STUDIES OF STUDDED-TIRE DAMAGE AND PERFORMANCE IN ONTARIO DURING THE WINTER OF 1969-70

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Measurements and observations during the winter of 1969-70 show that, with 32 percent of passenger vehicles in Ontario equipped with studded tires, substantial pavement wear and widespread loss of traffic markings continue and that the prior estimates of the remedial work that may be required over the next decade remain unchanged. The performance to date of experimental wear-resistant concrete and bituminous pavements and of traffic markings indicates that although improvements are possible no lasting solution has yet been found. Studded-tire performance tests carried out by the Ontario Provincial Police and the Canada Safety Council are reviewed. Data are presented on the occurrence of various road conditions in winter and the analysis of accidents. Little benefit is established from the use of studded tires except in icy conditions that occur relatively infrequently in Ontario.

•UNUSUALLY SEVERE WEAR on pavement surfaces and loss of traffic markings have become increasingly obvious on Ontario highways during each recent succeeding winter. The damage and its extent and severity have been coincident with the increasing use of studded snow tires. Similar effects causing widespread concern have been observed in other Canadian provinces, in the northern part of the United States, and in the Scandinavian countries.

In 1967 the Ontario Department of Highways launched a study to measure the extent of this damage, to devise remedial measures, and to predict the economic consequences over a 10-year period. The results of this investigation up to the start of the winter of 1969-70 have already been reported (1). During the winter of 1969-70, additional studies (2, 3, 4, 5, 6, 7, 8, 9) were undertaken to validate the predictions of future wear and cost and to determine the effectiveness of studded tires in the conditions that prevail on highways in Ontario during the winter. As a result of these studies, certain conclusions can be drawn as to the benefits and disbenefits of using studded tires in Ontario.

USE OF STUDDED TIRES

The use of studded tires has been permitted in Ontario between October 1 and April 30 each year provided that they are fitted on all four wheels or both rear wheels of a vehicle. Each winter, counting surveys have been made of the vehicles equipped with studded tires throughout the province. Table 1 gives the province-wide averages and the predicted increase, which were used to compile data in an earlier report (1). Considerable differences were found in the number of studded tires in use throughout the province. For example, Ottawa (48 percent, the highest recorded), Sault Ste. Marie, Thunder Bay, and Kenora areas all recorded that over 40 percent of passenger vehicles were equipped with studded tires. Less than 20 percent use was recorded in Chatham (12 percent, the lowest recorded), Hamilton, Kingston, Bancroft, and Cochrane areas. In the heavy traffic volume areas around Toronto, 30 to 35 percent of the vehicles had studded tires. Although the province-wide average of studded-tire use at 32 percent is slightly less than the 35 percent anticipated for last winter, the difference is not sufficient to warrant change to earlier predictions that 60 percent of passenger vehicles

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will be fitted with studded tires by the winter of 1971-72, if their use continues to be unrestricted.

TABLE 1

PERCENTAGE OF VEHICLES EQUIPPED WITH STUDDED TIRES

Winter	Actual	Range	Predicted
1966-67	2		
1967-68	8		
1968-69	18	2 to 27	
1969-70	32	12 to 48	35
1970-71			50
1971-72			60

Studded tires are mainly used on only the rear wheels of vehicles in Ontario, and an extension of their use to all four wheels of passenger cars or to heavier vehicles will likely increase the anticipated pavement damage discussed in the next section.

New types of tires (bias-belted and radial-ply) are gaining an increasing share of the market. It is not known whether studs in these tires will be less damaging to pavements than those in conventional tires, even though this has been suggested (11). The studded tires used in the Canada Safety Council stopping distance tests (12) were bias-belted, and the marks caused by these tires, when braking on ice or pavement, appeared similar to those caused by studs in conventional snow tires.

PAVEMENT WEAR

The nature of the pavement wear occurring to both bituminous and portland cement concrete pavements in Ontario and the method of measuring the depth of wear are both described in a previous report (1). Briefly, two types of wear have been identified. Where a pavement surface contains aggregate of similar wear resistance (hardness) to that of the matrix in which it is embedded, the surface generally wears down uniformly. However, where the aggregate particles are much harder, the softer matrix is preferentially denuded until a point is reached where the harder particles are dislodged by the studs because of the lack of embedment.

The photographic method of measuring pavement wear, developed by the department, allows the progression of wear to be observed from successive positions of a shadow line cast on the pavement surface by a thin wire stretched between reference pins. The reference pins are set at fixed height and placed on each side of the wheel tracks where concentrated wear occurs. Other areas of extreme wear are at locations where vehicles stop, start, or turn. At intersections and other places where vehicles rapidly change speed or direction, the wear may be more general and is usually more severe. Except for these special circumstances, there is a direct relationship between the amount of wear and the number of passes of the studded tires. If present traffic volumes and studded-tire use are known and an estimate of the likely increase in both can be made, it is then possible to use the relationship established to predict the amount of future wear that is likely to occur.

In predictions of the consequences of pavement wear in Ontario in terms of remedial measures that would be required and their cost, 1 in. (25 mm) of wear in the wheel track was established arbitrarily as the point at which resurfacing would be required. The highway network in the province was examined in terms of amount of pavement in each of a number of traffic volume ranges from 2,000 AADT (annual average daily traffic) upward. This was done to determine when resurfacing might be required. Costs were ascribed, by financial year, allowing for resurfacing work that would be required under normal maintenance demands irrespective of studded-tire wear. Other additional costs were also determined, such as those required to provide more wear-resisting traffic markings and pavement surfaces for new construction. From these data the additional costs that might be expected to be incurred in each financial year were tabulated to 1978-79 for both the provincial highways and the municipal roads and streets.

These estimates, made in the fall of 1969, are given in Table 2. More recent measurements of the wear that has occurred in one additional winter are now available for examination. These measurements permit the accuracy of earlier predictions of wear and costs to be checked.

Actual and Predicted Pavement Wear

Table 3 gives the wear recorded at the various measuring stations during the winter of 1968-69. It also gives the wear that was anticipated from these measurements for

TABLE 2

ESTIMATED ADDITIONAL COSTS FOR NEW CONSTRUCTION AND MAINTENANCE WORK ON PAVEMENT DAMAGED BY STUDDED TIRES

Year	Department of Highways				Municipalities				Grand Total
	New Pavement Construction	Resurfacing and Patching	Traffic Marking	Total	New Pavement Construction	Resurfacing and Patching	Traffic Marking	Total	
1970-71	608,000	589,000	1,078,000	2,275,000	458,000	470,000	1,078,000	2,006,000	4,281,000
1971-72	625,000	1,533,000	902,000	3,060,000	469,000	1,226,000	902,000	2,597,000	5,657,000
1972-73	855,000	4,298,000	778,000	5,931,000	641,000	3,438,000	778,000	4,857,000	10,788,000
1973-74	683,000	5,769,000	302,000	6,754,000	512,000	4,615,000	302,000	5,429,000	12,183,000
1974-75	625,000	5,960,000	325,000	6,910,000	469,000	4,768,000	325,000	5,562,000	12,472,000
1975-76	625,000	2,250,000	1,325,000	4,200,000	469,000	1,800,000	1,325,000	3,594,000	7,794,000
1976-77	625,000	8,569,000	1,325,000	10,519,000	469,000	6,855,000	1,325,000	8,649,000	19,168,000
1977-78	625,000	18,607,000	1,325,000	20,557,000	469,000	14,886,000	1,325,000	16,680,000	37,237,000
1978-79	625,000	8,578,000	325,000	9,528,000	469,000	6,860,000	325,000	7,654,000	17,182,000
Total	5,896,000	56,153,000	7,685,000	69,734,000	4,425,000	44,918,000	7,685,000	57,028,000	126,762,000

Note: Information is extracted from Smith and Schonfeld (Table 7, 1).

TABLE 3

ACTUAL AND ESTIMATED PAVEMENT WEAR RESULTING FROM STUDDED-TIRES DURING 1969-70 WINTER

Location[a]	Measured Wear in 1968-69 Winter (mm)			Measured Wear in 1969-70 Winter (mm)			Avg Anticipated Wear in 1969-70 Winter[c] (mm)	Avg Measured Wear as Percent of Anticipated Wear (percent)
	Stone[b]	Matrix[b]	Avg	Stone[b]	Matrix[b]	Avg		
Highway 401 (Toronto Bypass)								
Driving lane								
Don Valley, westbound	0.37	1.33	0.85	2.18	2.92	2.55	2.05	124
Avenue Road, eastbound	0.49	2.97	1.73	3.15	3.71	3.43	4.20	82
Spadina Expressway, eastbound	0.49	2.23	1.36	2.40	2.60	2.50	3.28	77
Center lane								
Don Valley, westbound	0.81	2.53	1.67	4.72	4.88	4.80	4.04	119
Avenue Road, eastbound	1.40	4.42	2.91	5.72	6.08	5.90	7.05	84
Spadina Expressway, eastbound	1.10	3.98	2.54	6.55	7.45	7.00	6.15	113
Passing lane								
Don Valley, westbound	0.59	2.87	1.73	7.41	6.49	6.85	4.20	163
Avenue Road, eastbound	1.91	5.68	3.80	7.08	7.42	7.25	9.20	79
Spadina Expressway, eastbound	2.25	5.09	3.67	6.35	6.65	6.50	8.90	73
Highway 126, southbound to Highway 401, westbound ramp	0.00	4.69	2.35	4.00	3.80	3.90	5.46	72
Highway 401								
London, eastbound, east of Highway 126	0.00	3.49	1.75	2.50	2.50	2.50	4.06	62
Highway 400								
Barrie, southbound, north of junction Highway 89	0.24	4.92	2.58	5.20	5.60	5.40	6.00	90

Note: Pavement types are as follows: Toronto Bypass (portland cement concrete); Highway 126, HL3 (bituminous); and Highway 401, London, and Highway 400, Barrie, HL1 (bituminous). Descriptions of these types of pavement are given in the earlier report (1).

[a]Pavements on Highway 11B, Huntsville, which were included in the 1968-69 measurements, where the greatest wear was recorded had to be resurfaced in 1969 and are consequently deleted from the study.

[b]When this table is compared with Table 1 or 2 in the earlier report (1), the terms "stone wear" (which corresponds to minimum wear) and "matrix wear" (maximum wear) are introduced to describe these parameters more clearly.

[c]The anticipated 1969 winter wear was calculated on the assumption that the AADT for 1969 would increase by 5 percent and that the proportion of passenger vehicles equipped with studded tires would increase from 15 percent in 1968 to 35 percent in 1969, i.e., 2.3 times the 1968 figure. The anticipated wear for the 1969 winter was, therefore, 1.05 x 2.3 = 2.42 of the 1968 winter wear. It should be noted that monthly spot counts of the proportion of studded tires varied from place to place; this may partly account for the variations in the rate of pavement wear in different locations within the overall average. For example, the studded tire counts on Highway 401 near London averaged 23 percent in 1969, which can be expected to result in 1.5 times the 1968 wear, and not 2.3 times as estimated on the basis of the overall average for Ontario.

the winter of 1969-70 and the actual 1969-70 measured wear. Data given in the last column of Table 3 show that the actual wear over the winter of 1969-70 ranged from 72 to 163 percent of the anticipated wear, with an overall average of 90 percent.

Considering the many variables involved in studded-tire wear, the authors would have been surprised if their prediction of wear at each of the test locations had been more precise. However, it is felt that, on the basis of the measurements and observations of the damage to pavements and traffic markings during the past two winters, the long-term predictions of remedial work and its associated costs are reasonably accurate.

Measurements at other locations within the highway system are being undertaken to provide more exhaustive validation of actual and predicted wear. This study includes highways with lower traffic volumes that are subjected to different climatic and other conditions from those prevailing on the main highways in southern Ontario that have been measured and reported thus far. It is too early at this time, however, to draw any conclusions from the limited data gathered thus far from other highways.

Obliteration of Traffic Markings

In addition to the wear of pavement surfaces, studded tires have noticeably worn painted traffic markings. Numerous complaints have been received regarding the inconvenience and hazards that this has caused. At places where traffic weaving occurs, at curves where the centerline is frequently crossed, and at stop lines, all traces of conventional paint markings were obliterated before the winter was half over. In the critical areas, the resulting emergency situation was dealt with by repainting the markings on clear days in January and February. However, because of poor adhesion resulting from low temperature, dirt, or moisture, the repainted lines usually lasted only a few days. The performance of experimental (more wear-resistant) markings is discussed in the next section of this report.

Skid Resistance

Because studded-tire wear changes the characteristics of a pavement surface both on a macroscale and on a microscale, this might be expected to have an effect on surface properties such as skid resistance. However, the changes in skid resistance during the past 3 years, as given in Table 4 and shown in Figure 1, are surprisingly small, and the advent of studded-tire wear has neither significantly worsened nor improved the skid resistance of most Ontario pavements.

Pavements containing hard, coarse aggregate (HL1 and some HL4 asphalt mixes) show no overall loss in skid resistance. The pavements that wear uniformly, such as

TABLE 4

CHANGES IN SKID RESISTANCE OF SOME PAVEMENTS IN ONTARIO SINCE INTRODUCTION OF STUDDED TIRES

Pavement Type	Aggregate	Number of Pavements Tested	Test Speed (mph)	Range of Skid Numbers	Average Skid Number of Pavements Tested	Change From Preceding Year (skid number points)		
						1968	1969	1970
Asphalt mix HL1	Traprock coarse	9	30	40 to 62	53	-1	0	+2
			60	24 to 44	35	-1	+1	0
Asphalt mix HL3	Limestone coarse	11	30	38 to 57	51	-4	+1	+3
			60	25 to 40	37	-1	0	0
Asphalt mix HL4	Igneous coarse	5	30	48 to 61	55	-1	0	+2
			60	32 to 49	42	-1	0	+1
Thin bituminous overlays, including asbestos, latex and rubber-modified mixes		19	30	32 to 60	50	-3	-1	-3
			60	24 to 46	37	0	-1	+2
Concrete	Limestone coarse	8	30	31 to 58	47	-7	-5	0
			60	19 to 36	37	-2	-4	-1

Note: The studded-tire proportion of all passenger vehicles increased from 2 percent in 1967 to approximately 32 percent in 1970.

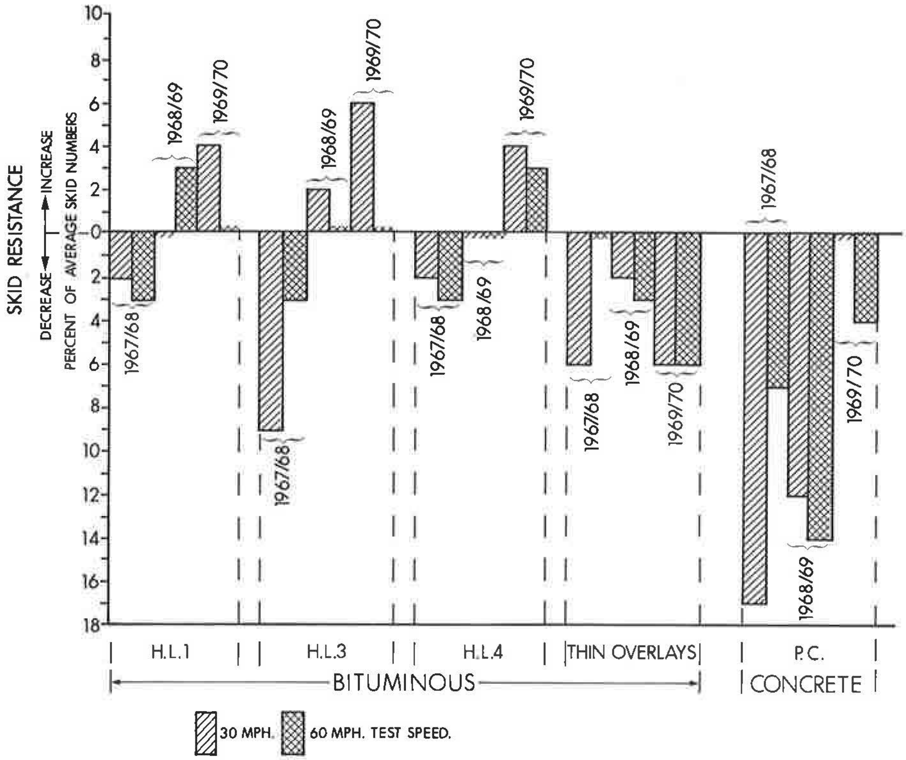

Figure 1. Changes in skid resistance of some pavements in Ontario with increasing use of studded tires.

the thin overlays of finer texture or the concrete pavements that contain softer aggregate and depend on a broom-finished texture for their initial skid resistance, have shown an overall decline in skid resistance. This decline, although small in terms of skid number increments, is more critical because these pavements had lower initial skid-resistance values.

PERFORMANCE OF EXPERIMENTAL WEAR-RESISTANT SURFACES AND TRAFFIC MARKINGS

In a previous report (1), a review was made of the work (largely European) done to develop surfaces for pavements that would be more resistant to damage by studded tires than those presently in use. In general terms, it was concluded that the most promising avenue to explore was the incorporation of the maximum amount of the hardest available coarse aggregate in the surfacing material.

To further evaluate this theory, the department constructed a number of trial sections of concrete pavement in 1968, and sections of bituminous mixtures of different composition were laid in the late fall of 1969. The features incorporated in these experiments are described elsewhere (1). Both trials were on roads subjected to heavy traffic, and the performance results of the concrete sections after two winters and the bituminous sections after one winter are now available. In addition, visual observations of experimental traffic markings after one winter's service can be reported.

Concrete Pavement

Of the 14 concrete sections laid in 1968, only three sections containing traprock coarse aggregate have shown performance that was significantly different from the adjacent

TABLE 5

PERFORMANCE OF CONCRETE AND PLASTIC WEAR-RESISTANT SURFACES

Location	Section	Pavement Type	Pavement Age (year)	Annual Average Daily Traffic	Vehicle Maneuver	Pavement Wear Stone	Pavement Wear Matrix	Pavement Wear Avg	Skid Number[a] 1969	Skid Number[a] 1970
Highway 401, Toronto Bypass, passing lane at Dixon Road, westbound	1	Traprock coarse aggregate, 100 percent silica sand	2	6,800	Straight	1.50	3.00	3.25	37	45
	2	Traprock coarse aggregate, 67 percent silica sand, 33 percent calcareous sand	2	6,800	Straight	3.50	3.50	3.50	34	44
	3	Traprock coarse aggregate, 33 percent silica sand, 67 percent calcareous sand	2	6,800	Straight	3.00	3.50	3.25	30	42
	4[b]	Limestone coarse aggregate	2	6,800	Straight	3.17	3.54	3.36	22	22
Highway 27, Toronto, south-bound, to west-bound Q.E.W. ramp	5	Plastic surfacing (polyurethane and glass chips)	1	6,200	Curve	N.A.	N.A.	1.1	48[c]	20[c]
					Ramp	N.A.	N.A.			
Highway 49, Quinte Skyway deck	6	Plastic surfacing (polyurethane and glass chips)	1	800	Straight	N.A.	N.A.	1.0	48	46

[a]Measured by ASTM brake force trailer at 60 mph. [b]Control section. [c]Measured at 50 mph.

concrete. After one winter's wear, the traprock aggregate became exposed with wear that was concentrated in the surrounding matrix, and it was postulated (1) that the rate of wear would be slowed down until dislodgment of the coarse aggregate occurred. Table 5 gives the measured wear that occurred during the second winter.

Somewhat disappointingly, the wear measured on the stone is almost equal to that measured on the matrix, and the resulting average wear is no less than that occurring to the adjacent concrete surfaces containing a much softer limestone aggregate. Matrix wear was some 16 percent less in the second section, which had 100 percent silica fine aggregate, and the wear of the coarse aggregate in this section was less than one-half of that in the sections having a less wear-resistant matrix.

The reason for this difference in wear appears to be that some dislodgment of trap-rock particles has occurred that allowed the studs to further abrade the matrix. Furthermore, the nominal maximum size of the available traprock aggregate used was only ½ in. It would appear that a larger size of hard coarse aggregate and a greater proportion of it in the immediate surface area are required if studded-tire wear on concrete is to be resisted over a long period.

Table 5 also gives the wear during one winter on two experimental sections of a thin polyurethane pavement coating treated with small glass chips. Although the chips were partially lost, the overall wear resistance of this coating was very good. This was probably due to both its toughness and its resilience under stud impact. It remains to be seen, however, if the film, which was only about 40 mils (1.0 mm) thick, will survive another year. This particular material is under evaluation as a waterproof bridge-deck surfacing. However, this and other "resilient" surfacings, although usually expensive, are worthy of further study as an alternative to providing hard abrasion-resistant surfaces to resist stud damage.

Even though considerable wear is occurring in the experimental concrete sections, the presence of the traprock and the differential texture between this and the matrix is maintaining a very high pavement skid resistance as given in the last column of Table 5.

Bituminous Pavements

Table 6 gives details of the experimental bituminous pavements placed on Highway 400, northbound (north of the King Side Road), in the late fall of 1969 and observations

TABLE 6

PERFORMANCE OF BITUMINOUS WEAR-RESISTANT SURFACES

Section	Type of Mix	Mix Composition (percent weight): Retained on No. 4 Screen	Mix Composition (percent weight): Pass No. 4 Screen to Make 100 Percent Weight of Aggregate	Asphalt Content (percent weight of mix)	Avg Wear (mm)	Skid No.[a] May 1970	Skid No.[a] Dec. 1969	Pavement Wear Comments
1	HL1 with increasing stone contents	40 TR	LS + LSS, 3:1	5.8	2.9	52.2	46	Sections 1 and 2 moderate loss of FA; section 3 loss of CA; fair performance; mix impermeable
2		50 TR	LS + LSS, 4:1	5.4	2.3	52.5	47	
3		60 TR	LS	4.9	2.2	54.9	49	
4	TR and TRS only, no intermediate sand	40 TR	TRS	4.5	4.0	53.5	57	Very permeable; difficult to compact; large loss of FA and CA; sections 4 and 5 poor performance; section 6 very poor
5		50 TR	TRS	4.3	4.1	53.7	56	
6		60 TR	TRS	4.0	3.6	54.5	56	
7	HL1 as on sections 1, 2, and 3 but with SS and TRS	40 TR	TRS + SS, 2:1	4.8	3.4	51.4	52	All somewhat permeable; sections 7 and 8 moderate loss of FA and CA and fair performance; section 9 good
8		50 TR	TRS + SS, 2:1	4.7	3.0	53.9	51	
9		60 TR	TRS + SS, 2:1	4.1	3.2	52.9	52	
10	Same as on sections 7, 8, and 9 but with the ratio of SS:TRS reversed	40 TR	TRS + SS, 1:2	6.2	3.2	51.5	51	Relatively impermeable; sections 10 and 12 some loss of FA and fair performance; section 11 good
11		50 TR	TRS + SS, 1:2	5.3	2.3	52.2	50	
12		60 TR	TRS + SS, 1:2	4.7	2.2	53.7	51	
13	HL1 with SS and filler	40 TR	SS + 7 percent F	5.8	2.1	49.5	47	Impermeable; slight loss of FA; good performance
14		50 TR	SS + 4 percent F	5.4	2.1	49.0	46	
15		60 TR	SS + 2 percent F	4.8	1.8	53.4	49	
16	Asbestos filler mixes	45 TR	TRS + 2 percent A	6.5	2.0	47.0	47	Somewhat permeable; slight loss of FA; good performance
17		45 TR	TRS + LS, 1:1 + 2 percent A	6.5	1.9	43.2	40	Impermeable; good to very good performance
18	S ½ in. maximum size and regular fine aggregate	30 S	LS + LSS, 3:1	6.7	2.9	53.0	49	Permeability of section 18 to 23 not detectable; visually some loss of FA; performance generally good
19		40 S	LS + LSS, 3:1	6.6	2.7	52.7	50	
20		50 S	LS + LSS, 3:1	6.2	2.0	53.2	52	
21	Same as on sections 18, 19, and 20 but with the addition of TRS	30 S	LS + TRS, 2:1	6.7	2.2	53.9	54	
22		40 S	LS + TRS, 2:1	6.6	2.2	53.7	51	
23		50 S	LS + TRS, 2:1	6.1	2.0	52.7	51	
24	Crusher run, hard steel slag mixes ⅜ in. (2 types)	21 SL 1	SL 1	6.5	2.2	39.4	53	Slight loss of FA; performance good
25		15 SL 2	SL 2	5.8	2.4	41.9	54	
26	Carpet seal with reduced fines content	30 TR	TRS	5.7	4.1	52.2	55	Loss of FA and surfacing slightly removed in patches; variable performance from poor to fair
27[b]	Standard HL3 mix with limestone coarse aggregate for comparison of wear	40 L	LS + LSS, 3:1	6.1	3.8	37.4	59	Considerable wear to both CA and FA; performance fair
28-32			Sections planned but not placed in 1969					
33	Precoated traprock chips rolled in mix 27			6.1	-	-	-	Precoated chips resisted wear; matrix (FA) picked out
34	Precoated Sinopal chips rolled in mix 35			5.7	-	-	-	
35	Regular HL1 surface mix	49 TR	LS + LSS, 3:1	5.7	2.9	-	-	Loss of FA; fair performance

Note: CA = coarse aggregate; FA = fine aggregate; TR = traprock (Marmora), ½ to +4; S = Sinopal (synthetic rock), ½ to +4; L = crushed limestone (Acton), ½ to +4; LS = limestone sand (Harris pit); SL 1 = basic oxygen furnace slag; SL 2 = open hearth furnace slag; LSS = limestone screenings (Uhthoff quarry); TRS = traprock screenings (Marmora); SS = silica sand (Nicholson pit); F = mineral filler (limestone); and A = asbestos fiber.

[a]Measured by ASTM brake force trailer at 50 mph.

[b]Control section.

of pavement performance during one winter (approximately 4½ months). The table includes two columns that give the skid resistance and average depth of wear in the wheelpaths for each type of mix.

Skid-resistance measurements were made with an ASTM type of brake force trailer at 50 mph. Wear measurements were made at five randomly chosen locations in each section, and the average wear was calculated.

The amount of wear was determined by stretching a string line across both wheelpaths of the driving lane at each location. The line was run from an unworn area at the outside edge of the pavement. Three points were randomly chosen along the string line near the center of each wheelpath and the distance was measured from the string line to the pavement surface. The average of the 30 measurements in each section gave the mean pavement wear.

The analysis of variance was applied to the results to determine what results could be considered significant. The mean pavement wear for each section is given in Table 6. Wear measurements were also made by the photographic method, but these are not reported because problems with the camera operation in cold weather prevented a complete set of photographs of the unworn pavement from being obtained.

The following comments can be made on the results obtained, and these may be helpful in selecting more suitable wear-resistant surfaces in the future:

1. The normal HL1 surfacings on Highway 400, adjacent to the trial sections, and most of the trial sections themselves show signs of unusual wear and particularly raveling of the matrix.
2. As the percentage of coarse aggregate was increased (sections 1 to 15 and 18 to 23), wear generally decreased.
3. The best performance of the traprock mixes (sections 1 to 15) occurred in sections 13, 14, and 15. In these cases, a fine, hard sand was used, and this resulted in a dense mix that exhibited only a slight loss of fine aggregate.
4. The use of large amounts of traprock screenings made the mixes more difficult to compact, with the result that the surfaces were more permeable, and there was a greater loss of fine aggregate.
5. The use of asbestos fiber in sections 16 and 17, together with a higher asphalt content that was then possible, produced a tough mix that lost only a slight amount of fine aggregate. Section 17 was better than section 16, because the latter contained traprock screening and was more permeable.
6. The Sinopal coarse aggregate (in sections 18 to 23) exhibits good performance and a brilliant whitish surface after traffic wear. It is difficult, however, to judge the permeability of the surfaces visually because of their light color. Mixes in sections 21, 22, and 23 were equivalent statistically to the traprock mixes in sections 13, 14, and 15.
7. The slag mixes, in sections 24 and 25, have a hard and dense surface and have resisted wear reasonably well.
8. A large, yet even, amount of wear was exhibited by section 27, which was an HL3 mix containing a limestone aggregate. In this case, wear of the coarse aggregate and matrix was uniform and amounted to about 3.8 mm in 4 months (1 in. in about six winters, if wear continues at the same rate). In other sections containing hard traprock, slag, or Sinopal coarse aggregate, wear was not uniform. Even though the matrix surrounding the coarse aggregate particles was considerably eroded, the coarse aggregate particles themselves resisted the wear reasonably well and now stand proud of the surface. So far, only occasional dislodgment of the coarse aggregate has been noted.
9. The sections into which precoated, hard aggregate chips were rolled hot have shown good wear resistance even though the surrounding matrix has been eroded by wear, as in the other sections.
10. Comments 3 and 9 in the foregoing suggest that BS 594 mixes (which could not be placed because of the onset of winter) might perform very well and that trial sections of these mixes should be placed.
11. The performance of the regular HL1 mix, in the passing lane paralleling the trial sections and at the end (section 30), showed a considerable loss of fine aggregate and

poorer performance than some of the trial mixes. From the information obtained from these test sections, it may be possible to generate improvements applicable to HL1 mixes.

The skid numbers for the sections are given in Table 6. The following comments can be made on these results:

1. The traprock and Sinopal mixes (sections 1 to 15 and 18 to 23) generally showed a slight increase in skid resistance after winter wear. This was due to removal of some surface matrix that left the coarse aggregate more exposed. There was, however, one exception in the case of the mix in sections 4 to 6 where the skid resistance decreased. These were the most severely worn sections, and the loss of coarse aggregate caused a drop in skid resistance.
2. The skid resistance of the asbestos mixes was generally lower and remained that way during the winter.
3. The slag mixes (sections 24 and 25) and the HL3 mix (section 27) showed skid resistance to decline earlier than in the case of some traprock mixes, but it appeared to stabilize at about the same level at the end of the present period of observation. Full details of this experiment and the results are given elsewhere (4).

Traffic Markings

Several types of trial markings were laid in the fall of 1969. These were as follows:

1. Broken lines formed by spreading a white thermoplastic material. These were applied on selected asphalt and concrete pavements in the Toronto area. Snowplow and stud damage to these experimental lines is evident, particularly where traffic weaving occurs. In general, however, these markings were clearly visible after one winter. It remains to be seen how long they will last in relation to their greater cost.
2. Parallel grooves cut into the pavement along the original white lines. It was expected that, even though the surface paint would be scraped away by the studs, the white lines would not be removed from the grooves. This experiment has not been successful because, although the grooves themselves remain fairly visible, the paint in them has poor reflectivity.
3. A white synthetic aggregate (Sinopal) embedded in new concrete as the traffic lane marker. The visibility of this material has proved inadequate and must be improved before this method of lane marking can be acceptable for use.
4. White Sinopal aggregate embedded in new asphaltic concrete. It was not possible to test this on a full scale, but some small patches have performed well.

All of the preceding markings were capable of breaking the water film during rain and should increase the visibility of traffic markings under such circumstances. It is too early to assess their long-term suitability, however, and further experiments are planned.

PERFORMANCE OF STUDDED TIRES

Performance tests to evaluate the effectiveness of studded tires have been made by many authorities (14). Differences in test conditions, however, make it difficult to reconcile the various results, most of the stopping distance tests on ice have been carried out only at low speed (20 mph), and the information available on stopping distance on bare, wet, or dry pavements is more limited than that on ice. For these reasons, the Ontario Department of Highways welcomed proposals by both the Ontario Provincial Police and the Canada Safety Council to conduct stopping distance tests and certain maneuverability tests to compare the effectiveness of studded snow tires with other types of tires under the conditions prevailing on highways in Ontario and elsewhere in Canada.

Ontario Provincial Police Tests

Two identical regular police cars were used; one was equipped with snow tires with studs on the rear wheels and the other was fitted with similar snow tires but without studs. Stopping tests were conducted on a number of highways in north-central Ontario and on unprepared (natural) snow-covered ice and packed snow surfaces with the vehicles traveling at speeds of 50 and 30 mph as prevailing conditions permitted.

Although these tests were not performed under the same carefully controlled conditions as were attained in the Canada Safety Council tests, the results are still meaningful. They included locked-wheel braking, hard braking, pumped braking, and emergency stops and are probably representative of what might be expected in similar winter circumstances by a skilled driver. The results of the 35 different comparative tests carried out are given in Table 7.

TABLE 7

LONGER STOPPING DISTANCES REQUIRED FOR STUDDED TIRES THAN FOR SNOW TIRES

Surface	Speed (mph)	Longer Stopping Distance	
		Feet	Percent
Dry asphalt	30	2	6
	50	12	7
Wet asphalt	30	3	8
	50	24	22
Packed snow	30	5	5
Thin snow on ice	50	27	11
Thick snow on ice	50	7	4

The overall analysis indicates that in all cases longer stopping distances were recorded with studded tires than with plain snow tires. However, in 8 of the 35 individual tests, marginally shorter stopping distances were noted for studded tires. No single factor common to these particular results could be pinpointed. In common circumstances, locked brakes produced the shortest stopping distance. With hard or pumped braking, slightly long stopping distances were recorded. However, where brakes are pumped this disadvantage should be offset by less risk of skidding and consequent loss of directional control. Certain additional tests by the Department of Highways were made that confirmed the finding that locked braking produces the shortest stopping distances.

It is interesting to note that the Ontario Provincial Police vehicles are not equipped with studded tires in the winter. Evidently experience has shown that conventional snow tires are quite satisfactory for the winter driving conditions encountered by the police.

Canada Safety Council Tests

A series of studded-tire performance tests (12) were carried out by Damas and Smith Consulting Engineers in March and April 1970 for the Canada Safety Council. Stopping distance tests at 20, 35, and 50 mph with locked brakes were carried out on icy surfaces at temperatures ranging from -5 to 33 F and on both wet and dry bare asphalt and concrete pavements. Limited demonstrations of maneuverability on ice and of stopping distances on sanded ice were also carried out. Details of the tests and the results are contained in a companion paper (12).

The findings of both the Ontario Provincial Police and the Canada Safety Council tests are in line with those reported by other investigators (14). The particular importance of the Ontario tests is that they extend the observations into the speed range of normal highway driving and show that, even though studded tires are of distinct advantage on ice especially when fitted on all four wheels, they afford no advantage on bare, wet, or dry pavements. They also bring out the point that, once an icy road surface is sanded (which is done as soon as possible in normal winter maintenance practice in Ontario), stopping distances with any type of tire are greatly improved and are much less than those of studded tires on unsanded ice.

WINTER DRIVING—ROAD CONDITIONS

In an evaluation of the contribution of studded tires to driving safety, it is necessary to establish how much icy pavement a driver is likely to encounter during the winter as compared with other conditions in which the use of studded tires may be of little or no advantage. This has been determined from the daily road-condition reports made from the beginning of November to the end of March by the district patrols for each King's Highway in Ontario. Because of varying traffic volumes on the different sections of each highway and because the maximum amount of information was desired from the available reports, it was not possible to express pavement conditions in terms of vehicle-miles. They are expressed, therefore, as day-miles; that is, the number of days times the miles where each condition prevailed. Table 8 gives this information. Districts

TABLE 8

WINTER ROAD CONDITIONS

Area[b]	King's and Other Highways		Road Condition[a]								Temperature (percent of days)			
			Bare, Dry		Bare, Wet, or Damp		Snow or Slush		Icy					
	Total Miles	Total Day-Miles	Day-Miles	Percent	Day-Miles	Percent	Day-Miles	Percent	Day-Miles	Percent	<10 F	10 to 30 F	30 to 35 F	>35 F
1	6,547	925,824	558,647	60.3	253,201	27.3	111,413	12.1	2,563	0.3	13.2	49.8	17.1	19.9
2	3,563	530,887	223,676	42.1	94,134	17.7	211,909	39.1	1,168	0.3	24.5	46.7	13.4	15.4
3	4,882	726,335	222,846	30.6	52,289	7.2	431,277	59.5	19,923	2.7	37.2	46.8	7.3	8.7
Total	14,992	2,183,046	1,005,169	46.0	399,624	18.3	754,599	34.6	23,654	1.1	24.7	48.0	12.6	14.7

[a]Based on daily road condition reports submitted by each patrol in each district. Two reports were analyzed: one representing the early morning conditions and the other the midafternoon conditions each day from November 1 to March 30.
[b]Area 1, southern tier of districts (Chatham, London, Stratford, Hamilton, Toronto, Port Hope, Kingston, Ottawa); area 2, middle tier of districts (Owen Sound, Bancroft, Huntsville, North Bay, Sudbury); and area 3, northern tier of districts (New Liskeard, Cochrane, Sault Ste. Marie, Thunder Bay, Kenora).

with a similar pattern of road conditions and weather have been grouped into three geographical areas to show the total day-miles by road condition prevailing in the areas during the past winter. Table 9 gives information on the precipitation and visibility in the three areas during the test period. Corresponding information was not obtained for county, city, and township roads, and estimates cannot be made on the basis of the Provincial roads because road conditions are dependent on the particular maintenance standards employed.

The performance studies have shown that studded tires are advantageous only on icy surfaces. They are particularly advantageous when temperatures are near the freezing point or when freezing rain coats the pavement with ice and when maintenance crews are hard pressed to spread sand and salt on the highways quickly enough. The province-wide road conditions that prevailed on the King's Highways last winter were as follows:

Condition	North	Central	South	Avg
Icy pavements, percent of day-miles	2.7	0.3	0.3	1.1
Temperatures 30 to 35 F, percent of days	17.1	13.4	7.3	12.6
Freezing rain, percent of time		0.5 to 1.0		

The bare, dry pavement condition prevailed 46 percent of the day-miles, and the bare, wet pavement condition prevailed 18.3 percent of the day-miles. In both these circumstances, regular summer tires would have been adequate. Snow tires, not necessarily fitted with studs, would have been preferable on 34.6 percent of the day-miles when the highways were slushy or covered with snow.

Regional differences and differences between King's Highways and county, township, or city roads and streets exist because of varying climatic conditions, level of maintenance, and highway use. However, it is generally true to state that studded tires are not essential to ensure mobility and reasonably safe and convenient use of highways in Ontario during winter conditions.

TABLE 9

AVERAGE PRECIPITATION AND VISIBILITY IN THREE AREAS

Precipitation and Visibility	Percent of Time
Precipitation	
None	75 to 82
Snow	12 to 19
Rain	2 to 6
Freezing rain	0.5 to 1
Visibility	
Adequate	85 to 94
Poor or limited by drifting snow	6 to 15

WINTER ACCIDENT ANALYSIS

This part of the study was an analysis of the accidents in which vehicles with studded tires were involved. The analysis was performed on 2,790 vehicles involved in accidents on King's Highways during February 1970 (932 vehicles in accidents on icy roads and 1,858 in accidents on roads without ice). The analysis consisted of two parts.

The first part was an examination of the percentage of vehicles equipped with studded tires in accidents on roads both with and without ice. The data were obtained from Ontario Provincial Police accident reports. Unfortunately, these data were incomplete, and it was necessary to carry out a questionnaire survey of the drivers involved to determine the extent of the underreporting of vehicles with studded tires. The results of this part of the analysis are given as follows:

Source of Data	On Roads With Ice (percent)	On Roads Without Ice (percent)
Ontario Provincial Police reports	11.2	4.8
Questionnaires (sent only to drivers for whom presence or absence of studded tires was not confirmed on accident report)	19.3	21.3
Revised estimate of vehicles equipped with studded tires involved in accidents	20.6	18.5

Thus, the estimated percentage of vehicles equipped with studded tires involved in accidents on icy roads is not markedly less than the percentage involved in accidents on roads without ice, which is contrary to expectations if studded tires afford a significant contribution to safety. In fact, the estimated percentage involvement of studded tires in accidents on icy roads is greater than in accidents on roads without ice, although the difference is not statistically significant.

However, these figures of 18 to 21 percent are much lower than the approximately 30 percent of the vehicles equipped with studded tires on Ontario roads, as indicated by road counts. This difference could be caused by several factors: inaccuracy in either the estimated population percentage (30 percent) or the percentage of vehicles equipped with studded tires involved in accidents (incomplete questionnaire returns); differences in driving skill; the differences regard for safety between users of studded tires and those who do not use studded tires; or differences in the various driving conditions between users and nonusers (this difference was in fact indicated by the questionnaire returns).

Even though it is recognized that the analysis is based on limited information and a short time period, it seems to indicate that studded tires do not produce improved safety on icy roads, where they are claimed to be most effective. The differences between percentages of vehicles with studded tires in the vehicle population and in accidents can probably be accounted for by differences in driving skill, concern for safety, and exposure to various driving conditions, or by inaccuracies in the data.

The second part of the analysis was a subjective rating of the influence of studded tires in accidents on icy roads. A panel of four people rated each accident as to the usefulness of studded tires in the prevention of the accident or the reduction of its severity. Rating results are summarized as follows:

Usefulness of Studded Tires	Percent of Accidents
Definitely would not have helped	21
Probably would not have helped	20
No decision	38
Probably would have helped	21

Thus, even in accidents on icy roads, studded tires appear to be relevant in about 59 percent of the accidents, although this figure may be as low as 21 percent.

Additional factors affecting accidents and safety, for which no information is available, are the dangers resulting from the premature loss of traffic lane markings in winter; and the year-round effects of pavement rutting caused by studded-tire wear, which might be expected to adversely affect the control of vehicle direction and to contribute to the ponding of water, an increase in splashing, and the risk of skidding.

PUBLIC OPINION SURVEYS

To gage public opinion of studded tires, two questionnaire surveys were made: the first by the Ontario Department of Highways to assist in the analysis of accident data; and the second by the Rubber Association of Canada (10).

Department of Highways Survey

The Department of Highways survey consisted of two types of questionnaires. The direct questionnaire referred to the accident in which the person surveyed was involved. The general questionnaire asked general questions about winter driving habits of the person surveyed. The responses to these two questionnaires are given in Table 10.

In considering the responses in Table 10, it should be kept in mind that, in the direct questionnaire, 15.1 percent of those responding had cars equipped with studded tires, and, in the general questionnaire, 25.8 percent of those responding had cars equipped with studded tires. In both cases, less than 10 percent specifically noted that they considered studded tires to be beneficial, while no opinion was expressed by the majority.

Rubber Association of Canada Survey

The study for the Rubber Association of Canada was carried out by Market Facts of Canada, Ltd., by means of a telephone survey of 1,000 persons "responsible for the maintenance and servicing of the family car." The survey was carried out in five geographical areas of Ontario having climatic and other differences.

The survey was undertaken in March and April 1970 to obtain background information on the knowledge that each person had of studded tires and the attitudes toward studded tires. It also sought to establish the advantages or disadvantages of studded tires from the experiences of those who had used studded tires.

It is not practical in this paper to present the large amount of data obtained from the 22 main questions asked. Instead, the main points of the report (10) are given.

1. The driving public is virtually split on the issue of studded snow tires. They definitely find it difficult to decide whether the advantages of studded tires outweigh the road-damage problem. However, at the present time, a slight majority of drivers believes that studded snow tires should be permitted on the roads.
2. The public is indeed aware of the advantages of studded tires as well as of the criticism that has been directed at this type of tire.
3. Present users of studded tires are convinced that studded tires contribute to safer driving. This belief is held even more strongly by rural drivers.
4. Users of studded tires are in strong agreement that studs improve winter driving performance on icy roads and on hard-packed snow, but they also seriously question their usefulness on dry and wet roads.

TABLE 10

PUBLIC OPINION OF STUDDED TIRES

Comments	Respondents (percent)	
	Direct Questionnaire[a]	General Questionnaire[b]
Accident was result of poor highway maintenance	17.2	
Highway was bare and dry at time of accident	2.8	
Studded tires were useful in winter driving	8.3	9.2
Studded tires were not useful in winter driving	10.0	15.4
Other comment	31.0	19.4
No comment	30.7	56.0

[a]Sample size, 496; percentage responding, 50.6. [b]Sample size, 496; percentage responding, 35.9.

5. Approximately 80 percent of present users of studded tires intend to purchase this type of tire again.

6. It would appear that the main opposition to not buying studded tires is the lack of any perceived need for them. Ontario drivers essentially believe either that there is no real need for them in their particular area or that regular snow tires do the job just as well.

7. Ontario drivers are not convinced that there needs to be a law requiring snow tires in the Province, and they are even less convinced that there needs to be a law requiring studded snow tires.

Both the survey made by the department and that undertaken for the Rubber Association of Canada produced findings that are not inconsistent with those that might be expected from the performance studies reported previously. These findings suggest that, although the users may feel that studded tires are an aid to safer winter driving on icy roads, studded tires are by no means regarded by the public as essential to winter motoring in Ontario. It is of interest to note that, at the time these surveys were made, the results of the studded-tire performance tests and information on road conditions in Ontario throughout the winter had not yet been published.

CONCLUSIONS

From the studies and observations contained in this report and its predecessor (1), the following may be concluded:

1. The use of studded tires in Ontario has generally increased to about 32 percent of passenger vehicles, and, if unrestricted, the increase appears likely to continue to the extent used in predicting the resulting pavement wear.

2. Wear measurements during the winter of 1969-70 show that serious wear is occurring on all types of pavements other than those carrying only light traffic and is continuing at about the rate predicted.

3. No change is indicated, therefore, in the estimates of the repair costs of remedial work that will be required because of the continued use of studded tires. The total additional costs in Ontario through to financial year 1978-79 are estimated to be $127 million.

4. Experiments to develop more wear-resisting surfaces and traffic markings have been only partially successful. Although improvements to currently used surfacing materials and markings can be recommended at additional cost, there is no assurance as to their long-term value or service life.

5. The performance tests made by the Canada Safety Council and Ontario Provincial Police confirm that studded tires are of benefit in reducing stopping distances on icy surfaces and improving maneuverability, especially when studded tires are fitted on all four wheels. On bare asphalt and concrete pavements, in wet, dry, or snow conditions, studded tires are not superior with respect to stopping ability and are often significantly inferior to conventional snow tires.

6. On icy surfaces, sanding contributes greatly to reduced stopping distances that are applicable to all types of tires.

7. Icy road conditions prevailed on the King's Highways in Ontario for only 1.1 percent of the day-miles. Bare, wet pavements prevailed for 18.3 percent of the day-miles. Slush or snow cover prevailed for 34.6 percent of the day-miles. For the remaining 46 percent, pavements were bare and dry during the winter months.

8. A limited analysis of winter accidents failed to show that studded tires contributed significantly to the reduction of the number and the severity of accidents or the chance of accident on icy roads. No judgment is possible on the adverse effects of the loss of traffic markings or the year-round effects of rutting resulting from wear.

When consideration is given to performance data, prevailing road conditions, accident statistics, and problems and costs associated with pavement and traffic-marking wear, it appears that the use of studded tires offers few benefits to the safe and economical operation of highway transportation in Ontario. As a result of these findings, the use of studded tires in Ontario is prohibited with effect from May 1, 1971 (by Regulation 423/70 under the Highway Traffic Act).

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