L TRANSPORTATION SAFETY BOARD

RAILROAD ACCIDENT REPORT

DERAILMENT OF AN AMTRACK TRAIN ON THE TRACKS OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY COMPANY AT MELVERN, KANSAS

JULY 5, 1974

NATIONAL TRANSPORTATION SAFETY BOARD
Washington, D.C. 20591
REPORT NUMBER: NTSB-RAR-75-1

SS-R-30

RAILROAD ACCIDENT REPORT.

DERAILMENT OF AN AMTRAK TRAIN ON THE TRACKS OF THE ATCHISON, TOPEKA AND SANTA FE RAILWAY COMPANY AT MELVERN, KANSAS JULY 5, 1974

ADOPTED: FEBRUARY 5, 1975

U.S. NATIONAL TRANSPORTATION SAFETY BOARD,
Washington, D.C. 20591
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15 Supplementary Notes

This report contains Railroad Safety Recommendations R-75-1 through R-75-5.

16.Abstract

This report describes and analyzes a derailment of an Amtrak passenger train which occurred as the train was moving eastward at a speed of about 77 mph. The derailment occurred on a trailing point turnout which connected the southerly main track with a siding. The rear six cars turned over as they slid down a bank. Fifteen employees and 87 passengers were injured as a result of the accident.

The National Transportation Safety Board determines that the probable cause of the accident was the broken closure rail of the turnout leading from the south main track to the siding. The insufficient strength of the track bolt and the apparent stressed condition of the nail contributed to the cause of the broken rail.

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FOREWORD

The accident described in this report has been designated a major accident by the National Transportation Safety Board under the criteria established in the Safety Board's regulations.

This report is based on facts obtained from an investigation conducted by the Safety Board, in cooperation with the Federal Railroad Administration. The conclusions, the determination of probable cause, and the recommendations herein are those of the Safety Board.

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NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D. C. 20591

RAILROAD ACCIDENT REPORT

Adopted: February 5, 1975

Atchison, Topeka, and Santa Fe Railway Company
Amtrak Train 4-C Derailment
Melvern, Kansas
July 5, 1974

SYNOPSIS

At 4:57 a.m. on July 5, 1974, Amtrak Train No. 4-C was operating on the tracks of the Atchison, Topeka, and Santa Fe Railway Company just east of Melvern, Kansas. As the train moved over a turnout leading from the south main track to a siding located between the two main tracks, the rear 13 cars of the 18-car train derailed. The rear six cars turned over, slid down an embankment, and came to a stop on their sides. Fifteen employees and 87 passengers were injured as a result of the accident. One of the injured passengers died several weeks later.

The National Transportation Safety Board determines that the probable cause of the accident was the broken closure rail of the turnout leading from the south main track to the siding. The insufficient strength of the track bolt and the apparent stressed condition of the rail contributed to the cause of the broken rail.

FACTS

The Accident

On July 3, 1974, at 7:56 p.m., Amtrak train No. 4-C, which consisted of 3 diesel-electric locomotive units and 18 cars, departed Los Angeles, California, bound for Chicago, Illinois. The train, which operated over the tracks of the Atchison, Topeka, and Santa Fe Railway Company (Santa Fe), had been inspected and tested before it departed. Although additional inspections and tests were performed en route, no discrepancies or malfunctions were reported.

On July 5, at 3:05 a.m., the train arrived in Newton, Kansas, where the Santa Fe engine crew and traincrews were changed. The train was inspected and its air brakes were tested, but no defects were detected. The train's last stop before the derailment was at Emporia, Kansas, at which time there were 384 passengers on the train.

As the train approached Melvern, Kansas, it was being operated on the south track of the double-track system at 70 mph to comply with a speed restriction around a curve just west of the accident site. The train's speed was not increased to 90 mph after passing the curve because another curve 2 miles farther east had an 80 mph restriction. The engineer said that, after departing Emporia, all signals governing the operation of train 4-C had been clear.

At 4:57 a.m., as the train passed over the switch on which the accident occurred, the engine crew saw fire flying from under the middle of the train and immediately applied the emergency brakes. The engineer reported the derailment to the dispatcher as the train stopped.

The members of the traincrew became aware of the accident when the cars derailed and the emergency brakes were applied. After the train stopped, the conductor and front brakeman went back along the train and found that Cars 6 through 18 had derailed and that the rear six cars had slid over the embankment along the south side of the track. At first, the conductor believed that the rear of the train was behind the first four overturned cars. It was not until later that he found the last two overturned cars which had separated from the others. After the train dispatcher was notified, he called for ambulances and assistance from the various police departments and notified railroad personnel.

Accident Site and Method of Operation

At Melvern, a siding is located between the two main tracks. The east switch, which connects the siding to the south track, is located 3,254 feet east of the station. The turnout is in a $1^{\circ} 4'$ curve, which is 678 feet long and begins 74 feet east of the point of switch. The track west of the spiral is straight. In the general area of the derailment, the tracks are laid on a fill which is about 20 feet high. For eastbound trains, the grade descends slightly as they approach the east siding switch. (See Figure 1.)

Amtrak trains are operated over the Santa Fe tracks between Los Angeles and Chicago by Santa Fe train and engine crews. The crews are governed by Santa Fe rules and instructions.

Trains are operated on both tracks in both directions by signals of a traffic control system which is controlled by a train dispatcher in Emporia. The maximum authorized speed for passenger trains is 90 mph.

The Track

Structure. -- The south main track consists of 136-lb. rail, continuously welded. The track was laid in October 1965 on an average of 24 crossties per 39 feet of track. The track was fully equipped with double shoulder tie plates, and each was secured with two line cut spikes and two "Racor Stud" anchor spikes. The rail was box-anchored on alternate ties with 48 rail anchors per 39 feet of track. The track was ballasted with crushed slag to a depth of 8 inches below the bottom of the ties.

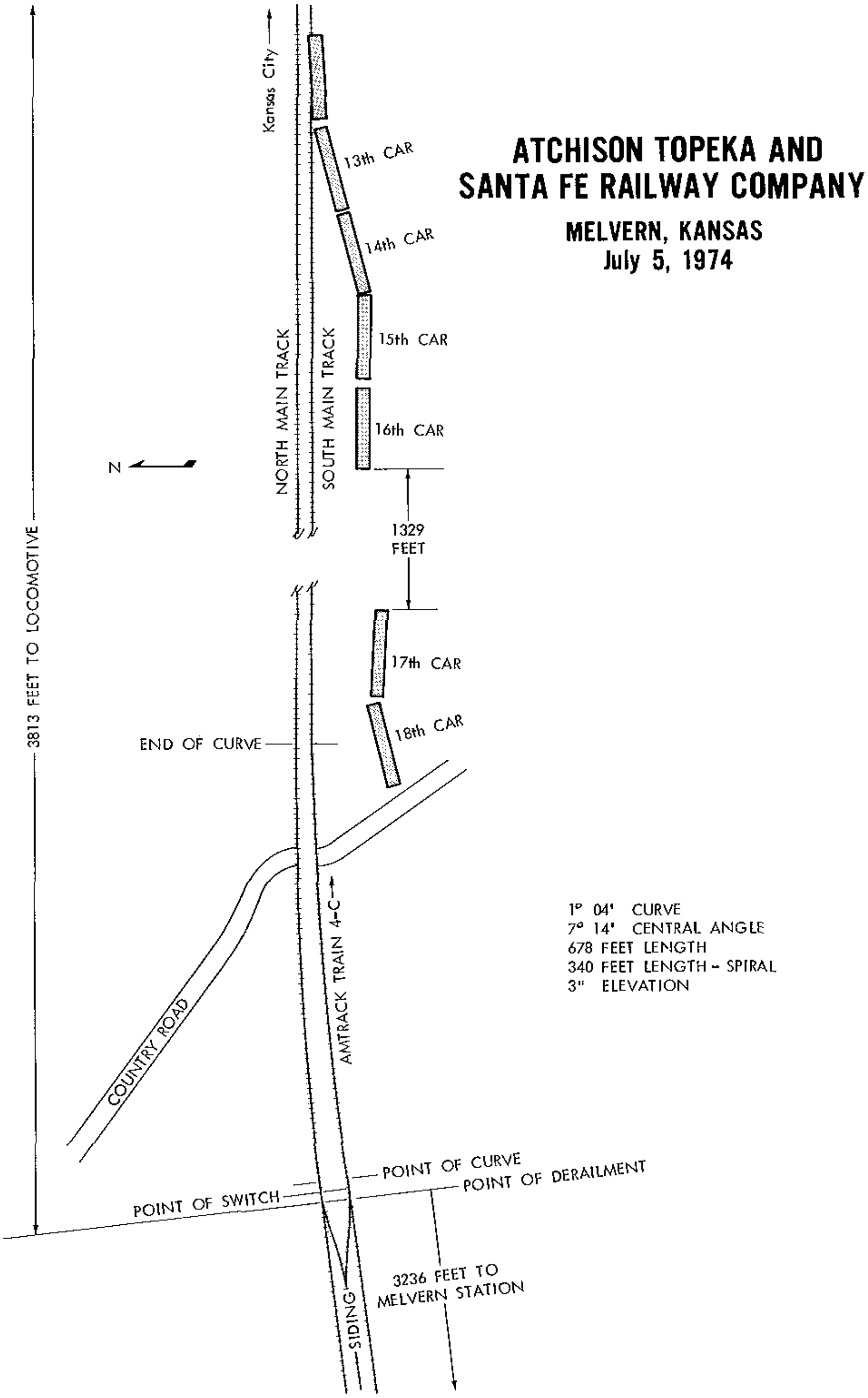

Figure 1. Area of the derailment.

A right-hand turnout, with 136-lb. rail, 16-foot 6-inch switch points, and a No. 10 spring-rail frog, connects the east end of the siding with the south main track. The straight closure rail is 30 feet long and was also installed in October 1965. The closure rail is connected to the switch point by a four-bolt heelblock assembly. The signal bond wires span the heelblock and are connected to the rails on each side of the heelblock. (See Figure 2.)

Marks of the Derailment and Damage to the Track. -- The rail ends adjacent to the straight closure rail and the switch point of the east siding turnout were broken. The first wheel marks of the derailment appeared on the track structure beyond the gap in the north rail which had been created by the broken rail ends. Wheel marks appeared on the ties and base of the rail between the switch point and the running rail. The switch point was displaced southward. Eastward from the switch, the south rail of the main track was displaced southward for a distance of 2,400 feet. Ties were destroyed or heavily damaged where the rail was displaced.

Maintenance. -- On March 27, 1974, a portable ultrasonic device was used to test the rails of the turnout for internal defects; no defects were detected. On May 27, 1974, a visual inspection of the turnout disclosed three loose heelblock bolts. The bolts were then replaced by the track supervisor. On May 30, 1974, the heelblock assembly was replaced. The turnout was last inspected on July 3, 1974; no defects were detected.

The track on which the accident occurred was classified as Class 5 track in accordance with the FRA Track Safety Standards. The standard permits freight train speeds of 80 mph and passenger train speeds of 90 mph. FRA personnel examined the undamaged portion of the track and the maintenance records of the carrier and determined that the track was being maintained as required by Federal regulations.

The Train

Locomotive. -- The locomotive consisted of three Amtrak diesel electric units, type SDP-40, manufactured by General Motors. The locomotive units had six wheel trucks. Each unit was equipped with speed recorders and tapes. The speed tape from the first unit indicated that, after leaving Emporia, the train's maximum speed was 90 mph and that the speed was reduced to 70 mph about 7 miles west of the accident. The speed tape further indicated that speed was increased slightly and that the train was moving 77 mph when the emergency brakes were applied. The locomotive stopped 3,813 feet east of the broken closure rail.

Car Equipment. -- The cars were constructed of lightweight stainless steel and equipped with tightlock couplers. Cars 3 through 9 and Car 13 were Hi-Level design, and the remaining cars were standard design.

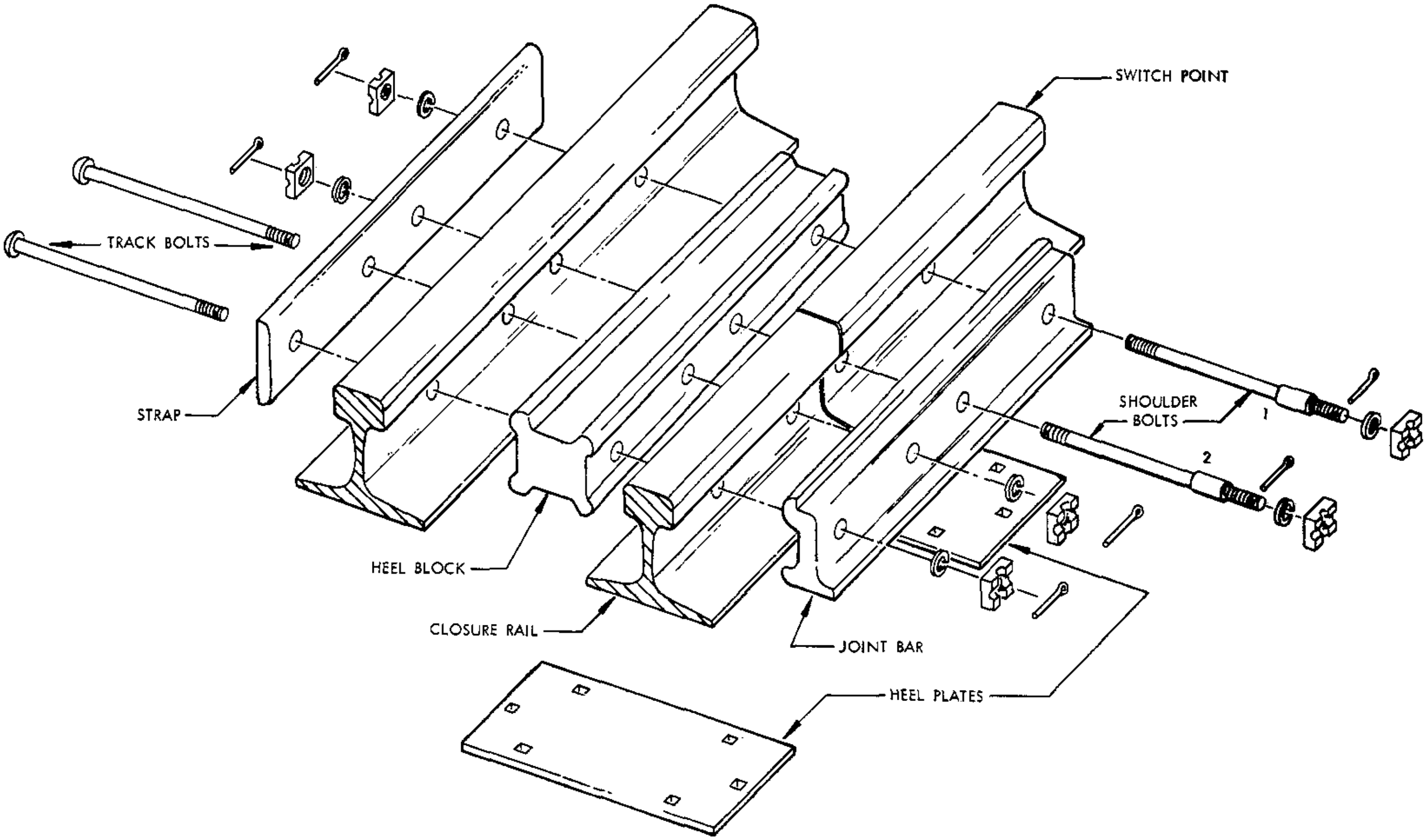

Figure 2. Assembly diagram of the heel portion of a 16-ft. switch.

Each car was equipped with a self-contained electrical system. A generator, driven by the car's wheels, provided current when the car was moving; wet cell batteries, located under the car's floor, provided current when the car was stopped. All lights were powered by this system; most cars were equipped with a train line connection which was used to provide power from one car to another if there was an electrical failure in one of the cars.

When the train stopped after the derailment, the wheels of Car 6 were on the rail; however, an examination of the car disclosed that the inside pair of wheels of the lead truck contained evidence that they had been derailed. The outside rim of the wheel on the north side was scored from contact with the gage side of a rail and the tread and flange of the wheel were scored from contact with the track structure. Marks were found on the flanges of the north wheel of the leading pair of wheels and on the north wheel of the leading pair of wheels of the trailing truck which indicated that they had struck a rail or a part of the track structure.

Cars 6 through 12 derailed and stopped on the track. Cars 13 through 16 derailed and separated from the forward portion of the train because the coupler pulled from Car 12. These cars slid over the south bank and stopped on their right sides. Cars 17 and 18 derailed. Because of broken couplers, they separated from Car 16 and from each other, went over the south bank, turned over, and stopped on their left sides. The cars started over the bank west of the highway underpass. Marks on the 18th car and on the abutment wall indicate that the car had struck the wall.

Originally, the double-pane windows of the passenger carrying cars were glazed with laminated safety glass on the inside and a tempered plate glass on the outside which was secured in the window frame with a rubber molding. Recently, Amtrak issued instructions that any broken windows should be replaced with Lexan MR-4000, or other equal polycarbonate material. Lexan MR-4000 is a shock resistant, shatterproof material which is difficult to break. Lexan windows had been installed in several of the rear cars which turned over during the derailment.

It was possible to remove the window panes from the car from the outside by cutting the rubber molding and pulling it from the frame. Instructions on this operation had not been issued generally to railroad operating personnel.

Rescue Activities

The police activities, which included the evacuation of the injured, were directed by the Osage County Sheriff's Department. Even though Osage County had no emergency or rescue equipment of its own, equipment was provided from surrounding communities. Ambulances were dispatched from Ottawa, Emporia, and Topeka. Rescue forces arrived within 30 minutes after the accident.

Most passengers were located in the front portion of the train in those cars which either did not derail or stayed on the track structure. Of the six cars that went over the bank, the lounge and the dining car were unoccupied. The remaining four cars were sleeping cars; most injured passengers were in these four cars.

The end doors of the rear four cars could not be used to remove the injured passengers readily because of the position of the cars. Therefore, the injured passengers were removed through the windows. Rescue personnel complained that some windows were almost impossible to break. Also, since passengers were in the compartment directly below the windows, it was difficult to break those windows without showering the passengers with broken glass. Rescue personnel did not know that the window panes could be removed by cutting the rubber molding and pulling it from the frame.

Eighty-seven passengers and 15 employees were injured. One passenger died several weeks after the accident following an operation to correct injuries sustained in the accident.

Inspection of the Broken Rail

An examination of the broken rails disclosed that 13 5/8 inches of the head of the east end of the straight closure rail, 24 1/4 inches of the head of the west end of the switch point, and the corresponding sections of the web and base were broken and dislodged. The heelblock bolts were broken and the joint bars were found on the ties near their original positions. The heelblock was found about 75 feet north of the track.

The original crack of the straight closure rail began at the first bolt hole and progressed 4 3/4 inches to the second hole and 3 inches to the rail's end. The crack then progressed rapidly up through the head and down through the base. (See Figure 3.) Rubbing between the bolt holes and the end of the rail had deformed the surfaces of the crack. The other broken surfaces of the closure rail and the switch point were bright and contained a granular structure with a minimum of plastic flow which indicated a rapid brittle cleavage fracture. The broken head of the switch point was not found.

The ends of the rail heads adjacent to the broken portions of each rail had been battered. On the closure rail, the battered surface was 3/4-inch long by 5/16-inch deep.

There was a pattern of widely spaced fatigue failure marks on the fractured surfaces of the two heelblock bolts. Except for the fractured surfaces of the two heelblock bolts, there was little visible corrosion on the fractured surfaces. The corrosion on the bolts indicated that they had been exposed to water. However, it had not rained since the July 3 inspection.

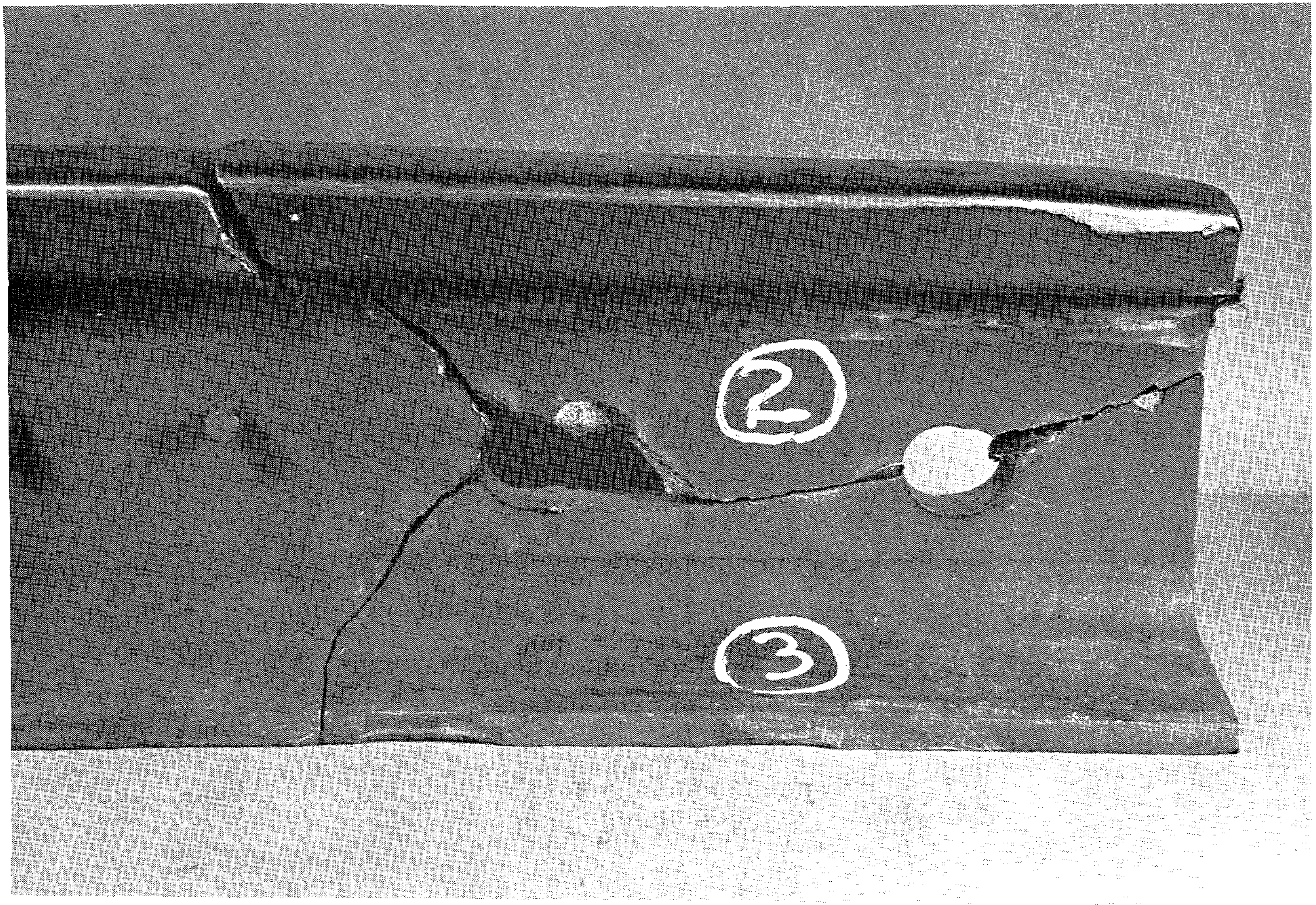

Figure 3. Closeup of bolt hole break in straight closure rail of switch.

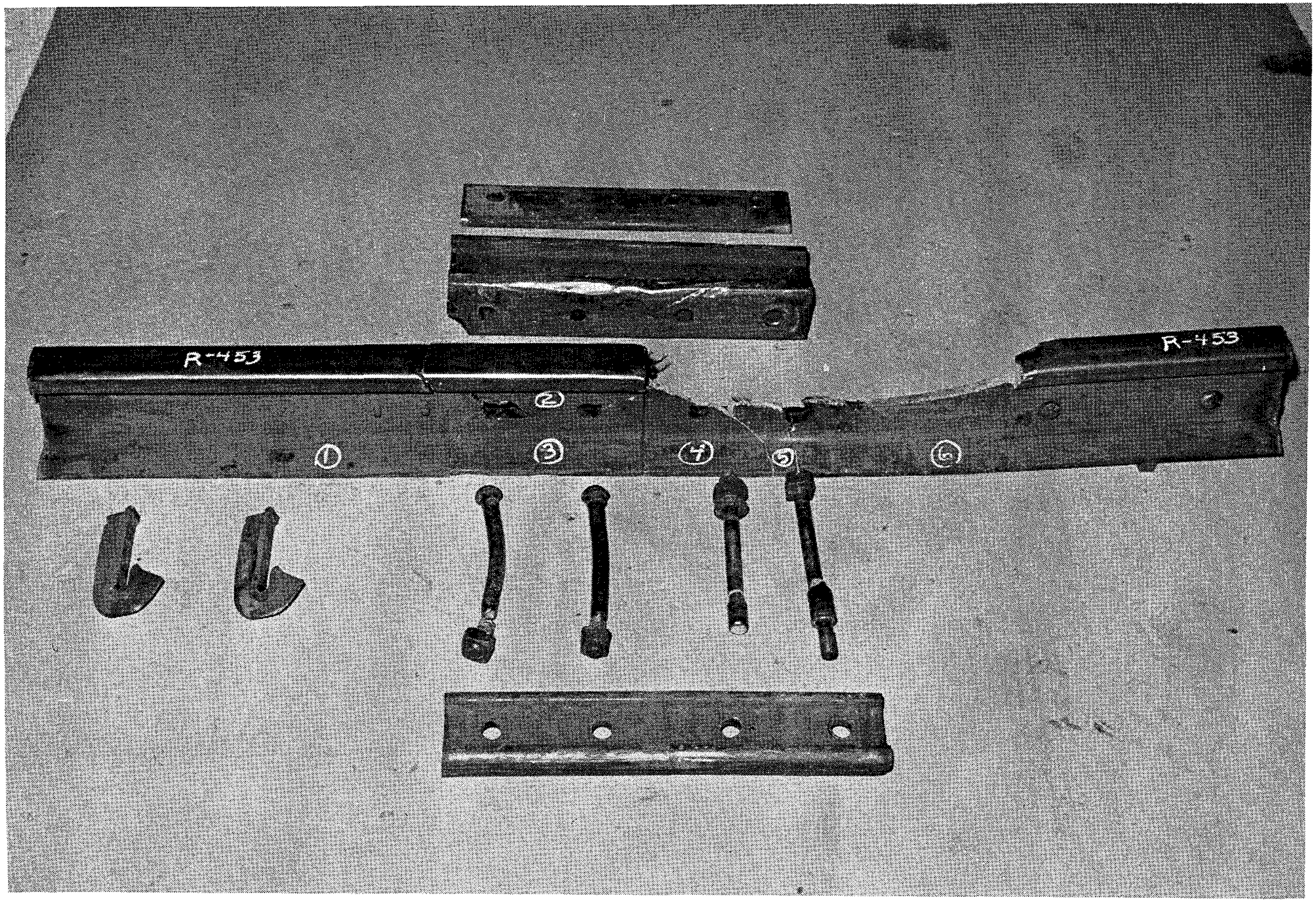

Figure 3A. Broken switch involved in derailment at Melvern, Kans., July 5, 1974.

Chemical, physical, and microstructure analyses were performed on the broken rail and on the heelblock bolts. (See Appendix A.) The tests of the rail indicated that it conformed to the required specifications. Tests indicated that one of the heelblock bolts was significantly softer than the other bolts and that its tensile strength was lower.

Wear marks on the underside of the base near the end of the closure rail indicated that the heelplate had provided uneven support. (See Figure 4.) Other support areas along the base of the switch point and the closure rail indicated that the plates had provided support evenly throughout the width of the base. However, in the area where the rail fracture initiated, support had been provided only along one side of the base.

ANALYSIS

The Accident

The examination of the broken closure rail disclosed that the original fracture between the bolt holes and the end of the rail had occurred before the accident. The fractured surfaces had been distorted from rubbing against each other. The other fractures of the closure rail and all of the fractures of the switch point were bright and well defined, which indicated that they were recent.

The batter marks on the head at the west end of the broken closure rail could not have been caused by the wheels of the derailing cars of eastbound train 4-C. In order to create such batter marks, it would have been necessary for the broken head portion of the closure rail to have been slightly displaced while a westbound train moved over the rail.

A westbound passenger train was the last train to use the south track before the accident. Therefore, the closure rail could have fractured completely during the passing of this train and the broken head, which was held in place by the joint bars, could have been displaced far enough to permit the wheels of the westbound train to strike and batter the end of the closure rail. The joint bars would have supported the broken piece of rail until the bolts broke.

Although signal systems are designed to detect broken rails, the extent of detection in the joint-bar area depends on the type of bond wire used to connect the rails electrically and how the wires are installed. In this case, the bond wire was connected to the rails at the outbound ends of the heelblock and spanned the heelblock joint. With this type of installation, a broken rail within the heelblock joint would not be detected by the signal system. Federal regulations do not require that the breakage of rail within the joint area be detected by a signal system.

The broken closure rail would not have been apparent to the engine crew as train 4-C approached the turnout. If the joint bars still sup-

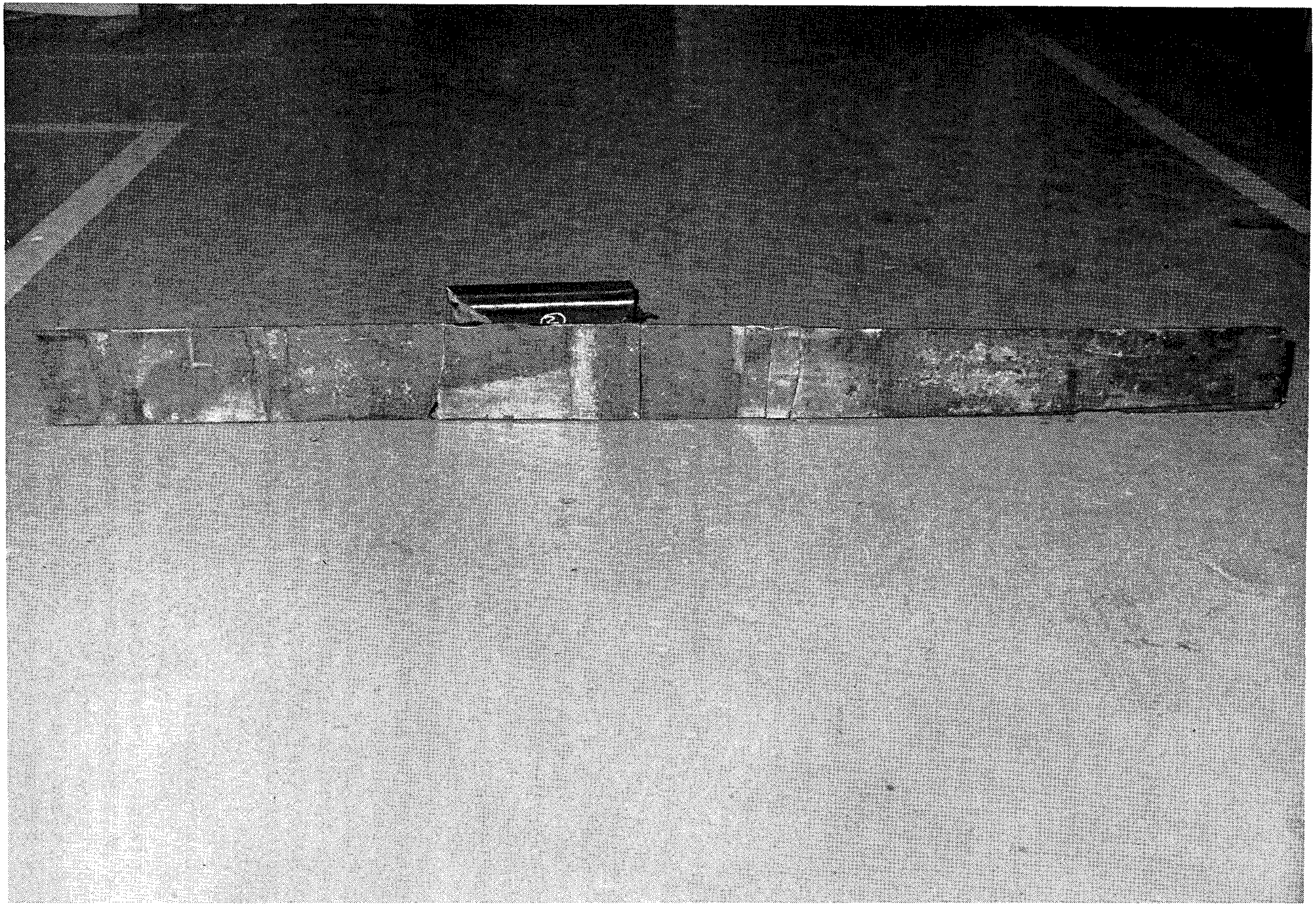

Figure 4. Base of broken switch showing rail support.

ported the broken rail when the forward portion of the train passed over it, the crew would have noticed little unusual noise or movement of the locomotive. As the train moved over the broken closure rail, the remaining heelblock bolts were probably broken, which allowed the broken head to be displaced from the rail. The oncoming wheels would have then dropped into the gap created by the displaced rail, struck the end of the switch point, and broken the switch point.

Based on the inspection of the forward portion of the train and on the marks on the wheels of Car 6, it was the first to derail. The wheels of Car 6 tore out the switch point, dropped between the rails, turned out the south rail, and caused the destruction of the track. Each of the following cars were derailed when they came to the broken rail. The failure of the south rail permitted the derailed cars to move toward the south bank.

Cars 6 through 12 were kept on the track structure because they remained coupled and the derailed wheels were confined between the damaged rails of the south track. Some of the wheels of the derailed cars rerailed. However, when Cars 13 through 18 derailed, the south rail had been pushed to the south bank, which permitted those cars to slide over the bank. As Cars 13 through 16 started over the bank, the excessive strain placed on the couplers at each end caused them to break and the train to separate. The separation permitted Cars 17 and 18 to roll down the bank.

The Broken Rail

On May 30, 1974, when the heelblock assembly and bolts were replaced, the track foreman's inspection of the closure rail did not disclose any cracks in the end of the rail or between the bolt holes. If his inspection was accurate, the closure rail cracked between May 30 and July 5.

Based on the examination of the track bolts after the accident, which disclosed that one of the bolts was softer and had a lower tensile strength than the other bolts, this bolt probably broke first and caused more stress to be placed on the other bolts. Of the two bolts that initially failed, the one with the lower strength showed evidence of a rapid fatigue fracture. The fractured surfaces of both bolts had corroded sufficiently to indicate that they had been exposed to water. These bolts would have had to break before the track inspection on July 3 since there had been no rain in the area between the dates of inspection and the accident. (At this location, the only plausible exposure to water would have been from rain.) The uneven support beneath the area may have resulted from a bent plate, a twisted rail or switch tie, or for several other reasons. No matter what the reason, however, the results would have been the same--additional stress would have been placed on the closure rail when a train passed over it. In turn, more stress would have been placed on the web of the rail at the bolt-hole area. The stressed condition could have been responsible for the original fracture. The wear pattern indicated that the condition had existed for some time.

On May 27, the heelblock bolts were found to be broken and loose, after which it was decided to replace the heelblock assembly. On July 5, the heelblock bolts were again found to be broken and loose, and the closure rail was broken. Apparently, heavy stress was present, which was not detected on May 27 and 30, or on July 3.

An experienced track foreman supervised the renewal of the heelblock assembly. The inspection of July 3 was performed by an inspector with over 30 years experience. Although the track was maintained as required and maintenance had not been deferred, a derailment resulted from a broken rail which was caused by an undetected defect that had existed for some time. The initiation of the bolt-hole crack and its progression to failure could not have been predicted because of the unevenly supported joint, but the continued heelblock wear and bolt breakage should have alerted someone that the joint was abnormal.

The Safety Board, in its Special Study, "Broken Rails: A Major Cause of Train Accidents," reported that from 1963 through 1972 broken rails caused 5,756 train accidents and that rail failure was the largest single cause of train accidents in 1972.

The study revealed the following with respect to failures in the joint area:

> "Welded Rail. Continuous welded rail helps to minimize rail failures. In 1971, 58.5 percent of the rail defects detected by the Sperry Rail Service were within the area of the rail enclosed by joint bars. FRA accident statistics indicate that from 1963 to 1972, 1,522 train accidents resulted from rail failure within the joint area or failure of the joint itself. In addition, derailments that result from improper gage or surface often occur at the rail joint, the weakest part of the rail structure."

The rail in this accident failed in the joint between two rails of the turnout. Even though the Santa Fe has many miles of continuous welded rail, so long as there still are jointed rails in use, this type failure can occur. During the investigation, the Santa Fe advised the Safety Board that it is attempting to design an all welded turnout for use in welded rail track, and thereby eliminate many of the existing joints in welded rail track.

Car Equipment

Passengers were thrown around in the four rear cars as the cars slid down the embankment. Inspection of the interior of the cars disclosed that many passenger injuries were caused by projections such as lights, fixed clothes hangers, and ash trays and by loose furniture. In some cars, the metal ceiling separated and produced sharp edges. Ceiling fixtures were torn loose and fell on passengers. The flagman, who was seated in a roomette in the rear car, was seriously injured when the ceiling light fixture was torn loose and fell on him. The Safety Board has addressed the need to eliminate the injury-producing fixtures in the interior of railroad passenger cars and has issued recommendations for their correction. 1/ Many of the passengers were in bed when the accident occurred and consequently were protected to some degree by bedding.

The exterior framing and sheathing of the cars were bent in some areas but still maintained their continuity. They had not been crushed. When the cars overturned, their batteries became inoperative and the lighting in the cars was lost. Therefore, the passengers were confined in total darkness.

There was no way for many of the passengers to escape from the sleeping compartments except through the compartments' sliding doors which led to the aisleway. It was especially difficult to open the doors since the cars were lying on their sides. However, after a door was opened, it was even more difficult to crawl along the aisleway because it was only 30 inches high.

In order to avoid a repeat of this situation, other routes of escape must be provided. If all cars were provided with the removable rubber molding for the windows, and if the information on its use were circulated to railroad and rescue personnel, ready access could be gained to the car from the outside. As more unbreakable plastic windows are installed, the problem of gaining access to the car under these circumstances becomes more severe. Since the rubber molding cannot be removed from inside the car, it is imperative that additional means of escape be provided.

FRA Track Standards

The FRA has no specifications for the size or quality of rails, track bolts, ties, tie plates, or any other items that are used in the construction of track. Instead, it relies on the industry to provide suitable material. In this accident, the heelblock bolt, which was found to be inferior, complied with the industry's requirements. In order to provide safe track, it is not only necessary to require that it be maintained to certain specifications, but it is also necessary to require that the various components be able to endure the stress to which they will be subjected. It does not seem feasible to require that rails be connected with at least two bolts in each rail and not require that they be a certain size or of a certain quality. In addition, the frequency of

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1/ Report Number NTSB-RAR-72-5, Derailment of Amtrak Train No. 1 while operating on Illinois Central Railroad near Salem, Illinois, June 10, 1971.

internal inspection is not based on the method of manufacture of the rail or on the size and quality of the material used. The same is true of the rails and of the requirements for internal inspection. The method employed in the manufacture, or the size and quality of the material, is not considered when the frequency of inspection is applied.

CONCLUSIONS

1. The original fracture of the closure rail, which was detectable for some time before the accident, began at a bolt hole, progressed to the other bolt hole, and proceeded to the end of the rail.
2. The closure rail was unequally supported throughout the width of its base.
3. One of the heelblock bolts installed on May 30, 1974, was softer and had a lower tensile strength than the other bolts used for securing the heelblock.
4. The heelblock bolts broke before July 3, 1974.
5. Observations of the closure rail of the turnout on May 30, 1974, did not disclose any fractures.
6. Inspection of the track on July 3, 1974, did not reveal the broken bolts.
7. Ready means to remove the plastic window panes from all cars are not provided.
8. Information on the method for removing the windows was not disseminated to railroad or emergency rescue personnel.
9. No emergency exits were provided.
10. No emergency lighting was available when the batteries failed.
11. The complete fracture of the closure rail occurred during the passing of a westbound train before train 4-C.
12. The broken head of the closure rail was displaced and the head of the switch point was broken when train 4-C passed over the turnout.
13. The fractured closure rail would not have been apparent to the engine crew on train 4-C.

14. The signal system did not warn the engineer of train 4-C of the broken rail.

15. The derailed cars remained in line until the tightlock couplers broke from the twisting action of the rear cars as they started over the bank.

16. Amtrak train No. 4-C was being operated according to Santa Fe procedures as it approached the turnout on which it derailed.

17. The tracks were maintained as required by Federal Track Safety Standards for Class 5 track.

18. The manufacture of the closure rail conformed to the industry specifications, except for minor deviations.

PROBABLE CAUSE

The National Transportation Safety Board determines that the probable cause of the accident was the broken closure rail of the turnout leading from the south main track to the siding. The insufficient strength of the track bolt and the apparent stressed condition of the rail contributed to the cause of the broken rail.

RECOMMENDATIONS

The National Transportation Safety Board recommends that the Federal Railroad Administration:

1. Develop, together with the railroad industry, a turnout that will eliminate as many bolted track joints as possible for use in welded track territory and develop a rail connection that will eliminate stresses which contribute to rail failures or separations at the joint. (Recommendation R-75-1)

2. Promulgate regulations to establish minimum standards for the size and quality of all components used in the construction of track. (Recommendation R-75-2)

3. Promulgate regulations to require that all passenger-carrying railcars be provided with emergency exits and with emergency lights that will function when regular power is lost. (Recommendation R-75-3)

The National Transportation Safety Board further recommends that Amtrak:

4. Install windows in passenger-carrying railcars that can be removed from the outside of cars, and instruct appropriate

railroad and emergency rescue personnel on the removal of the windows. (Recommendation R-75-4)

5. Require the installation of the latest practical crashworthiness features when rolling stock is renovated or when new cars and locomotives are purchased. (Recommendation R-75-5)

The Safety Board reiterates and reemphasizes the importance of the following recommendation made in a previous accident report to the Federal Railroad Administration which has not been fully implemented and is applicable to this accident:

Special Study Report NTSB-RSS-74-1, Broken Rails: A Major Cause of Train Accidents.

"4. Study the factors that affect rail failures and develop criteria that will promote effective rail inspection procedures and regulations." (Recommendation No. R-74-4)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JOHN H. REED
Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ ISABEL A. BURGESS
Member

/s/ WILLIAM R. HALEY
Member

Louis M. Thayer, Member, did not participate in the adoption of this report.

February 5, 1975

APPENDIX A

EXCERPTS FROM REPORT OF TESTS ON BROKEN RAIL

MRI

MIDWEST RESEARCH INSTITUTE
425 Volker Boulevard
Kansas City, Missouri 64110
Telephone (816) 561-0202

September 19, 1974

Atchison, Topeka and Santa Fe
Railway Company
Motive Power Building
1001 East Crane
Topeka, Kansas 66616

Attn: Mr. C. R. Kaelin, Director
Department of Technical Research and Development

Subject: Final Report on Railway Switch Failure Analysis (MRI Project No. 3967-E)

Dear Mr. Kaelin:

This report summarizes results and conclusions based on our analysis of a railway switch failure. As part of the analysis procedure, we have made mechanical tests, chemical analyses, and metallographic examinations of the switch components, and have performed fractography by optical and scanning electron microscopy.

This report is organized into six sections dealing with (1) the background and description of the switch and its operating environment, (2) analysis of component deformation, (3) the fracture surfaces, (4) metallurgy, (5) conclusions, and (6) recommendations.

I. Background - Description of Switch and Operating Environment

Switch failure has been reported to be the cause of derailment of an eastbound AMTRAK passenger train just east of Melvern, Kansas, on the morning of July 5, 1974.* Figure 1 shows a portion of a Santa Fe track chart identifying the derailment site. The failed switch was a part of a right-hand turnout from the south track. Figure 2 shows a diagram of the portion of the turnout involved and a plan view of such a switch. The circled portion Figure 2 is shown in exploded view in Figure 3 so that the components involved can be identified.

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* Train 4-C derailed at approximately mile post 78 + 4,940 ft.

The south track is a tangent track having a gentle downhill (easterly) grade of 0.3 degrees. Eastbound trains such as the derailed AMTRAK leave Curve 83-S (see Figure 1) at no more than 70 mph and approach the subject switch at no more than 80 mph. The derailed train is reported to have been traveling at approximately 78 mph.

Approximately 1 hr before the derailment, a westbound train* passed over the switch without incident.

The south track recently has carried 60-80% of the traffic (both east- and westbound). Annual traffic information is summarized in Table I along with estimates of traffic on the south track shortly prior to the derailment.

Analysis indicates that the primary fracture was a split web, near the end of the closure rail (very similar to Figure 11 of the standard AREA Rail Failure Report). The fractured closure rail had been laid new in October 1965. Records provided by Santa Fe indicate that the section of track was inspected recently before the derailment (see Table II) and a repair of the subject switch made only 36 days before the derailment.

Roadway maintenance records were not available at the time of this report, but the roadway at this point is reported to be stable with adequate drainage.

II. Component Deformation - Description and Interpretation

Fifteen components and major fragments of components were supplied to MRI for analysis. Figure 4 is a Santa Fe photograph of the recovered portions of the failed switch. The components can be identified by reference to Figure 3. All of these components and pieces were supplied to MRI except for small portions of some components which were used by Santa Fe in the pursuit of its own failure analysis.

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* Train 3-D.

Numerous dents and gouges were sustained by the components before, during or possibly after the derailment. A few of the deformations provide clues to the failure process.

The two pieces of rail--the closure rail (left in Figure 3) and the switch point (right on Figure 3)--show evidence of battering deformation at the crown adjacent to the fracture. The battering sustained by the fractured switch point is clearly the result of wheels striking the rail after jumping the gap produced by the rail fracture.

The deformation adjacent to the fractured crown of the closure rail (see Figure 5) is clearly the result of battering by wheels, but could not have been produced by eastbound traffic.* This battering was caused by westbound traffic and could only have occurred after the rail fracture was complete and piece No. 2 (Figure 5) has separated from the rest of the closure rail.

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* The deformation at the crown of the closure rail (Figure 5) consists of a depression on the order of 0.2 in. over a linear distance on the order of 1 in. In order for an eastbound train to produce such damage, its wheels would have had to have been able to follow such a depression, i.e., "fall" 0.2 in. in 1 in. distance while traveling at $\approx$ 80 mph. A simple calculation shows this to be impossible. The distance d fallen in time t due to an acceleration a is

$$d = 1/2\ at^2$$

If the speed of the train is v and the length of the deformed area is x, then

$$t = \frac{x}{v}$$

and

$$d \approx \frac{1}{2}\frac{ax^2}{v^2}$$

For $x = 1$ in., $V = 80$ mph, and $a = 32$ ft/sec^{-2} (acceleration of gravity), $d = 8 \times 10^{-6}$ in. In order for d to equal the observed 0.2 in., the acceleration would have to be $\approx 8 \times 10^5$ ft/sec^2 or $\approx 2.5 \times 10^4$ times the acceleration of gravity.

This observation indicates that this web fracture was complete when westbound train 3-D passed over the switch, but since train 3-D encountered no difficulty, the piece (No. 2 in Figure 5) was probably in place--restrained there by the joint bar and heel block (see Figure 3) on either side--during most of the passage. Evidence of severe rubbing (Figure 6) between pieces 2 and 3 (Figure 5) confirms that the two pieces were separate but in place for some time before the derailment.

Wear marks on the bottom of the rails (Figure 7) indicate where the rail was supported. Heel plates (see Figure 3) are normally located approximately 10 in. from the ends of the rails. The wear pattern on the switch point (right hand side Figure 7) indicates a broad area had been supported evenly by the heel plate. However, the wear pattern on the closure rail suggests an uneven support. In the absence of adequate base support, the wheel loads would be carried by the supporting heel block and joint bar (see Figure 3), but with resultant extra stress on the track bolts.

III. Fracture Surfaces - Description and Interpretation

Both rails and all four bolts were fractured. These fracture surfaces were carefully examined by optical and scanning electron microscopy (SEM).

The fracture surfaces of both track bolts exhibited fatigue striations which were visible at low magnification (Figure 8). The spacing of these striations range from approximately 0.002 to 0.070 in. Scanning electron microscopy (Figure 9) shows the nature of the striations in more detail and confirms that no finer striations are present between those which are visible optically. The fracture surface is typical of ductile fatigue fracture with fine dimples covering the space between striations (Figure 10).

Four portions of the web fracture in the closure rail were removed and carefully examined by SEM. Figure 11 shows a typical area with parallel wear marks caused by the rubbing action between the two mating fracture surfaces.* Other portions of the surface are covered by corrosion products (Figure 12).

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* Such wear marks were originally misinterpreted as fatigue striations when examined by optical microscopy.

Portions of the closure rail web fracture have a brittle fracture appearance (arrows in Figure 5). One such area was examined by SEM and found to have faceted grains with "river patterns" unmistakedly indicating fast, brittle fracture (Figure 13). All of the fracture surfaces on the switch point have the same appearance of brittle failure.

No evidence of fatigue was found on any of the web fracture surfaces. However, such evidence could have been obliterated by the rubbing action between the mating fracture surfaces.

There was very little visible evidence of corrosion on most of the fracture surfaces. This fact suggests that all of the fractures (even the fatigue fractures) were fairly recent. However, an interesting contrast exists between mating fracture surfaces of the two track bolts. The fracture surfaces on the threaded ends of these bolts are much more severely corroded than the mating fracture surfaces on the remaining portions of the bolts (see Figure 8). Only if the bolt end fragments had lain in water for some time would they have been so much more highly corroded than the mating fragments. Since the last rain in the area occurred on July 3, the fact that the bolt end fragments are more heavily corroded suggests that the bolts were fractured on or before July 3.

IV. Metallurgy and Mechanical Tests

Chemical analyses and tensile tests were performed on both the closure rail and the switch point rail. Results are listed in Tables III and IV.

The chemical analyses indicated slightly high carbon and silicon contents. However, these deviations from AREA standard are not believed to be significant.

The tensile properties of the rail steel were typical. The elongation of the tensile specimens indicated acceptable ductility.

The track bolts had been sectioned before receipt at MRI and were too short for tensile testing, so hardness measurements were made on their cross sections. The track bolt No. 1 (see Figure 4), was significantly softer than the rest (R_c 21 compared to R_c 26 for the other track bolt and R_c 32 and 28 for shoulder bolts 1 and 2). From the hardness values, we estimate the tensile strengths to be 110, 125, 130, and 145 ksi for track bolts 1 and 2 and shoulder bolts 1 and 2, respectively.* The 110 ksi tensile strength for track bolt No. 1 is unusually low and suggests that it may have been the "weak link" in the switch structure.

The rails and track bolt No. 1 were examined metallographically. Figure 14 shows the unetched microstructure in the closure rail near the web fracture. Silicate stringers and MnS particles are evident. Figure 15 shows the etched microstructure in the same sample at high magnification. The steel is clearly pearlitic throughout with ferrite/cementite spacing $\sim 30 \times 10^{-6}$ in. The microstructure of the switch point rail was virtually identical. None of the observations suggested any fault in the microstructure or mechanical properties of the rail steel.

Figure 16 shows the etched microstructure of the track bolt No. 1. The structure is primarily pearlitic with a significant volume of ferrite grains. The fine spacing (barely resolvable) within the pearlite indicates a low undercooling temperature during the transformation to the pearlitic structure.

V. Conclusions

There is insufficient evidence to determine the nature of the failure process with any certainty. Some observations do suggest important aspects of the process, however.

For example, track bolt No. 1, which failed by ductile fatigue fracture, has an abnormally low hardness. This component may have been the first to fail. The other track bolt also fractured part through by fatigue; and both were apparently fractured for some time before the derailment.

The nature of the web fracture in the closure rail is obscured by the deformation suffered after fracture. It is clear however, from this rubbing damage that this fracture too occurred sometime before the derailment.

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* Based on the approximate relation between hardness and tensile strength in ASTM Standard A370-65.

Wear marks on the underside of the closure rail indicate uneven support was provided by the heel plate. Such uneven support may have contributed to the failure of the track bolts and possibly to the web fracture in the closure rail. It is even possible that faulty support had caused the bolt fractures which necessitated switch repair on May 30, 1974 (see Table II) and that this same problem caused the subsequent failure; but this speculation cannot be supported by hard evidence.

If we assume that the closure rail web fracture is a fatigue fracture, then we can advance the following hypothesis:

The failure was a case of fatigue fracture caused by wheel loads. Such loads were able to initiate and propagate a web crack in the closure rail because of abnormal conditions of support at the end of the closure rail.

This sequence of events is suggested

- Fatigue cracking begins in the web of the closure rail at a bolt hole.
- Fatigue cracking also begins in the track bolts because of the same abnormal load conditions.
- In a relatively short time, the web fracture spans the distance between the bolt holes and extends to the end of the rail.
- The track bolts fracture days before the derailment.
- The closure rail fracture is completed shortly before the derailment (probably during passage of the westbound train 3-D on July 5).
- The receiving end of the switch point rail is battered by the front portion of the eastbound train 4-C on July 5.
- The shoulder bolts fracture allowing the joint bar to fall away.
- The unsupported switch point fractures under continued battering.

- A gap about 3 ft long is created in the rail by the fractures.
- Derailment occurs.

VI. Recommendations

On the basis of our analysis, which does not provide a clear picture of the switch failure process, we can only suggest procedures which are of speculative value in preventing such accidents in the future.

One recommendation is to preserve fractured bolts removed during switch repairs and to have them examined for evidence of unusual damage. If, for example, the track bolts removed during the repair operation on May 30, 1974, had shown evidence of rapid fatigue cracking as did those removed after the derailment, then a serious structural defect other than a "worn block" (see Table II) would have been indicated and a subsequent inspection called for.

A second recommendation is to place more emphasis on inspection for proper placement of rail supports such as heel plates.

Sincerely,

MIDWEST RESEARCH INSTITUTE

David K. Benson

David K. Benson
Senior Physicist

Approved:

F V Morriss

F. V. Morriss, Vice President
Scientific Affairs

TABLE I

TRAFFIC INFORMATION

Tonnage (gross) in Millions

Year	Eastbound	Westbound	Total
1966	31.2	28.8	60.0
1967	30.2	27.5	57.7
1968	29.6	27.6	57.2
1969	29.5	27.5	57.0
1970	28.0	26.8	54.8
1971	28.0	27.6	55.6
1972	28.8	29.2	58.0
1973	29.1	30.1	59.2
		Average	57.4

Note: The south track carries more than 60% and at times as much as 80% of the total traffic. If 80% of annual average was carried on the south track in 1974, then as much as 1.2×10^5 tons per day or $\sim 5 \times 10^3$ wheels per day could pass over the rail.

TABLE II

TRACK INFORMATION

Installation date - 136 lb/yd "RE"* continuous welded rail; laid new 10/65.

Inspection dates and type of inspection -

Prior to accident, last	Audigage inspection	3-27-74
	Rail Detector Car inspection	11-15-73
	Track Geometry Test Car inspection	3-11-74
	Track Supervisor inspection	7-3-74

Repair dates and type of repair--new heel block assembly installed 5-30-74, after finding on 5-27-74 that three bolts needed replacement and deciding this was due to worn block.

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[*] "RE" - Railway Engineers Association approved rail.

TABLE III

CHEMICAL ANALYSIS OF RAIL

(weight percent)

Sample	Carbon	Manganese	Phosphorus	Sulfur	Silicon
Closure Rail (near fracture)	0.81	0.89	0.013	0.036	0.26
Closure Rail (remote end)	0.83	0.90	0.012	0.035	0.25
Switch rail	0.83	0.91	0.012	0.033	0.26
AREA Standard*	0.69-0.82	0.70-1.00	max 0.04	max 0.05	0.10-0.25

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* American Railway Engineering Association Specifications for Steel Rails - ladle analysis for 121 lb/yd and heavier rails.

TABLE IV

Summary of Mechanical Tests Results

	Tensile			Hardness
Sample	Yield (0 2% offset) (Ksi)	Ultimate (Ksi)	Elongation (in 1-in) (percent)	(Rockwell C)
Switch Point Web (transverse)	86	139	10 3	29
Closure Rail Web (longitudinal)	89	144	9 1	31
Closure Rail Web (transverse)	78.6	141	9.6	31
Track bolt No. 1				21
Track bolt No. 2				26
Shoulder bolt No. 1				32
Shoulder bolt No. 2				28

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July 26, 1974

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

Attention: Mr. David K Benson

Purchase Order Number 14690
Laboratory Control Number 74-288

Subject: Three (3) samples of RR track steel
Sample designation Numbers 1, 2 and 6

Requested: Chemical Analysis: Carbon, Manganese, Sulfur, Phosphorus and Silicon

RESULTS

Element	Concentration %		
	Sample Number 1	Sample Number 2	Sample Number 6
Carbon	0.83	0.81	0.83
Manganese	0.91	0.89	0.91
Sulfur	0.035	0.036	0.033
Phosphorus	0.013	0.012	0.012
Silicon	0.25	0.26	0.26

Sincerely,

JAMES W. WELDON LABORATORY, INC.

Donald C Krenkel

DCK:pms

SPECTROGRAPHIC ANALYSES ◦ CHEMICAL ANALYSES ◦ PHOTOMICROGRAPHS ◦ MACROGRAPHS ◦ ENGINEERS ◦ METALLURGISTS
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