NATIONAL TRANSPORTATION SAFETY BOARD

HIGHWAY ACCIDENT REPORT

CHARTERED INTERSTATE BUS CRASH
INTERSTATE ROUTE I-80S
NEAR BEAVER FALLS, PENNSYLVANIA
DECEMBER 26, 1968

NATIONAL TRANSPORTATION SAFETY BOARD
Bureau of Surface Transportation Safety
Washington, D. C. 20591

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ADOPTED: JANUARY 23, 1970

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FOREWORD

This accident was declared to be a "major accident" within the definition of the National Transportation Safety Board because of its severity and its catastrophic potential. This analysis and report are based on information from a report by the Bureau of Motor Carrier Safety, Federal Highway Administration, a report by the Research Accident Investigation Group, University of Rochester (New York) School of Medicine and Dentistry under contract to the National Highway Safety Bureau, and the official Pennsylvania State Police report. Photographs were obtained by subsequent Safety Board visit to the scene, and additional information was obtained from persons who had participated in the initial investigations. There was consultation with members of the University of Rochester (RAI) group to correlate interpretations, analyses, and reconstruction of vehicle and passenger dynamics. The RAI group report has been used as evidence in drawing the conclusions of the Board. However, the Board does not concur in all the conclusions of the RAI group report.

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PART I - SYNOPSIS

On December 26, 1968, about 2:40 a.m., a chartered 39-passenger intercity bus enroute from Chicago, Illinois, to Washington, D. C., was traveling east on Interstate Highway, I-80S, the Pennsylvania Turnpike, near Beaver Falls interchange, at a speed of about 60 to 65 m.p.h. Shortly after the bus entered a transitional curve to the left, it ran off the traveled lane to the right, and the rear of the bus slid to the right on a snow-covered shoulder, which sloped down away from the pavement. Following a hard left steering action, the bus yawed to the left. After another over-corrective steering action, it yawed to the right, then headed off the right side of the highway. It crossed the shoulder and ran up onto a raised grassy terrace in front of a turnpike maintenance building. On the frozen snow-covered terrace, the bus veered abruptly to its left as the driver tried to return to the roadway, then vaulted onto the right side of its roof after the right wheels dug into the frozen turf. Still on its roof, the bus slid and bounced off the east end of the terrace and down into a drainage gully, a drop of 10 or 12 feet, and came to a stop with its top and left side resting in the bottom of the gully, its front facing westward (see Attachment 1 for sketch of accident scene).

Three passengers were killed in the crash. Two had been seated at points of major inward collapse of the bus roof and support structure, and one had been seated near the point of maximum deceleration and is believed to have been hurled forward and to the right. A fourth (elderly) passenger died about two months after the accident from causes not directly related to accident injuries. Fourteen occupants, including the driver, were injured severely enough to be hospitalized, and the remaining 23 were examined, treated, and released. A lone attendant at the maintenance base summoned rescue agencies, and units began arriving some 20 minutes later. There was no delay in rescue or medical aid which aggravated the condition of the injured persons. No fire or panic ensued, and occupants made their way out through the broken-out windshield and right-side window areas. Many passengers elected to stay in the bus until rescue arrived, and some had to be extricated from under collapsed structures.

No mechanical or tire failures were found, and the driver was apparently sober, awake, and in sound physical condition. He had been talking with a passenger and bending down while adjusting a heater just before the crash sequence began. The temperature was near zero. The highway was clear and dry, but there was a half-inch cover of snow over the frozen shoulders and off-highway terrain. Traffic volume was extremely light.

PROBABLE CAUSE

Probable cause of the initial crash was:

Driver error, in failing to give full attention to the task of steering the vehicle at a critical point where the highway entered a transitional curve to the left, so that the bus strayed off its intended course and onto the shoulder area.

Contributing causes of the crash were:

Termination of the right guardrail, which had afforded a visual reference to the edge of the roadway, at a transitional point of a highway curve where there was minimal visual contrast between the white concrete pavement and the snow-covered shoulder and off-highway terrain;

The necessity of diversion of attention by the driver to operate any of the heater controls, as determined by their design, and the absence of any direction in the Operator's Manual as to safe procedure for operating the heater controls while the vehicle is in motion;

Excessive reverse slope of the highway shoulder, which exceeded the maximum (AASHO) recommended cross-slope break, and which dropped away from the pavement, creating a situation adversely affecting the control of any vehicle inadvertently running onto the shoulder at highway speeds;

Slipperiness of the shoulder from a layer of snow, which aggravated the conditions of the reverse shoulder slope and centrifugal force, to cause the bus to slide or skid to the right;

Lack of salting or cindering of the highway shoulder, permitting the slippery condition to persist; and

Probable inability of the driver to determine the necessary amount of steering action to correct his heading, once the bus began to go out of control, due to the absence of any indication to the driver of front-wheel direction relative to the bus, and a slow response of the bus to steering-wheel input.

Causes of injuries to occupants were:

1. Deceleration of passengers against the non-crash-protected right side, right roof structure, edge of overhead parcel shelf, and seat frames, during the initial overturn;

2. Sharp surfaces of interior bus components, many of which were fractured and presented sharp or jagged edges against which passengers were impacted during subsequent movements of the bus as it slid and bounced down into the gully and came to rest on its top;

3. Lack of occupant restraints which, had they been available and in use, would have held occupants more securely in place, preventing some, but not all injuries; and

4. Crushing of some passengers between seats and collapsing roof support structures or restroom partitions in those areas where the bus structure did not resist the forces of rolling and impacts.

Causes of the deaths to passengers were:

1. Crushing of one passenger between seat and collapsing roof support;

2. Partial ejection of one passenger through a collapsed window structure, and subsequent pinning within the framework of the window as the bus came to rest; and

3. Repeated impacts sustained by one elderly and unusually heavy passenger, which would probably have resulted in lesser injuries had seat restraints been available and in use.

During rescue operations, a few passengers sustained minor cuts and bruises from jagged edges of torn metal or from slipping and falling on the frozen embankments of the gully.

PART II - FACTS AND ANALYSIS

At about 2:40 a.m., December 26, 1968, a "Challenger" MC5A bus was on a charter run from Chicago, Illinois, to Washington, D. C., eastbound via the Pennsylvania Turnpike, carrying 39 members of a church group, aged 6 to 82 (median age 30). At a point about a mile west of the Beaver Falls interchange, the highway makes a 3° curve to the left, has a superelevation of about 6 percent and a downgrade of about 1.9 percent (see Attachment 1). While traveling 60 or 65 m.p.h. in the right-hand lane, and shortly after entering the curve, the bus strayed onto the right shoulder, which was covered with a one-half-inch layer of snow. The shoulder slopes down away from the pavement, and at this location, it leads into a large flat parking area of a Pennsylvania Turnpike maintenance base.

The driver had been talking with a passenger, behind and to his right in seat No. 3, who had complained of feeling cold. The driver had been checking the heater adjustments just before he felt the bus swerve. He observed that the rear of the bus was sliding to the right, and he tried to steer back onto the pavement. The downslope of the shoulder was slippery. In coming back onto the pavement, the bus then veered sharply to the left, towards the median. The driver then steered hard to the right, and the bus then headed off the right side of the highway at a point just east of the entrance to the maintenance base building. The bus crossed the right shoulder and ran up onto a raised grassy terrace in front of the maintenance building. In going up the terrace incline, a height of about 18 inches above the shoulder, the front of the bus was jolted upward and the right front step area cut into the embankment. There was a covering of snow on the terrace, overlaying the frozen turf. Once on the terrace, which is virtually flat and level in the east-west direction, the driver applied the brakes and steered hard to the left in an apparent effort to return to the highway. The front wheels locked and slid, producing a mild tiller effect, and the front of the bus gradually swung around to the left. As the bus yawed farther left, the rear swung around counterclockwise, and the right wheels, both front and rear, began to exert sufficient force to break through the frozen turf and to dig into the ground. When it had yawed about 90° left, the bus vaulted off the ground and impacted on the right side roof-support structure (described more fully on page 14). The rear of the bus continued to yaw, and while on its roof, the bus slid and bounced, rearend foremost, down into a drainage gully beyond the east end of the terrace. As it went down into the gully, a drop of 10 or 12 feet, the top of the bus impacted the gully embankments. The bus finally came to rest in the bottom of the gully, its roof against the south embankment, its left side against the north embankment, and its front pointing approximately west.

There was no fire, smoke, or noxious fumes to create panic or aggravate the situation. Passengers seemed in no hurry to evacuate the bus, due probably to the prevailing conditions such as the extreme cold, the unfavorable terrain, disabling injuries, and the relative security which the bus offered. Rescue units arrived about 20 minutes later. Two passengers were killed outright, one died about an hour later, and 14 (including the driver) were injured severely enough to be hospitalized. Of the remaining 23 passengers, treated and released, many had virtually no injury.

Details of the Highway

The accident occurred off the eastbound lanes of Interstate I-80S, the Pennsylvania Turnpike, west of the Beaver Falls interchange, at milepost 11.8 in front of the Homewood Maintenance Base of the Turnpike. The highway at this point slopes downward to the east (-1.9 percent) and is near the end of a 1,000-foot curve to the left of 1,909-foot radius (3 percent per 100 feet). There are two eastbound 12-foot lanes of concrete in excellent state of repair. Superelevation at this point is about 3/4 of an inch per foot (or plus 6 percent). (Highway data from Pennsylvania State highway design blueprints. See Attachment 1 for drawing of accident scene.)

The median strip is 10 feet wide, with a steel guardrail about 6 feet from the left edge of the eastbound lanes. There is an opening in the median guardrail opposite the maintenance base entrance for official use. The outer guardrail of the eastbound lanes is about 9 feet from the pavement. It terminates about 500 feet west of the maintenance base driveway, and resumes about 250 feet east of the driveway, leaving a gap of some 750 feet where there is no guardrail. The off-highway terrain at this point is flat and leads into the maintenance yard parking area. A solid white 4-inch painted line marks the inner and outer edges of the pavement, and a broken 4-inch line separates the two eastbound lanes.

The outer shoulder is of asphaltic concrete, averaging about 5 feet wide, but flaring out where the maintenance yard driveway enters the turnpike. It slopes down away from the pavement at approximately 8 percent, at the point where it is estimated the bus first left the roadway.[1/] NTSB photographs taken of the scene on September 24, 1969, (Attachment 2) show a patched strip in the shoulder adjacent to the pavement. Maintenance base personnel say this work was done in June 1969, 6 months after the accident, because of the installation of an underground drain pipe and not because of a need for repairs to the shoulder.

Just east of the maintenance base driveway is a grassed terrace which is raised about 18 inches away from the highway and extends eastward about 200 feet, approximately flat. This terrace ends in a 45° downslope into a drainage gully, the center of which is about 20 feet south of the guardrail, approximately parallel to the highway, and about 10 or 12 feet below the level of the flat area of the terrace. At the head of the gully is a concrete culvert headwall, through which runoff is drained to the east. Side slopes of the gully vary in slope from 30° to 45°, with the south wall being eroded and rocky, and the north wall relatively smooth, graded down from the highway shoulder (photo in Attachment 2).

The Environment

The accident occurred at approximately 2:40 a.m., on December 26, 1968. The temperature at Pittsburgh was 8°F., and the wind southeast at 5 m.p.h.[2/] According to an employee at the maintenance base, the temperature there was 4° below zero at 4:00

1/ The policy manual of the American Association of State Highway Officials (AASHO) states on page 238, 1965 edition: "Shoulder edges that drain away from the paved surface on the outside of well superelevated sections should be designed to avoid too great a cross-slope break . . . For desirable operation, all or part of the shoulder should be sloped upward at about the same or at a lesser rate than the superelevated pavement . . ." AASHO recommends a maximum "grade break" -- differential in slope between pavement and shoulder -- not to exceed .07 foot per foot (or 7 percent). In the Beaver Falls accident, the highway superelevation was plus 6 percent and the shoulder was minus 8 percent, making a differential of 14 percent.

2/ Reported by U. S. weather station at Greater Pittsburgh Airport, about 35 airport miles southeast of the accident site.

that morning. No written report was made as to traffic volume in the eastbound direction, but the State Patrolman who was on patrol in the accident vicinity at the time of the accident reported orally that traffic was extremely light, as would be expected at this hour on the morning after Christmas.

No precipitation was reported just before or during the accident. The pavement was reportedly clear and dry; it had been salted during the morning of December 25th, but a half-inch of snow overlay the shoulder, the median, and the frozen terrain south of the highway. Photographs (Attachment 3) taken during rescue operations at the scene show a covering of snow on the south highway shoulder, right up to the edge of the pavement. Maintenance base personnel and the State Patrolman are certain there was no frosting or slipperiness of the pavement at the time this accident occurred. There was no highway lighting in the area, and because of the dark and overcast conditions, ambient light was almost nil.

The Vehicle

The bus is a 1968 Challenger, Model MC5A, made by Motor Coach Industries, 39-passenger capacity, V-8 diesel engine mounted in the rear, with single 14-ply 11.5-inch by 22.5-inch tires on the front wheels and dual tires of the same size and type on the rear dual wheels. Power is transmitted to the rear axle through a rear transmission. Suspension is beam-type axles, with four air bellows for each axle, stabilized in the front by a trailing arm and on the rear by a leading arm. Steering employs variable ratio cam and lever, with 26-to-1 ratio in center position and 32-to-1 ratio in extreme turn position, hydraulic power assisted. Steering wheel outer diameter is 21 inches, and 5-1/2 turns are required to move the front wheels from extreme left to extreme right. Total effective brakeshoe area is 764 square inches. Front drums are 14-1/2 inches by 5 inches. Rear drums are 14-1/2 inches by 8 inches. Center of gravity, with full load, is 49 inches above the roadway, which, for a 96-inch maximum width of tire contact provides a calculated stability factor of $\frac{48 \text{ inches}}{49 \text{ inches}}$ or .98. About 37.5 percent of the load is on the front wheels, and 62.5 percent on the rear wheels. With a 261-inch wheelbase, this puts the center of gravity 163 inches back of the front axle, 5/8 of the wheelbase length rearward of the front axle. The odometer reading at the time of the accident was 83,206, but a company official said the correct mileage was about 52,000. No significance is attached to the difference.

Investigations by the Bureau of Motor Carrier Safety (BMCS) at the scene, and subsequent examinations of the bus at the Chicago yard of the operating bus company by members of the Research Accident Investigation Group (RAI) of the University of Rochester School of Medicine and Dentistry (National Highway Safety Bureau Contract), revealed no failures or deficiencies of safety systems and components -- brakes, tires, suspension, steering, or lights -- which had any apparent bearing on the cause of the crash. The fuel tank contained 80 to 85 gallons of a blend of No. 1 and No. 2 diesel fuel. The tank did not leak any fuel. All undamaged lights were operative after the crash, and two (24V) batteries remained anchored and lost no acid.

A detailed examination of the 6 tires by both the BMCS and RAI group showed that all tires were well within BMCS regulations in pressure, tread wear, and resilience (see Attachment 4). All tires appeared sound, with no visible significant cracking of tread or sidewalls.

The bus was equipped with a restroom, so the three seats in the extreme rear, Nos. 37, 38, and 39, were contiguous on the left to provide access to the restroom. Side windows were the typical "picture window" type, of pushout design requiring a positive lift on the lower frame, and meeting BMCS regulations. Seats were the highback headrest type, individually semi-reclining. The bus roof structure was of transverse stringers covered with an aluminum skin, and the interior roof liner was of "melamine" plastic with a pressed wood backing. Body side panels were of truss design with a stainless steel skin riveted throughout, which permitted some elastic lateral flexing. Interior overhead parcel shelves were of 3/16-inch plywood suspended from the roof stringers, painted surface, and with the edges facing the aisles finished off with extruded aluminum mouldings.

Principal damage to the bus, in sequence of occurrence, consisted of the following:

1. A slight inward bending and grinding of metal in the leading edge of the right front body (ahead of the door-step) was the first damage incurred when the bus first climbed the terrace embankment, gouging into the slope.

2. Downward and leftward collapse of the right roof area occurred when the roof impacted ground after the bus overturned on the terrace. Because it struck first and

hardest, the right front roof area suffered more damage on initial impact than the rear roof area.

3. Under a combination of impact and diagonal stress forces, the windshields and rear window were dislodged and popped out in the initial rollover impact.

4. Displacement of the roof structure to the left, in initial rollover, was also transmitted to the left top and window structure, which were bent outward. This shows that the strength of the roof support columns on both the left and right sides of the bus was available to resist the displacement to the left.

5. The right body wall in the front area was flexed inward in the initial rollover, but recovered almost to its original alignment.

6. Further collapse of the left side of the roof, inward and to the left, was incurred when the bus impacted the north embankment of the gully in an inverted position. This also bent the left body sidewall inward about 8 inches (although initial elastic bending was probably greater than this).

7. When the bus rebounded against the south embankment, the right side of the roof was further crushed inward and to the left. The right rear roof area was torn and crushed inward and forward when it impacted the rocky outcropping in the south embankment.

8. The rearward motion of the bus in the gully forced the entire roof structure forward.

9. Some seats were bent backward by the collapse of the roof structure, and some were distorted inward by the flexing of the body sidewalls. Seats principally involved were Nos. 5, 9, 13, 17, and 25 on the left side, against the windows, and Nos. 12 and 20 against the right windows. The backrest of the driver's seat was bent backward by the weight of the driver's body in the final deceleration. No seats were torn loose from their mountings.

10. Windows or window frames were dislodged or broken in the successive impacts in the gully.

11. The interior plastic roof lining was shattered and mouldings were torn loose or broken off, leaving many sharp edges.

The Driver

Driver of the bus was a male, aged 40, employed as a relief driver, properly licensed and certificated, who had been working for the bus company about 5-1/2 years with no prior accidents. He was familiar with this type of bus and this route. He had no record of alcohol or drug usage during his 5-1/2 years' employment, and his health was good. No report of an alcohol-influence test is shown by the Pennsylvania State Police, suggesting there was probably no reason observed to raise any question of alcohol involvement. He had reportedly had adequate rest before picking up this bus as relief driver at the Towpath Plaza on the Ohio Turnpike at 1:15 a.m., and was to drive it to the Oakmont Plaza on the Pennsylvania Turnpike. Only one traffic citation showed on his record, for violating a stop sign on November 11, 1968 (no disposition given).

The driver said he had been driving in the right-hand lane, about 60 or 65 m.p.h. He had been talking with the group leader, seated in seat No. 3 behind him and to his right, and had also been checking the adjustment on the heater fan. It is not entirely clear from the evidence available to the Board which of four different heater controls was being operated by the driver at that time. He suddenly felt the back of the bus skid, and in the rearview mirror he saw the rear of the bus move to the right. He tried to correct by removing his foot from the accelerator and steering rather than by braking, as he thought the surface was slippery. He said that he turned to the right, but that statement is regarded as confused with his second turn to the right. The first steering movement could only have been to the left. He felt the vehicle drop, and "everything ahead looked white." He said that the bus then swerved over to the left and he turned to the right. The bus then ran off the roadway to the right. He said that after the bus struck the mileage marker post (11.8) in the terrace embankment, he didn't remember anything further.

Witnesses

There was one non-involved witness to the accident, a lone night clerk at the maintenance base, who saw the bus go by the building on the terrace. The leader of the charter group, who was in seat No. 3, stated that the driver had been talking to him and adjusting the heater just before the initial swerve of the bus. He felt the bus swerve back and forth. No passenger stated what had happened. It is presumed that most passengers were asleep or inattentive in the initial phases of the accident.

Reconstruction of the Accident

An analysis of vehicle kinematics, based on driver and passenger statements, markings left by the bus on the terrain, and damages to the bus, offers a supportable explanation of what took place.

The roadside and shoulder were frozen and snow-covered. The right side guardrail terminated about 1/10 mile west of the point where the bus finally left the roadway. With his attention diverted by his conversation with a passenger, and while adjusting the compartment heater, the driver was not giving full attention to the road ahead.

Four of the five heater operating controls indicated in the Operator's Manual would require some change in the position of the driver involving less-than-complete and uninterrupted observation to the front, and a fifth control was subject to confusion because it was not shape-coded. The heat control is a nine-position switch located on the sidewall to the left rear of the driver's left elbow when his left hand is on the steering wheel. Operation of this control would require moving the left hand from the steering wheel and might require a leftward and downward direct observation of the switchplate face to observe the selected position. The driver had already turned this control to maximum before the accident occurred.

The driver could have been operating any of four other controls at this time. Operation of the driver's heater air control would require removal of the left hand from the steering wheel and some degree of forward movement of the upper torso. Operation of the driver's heater/defroster selector lever would require removal of the right hand from the steering wheel and considerable forward bending of the torso to reach the control, which is located on an extension of the front wall above and to the right of the accelerator pedal. The driver's heater/defroster fan switches (two switches) are located to the left wall of the driver's compartment, below the steering wheel, and accessible to the driver's left hand. There are three identical knobs in this location, two of which control the fan switches, while the third controls the instrument panel lights. The identification of the correct switch might pose a problem which would tend to make a driver remove his gaze from the road ahead.

As indicated earlier, the evidence available to the Board does not indicate which of these controls was being operated; however, it appears that operation of any of the last four named switches or lever controls would have involved some degree of distraction from the task of observing the road ahead.

The question arises as to whether the driver could have delayed the operation of heater controls or whether he could have slowed or stopped, adjusted the heater controls at reduced risk, then proceeded. In can be seen in Attachment 2-B that this section of the Pennsylvania Turnpike presents a high percentage of winding road. The curve in question was not a sharp one, having a radius of about 1,900 feet. The Operator's Manual does not indicate that any controls would require slowing or stopping. The general observation may be made that when the task load on a machine operator rises beyond his ability to execute in safety, he may be inhibited from realizing it by the concentration necessary to consider the several tasks.

It appears that, in this case, the driver momentarily lost orientation with the roadway (". . . everything ahead looked white . . .") at this time. At this point, the right wheels ran onto the frozen snow-covered shoulder, and the bus lurched to the right. Both the outward and downward slope of the shoulder and the centrifugal force of turning tended to pull the bus away from the roadway. This was resisted by the friction of the outside wheels on the snowy shoulder, with its poor traction, and the traction of the left wheels which were probably still on the dry pavement. When the driver first realized that the rear of the bus was skidding to the right, he also observed a white expanse ahead. This was the flat terrain to the right off the roadway, leading to the parking area.

The driver stated that he turned the steering wheel to the right, which would have served to counter the skid, at the cost of running off the pavement. However, his statement is not entirely clear as to when this was done. The driver's action in attempting to correct the runoff included action in steering to the left, back to the highway lane, as indicated by events. This may also have been logical, since the left wheels were probably still on dry pavement. At this time, the right front wheel of the bus was necessarily off the pavement on the frozen snow-covered shoulder and affected by the outward and downward slope of the shoulder and the reduced friction of the surface.

Thus the driver's leftward steering correction would necessarily be that amount required to overcome the slope of the shoulder acting on both right wheels, and the reduced traction on both right wheels. Furthermore, steering force was essentially available only from the left front wheel, apparently still on dry pavement. Considerable corrective steering force would have been required to bring the bus back to the left and onto the pavement under these conditions. The driver would necessarily have turned the steering wheel much farther to the left than would normally be necessary to maintain a turning path in the normal lane.

When the bus followed this high steering correction and returned over the hump formed by the sloped shoulder onto the dry pavement, the steering effect of the right front wheel would have suddenly been added to that of the left front wheel, while at the same time, the traction against centrifugal force of the right rear wheel would have returned. Thus, almost instantaneously, the front wheel steering would become sharply excessive over the steering needed to maintain a path around the curve and a sharp left swerve would ensue. In order to correct such a swerve, the driver would first have to sense that it was occurring, which was possible only after some swerving had already taken place. He would then be required to turn the steering wheel rapidly to the right and to stop the steering wheel and the front wheels at the correct degree of rotation to return the bus toward the axis of the highway. This reversal of steering on the part of the driver would have necessitated several changes in steering wheel hand position; we cannot say how many. This corrective action would also have been made difficult by the very slow steering ratio of 26-to-1, which required a movement of 26° at the steering wheel in order to change the direction of the front wheels 1°. At this time, furthermore, the bus driver would have had very little sense of the direction of the front wheels in relation to the bus axis. It is impossible to sense the direction accurately due to the five and one-half rotations of the steering wheel needed to turn the front wheels from extreme left to extreme right, and the position of the steering wheel does not in any way indicate the direction of the wheels. There is no indicator on motor vehicles such as the rudder angle indicator of a ship steering system. The power steering of the bus would have reduced or eliminated any sense of wheel position which might have been carried to the driver's hands as steering reaction forces.

Thus in attempting to correct the swerve to the left, the driver had no means to determine how far to turn the wheels to the right, and the event shows that his action went beyond the necessary degree of turning, producing a second swerve to the right. The bus then departed the roadway to the right and entered upon the frozen and snow-covered terrace where steering and braking action was relatively ineffective.

The steering action described above can also be explained in terms of instability in the man-vehicle-highway control loop, which is a classic feedback control dependent upon the observations of the driver to close the loop and maintain stability. It was not possible to determine the parameters of the control system, and therefore, a stability analysis could not be made. However, the increasingly severe swerves were divergent (increasing) rather than convergent (decreasing to a desired position) possibly indicating the first two swings of a building-up oscillation.

In the foregoing analysis, another subject was also considered, namely, the possibility that the bus exhibited the characteristic called "oversteer." If present, this characteristic would have contributed to difficulty in regaining control. No specific evidence was available which would allow separation of any possible oversteer condition from other aspects of loss of control. The absence of oversteer would be expected to be confirmed by manufacturers' development tests. This possibility could not be ruled out, but is not considered a probable difficulty.

From the marks gouged into the turf (see Attachment 5), it appears that the driver then turned the steering wheel hard to the left in an effort to return to the roadway; he most probably also applied the brakes, though he does not say that he took either of these actions. With or without any braking action, the front of the bus turned gradually to the left. Marks indicate that the front wheels started to "plow" because of being cramped far to the left. The bus yawed sharply to the left, and the right rear wheel also began to plow through the frozen turf. In the counterclockwise yaw, the left wheels lifted off the ground. At that point, the front of the bus was heading at almost 90^{o} back toward the highway, and the center of mass was moving in a flat angle back toward the highway. When the right wheels dug into the turf, the sudden deceleration of the lower part of the bus caused a clockwise rotation along the longitudinal axis, elevating the center of mass and producing a right roll accompanied by a vaulting action. Marks on the terrace show a clear leap with no contact with the ground for about 27 feet at the front and 35 feet at the rear of the bus, while the bus was rolling, and before the bus came back to earth on the right side of its top. It struck first and hardest on the right front top area, which briefly formed a pivot around which the back of the bus swung in a counterclockwise arc. The rear of the bus swung around, sliding on the right top area; by the time the bus reached the sharp decline at the east end of the terrace, it was sliding on its roof, rear end foremost, and it partly slid and partly bounced down into the gully. During its reversal of heading, the front of the bus broke one support of a small highway sign just inside the guardrail below the terrace. In descending into the gully, the left side of the bus roof first impacted the north embankment of the gully, further crushing the top structure of the bus inward and to the left. It rebounded to the south bank, further crushing the right roof area inward and to the left. Just before coming to rest in the bottom of the gully, the rear roof portion impacted a rocky outcropping in the south embankment, crushing in the rear top and forcing the whole roof structure forward. The bus then settled into the bottom of the gully, its left side against the north embankment, its top against the south embankment, and its front facing west (Attachment 9).

Deceleration Forces

During its initial actions on the highway, when the bus swerved left, then right, some forward energy was absorbed in turning the bus. Normal friction and engine compression created additional drag, so that the gravitational pull of the minus 1.9 percent grade would have been more than overcome, resulting in some slowing. The bus was moving about 50 miles an hour when it ran up onto the terrace. Significant deceleration force acted during the gradual turning on the terrace, and in the severe yawing when the right wheels dug into the turf. The lateral velocity of the bus when it vaulted is estimated to have been about 24 to 25 m.p.h. (See Attachment 6 for these estimating calculations). Additional deceleration in the eastward motion occurred when the bus struck the earth after vaulting, and then intermittently as it slid and bounced down into the gully. Its speed at the final impact against the rocky outcropping is estimated at no greater than 15 m.p.h.

Occupant Kinematics

The Report of the Research Accident Investigation Group of University of Rochester, School of Medicine and Dentistry, John D. States, M. D., Principal Investigator, includes a review and analysis of bus occupants' injuries and the source thereof on a seat-by-seat analysis. Reconstruction of the bus dynamics and successive deceleration forces provided the basis for explaining the movements of the bus occupants during the accident sequence:

1. When the vehicle went up onto the terrace occupants were subjected to jolt, but it is considered unlikely that any one was dislodged from his seat.

2. During the next sharp left swerve preceding the upset, left-side passengers were probably dislodged from their seats over to the right side, and right-side passengers were probably pressed hard against the right bus sidewall. Some passengers would have been expected to be bruised and shaken up during this action.

3. When the bus impacted the ground after rollover, many passengers who had not been dislodged earlier were probably severely thrown to the right, impacting the top, the edge of the parcel shelf, the bus body, or the seat structures. Those already on the right side were thrown towards the top right of the bus. Many passengers may have been severely shaken, cut, or bruised, or incurred fractures in this event. It is unlikely that any of the fatal injuries were incurred to this point, except possibly for the occupant of seat No. 1, who was elderly and unusually heavy, and who was near the point of maximum deceleration in the rollover impact. The right-side parcel shelf, and parcels stored there, probably helped to absorb occupant impact, although its rigid edge is believed to have caused some injuries.

4. When the bus landed upside down in the gully, at least one passenger (seat No. 12) was killed by the inward and leftward collapse of the roof support structure. The occupant in seat No. 33 was partially ejected through the broken out window structure, and crushed in the collapse of that structure. The occupant of seat No. 1 would logically have been further thrown about, possibly aggravating already-serious injuries (death followed about an hour later). Other occupants impacted the bent-in side and roof structure, or were cut by the fractured edges of the plastic roof liner and parcel shelf; some were injured by the crushing

in of roof support structures, the collapsing restroom door and partitions, or the inward flexing or deformation of the bus sidewalls. The roof structure was far above the normal seated position and could only be contacted by persons ejected from their seats. Those passengers who fell against or on top of others were probably protected by the cushioning effect, and were less severely injured. (See Attachment 11, Analysis of Occupant Injury.)

Passenger seating in relation to injury is depicted in the seating diagram in Attachment 8, and a diagram of vehicle damage is shown in Attachment 7. That there were not many more fatalities can be attributed to the earlier deceleration sequences, which reduced the velocity in the unusual attitude at final impact, to the inward pressing of the overhead parcel shelves of relatively thin plywood, which yielded to some degree on impact but which helped to contain passengers in place, and to the absence of fire.

Post-Accident Activities

Notification of the accident to police and emergency facilities was given by telephone by a night employee at the turnpike maintenance base, in accordance with a standard plan. He began rendering what assistance he could, and outside emergency units arrived in about 20 minutes.

Response of emergency services to the accident scene is an excellent example of the results of coordinated planning by State and local agencies. Each exit and maintenance base of the Pennsylvania Turnpike Authority has a list of all types of emergency services, and there are contractual arrangements in some cases. Among the service units which responded were the State Police, the Homewood Fire Department, the Rochester Canteen, the Salvation Army, Lutton's Ambulance Service of Beaver Falls, the Homewood turnpike ambulance (No. 140), the Gibsonia turnpike ambulance (No. 141), and others. Rescue and removal of the victims were effected or supported by these various groups. Two of the fatally injured passengers were declared dead at the scene by the Beaver County Coroner, and the third was dead at the time of admission to the hospital.

Two area hospitals received the victims, at times noted from about 4 a.m. to noon. Times of initial arrival at the two hospitals were reported to be earlier than the admission times noted. There is no indication that delay in receiving medical attention contributed to any fatality or to the degradation of condition of any of the injured. A large measure of credit for this must go to the work of the emergency agencies at the scene.

There was no fire, smoke, or noxious fumes which could have caused panic or materially worsened the outcome of the accident. The bus chassis remained intact, and there was only moderate lateral distortion of the body structure below the window line. There was no rupturing of the fuel tank or fuel lines, or failure of battery mounts or power cables.

A mobile crane hoisted the bus to an upright position, lifted it up the gully embankment to the turnpike, and then carried it to the adjacent maintenance base yard. It was covered with a tarpaulin because of rain which commenced the afternoon of December 26th, and on January 3rd transported by flatbed trailer to the repair base of the operating bus company at Chicago, Illinois.

PART III - CONCLUSIONS

The following conclusions have been derived from analysis of the available evidence:

1. The bus was moving about 60 to 65 m.p.h. just before the accident sequence began (Page 10).

2. The driver's attention was diverted by another operating task at a point where the highway curved to the left, thus he did not give full attention to the roadway ahead or to the course of the bus (Page 10). Although the Board cannot determine which of several heater operating controls was being manipulated, it is apparent that several controls had design features which required diversion of attention to obtain correct operation. The operation of the heater controls during a curve was not essential, but would have required some diversion of attention whenever performed. The heater controls could have been adjusted safely by stopping or slowing, but such action is not directed by the Operator's Manual (Page 12).

3. The driver may have lost visual reference with the right edge of the roadway after the right guardrail terminated, and there was minimal contrast between the light-colored concrete roadway and the snow-covered shoulder and roadside (Pages 5, 7, 10).

4. The bus strayed off course to the right following a brief period when the driver's attention was diverted, and ran onto the slippery snow-covered shoulder which sloped down away from the pavement (Page 10).

5. One purpose of a highway shoulder is to allow safe return to the pavement after a vehicle has run off the pavement for whatever reason. This particular shoulder design, however, was below current standards, and under a predictable weather condition was of inadequate design to insure safe return to the pavement (Page 6).

6. Proper corrective action by the driver to return the right wheels to the pavement after the bus initially left the pavement would have been a virtual impossibility,

given the slow steering ratio of the bus, the absence of any indication to the driver of the direction of the front wheels relative to the bus, and the very sudden swerve necessarily produced when both wheels again entered on the dry pavement. This condition of difficulty in regaining control against lateral resistance is not unusual, and is duplicated, except as to degree, in ordinary driving when a vehicle must return to the pavement from a shoulder dropoff. However, each condition is unpredictable and this one was unusually difficult because of the inadequate shoulder design and snow. The steering system of the bus, part of the driver-vehicle-highway control loop, lacked feedback information of the position of the front wheels and forces being exerted on the front wheels, and thus did not provide information to the driver by which he could determine how much steering correction was necessary (Pages 12-14).

7. A safe recovery, after the bus initially left the pavement, by steering off the road into the parking area, would have been possible as there was considerable space in which safe recovery could have been made (Page 5). However, the parking area was obscured by snow and the driver would have had no means to identify it as a useful recovery area. Such recovery areas are unusual, and their use in emergencies is not a normal action.

8. Vehicle condition, as distinct from vehicle design, and driver condition were not factors in the initial runoff or the second runoff onto the terrace. The driver's action in avoiding braking and simply removing his foot from the accelerator was the correct one to take when the runoff occurred for the bus braking systems now in use. (Page 8). However, the Board notes that several types of superior braking systems, such as anti-locking systems and interlocked four-wheel-drive systems are technically feasible, and that these systems allow a straight stop when wheels are partially on dry pavement and partially on the shoulder.

9. The number of fatalities and serious injuries was kept to a relatively low figure because (1) passengers had been pressed against the right side during the swerve prior to rollover and during rollover and thus did not

contact the side at high velocity when the impact occurred; (2) the inward distortion of the bus and the cushioning afforded by the overhead parcel shelf helped to reduce the later deceleration impact and provided a measure of containment; and (3) the total deceleration was distributed through a fortuitous succession of forces, each of which slowed linear motion cumulatively, rather than in one massive impact (Pages 15-17).

10. The absence of fire was a major factor in minimizing the number of fatalities. Had fire ensued (as in the Baker, California, bus accident in March 1968), it is probable that a large percentage of the occupants would have been killed. Problems created by injuries, by the unfavorable position of the bus, and by reduction of available egress routes, would have made rapid evacuation impossible (Pages 5,18).

11. Delay in passenger egress occurred, but was not a factor in the injury or fatality outcome. However, with most of the side-window exits and the rear window exits blocked by damage, it is fortunate that the windshield opening was available to permit escape. (Pages 8-10,17). This was a happenstance, not an intention.

12. Occupant restraints would have reduced the number of injuries, and possibly have reduced injuries of the passengers at seat No. 1 below the fatality level, as reflected in analysis of individual injuries reported by the RAI group, most of which were produced by deceleration against interior bus components other than seat backs (Page 16 and Attachment 11). It is not certain whether restraints would have prevented the other two fatalities, because of the structural crushing circumstances which caused the deaths in this case (Page 3).

PART IV - RECOMMENDATIONS

The National Transportation Safety Board recommends that:

1. The Bureau of Public Roads, FHWA, consider the establishment and enforcement of a firm requirement that all existing highways, Federally aided or not, which are brought into the Interstate System must meet current Federally approved highway design standards, prior to being designated as Interstate routes and given Interstate numbers. Highway users in general should not have the experience of being able to steer one wheel onto a shoulder and return safely on some parts of the Interstate System and finding a hazardous result on another part of the Interstate System. The designation of a highway as an Interstate route should presume that such highway meets all basic design standards for safety. This requirement should include a standard for the slope of shoulder areas or curves relative to the superelevation of adjacent pavement (.07 foot per foot maximum differential in cross-slope break).

2. Pending the establishment and enforcement of the requirement recommended above, motorists should be informed by signs of hazards created by sub-standard conditions, and the Pennsylvania Turnpike Authority and other affected turnpike and highway authorities of the several States and the District of Columbia should consider a requirement that salting and cindering of highways during frosting, icing, or snow conditions be extended to include the outer shoulder area of highway curves wherever shoulder design is below the AASHO standard.

3. The Bureau of Public Roads, FHWA, consider the feasibility of requiring some sort of visual reference, such as guardrails or reflectors, along the outer edges of all curves on Federally aided and Interstate numbered highways, so that drivers may maintain visual reference with the highway during periods of reduced visibility, reduced contrast between roadway and shoulder, or when other environmental conditions may increase the difficulty of determining vehicle alignment or position on the highway. Such visual references are used on many highways, but are not a requirement.

4. The Federal Highway Administration take additional steps toward making available to the bus-traveling public convenient restraints against being ejected from their seats in a crash, such as are available to motorists and airline passengers, so that passengers will not be denied the opportunity to employ them if they so desire. In the Board's view, a decision to make available suitable restraints which would reduce injuries is not dependent upon a showing that all passengers would use them, nor should it be limited by the fact that past bus passenger seat designs do not accommodate the lap belt type of restraint. The retention of passengers in their seats during the crash phase is clearly desirable, as indicated by this case and others, and making restraints available is a first step in obtaining their use. The Bureau of Motor Carrier Safety on June 28, 1969, proposed rulemaking (Docket MC-11) requiring seat restraints and their use for drivers of interstate carriers, and the opportunity to employ some form of restraint should not be withheld from passengers.

5. The National Highway Safety Bureau, FHWA, study the feasibility and practicality of a standard for passenger buses requiring that surfaces overhead of passengers, including roof linings, mouldings, parcel or luggage shelves, edges and support hardware be designed so as to reduce or prevent direct contact injuries in rollover and upset accidents, and that such areas resist separation or fracture of a type which would expose edges to passengers. This protection will continue to be of importance in the absence of passenger restraints, currently not required.

6. The National Highway Safety Bureau and the Bureau of Motor Carrier Safety, in connection with their research programs and standards work in regard to motor vehicle handling properties, consider whether the combination of relatively slow steering ratios, and the absence of any indication to the driver of direction of the vehicle front steering wheels may in some vehicles tend to create lags of time response and overcorrections in the driver-vehicle-highway control loop, irrespective of the skill of the driver. A goal of such research and standards work should be to insure that drivers are able

to determine the direction of front wheels and the necessary steering wheel movement, not only for small movements necessary in ordinary driving, but also for larger movements typically needed to recover from emergency situations.

7. The manufacturers and prospective purchasers of high-speed intercity buses review the designs of vehicle instruments and controls used by the driver from the viewpoint of correcting designs and layouts which may impose upon the driver more simultaneous tasks than he can execute. It must be remembered that high-speed vehicle driving requires almost uninterrupted observation of the road. Controls which require direct visual observation and large angular eye movement to operate correctly, or require unusual driver attitude to operate, or which can be confused with other nearby controls when located only by touch, or which require close reading of placards, all tend to divert the driver's attention from the road. It is further recommended that where existing vehicles having such control problems must continue to be operated, drivers be specifically warned of any tendency of the operation to distract attention.

8. The National Highway Safety Bureau continue its studies toward the development of techniques for standards for vehicle instruments and controls with special attention to the problems posed by the high-speed intercity bus situation, which requires road vigilance equal to that of a passenger car or truck, but with the necessity to operate a significantly larger number of auxiliary controls while moving at high speed.

9. The Federal Highway Administration review our recommendation in the report of the Interstate bus-auto collision near Baker, California, to "change the basis of its regulatory requirements intended to insure escape from buses so that they are based upon tests of performance of occupants in escaping from buses standing or lying in all basic attitudes. In the development of test criteria, it is suggested that consideration be given to test procedures employed by the Federal Aviation Administration for the regulation of the adequacy of escape techniques and systems.

Further, consideration should be given to adopting for buses, the airline practice of placing emergency escape instructions at each passenger location. It is further recommended that necessary regulations be expedited to insure that no new types of buses go into service which have not been tested to insure that all occupants can escape rapidly when the bus is in any of its basic attitudes after a crash. This recommendation refers to Docket 2-10 of the National Highway Safety Bureau as well as to Motor Carrier Safety Regulations."

BY THE NATIONAL TRANSPORTATION SAFETY BOARD:

/s/ JOHN H. REED
Chairman

/s/ OSCAR M. LAUREL
Member

/s/ FRANCIS H. McADAMS
Member

/s/ LOUIS M. THAYER
Member

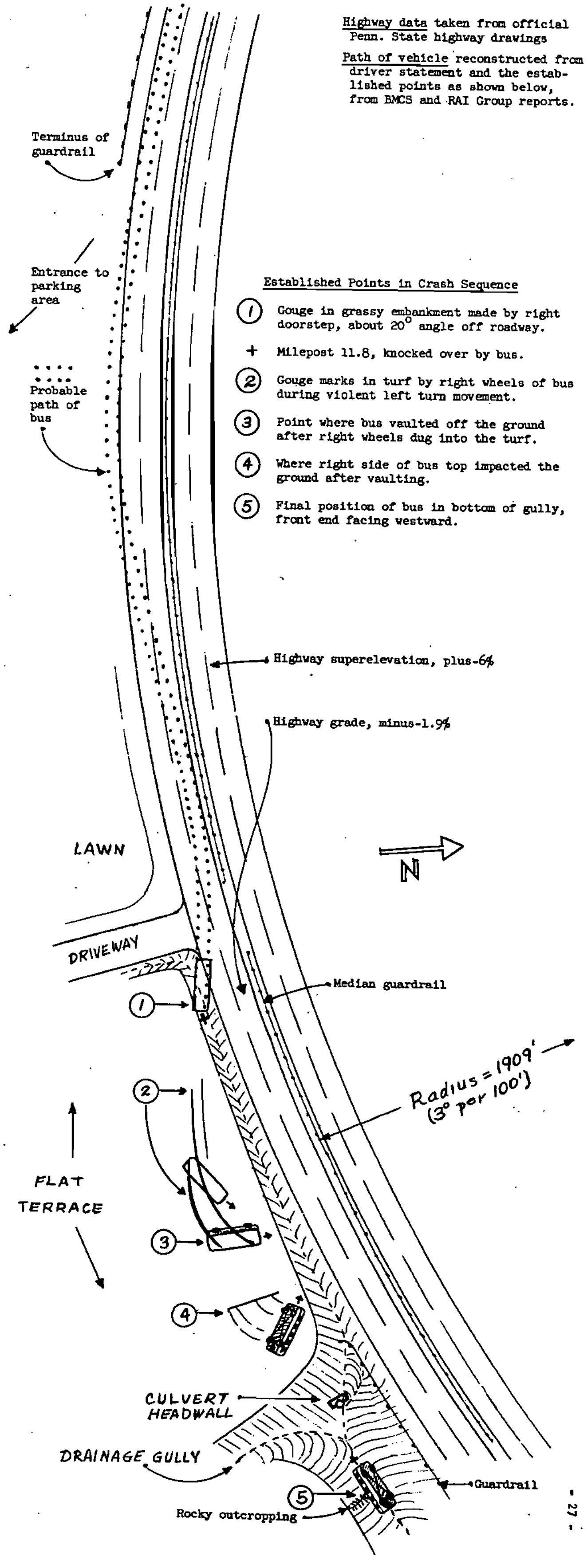
/s/ ISABEL A. BURGESS
Member

January 23, 1970

PART V - APPENDIX

ATTACHMENTS 1 - 11

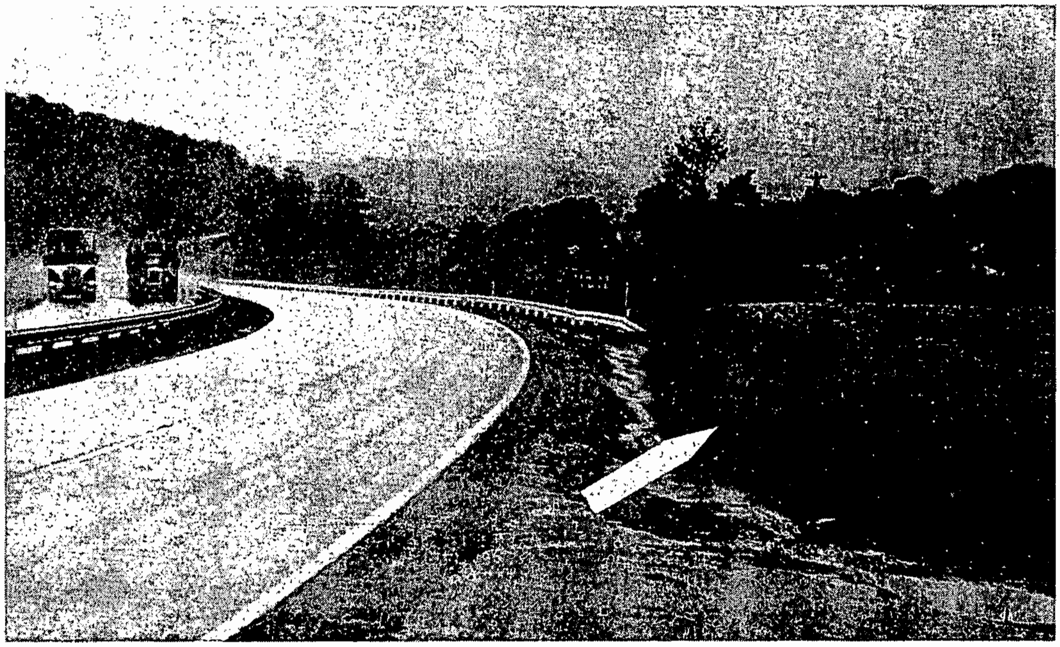
PICTORIAL REPRESENTATION OF ACCIDENT SCENE
(not to scale)



ATTACHMENT 1

ATTACHMENT 2A Interstate I-80S, looking east. Immediate foreground shows the estimated location where the bus first swerved off the pavement. Safety Board photo taken 9/24/69.

ATTACHMENT 2B



Point at which bus left the highway, just east of the maintenance base driveway, and ran up onto terrace embankment. Safety Board photo taken Sept. 24, 1969.

Gully into which bus crashed, looking westward, showing the terrace on which the bus overturned and the highway approach. Safety Board photo taken September 24, 1969.

ATTACHMENT 3. Bus lying in ditch, facing west. Note presence of snow overlaying the area, and snow on highway shoulder. Photo by Beaver Falls News-Tribune, December 26, 1968.

ATTACHMENT 4

REPORT OF TIRE EXAMINATIONS

The results of tire examinations by the Bureau of Motor Carrier Safety (BMCS) and the Rochester Accident Investigation (RAI) Group are tabulated below. BMCS did not make "Durometer A" tests (see footnote).

TIRE POSITION	AIR PRESSURE 2/		MINIMUM CENTER TREAD DEPTH		DUROMETER A 1/
	BMCS	RAI	BMCS	RAI	RAI
Right Front	85	88	12/32"	14/32"	67
Left Front	84	88	12/32"	14/32"	62
Right Rear - Outside	70	74	6/32"	8/32"	64
Right Rear - Inside	65	72	10/32"	12/32"	59
Left Rear - Outside	70	74	5/32"	4/32"	64
Left Rear - Inside 3/	65	72	7/32"	8/32"	61

1/ "Durometer A" represents a hardness rating. Of five new comparable tires tested by RAI Group, the average rating was 62, with a range of 60-67.

2/ Pressure differences are apparently due to differences in ambient temperature at the time of individual tests and/or minor tire-gauge variations. Pressures and tread depths are not significantly different between the two sets of data.

3/ Left Rear Inside tire was regrooved in a large diamond pattern. All other tires had the original manufacturer's tread design.

ATTACHMENT 5

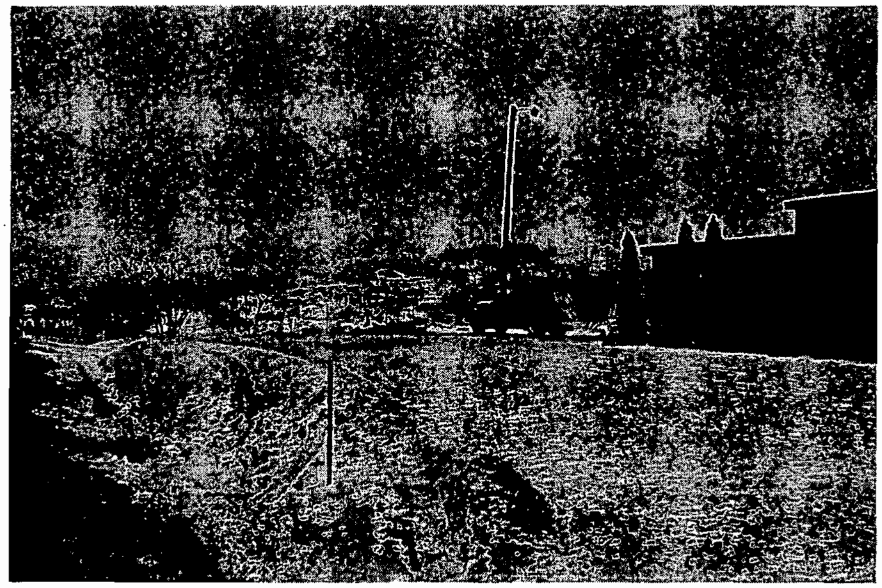


Fig. A Marks of bus wheels as it went up onto the snow-covered terrace. (Mileage marker had been knocked over, but was replaced by maintenance crew.)

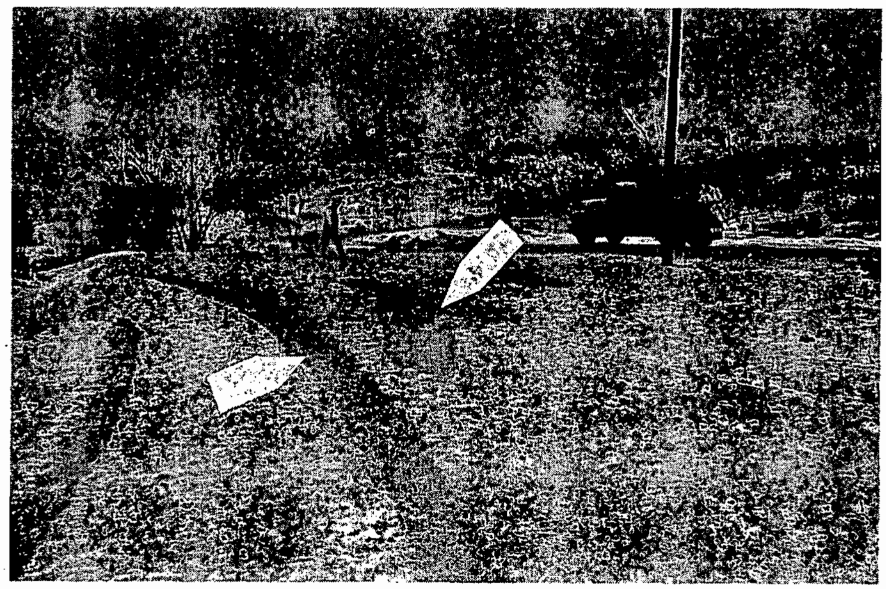
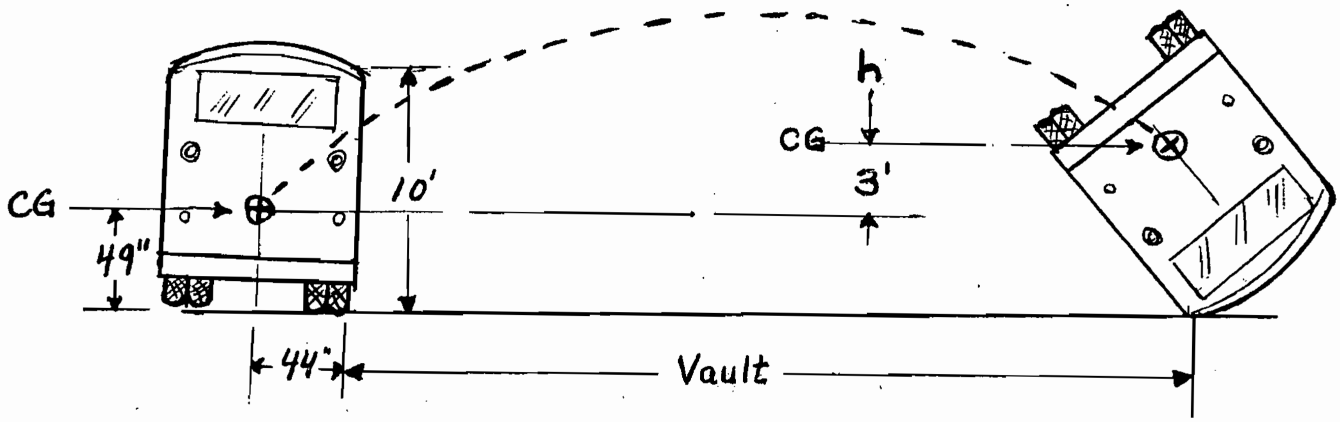


Fig. B Marks of bus tires as bus swerved left on the terrace. Points where wheels broke through the frozen surface are indicated by arrows.

ATTACHMENT 6

ESTIMATION OF VAULT SPEED



VEHICLE DATA: Center of Gravity (CG), loaded, is:

49" above ground
44" inboard of outer wheel rims (or 3.7')
62.5% of Wheelbase length back of Front Axle

VAULT DISTANCE OF CG:

Vault Distance at Front (V_F) is: 27 feet

Vault Distance at Rear (V_R) is: 35 feet

Vault Distance of Center of Gravity (V_{CG}) is computed thus:

$$V_{CG} = V_F + .625 \times (V_R - V_F) + 3.7'$$

$$= 27' + .625 \times (8) + 3.7'$$

$$V_{CG} = \underline{\underline{35.7 \text{ feet}}}$$

HEIGHT DIFFERENTIAL (h), as shown in drawing, above, is: 3 feet

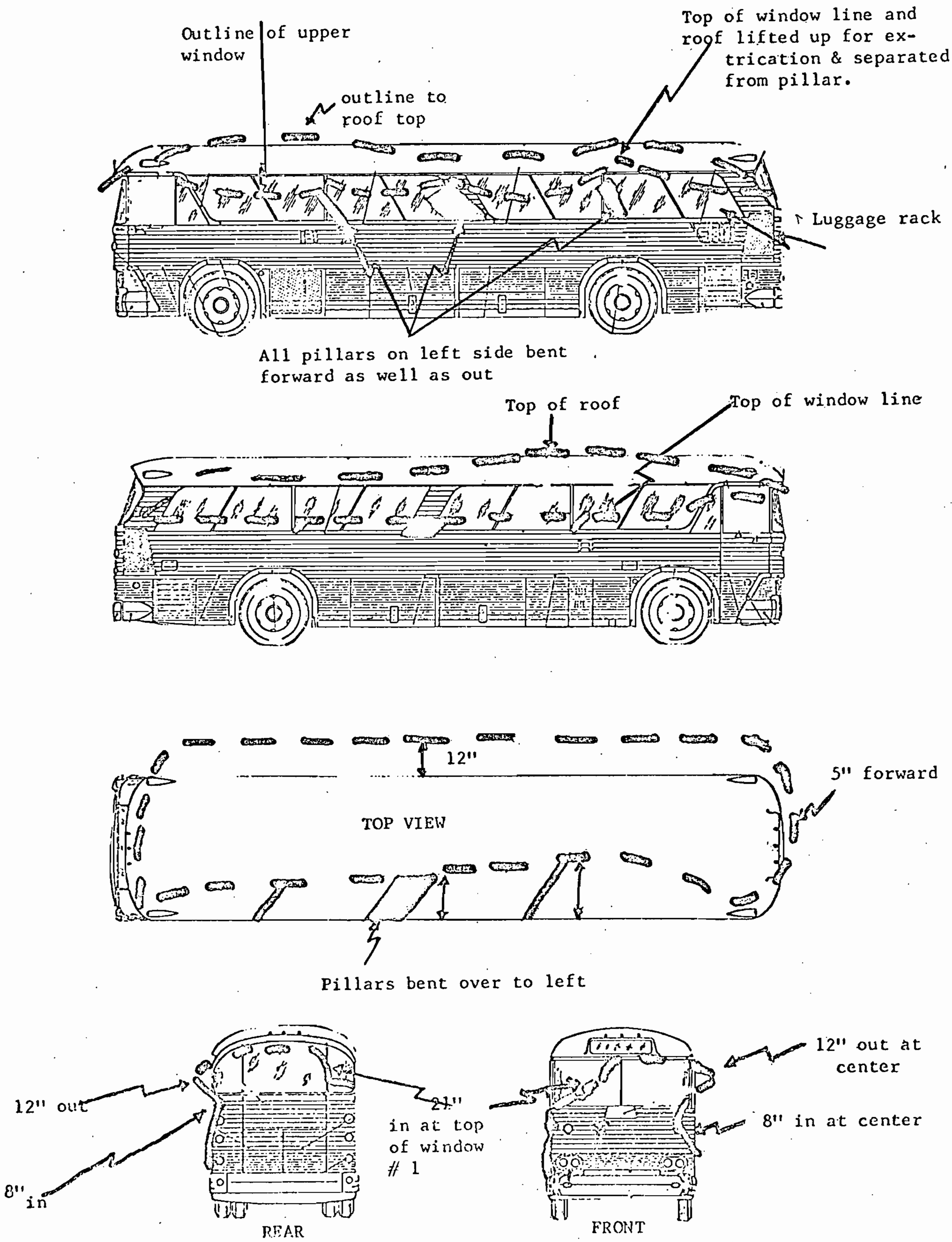
VAULT TAKEOFF SPEED (S) is computed thus:

$$S = 3.9 \times \frac{V_{CG}}{\sqrt{V_{CG} - h}}$$

$$= 3.9 \times \frac{35.7'}{\sqrt{35.7 - 3}}$$

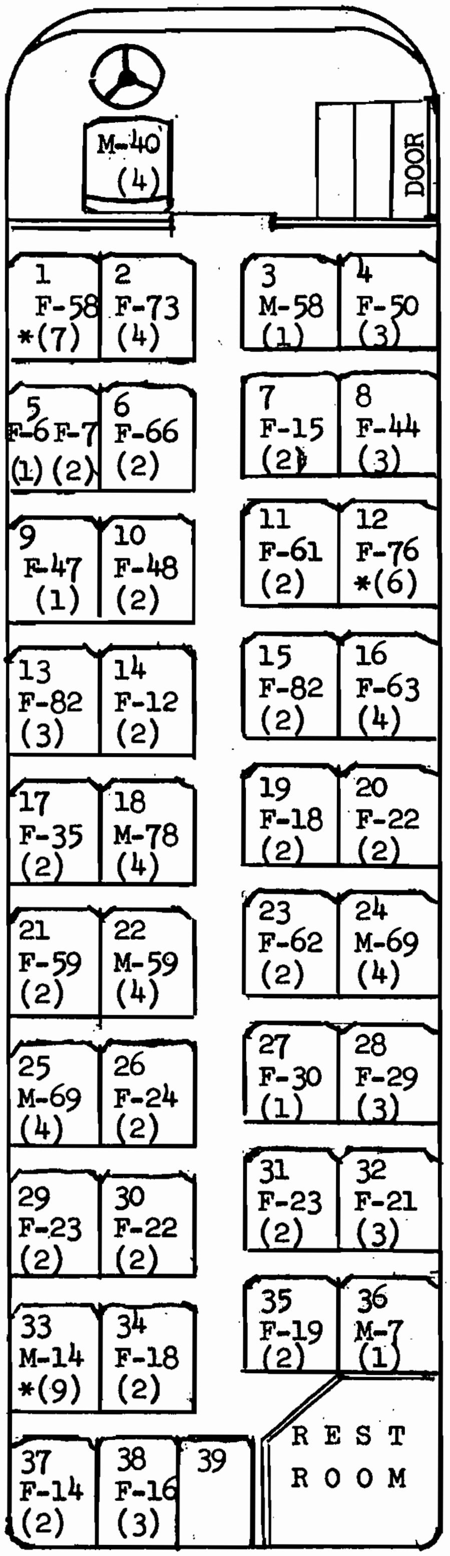
Vault Speed $= \dfrac{3.9 \times 35.7}{5.7} =$ 24.4 miles per hour

DEFORMATION OF BUS ROOF



ATTACHMENT 8

SEAT LOCATION OF PASSENGERS



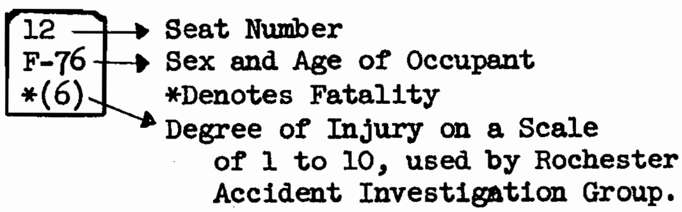
Seat locations shown represent a composite of information, based on patient statements when interviewed by the Rochester Accident Investigation Group, and information supplied by the Pennsylvania State Police and the Bureau of Motor Carrier Safety (FHWA).

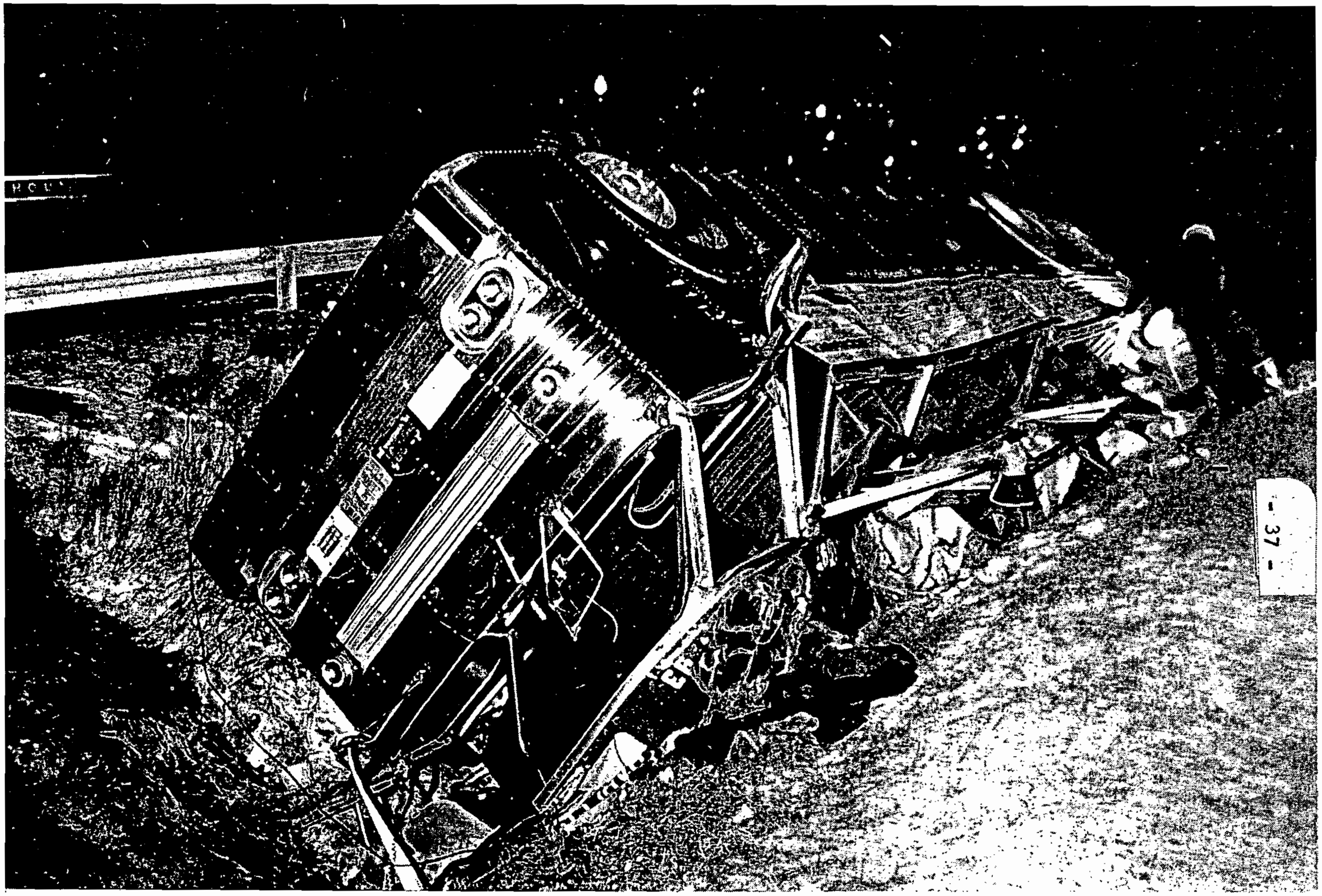
The only significant uncertainty concerns occupancy of Seats 1 and 2. The survivor, Seat 2, said she was sitting by the window, but this was not substantiated by the State Police or BMCS. Further, she said she fell into the doorway and that the fatally injured passenger fell on top of her.

Seat 5 occupied by two small girls.

Seat 39 was not occupied.

EXPLANATION OF SEATING CODE





ATTACHMENT 9

Photograph of bus in bottom of gully, facing west, showing extensive inward crushing of right-side window and roof support structure and inward flexing of the body side panel. (Photo by Beaver Falls News-Tribune)

ATTACHMENT 10

INTERIOR PHOTO OF BUS, SHOWING ROOF COLLAPSE

One of the roof support pillars on the right side was bent over and significantly reduced the available space for the occupant in seat No. 12.

ATTACHMENT 11

ANALYSIS OF OCCUPANT INJURY

The following 12 pages are taken from the RAI Group Report (RAI Case No. 36) and represent the efforts of that Group to correlate passenger injury with bus components and occupant kinematics. The Board generally agrees with the findings reported herein, but because there are subjective interpretations in some instances, based on logic rather than on any clear evidence, the Safety Board does not necessarily concur with all the conclusions.

Individual Occupant Kinematics

Bus Driver : Male, aged 40, 6'3", 190 pounds

Diagnoses : Compound fracture of the nose; fractures of right 3, 4, and 5 ribs; contusion of right arm; laceration of left hand and laceration of right eyebrow and contusion of abdomen. AIS-4

The bus driver was thrown forward and to the left as evidenced by damage to the left side of the steering wheel and to the instruments on the left side of the steering column. The first impulse caused the driver's facial, chest, and abdominal injuries. The back of the bus driver's head appears to have contacted the sunvisor which was bent upwards, presumably when the roof collapsed. His nose fracture and facial lacerations were caused by the windshield frame or glass. The windshield glass probably did not fall out until the bus rolled.

The driver appears to have been holding on to the steering wheel so that he remained in his seat rather than falling to the ceiling of the bus. Furthermore, the roof of the bus was pushed downwards over his head, giving him additional support and denting the sunvisor.

The driver was then thrown backwards against the back of the seat when the bus came to its final resting point after sliding backwards on its roof. This broke his seat back and broke the tubular "U"-shaped railing behind his seat. The back of the seat itself contacted the guardrail and prevented the guardrail from injuring the driver.

The outboard anchorage of the "U"-shaped railing was angulated and bent inwards when the bus rolled over, collapsing the roof structure and buckling inward the window pillar. This almost certainly weakened the junction between the tube and its male-anchorage-casting.

Seat No. 1 : Left window, 58-year-old female, 300 pounds (estimate by Medical Examiner)

Diagnoses : Fatal injuries to chest and head (crushed chest, compound laceration of cranium and scalp). AIS-7

The patient was initially thrown forward and to the left into the "U"-shaped tubular guardrail behind the driver's seat and the window pillar to which the tubular guardrail was anchored. This contact probably caused her head and chest injuries because the force was highly concentrated (diameter of the guardrail 1-1/8 inches). Patient's excessive weight contributed to the severity of injuries because of the excessive energy dissipation necessary to decelerate her body. She then appears to have fallen from her seat, landing on top of the occupant of seat No. 2 near the front door.

The outside wall of the bus buckled inward adjacent to her chest. It is possible her chest and possibly her head injuries were caused by this inward buckling. The roof by that point had come down on top of her, holding her next to the point of maximum inward buckling of the sidewalls of the bus. However, examination of the bus structure reveals that the driver's seat, located directly in front of her, prevented excessive inward protrusion of the buckled sidewall and protected her somewhat. Furthermore, it is likely that she had already been ejected from the seat at this point and was traveling toward the right-hand side of the bus to the door.

Seat No. 2 : Left aisle, 73-year-old female, 130 pounds, 5'3"

Diagnoses : Contusion of right chest, right shoulder, right ankle; Fracture of left ribs 2 through 8. AIS-4

The patient may have received her rib fractures when she was thrown forward against the "U"-shaped tubular guardrail behind the driver's seat. However, it is also possible that she may have received all her injuries when she fell into the right upper corner of the bus next to the door and the 300-pound (seat No. 1) occupant fell on top of her.

Seat No. 3 : Male, aged 56, 5'8" (estimate). Right aisle.

Diagnoses : Contusion of right shoulder and right chest. (Acute strain lumbar-sacral spine occurred when helping others out of the bus). AIS-1

The occupant received only minor injuries and was able to help the driver out of the bus. His right shoulder and right chest injuries were probably caused during the first decelerative impulse which threw him forward. He contacted the forwardmost structures in the bus, the body work below the windshield, and then fell against the ceiling.

Seat No. 4 : Right window, 50-year-old female, 5'3", 115 pounds

Diagnoses : Fracture of right clavicle, contusion of right forearm, right lower leg, right side of face, and three broken fingernails on right hand (due to climbing up the embankment). AIS-3

The precise cause of this occupant's injuries could not be determined with certainty. It is most likely that she was thrown forward and to the left, contacting the guardrail and partition between her seat and the bus doorway. All of her injuries were on the right side. The injuries to her right forearm and right lower leg were caused by the bus door partition. The fracture of her right clavical and the contusion of the right side of her face may have been produced by contact with the ceiling of the bus when she fell from her seat.

Seat No. 5 : There were two children, ages 6 and 7, seated together in one seat. The exact location of each is not known.

Female, age 6:

Diagnoses : Abrasions of abdomen and left flank. AIS-1

Female, age 7:

Diagnoses : Abrasion of left arm. AIS-2

Both were seated adjacent to the left side of the bus and sustained injuries to their left sides (left arm and left side of abdomen and left flank). These injuries were probably caused by being thrown to the left during the rollover and possibly the left side of the bus buckled inward.

Seat No. 6 : Left aisle, female, aged 66, 5'4", 165 pounds

Diagnoses : Fracture of right 9 and 10 ribs; abdominal contusions. AIS-2

The occupant injuries appear to have been caused by contact of her right lower chest and abdomen either with the luggage rack when she fell out of the seat or the back of the seat in front of her. Contact with the luggage rack seems to be the most likely because the seat back in front of her was well-padded.

Seat No. 7 : Right aisle, female, aged 15

Diagnoses : Contusion strain of right shoulder; contusion left patella. AIS-2

The right shoulder injury was probably caused by the luggage rack which was pushed down on top of her. Her knee injury was caused by the initial forward impulse which occurred when the bus reversed directions.

Seat No. 8 : Right window, female, aged 44

Diagnoses : Fracture of right 8 and 9 ribs; contusion of forehead; strained right ankle and lumbo-sacral spine; abrasion of left knee. AIS-3

The patient's chest and lumbo-sacral spine injury was caused by her being thrown against the bus. Her forehead injury was caused by being thrown forward and the primary change in direction of the bus. Abrasion of the left knee may have occurred at the same time.

Seat No. 9 : Left window, vacant.

Seat No. 10 : Left aisle, female, aged 40

Diagnoses : Acute strain of cervical spine; contusion of right knee. AIS-2

Her knee injury was caused possibly by her being thrown forward. Her neck injury occurred when she fell out of her seat and landed on the roof of the bus.

<u>Seat No. 11</u> : Right aisle, female, aged 61

<u>Diagnoses</u> : Contusion of right shoulder, chest, and knees. AIS-2

The patient stated glass hit the right side of her face. The patient's right shoulder and chest injuries were caused by her being thrown against the side of the bus. The window literally broke over her head because the roof and upper frame of the window was pushed to the right over her head. Her knee injuries occurred probably with ejection with the seat.

<u>Seat No. 12</u> : Right window, female, aged 76 <u>Fatally Injured</u>.

<u>Diagnoses</u> : Crushed left chest; contusion of left shoulder; scalp laceration. AIS-6

The patient was alive at the scene of the accident and was transferred to a hospital where mechanical respiratory assistance was given to her after an airway was established. Patient expired approximately one hour after the accident.

The patient was seated next to the right side of the bus. The window pillar was bent across her seat to the region of her chest, crushing her chest and causing the fatal injury. The seat back was also partially telescoped against the aisle seat adjacent to it. Her scalp was cut by the luggage rack in the bus, which was pushed downward an estimated 16 to 20 inches at the seat location.

The roof and upper rails of the windows were pushed to the left. Permanent lateral displacement to the left of the upper window rail measured approximately 20 inches. The elastic deformation was undoubtedly greater. It is reasonable to assume that the window pillar was angulated at least 90 degrees instantaneously during the impact, although its permanent deformation measures only 65 degrees. In spite of this, the pillar did not become detached at either end.

<u>Seat No. 13</u> : Left window, female, aged 82, 5'3", 159 pounds

<u>Diagnoses</u> : Fracture of right 3 and 4 ribs; fracture of right 3rd metacarpal; laceration and contusion of right ear. AIS-3

The patient's injuries were caused by inward buckling of the left side of the bus and by the luggage rack which was collapsed to the top of the seats. During the elastic deformation phase of the accident, the luggage rack was pressed down to the top of the seat back, possibly forcing the seat back to bend backwards; at the same time, the patient was thrown against the luggage rack which restrained her in her seat.

The patient was also thrown to the left as the bus was rotating around its yaw axis with the rear of the bus leading. The patient's seat was probably in a reclining position at the time of the accident. The left side of the bus buckled in and forced her chest against the back of the seat next to her, which was in an upright position, producing her rib fractures. The right hand and right ear injuries were caused by the luggage rack.

Seat No. 14 : Left aisle, female, aged 12, 5'3", 105 pounds

Diagnoses : Contusion of right groin and hip; acute lumbo-sacral spine strain. AIS-2

The patient appears to have been thrown to the right over the right-hand arm rest of her seat. This may have occurred as the bus rolled. It is also possible that these injuries occurred after landing on the roof, after falling out of her seat.

Seat No. 15 : Right aisle, female, aged 79

Diagnoses : Contusion of right chest. AIS-2

The patient's injuries may have been caused either by the luggage rack coming down on top of her or by her falling out of her seat onto the luggage rack and roof.

Seat No. 16 : Right window, female, aged 63, 4'9", 140 pounds

Diagnoses : Fracture of left humeral shaft with radial palsy, contusion of left hip. AIS-4

The patient was seated next to the window on the right-hand side. The bus roof and upper window frame were displaced to the left 12 inches directly above the patient.

The patient appears to have put her left arm above her head to protect herself as the bus began to roll. In doing so, the arm was caught between the luggage rack and the seat back in front of her, which was bent backwards by the downward force of the luggage rack, simultaneously fracturing her upper arm (humeral shaft) and pinning her arm which had to be freed by the police before the patient could be removed through the window on her side. The contusion of her left hip was caused by being thrown against the arm rest of the seat.

Seat No. 17 : Left window, female, aged 35, 5'7", 230 pounds

Diagnoses : Superficial abrasions of right side of neck, 2 cm. diameter of right and left hands. AIS-2

The patient was thrown about as the bus rolled. Her neck was injured when her head hit the luggage rack above her. The moulding of the luggage rack separated, resulting in some sharp exposed edges which produced the abrasions.

Seat No. 18 : Left aisle, male, aged 78, 5'11", 252 pounds

Diagnoses : Two deep longitudinal scalp lacerations, slightly curved, but running approximately parallel in an AP direction right 8 cm. long, left 7 cm. long; contusion of left shoulder; acute strain of cervicle spine; fracture of right ribs 8, 9, 10, and 11. AIS-4

This patient sustained his injuries when he was thrown against the luggage rack. The moulding separated and produced two parallel edges identical to the lacerations he received on his head and directly above him. It appeared that he continued to fall, striking his right chest against the edge of the luggage rack.

His heavy weight contributed to the force which was dissipated in his right rib cage, accounting for the multiple fractures of his ribs. Contusions of his left shoulder may have been caused by the luggage rack as well, when it came down on top of him.

The patient stated that he hit his head on a window moulding, but there was none in the immediate area where the patient apparently landed. There was blood on the luggage rack directly above his seat. It is possible that he was thrown across the bus and then rolled back to the left-hand side of the bus, which was down. The window moulding was exposed over the right-hand-most seat (seat No. 20). However, the luggage rack was on top of the seat and would have effectively prevented someone from being thrown into this area.

Seat No. 19 : Right aisle, female, aged 18

Diagnoses : Contusion of right chest, lateral aspect; abrasion of back. AIS-2

The patient was probably injured by falling out of her seat onto the luggage rack, which was beneath her after the rollover.

Seat No. 20 : Right window, female, aged 22

Diagnoses : Contusion of right shoulder. AIS-2

Injury was caused when she fell downwards onto the roof above her head after the rollover.

Seat No. 21 : Left window, female, aged 59

Diagnoses : Abrasions of left shoulder, right wrist, right ring finger; contusion of low back. AIS-2

Patient's injuries were probably caused after the bus rolled and she fell onto the roof.

Seat No. 22 : Left aisle, male, aged 59

Diagnoses : Displaced fracture of ulna. AIS-4

Patient's injuries were probably caused when he tried to protect himself by holding his arm over his head, causing his left arm to be struck by the roof rack. As the vehicle rolled, he fell toward it.

Seat No. 23 : Right aisle, female, aged 62, 5'5", 146 pounds

Diagnoses : Contusion of strained cervical spine; contusion of left elbow. AIS-2

Injuries were caused by her falling out of seat or by the roof rack coming down on top of her head and neck.

Seat No. 24 : Right window, male, aged 69, 5'7", 140 pounds

Diagnoses : Fracture of right ribs 5 and 6 and pneumothorax. AIS-4

Chest injuries were almost certainly caused by being thrown against the right side of the bus. He was held in his seat by the roof rack when the seat in front of him was pushed backwards somewhat and may have attributed to his chest injuries.

Seat No. 25 : Left window, female, aged 24

Diagnoses : Acute strain cervical spine; contusion of right shoulder

The patient's injuries were caused when she fell out of her seat onto the roof of the bus.

Seat No. 26 : Left aisle, female, aged 30

Diagnoses : Acute strain of right flank; contusion of left eye. AIS-2

The patient's injuries were caused when she fell out of her seat onto the roof of the bus. She must have landed on the left side of her face, injuring her left eye. It is possible that her right flank injury may have been caused by being thrown over the right arm of the seat.

Seat No. 27 : Right aisle, female, aged 30, 5'4", 145 pounds

Diagnoses : Contusion of head.

The patient's injuries were caused by the downward displacement of the roof rack, combined with her falling out of her seat against it.

Seat No. 28 : Right window, female, aged 29, 5'8", 185 pounds

Diagnoses : Contusion of right flank, right chest, hemoptysis, abrasion of right ankle. AIS-3

The patient probably was thrown against the right side of the bus when it struck on the right side of the roof as it rolled over. The luggage rack came down on top of her seat, but was displaced to the left because of the roof displacement. This most likely kept the patient in her seat during the rollover phase.

Seat No. 29 : Left window, female, aged 23

Diagnoses : Contusion of skull, occiput, right lower leg. AIS-2

The patient's head injury was caused when she fell out of her seat. The right lower leg injury may have been caused by being thrown against the arm rest of her seat.

Seat No. 30 : Left aisle, female, aged 22

Diagnoses : Contusion of right hip, right forearm; abrasion of right foot. AIS-2

The right hip injury may have been caused by her being thrown against the arm rest of her seat. However, this injury and other injuries may have been caused by falling from her seat onto the roof of the bus.

Seat No. 31 : Right aisle, female, aged 23

Diagnoses : Contusion and hematoma of forehead; contusion of right thigh. AIS-2

The patient's injuries were probably caused by the roof rack which came down on top of her, but they may also have been caused by her falling out of her seat when the bus rolled over.

Seat No. 32 : Right window, female, aged 21, 5'5", 125 pounds

Diagnoses : Contusion of left eye, left hand, and left mandible; concussion. AIS-3

The patient's injuries were probably caused by a window pillar which bent downwards into the occupant's space of her seat.

Seat No. 33 : Left window, male, aged 16

Diagnoses : Crushed chest and head. Fatal AIS-9

The patient was sitting in the left window seat in the second row from the back and at the point of maximum roof depression. He was found partially ejected and pinned in the bus by the roof and luggage rack. He could not be extricated until the bus was righted and the roof elevated with a hoist.

The patient was probably thrown to the right when the bus first contacted the right-hand side of the roof. He then rebounded, probably off the left-hand window which had fallen out from the impact of the right side of the roof. The roof and window frame then collapsed about him, crushing his head and chest between the vehicle structures and the side of the ravine. The decelerative forces were applied to this area of the bus in the final phase of the accident sequence and account for the extreme damage to the left rear upper corner of the bus and for this patient's fatal injuries.

Seat No. 34 : Left aisle, female, aged 18

Diagnoses : Contusion of right lower leg. AIS-2

The patient was pinned in the seat by the restroom door or partition. She had only minor injuries because she was trapped within the bus and there was sufficient occupant space remaining in spite of the collapse of the restroom partition.

Seat No. 35 : Right aisle, female, aged 19

Diagnoses : Laceration of right ear. AIS-2

The patient's injury was caused by the patient dropping out of her seat onto the luggage rack which was pushed down on top of her somewhat.

Seat No. 36 : Right window, male, aged 7

Diagnoses : No injury. AIS-1

The patient was uninjured because of his small size and the normal resiliency which a child has for trauma.

Seat No. 37 : Left window, female, aged 14, 5'3", 140 pounds

Diagnoses : Contusion of right side of face. AIS-2

The patient's injury was caused by being thrown to the right when the bus landed on the right side of its roof. For reasons not obvious, she did not rebound and survived with minor injuries in spite of the fatal injuries of the 16-year-old boy seated directly in front of her.

Seat No. 38 : Left aisle, female, aged 16, 5'4", 106 pounds

Diagnoses : Laceration of right eye 3 cm. long; contusion and strain of left hip; cervical and dorsal spine. AIS-3

The passenger was sitting next to the restroom door which collapsed on top of her and produced her injuries, except possibly for the left hip injury. This may have been caused by her falling out of her seat or against the seat in front of her.