EFFECTIVENESS OF TIRES UNDER WINTER DRIVING CONDITIONS

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This paper compares the effectiveness in winter of snow tires with studs, without studs, and with controlled protrusion studs; elastomeric tire attachments and reinforced steel tire chains; and standard bias-belted highway tires. Correlations between each wheel combination and temperature variation were obtained for each set of tests for the following conditions: locked-wheel stopping from 35 mph on clear ice, sanded ice, and wet asphalt; breakout speed on a course designed to simulate a lane-change manuever on clear ice; and starting traction on clear ice and packed snow.

•IN 1970, 352 tests were carried out to determine the effectiveness of studded tires at various speeds and on different surfaces (1). These tests were limited to locked-wheel stopping and showed that temperature was a critical factor in tire performance on ice. A further series of tests was conducted during the winter of 1971 to evaluate different types of tires (2, 3) and tire attachments in use under winter driving conditions and to assess performance under driving as well as stopping situations.

TEST PROGRAM AND EQUIPMENT

The 1971 test program was set up to measure the following:

1. Stopping distances at a typical speed, i.e., 35 mph, on clear ice at temperatures ranging from -5 to +32 F, on sanded ice at temperatures ranging from -5 to +32 F, and on wet asphalt;
2. Lane-change speeds on clear ice; and
3. Starting traction on clear ice at temperatures ranging from -5 to +32 F and on packed snow.

For each series of tests the following different tire types and attachments were used:

1. Standard highway tread F78 × 15 bias-belted tires;
2. Similar tires refinished with oil-extended synthetic rubber snow tread;
3. Similar tires refinished with oil-extended natural rubber snow tread;
4. Similar tires refinished with oil-extended natural rubber snow tread and fitted with 72 studs;
5. Similar tires refinished with oil-extended synthetic rubber snow tread and fitted with 72 studs;
6. Commercial bias-belted snow tires fitted with 122 controlled protrusion studs designed to reduce the dynamic force on the road and thus reduce wear (these have a special shape and project 33 percent less than normal studs);
7. Standard highway tread tires fitted with reinforced steel tire chains; and
8. Standard highway tread tires fitted with elastomeric tire attachments intended to provide the advantage of chains without requiring their removal in use on bare pavement.

Four 1970, 8-cylinder sedans of the same make equipped with automatic transmission were used as test vehicles. The different tires and attachments were fitted on wheels and tested in combinations given in Table 1. Before each series of tests, each vehicle was checked for mechanical fitness, brake pressure, alignment, wheel balance, speedometer accuracy, tire pressure, and loss of studs.

TEST PROCEDURES

Ice tests were carried out on Lake Temiskaming in northern Ontario and road tests on Highway 115 near Peterborough, Ontario. The vehicles were driven by experienced Ontario provincial police officers, and all tests were carried out in accordance with the following procedures.

For stopping-distance measurements, the vehicles were allowed to decelerate from a speed slightly above 35 mph; at 35 mph, the brakes were applied to lock the wheels while the vehicle was maintained in the straight-ahead position. The test surface was swept for the tests on clear ice. For tests on sanded ice, the swept surface was covered in 2 overlapping passes with a salt-free sand mixture. For tests on asphalt, the surface was kept uniformly wet by pumping water over the surface after every second test.

Lane-change speeds were determined by simulating the lane-change maneuver shown in Figure 1. Only one driver was used for this test. He entered the swept course at increasing entry speeds. The vehicle was allowed to decelerate from the point of entry where its speed was recorded by radar. The breakout speed was defined as that entry speed at which the driver just failed to keep the vehicle within the course.

Starting traction was determined by hitching the vehicle through a series of pulleys to a vertically moving platform on which weights were incrementally placed until the rear wheels would spin (Fig. 2). For tests on clear ice, the area was simply swept; for those on packed snow, the ice surface was first wet and then covered with approximately 8 in. of snow that was then compacted with a wobble roller to about 6 in. to give a density of between 0.59 and 0.62 gr/cm^3.

All test results were verified by repetition. Care was taken to ensure that they were not influenced by previous activity in the area, and, where surface polishing or wear was noted, the site was changed immediately. This was accomplished smoothly and without delay by having several identical test sites laid out on a 1,500- by 300-ft area of the lake surface.

ANALYSIS OF TEST RESULTS

It was recognized that, no matter what the pavement conditions, vehicle performance in braking, handling, or traction is dependent on many factors other than the tires. With different types of tires, or tire attachments, the relative importance of different factors may vary.

Stopping Distance on Clear Ice

A linear model was postulated in the following form:

$$\overline{D_1} = B_0 + B_1 T_1 \pm 2S$$

where

$\overline{D_1}$ = statistically unbiased estimate of average stopping distance at temperature T_1;

B_0 and B_1 = statistically unbiased estimates of coefficients whose values depend on the tires or tire attachments used; and

$2S$ = estimated statistical limit within which approximately 95 percent of the observations might be expected to occur.

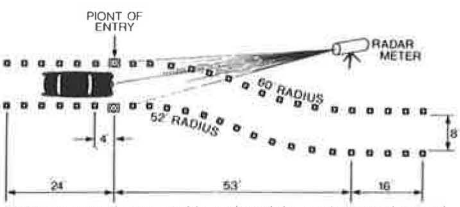
Field data from some 621 test runs were separately curve-fitted by linear regression to establish values of coefficients B_0 and B_1 for the various tires and tire attachments used (Table 2). The results were also plotted and are shown in Figure 3.

Table 1. Comparison of results of tests on highway tires and all other wheel combinations.

Wheel Combination	Stopping Distance (ft): Clear Ice, 0 F, No.	Per-cent	Clear Ice, 30 F, No.	Per-cent	Sanded Ice, 30 F, No.	Per-cent	Wet Asphalt, No.	Per-cent	Lane-Change Breakout Speed (mph): 0 F, No.	Per-cent	30 F, No.	Per-cent	Starting Traction (lb): Ice, No.	Per-cent	Snow, No.	Per-cent
1	312	—	466	—	187	—	62.7	—	16.4	—	11.7	—	177	—	659	—
2	-3	-1	+11	+2	-4	-2	+3	+5	+1	+6	0	0	+9	+5	+12	+2
3	+30	+10	0	0	-12	-6	+8	+13	0	0	+1	+9	+11	+6		
4	+12	+4	-45	-10	-50	-24	+7	+11	-2	-12	+2	+17	+51	+29	+28	+4
5	-15	-5	-127	-27	-24	-12	+1	+2	0	0	+4	+34	+33	+19		
6	+30	+10	-30	-6	-40	-20	+4	+6	-2	-12	+3	+26	+25	+14	+56	+8
7	+18	+6	+9	+2	-36	-18	+2	+3	0	0	+1	+9	+22	+12		
8	+12	+4	-65	-14	-26	-13	0	0	-3	-18	+2	+17	+45	+25	+55	+8
9	+6	+2	-102	-22	-29	-14	-1	-2	-1	-6	+4	+34	+21	+12		
10	+30	+10	-50	-11	-46	-22	+4	+6	+3	+18	+2	+17	+25	+14	+56	+8
11	0	0	-70	-15	-34	-17	+3	+5	+1	+6	+6	+51	+4	+2		
12	-8	-3	-93	-20	-34	-17	+6	+10	0	0	+5	+43	+65	+37	+67	+10
13	-27	-9	-53	-11	-35	-17	—	—	—	—	—	—	+7	+4	+160	+24

Note: Data for wheel combinations 2 through 13 represent increases or decreases in performance as compared with wheel combination 1.

Figure 1. Speed test course for lane-change breakout.



NOTE: At point of entry the driver released the accelerator and coasted through the course. The speed was also recorded at this point.

Figure 2. Testing arrangement for starting traction.

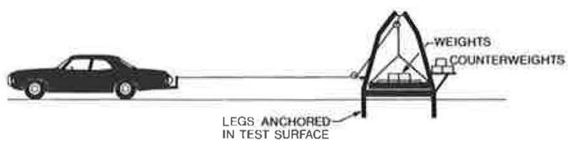


Table 2. Estimating formulas.

Wheel Combination No.	Description	Stopping Distance: Clear Ice	Sanded Ice	Lane-Change Breakout Speed
1	Highway tires, 4 wheels	$312 + 5.15 T_1 \pm 74$	$288 + 5.15 T_1 - 0.26 T_1^2 \pm 72$	$16.4 - 0.157 T_1 \pm 4.9$
2	Synthetic snow tires, rear wheels only	$309 + 5.63 T_1 \pm 86$	$319 + 5.63 T_1 - 0.32 T_1^2 \pm 68$	$17.4 - 0.183 T_1 \pm 5.0$
3	Synthetic snow tires, 4 wheels	$342 + 4.17 T_1 \pm 54$	$306 + 4.17 T_1 - 0.27 T_1^2 \pm 84$	$16.9 - 0.144 T_1 \pm 4.3$
4	Studded synthetic snow tires, rear wheels only	$324 + 3.28 T_1 \pm 56$	$306 + 3.28 T_1 - 0.28 T_1^2 \pm 77$	14 ± 3.5
5	Studded synthetic snow tires, 4 wheels	$297 + 1.44 T_1 \pm 40$	$334 + 1.44 T_1 - 0.22 T_1^2 \pm 77$	16.1 ± 3.3
6	Natural rubber snow tires, rear wheels only	$342 + 3.15 T_1 \pm 79$	$357 + 3.15 T_1 - 0.32 T_1^2 \pm 88$	14.4 ± 4.1
7	Natural rubber snow tires, 4 wheels	$330 + 4.86 T_1 \pm 81$	$310 + 4.86 T_1 - 0.32 T_1^2 \pm 75$	$16.8 - 0.142 T_1 \pm 5.5$
8	Studded natural rubber snow tires, rear wheels only	$324 + 2.60 T_1 \pm 48$	$319 + 2.60 T_1 - 0.24 T_1^2 \pm 73$	13.5 ± 4.6
9	Studded natural rubber snow tires, 4 wheels	$318 + 1.56 T_1 \pm 40$	$339 + 1.56 T_1 - 0.23 T_1^2 \pm 27$	15.4 ± 4.5
10	Controlled protrusion studded snow tires, rear wheels only	$342 + 2.51 T_1 \pm 67$	$313 + 2.51 T_1 - 0.26 T_1^2 \pm 77$	$18.0 - 0.129 T_1 \pm 3.0$
11	Controlled protrusion studded snow tires, 4 wheels	$312 + 2.84 T_1 \pm 46$	$303 + 2.84 T_1 - 0.24 T_1^2 \pm 84$	17.6 ± 2.4
12	Elastomeric tire attachment, rear wheels only	$304 + 2.33 T_1 \pm 64$	$317 + 2.33 T_1 - 0.24 T_1^2 \pm 86$	6.3 ± 5.2
13	Reinforced steel tire chains, rear wheels only	$285 + 0.98 T_1 \pm 60$	$291 + 0.98 T_1 - 0.17 T_1^2 \pm 89$	—

Figure 3. Stopping distance versus ice temperature.

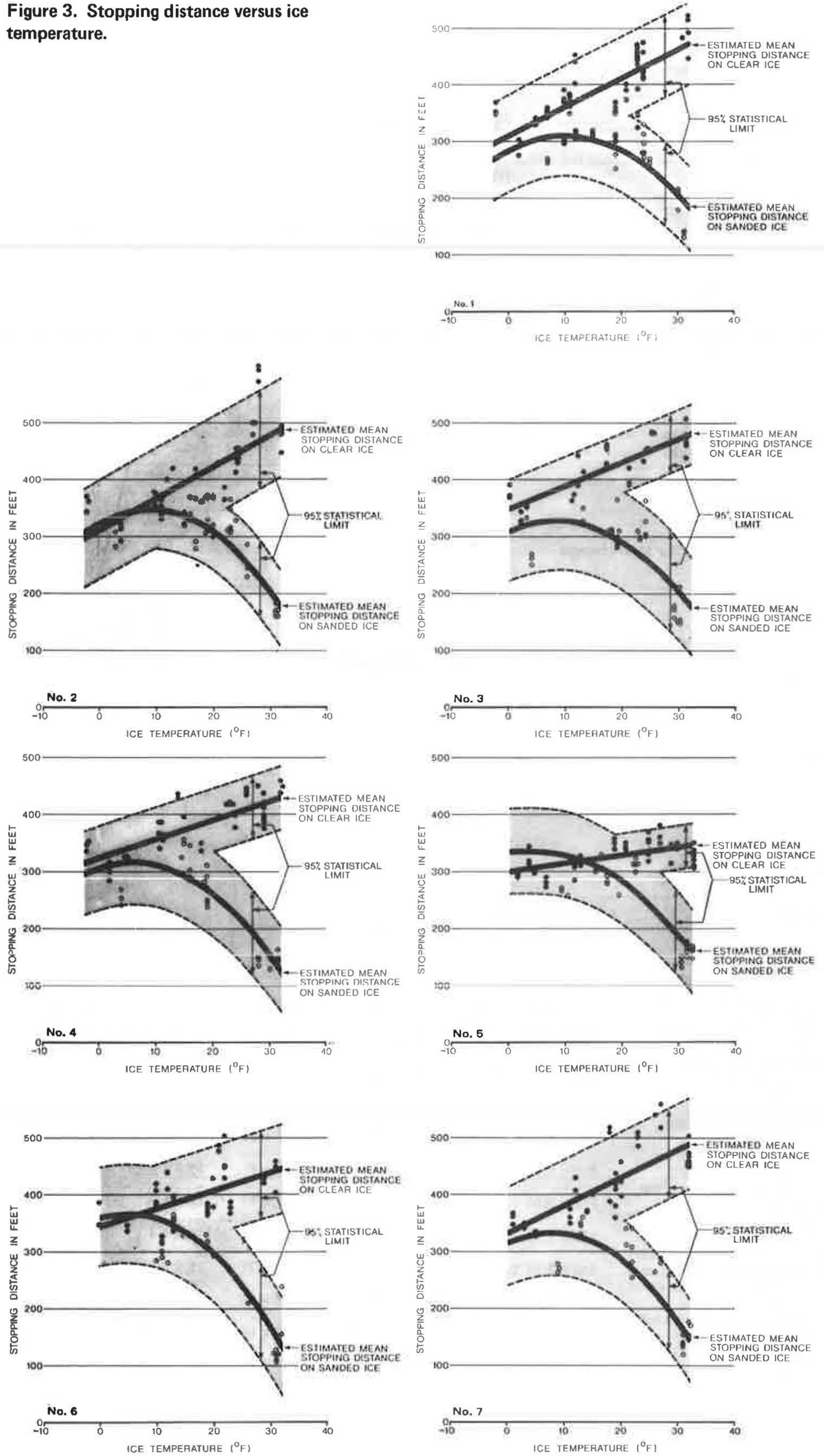


Figure 3. Continued.

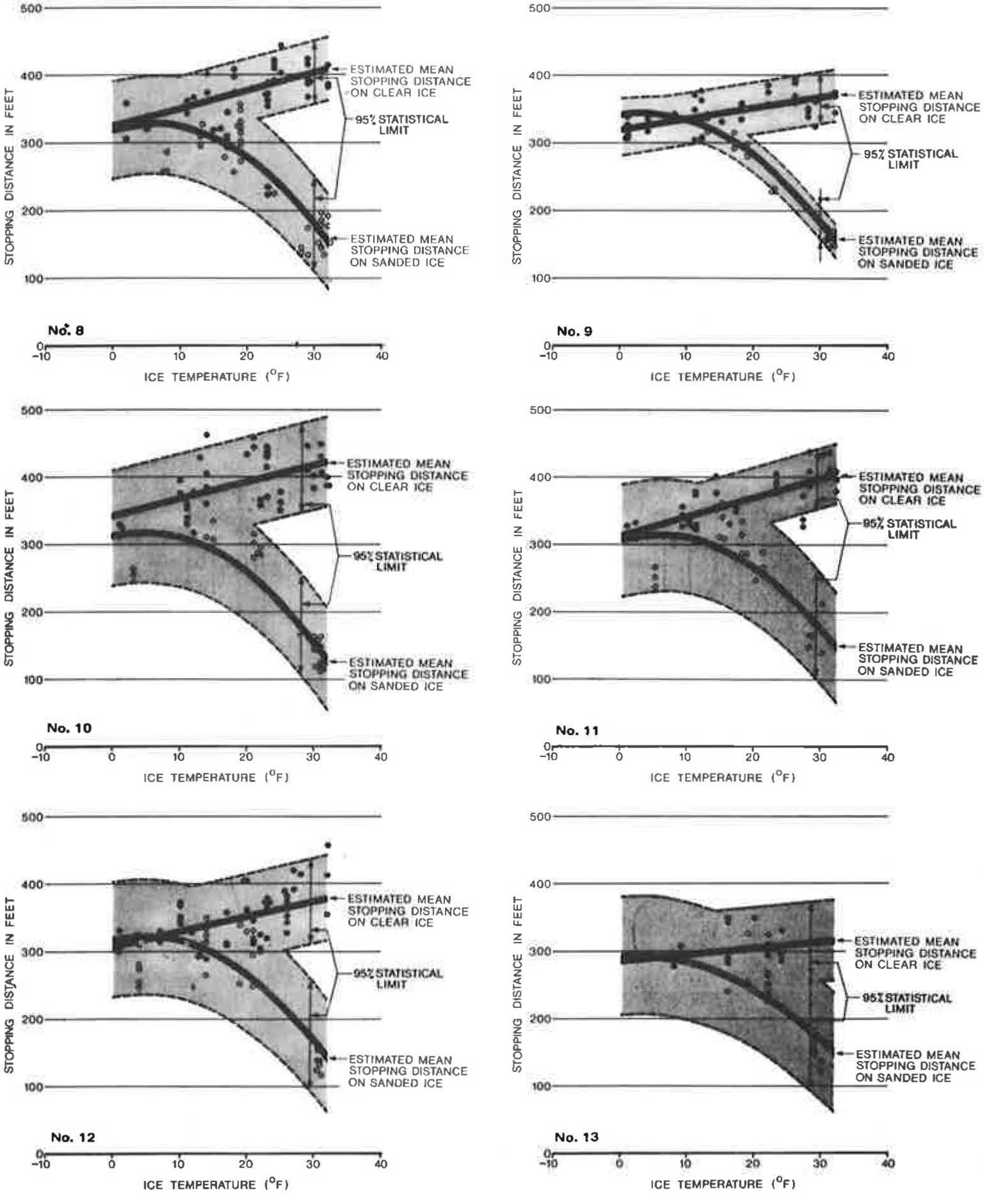
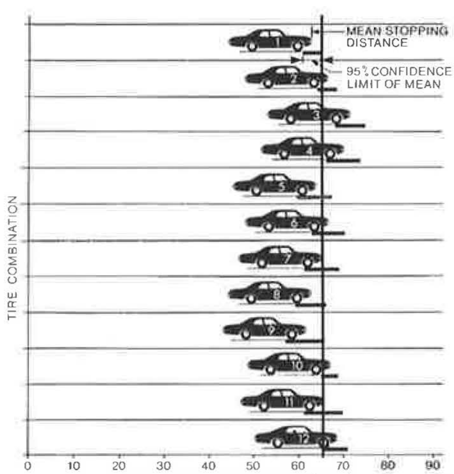


Figure 4. Stopping distance on wet asphalt.



Stopping Distance on Sanded Ice

On the basis of data point plots, a quadratic model was postulated in the following form:

$$\overline{D_i} = A_0 + B_1T_i + A_2T_i^2 \pm 2S$$

where

$\overline{D_i}$ = statistically unbiased estimate of average stopping distance at temperature T_i;

A_0 and A_2 = statistically unbiased estimates of coefficients whose values depend on the tires or tire attachments used;

B_1 = statistically unbiased estimate of the coefficient determined for the same tire or attachments in the clear ice stopping test; and

2S = estimated statistical limit within which approximately 99 percent of the observations might be expected to occur.

Field data from some 354 test runs were separately curve-fitted by linear regression to establish the values of coefficients A_0 and A_2 for the various tires and tire attachments used (Table 2). The results were also plotted and are also shown in Figure 3.

Stopping Distance on Wet Asphalt

Field data from some 312 test runs were analyzed by standard statistical methods to determine the estimated mean stopping distance and the confidence limits at the 95 percent t-distribution value for each tire or tire attachment combination used (Fig. 4).

Lane-Change Breakout Speed

On the basis of data point plots, a linear model was postulated similar to that for stopping distance on clear ice. After standard statistical tests were applied, it was found, however, that in some cases the effect of temperature was not significant at the $\alpha = 0.05$ level.

Field data from some 149 test runs were either separately curve-fitted by linear regression or simply averaged to establish the value of the coefficients or the estimated mean stopping distance for the tires and tire attachments used (Table 2). The results were also plotted and are shown in Figure 5.

Starting Traction on Clear Ice

Though a linear model similar to that for stopping distance was postulated, it was found, after standard statistical tests were applied, that the effects of temperature were not statistically significant. The field data from some 233 test runs were simply averaged to provide the results shown in Figure 6.

Starting Traction on Packed Snow

Field data from some 75 tests were analyzed by simple statistical methods to provide the results as shown in Figure 7. These results have been summarized for the tire type or attachment used on the rear wheels only because significance tests indicated that draw-bar pull depended entirely on the rear wheels and not on the front wheels.

CONCLUSIONS

On the basis of the test procedures and conditions outlined, and to the extent that the tires, attachments, and vehicles used may be considered typical, the following conclusions may be derived from the 1971 test results.

Figure 5. Lane-change breakout speed versus ice temperature.

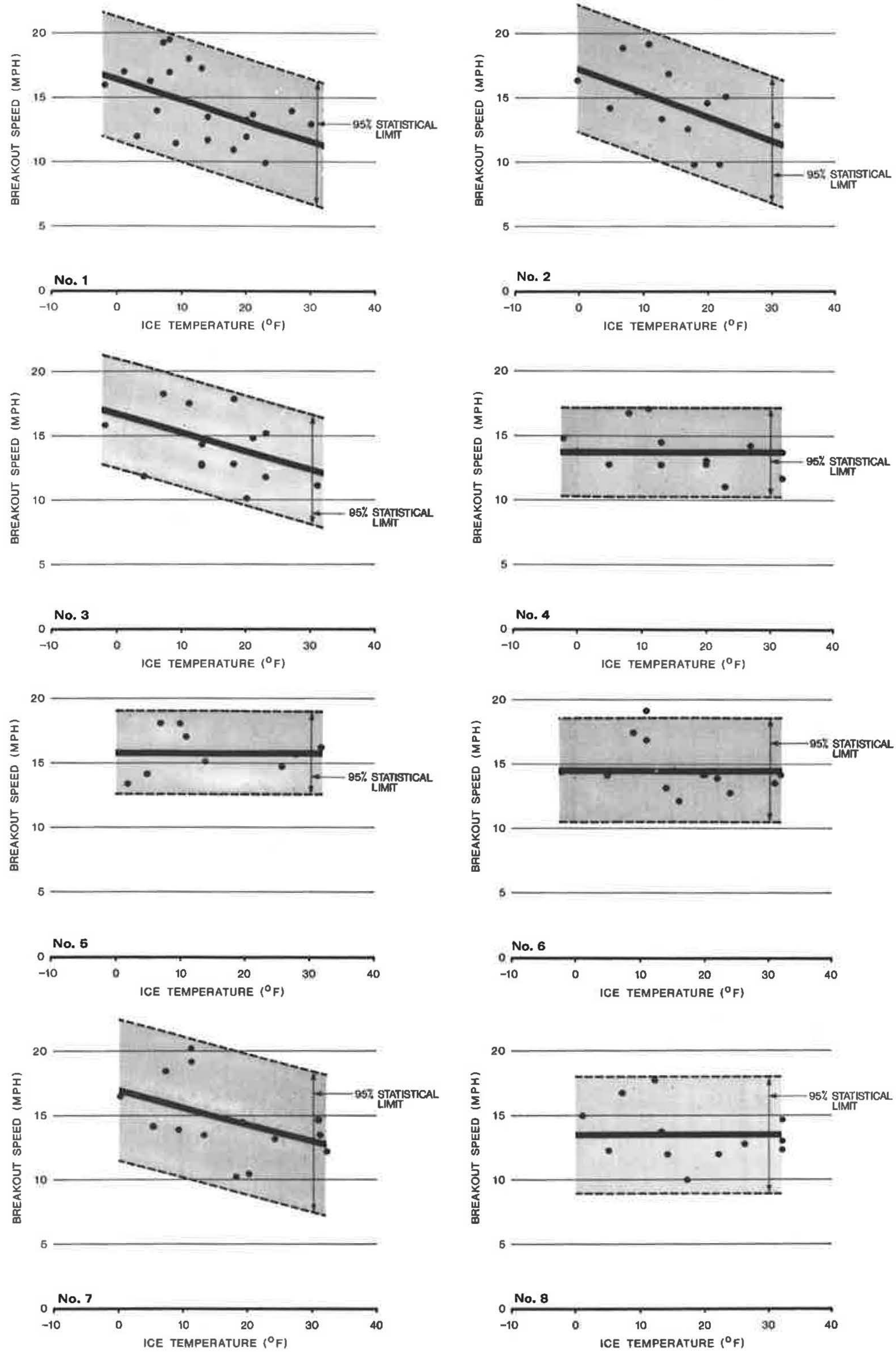


Figure 5. Continued.

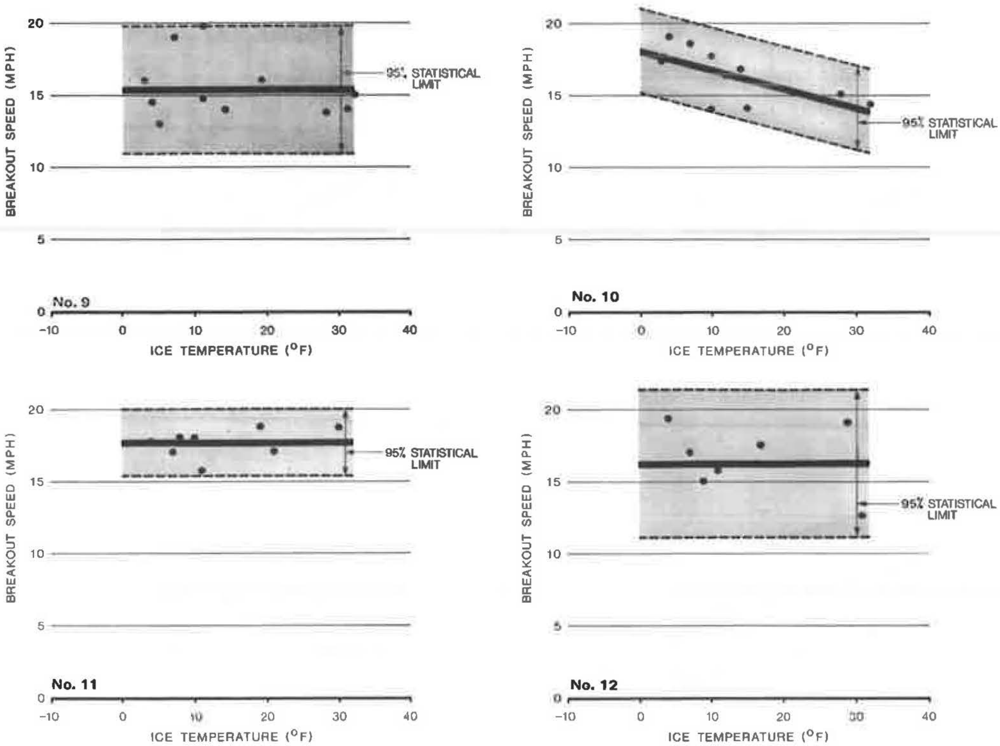


Figure 6. Starting traction on clear ice.

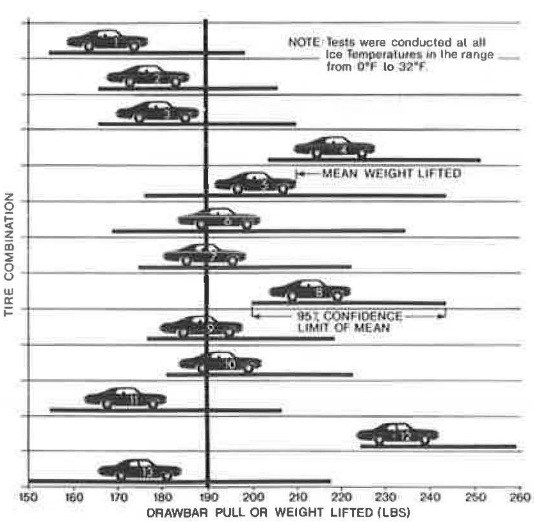


Figure 7. Starting traction on packed snow.

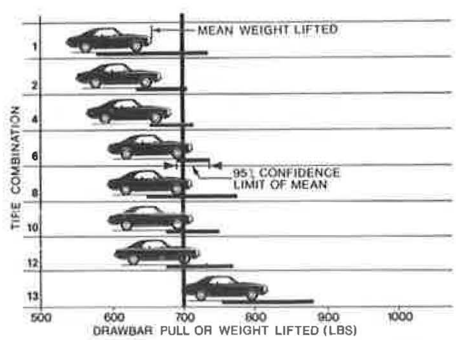
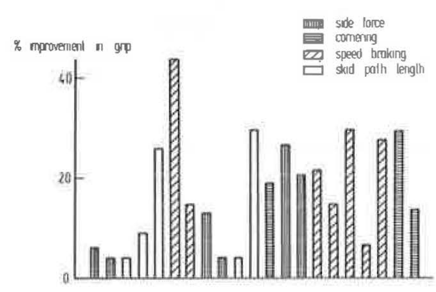


Figure 8. Improved grip of natural rubber tires over conventional synthetic tires.



Stopping Distance

Compared with standard highway tread tires, tire chains, studded snow tires on all 4 wheels, elastomeric attachment, and studded snow tires on the rear wheels only (in order of importance) significantly reduced the stopping distance on clear ice. This effect was most noticeable at temperatures near 32 F and diminished to become negligible at temperatures approaching 0 F. Controlled protrusion studs gave results similar to those obtained with the regular studs. Snow tires on the rear wheels had little effect on stopping distance, but, when used on all 4 wheels, they were less effective than regular highway tread tires.

On sanded ice, the effect of tire type or attachment was of much less importance, though for all combinations the stopping distance as compared to that on clear ice was reduced by more than half at 32 F. This effect diminished with decreasing temperature and became negligible at about 10 F.

On wet asphalt, the type of tire or attachment made little significant difference in stopping distance.

Lane-Change Breakout Speed

Compared with standard highway tires, studded snow tires and elastomeric attachments—either normal or controlled protrusion—on all 4 wheels (in order of importance) increased the speed at which a lane-change maneuver could be made on clear ice. This effect was greatest at about 32 F and diminished to negligible differences in speed at about 0 F.

Starting Traction

Compared with standard highway tread tires, elastomeric attachments and studded snow tires—either synthetic or natural rubber—on the rear wheels only (in order of importance) increased the starting traction on clear ice. The use of studded snow tires on all 4 wheels appeared to be a disadvantage. This effect was not significantly temperature-dependent.

On packed snow, starting traction was increased by reinforced steel chains and, to a lesser extent, by elastomeric tire attachments, controlled protrusion studded snow tires, and natural rubber snow tires (studded and unstudded). This effect was not significantly temperature-dependent.

ACKNOWLEDGMENTS

This research was sponsored by the Canada Safety Council in cooperation with the Ottawa Ministry of Transport, the Québec Ministère de la Voirie, and the Ontario Department of Transportation and Communications.

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DISCUSSION

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The friction of rubber on ice is extremely variable, and it is necessary to carry out large numbers of measurements under a variety of conditions if meaningful results are to be obtained. Our own tests have shown that an oil-extended natural rubber compound has better grip than synthetic rubber on ice and hard-packed snow. The improvement ranges from 0 to more than 40 percent, and tests carried out under 1 set of conditions only could give a mean value anywhere within this range. An example of the variability of friction on ice is shown in Figure 8. Data shown are for separate tests on the same ice surface during a period of a few days. Each test is normally an average of at least 6 measurements. Different test methods have been used as shown, but the variation in the results is not confined to 1 test method. In these circumstances, it is obvious that large numbers of tests on different occasions are necessary to obtain a reliable estimate of the average improvement. The reason for this variability is not certain, but it may be due to variations in the ice itself. Extensive tests in 3 separate trials involving more than 2,000 measurements have shown that the average overall improvement is about 15 percent on hard-packed snow and ice. We feel, therefore, that data presented by Smith and Clough are not typical of the average improvement that can be expected in practice.