BRAKING AND TRACTION TESTS ON ICE, SNOW, AND ON BARE PAVEMENTS

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SYNOPSIS

The Committee on Winter Driving Hazards of the National Safety Council was organized in 1939 to make a thorough investigation of the dangers peculiar to winter driving. Studies of traffic accident statistics by the Committee indicated that the mileage death rate for the northern half of the United States was 24 to 53 percent higher for the winter months than for the summer months. Also, it was found that the major hazards of winter driving are inadequate traction and reduced visibility

The importance of skidding as a major cause of winter accidents was indicated in a study of the accident reports from seven northern states which revealed that of all accidents involving skidding, less than 1 percent occurred on dry pavements, 18 percent on wet pavements, and 40 percent on pavements covered with snow and ice. Accordingly, a major activity of the Committee has been to conduct exhaustive research studies involving braking, skidding, and traction tests with passenger cars and all types of trucks on lake ice, road ice, packed snow, and on concrete pavements. In this paper the results of the 1946 and 1947 tests on frozen lakes, ice-and-snow covered roads, and on concrete pavements in Michigan and Wisconsin are given

During the past two winters the Committee has investigated all of the major types of winter driving equipment and the special driving techniques used to prevent skidding accidents. Also, tests have been run under many different ice and snow conditions and on icy surfaces treated with abrasives, to determine the skidding hazards for all of these conditions. An extensive series of tests was run in 1946 and again in 1947 to compare the skidding characteristics of synthetic rubber tires with natural rubber tires on glare ice.

The results of all of the 1946 and 1947 tests revealed that ice is an extremely variable and unpredictable substance and that the performance of vehicles on ice is extremely variable. Factors affecting the slipperiness of ice, such as temperature, whether the ice is wet or dry, whether it is sunny or cloudy, the graininess of the ice, and others, were found to influence braking distances to a greater extent than the type of vehicle, load, tires, tire pressures, pumping the brakes, or power braking. Thus, the braking distance from 20 mph. for a passenger car ranged from 107 to 238 ft. on glare ice as compared with 17 ft. on dry concrete pavement. For a loaded 5-ton truck the corresponding braking distances were 116 to 306 ft. on glare ice and 24 ft. on dry concrete pavement.

Of all the remedies investigated to prevent skidding on ice and snow, not one provided the margin of safety obtainable on dry concrete pavement. For this reason the extremely hazardous operation on ice and snow emphasizes the need for: (1) bare pavement maintenance—the prompt and complete removal of ice and snow; or (2) the treatment of these surfaces with abrasives and operation at reduced speeds; and if this is not done, (3) the use of tire chains and operation at greatly reduced speeds.

Typical results of the tests are as follows: Braking distances for cars and trucks were about ten times as long on glare ice as on dry concrete and from three to five times as long on packed snow as on dry concrete. Braking distances for vehicles equipped with tire chains were two to four times as long in the tests on ice as in the tests with bare tires on dry concrete. The shortest braking distances on ice were obtained with a new type chain specially designed for use on ice. Sanders provided a slight reduction in braking distance in the tests in which a special sharp angular grit was used. For maximum effectiveness with

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sanders, the "pumping" braking technique was used with the best grit and reduced braking distances 30 to 40 percent below the locked wheel stops depending upon whether sanders were used on the driving wheels only or on all wheels. Certain special driving techniques when properly used, such as "pumping" and "power-braking" reduced braking distances 20 percent below the locked wheel stops. Another important advantage of these techniques, especially "pumping", is the increased steering control possible if the proper technique is used. The glare ice braking distances with natural rubber tires were from 20 to 30 percent less than with synthetic rubber tires. The braking distances on natural road ice were slightly lower than on glare lake ice, largely due to patches of snow on the road ice. The results in the acceleration and circle tests for the various test conditions closely paralleled the results in the braking tests for corresponding conditions.

The Committee on Winter Driving Hazards was appointed in 1939. The primary objectives of the Committee have been to develop comprehensive and authentic information concerning the friction or traction available on snowy and icy road surfaces, and data concerning practical remedies to eliminate or minimize the hazards inherent in winter driving, particularly in the northern half of the United States.

The Committee has conducted four research projects, the first of these being the preliminary traction and skidding tests conducted in March, 1939, on the frozen surface of Lake Calhoun at Minneapolis, Minnesota. More thorough and comprehensive tests with a fleet of passenger cars were conducted in February, 1940, on the frozen surfaces of Lake Cadillac, Cadillac, Michigan. In January and February, 1946, further tests with passenger cars and also with light trucks and various types of heavy duty trucks were conducted on Houghton Lake and on roads near Roscommon, Michigan. A fourth research project was conducted during the winter of 1947 on Pine Lake and on nearby roads and streets at Clintonville, Wisconsin.

In all of these tests the main responsibility for directing the field work was placed in the hands of one or two members of the engineering staff of the National Safety Council, and included Donald S. Berry, Director of the Traffic and Transportation Division, John B. Massen, Secretary of the Committee for the 1939 and 1940 tests, George E. Miller, Assistant Director of the Traffic and Transportation Division, and Ross G. Wilcox, Secretary of the Committee for the 1946 and 1947 tests. The test programs were conducted with the aid of many cooperating organizations who furnished vehicles, equipment, and personnel, such as the city, state, and county highway departments for the area in which the tests were run, the Four Wheel Drive Auto Company, General Motors Proving Ground, International Harvester Company, and the Ford Motor Company. The writer has been Chairman of the Committee since it was organized and has helped to plan each of the testing programs, assisted in conducting some of the tests, in assembling the data, and in preparing reports of each of the research projects. This report provides an account of the research projects conducted by the Committee during the past two winters in Michigan and in Wisconsin. The National Safety Council recently published a comprehensive report entitled "Winter Accident Prevention" in which all phases of the winter driving problem are discussed including a summary of the results of the four research projects.

THE WINTER DRIVING PROBLEM

The nation-wide mileage traffic death rate reaches its highest value in January, although, as shown in Figure 1, the motor vehicle travel in January is, next to February, the lowest during the year. Special studies by the Committee have shown that in the northern half of the United States, the mileage death rate is from 24 to 53 percent higher during the winter than in the summer months.

The two major factors peculiar to winter in all sections of the United States are inadequate traction and reduced visibility. Inadequate traction on road surfaces is primarily due to snow and ice and, to a lesser degree, to wetness, particularly on certain types of pavement. Combined with faulty driving practices of lack of winter safety equipment, poor traction generally results in skidding, a factor frequently contributing to motor vehicle accidents. Reduced visibility in winter driving is due to one or more of three causes: (1) longer hours of darkness; (2) snow or sleet storms, blizzards, fogs and mists, and (3) frosted and fogged, snow, ice, or sleet covered windshields and windows or any other obstructions to driver vision. Good visibility is of prime importance to safe driving and lack of it has caused many accidents. Studies by the National Safety Council have shown that the fatal accident rate per mile of travel is about three times as high during the night as during the day.

A special study made in 1947 by the Committee in cooperation with four typical snowbelt states (Connecticut, Indiana, Minnesota, and Wisconsin), showed that approximately

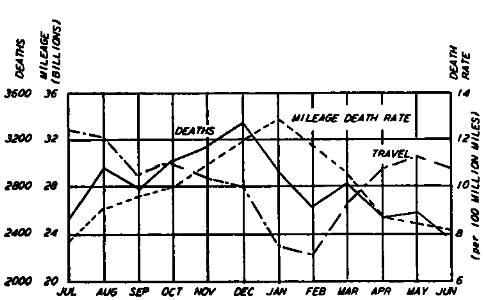

Figure 1. 1946 Monthly Deaths, Mileage, and Mileage Death Rate for the United States

two-thirds of the total number of traffic accidents during the three winter months occurred on snowy or icy surfaces, varying from a low of 47 percent in Indiana to a high of 83 percent in Minnesota. In an earlier study of accident reports from 7 states in the snow-belt, it was found that of all accidents involving skidding less than 1 percent occurred on dry pavements, 18 percent on wet pavements, and 40 percent on pavements covered with ice and snow.

Research projects directed toward a study of the factors contributing to reduced visibility during the winter months and toward methods to improve visibility, such as improved headlights, highway lighting, defrosters, special windshield wipers and sprays, frost shields, etc., would no doubt have considerable merit. However, the Committee decided that research studies related to braking and traction would yield more significant results than visibility tests and would be more easily adaptable to the type of work which the Committee could do with the limited time and funds at its disposal. Accordingly, the Committee has conducted the four research projects referred to above. In this paper, the test procedures and test results obtained in the 1946 and 1947 research projects will be reported. It is believed that this report will be of special interest to highway engineers and to highway traffic and safety officials who are responsible for winter road maintenance and other traffic services which will provide for greater safety on our streets and highways during the hazardous winter months.

TEST VEHICLES

For the 1946 tests, the test vehicles included two passenger cars, two ½-ton pick-up trucks (4,700-lb. gross weight rating), one 1½-ton truck (12,500-lb. gross weight rating), two 5-ton trucks (28,000-lb. gross weight rating) one single axle tractor-trailer (34,000-lb. gross weight rating), and one tandem-axle tractor-trailer (60,000-lb. gross weight rating). All of the trucks except the pick-ups were equipped with dual tires on the rear wheels. Likewise, all of the trailers had dual tires. With the exception of the single axle tractor-trailer, all vehicles were new and in excellent mechanical condition.

The test vehicles for the 1946 tests and weights for the empty and loaded condition are shown in Table 1. It should be noted that the trucks in the 1946 tests were seldom loaded to their rated capacity. A January thaw and rains melted the lake ice from 16-in. average thickness to about 10 to 12 in. and it was found that the ice was not strong enough to support the full load, especially of the heavier trucks.

For the 1947 tests, the majority of the tests were run with a passenger car and two 5-ton trucks (28,000-lb. gross weight rating). In addition, two other passenger cars, a station wagon, and a tractor-trailer (42,000-lb. gross weight rating) were used for certain special tests. The trucks were equipped with dual tires on the rear wheels. Likewise, the tractor and trailer each had dual tires. These vehicles were all new and in excellent mechanical condition. The test vehicles used in the 1947 tests and their weights are shown in Table 2.

All of the vehicles in these tests except one of the passenger cars were equipped with standard synthetic rubber tires.

TABLE 1
TEST VEHICLES AND LOADS USED IN THE 1946 TESTS

Test Vehicle	Vehicle Loads: Axles from Front to Rear 1	2	3	4	5	Total	Ratio W_t/W_d[a]
						lb.	
Ford Coach (Empty)	1,840	1,600				3,440	2.15
Ford Coach (Loaded)	2,000	2,220				4,220	1.90
Ford ½ Ton Truck (Empty)	1,810	1,260				3,070	2.44
Ford ½ Ton Truck (Loaded)	1,830	2,620				4,450	1.70
Ford 1½ Ton Truck (Loaded)[b]	2,980	10,100				13,080	1.29
Ford 1½ Ton Truck (Empty)	2,400	3,070				5,470	1.78
Ford 1½ Ton Truck (Loaded)[c]	2,660	5,810				8,470	1.46
International 5 Ton Truck (Empty)	5,090	7,480				12,570	1.68
International 5 Ton Truck (Loaded)	7,030	13,370				20,400	1.53
F.W.D. 5 Ton Truck (Empty)	8,160	7,170				15,330	1.00
F.W.D. 5 Ton Truck (Loaded)	10,295	17,270				27,565	1.00
Chev. Tractor-Semi-Trailer (Empty)	2,610	3,960	3,000			9,570	2.42
Chev. Tractor-Semi-Trailer (Loaded)	2,610	6,880	6,020			15,510	2.26
	Tractor		Tandem Axle Semi-Trailer				
Fed. Tractor-Semi-Trailer (Empty)	5,650	7,670	4,240	4,270		21,830	2.85
	Tractor		Tandem Axle Trailer				
Int. Truck-Trailer (Empty)	5,090	7,480	5,700	4,240	4,270	26,780	3.58

[a] $\frac{W_t}{W_d} = \frac{\text{Total Vehicle Weight}}{\text{Weight on Drive Wheels.}}$
[b] As Tested Prior to Jan. 14, 1946
[c] As Tested on and after Jan. 14, 1946.

TABLE 2
TEST VEHICLES AND LOADS USED IN THE 1947 TESTS

Vehicle	Load Condition	Load: Front Axle	Rear Axle		Total
		lb.	lb		lb.
Four wheel drive 5-ton truck	Empty	7,275	8,395		15,670
	Loaded	10,850	16,920		27,770
International 5-ton truck	Empty	4,965	6,595		11,560
	Loaded	7,445	20,815		28,260
		Front Axle	Tractor Axle	Trailer Axle	
International tractor-trailer	Loaded	6,000	18,000	18,000	42,000
Oldsmobile "66"	a				4,240
Ford tudor sedan	b				3,690
Cadillac sedan	b				4,770
Ford station wagon	b				3,820

[a] Driver and observer in front seat, 300 lb. load distributed over rear axle
[b] Driver and observer in front seat

In both the 1946 and 1947 tests, one of the passenger cars had two complete sets of tires of identical tread pattern and the same amount of tread wear. One set of tires was made of GRS synthetic and the other was made of natural rubber. With the exception of some runs made to determine the effectiveness of reduced tire pressures, passenger car tires were run at a pressure of 32 lb., and truck tires were run at their rated pressures.

In 1946 the 1½-ton truck and the 5-ton trucks were equipped with sanders. Likewise in 1947, the 5-ton trucks and the station wagon were equipped with sanders. Tire chains were provided for all the test vehicles so that tests could be made with and without tire chains.

Photographs of some of the vehicles used in the tests are shown in Figure 2.

TEST CONDITIONS INVESTIGATED

The general program as planned provided for braking tests, acceleration tests, and circle tests under a number of different conditions, including varying degrees of "wetness" and "dryness" of the ice at temperatures ranging from 32 F. to sub-zero values, tests at different tire pressures and loads, with and without tire chains, with and without sanders, of synthetic rubber tires versus natural rubber tires, of special coil spring tires, of passenger cars equipped with rubber tire chains, and a series of tests in which certain special driving techniques were used such as pumping the brakes (intermittent brake application) and power-braking (applying power without accelerating with the right foot while braking with the left foot). In addition to the above tests which were run on lake ice to the extent that weather and ice conditions permitted, braking and acceleration tests were also run on natural road ice, packed snow, and on dry concrete pavements.

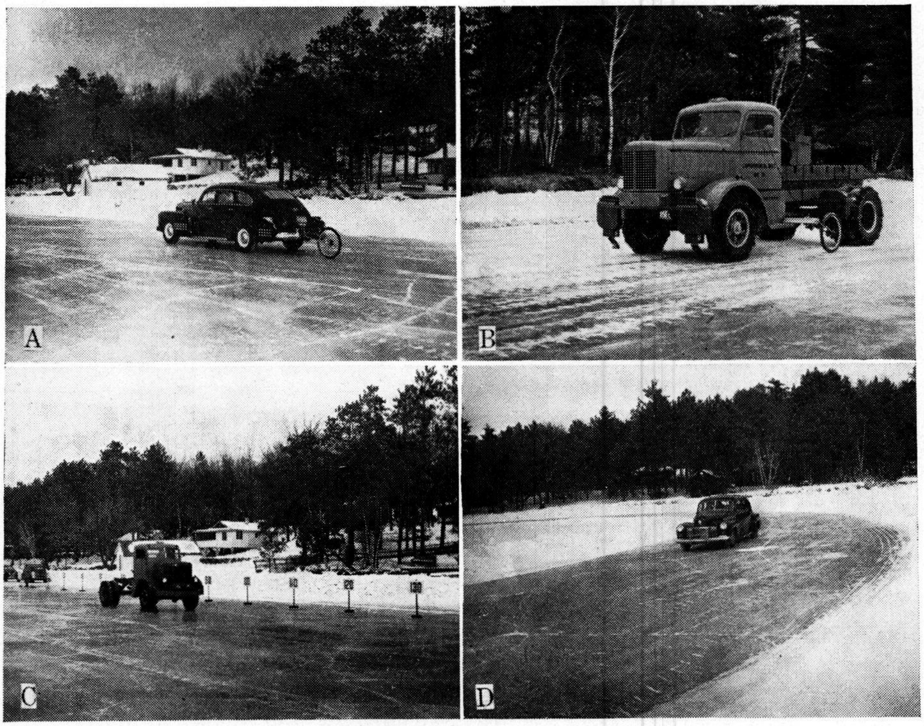

Figure 2. A. Passenger Car In Braking Test on Glare Ice with Fifth Wheel Tachometer Used to Provide an Accurate Measure of Speed. B. Experimental Truck Loaded Equipped With Tire Chains and With Sanders. C. Braking Test on Glare Ice With FWD Experimental Truck Empty. Distance markers were used as aid in taking motion pictures of tests. D. Circle Test With Passenger Car to Determine Maximum Speed on Ice With Bare Tires for 150-foot Radius Curve

Tests with sanders included a comparison of the relative effectiveness of four different types of grits commonly used in sanders. Tests were also run to compare the accelerating characteristics of a four-wheel drive truck and a conventional drive truck under the same load and road surface conditions. A limited number of tests were made to determine the acceleration of a standard differential pick-up truck versus an identical truck equipped with an automatic locking differential.

The tire chain tests included two general types of chains: (1) regular plain round wire chains of the type designated as standard by most chain companies; (2) premium chains specially designed for use on ice, with each link of the cross-chain reinforced with projecting teeth or lugs. All chains used in these tests were new. Previous Committee tests have shown that braking distances for half worn chains were from 15 to 50 percent longer than for new chains; acceleration and circle test performance was likewise poorer than with new chains.

TEST PROCEDURES, TECHNIQUES, EQUIPMENT AND CREW

Types of Tests—Braking distance, acceleration, and circle tests were made for most test conditions on lake ice. On natural road ice and on packed snow only the braking distance tests were run. On the dry concrete pavement, braking distance and acceleration tests were run with cars at the normal load as listed in Tables 1 and 2 and with trucks empty and loaded as listed in the same tables.

Braking distance tests were made from a speed of 20 mph., with the brakes locked for all test conditions, and with brakes applied intermittently for a few test conditions. While an attempt was made to lock all wheels simultaneously, this condition was not exactly realized at all times, especially in the case of the heavy trucks and semi-trailers where lag was a factor. A braking distance, as used in this report, is the distance travelled from the instant of brake application to the point at which the vehicle comes to rest. A skid distance, on the other hand, is the distance travelled from the point where the wheels lock to the point where the vehicle comes to rest. The difference between this braking distance and the corresponding skid distance is referred to as lag.

Acceleration tests provided a measure of the time required to accelerate the vehicle from a standing start to a speed of 20 mph. For certain test conditions the time to accelerate through a 10 mph. speed range (usually from 10 to 20 mph.) was measured since in this way the test could be made in the one gear which produced the best acceleration time for the given test condition. The latter test procedure is preferred in the tests on ice where the acceleration rates are very low and where it is difficult to prevent wheel slippage, especially when shifting gears or when accelerating from a standing start.

The circle tests provided a measure of the maximum uniform speed which could be maintained by the test vehicle for the given test condition on a circle of known radius. Circles of 150 to 250 ft. radii were used in these tests. A fifth wheel tachometer was used to provide an accurate measure of speed. In view of the hazardous nature of this test and the large area required, the circle tests were only run on lake ice. In some of the circle tests with the trucks, the maximum uniform lateral acceleration which could be developed on a circle of given radius was measured by a recording Miller Oscillograph, adapted for thus use by the General Motors Proving Ground. The lateral acceleration values measured in this way could be converted into the side skid coefficient of friction for comparative purposes. The results with the oscillograph were not consistent and were not considered to be reliable. Accordingly, the maximum uniform speed values in the circle tests as given in this report provided the best measure of vehicle performance when driving on curves.

Test Equipment—Electrically operated stopping distance guns were used in the braking tests on dry concrete and in some of the tests on lake ice and on snow and ice covered roads. In most of the braking tests on lake ice the braking distances were determined by measuring the skid distance and correcting for lag. The point where the wheels were locked could be spotted quite accurately by one of two observers, and the braking tests could be run much faster in this way than if the guns were used.

Two types of guns were used in the braking tests. One type was the General Motors Proving Ground gun actuated by the stop light switch. With this gun dynamite caps were used to mark the spot where the brakes were applied. The other gun was developed by the American Automobile Association Safety and Traffic Dept. It was actuated by the brake pedal and used 22 cal. ammunition and a paint capsule to mark the spot on the road surface where the brakes were applied. In some of the 1946 tests the guns were operated manually by an expert test driver and were discharged at the instant the brakes were applied. The braking distances were measured with steel tapes from the mark made by the guns to the point where the vehicles came to rest.

In the acceleration tests a stop watch was used to measure time and a fifth wheel tachometer was used to measure speeds accurately. The fifth wheel tachometer was attached to the test vehicle and consisted of a bicycle wheel geared directly with a magneto generator, the output voltage of which varied with the speed. A sensitive voltmeter graduated in miles per hour was used to provide an accurate measure of speed. In some of the acceleration tests the Miller Oscillograph was used but the results with this instrument were not as satisfactory as the results obtained with the stop watch and fifth wheel tachometer.

In the circle tests, the fifth wheel tachometer was again used to provide an accurate measure of speed. The radius of the circular path of the test vehicle was measured with a steel tape.

Drivers and Observers—Since the major objective of these tests was to measure the frictional properties of the tires and the testing surfaces for many different types of vehicles and conditions of tests, it seemed essential that the variable factor in the form of driver ability to be held to a minimum. Accordingly, the drivers were either expert test drivers or test engineers of the motor companies who cooperated in this testing program. While many of the tests were not a function of driver skill, there were certain tests which were definitely dependent upon the drivers' skill. For example, it was found that the results obtained in the braking tests by applying brakes intermittently and by gearing down were considerably better than could be expected of the average driver. Likewise, only a skillful driver could obtain the advantages of reduced stopping distance and steering control possible with power braking. On the other hand, braking distance tests where the brakes were locked, definitely did not require the skill of an expert driver.

Observers were required to observe the speed, to measure the time and distance in the tests, and to record the data. Members of the Committee and representatives from the many cooperating organizations were used as observers.

Test Procedures—For the braking tests, the speedometers of the test vehicles were carefully calibrated by use of the fifth wheel tachometer. In fact, in many braking tests the speed was measured directly using the fifth wheel tachometer. All braking distance tests were made from a speed of 20 mph. In making the test, the driver would bring the vehicle to a constant speed slightly in excess of 20 mph., remove his foot from the accelerator, depress the clutch, and apply the brakes at exactly 20 mph. Four to six trials were made from each test condition to average out the effect of certain variables. The test runs were always made in opposite directions to equalize wind effects. With the exception of a few tests involving special driving techniques such as pumping the brakes, gearing down, or power-braking, all braking distance tests were made by locking the brakes. While locking is not the recommended method of braking on an icy road, it was used for the sake of uniformity to eliminate the variable due to individual driver skill when trying to stop in the shortest distance without locking the brakes.

The acceleration tests were run through a speed range of from 0 to 20 mph. or through a 10 mph. range usually from 10 to 20 mph. On dry concrete pavements, the tests were made in all gears accelerating from 0 to 20 mph. in the lower gears and from 10 to 20 mph. in high gear. On ice, the tests were made in a gear which would provide the maximum acceleration with the minimum spin of the drive wheels. Acceleration tests on ice temperatures above 20 F. from a standing start were difficult to run with bare tires especially with synthetic rubber tires, since the heat of the tires melted the ice and thus formed a depression and a wet ice condition which made starting very difficult. For this reason better results were obtained on ice by accelerating through a speed range of from 10 to 20 mph.

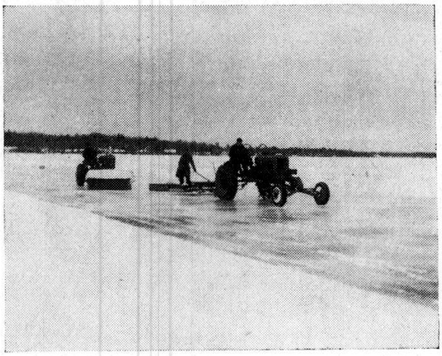

Figure 3. Ice Conditioning Equipment, Ice Planer, and Rotary Power Broom Sweeper, In Operation on Houghton Lake

In the circle tests, the object was to determine the maximum speed at which the vehicle would hold to a circular path of predetermined radius. The speed of the vehicle was increased slowly around the circle, doing so very slowly when approaching the critical speed so that skidding would not be due to acceleration. Here again a fifth wheel tachometer was used to provide an accurate measure of speed.

Ice Conditioning—After the snow had been plowed from the lake ice, the ice was shaved with a special ice-rink planer to provide a smooth glare ice surface. The ice shavings, snow, and other foreign matter was swept off the runways by using a rotary power broom sweeper. The ice conditioning equipment in operation is shown in Figure 3. The layout of the Houghton Lake test area is shown in Figure 4.

The ice was reshaved when necessary to keep it in a uniform condition, especially after

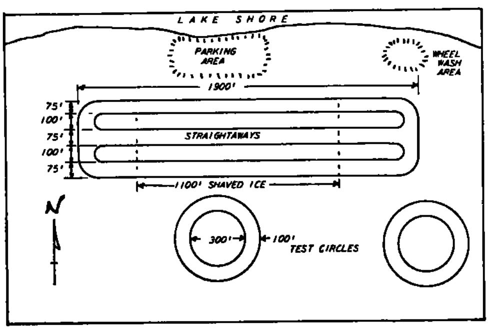

Figure 4. Layout of Houghton Lake Test Area

the chain tests. Tests using tire chains were always made on fresh smooth ice rather than on ice roughened by chains; in actual practice, this meant making each trial about 2 ft. to one side of the line of the previous trial rather than using an entirely new lane. In the chain tests it was not possible to keep the circles as smooth and clean as the straight runways because this involved too much reconditioning; however, the amount of repetition of chain circle tests on the same ice was held to a minimum. It should be noted in Figure 4 that a space was provided where the wheels of all of the test vehicles could be washed to remove sand and other foreign material before the vehicles entered the testing area on the lake ice.

RESULTS OF TESTS

Temperature Effect—While a primary objective of the tests conducted by the Committee in 1946 and 1947 was to develop reliable experimental data concerning the friction or traction available on snowy or icy surfaces as compared to that which is available on dry concrete pavement, it was expected that data would also be obtained which would accurately portray the variations in friction or traction for various test conditions on ice and snow, as for example, the variations due to type and weight of vehicle, the effect of natural rubber versus synthetic rubber tires, and the effect of the use of certain special equipment such as sanders and tire chains. However, from the 1940 tests on Lake Cadillac, the Committee knew that air temperature and the condition of the ice had a marked effect on the results of the tests. Braking distances at 32 F. for bare tires in those tests were just about double the braking distances at zero. Therefore, for results to be directly comparable, it was highly desirable to run each comparative series of tests simultaneously, or at least within a very short time interval before the temperature and ice conditions could change. In actual practice, it was not always possible to do this. For example, after making a series of braking tests with an empty truck, it was often a matter of three or four hours before the truck could be loaded and ready for testing. During that time interval, changes in temperature and in the ice condition were almost certain to take place.

An attempt was made to correlate the results of tests run at different temperatures by running braking tests continuously with one passenger car equipped with synthetic tires whenever any other tests were being run. By this means it was hoped that a correction factor based on temperature could be obtained. The results of the check car runs are plotted in Figure 5, the values given are average braking distances for each series of tests in 1946 and 1947 at various air temperatures. They are enclosed in an envelope to indicate the range in braking distance at the various temperatures.

While this graph confirmed the findings in the 1940 tests, it was obvious that a temperature correction factor could not be computed from these data. The spread in the data in the 1946 and 1947 tests was much greater than in the 1940 tests. Thus, for tests at or near the same temperature, as for example at 20 F., the braking distances on glare ice ranged from 125 to 220 ft. in the 1946 and

1947 tests. For the entire range of temperatures at which the tests were run, the braking distances varied from a low value of 110 ft. at −4 F. to a high value of 250 ft. at 32 F.

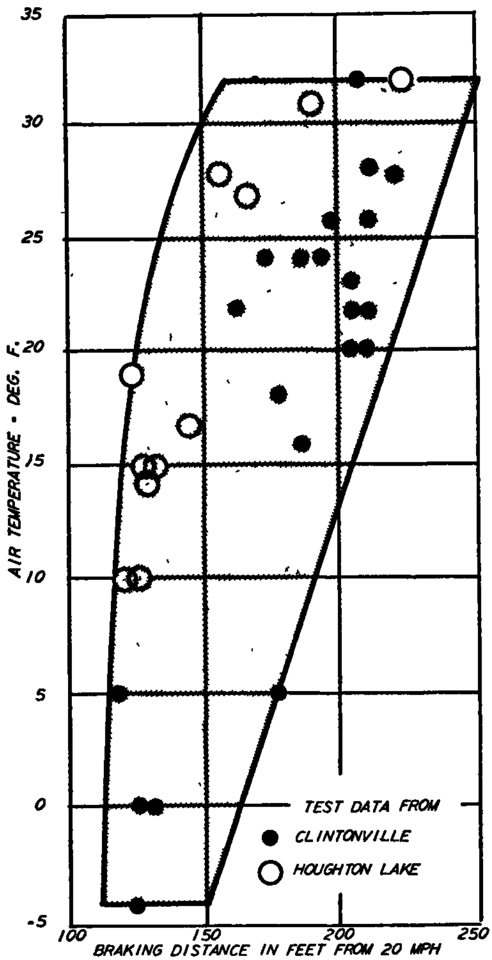

Figure 5. Relation of Braking Distance to Air Temperature in Passenger Car Tests on Glare Ice. Each symbol represents the average value of a series of runs with the various passenger cars used in the Houghton Lake and Clintonville tests. All vehicles equipped with Synthetic tires

Apparently, there are many factors other than temperature which influence the slipperiness of ice. The worst condition was at 32 F. when the ice was wet, making it very slick with the water serving as a lubricant. Even with temperatures as low as 20 F., the synthetic rubber tires were observed to be moist after a braking test. This is a characteristic of synthetic rubber tires since they normally run hotter than natural rubber tires under similar operating conditions. Other factors that, no doubt, contributed to the wide range in the test results were; whether it was clear and sunny or cloudy; the relative humidity; variable wind effects; thin coatings of drifting snow on the ice; the graininess of the ice; the time elapsed after the ice was shaved; and possibly others. The braking distances on freshly shaved runways were generally lower than on ice which had been shaved and then allowed to glaze over after several hours exposure to the sun. According to the above analysis it seems logical to conclude that, while braking distances bear a relationship to air temperature, there are many other factors which combined with temperature determine the actual skid resistance of tires on an icy surface. In order to minimize the effect of temperature in the results to be reported later where test runs could not be made simultaneously, the results are grouped into fairly narrow temperature ranges, as from 23 to 28 F.

As a general observation based on the above analysis, it may be concluded that ice or its counterpart, sleet on a hard surfaced road, is an extremely variable and unpredictable substance and every driver should expect to encounter wide variations in motor vehicle performance on such a surface. For drivers it suggests the need for operating at greatly reduced speeds. For highway departments it suggests the need for prompt and complete snow and ice removal if that is at all possible or practicable.

BRAKING DISTANCES

Bare Tires—The average braking distances in feet from 20 mph. as measured in the 1946 tests for various types of vehicles when operated with bare tires on dry portland cement concrete pavement and on glare ice are given in Table 3. The results in the 1947 tests for braking distances for various types of vehicles with bare tires on dry concrete pavement, packed snow, and glare ice are shown in Figure 6. The braking distances varied from the low value of 13 to 17 ft. for passenger cars on dry concrete to the high values of 232 to 248 ft. for the heaviest trucks and the tractor-trailer (gross weight 42,000 lb.) on glare ice. These results show that

TABLE 3
AVERAGE BRAKING DISTANCES FOR VARIOUS TEST VEHICLES USED IN 1946 TESTS ON DRY CONCRETE PAVEMENT AND WITH BARE TIRES ON GLARE ICE. AIR TEMPERATURES 24 to 30 F.

Vehicle	Braking Distance from 20 mph.	
	On Dry Concrete	On Glare Ice
	ft.	*ft.*
Passenger car...	13	149
¾-Ton truck		176
1½-Ton truck	16	215
5-Ton truck	25	182
Tractor-trailer (single axle)		166
Tractor-trailer (tandem axle)	20	117
Truck-trailer..	27	

braking distances with passenger cars and straight trucks on glare ice are about 10 times the braking distances obtained on dry concrete. Even on packed snow, braking distances are from 3 to 5 times the dry concrete braking distances. Although the highest braking distances for a given condition as reported in Table 3 and Figure 6 are for the heaviest vehicle, the ratio for the braking distance on glare ice versus dry concrete for this unit was about 6 to 1 instead of 10 to 1 usually found for the other test vehicles. This lower ratio was due to the relatively greater braking distance on dry concrete for this very heavy unit for which the lag was greater than for the other vehicles and the brakes were not powerful enough to lock the wheels on dry concrete from a speed of 20 mph.

While the above values provide a good comparison for a narrow temperature range, wide variations from these values were found at other temperatures. For example, in the 1947 tests the average braking distances of the passenger car equipped with synthetic tires ranged from a low of 125 ft. at −4 F. to a high of 210 ft. at 28 F. For the same car equipped with natural rubber tires, braking distances of 84 ft. at −4 F. to 169 ft. at 28 F. were measured. The straight 5-ton trucks loaded varied from 116 ft. at −4 F. to 306 ft. at 32 F. These same trucks empty varied from 175 ft. at 2 F. to 299 ft. at 32 F.

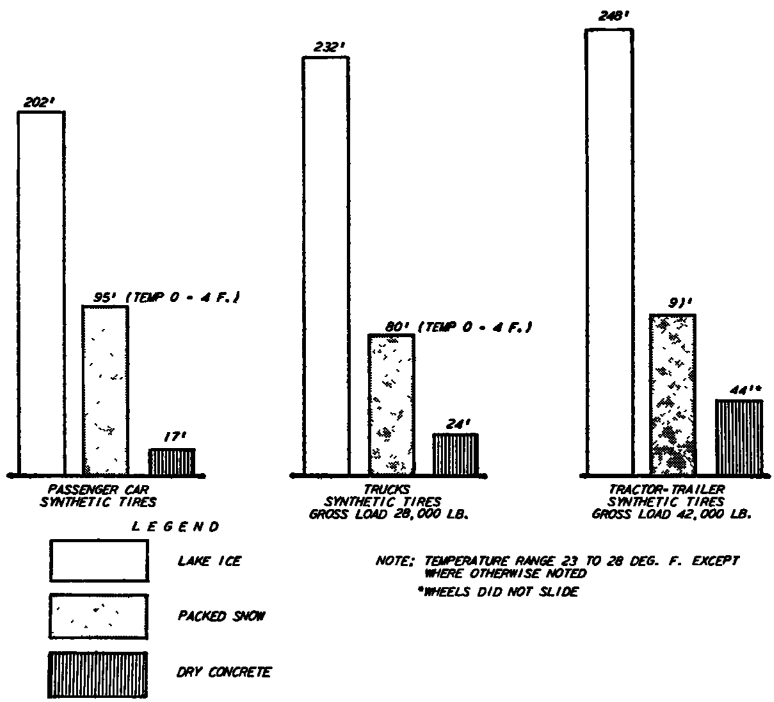

Figure 6. Average Braking Distances From 20 MPH on Glare Ice, Packed Snow, and Dry Concrete

The above values for braking distance on glare ice are highly significant, not only because the values cover a wide range in braking distance for various temperatures but the braking distances of 300 ft. or more at 32 F. for heavy vehicles are unusually high considering the low speed of 20 mph. at which the tests were run. Many drivers of heavy vehicles (trucks and buses) have assumed that since the heavy vehicles hold to the road better than the light vehicles, they are justified to drive them at higher speeds on ice and packed snow. The unusually long braking distances for the heavy vehicles on glare ice as measured in these tests makes it extremely doubtful if higher speeds for them are justified. In fact, if the large amount of damage which a heavy vehicle can inflict upon itself and others when out of control is considered with their longer braking distances, it would appear that heavy vehicles should be operated at lower speeds than passenger cars in the interest of greater safety on icy roads.

Bare Pavements—The short braking distances for the various test vehicles on dry concrete pavement as given in Table 3 and in Figure 6 when compared with the very long braking distances for the same vehicles on glare ice, clearly indicate the marked advantage of driving on dry pavements to prevent skidding accidents. The short braking distances on dry pavements, no doubt, provide the best explanation for the general absence of skidding accidents on dry pavements while the long braking distances on glare ice indicate why 40 percent of the accidents on ice are skidding accidents. It is for these reasons that state highway and city street departments should adopt a bare pavement winter maintenance policy which provides for the prompt and complete removal of snow and ice on the major streets and highways in so far as funds permit.

The complete removal of snow and ice during a winter thaw rarely results in a dry pavement but usually leaves the pavement wet and in this condition may be almost as serious a skidding hazard as ice or snow. The Committee has not conducted braking tests on wet pavements since this has been the subject of an exhaustive investigation by the Engineering Experiment Station at Iowa State College under the direction of the writer. It seems appropriate at this point to refer briefly to one chart (Fig. 7) based on this investigation. In Figure 7 the slipperiness of the various surfaces on which tests were run is shown in terms of the coefficients of friction at various speeds. A significant fact brought out in this study was that the coefficients of friction of certain surfaces, such as on the penetration macadam surface (A-9) with the soft seal coat, were almost as high at low speeds for the wet surface condition as for the dry condition but dropped very sharply for the wet surface condition as the speeds were increased. In fact, at 40 mph. this surface when wet was more slippery than packed snow and was almost as slippery as ice. While smooth tread tires contributed to the low coefficients on this surface at 40 mph., they are not always the reason for the low coefficients on wet surfaces as is evident from an examination of the results of the tests on the wet asphaltic concrete surface (A-1) shown in Figure 7. This surface had a coarse-grained sandy texture with no excess asphalt present on any part of the surface. The squeegee action of the tread pattern of the new tires provided no advantage over the smooth tread tires on this surface when wet. In fact, even at 40 mph. the smooth tread tires developed higher coefficients than the new tires with the special non-skid tread pattern. The advantages of providing a coarse-grained sandy texture or a gritty rock-chip texture in building non-skid road surfaces has been thoroughly covered in papers by the writer presented at the Annual Meetings of the Highway Research Board in 1933, 1934, 1936, and 1942. By the use of certain proven methods of construction and maintenance, the highway engineer can provide road surfaces on which the skidding hazards are only slightly greater when wet than when dry. There is considerable evidence that the elimination of many miles of slippery-when-wet pavements in all parts of the United States would be a major contribution in a nation-wide program to reduce winter traffic accidents.

Tire Chains—The effect of tire chains in reducing braking distances for various types of test vehicles operated on glare ice is shown in the results of the 1946 tests given in Figure 8. Similar results were obtained in the 1947 tests using a 5-ton truck loaded and empty with which a variety of tire chain tests were run as indicated in Figure 9. The results with the loaded 5-ton truck are typical of the effect obtained with tire chains. At temperatures ranging from 22 to 28 F. the average braking distance for this truck with bare tires on glare ice was 232 ft. With regular (round-wire) chains on the rear wheels this distance was reduced to 79 ft. or only about one-third the distance with bare tires. This was further reduced to 61 ft. with regular chains on all wheels, to 55 ft. with premium chains on the rear wheels, and to 42 ft. with premium chains on all wheels. It should be noted that while the braking distance with premium chains on all wheels was only one-fifth the distance required with bare tires, it was still nearly twice as great as on dry concrete.

Results of the chain tests with the empty trucks followed the same trend as with the loaded trucks. The percentage reduction, however, was not as great, partly due to the shorter bare tire braking distances obtained with the empty trucks which were operated over a wider temperature range than the loaded trucks. Also, the effect of temperature on the braking distances with tire chains was not as great as in the bare tire tests.

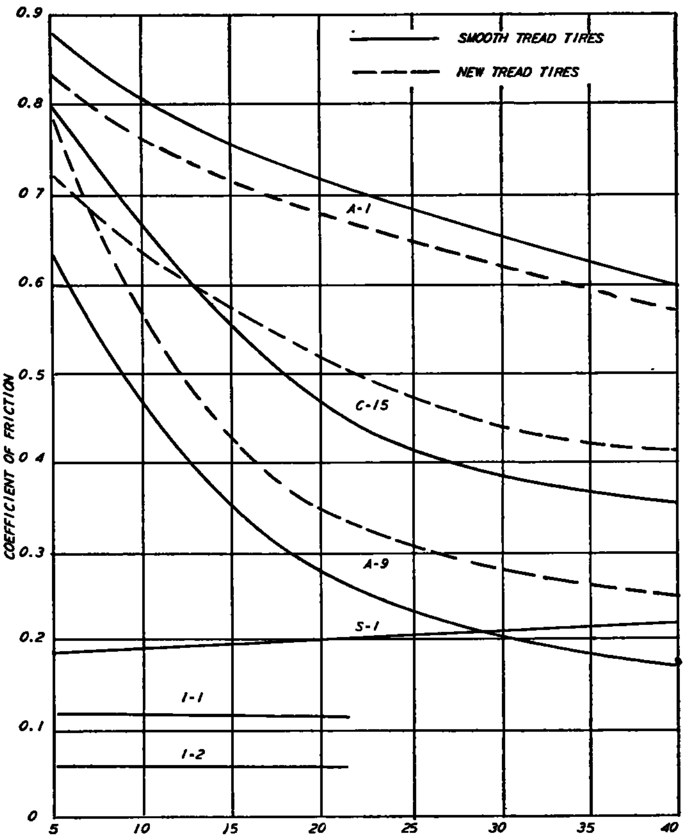

Figure 7. Coefficients of Friction for New Tread and Smooth Tread Passenger Car Tires on Various Types of Surfaces. All tests conducted on wet surfaces except as noted. Engineering Experiment Station, Iowa State College, Ames, Iowa. Curves A-1, Asphaltic Concrete; A-9, Penetration Macadam with Excess Asphalt; C-15, Coarse Sandy Belted Concrete; S-1, Packed Snow; I-1, Dry Ice at Zero F.; I-2, Wet Ice at 30 F.

On packed snow the braking distance with bare tires for the 5-ton truck loaded averaged 80 ft. (see Fig. 9). With regular chains on the rear wheels this was reduced to 47 ft. and with premium chains to 45 ft. The difference due to the type of chain was slight because on snow sharp lugs on the chains are not required to cut into the snow to reduce braking distances to the same extent that they are required on ice.

the tests with the passenger car equipped with synthetic tires the average braking distance at 32 F. was reduced from 225 ft. with bare tires to 111 ft. with regular chains on rear wheels

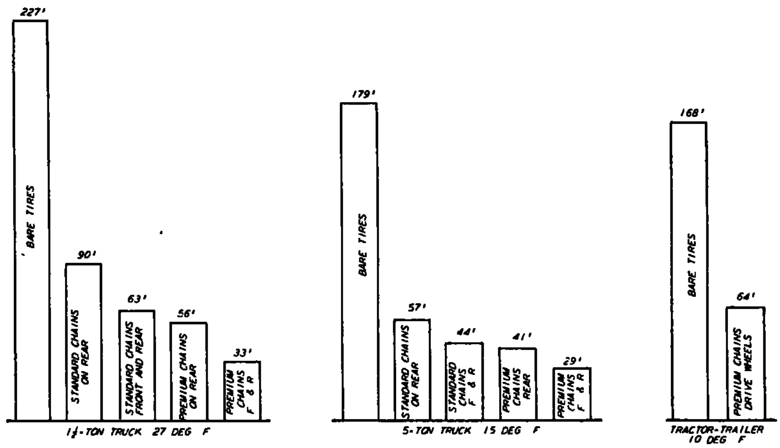

Figure 8. Braking Distances from 20 MPH for Various Test Vehicles Operated With Bare Tires and With Tire Chains on Glare Ice in 194€ Tests

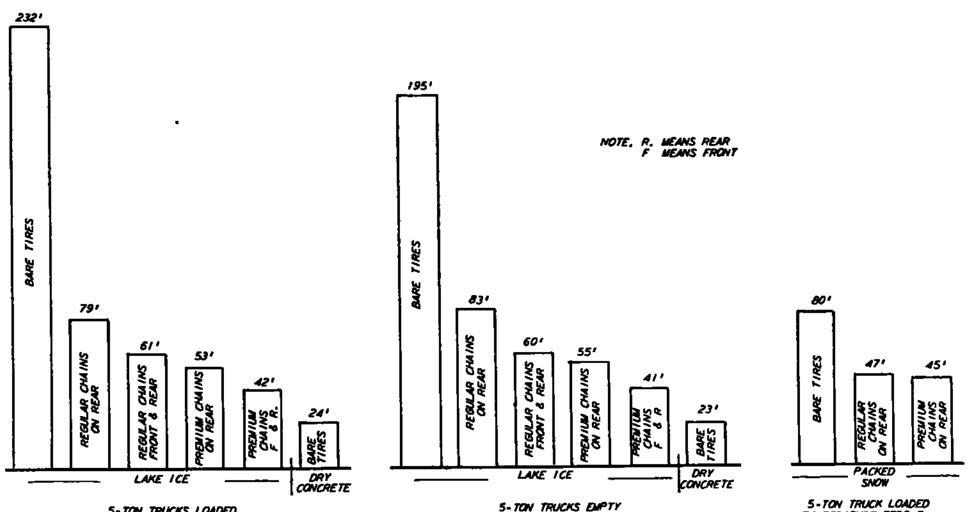

Figure 9. Braking Distances for 20 MPH for 5-ton Trucks Loaded and Empty Operated With Bare Tires and With Tire Chains on Lake Ice and Packed Snow, Also With Bare Tires on Dry Concrete Pavement in the 1947 Tests

The results of the tire chain braking tests with passenger cars followed the same trend as the tests with trucks, although the stopping distances for passenger cars equipped with chains were slightly greater than for the trucks with chains for corresponding tests. Thus, in

and to 61 ft. with premium chains on the rear wheels. For the 5-ton truck loaded the corresponding distances for tests at temperatures ranging from 22 to 28 F. were 232 ft. for bare tires, 79 ft. for regular chains on rear, and 53 ft. for premium chains on the rear. No doubt, the increased weight of the loaded truck caused the chains to cut deeper into the ice and thus reduced stopping distances. This action is also evident when comparing the results for the chain tests with the loaded versus the empty 5-ton truck.

The slightly higher braking distances obtained in the chain tests for passenger cars equipped with natural rubber tires as compared with the results in corresponding tests with synthetic tires shown in Figure 10 are not so readily explainable as the differences obtained for certain other test conditions.

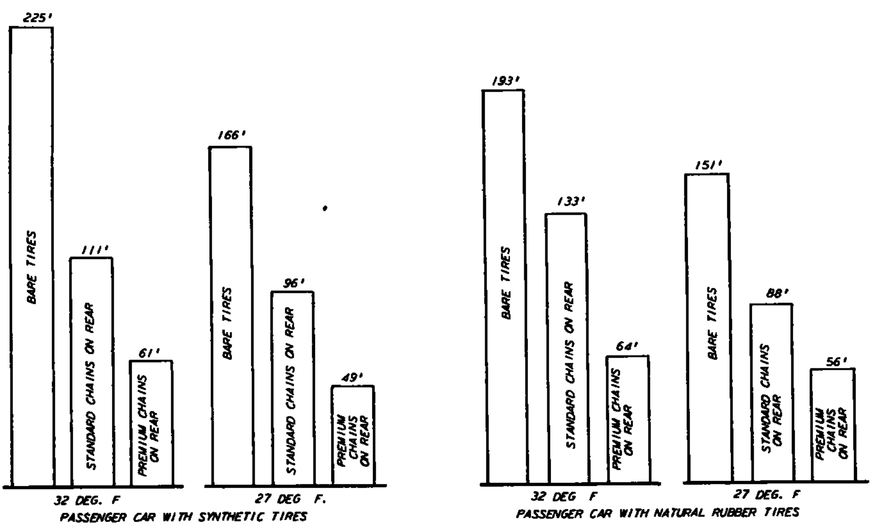

Figure 10. Braking Distances for 20 MPH for Passenger Cars with Bare Tires (Synthetic and Natural Rubber) and With Tire Chains on Glare Ice in the 1946 Tests

While a reduction in braking distances is desired for any given driving condition whenever possible, it should be recognized that small differences of the type referred to above are not significant because they cannot always be depended upon. The average braking distances, as for example with tire chains for passenger cars referred to above, are still 4 to 5 times the distances obtained on dry concrete on which driving habits are formed which frequently contribute to accidents on slippery surfaces.

The use on all wheels of the premium tire chains which were specially designed to cut into the ice, provided the best performance in the tests on glare ice with all types of vehicles using all types of devices and driving techniques.

BRAKING TECHNIQUE

Pumping versus Locking Brake Tests—In the braking tests reported thus far, the brakes at all wheels were locked because this is the easiest method of braking to provide consistent results, and also it is the type of braking most frequently used by the average driver when making an emergency stop on a slippery surface. While locked wheel stops are fairly effective in holding braking distances to the minimum value for the given surface or test condition, they are dangerous because when the wheels are locked all steering control is lost. On the typical crowned highway, the vehicle with all wheels locked will slide sideways but if only the rear wheels are locked, it will not only slide sideways but it may go into a spin and, if it is a semi-trailer truck, it may go into a jackknife. Many bus and truck drivers have developed special braking methods which they use on slippery roads not only to prevent the dangerous side skids referred to above but also to obtain the shortest possible stopping distances. Two of these methods were investigated in the 1947 tests. The first method is referred to as "pumping" or "fanning" the brakes while a second method is referred to by professional drivers as "power braking." Tests of these two methods of braking were run with two purposes in mind: (1) to determine the relative advantage of each method in reducing stopping distances on ice when compared with the stopping distances for locked wheel braking; and (2) to determine the proper technique for "pumping" and for "power braking" to achieve the best results.

The effectiveness of pumping brakes in reducing braking distances on glare ice is indicated by the results of tests with two passenger cars and one 5-ton truck (Table 4). With expert drivers operating the vehicles, pumping reduced braking distances from 5 to 18 per cent below the locked wheel braking distances for these vehicles. In one series of tests an average driver was selected and instructed to pump the brakes to obtain the shortest possible stop, the actual technique of pumping being left to his judgment. Under this condition, the average braking distance was slightly longer than that obtained by locking the wheels.

TABLE 4

PUMPING VERSUS LOCKING BRAKING DISTANCES IN FEET FROM 20 MPH ON GLARE ICE FOR TWO PASSENGER CARS AND FOR A CONVENTIONAL 5-TON TRUCK

Vehicle	Temperature	Lock Stop	Pump Stop	Improvement
	deg.	*ft.*	*ft.*	%
Ford sedan	22	160	166	−4[a]
Ford sedan	22	161	152	6
Cadillac sedan	22	208	171	18
Convention 5-ton truck (Loaded)	24	161	153	5
	24	161	144	11
	0	129	109	16

[a] Driver in this first series was an average driver rather than a test driver. The proper technique of pumping the brakes was not explained to him, his only instruction was to pump the brakes to obtain the shortest possible stop.

In the 1940 tests on Lake Cadillac a few pumping tests were run in which a gentle pumping action was used on the theory that this was necessary to prevent locking the wheels. Further experimentation in the 1947 tests on Pine Lake demonstrated that the proper technique to achieve the best results consists of a series of very rapid and hard jabs on the brake pedal, continuing until the vehicle is brought to a stop and making certain that the brakes are completely applied and completely released on each stroke of the brake pedal. This technique has a logical theoretical explanation. Many tire and road friction tests by the writer have shown that the friction developed by a tire on a hard surface reaches a maximum at the instant just before the wheels lock and sliding commences. Therefore, the shortest braking distance should be obtained by reaching this peak friction the greatest possible number of times during the stop. Since it is extremely easy to lock the wheels on glare ice and since it is very difficult to tell by feel whether the wheels are locked or sliding, a gentle pumping action will not lock and release the brakes rapidly enough to produce a shorter stop than a locked wheel stop. It should, of course, be realized that pumping is most effective only for a braking system with brakes which can lock and unlock the wheels with great rapidity and that with a sluggish braking mechanism it is very likely that pumping will not reduce the stopping distance below the locked wheel braking distance. But even under these circumstances pumping may have merit if it is properly done, when the important factor of steering control is considered.

Power Braking—Power Braking consists of applying power, without accelerating, using the right foot while the left foot actuates the brake pedal. The sudden removal of the right foot from the throttle may develop a braking force at the driving wheels due to motor compression large enough to cause dangerous side skids or a jack-knife in the same way that locked rear wheels cause side-skids and jack-knifing. The continued slight application of power minimizes the side skid hazard and provides a better balance of the braking forces on all wheels which may produce shorter stops than locked wheel braking. The greatest advantage, however, of this type of braking is the improved steering control made possible by it when driving on a slippery surface.

Two series of tests were made to determine the effectiveness of power braking, one with a standard 5-ton truck and the other with a four wheel drive 5-ton truck. With the standard truck equipped with air brakes no appreciable difference in braking distances was noted, the locked wheel stops averaged 259 ft. at a temperature of 31 F. while the stops with power braking averaged 257 ft. at the same temperature. However, in the tests with the four wheel drive truck equipped with hydraulic brakes operated by a vacuum booster, locked wheel stops averaged 299 ft. at 32 F. compared with power braking stops averaging 261 ft. with the truck empty. With this same truck loaded the locked wheel stops averaged 313 ft. at 22 F. as compared with 246 ft. with power braking stops.

The experience in these tests indicated that power braking requires more skill to obtain the best results than when the pumping method is used. In power braking the driver must get the feel of the brakes to a very fine point to cut stopping distances to a minimum. These tests indicated that this was easier to do with vacuum booster brakes than with air brakes.

BRAKING TESTS

Sanders—Four types of grits commonly used in sanders were used in the braking tests with sanders: Grit No. 1 was a lake beach sand with rounded particles; Grit No. 2 was an angular flint abrasive type grit; Grit No. 3 was an angular calcite grit; Grit No. 4 was a specially processed sharp angular slag product. All of the grits were approximately of the same size with 100 percent passing a No. 4 mesh sieve and 90 to 100 percent retained on a No. 20 mesh sieve. The average diameter of the grit particle was about 0.07 inches. Also, the grits were quite hard except the calcite grit (No. 3) which crushed rather easily into angular fragments.

The results of the tests with sanders are given in Figures 11 and 12. In the tests comparing the four grits, the wheels were locked in the customary manner and it was found that braking distances were actually increased slightly with three of the grits and only with grit No. 4 were braking distances reduced over those obtained with bare tires on glare ice at the same temperature. The stopping distance at −4 F. with bare tires was 124 ft. as compared with 111 ft. using grit No. 4. It was observed in these locked wheel stop tests that most of the particles of grit were swept to one side or ahead of the wheels and did not get under the tire in contact with the ice. Also, three of the grits did not cut sharply into the ice and appeared to develop a skate-like action under the tires, thereby increasing the stopping distances for these three grits above the values obtained when no grits were used. Unfortunately, these tests were run at extremely low temperatures only and it is possible that better results would be obtained at higher temperatures.

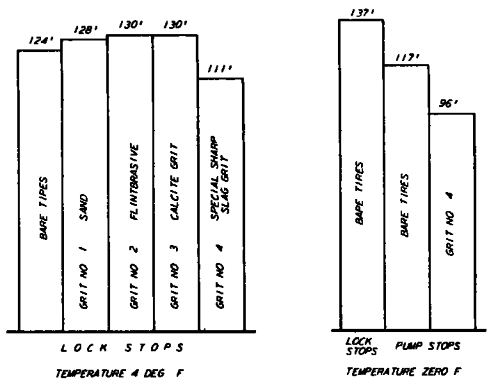

Figure 11. Braking Distance Tests With Sanders. Conventional 5-ton Truck Loaded—Braking Distance in Feet from 20 MPH on Glare Ice

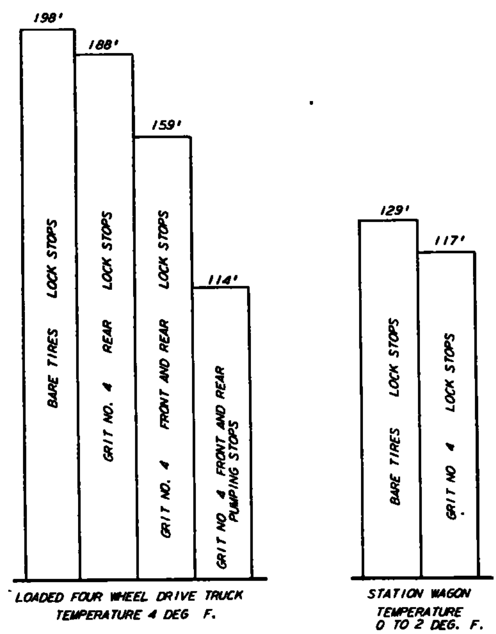

Figure 12. Braking Distance Tests With Sanders on Pine Lake—In Feet from 20 MPH on Glare Ice

The results in Figures 11 and 12 of tests in which pumping stops were made indicated a definite advantage of this method of braking when sanders are used probably because this technique permits a high percentage of the grit to be lodged under the tire and to cut sharply into the ice. Thus, with bare tires at 0 F., the locked wheel stops were made in an average distance of 137 ft. with a loaded 5-ton truck as compared with 96 ft. with grit No. 4 applied at the rear wheels when the pumping method was used. With sanders at all four wheels of the four-wheel drive truck, the advantage of the pumping method was even greater with bare tire stops averaging 198 ft. at 4 F. and 114 ft. when pump stops were made with No. 4 grit.

Road Ice versus Lake Ice—A series of braking tests was made on natural road ice, approximately ⅜ in. thick, with a thin coating of snow in spots, to compare its slipperiness with that of lake ice. At a temperature of −4 F., braking distances of the passenger car equipped with synthetic tires averaged 113 ft. on road ice and 133 ft. on lake ice. Under the same conditions, braking distances on packed show averaged 103 ft. Braking distances with a loaded 5-ton truck run at air temperatures of zero to −4 F., averaged 131 ft. on lake ice, 81 ft. on road ice, and 80 ft. on packed snow. One of the principal reasons for the shorter stops on road ice as compared with the stops on lake ice was the presence of spots of snow on the road ice and the fact that the crown of the road caused the rear wheels to slide sideways onto a strip of packed snow which also reduced the stopping distances.

TABLE 5

AVERAGE ACCELERATION ON GLARE ICE FOR VARIOUS TEST VEHICLES AND TEST CONDITIONS IN TERMS OF THE TIME IN SECONDS TO ACCELERATE THROUGH A SPEED RANGE OF 10 MPH

Vehicle	Acceleration Time		
	Bare Tires	Standard Chains	Premium Chains
	sec.	*sec.*	*sec.*
Passenger car	19.8	4.2	4.1
½-Ton truck	21.1		
1½-Ton Truck	14.6	3.8	3.5
5-Ton truck	10.3		3.8
Tractor-trailer (single axle)	25.6		4.0
Tractor-trailer (tandem axle)	43.6		
Average	23.9	3.9	3.8

Coil Spring Tires and Rubber Tire Chains—A series of special braking tests was run with a passenger car equipped with coil spring tires. These tires were built with continuous steel coil springs about ¼ in. in diameter embedded in each of four ribs in the tread of the tire. At a temperature of 5 F. the average braking distance with the coil spring tires was 148 ft. as compared with 168 ft. with the regular synthetic tires. Thus, the coil spring tires can hardly be considered to provide a significant advantage in the braking tests.

Tests to determine the effectiveness of rubber tire chains were made on lake ice and on packed snow. At a temperature of 26 F., the braking distances on lake ice with rubber tire chains averaged 250 ft. as compared with 234 ft. for the bare synthetic tires. On packed snow, the rubber tire chains showed an advantage, with an average braking distance of 69 ft. for the rubber tire chains as compared with 84 ft. for synthetic tires without the chains. These results are about as might be expected, that is, rubber tire chains are of no value on glare ice and reduce braking distances only slightly on packed snow.

ACCELERATION TESTS

Bare Tires versus Tire Chains—The acceleration tests provided a measure of the maximum traction which the various test vehicles could develop for the given test conditions. They also indicated the relative hill climbing ability of these vehicles for the various test conditions. The results of the acceleration tests on Houghton Lake run in 1946 are shown in Table 5 and Figure 13 and for similar tests on Pine Lake in 1947 are shown in Table 6.

All of the acceleration values in Tables 5 and 6 are given in terms of the time in seconds required to accelerate through a speed range of 10 mph. With bare tires on glare ice, this acceleration time for all vehicles and all conditions varied from 10.3 to 43.6 sec. as given in Table 5 and from 6.0 to 21.2 sec. for the conditions in Table 6. The large differences in acceleration are due to three factors: (1) the wide range in ratios of total weight to the weight on the drive wheels as given in Table 1; (2) the variations in engine power available to drive the vehicles; and (3) the wide range in the weights of the vehicles or the total mass to be accelerated.

Using standard tire chains the time to accelerate through a 10 mph. speed ranged from 3.0 to 4.4 sec., with an average value for all tests of 3.9 sec.; using premium chains this time ranged from 2.3 to 4.6 sec. for an average of 3.8 sec. Corresponding acceleration times on dry concrete (in the gear producing the best acceleration) ranged from 1.8 sec. to 4.2 sec., for an average of 2.8 sec. It is interesting to note the uniformity in the time for all of the chain tests and the marked advantage in acceleration which they provide when compared with the results in the bare tire tests. These tests clearly indicated that one of the most effective uses of tire chains is to provide traction. It was observed in the tests with the heavy trucks that the chains were cutting into the ice so deeply that the driving wheels were "geared" to the ice, and engine torque rather than traction was the limiting factor which determined the acceleration time.

The results in Table 6 for the acceleration tests on Pine Lake indicate the advantage of a four wheel drive truck over a conventional truck when accelerating with bare tires on glare ice. The acceleration time for the four wheel drive truck averaged 6.0 sec. as compared with 11.0 sec. for the convention truck. With the entire weight of the four wheel drive truck available to provide traction and only 60 percent of the weight of the conventional truck for this purpose, the above results for acceleration time are quite reasonable. These results also indicate the advantage of the four wheel drive truck over standard trucks in climbing hills when roads are icy.

In Figure 13 the results of acceleration tests with a passenger car equipped with synthetic rubber tires, with and without tire chains, and with bare tires on dry concrete are given. In these tests the time to accelerate from 0 to 20 mph. in second gear is given for each test condition. These results parallel closely the acceleration test results given in Table 5.

Sanders—Acceleration tests were run with the station-wagon which was equipped with sanders using grit No. 4. The acceleration time through a 10-mph. speed range for this vehicle was found to be 10.8 sec. with bare tires on glare ice, 5.1 sec. with the sanders, and 1.9 sec. on dry concrete. Thus, while the use of sanders may cut acceleration time in half, they are not as effective on glare ice as tire chains to provide traction, or to accelerate, or to climb hills.

Automatic Locking Differential—Two ½-ton trucks, one equipped with a standard differential and the other with an automatic locking differential were subjected to acceleration tests. Using the standard procedures described above, no appreciable differences in accelerating ability were noticeable. However, a special technique was devised to determine whether or not an automatic locking differential has any advantages in situations where only one drive wheel is able to develop

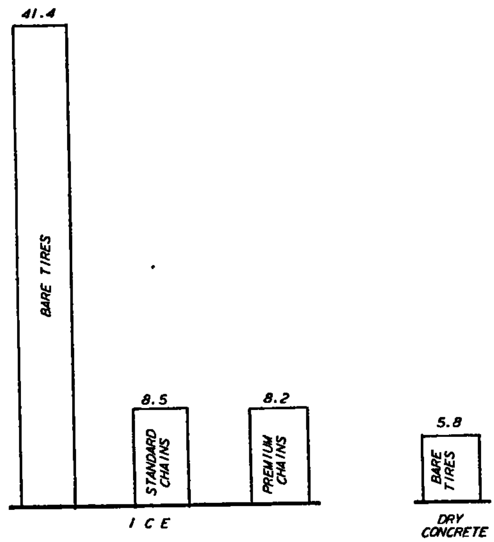

Figure 13. Time in Seconds to Accelerate from 0 to 20 MPH in Tests on Glare Ice on Houghton Lake and on Dry Concrete Pavement With Passenger Car Equipped With Synthetic Rubber Tires. Air Temperature 25 F. Tests Run in Second Gear

TABLE 6
ACCELERATION TESTS FOR 1947 TEST VEHICLES WITH BARE TIRES ON GLARE ICE. ACCLERATION GIVEN IN TERMS OF TIME IN SECONDS TO ACCELERATE THROUGH A 10-MPH SPEED RANGE

Vehicle	Speed Range	Gear	Temperature	Acceleration time
	mph.		*deg.*	*sec.*
Conventional 5-ton truck (Empty)	9–19	3–4	21–26	11.0
Four wheel drive 5-ton truck (Empty)	10–20	4	20	6.0
Passenger car with synthetic Tires	10–20	3	23–26	21.2

traction. To meet this condition, tire chains were used on only one drive wheel of each vehicle, the other being free to spin on the glare ice surface. Acceleration tests under this condition showed the marked superiority of the automatic locking differential. In first and second gears the vehicle equipped with the locking differential required only about one-fifth of the time to accelerate from 0 to 20 mph. as did the standard vehicle under similar conditions. In third gear, the standard vehicle could accelerate slowly from 0 mph., whereas the vehicle with the automatic locked differential stalled under the same conditions. This, of course, is analogous to trying to start in third gear on a dry concrete pavement.

TABLE 7

CIRCLE TEST RESULTS—MAXIMUM SPEEDS MAINTAINABLE ON ICE ON A CIRCULAR PATH OF APPROXIMATELY 200-FT. RADIUS

Vehicle	Maximum Speed Maintainable on Ice				
	Bare Tires	Standard Chains on Drive Wheels	Premium Chains on Drive Wheels	Standard Chains on All Wheels	Premium Chains on All Wheels
	mph.	mph.	mph.	mph.	mph.
Passenger car	14.7	18.6	20.4	20.5	
1½ Ton truck (empty)	12.4	14.0	14.4	15.5	19.5
1½ Ton truck (loaded)	15.1	20.0	20.8	25.0	27.9
5-Ton truck (empty)	13.0		20.7		21.8

CIRCLE TESTS

The results of the circle tests on glare ice for a passenger car, a 1½-ton truck empty and loaded, and a 5-ton truck are given in Table 7. The tests were run to determine the maximum speed maintainable on ice on a circular path of approximately 200-ft. radius for the test vehicles with bare tires, and with standard chains on the drive wheels, premium chains on the drive wheels, with standard chains on all wheels, and with premium chains on all wheels. In the tests with the bare tires, the maximum speeds were in the low range of 12.5 to 15 mph. for all three vehicles. With chains on rear wheels only, the speeds were increased 2 to 5 mph. above the speeds in the bare tire tests. With chains on all wheels, the maximum speeds were from 3 to 13 mph. greater than in the bare tire tests.

In the circle tests, friction must be developed at the front and rear wheels to hold the vehicle in the fixed circular path. The higher the speed, the greater the friction forces must be at both the front and rear wheels. With tire chains at the rear wheels, there is a substantial increase in the friction which can be developed at the rear wheels, however, if chains are not used on the front wheels, the driver will have difficulty steering the front wheels along the curved path at speeds higher than the maximum bare tire speeds. Under these conditions the front wheels will slide out away from the curve and a reduction in speed is required to bring the vehicle under control.

With chains on both front and rear wheels, a substantial increase in friction can be developed on a given curve at both the front and rear wheels. Furthermore, the deeper the chains cut into the ice, the greater the friction developed at each wheel and the higher the speed on the curve. This latter action was evident in the tests with the loaded 1½-ton truck equipped with premium chains where a maximum speed of 27.9 mph. was obtained with a wide open throttle. The maximum permissible speed on a similar curve on dry concrete pavement is about 30 mph. At this speed the side-skid coefficient of friction is about 0.3 which is double the design value generally used in highway curve design and this indicates the margin of safety provided on curves when premium chains are used on all wheels.

SYNTHETIC VERSUS NATURAL RUBBER TIRE TESTS

A comparison between the braking and accelerating ability of natural versus synthetic rubber tires is shown in Figure 14 in which the results of the 1947 tests on Pine Lake are summarized. Results of like nature were obtained in the 1946 tests on Houghton Lake although these tests were limited to a temperature range of only 25 to 32 F.

The braking distances on lake ice as given in Figure 14 ranged from a low average of 125 ft. to a high average of 210 ft. with synthetic tires as compared with a range of 84 to 169 ft. for natural rubber tires. This represents a difference in braking ability between the two types of tires of from 20 to 33 percent. One explanation for the longer braking distance obtained with the synthetic rubber tires may be in the fact that synthetic tires run considerably hotter than natural rubber tires and melt the ice more easily causing the tires to slide farther.

Braking distances on packed snow at a temperature of zero averaged 95 ft. with the synthetic tires versus 89 ft. with the natural rubber tires, a difference of only 6 percent.

Acceleration tests on glare ice through a speed range from 10 to 20 mph. averaged 21.2 sec. with the synthetic tires and 16.3 sec. with the natural rubber tires, a difference of 23 percent. The heating effect of the synthetic tires was quite noticeable in the acceleration tests at temperatures close to 30 F. when the tires of standing vehicles melted the ice and formed a depression from which it was almost impossible to start even on a level lake ice surface. This adds emphasis to the importance of removing snow and ice from streets and highways or if this is not done, to treat these surfaces with abrasives to keep traffic moving.

CONCLUSIONS

1. Ice and snow on streets and highways are the principal reasons for the 24 to 53 percent higher traffic death rate during the winter months than during the summer months in the northern half of the United States.

2. Factors affecting the slipperiness of ice, such as temperature, whether the ice is wet or dry, relative humidity, wind velocity, whether it is sunny or cloudy, conditions under which the ice surface was formed, the graininess of ice, and possibly others cause a much wider spread in the braking distances than the type of vehicle, load, tires, tire pressures, pumping the brakes, or power braking.

3. As a corollary to 1 and 2 above, the extremely variable performance of icy road surfaces emphasizes the need for: (1) complete ice and snow removal or surface treatment with abrasives; and if this is not done, (2) the use of tire chains and operation at greatly reduced speeds.

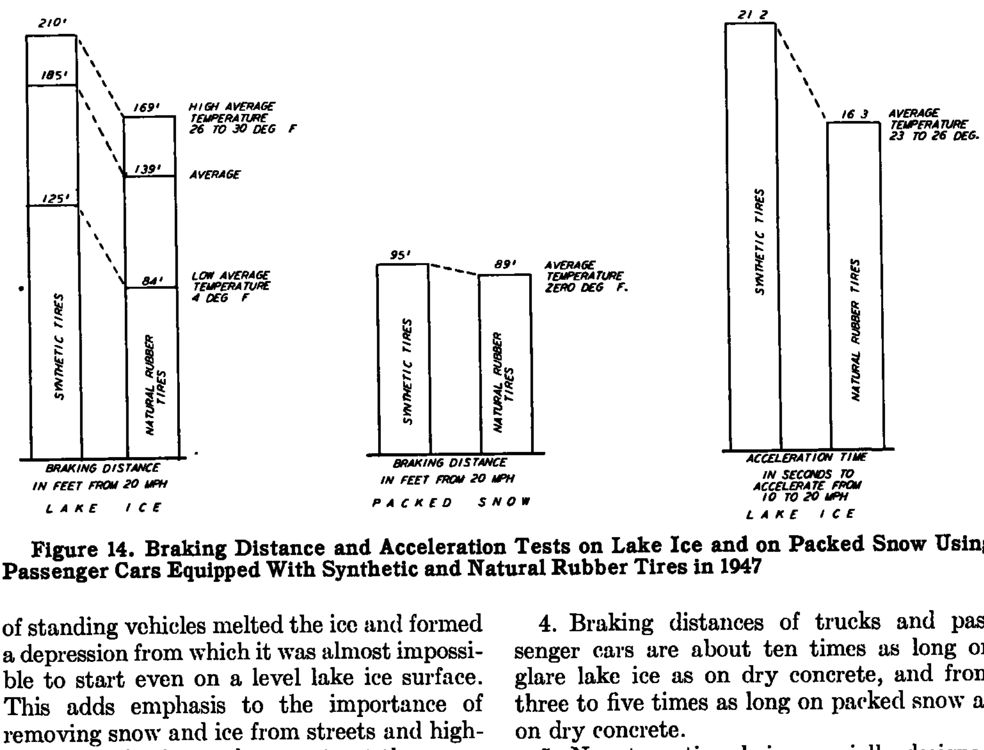

Figure 14. Braking Distance and Acceleration Tests on Lake Ice and on Packed Snow Using Passenger Cars Equipped With Synthetic and Natural Rubber Tires in 1947

4. Braking distances of trucks and passenger cars are about ten times as long on glare lake ice as on dry concrete, and from three to five times as long on packed snow as on dry concrete.

5. New type tire chains specially designed for use on ice reduce truck braking distances to 20 or 30 percent of the braking distances obtained with bare tires on glare ice, depending on load and whether the chains are used on rear wheels only or on all wheels. Even with the best chains on all wheels, however, braking distances on ice are still nearly twice the dry concrete braking distances.

6. Sanders provide a slight reduction in braking distances on glare ice providing the

proper type of grit is used. Even the best grit reduces braking distances at low temperatures only 5 to 10 percent using a lock wheel stop. For maximum effectiveness with sanders, the pumping braking technique should be used—under this condition, the best grit reduces braking distances 30 to 40 percent below the locked wheel stop, depending on whether sanders are used on the rear wheels only or on all wheels.

7. Acceleration time with an empty (15,670 lb.) four wheel drive truck through a speed range of 10 mph. on glare ice is about half that obtained with a standard truck. This indicates approximately the advantage of four wheel drive trucks over standard trucks when climbing hills on icy roads.

8. Pumping the brakes can reduce braking distances as much as 20 percent, providing the proper technique is used. Because of the increased steering control possible by pumping, this method of braking is recommended even for the inexpert driver.

9. Power Braking (applying power without accelerating with the right foot while braking with the left) can reduce braking distances about 20 percent for a truck equipped with hydraulic or electric brakes; with air brakes this technique is not effective.

10. Natural road ice may closely approach glare lake ice in slipperiness.

11. Glare ice braking distances with natural rubber tires range from about 20 to 30 percent less than with synthetic tires. Acceleration time through a speed range of 10 mph. is about 25 percent less with rubber tires than with synthetic tires.

CERTAIN STRUCTURAL COMPONENTS OF LETTERS FOR IMPROVING THE EFFICIENCY OF THE STOP SIGN[1]

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SYNOPSIS

In 1930–31 studies were carried out by the writer under the National Research Council to determine the most efficient type of license plate. The results obtained with numbers suggested a further study of letters on highway signs. In 1939 Forbes presented a paper before the Highway Research Board giving certain constants for spacing of Series B, Series D, and Series E letters used at that time on standard highway signs.

These various studies suggested the need for exploration of types, stroke, and spacing of letters and background combinations which could be made to give a greater legibility distance and efficiency than those used heretofore. Accordingly studies were begun in 1940 at Iowa State College as a cooperative study of the Committee on Motor Vision for the American Optometric Association, the Engineering Experiment Station, Iowa State College, and the Public Roads Administration, to ascertain the basic principles for improving letter designs using Forbes' formulae as a basis of departure. It became obvious that improved letters could be designed if more study were given the individual characteristics of each letter, especially in four-letter words. It was found that a stroke somewhere between 0 18 to 0.25 the width of the letter would give best results and that it would need to be proportional to the height or width It was also found that letters are crowded together much too closely for maximum efficiency. Optimal spacings were studied and optimal limits established.

[1] Study inaugurated as a cooperative project of the Committee on Motor Vision of the American Optometric Association, the Engineering Experiment Station, Iowa State College, and the Public Roads Administration.