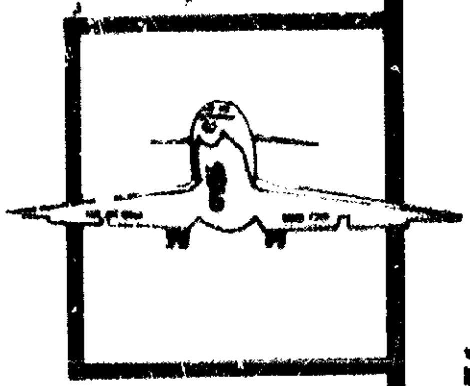
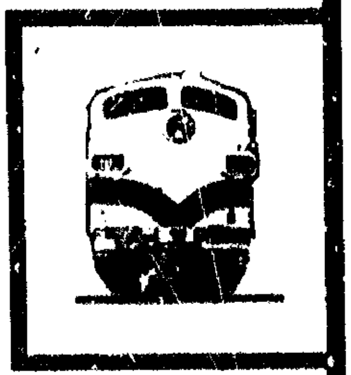
PB 277 961

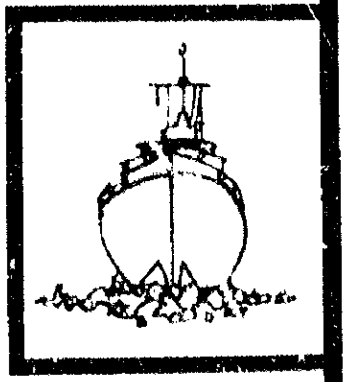


NATIONAL TRANSPORTATION SAFETY BOARD



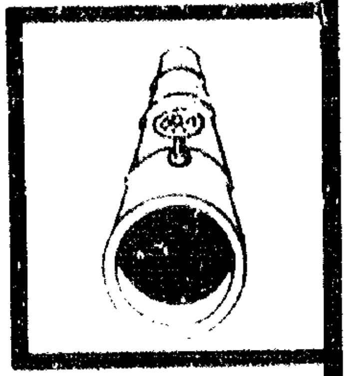
WASHINGTON, D.C. 20594

RAILROAD ACCIDENT REPORT



REAR END COLLISION OF TWO CHICAGO TRANSIT AUTHORITY TRAINS

CHICAGO ILLINOIS



FEBRUARY 4, 1977

REPORT NUMBER: NTSB-RAR-77-10

UNITED STATES GOVERNMENT

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. NTSB-RAR-77-10	2. Government Accession No.	3. Recipient's Catalog No. PB277961

4. Title and Subtitle Railroad Accident Report - Rear End Collision of Two Chicago Transit Authority Trains, Chicago, Illinois, February 4, 1977	5. Report Date November 29, 1977
	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. 2111A
	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 February 4, 1977
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

About 5:27 p.m., c.s.t., on February 4, 1977, Chicago Transit Authority Lake-Dan Ryan train No. 930 struck the rear of Ravenswood train No. 415, which was standing on the elevated rail structure at the intersection of Wabash Avenue and Lake Street. The four lead cars of the eight-car Lake-Dan Ryan train overturned and fell from the elevated structure to the street. One end of each of the two rear cars of the Ravenswood train derailed. Eleven persons were killed and 266 persons were injured. Property damage was estimated to be $1.2 million.

The National Transportation Safety Board determines that the probable cause of this accident was the failure of the motorman to exercise due care in meeting his responsibilities and the unauthorized operation of the Lake-Dan Ryan train into a signal block occupied by the standing Ravenswood train, at a speed that was too fast to stop after the operator sighted the standing train.

As a result of its investigation of this accident, the National Transportation Safety Board made four recommendations to the Chicago Transit Authority.

17. Key Words Rapid transit; elevated; automatic train control; overspeed control; cab signals; AF track circuits; magnetic track brakes; restricted speed; third rail power; emergency lights; ejection through windows.	18. Distribution Statement This document is available to the public through the National Technical Information Service, Springfield, Virginia 22152

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	38	PC A03 MF A01

NTSB Form 1765.2 (Rev. 9/74)

CONTENTS

	Page
SYNOPSIS	1
INVESTIGATION	2
The Accident	2
Injuries to Persons	8
Damage to Trains	8
Crew Information	8
Train Information	9
Method of Operation	10
Meteorological Information	13
Survival Aspects	13
Tests and Research	14
Other Information	15
ANALYSIS	15
CONCLUSIONS	20
Findings	20
Probable Cause	21
RECOMMENDATIONS	21
APPENDIXES	23
Appendix A - Excerpts from CTA brochure "Cab Control Signalling"	23
Appendix B - Mathematical Analysis from IITRI	24
Appendix C - CTA Bulletin S-511-76	26
Appendix D - Wabash-Lake Curve Data	28

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

RAILROAD ACCIDENT REPORT

Adopted: November 29, 1977

REAR END COLLISION OF TWO CHICAGO TRANSIT AUTHORITY TRAINS CHICAGO, ILLINOIS FEBRUARY 4, 1977

SYNOPSIS

About 5:27 p.m., c.s.t., on February 4, 1977, Chicago Transit Authority Lake-Dan Ryan train No. 930 struck the rear of Ravenswood train No. 415, which was standing on the elevated rail structure at the intersection of Wabash Avenue and Lake Street. The four lead cars of the eight-car Lake-Dan Ryan train overturned and fell from the elevated structure to the street. One end of each of the two rear cars of the Ravenswood train derailed. Eleven persons were killed and 266 persons were injured. Property damage was estimated to be $1.2 million.

The National Transportation Safety Board determines that the probable cause of this accident was the failure of the motorman to exercise due care in meeting his responsibilities and the unauthorized operation of the Lake-Dan Ryan train into a signal block occupied by the standing Ravenswood train, at a speed that was too fast to stop after the operator sighted the standing train.

INVESTIGATION

The Accident

Chicago Transit Authority (CTA) train No. 415 (Ravenswood) left Kimball Terminal at 4:35 p.m. on February 4, 1977. The train consisted of six 6,000-series, self-propelled cars. The trip to downtown Chicago was routine and about 5:22 p.m. the train passed Tower 12 onto the northbound track on the east side of the elevated track structure 1/ over Wabash Avenue. (See figure 1.) When the train departed the Randolph Street Station and entered the curve at Wabash Avenue and Lake Street, the cab signal changed from a yellow aspect to a red aspect, because of a train ahead. After the Ravenswood train stopped, the red aspect changed to a flashing red aspect. The motorman knew that the reason for the red signal aspect was a train ahead and, in accordance with CTA rules, he kept his train standing at that point with the parking brakes applied and waited for a proceed signal. The curve begins 18 feet past the Randolph-Wabash Street Station.

CTA train No. 930 (Lake-Dan Ryan) departed the 95th Street Terminal on the West-South Line at 5:01 p.m. It consisted of eight 2,000-series, self-propelled cars and was operated by a motorman and a conductor. There were no known equipment defects. The train made regularly scheduled stops en route to downtown Chicago with no reported problems. At Tower 12, the Lake-Dan Ryan train followed the Ravenswood train onto the elevated track structure. The motorman saw the Ravenswood train ahead with its lighted marker lights. Following his usual procedure, the motorman operated his train so that it was one station behind the Ravenswood train. He said that he saw the Ravenswood train when it left the Randolph Street Station and passed through the curve at Wabash Avenue and Lake Street.

According to the motorman's testimony, "When I stopped at Randolph, I did not see the train prior to my stopping at Randolph and Wabash. I thought he was in State and Lake because I felt assured that he had already cleared the curve because I did not see him in the curve." He also knew from experience that a Ravenswood train would be diverted to another route at Tower 18 and that it would no longer be of concern to him.

When the Lake-Dan Ryan train entered the Randolph Street Station, just south of the curve, the cab signal aspect should have changed from a "yellow 35" to a "yellow 15" which would have allowed a maximum speed of 15 mph. However, when the train passed the four-car mark on the

1/ The structure forms approximately a 2-mile "loop" around several blocks in downtown Chicago. There are two parallel tracks on the structure.

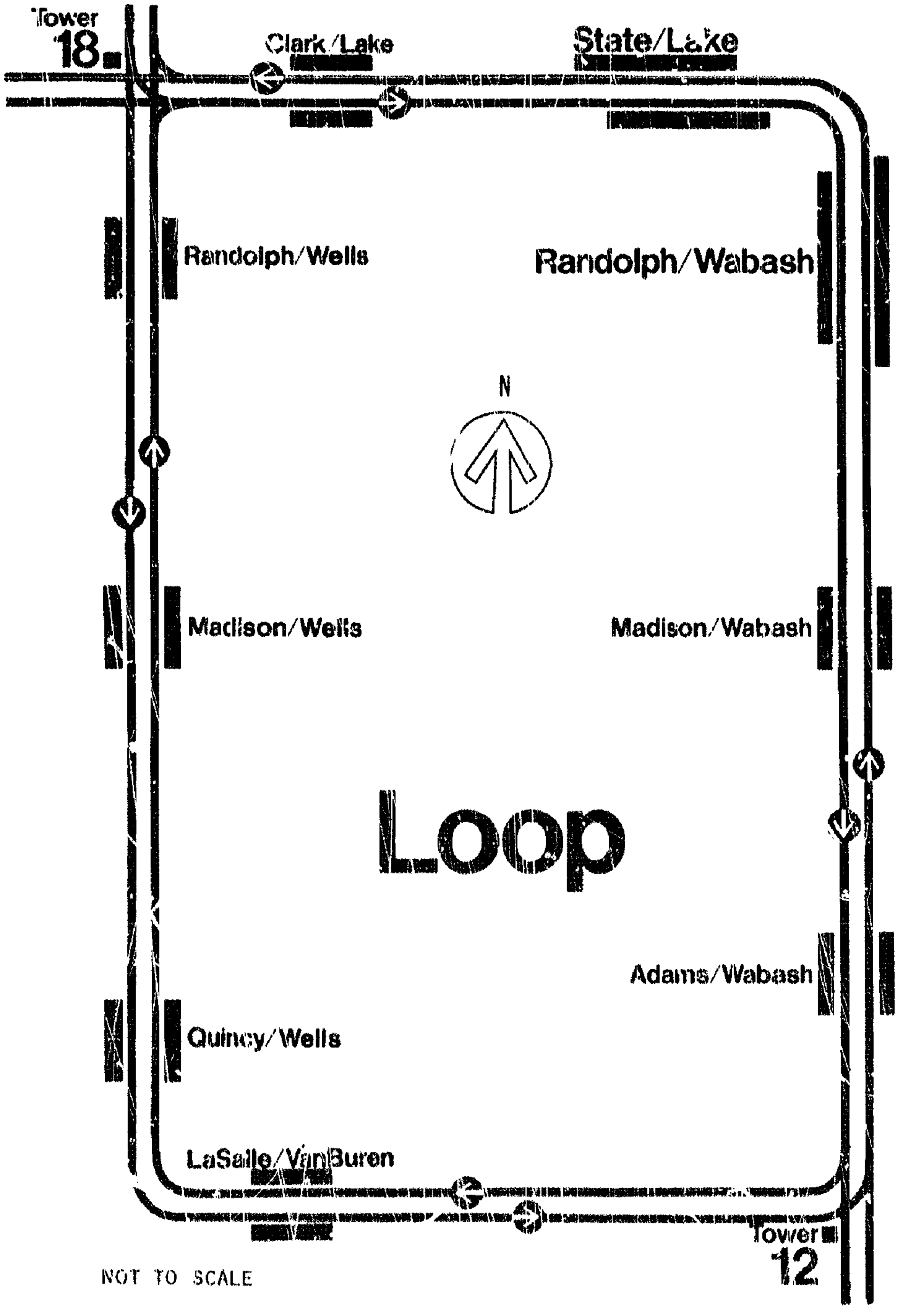


Figure 1. Plan of elevated track structure.

platform, the motorman said that the cab signal changed directly from a "yellow 35" to a flashing red aspect and that he did not hear an audible overspeed alarm. He continued moving into the station and stopped the train at the eight-car mark.

When the conductor signalled him to proceed, the motorman applied minimum power and moved out of the station with the cab signal displaying a flashing red aspect; he did not receive authorization to proceed from CTA central control. He stated later that he believed that he was not required to obtain permission to move on the flashing red cab signal because there were other locations on the CTA system where a train could be operated on a flashing red cab signal without first having to obtain permission. He also cited a CTA training brochure on "Cab Control Signalling" which does not state that operators must obtain permission to move on a flashing red cab signal as giving him authority to move. (See appendix A.) According to his testimony, he believed that a flashing red cab signal aspect was the best proceed signal that he could obtain because he said that it was the only signal he had ever received at Wabash Avenue and Lake Street. He also stated that he did not know of a "yellow 15" cab signal aspect, but that he was familiar with a "yellow 25" aspect. A "yellow 25" cab signal aspect is not used on the West-South Line.

When the Lake-Dan Ryan train entered the offset curve (see figure 2) to the right at a speed of about 10 mph, the motorman moved the cineston 2/ to the coast position. This is a normal operating procedure. He was standing at the car controls, as CTA operating rules required. When the train entered the curve to the left, the motorman saw the rear car of the standing Ravenswood train. He claimed that this was his first view of the train since before he entered the Randolph Street Station. He also said that his view from within the operating compartment was obstructed by the windshield wiper motor, the door at his left, and the trainphone equipment. He further stated that he could not have seen the rear of the Ravenswood train from his location in the cab before he entered the curve, because the train was hidden from his view by a building in the southwest corner of the intersection. (See figure 2.) When he sighted the train, he testified that he immediately applied the maximum service brakes; he claimed they were not effective, however. He then applied the emergency brakes. He said he heard the magnetic track brakes drop but that the train still did not seem to slow, and it struck the Ravenswood train at 7 to 9.5 mph. (See appendix B.)

2/ The cineston control lever is rotated in a horizontal plane to apply power or brakes or to allow coasting. The lever must be kept depressed while the train is moving; if released, the brakes automatically apply in emergency.

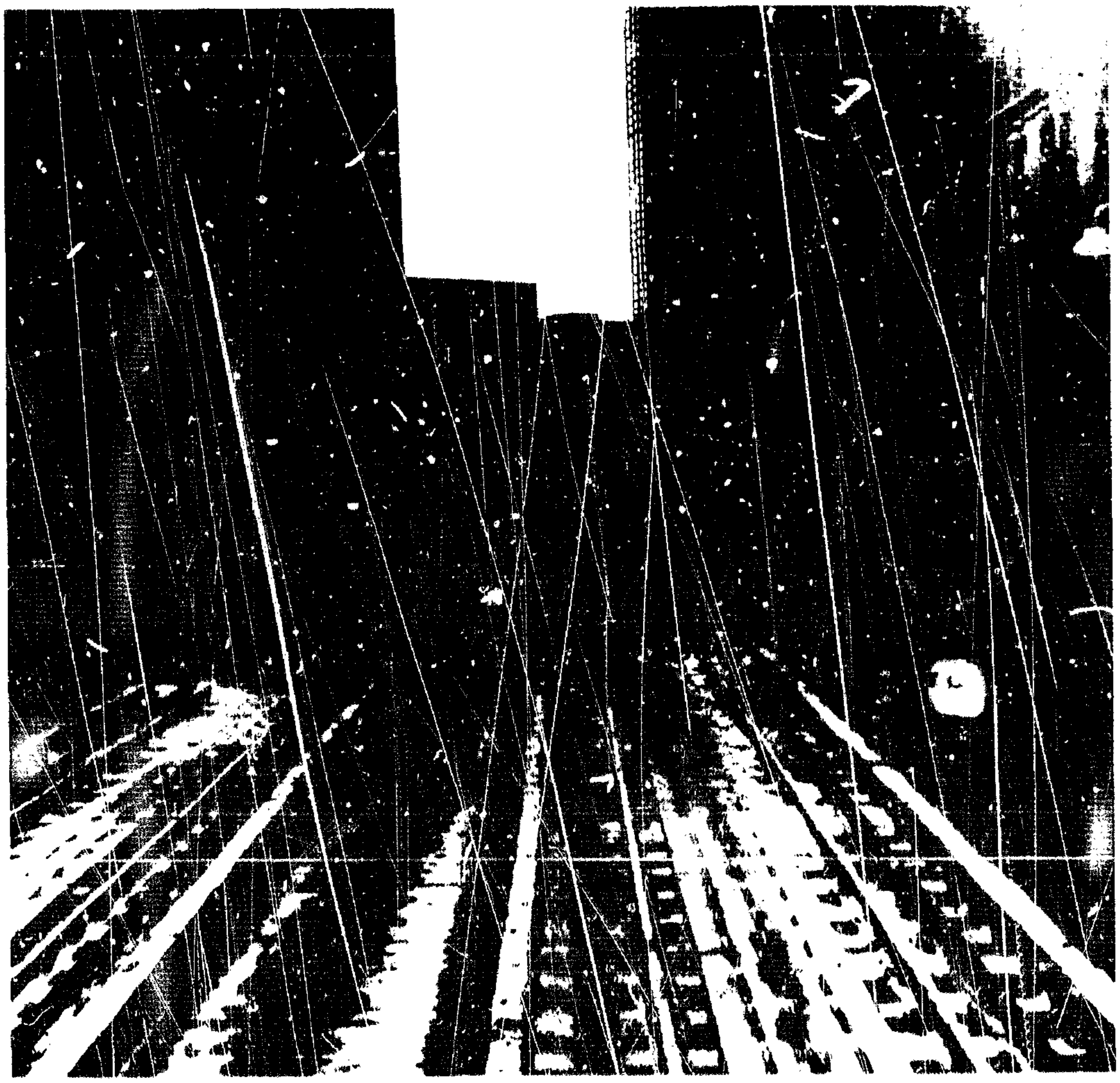


Figure 2. View of curve at Lake and Wabash from 250 feet south of collision point.

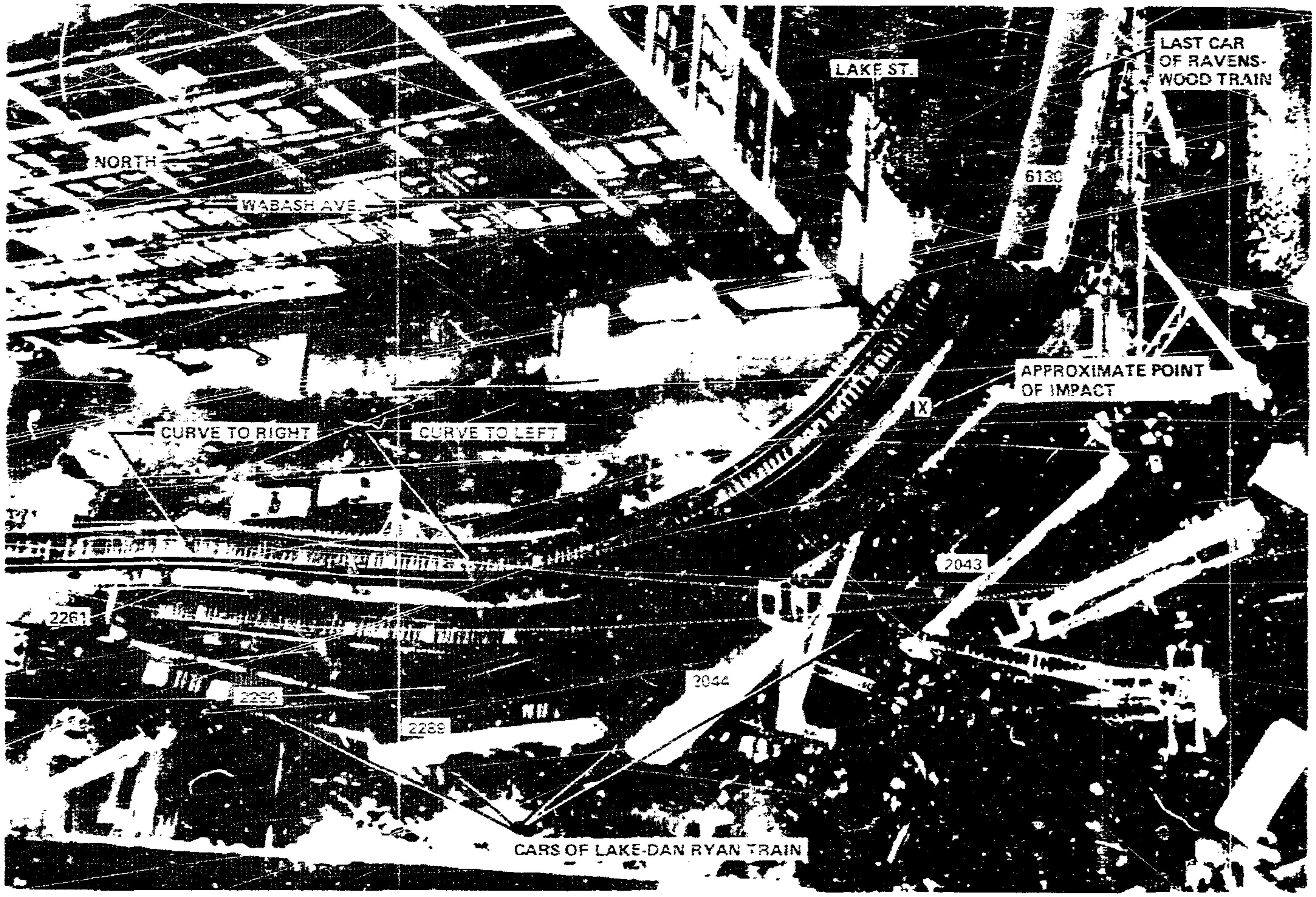


Figure 3. Aerial view of accident site.

Upon impact, about 5:27 p.m., the first car of the Lake-Dan Ryan train began rocking slowly from side to side, moved slightly back, and then fell from the track structure. Several witnesses reported seeing a high-intensity, electrical arc flash and hearing a loud noise at that time. The next three cars reportedly stopped and then turned over slowly and fell from the elevated structure. (See figure 3.)

Train propulsion power, which was supplied by a third rail, was not interrupted completely at the time of the accident. Electric power is fed to a power section from both ends but only one circuit breaker for the power section on the outer track opened momentarily at 5:27 p.m. at the time of the accident. Power was ultimately cut off for both tracks about 5:46 p.m. One southbound train on the inner track passed the accident site about 10 minutes after the derailment. The motorman of that train moved past the site under the direction of a company official, although the central controller had ordered all trains in the area to stop and remain standing.

The motorman of a train following the Lake-Dan Ryan train operated his train to within an estimated one-car length of the rear car of the derailed train. He said he was able to move that close on a cab signal indication which he identified as an "amber 15 or yellow 15."

The accident occurred at the northeast corner of the "loop" where the elevated track structure turns west from Wabash Avenue to Lake Street. (See figure 1.)

The tracks are laid on an elevated steel structure approximately 21 feet above the street. Six hundred volts d.c. electrical power is supplied by a third rail for propulsion on each track. The 6-inch by 8-inch crossties are laid on steel girders which form part of the elevated structure. The 90-pound, 33-foot rails for the main tracks rest on 10-inch, flat, single-shoulder tie plates. Each rail is fastened with two spikes per crossties and was laid in 1967. There are two 6-inch by 8-inch timbers secured on the ends of the crossties on the outside of each track, perpendicular to each crosstie. The main tracks are standard 4-feet 8 1/2-inch gage but the curve at Wabash and Lake is one-quarter inch wider.

Between the running rails in the curve are two supplemental rails. A horizontal restraining rail bent to the radius of the curve is mounted along the inside of the low rail. It is laid on its side with a nominal spacing of 1 7/8 inches from the running rail. The back of the car wheel contacts the restraining rail so there will be added resistance against centrifugal force. Another guard rail is located 7 inches from the outside of the high rail to protect against derailment.

A wheel flange lubricator is located 160 feet south of the point of impact. There was no excess of lubricant observed on either the sides or the tread surface of the rails.

Injuries to Persons

Injuries	Crewmembers	Passengers	Others
Fatal	0	7	4
Nonfatal	2	266	unknown
None	2	unknown	unknown

Damage to Trains

The damage to the Ravenswood train was minor. The end sill of the rear car was slightly damaged. The initial point of contact on the rear car was just to the left of the car center. The rear trucks of the fifth and sixth cars were derailed. The train was moved forward approximately 25 feet by the force of impact. There were no derailment marks south of the point of the impact.

The first four cars of the Lake-Dan Ryan train fell from the elevated structure. The first and third cars landed on their right sides in the street. The second and fourth cars each stopped with one end suspended on the structure and the other end on the street. The front truck of the fifth car was derailed. The major damage to the four leading cars of the Lake-Dan Ryan train resulted from their fall from the elevated structure. The impact caused broken glass and bent car frames and car bodies. The track brakes and traction motors were broken or bent. Stanchions and seat backs were bent and some seats were pulled loose from the floor probably as a result of passengers striking them. The remainder of the cars were undamaged.

The total estimated damage to the equipment was $1,138,584.

Crew Information

The motorman of the Lake-Dan Ryan train was employed by the CTA on September 6, 1968. He attended a CTA training program before being advanced to the position of motorman on May 14, 1969, and to switchman on November 11, 1970. His last physical examination was October 29, 1976. He had prescription glasses for reading, but he was not required to wear them while on duty or by Illinois State law while operating a motor vehicle. He was not wearing glasses at the time of the accident. He operated the Lake-Dan Ryan train on Fridays only; he operated trains over another line on other day.

The motorman's operating record contained several rule violations, such as not being on train at scheduled time; improperly displaying the front marker lights; not securing safety chains; improper use of emergency brakes; rough stops; wearing an improper uniform; reading while train was in motion; and failing to stand in cab at required locations. In two instances he operated past a stop signal; the train derailed in one case. He had been reinstructed in operating rules several times and he had been suspended from duty at times because of rule violations. One accident was attributed to him. His record contains at least one commendation for alertness and his work record had shown some improvement during 1975. The motorman indicated that he had rested well the night before the accident, and that he was not under any emotional or mental stress at the time.

The Amalgamated Transit Union contract with the CTA covers the Lake-Dan Ryan motorman. The contract limits the use of an employee's discipline record to 1 year for disciplinary purposes.

According to information received from the Chicago Police Department, four marijuana cigarettes were allegedly found in a handbag belonging to the motorman of the Lake-Dan Ryan train after the accident. He voluntarily submitted blood and urine samples for analysis. The blood tests were negative for alcohol, barbiturates, and amphetamines. The urine samples were submitted to two laboratories for analysis. One laboratory showed traces of THC [3/] in the urine. The second laboratory failed to detect anything unusual on its first test. A second test, performed after the laboratory's instruments were recalibrated, detected the presence of THC. Neither laboratory could determine how long before the accident the marijuana had been ingested.

Train Information

Each CTA train has at least one set of two cars which are connected semi-permanently. Each end of these two-car sets has energy-absorbing, automatic, electric couplers. The draft arrangements at the ends of each car are designed so that when compression or buff forces exceed 125,000 pounds, bolts are sheared and the draft gears compress; this allows the anti-climbers located on the car ends to engage.

The cars on the Ravenswood train were manufactured by the St. Louis Car Company about 1950. The train weighed about 312,000 pounds. The end posts were designed to absorb energy by yielding and deforming

---

3/ THC is the abbreviated signature for a metabolite delta-9-THC-acid found in human urine after ingesting delta-9-tetrahydrocannibinol, the active substance found in marijuana.

rather than by breaking away from their attachment to the frame. The interior of the cars had cushioned seats which faced both ends of the cars. The seat backs were covered with padding and were enclosed by tubular steel frames which served as handholds on top of the seats. Vertical stanchions were located at the doors and at several seat locations throughout the cars. There were two sets of doors on each side of the cars located about one-fourth car length from each end.

The cars on the Lake-Dan Ryan train were manufactured of stainless steel by the Budd Company in 1969 and 1970 and were similar to those in the Ravenswood train. The train weighed about 360,000 pounds.

The equipment of both trains was propelled electrically by traction motors on each truck. The primary braking mode was electro-dynamic. The drive shafts of each car were provided with a friction disc brake that automatically operated below 5 mph and in emergency braking. Magnetic track brakes were also provided for emergency braking.

The two trains were equipped with either four or six emergency lights per car which were operated from the train batteries. In some instances battery power was train-lined between the two cars because only one car was equipped with batteries.

Method of Operation

Trains on the east and north sections of the elevated "loop" are operated by cab signal indications of an automatic block signal system and by an automatic train control system (ATC) provided with overspeed control. The cab signal aspects and their indications are:

Color Displayed by cab signal	Indication	Maximum speed indicated by illumination of yellow light on speedometer
Green (not presented in "loop" area)		
Yellow	Two blocks ahead are unoccupied.	35 mph
Yellow	Block ahead is unoccupied; second block is occupied; or Special speed restrictions.	15 mph

Color displayed by cab signal	Indication	Maximum speed indicated by illumination of yellow light on speedometer
Red	Block ahead is occupied. Stop.	(no speed indicated)
Flashing Red	Block ahead is occupied; stop. After obtaining permission from controller, train may proceed at a restricted speed.4/	15 mph (flashing)

CTA bulletin S-511-76, issued December 8, 1976, and reissued on February 7, 1977, (see appendix C) requires that a train be immediately stopped on receipt of a red cab signal and that it not proceed on either a steady red or a flashing red cab signal without the operator first obtaining permission of the central controller. However, the bulletin did not supersede or annul any part of CTA training brochure "Cab Control Signalling." There are several locations on the CTA system where the only cab signal to proceed is a flashing red indication because the present track facilities cannot be adapted to give other signal aspects. Those locations are governed by special instructions permanently posted at those points. There are no such locations on the West-South Line.

The central controller has operational control over all trains. He monitors the passage of trains past specific points by means of time-synchronized pen charts, and directs train movements in the event of trouble. He contacts the train by means of the trainphone system.

The cab signals and ATC receive command signals from audio frequency transmitters along the track at the exits of signal blocks. In the "loop" area the signal blocks average about 300 feet. The signal system in the "loop" is designed so that there is at least one unoccupied signal block behind an occupied block to provide necessary stopping distance for an approaching train. The approach to the unoccupied red signal block is governed by a "yellow 15" cab signal aspect.

4/ A red cab signal aspect will automatically change to a flashing red cab signal aspect when the train's speed is reduced to 3 mph or less. It permits the train to be moved but restricts the speed to a maximum of 15 mph.

In addition to the cab signals displayed in the operating compartment, an amber light on the speedometer indicates the maximum permitted speed for each block condition. The light is extinguished for a red cab signal and it flashes to 15 mph for a flashing red cab signal. Anytime the maximum allowable speed is exceeded, the overspeed control will sound an audible tone, and if the operator does not begin to reduce the speed of his train within 1 1/2 to 2 1/2 seconds, the train will be stopped automatically with a full service brake application. When the cineston is placed in the B-2 or B-3 positions, the audible tone is silenced, or if the cineston is in one of these positions when an overspeed occurs, the alarm does not sound. No alarm sounded when the cab signal changed to a less favorable indication as the Lake-Dan Ryan train entered the Randolph Street Station because the train was in a braking mode.

The ATC restricts speed to 15 mph on the Wabash and Lake curve when the track ahead is clear or for a red block condition. A speed board further restricts speed to 10 mph on the curve. The speed board supersedes the ATC because it specifies the most restrictive speed. The motorman of the Lake-Dan Ryan train did not testify that he did not know of the speed board's significance, but only that in one point of power, he could not exceed 15 mph on a flashing red cab signal.

The CTA's book of operating rules in effect on the day of the accident was revised and reissued to employees during 1969-1970. 5/ Changes to the operating rules or procedures are issued in the form of bulletins which are posted at crew registering points. Crewmembers are required to acknowledge, by initialling a "responsibility log," their reading and understanding only of such posted bulletins that are considered critical or complex. In some instances, where changes are felt to be complex or of a critical nature, supervisory personnel will contact motormen individually and instruct them on the bulletins. The motorman of the Lake-Dan Ryan train signed the "responsibility log" for bulletin S-511-76 on December 11, 1976.

The CTA employs roving instructors and inspectors who monitor the performance of operating employees during scheduled main track service. Rules violations are reported to the crewmembers' supervisors and corrective action is taken either by a reprimand and re-instruction in the rule violated or by a suspension. The CTA records approximately 8,000 supervisory checks monthly. Mandatory followup refresher training is not provided to CTA employees after they finish their initial training, except when they are reinstructed because of a rule violation.

5/ The CTA issued a new operating rules book effective June 8, 1977.

Meteorological Information

The temperature was about 22°F at the time of the accident and the wind was from the north at 11.5 mph. There was no precipitation. Visibility was reported at 9 miles, but it was about twilight and natural light was waning.

Survival Aspects

It was difficult to determine if some of the fatalities had been passengers or were pedestrians. The best information developed by investigators indicates that five fatalities were passengers, two others were probably passengers, and four fatalities probably were persons on the street. At least three passengers -- two in the second car and one in the fourth car -- were ejected from the Lake-Dan Ryan train through the large windows. One of these two passengers in the second car was partially ejected from the car but was able to recover from the fall and return to the car. The fate of the other ejectee from Car No. 2 could not be determined. The ejectee from Car No. 4 survived. There were no known ejections through the doors.

Personal injuries that were attributed to the collision were minor. Personal injuries received when some cars fell to the street were more serious and were caused by seats and seatbacks, stanchions, modesty panels, the sides of the cars, and other passengers.

Injury data were collected shortly after the accident for 189 passengers who were injured. This does not include injuries reported after the initial data were compiled. A summary of the injuries of the 189 passengers, according to the American Medical Association's Abbreviated Injury Scale (AIS) is:

	Severity of Injury	Number of Passengers
1.	Minor	144
2.	Moderate	19
3.	Severe (Not life-threatening)	8
4.	Serious (Life-threatening, survival probable)	1
5.	Critical (Survival uncertain)	0
6.	Fatal	11
7.	Insufficient Information	6
	Total	189

Passengers of the Ravenswood train walked through the train to the lead car and exited to the station platform at the State Street Station. Some passengers on the Lake-Dan Ryan train left the cars unassisted through end doors or windows from which the glass had fallen out. Others were assisted from the cars by rescue personnel through doors, windows, or openings made in the car bodies. Most passengers were transported quickly to hospitals by rescue vehicles. The lights went off in three of the cars that fell from the structure. The lights remained lighted in the rear five cars.

Tests and Research

Immediately following the accident, the trackside signal system was tested and no descrepancies were found. The motormen on the Ravenswood and the Lake-Dan Ryan trains, and on the train following the Lake-Dan Ryan train indicated that their cab signals were correct for the block conditions.

The ATC equipment on the first and second units of the Lake-Dan Ryan train was tested and found to be operating properly. The trainphone, which was not connected when found, was tested and found to operate satisfactorily.

The ATC system was tested to determine if under any operating conditions a "yellow 35" or "yellow 15" cab signal aspect could change directly to a flashing red aspect. The steady red aspect was displayed about 4 seconds before it changed to a flashing red and the cab signal would not change directly from a yellow to a flashing red.

Tests of the available brake equipment on the four cars that fell to the street and the brakes of the other four cars on the Lake-Dan Ryan train disclosed that they functioned properly.

About 48 hours after the accident, test trains, similar in consists and appearance to the two involved in the crash, were used to determine visibility factors and stopping distance at the accident site. No obstructions in the operating compartment of the approaching train or in the foreground were found to block the view of the train standing in the curve as the test train moved from Randolph Street Station through the compound curve to the collision point.

In another test the test train was accelerated as rapidly as possible from the eight-car mark at Randolph Street Station until it actuated the overspeed alarm at 15 mph. At that time a full service brake application was made and the train stopped short of the point of impact. The total distance covered was about 118 feet. There was no indication that the stopping capability of the test train was affected by the presence and operation of the flange lubricator.

A mathmetical analysis concluded that, under the best simulation of the prevailing conditions, an impact at 9.5 mph would have caused instability and the overturning of the train. (See appendix B.)

Other Information

One witness who was seated along the left side of the first car of the Lake-Dan Ryan train stated that she saw the entire rear car of the Ravenswood train while the Lake-Dan Ryan train was standing in the Randolph Street Station and as it moved out of the station.

ANALYSIS

Safety Board investigations of a number of collisions on intercity railroads have indicated that a primary problem of human failure develops where stop and proceed signals are used and a train is allowed to enter an occupied signal block. A passenger train should not be allowed to move into an occupied signal block except under the most stringent controls, and then only in cases of an operational emergency. The ATC should preclude a motorman's inadvertent or arbitrary movement of a train into an occupied signal block. Even though the CTA is operating virtually on an absolute block system, the operating rules still permit the motorman to move a train into an occupied block.

The rules require that the motorman obtain permission from central control before he can move his train into an occupied block. The motorman's compliance with this rule does not insure against an accident because in most instances the motorman is the only crewmember onboard the train who knows what is happening. To enhance safety and to provide more positive assurance that a motorman will not arbitrarily operate past a stop signal, an electronic or mechanically operated system should be provided that requires a conscious effort before the train can be moved past the signal or into an occupied block.

Signal indications that are similar or that could result in ambiguous interpretation should not be used. The use of a red and yellow cab signal light in conjunction with the yellow speedometer arc light to present aspects with different indications could be confusing. A motorman can only determine which indication will govern his movement by correlating the cab signal indication with the speedometer arc light. It is possible that a motorman under stress might misinterpret these indications. Elimination of confusing signal aspects is essential in a rapid transit or commuter line operation because of the close headway of traffic. This same situation exists where motormen are allowed to proceed on a flashing red cab signal by authority of posted instructions which do not require permission of central control. Even though there are facilities at those points that temporarily require this operation, it requires two operational techniques for the same signal indication over different lines.

The motorman of the Lake-Dan Ryan train noticed the lighted rear marker lights on the Ravenswood train. In recognition of the train's presence, he maintained a station-to-station interval between the trains.

From some point between Tower 12 and Randolph Street Station, he saw the lead cars of the Ravenswood train as it began to round the curve at Wabash and Lake. He testified that he knew that the train would be diverted at Tower 18 and that it would no longer be a concern for him. However, he failed to observe that the train stopped before clearing the curve. The train was standing where it was visible from the Randolph Street Station, even though he testified that, "When I stopped at Randolph, I did not see the train prior to my stopping at Randolph and Wabash. I thought he was in State and Lake because I felt assured that he had already cleared the curve because I did not see him in the curve." The test train run reenacting the events leading up to the accident could only lead the participants to the conclusion that the motorman of the Lake-Dan Ryan train should have seen the Ravenswood train. Since he did not see the train until just before the collision, he obviously was not fully alert to the conditions ahead. He stated that it was his belief that the train ahead was gone. This belief may have been strengthened by his receiving proper cab signal aspects for a clear track condition on his entry into Randolph Street Station.

He also believed that the flashing red cab signal aspect, which according to his testimony was displayed beginning with the train's arrival at the four-car mark at Randolph Street Station, was correct. It is possible that the steady red cab signal indication could have been missed by the motorman because of its short display time and because his attention was directed at bringing the train into the station. Thus, when he saw the train standing in the curve in front of him, it was in total disbelief and he was taken entirely by surprise. This element of surprise could have affected his judgment and response.

An eyewitness on the Lake-Dan Ryan train established that the rear car of the standing Ravenswood train was visible before and at the time the Lake-Dan Ryan train moved from the Randolph Street Station. Once more it is clear that if the motorman had been observing the track ahead he should have seen the train. If he had known his cab signal indications, he would have known that the track was not clear.

The stopping tests made with a train consist similar to that of the Lake-Dan Ryan train indicates that even if the motorman had not sighted the standing train until after he left the Randolph Street Station and had accelerated up to 15 mph, his train could have been stopped short of the collision point.

The motorman of the Lake-Dan Ryan train said that he had seen CTA bulletin S-511-76, but that he did not relate its application to the circumstances involving his train on the day of the accident. He explained this by saying that at other locations on the CTA system a train could be operated on a flashing red cab signal without first receiving permission from the controller to proceed. This could have generated confusion, especially if one's knowledge of the rules was vague. The motorman's understanding that the lack of an audible alarm negated the requirement of bulletin S-511-76 for him to contact the central controller for permission to move was not correct. When an overspeed situation existed, the alarm was actuated; however, it would not operate if the train was braking. Therefore, he would not have gotten an alarm as he was stopping at Randolph Street. He further attempted to justify his moving on a flashing red cab signal aspect, without obtaining permission from the controller, by reference to the training brochure. Bulletin S-511-76 did not specifically mention how it affected part 2 of the training brochure, but even so the motorman should have obeyed the bulletin which in application and practice supercedes existing instructions on the subject matter to which it is addressed.

The motorman of the train following the Lake-Dan Ryan train apparently moved his train into a red signal block in violation of bulletin S-511-76. He would have had to move his train into the block occupied by the Lake-Dan Ryan train on a flashing red cab signal and there is no record of his first receiving permission from the controller. This action may have been prompted by the emergency situation so that passengers could detrain at the platform rather than on the elevated track structure.

The Lake-Dan Ryan motorman, having operated a train over the West-South Line for an appreciable time, should have known the correct cab signal aspects he would obtain for the varied track occupancy conditions. Further, since he testified that he knew the meaning of bulletin S-511-76, he should have known its application. It is possible that he may have been influenced by operating requirements over other lines on which he operated. The scope of the CTA training program may be adequate as an initial indoctrination, but because of the seniority system by which the motormen operate, the younger men may operate infrequently as motormen and there is a risk that their knowledge of the meaning and application of the rules and procedures will become obscure. The present method of reinstructing and retraining employees covers only those rules or procedures that are violated. The program does not include a comprehensive review of all of the operating rules and procedures, nor is there a program which periodically schedules complete reviews. 6/

The CTA's system of randomly monitoring the performance of motormen and conductors does not insure that those individuals being monitored can be assessed accurately on their knowledge and understanding of the rules. It is quite likely that during the time an employee is being observed, a situation may not arise that would require him to exercise his understanding of a rule. Reinstructing an employee on a rule that has been violated is a necessary practice, but it is an after-the-fact corrective action. A greater effort must be expended toward educating the employee to understand the rules and to apply them correctly in various situations. Based on the

6/ This analysis reflects the policy at the time of the accident. CTA has initiated post-accident changes.

performance of the motorman of the Lake-Dan Ryan train and his testimony about his understanding of the rules, the Safety Board concludes that he was not adequately counselled by one of the roving supervisors when bulletin S-511-76 was first issued.

Even though the "responsibility log" insures that an employee reads the new rules or changes, it does not insure that he understands the rule nor how it should be applied. This can be accomplished only by reviews or instruction of the rules with each employee.

The extent that the motorman may have been under the influence of marijuana at the time of the accident could not be determined by tests. Because of the nature of THC and its chemical behavior in a human body, tests could conclude only that the operator had ingested marijuana at some time before the accident. There is no scale available to relate levels of THC or its effect on the behavior of individuals.

The present agreement between the CTA and the operator's union to use only an employee's record for 1 year to determine his past performance for disciplinary purposes does not provide a sufficient time span for management to properly evaluate an employee and to decide if he is a potentially high-risk employee. The Safety Board believes that more than 1 year of an operator's service record should be considered in a performance evaluation. If the Lake-Dan Ryan motorman's entire service record had been used as a basis for his performance evaluation, it may have conveyed to the CTA that he needed help in some areas and that he may have been a potentially high-risk employee.

A dynamics analysis based on the fact that the Lake-Dan Ryan train moved the standing Ravenswood train forward 25 feet when they collided indicates that the Lake-Dan Ryan train was moving at 9.5 mph into the curve. The resulting potential energy and the location of the cars in a sharp surve led to jackknifing between cars. The dynamic forces reacted greatest between the first and second cars, since their coupling was in the sharpest portion of the curve. When these cars began to jackknife because of the forward force from the rear, they began to fall over the side of the elevated structure. The second car apparently pulled the first car backward causing it to fall; while it was being pushed by the third car, the second car forced the third car to the right. The third car pulled the fourth car off the structure and the fifth car apparently was being pulled off by the fourth car when it was stopped by the station platform.

Some impact energy was absorbed by the draft arrangement of the cars on each train and a considerable amount of energy was absorbed by the jackknifing of the cars. Even so, the cars in the Lake-Dan Ryan train moved the Ravenswood train ahead. This force appears to be unrealistic for the speed and physical parameters of the Lake-Dan Ryan train. The high-intensity electrical arc that was observed and heard by eyewitnesses immediately following the collision indicates a heavy electrical power load. The electrical load of lights, heaters, and other components only does not appear to be heavy enough to produce such an arc.

The motorman said that he operated the train around the Wabash and Lake curve in a normal manner. It is unlikely that an eight-car train that entered the curve at from 8 to 10 mph could coast completely through the curve. Therefore, it is logical to assume that at some point, propulsion power was reapplied to maintain the train's speed. If power was being applied at the time of the impact, it more readily explains the heavy electrical arc that was reported. It also would account more readily for the reaction of the cars following the collision. It is possible that the motorman could have inadvertently applied power instead of the brakes when he first saw the Ravensood train, or he may have struck the cineston with his body when the trains collided.

Some persons were seriously injured as a result of the fall of the cars from the elevated structure. There is no evidence to indicate that the integrity of the cars was compromised. Some persons were ejected through the car windows. The size of the windows may have been a factor in the ejection. This subject has been discussed by the Safety Board in other accident reports and it will not be discussed here. 7/

Interior lights on the Ravenswood train remained on until power was cut off. The interior lights went out in the first three cars of the Lake-Dan Ryan train as soon as they overturned. This is an undesirable situation because darkness tends to generate panic and hysteria in a confused environment. The CTA feels that terminating power to the third rail immediately after an accident is not a good practice because it causes the cars to be dark inside. Adequate emergency lights powered from a car's batteries or from dry cell emergency packs could provide the necessary light and still permit the primary power to shut off. This would eliminate the hazards of the third rail.

7/ "Railroad Accident Report - Richmond, Fredericksburg and Potomac Railroad Company Train No. 10/76 Derailment with Three Fatalities and Numerous Personal Injuries, Franconia, Virginia, January 27, 1970." (NTSB-RAR-71-1)
"Railroad Accident Report - Penn Central Transportation Company Freight Train Derailment - Passenger Train Collision with Hazardous Material Car, Soundview, Connecticut, October 8, 1970." (NTSB-RAR-72-1)
"Railroad Accident Report - Derailment of Amtrak Train No.1 While operating on the Illinois Central Railroad Near Salem, Illinois, June 10, 1971." (NTSB-RAR-72-5)

The central controller correctly instructed all trains in the immediate area of the accident to stop and remain standing. Supervisors or company officials should not take it upon themselves to countermand the controller's orders except in extreme emergencies and then, if it is not possible to check with him before the move, notify him as quickly as possible. Otherwise the controller loses control of the situation. Vibrations from the movement of the southbound train past the location of the derailed cars could have caused the some of the remaining cars which were unstable to dislodge and fall from the structure. Under different circumstances, rescue personnel or confused passengers might have been struck.

CONCLUSIONS

Findings

1. There were no mechanical or electrical defects in the equipment of either train that would have contributed to the accident.

2. The ATC equipment and the brake systems on the Lake-Dan Ryan train were operating properly.

3. Proper cab signal aspects were displayed to all trains for the corresponding track occupancy conditions in the vicinity of the accident on February 4, 1977.

4. The rear car of the Ravenswood train was standing in the curve at the time of impact, and it could have been seen by the motorman of the Lake-Dan Ryan train as it approached from the Randolph Street Station.

5. The motorman of the Lake-Dan Ryan train should have been able to stop the train before the collision if he saw the Ravenswood train at the point where he claimed to have first seen the train.

6. The overturning movement of the cars was a result of lateral force components which resulted from the cars' positions on the curve.

7. Propulsion power was probably being applied either at the time of impact or immediately thereafter.

8. A more extensive study of the motorman's service record may have initiated action that would have prevented this accident.

9. The lack of systematic review of the operating rules and procedures is a factor in the confusion about the rules exhibited by CTA employees.

10. Roving supervisors cannot assess adequately a motorman's complete understanding of operating rules.

11. The display on the same indicator units of cab signal aspects that are similar but which require different responses can be confusing to an operator in an emergency situation.

Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the failure of the motorman to exercise due care in meeting his responsibilities and the unauthorized operation of the Lake-Dan Ryan train into a signal block occupied by the standing Ravenswood train, at a speed that was too fast to stop after the operator sighted the standing train.

RECOMMENDATIONS

As a result of its investigation of this accident, the National Transportation Safety Board made the following recommendations to the Chicago Transit Authority on June 29, 1977:

"Initiate a program which will:

1. Provide a systematic review of the operating rules so that all employees will have a clear understanding of such rules and of any changes.

2. Insure employee compliance with the rules. (Class II, Priority Followup) (R-77-14)

"Discontinue the automatic display and control function of the flashing red cab signal and its associated flashing yellow 15 mph on the speedometer. (Class II, Priority Followup) (R-77-15)

"Operate trains on an absolute block. If it becomes necessary to enter an occupied block in emergency, provide procedures that will insure safe operation. (Class II, Priority Followup) (R-77-16)

"Consider an operating employee's complete service record when judging the employee's operating capabilities. (Class II, Priority Followup) (R-77-17)"

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ KAY BAILEY
Acting Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ PHILIP A. HOGUE
Member

/s/ JAMES B. KING
Member

November 29, 1977

APPENDIX A
EXCERPTS FROM CTA TRAINING BROCHURE "CAB CONTROL SIGNALLING"

Train operation with cab control signalling

ASPECT PANEL

1. .....

2. SIGNAL ASPECTS (RED, YELLOW AND GREEN) - indicate the following:

Signal Aspect	Signal Indication	Speed Indication (Dial-Type)	Speed Indication (Digital Type)
Green	Proceed	0-65 or 70	70 or 55
Yellow	Proceed with caution	0-35, 0-25, or 0-15	35, 25, or 15
Red	Stop (after stop aspect changes to Flashing Red)	0	0
Flashing Red	Proceed with caution prepared to stop within vision	0-15 (Flashing)	15 (Flashing)

NOTE: Flashing red is given where low speeds are required, such as in yards or when closing in on trains ahead. Motorman must exercise extreme caution under this aspect.

Motorman must operate within the range of speeds indicated by the signal aspect and speedometer.

3. .....

APPENDIX B

Engineering Mechanics Division
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

IITRI Project J6366

Report: Technical Directive 2

INCREASED RAIL TRANSIT VEHICLE
CRASHWORTHINESS IN HEAD-ON COLLISIONS

Contract DOT-TSC-1052

March 1977

Prepared by

E. E. Hahn

for

Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge, Massachusetts 02142

IIT Research Institute
10 West 35 Street Chicago, Illinois 60616
312/567-4000

March 8, 1977

Mr. F. Rutyna
U.S. Department of Transportation
Transportation Systems Center
Kendall Square, Cambridge MA 02142

Dear Mr. Rutyna:

Transmitted herewith are two copies of the February 4, 1977 CTA accident analysis which was performed as a "technical directive" under IITRI Project J6366, Contract DOT-TSC-1052. Should you have any questions on any part of it, please contact the undersigned or Dr. E. E. Hahn.

Cordially,

/s/ A. Longinow
Manager
Structural Analysis

AL:ms

Encl.

cc: E. Boyle, UMTA

3-11

Longinow telephone input

Impacted Consist Movement	Collision Speed	
5 ft	7.02 mph	(Minimum to cause instability)
10 ft	7.54 mph	
15 ft	8.25 mph	
20 ft	8.97 mph	

APPENDIX C

Chicago Transit Authority
General Operations Division
Transportation Department

S511-76
Supercedes S215-76

SERVICE BULLETIN

TO: Motormen, Switchmen and Yard Foremen

SUBJECT: Train operating procedures on all rail routes at permissive signals displaying red aspect

EFFECTIVE: Wednesday, December 8, 1976

ON ANY MAIN LINE TRACK, BETWEEN TERMINALS:

When a train receives a red aspect at an interlocking approach signal or an automatic block signal, or receives a red or flashing red aspect of a cab signal, it must be brought to a stop and must NOT proceed until the employee operating the train has been instructed to do so by the controller.

If the reason for the stop is a train ahead which can be expected to proceed shortly, wait for the signal aspect to change to a "proceed" indication. If the reason for the stop is not evident, or if it does not clear within a reasonable time, call controller for instructions.

The train MUST REMAIN STANDING until the controller has issued specific instructions, for example, to authorize the train to proceed after operation of the track trip manual release (key-by) or, in cab signal territory, to proceed on the "flashing red."

If communication cannot be established with the control center, the train will proceed to the next wayside signal bond or wayside signal at not to exceed 15 MPH (on sight*). If the signal then fails to clear, the train will proceed from block to block at not to exceed 15 MPH (on sight*) to the first point where communication can be established with the control center by trainphone or telephone.

WITHIN YARD LIMITS, and AFTER ARRIVAL IN A TERMINAL:

When cab signal displays flashing red aspect, it is permissible to proceed on sight without calling controller only under the following conditions:

a. An arriving train may be operated into the yard or turnback after it has made the regular station stop at the terminal and the passengers have alighted.

b. Within yard limits.
c. From the yard or turnback into the regular station berth.
d. When sign is posted which says "Begin Operation on Sight."
e. Within non-ATC territory.

ALTERNATIVE COMMUNICATION WITH CONTROLLER:

The controller may designate a supervisory person on the scene to convey instructions.

CAUTION:

*"On Sight" operation means that the train must be operated at a speed, not exceeding 15 MPH, which will enable it to be stopped short of a train ahead.

Under all circumstances, responsibility rests with the employee operating the train for safe movement on a track which may be occupied by a train ahead or on which signal protection is not available.

APPENDIX D

The geometry of the curve at Wabash and Lake, proceeding north and west is as follows:

Curvature	Radius (ft)	Length (ft)	Superelevation (in.)
Righthand	294	26	0 to 1
Tangent	-	30	1 to 1 1/2
Lefthand	155	33	1 1/2 to 4
Body of curve	89.77	85	4
Lefthand	150	73	4 to 2
Tangent	-	-	2 to 0

Run off is 1/8 inch in 3 feet.

The equilibrium speed for the 89.77-ft radius curve is 10 mph. The theoretical overturning speed is in excess of 30 mph.

APPENDIX E

INCREASED RAIL TRANSIT VEHICLE CRASHWORTHINESS IN HEAD-ON COLLISIONS

Closing Velocity Analysis of 4 February 1977 CTA Accident

The objective of this analysis is to calculate the speed of the Lake Dan Ryan Transit Car Train when it impacted a Ravenswood Train which was stopped at the end of a curve in Chicago's Loop. Data for the analysis was obtained from the Chicago Transit Authority in response to IIT Research Institute letter of February 15, 1977 and other private conversations. Table 1 lists data used in the analysis.

The total energy in the two consists just prior to the collision is

$$E_I = (V_o^2/2g) \sum_{i=1}^{8} W_i$$

where V_o is the closing velocity of the impacting consist. If the data from Table 1 is substituted into this formula

$$E_I = 549\ V_o^2$$

Here E_i will be in in.-lb if V_o is in in./sec.

The energy required to overturn the leading car of the impacting consist is

$$E_o = W_1\ [(\sqrt{G^2/4+Y_c^2} - Y_c) + E/2]$$

Again substituting data from Table 1

$$E_o = 599{,}000 \text{ in.-lb}$$

The energy stored in the draft gear and drawbars due to their stroke is given by

$$E_D = (N+N')(K \cdot S^2/2 + P \cdot S)$$

Taking data from Table 1 this becomes

$$E_D = 600{,}000 \text{ in.-lb.}$$

TABLE 1. TRANSIT CAR ACCIDENT DATA

Symbol	Value	Explanation
g	386 in./sec^2	Acceleration due to gravity
W_1	54,000 lb	Weight, leading car, impacting consist
W_2	54,000 lb	Weight, second car, impacting consist
W_3	52,000 lb	Weight, third car, impacting consist
W_4	52,000 lb	Weight, fourth car, impacting consist
W_5	52,000 lb	Weight, fifth car, impacting consist
W_6	52,000 lb	Weight, sixth car, impacting consist
W_7	54,000 lb	Weight, seventh car, impacting consist
W_8	54,000 lb	Weight, eighth car, impacting consist
W'_1	56,000 lb	Weight, leading car, impacted consist
W'_2	56,000 lb	Weight, second car, impacted consist
W'_3	56,000 lb	Weight, third car, impacted consist
W'_4	56,000 lb	Weight, fourth car, impacted consist
W'_5	56,000 lb	Weight, fifth car, impacted consist
W'_6	56,000 lb	Weight, sixth car, impacted consist
G	56.5 in.	Track gage
e	3.5 in.	Track superelevation
Y_c	42 in.	Height of c.g., leading car of impacting consist
N	14	Number of gears stroked, impacting consist
N'	10	Number of gears stroked, impacted consist
K	24,000 lb/in.*	Draft gear spring constant
S	1.25 in.*	Draft gear stroke
P	5,000 lb*	Draft gear spring preload
R	49 in.	Anticlimber radius
σ_Y	36,000 psi	Anticlimber yield stress
δ_1	3/4 in.	Anticlimber deflections, leading cars
δ_2	1/4 in.	Anticlimber deflections, remaining cars
V	90,000 lb	Shear pin load
d	1/4 in.	Shear pin deflection
n	12	Number of sets of pins sheared
B	3.2 mph/sec	Braking rate, impacted consist
D	25 ft	Total movement, impacted consist

* Estimated data

Figure 1 is a representation of the anticlimbers.

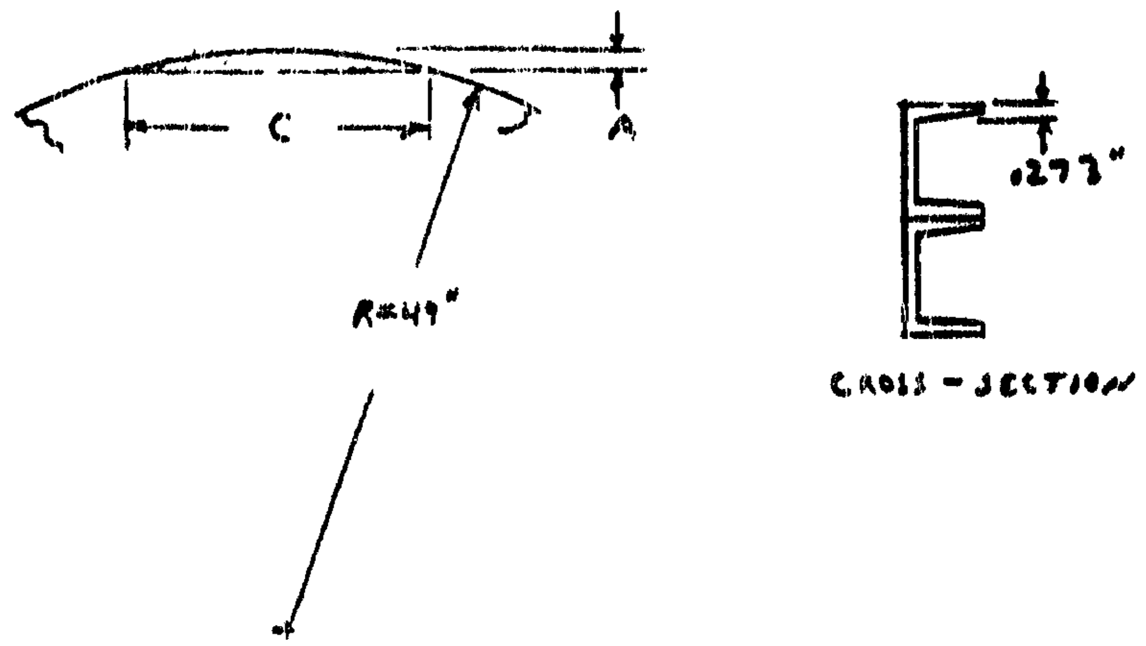


Figure 1. Anticlimber Geometry

The crush width, c, and the crush distance, A, are related by

$$c = 2\sqrt{2AR - A^2}$$

The anticlimber area being crushed is merely the crush width times the total thickness being crushed. Using this, along with the anticlimber yield stress, the crush force becomes

$$F_c = \sigma_y \; c \; t_T$$

or substituting data

$$F_c = (36,000) \; c \; (4 \cdot .273)$$
$$= 39,300 \quad c.$$

The energy required to deform the anticlimber any amount δ is given by

$$E_c = \int_0^\delta F_c \, dA$$

Substituting the above equations into this formula and carrying out the integration

$$E_c = 39,300(R^2[\pi/2-\sin^{-1}(1-\delta/R)]-(R-\delta)\sqrt{2\delta R-\delta^2})$$

For the leading car anticlimbers δ = 3/4 in. and R = 49 in.

$$E_c' = 336,000 \text{ in.-lb}$$

For the remaining anticlimbers δ = 1/4 in. and R = 49 in

$$E_c'' = 65,000 \text{ in.-lb}$$

The total energy required to deform all the anticlimbers is given by

$$E_c = 2\,E_c' + 24\,E_c''$$

or

$$E_c = 2,232,000 \text{ in.-lb}$$

The energy required to shear the shear pins is given by

$$E_s = nVd$$

Substituting data from Table 1, we obtain

$$E_s = 270,000 \text{ in.-lb}$$

Let us now determine the energy required to move the impacting consist. The braking rate was given at

$$B = 3.2 \text{ mph/sec}$$

for a light train (42,200 lb car). Expressing this rate in terms of the acceleration due to gravity

$$B = 0.146 \text{ g}.$$

The force resisting motion is merely

$$F_D = WB = (42,200)(0.146)$$
$$= 6,160 \text{ lb per car.}$$

The total energy required to move the impacting consist is given by

$$E_F = 6F_D D$$

Substituting data in this equation

$$E_F = 11,088,000 \text{ in.-lb}$$

From a momentum balance just prior and after impact

$$V_o \sum_{i=1}^{8} W_i = V_F \sum_{i=1}^{8} W_i + V' \sum_{i=1}^{6} W'_i$$

Substituting known data into this equation and solving for V_F (the velocity of the impacting consist immediately after the collision)

$$V_F = 37 \text{ in./sec}$$

The kinetic energy due to this velocity is

$$E_V = (V_F^2/2g) \sum_{i=1}^{8} W_i$$

Substituting into this equation

$$E_V = 752{,}000 \text{ in./lb}$$

This results in an error of approximately 5 percent in the total collision energy and only an error of 2.6 percent in the closing velocity. A more accurate prediction of the closing velocity would be

$$V_o = \underline{9.5} \text{ mph.}$$

By the law of conservation of energy

$$E_I = E_O + E_D + E_C + E_s + E_F$$

From the preceding energy evaluations

$$549\ V_o^2 = 599,000 + 600,000 + 2,232,000 + 270,000 + 11,088,000$$

Solving for V_o

$$V_o = 164 \text{ in./sec}$$

or

$$V_o = \underline{9.3} \text{ mph}$$

Note that the energy requirement for overturning the lead car of the impacting consist is very low (approximately 4 percent) in comparison to the total energy available in the collision. This indicates the likelihood of car overturning in any accident situation where the energy transfer mechanism is such that rollover may occur. Impact on a curve provides such a mechanism since the lateral component of the contact forces between cars will provide an overturning moment about the wheel rail interface. It should also be noted that the major source of energy loss (approximately 75 percent) was in moving the standing consist. Any error in the distance this consist moved or in its braking force would have a major effect on the calculated closing speed.

In this analysis the kinetic energy due to the velocity of the cars after the collision was neglected. The following analysis justifies this assumption. The drag force on each impacted car was computed as

$$F_d = 6,160 \text{ lb}$$

The deceleration of each car is given by

$$a = F_d\ g/W_i' = (6,160)(396)/(56,000) = 42.5 \text{ in./sec}^2$$

The velocity of the cars just after impact is

$$V' = \sqrt{2aD} = \sqrt{(2)(42.5)(25\cdot 12)} = 160 \text{ in./sec}$$