TIRE TRACTION TESTING OF HIGHWAY, SNOW & STUDDED TIRES ON WET & DRY PAVEMENT SURFACES

RESEARCH PROJECT

HR 475

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RESEARCH AND SPECIAL ASSIGNMENTS
PLANNING, RESEARCH AND STATE AID
DEPARTMENT OF HIGHWAYS

PREPARED FOR
WASHINGTON STATE HIGHWAY COMMISSION
IN COOPERATION WITH
WASHINGTON STATE PATROL

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Highways or the Washington State Patrol. This report does not constitute a standard specification or regulation.

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ABSTRACT

This study was conducted to collect data on the operational characteristics of highway, snow and studded snow tires and other winter traction aids. The objective of the study was to perform various vehicle maneuvers to evaluate the tire characteristics on wet and dry pavement surfaces. Tests took place on the Washington State Patrol Driver Training Course at Sanderson Field, located west of Shelton, Washington. The testing was done with the cooperation of the Washington State Patrol who furnished personnel and equipment to assist in this research effort.

The test maneuvers evaluated during the study are as follows:

Test No. 1 - MANEUVERING (Serpentine Course)

Test No. 2 - HAIRPIN CURVE

Test No. 3 - HIGH SPEED LANE CHANGE

Test No. 4 - LOCKED-WHEEL STOP

In addition to the three tire types described above, other new traction type products and tires were evaluated. These consisted of studded snow tires with "Norfin" studs, and Garnet impregnated snow tires. Studded tires on all four wheels were also evaluated, at the request of the Washington State Patrol. This combination is used by Troopers assigned to mountain highway passes and areas where there is a large buildup of snow and ice during the winter.

This report consists of two areas of evaluation. One involves tire combinations (front and rear) and the other is the evaluation of individual tire types. In addition to these two areas, a separate section

is devoted to the tire and vehicle maneuvering characteristics of Washington State Patrol's vehicle when compared with a Department of Highways' Motor Pool vehicle. Included also is the test vehicles' description.

INTRODUCTION

A number of research studies have been conducted in the United States and Canada which have established the fact that studded tires perform better than snow and highway tires on hard packed snow and ice under certain temperatures and surface conditions. These studies were primarily concerned with stopping distances and to a lesser degree vehicle maneuverability. These studies also showed that studded tires were less effective in loose snow and on bare pavements, a condition which exists in many locations during a large part of the winter months. As a result of these studies, the Department of Highways became interested in the comparative effectiveness of various tire types on vehicles performing maneuvering tasks on wet and dry pavement surfaces. After a review of available reports, it was determined that no such tests had been carried out. Therefore, a series of tests were conducted to assist in the evaluation of winter driving aids.

The test location selected was the Washington State Patrol Driver Training Course at Sanderson Field in Shelton, Washington. An in-service State Trooper was selected to perform the various driving tasks. The State Patrol indicated interest and enthusiasm for the study and requested that one of their vehicles be evaluated along with the Department's Motor Pool vehicle. As a result of the Patrol's interest, a driver, mechanic, and tires were provided; the Federal Aviation Administration was requested to control the air traffic at Sanderson Field during test periods. Personnel at the State Patrol Academy in Shelton assisted in coordinating this study effort.

The personnel involved consisted of a project supervisor, observers for data collection, a driver, and a mechanic for the changing of tires. The observers and mechanic also assisted in setting up the various test courses and operated a water truck which was used for watering down the various courses during periods when natural rainfall did not wet the pavement surfaces sufficiently. Skid values of the test course surfaces were measured by Department Materials Division personnel.

CONCLUSIONS

1. The highway tread tire combination performed better than the other tire combinations during the majority of test maneuvers.
2. Of the four tests conducted, only two provided data which would indicate the traction or potential traction characteristics of the various tire combinations and tire types. These were Test No. 3 - High Speed Lane Change and Test No. 4 - Locked-Wheel Stop.
    (a) During Test No. 3 (High Speed Lane Change) the highway combination performed better than the other tire combinations on wet pavement and was equal to the highway tungsten/snow tungsten and snow garnet combinations, and performed better than the snow, tungsten and snow Norfin combinations on dry pavement.
    (b) During Test No. 4 (Locked-Wheel Stop) the highway combination performed better than the other tire combinations on both wet and dry pavements.
3. The difference in traction characteristics between the various tires tested was slight.
4. The test maneuvers were conducted with the vehicles under constant power, an abnormal driving situation. Had the driver been able to manipulate the accelerator during the maneuvers he may have been able to obtain higher speeds before extreme slippage occurred and the type of slip may have been different than that reported.
5. The Washington State Patrol vehicle performed better than the Department of Highways' vehicle during all test maneuvers.

SECTION I

Test Site

The site selected and maneuver areas are shown on Figure 1. The pavement was asphalt concrete with average skid resistance values ranging from 42 to 53. Measurements were taken using a locked-wheel skid test trailer, (Soil Test, Model ML 350E).

Test No. 1 - Maneuvering (low speeds). The configuration of the test course was a serpentine as shown in Figure 2. Skid resistance values of the pavement were in the range of 38 to 56 with an average of 47.

Test No. 2 - Hairpin Curve, shown in Figure 3, pavement skid resistance values ranged from 46 to 59 with an average skid resistance of 53.

Test No. 3 - High Speed Lane Change, shown in Figure 4, pavement skid resistance values ranged from 40 to 46 with an average of 42.

Test No. 4 - Locked-Wheel Stop, pavement skid resistance values ranged from 36 to 58 with an average of 43.

The skid resistance values for the various testing maneuvers were all above the Department's desirable skid value of 35. All of the test maneuvers, except for the stopping tests, were designed to channel the driver through the course eliminating as many driver variables as possible (Figure 5).

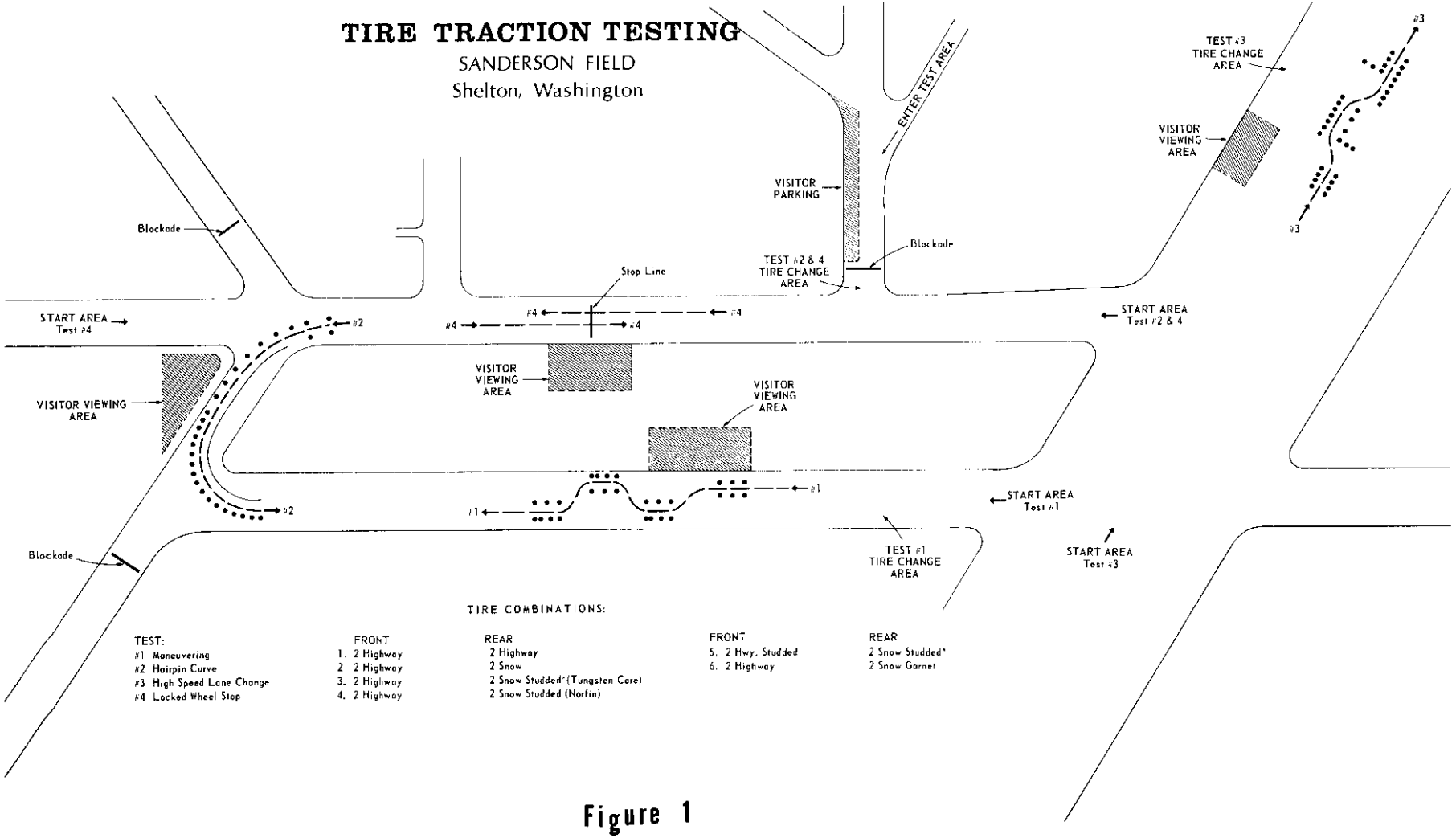

TIRE TRACTION TESTING
SANDERSON FIELD
Shelton, Washington
ENTER TEST AREA
VISITOR PARKING
Blockade
Blockade
TEST #2 & 4 TIRE CHANGE AREA
Stop Line
TEST #3 TIRE CHANGE AREA
VISITOR VIEWING AREA
#3
#3
START AREA Test #4
#2
#4
#4
#4
START AREA Test #2 & 4
VISITOR VIEWING AREA
VISITOR VIEWING AREA
VISITOR VIEWING AREA
#2
#1
#1
START AREA Test #1
Blockade
TEST #1 TIRE CHANGE AREA
START AREA Test #3
TIRE COMBINATIONS:
TEST:
#1 Maneuvering
#2 Hairpin Curve
#3 High Speed Lane Change
#4 Locked Wheel Stop
FRONT
1. 2 Highway
2. 2 Highway
3. 2 Highway
4. 2 Highway
REAR
2 Highway
2 Snow
2 Snow Studded* (Tungsten Core)
2 Snow Studded (Norfin)
FRONT
5. 2 Hwy. Studded
6. 2 Highway
REAR
2 Snow Studded*
2 Snow Garnet

Figure 1

TEST No.1
MANEUVERING

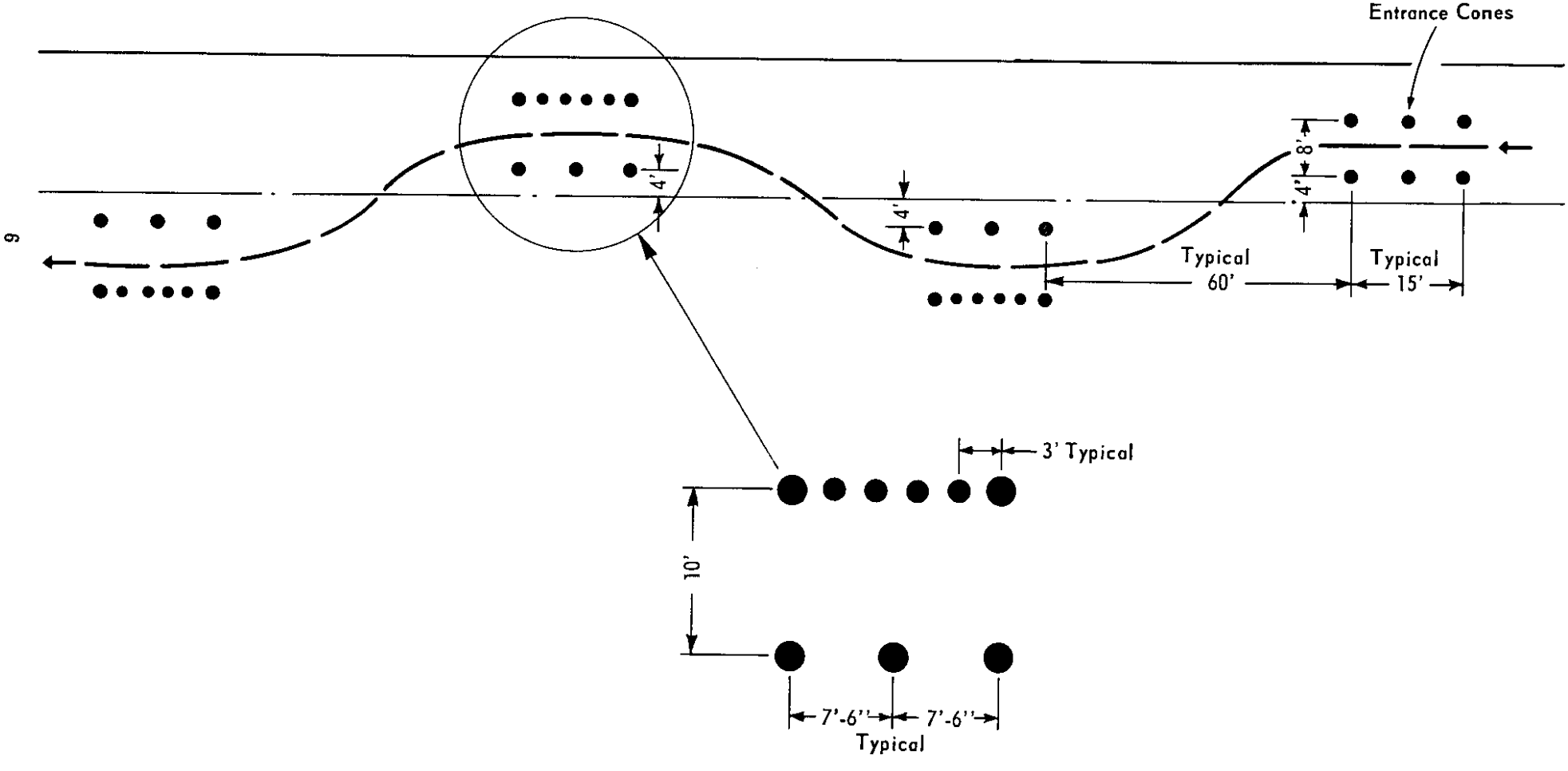


Figure 2

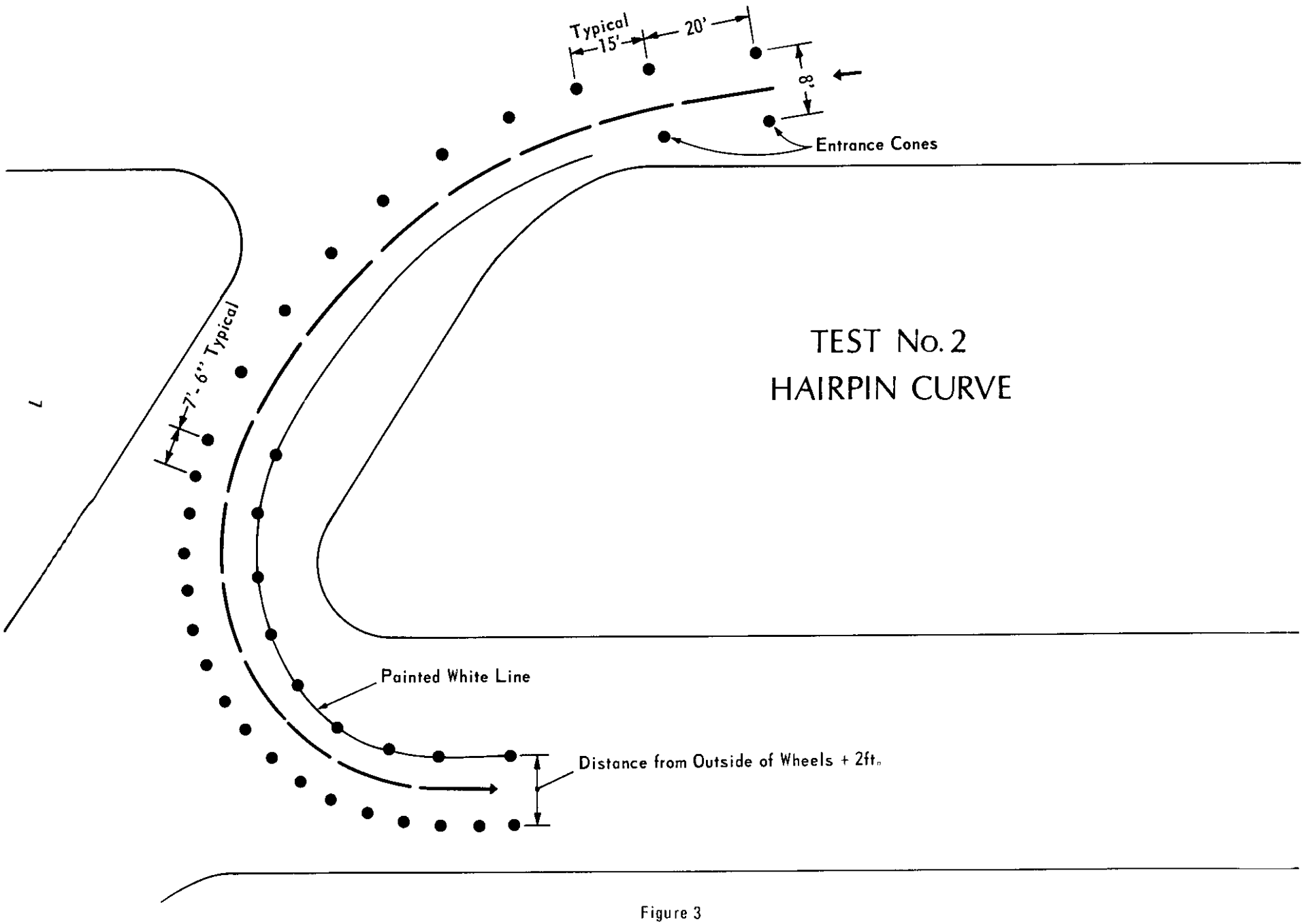

Typical
15'
20'
8'
Entrance Cones
7'-6" Typical
TEST No. 2
HAIRPIN CURVE
Painted White Line
Distance from Outside of Wheels + 2ft.

Figure 3

TEST No. 3
HIGH SPEED LANE CHANGE

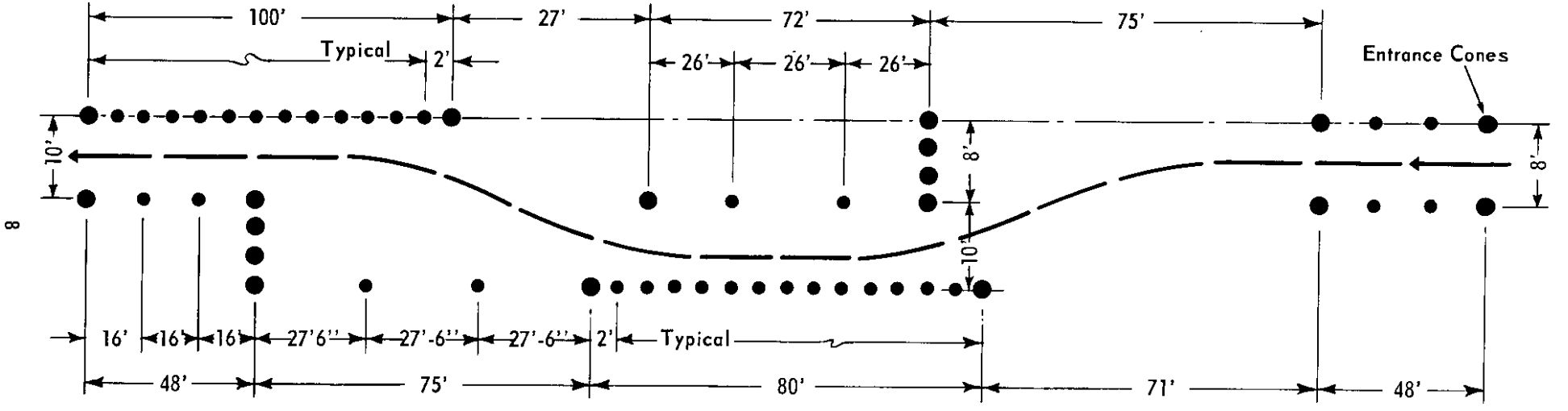


Figure 4

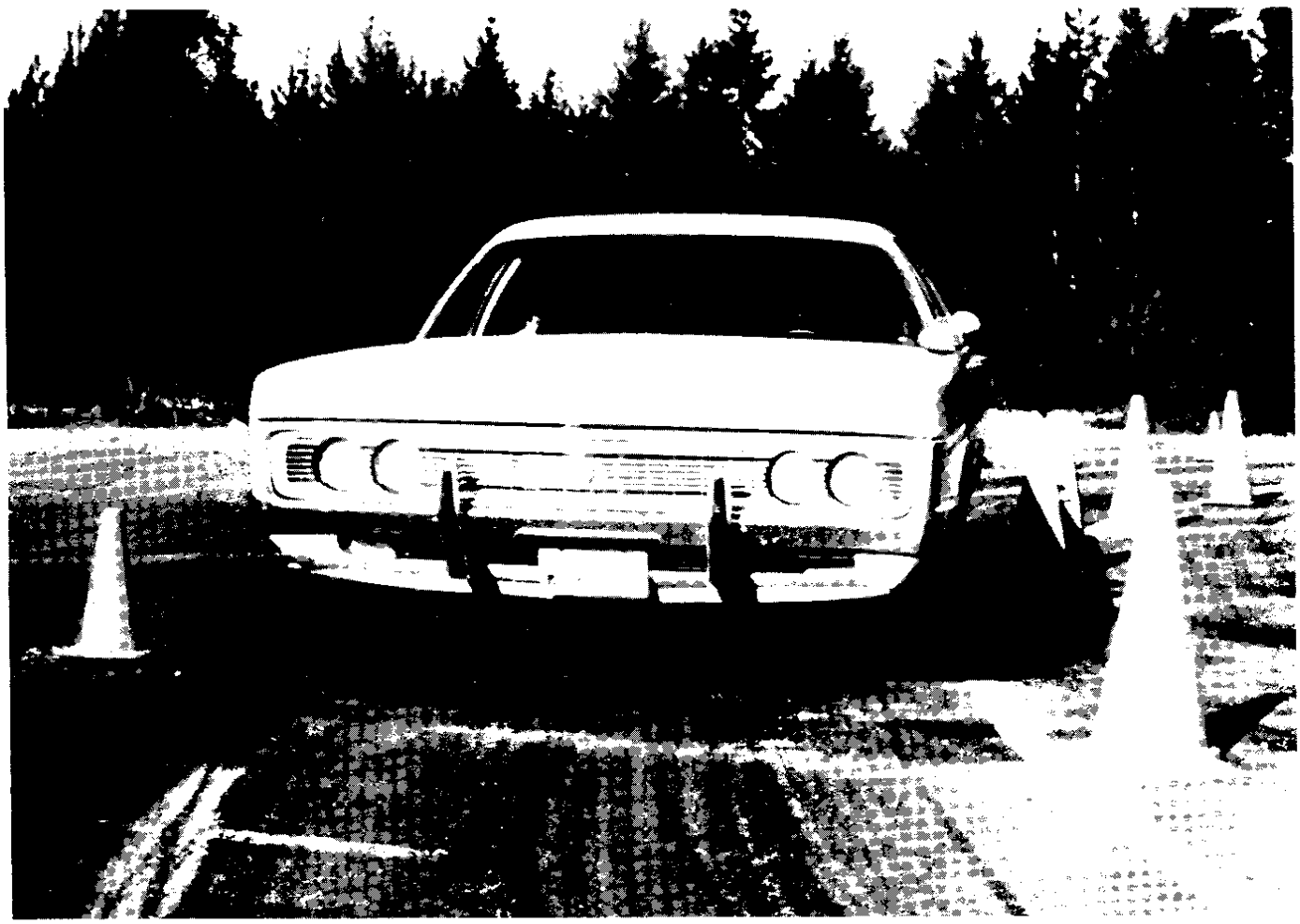


Figure 5: Cone Placement in Relation to Test Vehicle on Hairpin Curve Test

SECTION II

EQUIPMENT

Vehicles:

Two vehicles were used during the testing. One was a Department of Highways' Motor Pool vehicle, a 1970 Plymouth Fury III with a 318 cubic inch V8 engine, equipped with power steering, power brakes and automatic transmission. The other vehicle was a 1970 Washington State Patrol Plymouth pursuit vehicle with a 440 cubin inch V8 engine, equipped with power steering, power brakes (disc brakes in the front) and automatic transmission. The State Patrol vehicle also had police special (heavy duty) suspension and a roll bar installed. The gross weight of the Motor Pool vehicle was 3,750 lbs. (2,000 lbs. over the front wheels and 1,750 lbs. over the rear wheels). The State Patrol vehicle had a gross weight of 4,450 lbs. (2,400 lbs. over the front wheels and 2,050 lbs. over the rear wheels). The difference in gross weight of the two vehicles was 700 lbs. Each vehicle was specially equipped for these tests with a Chrysler Motors' speed control unit and a hand throttle (Figure 6 & 7). The speed control units were used to maintain a constant speed when speeds were 35 mph or over and the hand throttles were used to maintain a constant speed at speeds below 35 mph.

Tires:

The following are the tire types and sizes used during the test.

1. Highway tread tires, size H 78 x 15, belted, load range B, 4 ply sidewalls, 6 ply tread.

2. Snow tires, size H 78 x 15, belted, load range B, 2 ply sidewalls, 4 ply tread.
3. Tungsten studded snow tires, size H 78 x 15, belted, load range B, 2 ply sidewalls, 4 ply tread.
4. Norfin studded snow tires, size H 78 x 15, belted load range B, 2 ply sidewalls, 4 ply tread.
5. Highway studded (Pathfinder) tires, size G 78 x 15, belted, load range B, 2 ply sidewalls, 4 ply tread.
6. Garnet snow tires were recapped tires, size H 78 x 15, belted, 2 ply sidewalls, 4 ply tread.

The tungsten studs used for this test were the controlled protrusion type. The other studs used were Norfin studs. (See Figure 8 for both stud types.)

The following is a listing of the equipment used during the tire traction test.

EQUIPMENT

Quantity	Description	Furnished By
1	1970 Plymouth Fury III (318 V8)	DOH
1	1970 Plymouth Fury III (440 V8)	WSP
2	Speed Control Units (one for each car)	DOH
2	Hand Throttle (one for each car)	DOH
60	Cones	WSP
2	100' Steel Tape	DOH
10	Spray Paint White	DOH
1	Skid Test Trailer/with Tow Truck	DOH
22	Tires:	
	8 - Standard Highway w/wheels	WSP
	4 - Snow w/wheels	DOH
	4 - Studded Snow w/wheels (2 Tungsten) (2 Norfin)	WSP
	4 - Studded Highway (Pathfinder) w/wheels	WSP
	2 - Garnet Snow w/wheels	WSP
1	Tape Recorder (w/5 tapes)	DOH
1	Video Tape Unit (w/2 one-hour tapes)	DOH
1	35 mm Camera (w/10 rolls film)	DOH
1	16 mm Movie Camera w/zoom lens (w/10 rolls film)	DOH
1	Water Truck	Mason County
1	Van (to haul equipment)	DOH
1	Pickup (haul tires and equipment)	WSP
1	Bull Horn	WSP
10	Safety Vests	DOH
1	Heavy Duty Jack	WSP
1	Generator (115 V)	DOH
1	Air Compressor	DOH
1	Electric Impact Wrench	WSP
2	Flag (traffic warning)	DOH
12	Blockade Sawhorse	DOH
1	Thermometer	DOH
2	Helmet	WSP
1	Roll Field Ribbon (red)	DOH
1	Roll 4" Tape (white)	DOH
8	"C" Batteries (for tape recorder)	DOH

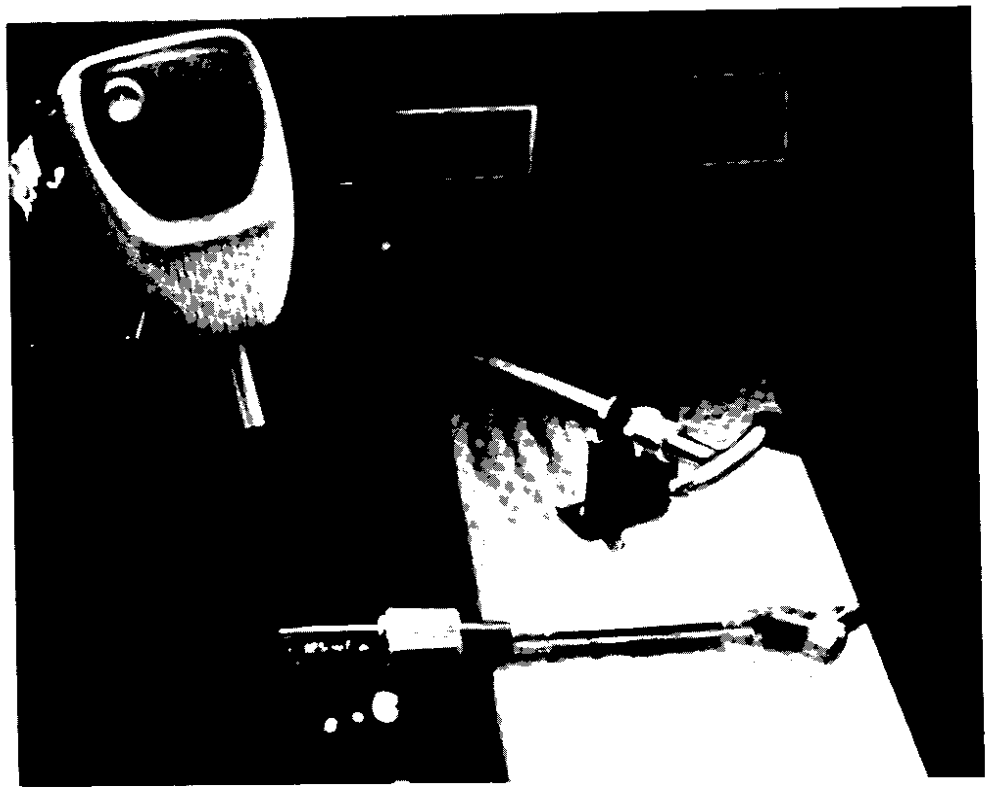


Figure 6: Speed Control Unit and Hand Throttle Mounted in State Patrol Vehicle

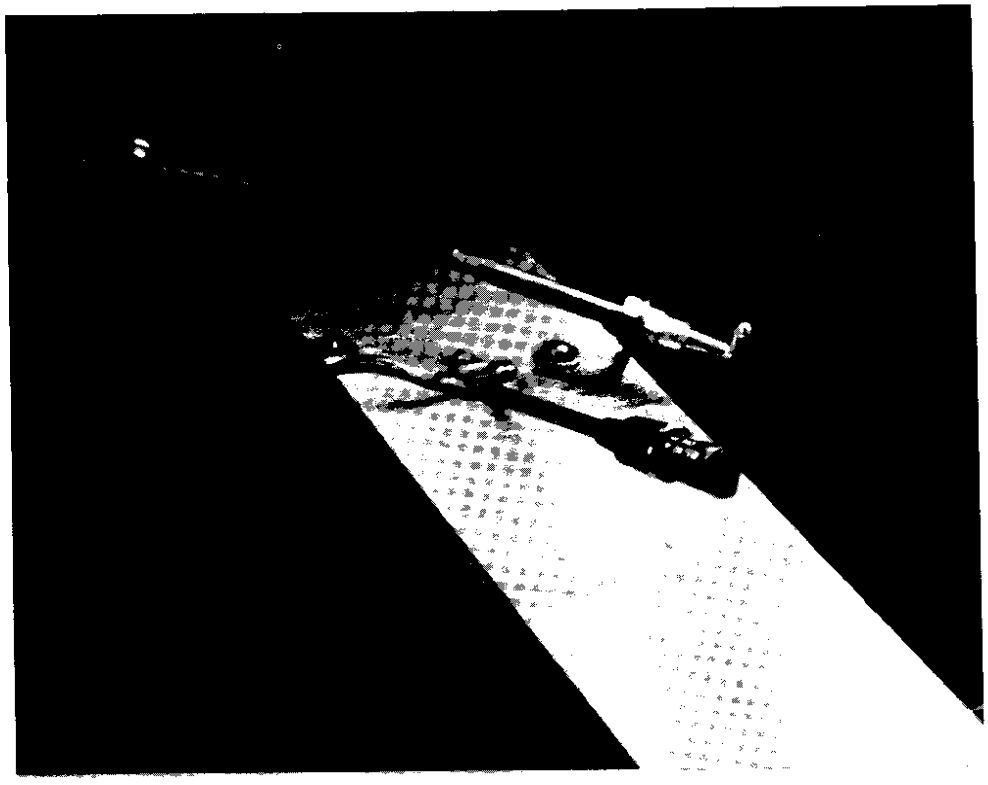


Figure 7: Speed Control Unit and Hand Throttle Mounted in Department of Highway Vehicle

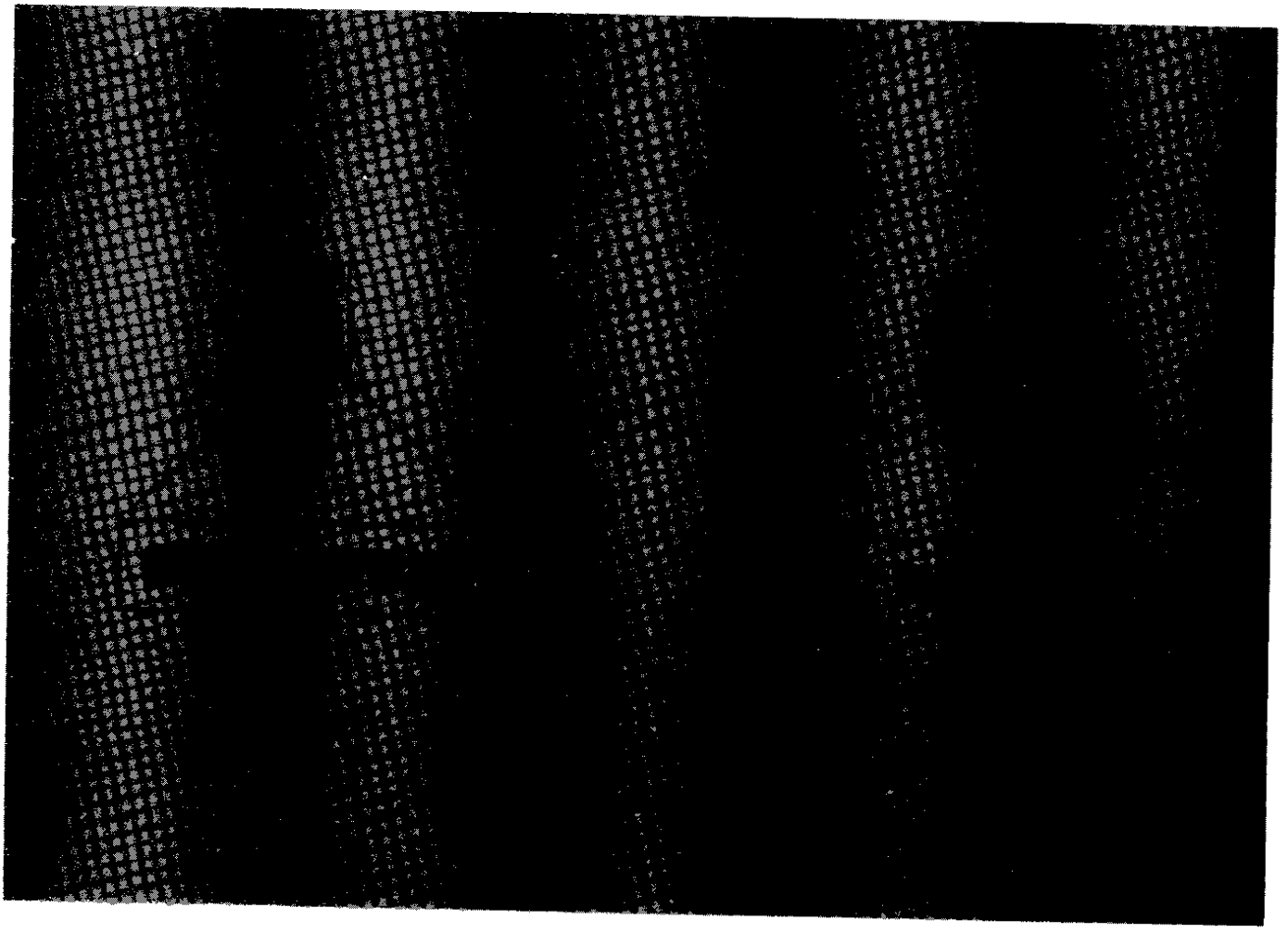


Figure 8: Two Types of Studs Used
During Tire Traction Testing

SECTION III

Personnel

The personnel conducting the study consisted of the following:

1. Project Supervisor - The duties of the Project Supervisor were to coordinate the research study, set up the testing program indicating the type of data required, monitor the observers to insure that the data obtained was valid and to assist with the observation tasks when necessary.
2. Driver - The Driver's duties were to drive the vehicles through the various test maneuvers maintaining a constant speed, advising Observer 1 of the entrance and exit speeds and to make comments on tape of each test run and series as to the vehicle reactions and handling capabilities.
3. Observers - (data collection and test course preparation)

   Observer 1 - The duties of Observer 1 were to ride with the Driver, set and disengage the hand throttle, record the entrance and exit speeds and observe and report vehicle reactions during the test maneuvers.

   Observer 2 - The duties of Observer 2 were to observe the amount of tire slip and the cones struck by the vehicle during tests 1, 2 and 3 and to take measurements of the stopping distance during test 4.

   Observer 3 - The duties of Observer 3 were the same as those for Observer 2.

Observer 4 - The duties for Observer 4 were to record the observations of Observer 1, 2 and 3 on data sheets and to assist with the observation tasks.

Observer 5 - The duties of Observer 5 were to assist and relieve the other observers as well as document the various test runs on video tape, 16 mm movie camera, and 35 mm camera, (Fig. 9) as well as operate the water truck when water was needed for wet pavement testing (Fig. 10 & 11).

4. Mechanic - The Mechanic's duties were to change tires for the various test runs, check tire inflation, check wheels for fatigue and assist Observer 5 with the water truck operation.

Figures 12, 13, 14, 15 & 16 show the location of the observers during each of the test maneuvers.

Figure 9: Observer 5 operating 16 mm movie camera from the top of van.

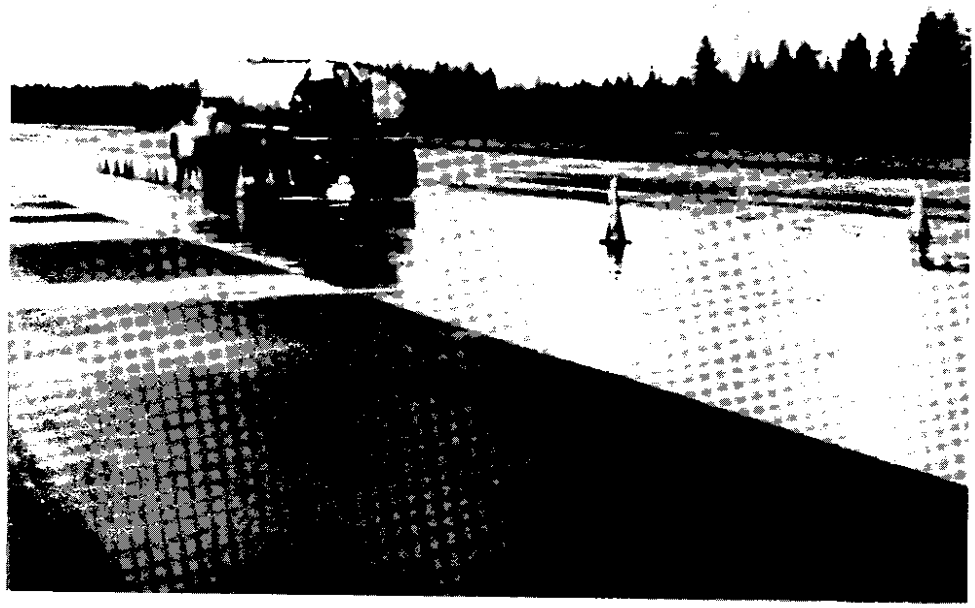


Figure 10: Watering pavement with water truck-
High Speed Lane Change test site.

Figure 11: Watering pavement by hand-
Locked-Wheel Stopping test site.

TIRE TRACTION TESTING

TEST NO. 1

MANEUVERING

OBSERVER LOCATION

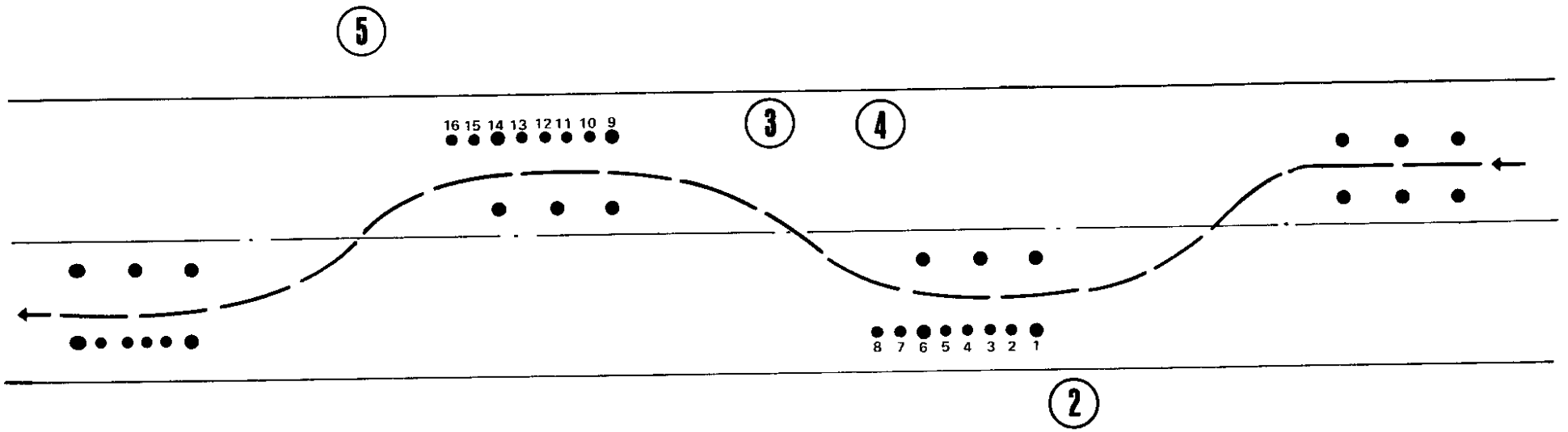


Figure 12

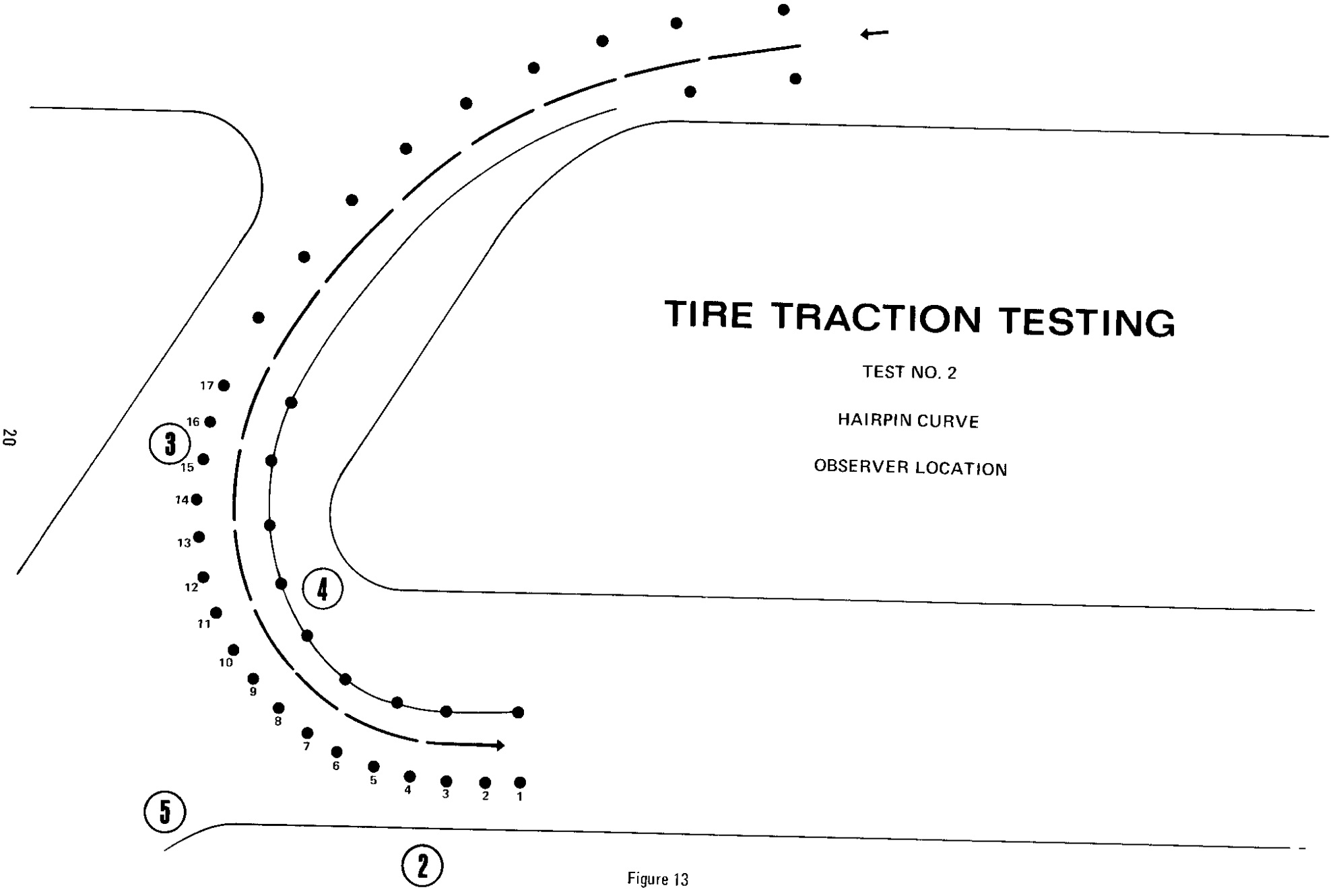

TIRE TRACTION TESTING
TEST NO. 2
HAIRPIN CURVE
OBSERVER LOCATION
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
2
3
4
5

Figure 13

TIRE TRACTION TESTING

TEST NO. 3

HIGH SPEED LANE CHANGE

OBSERVER LOCATION

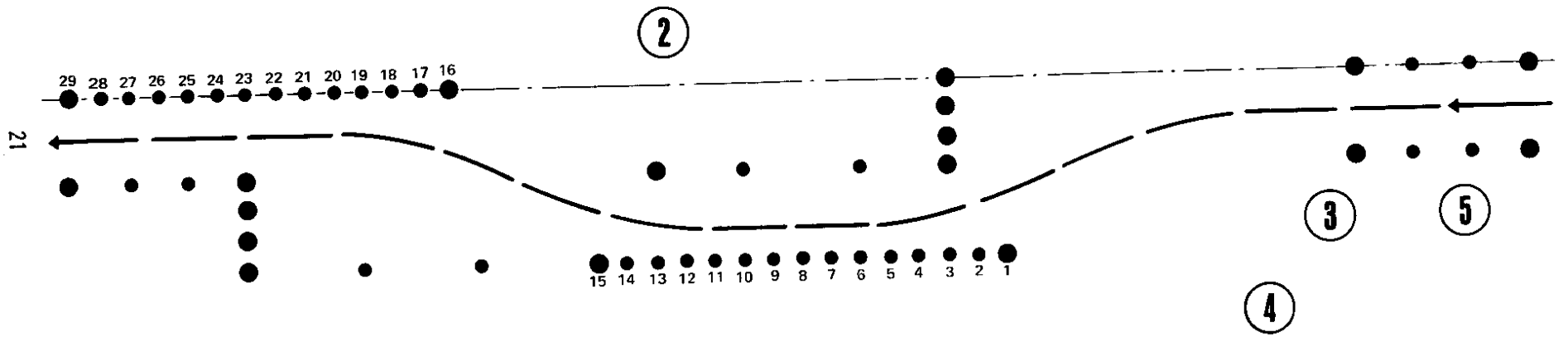


Figure 14

TIRE TRACTION TESTING

TEST NO. 4

LOCKED WHEEL STOP

OBSERVER LOCATION

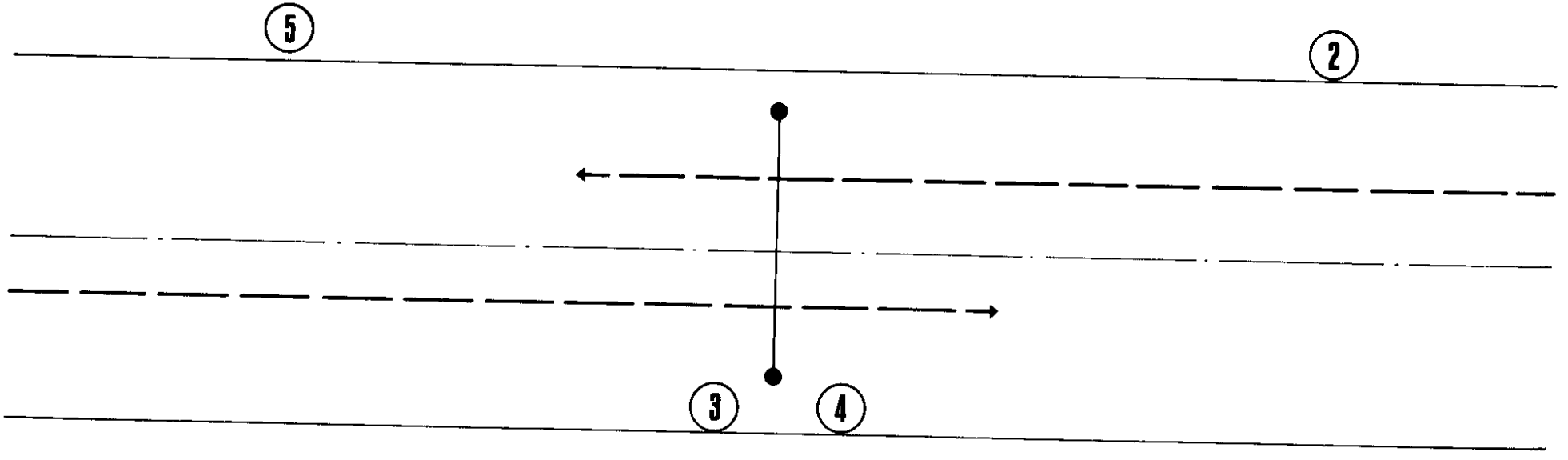


Figure 15

Figure 16: Location of Observers 3 & 4 during Hairpin Curve Testing

SECTION IV

Data Collection

The observations were recorded on data sheets prepared for each of the test maneuvers, see Figures 17, 18, 19 and 20. A data sheet was completed for each test run for each tire combination during a specific testing maneuver. The information on the data sheets was correlated with the comments from the driver and the notes of Observer 1.

After the tests were completed the data covering amount and type of slippage which had occurred were extracted from the data sheet for analysis. After analysis, the resultant data was placed in graphic form.

For Test 1, 2 and 3 the amount of slip was determined by use of the following criteria:

1. Slight Slip - 1" to 12" lateral movement of the tires
2. Moderate Slip - 12" to 24" lateral movement of the tires
3. Extreme Slip - 24" and more lateral movement of the tires

The data was gathered from visual observation, so reference marks were placed at the slip points of the various test maneuvers (Fig. 21). The reference marks were placed on 12" centers starting from the inside of the slip point area and extending 36" toward the outside. As the test tires passed over the reference marks observations were made to determine whether the tires slipped within the slip zone and the amount of slip was noted as either/slight (s),/moderate (m), or/extreme (e).

The lateral movement of the studded tires caused scratch marks on the pavement (Figure 22).

DATA SHEET – TIRE TRACTION TESTING

Test No. _____
Run No. _____
Speed _____
PSI 28

Date _____ Time _____

Weather: ☐ Clear ☐ Sunny ☐ Cloudy ☐ Overcast ☐ Rain ☐ Snow

Pavement Condition: ☐ Dry ☐ Damp ☐ Wet ☐ Ice ☐ Snow Temperature _____

Tire Combination: Front _____ Rear _____ Type Studs _____

Entrance Speed: _____ Exit Speed _____

Breakaway: ☐ None ☐ Front ☐ Rear ☐ All ☐ Side Slip ☐ Spin Out

Chute #1___ F___ R Chute #2___ F___ R

Tire Condition After Test: _____

Remarks: _____

_____

_____

_____

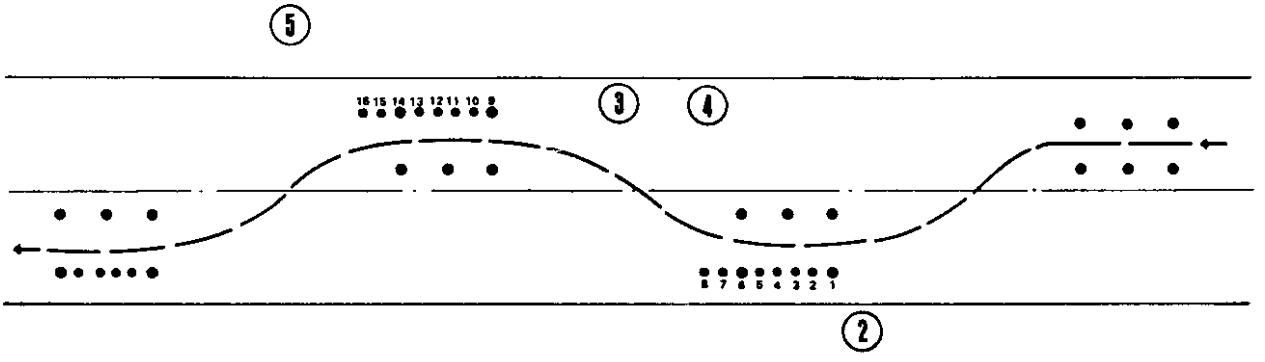
Distance From Reference Line

Cone # 5 _____
Cone # 8 _____
Cone # 9 _____
Cone #12 _____

Cones Hit ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩ ⑪ ⑫ ⑬ ⑭ ⑮ ⑯ ⑰ ⑱ ⑲ ⑳ ㉑ ㉒ ㉓ ㉔ ㉕ ㉖ ㉗ ㉘ ㉙ (✓ -Tick, x-Wipe-out)

TEST NO. 1

MANEUVERING



Driver Comments: _____

_____

_____

_____

_____ Observer _____

Figure 17

DATA SHEET – TIRE TRACTION TESTING

Test No. _____
Run No. _____
Speed _____
PSI 28

Date _____ Time _____

Weather: ☐ Clear ☐ Sunny ☐ Cloudy ☐ Overcast ☐ Rain ☐ Snow

Pavement Condition: ☐ Dry ☐ Damp ☐ Wet ☐ Ice ☐ Snow Temperature _____

Tire Combination: Front _____ Rear _____ Type Studs _____

Entrance Speed: _____ Exit Speed _____

Breakaway: ☐ None ☐ Front ☐ Rear ☐ All ☐ Side Slip ☐ Spin Out

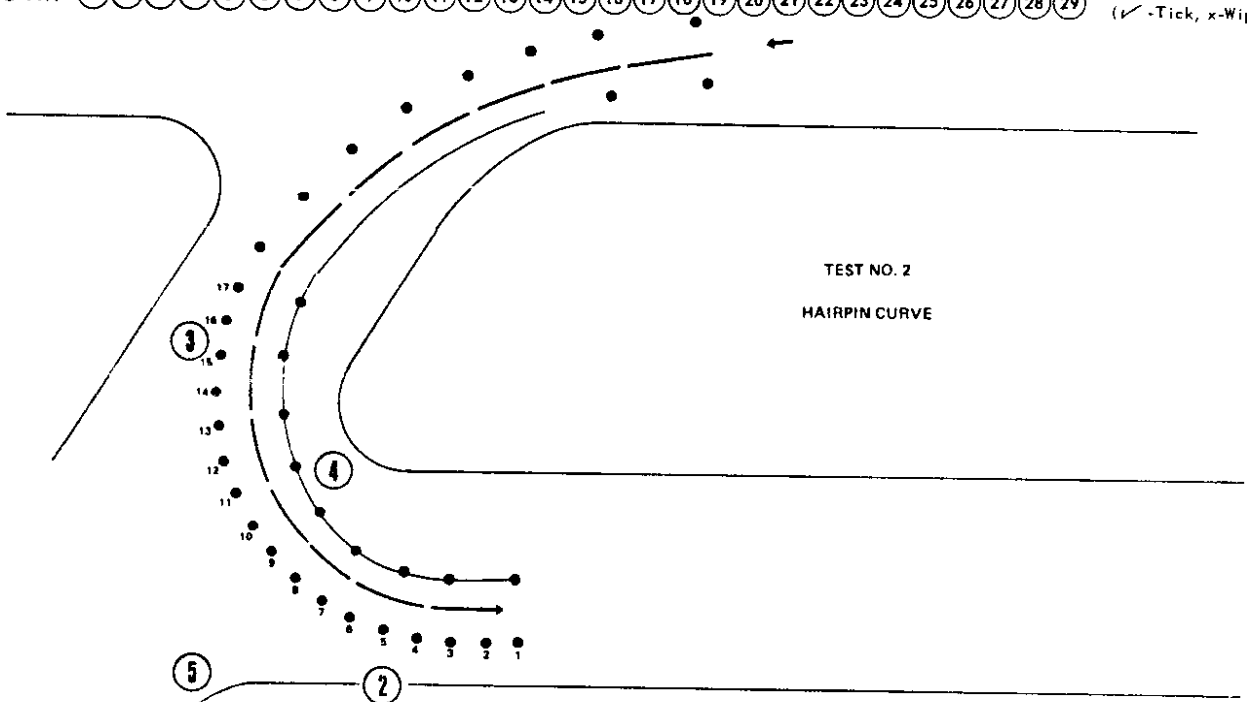
Chute #1 ___ F ___ R Chute #2 ___ F ___ R

Tire Condition After Test: _____

Remarks: _____

Distance From Reference Line
Cone # 8 _____
Cone #10 _____
Cone #13 _____

Cones Hit ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩ ⑪ ⑫ ⑬ ⑭ ⑮ ⑯ ⑰ ⑱ ⑲ ⑳ ㉑ ㉒ ㉓ ㉔ ㉕ ㉖ ㉗ ㉘ ㉙ (✓-Tick, x-Wipe-out)



Driver Comments: _____

Observer _____

Figure 18

DATA SHEET – TIRE TRACTION TESTING

Test No._____
Run No._____
Speed _____
PSI 28

Date_____ Time _____

Weather: ☐ Clear ☐ Sunny ☐ Cloudy ☐ Overcast ☐ Rain ☐ Snow

Pavement Condition: ☐ Dry ☐ Damp ☐ Wet ☐ Ice ☐ Snow Temperature _____

Tire Combination: Front_____ Rear _____ Type Studs _____

Entrance Speed:_____ Exit Speed _____

Breakaway: ☐ None ☐ Front ☐ Rear ☐ All ☐ Side Slip ☐ Spin Out

Chute #1____F____R Chute #2____F____R

Tire Condition After Test: _____

Remarks: _____

Distance From Reference Line

Cone # 8 _____

Cone #15 _____

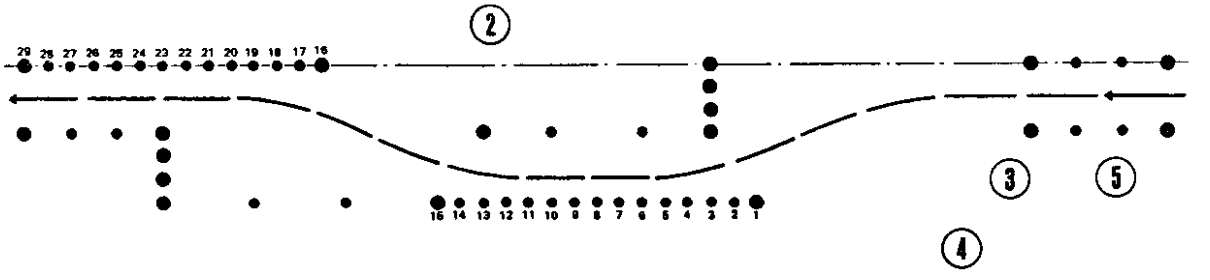
Cone #16 _____

Cone #23 _____

Cones Hit ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩ ⑪ ⑫ ⑬ ⑭ ⑮ ⑯ ⑰ ⑱ ⑲ ⑳ ㉑ ㉒ ㉓ ㉔ ㉕ ㉖ ㉗ ㉘ ㉙ (✓-Tick, x-Wipe-out)

TEST NO. 3

HIGH SPEED LANE CHANGE



Driver Comments:_____

_____

_____

_____

_____ Observer _____

Figure 19

DATA SHEET – TIRE TRACTION TESTING

Test No. _____
Run No. _____
Speed _____
PSI 28

Date _____ Time _____

Weather: ☐ Clear ☐ Sunny ☐ Cloudy ☐ Overcast ☐ Rain ☐ Snow

Pavement Condition: ☐ Dry ☐ Damp ☐ Wet ☐ Ice ☐ Snow Temperature _____

Tire Combination: Front _____ Rear _____ Type Studs _____

Entrance Speed: _____ Exit Speed _____

Breakaway: ☐ None ☐ Front ☐ Rear ☐ All ☐ Side Slip ☐ Spin Out

Chute #1 ___F___R Chute #2 ___F___R

Tire Condition After Test: _____

Remarks: _____

Distance From Reference Line
Cone # _____
Cone # _____
Cone # _____
Cone # _____

Cones Hit ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩ ⑪ ⑫ ⑬ ⑭ ⑮ ⑯ ⑰ ⑱ ⑲ ⑳ ㉑ ㉒ ㉓ ㉔ ㉕ ㉖ ㉗ ㉘ ㉙ (✓ -Tick, x-Wipe-out)

TEST NO. 4
LOCKED WHEEL STOP

35 MPH	Dry	Wet
1.	_____	_____
2.	_____	_____
3.	_____	_____
4.	_____	_____
5.	_____	_____
6.	_____	_____
7.	_____	_____
8.	_____	_____
9.	_____	_____
10.	_____	_____

50 MPH	Dry	Wet
1.	_____	_____
2.	_____	_____
3.	_____	_____
4.	_____	_____
5.	_____	_____
6.	_____	_____
7.	_____	_____
8.	_____	_____
9.	_____	_____
10.	_____	_____

Driver Comments: _____

_____

_____

_____

_____ Observer _____

Figure 20

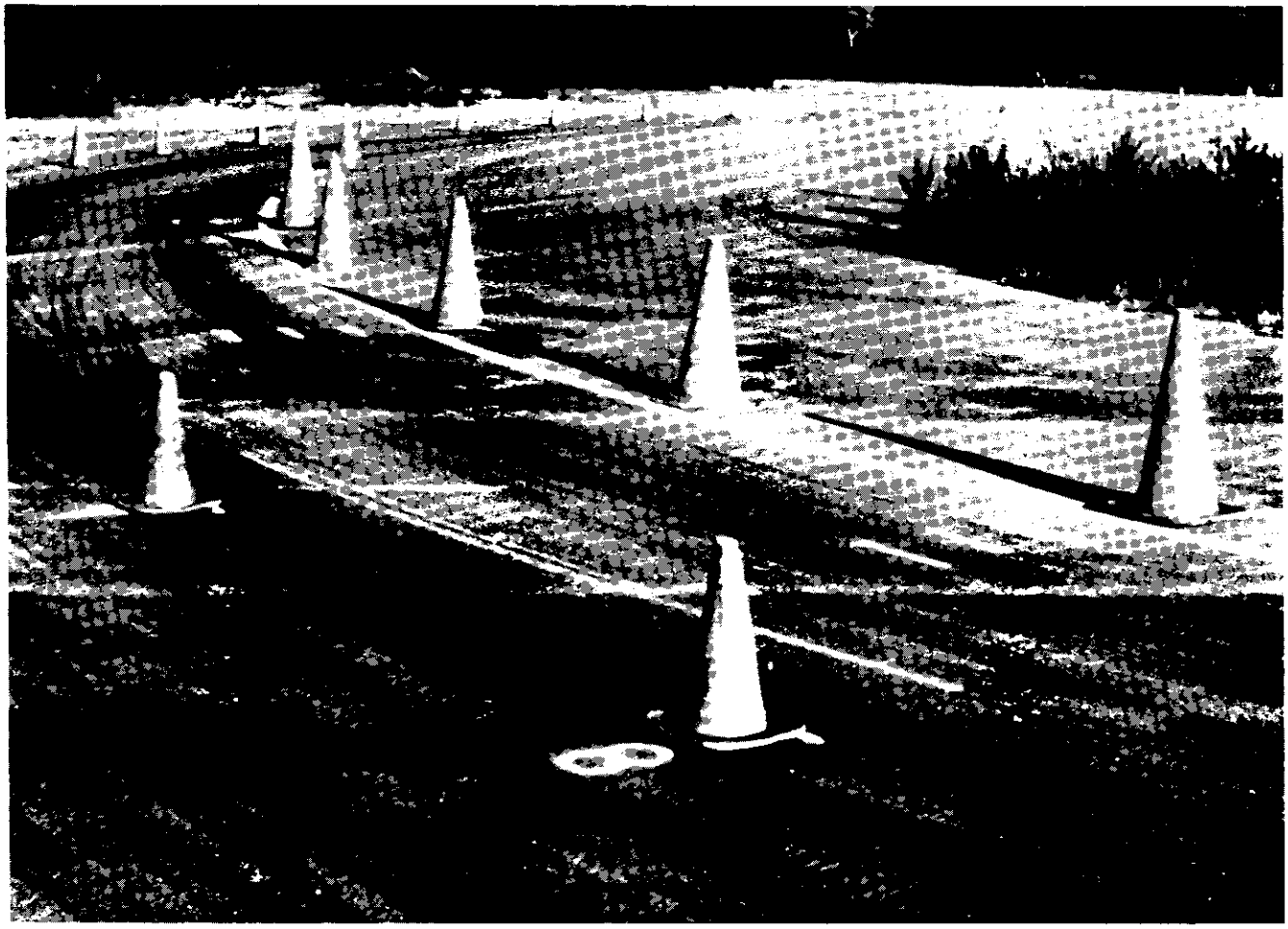


Figure 21: Painted reference lines shown on pavement at Hairpin Curve test site.

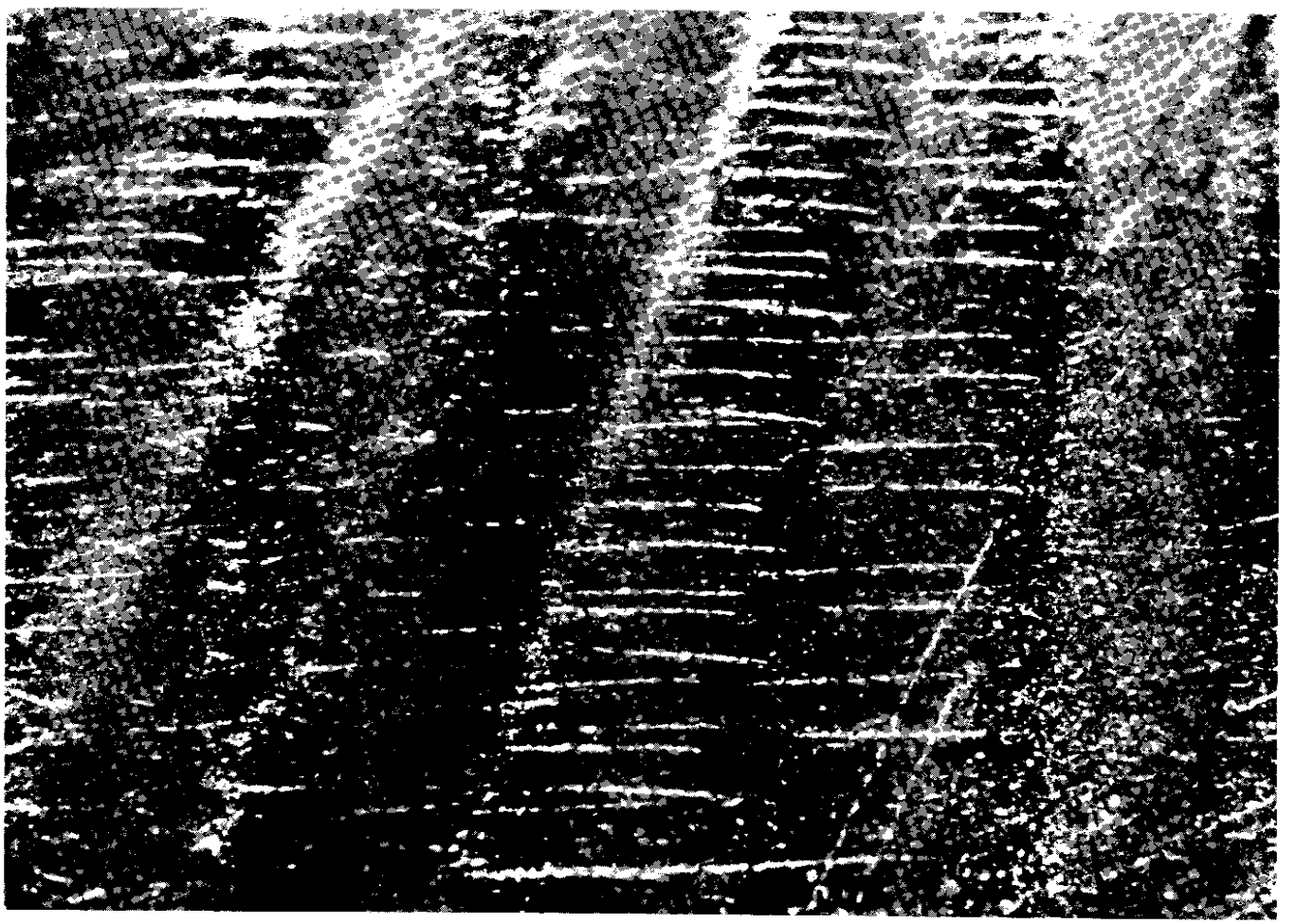


Figure 22: Marks on pavement showing slip action of studded tires.

SECTION V

Data - Department of Highways' Vehicle

This section presents data obtained for the Department of Highways' Motor Pool vehicle except for Test No. 3, High Speed Lane Change. In this test, for safety reasons, the Washington State Patrol vehicle was used because it was equipped with a roll bar.

The data presented will be discussed using two approaches: (1) tire combination traction characteristics and (2) specific tire traction characteristics. Combination tire traction data was available from Tests No. 1, 2 and 4 and specific tire traction data was available from Tests No. 1, 2 and 3.

Using the highway tread tires as a standard the following data are presented:

TEST NO. 1 - MANEUVERING - DRY PAVEMENT (Figures 23 & 24)

The highway tread front/highway tread rear combination (highway combination) performed better than the other tire combinations during the maneuvering tests on dry pavement. This combination started slipping at 31 mph and had extreme slippage at 34 mph. The highway tread front/snow tread rear combination (snow combination) started slipping at 31 mph, (the same speed as the highway combination) and had extreme slippage at 32.5 mph, (2 mph lower than the highway combination). The highway tread front/snow tread tungsten studded rear combination (snow tungsten combination) started slipping at 31 mph, (the same speed as the highway combination) and had extreme slippage at 33 mph, (1 mph lower than the highway combination). The highway tread front/snow tread Norfin studded rear combination (snow Norfin combination) started slipping at 30 mph, (1 mph lower than the highway combination) and had extreme slippage at 33 mph, (1 mph lower than the highway combination). The highway Pathfinder tread tungsten studded front/snow

tread tungsten studded rear combination (highway tungsten/snow tungsten combination) started slipping at 29 mph, (2 mph lower than the highway combination) and had extreme slippage at 31.5 mph, (2.5 mph lower than the highway combination). The highway tread front/snow tread garnet rear combination (snow garnet combination) started slipping at 30 mph, (1 mph lower than the highway combination) and had extreme slippage at 34 mph, (the same speed as the highway combination). The above data is presented in Figure 25.

It was noted during the maneuvering tests on dry pavement that the difference in the speeds where slippage began was slight. This also held true for the speed where extreme slippage occurred.

The type of slippage that occurred should be noted as this would give a clue as to whether the specific tire types had better or poorer traction than the highway tires.

There were two chutes in this test maneuver (Table I). In chute 1 the highway combination and the snow combination had extreme slippage in front. The snow tungsten combination had extreme slippage both front and rear. The snow Norfin combination had extreme slippage in the rear. The highway tungsten/snow tungsten combination had extreme slippage in the front and the snow garnet combination had extreme slippage in the rear. In chute 2 the highway combination had extreme slippage both front and rear. All of the other tire combinations except for highway tungsten/snow tungsten combination had extreme slippage in the rear. This combination had extreme slippage in the front.

These data indicate that when slippage occurred in the front, the rear tires had good traction. When rear slippage occurred, the rear tires had poor traction and when extreme slip occurred on all four tires at the same time, they had poor traction and the vehicle was out of control.

TEST NO. 1 - MANEUVERING - WET PAVEMENT

During the wet pavement maneuvering tests, the highway combination performed better than the other tire combinations as to the speed where the vehicle started slipping. The snow combination performed better than the other tire combinations as to the speed at which extreme slippage occurred. The highway combination started slipping at 30 mph with extreme slippage occurring at 32 mph. The snow combination started slipping at 28 mph, (2 mph lower than the highway combination) with extreme slippage occurring at 33 mph, (1 mph higher than the highway combination). The snow tungsten combination started slipping at 28.5 mph, (1.5 mph lower than the highway combination) with extreme slippage occurring at 32.5 mph. (.5 mph higher than the highway combination). The snow Norfin combination started slipping at 29 mph, (1 mph lower than the highway combination) with extreme slippage occurring at 32 mph, (the same speed as the highway combination). The highway tungsten/snow tungsten combination started slipping at 26 mph, (4 mph lower than the highway combination) with extreme slippage occurring at 31 mph, (1 mph lower than the highway combination). The snow garnet combination started slipping at 27 mph, (3 mph lower than the highway combination). Both the snow combination and the snow tungsten combination had extreme slippage occur at a higher speed than the highway combination (Figure 26).

Again, the reaction of the tires through chute 1 and chute 2 should be noted (Table II). In chute 1 the highway combination had extreme slippage in the front which indicates good traction by the rear tires. The snow combination had extreme slippage front and rear which indicates poor traction on all four tires. The snow tungsten combination had extreme slippage in the front indicating good traction by the rear tires. The snow Norfin combination had extreme slippage in the rear indicating poor rear tire traction. The highway tungsten/snow tungsten rear had extreme slippage in front and rear which indicates poor traction by all four tires. The snow garnet combination had extreme slippage in the rear indicating poor rear tire traction.

In chute 2 the highway combination continued to have extreme slippage in the front as did the snow combination indicating good rear tire traction. The snow tungsten combination had extreme slippage in front and rear, poor traction by all four tires. The snow Norfin combination had extreme slippage in the rear indicating poor rear tire traction. The highway tungsten/snow tungsten had extreme slippage in the front which indicates good rear tire traction. The snow garnet combination had extreme slippage front and rear, poor traction on all four tires.

The maneuvering test simulates a driving situation in town or urban traffic where a driver would have to make a sudden veering motion at speeds of 30 to 35 mph.

SUMMARY

DRY PAVEMENT

1. During the maneuvering tests on dry pavement the highway combination

performed better than the other tire combinations, both at the speed where slippage started and the speed where extreme slippage occurred.

WET PAVEMENT

1. During the maneuvering tests on wet pavement, the highway combination performed better than the other tire combinations with respect to the speed at which slippage started.
2. During the wet maneuvering tests, the snow combination performed better than the other tire combinations with respect to the speed at which extreme slippage occurred.
3. During the wet maneuvering tests, the snow combination and snow tungsten combination had extreme slippage at a higher speed than the highway combination.

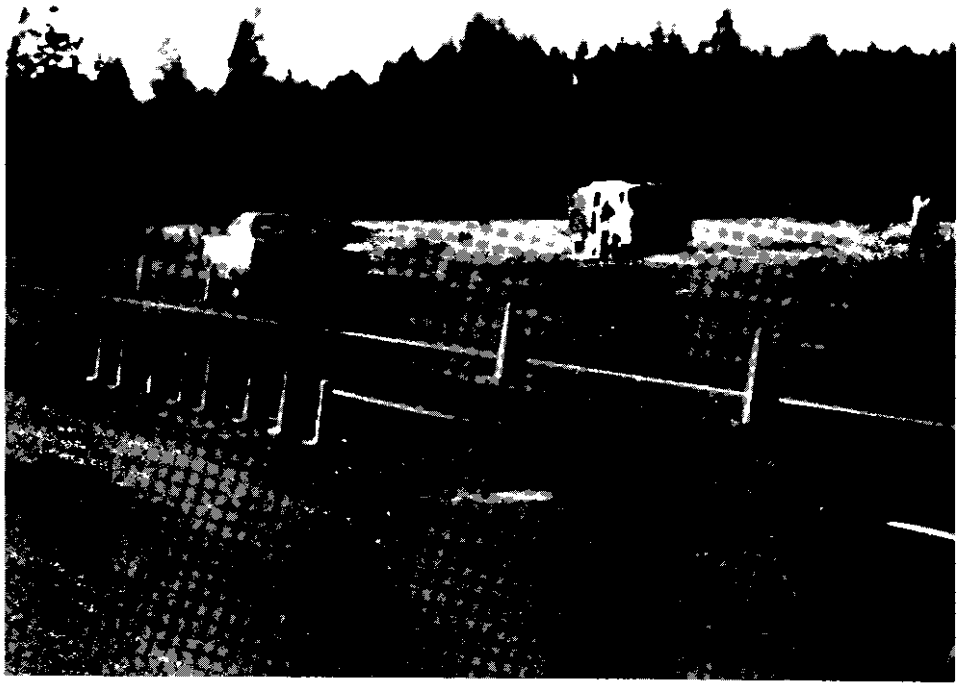


Figure 23: Maneuvering - Department of Highways' Vehicle - Dry Pavement

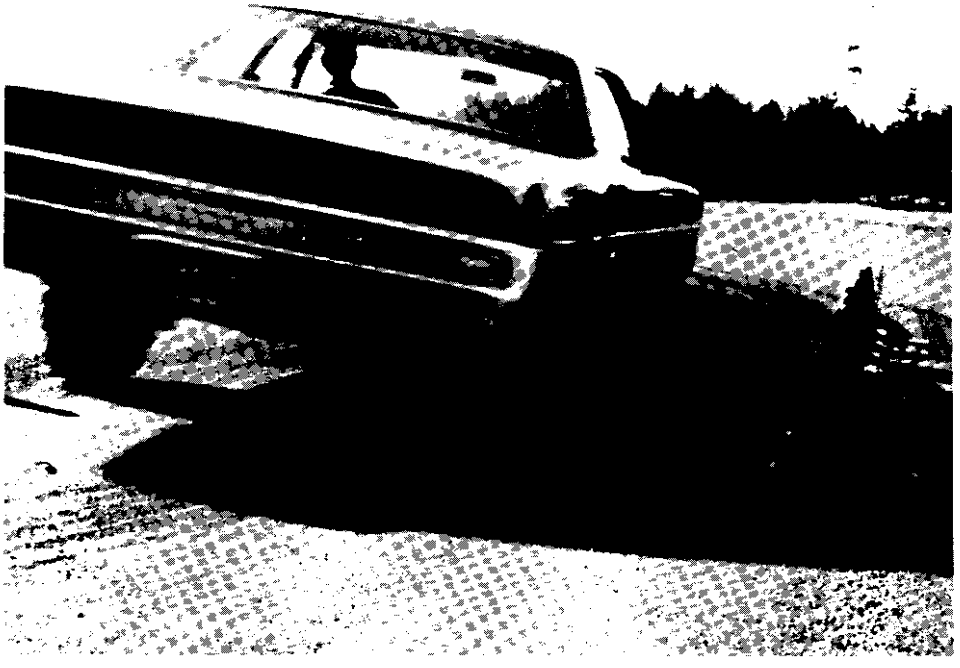


Figure 24: Maneuvering - Chute 2
Department of Highways' Vehicle
Dry Pavement

TIRE TRACTION TESTING

TEST NO. 1

MANEUVERING

DRY PAVEMENT

START SLIP

DOH VEHICLE

EXTREME SLIP

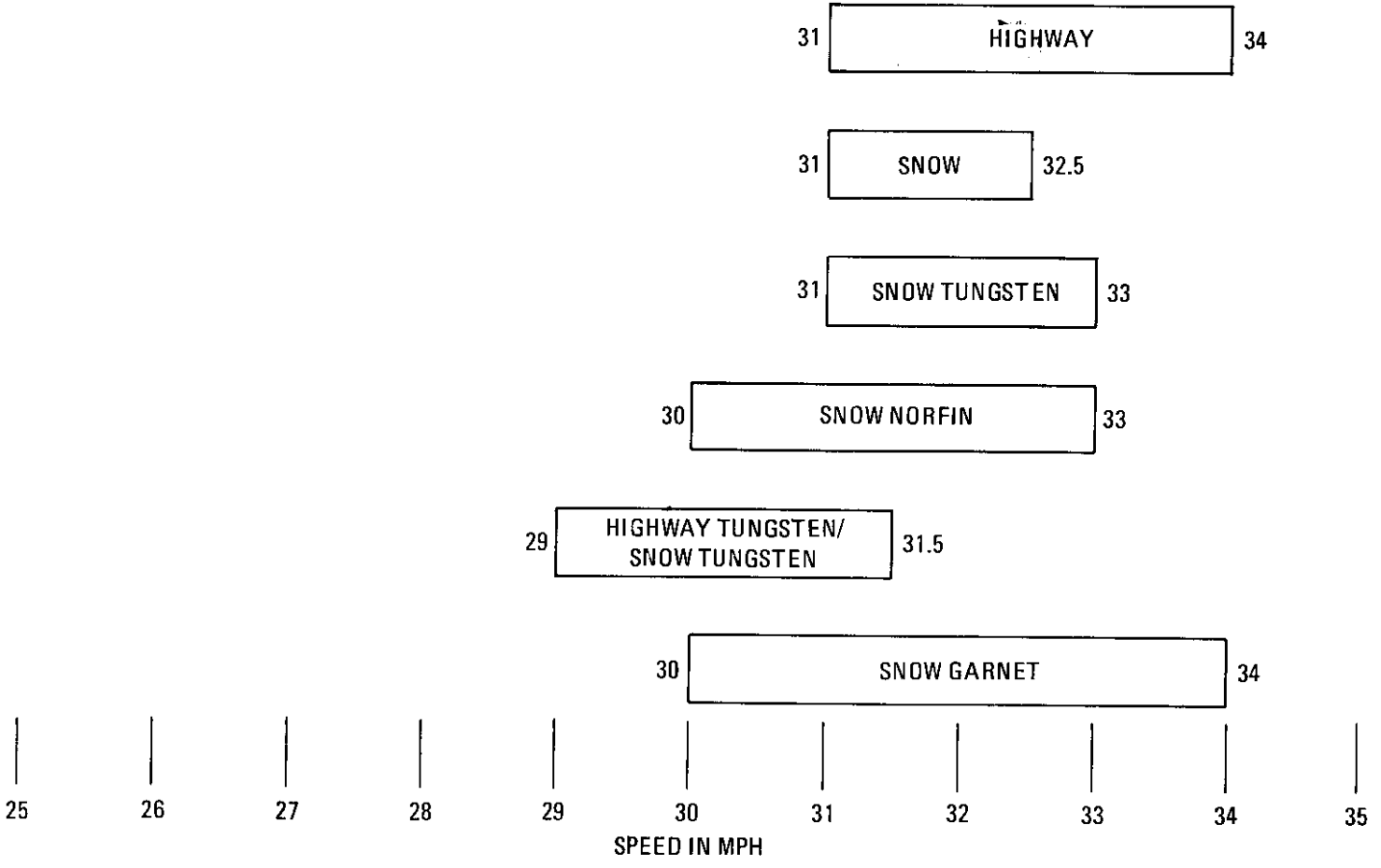


Figure 25

TIRE TRACTION TESTING

TEST NO. 1

MANEUVERING

DRY PAVEMENT

DOH VEHICLE

TYPE OF EXTREME SLIP

TIRE COMBINATION	CHUTE NO. 1	CHUTE NO. 2
HIGHWAY	FRONT	FRONT/REAR
SNOW	FRONT	REAR
SNOW TUNGSTEN	FRONT/REAR	REAR
SNOW NORFIN	FRONT/REAR	REAR
HIGHWAY TUNGSTEN/ SNOW TUNGSTEN	FRONT	FRONT
SNOW GARNET	REAR	REAR

NOTE

FRONT SLIP INDICATES GOOD TRACTION BY REAR TIRES
REAR SLIP INDICATES POOR TRACTION BY REAR TIRES
FRONT/REAR SLIP INDICATES POOR TRACTION BY ALL FOUR TIRES

Table I

TIRE TRACTION TESTING

TEST NO. 1

MANEUVERING

WET PAVEMENT

START SLIP

DOH VEHICLE

EXTREME SLIP

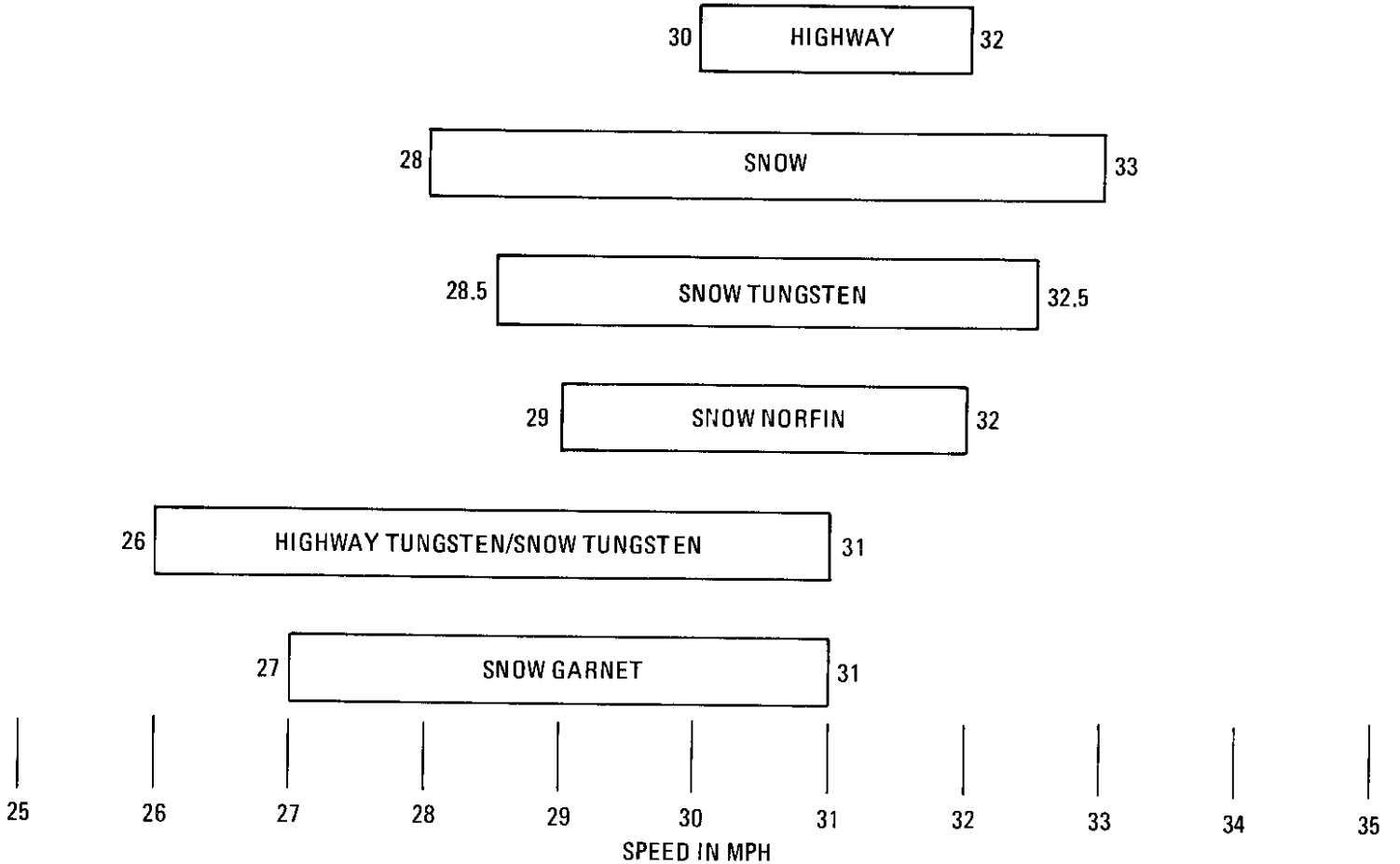


Figure 26

TIRE TRACTION TESTING

TEST NO. 1

MANEUVERING

WET PAVEMENT

DOH VEHICLE

TYPE OF EXTREME SLIP

TIRE COMBINATION	CHUTE NO. 1	CHUTE NO. 2
HIGHWAY	FRONT	FRONT
SNOW	FRONT/REAR	FRONT
SNOW TUNGSTEN	FRONT/REAR	FRONT
SNOW NORFIN	REAR	FRONT/REAR
HIGHWAY TUNGSTEN/ SNOW TUNGSTEN	FRONT/REAR	FRONT
SNOW GARNET	REAR	FRONT/REAR

NOTE

FRONT SLIP INDICATES GOOD TRACTION BY REAR TIRES
REAR SLIP INDICATES POOR TRACTION BY REAR TIRES
FRONT/REAR SLIP INDICATES POOR TRACTION BY ALL FOUR TIRES

Table II

TEST NO. 2 - HAIRPIN CURVE - DRY PAVEMENT (Figure 27)

The highway tungsten/snow tungsten combination performed better than the other tire combinations as to the speed at which slippage started. The snow Norfin combination and highway tungsten/snow tungsten combinations both performed better than the other combinations as to the speed at which extreme slippage occurred (Figure 28). As compared to the highway combination, the snow tungsten and the snow Norfin combinations started slipping at a slower speed and the snow combination and snow garnet combination started slipping at the same speed. The highway tungsten/snow tungsten combination started slipping at a higher speed than the highway combination. Extreme slip occurred at the same speed for the highway combination, the snow combination, the highway tungsten/snow tungsten combination and the snow garnet combination. The snow tungsten combination had extreme slippage at a lower speed than the highway combination and the snow Norfin combination had extreme slippage at a higher speed than the highway combination.

The highway combination, snow combination and snow garnet combination started slipping at 30 mph. The snow tungsten combination started slipping at 29.5 mph, as did the snow Norfin combination, (.5 mph lower than the highway combination). The highway tungsten/snow tungsten combination started slipping at 30.5 mph, (.5 mph higher than the highway combination).

Extreme slip occurred at 31 mph for the highway combination, snow combination, and snow garnet combination. Extreme slippage for the snow

tungsten combination was 30 mph, (1 mph lower than the highway combination). Extreme slippage for the snow Norfin combination and highway tungsten/snow tungsten combination was 32 mph, (1 mph higher than the highway combination).

The type of slippage that occurred should be noted as an indicator of the amount of traction of the specific tire types. The highway combination had extreme slippage in the front which indicates the rear tires had good traction. The snow combination had extreme slippage in the rear which indicates the rear tires had poor traction. The snow tungsten combination had extreme slippage in the rear which indicates the rear tires had poor traction. The snow Norfin combination also had extreme slippage in the rear. The highway tungsten/snow tungsten combination had extreme slippage in the front and rear which indicates poor traction on all four tires when extreme slippage occurred. The snow garnet combination had extreme slippage in the rear which again indicates poor traction by the rear tires. The above data indicates that the highway tires had better traction than the other tire types during Test 2, Hairpin Curve, on dry pavement (Table III).

TEST 2 - HAIRPIN CURVE - WET PAVEMENT (Figure 29)

The highway combination performed better than the other tire combinations as to the speed at which slippage first occurred and the snow garnet combination performed better than the other tire combinations as to the speed at which extreme slippage occurred. The highway combination started slipping at 31.5 mph. The snow combination started slipping at 29 mph, (2.5 mph lower than the highway combination). The snow tungsten combination started slipping at 30 mph, (1.5 mph lower than the highway combination).

The snow Norfin combination started slipping at 29.5 mph, (2 mph lower than the highway combination). The highway tungsten/snow tungsten combination started slipping at 30 mph, (.5 mph lower than the highway combination). The snow garnet combination started slipping at 31 mph, (1 mph lower than the highway combination.

The highway combination had extreme slippage at 33 mph. The snow combination had extreme slippage at 31.5 mph, (1.5 mph lower than the highway combination). The snow tungsten combination had extreme slippage at 32 mph, (1 mph lower than the highway combination). The snow Norfin combination had extreme slippage at 31 mph, (2 mph lower than the highway combination). The highway tungsten/snow tungsten combination had extreme slippage at 31 mph, (2 mph lower than the highway combination). The snow garnet combination had extreme slippage at 34 mph, (1 mph higher than the highway combination). (Figure 30).

The type of slippage that occurred should again be noted. The highway combination had extreme slippage in the front which indicates good traction by the rear tires. The snow combination had extreme slippage in the front, again good rear tire traction. The snow tungsten combination had extreme slippage on all four tires which indicates poor traction on all four tires when extreme slippage occurred. The snow Norfin combination had extreme slippage in the rear which indicates poor traction by the rear tires. The highway tungsten combination/snow tungsten combination had extreme slippage on the front tires which indicates the rear tires had good traction. The snow garnet combination had extreme slippage on all four tires which indicates poor traction on all four tires when extreme slippage occurred. (See Table IV).

The hairpin curve tests simulates a driving situation where the driver would have to make a 90^{o} turn at speeds between 29 and 34 mph.

SUMMARY

Dry Pavement

1. During the hairpin curve tests on dry pavement, the highway tungsten/snow tungsten combination performed better than the other tire combinations as to the speed where slippage started.
2. The snow Norfin studded combination performed better than the other tire combinations as to the speed where extreme slippage occurred.

Wet Pavement

1. During the hairpin curve tests on wet pavement, the highway combination performed better than the other combinations as to the speed where slippage started.
2. The snow garnet combination performed better than the other tire combinations as to the speed where extreme slippage occurred.

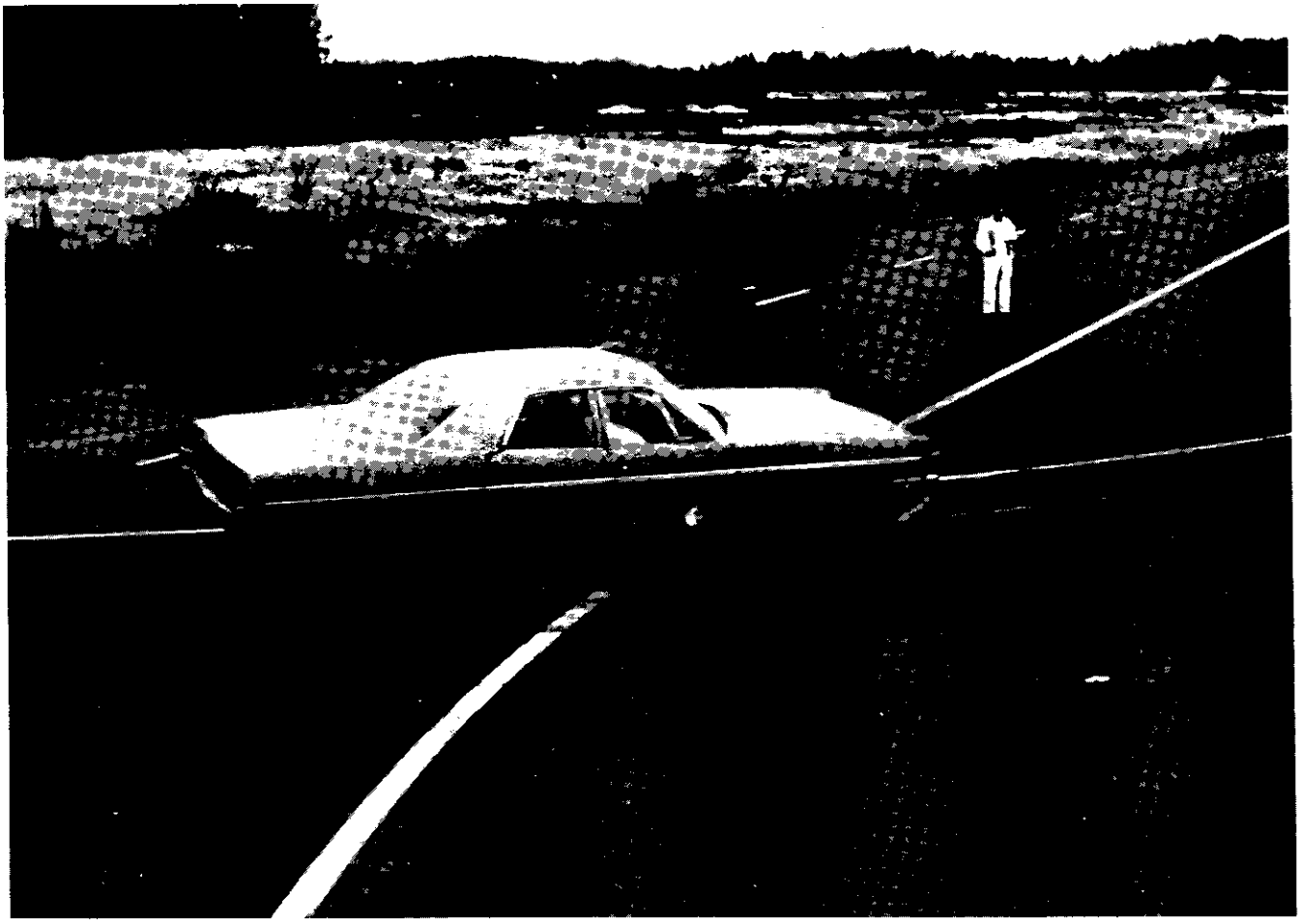


Figure 27: Hairpin Curve
Department of Highways' Vehicle
Dry Pavement

TIRE TRACTION TESTING

TEST NO. 2
HAIRPIN CURVE

DRY PAVEMENT

START SLIP

DOH VEHICLE

EXTREME SLIP

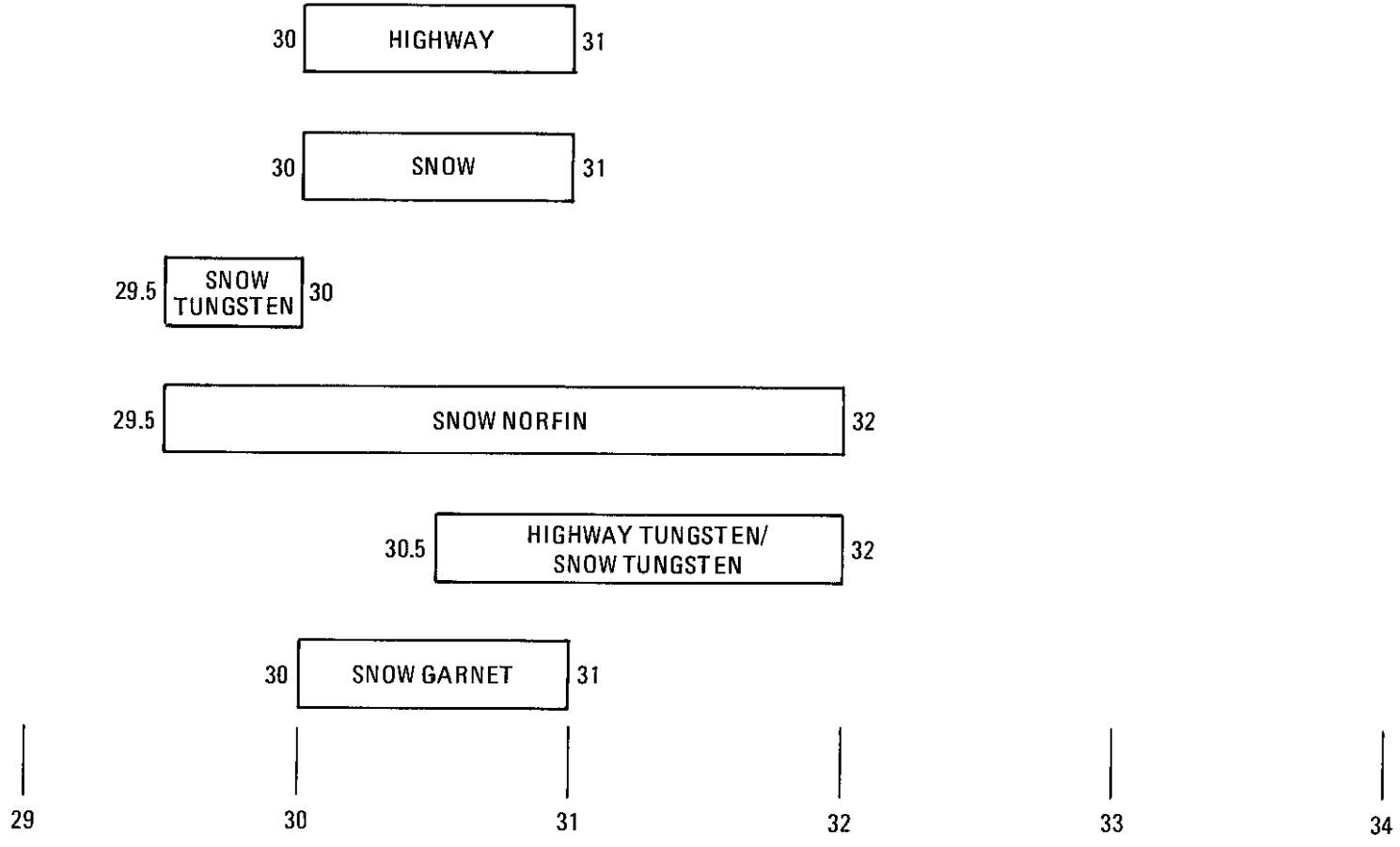


Figure 28

TIRE TRACTION TESTING

TEST NO. 2

HAIRPIN CURVE

WET PAVEMENT DOH VEHICLE

TYPE OF EXTREME SLIP

TIRE COMBINATION	TYPE SLIP
HIGHWAY	FRONT
SNOW	FRONT
SNOW TUNGSTEN	FRONT/REAR
SNOW NORFIN	REAR
HIGHWAY TUNGSTEN/ SNOW TUNGSTEN	FRONT
SNOW GARNET	FRONT/REAR

NOTE

FRONT SLIP INDICATES GOOD TRACTION BY REAR TIRES
REAR SLIP INDICATES POOR TRACTION BY REAR TIRES
FRONT/REAR SLIP INDICATES POOR TRACTION BY ALL FOUR TIRES

Table III

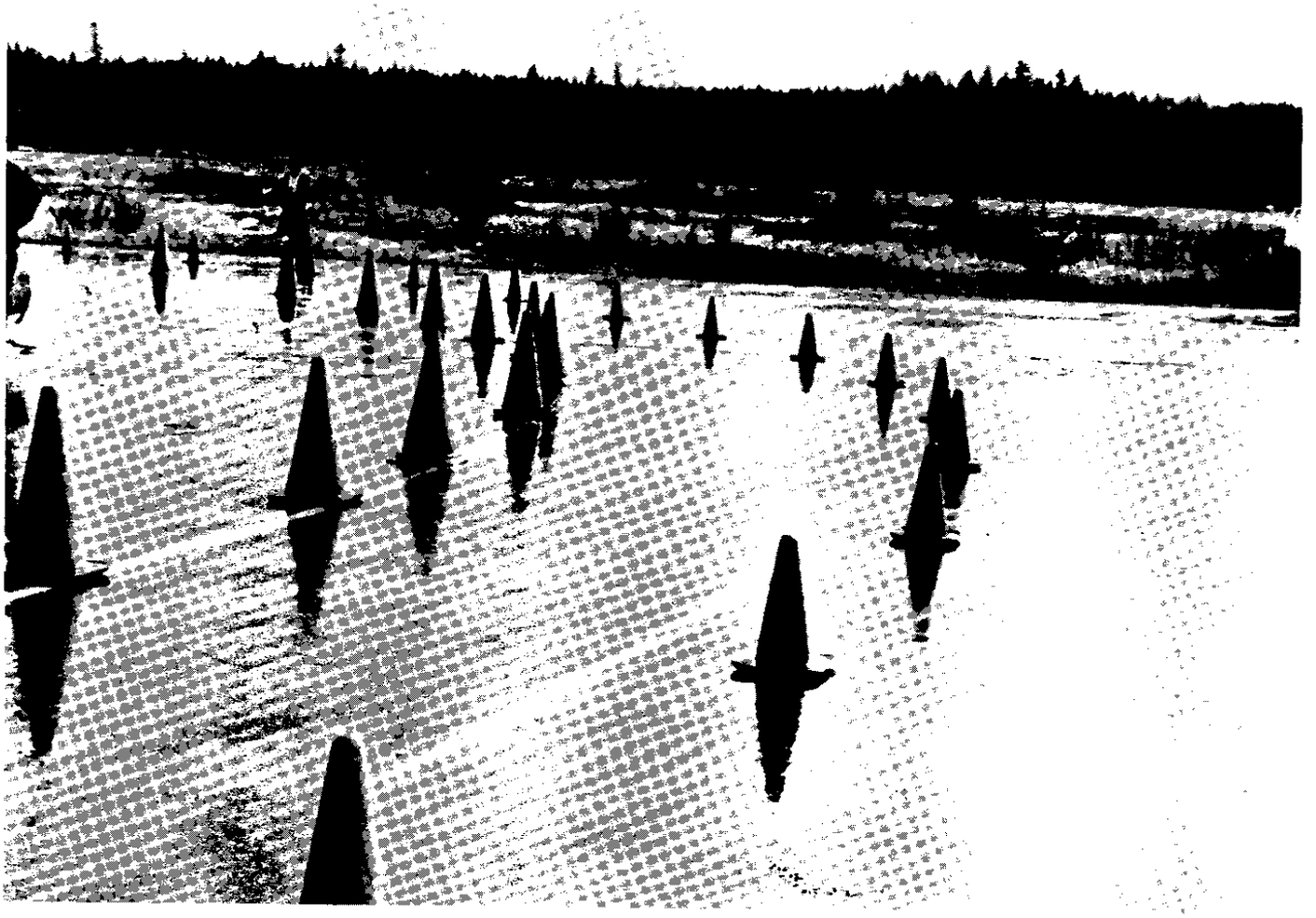


Figure 29: Wet Pavement Prior to Run at Hairpin Curve

TIRE TRACTION TESTING

TEST NO. 2
HAIRPIN CURVE

WET PAVEMENT

START SLIP

DOH VEHICLE

EXTREME SLIP

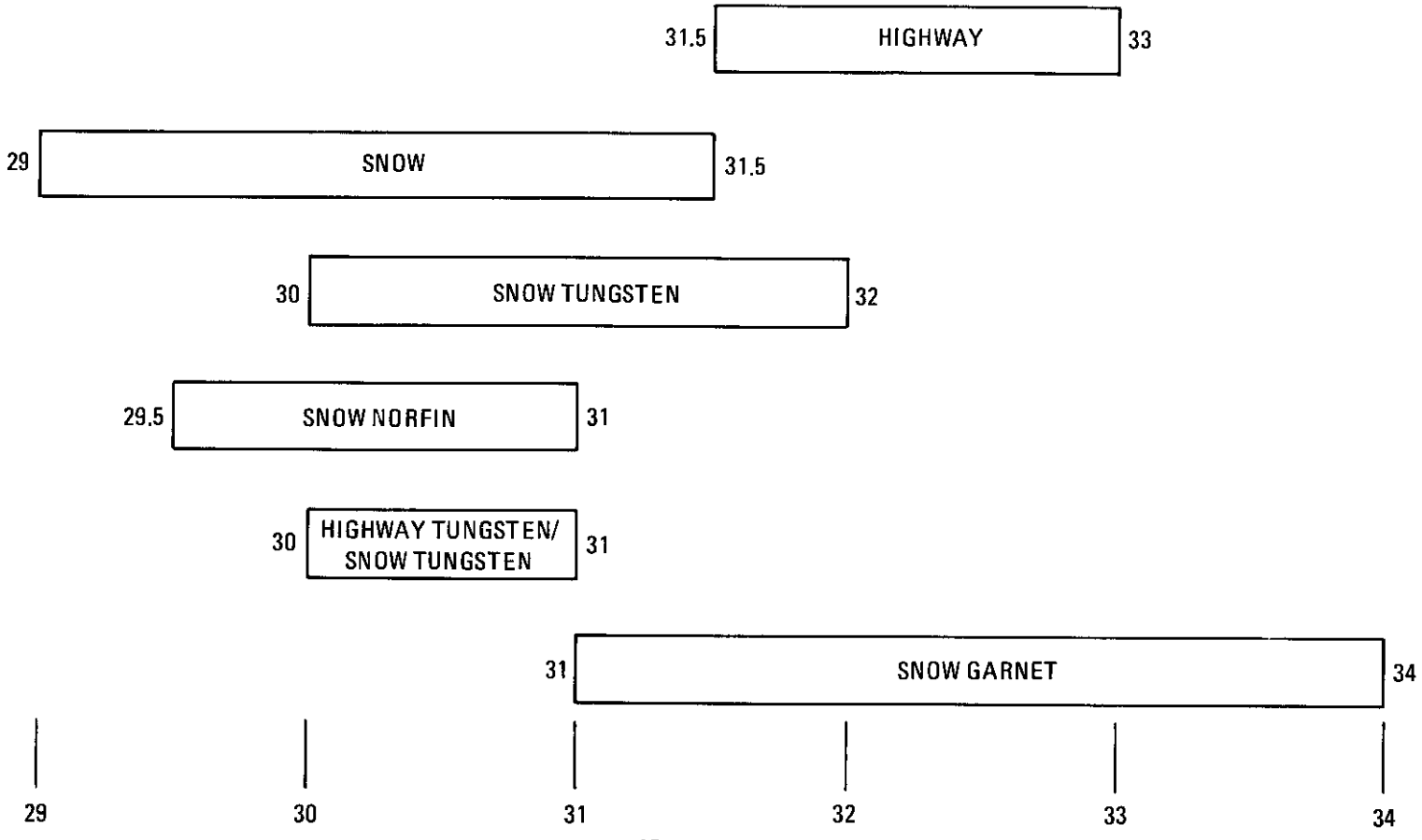


Figure 30

TIRE TRACTION TESTING

TEST NO. 2

HAIRPIN CURVE

DRY PAVEMENT DOH VEHICLE

TYPE OF EXTREME SLIP

TIRE COMBINATION	TYPE SLIP
HIGHWAY	FRONT
SNOW	REAR
SNOW TUNGSTEN	REAR
SNOW NORFIN	REAR
HIGHWAY TUNGSTEN/ SNOW TUNGSTEN	FRONT/REAR
SNOW GARNET	REAR

NOTE

FRONT SLIP INDICATES GOOD TRACTION BY REAR TIRES
REAR SLIP INDICATES POOR TRACTION BY REAR TIRES
FRONT/REAR SLIP INDICATES POOR TRACTION BY ALL FOUR TIRES

Table IV

TEST NO. 3 - HIGH SPEED LANE CHANGE - DRY PAVEMENT - WSP VEHICLE (Figure 31)

The high speed lane change tests are a good indicator of the traction of the various tire types as no noticeable slippage occurred at the front end of the vehicle, all of the slipping occurred at the rear.

The snow garnet combination performed better than the other combinations as to the speed when slinpage started and the highway combination, highway tungsten/snow tungsten combination and the snow garnet combination had equal performance at the speed where extreme slippage occurred and performed better than the other combinations. The highway combination started slipping at 55 mph and had extreme slippage at 63 mph. The snow combination started slipping at 55 mph, (the same speed as the highway combination) and had extreme slippage at 62 mph, (1 mph lower than the highway combination). The snow tungsten combination started slipping at 50 mph, (5 mph lower than the highway combination) and had extreme slippage at 62 mph, (1 mph lower than the highway combination). The snow Norfin combination started slipping at 53 mph, (2 mph lower than the highway combination) and had extreme slippage at 62 mph, (1 mph lower than the highway combination). The highway tungsten/snow tungsten combination started slipping at 53 mph, (2 mph lower than the highway combination) and had extreme slippage at 63 mph, (the same speed as the highway combination). The snow garnet combination started slipping at 58 mph, (3 mph higher than the highway combination) and had extreme slippage at 63 mph, (the same speed as the highway combination). (Figure 32).

TEST NO. 3 - HIGH SPEED LANE CHANGE - WET PAVEMENT - WSP VEHICLE

The highway combination performed better than the other combinations as

to the speed at which slippage started and also the speed when extreme slippage occurred. This combination started slipping at 59 mph and had extreme slippage at 69 mph. The snow combination started slipping at 55.5 mph, (3.5 mph lower than the highway combination) and had extreme slippage at 64 mph, (5 mph lower than the highway combination). The snow tungsten combination started slipping at 56 mph, (3 mph lower than the highway combination) and had extreme slippage at 65 mph, (4 mph lower than the highway combination). The snow Norfin combination started slipping at 50 mph, (9 mph lower than the highway combination) and had extreme slippage at 62 mph, (7 mph lower than the highway combination). The highway tungsten/snow tungsten combination started slipping at 56.5 mph, (2.5 mph lower than the highway combination) and had extreme slippage at 64 mph, (5 mph lower than the highway combination). The snow garnet combination started slipping at 57.5 mph, (1.5 mph lower than the highway combination) and had extreme slippage at 65 mph, (4 mph lower than the highway combination. (Figure 33).

This test maneuver is similar to a high speed lane change maneuver on a freeway. The vehicle reactions are similar to those which occur during normal driving conditions when an emergency condition occurs and the driver has to maneuver his vehicle to avoid a potential collision.

SUMMARY

Dry Pavement

1. The snow garnet combination performed better than the other combinations as to the speed where slippage first occurred.
2. The highway combination, highway tungsten/snow tungsten combination and the snow garnet combination had extreme slippage at the same

speed. This was faster than the snow combination, snow tungsten combination and snow Norfin combination.

Wet Pavement

1. The highway combination performed better than the other combinations at both the speed where slippage started and where extreme slippage occurred.
2. The snow Norfin combination was the poorest as to the speed where slippage started and extreme slippage occurred.

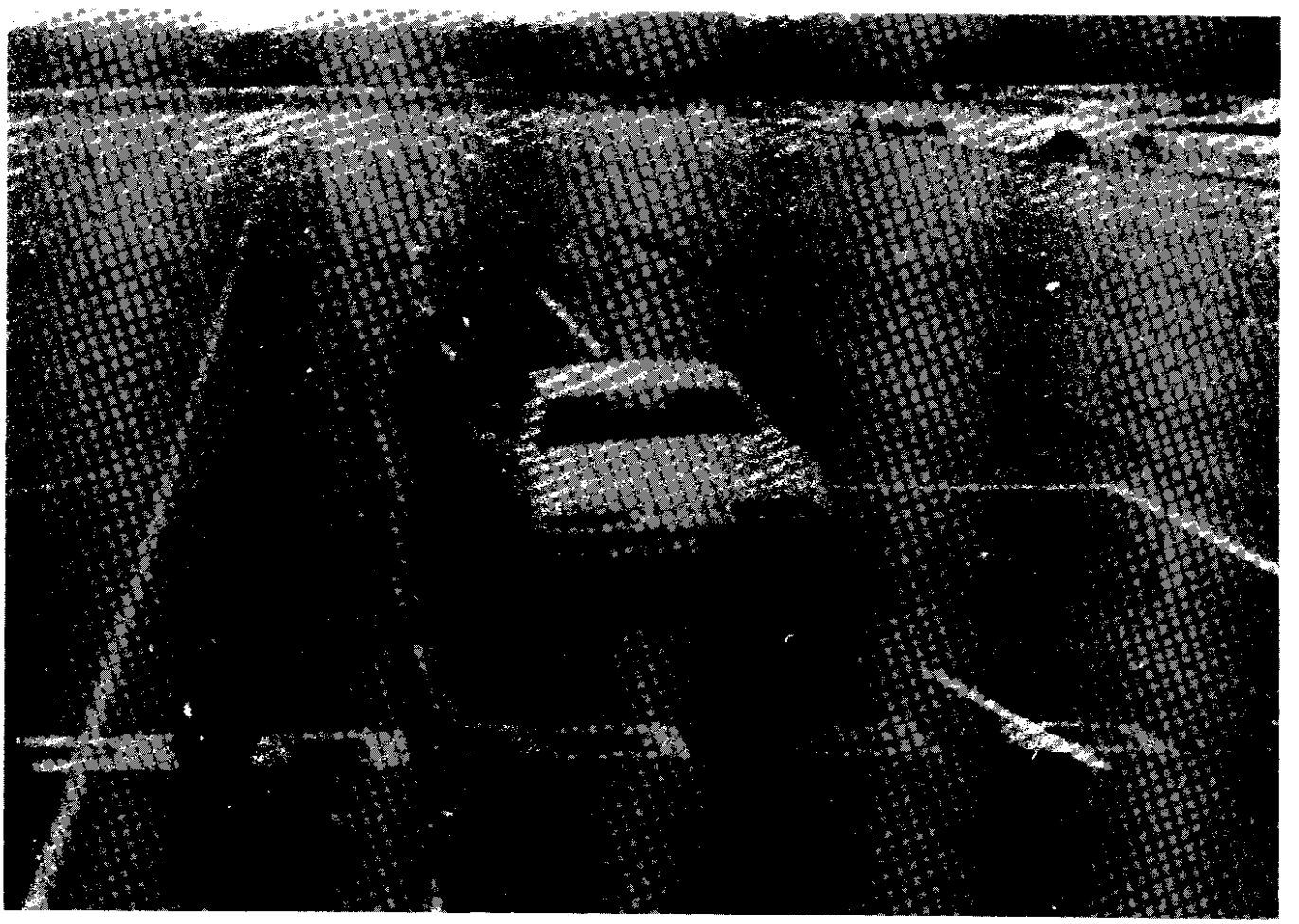


Figure 31: State Patrol Vehicle during High Speed Lane Change

TIRE TRACTION TESTING

TEST NO. 3

HIGH SPEED LANE CHANGE

DRY PAVEMENT

START SLIP

WSP VEHICLE

EXTREME SLIP

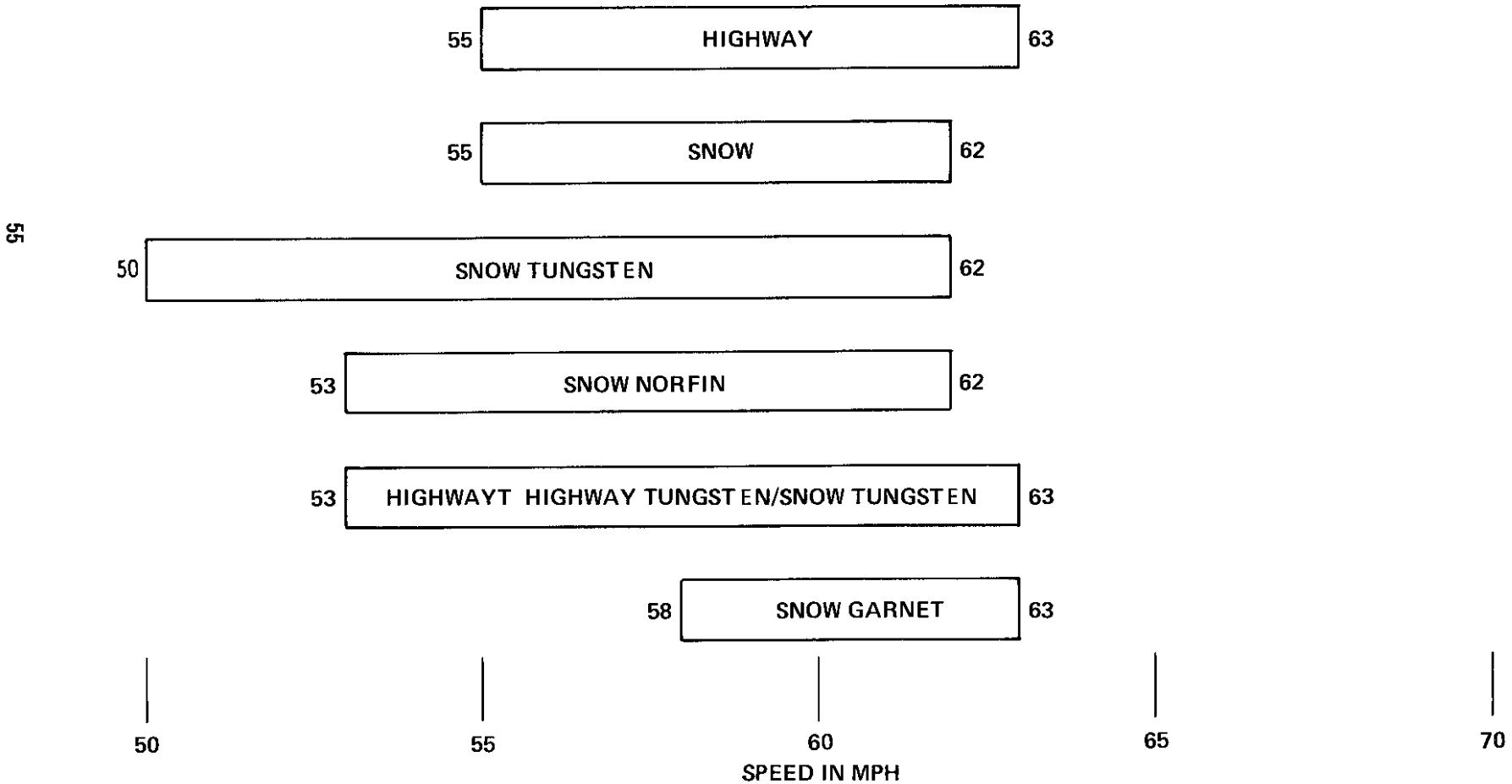


Figure 32

TIRE TRACTION TESTING

TEST NO. 3

HIGH SPEED LANE CHANGE

WET PAVEMENT

START SLIP

WSP VEHICLE

EXTREME SLIP

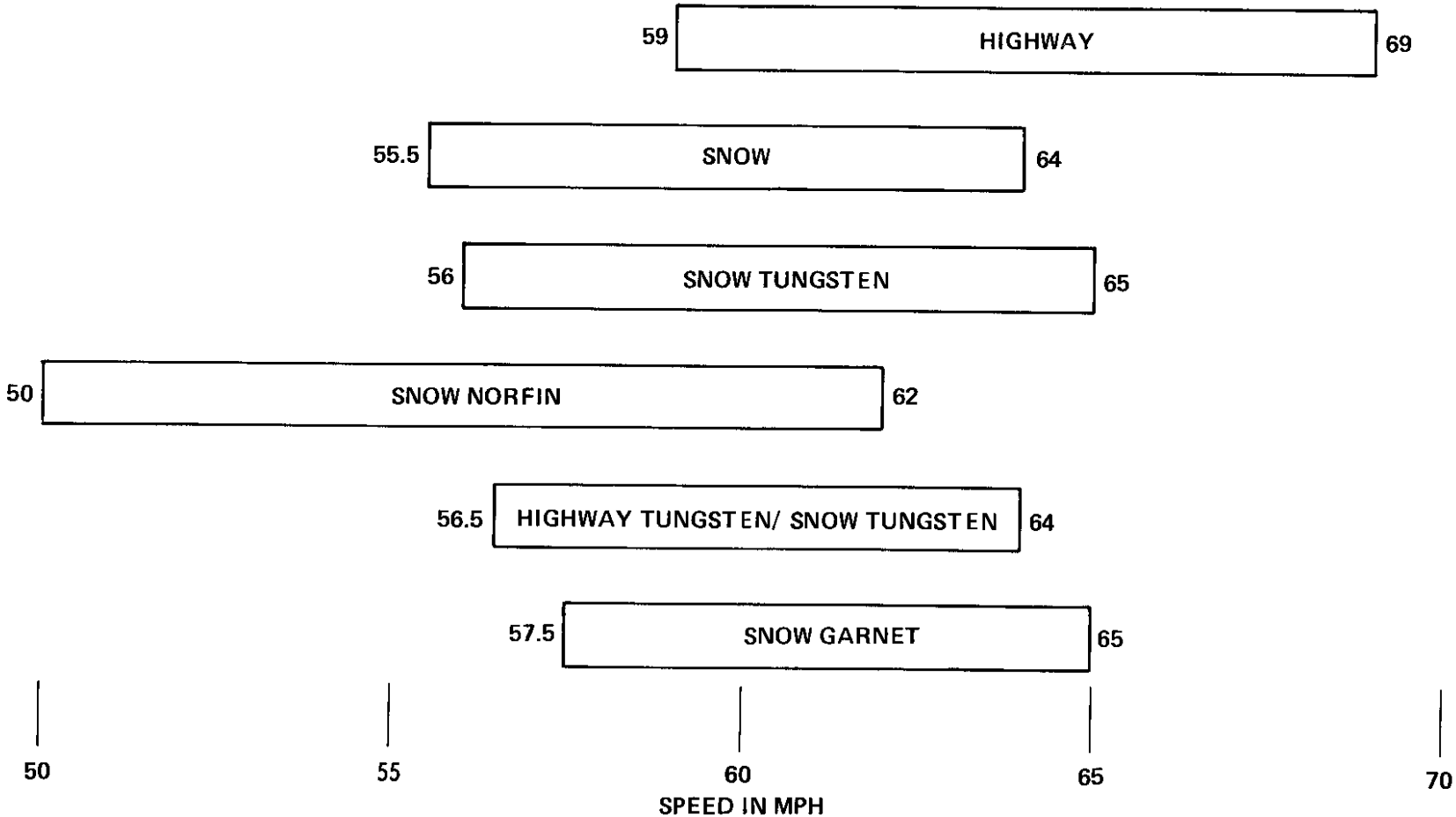


Figure 33

TEST NO. 4 - LOCKED-WHEEL STOP AT 35 MPH ON DRY PAVEMENT (figure 34)

The snow garnet combination was not tested during this stopping maneuver due to the extreme wear which occurred to the tire tread. The highway combination stopped in a shorter distance than the other tire combinations during the locked-wheel stopping tests at 35 mph on dry pavement. The stopping distance for the highway combination was 56'. The stopping distance for the snow combination was 61', (5' more than the highway combination). The stopping distance for the snow tungsten combination was 64', (9' more than the highway combination). The stopping distance for the snow Norfin combination was 61', (5' more than the highway combination). The stopping distance for the highway tungsten/snow tungsten combination was 63', (8' more than the highway combination). (Figure 35).

TEST NO. 4 - LOCKED-WHEEL STOP AT 50 MPH ON DRY PAVEMENT

The highway combination and snow combination performed equally well during the 50 mph dry pavement stops and stopped in a shorter distance than the other tire combinations. The highway garnet combination was not tested during the 50 mph stop tests due to the extreme wear to the tire tread. The highway combination and the snow combination both stopped at 126'. The snow tungsten combination stopped at 141', (15' more than the highway combination). The snow Norfin combination and the highway tungsten/snow tungsten combination both stopped at the same distance - 128', (2' more than the highway and snow combinations). (Figure 36).

TEST NO. 4 - LOCKED-WHEEL STOP AT 35 MPH ON WET PAVEMENT

The highway combination and the snow garnet combination both stopped in the same distance. Both stopped in a shorter distance than the other tire

combinations - 64'. The snow combination stopped in 76', (12' more than the highway combination). The snow tungsten combination stopped in 67', (3' more than the highway combination). The snow Norfin combination stopped in 70', (6' more than the highway combination). The highway tungsten/snow tungsten combination stopped in 69', (5' more than the highway combination). (Figure 37).

TEST NO. 4 - LOCKED-WHEEL STOP AT 50 MPH ON WET PAVEMENT

The highway combination stopped in a shorter distance than the other tire combinations during the stopping test at 50 mph. The highway combination stopped in 137'. The snow combination stopped in 154', (17' more than the highway combination). The snow tungsten combination and the snow Norfin combination stopped in 167', (30' more than the highway combination). The highway tungsten/snow tungsten combination stopped in 166', (29' more than the highway combination). The snow garnet combination stopped in 160', (23' more than the highway combination). (Figure 38).

SUMMARY

Dry Pavement

1. The highway combination stopped in a shorter distance than the other tire combinations during the dry stopping maneuver at 35 mph.
2. The highway and snow combinations stopped in the same distance during the 50 mph stopping maneuver on dry pavement. This was less distance than the other tire combinations.
3. The snow tungsten combination had the poorest performance during both the 35 mph stopping test and the 50 mph stopping test on dry pavement.

Wet Pavement

1. The highway and snow garnet combinations stopped in the same distance during the 35 mph stopping maneuver on wet pavement. This was shorter than the other tire combinations.
2. The highway combination stopped in a shorter distance during the 50 mph stopping maneuver on wet pavement than the other tire combinations.

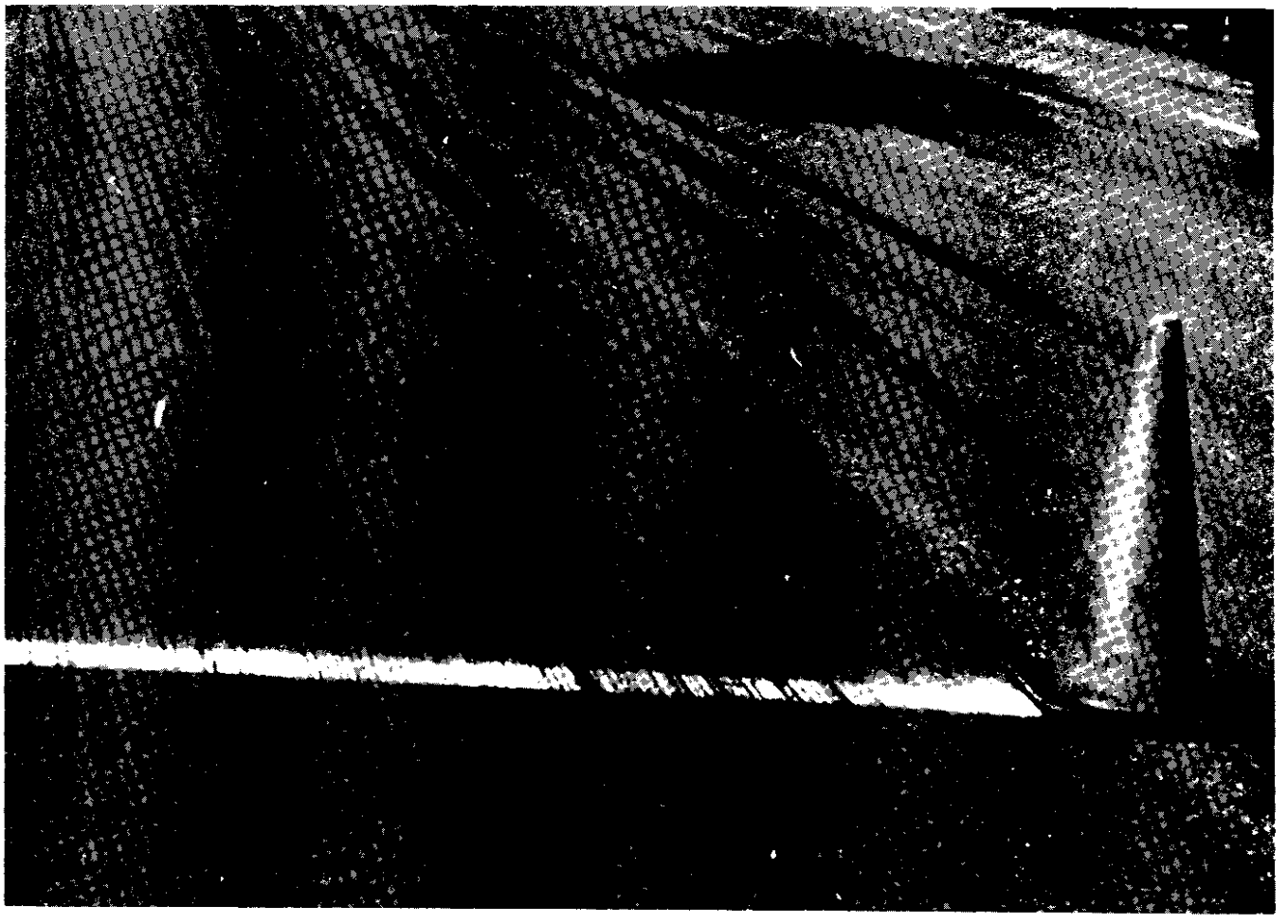


Figure 34: Locked-Wheel Stop - Pavement Conditions after Testing

TIRE TRACTION TESTING

TEST NO. 4

LOCKED WHEEL STOP

DRY PAVEMENT 35 MPH

DOH VEHICLE

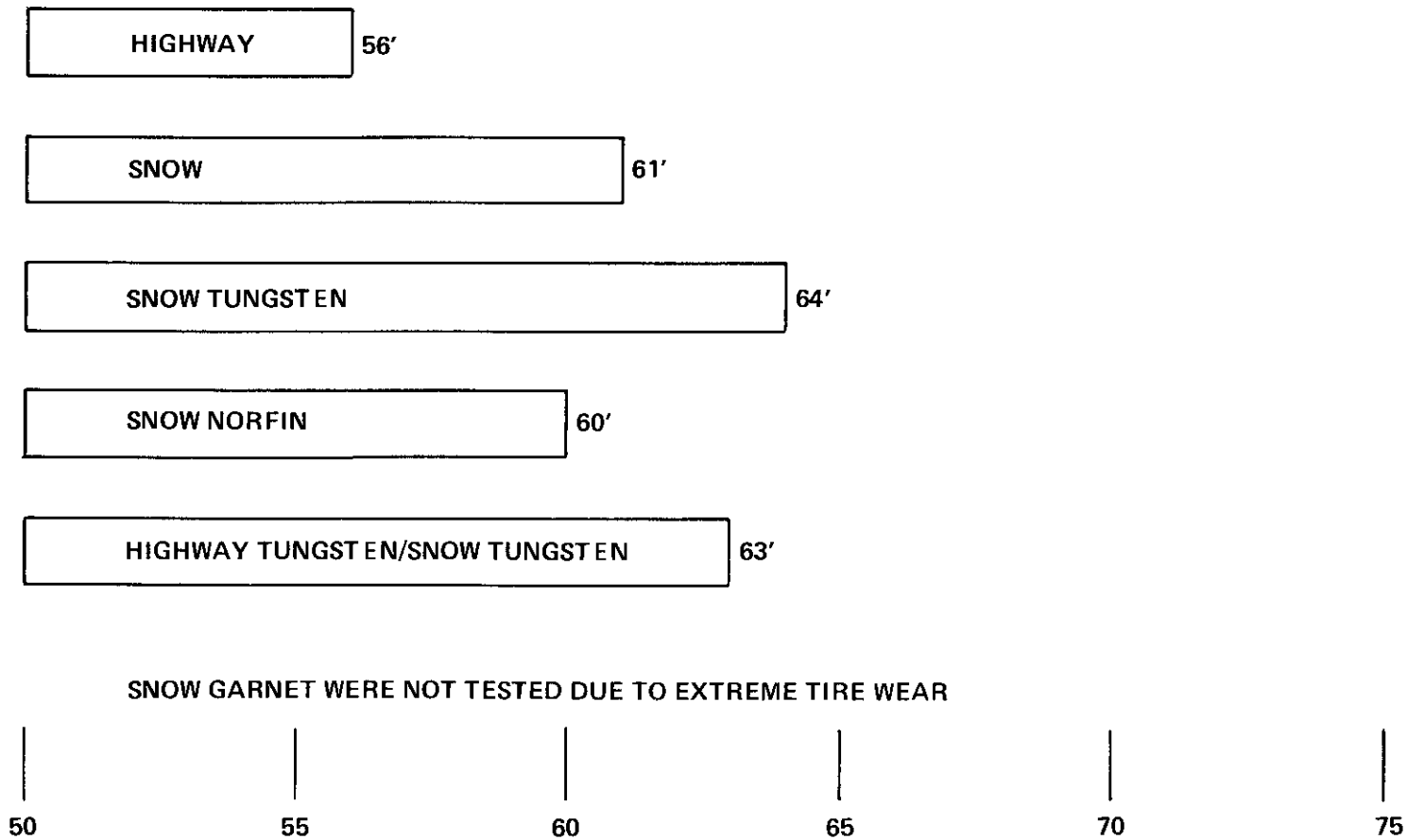


Figure 35

TIRE TRACTION TESTING

TEST NO. 4

LOCKED WHEEL STOP

DRY PAVEMENT 50 MPH

DOH VEHICLE

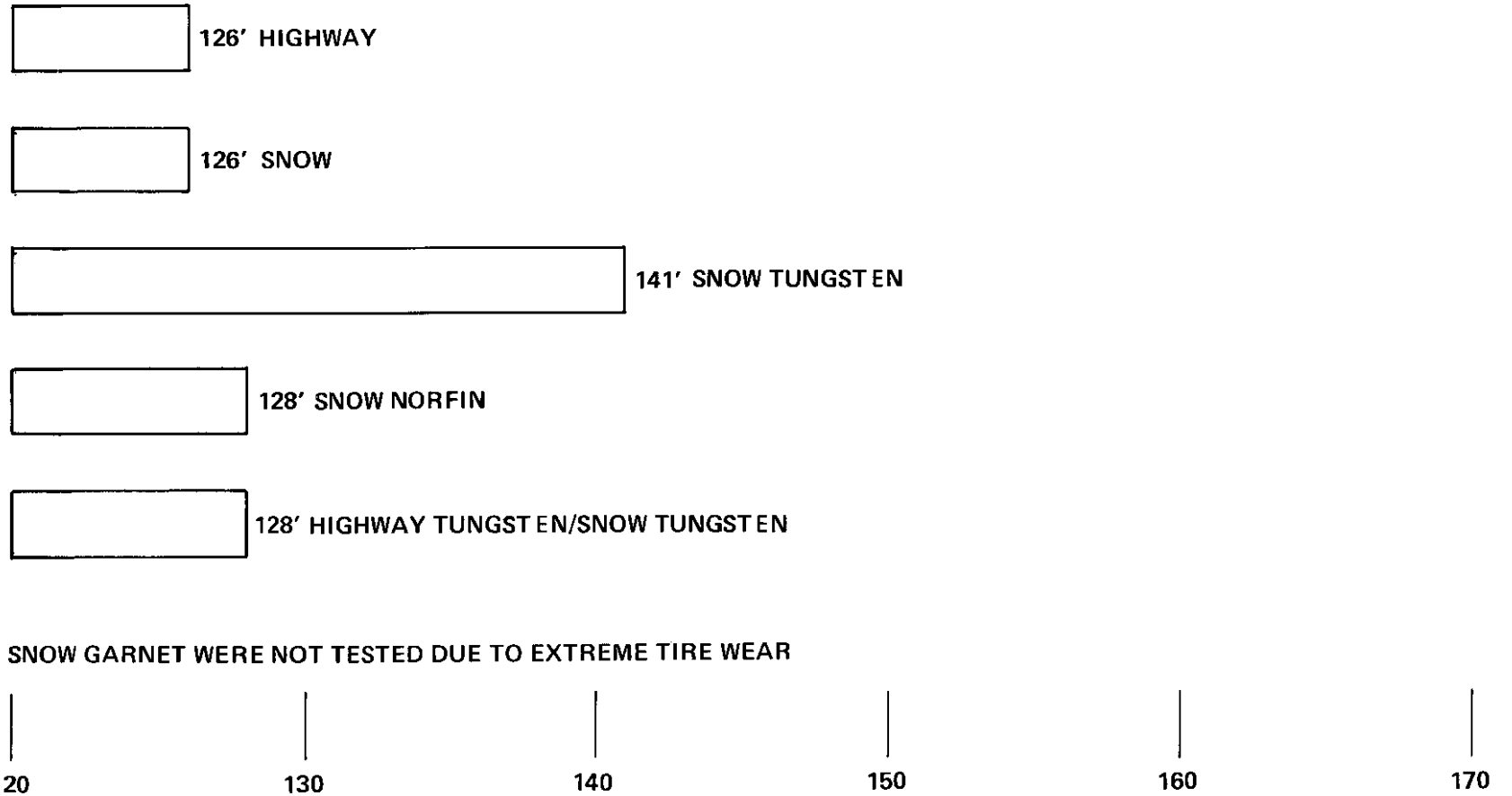


Figure 36

TIRE TRACTION TESTING

TEST NO. 4

LOCKED WHEEL STOP

WET PAVEMENT 35 MPH

DOH VEHICLE

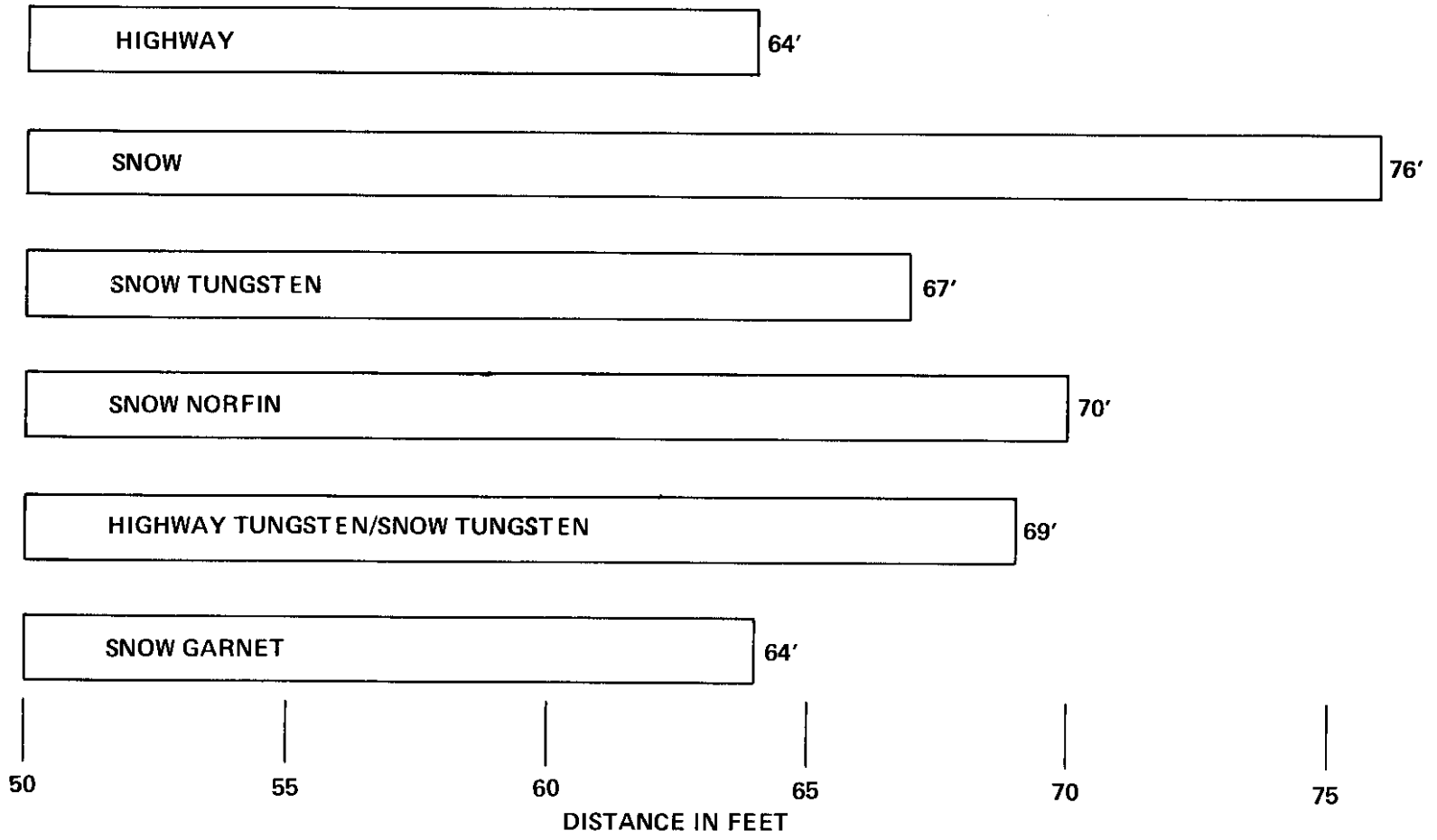


Figure 37

TIRE TRACTION TESTING

TEST NO. 4

LOCKED WHEEL STOP

WET PAVEMENT 50 MPH

DOH VEHICLE

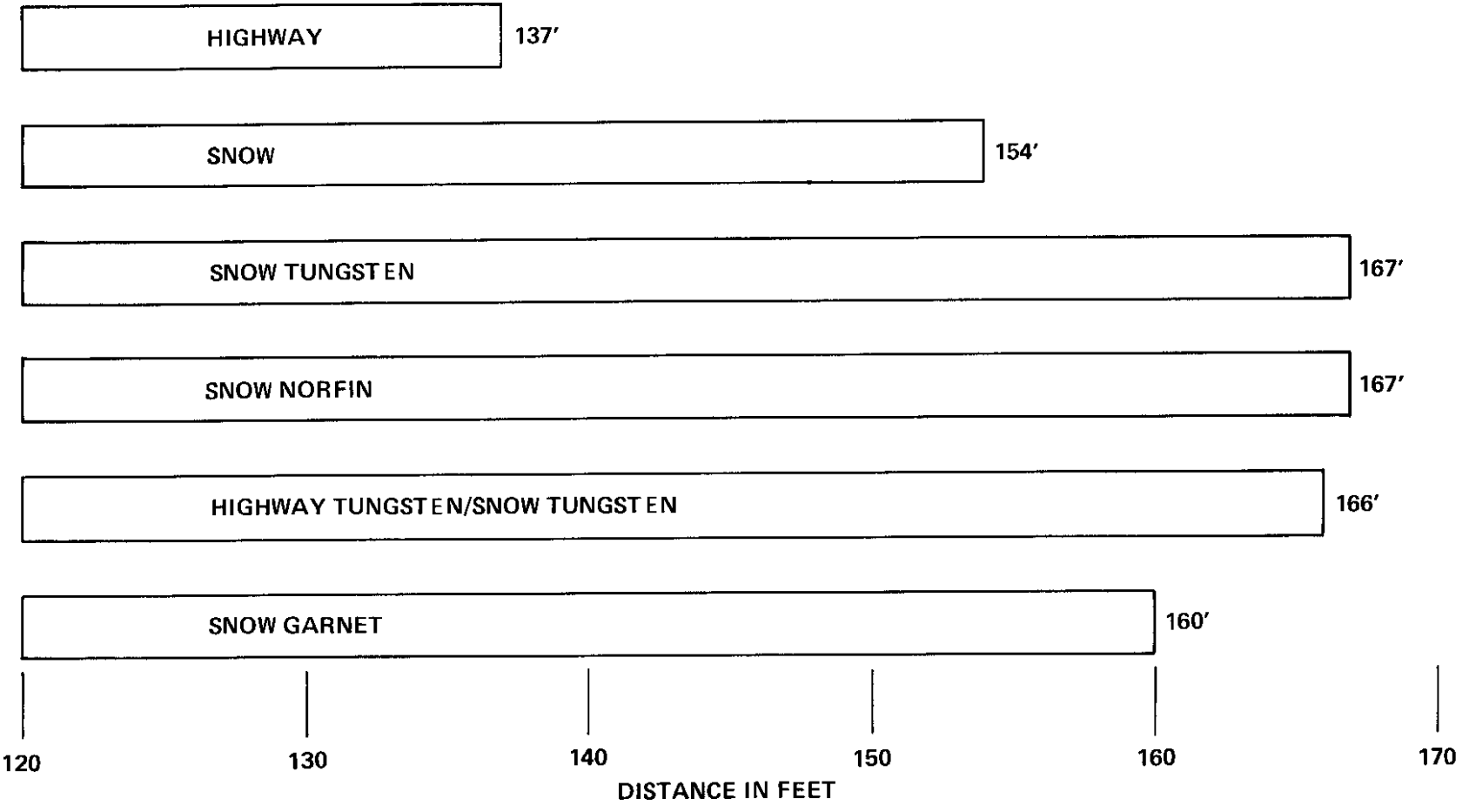


Figure 38

SECTION VI

Data - Washington State Patrol Vehicle

This chapter presents the data obtained for the Washington State Patrol Test vehicle. Only Tests No. 1, 2 and 4 will be discussed as Test No. 3 is discussed in Section V. The reaction of the State Patrol vehicle was slightly different than the Department of Highways' Motor Pool vehicle. The reason for this was that the gross weight of the Patrol vehicle was greater than the Motor Pool vehicle and the State Patrol vehicle had a police special suspension system with the weight distribution being about equal over both axles whereas the Motor Pool vehicle had the majority of weight over the front axle.

The data presented will be discussed using two approaches: (1) tire combination traction characteristics and (2) specific tire traction characteristics. Combination tire traction data was available from Tests No. 1, 2, and 4 and specific tire traction was available from Tests No. 1 and 2. The snow garnet tires were not used during these tests due to the lack of time.

Using the highway tread tires as a standard the following data is presented:

TEST NO. 1 - MANEUVERING - DRY PAVEMENT (figure 39)

The highway combination, snow combination snow tungsten combination and snow Norfin combination all started slipping at the same speed, 31 mph, (1 mph lower than the highway tungsten/snow tungsten combination).

The snow tungsten combination performed better than the other tire combinations as to the speed at which extreme slippage occurred, 35 mph, (1.5 mph higher than the highway combination). The highway combination had extreme

slippage at 33.5 mph. The snow combination had extreme slippage at 33 mph, (.5 mph lower than the highway combination). The snow Norfin combination had extreme slippage at 34 mph, (.5 mph higher than the highway combination). The highway tungsten/snow tungsten combination had extreme slippage at 32 mph, (1.5 mph lower than the highway combination). (Figure 40).

As discussed in Section V, there were two chutes used in this test maneuver. The type of slippage which occurred in each chute indicates whether particular tire types had good traction or were slipping. The highway combination had extreme rear end slippage in chute 1 which indicates poor rear tire traction and extreme front end slippage in chute 2 indicating good rear tire traction. The snow combination had extreme front end slippage in chute 1 which indicates good rear tire traction and extreme rear end slippage in chute 2 which indicates poor rear tire traction. The snow tungsten combination had extreme rear end slippage in chute 1 and 2 indicating poor rear tire traction in both chutes. The snow Norfin combination had extreme front and rear slippage in chute 1 which indicates poor traction by all four tires, and extreme rear end slippage in chute 2 indicating poor rear tire traction. The highway tungsten/snow tungsten combination had extreme front end slippage in chute 1 and 2 which indicates good traction by the rear tires in both chutes (Table V).

In chute 1 the snow tires and the highway tungsten/snow tungsten tires had better traction in the rear than the other tire types and the highway tires, snow tungsten tires, and snow garnet tires had poorer traction. The snow Norfin combination had equally poor traction both front and rear which resulted in all four tires slipping at the same time causing

total loss of control. In chute 2 the highway tires and highway tungsten/snow tungsten tires had better traction than the other tire types.

TEST NO. 1 - MANEUVERING - WET PAVEMENT

The highway combination and the snow combination performed better than the other tire combinations as to the speed at which slippage first occurred. The snow tungsten combination performed better than the other tire combinations as to the speed where extreme slippage occurred. The highway combination and the snow combination started slipping at the same speed, 30 mph, and had extreme slippage at the same speed, 33 mph. The snow tungsten combination started slipping at 29.5 mph, (.5 mph lower than the highway combination) and had extreme slippage at 34 mph, (1 mph higher than the highway combination). The snow Norfin combination started slipping at 29 mph, (1 mph lower than the highway combination) and had extreme slippage 33.5 mph, (.5 mph higher than the highway combination). The highway tungsten/snow tungsten combination started slipping at 27 mph, (3 mph lower than the highway combination) and had extreme slippage at 32 mph, (1 mph lower than the highway combination). (Figure 41).

The type of slippage which occurred during the maneuvering tests on wet pavement again indicates the type (good or poor) of traction for the specific tire types. The highway combination had extreme slippage both front and rear in chute 1 and extreme slippage in the front in chute 2 which indicates poor traction on all four tires in chute 1 and good traction by the rear tires in chute 2. The snow combination had extreme slippage in the rear in chute 1 and extreme slippage in the front and rear in chute 2, which indicates the rear tires had poor traction in chute 1 and all four tires

had poor traction in chute 2. The snow tungsten combination had extreme slippage in the front and rear in both chute 1 and 2 which indicates poor traction by all four tires in both chutes. The snow Norfin combination had extreme slippage front and rear in chute 1 and extreme slippage in the rear in chute 2 which indicates poor traction on all four tires in chute 1 and poor traction on the rear tires in chute 2. The highway tungsten/snow tungsten combination had extreme slippage in the front in both chute 1 and 2 which indicates that the rear tires had good traction in both chutes (Table VI).

SUMMARY

Dry Pavement

1. The data indicates that all tire combinations tested had relatively equal performance at the speed where slippage first occurred.
2. The snow tungsten combination performed better than the other tire combinations as to the speed at which extreme slippage occurred.

Wet Pavement

1. The highway combination and snow combination performed better than the other tire combinations as to the speed where slippage first occurred.
2. The snow tungsten combination performed better than the other tire combinations as to the speed where extreme slippage occurred.

Figure 39: State Patrol Vehicle out of Chute 1 going into Chute 2 during Maneuvering Test on Dry Pavement

TIRE TRACTION TESTING

TEST NO. 1

MANEUVERING

DRY PAVEMENT

START SLIP

WSP VEHICLE

EXTREME SLIP

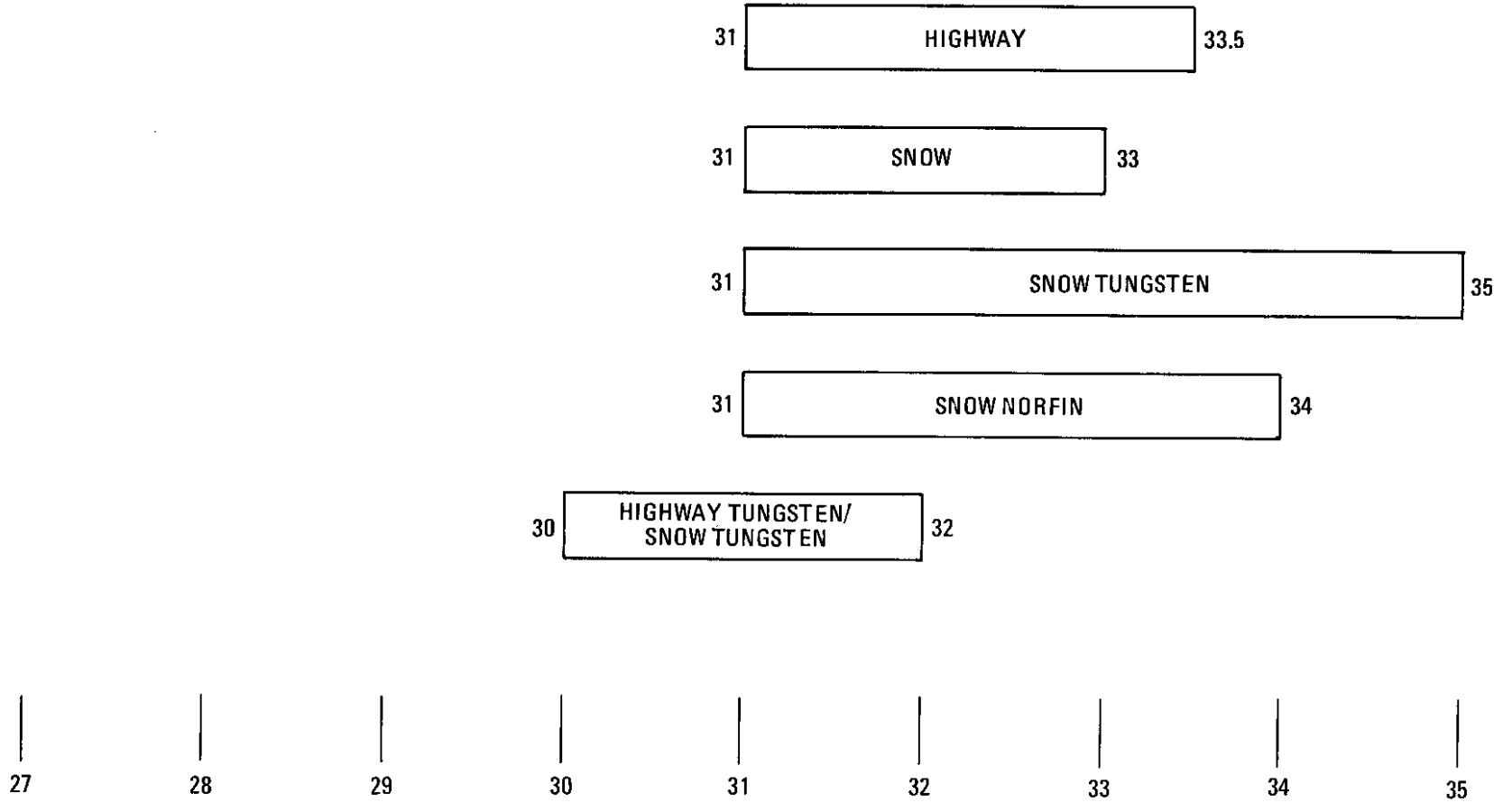


Figure 40

TIRE TRACTION TESTING

TEST NO. 1

MANEUVERING

DRY PAVEMENT

WSP VEHICLE

TYPE OF EXTREME SLIP

TIRE COMBINATION	CHUTE NO. 1	CHUTE NO. 2
HIGHWAY	REAR	FRONT
SNOW	FRONT	REAR
SNOW TUNGSTEN	REAR	REAR
SNOW NORFIN	FRONT/REAR	REAR
HIGHWAY TUNGSTEN/ SNOW TUNGSTEN	FRONT	FRONT

NOTE

FRONT SLIP INDICATES GOOD TRACTION BY REAR TIRES
REAR SLIP INDICATES POOR TRACTION BY REAR TIRES
FRONT/REAR SLIP INDICATES POOR TRACTION BY ALL FOUR TIRES

Table V

TIRE TRACTION TESTING

TEST NO. 1

MANEUVERING

WET PAVEMENT

WSP VEHICLE

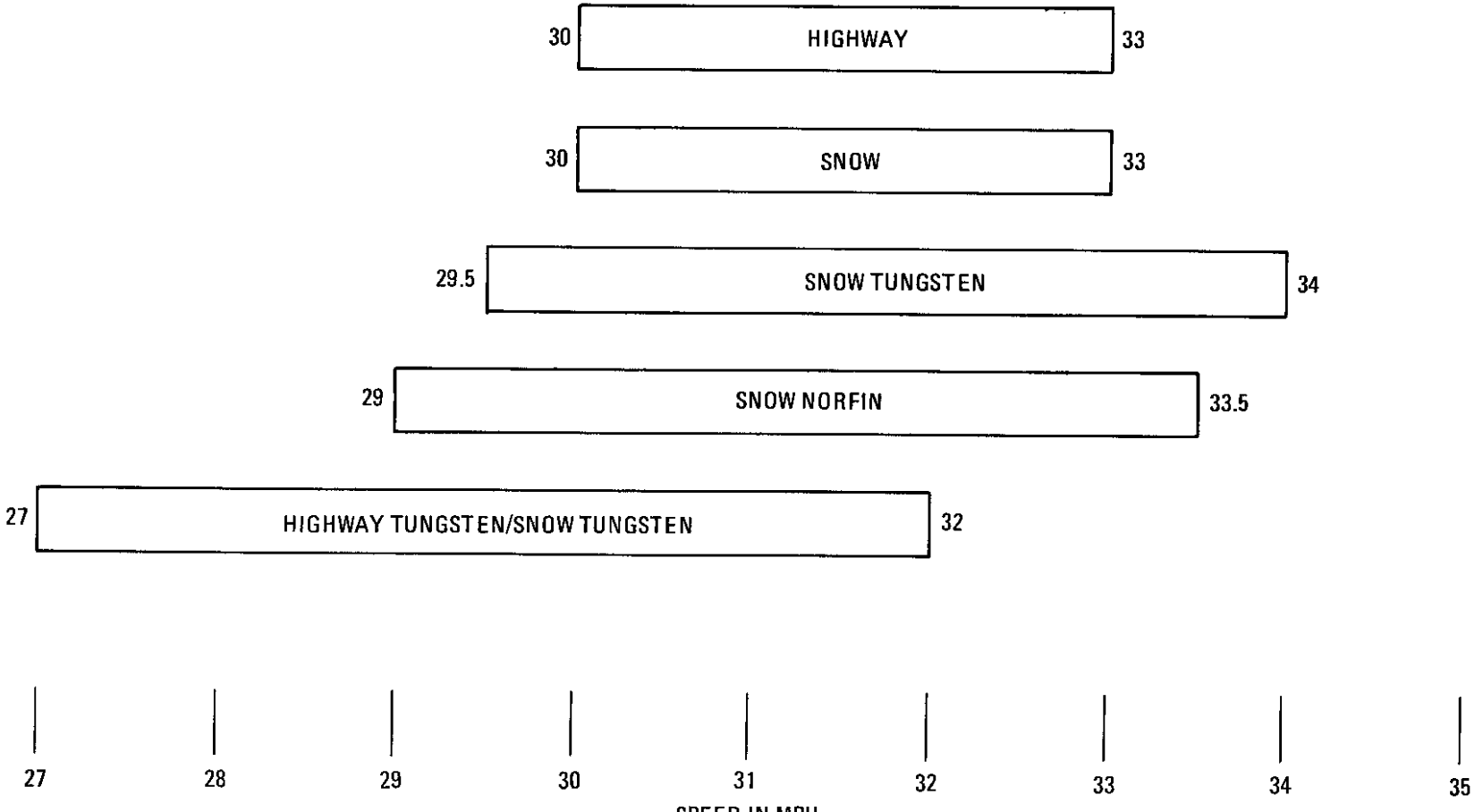


Figure 41

TIRE TRACTION TESTING

TEST NO. 1

MANEUVERING

WET PAVEMENT

WSP VEHICLE

TYPE OF EXTREME SLIP

TIRE COMBINATION	CHUTE NO. 1	CHUTE NO. 2
HIGHWAY	FRONT/REAR	FRONT
SNOW	REAR	FRONT/REAR
SNOW TUNGSTEN	FRONT/REAR	FRONT/REAR
SNOW NORFIN	FRONT/REAR	REAR
HIGHWAY TUNGSTEN/ SNOW TUNGSTEN	FRONT	FRONT

NOTE

FRONT SLIP INDICATES GOOD TRACTION BY REAR TIRES
REAR SLIP INDICATES POOR TRACTION BY REAR TIRES
FRONT/REAR SLIP INDICATES POOR TRACTION BY ALL FOUR TIRES

Table VI

TEST NO. 2 - HAIRPIN CURVE - DRY PAVEMENT (Figures 42, 43 & 44)

The highway combination performed better than the other tire combinations during the hairpin curve test on dry pavement. The highway combination started to slip at 33 mph and had extreme slippage at 34 mph. The snow combination started slipping at 30.5 mph, (2.5 mph lower than the highway combination) and had extreme slippage at 31 mph, (3 mph lower than the highway combination). The snow tungsten combination started slipping at 30 mph, (3 mph lower than the highway combination) and had extreme slippage at 32 mph, (2 mph lower than the highway combination). The snow Norfin combination started slipping at 30 mph, (3 mph lower than the highway combination) and had extreme slippage at 32 mph, (2 mph lower than the highway combination). The highway tungsten/snow tungsten combination started slipping at 31 mph, (2 mph lower than the highway combination) and had extreme slippage at 33 mph, (1 mph lower than the highway combination). (Figure 45).

Again, the type of slippage indicates whether a specific tire type had good or poor traction during the hairpin curve test on dry pavement. The highway combination had extreme slippage in the rear which indicates poor traction by the rear tires. The snow combination had extreme slippage in the front which indicates good traction by the rear tires. The snow tungsten combination and the snow Norfin combination both had extreme slippage in the rear indicating poor rear tire traction. The highway tungsten/snow tungsten combination had extreme slippage on all four tires which indicates that all of the tires had poor traction (Table VII).

TEST NO. 2 - HAIRPIN CURVE - WET PAVEMENT (Figure 46)

The highway combination performed better than the other tire combinations as to the speed at which slippage first occurred. The highway combination

and the highway tungsten/snow tungsten combination had extreme slippage at the same speed, both performed better than the other tire combinations. The highway combination started slipping at 32.5 mph and had extreme slippage at 34 mph. The snow combination started slipping at 30.5 mph, (2 mph lower than the highway combination) and had extreme slippage at 32 mph, (2 mph lower than the highway combination). The snow tungsten combination started slipping at 30.5 mph, (2 mph lower than the highway combination) and had extreme slippage at 33 mph, (1 mph lower than the highway combination). The snow Norfin combination started slipping at 30 mph, (2.5 mph lower than the highway combination) and had extreme slippage at 31 mph, (3 mph lower than the highway combination). The highway tungsten/snow tungsten combination started slipping at 31 mph, (1.5 mph lower than the highway combination) and had extreme slippage at 34 mph, the same speed as the highway combination (Figure 47).

The type of slippage that occurred again indicates whether a specific tire type had good or poor traction during the hairpin curve maneuver on wet pavement. The highway combination had extreme slippage in the front which indicates good traction by the rear tires. The snow combination and snow tungsten combination both had extreme slippage in the rear which indicates poor traction by the rear tires. The snow Norfin combination had extreme slippage in the front indicating good traction by the rear tires. The highway tungsten/snow tungsten combination had extreme slippage both front and rear indicating equally poor tire traction on all four tires (Table VIII).

SUMMARY

Dry Pavement

1. The highway combination performed better than the other tire combinations

at both the speed where slip first started and where extreme slippage occurred.

Wet Pavement

1. The highway combination performed better than the other tire combinations as to the speed at which slippage first occurred.
2. The highway combination and the highway tungsten/snow tungsten combination both performed better than the other tire combinations as to the speed where extreme slippage occurred.

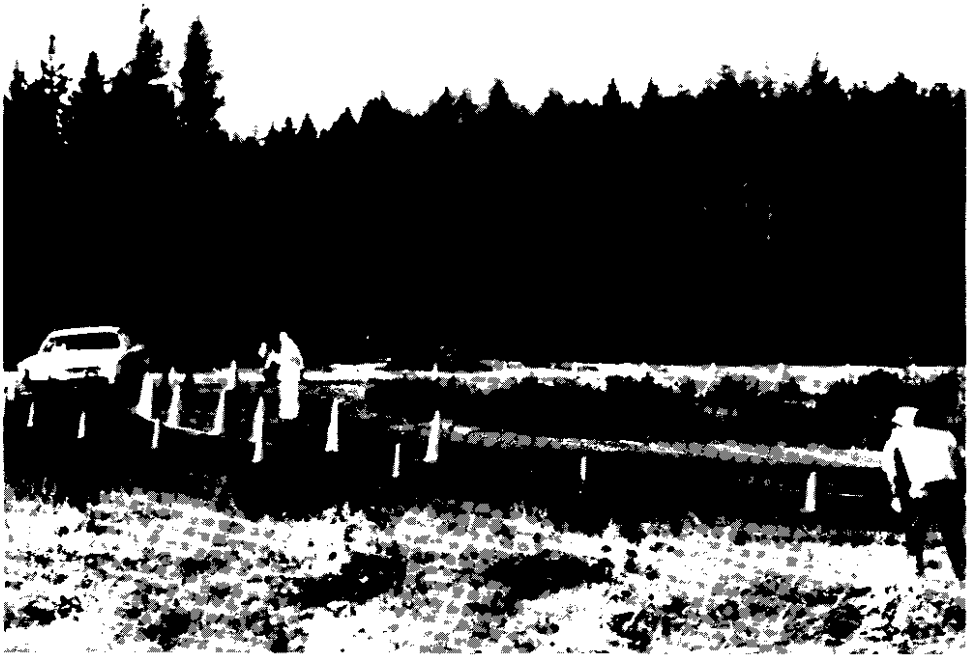


Figure 42: Hairpin Curve
Washington State Patrol Vehicle
Dry Pavement

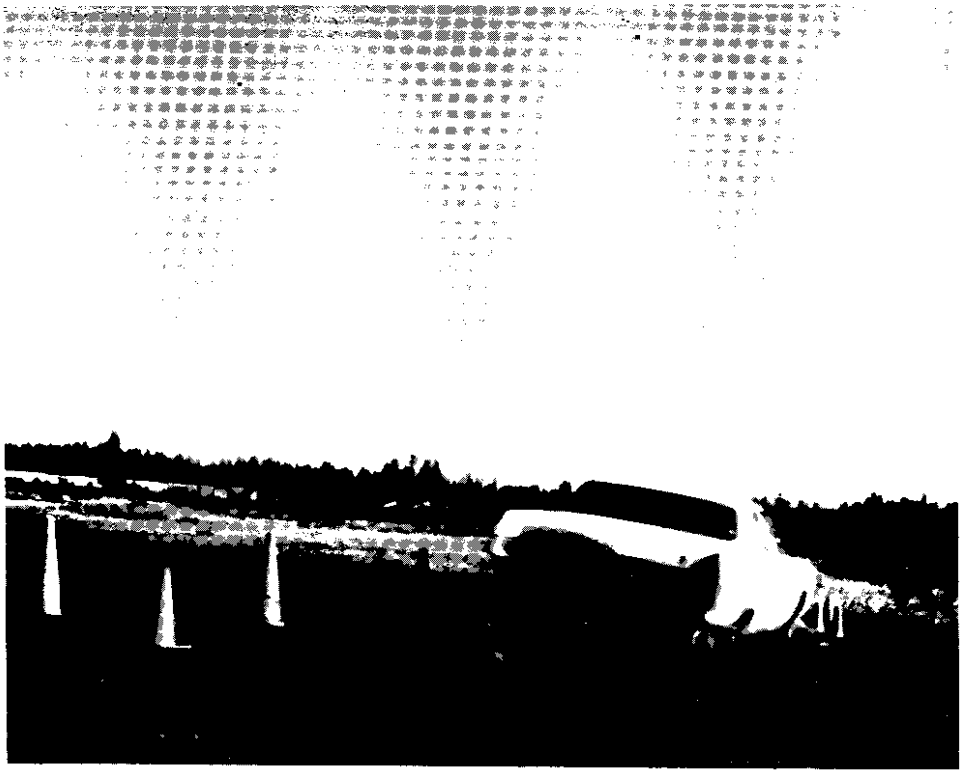


Figure 43: Hairpin Curve
Washington State Patrol Vehicle
Dry Pavement

TIRE TRACTION TESTING

TEST NO. 2

HAIRPIN CURVE

DRY PAVEMENT

START SLIP

WSP VEHICLE

EXTREME SLIP

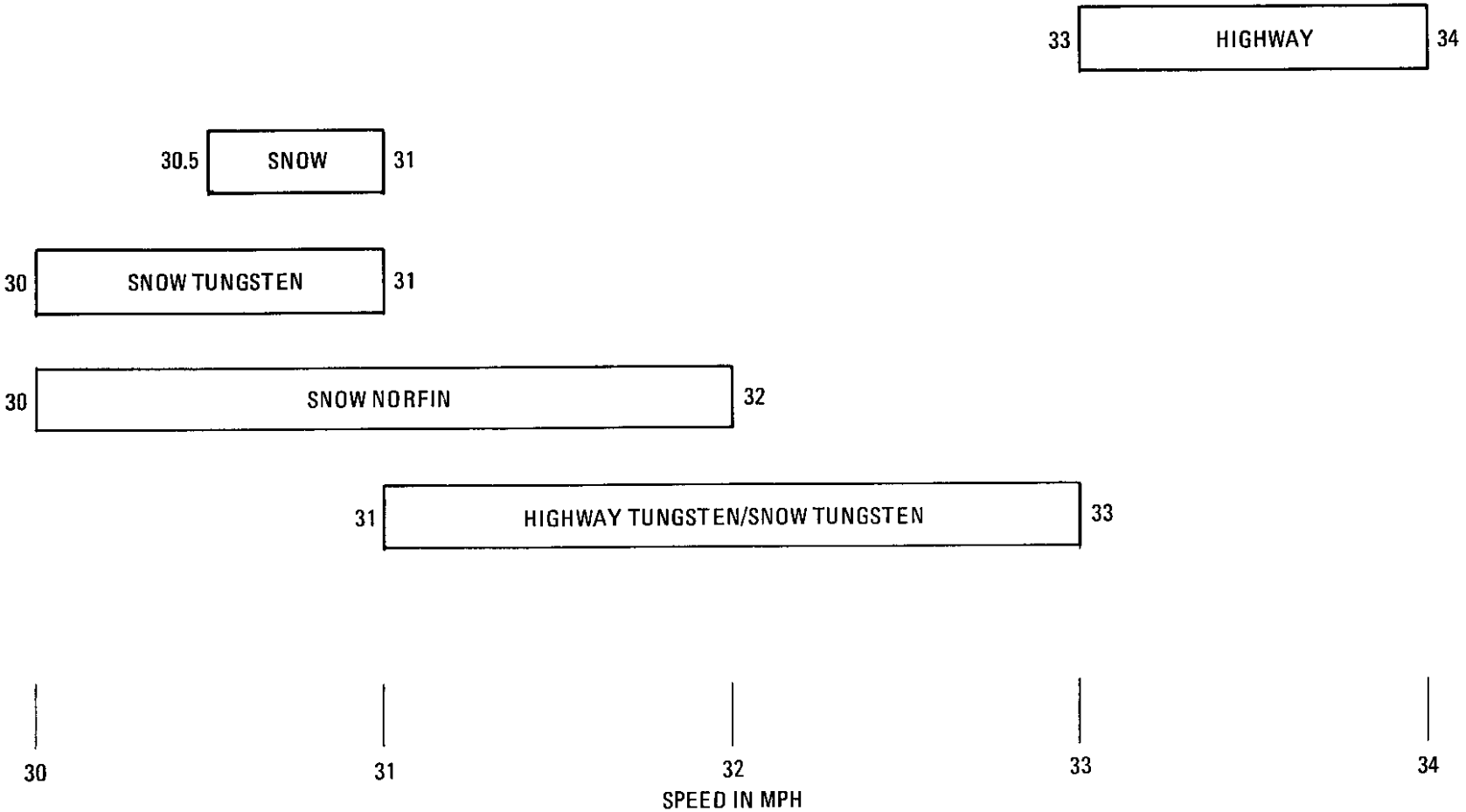


Figure 44

TIRE TRACTION TESTING

TEST NO. 2

DRY PAVEMENT

WSP VEHICLE

TYPE OF EXTREME SLIP

TIRE COMBINATION	TYPE SLIP
HIGHWAY	REAR
SNOW	FRONT
SNOW TUNGSTEN	REAR
SNOW NORFIN	REAR
HIGHWAY TUNGSTEN/ SNOW TUNGSTEN	FRONT/REAR

NOTE

FRONT SLIP INDICATES GOOD TRACTION BY REAR TIRES
REAR SLIP INDICATES POOR TRACTION BY REAR TIRES
FRONT/REAR SLIP INDICATES POOR TRACTION BY ALL FOUR TIRES

Table VII

Figure 45: Washington State Patrol Vehicle making test run on wet pavement at hairpin curve

TIRE TRACTION TESTING

TEST NO. 2

HAIRPIN CURVE

WET PAVEMENT

START SLIP

WSP VEHICLE

EXTREME SLIP

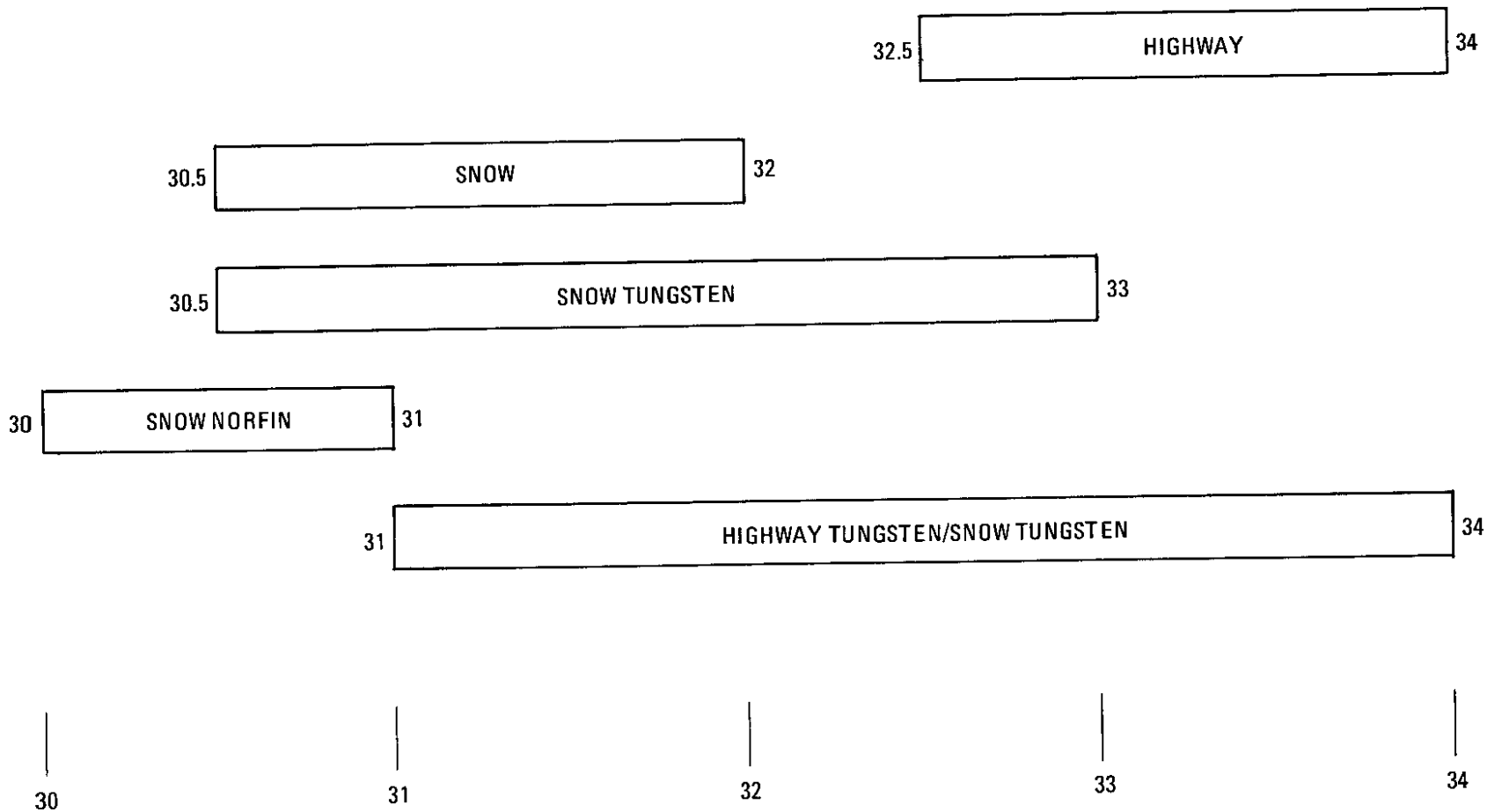


Figure 46

TIRE TRACTION TESTING

TEST NO. 2

WET PAVEMENT

WSP VEHICLE

TYPE OF EXTREME SLIP

TIRE COMBINATION	TYPE SLIP
HIGHWAY	FRONT
SNOW	REAR
SNOW TUNGSTEN	REAR
SNOW NORFIN	FRONT
HIGHWAY TUNGSTEN/ SNOW TUNGSTEN	FRONT/REAR

NOTE

FRONT SLIP INDICATES GOOD TRACTION BY REAR TIRES
REAR SLIP INDICATES POOR TRACTION BY REAR TIRES
FRONT/REAR SLIP INDICATES POOR TRACTION BY ALL FOUR TIRES

Table VIII

TEST NO. 4 - LOCKED-WHEEL STOP - DRY PAVEMENT AT 35 MPH

The snow combination stopped in a shorter distance than the other tire combinations during the stopping tests at 35 mph on dry pavement. The highway combination stopped at a distance of 48', (5' more than the snow combination - 43'). The snow tungsten combination stopped at a distance of 49', (1' more than the highway combination). The snow Norfin combination stopped at a distance of 47', (1' less than the highway combination) and the highway tungsten/snow tungsten combination stopped at 52', (4' more than the highway combination). (Figure 48).

TEST NO. 4 - LOCKED-WHEEL STOP - WET PAVEMENT AT 35 MPH

The highway combination stopped in a shorter distance than the other tire combinations during the stopping maneuver at 35 mph on wet pavement. The highway combination stopped in a distance of 54'. The snow combination stopped in a distance of 59', (5' more than the highway combination). The snow tungsten combination stopped in 60', (6' more than the highway combination). The snow Norfin combination stopped in 64', (10' more than the highway combination) and the highway tungsten/snow tungsten combination stopped in 67', (13' more than the highway combination). (Figure 49).

TEST NO. 4 - LOCKED-WHEEL STOP - DRY PAVEMENT AT 50 MPH

Due to severe bouncing and control problems of the State Patrol vehicle during the dry pavement stopping tests at 50 mph, the tests were cancelled and no data obtained.

TEST NO. 4 - LOCKED-WHEEL STOP - WET PAVEMENT AT 50 MPH (Figure 50)

The highway combination stopped in a shorter distance than the other tire combinations during the stopping tests at 50 mph on wet pavement. The

highway combination stopped in a distance of 116'. The snow combination stopped in a distance of 139', (23' more than the highway combination). The snow tungsten combination stopped at 137', (21' more than the highway combination); the snow Norfin combination stopped at 149', (33' more than the highway combination) and the highway tungsten/snow tungsten combination stopped in a distance of 151', (35' more than the highway combination). (Figure 51).

SUMMARY

Dry Pavement

1. The snow combination stopped in a shorter distance than the other tire combinations during the stopping maneuver on dry pavement at 35 mph.
2. The stopping maneuver at 50 mph on dry pavement was not conducted due to severe bouncing and control problems of the vehicle.

Wet Pavement

1. The highway combination stopped in a shorter distance than the other tire combinations during the stopping maneuver on wet pavement at 35 mph.
2. The highway combination stopped in a shorter distance than the other tire combinations during the stopping maneuver on wet pavement at 50 mph.

TIRE TRACTION TESTING

TEST NO. 4

LOCKED WHEEL STOP

DRY PAVEMENT 35 MPH

WSP VEHICLE

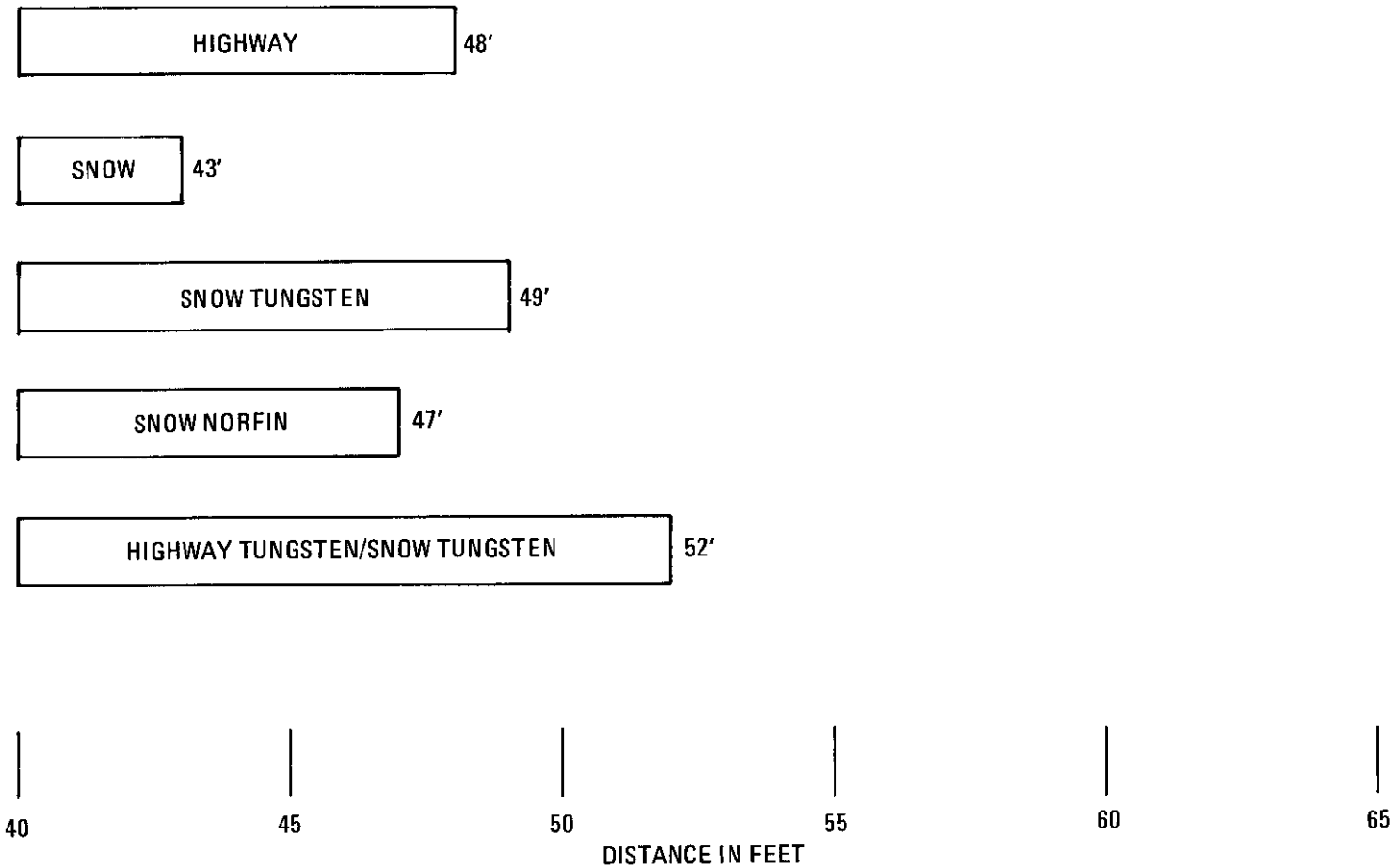


Figure 47

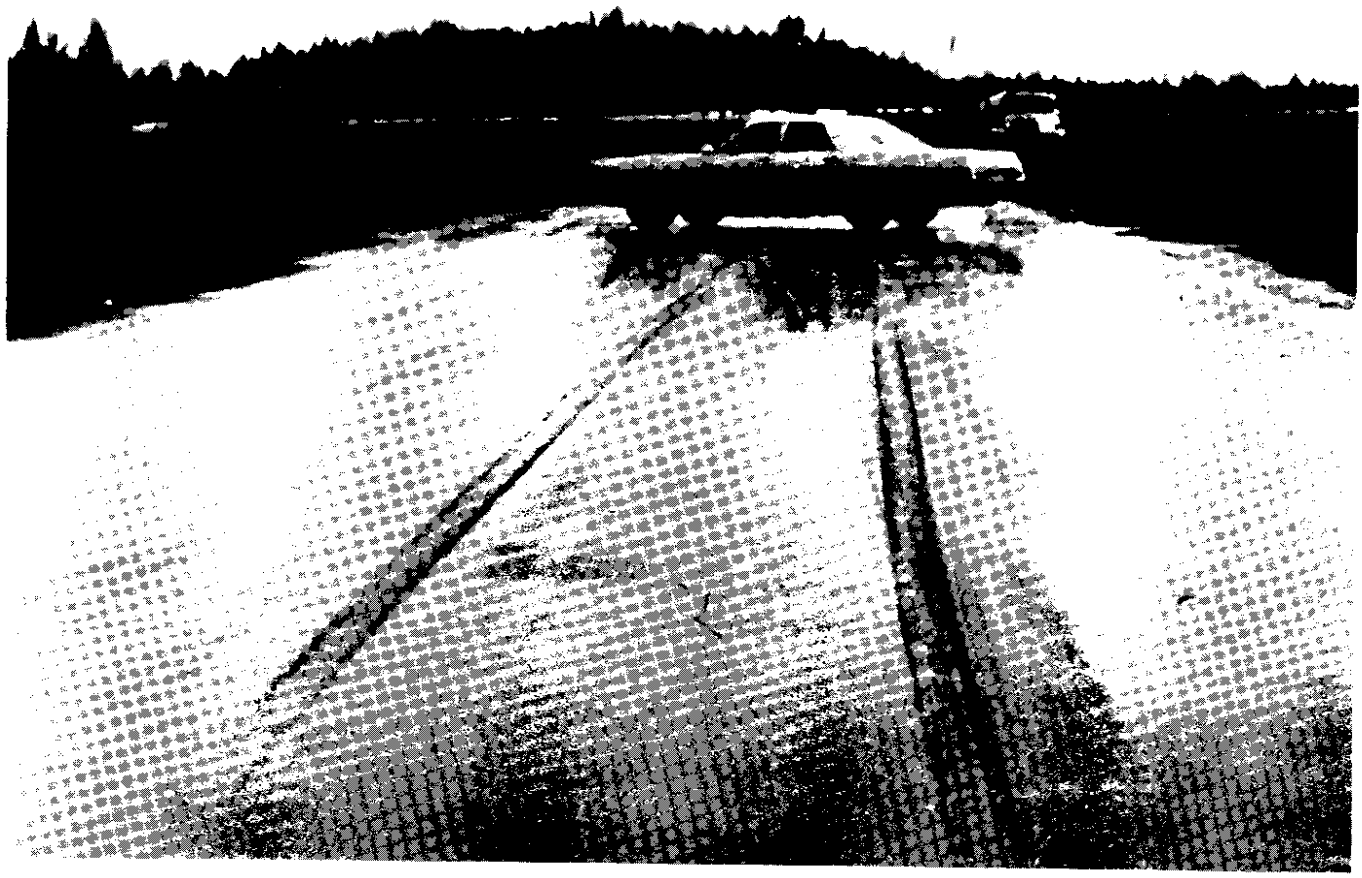


Figure 48: Locked-Wheel Stopping
Washington State Patrol Vehicle
Wet Pavement

TIRE TRACTION TESTING

TEST NO. 4

LOCKED WHEEL STOP

WET PAVEMENT 35 MPH

WSP VEHICLE

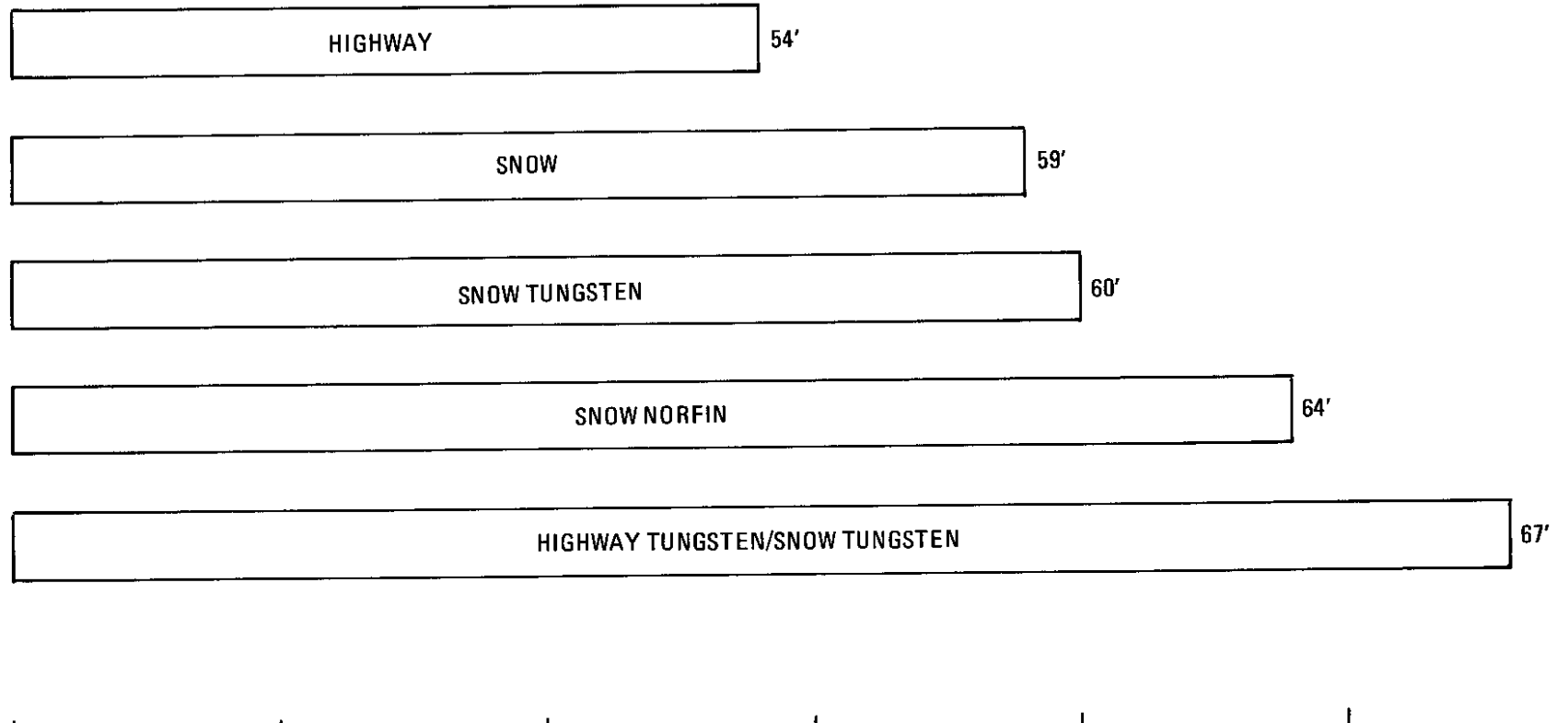


Figure 49

TIRE TRACTION TESTING

TEST NO. 4

LOCKED WHEEL STOP

WET PAVEMENT 50 MPH

WSP VEHICLE

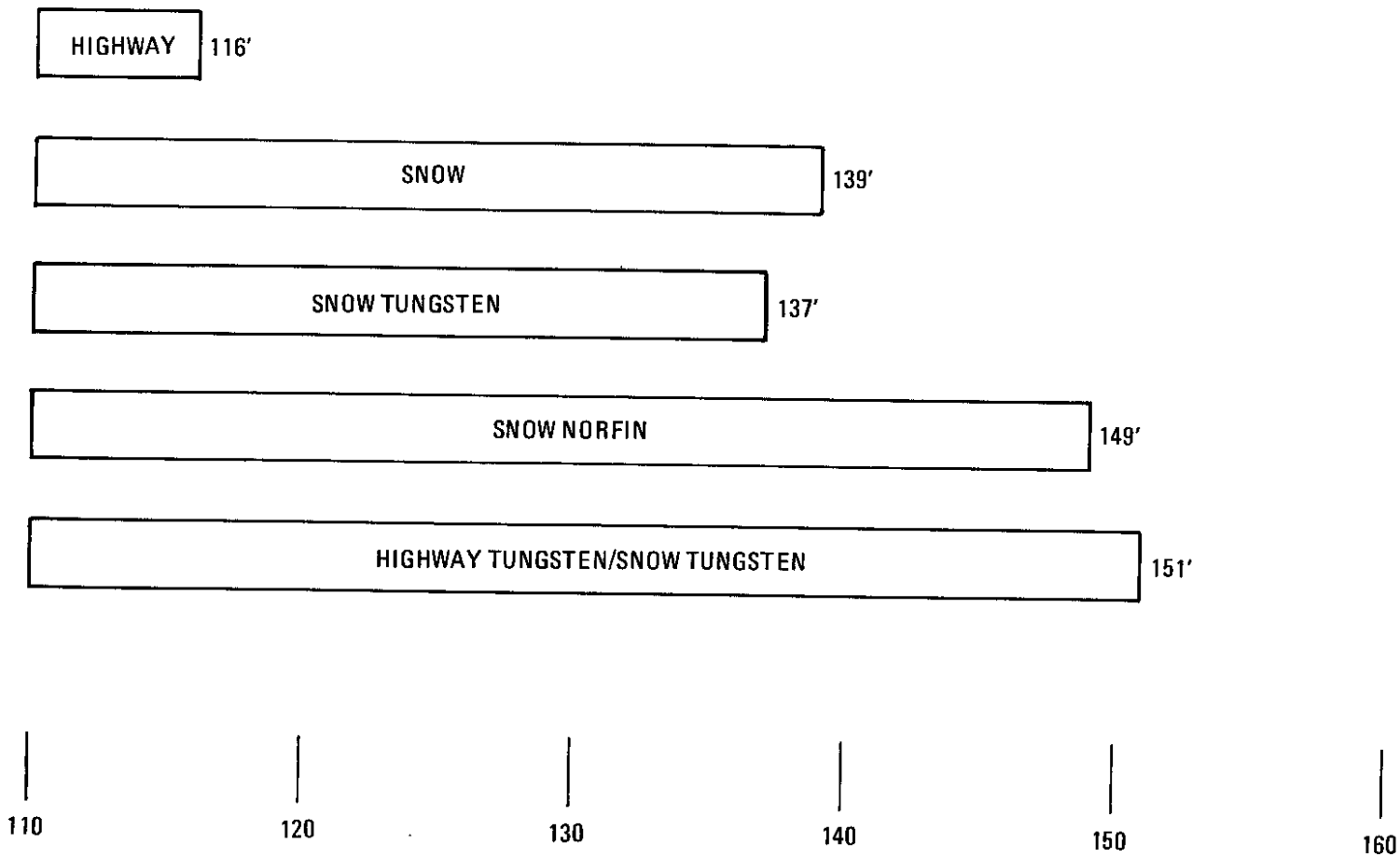


Figure 50

SECTION VII

COMPARISON OF TEST VEHICLES

TEST NO. 1 - MANEUVERING TEST ON DRY PAVEMENT (Figure 51 & Table IX)

HIGHWAY COMBINATION:

Both vehicles started slipping at the same speed. The WSP vehicle had extreme slippage at .5 mph less than the DOH vehicle with this combination.

SNOW COMBINATION:

Both vehicles started slipping at the same speed. The DOH vehicle had extreme slippage at .5 mph less than the WSP vehicle.

SNOW TUNGSTEN COMBINATION:

The DOH vehicle started slipping at 1 mph less than the WSP vehicle and had extreme slippage at 2 mph less than the WSP vehicle.

SNOW NORFIN COMBINATION:

Both vehicles started slipping at the same speed. The DOH vehicle had extreme slippage at .5 mph less than the WSP vehicle.

HIGHWAY TUNGSTEN/SNOW TUNGSTEN COMBINATION:

The DOH venicle started slipping at 1 mph less than the WSP vehicle and had extreme slippage at .5 mph less than the WSP vehicle.

TEST NO. 1 - MANEUVERING ON WET PAVEMENT (Figure 52 & Table X)

HIGHWAY COMBINATION:

Both vehicles started slipping at the same speed. The DOH vehicle had extreme slippage at 1 mph less than the WSP vehicle.

SNOW COMBINATION:

The DOH vehicle started slipping at 2 mph less than the WSP vehicle and had extreme slippage at the same speed as the WSP vehicle.

SNOW TUNGSTEN COMBINATION:

The DOH vehicle started slipping at 1 mph less than the WSP vehicle and had extreme slippage at 1.5 mph less than the WSP vehicle.

SNOW NORFIN COMBINATION:

Both vehicles started slipping at the same speed. The DOH vehicle had extreme slippage at 1.5 mph less than the WSP vehicle.

HIGHWAY TUNGSTEN/SNOW TUNGSTEN COMBINATION:

The DOH vehicle started slipping at 1 mph less than the WSP vehicle and had extreme slippage at 1 mph less than the WSP vehicle.

TIRE TRACTION TESTING

TEST NO. 1
MANEUVERING

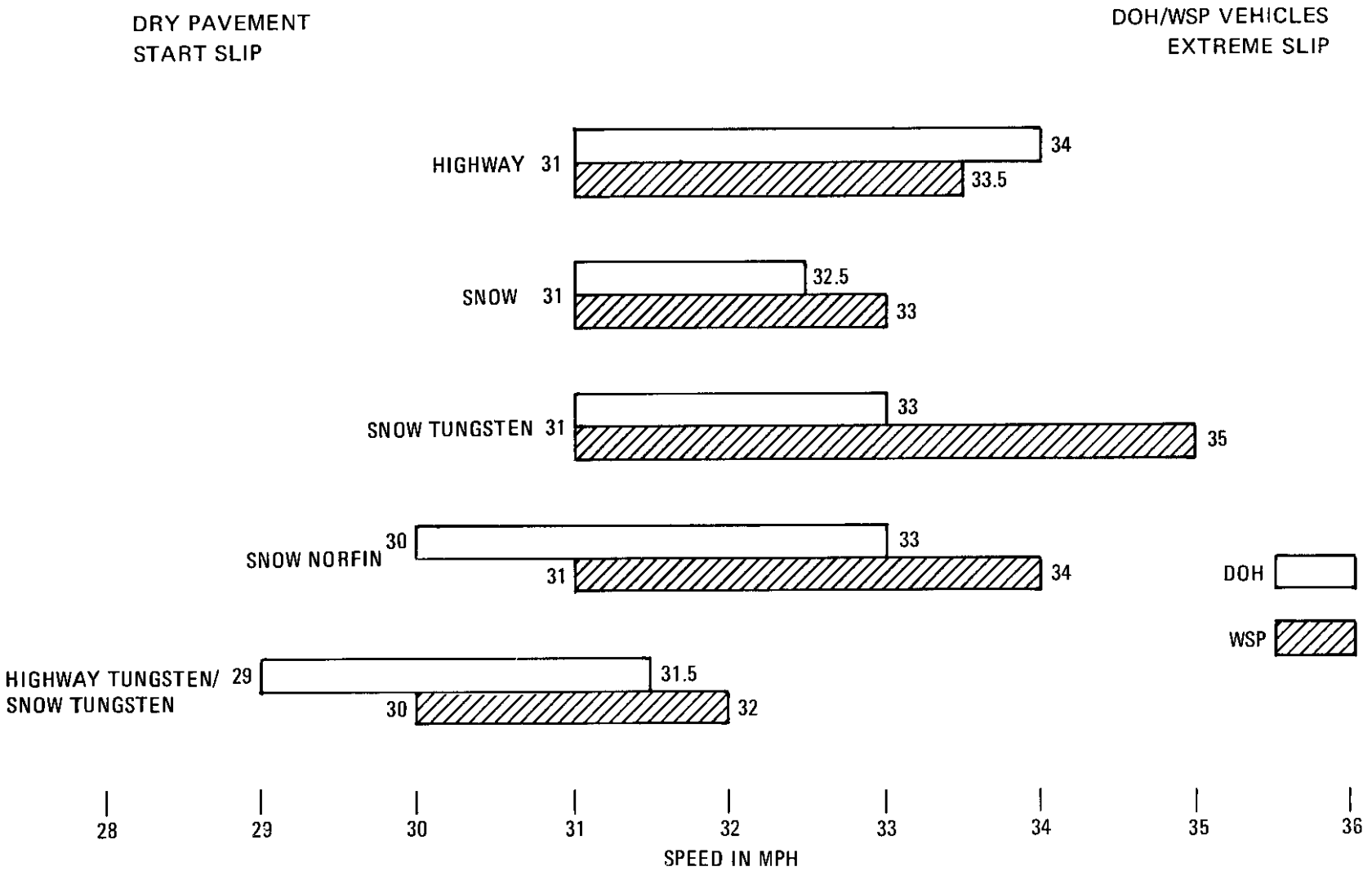


Figure 51

TIRE TRACTION TESTING

TEST NO. 1

MANEUVERING

DRY PAVEMENT

DOH/WSP VEHICLES

TYPE OF EXTREME SLIP

TIRE COMBINATION		CHUTE NO. 1	CHUTE NO. 2
HIGHWAY	DOH	FRONT	FRONT/REAR
	WSP	FRONT/REAR	FRONT
SNOW	DOH	FRONT	REAR
	WSP	REAR	FRONT/REAR
SNOW TUNGSTEN	DOH	FRONT/REAR	REAR
	WSP	FRONT/REAR	FRONT/REAR
SNOW NORFIN	DOH	FRONT/REAR	REAR
	WSP	FRONT/REAR	REAR
HIGHWAY TUNGSTEN/ SNOW TUNGSTEN	DOH	FRONT	FRONT
	WSP	FRONT	FRONT

NOTE
FRONT SLIP INDICATES GOOD TRACTION BY REAR TIRES
REAR SLIP INDICATES POOR TRACTION BY REAR TIRES
FRONT/REAR SLIP INDICATES POOR TRACTION BY ALL FOUR TIRES

Table IX

TIRE TRACTION TESTING

TEST NO. 1

MANEUVERING

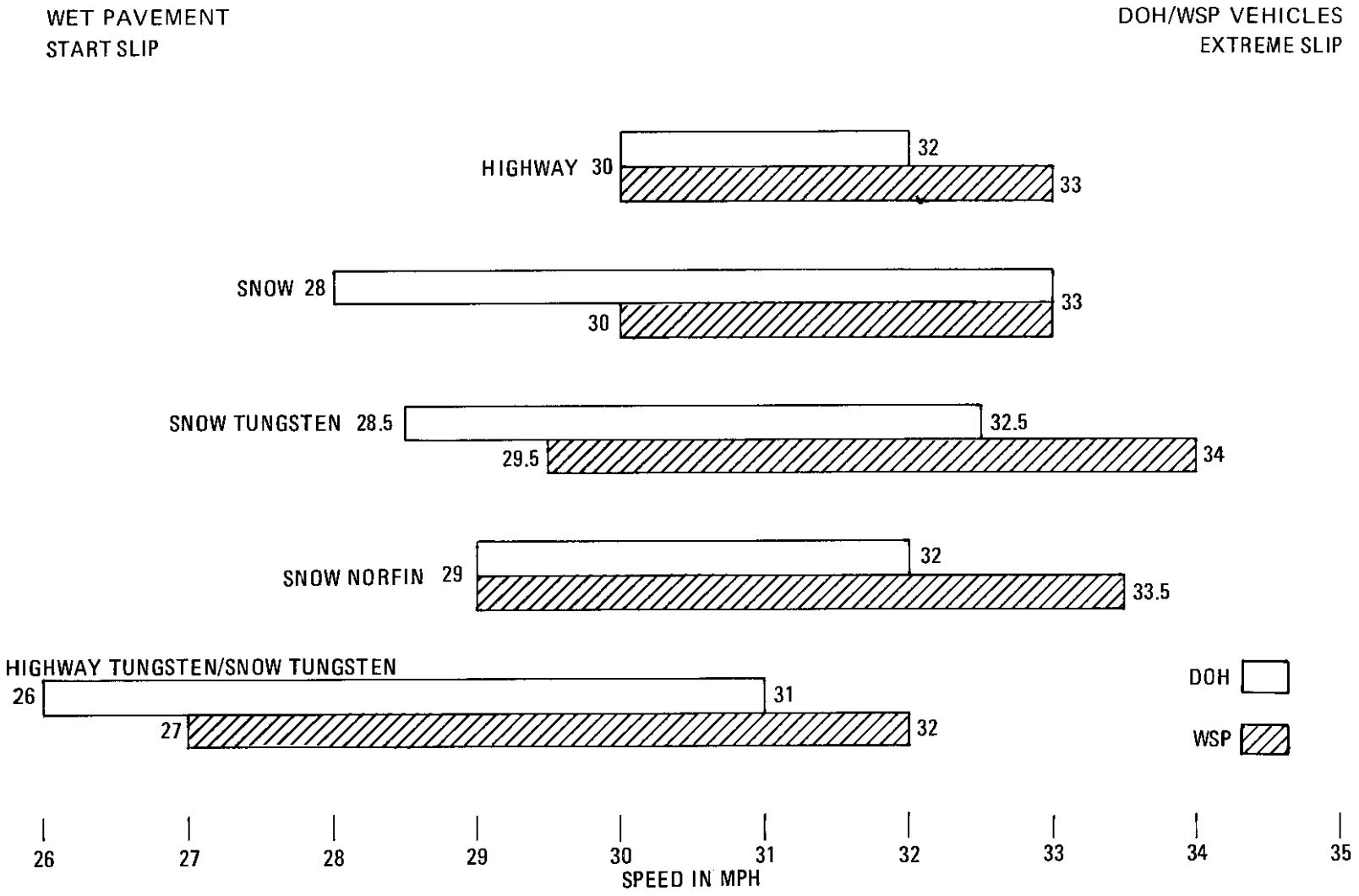


Figure 52

TIRE TRACTION TESTING

TEST NO. 1

MANEUVERING

WET PAVEMENT

DOH/WSP VEHICLES

TYPE OF EXTREME SLIP

TIRE COMBINATION	CHUTE NO. 1		CHUTE NO. 2
HIGHWAY	DOH	FRONT	FRONT
	WSP	REAR	FRONT
SNOW	DOH	FRONT/REAR	FRONT
	WSP	FRONT	REAR
SNOW TUNGSTEN	DOH	FRONT/REAR	FRONT
	WSP	REAR	REAR
SNOW NORFIN	DOH	REAR	FRONT/REAR
	WSP	FRONT/REAR	REAR
HIGHWAY TUNGSTEN/ SNOW TUNGSTEN	DOH	FRONT/REAR	FRONT
	WSP	FRONT	FRONT

NOTE
FRONT SLIP INDICATES GOOD TRACTION BY REAR TIRES
REAR SLIP INDICATES POOR TRACTION BY REAR TIRES
FRONT/REAR SLIP INDICATES POOR TRACTION BY ALL FOUR TIRES

Table X

TEST NO. 2 - HAIRPIN CURVE - DRY PAVEMENT (Figure 53 & Table XI)

HIGHWAY COMBINATION:

The DOH vehicle started slipping at 3 mph less than the WSP vehicle and had extreme slippage at 3 mph less than the WSP vehicle.

SNOW COMBINATION:

The DOH vehicle started slipping at .5 mph less than the WSP vehicle and had extreme slippage at the same speed as the WSP vehicle.

SNOW TUNGSTEN COMBINATION:

The DOH vehicle started slipping at .5 mph less than the WSP vehicle and had extreme slippage at 1 mph less than the WSP vehicle.

HIGHWAY TUNGSTEN/SNOW TUNGSTEN COMBINATION:

The DOH vehicle started slipping at 1 mph less than the WSP vehicle and had extreme slippage at 2 mph less than the WSP vehicle.

TEST NO. 2 - HAIRPIN CURVE ON WET PAVEMENT (Figure 54 & Table XII)

HIGHWAY COMBINATION:

The DOH vehicle started slipping at 1 mph less than the WSP vehicle and had extreme slippage at 1 mph less than the WSP vehicle.

SNOW COMBINATION:

The DOH vehicle started slipping at 1.5 mph less than the WSP vehicle and had extreme slippage at .5 mph less than the WSP vehicle.

SNOW TUNGSTEN COMBINATION:

The DOH vehicle started slipping at .5 mph less than the WSP vehicle and had extreme slippage at 1 mph less than the WSP vehicle.

SNOW NORFIN COMBINATION:

The DOH vehicle started slipping at .5 mph less than the WSP vehicle and had extreme slippage at 2 mph less than the WSP vehicle.

HIGHWAY TUNGSTEN/SNOW TUNGSTEN COMBINATION:

The DOH vehicle started slipping at 1 mph less than the WSP vehicle and had extreme slippage at 3 mph less than the WSP vehicle.

TIRE TRACTION TESTING

TEST NO. 2
HAIRPIN CURVE

DRY PAVEMENT
START SLIP

DOH/WSP VEHICLES
EXTREME SLIP

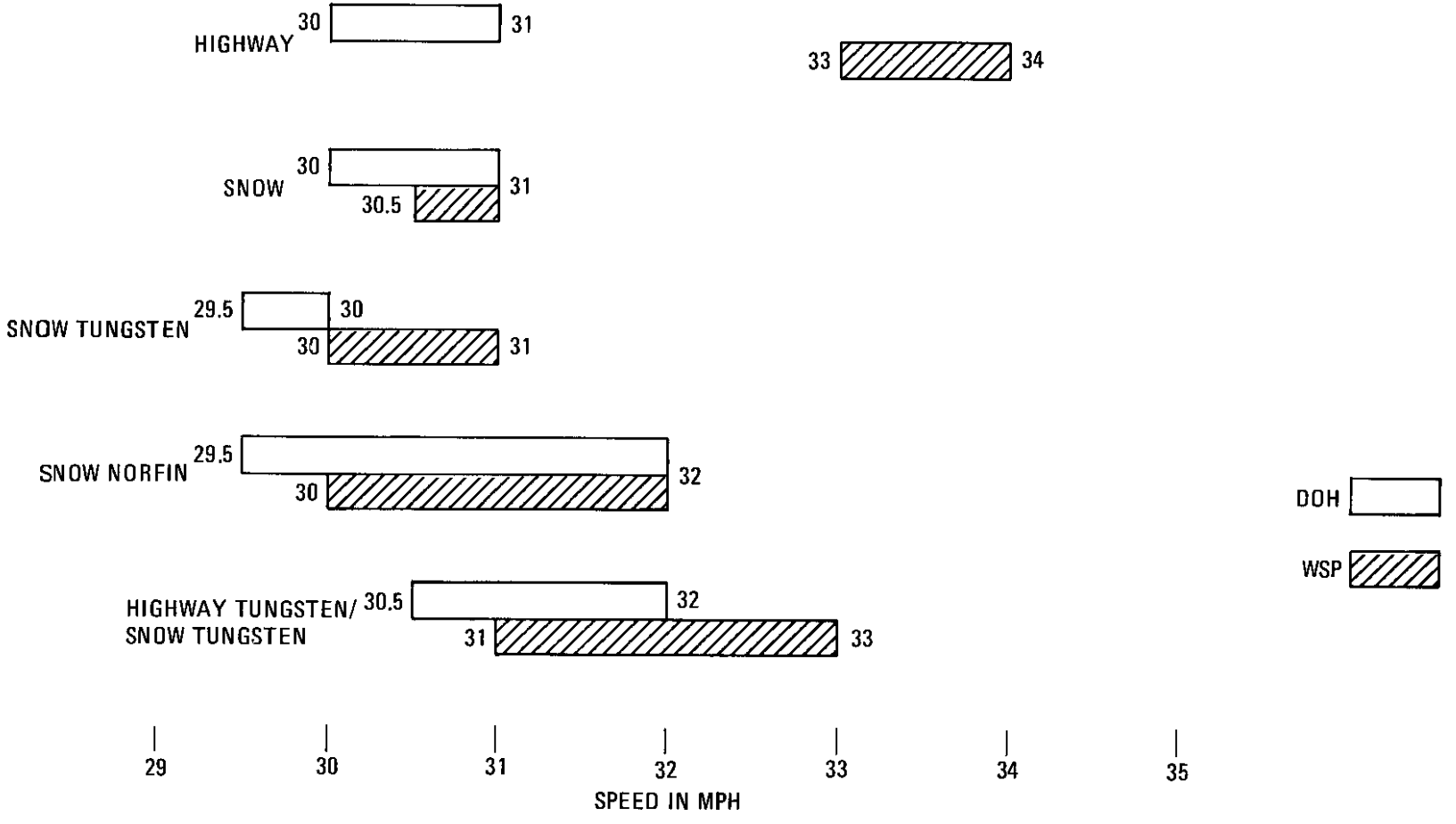


Figure 53

TIRE TRACTION TESTING

TEST NO. 2

HAIRPIN CURVE

DRY PAVEMENT

DOH/WSP VEHICLES

TYPE OF EXTREME SLIP

TIRE COMBINATION	TYPE SLIP	
HIGHWAY	DOH	FRONT
	WSP	REAR
SNOW	DOH	REAR
	WSP	FRONT
SNOW TUNGSTEN	DOH	REAR
	WSP	REAR
SNOW NORFIN	DOH	REAR
	WSP	REAR
HIGHWAY TUNGSTEN/ SNOW TUNGSTEN	DOH	FRONT/REAR
	WSP	FRONT/REAR

NOTE
FRONT SLIP INDICATES GOOD TRACTION BY REAR TIRES
REAR SLIP INDICATES POOR TRACTION BY REAR TIRES
FRONT/REAR SLIP INDICATES POOR TRACTION BY ALL FOUR TIRES

Table XI

TIRE TRACTION TESTING

TEST NO. 2

HAIRPIN CURVE

WET PAVEMENT
START SLIP

DOH/WSP VEHICLES
EXTREME SLIP

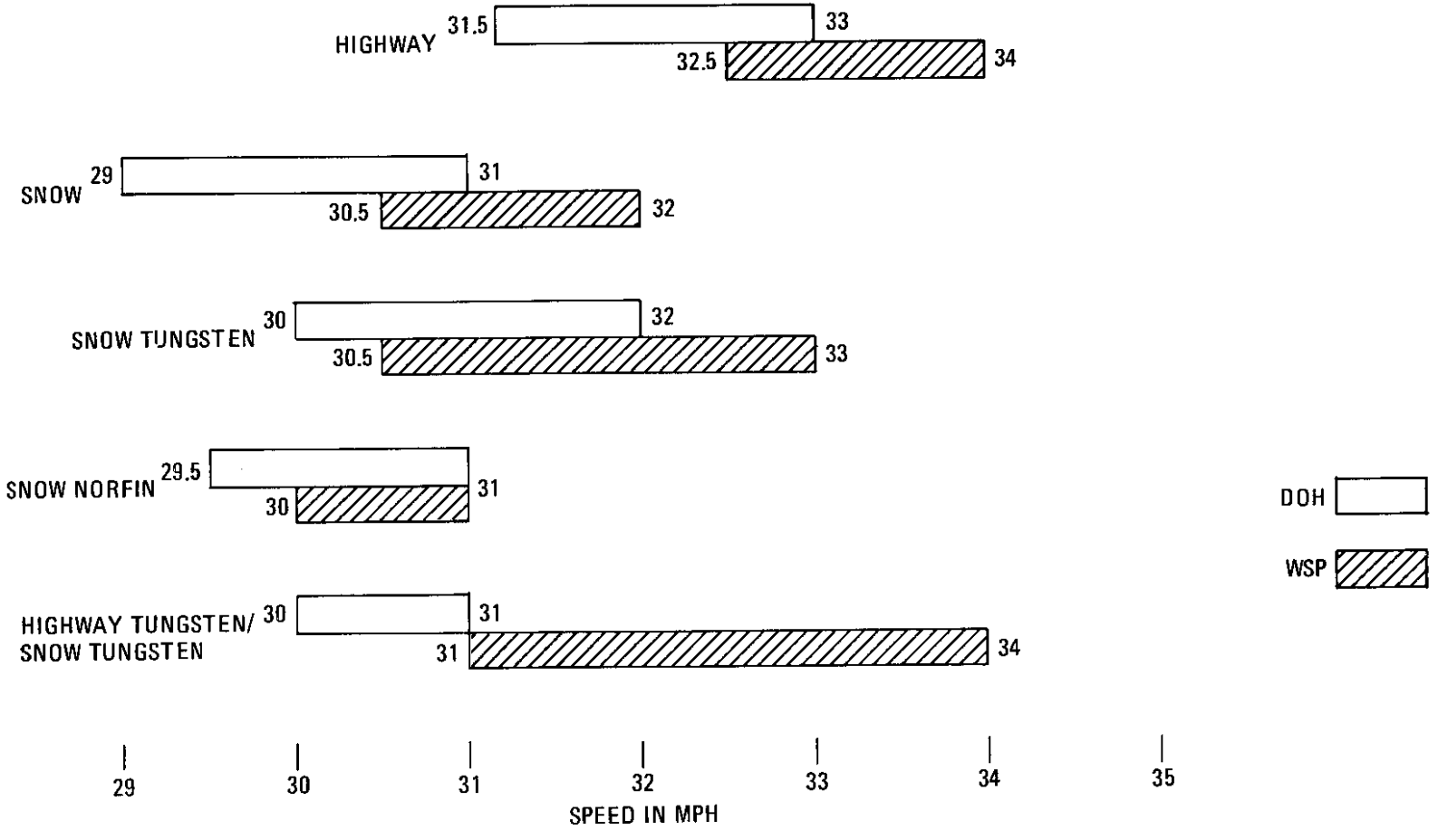


Figure 54

TIRE TRACTION TESTING

TEST NO. 2

HAIRPIN CURVE

WET PAVEMENT

DOH/WSP VEHICLES

TYPE OF EXTREME SLIP

TIRE COMBINATION	TYPE SLIP	
HIGHWAY	DOH	FRONT
	WSP	FRONT
SNOW	DOH	FRONT
	WSP	REAR
SNOW TUNGSTEN	DOH	FRONT/REAR
	WSP	REAR
SNOW NORFIN	DOH	REAR
	WSP	FRONT
HIGHWAY TUNGSTEN/ SNOW TUNGSTEN	DOH	FRONT
	WSP	FRONT/REAR

NOTE
FRONT SLIP INDICATES GOOD TRACTION BY REAR TIRES
REAR SLIP INDICATES POOR TRACTION BY REAR TIRES
FRONT/REAR SLIP INDICATES POOR TRACTION BY ALL FOUR TIRES

Table XII

TEST NO. 4 - LOCKED-WHEEL STOP - DRY PAVEMENT AT 35 MPH (Figure 55)

HIGHWAY COMBINATION:

The DOH vehicle stopping distance was 8' more than the WSP vehicle.

SNOW COMBINATION:

The DOH vehicle stopping distance was 18' more than the WSP vehicle.

SNOW TUNGSTEN COMBINATION:

The DOH vehicle stopping distance was 15' more than the WSP vehicle.

SNOW NORFIN:

The DOH vehicle stopping distance was 13' more than the WSP vehicle.

HIGHWAY TUNGSTEN/SNOW TUNGSTEN COMBINATION:

The DOH vehicle stopping distance was 11' more than the WSP vehicle.

TEST NO. 4 - LOCKED-WHEEL STOP - WET PAVEMENT AT 35 MPH (Figure 56)

HIGHWAY COMBINATION:

The DOH vehicle stopping distance was 10' more than the WSP vehicle.

SNOW COMBINATION:

The DOH vehicle stopping distance was 15' more than the WSP vehicle.

SNOW TUNGSTEN COMBINATION:

The DOH vehicle stopping distance was 7' more than the WSP vehicle.

SNOW NORFIN COMBINATION:

The DOH vehicle stopping distance was 6' more than the WSP vehicle.

HIGHWAY TUNGSTEN/SNOW TUNGSTEN COMBINATION:

The DOH vehicle stopping distance was 3' less than the WSP vehicle.

TEST NO. 4 - LOCKED-WHEEL STOP - WET PAVEMENT AT 50 MPH (Figure 57)

HIGHWAY COMBINATION:

The DOH vehicle stopping distance was 21' more than the WSP vehicle.

SNOW COMBINATION:

The DOH vehicle stopping distance was 20' more than the WSP vehicle.

SNOW TUNGSTEN COMBINATION:

The DOH vehicle stopping distance was 30' more than the WSP vehicle.

SNOW NORFIN COMBINATION:

The DOH vehicle stopping distance was 18' more than the WSP vehicle.

HIGHWAY TUNGSTEN/SNOW TUNGSTEN COMBINATION:

The DOH vehicle stopping distance was 15' more than the WSP vehicle.

TIRE TRACTION TESTING

TEST NO. 4

LOCKED WHEEL STOP

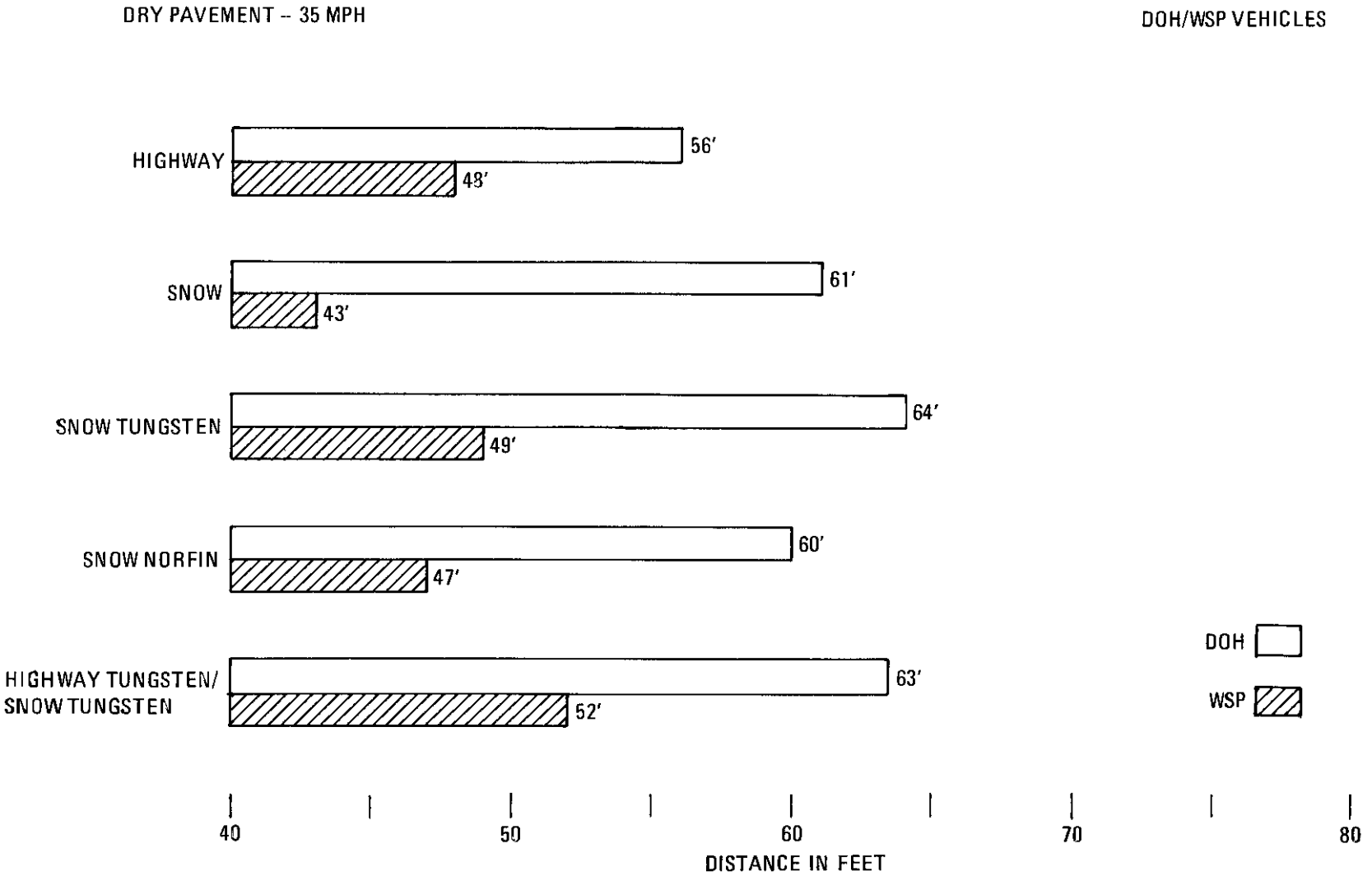


Figure 55

TIRE TRACTION TESTING

TEST NO. 4

LOCKED WHEEL STOP

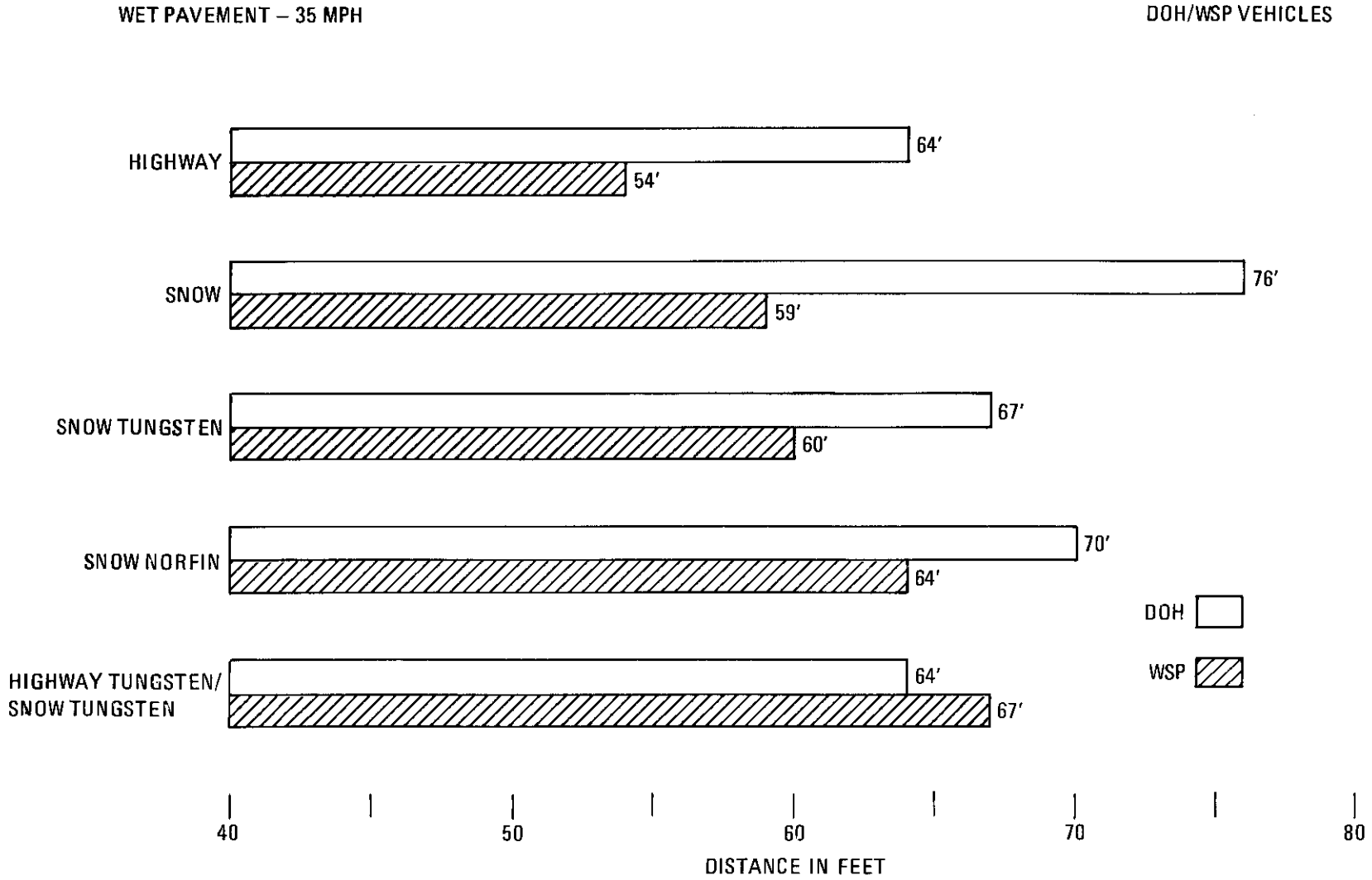


Figure 56

TIRE TRACTION TESTING

TEST NO. 4

LOCKED WHEEL STOP

WET PAVEMENT – 50 MPH

DOH/WSP VEHICLES

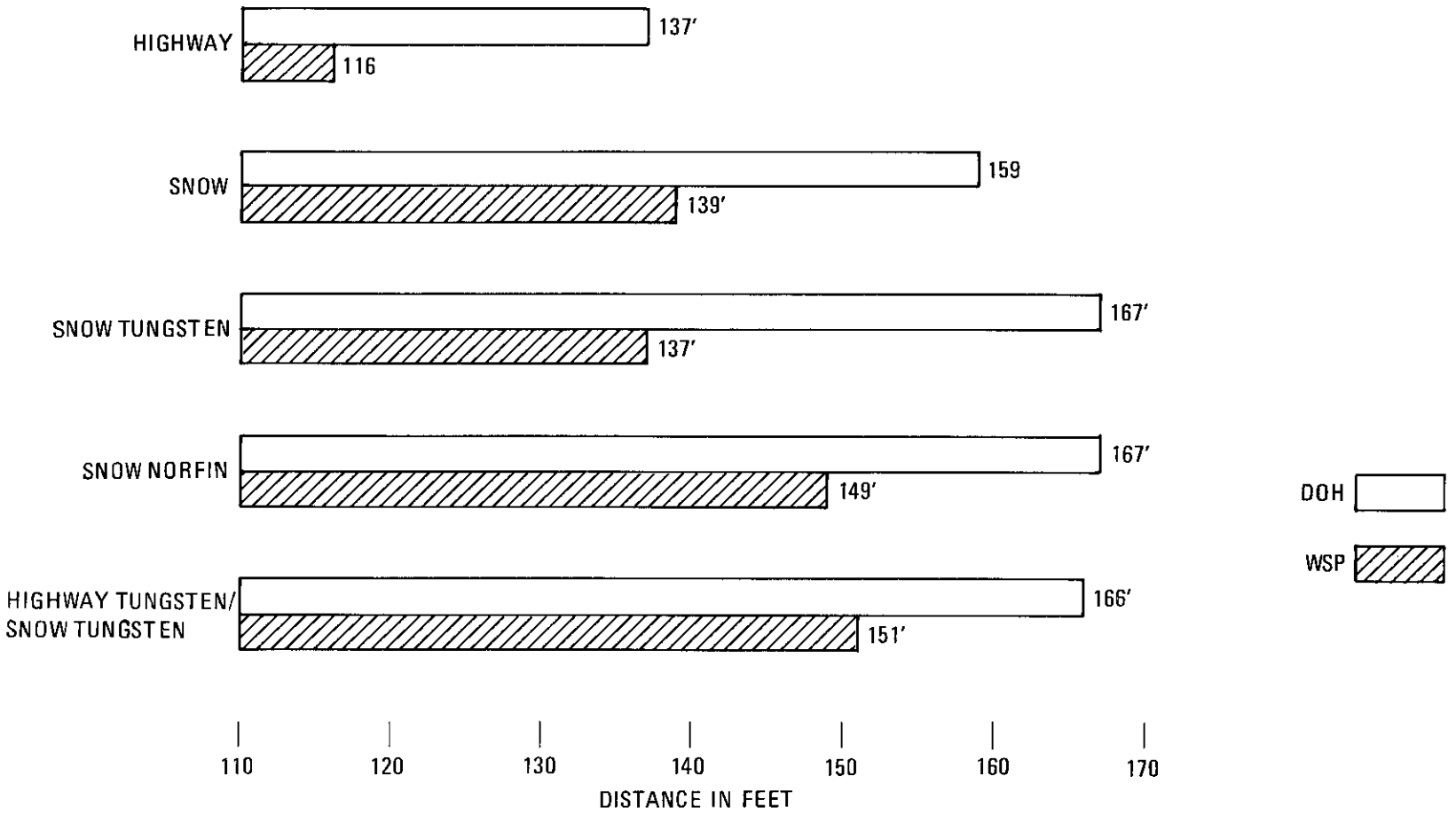


Figure 57

SECTION VIII

TIRE WEAR

An inspection was made of the tires after each test maneuver. During the first three test maneuvers, there was no apparent damage to the tires other than a small amount of wear to the studs on the studded tires. During the locked-wheel stop maneuver, Test No. 4, all of the tires developed flat spots due to the severity of the maneuver. When driving with the test tires after this maneuver, a definite thumping and vibration was noted.

The tungsten studs had moderate wear at the conclusion of the tests whereas the Norfin studs had extreme wear and damage. The snow garnet impregnated tires had extreme wear and the majority of the garnet particles were gone by the end of the testing program. The highway tires appeared to be in better condition than the other tire types at the conclusion of the test maneuvers.

Figures 58 thru 69 are before and after photos of the tires used during the tire traction testing.

Figure 58: Highway Tread Tire
before testing

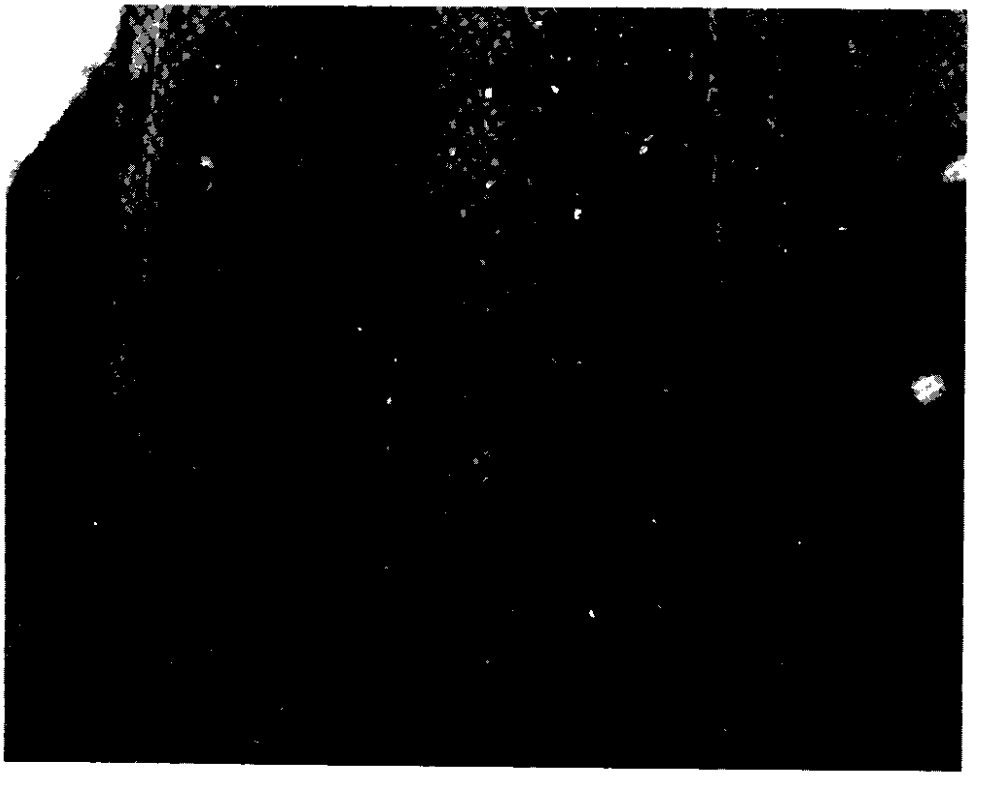


Figure 59: Typical Highway Tread Tire
after testing

Figure 60: Snow Tread Tire
before testing

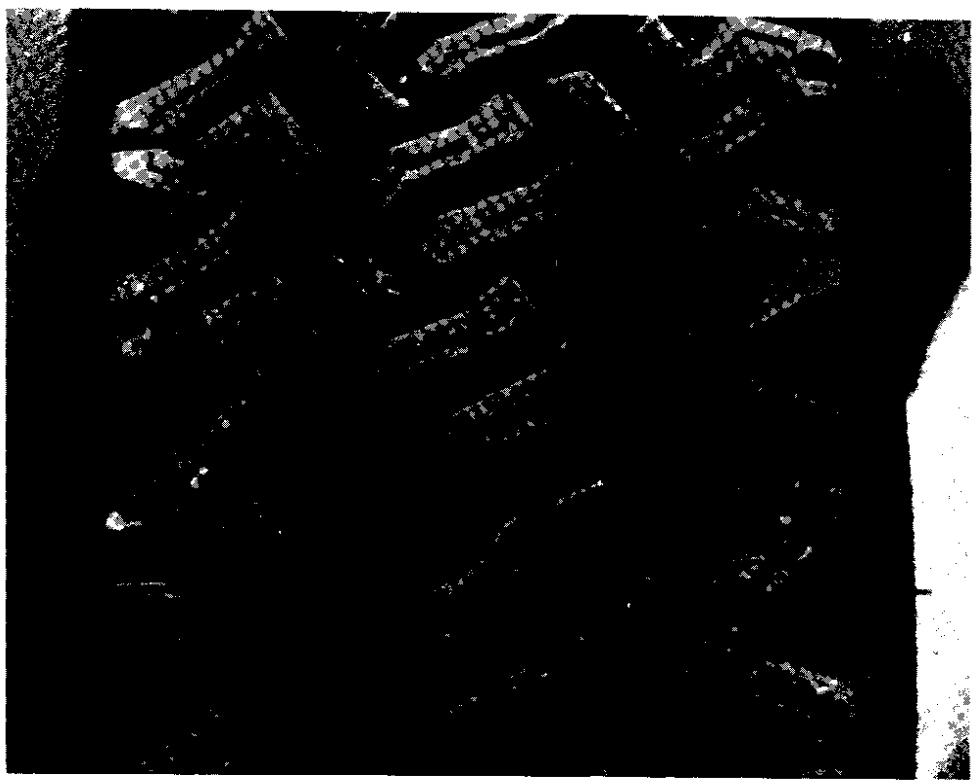


Figure 61: Snow Tread Tire
after testing

Figure 62: Snow Tread Tungsten Studded Tire before testing

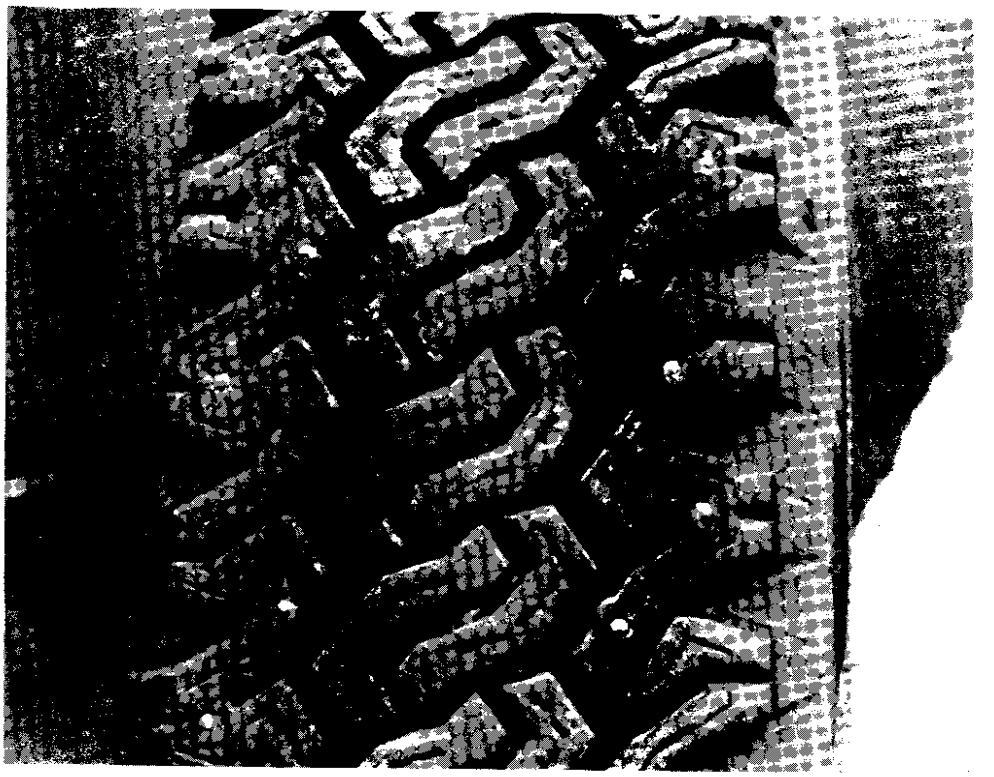


Figure 63: Snow Tread Tungsten Studded Tire after testing

Figure 64: Snow Tread Norfin Studded Tire before testing

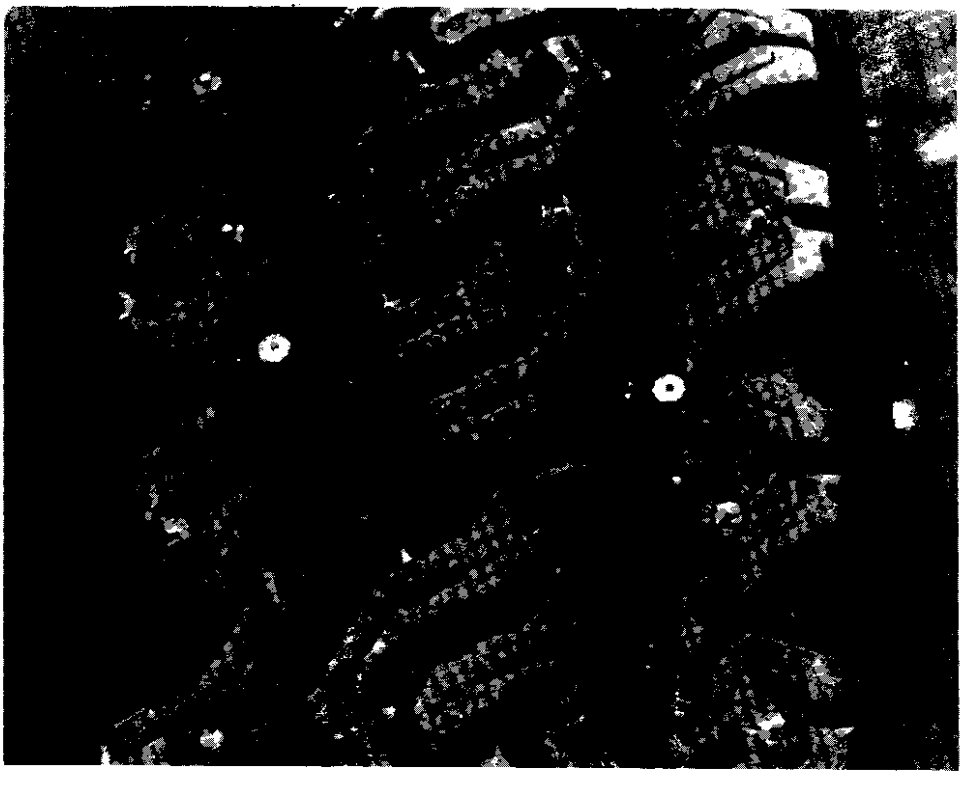


Figure 65: Snow Tread Norfin Studded Tire after testing

Figure 66: Highway Pathfinder Tread Tungsten Studded Tire before testing

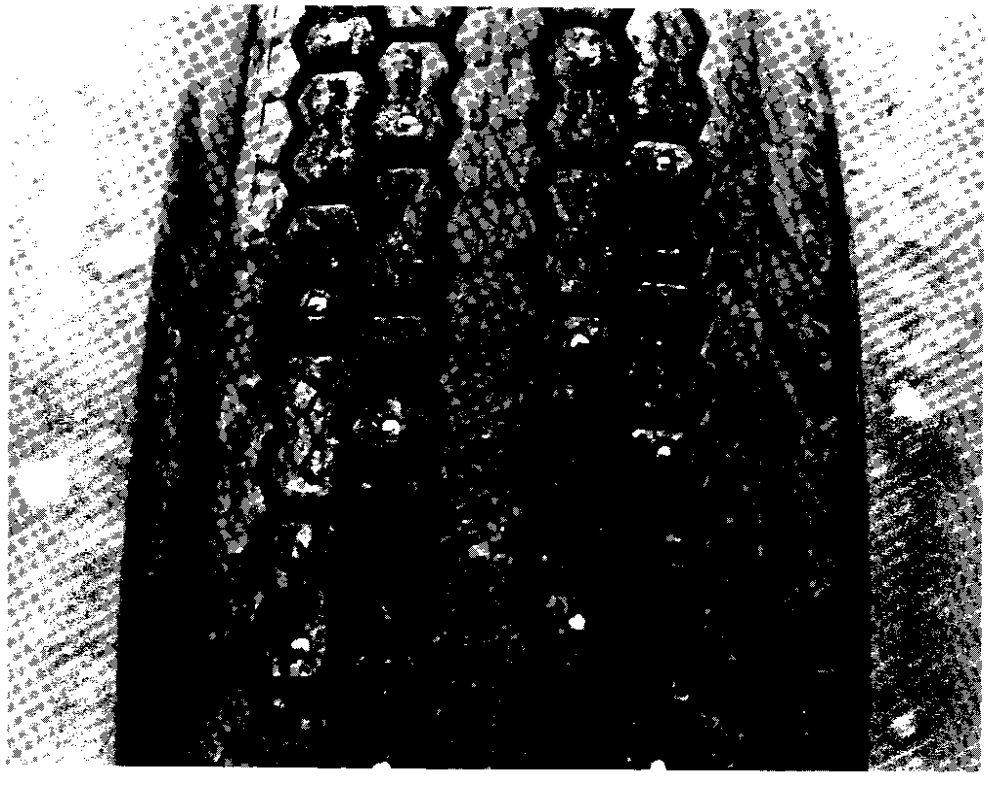


Figure 67: Highway Pathfinder Tread Tungsten Studded Tire after testing

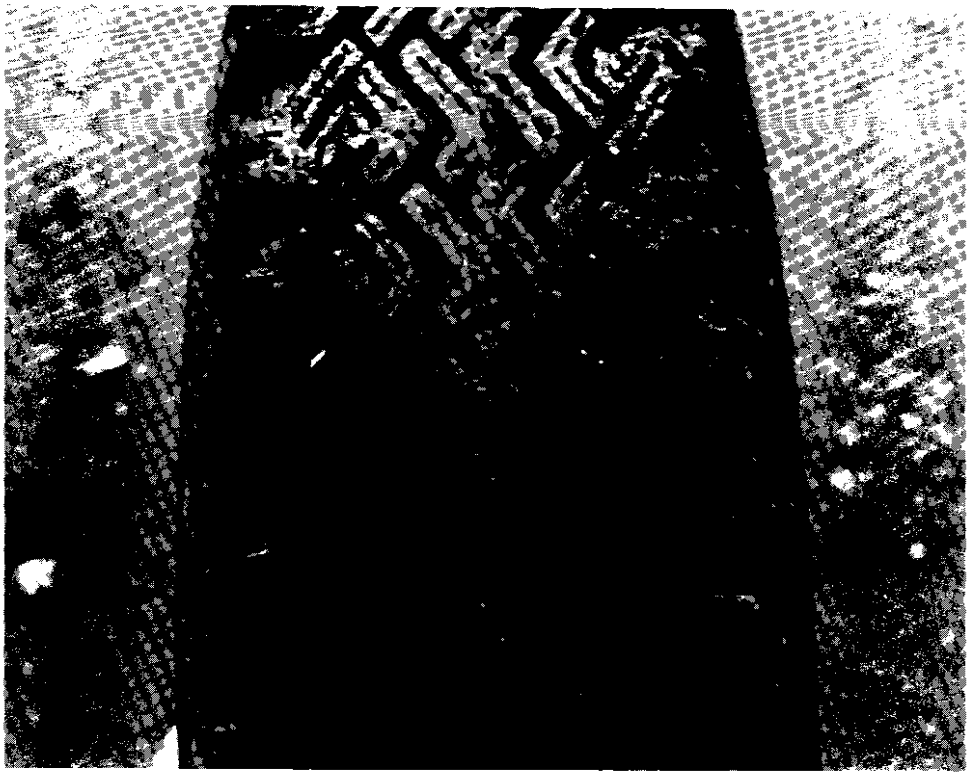


Figure 68: Snow Tread Garnet Tire before testing

Figure 69: Snow Tread Garnet Tire after testing