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Downtown People Mover (DPM) Winterization Test Demonstration: Westinghouse

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January 1982
Final Report

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16. Abstract

The Westinghouse Downtown People Mover (DPM) Winterization Test Demonstration (WTD) Final Report covers the 1978-1979 and 1979-1980 winter periods. Testing over the 2-year period addressed all areas of the WTD system which could be affected by cold weather conditions. Product modifications were incorporated where necessary, and the resulting system tested under winter conditions. The 1978-79 winter season testing concentrated on testing of individual subsystems and of system enhancements designed to improve winter operation. The 1979-80 winter season testing was primarily concerned with overall system operation, incorporating additional product enhancements recommended at the conclusion of the previous winter. Over the 2-year testing period, the WTD system demonstrated its ability to operate in automatic mode in winter environments.

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PREFACE

This report was prepared by the Transportation Division of the Westinghouse Electric Corporation, West Mifflin PA, under contract DOT-TSC-1583 to the U.S. Department of Transportation's Urban Mass Transportation Administration's Office of Technology Development and Deployment. The contract was managed by the Transportation Systems Center (TSC), Cambridge MA; Neil G. Patt and Lawrence P. Silva were the contract technical monitors. The principal Westinghouse participants were Stanley Jones, who was responsible for initial program organization; Linda Sue Boehmer, who was project manager during the second year of the contract; and Art Holbrook, who along with Thomas Burke and other test track staff managed field activities, development of test data, and preparation of major report documents.

The objective of the program was to demonstrate that fully automated and simple Downtown People Mover (DPM) Systems can be a reliable urban transit alternative in severe cold climates. This demonstration was intended to determine the capabilities and limitations of Westinghouse's People Mover through a combination of system and subsystem level testing. The testing included evaluation of the system's traction and propulsion, braking and steering, power collection, vehicle and guideway electronics, switching and overall system performance. The test results can be used or extrapolated for quantitative design and performance criteria to be applied by DPM candidate cities located in areas of severe winter weather.

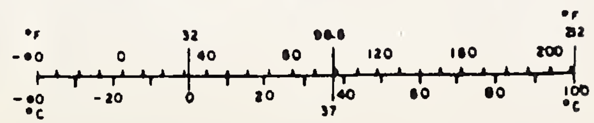
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

The Westinghouse Transportation Division (WTD) conducted a series of system and subsystem tests over a period of two years to demonstrate the capabilities of the WTD People Mover System as it would be used in a cold-weather Downtown People Mover application. The tests were performed at the WTD Test Track, located in Pittsburgh PA. The primary test vehicle was the Engineering Test Car, which simulates the vehicles being used in operating WTD systems and currently marketed by WTD for DPM applications. Testing was performed in manual and automatic modes at speeds up to 25 mph and at grades up to 10 percent. Pittsburgh's natural snow was supplemented by man-made snow and ice, when required, to provide severe winter conditions. Testing followed detailed plans and procedures, which were developed prior to testing and refined throughout testing as dictated by the test data.

Extensive tests were performed to determine the WTD System level of performance of the vehicle control and guidance during winter conditions. The tests demonstrated that only minor variations exist in those areas.

To eliminate the cause of these variations, a series of tests was performed to evaluate methods of maintaining the guideway running surface free from ice and snow. The final mechanical method, a bogie-mounted automatic plow system for the vehicle, evolved through testing a lighter, body-mounted scraper design and a series of brush designs, which produced a sophisticated brush/plow/shroud combination. The conventional sturdy blade emerged as the most efficient, most cost effective and easiest to maintain, due to its simple, durable design. Electrical methods of snow removal also evolved through a series of tests to a final design which is energy-efficient and easy to maintain. Electrical heating is needed in selected guideway locations for climates which are conducive to primary ice (secondary ice is snow which becomes compacted, a situation prevented by plowing).

Other areas tested included vehicle and station door tracks, both of which were successfully heated, but which demonstrated satisfactory operation without heating. The guideway switch operated well during thousands of winter cycles. Any difficulties from ice and snow packing were easily remedied through heating or minor mechanical modification, the latter being preferred for its energy savings. Power and signal rails needed some heating to remove primary ice. Window deicers, resistive heaters and radiant heaters were tested to prevent vehicle freeze-up when vehicles are stored outside in winter conditions. The systems worked well, but were not needed in the mild winter experienced during the 1979-80 test period. Quantitative tests showed that WTD ride quality meets International Standard Organization (ISO) specifications even under the severe weather conditions.

The test program has demonstrated that the WTD system hardware and operating philosophy are directly applicable to the cold weather environments of Northern DPM cities. Product improvements have been performed or are underway to eliminate limitations identified during testing. The WTD System has no other known limitations when applied to a cold weather DPM.

1.0 INTRODUCTION

1.1 BACKGROUND

Westinghouse Transportation Division (WTD) experience to date indicates that there are no major technological hurdles to the successful deployment of a Downtown People Mover (DPM System) in any of the potential DPM cities including those in severe weather climates, such as St. Paul MN, and Detroit MI. WTD experience includes People Mover Systems located at South Park at Pittsburgh PA, the WTD Test Track at West Mifflin PA; the operational systems located at Busch Gardens in Williamsburg VA, Sea-Tac Airport in Seattle WA, Tampa Airport in Tampa FL, and Miami International Airport in Miami FL.

Work performed at the WTD Test Track and at South Park prior to this program revealed that a certain amount of guideway, power rail and switch heating may be required to keep a DPM system operational during severe ice and snow conditions. On the other hand, experience showed that total roadway heating is not required. Depending upon land profile and whether the guideway is elevated or at grade, non-critical sections of roadway may require no heating. It was also believed that the amounts of guideway, power rail, and switch heating required would vary for each DPM application depending on operating philosophy and physical configuration.

Funded by the United States Department of Transportation's Urban Mass Transportation Administration and monitored by the Transportation Systems Center, a contract was awarded to WTD to support part of the cost of evaluating capabilities and limitations of the Westinghouse DPM system in severe winter weather. Portions of the plan were funded by Westinghouse and other portions were funded by the Department of Transportation (DOT). Essentially, the portions of the test concerned with overall systems operation were DOT funded and the portions concerned with subsystems or track modifications were WTD funded. A detailed test program incorporating energy management and system operating strategies was developed and documented through flow charts and written test procedures. Results of the program were documented on Video Tape (see Appendix A) and through photographs.

1.2 PROGRAM OBJECTIVES

The objective of the Winter Test Program was to determine the overall system performance in winter environments. In order to achieve this objective, it was necessary to determine the capabilities and limitations of the Westinghouse DPM system in the areas of traction, propulsion, guidance, braking, steering, power collection, vehicle and guideway electronics, switching and overall system performance in severe winter weather. These objectives have been accomplished through a combination of subsystem and system level testing.

1.3 SCOPE OF STUDY

The two year test program began with extensive testing of subsystems which required modification in order to optimize system availability under winter conditions. Tests during the 1978-79 winter at the Westinghouse West Mifflin Test Track confirmed that the basic system is adequate for operation under these conditions, allowing the test program scope to expand into subsystem improvements and system tests. Additionally, several alternative approaches toward handling winter weather were conceived and were investigated during the 1979-80 tests. The overall scope of the subject test program was to evaluate the winter performance of the People Mover System from the standpoint of incorporating the modifications and components, subsystems and overall system operations. The scope also included evaluation of energy management and system operating strategies to improve system availability and operational efficiency in a winter environment.

The tests performed and covered in this document fall into three general categories:

1. System start-up at low temperatures.
2. System operational tests in snow.
3. System operational tests with ice.

The results of the two-year Winter Testing Program were compared to baseline parameters established during non-winter conditions.

2.0 DESCRIPTION OF TEST FACILITY

2.1 TEST TRACK

Testing for the Winter Test Program, performed during the winters of 1978-79 and 1979-80, was conducted at the Test Track located at the Lebanon Church Site in West Mifflin, a suburb of Pittsburgh PA.

The Test Track consists of 1480 feet of guideway, 1230 feet of which is the original portion and 250 feet of which is an extension added in the fall of 1978, prior to the beginning of the Winter Test Program. The Test Track layout is shown in Figure 2-1, and a cross-sectional view of the guideway is shown in Figure 2-2. The guideway configuration shown minimizes both surface area from which snow must be removed and mass which becomes a heat sink if electrical heating is used. The guideway is open and elevated to allow some self-cleaning from snow.

The original track is at grade level, reaching a maximum grade of 2.95%, and contains two superelevated curves, a 191-foot radius curve and a 940-foot radius curve.

The spur line contains two curves, a 75-foot radius curve and a 200-foot radius curve. Neither is superelevated because of the restricted speed into the assembly area.

The extension consists of two spans of minimum height structures and six spans of elevated structures. Included within the expansion is a maximum grade of 10% and a superelevated 190-foot radius curve.

A guideway switch (Figure 2-3) is utilized for traffic routing between the main track and the 130-foot spur leading into the manufacturing plant. The switch is the same as the thirteen switches used in the Atlanta Airport system.

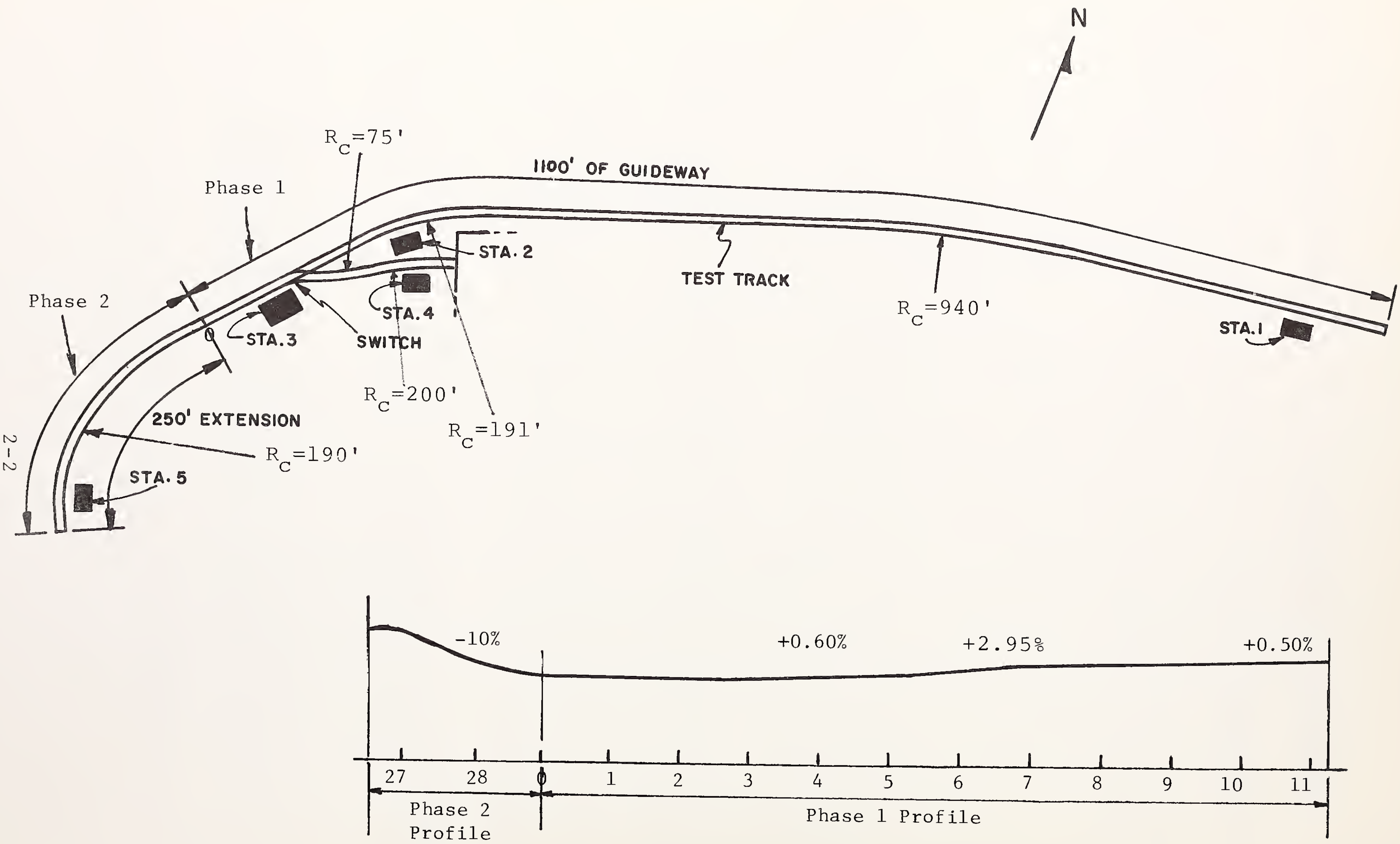


FIGURE 2-1. TEST TRACK LAYOUT

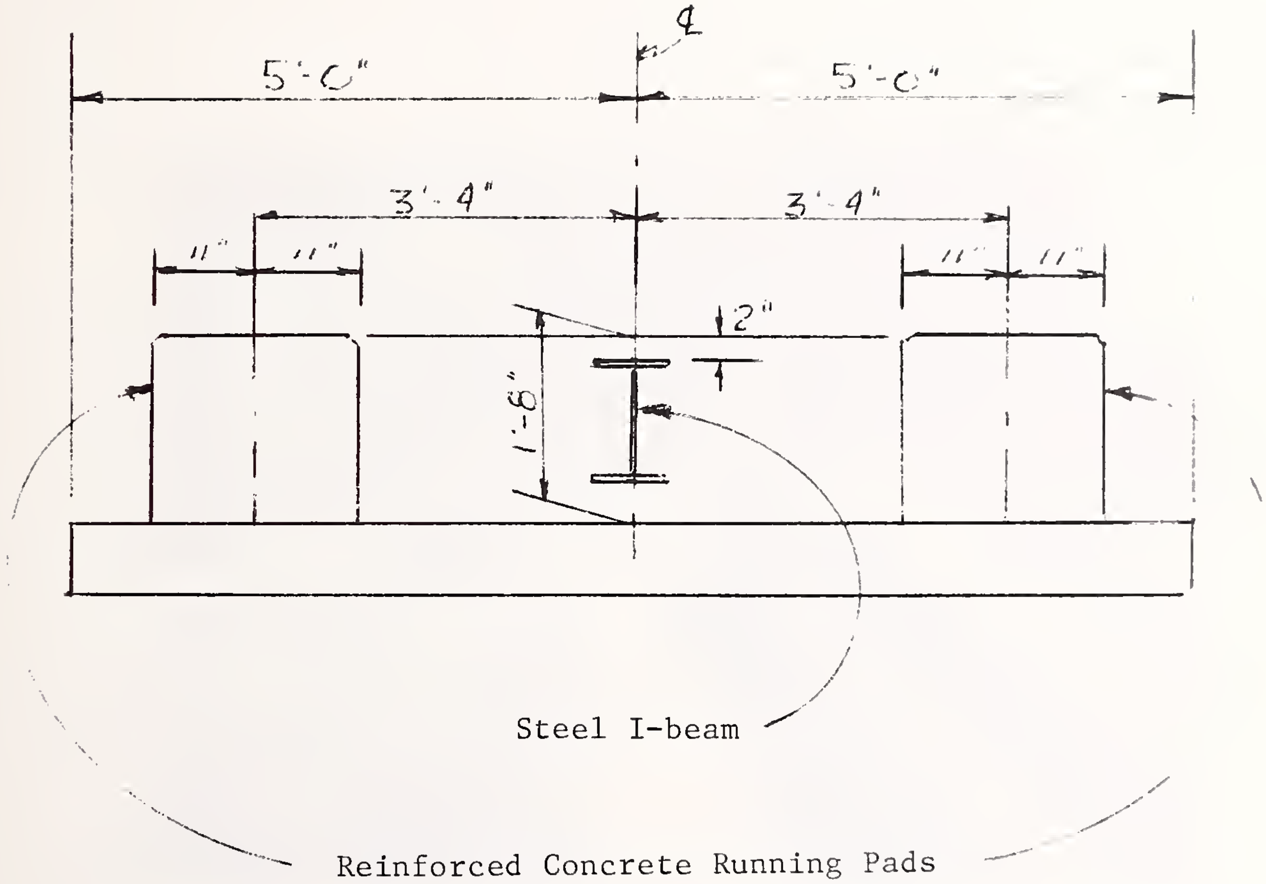


FIGURE 2-2. CROSS-SECTIONAL VIEW OF GUIDEWAY

FIGURE 2-3. STANDARD GUIDEWAY SWITCH

Five (5) stations are located along the guideway. Stations 1, 2, 4 and 5 are basically boarding platforms, while Station 3 is a permanent structure housing all the controls for automatic operation of the facility.

Automatic operation of the facility includes the ability to operate a vehicle in any one of four different automatic modes. This enables the selection of routes, short or long shuttles, multi-station stopping, and high-speed operation through the guideway switch. Also, included in Station 3 is an operational set of standard station doors which can be operated in a normal mode or can be placed in an accelerated cycling mode.

Guideway surface heating is provided over the entire length of the 250-foot extension, as well as in a 30-foot test surface west of Station 3. Controls, which allow adjustment of heat up to 90 watts per square foot, are located in Station 3.

Each power, signal, and ground rail is equipped with two 1 ohm per foot resistive heating wires. These are connected in such a manner that various heating levels can be maintained concurrently. A central time-on, time-off control is located in Station 3 and power on-off control boxes are located along the guideway, each controlling approximately 500 linear feet of guideway rail heating.

A parking area heating system is located in the spur parking area and is controlled from Station 3.

2.2 TEST VEHICLE

The Westinghouse People Movers are automated rubber tire vehicles which operate on concrete surfaces utilizing a center steel guidance beam. The WTD standard "C-100" vehicle is approximately 9 feet wide by 36 feet long by 7 feet tall, easily carrying 100 passengers. (A more detailed description of the standard C-100 vehicle is in Appendix B.) The vehicle has two axles with two dual - tire wheels per axle and is positively steered and permanently locked to the guideway through guidewheels positioned along each side of the I beam. Both the guidewheels and main support tires employ steel safety discs to prevent the vehicle from leaving the guideway, allowing the system to operate even in the case of dual flat tires.

The Engineering Test Car, (E.T.C.) used to collect most of the vehicle data during the winter is the WTD standard C-100 vehicle, except for the following differences, which were included for testing purposes (Figure 2-4).

1. Door set 7-8 is a prototype of a newly designed single operator system which is undergoing reliability testing on the vehicle. Door set 5-6 is a standard door set used on the Busch Gardens and the Miami, Atlanta and Orlando Airport systems.

2. The door sill for door set 5-6 is a standard Atlanta Airport door sill which was modified so that the sill would be less susceptible to ice and snow accumulation.

3. Door sills for both door sets were equipped with heating elements.

4. The large windows at either end of the vehicle were equipped with electric window deicers.

5. Rotating snow brushes, equipped with a plow shaped shroud, were located just aft of the #2 axle roadway tires.

6. Plows were located forward of the #1 axle roadway tires. The plows and brushes were pneumatically and electrically controlled from the control panel located in the passenger compartment.

7. Brake heaters were installed beneath the friction brakes and at each spring brake cylinder.

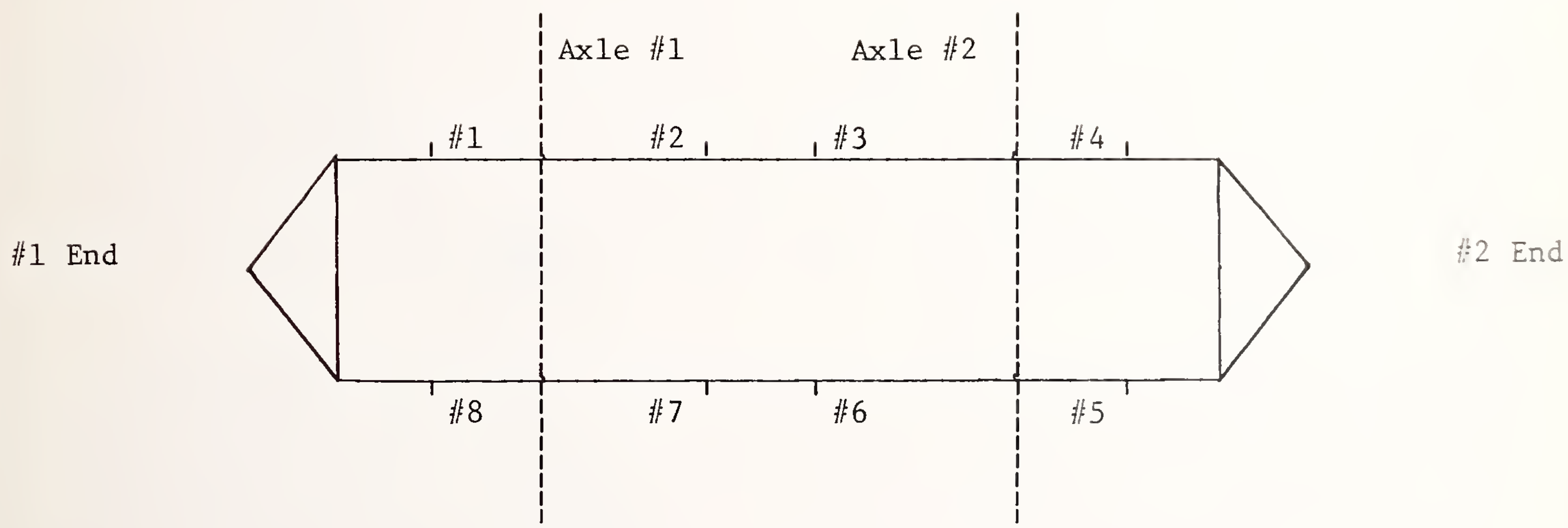


FIGURE 2-4. TEST CAR DOOR AND AXLE NOTATION

2.3 SNOW MAKING EQUIPMENT

To supplement natural snow fall, snow making equipment was installed at the test facility. The equipment consisted of the following components:

Components	Vendor
Air Compressor	Kellog-American
Water Pump	Worthington
Snow Towers	Seven Springs Facility
Air Hosing	Stock Supplies
Water Hosing	Stock Supplies
Misc. Valves and Gauges	Stock Supplies

Figure 2-5 is a sketch of the air and water hose lay-out and the snow tower locations. The air compressor and water pump were located in the manufacturing plant. Five (5) snow tower supports were located on the North side of the new expansion and four (4) on the South side. To test the Station 3 doors and wayside switch, three (3) snow tower supports were installed on the North side of the Test Track opposite Station 3. Figure 2-6 is a sketch of the snow tower, tower support, water and air valves and spray nozzles.

During the initial check-out of the system, freeze-up of hosing and piping presented the biggest problem. Once the test personnel became familiar with the equipment and the winter conditions, and developed a standard operating procedure, the system could be operated for extended periods of time. With five (5) snow towers in operation, snow could be made when the ambient air temperature was below 26° F, at a rate of 2 inches per hour and at a density of approximately 0.40 grams per cubic centimeter. This 0.40 snow density was the lowest achieved during the test program. Efforts to reduce the snow density to that more representive of natural snow were unsuccessful. These efforts included varying the air and water flows and testing spray nozzles of different configurations.

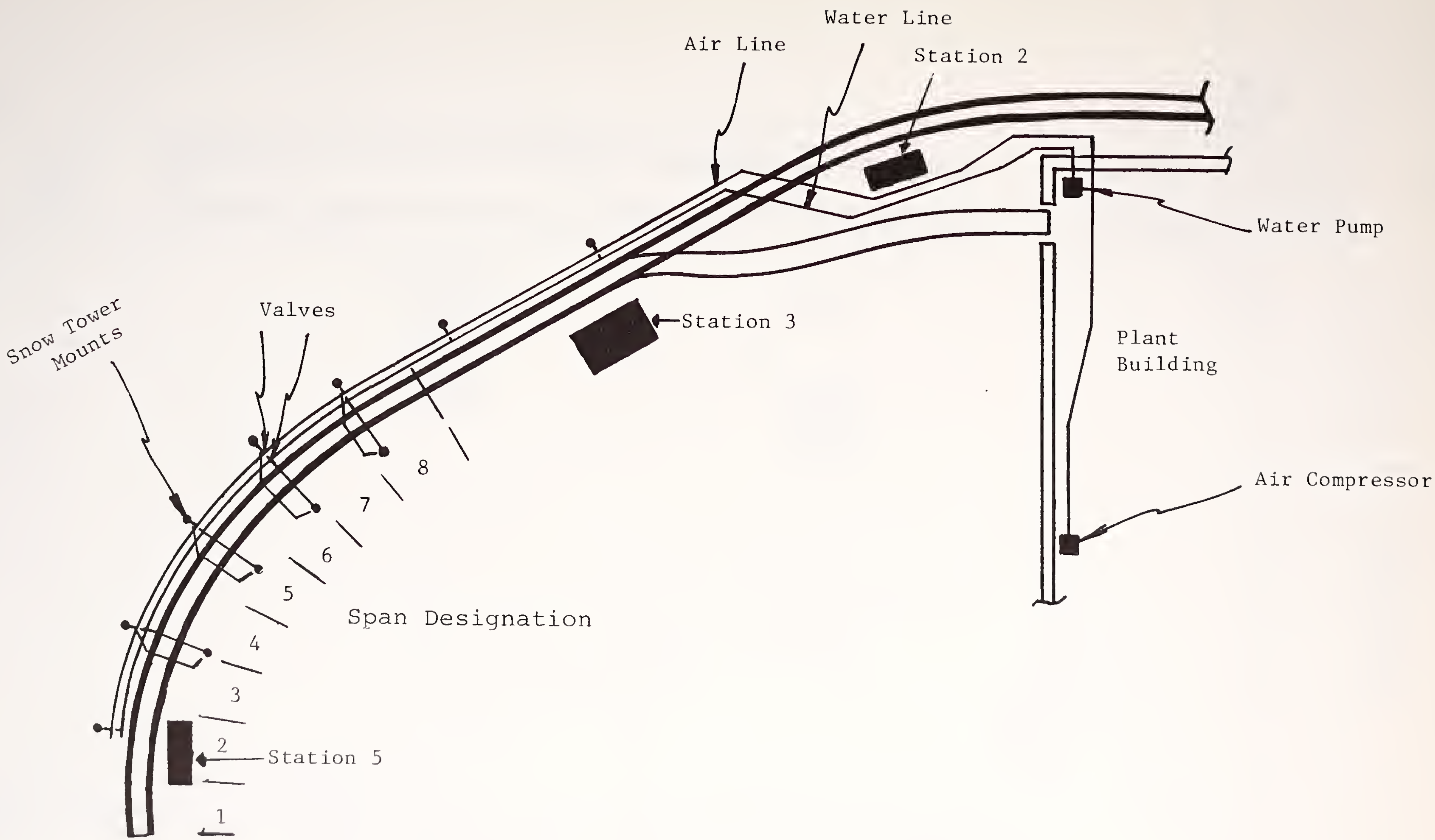


FIGURE 2-5. SNOW MAKING TOWERS AND OUTSIDE PIPING LAYOUT

SNOW TOWER

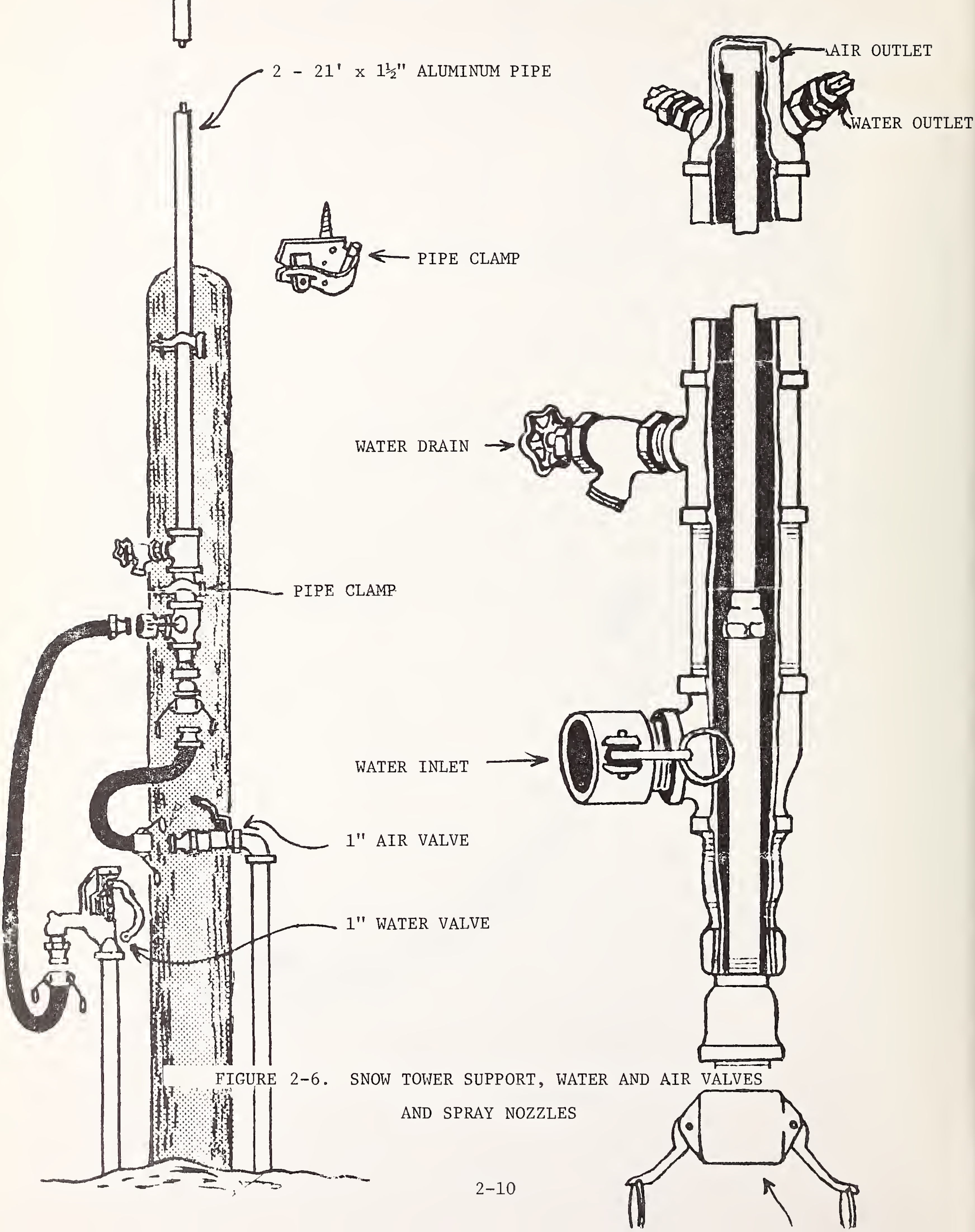


FIGURE 2-6. SNOW TOWER SUPPORT, WATER AND AIR VALVES AND SPRAY NOZZLES

2.4 METEORLOGICAL INSTRUMENTATION

The instrumentation utilized for gathering meteorological data during the Winter Test Program is listed in Table 2-1.

Table 2-1. DESCRIPTION OF METEOROLOGICAL INSTRUMENTATION

MEASURED PARAMETER OR USE	MEASUREMENT INSTRUMENT	VENDOR PART NO.	SOURCE
Ambient Temperature Humidity & Pressure	Meteorgraph With C-701-D MB-1F	M701-E Charts	Weather Measurement P.O. Box 41257 Sacramento, CA (916) 481-7565
Wind Velocity & Direction, Temperature and Pressure	 Skyvane I Wind Sensor Wind Translator Cable, 7 Conductor Electronic Weatherman	W102-P/AC WTD101-AC/360 W102-7C (.45/ft.) IDW-4001	or Giangario Scientific 3237 Dawson Pittsburgh, PA 15213k (412) 682-7012 Heathkit Corporation
Snow Fall Rate	Heat Snow Gauge & Record Cable, AC Power Cable, Record	P511-E-E 1/7 P511-3C (.60/ft) P511-2C (.15/ft)	Same Source as above
Snow Density			U.S. Army Cold Region Research and Development Laboratory, Hanover, N.H.
Temperature	Fluke, Digital Temp. Readout 24 Ch. Esterline Angus Multipoint Temp. Recorder	2100A E-1124E	Rental Electronics Oakland, N.J. (201) 337-3757 Same As Above
	CU-Constantan Thermo-Couple Wire, Type-T, Plastic Polyvinyl Coating 20 awg.	T20-5-502	Claude S. Gordon Co. 1703 Maine St. West Mifflin, PA 15122 (412) 271-2600

3.0 TEST ENVIRONMENT

3.1 DESIRED CLIMATOLOGICAL EXTREMES

The climatological extremes of interest desired for an all-encompassing test program would include frequent cold weather changes and extremes of climatic elements, such as occurs in most Northern cities. There, extreme weather phenomena occur from time to time due to the migration of disturbances from the Northwestern United States and the introduction of polar air masses from Canada.

Long winter cold spells with a number of consecutive days during which the temperature does not go above freezing are ideal. Also desired are long periods of time with the temperature below $0^{O}F$ to determine the effect of prolonged extreme cold on the equipment and system operation. Frequent snowfalls with single events of at least 16 inches in depth would be desired.

Freezing rain and heavy wet snow would provide ideal worst-case test conditions. Drifting, dry snow is not a factor with the Westinghouse System because of the elevated track configuration.

3.2 CLIMATOLOGY OF TEST LOCATION

3.2.1 Pittsburgh Climatological Study

The predominant type of air which influences the climate of Pittsburgh has a polar continental source in Canada and moves in upon the region by way of tracks which vary from almost due north from the Hudson Bay region, to a long westerly trajectory resulting from polar outbreaks into the Rockies which progress eastward. There are frequent invasions of air from the Gulf of Mexico during the summer season with resulting spells of warm humid weather. During the winter season air from the Gulf occasionally reaches as far north as Pittsburgh and causes the normal alternate periods of freezing and thawing.

Precipitation is distributed well throughout the year. During the winter months about a fourth of the precipitation occurs as snow and there is about a 50% chance of measurable precipitation on any day. Thunderstorms occur normally during all months, except the midwinter ones, and have a maximum frequency in midsummer. The first appreciable snowfall is generally late in November and usually the last occurs early in April. Snow lies on the ground in the suburbs an average of about 33 days during the year.

Range of Recorded Temperatures

High, 103^{o}F, July 1936

Low, -20^{o}F, Feb. 1899

Average Cold Season (32^{o} or less) 185 days

Avg. Date First Freezing Temp. October 20

Avg. Date Last Freezing Temp. April 21

Average Number of Days Per Year

Max. Temp. 32^{o} or lower 42 days

Min. Temp. 32^{o} or lower 124 days

Min. Temp. 0^{o} or lower 5 days

Record snowfall figures indicate that the monthly snowfall amount can be as high as 26.5 inches, with seasonal totals averaging about 45.3 inches. The highest single snow event, however, reached a maximum of 17.5 inches in a 24-hour period. The following is a breakdown of snowfall data using data accumulated from 1949 -1976:

Breakdown for Average Year

Amount of Snow/Event	Number of Events
1.0 to 2.5 inches	10.1
2.6 to 5.0 inches	2.4
5.1 to 10.0 inches	1.1
10.1 inches or more	.4

Snow Consistency

Type	Ratio (Snow/Water Equiv.)	Number of Events/Year
Dry, powdery	10:1	9.4
Moderately heavy	(5 to 10):1	3.4
Heavy, Wet	5:1	1.2

3.2.2 Climatological Conditions (1978-1979)

During the performance of the test program, certain weather parameters were measured to allow evaluation of the capability of the Westinghouse DPM System to function under winter conditions. The weather parameters measured were ambient air temperature, relative humidity, barometric pressure, wind velocity and direction, snow fall rate, snow density and total 24-hour snow accumulation. Measurements were recorded at the test site and were also provided by the DeNardo/McFarland Weather Services, Inc., located approximately one mile from the test site (a sample form is shown in Figure 3-1).

Figure 3-2 shows the maximum and minimum daily ambient air temperatures recorded for the testing interval. Only a minimum amount of winter testing could be performed in December and March. With the snow making equipment available, testing could be accomplished during most of January and all but the last few days of February. However, the test plans required a significant number of tests to be run at temperatures below zero ^{o}F and only four days had temperatures that met this requirement.

Day: 462-6464 DENARDO AND MCFARLAND WEATHER SERVICES, INC. Night: 469-0950

WESTINGHOUSE ELECTRIC CORPORATION - TRANSPORTATION DIVISION

DATE:________________

PART A	TEMPERATURE, °F			R.H. %			DIRECTION			Speed (mph)		
	FCST.	REV.	ACT.	FCST.	REV.	ACT.	FCST.	REV.	ACT.	FCST.	REV.	ACT.
Noon												
1600												
2000												
2400												
0400												
0800												
Noon												

	Date	Temperature	Time	Probability of Precip.
Max.				
Min.				
Max.				
Min.				
Max.				
Min.				

PART B. Frozen Precipitation ☐ will ☐ will not occur next 24 hours

☐ Precipitation of 1/2" of snow or more, freezing rain or sleet

Type of Precipitation: __________ SW S FR E

Time of Beginning __________/Date__________ Time of Ending__________/ Date______

Amount of Precipitation__________

Period of Heaviest Accumulation: __________ and __________

Time/Date Time/Date

ACTUALS

SNOW: ________

RAIN: ________

This service is daily, 7 days per week. Original forecast issued at 10:00 AM daily, revisions as required.

WESTINGHOUSE NUMBERS TO CALL: Daily - 256-6078 - Record - A - Message

After 5 PM Monday - Friday - Sat.,Sun., Holidays - Art Holbrook 863-1849- call only during snow or drastic revisions of temperatures. If you need to talk to someone during working hours, call Art Holbrook at office # 256-6078 or 256-6097

SW = Snow Showers S = Snow FR = Freezing Rain E = Sleet

ISSUED BY:/RECEIVED BY: __________/__________ Time:______ Date:______________

FIGURE 3-1. DeNARDO/McFARLAND WEATHER FORECAST FORM

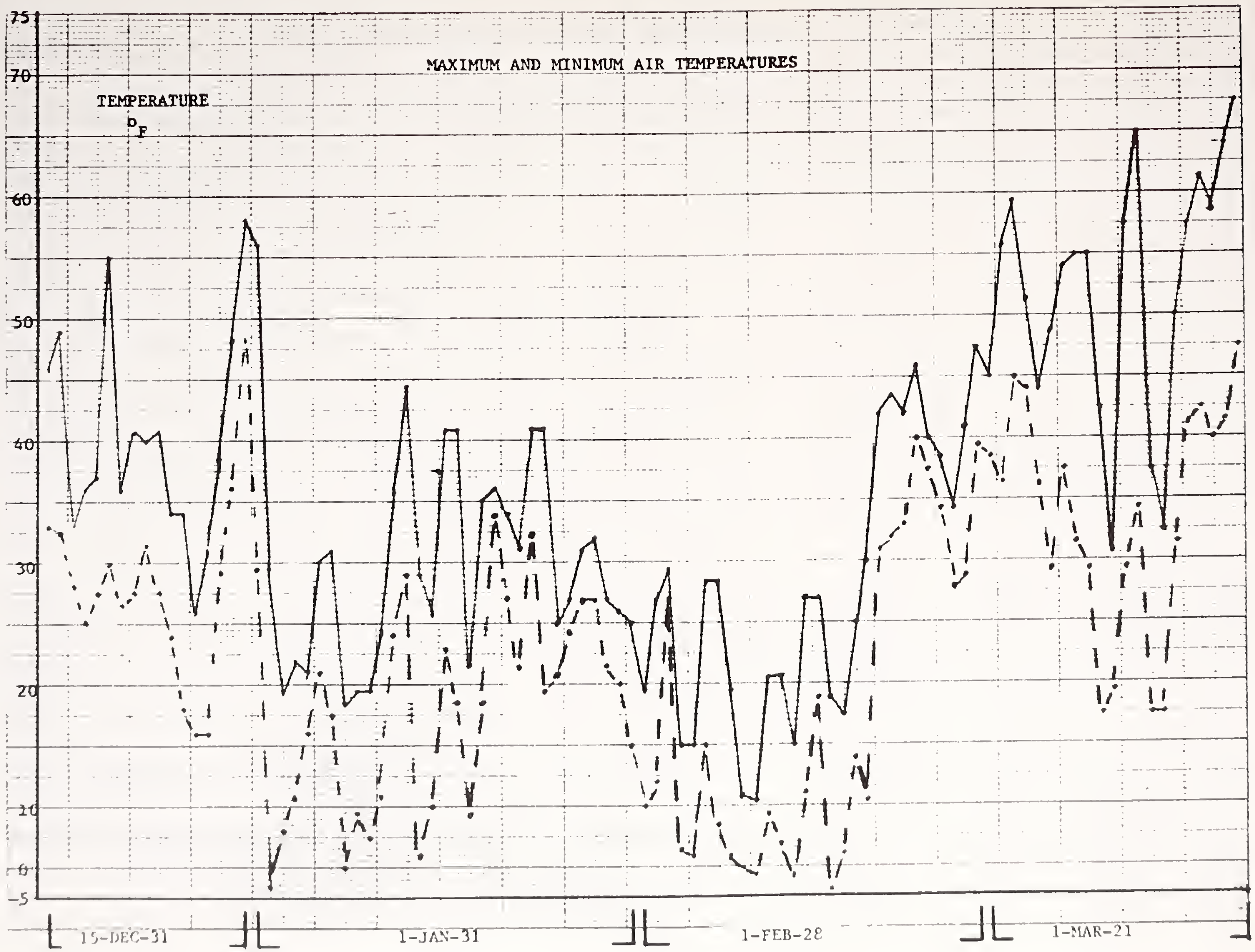


FIGURE 3-2. MINIMUM/MAXIMUM DAILY AMBIENT AIR TEMPERATURES (1978–1979)

Figure 3-3 shows the maximum and minimum daily relative humidity values.

Figure 3-4 sets forth the total daily snow fall occurring during the test program. There were only nine days when the total snow fall was greater than one (1) inch. This figure points out very clearly the importance to the test program for the snow making equipment to be operational and capable of making low density snow.

3.2.3 Climatological Conditions (1979-1980)

During the second year of the test program, the winter of 1979-80, the weather parameters were again measured at the test site and were provided by DeNardo/McFarland Weather Services, Inc. Figure 3-5 shows a sample of the forecast and actual weather for the 1979/1980 period.

Figure 3-6 is a plot of the maximum and minimum daily ambient air temperatures for the period. The test plan called for testing at $0^{o}F$ and below but, during the 79-80 winter reporting period, November 15 through April 1, there were only seven occasions when the temperature fell below $10^{o}F$ and at no time did the temperature drop to $0^{o}F$ or below.

Figure 3-7 shows maximum and minimum daily relative humidity values.

The snow fall occurring during the 1979-80 winter is indicated on Figure 3-8. The greatest single snowfall was only 3 inches and that occurred on March 13. The snow fall on 24 separate occasions totaled only 22 inches. The wind velocities during the 79-80 test period reached speeds of up to 30 miles per hour.

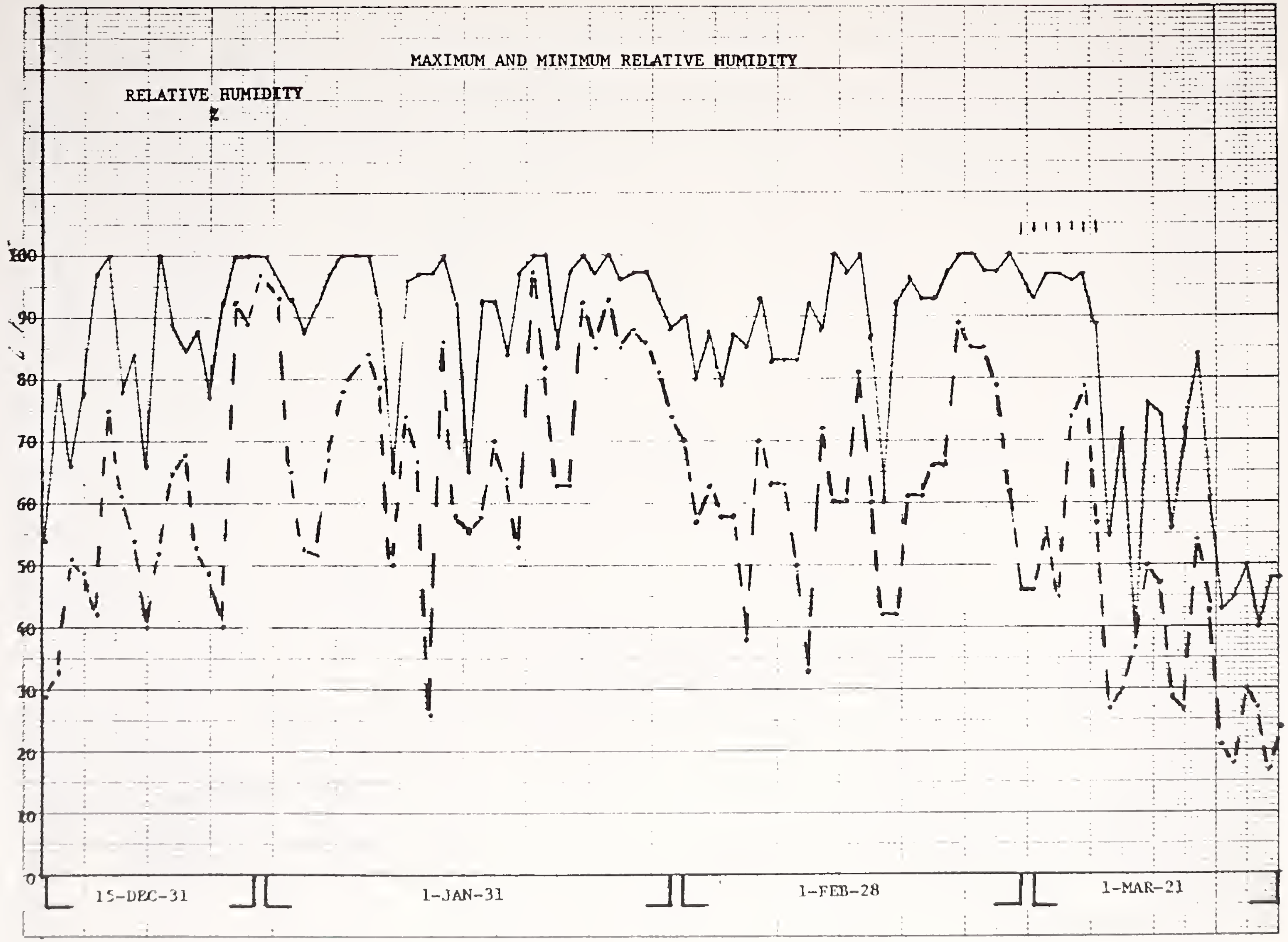


FIGURE 3-3. MINIMUM/MAXIMUM DAILY RELATIVE HUMIDITY (1978-1979)

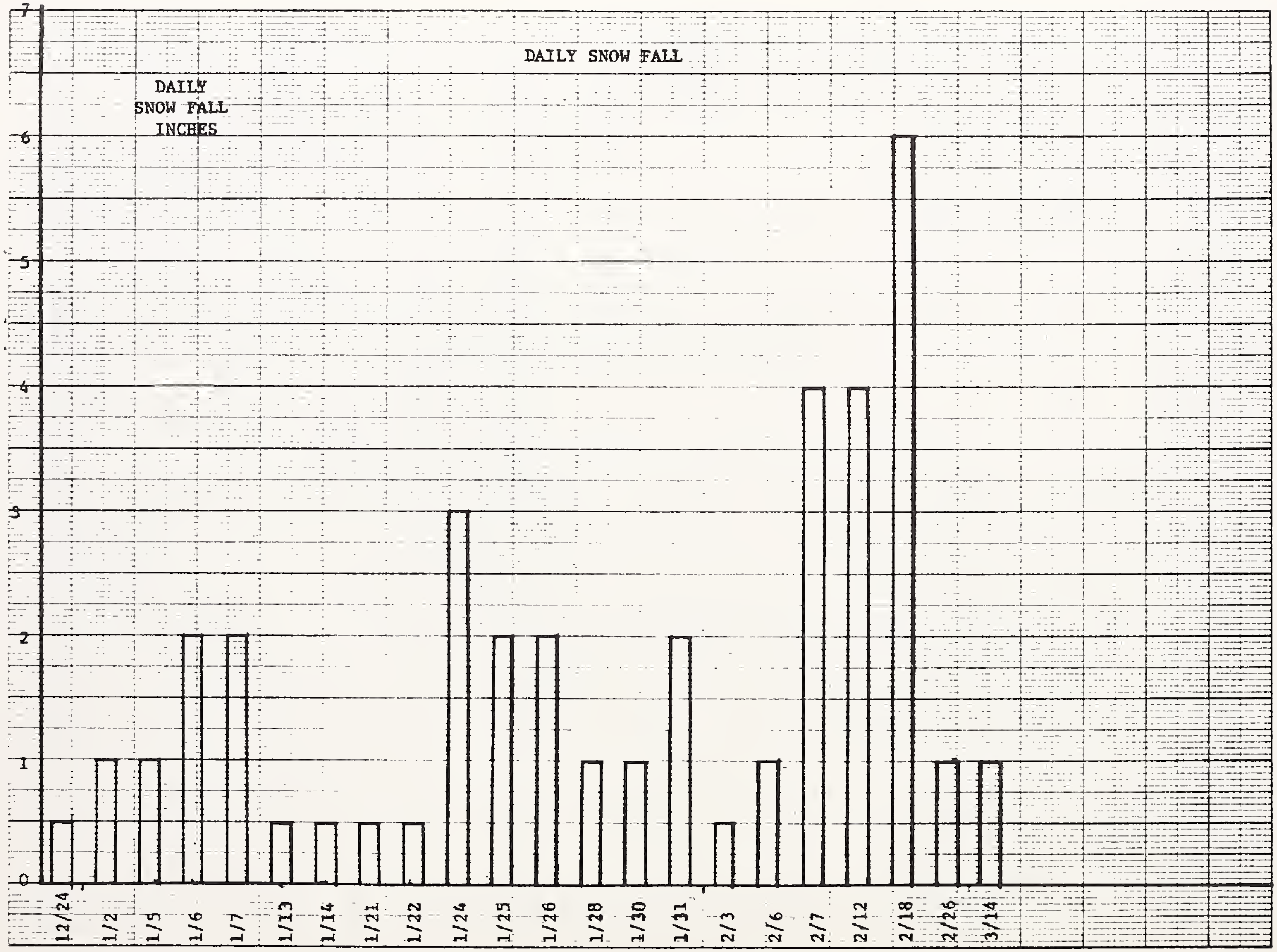


FIGURE 3-4. DAILY SNOW FALL (1978-1979)

Day: 462-6464 DENARDO AND MCFARLAND WEATHER SERVICES, INC. Night: 469-0950

WESTINGHOUSE ELECTRIC CORPORATION - TRANSPORTATION DIVISION

DATE: JAN 24 '80

PART A	TEMPERATURE, °F FCST.	REV.	ACT.	R.H. % FCST.	REV.	ACT.	DIRECTION FCST.	REV.	ACT.	Speed (mph) FCST.	REV.	ACT.
Noon	15		15	72		73	SSW		SE	6		7
1600	19		18	87		77	SSE		ESE	12		7
2000	23		20	92		74	S		ESE	10		5
2400	26		23	95		81	SW		SE	8		5
0400	28		26	90		82	SW		NW	8		5
0800	29		27	90		83	WSW		SSE	10		6
Noon	31		36	75		85	WSW		SSW	13		13

	Date	Temperature	Time	Probability of Precip.
Max.	24	26	2300	100
Min.	25	26	0100	70
Max.	25	33	1500	40
Min.	26	25	0700	50
Max.	26	29	1500	30
Min.	27	16	0700	10

PART B. Frozen Precipitation ☒ will ☐ will not occur next 24 hours

☑ Precipitation of 1/2" of snow or more, freezing rain or sleet

Type of Precipitation: ________ SW S FR E

Time of Beginning NOW /Date 24 JAN Time of Ending 1000 / Date 25 JAN

Amount of Precipitation 2-3"

Period of Heaviest Accumulation: 1300/24 (Time/Date) and 1900/24 (Time/Date)

ACTUALS

SNOW: 2"

RAIN: ________

This service is daily, 7 days per week. Original forecast issued at 10:00 AM daily, revisions as required.

WESTINGHOUSE NUMBERS TO CALL: Daily - 256-6078 - Record - A - Message

After 5 PM Monday - Friday - Sat.,Sun., Holidays - Art Holbrook 863-1849 - call only during snow or drastic revisions of temperatures. If you need to talk to someone during working hours, call Art Holbrook at office # 256-6078 or 256-6097

SW = Snow Showers S = Snow FR = Freezing Rain E = Sleet

ISSUED BY:/RECEIVED BY: DON / DIENNA Time: 1025 Date: JAN 24 '80

FIGURE 3-5. DeNARDO/McFARLAND PRECIPITATION FORECAST (1979—1980)

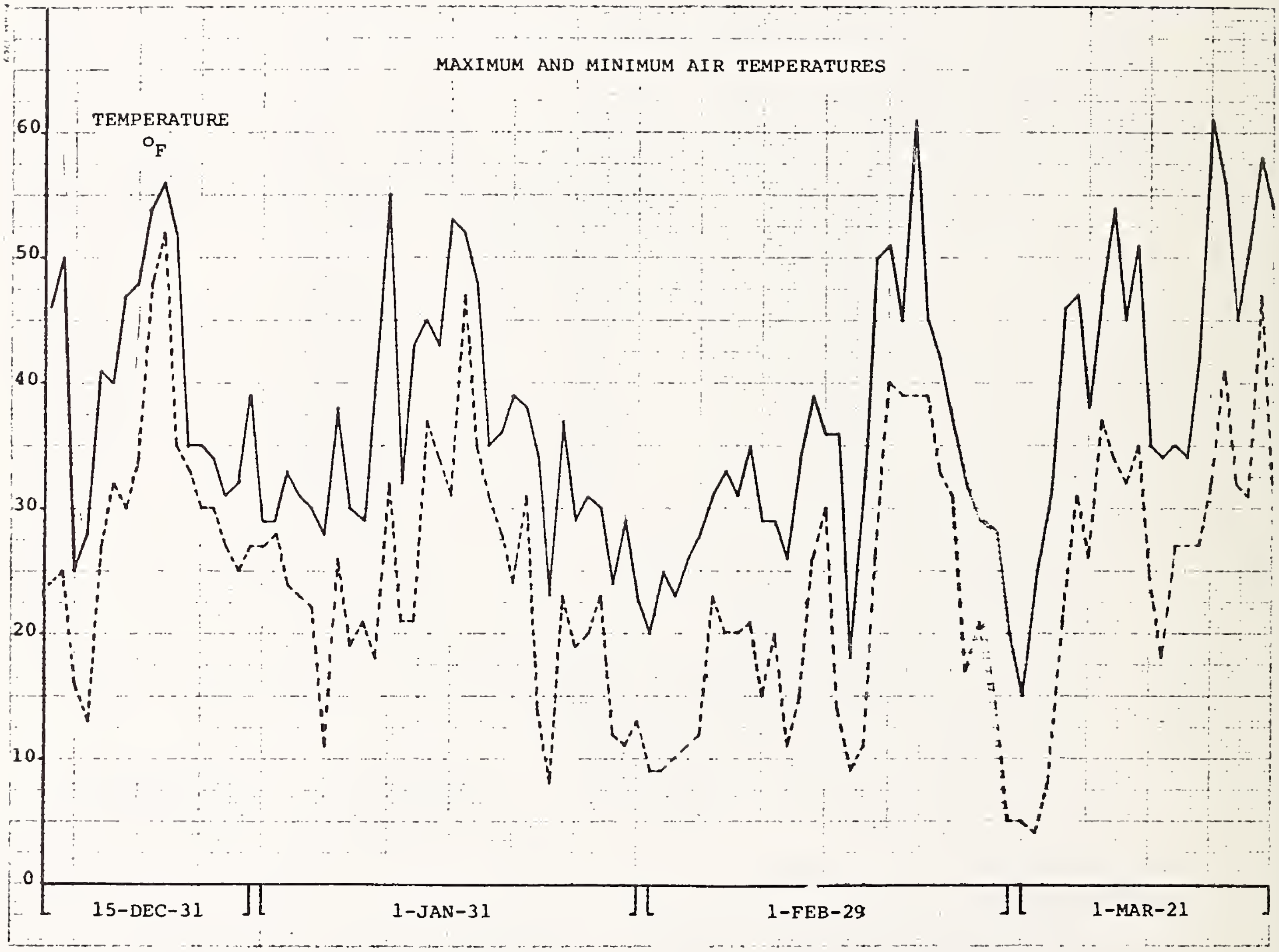


FIGURE 3-6. MINIMUM/MAXIMUM DAILY AMBIENT AIR TEMPERATURES (1979-1980)

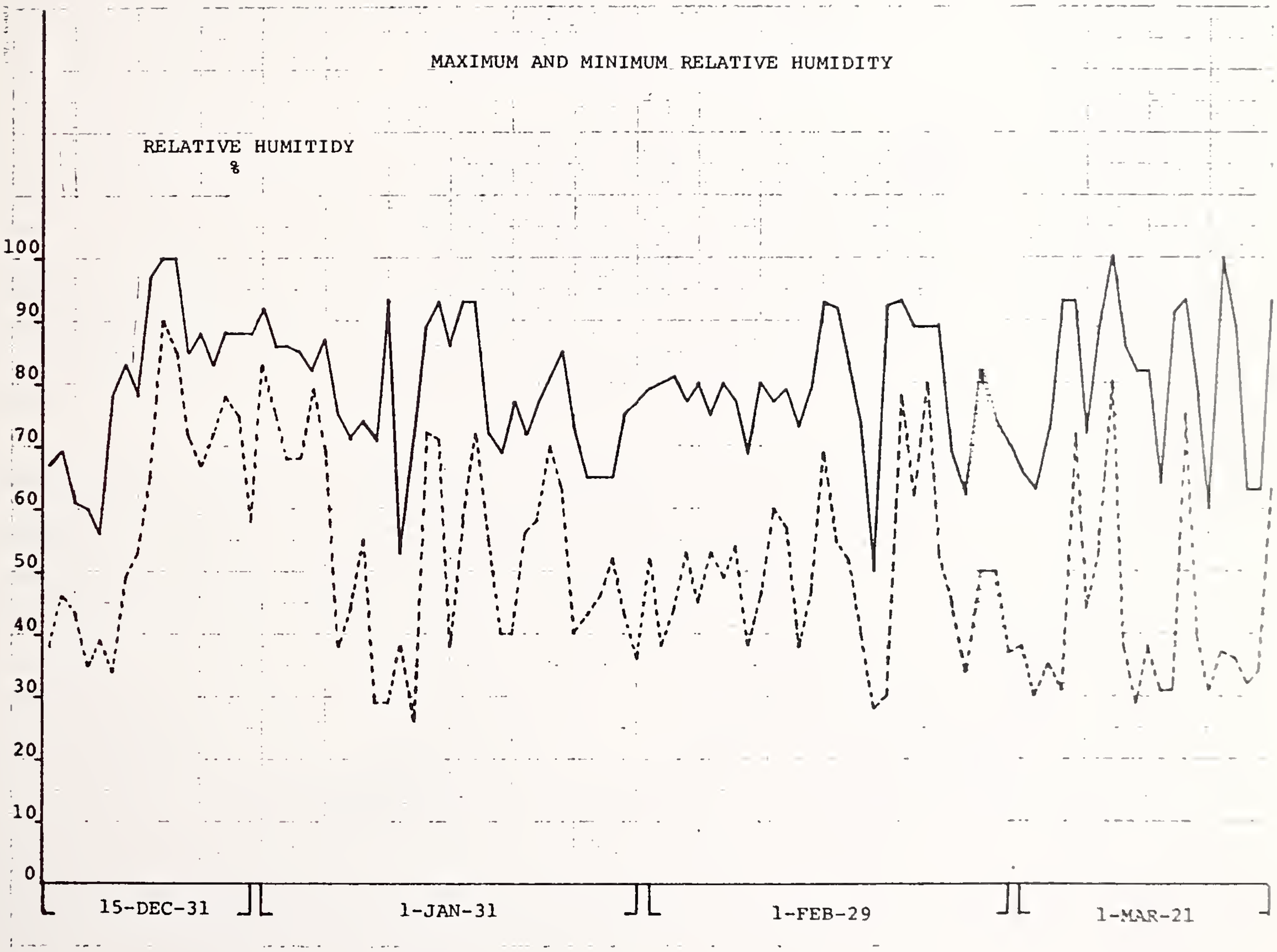


FIGURE 3-7. MINIMUM/MAXIMUM DAILY RELATIVE HUMIDITY (1979-1980)

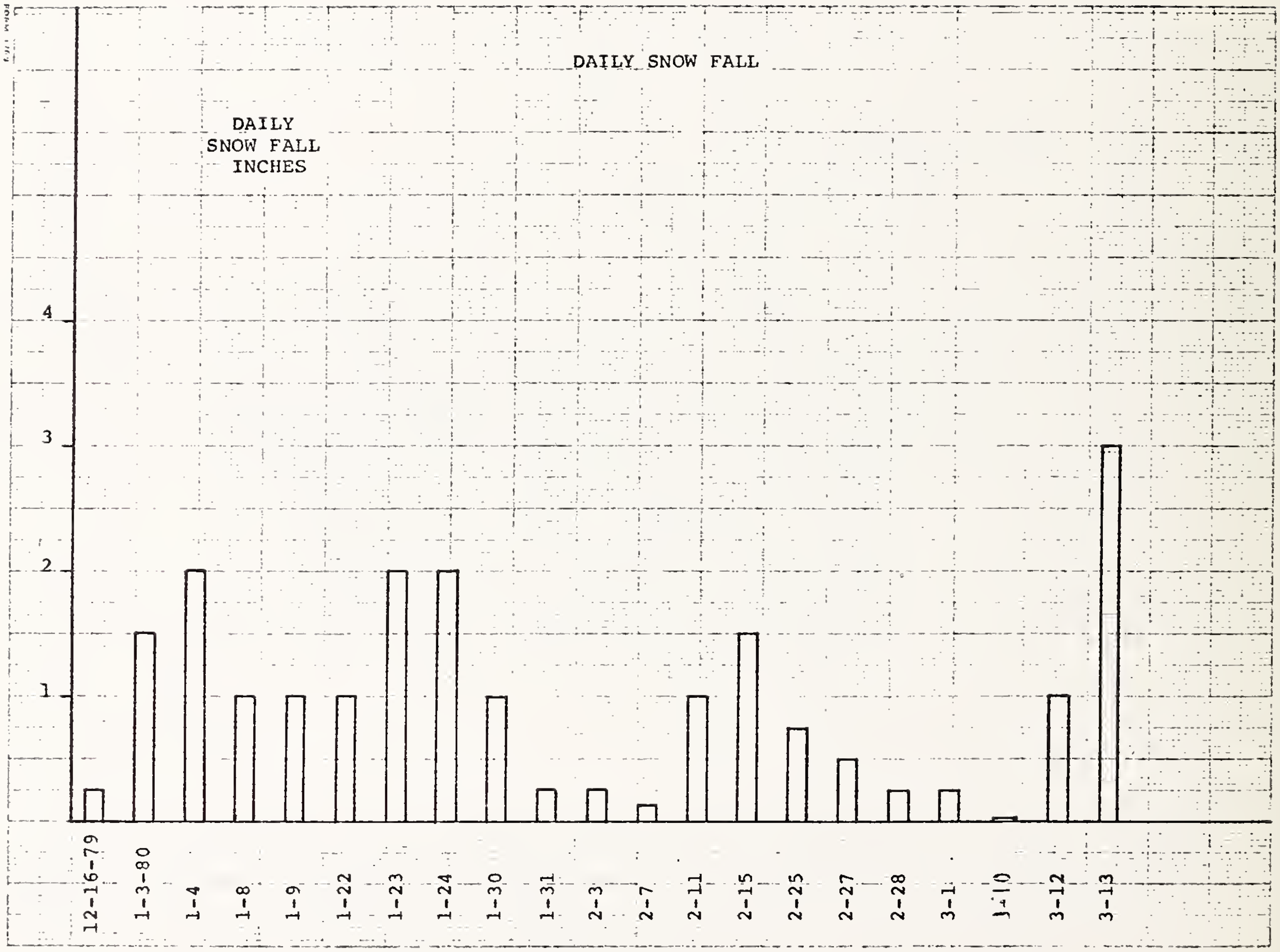


FIGURE 3-8. DAILY SNOW FALL (1979-1980)

3.3 SUPPLEMENTAL MEASURES

Supplemental measures taken consisted of artificial snow making equipment using detailed test procedures. Snow making equipment was described in Section 2.3.

Relative humidity is considered to be an important factor in making low density snow. For the 1978-1979 winter, the relative humidity levels experienced were significantly higher than normal. During snow making operations, the high levels of relative humidity experienced during the test period may have inhibited the production of such snow.

As described in Section 3.2.1, density of natural snow varies from approximately 0.1 to 0.2 grams per cubic centimeter, as compared with 0.4 (Section 2.3) for man-made snow. This means that the man-made snow used during tests was two to four times more dense than natural snow, making plowing and brushing more difficult. The denser snow also tends to compact more easily into ice, but melts off faster than natural snow.

Since proper snow making requires a temperature below 26° for a period in excess of eight hours, the ability to supplement the snowfall was somewhat hindered during the 1979/1980 test period.

4.0 DETAILED TEST PLAN

The WTD Winter Test Program went through an intensive period of planning and analysis prior to the start of testing in the winter of 1978-79 and again in the winter of 1979-80. This process began with the general objectives provided by the Department of Transportation, as applied specifically to the WTD People Movers.

4.1 IDENTIFICATION OF CRITICAL SUBSYSTEMS

Certain parts of the People Mover System are of possible interest when cold climate operation is one of the DPM requirements. In the WTD System, these general areas are:

1. Mechanical interface between tractive tires and running surface.
2. Electrical interface between collector shoes and power/signal rail.
3. Guideway Switch Operation.
4. Vehicle and Station Door Operation.

Each of these areas was examined further to identify specific subsystems requiring investigation. For the 1978-79 program, the scope of work was wide, to establish a firm base of winter operation data. The identification of critical subsystems for 1979-80 testing came as a direct result of findings and conclusions from 1978-79 testing.

4.2 DEVELOPMENT OF POTENTIAL SOLUTIONS

Longitudinal control and lateral guidance tests and mechanical and electrical methods of snow removal from the guideway running surface came out of Item 1 above. Power and signal rail heating addressed Item 2. Item 3 was addressed experimentally, with heating proposed as a backup solution. The same approach, observation of operation with heating as a backup, was proposed for Item 4. Potential solutions for areas still considered critical at the end of the 1978-79 testing were developed based on 1978-79 test data. Sections 5 through 8 describe the subsystems and effectiveness of the solutions in detail.

In all of these critical areas, heating was known to be an effective solution. The objective of testing was to develop alternate solutions with lower energy requirements.

4.3 PRIORITIZATION OF TEST ACTIVITIES

Basic priority determination was made with systems safety and availablity in severe winter conditions as the primary goals. The primary safety concern was thought to be ice on the running surface, with the general winter environment contributing to the question of availability. Of the winter conditions which might affect system availability, snow on the running surface was considered the most frequent event, followed by ice on the rails and in the door tracks and snow or ice in the switch area. A test MATRIX, Figure 4-1 was developed to guide the initial data collection phase of testing in 1978-79. Priorities were assigned from I to IV, where I and II are higher priorities than III and IV. Priorities for 1979-80 Testing were based on results of 1978-79 Testing and further defined during the course of the testing based on results accomplished and because of the limitations of the mild 1979-80 weather.

4.4 TEST PLANS AND PROCEDURES

Test plans were formulated for 1978-79 Testing and then for 1979-80 Testing (based on 1978-79 Test results). Individual test procedures were written each year, submitted to DOT for approval and used by Test Engineers and Technicians to perform the tests.

The test plans and procedures for 1978-79 were directed toward gathering data on the subsystems under investigation, on general system behavior during severe weather conditions and on the potential solutions dealing with the conditions. The test plans and procedures in 1979-80 converged on specific aspects of subsystems or solutions from the prior year's testing which were modified or required further investigation. The 1979-80 Testing was aimed at gathering winter weather automatic operation experience on a system level rather than gathering subsystem data, as in 1978-79. Tests in 1978-79 could be considered prototype tests, while 1979-80 tests were of final product configuration.

System Test \ Snow Type*	0	1 (.15 g/cc)			2 (.30 g/cc)			3 Man-Made Snow		4 Freezing Rain	
	0 in/hr	.5 in/hr	1 in/hr	2 in/hr	.5 in/hr	1 in/hr	2 in/hr	.25 in/hr	.5 in/hr	.25 in/hr	.5 in/hr
2.1.1 Vehicle Longitudinal Control	I	III	IV	II	III	IV	I	IV	I	IV	I
2.1.2 Vehicle Lateral Guidance Control	I	III	IV	II	III	IV	I	IV	I	IV	I
2.1.3 Vehicle Door Track Heating	I	IV	IV	II	IV	IV	II	III	I	III	I
2.2 Power & Signal Rail Heating	I	IV	IV	II	IV	IV	II	III	I	III	I
2.3.1 Electrical Snow Removal	I	III	IV	II	III	IV	I	IV	I	III	I
2.3.2 Mechanical Snow Removal (Scraper)	I	III	IV	II	III	IV	I	IV	I	III	I
(Brushes)	I	III	IV	II	III	IV	I	IV	I	III	I
2.4 Guideway Switching	I	IV	IV	II	III	IV	I	IV	I	IV	I
2.5 Station Door Track Heating	I	IV	IV	II	IV	IV	II	III	I	III	I
3.0 DPM System Performance Evaluation	I	III	IV	II	III	IV	I	IV	I	IV	I

FIGURE 4-1. WINTER TEST PROGRAM MATRIX

5.0 GUIDEWAY-RELATED TESTING

5.1 RUNNING SURFACE SNOW/ICE REMOVAL - MECHANICAL

The objective of this series of tests was to determine the energy and time required for mechanical snow removal as a function of snow type, snow depth, snowfall rate, temperature and wind velocity. Criteria for establishing whether or not a snow removal operation is necessary were developed. Methods of snow removal using the operational capabilities, with and without the operation of snow plows and brushes, were investigated.

The work performed during this series of tests was directed at choosing the most effective snow removal equipment and procedures.

5.1.1 <u>Snow Scrapers</u>

The prototype snow scrapers tested in 1978-1979 were constructed of light sheet metal with a rubber scraping edge. The car body mounting provided for relative ease of installation and removal, but gave less than optimum contact between the scraping edge and the guideway surface, due to car suspension movement.

The tests performed and their results are summarized in Table 5-1 and described in more detail in the next few pages.

Testing was conducted with the guideways covered with 1.5 inches of natural snow deposited over 1/8 inch of crusty ice to determine the capability of the snow scrapers to remove the accumulation. The snow on the guideways fell on the previous day. Weather conditions were; an ambient air temperature of +24°F, a wind velocity of 5-10 miles per hour, a snow density of 0.160 grams per cubic centimeter and zero snow fall rate. During the test the vehicle was operated in the manual mode. Figure 5-1 is a view of the guideways being scraped.

TABLE 5-1. SNOW SCRAPER TEST SUMMARY

Running Surface Condition					
Depth	Type	Density	Other	Test Description	Results
1.5"	Natural	0.16	Over 1/8" crusty ice	Manual, up grade	No difficulty
As above; compacted by wheels				Manual, up grade	No problems
6"	Man-made	0.48		Manual	Would not clear
6" max.	Man-made	0.48	Snowing 2" per hour	Manual, 3 mph, 5 passes	Did not remove snow, vehicle wheels slipped, guidewheel safety discs rubbing

FIGURE 5-1.   MECHANICAL SNOW REMOVAL UTILIZING SCRAPERS

No problems were experienced in removing the 1.5 inches of snow from the guideway. The 1/8" of crusty ice remained. However, the vehicle negotiated the 10% grade with no slippage of the wheels. A portion of the track was intentionally left unscraped and the vehicle wheels used to compact the snow. Again, no problems were experienced with the vehicle's movement over the guideway surfaces. Figure 5-2 is a view of the guideways after scraping.

Another test was run to determine the capability of the snow scrapers to remove a 6 inch depth of man-made snow with a density 0.48 grams per cubic centimeter. Weather conditions were; an ambient air temperature of +20°F, a wind velocity of 16-20 miles per hour and zero snow fall rate. The vehicle was operated in the manual mode.

It became clear during the early part of the test that the snow scrapers would not clear the guideway surfaces. The snow scrapers bent backward against their spring restraints and the vehicle wheels rode up on the packed snow. Figure 5-3 shows the accumulation of man-made snow on the guideway surface prior to the test and Figure 5-4 is a view after scraping and compacting by the vehicle wheels.

During further testing with five snow towers operating, man-made snow was produced at a rate of 2 inches per hour with a density of 0.48 grams per cubic centimeter. The vehicle was operated in the manual mode at approximately 3 miles per hour. Ambient air temperature was +22°F and the wind velocity was 10-15 miles per hour.

At the beginning of the test, the snow was scraped the length of the new expansion guideway. A second scraping of the guideway was performed 1/2 hour later. One hour later, only one half the guideway surface was scraped and the remaining half left to accumulate additional snow. The fourth operation, performed an hour later, consisted of scraping three-quarters of the length of the surfaces, thus permitting additional accumulation on the remaining one quarter length. An attempt was made to clear the full length of the guideways an hour afterwards.

FIGURE 5-2. VIEW OF GUIDEWAY AFTER SCRAPING

FIGURE 5-3 . MAN-MADE SNOW ACCUMULATION BEFORE TEST

FIGURE 5-4. VIEW AFTER SCRAPING AND COMPACTING BY WHEELS

During the first, second, third and fourth scrapings, the snow scrapers did not completely remove the snow and any remaining accumulation was compacted by the vehicle wheels. Snow was also accumulating in the power and signal rails and caused a loss of power on the first scraping. For the fifth scraping, snow had accumulated to a level of 6 inches on the last one quarter length of the guideway surface and the snow scrapers were bending backwards with negligible snow being removed. The vehicle wheels were slipping and the guide axle safety discs were rubbing on the guidebeam flange due to the increased height of the compacted snow.

The light construction and car body mounting of the scrapers limited their performance. They were frequently bent backwards when in operation. The limited success of the scrapers' operation led to the decision to develop the snow plows tested during 1979-80, utilizing a more robust construction and mounting them on the bogies and not the vehicle chassis.

5.1.2 Snow Brushes

During the 1978-79 winter test period, two different snow removal systems utilizing rotating brushes were tested. Both were motor driven. One was a 13 inch diameter nylon bristle unit, chain driven and mounted in a horizontal axis (Figure 5-5). The other, a 22 inch diameter nylon bristle brush was direct driven in a vertical axis (Figures 5-6 through 5-8). The horizontal brush was a drum unit with a spiral designed brush pattern, driven in such a manner as to cause the snow to be thrown in advance of vehicle travel and toward the outside of the running surfaces.

Both units were pneumatically raised and lowered and had means to adjust brush/surface pressures.

As a result of 1978-79 testing, the brushes used during the 1979-80 winter were the chain-driven, horizontal units equipped with removable plow/shroud attachments (Figures 5-9 through 5-12). For testing, three different sprocket ratios were available to produce brush speeds of 350, 525 and 700 RPM.

FIGURE 5-5. HORIZONTAL SNOW BRUSH UNIT

FIGURE 5-6. VERTICAL SNOW BRUSH UNIT

FIGURE 5-7. VERTICAL SNOW BRUSH UNIT

FIGURE 5-8. VERTICAL SNOW BRUSH UNIT

FIGURE 5-9. HORIZONTAL SNOW BRUSH WITH PLOW/SHROUD ATTACHMENT SIDE VIEW

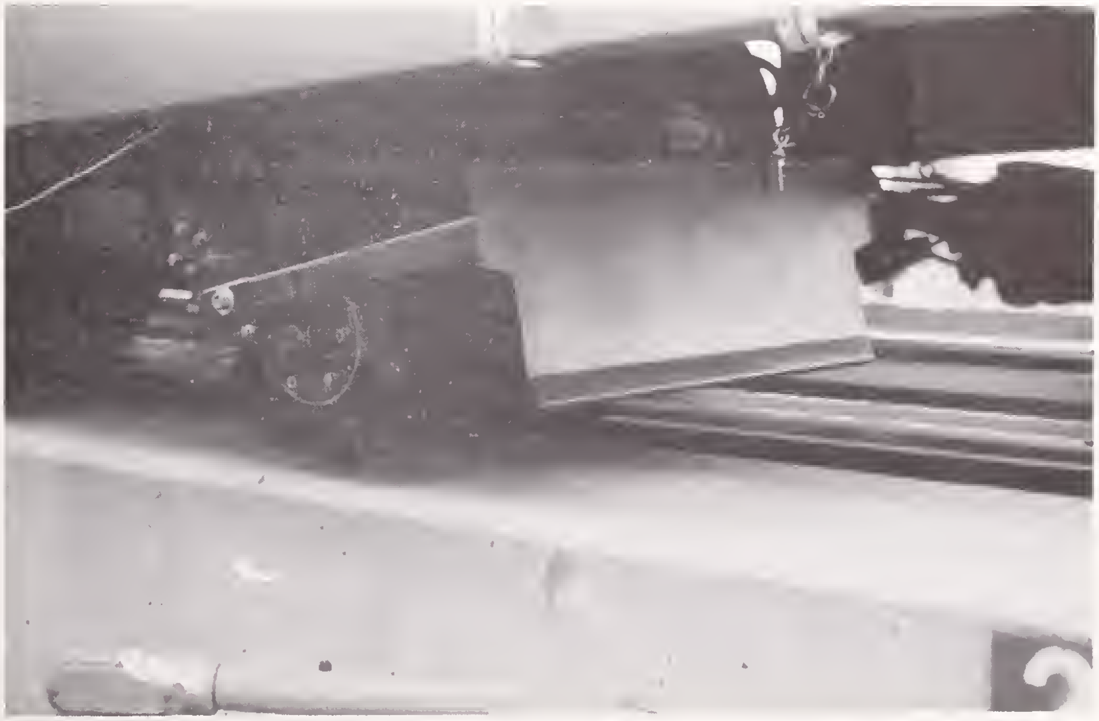


FIGURE 5-10. HORIZONTAL SNOW BRUSH WITH PLOW/SHROUD ATTACHMENT SIDE VIEW

FIGURE 5-11. HORIZONTAL SNOW BRUSH WITH PLOW/SHROUD REMOVED
SIDE VIEW

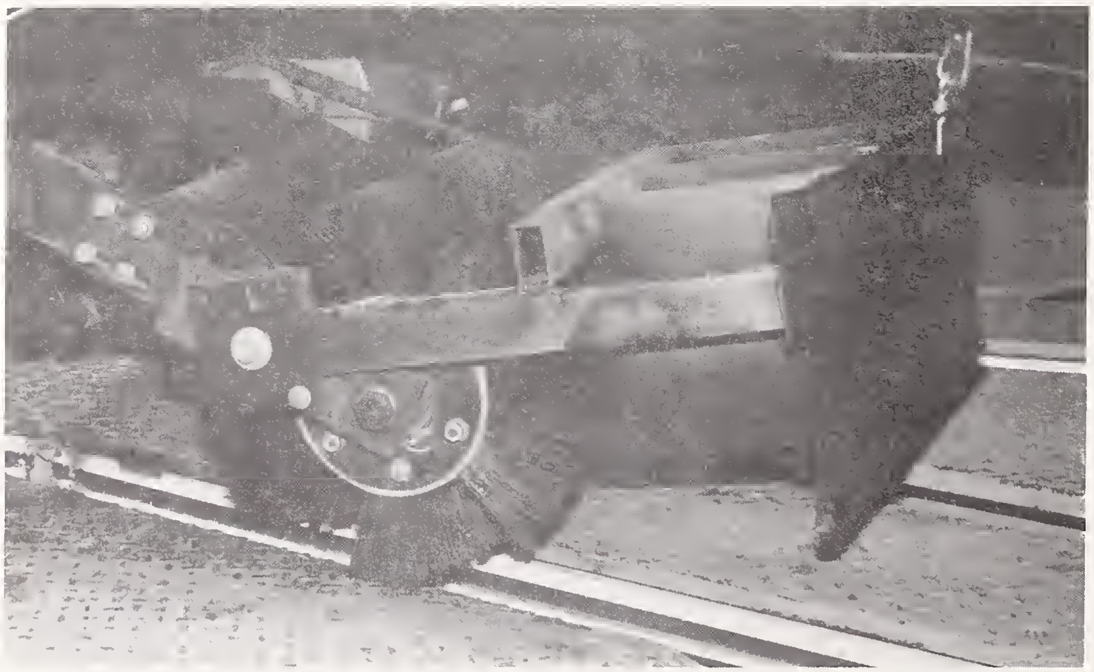


FIGURE 5-12. HORIZONTAL SNOW BRUSH WITH PLOW/SHROUD ATTACHMENT
SIDE VIEW

The objectives of testing snow brushes, as a snow removal technique, were to determine the feasibility of such a method, the type of brushing action required, the ability of brushes to remove varying depths of snow, the ability of the brushes to remove ice, and the maintainability of the units. Because of 1978-1979 test results, further objectives were to determine methods of removing deep snow in advance of brushes and to prevent snow accumulation on underside of vehicle. Testing procedures were developed to best utilize any natural snowfall which might occur and to cope with the high density snow which was man-made.

During the 1978-79 testing period a number of snow brush tests were conducted. Some of these tests are summarized in Table 5-2 and described in more detail below.

Two horizontal brushes were installed on the #2 bogie with a rotation speed of 348 RPM. This test was conducted between Stations 3 and 1. The weather conditions were; an ambient air temperature of +37°F, wind speeds of 1-4 miles per hour and zero snow fall rate. The guideway running surface had from 1/8 to 1/4 inch of ice covered by varying levels of natural snow accumulation from a 5-inch snow fall having occurred two days prior to this test. Drifting caused the snow to accumulate up to 20 inches in some locations. Snow densities varied between 0.148 grams per cubic centimeter in the shade to 0.268 grams per cubic centimeter in the sunlight.

As this test was conducted on the original portion of the track, which is at grade-level, the snow accumulated within the trough between running surfaces was removed to simulate an elevated guideway structure.

The vehicle was operated in a manual mode at varying speeds to observe the action of the brushes with different snow depths (see Figures 5-13 and 5-14).

Three passes were made over the track from Station 2 to Station 1. On the first run, when the snow was greater than the radius of the brushes, excess snow was carried up and over the brushes and deposited between the brushes and the tractive tires which then compacted the snow on the running surfaces (see Figure 5-15).

TABLE 5-2. SNOW BRUSH TEST SUMMARY

Equipment	Running Surface Conditions: Depth	Type	Density	Other	Test Description And Results
Horizontal Brushes 348 RPM	5"	Natural	.148 to .268	Over 1/4" of ice, 20" drifts	After 5 manual passes, the guideway was cleared. A large amount of snow accumulated on the underframe.
Horizontal Brushes 348 RPM North, 522 RPM South	1/4"	Man-made	0.6	Snowing .6" per hour turning to slush	After 2 manual passes, snow was removed but 1/16" slush remained. Brush speed had no effect.
Horizontal Brushes, 20% force increase	1 to 6"	Snow, slush, ice			All conditions were removed but ice and compacted slush. Increased force had no effect.

TABLE 5-2. SNOW BRUSH TEST SUMMARY (CONT'D)

Equipment	Running Surface Conditions				Test Description And Results
	Depth	Type	Density	Other	
Vertical Brush, 190 RPM Horizontal Brush, 522 RPM	1 to 2.5"	Man-made	.4	Ice and slush	Each of 4 manual runs removed some snow, but did not clear surface.
Horizontal Brushes, 700 RPM	1"	Natural			During automatic runs, brush motors overloaded. Brushes free wheeled to clear surface.
Horizontal Brushes, 350 RPM (Performed twice)	1"	Natural			1 pass with shroud channeled snow away from guideway. 1 pass without depositing snow on the power rails.

FIGURE 5-13. VIEW OF BRUSH ACTION

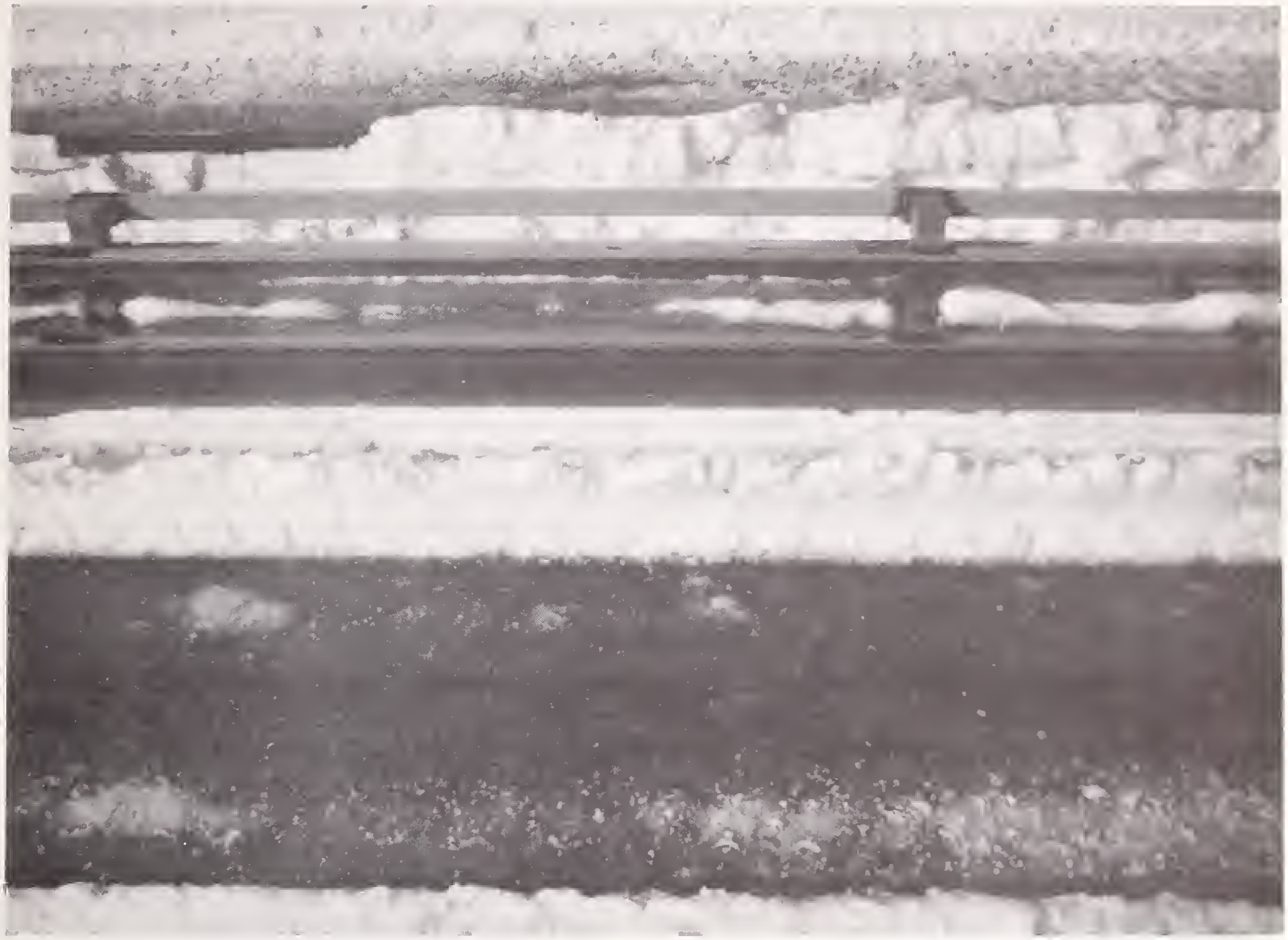


FIGURE 5-14. CLEARED AREA AFTER FIRST BRUSHING

FIGURE 5-15. SNOW BRUSH ACTION DURING FIRST BRUSHING

Snow was brushed up onto the vehicle underframe creating a large accumulation (see Figure 5-16). After two more passes the surface was brushed clean except for 1/8 to 1/4 inch of ice which remained.

The weather conditions during the next test were, a wind velocity of 2-5 miles per hour, air temperature of $30^{O}F$, man-made snow fall rate of 0.60 inches per hour at a density of 0.60 grams per cubic centimeter. Approximately 1/4 inch of man-made snow was on the guideway at the start of the test. The horizontal brush speeds were adjusted for 348 RPM on the North brush and 522 RPM on the South brush.

The vehicle was operated from Station 3, up the grade to Station 5 with the brushes raised. The vehicle was returned to Station 3, brushing the snow, which had turned to slush. Immediately the vehicle was returned to Station 5, where it remained for 15 minutes and then returned to Station 3, brushing. All snow was brushed from the guideway except for 1/16 inch of slush. No difference in performance was observed due to the different brush speeds.

Another test was performed with an air temperature of $25^{O}F$, a wind velocity of 0-1 miles per hour, man-made snow fall rate of 2 inches per hour and snow density of 0.50 grams per cubic centimeter. A single pass was made between Stations 5 and 3 at a speed of 10 MPH with brush force on surfaces increased by 20%. Attempts were made to remove from 1 to 6 inches of snow, slush and ice. All the accumulation was removed, except for a 1/4 inch film of ice and compacted slush. Due to a frozen air line, one of the brushes failed to lower. However, the accumulated slush was squeegeed by the vehicle wheels. No improvement in performance was noted by the increase in force.

For another test, the north horizontal brush was replaced with a vertical brush which rotated at 190 RPM, whereas the horizontal brush rotated at 522 RPM. Brush force on the guideway surface was 125 pounds for the vertical unit and 85 pounds for the horizontal brush.

Weather for this test was air temperature between $17^{O}F$ and $20^{O}F$, wind speed of 1 to 8 miles per hour, man-made snow fall rate of 1.5 to 2.1 inches per hour at a density of 0.40 gram per cubic centimeter.

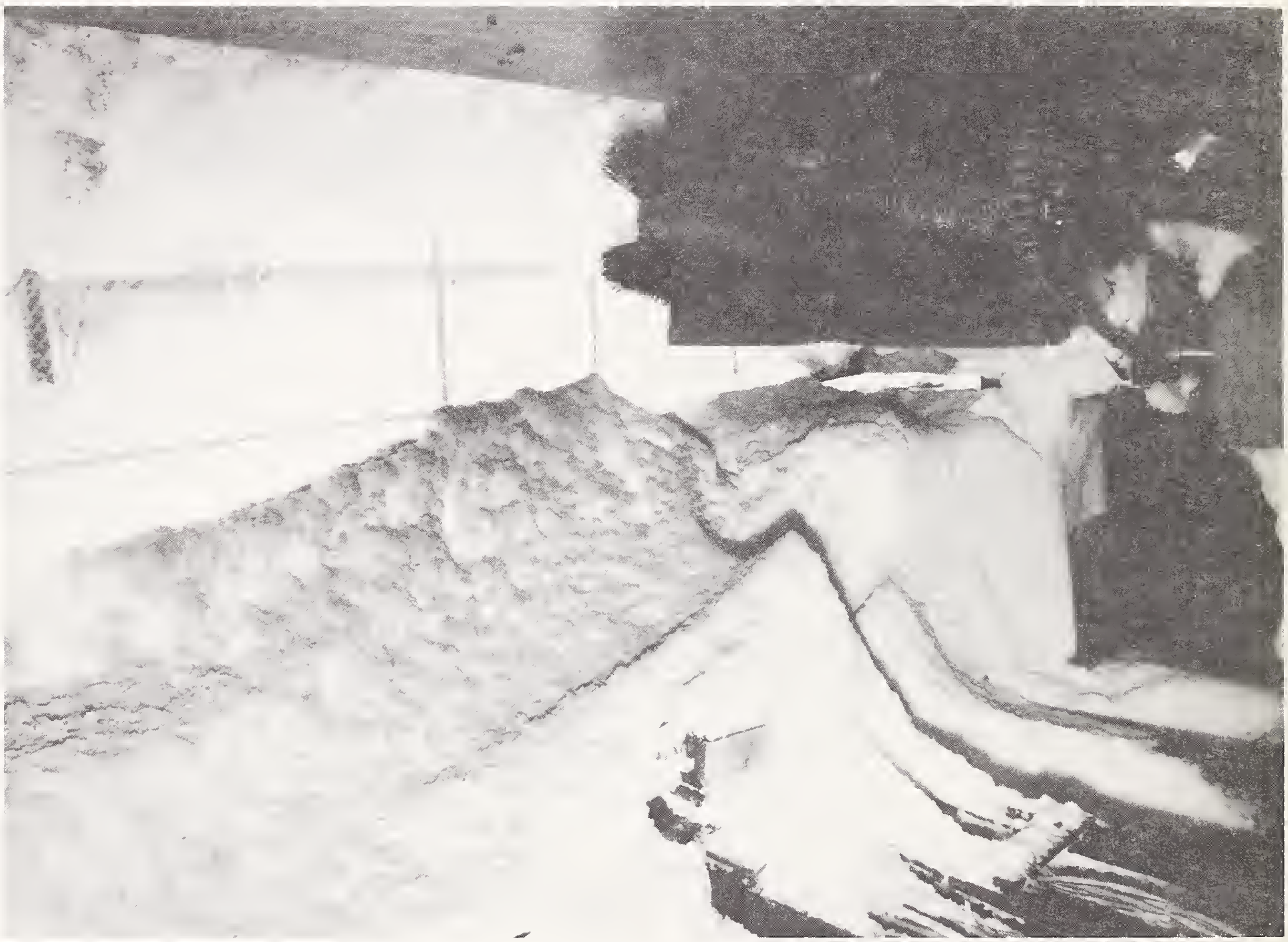


FIGURE 5-16. SNOW ACCUMULATION UNDER VEHICLE AFTER THIRD BRUSHING

The test was conducted over a four hour period. With the vehicle in manual, operated at 2 MPH, the guideway was brushed from Station 5, eastward to Span 8, where power was lost due to ice and snow on the power rail. Snow on the guideway varied from 1/2 to 2 1/2 inches. The brush force on the horizontal brush was increased to 115 pounds.

The vehicle was returned to Station 5 and again manually operated eastward at 2 MPH brushing the guideway. At Span 8, the vehicle lost power again due to ice and snow on power rails. The rails were then manually scraped.

The vehicle was repositioned at Station 5. Three hours later, with an accumulation of 1 to 2 1/4 inches of ice and slush on the guideway surfaces, four manual runs at 3 MPH from Station 5 to 3 were performed brushing an estimated 1/2 inch of accumulation per run.

Although the brushes did not completely remove all accumulation from the guideway surfaces under the conditions of high snow fall rate and high density snow produced by the snow making equipment, multiple brushings over a compacted surface did result in an incremental reduction in snow depth.

During the 1979-80 winter, additional brush tests were performed to observe the effect of the plow/shroud attachment and to test modifications to the unit. Also, during this period, various brush speeds were tested. Representative tests performed are listed on Table 5-2.

With 1 inch of light snow on the guideway, a brush test was performed using a sprocket ratio which produced a brush speed of 700 RPM. The vehicle was dispatched in an Automatic Normal 1 mode from Station 3 after the brushes had engaged the surfaces. As the vehicle accelerated past 4 MPH, the breakers controlling the brush motors tripped. The vehicle continued towards Station 1 but with the brushes free-wheeling. The vehicle was returned to Station 2 and manually operated back to Station 1. As the vehicle accelerated beyond 5 MPH, the breakers tripped again. The test was terminated and sprockets changed to produce a brush speed of 350 RPM.

To record on video tape the superiority of the brushes with a plow/shroud attachment vs a brush without the plow/shroud, two eastbound passes were made on the guideway from Station 1 to the eastern end of the guideway. A light snow had accumulated a total of 1 inch on the running surfaces. The vehicle, using only the south brush/plow combination, was moved eastward. The effect of the plow/shroud attachment was to channel the snow off the roadway as planned. On the second pass, only the north brush was used. The brush did raise the snow from the surface but because of a slight breeze, the airborne snow was blown onto the power/signal rails. The test was terminated.

This test was conducted to gather more information on the operation of the brushes with and without plow/shroud attachments. One inch of light snow covered most of the guideway surfaces. The vehicle was operated from Station 3 to Station 1 at 7 MPH. Again the brush without a plow/shroud attachment caused considerable snow to be thrown onto the underside of the vehicle, as well as the power signal rails (Figures 5-17 and 5-18).

The following six findings resulted from the brush testing.

1. The horizontal and vertical brush system had the ability to remove low density snow from the guideway surfaces, but difficulties were encountered in removing high density man-made snow and deep snow.

2. The vertical brush threw snow on the power/signal rails.

3. Horizontal brushes without the plow/shroud attachment did not divert the snow to the outside of the guideway, but instead, deposited snow on the vehicle underframe (Figure 5-19).

4. The brush assembly with plow/shroud attachment would not rise properly when laden with snow accumulations (Figure 5-20).

5. The plow/shroud attachment had clearance problems with vehicle body.

FIGURE 5-17. SNOW ACCUMULATION AFTER BRUSHING

FIGURE 5-18. SNOW ACCUMULATION AFTER BRUSHING

FIGURE 5-19. SNOW ACCUMULATION ON UNDERFRAME

FIGURE 5-20. CLOGGED PLOW/SHROUD ATTACHMENT

6. The correct brush speed is dependent on vehicle speed for optimum performance.

The brushes were effective in removing accumulations up to 6 inches in depth after one pass and up to 20 inches in depth after five passes. However, problems of snow being thrown on the undercarriage and power rails indicated that a shroud was needed to divert the thrown snow from these areas. Tests of the shroud operation were successful except for snow accumulation in the shroud itself. The brush system was scratched because of the superior performance, reliability, low cost, and simplicity of the snow plow system. No further work is planned for the snow brush system.

5.1.3 Snow Plows

As a result of the testing performed with the snow scrapers during the 78-79 winter season, the interval between winter seasons was devoted to the design, fabrication and installation of snow plows on the Test Car. The new plow units were bogie mounted and electro/pneumatically operated (Figures 5-21 through 5-24). The plow blades were standard units modified to meet the guideway interface requirements. The blades were equipped with a flexible leading edge to enable a continuous contact with the running surfaces when in use. The objective was to determine the advantages or disadvantages of the plows, their ability to handle deep (10-20 inches) snow as well as ice, and the maintainability of the units. Test procedures were developed to determine proper downward pressures and plowing speed restrictions, if any.

Besides conducting specific tests with the plow units, they were also used to maintain clear guideway surfaces during the testing of a number of Atlanta Airport vehicles (Figures 5-25 and 5-26) which utilized the test facility during this time. Table 5-3 summarizes the tests described in greater detail below.

A test was performed with one inch of light snow covered most of guideway surfaces. Ambient temperature was 19°F with a wind of 5 MPH from the northwest. The vehicle was manually operated from Station 3 west to Station 5 with

FIGURE 5-21. SNOW PLOW, FRONT VIEW

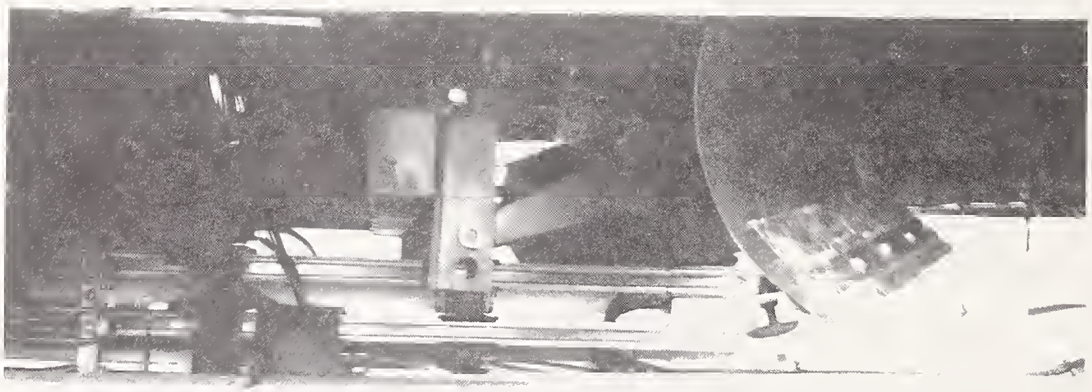


FIGURE 5-22. SNOW PLOW, SIDE VIEW

FIGURE 5-23. SNOW PLOW IN ACTION

FIGURE 5-24. SNOW PLOW IN ACTION

FIGURE 5-25. ATLANTA AIRPORT VEHICLE IN SPUR AWAITING TEST

FIGURE 5-26. ATLANTA AIRPORT VEHICLE AT STATION 1

TABLE 5-3. SNOW PLOW TEST SUMMARY

Running Surface Condition			Test	Test
Depth	Type	Density	Description	Results
1"	Natural	Light	Manual	Surface Cleared
As above, compacted twice			Manual	Surface not completely clean
10" Max.	Man-made	0.40	Manual, plow pressure is 40, 60, 100 psi (3 passes)	Snow and compacted snow removed first pass. Plows rode up on ice instead of removing it.
16 1/2" Max.	Man-made	ice covered	Manual, up grade	All snow removed, 1 pass
1"	Natural	Light	Automatic, High speed	Excellent plowing, snow dispersed 5 feet away.
13"	Man-made	Manually Piled	High speed	Surface cleared, 1 pass
1/2"	Natural	Light	Through switch	Surface is cleared

the left plow engaging the running surface and the right plow raised so that snow on the north running surface was compacted. After proceeding to Station 5, the vehicle was returned to Station 3, again compacting the snow on the north surface. The right plow was lowered and the vehicle proceeded back to Station 5, plowing the compacted snow. The plow removing the non-compacted snow, on the first run, completely cleared the running surface, whereas the plow clearing the compacted snow could not remove all snow on the first plowing run.

In another representative test, man-made snow was deposited on the roadway to a maximum depth of 10 inches. The snow density was 0.40 grams per cubic centimeter. Prior to the test, two of the snow towers had failed and, instead of snow, had produced solid ice on the guideway. At the starting time of the test, the ambient temperature was 22^{O}F, the relative humidity was 85%, and a 1 MPH wind was blowing from the northwest. With the plow downward pressures set at 40 psi, the vehicle was moved from Station 3 west to position E80 (Figures 5-27 and 5-28). On the second pass, the north, or right plow, pressure was increased to 60 psi. The plows removed the compacted snow, but had no effect on the ice. Both plows were raised to 100 psi. Plowing at this pressure did not remove the ice. The plow blades rode up onto the ice.

The vehicle was frequently operated during snow making. Prior to this test, trips had been made every 10 minutes between Station 3 and Station 5 with the plows used once per hour. The vehicle had not traveled west of E160. From this point to E250, the western termination of the guideway, the snow depths varied from 1/2 inch to 16 1/2 inches at E202. The outer surface of the snow was ice encrusted. The vehicle was manually operated from Station 3 west until the plows reached E200. This was up the hill where the maximum grade of 10% is reached at E180. No problem was encountered. The vehicle was moved back towards Station 3 to allow on-board operators to view the plowed area. Again the vehicle was moved west until all snow was plowed to E220. Video records were made of the plowing of large chunks, 16" x 24" x 72", of snow/ice from the guideway. WTD does not recommend that this much snow be allowed to accumulate, because it would fall off the guideway in chunks. However, the WTD plows handle it easily.

FIGURE 5-27. VEHICLE PLOWING MAN-MADE SNOW

FIGURE 5-28. GUIDEWAY AFTER PLOWING

The next test was performed to record how light snow, approximately 1 inch deep, is dispersed through the air when the plows are used at high speeds. The vehicle was operated in an automatic mode from Station 1 west to Station 5. Untouched snow was on the guideway surfaces from Station 3 west. The plows were lowered to the roadway as the vehicle passed Station 3 at 25 MPH. The speed decreased until the vehicle stopped at Station 5. The snow plowed from the roadways at high speed was deflected approximately 5 feet away from the running surfaces.

Other tests performed included the plowing of 13 inches of manually piled up snow on the south guideway surface between E-0 and E40 (performed for a photographic crew under contract to T.S.C.) and high speed plowing from Station 1 east to Station 2. Also, tests were run of plowing through the guideway switch from both the main line and spur to check plow clearances.

The following eight findings resulted from plow testing.

1. The plows could remove any depth of snow which accumulated on guideway running surfaces.

2. The plows could be used effectively at any speed up to the test car's maximum of 25 MPH.

3. The plows had adequate clearance through the switch and all other guideway equipment.

4. Slight modifications had to be made to the plow units for vehicle clearance problems.

5. Plows were easily removable for maintenance purposes.

6. The rubber snow blade edge used had a relatively short mileage wear life due to the use of excessive pressures for testing purposes.

7. Due to required squeegee action on dry surfaces, the rubber plow edge had a tendency to chatter at high pressures.

8. Units would not remove ice built up on guideway running surfaces.

The snow plows, used on the Engineering Test Car, performed exceptionally well in removing all snow up to the maximum amount available of 16 inches. Due to the WTD elevated guideway configuration, no more than 16 inches could accumulate without falling off. If used on operational systems, the units should be mounted on all vehicles or to the first vehicles allowed on a snow covered guideway. Every effort should be made to remove all snow prior to running on surfaces.

5.2 RUNNING SURFACE SNOW/ICE REMOVAL - ELECTRICAL

5.2.1 Cast in Place Heating Elements

The test objective of the cast in place heating element tests was to determine the energy and time required for the snow removal by electrical heating devices as a function of snow type, snow depth, snow fall rate, air temperature and wind velocity. Three types of electrical heating elements were installed in the new expansion guideway surfaces during construction of the guideway. These were operated at differing power levels and observations of the effects of the heating were made at various intervals.

Spans 2B and 3B, on the north side of the guideway, contained the piped heating elements. The heating elements were encased in an insulated metal sheath which contained two electrical conductors. These were installed in pipes containing an ethylene glycol solution.

Spans 2A and 3A, on the south side of the guideway, contained heating elements embedded directly in the concrete. These embedded heating elements were encased in an insulated metal sheath which contained two electrical conductors.

The remaining Spans, 1 thru 8, contained heating elements embedded directly in the concrete. These embedded elements were encased in an insulated sheath which contained a single electrical conductor.

Figure 5-29 is an installation diagram of the heating elements.

For recording the performance of the three different types of heating elements, Spans 3A, 3B and 5A were instrumented with thermocouples to determine the guideway temperatures. Figure 5-30 shows the location and installation of the thermocouples.

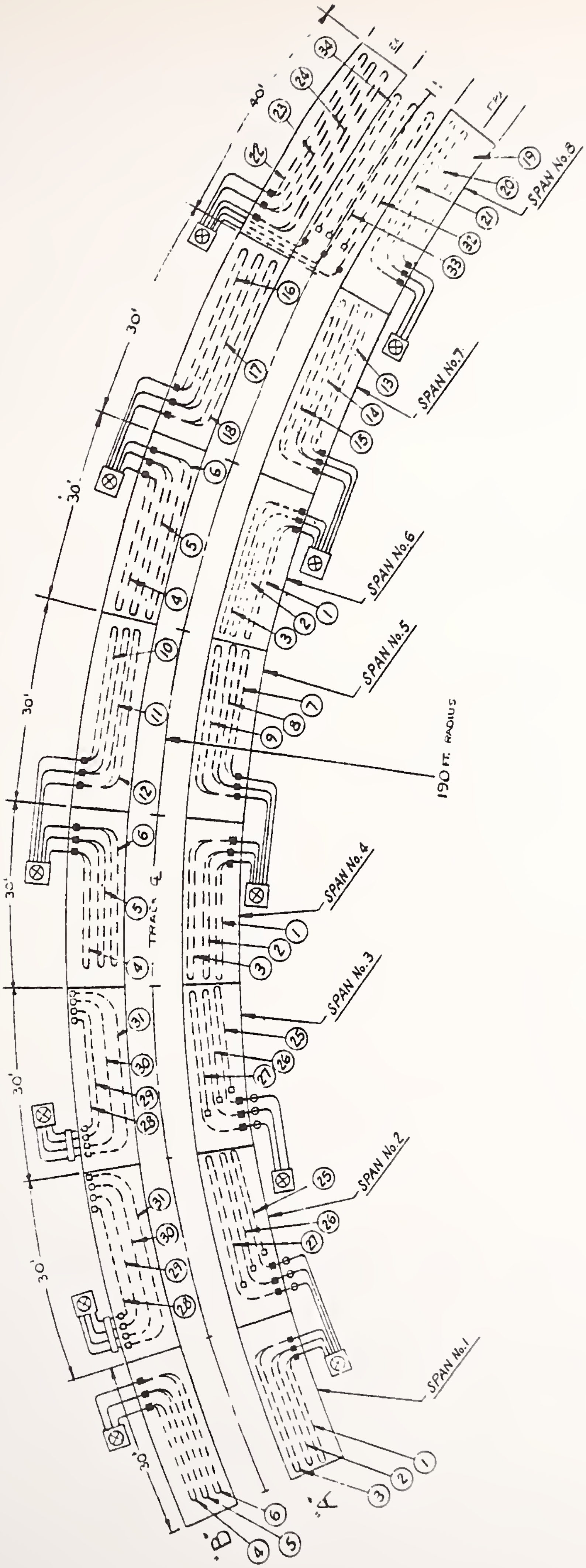
The characteristics of the heating system were determined through the following tests.

With the embedded elements energized to a power level of 60 watts per square foot,* a test was run to determine the heating elements' capability of maintaining the guideways free of ice and snow. Power level to the piped heating elements was 15 watts per square foot. Man-made snow was falling at a 1.5 inches per hour rate and of a 0.48 grams per cubic centimeter density. The ambient air temperature was +27°F and the wind velocity was 10 miles per hour.

Due to the high density of man-made snow, neither type of heating element was capable of maintaining the guideways free of accumulation at the power levels established for the test.

Another test was run with 1.5 inches of natural snow with a density of 0.17 grams per cubic centimeter deposited on 1/8 inch of ice to determine the time required to remove the accumulation. For the test, 1/2 of the new expansion length was plowed until only 1/8 inch of ice remained on the guideway. On the remaining half, the 1.5 inches of snow was compacted with the vehicle wheels. Power level of the heating elements was 90 watts per square foot for the embedded heaters and 76 watts per square foot for the heaters encased in pipe. Weather conditions were; an ambient air temperature of +24°F and a wind velocity of 5-10 miles per hour.

*Watts per square foot refers to net amount of power (considering losses) to the guideway surface.


SPAN No.1
SPAN No.2
SPAN No.3
SPAN No.4
SPAN No.5
SPAN No.6
SPAN No.7
SPAN No.8
190 FT. RADIUS
40'
30'
'A'
'B'

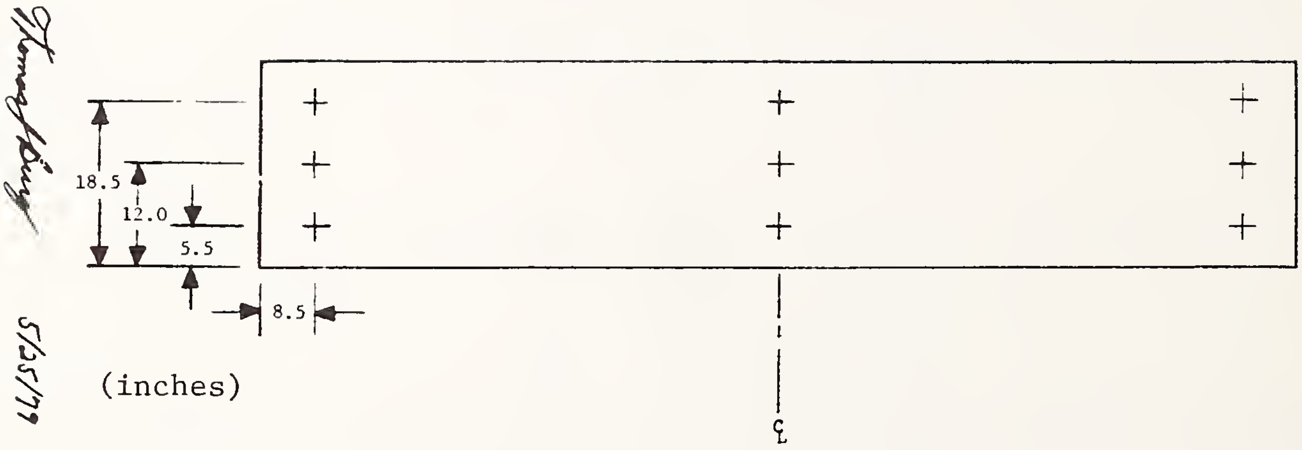


FIGURE 5-30. GUIDEWAY SURFACE THERMOCOUPLE LOCATION

It required 90 minutes for the embedded heating elements and 2 hours and 45 minutes for the pipe encased heating elements to remove the accumulation. Compaction or plowing had no noticeable effect on the snow removal time.

Problems with two embedded heater elements were experienced during the above testing. After installing a vehicle overtravel stop on the south side of Span 4, it was found that an AC voltage could be measured between the guideway structure and ground in this region. It was determined that an overtravel stop mounting stud had crimped the heating element sheath.

After a few hours of normal operation, an element in Span 2 ceased functioning and was measured as an open circuit. In order to minimize disruption of the test program, both elements were disconnected.

Preparations were then made for performing another electrical snow removal test. Weather conditions for this test were; an ambient air temperature of $+22^{o}F$, and a wind velocity of 5-10 miles per hour. Man-made snow of a density of 0.48 grams per cubic centimeter was deposited with depths ranging between 3.75 and 8.5 inches measured on the guideway surface.

The embedded guideway heating elements were energized to deliver 80 watts per square foot. Average guideway temperature before energizing the heaters was $+38^{o}F$.

After the guideways had been heated for 10 hours and 45 minutes, the average surface temperature had reached $+109^{o}F$.

Snow was still present on the guideways at the completion of testing. This was partially due to large air pockets being formed between the guideway surface and the snow. These pockets were formed by the snow melting on the surface and the water running off, leaving a space which insulated the snow and reduced the melting rate. Figure 5-31 shows the guideway surface air pocket condition.

FIGURE 5-31. ELECTRICAL SNOW REMOVAL

To determine the rate of guideway surface cooling, the guideway heaters were de-energized with the guideway surface temperatures at +109°F. All snow had been manually removed from the guideways. The ambient temperature during the test was +18°F and the wind velocity was 17-25 miles per hour.

The surface temperature had fallen to +52°F after cooling for a period of 5 hours. The guideway cooling surface characteristic is shown in Figure 5-32. This shows the temperature falling exponentially within a time constraint of 330 minutes under these ambient conditions.

To determine the capability of the electric heaters to maintain the guideways clear of falling snow, the heaters were energized to a 40 watt per square foot level in expectation of natural snow fall predicted. Ambient air temperature was +16°F and the wind velocity was 1-2 miles per hour. The average temperature of the guideway surface was +18°F with no precipitation.

Snow began to fall at a 0.35 inches per hour rate, with an average density of .15 grams per cubic centimeter. The ambient air temperature had increased to +21°F and the wind velocity was 4-5 miles per hour. Guideway temperatures at this time averaged +59°F.

One hour after the start of snowfall, the guideway temperatures had decreased to an average of +55°F. Power to the heaters was reduced to 30 watts per square foot and the roadway temperatures dropped to an average of +53°F. One hour and 15 minutes later, the power to the heaters was decreased to 20 watts per square foot and the guideway temperatures dropped to an average of +47°F two hours and 45 minutes later. All testing was then terminated. During the test, the guideway was maintained free of any accumulation.

For this test, the pipe encased heating elements were energized at a power level of 75 watts per square foot. The weather conditions were an ambient air temperature between +17°F and +20°F, a wind velocity from 1 to 8 miles per hour, a man-made snow fall rate of 1.5 to 2.1 inches per hour and a snow density of 0.42 grams per cubic centimeter.

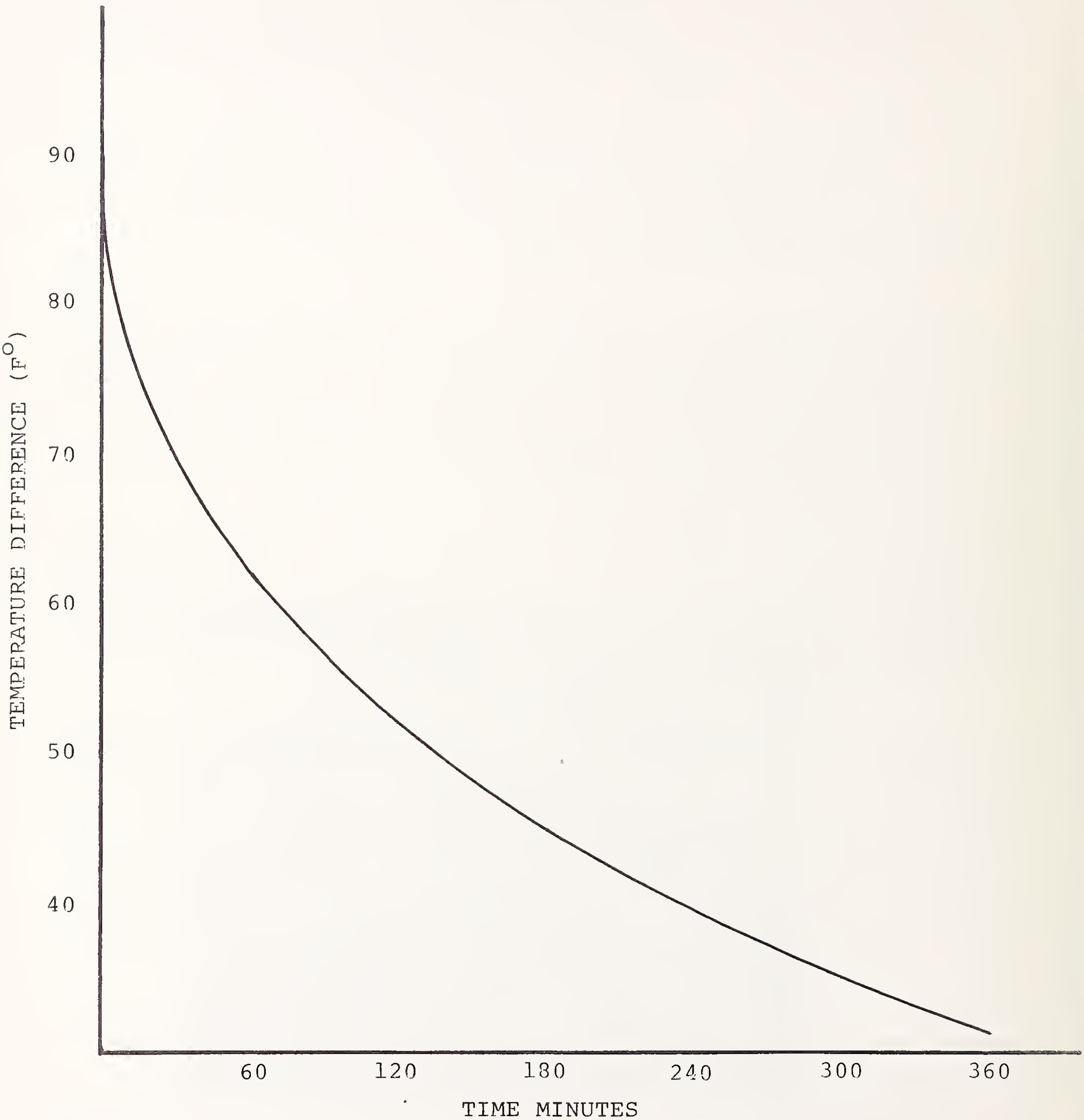


FIGURE 5-32. GUIDEWAY SURFACE COOLING CHARACTERISTIC

Temperatures on the guideway surfaces at the start of the test were an average of $+34^{\circ}F$ with 1/2 to 1 inch depth of snow and slush deposited on the guideway surfaces. Figure 5-33 shows the guideway surface condition at the start of testing.

After six (6) hours of testing, the guideway surface temperatures had risen to $+53^{\circ}F$, a $+19^{\circ}F$ temperature rise. An accumulation of snow and slush covered the guideway surface at which time testing was terminated. Figure 5-34 shows complete melting of the accumulation in the vicinity of heating element expansion box.

With the guideway surfaces free of precipitation and at a temperature of $+36^{\circ}F$, the electrical snow removal heating elements were energized to a power level of 20 watts per square foot. Weather conditions were; an ambient air temperature of $+35^{\circ}F$, a wind velocity of 5-15 miles per hour and zero snow fall.

The above test was run in anticipation of a snowfall which did not occur.

After 9 hours of guideway surface heating, the surface temperature was $+49^{\circ}F$.

If snow covers the guideway surface prior to energizing the heating elements, air pockets may form and hinder further melting. To obtain the maximum benefits from the Electrical Snow Removal System, the guideway surfaces should be brought to and held at a temperature above $32^{\circ}F$ prior to snow fall.

Figure 5-35 shows the guideway surface heating characteristic for the range of ambient conditions which occured during testing. This data will assist in planning how far ahead of a predicted snow fall and at what power level setting the heating elements should be energized to maintain the guideway free of snow at minimum cost.

FIGURE 5-33. ELECTRICAL SNOW REMOVAL

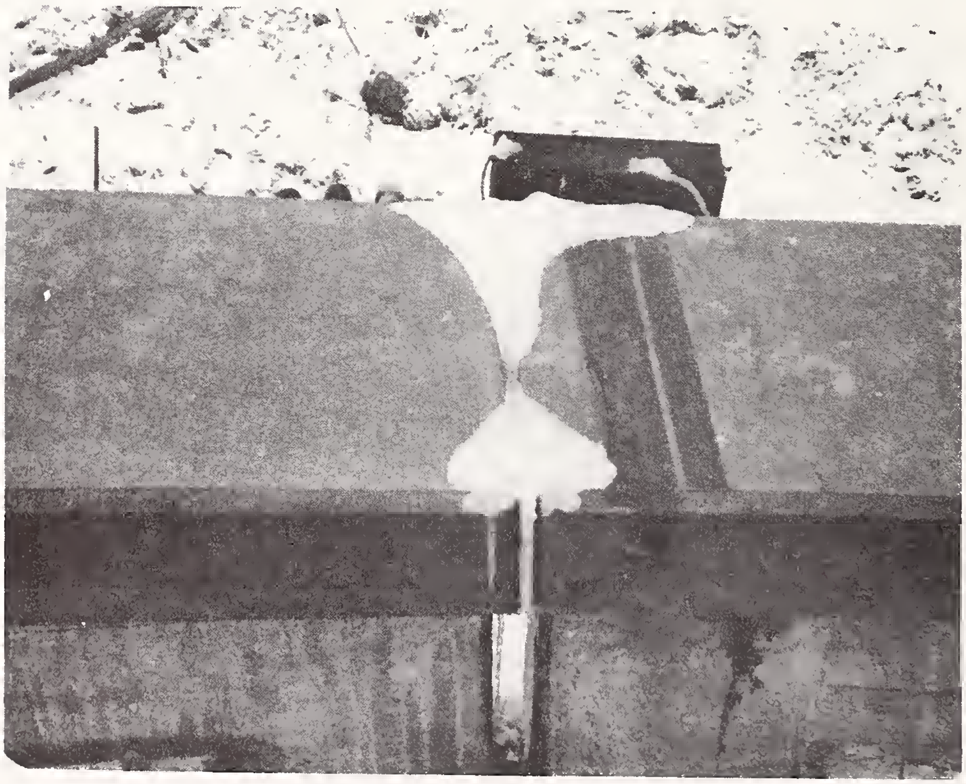


FIGURE 5-34. SNOW MELTED IN VICINITY OF EXPANSION BOX

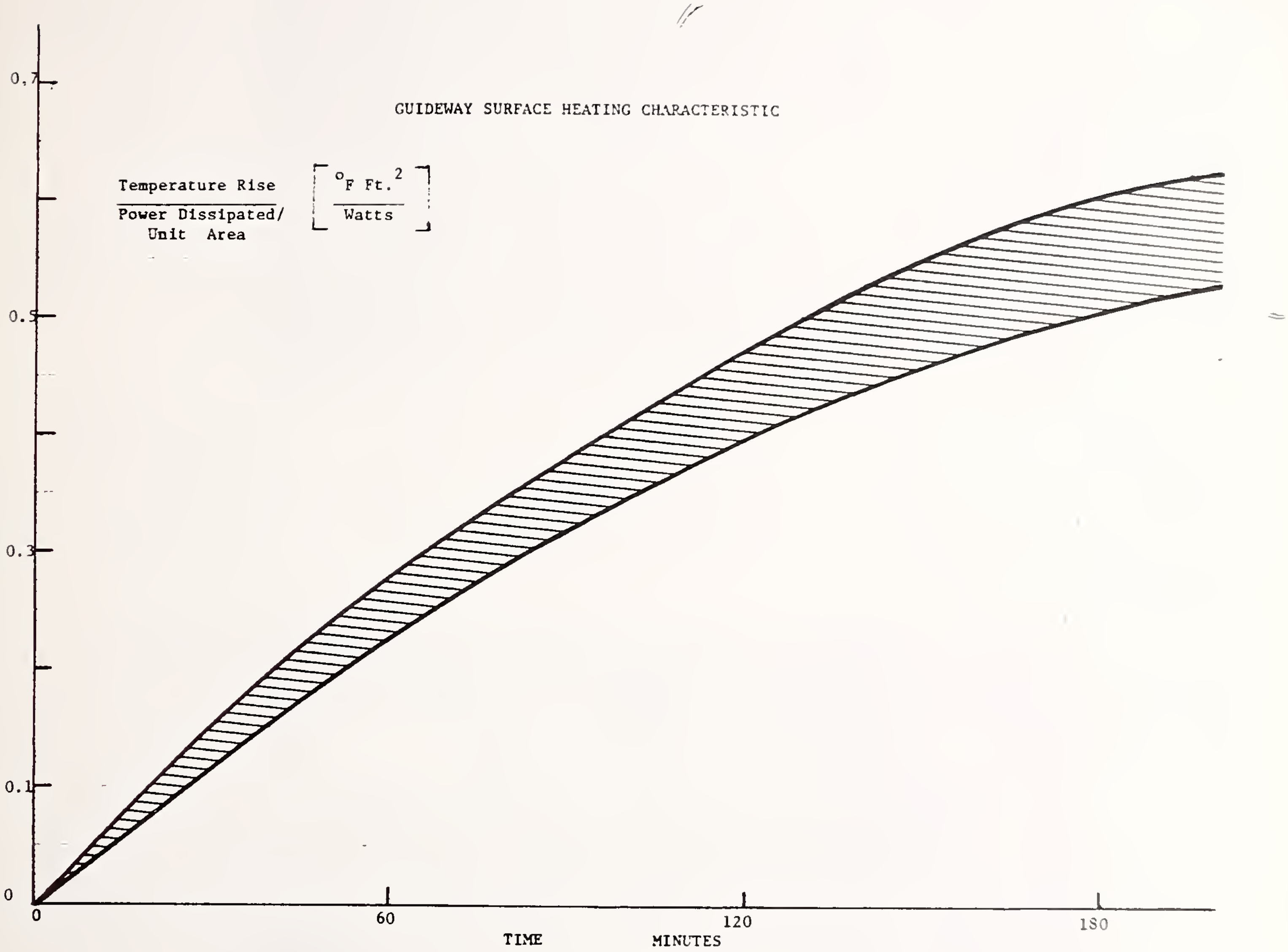


FIGURE 5-35. GUIDEWAY SURFACE HEATING CHARACTERISTIC

5.2.2 Retrofitted Heating Elements

Experience with the cast in place units prompted exploration of the possibility of grooving the running surface and installing heating elements using various combinations of sealants.

Two heating elements, embedded in the extension track during the construction of the extension in the fall of 1978, failed. One unit failed due to a rupture of the element when a cement bolt was placed into the edge of the running surface. The other element failed shortly after initial turn-on. Considerable work was performed on digging up the ruptured unit, drying the inner element, splicing in a new piece and recementing the guideway. The open circuit in the second element has not been located as of this time.

In January 1980, thirty (30) linear feet of the original guideway running surface were grooved, using a concrete saw, to accommodate six heating elements (Figures 5-36, 5-37, 5-38 and 5-39). Both the north and south surfaces were prepared.

Six standard heating elements were installed and five different sealants used. They were;

- Polyurethane
- Sand topped with Polyurethane
- Sand topped with asphalt
- Clay topped with asphalt
- Cement

The objective of these tests was to examine the capability of installing retrofitted heaters with the ultimate goal of providing proper heat distribution plus the ability to repair or replace entire units rapidly and efficiently. The technique could be adapted to the original construction of running surfaces as well as to existing set concrete.

FIGURE 5-36. RETROFITTED HEATER GROOVES

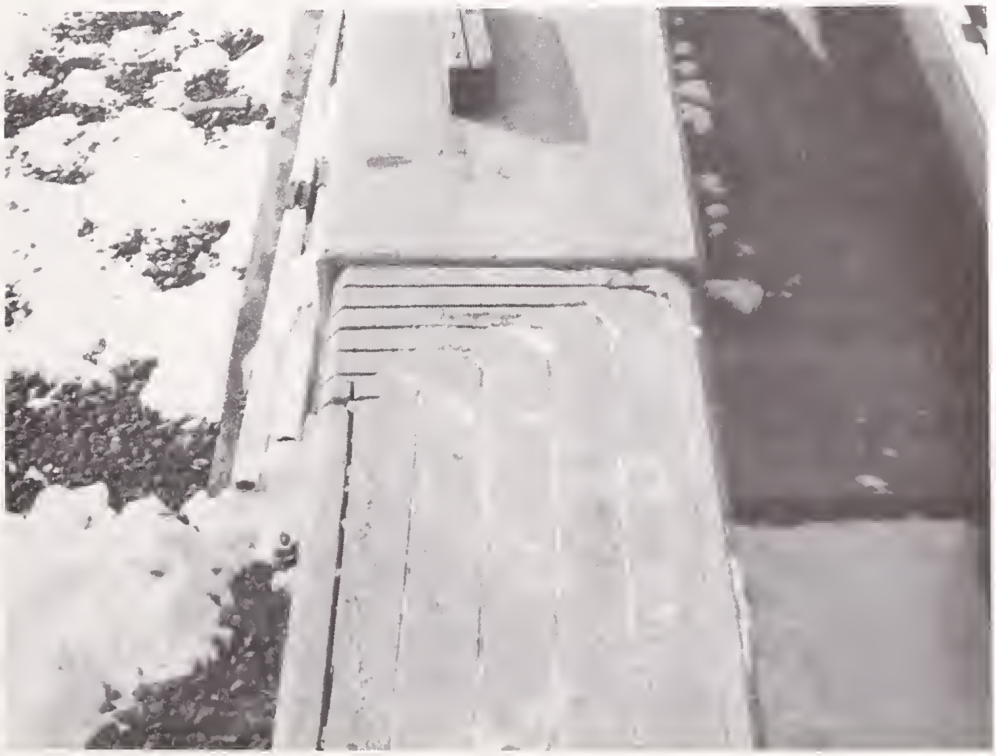


FIGURE 5-37. RETROFITTED HEATER GROOVES

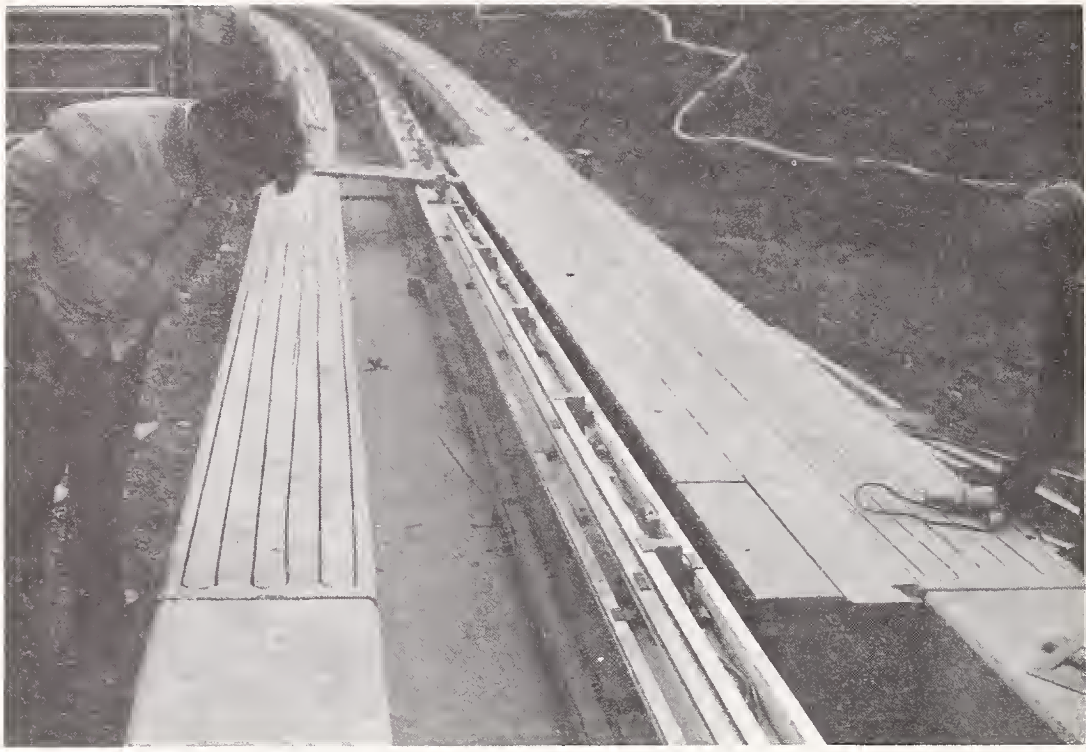


FIGURE 5-38. RETROFITTED HEATER GROOVES

FIGURE 5-39. RETROFITTED HEATER GROOVES

To achieve this end, six heating elements were installed for testing during the winter of 1979-80. These units were connected to the controls governing the roadway heaters installed on the extension.

With 1-1/4 inches of snow on the running surfaces, a snow fall rate of 1/2 inch per hour and an ambient temperature of 18^{O}F, the heating elements on the track extension plus the retrofitted units were energized to produce 50 watts per square foot on the running surfaces.

After two hours, the retrofitted area was clear of all snow, whereas the extension surfaces were only half cleared.

Retrofitted heating elements findings, from the the limited testing performed, are listed below. Tests will be conducted to determine the ease of replacement of faulty units.

1. Installation of heating elements in a completed guideway is not difficult.

2. Polyurethane or ployurethane topped sand demonstrate the best heat transfer characteristics.

3. Clay topped with asphalt was not desirable due to overheating of the asphalt.

4. The technique used for retrofitting was superior in heat transfer characteristics to the cast in place techniques.

WTD testing of guideway heating units showed that electrical heating removes snow and ice and can prevent the buildup of both. However, mechanical methods are faster for snow removal than electrical heating, and leave a surface which is not prone to ice formation. WTD recommends use of electrical heating only for removal of ice on critical sections of the guideway. Mechanical methods are preferable for removal of snow.

5.3 SWITCH OPERATION

The guideway switch used at the Test Track is a pivoting guide beam unit. This unit is similar to the ones installed at the Atlanta Airport. When commanded by wayside controls, the guidebeams, with their associated power and signal rails, and program stop antenna are hydraulically driven to the desired position and locked to provide safe guidance in negotiating the train to either the tangent or spur tracks.

The switching unit installed on the original track in 1975 was a prototype unit which had undergone reliability testing for approximately 300,000 operations prior to being moved and installed at the test track. This unit, without any major modifications other than power rail and antenna changes, was the unit which was used during the winter testing of 1978-79.

During the summer of 1979, the five major pieces of the switch were updated for general testing purposes with the latest manufactured items used in Atlanta. They were the roller plate assembly, the beam stop assembly, the pivot bearing beam assembly and the two guide beams. The side structures which contain the running surfaces were the only mechanical items retained from the original unit. Minor modifications were made to the hydraulic unit in that an additional valve was added to bring the unit as close as possible to standard manufactured units.

As the switch has moving parts which are exposed to the elements, the objectives of these tests were to determine critical areas of the switch which might have to be protected, changed or heated.

A potential problem area was the roller beam. Here snow could be compacted, preventing the switch from completing its travel. A heater element was installed under the plate along with a roller beam protective cover. This cover consisted of two side plates and two venetian blind type screens which could move with the beam.

A test performed after man-made snow had accumulated to a depth of 7 1/2 inches on the roller plate was not successful as the beam failed to travel the final 1/4 inch to allow the beam locking pin to seat. It appeared that snow had been compressed on the roller beam preventing it from locking. An investigation found that snow had compacted on the stop beam rather than the roller beam. With the removal of the compacted snow on the stops, the switch functioned properly.

Further attempts to get the switch to fail during the winter of 1979-80 were unsuccessful. Consequently, tests which were to be conducted using the protective cover or heating were not performed.

From the tests conducted, indications are that the roller beam is not the problem area on the switch. Instead, the stop plates, which are presently uncovered, are the source of the problem.

A small mechanical cover installed between beams would prevent snow from accumulating in that area. This unit will be manufactured and installed.

6.0 VEHICLE-RELATED TESTING

6.1 VEHICLE DOOR TRACKS

6.1.1 <u>Door Track Designs</u>

The standard lower door track available on all C-100 vehicles prior to the Atlanta Airport vehicle, and used for the 1978-79 test period, was an extrusion which guided the bottom of the vehicle doors during operation of the doors. The extrusion had a limited number of drain holes by which any accumulated water could escape. For the 1979-80 winter testing period a standard Atlanta Airport style sill (Figure 6-1), was modified and installed for doors 5 and 6 on the Engineering Test Car (Figures 6-2 and 6-3). One half of the modified unit was Teflon® coated while the other half was untreated.

Both the old style sill used for doors 7 and 8 and the new style used for doors 5 and 6 were equipped with a method of electrical heating.

For the newly designed door track, the objective was to determine its ability to perform the function of guiding the lower portions of the doors without causing blockages due to ice or snow accumulation and to determine if a Teflon® coating would alleviate the possibility of ice blockage. To test the design and its features, both the old style and the new style, coated and uncoated, would be subjected to the same winter environmental conditions since they are all on the same side of the vehicle.

In previous years, door sills had become clogged with frozen snow and/or ice when the door tracks were not used for prolonged periods of time, such as overnight. During the times that the doors have been in normal use, no clogging or stoppages have occurred. The procedure was to allow the vehicle to remain stationary for overnight periods with all vehicle power turned off so no body heat would effect the test (Figures 6-4, 6-5 and 6-6). Whenever the vehicle was started for testing, a cold startup procedure was initiated wherein the doors were operated electrically and timed without any manual removal of snow and/or ice.

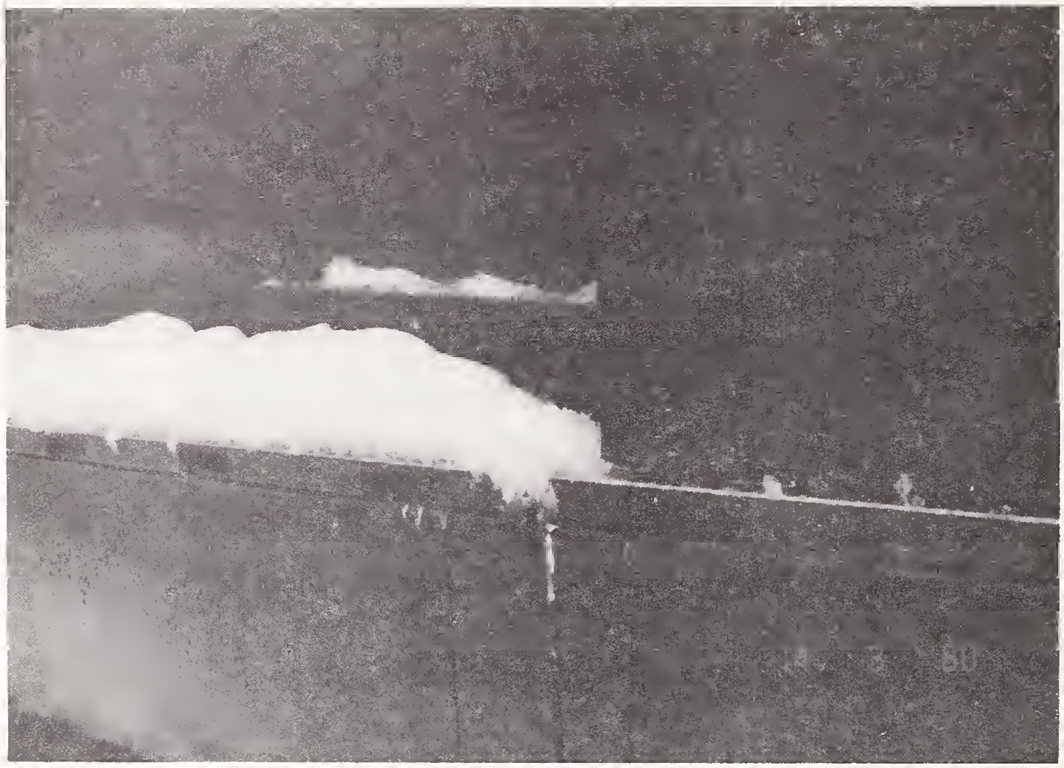


FIGURE 6-1. ATLANTA AIRPORT VEHICLE DOOR SILL

FIGURE 6-2. MODIFIED DOOR SILL, DOOR 6 UNCOATED

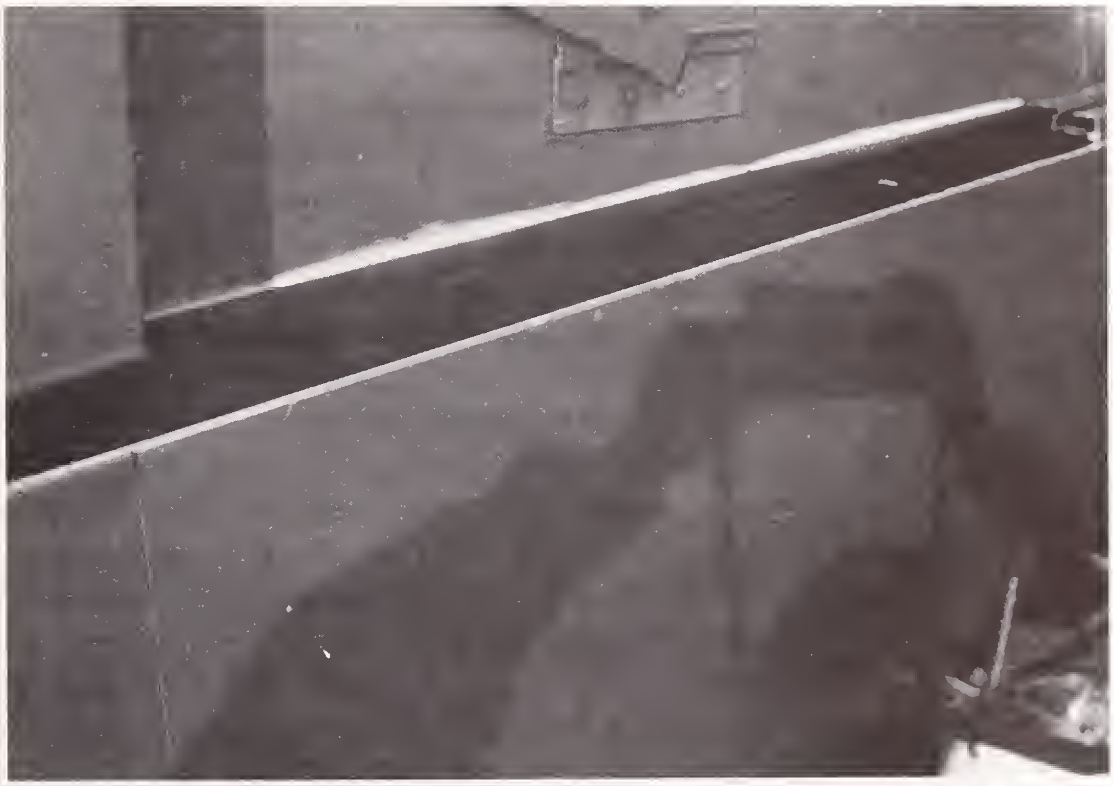


FIGURE 6-3. MODIFIED DOOR SILL, DOOR 5 COATED

FIGURE 6-4. SNOW ON DOOR #5 SILL

FIGURE 6-5. CLOSE-UP OF DOOR #6 SILL

FIGURE 6-6. CLOSE-UP OF DOOR #5 SILL

The newly designed track was very successful in that it offered maximum area for snow and water to be drained or pushed away as doors opened.

No noticeable difference was detected between coated and non-coated sills.

6.1.2 Door Track Heating

The objective of this test was to determine a level of heating required to free the door sill of ice, if necessary, and also to determine a level which might be required if door sill heaters were to be utilized while the vehicle was in overnight storage. The procedure was to measure heat required to free doors and to determine storage heating requirements.

Doors 5-6 and 7-8 functioned properly during the entire 79-80 season with respect to door sills becoming clogged with ice. Nothing was done to remove any ice or snow which might have accumulated on the sills prior to their electrical operation. A cold soak test (Figures 6-7 and 6-8), was performed by aiming two snow towers directly towards the left side of the vehicle. Snow was generated for 6-1/2 hours producing up to 24 inches of snow and ice not only on the door sill but also on the roof of the vehicle overhanging the left side. The vehicle was energized and the door track heaters turned on. Forty-five minutes later it was discovered that door sill heaters for doors 7 and 8 had not been on, due to a faulty plug. The plug was repaired. Two hours and 15 minutes after the start of the test, the ambient temperature was 26°F with the temperature measured inside the vehicle of 44°F. For 3 inches above tracks, the ice had been turned into slush. Doors could not be opened because of a large accumulation of snow/ice overhanging side of vehicle. The test was then terminated.

The conditions experienced are unrealistic and the failure was not related to the door sills. WTD does not recommend storing vehicles under the conditions described in this test. This test demonstrated the ability of door track heaters to function under extreme conditions, but sufficient test data was not collected to demonstrate a requirement for heating.

FIGURE 6-7. VEHICLE AFTER COLD SOAK

FIGURE 6-8. VEHICLE AFTER COLD SOAK

6.2 COLD CAR START-UP

The purpose of these tests was to gather information on the relative ease or difficulty in bringing a vehicle up to automatic operation status after having been stored outside in various winter conditions. To reach this status, it was determined that an operator would have to board the vehicle, turn on equipment breakers, check proper operation of the compressor, and check and time operation of vehicle doors. The operator may have to manually operate the vehicle from the storage area to automatic signal territory, which would require visibility through end windows. To this end, window deicers, brake heaters and an air dryer were tested.

6.2.1 Window Deicers

On each end window of the Engineering Test Car, two 12 volt automotive stick-on resistive window deicers (Figures 6-9, 6-10 and 6-11), were attached and wired in parallel, and through a manual switching arrangement, were connected to the vehicle's 24 volt battery system. The position of the two units in the windows was varied from end to end to offer the operator the maximum field of vision for observing signals, switch positions and other wayside and track equipment.

The objective of these tests was to determine if electrical deicing was a feasible method of removing ice from vehicle end windows.

Tests were conducted to determine energy consumed to melt ice from the end windows. With 1/8" of ice on the windows, the deicers were turned on, and in 5 minutes the window area was cleared. Power consumed was 100 watts for 5 minutes.

With light snow of a density of 0.15 covering the window at a depth of 1 inch at the bottom of the window to 1/4 inch at the top of the window, heater elements were energized for 30 minutes at 100 watts. Although the snow was light enough to brush off, it was decided to exercise the window deicers.

FIGURE 6-9. WINDOW DEICER

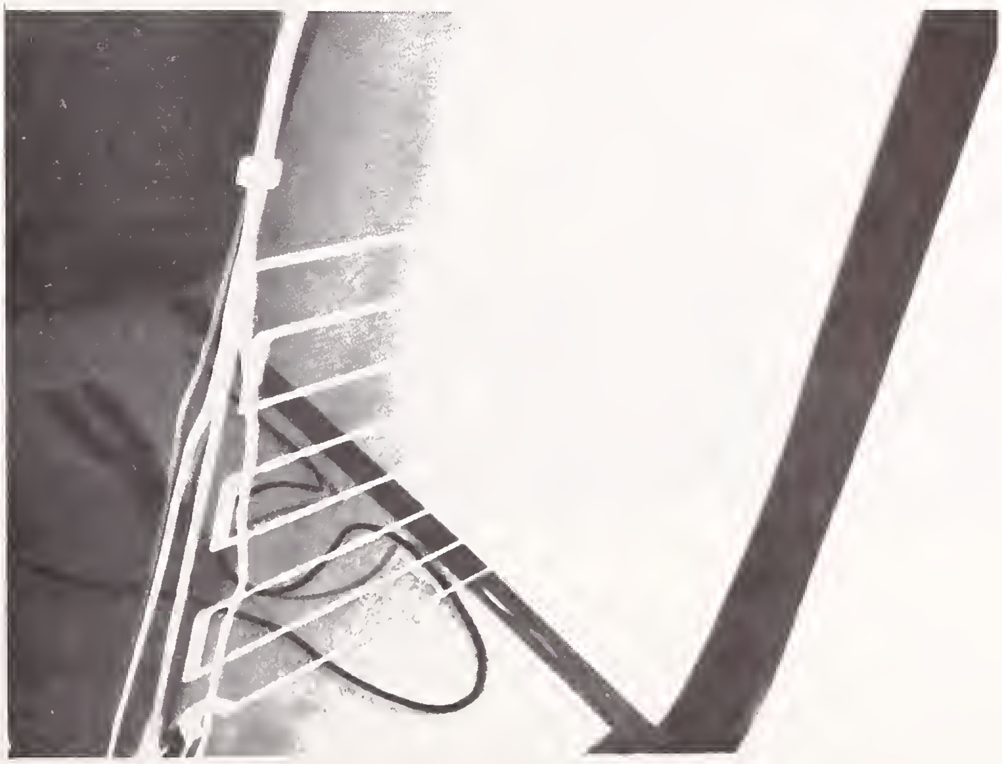


FIGURE 6-10. WINDOW DEICER

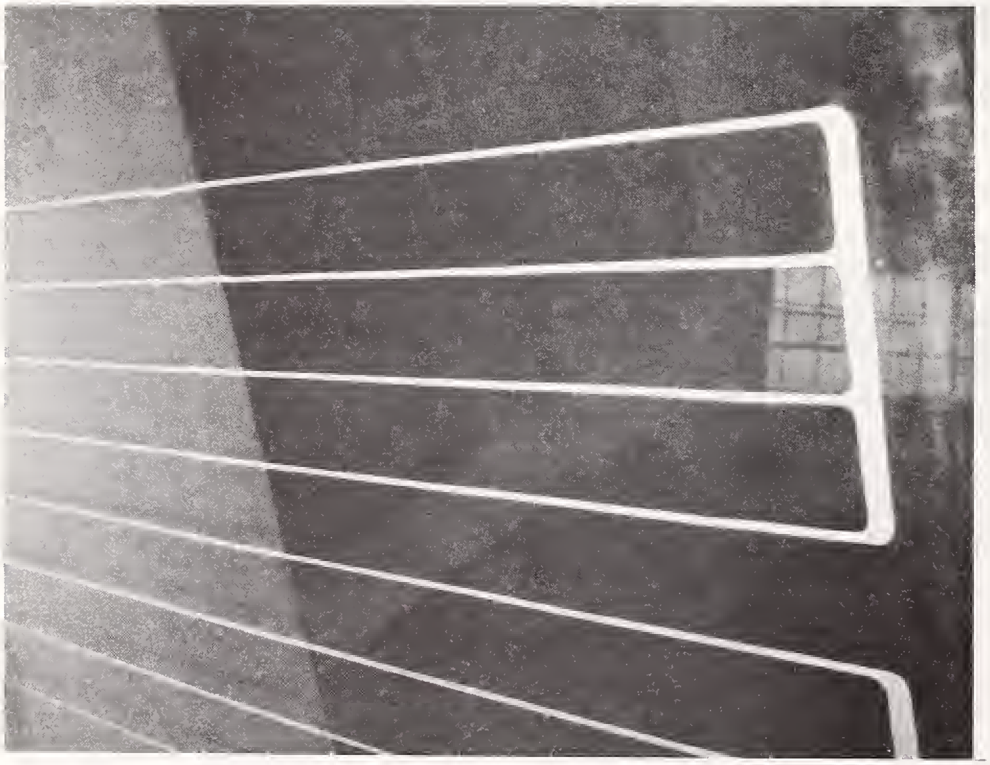


FIGURE 6-11. WINDOW DEICER

The window deicer units functioned as planned and could be incorporated on vehicles destined for use in areas subjected to ice and/or snow conditions. It is recommended that manual scraping or brushing be used when possible, for speed and energy conservation.

6.2.2 Brake Heaters

Due to problems with occasional brake shoe/drum freeze-ups during the 1978-79 winter season, heaters were selected to be used for the 1979-80 season. Two types of units were selected, one a strip heater (Figures 6-12 and 6-13), which was mounted to the bottom of the axles below the brake areas, and the other a cylinder heater (Figures 6-14 and 6-15), which was mounted to the spring brake units. The strip heaters were 115 volt, 250 watt units while the cylinder heaters were 30 volt, 50 watt units.

Tests were scheduled to be performed in the event of a brake shoe/drum or a spring brake freeze-up to test the benefits of two different heating devices.

For a considerable period of the winter test season 1979-80, automatic operation of the system was conducted each evening for approximately 6 hours. On nights when the temperature was to stay below freezing, the dynamic brakes on the vehicle were turned off for the final 10 round trips so that the service brakes would be used for the entire braking period. This operation heats the brakes. Before the brakes could cool, the vehicle was parked in the spur. It was felt that the condensation formed would freeze during the night. Cold weather start-up was performed on the following mornings.

Due to mild weather conditions, no conclusive data were obtained to evaluate the heaters' performances, other than initial tests to determine that the units functioned. There were no cases during the 1979-80 winter season when the brakes froze, so a requirement for brake heating was not established. However, the design concept developed and the standard hardware used could be integrated into the standard car design if needed.

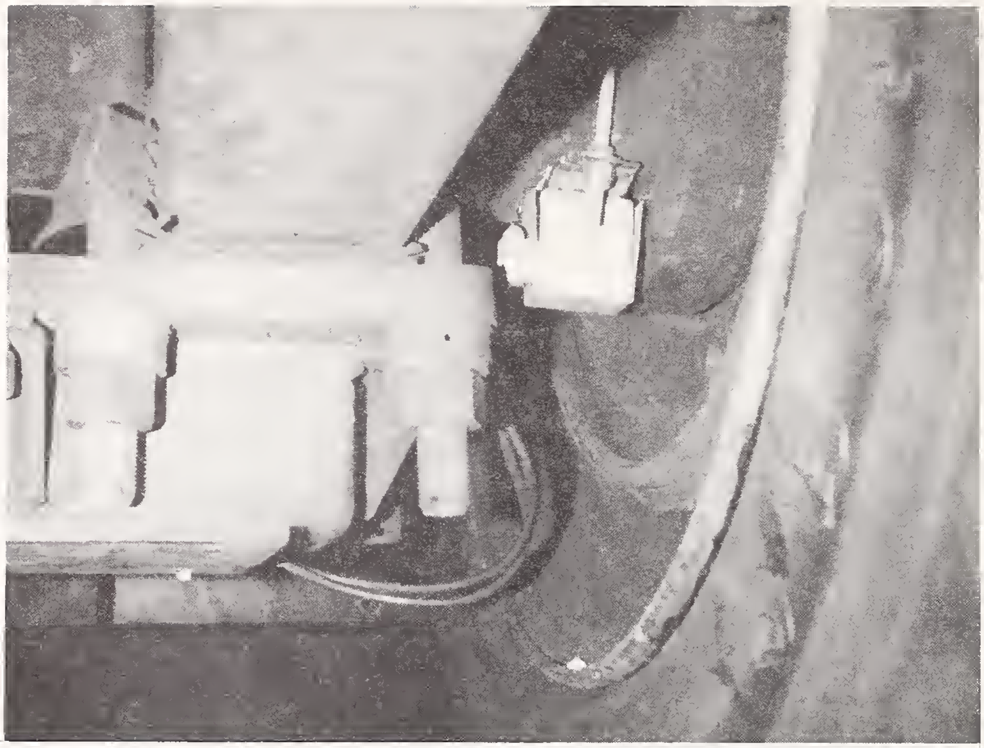


FIGURE 6-12. STRIP HEATER

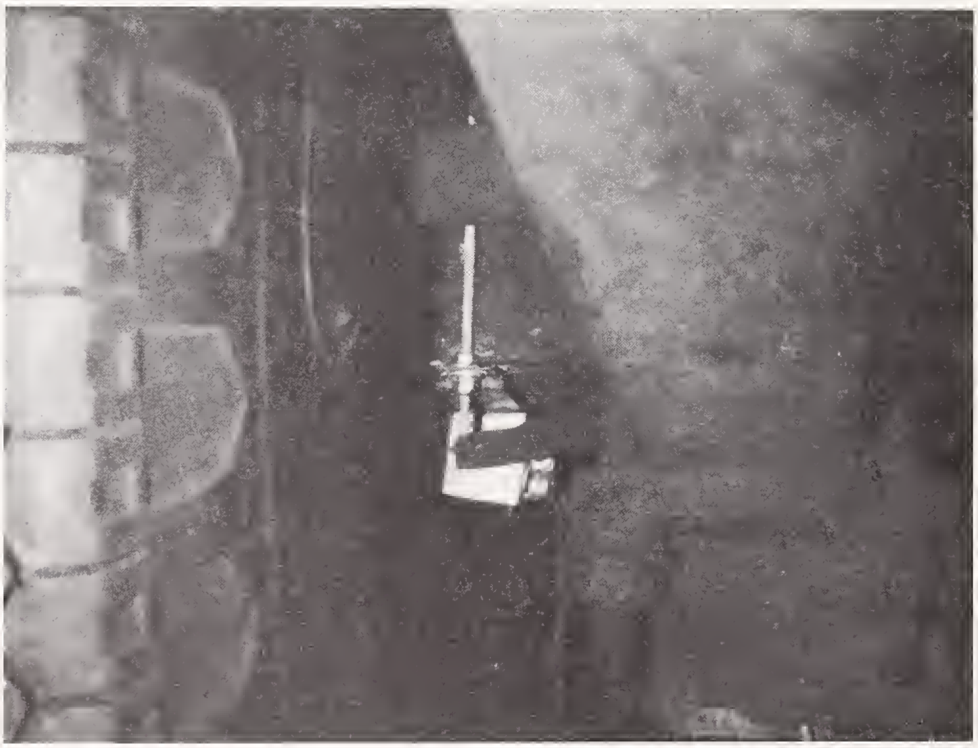


FIGURE 6-13. STRIP HEATER

FIGURE 6-14. CYLINDER HEATER

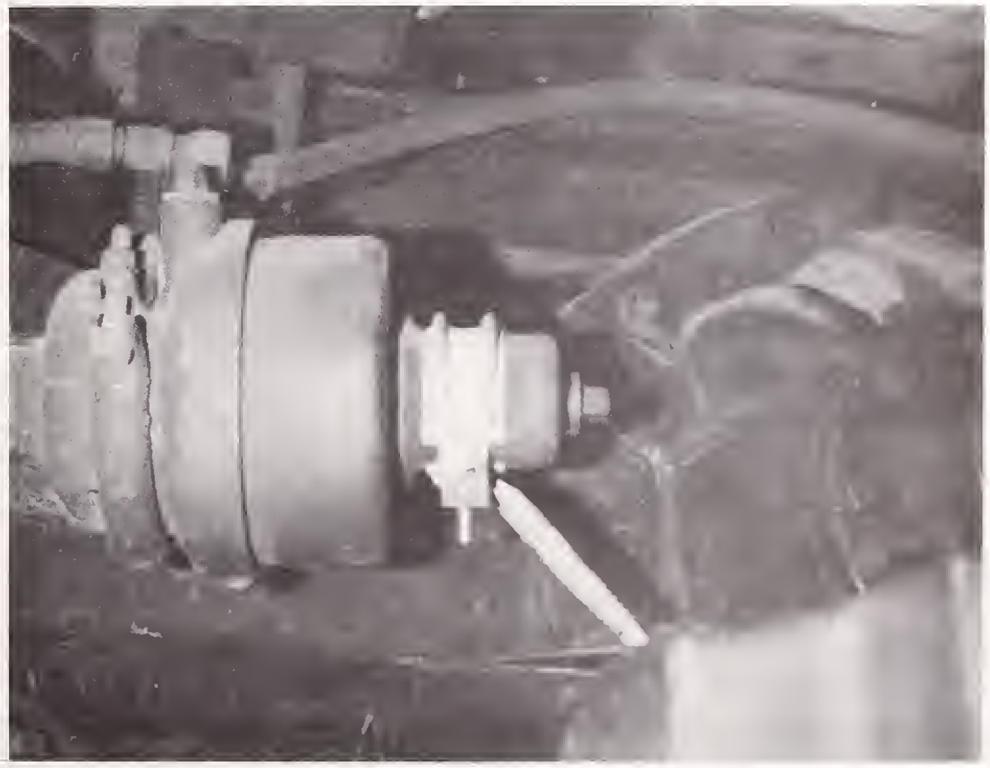


FIGURE 6-15. CYLINDER HEATER

6.2.3 Air Dryer

Operation of the vehicle, either manually or automatically, requires air to support the braking system as well as the suspension system. Air line freeze-up, if it occurred, would be observed in cold startup procedures or in automatic operation.

The standard C-100 vehicle is equipped with a Westinghouse-Bendix AD2 Air Dryer. During the testing period of 1978-79, on a number of occasions, air line freeze-ups occurred which prevented operation of the vehicle. For the 1979-80 season, a Cyclo-Gard dryer was evaluated (Figure 6-16).

The objective of testing a new air dryer was to determine if a different style unit would reduce the problems with air line freeze-up which occurred during the 1978-79 winter season.

Only once during the 1979-80 winter season was there a case of a frozen airline and that was a line to one of the snow removal devices. This freeze-up was traced back to a failure to drain air tanks (standard operating procedure) at the close-down after an operating period.

Due to the mild winter during the 1979-80 season, no conclusive data were obtained which support the need for a special air dryer. However, there were no operational problems and the new air dryer is tested and available.

6.3 LONGITUDINAL CONTROL AND LATERAL GUIDANCE

Due to similarities in instrumentation and test procedure requirements, the longitudinal control and lateral guidance tests were combined.

To determine the riding quality of the vehicle, accelerometers were installed on the vehicle floor for detecting lateral, longitudinal and vertical motion of the vehicle while accelerating and braking.

FIGURE 6-16. AIR DRYER

The vehicle speed was recorded through tachometers on both the #1 and #2 bogies and a fifth wheel. The tests were performed with the vehicle loaded with the test operators and instrumentation.

The subsystem tests conducted in 1978/1979 were to determine that the vehicle could be operated and controlled to provide a safe, comfortable ride and can function normally through the wayside switch and while braking on curves under severe winter conditions. These tests were deliberately performed under worst-case conditions, in an attempt to force the worst conceivable performance from the vehicle.

To simplify comparison of acceleration data with limits set by International Standard Organization Specification ISO 2631, the accelerometer outputs were processed by weighting filter circuits. The weighting filter responses, the ISO 2631 ideal characteristics to which they approximate and acceleration measurement techniques, are discussed in more detail in Appendix D.

The following provides a short summary of the results of the test runs.

Weather conditions for this test were an ambient air temperature of +26°F, and a wind velocity of 0 miles per hour. The guideway surfaces were covered with 1/8 inch of natural ice. The following manually controlled runs were performed to assess the capabilities of the system to provide a safe, comfortable ride while accelerating and braking on a curve at grades up to 10%.

RUN 1.1 Vehicle departed from Station 3 for Station 5. On Span 4 the vehicle wheels started spinning. Brakes were applied and the vehicle slid eastward, stopping 20 feet west of Station 3.

RUN 1.2 Vehicle proceeded from Station 3 to Station 5 with continuous wheel spinning. Brakes were applied at Span 4 and the vehicle slid eastward into Station 3.

RUN 1.3 Vehicle departed Station 3 for Station 5 with wheels spinning and emergency braking was executed on Span 6. The vehicle slid to Span 5, came to a halt and then reversed direction and slid eastward into Station 3.

A recording of the vehicle wheels spinning is shown in Figure 6-17. The area within the brackets shows zero speed for the fifth wheel and up to 6 miles per hour and 10 miles per hour on the axle speeds. Due to icy guideway surface, the vehicle could not traverse the 10% grade to Station 5. Figure 6-18 shows the effects of the wheel locked and the vehicle sliding back toward Station 3. The fifth wheel is at 4 miles per hour during the slide while the two tachometers are registering zero speed. Figure 6-19 shows a manual simulation of the automatic control system response to detection of wheel spin by applying emergency brake. Again the vehicle came to a stop and slid back toward Station 3.

Another test on an automatic mode of operation was set up which would permit operation over the full length of track from Station 5 to Station 1. The weather conditions during the test were: an ambient air temperature of +35°F, wind velocity of 7-15 miles per hour and 0.10 inches per hour of rain.

The following runs were performed to assess the capabilities of the system with a wet track surface which may be the condition existing after snow removal operations.

RUN 2.1 The vehicle proceeded eastward in automatic from Station 5 at 23 miles per hour maximum and stopped at Station 1.

RUN 2.2 An automatic run at 25 miles per hour was performed proceeding from Station 1 and stopping at Station 5.

Figures 6-20 through 6-23 are recordings of speed and of the longitudinal, lateral and vertical accelerometer readings taken during Runs 2.1. and 2.2 for the purpose of comparison of the vehicle ride quality characteristics with the ISO 2631 specification.

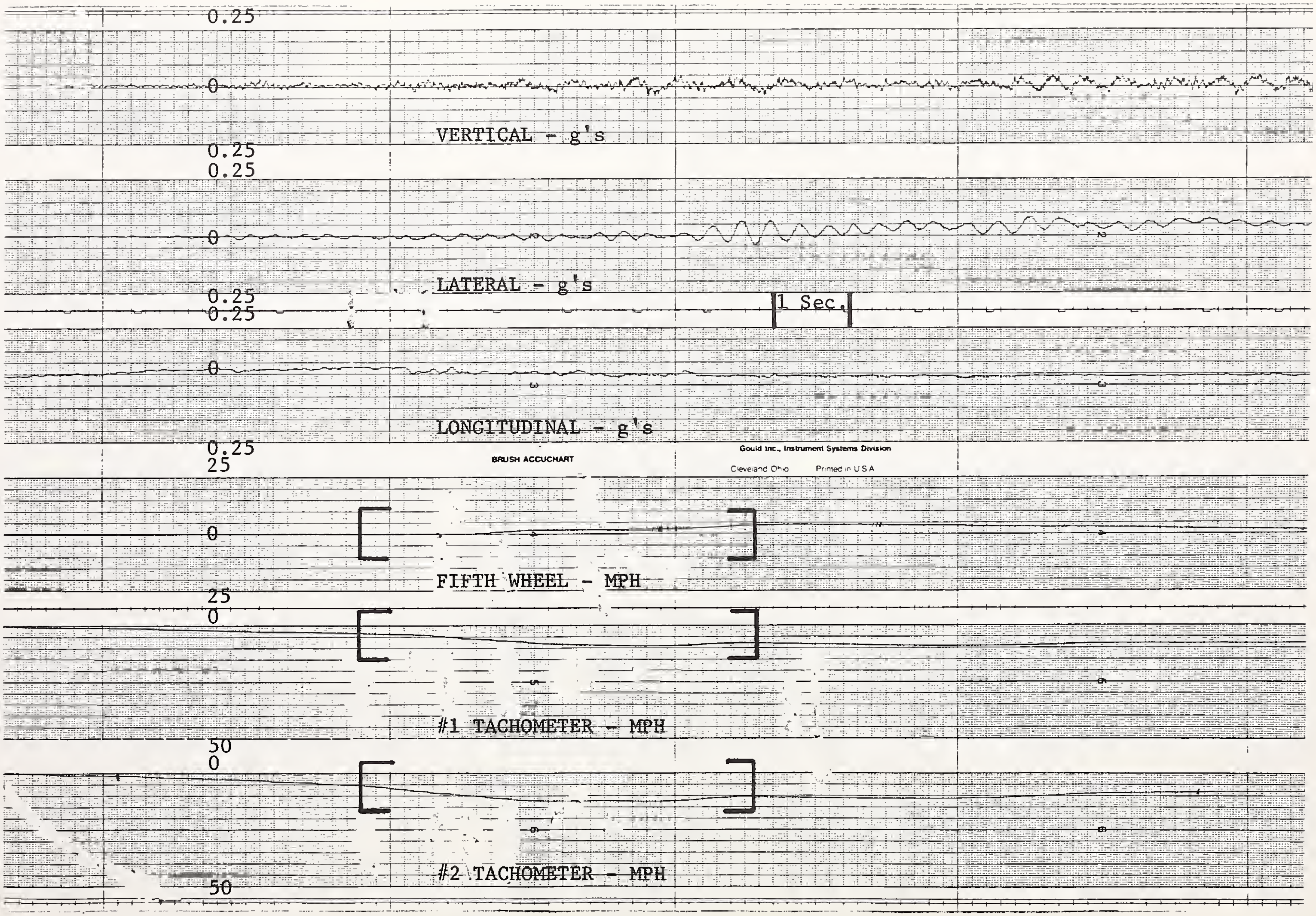


FIGURE 6-17. VEHICLE WHEELS SPINNING, TEST 1.0, RUN 1.1

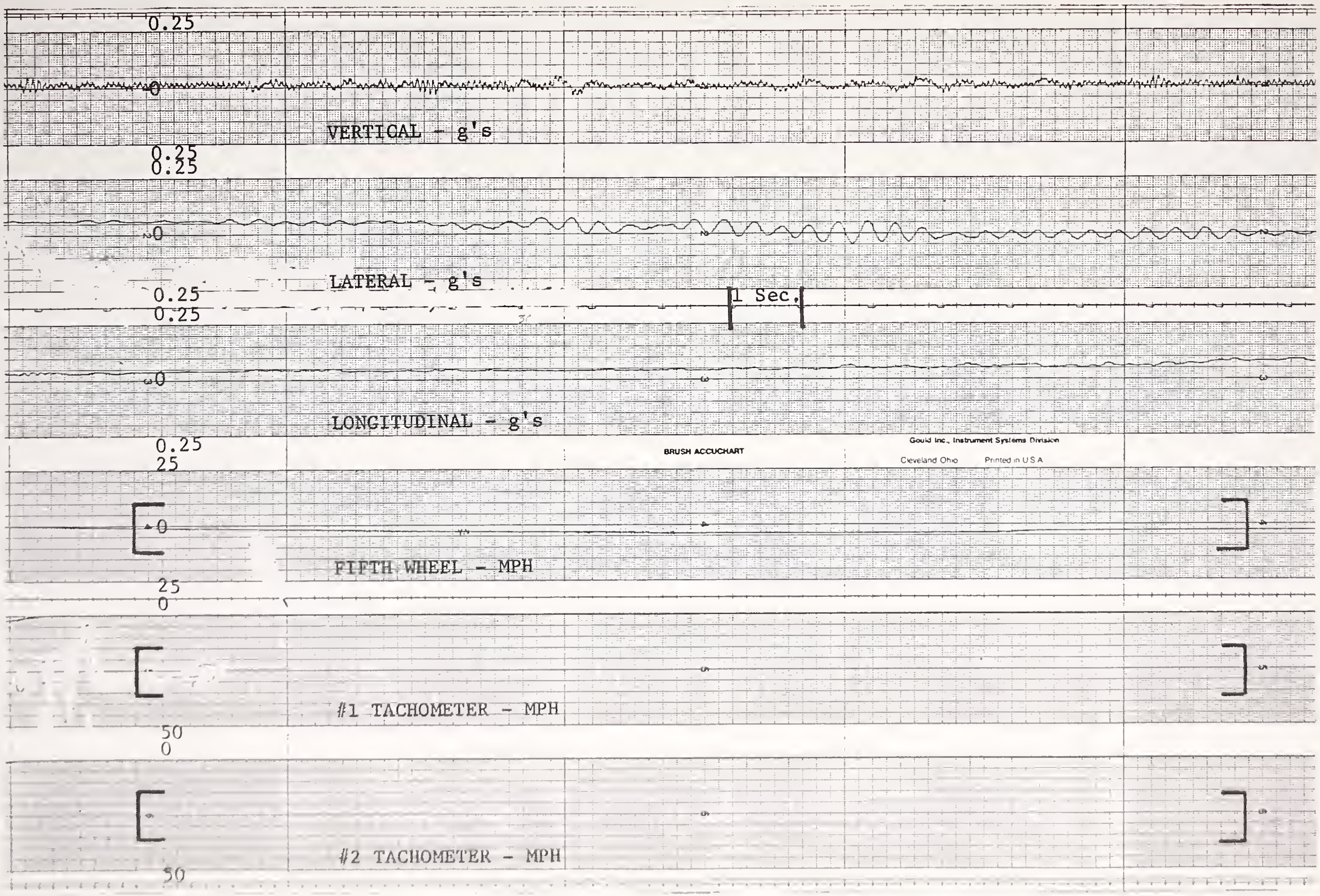


FIGURE 6-18. VEHICLE WHEELS SPINNING, TEST 1.0, RUN 1.2

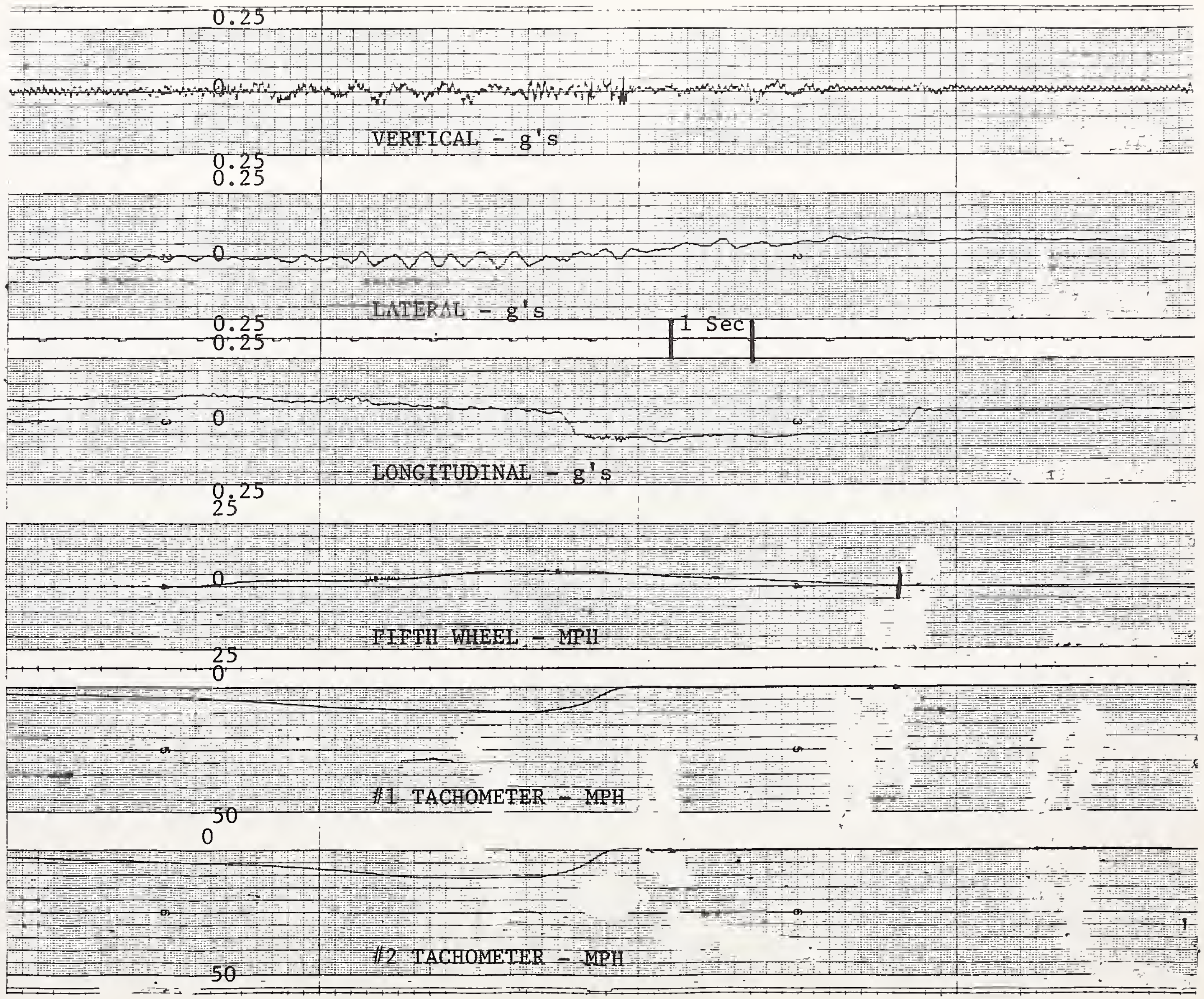


FIGURE 6-19. VEHICLE WHEELS SPINNING, TEST 1.0, RUN 1.3

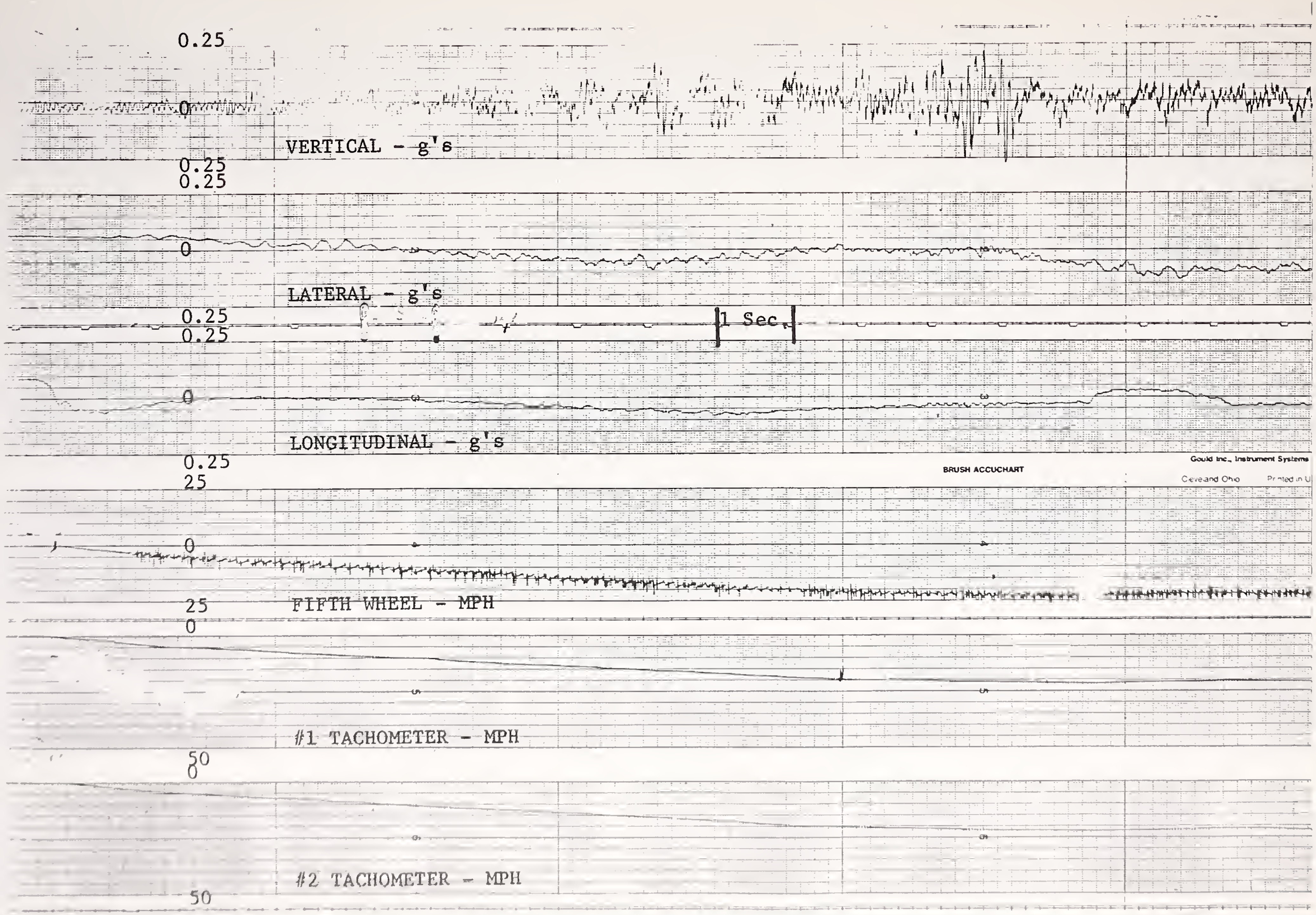


FIGURE 6-20. WET TRACK ACCELERATION, TEST 2.0, RUN 2.1

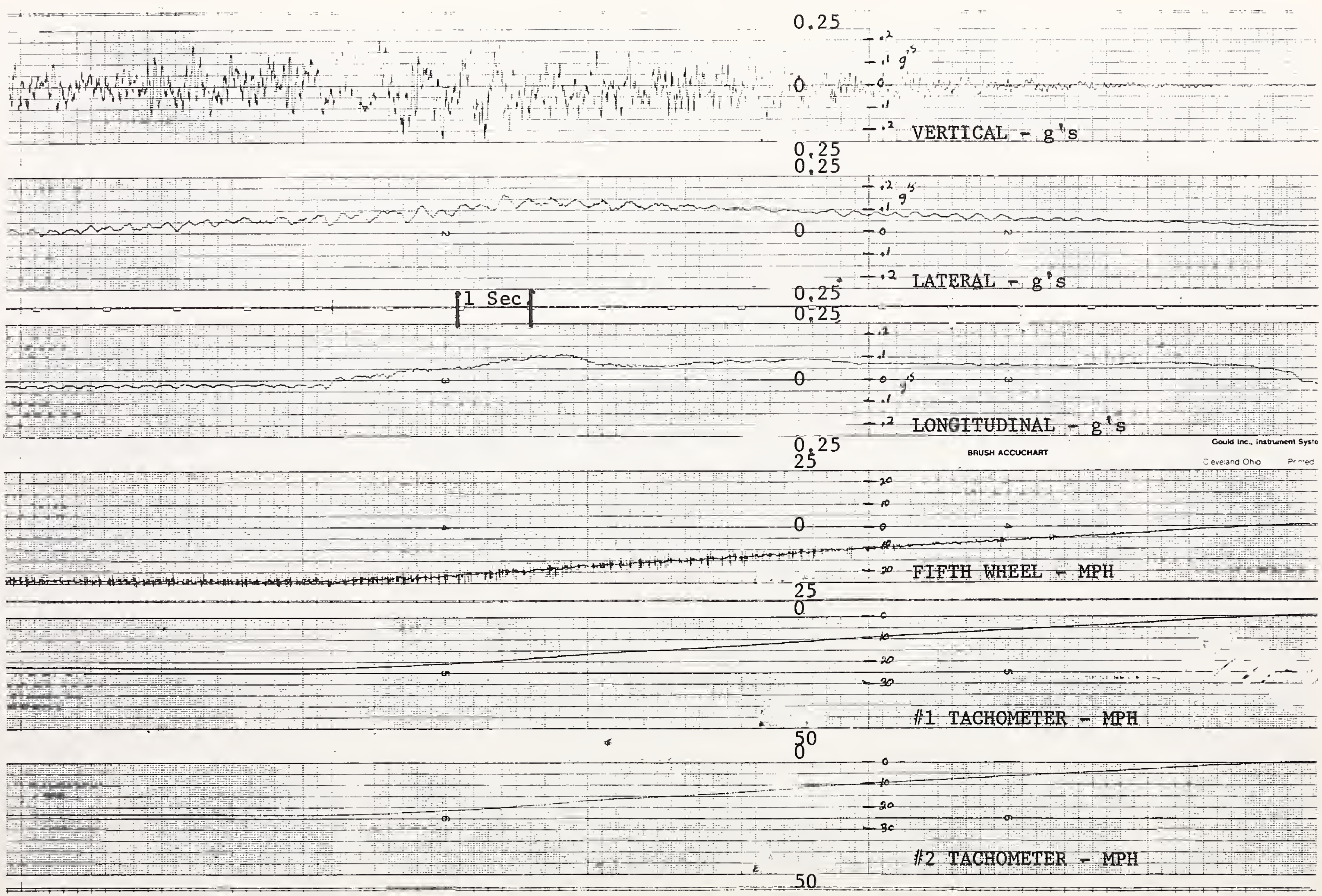


FIGURE 6-21. WET TRACK BRAKING, TEST 2.0, RUN 2.1

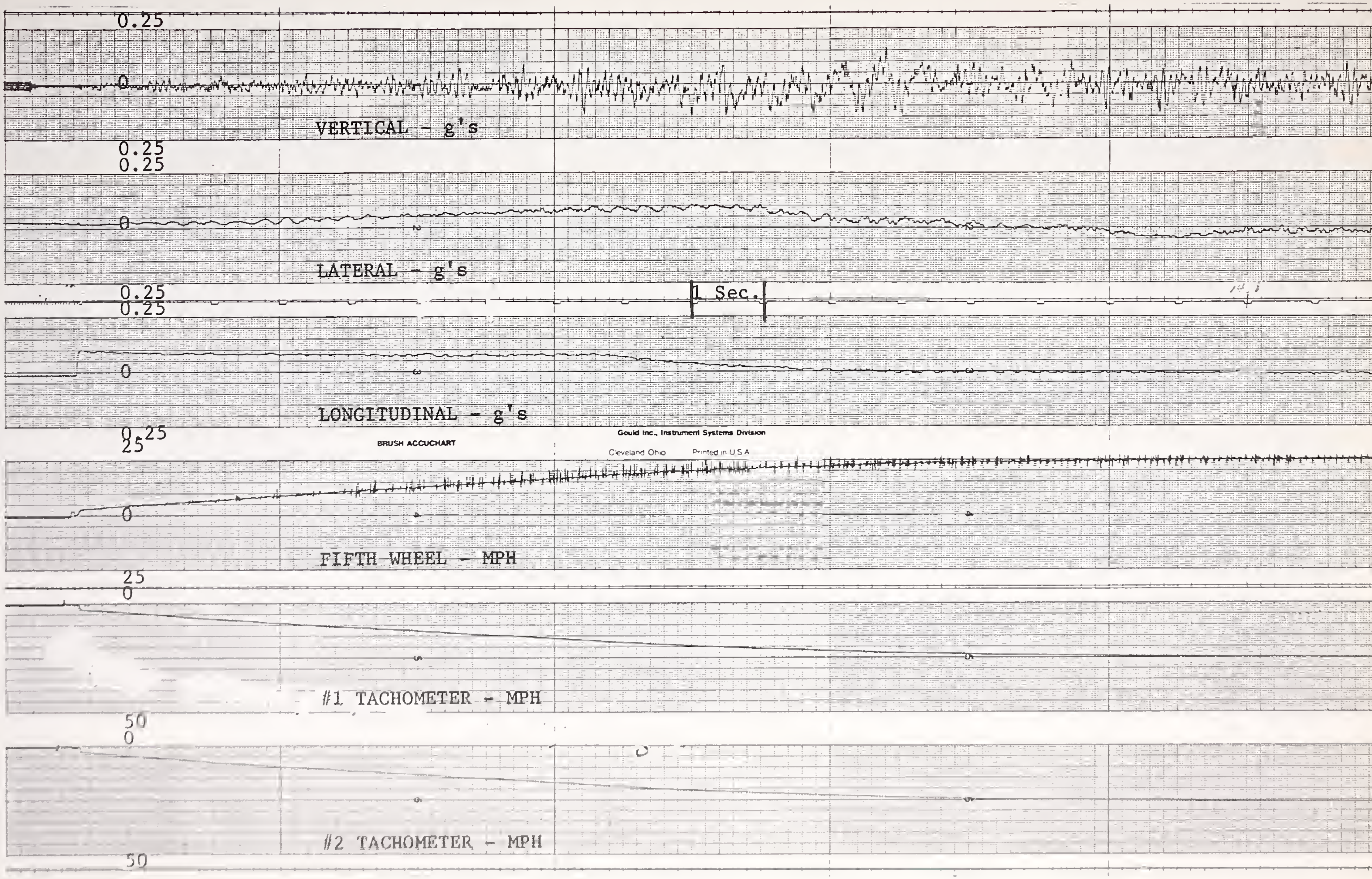


FIGURE 6-22. WET TRACK ACCELERATION, TEST 2.0, RUN 2.2

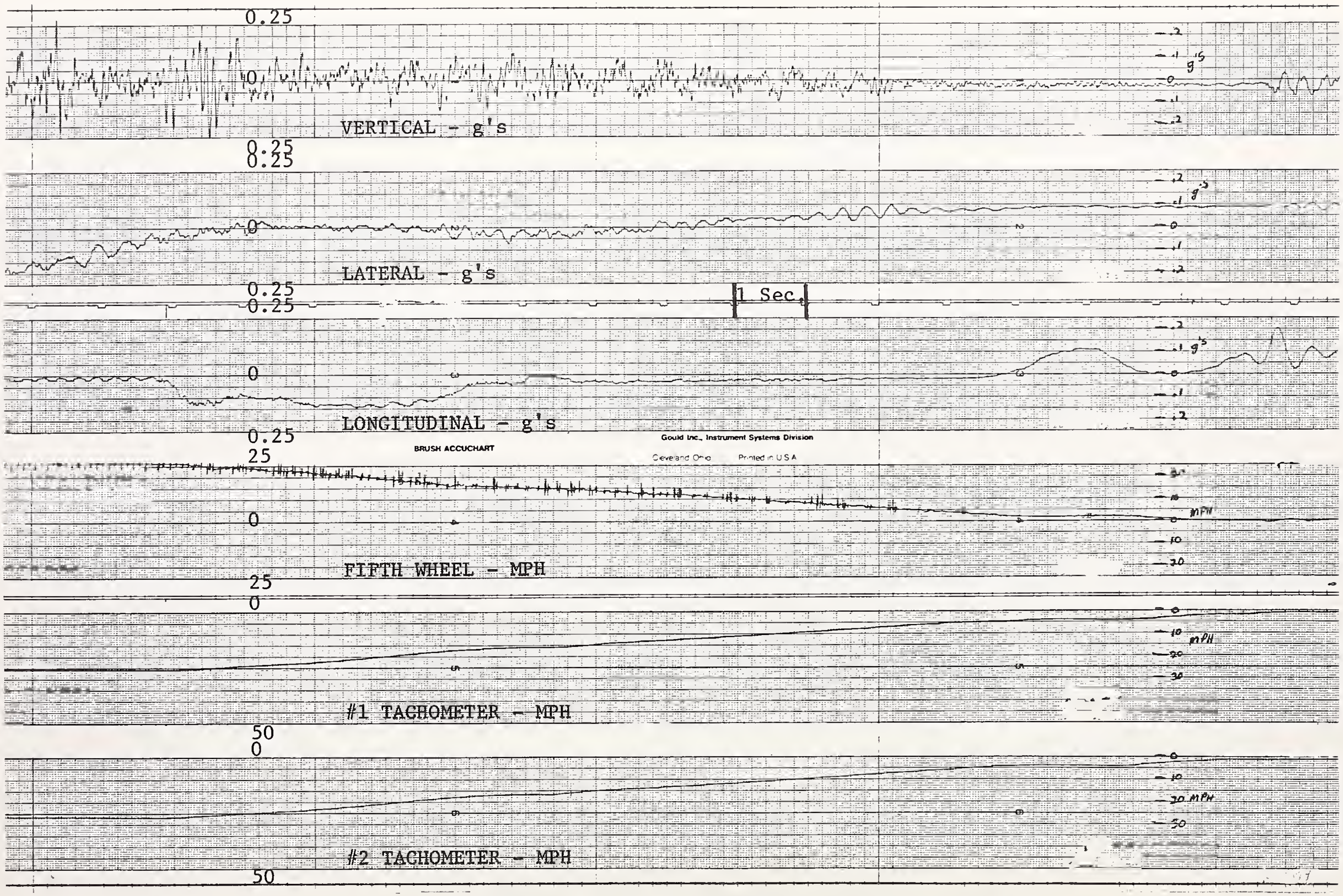


FIGURE 6-23. WET TRACK BRAKING, TEST 2.0, RUN 2.2

A test was run to determine the operational characteristics of the vehicle on a level, ice-covered guideway surface. A smooth, icy guideway surface was formed by spraying water on the surface at below freezing temperatures. Figure 6-24 shows test personnel water spraying guideway surface. For this test, the guideway surfaces between the 150 foot and 615 foot marker were selected for water spraying because this test section of the guideway surface is shadowed by the factory building and minimizes any melting of the ice by the sun.

The weather conditions during the test were: an ambient air temperature of between +22°F and +28°F, a wind velocity of 4 miles per hour and zero snow fall rate. A 1/16 inch layer of ice covered the guideway surface between the 150 foot and 615 foot marker at the start of testing. The smooth surfaces are shown in Figure 6-25.

Some typical runs are described below:

RUN 3.1 The vehicle was placed in NORMAL-1 automatic mode and proceeded from Station 3 to Station 1 at 23 miles per hour maximum speed. At the 520 foot marker the vehicle lost the speed code and the vehicle brakes were automatically applied. With all four wheels locked, the vehicle slid on the icy surface to the 615 foot mark and then onto the dry guideway surface. Due to the high deceleration at the 615 foot mark, the prototype snow brush assembly was pitched downward, contacting the power rail and damaging an insulating block and the air supply to the brush assembly.

RUN 3.2 With the car proceeding westward at 18 miles per hour maximum, an emergency stop was executed at the 410 mark. With the four vehicle wheels locked, the vehicle slid on the icy surface from the 410 foot mark to the 195 foot mark and then onto a combination of wet-dry surface. The sun had melted the ice on the guideway surface at the 195 foot mark.

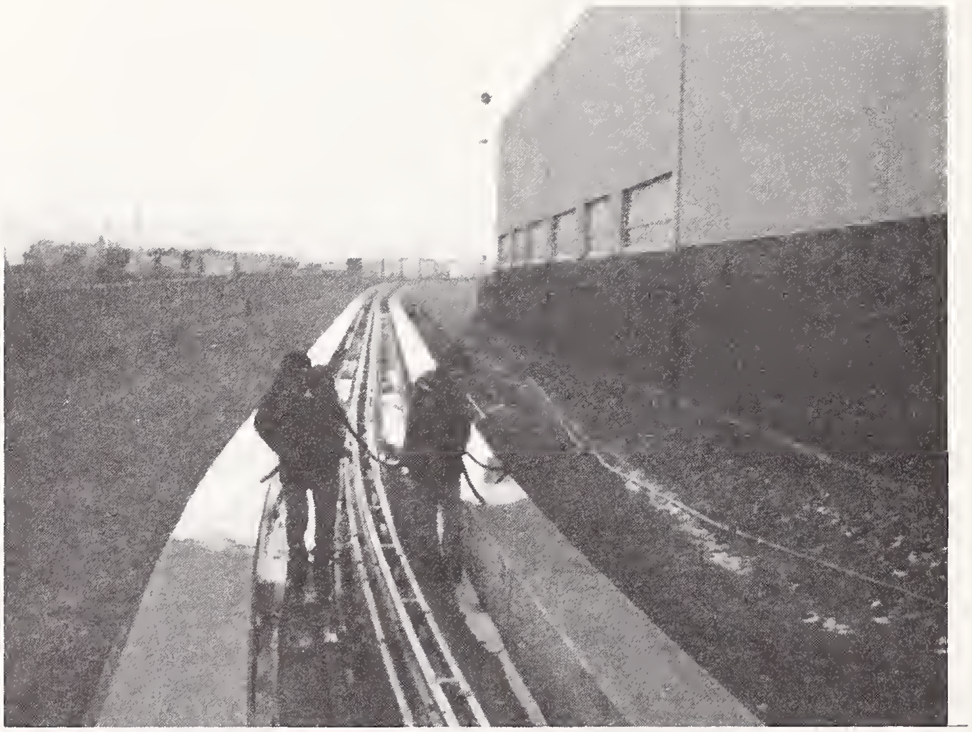


FIGURE 6-24. WATER SPRAYING GUIDEWAY SURFACES

FIGURE 6-25. ICE COVERED GUIDEWAY SURFACES

RUN 3.3 Additional tests were run on the icy guideway surface with the objective of stopping the vehicle with precision under manual controlled braking. The vehicle proceeded from Station 1 at maximum speed of 25 miles per hour and by manual controlled braking, the vehicle was stopped accurately at Station 2. No locking or sliding of the vehicle wheels was observed during the tests.

For Run 3.1, see Figure 6-26 for the recording of the performance of the vehicle rapidly decelerating from 23 to 0 miles per hour in approximately 3.5 seconds. This is equivalent to approximately 0.3 g.

Run 3.2 is shown in Figure 6-27. This is a typical braking characteristic for the ice covered guideway measured in this series of tests. The guideway surface and other conditions of this test allowed an average braking effort of 0.63 g to be supported.

No chart recordings were made for Run 3.3. It was observed that the vehicle could arrive at an accurately controlled stop on an ice covered guideway under manual control.

The following conclusions may be drawn from the longitudinal control and lateral guidance tests performed during the 1978-79 winter.

1. The vehicle could climb a 10% grade under the winter conditions tested, except on a smooth ice surface. Then, the wheels lost adhesion and with the wheels locked by the brakes, the vehicle slid backwards down the grade. It is recommended that a smooth ice surface be prevented or removed from 10% grades.

2. The ride quality, compared with the "reduced comfort boundary" guideline, the most stringent limit in the ISO 2631 specification, met the guideline for the vertical axis at the 16 minute exposure time. For the longitudinal and lateral axes, with a 16 minute exposure time, the vibration levels were better than 8 and 3.5 times

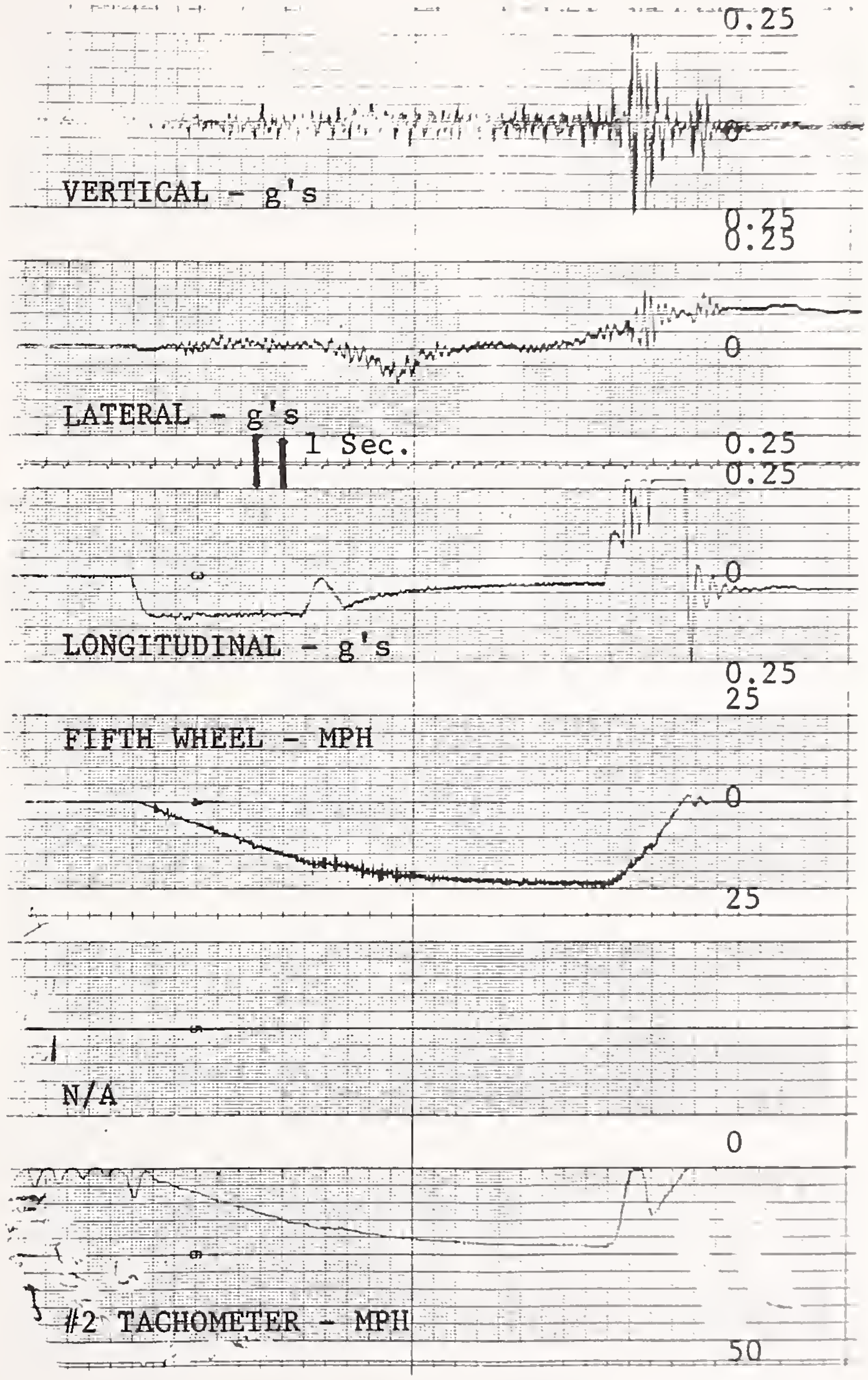


FIGURE 6-26. RAPID DECELERATION ON ICE, TEST 3.0, RUN 3.1

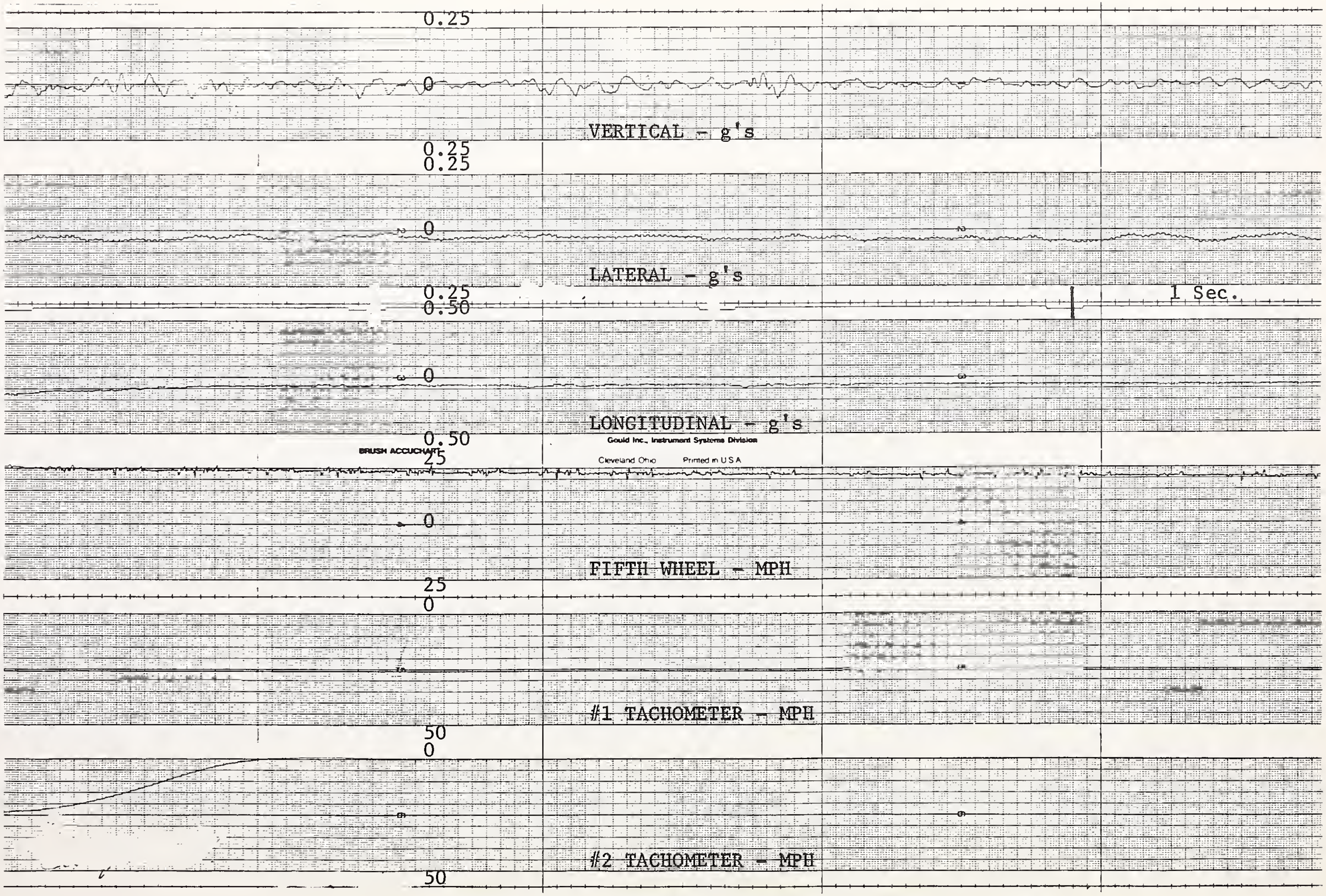


FIGURE 6-27. EMERGENCY STOP ON ICE, TEST 3.0, RUN 3.2

lower than the "reduced comfort boundary", respectively. Appendix C describes how comparison of the system performance with the ISO 2631 specification was made.

These results were for wet track. Tests performed with a dry guideway surface gave similar results.

3. Test runs on the vehicle with wheels locked, when passing from ice covered guideway to a wet guideway surface, showed that greater clearance is required between the power rail structure and bogie mounted equipment. The required changes have been incorporated.

4. The ice covered guideway surface measured during these tests allowed an average braking effort of 0.63g to be supported. This is equivalent to 1.39 miles per hour per second, or approximately 55% of the nominal full scale service braking rate of 2.5 mph/s for the DPM system with normal adhesion levels.

5. Under all test conditions, the lateral guidance system provided safe and accurate guidance control.

7.0 POWER AND SIGNAL SYSTEM TESTING

The WTD power and signal rail configuration is shown in Figure 7-1. Figure 7-2 shows the collectors, attached to the vehicle, which interface with the rails.

An electrical heating system was developed and tested over the two year period covered by the Winter Test Program. Figure 7-3 shows the basic rail heating design used throughout the test period. Two areas of change between 1978-79 testing and 1979-80 testing were the shape of the groove and the selection of the heater wire. For 1979-80 testing, the rail expansion joints (Figure 7-4) and power feed ramps (Figure 7-5) were also heated. Figure 7-6 shows detail at rail ends in the guideway switch area.

The overall objective was to demonstrate the ability of the heating system to control ice and snow build-up on the power and signal rails. This objective includes the aspects of ease of installation, reliability and energy consumption. A secondary objective was to determine which extreme winter conditions require heating and which do not.

These objectives were accomplished in several testing sequences. The first tests were in 1978-79 on the newly installed extension of the Test Track. Following reliability difficulties during these early tests, a "bench" test arrangement was used to continue testing without interfering with other tests being performed on the Test Track. Between the 1978-79 tests and the 1979-80 tests, WTD funded development work in a cold box, the results of which were incorporated in the design tested on the Test Track rail system during 1979-80 testing.

A test was run to determine the ability of the electric heaters to maintain the guideway power and signal rails free of snow with a natural snowfall rate of 0.3 inches per hour and at a density of 0.16 grams per cubic centimeter. Three inches of snow accumulated while testing. The ambient air temperature was +24°F and the wind velocity was 5 to 10 miles per hour. Power level to the heating elements was 5 watts per lineal foot. Under the test conditions,

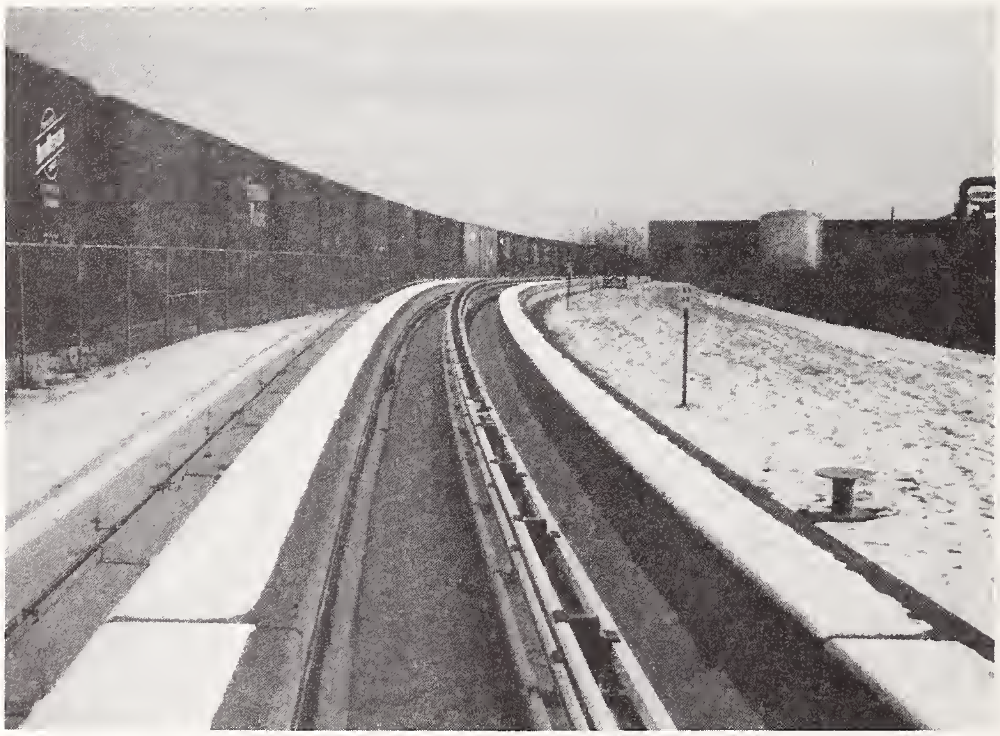


FIGURE 7-1. POWER AND SIGNAL RAIL CONFIGURATION

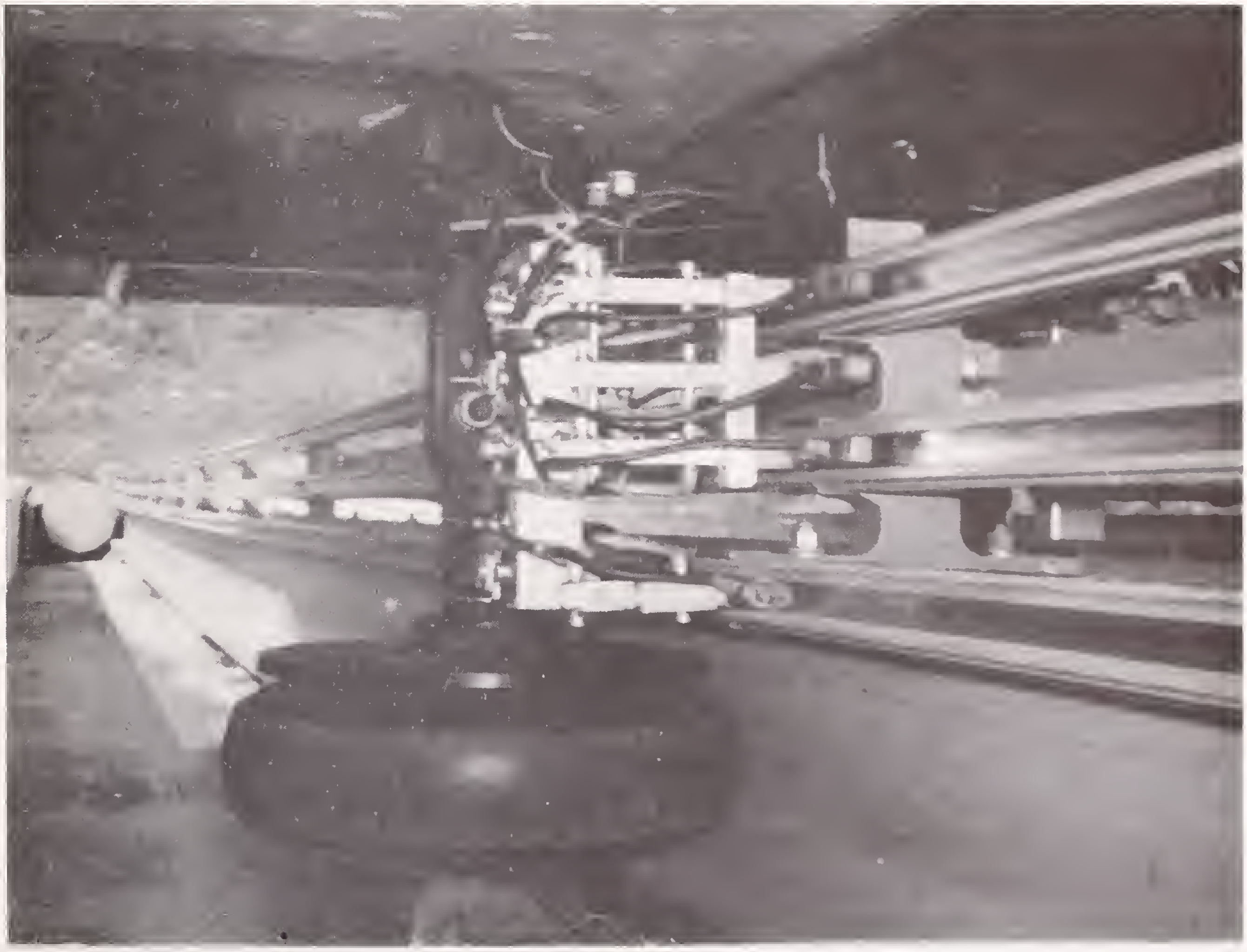


FIGURE 7-2. POWER AND SIGNAL RAIL COLLECTOR

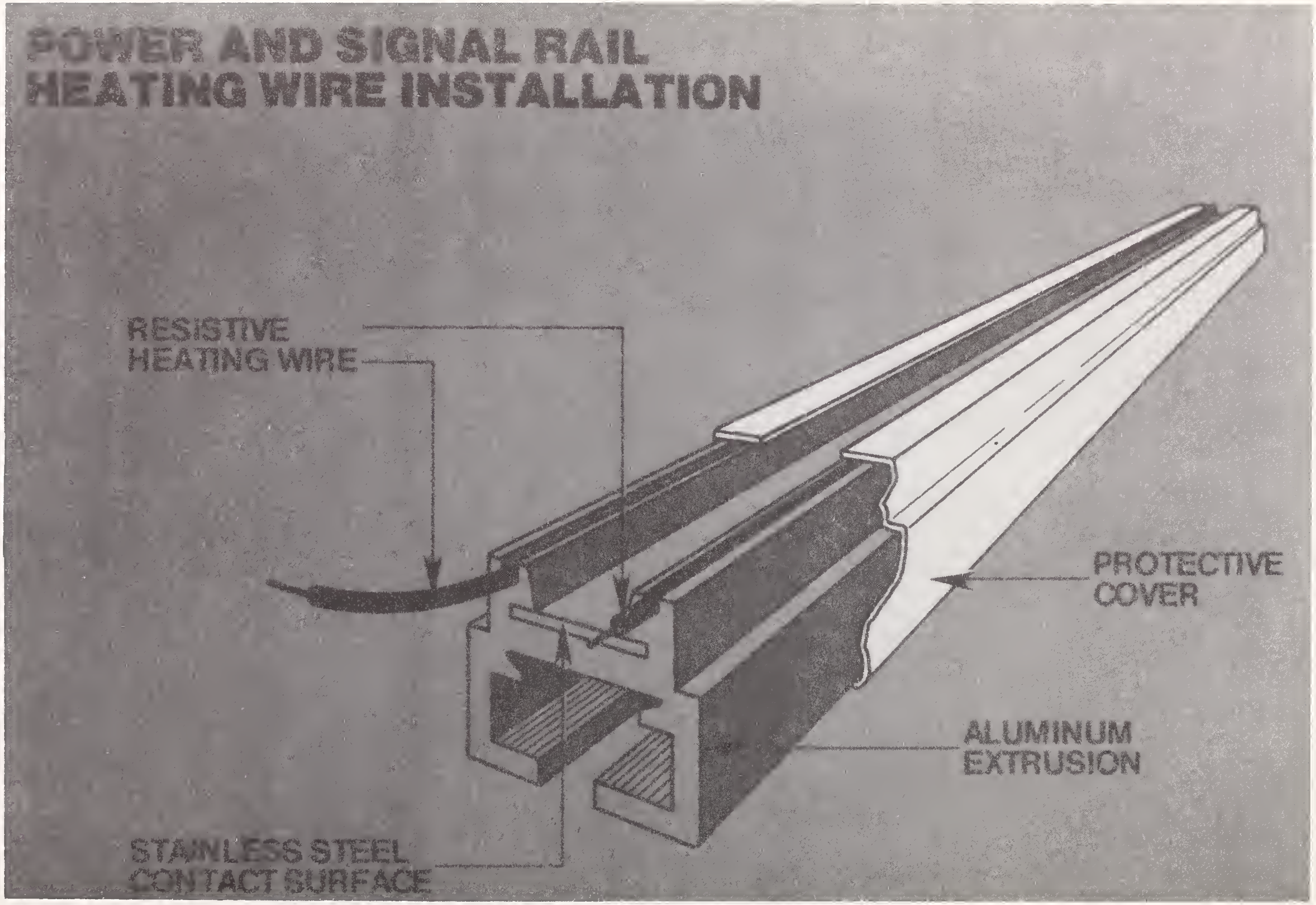


FIGURE 7-3. BASIC RAIL HEATING DESIGN

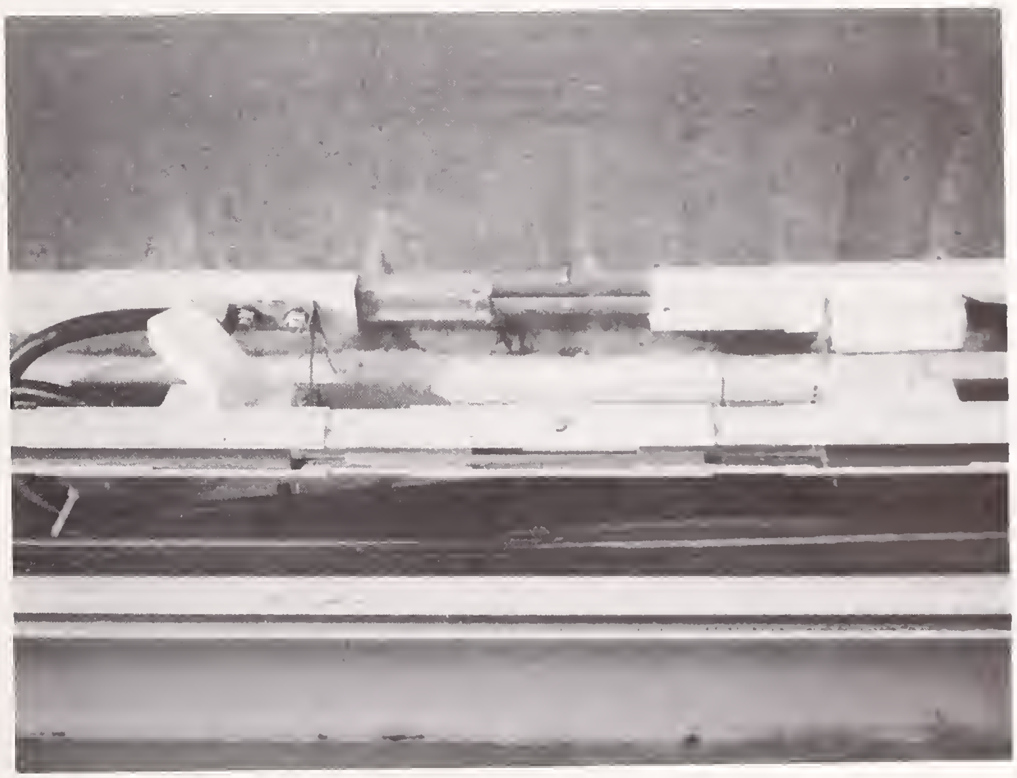


FIGURE 7-4. RAIL EXPANSION JOINTS

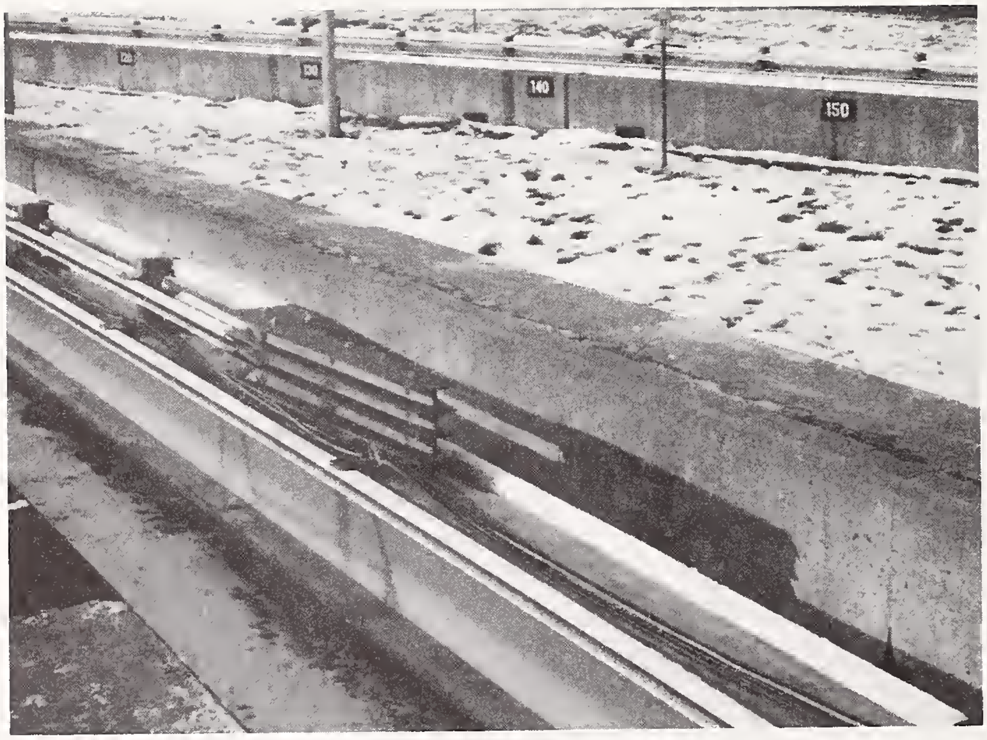


FIGURE 7-5. POWER FEED RAMPS

FIGURE 7-6. RAIL ENDS IN GUIDEWAY SWITCH AREA

the power and signal rails were maintained free of snow with the average temperature of the rails rising to +35°F.

Frequent failures were experienced with early tests of the power and signal rail heating elements. Short circuiting of the wires to the rail structure and broken and burned elements prevented the system from being tested satisfactorily and caused damage to the track circuit components.

Due to these problems, three 30-foot sections of rail were erected alongside the guideway for heater wire testing. The rails were mounted with the wire surface up to accumulate the maximum amount of precipitation. Installation of the heater wire on the rails was identical to that of the Test Track. Thermocouples were placed along the rails at discrete locations to determine the effects of electrical heating. The power supplies to the individual test rail's heating wire was capable of producing 13.4 watts per lineal foot for the No. 1 test rail, 6.7 watts per lineal foot for the No. 2 rail, and 3.4 watts per lineal foot for the No. 3 rail. No voltage was applied directly to the rails.

During a test with ambient air temperature between +16°F and +21°F, a wind velocity of 3 to 7 miles per hour and a man-made snow fall rate of approximately 1 inch per hour and a snow density of 0.40 grams per cubic centimeter, the test rail heating wire was energized. Ice and snow from the previous day's precipitation completely filled the test rail channels as shown on Figure 7-7. Prior to the start of testing, average temperatures of the test rails were +22°F.

After 3 hours, the average temperature had increased to +55°F, +34°F, and +27°F for No. 1, No. 2, and No. 3 test rails, respectively. At this time the power to the heating wires was increased to 16.9, 8.4 and 4.2 watts per lineal foot for rails No. 1, No. 2, and No. 3, respectively. The test rail temperature stabilized at +56°F for the No. 1 test rail, +39°F for the No. 2 test rail, and +29°F for the No. 3 test rail. Figure 7-8 shows that approximately 50% of the snow and ice was melted on the No. 1 test rail and approximately 90% of both the No. 2 and No. 3 test rail surfaces were still

FIGURE 7-7. SNOW-FILLED TEST RAIL CHANNELS

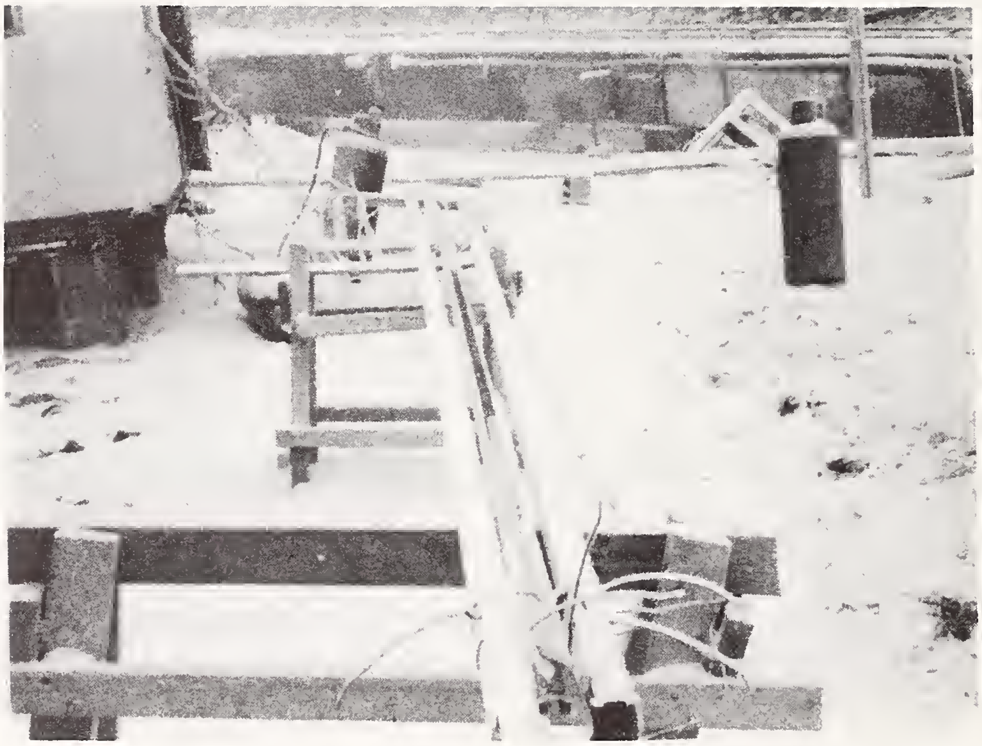


FIGURE 7-8. SNOW MELT CONDITION

covered with ice and snow. There were no problems with the heater wire during the test, which was discontinued after 4-1/2 hours.

With the same installation and power conditions described above, a similar power and signal rail heater wire test was run during slightly warmer weather. All test rail channels had been cleared of ice and snow from the previous day's test and natural snow of 0.04 grams per cubic centimeter was placed on the test rail channels. Weather conditions were: an ambient air temperature of between +20°F and +30°F, a wind velocity of 0 to 5 miles per hour and zero snow fall rate. At the start of the tests the average temperature of the test rails was +18°F and the power supplied to the No. 1, No. 2, and No. 3 rail heating wire was 16.9, 8.4, and 4.2 watts per lineal foot, respectively. Figure 7-9 shows the accumulation in the test rails at the start of testing.

After being energized for 7 hours and 20 minutes, the test rail heating wires were de-energized. The average temperature of the No. 1, No. 2, and No. 3 test rails was increased to +78°F, +60°F, and +52°F respectively. All the snow had been melted in the three test rails as shown in Figure 7-10. No test rail heating wire problems of any type were experienced during the testing.

Initial tests during 1979 in the cold box proved that the new groove shape and wire performed as designed, both at normal power levels and at power levels five times the maximum design level. There was no sign of heater wire popping out of the grooves. Heater wire which was not enclosed in the rails showed a tendency to overheat.

The heater wire installed in the Test Track rails was energized at two power levels. Although natural conditions during the 1979-80 winter were not conducive to ice formation on the rails, tests with the rail heating energized demonstrated melting of snowballs thrown on them within 10 seconds for the rail at 5.5 amps and within 1 minute for the rail at 1.6 amps.

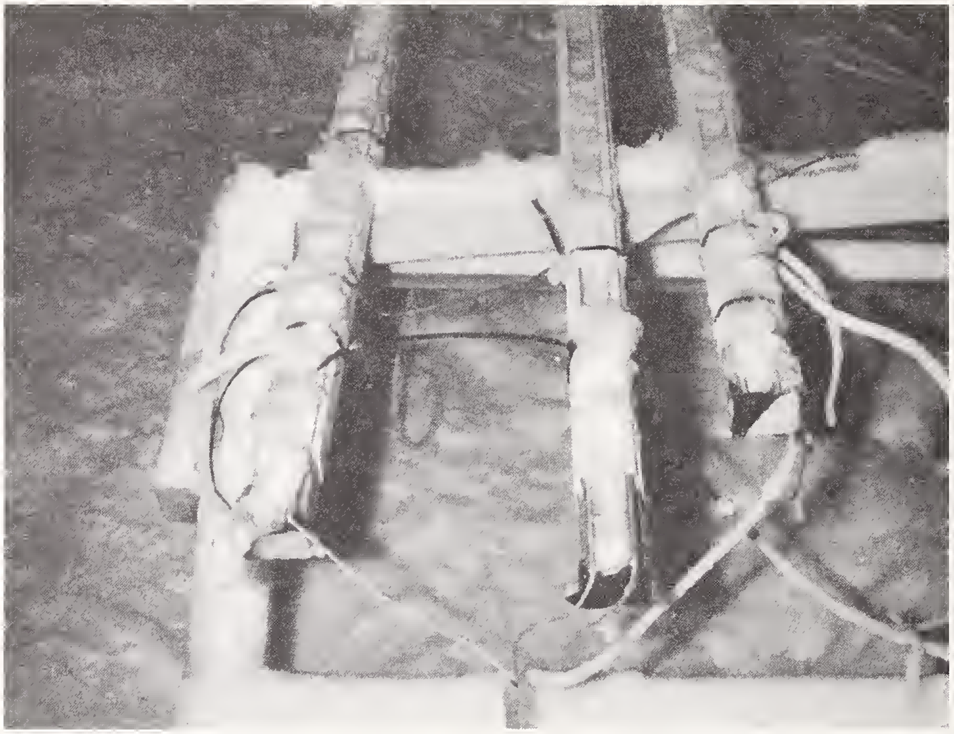


FIGURE 7-9. ACCUMULATION AT START OF TEST

FIGURE 7-10. MELTED SNOW AFTER TEST

During 1978-79 testing, the following problems were identified:

1. Inadequate size grooves in rail
2. Heating wire with poor expansion characteristics
3. Rail joints slipped
4. Inadequate wire installation tool

These areas were redesigned for 1979-80 testing, with the result that most problems were eliminated. The new groove configuration and wire expansion characteristics are suited for use in a winter city DPM environment. The rail joints no longer slip, and expansion gaps and power feed ramps are adequately heated. The wire installation tool has also been significantly improved. However, one area remains to be perfected for ease of maintenance and operational reliability for a large scale DPM application. This one problem is the splicing technique needed to join adjacent heater wire sections securely without exposing heater wire ends to the air. WTD plans life cycle tests on the rail heating system installed at the Test Track to demonstrate the effectiveness of new splicing techniques to improve Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR).

8.0 OTHER SUBSYSTEM TESTING

8.1 STATION DOORS

The door track for guiding the station doors during their operation is an inverted "T" shaped 16-foot long open-channel metal guide. An extension of the door bottom fits into this channel and prevents any door lateral movement. The door track was heated by placing heating elements inside the door track channel. For testing purposes, thermocouples were placed at each end and at the center of the door track to determine the temperatures of the track during heating. None of the working parts of the door are exposed to the weather in the Test Track's "pocket door" configuration.

During winter conditions, snow and ice might accumulate in the door tracks and cause door binding in spite of the semi-sheltered configuration of the station. The objective of the tests was to determine the ability of the station doors to function reliably and smoothly during winter conditions, with and without the use of electrical snow removal systems for the door track.

Tests demonstrating the use of heat to keep the door tracks free of ice and snow were performed during 1978-79 testing.

The station door track heating elements were energized at a level of 8 watts per lineal foot. The weather conditions were an ambient air temperature of $+24^{\circ}$ F, a wind velocity of 5-10 miles per hour, a natural snow fall rate of 3 inches in 10 hours and of a 0.16 grams per cubic centimeter density. The objective of the test was to determine the capability of the heating elements to maintain the door track clear of accumulation.

The door track was maintained free of accumulation. Temperatures of the middle and both ends of the door track were $+38^{\circ}$ F. It was also observed that 1" of concrete on either side of the door track was free of accumulation. Figure 8-1 shows the condition of the door track at the completion of testing.

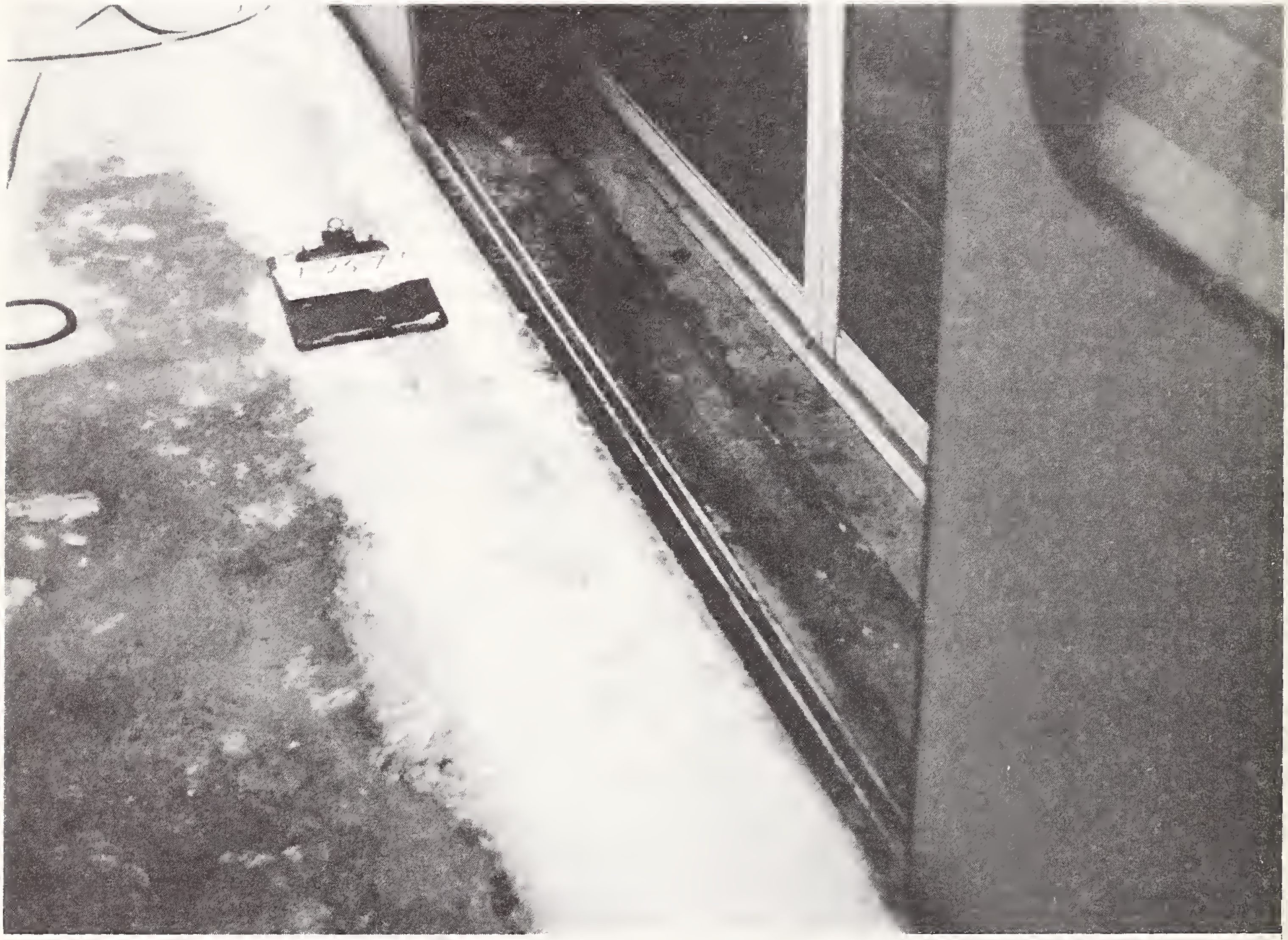


FIGURE 8-1 STATION DOOR TRACK HEATING

Weather conditions for the test were an ambient air temperature between $+1^{\circ}$ F and $+4.5^{\circ}$ F, a wind velocity of 1 to 3.5 miles per hour and zero precipitation.

At the test start, the door track temperature was $+20^{\circ}$ F. The door tracks were frozen solid. After 75 minutes, melting began and after 2 1/4 hours melting had occurred along the whole length of the track. The test was terminated after 4 1/2 hours when most of the ice had melted. At that time the door track was drained and the doors operated normally.

During the 1979-80 winter testing program, no heat was applied to the door tracks. The doors were cycled automatically once each minute during automatic operation of the People Mover System. The only problem which occurred during the entire winter was a frozen airline on the safety edge. This was a result of the airline losing ductility at sub-freezing temperatures. This malfunction does not interfere with door operation, but only with edge-triggered recycle.

The standard WTD station door is applicable to cold city DPM situations. If the door mechanism is protected from the environment, as is recommended for any DPM application, no heating is required. If the door track is completely exposed to heavy snow and ice accumulation, the WTD heating level of 8 watts per lineal foot allows satisfactory operation.

8.2 VEHICLE STORAGE AREA

After the end of 1978-79 testing, it was hypothesized that storing the vehicles on an unprotected siding overnight or between daytime runs might cause vehicle freeze-up in severe weather conditions.

A parking area was designated on the Test Track spur. Four chromolox radiant heaters, rated at 0.8 Kw each were installed in the parking area as shown in Figure 8-2. The heaters were controlled by a thermostat located in direct line of sight of the heaters, Figure 8-3. As a back-up, an additional

FIGURE 8-2. VEHICLE STORAGE AREA RADIANT HEATERS

FIGURE 8-3. RADIANT HEATER THERMOSTATS

thermostat sensor was preset to shut off the heaters at 125° F in case of malfunction.

To use the vehicle storage area, the vehicle is parked with its axles over the heaters.

The objective of this test was to determine whether radiant heaters in the parking area reduce the possibility of brake shoe/drum freeze-up overnight in cold weather. This test was done in conjunction with the cold car startup tests described in Section 6.2. The first criterion for use of the vehicle storage area heaters was observation of vehicle freeze-up during one or more Cold Car Startup attempts.

Freeze-up of the vehicle brake shoes/drums was not observed during the 1979-80 winter. Although the winter was mild, one cold car startup was performed after a 57 hour cold soak from 0° F to +18° F without any evidence of freeze-up.

A calibration of the radiant heaters was performed to demonstrate operability of the heaters in this application. Thermocouples were located at the thermostats and at key positions on and around the vehicle. Measurements were taken before energizing the heaters and every five minutes afterwards, for a total of 85 minutes.

The thermostats controlling the heaters proved to read the same temperatures as the thermocouples, requiring no calibration. The maximum temperature of 62° F was reached after 70 minutes. The lowest thermocouple reading at that time was 38° F, which was considered to be warm enough to prevent all areas of the undercar from freezing.

During winter testing 1979-80 it was determined that vehicle storage area heaters are not needed at temperatures down to 0° F. Although there is no evidence to support the need for parking area heaters, the WTD radiant heater system has been demonstrated to keep the undercar at temperatures above freezing. A test using dry ice packed around the brake area is recommended for complete confidence that heaters are not needed in sub-zero temperatures.

9.0 SYSTEM LEVEL TESTS

For the purposes of this document, system level tests are defined as those tests which utilize the maximum number of subsystems at one time. These tests fall into two areas, manual operation of the vehicle and fully automatic operation.

Manual operation of the WTD People Movers at the Test Track requires that all wayside equipment be operational in the manual mode. This includes route selection through the switch, train detection and power distribution. Also for manual operation, all vehicle equipment must be operational with the exception of the on-board ATO package.

Automatic operation requires that all wayside and vehicle equipment must be functioning properly. The automatic modes selectable from the central control console are described in Section 2.1.5.

During 1978-79 testing, manual operation was used almost exclusively, due to the heavy emphasis on subsystem testing and to low reliability of portions of the vehicle and wayside automatic equipment, which was all prototype equipment.

During the summer of 1979, extensive updating of both wayside and vehicle equipment was conducted, resulting in a system which closely simulates functional operating systems marketed to WTD People Mover customers.

The test objective was to demonstrate reliability of this type system in adverse winter conditions. To this end, automatic operational procedures were established. These included various automatic schedules representing peak and non-peak passenger demands in a typical DPM and accelerated cycling of guideway switch and station doors.

During the period of February 4, 1980 through March 27, 1980, 30 different periods were selected for performing automatic operation tests. Time periods from 2-1/2 hours to 14-1/2 hours were scheduled for a total operating time of

184-3/4 hours. The vehicles, either the Engineering Test Car or (in three periods), a customer vehicle, traveled a total of 904.4 miles on 7001 trips. A trip was considered travel from one end of the selected route to the other.

During this same period of time the guideway switch was cycled 2,744 times, and the station doors were cycled 7,155 times.

Prior to the beginning of each testing period, the existing weather conditions or the forecasted conditions were considered with the desire to select that schedule which would reflect various conditions to which a typical DPM system would be subjected.

Appendix E contains the various schedules which were available to the Test Engineer.

Operating personnel were required to maintain the assigned schedule as closely as possible, recording all downtime events or failures and taking corrective action to return the system back to the schedule.

Measured System Availability was 87.7% with Schedule Adherence of 83.9%, both figures quite good for a test car and test system, which are constantly used to test and debug new designs.

For each downtime event, an incident report (Figure 9-1), was prepared.

Although the winter of 1979-80 was not as severe as was expected, either in cold extremes or snowfalls, sufficient automatic operational data was gathered. In those cases where a glaze of ice was allowed to form on running surfaces within acceleration or deceleration zones, there were chances of slip/spin occurring. Reduction of acceleration/deceleration rates in cases where slip/spin is expected minimizes the probability of slipping.

Report Number_______

TEST TRACK INCIDENT REPORT

PROJECT____________________

DATE__________ CAR NUMBER______________TEMPERATURE OUTSIDE_________

TIME__________ MILEAGE__________________TEMP. INSIDE VEHICLE_______

TRIP__________ ELAPSED TIME____________TEMP. INSIDE STATION_______

DEPTH OF SNOW ON TRACK___________(inches)

TRAFFIC DIRECTION - East ____ West____ LOCATION___________________

OPERATING MODE-NORMAL 1____,SPECIAL 1____,NORMAL 2____

SPECIAL 2_____, MANUAL______.

VEHICLE -ATO___,PROPULSION___,POWER COLLECTION___,BATTERY___,

DOORS___,OVERTRAVEL___, OVERSHOOT___, OTHER(specify)__

WAYSIDE - ATO(LOOP)____,ATO(SHUTTLE)____,POWER COLLECTION____,

SWITCH___, RAIL HEATING_____, OTHER(specify)_________

SYMPTOM -

CORRECTIVE ACTION -

WAS THIS FAILURE DUE TO A RECENT MODIFICATION ?__________________

WHAT MODIFICATION ?____

DOWN TIME - ________

FAILURE DATA TAG NO._______ FAILURE DATA REPORT NO.____________

OPERATOR

FIGURE 9-1. TEST TRACK INCIDENT REPORT

Of the incidents reported during this period, only seven were winter related. Six incidents were caused by the motor overload breaker tripping due to wheel spin during acceleration and one incident was caused by a broken piece on a non-energized heater wire producing a false occupancy.

In conclusion, the results of the automatic operation demonstrate that the WTD People Mover System operated reliably in the winter environment encountered during the 1979-80 winter test period.

10.0 TEST PROGRAM FINDINGS AND CONCLUSIONS

Accumulated snow, regardless of density or depth, can be removed successfully by using the WTD bogie mounted plowing system.

Although the horizontal rotating brush system equipped with the plow/shroud attachment was capable of removing accumulated snow, there were major draw - backs. These were 1) the brushes produced a fine snow which could be deposited on the power/signal rails, 2) snow accumulations occurred on the underside of the vehicle, and 3) wet snow build-up on the attachment reduced its effectiveness.

Electrical heating of guideway running surfaces is a viable method of maintaining cleared tractive and braking areas. However, it is more efficient to remove accumulations of snow by plowing, rather than by expending electrical heating energy. If ice is allowed to build up in acceleration or braking areas, then the WTD electrical heating system removes this ice effectively.

The guideway switch performed exceptionally well during the winter testing season with the only exception being the time a 7-1/2 inch man-made snow fall was allowed to accumulate while the switch was inactive.

The newly designed door tracks provided a guide system which overcame previous design problems with ice accumulations. Door track heating was not required during the 1979-80 season although tests were conducted to test the feasibility of this method of dealing with ice.

Window deicers were effective in removing ice accumulations on windows.

The effect of brake heaters was not determined as no condition occurred which necessitated their use.

Air dryers were not sufficiently tested during the 1979-80 testing season to determine if air line freeze-up was still a problem area.

No safety problems were encountered with longitudinal control or lateral guidance during the winter season regardless of the winter conditions.

The power and signaling system operates properly under snow accumulations. However, heating is required to remove or prevent ice build-up. The tests on rail heating during 1979-80 were not conclusive, as the weather conditions that existed did not allow thorough testing under severe ice extremes.

The WTD standard station doors performed throughout the winter season without interruption.

As with a few of the other items tested, weather conditions were not severe enough to generate problems with frozen brakes. Therefore, sufficient test data is not available for the vehicle storage area.

11.0 RECOMMENDATIONS

The Westinghouse DPM system, as presently configured, is a viable system for those cities subjected to winter environmental conditions. Depending on the operational philosophies selected by DPM cities, various combinations of options would be recommended.

For worst case conditions, Westinghouse recommends: plows on head-end vehicle, window deicers if outside visibility is desired, power and signal rail heating when required and controlled guideway heating in accelerating and braking areas and selected grades. The operational philosophy behind this hardware selection is based on mechanical removal of snow from the running surface, thereby preventing the formation of compacted snow or secondary ice. Window deicers would be needed if vehicles are stored off line and moved on-line manually. Selected guideway heating would be recommended for climates where primary ice is common, but is available if a customer wants it or can be added later if a customer desires. Power/signal rail heating is recommended, but it would be used only briefly to melt ice from the rails. Snow would not be allowed to build up on the rails. If it did, a trip under manual control in the vehicle would remove it.

APPENDIX A
PHOTOGRAPHIC AND VIDEO DOCUMENTATION

APPENDIX A

The following is a tabulation of the various operations included on each of the video tapes made during the Winter Test Program.

The operations are listed in the order in which they appear in each respective video tape referenced.

DT-001

- Cold car start-up
- Operation of switch
- Plowing from spur to main line
- Track after plowing
- Snow at high-speed gap area
- Brushing - eastbound
- Plowing - westbound
- Brushing - eastbound
- Plowing and brushing action on extension
- Brushing at eastern end of track
- Roadway heating

DT-002

- Plowing of 16" accumulation
- Plowing from spur to Station 3
- Brushing-shroud vs no shroud
- Automatic plowing uphill
- Automatic high speed plowing and brushing
- Automatic plowing through switch
- Plowing and brushing of compacted snow
- Automatic plowing uphill
- Views of snow build-up under vehicle due to lack of shroud
- Plowing of 13" of piled up snow
- Cold car start-up
- Cold soak (ice cube test)
- Switch operation - light snow

Switch operation - heavy snow

Rail heating

Rail heating wire repair

Automatic operation on ice at different velocities

DT-003

Automatic operation with high-speed plowing from Station 1 after cold car start-up

Slip-spin conditions

Cold car start-up

Brushing operation

Automatic operation with plows

Sliding test

APPENDIX B

STANDARD CAR

APPENDIX B

WESTINGHOUSE STANDARD VEHICLE

WEIGHTS

Empty Car	30,000 lbs. (13500 kg)
Passenger Load	17,510 lbs. (7879.5 kg) (103 people @ 170 lbs. (76.5 kg))

DIMENSIONS

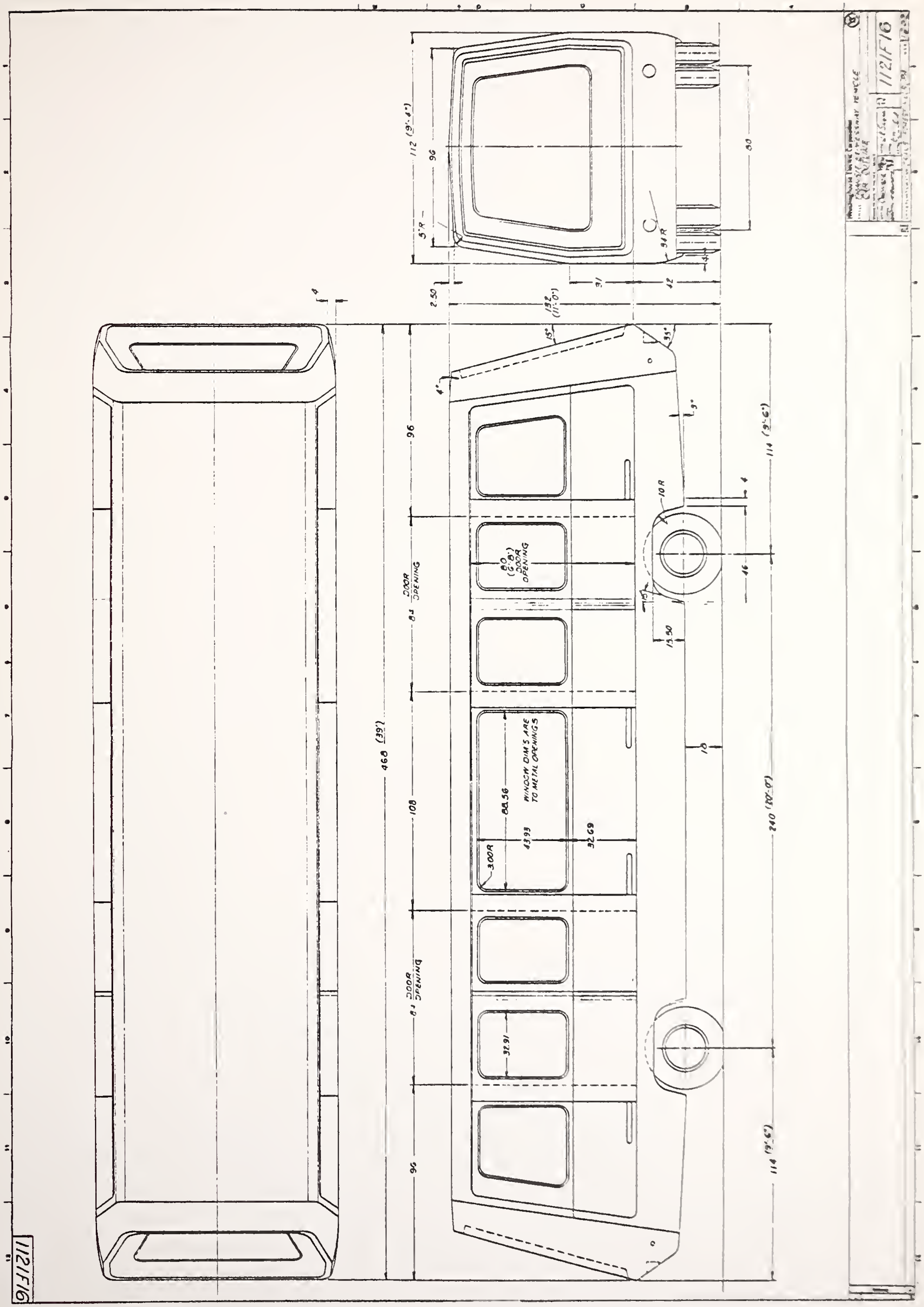
Height	11'1" (3.38 m)
Interior Height at low point	6'8" (2.03 m)
Interior Height at high point	7'2" (2.18 m)
Width	9'4" (2.84 m)
Width (interior)	7'9" (2.36 m)
Length	36'4" (11.07 m)
Length (usable interior)	32'2" (9.8 m)
Length of 2 cars	73'4" (22.35 m) (for minimum 150 ft. (45.72 m) radius curve operation)
	73'8" (22.45 m) (for minimum 75 ft. (22.86 m) radius curve operation)
Usable interior per car	249 sq. ft. (22.41 sq. m)

SEATING

Optional (arrangement optional)	0-34

WESTINGHOUSE ELECTRIC CORPORATION
Transportation Division
2001 Lebanon Road
West Mifflin, Pennsylvania 15122

May 1980 APH


1121F16
DOOR OPENING
80 (6'-8") DOOR OPENING
WINDOW DIM'S ARE TO METAL OPENINGS
468 (39')
240 (20'-0")
114 (9'-6")
112 (9'-4")
132 (11'-0")

APPENDIX C

ACCELERATION MEASUREMENT

ACCELERATION MEASUREMENT

In order to make a ready comparison with the limits defined in the International Organization for Standardization Specification ISO 2631-1977, weighting filters were used to process the outputs of the three accelerometers used for measurement on the vertical, lateral and longitudinal axes of the vehicle. A schematic diagram of these filters is shown in Figure 1.

This allows an RMS value of the vibration, measured for all frequencies in the 1-80 Hz range over the duration of the test run to be compared to the ISO specification permissible values in the 4 to 8 Hz band for the vertical axis and the 1 to 2 Hz band for the lateral and longitudinal axes.

This technique is suggested in Sections 3.5 and 4.2 of the ISO specification.

Single pole low-pass filters were designed to give a best fit to the high frequency roll-off for the a_z and a_x, a_y characteristics shown in the specification.

This simplified approach did not allow the weighting network accuracies required by Section 4.2, Note 2 to be met.

The filter schematic diagrams are shown in Figure 1 and the filter characteristics compared with the ISO 2631 requirements are shown in Figure 2.

For the longitudinal and lateral axes the filter characteristics were in error by -2.5 dB at the 2 Hz corner frequency and +1.7 dB at 31.5 Hz.

For the vertical axis the filter was in error by -2.1 dB at the 8 Hz corner frequency and +2.1 dB at 31.5 Hz. Also, it should be recognized that no attempt was made to match the low frequency roll-off for the vertical axis characteristic.

For the frequency ranges described above, Section 4.2 requires that the network accuracy be within ± 1 dB and for all other frequencies within the range 1 - 80 Hz, the accuracy should be ± 2 dB.

The majority of the approximations made by using weighting filters result in a conservative assessment of the effects of the vibration, however the corner frequency errors of up to -1.5 dB beyond the ISO specification ± 1 dB tolerancy range are in a direction to yield permissible vibration levels up to 19% higher than with filter disigns which would meet the ISO tolerance specification. No account of this error was taken when quoting vibration performance against the ISO specification.

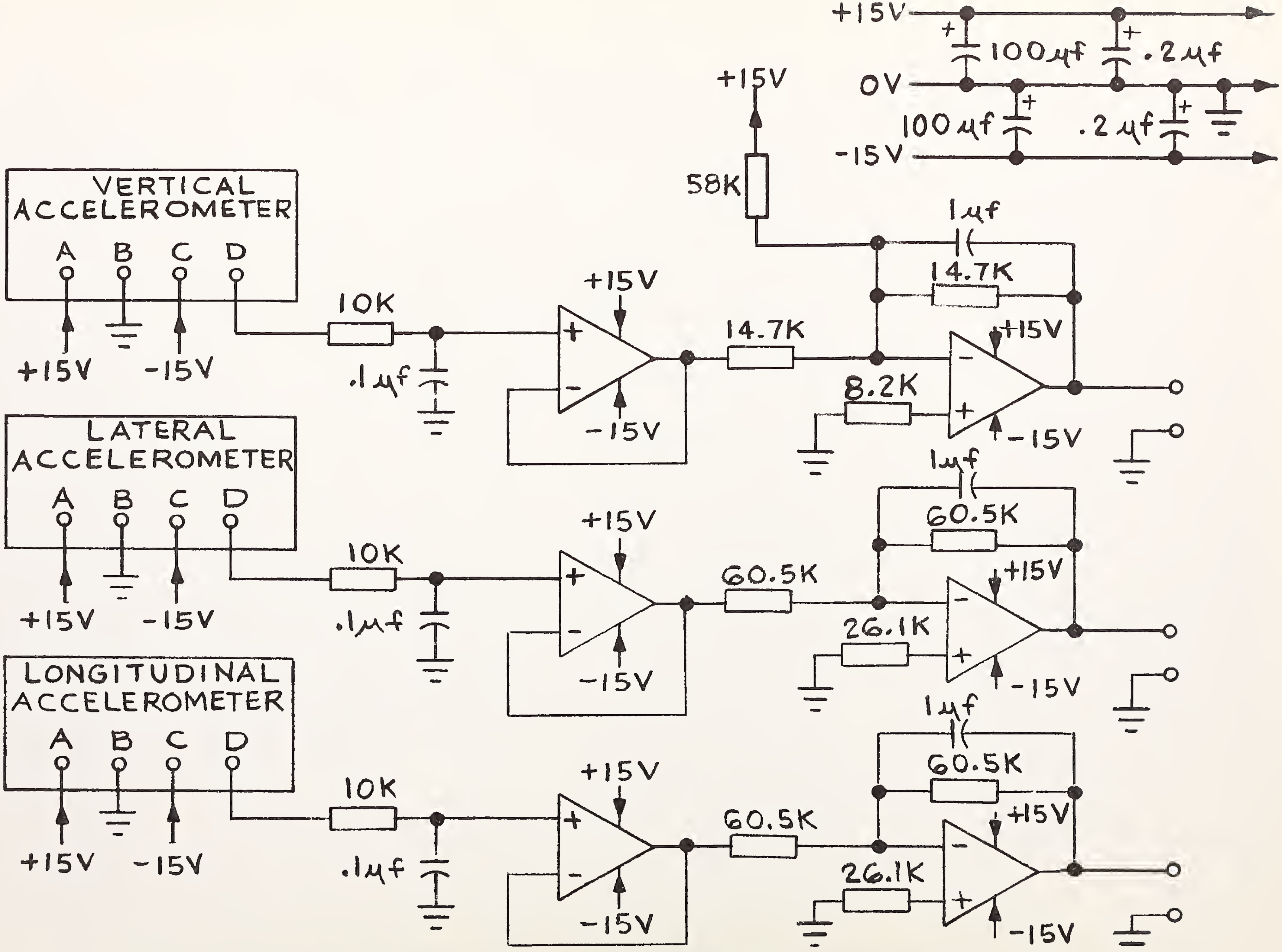


FIGURE 1.) SCHEMATIC DIAGRAM OF FILTER AND FOR ACCELEROMETERS

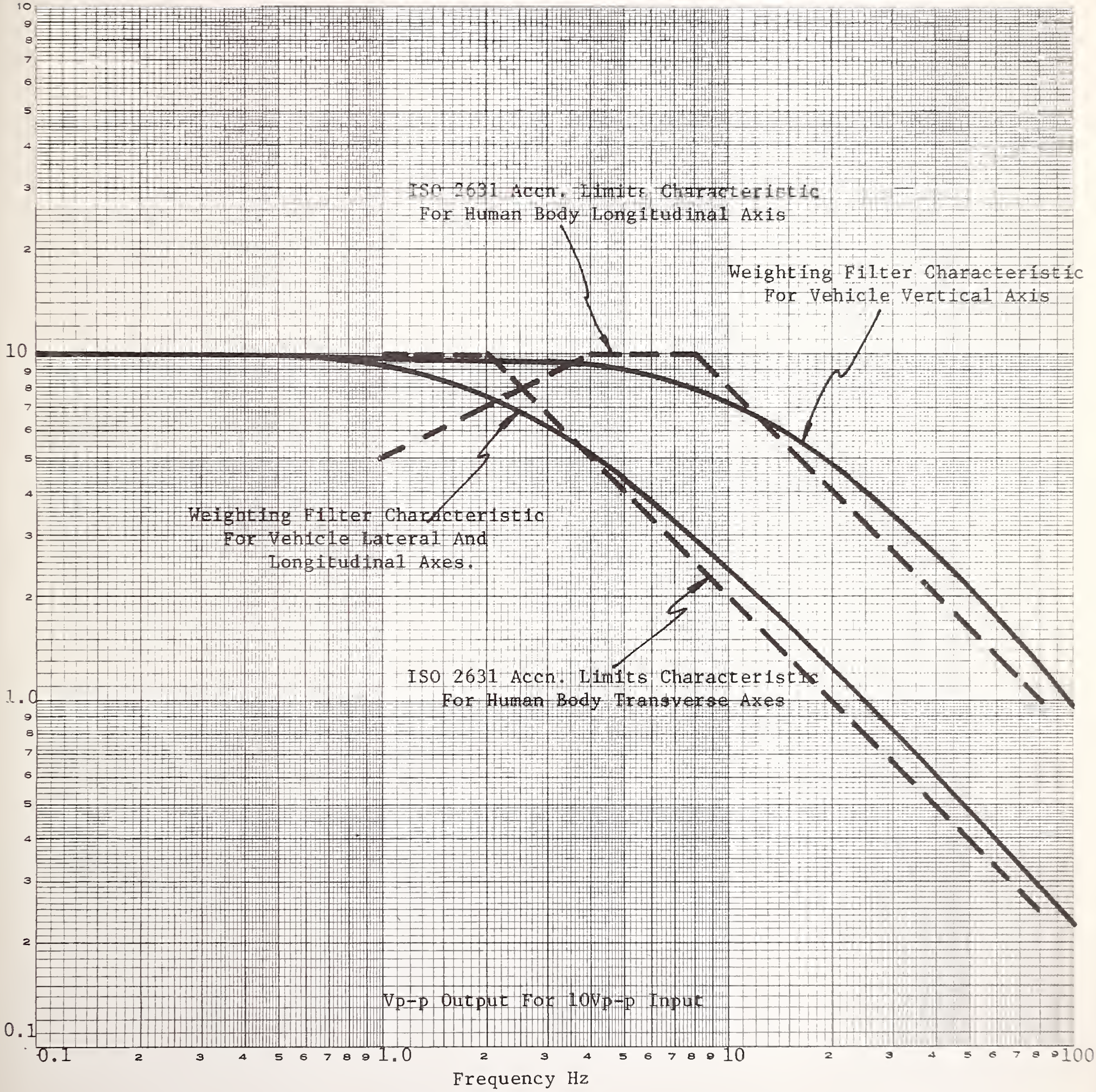


FIGURE 2. ACCELEROMETER WEIGHTING FILTER CHARACTERISTICS

APPENDIX D

OPERATING SCHEDULES

WORKS T
WESTINGHOUSE FORM 8295 E

AUTOMATIC OPERATION SCHEDULE A

BEGINNING TIME ______

ENDING TIME ______

MODE	TIME PERIOD (MIN)	CYCLE TIMER (MIN)	PROJECTED TRIPS	ACTUAL TRIPS
NORMAL 1	90	2	90	
NORMAL 1	150	5	60	
SPECIAL 2	150	10	30	
SPECIAL 2	90	3	60	

NUMBER OF DOWNTIME EVENTS = ______

TOTAL DOWNTIME = ______

SYSTEM SCHEDULED OPERATING HOURS = 8.0 ①

SYSTEM OPERATING HOURS = ______ ②

SYSTEM AVAILABILITY = $\frac{②}{①}$ = ______

NUMBER OF SCHEDULED TRIPS (N_s) = 240 ③

NUMBER OF SUCCESSFUL TRIPS (N_a) = ______ ④

SCHEDULED ADHERENCE = $\frac{④}{③}$ = ______

DATE ______

FORM DATE 12/19/79

WORK EET
WESTI USE FORM 8295 E

AUTOMATIC OPERATION SCHEDULE B

BEGINNING TIME ________

ENDING TIME ________

MODE	TIME PERIOD (MIN)	CYCLE TIMER (MIN)	PROJECTED TRIPS	ACTUAL TRIPS										
NORMAL 1	360	30	24											
NORMAL 1	60	10	12											
NORMAL 1	60	2	60											

NUMBER OF DOWNTIME EVENTS = ________

TOTAL DOWNTIME = ________

SYSTEM SCHEDULED OPERATING HOURS = 8.0 (1)

SYSTEM OPERATING HOURS = ________ (2)

SYSTEM AVAILIBILITY $= \frac{(2)}{(1)}$ = ________

NUMBER OF SCHEDULED TRIPS (N_s) = 96 (3)

NUMBER OF SUCCESSFUL TRIPS (N_a) = ________ (4)

SCHEDULED ADHERENCE $= \frac{(4)}{(3)}$ = ________

DATE ________

FORM DATE 12/19/79

WORK EET
WESTI ISE FORM 8295 E

AUTOMATIC OPERATION SCHEDULE C

BEGINNING TIME ______
ENDING TIME ______

MODE	TIME PERIOD (MIN)	CYCLE TIMER (MIN)	PROJECTED TRIPS	ACTUAL TRIPS
SPECIAL 2	360	30		24
SPECIAL 2	120	15		16

NUMBER OF DOWNTIME EVENTS = ______
TOTAL DOWNTIME = ______

SYSTEM SCHEDULED OPERATING HOURS = 8.0 ①
SYSTEM OPERATING HOURS = ______ ②
SYSTEM AVAILIBILITY = $\frac{②}{①}$ = ______

NUMBER OF SCHEDULED TRIPS (N_s) = 40 ③
NUMBER OF SUCCESSFUL TRIPS (N_a) = ______ ④
SCHEDULED ADHERENCE = $\frac{④}{③}$ = ______

DATE ______

FORM DATE 12/19/79

WORK ET
WESTING SE FORM 8295 E

AUTOMATIC OPERATION SCHEDULE D

BEGINNING TIME ______
ENDING TIME ______

MODE	TIME PERIOD (MIN)	CYCLE TIMER (MIN)	PROJECTED TRIPS	ACTUAL TRIPS										
NORMAL 1	60	3	40											
SPECIAL 2	120	5	48											
NORMAL 2	120	10	24											
SPECIAL 2	120	5	48											
NORMAL 1	60	3	40											

NUMBER OF DOWNTIME EVENTS = ______
TOTAL DOWNTIME = ______

SYSTEM SCHEDULED OPERATING HOURS = 8.0 ①
SYSTEM OPERATING HOURS = ______ ②
SYSTEM AVAILIBILITY = $\frac{②}{①}$ = ______

NUMBER OF SCHEDULED TRIPS (N_s) = 200 ③
NUMBER OF SUCCESSFUL TRIPS (N_a) = ______ ④
SCHEDULED ADHERENCE = $\frac{④}{③}$ = ______

DATE ______

FORM DATE 12/19/79

WORK ET
WESTIN JE FORM 6295 E

AUTOMATIC OPERATION SCHEDULE E

BEGINNING TIME ______
ENDING TIME ______

MODE	TIME PERIOD (MIN)	CYCLE TIMER (MIN)	PROJECTED TRIPS	ACTUAL TRIPS										
NORMAL 1	480	2	480											

NUMBER OF DOWNTIME EVENTS = ______
TOTAL DOWNTIME = ______

SYSTEM SCHEDULED OPERATING HOURS = 8.0 ①
SYSTEM OPERATING HOURS = ______ ②
SYSTEM AVAILIBILITY = $\frac{②}{①}$ = ______

NUMBER OF SCHEDULED TRIPS (N_s) = 480 ③
NUMBER OF SUCCESSFUL TRIPS (N_a) = ______ ④
SCHEDULED ADHERENCE = $\frac{④}{③}$ = ______

DATE ______

FORM DATE 12/19/79

WORK ΣET
WESTI ,SE FORM 8295 E

AUTOMATIC OPERATION SCHEDULE F

BEGINNING TIME ________
ENDING TIME ________

MODE	TIME PERIOD (MIN)	CYCLE TIMER (MIN)	PROJECTED TRIPS	ACTUAL TRIPS										
NORMAL 2	480	6	160											

NUMBER OF DOWNTIME EVENTS = ____
TOTAL DOWNTIME = ____

SYSTEM SCHEDULED OPERATING HOURS = 8.0 (1)
SYSTEM OPERATING HOURS = ____ (2)
SYSTEM AVAILIBILITY = $\frac{(2)}{(1)}$ = ____

NUMBER OF SCHEDULED TRIPS (N_s) = 160 (3)
NUMBER OF SUCCESSFUL TRIPS (N_a) = ____ (4)
SCHEDULED ADHERENCE = $\frac{(4)}{(3)}$ = ____

DATE ________

FORM DATE 12/19/79

WORK EET
WESTI JSE FORM 8295 E

AUTOMATIC OPERATION SCHEDULE G

BEGINNING TIME ______

ENDING TIME ______

MODE	TIME PERIOD (MIN)	CYCLE TIMER (MIN)	PROJECTED TRIPS	ACTUAL TRIPS										
SPECIAL 2	480	3	320											

NUMBER OF DOWNTIME EVENTS = ______

TOTAL DOWNTIME = ______

SYSTEM SCHEDULED OPERATING HOURS = 8.0 ①

SYSTEM OPERATING HOURS = ______ ②

SYSTEM AVAILIBILITY $= \frac{②}{①}$ = ______

NUMBER OF SCHEDULED TRIPS (N_s) = 320 ③

NUMBER OF SUCCESSFUL TRIPS (N_a) = ______ ④

SCHEDULED ADHERENCE $= \frac{④}{③}$ = ______

DATE ______

FORM DATE 12/19/79

APPENDIX E

REPORT OF NEW TECHNOLOGY

There were no patentable inventions or discoveries resulting from this work. The contractor did, however, fabricate snow removal equipment such as plows, brushes, and scrapers and develop winterization techniques and operating strategies which will benefit the automated transit industry in the future when severe winter climate deployments are considered. Effective winterization procedures and techniques will help provide reliable winter performance characteristics of AGT systems at reduced operating costs.

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