent occurrences. The normally accepted value for significant events, such as impending derailment situations, is now considered to be 0.3 of a second. However, these time dependent occurrences will be further substantiated by other research in the Track-Train Dynamics Program.

Vertical wheel forces are affected by car weight, speed, track curvature and superelevation. Research is incomplete on the relationship between speed and superelevation, and the lateral forces produced by long car - short car combinations. The lateral forces on a truck of an empty car weighing 40,000 lbs. corresponding to the critical L/V ratios mentioned above are:

1. 12,800 lbs. (unrestrained rail may overturn)
2. 15,000 lbs. (flange may climb worn rail)
3. 16,400 lbs. (wheel may lift disengaging flange)
4. 25,800 lbs. (flange may climb new rail)

The lateral forces on a truck of an empty car weighing 67,000 lbs. (33.5 tons) corresponding to the critical L/V ratios are:

1. 21,400 lbs. (unrestrained rail may overturn)
2. 25,100 lbs. (flange may climb worn rail)
3. 27,500 lbs. (wheel may lift disengaging flange)
4. 43,200 lbs. (flange may climb new rail)

Available research data has indicated that the lateral force produced by a drawbar reaction (draft) at a long car (89 ft. in length, having a 43 inch coupler) approaches a maximum when coupled to a short car (50 ft. or less in length, having a 33 inch coupler).

WITH 100,000 LBS. DRAWBAR FORCE

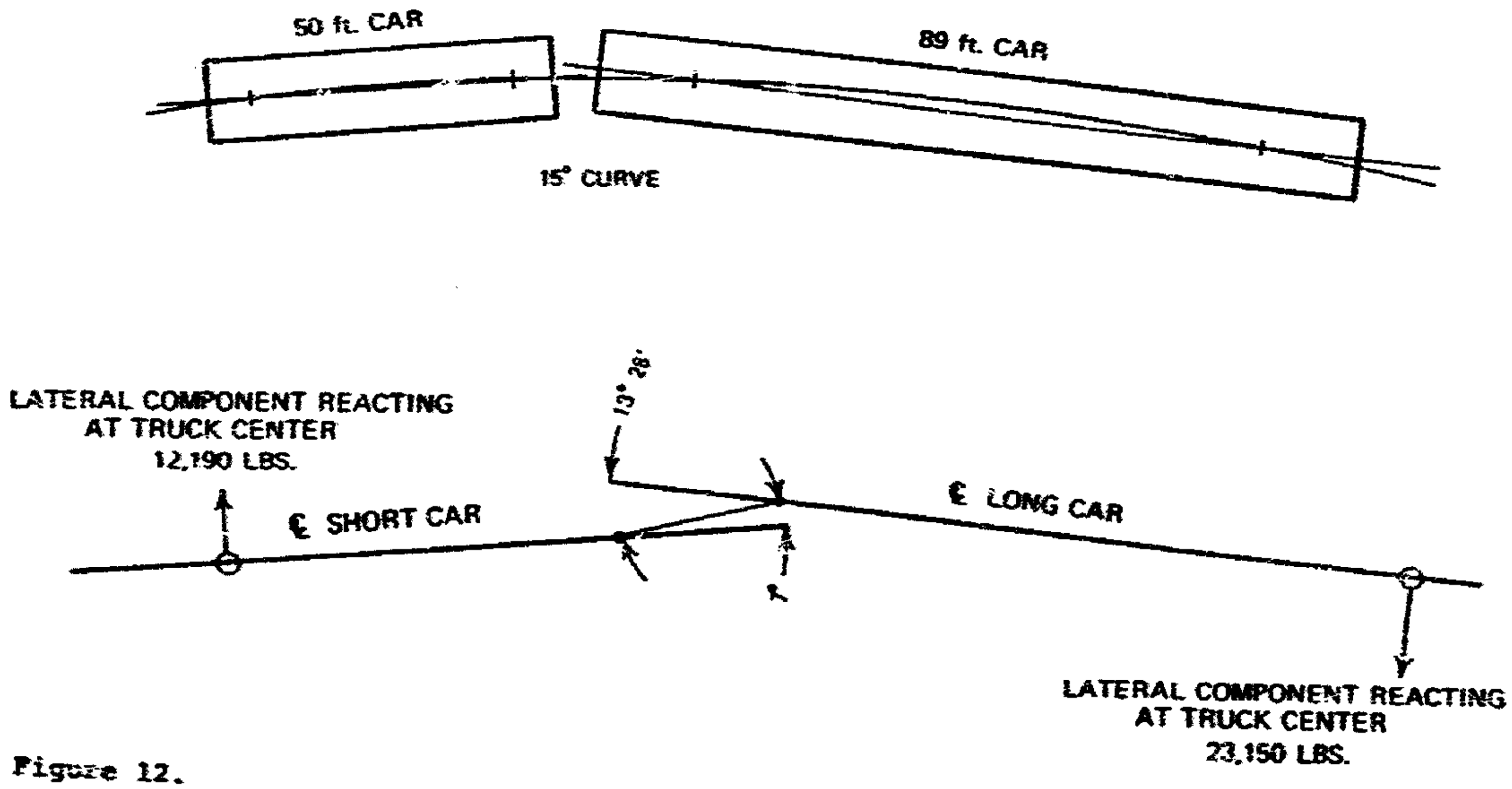

Figure 12.

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Table 3 shows the steady-state drawbar forces that will produce critical lateral forces for long - short car combinations for various degrees of curvature for a car weight of 33.5 tons.

TABLE 3

Derailment Condition	Unrestrained Rail May Overturn	Flange May Climb Worn Rail	Wheel May Lift Disengaging Flange
Critical L/V Ratio	0.64*	0.75	0.82
Critical Lateral Force	21,440 lbs.	25,125 lbs.	27,470 lbs.
Degree of Curvature	When Drawbar Forces Exceeds:	When Drawbar Forces Exceed:	When Drawbar Forces Exceed:
4°	300,000 lbs.	300,000 lbs.	300,000 lbs.
6°	205,000 "	240,000 "	262,000 "
8°	154,000 "	180,000 "	197,000 "
10°	123,000 "	144,000 "	158,000 "
12°	103,000 "	122,000 "	132,000 "
14°	88,000 "	103,000 "	113,000 "
16°	77,000 "	91,000 "	99,000 "

*Based upon the overturning characteristics of a rail and neglecting the torsional resistance produced by a heavier car both preceding and trailing the light car.

(3-7) *THOSE WHO ARE RESPONSIBLE FOR THE MAKE UP OF TRAINS SHOULD BE AWARE THAT HIGH L/V RATIOS CAN BE DEVELOPED WHEN CARS OF 86 FEET OR LONGER ARE COUPLED WITH CARS OF LESS THAN 50 FEET IN LENGTH.*

Many railroads tend to limit the drawbar pull of the locomotive(s) to 250,000 lbs. or less by limiting the tractive effort in the locomotive consists.

Most of the very high drawbar forces are experienced when heavy trains are ascending or descending those ruling grades that limit the maximum train tonnage. The three principal factors that are involved in the problems associated with the make-up of long car - short car combinations in the train are:

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1. Weight of the train trailing the long car - short combinations.

2. Effective grade beneath the segments of the train trailing the long car - short car combinations.

3. Degree of curvature being traversed by the long car - short car combinations.

The grade and degree of curvature are fixed characteristics of the particular route. The placement of long car - short car combinations in a train should vary depending upon the trailing tonnage.

For the suggested maximum allowable tonnage to trail an empty long car, which may be used by terminal operating personnel to govern their train make-up procedures, see Table 4.

When considering the placement of long car - short car combinations ahead of helper engines, the tonnage and the effective grade under the cars preceding the helper must be considered. The allowable steady-state drawbar forces (buff) because of increased coupler angularity, are approximately 20% higher than draft forces in a given degree of curvature. See Table 5.

Tables 4 and 5 do not take into consideration speed or superelevation for trains negotiating curves. However, if the speed and superelevation are in equilibrium, or reasonably close, the guideline table can be effectively used. If speed is significantly different than the equilibrium speed, a further reduction in trailing tonnage for long car - short car combinations must be made.

APPENDIX B

TABLE 4 Guideline Tonnage to Trail An 85 Ft. Empty Car in Draft

Sharpness of Curve		4°	6°	8°	10°	12°	14°	16°
Maximum Safe Drawbar Force (lbs.)		250,000	190,000	140,000	110,000	90,000	77,500	67,000
Steepness Of Grade	Drawbar Force/ Trailing Ton							
0.2%	10.1	24,700	18,800	13,800	10,900	8,890	8,650	6,610
0.4%	14.1	17,700	13,300	9,790	7,700	6,290	5,420	4,690
0.6%	18.1	13,800	10,500	7,720	6,070	4,960	4,280	3,700
0.8%	22.1	11,300	8,590	6,330	4,970	4,070	3,500	3,030
1.0%	26.1	9,570	7,270	5,360	4,210	3,440	2,970	2,560
1.2%	30.1	8,300	6,310	4,650	3,650	2,990	2,570	2,220
1.4%	34.1	7,330	5,570	4,100	3,220	2,640	2,270	1,960
1.6%	38.1	6,560	4,980	3,680	2,890	2,360	2,030	1,760
1.8%	42.1	5,930	4,510	3,320	2,610	2,140	1,840	1,390
2.0%	46.1	5,420	4,120	3,040	2,390	1,950	1,680	1,450
2.2%	50.1	4,990	3,790	2,790	2,190	1,800	1,550	1,340
2.4%	54.1	4,620	3,510	2,590	2,030	1,660	1,430	1,240
2.6%	58.1	4,300	3,270	2,410	1,890	1,550	1,330	1,150

NOTE: Above table based on the following criteria

Maximum Drawbar Force based upon Knuckle Strength = 250,000 lbs.

Grade Resistance = 20 lbs./ton/percent grade

Rolling Resistance = 6.13 lbs./ton for 35 ton cars at 21 MPH

APPENDIX B

TABLE 5 Guideline Tonnage to Preceed an 85 Ft. Empty Car in Buff

Sharpness of Curve		4°	6°	8°	10°	12°	14°	16°
Maximum Safe Drawbar Force (lbs.)		200,000	152,000	112,000	88,000	72,000	62,000	53,000
Steepness Of Grade	Drawbar Force/ Trailing Ton							
0.2%	10.1	19,700	15,000	11,100	8,690	7,110	6,120	5,290
0.4%	14.1	14,200	10,600	7,830	6,150	5,030	4,340	3,750
0.6%	18.1	11,000	8,380	6,180	4,850	3,970	3,420	2,960
0.8%	22.1	9,030	6,870	5,060	3,980	3,250	2,800	2,420
1.0%	26.1	7,650	5,820	4,290	3,370	2,760	2,370	2,050
1.2%	30.1	6,630	5,050	3,720	2,920	2,390	2,060	1,780
1.4%	34.1	5,860	4,450	3,280	2,580	2,110	1,820	1,570
1.6%	38.1	5,250	3,990	2,940	2,310	1,890	1,630	1,410
1.8%	42.1	4,750	3,610	2,660	2,[illegible]	1,710	1,470	1,270
2.0%	46.1	4,340	3,290	2,430	1,910	1,560	1,350	1,160
2.2%	50.1	3,990	3,030	2,230	1,760	1,450	1,240	1,070
2.4%	54.1	3,690	2,810	2,070	1,630	1,330	1,150	990
2.6%	58.1	3,440	2,610	1,930	1,510	1,240	1,070	992

NOTE: Above table based on following criteria:

Maximum Safe Drawbar Force based upon 250,000 lb. Guideline Drawbar Strength and 20% Increase in Coupler Angle when in Buff

Grade Resistance = 20 lbs./ton/percent grade

Rolling Resistance = 6.13 lbs.,/ton for 35 ton cars at 21 mph

APPENDIX B

4. TRACK AND STRUCTURES CONSIDERATIONS

Train handling is affected in many ways, both directly and indirectly, by the actions of personnel other than the train and engine "crew," just as the actions of the crew can also affect the rolling stock, track, structures and their maintenance.

It is important that maintenance and design personnel understand the dynamic forces involved in train operation and their effects on the track and supporting structures. Maintenance and design personnel must also be aware of the effects of their actions, such as the placement of speed restrictions, have on the crew's ability to handle trains through areas being repaired or re-built.

It is equally important that the crew be aware of the forces expended in starting, running and stopping a train and the manner in which these forces are transmitted through the cars and their component parts (drawbar, frame, wheel, etc.) to the track and its substructure, including bridges and trestles.

A crew that understands the reasons for limitations placed on train speeds will not exceed these limits and jeopardize the safety of the train operation.

The Track and Structures Considerations Section of this manual attempts to outline some of the dynamic problems without excessive use of technical terminology.

4.1 DYNAMIC FORCES ON RAIL

The forces expended by trains in starting, stopping, running, and negotiating curves and turnouts are transmitted from the wheel to the rail and can be divided into lateral and vertical components as illustrated in Figure 1.

If the Lateral (L) and the Vertical (V) forces generated by moving trains are not absorbed and restrained by the track, failures of some form will occur. These failures can often be predicted by studying the L/V ratios (the lateral forces divided by the vertical forces) at each wheel.

Critical L/V values vary greatly, according to dynamic situations being considered; for example, L/V ratios which present a problem in low speed draft situations are not the same as those that are of concern in high speed buff situations, due to such factors as the dynamic characteristics of the vehicles, trucks and track.

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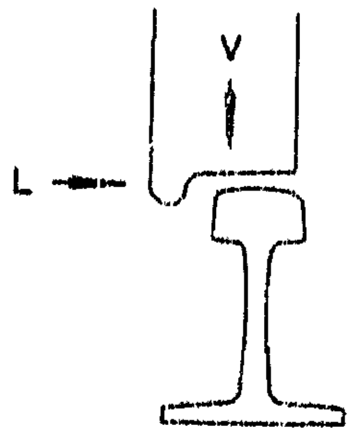

Figure 1. Forces on Rail

The consideration of L/V ratios is important in any study of the interaction of wheel and rail in dynamic situations and must be recognized as a "time dependent occurrence" (an occurrence whose importance varies with the elapsed time.) L/V ratios are especially important in predicting track shift, wheel climb, wheel lift, and rail turnover. (See Section 3.2.4 Train Make-Up)

While the L/V ratio is important in studying track situations, the actual lateral and vertical forces are the forces which must be absorbed by the track structure supporting the train. The lateral stability of the track must be such that it will resist any tendency to shift or increase gage.

Rail wear occurs in generally predictable patterns according to the tonnage handled, the speed, the curvature and the equipment. Whenever wear greatly exceeds expected limits at a particular location, cooperative interdepartmental studies should be initiated to determine circumstances of the track, the equipment, and the train handling. *SPECIAL LINES OF COMMUNICATION WITHIN THE*
(1-1) *COMPANY SHOULD BE ESTABLISHED SO THE PROBLEMS RELATING TO THE TRACK, THE EQUIPMENT, AND THE TRAIN HANDLING CAN BE MUTUALLY STUDIED AND EFFECTIVE SOLUTIONS IMPLEMENTED.*

4.1.1 SPEED RESTRICTIONS

Speed restrictions are imposed on train operations for many reasons including operating, legal and technical considerations, such as limitations of the equipment, track and structures.

Most speed restrictions are imposed for the safety of the train operations so the magnitude of the forces expended will not create an unsafe condition.

The magnitude of forces expended in train operations varies with the speed of the train, with some forces increasing in proportion with the square of the speed. The greatest forces occur in slowing or stopping a train and these forces are transmitted to the track. The main train forces are longitudinal in nature which in turn can also lead to undesirable lateral forces.

The allowable speed over a section of track must not exceed the speed from which an emergency stop can be made without creating excessive stresses in the track and structures not only from longitudinal forces but also excessive lateral forces at a wheel which might cause wheel climb or rail turnover.

Speed restrictions are either permanent, recognizing the inherent design limitations of the track and equipment; or temporary, for a variety of reasons, including track or bridge repairs, emergency situations (e.g., flooding, soft roadbed, etc.), or equipment considerations recognizing the problems of a particular car or combinations of cars being handled.

THE LIMITS OF SPEED RESTRICTIONS MUST BE CAREFULLY SELECTED, CONSIDERING NOT ONLY THE SPECIFIC STRUCTURE OR SECTION OF TRACK TO BE PROTECTED BUT ALSO THE DIFFICULTY EXPERIENCED BY LOCOMOTIVE ENGINEERS IN CONTROLLING THE TRAIN AS IT APPROACHES THE RESTRICTION. IN ORDER TO ADEQUATELY PROTECT CURVES AND STRUCTURES PRIOR TO THE RESTRICTED AREA, IT MAY BE ADVISABLE TO EXTEND THE LIMITS OF THE RESTRICTION. SINCE ALL CARS IN THE TRAIN MUST BE BROUGHT THROUGH THE RESTRICTION SAFELY, THE CREW HAS THE RESPONSIBILITY TO OBSERVE THE SPEED RESTRICTION FOR THE ENTIRE LENGTH OF THEIR TRAIN UNLESS OTHERWISE SPECIFIED i.e., such as the engine speed only being limited at a crossing. (4-2)

4.1.1.1 CURVES

A train is made to change direction by introducing curvature into the track. The rail on the outside of the curve guides the wheel and truck by resisting its tendency to go straight thus turning the locomotive or car.

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In the curve negotiation the lead wheel bears against the outside rail of the curve and the trailing wheels are restrained by the inside rail. The angle between the leading outer wheel and the outside rail is referred to as the "angle of attack." Figure 2 illustrates the relative position of a 3-axle rigid frame locomotive truck while traversing a curve.

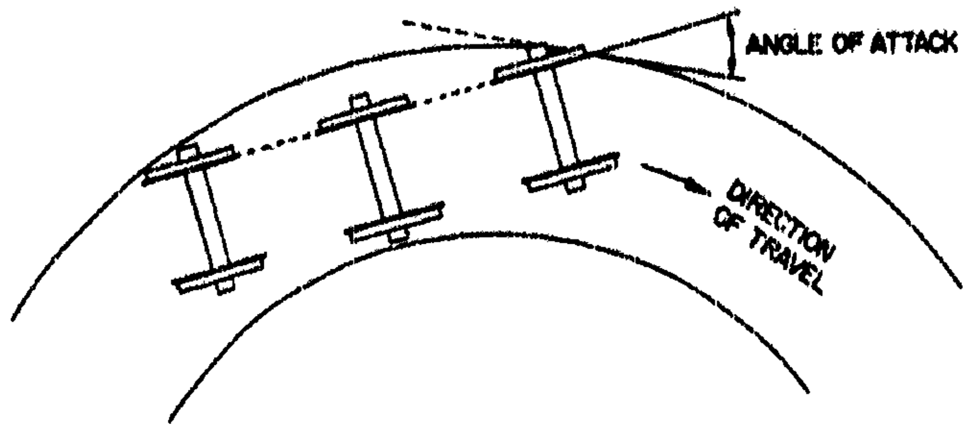

Figure 2. 3-Axle Rigid Frame Locomotive Truck

The axles can shift relative to one another due to the lateral freedom of motion built into equipment trucks. This lateral freedom allows the trailing axles to shift somewhat toward the outer rail and all axles to skew to a sharper angle of attack.

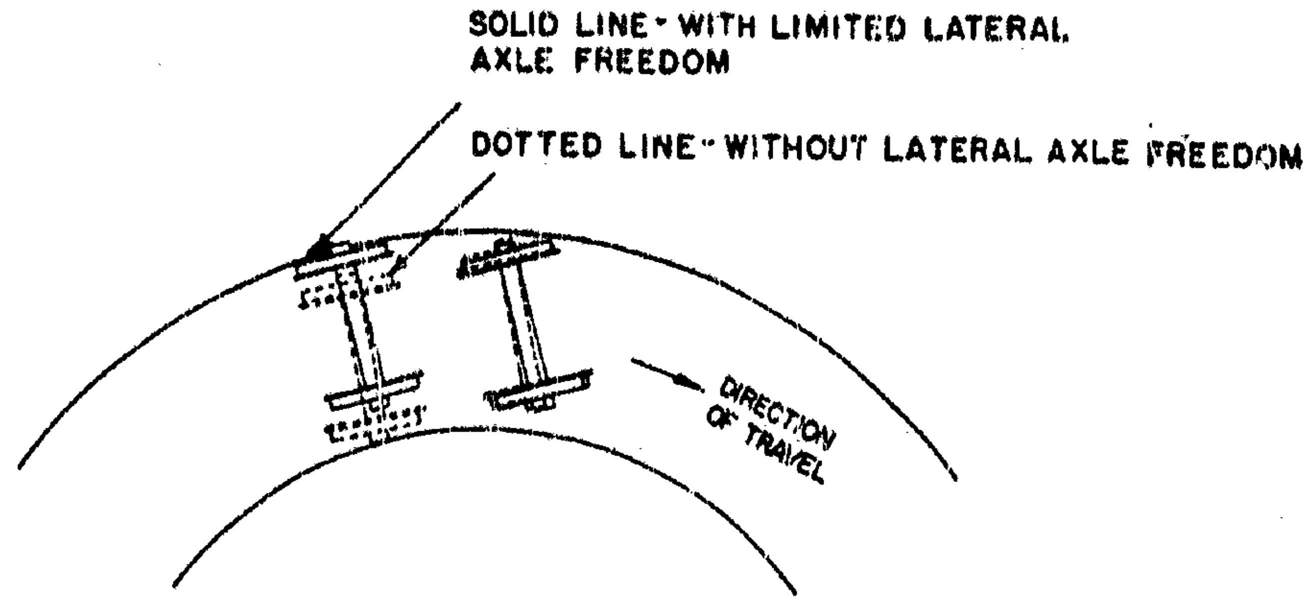

Figure 3. Standard 3-Piece Freight Car Truck

Figure 3 illustrates the relative position of the wheels and axles of a standard 3-piece freight car truck while traversing a curve with and without the effect of lateral freedom.

Wheel to rail frictional forces developed in curve negotiation are in addition to the normal forces generated in train operation and increase sharply as the degree of curvature increases. The relative magnitude of the lateral forces developed is shown in Figure 4.

As the frictional forces increase, the probability of wheel climb, rail turnover and lateral buckling of the track increases. There is a limit to the amount of curvature a truck can negotiate without excessive friction and binding. This depends on the truck wheel base, the gage of track, and the lateral freedom per axle.

EQUIPMENT MUST NOT BE PERMITTED TO OPERATE ON CURVATURE GREATER THAN THAT FOR WHICH THE EQUIPMENT IS DESIGNED UNLESS INCREASES ARE MADE IN THE LATERAL FREEDOM OF AXLES OR GAGE OF THE TRACK. WHERE GAGE IS WIDENED APPROPRIATE RESTRAINTS ON OPERATING SPEED MUST BE IMPOSED. 4-3

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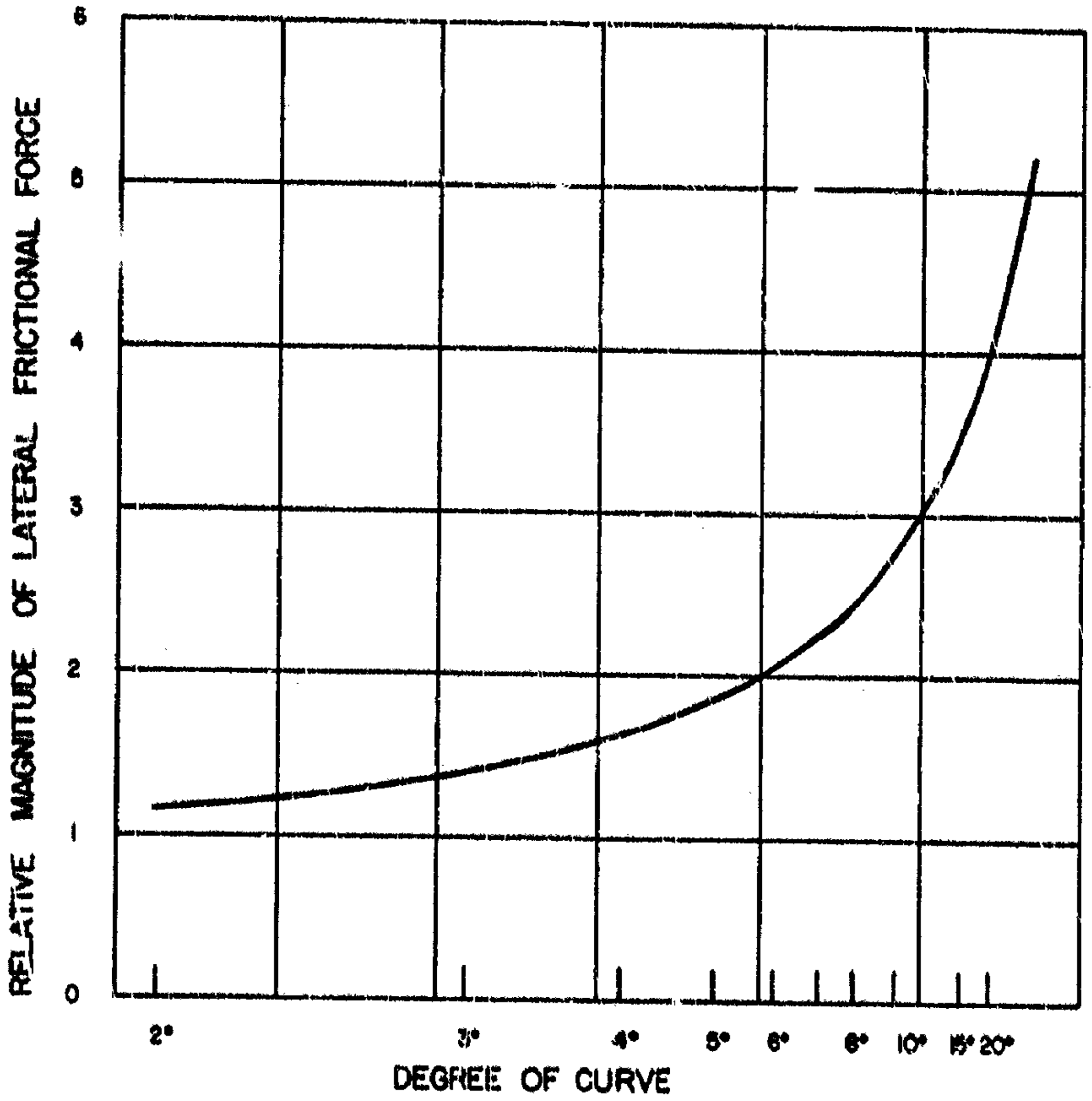

Figure 4. Relationship of Lateral Frictional Forces to Curvature

LIMITING CONDITIONS FOR VARIOUS 3-AXLE TRUCK LENGTHS ARE AS FOLLOWS:

Length of Truck Wheel Base	*Standard Gage (4'-8½"), Standard Lateral Freedom Per Axle (3/8")*	*Standard Gage, With 1/2" Lateral Freedom Per Axle*	*4'-9" Gage, Standard Lateral Freedom Per Axle*
11' - 6"	*22°*	*25°*	*36°*
13' - 6"	*16°*	*18°*	*26°*
15' - 6"	*12°*	*14°*	*20°*

(4-4)

The degree of curvature that can be safely negotiated is reduced when there is less than standard gage or standard lateral freedom per axle.

Trains operating in draft around curves exert inward lateral forces on the track because a train tends to "string line" or assume a straight line when traversing the curve.

In normal operation the rail absorbs this lateral force and it is transferred to the roadbed. *AVOID HEAVY FORCES TO START, DRAG OR ABRUPTLY INCREASE THE SPEED OF A TRAIN IN A CURVE, SINCE THE RESULTING "STRING LINE" EFFECT COULD SHIFT TRACK, TURN RAIL OVER OR OTHERWISE RESULT IN DERAILMENT.* (4-5)

AVOID HEAVY BRAKING FORCES WHEN TRAINS ARE BEING SLOWED OR STOPPED ON CURVES SINCE THE TRACK MUST ABSORB ALL FORCES CREATED BY THE BRAKING ACTION. The lateral forces in such action are often increased by sluggish truck or coupler action cocking the truck and/or car (jackknifing) at other than normal position relative to the curve. (4-6)

Trains traveling around curves are also affected by centrifugal force which acts away from the center of the curve and tends to overturn the cars as illustrated in Figure 5. This tendency directs the weight of the train toward the outside rail.

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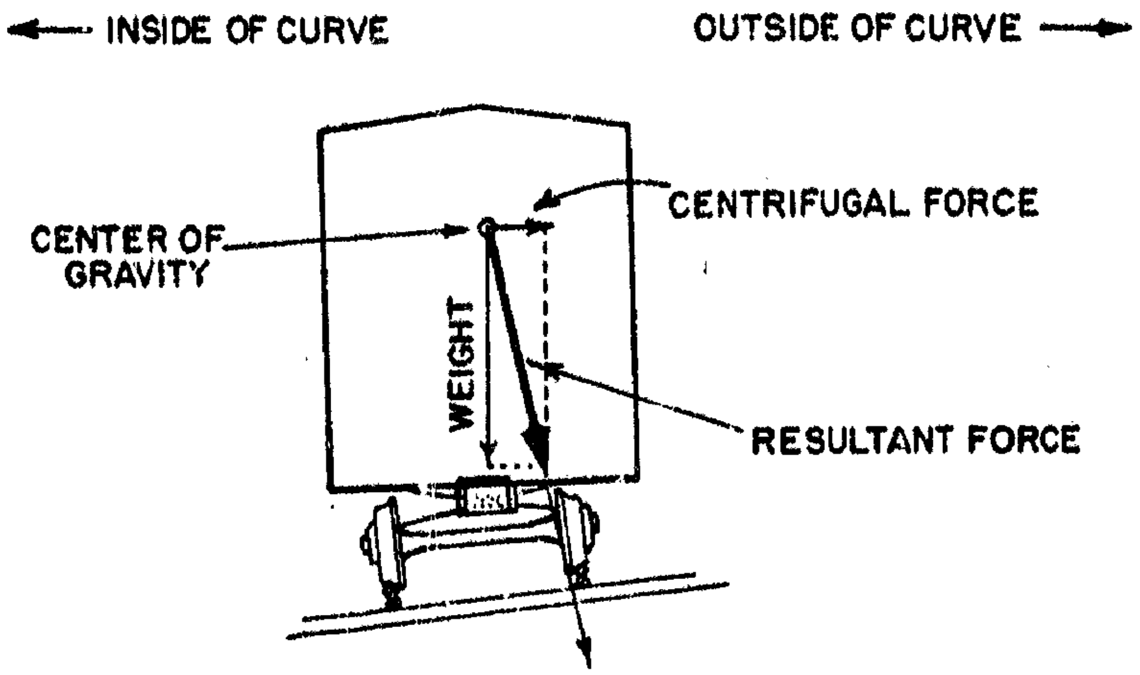

Figure 5. Effects of Centrifugal Force

Centrifugal force increases as the square of the speed and increases in direct proportion to the degree of curvature.

The dynamic forces of train operation are additive to the ordinary forces of curve negotiation.

4.1.1.1.A SUPERELEVATION

Superelevation is the raising of the outer rail on a curve to permit using the weight (gravitational force) to counteract the effect of centrifugal force. Raising the outer rail moves the effect of the weight force toward the inside rail. Combining the effects of the centrifugal force and weight produces a resultant force as illustrated in Figure 6.

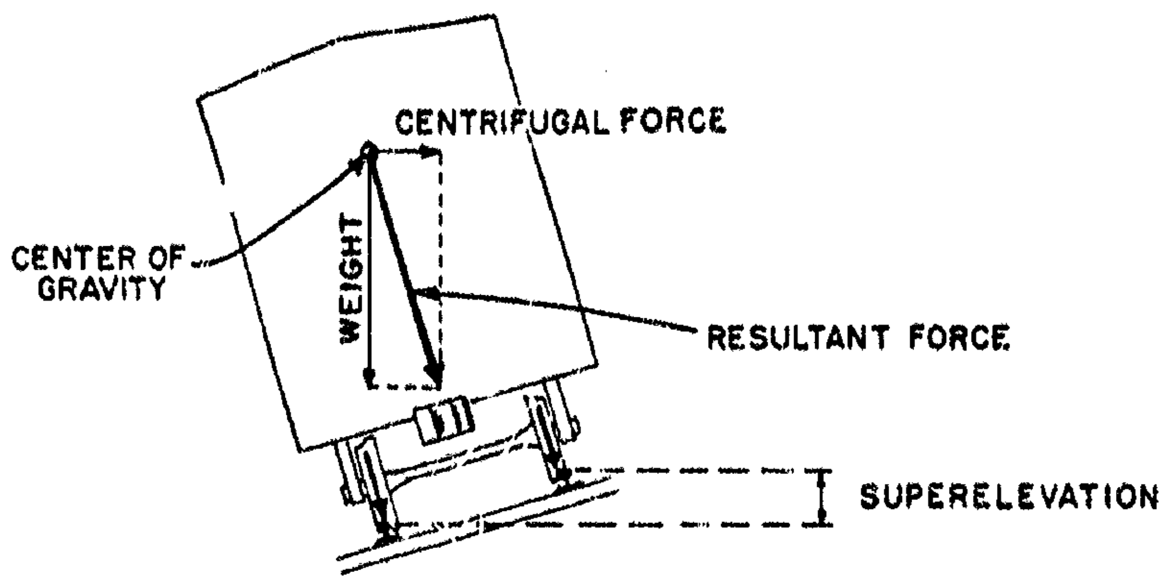

Figure 6. Superelevated Car In Equilibrium

When the direction of the resultant force coincides with the centerline of the equipment and track the curve is described as being balanced and equilibrium speed has been reached. In this condition the vertical forces on each rail are equal and minimal frictional forces are occurring between the wheels and the rail. This permits maximum utili_ation of tractive effort and minimum wear on wheels and rail. However, trains may operate at all speeds from the maximum allowable to a complete stop on a curve. Also, the consist may have many different types of cars with varying centers of gravity. Therefore, the design of superelevation of a curve and the speeds allowed must be carefully chosen. Insufficient superelevation may allow a car to climb the rail or overturn. However, railway equipment will generally "climb" over the rail due to lateral flange pressure and friction before the car

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will overturn. On the other hand, excessive superelevation may cause the wheels on the high rail to unload due to reduced vertical force and cause wheel lift.

Trains can operate around curves at speeds in excess of equilibrium with safety until reaching this point that wheel climb impends. The height of center of gravity becomes a major consideration when there is unbalance between speed, curvature and superelevation.

This is illustrated in Figure 7 which shows the approximate position of the dynamic resultant force of freight cars on curved track when traveling at speeds above 20 mph. As the center of gravity increases, less underbalance can be permitted.

It is recommended that the maximum speed permitted on a curve should not result in unbalanced superelevation beyond the limits where wheel climb impends.

When a train travels at less than the equilibrium speed around a superelevated curve there is an unbalance with the resultant force directed toward the inside or low rail. As more of the weight is carried by the low rail, there is an unloading of the outer or high rail. The extreme condition is for the low rail to carry the entire vertical force and the high rail to be completely unloaded. This is an unstable operating condition which can result in wheels lifting off the rail. Figure 8 illustrates the approximate position of the dynamic resultant force with overbalance to the low rail for a speed of 15 mph.

Figure 8 is based on lateral roll amplitudes running over track with normal irregularities. Equipment with 98 inch high center of gravity will not unload the high rail of well maintained track until the overbalance is slightly in excess of 6 inches. However, the "string line" effect of starting or pulling a drag train combined with overbalance effect may cause unloading of the high rail with less than 6 inches superelevation in the track.

When determining the superelevation of a curve, very slow operation and stopped condition must not be ignored. *WHERE PRACTICAL SUPERELEVATION SHALL BE PROVIDED FOR EQUILIBRIUM SPEED. OTHERWISE, IT IS RECOMMENDED THAT THE MAXIMUM SPEED OF THE 98" HIGH CENTER OF GRAVITY CARS (MAXIMUM HEIGHT CENTER OF GRAVITY ALLOWED IN FREE INTERCHANGE) BE RESTRICTED TO PROVIDE NO MORE THAN 3" UNBALANCE ELEVATION. A CURVE MUST NOT BE ELEVATED SO MUCH THAT UNLOADING OF THE HIGH RAIL MIGHT OCCUR AT VERY LOW SPEEDS OR WHEN STARTING.* (4-7)

UNDER NO CIRCUMSTANCES SHALL SUPERELEVATION EXCEED 6", BUT IN MANY INSTANCES THE MAXIMUM ALLOWED MUST BE LESS THAN 6" DUE TO CURVATURE, ALLOWABLE CENTER OF GRAVITY OR OTHER FACTORS.

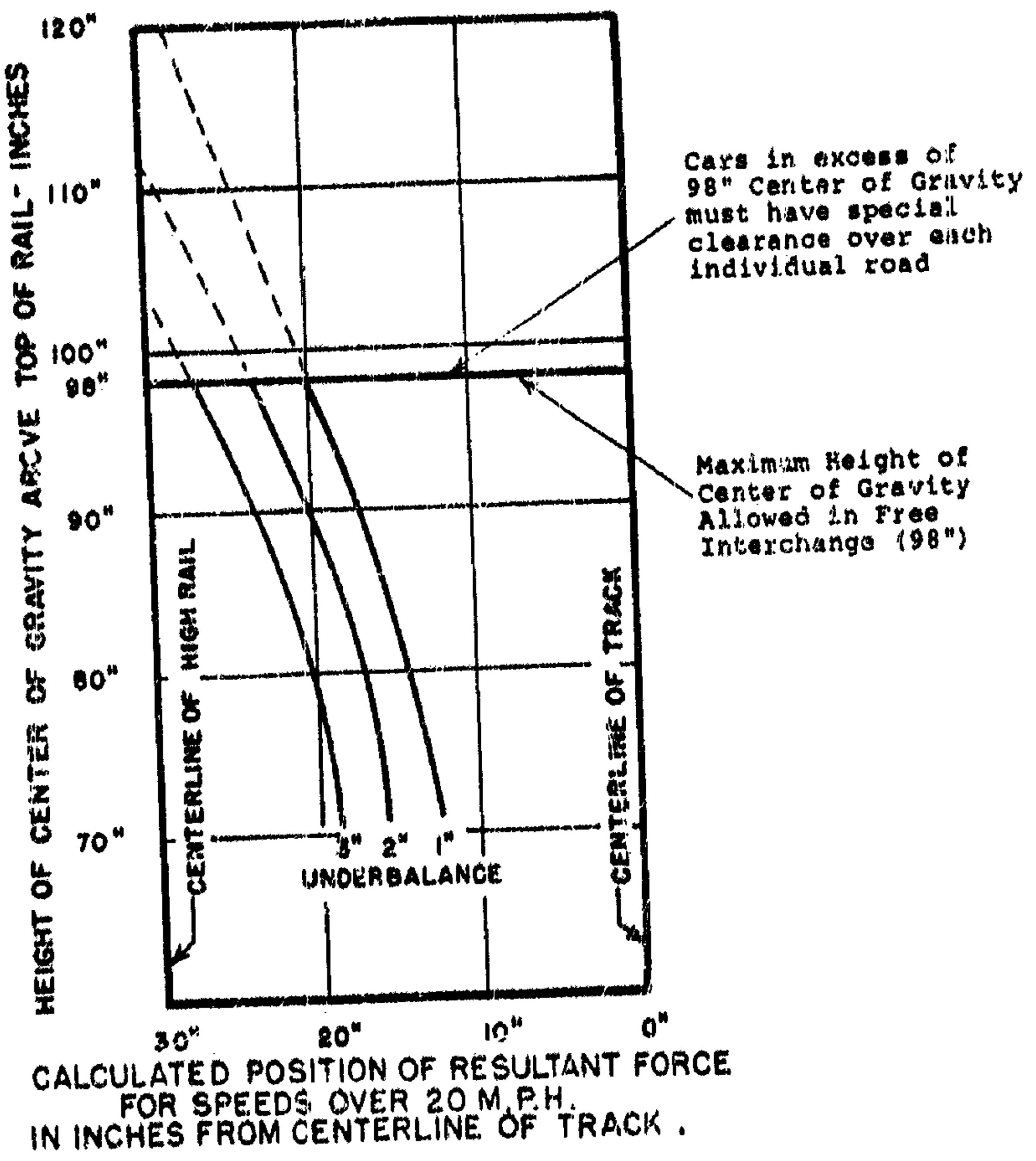

Figure 7. Effect of Unbalanced Superelevations (Underbalanced) on Vehicle Stability

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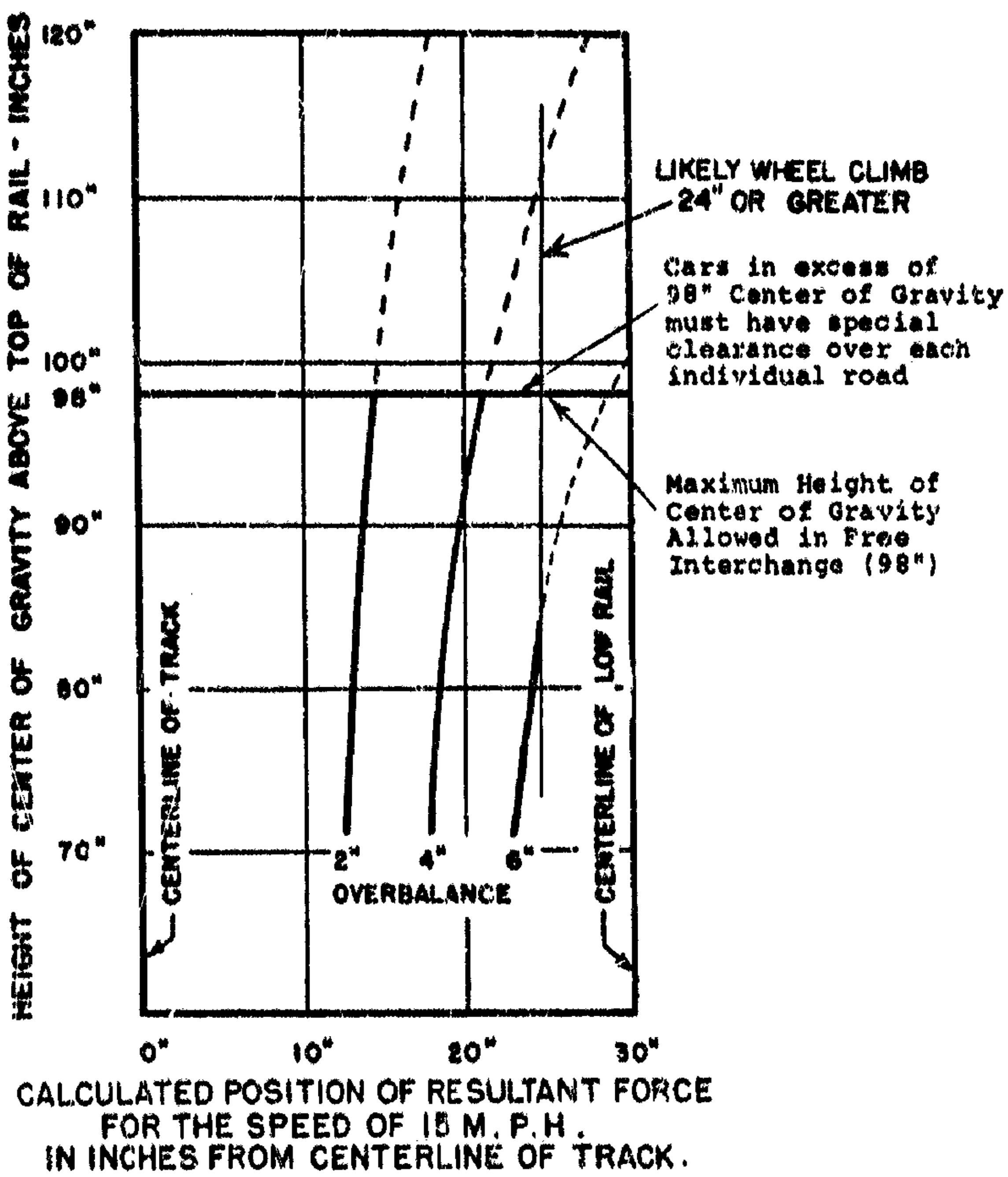

Figure 8. Effect of Unbalanced Superelevations (Overbalanced) on Vehicle Stability

APPENDIX C

Excerpts from Code of Federal Regulations

§ 230.220 Lateral motion.

The total uncontrolled lateral motion between the hubs of the wheels and boxes, between boxes and pedestals or both, on any pair of wheels shall not exceed the following limits: Truck wheels, 1 inch, driving wheels, more than one pair of wheels, ¾ inch. These limits may be increased if upon application to the Director, Bureau of Railroad Safety, his investigation shows that conditions require additional lateral motion. The lateral motion shall in all cases be kept within such limits that the driving wheels, rods, crank pins, or armatures will not interfere with other parts of the locomotive.

Interpretation: The "total uncontrolled lateral motion" referred to in this rule means the lateral motion provided for in the design of the parts, plus any additional lateral motion due to wear.

Subpart C—Track Geometry

§ 213.51 Scope.

This subpart prescribes requirements for the gage, alinement, and surface of track, and the elevation of outer rails and speed limitations for curved track.

§ 213.53 Gage.

(a) Gage is measured between the heads of the rails at right angles to the rails in a plane five-eighths of an inch below the top of the rail head.

(b) Gage must be within the limits prescribed in the following table:

Class of track	The gage of tangent track must be—		The gage of curved track must be—	
	At least—	But not more than—	At least—	But not more than—
1	4' 8"	4' 9½"	4' 8"	4' 9¾"
2 and 3	4' 8"	4' 9¼"	4' 8"	4' 9½"
4	4' 8"	4' 9"	4' 8"	4' 9¼"
5	4' 8"	4' 8¾"	4' 8"	4' 9¼"
6	4' 8"	4' 8½"	4' 8"	4' 9"

§ 213.57 Curves; elevation and speed limitations.

(a) Except as provided in § 213.63, the outside rail of a curve may not be lower than the inside rail or have more than 6 inches of elevation.

(b) The maximum allowable operating speed for each curve is determined by the following formula:

$$V_{max} = \sqrt{\frac{E_a+3}{0.0007d}}$$

where

V_{max} = Maximum allowable operating speed (miles per hour).

E_a = Actual elevation of the outside rail (inches).

d = Degree of curvature (degrees).

Appendix A is a table of maximum allowable operating speed computed in accordance with this formula for various elevations and degrees of curvature.

§ 213.59 Elevation of curved track; runoff.

(a) If a curve is elevated, the full elevation must be provided throughout the curve, unless physical conditions do not permit. If elevation runoff occurs in a curve, the actual minimum elevation must be used in computing the maximum allowable operating speed for that curve under § 213.57(b).

(b) Elevation runoff must be at a uniform rate, within the limits of track surface deviation prescribed in § 213.63, and it must extend at least the full length of the spirals. If physical conditions do not permit a spiral long enough to accommodate the minimum length of runoff, part of the runoff may be on tangent track.

APPENDIX A—MAXIMUM ALLOWABLE OPERATING SPEEDS FOR CURVED TRACK

Elevation of outer rail (inches) — Maximum allowable operating speed (mph)

Degree of Curvature	0	½	1	1½	2	2½	3	3½	4	4½	5	5½	6
0°30'	93	100	107										
0°40'	80	87	93	98	103	109							
0°50'	72	78	83	88	93	97	101	106	110				
1°00'	66	71	76	80	85	89	93	96	100	104	107	110	
1°15'	59	63	68	72	76	79	83	86	89	93	96	99	101
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[36 FR 20336, Oct. 20, 1971, as amended at 38 FR 875, Jan. 5, 1973]

APPENDIX D

Track Geometry Measurements

(IN DIRECTION OF TRAIN No. 407's TRAVEL, TOWARD SITE OF DERAILMENT)

	STATION (FEET)	GAGE (INCHES)	ELEVATION (INCHES)	DEGREE OF CURVE (BY MID-ORDINATE)
	310	56½	1/8	0
	300	56 3/8	-1/16	0
	290	56 5/16	1/16	-1/8
	280	56 3/16	½	-1/8
	270	56½	5/16	-1/8
	260	56 3/8	0	-1/8
	250	56½	3/16	0
	240	56 3/16	½	-1/8
	230	56 3/8	0	1/8
	220	56 3/8	1/8	1/8
	210	56½	3/8	0
	200	56 3/16	3/8	0
	190	56 3/16	5/16	½
	180	56 1/16	7/16	½
	170	56 1/8	5/8	1/8
	160	56 3/8	13/16	-1/8
	150	56½	11/16	-½
	140	56 3/16	15/16	-½
(Approximate	130	56 3/16	1	0
Start of Spiral)	120	56 3/8	1	½
	110	56 11/16	1½	3/8
	100	56 1/8	1 3/8	3/8
	90	56 3/8	1 5/8	½
	80	56 1/8	1½	3/8
	70	56	1 7/8	3/4
	60	56	2¼	3/4
Disturbed Track area	50	55 7/8	2 7/16	7/8
	40	55 3/4	2 3/8	1½
	30	55 3/4	2½	1 1/8
	20	55 11/16	2½	
	10	55 11/16	2 7/16	
	0	55 15/16	2 3/16	