NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 32

EFFECTS OF STUDDED TIRES

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
- PAVEMENT PERFORMANCE
- MAINTENANCE, GENERAL
- HIGHWAY SAFETY

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1975

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices without in fact making specific recommendations as would be found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available concerning those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of special interest and usefulness to highway and transportation administrators, safety engineers, and others who must pass judgment and act on the future use of studded tires. All significant available information relevant to the use and effects of studded tires was assembled, organized, and distilled, as a convenience to the reader in comprehending what is known to date. Information is presented on all facets of the studded tire-pavement system.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problems. In an effort to resolve this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems—a synthesis being identified as a composition or combination of separate parts or elements so as to form a whole greater than the sum of the separate parts. Reports from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

Almost from the time of their introduction more than a decade ago, studded tires have been a subject of controversy. They have received wide acceptance from highway users, who have seen in them a potential for improving mobility and safety in travel on icy and snowy pavements. Their popularity is attested to by the rapid increase in sales that took place following initial marketing. Primary opposition has come from highway and transportation officials, who have been concerned that the cost to the taxpayer of repairing the damage that studded tires do to pavements is not reasonably related to the benefits that may accrue from their use. This synthesis is an effort to present all of the known facts about studded tires and to point out the areas of inadequate or missing information. A few conclusions are offered where adequate support appears to make this justified. This synthesis is not intended to, and does not, proffer a resolution to the controversy.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information from many highway departments, stud manufacturers, safety research organizations, police agencies, and others who have been able to provide significant information on the effects of studded tires. A topic advisory panel was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records present knowledge of the effects of studded tires. As the processes of advancement continue, new knowledge can be expected to be added to that which is now available.

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EFFECTS OF STUDDED TIRES

SUMMARY

From the time studded tires were first introduced, research and controversy have centered about the advantages, disadvantages, and effects of studded tires on vehicles, drivers, and pavements. The objective of this synthesis is to assemble and organize the facts that are currently available on the effects of studded tires.

Studded tires were first introduced in the United States in 1963, and their use increased rapidly as state laws were changed to permit them on highways. However, as the damaging effects of studs on pavements became known, many states restricted or prohibited the use of studded tires.

The original (first generation) tire studs consisted of a tungsten carbide pin in a jacket held in the tread rubber by a flange. Newer studs (second generation) are similar in design but smaller and lighter, and the carbide pin is tapered so that it moves back into the jacket to maintain controlled protrusion of the tip. Current tire designs receive and hold the studs better and with greater stability.

Performance tests on ice have shown consistently better traction and stopping ability with studded snow tires than with unstudded snow tires, particularly at higher ice temperatures. The controlled-protrusion studs have reduced performance compared to earlier studs but have better traction and stopping ability on ice than unstudded tires. The performance differences between studded and unstudded tires tend to decrease as the tires wear.

Performance tests of studded and unstudded tires on wet and dry pavements indicate increased required stopping distances for studded tires on concrete but virtually no difference on asphalt.

New tire designs and devices are under study as possible alternatives to studs. Changes in the components of the rubber allow the tread to stay soft at low temperatures for better traction on ice or packed snow, and tire treads impregnated with abrasive material give stopping distances as short as studded tires. Other courses of action being taken or proposed include prohibiting or restricting studded-tire use, speed restrictions, special taxes, and allowing studded tires only on police, fire, and other emergency and special-use vehicles.

Pavement wear has received more attention than any other area of the studded-tire debate. Many laboratory and field studies have been made although correlation is difficult. Early (1965) field studies, though largely qualitative, showed pavement wear from studded tires. These studies also showed that the wear was greater on bituminous pavements than on concrete pavements. Later laboratory studies on circular test tracks and field measurements of actual pavement wear confirmed the earlier findings and were able to give quantitative values to wear rates in terms of inches of wear per million studded tire passes. It was also shown that when studs were banned pavement surface wear became negligible.

Other effects of studded tires on pavements have been studied. A potential for hydroplaning exists in ruts formed in pavement surfaces. Grooves placed in unrutted pavements to reduce the potential for hydroplaning have been worn away by studded tires. There has also been damage to pavement markings.

Reports and studies indicate that driving control is enhanced by the use of studded tires on icy pavements. Non-winter driving safety may be adversely affected by pavement wear in the wheelpaths and resultant potential for hydroplaning, but data to support this premise are not available. There is substantial agreement that studded tires improve mobility on ice.

An economic analysis of studded tires would include the cost of the studs, the cost of pavement wear, the benefits of increased mobility, the safety benefits and losses, and the costs of alternatives. Only the first two have been quantified.

In evaluating information on the effects of studded tires, few documented conclusions can be drawn. Much of the data are inconclusive or conflicting and based on conditions of studded-tire design and use that have changed. However, some general conclusions can be made:

- "First generation" studs provide improvement in vehicle stopping ability, traction, and control in transient maneuvers on ice. They also cause undesirable and expensive pavement wear when used by a large number of motorists in a given area.
- "Second generation" controlled-protrusion studs have reduced effectiveness compared to the earlier studs. They also have lower pavement wear rates, although still much greater than unstudded snow tires.
- Studies of safety performance of vehicles equipped with studded tires have been inconclusive. There is little evidence of reduction of accidents from studded-tire use or increased accidents from a studded tire ban.
- Although little assessment has been made of the degrees and effects of the hazards created by studded tires, concern has been expressed about hydroplaning, splash, loss of pavement markings, vehicle displacement, noise and vibration, and loss of skid-resistant surfacing and grooving.

Highway users have potentially conflicting objectives that add to the controversy over studded tires. On one hand, they want mobility and safety under adverse winter weather conditions; on the other hand, the highway user also wants a safe well-maintained pavement when there is no ice or packed snow on the road. The fundamental question is whether both of these objectives can be achieved in a practical, economically feasible way and specifically with the use of studded tires. The answer to that question is not found in the studies and research presently available.

Newer designs for studded tires and studless tires claim reduced pavement wear and good performance on snow and ice. It remains for these characteristics to be proved (i.e., that the performance is better than regular snow tires and the pavement wear is acceptable).

CHAPTER ONE

INTRODUCTION

OBJECTIVES

Since the winter of 1961-1962 when studded tires were first marketed successfully for general use in the Scandinavian countries, discussion, research, and controversy have centered about the advantages, disadvantages, and effects of the studded tire on vehicles, drivers, and pavement systems. Safety analysts, highway engineers and administrators, legislative study committees and others attempting to make judgments on this issue have faced an exhaustive collection of data, publications, research and editorial comment available in Europe and the United States on studded tires.

The objectives of this synthesis are to assemble, distill, and organize these data for the benefit of the reader and to identify those conclusions that can be drawn at this time from this still-evolving technology. This synthesis is organized into chapters dealing with the fundamental elements in the system: (1) the studded tire, (2) the pavement system, and (3) the vehicle and driver.

HISTORY OF STUDDED TIRE USE

The first significant consumer market for studded tires developed in the Scandinavian countries in the winter of 1961-1962. Studded-tire use in Finland has continued to increase for the past several years. Germany also experienced rapid acceptance of the studded tire. A test market was established by the tire industry in Canada in the 1963-1964 winter season with an estimated 1½ million tire studs sold that year, 6 million the following year, and over 25 million estimated by the 1965 winter season.

In the United States, a limited test market was established in the 1963-1964 winter season in two or three states because of the legal questions about their use in many states. The rapid increase in studded-tire use during the first three seasons of marketing in the United States is given in Table 1 (*1*).

By 1969 total sales of studded tires were estimated to be 830 million. In November 1972, a questionnaire on studded-tire use was completed by 44 states. The results are given in Table 2 (*2*).

LEGISLATIVE HISTORY

When the studded tire was introduced into the United States market in 1963, many states had legislation on their books that prohibited the use on public highways of vehicles equipped with tires that had "any block, stud, flange, cleat, or spike or other protuberance of any material other than rubber which projects beyond the tread. . . ."

According to preliminary legal searches it was estimated that only 13 states permitted the use of studded tires in 1963. As consumer acceptance of studded tires increased dramatically, the states initiated studies, research, and in some cases, legislative action on the use of studs. In 1965, studded tires were legal in an estimated 28 states and by 1967, 34 states had legalized the use of studs (*3*). By 1974, the trend had reversed, with studs legal without restriction in 16 states, restricted use permitted in 29 states and the District of Columbia, and use prohibited in 5 states (Fig. 1). The Federal Highway Administration has issued a policy statement that encourages states to ban or limit the use of studded tires (App. C).

Minnesota

The legal use of studded tires in Minnesota was first permitted during the period October 15, 1965 to April 15, 1966 following action by the 1965 session of the Minnesota State Legislature in amending the statutes that prohibited vehicle tires with steel lugs, protrusions, and the like. The action of the Legislature was subject to renewal after two years. The provisional amendment was renewed in 1967 and in 1969.

TABLE 1

INCREASE IN USE OF STUDDED TIRES DURING THE INITIAL PERIOD (1963–1966) OF MARKETING IN THE UNITED STATES (*1*)

Winter Season	No. Legal States	No. of States Marketed (legally)	No. of Tire Studs Sold in USA[a] (millions)	Approx. No. of Tires (100 studs/tire)
1963-1964	13	2-3	3-5	30.000
1964-1965	13	1-3	25-30	250,000
1965-1966	28	28	250-275+	2,500.000

[a]Estimate.

TABLE 2

ESTIMATED 1972 STUDDED-TIRE USE (*2*)

State	Use (percent)[a] 1972-73	Use (percent)[a] 1976-77	State	Use (percent)[a] 1972-73	Use (percent)[a] 1976-77
Alabama	1	1	Montana	60	77
Alaska	61	61	Nebraska	38	38
Arizona	1	1	Nevada	6	6
Arkansas	1	1	New Hampshire	30	50
California	NA[b]	NA	New Jersey	20	32
Colorado	30	40	New Mexico	NA	NA
Connecticut	25	25	New York	30	35
Delaware	18	18	North Carolina	2	2
Florida	NA	NA	North Dakota	32	32
Georgia	NA	NA	Ohio	20	30
Hawaii	NL[c]	NL	Oklahoma	1	2
Idaho	27	5	Oregon	10	11
Illinois	12	22	Pennsylvania	28	37
Indiana	10	12	Rhode Island	NA	NA
Iowa	25	40	South Carolina	3	3
Kansas	7	5	South Dakota	40	40
Kentucky	12	19	Tennessee	NA	NA
Louisiana	NL	NL	Texas	0	0
Maine	NA	NA	Utah	NL	NL
Maryland	NA	NA	Vermont	60	55
Massachusetts	32	45	Virginia	10	30
Michigan	12	26	Washington	35	45
Minnesota	NL	NL	West Virginia	10	10
Mississippi	NL	NL	Wisconsin	20	32
Missouri	14	14	Wyoming	35	40

[a]Figures shown are approximately middle values for those states that provided estimated ranges; for example, 20 to 30 percent is listed as 25 percent. Estimated studded-tire use is expressed as the percentage of registered passenger cars equipped with studded tires.
[b]NA = estimate not available.
[c]NL = not legal.

During the 1969 legislative session, the Minnesota State Legislature was made aware of the concern expressed by the Minnesota Commissioner of Highways about the pavement damage being observed at various locations on the state highway system, but recognized the public acceptance indicated by the growing use of studded tires. The Legislature, although extending the use of studded tires until May 1, 1971, directed the Commissioner of Highways to conduct a study of the effects of studded tires on safety and pavement wear.

The report was presented to the 1971 session of the Minnesota State Legislature (*34*). The report stated that "it seems reasonable to conclude, based on all findings as well as influences which cannot be quantified, that if studded tires were discontinued there would be little appreciable change in traffic safety in Minnesota." Acting on this information, the 1971 session of the State Legislature did not renew the provisional amendment permitting the use of studded tires.

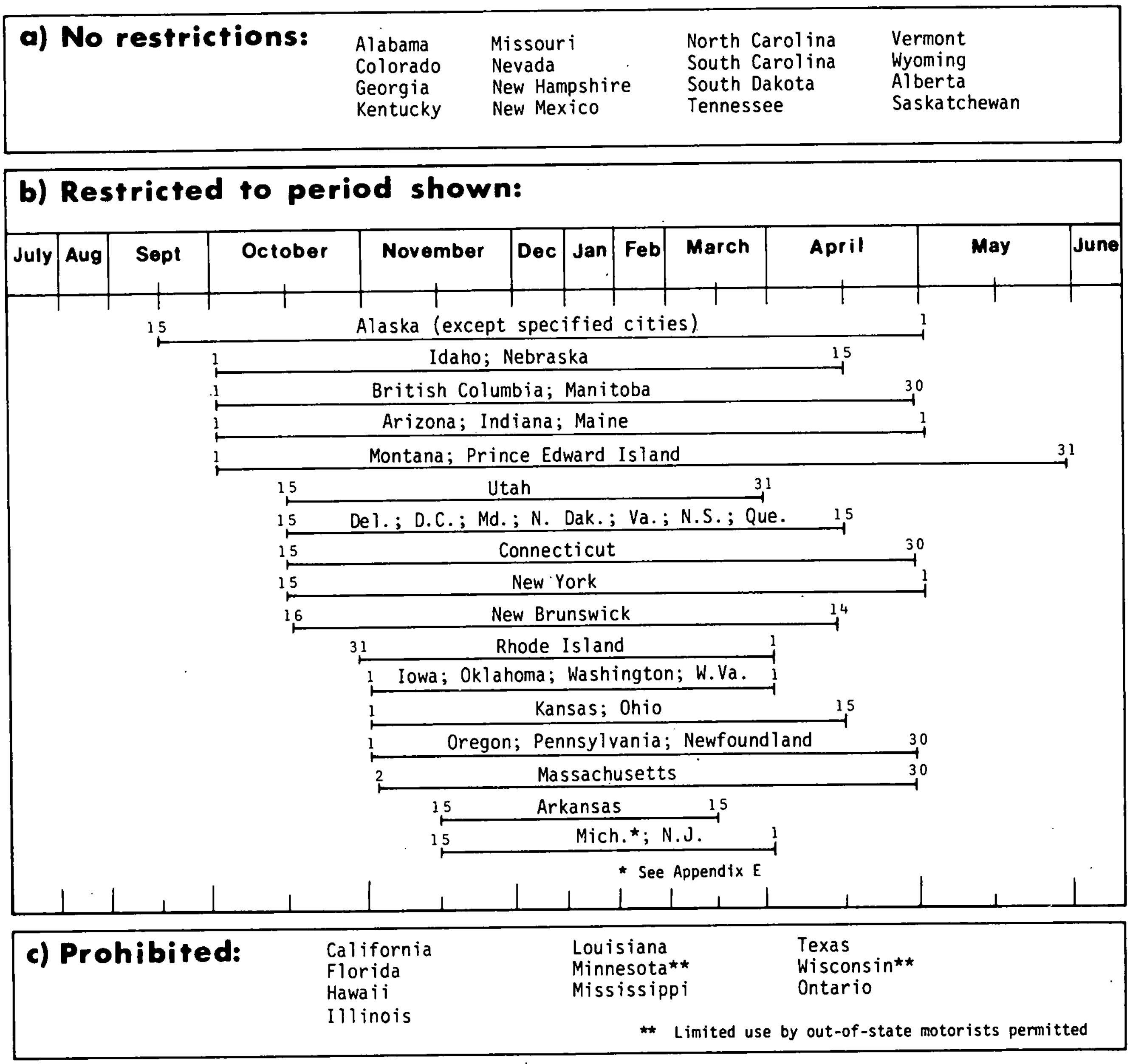
During the 1971-1972 winter season, the Minnesota Department of Highways conducted accident studies to determine what effect, if any, the ban on studded tires would have on the number of highway crashes on Minnesota roadways. This information was presented as part of a position statement on studded tires offered to the 1973 session of the Minnesota State Legislature in its consideration of bills to reinstate studded tires. The Department of Highways reported that a large increase in crashes did not occur on Minnesota's highways during the winter of 1971-1972. The accident study showed no statistically significant change in fatal crashes, personal injury crashes, or property damage crashes for the 1971-1972 winter season as compared with the three-winter average for the winters of 1968-1969, 1969-1970, and 1970-1971. The 1973 session of the State Legislature continued the ban on studded tires in Minnesota.

Utah

Another legislative case history with a reverse twist is offered by the State of Utah. Utah first permitted the use of studded tires, enacted a ban on studded tires, and then reestablished the legal use of studded tires on Utah roads and highways.

The authorization for the use of studded tires by the Utah State Legislature came in 1966 when the Utah State Road Commission was given regulatory authority to make exceptions to the general statutes, which precluded studs, cleats, and materials other than rubber from being used on motor vehicle tires. The State Road Commission then approved the use of studded tires.

By December 1970, the State Road Commission was aware of damage to Utah's Interstate system attributed to studded tires. At that time the Commission, by resolution, prohibited the use of snow tires between April 1 and October 15, inclusive, of each year.



Sources: American Automobile Association 12-1-74
Federal Highway Administration June 1975

Figure 1. Legal restrictions on use of studded tires.

In 1971, after reviewing data from the Minnesota study and Utah tests measuring pavement wear, the Utah State Road Commission ordered a phaseout of all studded tires over a period beginning October 15, 1971, and ending April 15, 1972. After April 15, 1972, there was to be no further use of studded tires. The ban was followed by public criticism and arguments, which finally brought the issue of studded tires to the State Legislature again. In January 1973, the Utah State Legislature relieved the State Road Commission of further regulatory authority regarding studded tires and granted studded-tire use each winter season beginning October 15 and ending March 31. The new legislation established a maximum permissible protrusion of the stud beyond the traction surface in the amount of 0.050 in. (1.3 mm) and prohibited the use of studs on vehicles with a maximum gross weight in excess of 9,000 lb (4080 kg). The legislation also established a fee of 1¢ per stud when sold in bulk or $1.00 per tire when sold with the tire by the wholesaler or distributor. Revenue from the fees was dedicated with 50 percent to the highway construction and maintenance fund and 50 percent distributed to cities and counties for maintenance and construction work (App. D).

Wisconsin

In Wisconsin, where studded tires had been legal since 1965, the 1974 session of the State Legislature enacted a ban on the future use of studded tires on all vehicles, effective May 2, 1975, except emergency vehicles and out-of-state motorists passing through.

Michigan

Legislation was passed in Michigan permitting the use of tire studs for the first time in the winter of 1967-1968 (Senate Bill No. 218). Although the Michigan Department of State Highways opposed legalizing the use of tire studs, research was not available at that time to document that pavement wear resulted from their use. Tire studs were promoted on the basis of increased safety, although there was also a lack of data to support this premise. By June 12, 1968, pavements located around Houghton-Hancock showed evidence of pavement wear where a large percentage of motorists were using tire studs. During the winter of 1969-1970 the first tire-stud survey was conducted. This survey showed that in the 83 counties in Michigan, use varied from 5 percent to 42 percent with a statewide average of 12 percent to 13 percent. In the winter of 1970-1971, tire-stud use varied by counties from 7.7 percent to 49 percent with a statewide average of 15.2 percent. The 1971-1972 average was 11.8 percent and the 1972-1973 average was 9.2 percent. The drop in tire-stud use was believed to be primarily due to the intensive effort in the Michigan State Legislature to ban their use in Michigan. In November 1973, Public Act No. 138 was signed by the Governor after passing the Legislature. This act mandates that the Department of State Highways and Transportation promulgate rules that will permit studs or other traction devices that will not cause excessive pavement damage. The rules were prepared by the Department and three public hearings were held in different parts of the state during 1974 to obtain public opinion on the rules. The rules were modified as a result of the hearings, and after April 1, 1975, no tire studs can be used that cause 25 percent or more wear when compared to conventional (first generation) studs (App. E).

CHAPTER TWO

THE STUDDED TIRE

DESIGN CHARACTERISTICS

The single-flange tire-stud design, developed through industry research, has been adopted as the basic design by most manufacturers. Tungsten carbide cores, with wear performance designed to be comparable to tread rubber, were first used in the late 1950's in Scandinavian countries. Subsequent use of softer carbides chosen to match the rate of wear of the tire surface rubber reduced the average tire stud protrusion during the late 1960's and early 1970's as given in Table 3 (*4*).

TABLE 3

AVERAGE TIRE-STUD PROTRUSION BY YEAR (*4*)

YEAR	PROTRUSION (IN.)
1966	0.087
1967	0.081
1968	0.076
1969	0.074
1970	0.068
1971	0.065
1972	0.034–0.064
1973	—

The basic components of the tire stud consist of a stud housing or body that is held in the tread rubber by a flange at the base (Fig. 2). The core or pin is the element that protrudes beyond the tire surface and provides the contact with the pavement surface.

Industry testing of stud designs and road wear were reported in 1972 (*4*). Variables tested in a road-wear simulator included:

1. Studs per tire.
2. Tire-stud protrusion.
3. Tire-stud flange diameter.
4. Tire-construction (radial, bias-belted, 4-ply bias).
5. Shape of carbide pin.
6. Weight of studs.

Road wear was shown to increase at a linear rate with an increase in the number of studs per tire and with an increase in stud protrusion.

Dynamic-force measurements also were made in the 1972 industry tests to show the dynamic force of the stud on the pavement surface at impact. These tests showed:

1. An increase in force with an increase in speed.
2. An almost linear relationship between tire-stud protrusion and dynamic force.

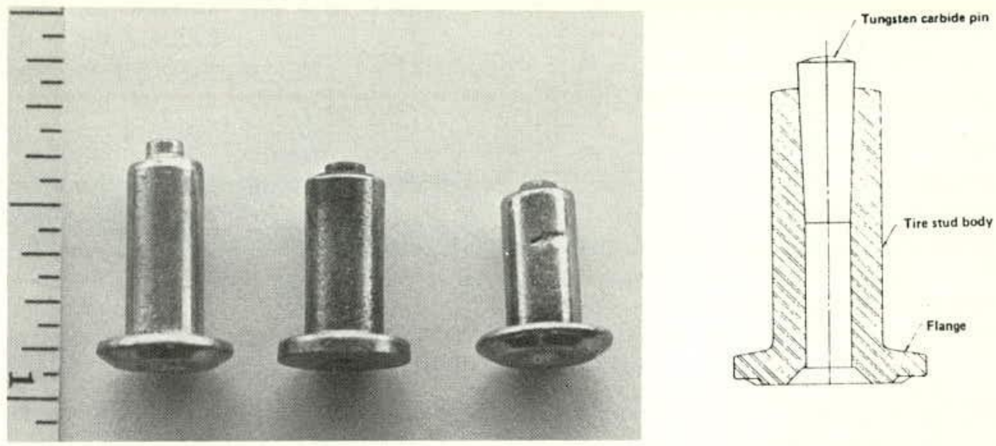


Figure 2. Single-flange tire stud.

3. Tire stud weight influences the dynamic force and the resulting pavement wear.

4. Tire inflation, wheel loads, and tire construction type show no substantial effect on dynamic forces.

5. Larger stud flanges create larger forces.

6. Increased undertread dimensions (thickness of the base rubber between the stud flange and tire cord) reduce dynamic forces.

7. Special studs with a center cavity and four symmetrically oriented pockets showed 4 percent lower dynamic force than flat flange studs.

Improved Tire Studs and Tire Designs

The tire-stud industry has continued a program of research and development in stud design and performance. Following the initial stud design introduced in the early 1960's, a second generation of studs was developed to provide control of the amount of protrusion achieved by the pin beyond the tire surface throughout the tire life. Called a controlled-protrusion (CP) stud, it is 18 percent lighter and has a 5 percent smaller flange than the standard fixed-core stud. The CP stud is designed with a tapered pin that moves back into the jacket as soon as a critical level of dynamic force is reached. Variations of the CP stud design include a threaded jacket design and a jacket of plastic with an embedded wire coil holding the pin. Road-wear reductions of 40 percent to 65 percent are claimed over conventional studs based on industry tests of these designs (*4*). Appendix B gives specifications for controlled-protrusion studs.

A third-generation tire stud being considered for manufacture is a spring-action stud (*5*) that consists of three parts: a cemented carbide core that moves freely within a plastic body, and a rubber pad (Fig. 3). This stud is designed on the premise that the force required to press through an ice surface is less than that required to penetrate a pavement surface. The rubber pad stiffness is designed to hold the stud core as it breaks through ice but to

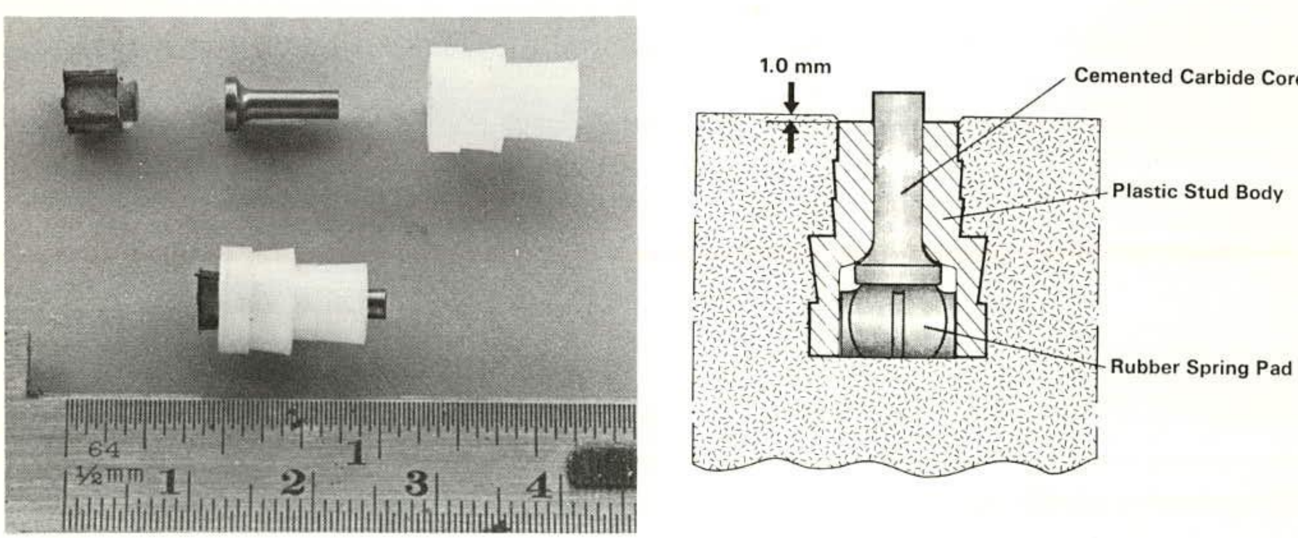


Figure 3. Spring-action stud (Fagersta Steels Limited).

give and permit the core to recede when in contact with a hard pavement surface. To reduce road wear caused by tire-stud impact with the pavement surface, the carbide pin and rubber pad weigh 12.5 g, which is about one-fourth the weight of conventional studs. Because the dynamic force is proportional to the mass of the stud for constant velocity, the spring action stud impact force is only one-fourth of that for conventional studs.

Tire design also has progressed to better accommodate studs. The provision of an increased section of rubber around the stud hole provides increased stability and reduces irregular lateral movement of the stud. Molding of tire-stud holes has been modified to provide a cavity at the base of the hole to receive the stud flange. This is reported to eliminate the irregularity in stud seating caused by variations in stud-gun pressure at the time of insertion. With a flange cavity molded into the tire, studs automatically seat themselves in correct position during the first 100 miles of use.

PERFORMANCE CHARACTERISTICS

Extensive testing of studded-tire performance, particularly for coefficients of friction, stopping distances, and cornering and handling characteristics, have been conducted since the introduction of the studded tire in the United States. Generally, the performance characteristics of the tire lend themselves to laboratory or controlled-field testing, with results that correlate well.

Although some history of studded-tire performance has been accumulated through these tests, the studded tire has undergone changes over this same period and new design concepts are evolving that may not conform to the characteristics established by prior tests. Most of the changes, largely in the stud itself, are directed toward reducing the resulting pavement wear rather than toward changing skidding or stopping characteristics.

Performance On Ice

The National Safety Council Committee on Winter Driving Hazards has conducted tests at Stevens Point, Wisconsin on studded-tire performance on ice in annual test programs since 1965 (*8*).

In the 1965 tests, new studded snow tires had coefficients of friction measured on a locked-wheel friction trailer ranging from 43 percent to 84 percent greater than new unstudded snow tires at 25 F (—4 C) ice temperature (Table 4). After 5,000 miles (8000 km) of use, the improvement of worn studded-snow tire performance over new unstudded snow tires was reduced. The worn studded snow tire coefficients of friction ranged from 1 percent to 49 percent greater than new unstudded snow tires (*8*). However, there is a lack of correlation between locked-wheel friction trailer results and vehicle stopping distances (*43*).

Table 5 gives the results of drawbar traction tests performed in the 1964 and 1965 Stevens Point programs. The

TABLE 4

SKID TRAILER COEFFICIENTS OF FRICTION AT 25 F ICE TEMPERATURE, 1965 (*8*)

Tire Mfg.	Tire Tread	No. Studs	Condition	Coeff.	Improvement Over New (%)		Reduction in Improvement Over New (%)[a]	
					Hwy Tread	Snow Tread	Hwy Tread	Snow Tread
A	Highway	–	New	0.084	–	–	–	–
	Highway	–	Worn	0.064	–	–	–	–
	Studded hwy	76	New	0.137	63	36	–	–
	Studded hwy	76	Worn	0.106	26	5	59	86
	Snow	–	New	0.101	20	–	–	–
	Snow	–	Worn	0.087	–	–	–	–
	Studded snow	108	New	0.151	80	50	–	–
	Studded snow	108	Worn	0.115	37	14	54	72
B	Studded snow	63	New	0.160	–	–	–	–
C	Highway	–	New	0.080	–	–	–	–
	Highway	–	Worn	0.080	–	–	–	–
	Snow	–	New	0.095	19	–	–	–
	Snow	–	Worn	0.080	0	–	–	–
	Studded snow	72	New	0.136	70	43	–	–
	Studded snow	72	Worn	0.096	20	1	71	98
D	Highway	–	New	0.083	–	–	–	–
	Snow	–	New	0.087	5	–	–	–
	Studded snow	84	New	0.160	93	84	–	–
	Studded snow	84	Worn	0.130	57	49	39	42
D	Highway w/reinforced chains	–	New	0.370	346	325	–	–

[a]After 5000 mi wear.

TABLE 5

TRACTION TEST DATA (*8*)

Tire Mfg.	Tire Tread[a]	No. Studs	Condition	Break-Away (lb)		Spinning (lb) 1965
				1964	1965	
A	Highway	–	New	120	–	–
	Studded hwy	–	New	394	–	–
	Studded snow	–	New	604	–	–
A	Highway	–	New	–	287	204
	Snow	–	New	–	358	300
	Studded snow	108	New	–	585	370
	Studded snow	108	Worn	–	385	350
B	Studded snow	63	New	–	615	610
D	Highway	–	New	–	316	290
	Snow	–	New	–	344	315
	Studded snow	84	New	–	492	–
	Studded snow	84	Worn	–	410	395
A	Highway w/reinforced chains	–	Tires worn chains new	–	1060	1112

[a]Rear wheels.

test vehicle was attached to a load and the pull in the bar was measured immediately before the wheels began to spin (breakaway traction) and while the wheels were spinning (spinning traction). As shown, the new studded snow tires exhibited greater traction than the other tested tires. Although a significant loss of traction was shown by the worn studded snow tires, they exhibited greater traction than the other tested tires except the new studded snow tires.

The 1966 Stevens Point tests were performed with tires containing 48, 72, and 144 studs per tire. The 72- and 144-stud new snow tires performed almost identically and the 48-stud tire performed at a slightly lower level (Table 6). On worn (5,000 miles) tires, the performance loss was inversely proportional to the number of studs in the tire ranging from 73 percent for 48-stud snow tires to 3 percent for the 144-stud snow tires.

In February 1970, the Canada Safety Council sponsored research to determine stopping distances on ice for various tire types and combinations (*9*). Figure 4 shows the results for various vehicle speeds and ice temperatures. Significant improvements in stopping distances were obtained with studded tires, particularly at higher ice temperatures. It should be noted that comparisons are shown for highway tires on four wheels, unstudded snow tires on rear only, studded snow tires on rear only, and studded snow tires on four wheels. Care should be taken to note the conditions being compared in the figure.

A further series of tests conducted in Ontario in 1971

TABLE 6

SKID TRAILER COEFFICIENTS OF FRICTION AT 25 F ICE TEMPERATURE, 1965 (*8*)

Tire Mfg.	Tire Tread	No. Studs	Condition	Coeff.	Improvement Over New (%)		Reduction in Improvement Over New (%)[a]	
					Hwy Tread	Snow Tread	Hwy Tread	Snow Tread
C	Highway	–	New	0.085	–	–	–	–
	Snow	–	New	0.094	11	–	–	–
	Studded snow	48	New	0.149	75	59	–	–
	Studded snow	72	New	0.162	91	72	–	–
	Studded snow	144	New	0.161	89	71	–	–
	Studded snow	48	Worn	0.109	28	16	63	73
	Studded snow	72	Worn	0.137	61	46	33	36
	Studded snow	144	Worn	0.159	87	69	2	3
	Highway w/reinforced chains	–	New	0.315	270	235	–	–

[a]After 5000 mi wear.

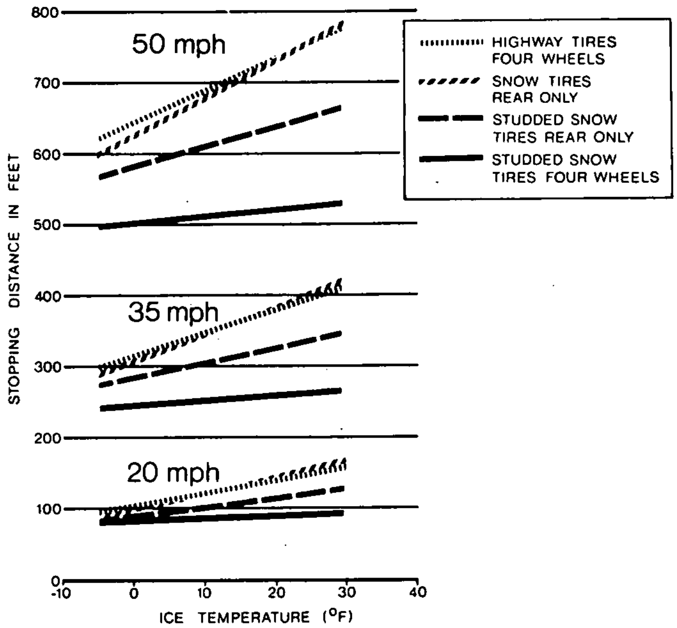


Figure 4. Stopping distance versus ice temperature for four cars traveling at 20, 35, and 50 mph (30, 60, and 80 km/h) (9).

evaluated stopping distances, lane-change speeds, and starting traction (*10*). Tests were made on clear ice and sanded ice. In addition to regular studs, tires equipped with controlled-protrusion studs also were tested. The various wheel combinations tested and the performance results are given in Table 7.

The 1971 National Safety Council Committee on Winter Driving Hazards tests at Stevens Point, Wisconsin (*11*) included stopping; traction and cornering capacity comparisons of highway; snow and studded tires inflated to 12, 24, and 32 psi (82, 165, and 220 kPa). Table 8 gives the skid trailer coefficient at 20 mph (30 km/h) for various tire pressures. As indicated, a reduction in tire pressure to 12 psi produced a reduction in coefficients for the highway tire and the studded snow tire although the unstudded snow tire remained essentially the same at all pressures. The committee could find no evidence from the data collected that reducing tire pressure below that recommended by the manufacturers results in improved traction, braking, pulling, or cornering on ice surfaces.

In 1972, the Stevens Point tests (*12*) included tests of the performance of controlled-protrusion (CP) studs on ice. The CP studs tested had an average protrusion of from 0.041 to 0.046 in. (1.04 to 1.17 mm). The earlier design stud had a protrusion range from 0.056 to 0.060 in. (1.42 to 152 mm). The test results shown in Figures 5 and 6 indicate that there is some reduction in performance by controlled-protrusion studs over earlier design studs, but tires equipped with CP studs develop higher coefficients and stop a vehicle in shorter distances than do identical unstudded tires.

The performance of studded tires on a vehicle during a transient lateral maneuver was tested at Stevens Point in 1973 (*13*). The tests were conducted to measure the magnitude of any improvement in the recovery of control after a skid was induced during a transient lateral maneuver on ice. As shown in Figure 7, the use of studded snow tires on the rear wheels resulted in a reduction in the required recovery distance.

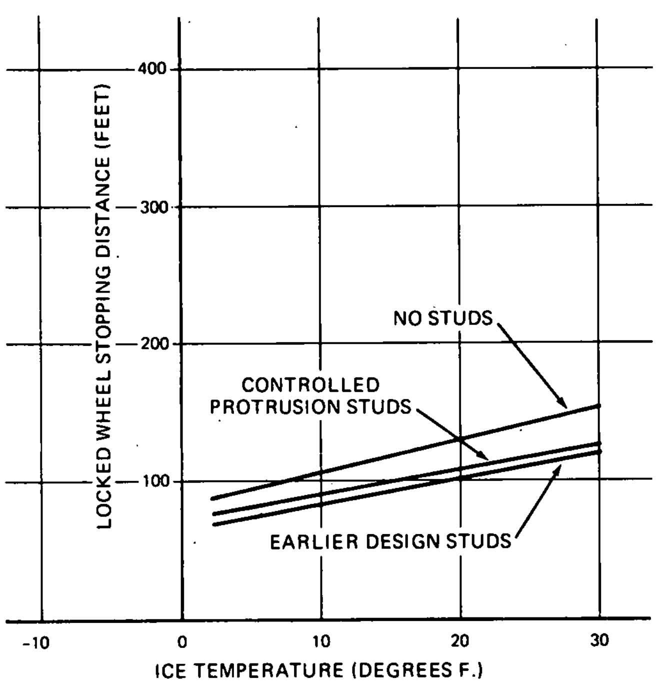


Figure 5. Relationship of stopping distance from 20 mph to ice surface temperature (12).

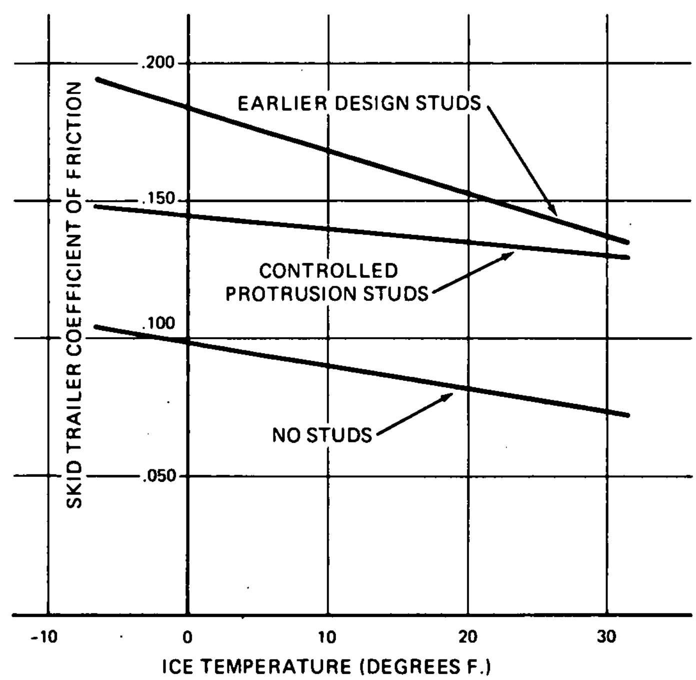


Figure 6. Relationship of coefficient of friction at 20 mph to ice surface temperature (12).

TABLE 7

COMPARISON OF RESULTS OF TESTS ON HIGHWAY TIRES AND ALL OTHER WHEEL COMBINATIONS (*10*)

Wheel Combination	Stopping Distance (ft)								Lane-Change Breakout Speed (mph)				Starting Traction (lb)			
	Clear Ice				Sanded Ice, 30 F		Wet Asphalt									
	0 F		30 F						0 F		30 F		Ice		Snow	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
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.

Wheel Combination	
No.	Description
1	Highway tires, 4 wheels
2	Synthetic snow tires, rear wheels only
3	Synthetic snow tires, 4 wheels
4	Studded synthetic snow tires, rear wheels only
5	Studded synthetic snow tires, 4 wheels
6	Natural rubber snow tires, rear wheels only
7	Natural rubber snow tires, 4 wheels
8	Studded natural rubber snow tires, rear wheels only
9	Studded natural rubber snow tires, 4 wheels
10	Controlled protrusion studded snow tires, rear wheels only
11	Controlled protrusion studded snow tires, 4 wheels
12	Elastomeric tire attachment, rear wheels only
13	Reinforced steel tire chains, rear wheels only

Performance On Wet And Dry Pavements

Tests were performed by the Tennessee Highway Research Program in 1965 on wet and dry pavements using new unstudded snow tires and new studded snow tires with 72 to 144 studs (*8*). Skid-trailer and stopping-distance tests were made on wet and dry bituminous surfaces and wet portland cement concrete. The test results showed no consistent differences between performance of the 72-stud tires and unstudded snow tires (Table 9).

The 1970 Canada Safety Council tests included stopping distances on wet and dry asphalt and portland cement concrete pavements (*9*).

As Figure 8 shows, on wet and dry asphalt the presence or absence of studs made little or no difference. On wet and dry portland cement concrete, studded snow tires caused an increase in stopping distance (Figure 9). Again, it should be noted that the curves record various combinations of tires and rear- or four-wheel applications. Care must be taken in comparisons of unlike combinations.

From the foregoing tests several trade-offs in performance are indicated. For instance, at 50 mph (80 km/h) on wet concrete, there is an increase in stopping distance of about 25 ft (7.6 m) with studded snow tires on the rear wheels only; on glare ice at 10 F (—12 C) ice temperature, there is a decrease in stopping distance of about 80 ft (24 m) with studded snow tires on the rear wheels only, both conditions as compared to unstudded snow tires on rear wheels only. At 35 mph (56 km/h), there is an increase of about 10 ft (3 m) when stopping on a wet concrete pavement and a decrease of about 50 ft when stopping on glare ice at 10 F ice temperature.

In 1974 at the Transportation Research Center of Ohio, tests sponsored by Kennametal, Inc., were conducted to compare stopping distances of studded snow tires and snow

TABLE 8

SKID TRAILER COEFFICIENT AT 20 MPH FOR VARIOUS TIRE PRESSURES AT 0 F ICE TEMPERATURE (*11*)

TIRE	COEFFICIENT AT INDICATED PRESSURE (PSI)		
	12	24	32
Highway	0.104	0.116	0.119
Unstudded snow	0.136	0.138	0.136
Studded snow	0.119	0.141	0.146

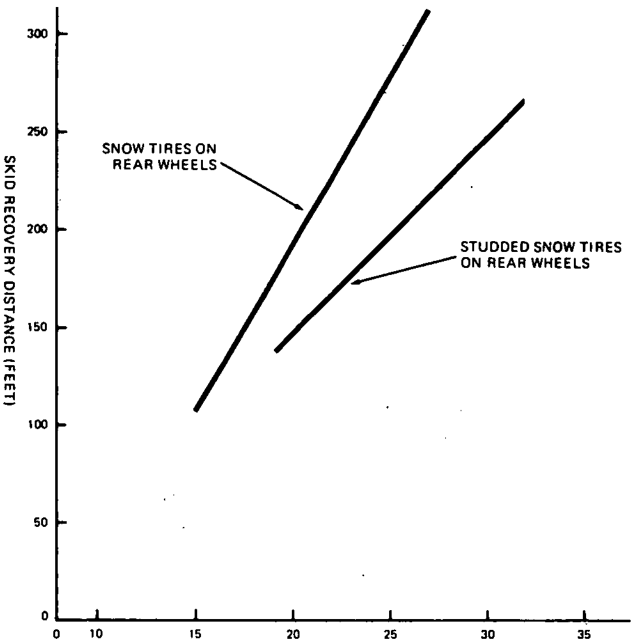


Figure 7. Effect of studded tires on skid recovery distance (13).

tires without studs (*39*). As shown in Figure 10, at 50 mph (80 km/h) on dry concrete, studded snow tires required 128 ft (39 m) to stop as compared to 122 ft (37 m) for unstudded snow tires. On wet concrete the studded tires required 5 ft (1.5 m) more stopping distance at 50 mph. For wet bituminous concrete, the 50-mph tests showed a reduction of 6 ft (1.8 m) stopping distance for studded tires. Reductions in stopping distances were noted for studded tires on all iced pavement surfaces. Care must be taken in comparisons of unlike combinations.

ALTERNATIVES TO STUDS

New Tire Designs and Other Alternatives

Concurrent with the continuing research and development of new types of studs and tires to receive studs, alternative design concepts are under study.

Several tire manufacturers have conducted research on the effect of tread compound on tire traction. Changes in the tread recipe, particularly the polymer, extender oil and carbon black components have been evaluated in terms of their effects on the four components of skid resistance—deformation, adhesion, wear, and tearing. The major properties sought for improving wet friction are greater hysteresis and lower hardness. Some advantages on wet ice are evident using tread stocks of oil-extended natural rubber.

New tire designs, available on the market in the 1974-1975 winter season for the first time, use a special blend of tread rubber that remains softer at low temperatures and provides better traction on ice or packed snow than conventional snow tires, according to the manufacturers (*6, 38*). One of these designs uses rubber compounds developed for the tires of the National Aeronautics and Space Administration's lunar exploration vehicles.

Another area of development in alternative tire tread designs is the impregnation of tread rubber with abrasive or skid-resistant substances. The garnet industry has experimented with the use of small sand-like garnet chips impregnated in recapping rubber. Tests with garnet-impregnated tire treads on the Washington State University test track were reported to show pavement wear rates approximately equal to unstudded tires (*40*) and Washington State Highway Department tests were reported to show locked-wheel stopping distances on wet pavements lower for garnet than for snow tires or studded tires.

Garnet-impregnated retreads were available on the market for the first time in the 1974-1975 winter season. The

TABLE 9

DRY AND WET PAVEMENT TESTS, TENNESSEE HIGHWAY RESEARCH PROGRAM, 1965 (*8*)
(MAX. IS AT SURFACE EDGE WITH NO WEAR; MIN. IS IN WHEELPATHS.)

		Snow Tires[a]				72 Studs[a]				144 Studs[a]			
		Stopping Distance (ft)		Trailer Coeff.		Stopping Distance (ft)		Trailer Coeff.		Stopping Distance (ft)		Trailer Coeff.	
Pavement	Speed (mph)	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	20	20	27	–	0.50	20	28	–	0.52	21	28	–	0.53
	30	42	63	0.79	0.45	42	62	0.77	0.45	44	63	0.78	0.47
	40	73	121	0.78	0.41	74	122	0.78	0.41	77	121	0.78	0.42
	50	–	–	0.79	0.38	–	–	0.75	0.39	–	–	0.78	0.39
2	20	20	22	0.81	0.57	20	23	0.79	0.57	22	22	0.79	0.61
	30	43	52	0.82	0.52	43	50	0.78	0.53	43	51	0.77	0.56
	40	75	93	0.81	0.48	74	93	0.80	0.48	75	99	0.78	0.51
	50	–	–	0.81	0.44	–	–	0.80	0.43	–	–	0.78	0.45
3	20				0.45				0.45				0.49
	40				0.38				0.36				0.36

[a]Highway tread on front wheels, indicated tread on rear wheels.

Oregon State Highway Division is testing them on some maintenance vehicles, according to reports (7).

Other alternatives to studs include tires using embedded wire coils in the tread rubber. Such tires are legal in Minnesota where studs have been prohibited.

Conventional steel tire chains of various designs have been used for improving traction in snow and ice for many years. The chains must be mounted and removed as pavement conditions change, a chore that can be unpleasant or inconvenient for the average motorist. Elastomeric tire chains offer some reduction in time and inconvenience when mounting and removal is required.

NCHRP Project 1-16, "Evaluation of Winter-Driving Traction Aids," is developing data on relative performance and costs of alternatives to studded tires.

Legislative Action

There are several courses of action available to state legislatures as alternatives to unlimited use of studded tires. A few states have prohibited the use of studs. Many others have restricted their use to certain periods (Fig. 1). Other alternatives in use in the United States or abroad or that have been considered include:

- Restriction on maximum speed of vehicles equipped with studded tires.
- Limit on weight of vehicles that may use studded tires.
- Requirement that if studded tires are used they must be used on all four wheels.
- Special taxes for use of studded tires.
- Permit only police and fire vehicles, ambulances, rural mail carriers, and the like, to use studded tires.
- Limit use of studded tires or chains to conditions of ice, snow, sleet, and the like.

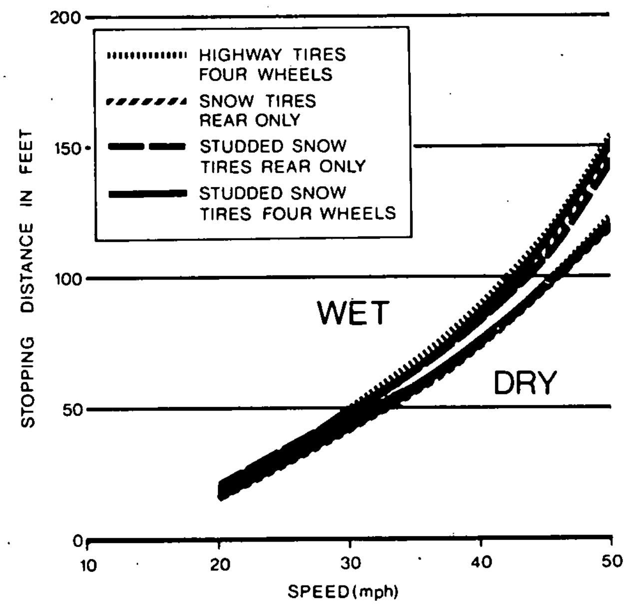


Figure 8. Stopping distance versus speed for cars traveling on asphalt pavement (9).

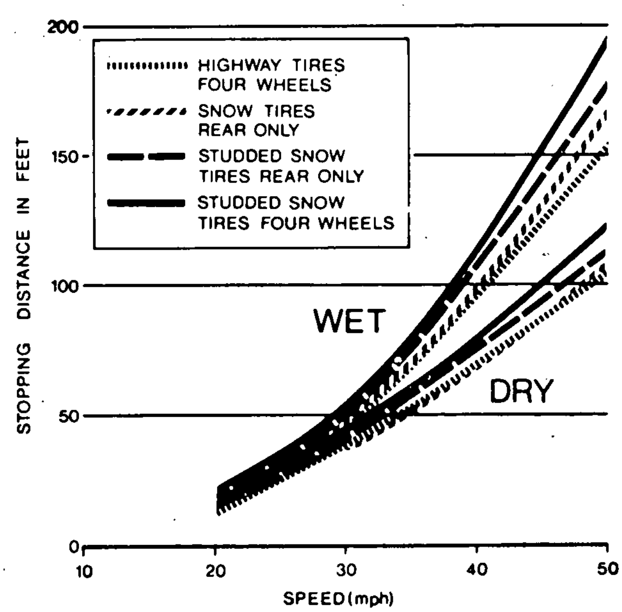


Figure 9. Stopping distance versus speed for cars traveling on concrete pavement (9).

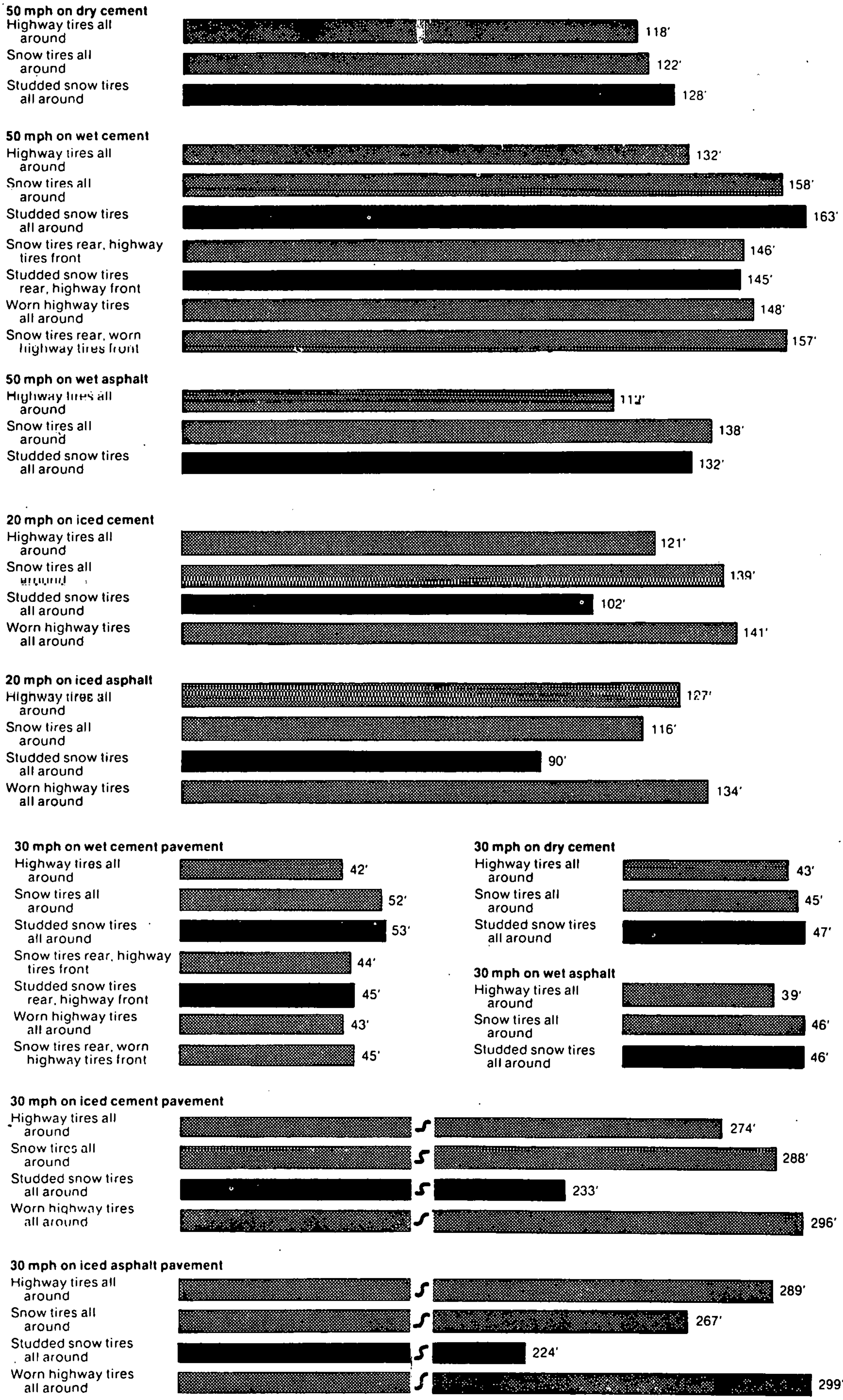


Figure 10. Stopping ability of studded tires (39).

CHAPTER THREE

THE PAVEMENT SYSTEM

WEAR

No single consideration has received greater attention in the studded-tire debate than that of pavement wear. Although tire performance lends itself to laboratory and field testing, laboratory testing of pavement wear is difficult to correlate with field experience as field observations are dependent on time and many variables. Where field data on pavement wear has been collected over a period of years, it reflects the collective results of several stages of studded-tire development and may not be fully representative of current studded-tire wear characteristics.

A number of states have been active in pavement-wear studies, including Connecticut, Illinois, Maryland, Massachusetts, Minnesota, New Jersey, New York, Oregon, Pennsylvania, Tennessee, Washington, and Wisconsin. In Canada, the provinces of Ontario and Quebec, the city of Montreal, and the Canada Safety Council have performed and reported on tests. A brief summary of pavement-wear study results follows.

New Jersey initiated early (1965) studies to measure wear and skid-resistance changes on typical New Jersey pavements. Tests were made on a short section of unused new pavement with the results shown in Figure 11 (*14*). As shown in Figure 11, the bituminous concrete was more severely affected than the portland cement concrete pavement. The portland cement concrete wear resulted primarily in loss of the burlap drag finish. On the bituminous concrete pavement the studded tires tended to expose and polish the coarse aggregate with loss of skid resistance (Table 10).

Minnesota also undertook tests in 1965 on two types of dry pavement surfaces on a section of highway not yet opened to traffic. Normal and panic stops and normal and rapid (drive wheels spinning) starts were performed but without quantitative measurements. Qualitative results were reported to show that studded tires caused abrasive damage to pavement surfaces; damage was most severe at locations of stopping and starting traffic; and bituminous pavements were subject to more damage than portland cement concrete.

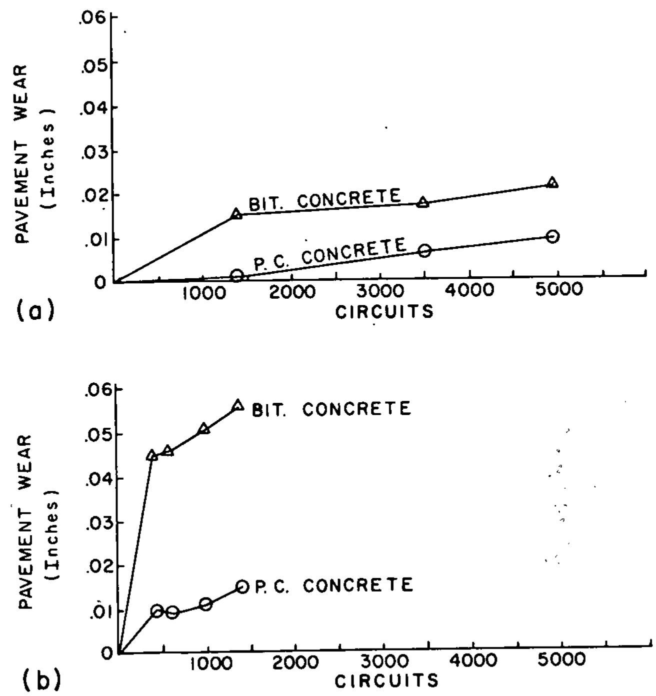


Figure 11. Average pavement surface wear: (a) abrupt stop site and (b) panic stop site, New Jersey (14).

In 1965, New York made approximately 100 tests of studded tires on ice, snow, and wet and dry bituminous and portland cement concrete pavements. Damage caused by skidding studded tires was not considered significant.

Oregon performed stationary spin tests intended to simulate an uphill start from a standstill by an inexperienced

TABLE 10

SKID-RESISTANCE MEASUREMENTS, NEW JERSEY (*14*)

Surface Type	Stopping Category	Accumulated Cycles	Drag Tester No.		
			Max	Min	Diff.
Bit. conc.	Panic	1400	51	35	16
Bit. conc.	Abrupt	4990	50	36	14
Bit. conc.	Abrupt (normal)	4990	50	42	8
PC conc.	Panic	1400	39	29	10
PC conc.	Abrupt	4990	45	42	3
PC conc.	Abrupt (normal)	4990	45	40	5

driver on thin ice or light loose snow. From these tests, it was concluded that studded tires were more destructive to any type of pavement surface than plain rubber tires. Multiple trip tests on a figure-8 track were made using studded tires on the front and rear left tires to increase the wheel passes in the test path. Approximately 5,330 trips were made by the test vehicle. Based on this test, it was concluded that an Oregon highway carrying 4,200 vehicles per day in a roadway lane with 25 percent of the vehicles equipped with studded tires on rear wheels, would experience wear in each 3-ft (0.9 m)-wide wheelpath of approximately 0.15 in. (3.8 mm) in 30 days.

Illinois undertook a short pilot study in 1965 on three pavement surface types: portland cement concrete, bituminous concrete, and bituminous surface treatment. Qualitative results were reported to show all pavements abrading under studded-tire passages with bituminous surface treatment showing the most abrasion.

Maryland made tests on two pavement loops including both rigid and flexible surfaces (*15*). Following 10,000 circuits of the test loops by test vehicles with front and rear studded tires, significant pavement wear was reported at both test loops for both pavement types:

	AVERAGE WEAR ON THE PASSENGER VEHICLE TEST LOOP	AVERAGE WEAR ON THE TRUCK TEST LOOP
Flexible	0.020 in.	0.031 in.
Rigid	0.009 in.	0.030 in.

These early tests by various agencies, largely qualitative in nature, were followed by more comprehensive testing programs under controlled conditions and by extensive observation and data collection on operating highway systems.

The National Road Research Institute of Sweden conducted tests in 1969 in the laboratory and in the field on pavement wear (*16*). Performance of various pavement types on a circular test track under studded-tire passage is given in Table 11.

Hode Keyser reported on the factors affecting pavement wear, based on an extensive literature review (*16*). Table 12 and Table 13 give factors affecting pavement wear and desirable characteristics of wear-resistant bituminous surfaces as identified by Hode Keyser.

Ontario measurements of pavement wear on highways subjected to traffic with not more than 20 percent studded tires indicated substantial wear during the 1968-1969 winter period (*17*). A photo-recorded pavement profile measuring technique was used for the field observations. From the Ontario observations, extrapolations were made to predict future wear on the same pavements, as shown in Figure 12. Further observations of pavement wear in the winter of 1969-1970, with 32 percent of the vehicles in Ontario equipped with studded tires, substantiated the earlier estimates of wear (Table 14) (*18*).

Studies were made in Montreal to determine, from field observations, the rate of pavement wear (*20*). Rate of wear was defined as the average wear in depth of a 6-in. (150 mm) strip of pavement in the wheelpath produced by 100,000 passes of studded tires. For concrete pavements, the Montreal study showed that the mean rate of wear stabilized after 100,000 passes to 0.26 in. (6.6 mm) per 100,000 passes in acceleration and 0.10 in. (2.5 mm) per 100,000 passes in deceleration. Laboratory studies (*19*) used a traffic simulator on a 4.0 ft (1.2 m) diameter circular runway to establish mix design criteria for wear-resistant bituminous mixes. The desirable characteristics identified by the Montreal study, given in Table 15, correlate well with those developed from the Ontario study.

Pavement-wear studies by Minnesota from 1969 to 1971 included field observations and pavement-wear measurements and laboratory pavement-wear tests by the American Oil Company (*21, 22*). Wear rates observed on typical Minnesota highways are shown in Figure 13. Laboratory wear rates observed in the American Oil Company tests (*22*) are shown in Figure 14.

Because studded tires were prohibited in Minnesota beginning the winter of 1971-1972 after six winters of legalized use, after-stud studies were made to continue wear measurements on previously established test points. Although legal studded-tire use had increased from about 3½ percent the first winter to approximately 40 percent in 1969-1970 and slightly less in 1970-1971, a survey in the winter of 1971-1972 showed excellent compliance with the ban on studded tires and less than 1 percent of all vehicles

TABLE 11

RELATIVE PERFORMANCE OF DIFFERENT TYPES OF BITUMINOUS OVERLAY (SWEDEN) (*16*)
(LOWER NUMBERS INDICATE LOWER WEAR.)

Section	Type of Mix	Quantity kg/m²	Quantity lb/sq yd	Penetration Grade of Bitumen	Relative Wear After 50,000 Passes of Vehicle or 100,000 Passes of Studded Tires
1	Topeka	80	145	80	37
2	Bituminous concrete	80	145	80	46
3	Bituminous concrete made with coal tar precoated coarse aggregate	80	145	80	38
4	Bituminous concrete made with coal tar precoated coarse aggregate	60	108	200	60
5	Bituminous concrete	60	108	200	63
6	Topeka with precoated chipping	80	145	80	37

TABLE 12

FACTORS AFFECTING PAVEMENT WEAR *(16)*

Factor	Component	Characteristic
Vehicle, tire, and stud	Vehicle	Type and weight Axle load Number of studded tires (front, rear)
	Tire	Type (snow or regular with or without stud receiving holes) Pneumatic pressure Age Configuration of studs Number of studs
	Stud	Type (material, shape) Protrusion length Orientation of studs with respect to tire wear
	Stud wear versus tire wear	
Pavement	Geometry	Cornering (curve, sharp turn) Straight section Intersection Slope (up and down)
	Surfacing material	Type and characteristics (bituminous mixtures, surface treatment, precoated chipping, portland cement, hardness) Age
	Surface condition	Surface texture and profile Icy Compacted snow (compactness) Sanded or salted icy surface Slush
Environment	Humidity, temperature	Wet, dry, humid
Traffic	Volume Speed	Number of passes and composition
	Wheel track	Width Distribution of wheel load
	Contact mode	Start (normal, abrupt) Stop (normal, abrupt) Acceleration (rate) Deceleration (rate) Spin Skid
Measure	Method and precision	

TABLE 13

DESIRABLE CHARACTERISTICS OF BITUMINOUS OVERLAY TO RESIST WEAR BY STUDDED TIRES *(16)*

Causes of Wear	Desirable Characteristics	Suggested Tests
Cutting and attrition of coarse aggregates and mixtures	Hard aggregates Aggregates of smooth surface texture Mix of close texture	Measure of the hardness of aggregate surface Los Angeles abrasion test Texture of coarse aggregate
Pullout of aggregates	Good adhesion between aggregate and bitumen High specific surface of coarse aggregate Mix of close surface texture	Immersion-compression test Stripping test Determination of the sphericity of particles Grading of mix
Fracture of coarse aggregate under the pressure of studs	Aggregate of high strength Aggregate of cubical shape	Compression test of aggregate Shape of particles
Indentation of studs in the bituminous mixture and shear	High resistance to indentation Mortar as stable as possible Minimum percentage of mortar High filler-bitumen ratio	Resistance to penetration of filler-bitumen-sand mixture Coarse to fine aggregate ratio Grading of fines Grading of mix; degree of compaction of pavement

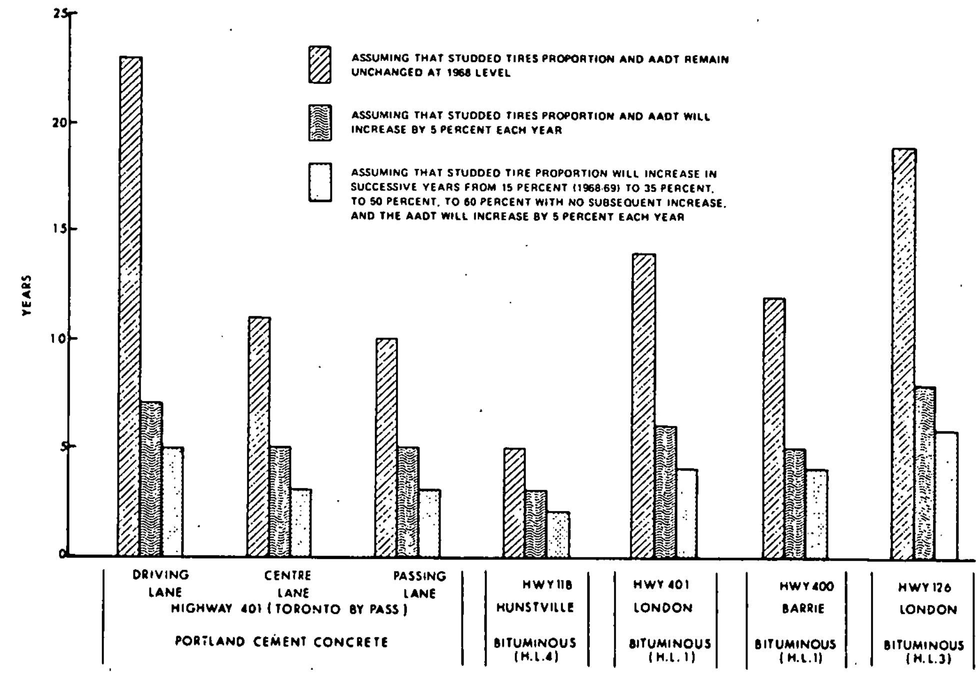


Figure 12. Number of winters for studded tire use to cause one inch of wear (Ontario) (17).

(out-of-state vehicles are permitted limited use) equipped with studded tires (*23*). The pavement-wear values measured over three to six years by the Minnesota Department of Highways at four test points are given in Table 16.

Pavement wear was tested in Washington in 1972 using a pavement testing apparatus operating on three concentric tracks (*24*). Comparative wear given in Table 17 for passenger tires refers to controlled-protrusion (CP) studs (Type 1), composite core studs with small tungsten carbide chips in a soft binding matrix (Type 2), and a conventional solid tungsten carbide pin encased in a steel jacket (Type 3). As indicated in the table, the composite core studs showed a significantly lower wear rate than either the CP or conventional studs.

Tests of wear caused by controlled-protrusion studs were performed by the American Oil Company for the Minnesota Highway Department (*42*). These tests showed wear rates 30 percent to 50 percent lower than those of previous studs. However, the best results were still 37 times the rate for unstudded snow tires with salt brine and sand.

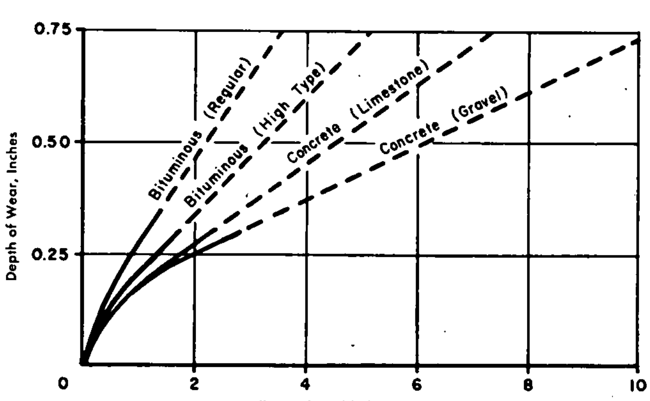


Figure 13. Wear rates of pavements of typical Minnesota highways. (Note that dashed lines are based on extrapolations while the solid lines are plotted from real data.) (21).

SKID-RESISTANCE CHANGES IN PAVEMENT SURFACE

Studded-tire wear on pavements influences skid-resistance characteristics of the surface in several ways. On both portland cement concrete and bituminous pavements, the matrix tends to erode away—exposing and polishing or abrading the coarse aggregate. Creswell et al. (*25*) found that the process causes skid-resistance characteristics to undergo a succession of changes and similar data were found in Ontario (Table 18). Skid-resistance values were recorded in the 1972 Washington tests also and are given in Table 19.

These tests indicate that studded-tire wear tends to change the skid resistance of some pavements; however, the data are so limited that no conclusion can be drawn. Some highway officials are finding it difficult to justify improved skid-resistant overlays if they will be subject to high-wear rates from studded tires.

HYDROPLANING

The hydroplaning potential of a pavement may be affected by studded tires through changes in the pavement texture and rutting of the wheelpath. Two types of tire hydroplaning have been defined. One is viscous hydroplaning where the removal of the water film from beneath the tire footprint is resisted by internal friction within the fluid layer. Because the viscous properties of water are relatively low, viscous hydroplaning usually is related to thin films on smooth surfaces.

TABLE 14

ACTUAL AND ESTIMATED PAVEMENT WEAR RESULTING FROM STUDDED TIRES DURING 1969–70 WINTER (ONTARIO) (*18*)

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.

TABLE 15

DESIRABLE CHARACTERISTICS OF WEAR-RESISTANT BITUMINOUS PAVEMENTS (*19*)

Wear Process	Desirable Characteristics	Suggested Requirements
Indentation, pulverization, and attrition	Coarse aggregate—high resistance to indentation and smooth texture Matrix—good grading and high filler bitumen ratio Mix—sufficient portion of surface covered with coarse aggregate and good compaction	Coarse aggregate Mohs' hardness, minimum 6 Absorption, maximum 0.5 percent Filler bitumen ratio of matrix, minimum 2 Stone content of mix, minimum 40 percent Minimum degree of compaction of mix, 94 percent of voids less density
Fragmentation	Sound isotropic aggregate particles of cubical shape; coarse aggregate particles minimum size of ⅜ in.	Los Angeles abrasion, maximum 15 percent Soundness ($MgSO_4$), maximum 10 percent Aggregate particles of cubical shape Single size coarse aggregate particle, minimum ½ in.
Dislodgment	Good adhesion between aggregate and binder Great surface area of contact between coarse aggregate and mortar (good embedment)	Hydrophobic aggregate (no stripping) Aggregate particles of cubical shape Minimum film thickness, 5 microns
Cutting and shear (when slip)	Exceptionally hard aggregate	Aggregate resistant to scratching

TABLE 16

DEPTH OF PAVEMENT SURFACE WEAR AT TYPICAL MINNESOTA HIGHWAY TEST POINTS (IN INCHES) *(23)*

	TP 6[a]		TP 33[b]		TP 32[c]		TP 83[d]	
Winter	Yearly	Cumulative	Yearly	Cumulative	Yearly	Cumulative	Yearly	Cumulative
1966-67	0.04	0.04						
1967-68	0.07	0.11						
1968-69	0.07	0.18	0.09	0.09	0.10	0.10		
1969-70	0.05	0.23	0.07	0.16	0.03	0.13	0.08	0.08
1970-71	0.05	0.28	0.06	0.22	0.07	0.20	0.07	0.15
* 1971-72	0.00	0.28	0.00	0.22	0.00	0.20	0.01	0.16

[a]Test point 6, portland cement concrete, gravel aggregate.
[b]Test point 33, portland cement concrete, limestone aggregate.
[c]Test point 32, asphaltic concrete, high type.
[d]Test point 83, bituminous, intermediate type.
*Studded tires illegal this winter.

TABLE 17

COMPARATIVE PAVEMENT WEAR (PASSENGER-CAR TIRES AND OUTSIDE TRACK ONLY, WASHINGTON) *(24)*

		Wheelpath 1, No Studs		Wheelpath 2, Type 1 Stud		Wheelpath 3, Type 2 Stud		Wheelpath 4, Type 3 Stud	
Section	Pavement	Percentage of Wear[a]	Wear Ratio[b]	Percentage of Wear	Wear Ratio	Percentage of Wear	Wear Ratio	Percentage of Wear	Wear Ratio
0-1bA	½-in. Wirand concrete	6.1	16.4	83.6	1.2	47.8	2.1	100	1
0-1bB	½-in. Wirand concrete	0.7	142.9	78.3	1.3	34.8	2.9	100	1
0-1bC	½-in. Wirand concrete	2.4	41.7	117.6	0.8	41.2	2.4	100	1
0-1bD	½-in. Wirand concrete	11.0	9.1	95.2	1.0	47.6	2.1	100	1
0-2aA	1-in. Wirand concrete	3.0	33.3	109.0	0.9	40.9	2.4	100	1
0-2aB	1-in. Wirand concrete	3.1	32.4	75.0	1.3	33.3	3.0	100	1
0-2aC	3-in. Wirand concrete	1.7	60.0	122.2	0.8	77.8	1.3	100	1
0-2bA	1-in. polymer concrete[c]	0.75	133.3	183.3	0.6	80.0	1.2	100	1
0-2bB	¼-in. polymer concrete	0.83	120.5	75.0	1.3	108.3	0.9	100	1
0-3a	Class E asphalt concrete	10.4	9.7	82.1	1.2	50.0	2.0	100	1
0-3b	Class E asphalt concrete, Gilsabind	2.1	47.1	71.9	1.4	46.9	2.1	100	1
0-4a	Class B asphalt concrete	4.5	22.3	96.6	1.0	41.4	2.4	100	1
0-4b	Class B asphalt concrete, Gilsabind	4.7	21.4	96.7	1.0	43.3	2.3	100	1
0-5a	Class G asphalt concrete	6.7	15.0	73.3	1.4	46.7	2.1	100	1
0-5b	Class G asphalt concrete	2.4	40.8	76.3	1.3	39.5	2.5	100	1
0-6a	Idaho chip seal	—	—	—	—	—	—	100	1
0-6b	Idaho chip seal	19.5	5.1	30.0	3.3	55.0	1.8	100	1

[a]Percentage of wear = type Y stud average wear/type 3 stud average wear x 100 percent.
[b]Wear ratio = 100/percentage of wear.
[c]Some of the wear was due to poor bond.

The second is dynamic hydroplaning, which can occur where water depth is relatively deep and the inertial effects of the fluid are dominant. The reaction force normal to the tire tread increases as speed increases and a hydrodynamic lift begins at the forward edge of the tire footprint and tends to separate the footprint from the road. The separation penetrates gradually through the length of the footprint as speed increases.

For a free-rolling tire, the factors that determine the speed at which dynamic hydroplaning occurs are reported by Yeager *(26)* to be:

- The ability of the pavement to rapidly drain water horizontally and vertically under pressure from the tire footprint.
- The ability of the tire tread to absorb and move water rapidly out of its path.

The estimated free-rolling hydroplaning speed as a function of water depth can be obtained from Figure 15. Ruts that allow water to accumulate can be a factor contributing to the hydroplaning potential.

In some areas, where portland cement concrete pavements have been grooved to reduce the hydroplaning potential, studded-tire wear has eroded the surface sufficiently

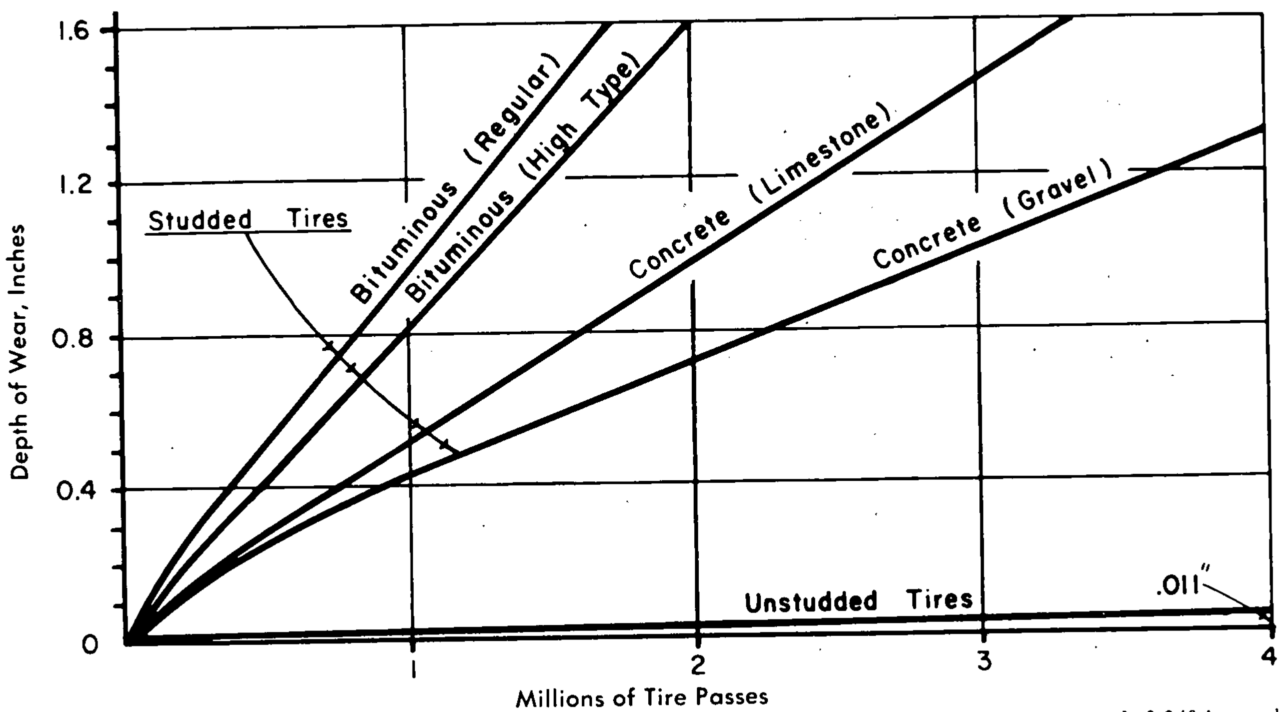


Figure 14. Channel depth versus wheel pass curves developed from average rates for studded snow tires with 0.040-in. stud protrusion. (Data from Ref. 22; Figure from Ref. 34.)

to obliterate the grooves in the wheelpath. Minnesota reported that ⅛ by ⅛ in. (3.2 by 3.2 mm) safety grooves on 1-in. (25 mm) centers in portland cement concrete pavements were worn away in two winters (169,000 studded-tire passes) in the pavement wheelpath (*27*).

Where pavements are rutted, snow and ice may accumulate in the depressions and fail to be removed by snowplow blades. This tendency may represent an added safety hazard under winter driving conditions.

PAVEMENT MARKINGS

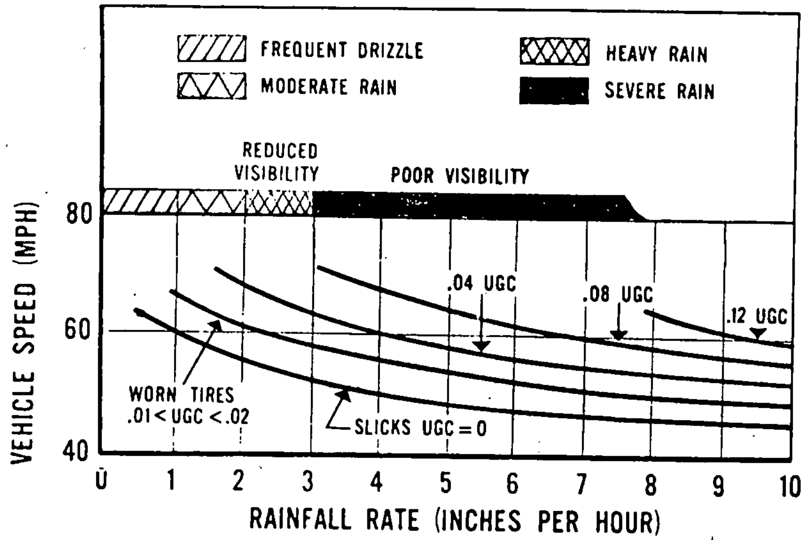
To the extent that pavement markings fall within the wheelpath (crosswalks, intersections, etc.), marking wear has been reported to be accelerated by studded-tire use. Ontario reported in 1970 that painted centerlines and stoplines were being worn away within a few weeks after the onset of winter. It was estimated that painted markings would have to be replaced by thermoplastic markings to sustain the marking system under studded-tire traffic.

TABLE 18

CHANGES IN SKID RESISTANCE OF SOME ONTARIO PAVEMENTS (*18*)

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.



WATER DEPTH (IN.)*											
d_1	.030	.045	.057	.067	.075	.082	.088	.093	.097	.101
d_2	.045	.060	.072	.082	.092	.102	.110	.117	.124	.130

*d_1 = 2.1% SLOPE, 11 FT DRAINAGE LENGTH
d_2 = 1.56% SLOPE, 22 FT DRAINAGE LENGTH

Note: UGC is the Unit Groove Capacity. Most commercial tires have a UGC of 0.04 to 0.06 with some radial tires as high as 0.08.

Conditions: relatively smooth surface, rounded footprint, and rated inflations and loads.

Figure 15. Estimated free-rolling minimum full dynamic hydroplaning speed for passenger tires (26).

The Minnesota Department of Highways conducted tests in the winter of 1968-1969 on an unopened section of Interstate highway using a car equipped with four studded tires (*28*). Extensive damage was done to a transverse stripe of traffic paint after 7,027 repetitive crossings with the test car moving at a constant speed of 50 mph (80 km/h).

The Southwest Research Institute conducted tests by running studded tires over pavement markings reflectorized with conventional glass beads (*28*). The Institute found that for a free-rolling tire, bead damage was of two general types: in soft substrates the beads were pushed in; in hard substrates the beads were crushed.

TABLE 19

COMPARISON OF PERCENTAGE OF REDUCTION IN SKID RESISTANCE VALUES (WASHINGTON) (*24*)

Section	Pavement	All Passes[a]	Unstudded Wheelpaths 1 and 8	Percentage of Reduction	Wheelpath 1, Studs 2 and 7	Percentage of Reduction	Wheelpath 2, Stud 3	Percentage of Reduction	Wheelpath 3, Stud 4	Percentage of Reduction
I-1a	Portland cement concrete	47	34	28	27	43	—	—	—	—
I-1b	Portland cement concrete	47	38	19	27	43	—	—	—	—
0-1bA	½-in. Wirand concrete	45	21	53	37	18	31	31	28	38
0-1bB	½-in. Wirand concrete	43	17	60	38	12	27	37	30	30
0-1bC	½-in. Wirand concrete	43	14	67	30	30	24	44	23	47
0-1bD	½-in. Wirand concrete	45	18	60	28	38	30	33	33	27
0-2aA	1-in. Wirand concrete	44	22	50	31	30	25	43	33	25
0-2aB	1-in. Wirand concrete	46	23	50	34	26	30	35	30	35
0-2aC	3-in. Wirand concrete	46	25	46	30	35	25	46	27	41
I-2aA	⅛-in. polymer cement	41	30	27	16	61	—	—	—	—
I-2aB	⅛-in. polymer flyash	25	22	12	14	44	—	—	—	—
I-2bA	⅛-in. polymer flyash	23	29	+26	13	43	—	—	—	—
I-2bB	⅛-in. polymer cement	25	26	4	14	44	—	—	—	—
0-2bA	1-in. polymer concrete	40	24	40	18	55	24	40	16	60
0-2bB	¼-in. polymer concrete	38	27	29	17	55	16	58	18	53
I-3a	Class E asphalt concrete	36	31	14	25	31	—	—	—	—
I-3b	Class E asphalt concrete	43	37	14	27	37	—	—	—	—
0-3a	Class E asphalt concrete	42	26	38	32	24	28	33	31	26
0-3b	Class E asphalt concrete, Gilsabind	35	23	34	35	0	24	31	33	6
I-4a	Class B asphalt concrete	39	32	18	25	36	—	—	—	—
I-4b	Class B asphalt concrete	45	31	31	25	44	—	—	—	—
0-4a	Class B asphalt concrete	40	24	40	28	30	22	45	29	28
0-4b	Class B asphalt concrete, Gilsabind	26	30	+15	39	+50	30	+15	26	0
I-5a	Class G asphalt concrete	34	30	12	32	6	—	—	—	—
I-5b	Class G asphalt concrete	44	37	16	26	41	—	—	—	—
0-5a	Class G asphalt concrete	40	31	23	40	0	32	20	43	+8
0-5b	Class G asphalt concrete	38	30	21	36	5	33	13	33	13

[a]Taken from the entire section. [b]Minus values except where noted.

CHAPTER FOUR

THE VEHICLE AND DRIVER

Any attempt to evaluate the use of studded tires must deal with the value—or cost—of studded-tire use in terms of the impact on the highway system, the highway user, and society at large.

THE DRIVER

The controlled tests of vehicles equipped with studded tires were reported in Chapter Two under "Performance Characteristics." Because data on the performance of vehicles equipped with studded tires in the normal traffic stream are not readily obtained, most research in this area has concentrated on statistical analyses of accident data for a partial answer to this need.

Obviously such statistics are influenced by driver behavior. It has been hypothesized that drivers in vehicles equipped with studded tires may tend to drive on icy or snow-covered pavements at a higher speed than they would in vehicles without studded tires, thus reducing if not eliminating, the safety advantage studs afford (*29*). The Connecticut Department of Transportation reported that a small increase in speed when using studded tires eliminates the advantage over conventional highway tires in stopping distance (*30*).

The Calspan study for the Minnesota Department of Highways reported that studded-tire ownership increased with owner age, newer vehicles, and auto size—factors often associated with conservative driving characteristics (*31*). In the Calspan survey, 84 percent of the studded-tire drivers answered affirmatively the question, "Do you think studded tires help one to drive nearer the speed limits on slippery roads?" However, many respondents supplemented their reply with comments that said, in effect ". . . but I do not choose to drive that way."

Connecticut State Police used studded tires on patrol cars for one year with the following subjective observations:

- Studded tires are dangerous for high-speed patrol.
- Studs provide no control on cornering or maneuvering on high-speed patrol.
- Studded tires make starting a little easier when the road surface is icy.
- Studs were good only in snow and ice, but after plowing of the roads, they tend to be dangerous.
- Connecticut State Police tests with studded tires confirmed longer stopping distance required on bare pavement with studs on the tires than without studs.

The Arizona Department of Public Safety uses studded tires on patrol vehicles and expresses a special interest in the added mobility provided by studs—particularly in mountainous areas of the state. The alternative use of tire chains would represent a significant additional operating cost to the Highway Patrol Division, which estimates a cost of $5 per car to put on or take off tire chains. Studded tires are removed from Arizona Patrol cars as soon as practical after the pavement is clear of ice.

The Wisconsin State Police estimated that studded tires were useful during their winter operations for 5 percent of the vehicle-miles on principal highways and for 40 percent of the vehicle-miles on local roads in that state.

A Utah report (*41*) provides comments by the Minnesota Highway Patrol as follows: "We found their use helpful on compacted snow or icy roads, but found them to be undesirable on dry roads, and concluded that the percentage of time they would be helpful to us would be a very small percentage of total time our cars were patrolling."

SAFETY

Winter Conditions

Extensive analyses of winter driving accident data have been performed in attempts to evaluate safety effects of studded tires.

Because Minnesota has had an opportunity for "before-and-after" stud studies, the statistics there are of interest. A study based on crash reports submitted to the Minnesota Department of Public Safety compares data for a three-winter average (1968-1971) with the after-stud winter of 1971-1972 (*32*). Figure 16 shows this relationship graphically. The variables in weather and roadway conditions, traffic volumes and characteristics, and other factors influencing safety make it difficult, however, to establish meaningful correlations between studded-tire use and traffic safety.

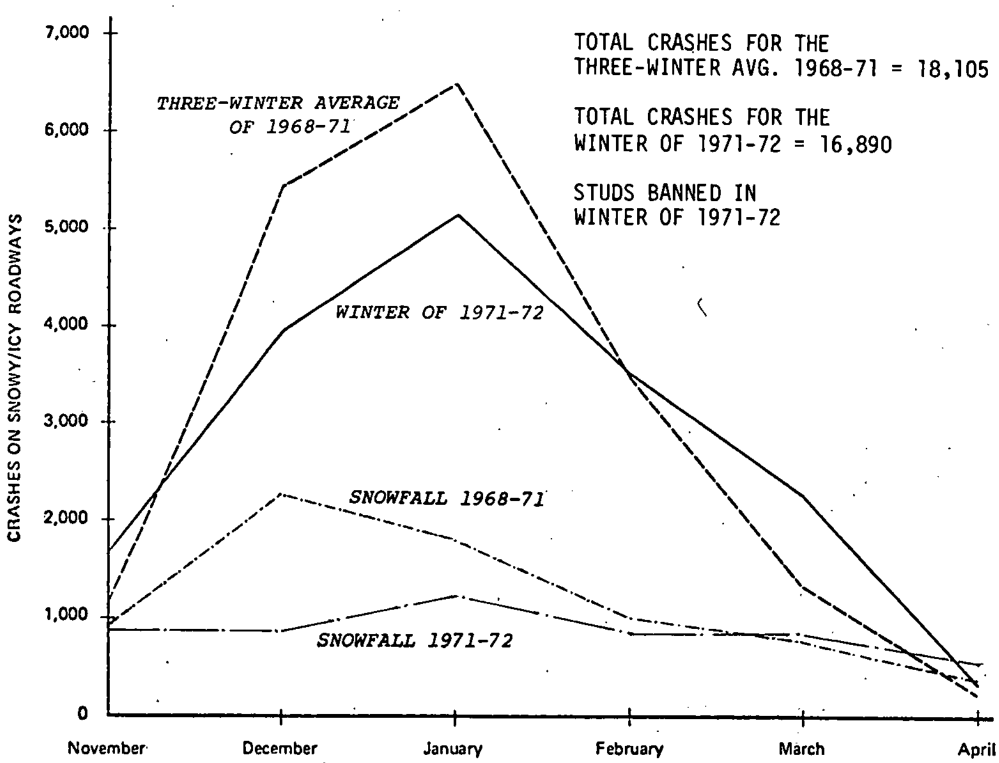


Figure 16. Crashes on snowy/icy Minnesota roadways and snowfall for the three-winter average of 1968-71 and the winter of 1971-72 (32).

The Province of Ontario studied 2,790 accident vehicles in February 1970 (*18*). As a part of the study, a panel rated each accident subjectively as to the usefulness of studded tires in the prevention of the accident or reduction of its severity. The panel ratings showed:

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

The study also indicated that the percent of studded-tire vehicles involved in icy-pavement accidents is not much less than those involved in other accidents.

An NCHRP study (*29*) collected data in Minnesota and Michigan to estimate the effects that banning studded tires would have on all winter accidents. Results showed studded tires to have been somewhat more effective, as compared to snow tires, in mitigating the effects of icy roads on accident involvement. A rough guideline for the magnitude of the benefit, when considering all winter accidents, would be a reduction of approximately one-half percent.

Figure 17 shows the relationship of accidents to vehicles with and without studded tires as recorded in Winnipeg, Manitoba in the winter of 1970-1971 (*33*). A survey of vehicles in the Metropolitan Winnipeg area at that time disclosed that 45 percent were equipped with studded tires. Theoretically, if studded tires had no safety benefit, the relative distribution of all two-car accident involvements (classes 1, 2, 3, and 4) would be: Both vehicles with studs—20 percent; neither vehicle with studs—30 percent; and one vehicle with studs—50 percent. (Actual distributions from Figure 17: 14 percent; 42 percent; and 44 percent.)

P. Smith, Ontario Ministry of Transport, reported to TRB Committee A3DO6 in January 1975, on winter-accident experience in Ontario during a five-year period, 1969-1974, three of which were winters following the banning of studded tires in Ontario. The results shown in Table 20 led Smith to conclude, "the proportion of winter accidents occurring on icy roads declined following discontinuance of the use of studded tires resulting in a contribution to safer winter driving." The reader can make his own interpretation of these data.

Safety—Non-Winter Driving

Minnesota reviewed the safety effects of studded tires related to pavement wear (*34*) and listed the following ad-

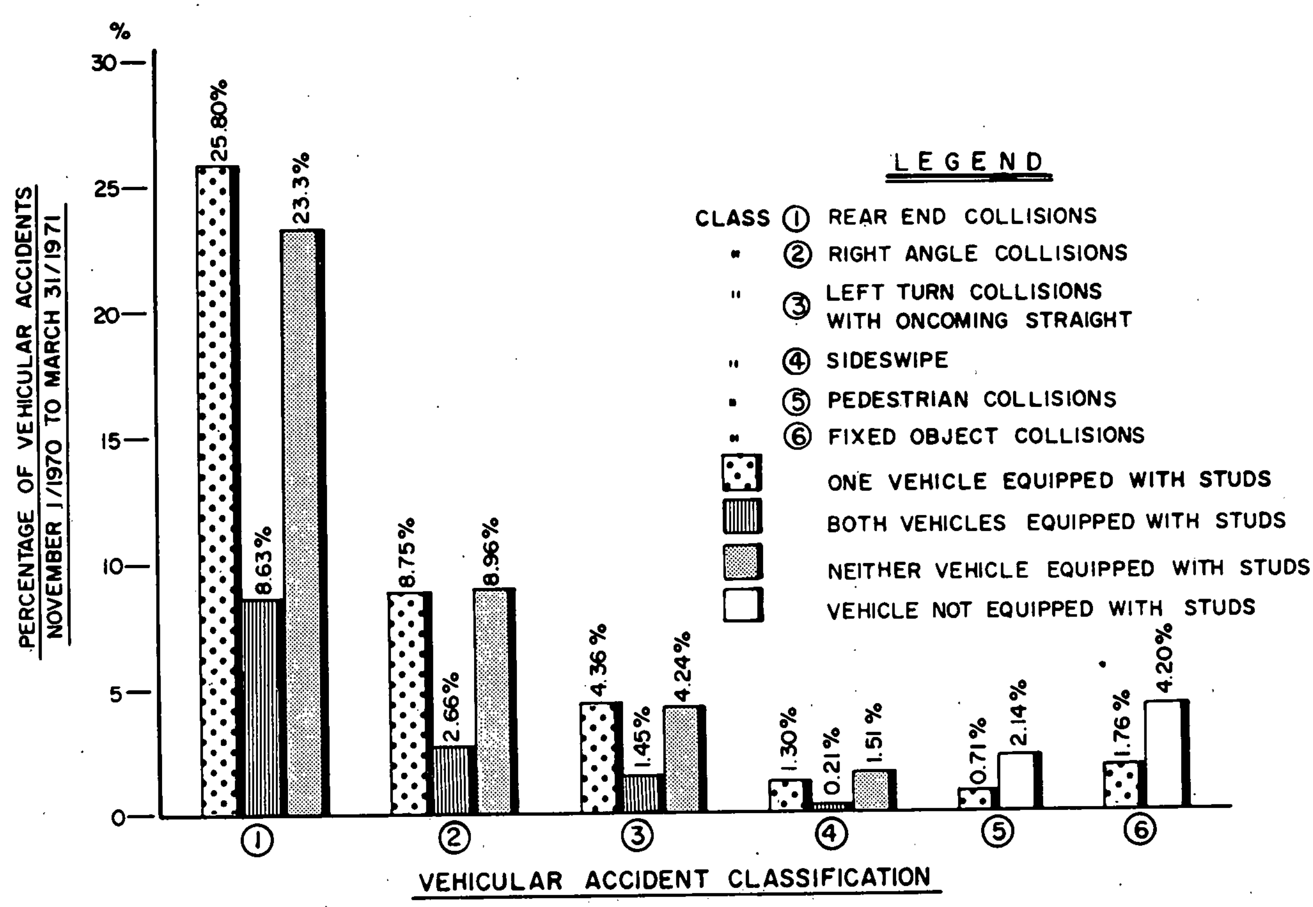


Figure 17. Vehicular accidents in metropolitan Winnipeg—winter season 1970-71 (33).

TABLE 20

WINTER ACCIDENT EXPERIENCE IN ONTARIO, CANADA[a]

WINTER	1969–1970	1970–1971	1971–1972	1972–1973	1973–1974
Total collisions	Not available	85099	99279	99475	105825
Collisions on icy roads	Not available	22348	22324	16254	17894
Percent total collisions	33 (February only)	26.25	22.48	16.33	16.90
Percent icy road, province-wide, entire winter	1.1	1.5	2.8	2.5	2.4

[a] Report by P. Smith to TRB Committee A3D06, January 1975.
NOTES: 1. Studded tires banned after 1970-71 winter.
2. Smith reports "Ontario did not have a shortage of gasoline and there was no consequent reduction in traffic or lowering of speed limits" in the winter of 1973-1974.

verse potential effects:

- Premature loss of paint striping used to delineate pavement lane lines and centerlines.
- Loss of pavement grooving where provided for skid prevention.
- Loss of skid resistance in pavement wheeltrack ruts.
- Reduction in driving visibility due to splash and spray from water accumulating in worn pavement wheel troughs.
- Hydroplaning from accumulated water in wheel troughs.
- Adverse vehicle-handling behavior caused by wheel troughs during lane-changing or passing maneuvers.
- Increased noise produced both inside and outside the vehicle from tires riding on roughened pavement.
- Danger from loosened stones and flying studs.

Evaluation of these effects has been limited largely to qualitative observations. Most studies have indicated a consensus that the increased potential for hydroplaning and splash or spray from water in worn wheelpaths are the most significant safety factors that could be affected by studded-tire use. Early loss of pavement markings also ranks high. Data on loss of pavement skid resistance is inconclusive. Stud loss is considered no greater threat than the casting of a small stone picked up by a tire tread, and evidence of stud-thrown damage to following vehicles is limited and qualitative.

Safety—Summary

Safety considerations related to the use of studded tires can be summarized in two parts: (1) Reports and studies indicate that winter driving control is enhanced by the use of studded tires on icy pavements, which constitute a minor but often critical part of the vehicle-miles of winter driving; however, studded-tire safety considerations also may be adversely affected on wet or dry pavements, which constitute a major part of the vehicle-miles of winter driving in the United States; (2) non-winter driving safety may be adversely affected by pavement wear in the wheelpaths and resultant water entrapment but data that support this premise are not available.

CONVENIENCE (MOBILITY)

The value of mobility—the opportunity to use vehicles on the streets and highways regardless of the weather—obviously has been set at a high level in the United States by motorists and highway agencies. Many agencies spend up to one-third of their annual maintenance budget on snow- and ice-control activities. This level of expenditure is undergoing questioning; however, in light of current concerns for budget increases, conservation, environmental protection, and other factors, winter maintenance quality levels may be lowered in the future. Mobility, as a function of studded-tire use, must then be evaluated in the context of winter highway maintenance.

Because there is substantial agreement that studded tires improve mobility on ice-covered highways but not on wet or dry pavements, several research reports have assessed the portion of vehicle-miles that are traveled on ice.

The 1971 Minnesota study (*34*) indicated that about 13 percent of all travel in the state during the winter of 1969-1970 was on ice or hard-packed snow where studs would be useful (Table 21).

For the 1970-1971 and 1971-1972 winters in Ontario, icy road conditions represented an average of 2.15 percent of the winter road conditions on provincial highways (Table 22) (*35*). The highways maintained by the Province of Ontario are the arterials serving the area and may be maintained at higher service levels than the roads and streets under municipal jurisdiction. When it is considered that most driver trips will originate or terminate, or both, on municipal roads or streets, the resulting driver exposure to icy conditions may be greater than that indicated by the conditions of provincial highways alone. Another modifying factor is the consideration of the number of hours of the day during which clear pavement conditions may exist. Where wet pavements may refreeze at night or new snowfall occur, the driver exposure to icing conditions may increase for those non-daylight hours where maintenance crew activity is often reduced. Traffic volumes, however, are usually much lower during these hours.

TABLE 21

PROPORTION OF MINNESOTA WINTER TRAVEL (1969–70) FOR DIFFERENT ROAD CONDITIONS, PERCENT (*34*)

Type of Road	Total All Conditions	Bare (Wet or Dry)	Icy or Hard Packed Snow	Other—Loose Snow, Slush, Etc.
Freeways	11	10.6	0.2	0.2
State Highways and Main Streets	37	33	2	2
County roads, Residential Streets, Township roads	52	31	11	10
Total All Roads	100	75	13	12

NOISE AND VIBRATION

In addition to engine and other vehicle noises, the contact of tires with pavement surfaces at high speeds generates noise. Noise levels for pavement-tire contacts are affected in part by the texture or roughness of the pavement surface. A significantly roughened pavement surface can impart vibration to the vehicle chassis, cause discomfort to vehicle occupants, and increase the rate of deterioration of the vehicle.

Tests were carried out in Connecticut in 1973 to determine noise-intensity increases, if any, of a studded snow tire compared to a standard snow tire and of a vehicle traveling in a heavily worn wheelpath and one traveling adjacent to the worn wheelpath (*30*). Changes in noise intensity for studded tires were greatest at low speed (20 mph—10 km/h) and 50-ft (15 m) range measurements (Fig. 18). For high speed (60 mph—100 km/h) and 100-ft (30 mm) range measurements, no differences were recorded (Fig. 19). For vehicle noise-intensity increases on roughened pavements compared to adjacent pavements, the differences were greatest when measured inside the vehicle (Fig. 20).

If drivers adjust the location of their vehicles to avoid worn and noisy wheelpaths, such maneuvers could adversely affect safety on high-volume highways where rough wheelpaths are most likely to occur. Study to determine the influence of wheelpath wear on the lateral placement of vehicles in the traffic stream has not produced meaningful results, however.

ECONOMIC EFFECT OF STUDDED TIRES

In its complete form, an economic analysis of the effects of studded tires would have to include a variety of factors such as:

1. Cost to the user for studs.
2. Cost to the taxpayer for highway pavement wear.
3. Benefit to the user in increased mobility.
4. Safety benefits to the stud user.
5. Safety losses to all highway users.
6. Alternative strategy costs to provide safety and mobility.

Of these factors, only items (1) and (2) have been dealt with in quantitative analyses. With the exception of the 1¢ per stud or $1.00 per tire fee collected in Utah, the direct cost to the user for studs is that cost collected by industry (including local, state, and federal taxes) for manufacturing and supplying the studded tire.

Several attempts have been made to quantify costs to the taxpayer for excess highway pavement wear attributed to studded-tire use. In 1971, PennDOT developed a 25-year projection of pavement resurfacing costs associated with the use of studded tires (*36*). The study projected a cost of $1.04 billion over a 25-year period to correct wear on Pennsylvania highways caused by continued use of studded tires (Table 23).

A Massachusetts task force study estimated an additional cost of $3.37 million per year for resurfacing of Interstate

TABLE 22

WINTER ROAD CONDITIONS IN ONTARIO (*35*)

Area	Provincial Highways Total Miles[b]	Winter Road Conditions (percent): Bare Dry 1970-71	Bare Dry 1971-72	Bare Wet 1970-71	Bare Wet 1971-72	Snow or Slush 1970-71	Snow or Slush 1971-72	Icy 1970-71	Icy 1971-72
Southern tier	6,547	48.9	56.1	33.1	30.3	17.2	12.6	0.8	1.0
Middle tier	3,563	42.3	31.0	26.7	33.4	30.2	34.0	0.8	1.6
Northern tier	4,882	27.0	27.7	30.0	27.3	40.0	39.0	3.0	6.0
Total	14,992	39.4	40.6	29.9	30.0	29.2	26.6	1.5	2.8

[a]Southern tier includes Chatham, London, Stratford, Hamilton, Toronto, Port Hope, Kingston, Ottawa, M.T.C. Districts; middle tier includes Owen Sound, Bancroft, Huntsville, North Bay, Sudbury, M.T.C. Districts; and northern tier includes New Liskeard, Cochrane, Sault Ste. Marie, Thunder Bay, Kenora, M.T.C. Districts.

[b]Provincial highways include those highways maintained by province of Ontario and exclude roads and streets under municipal jurisdiction. Mileages shown are in the following order: 10,536; 5,734; 7,857; and 24,127 km.

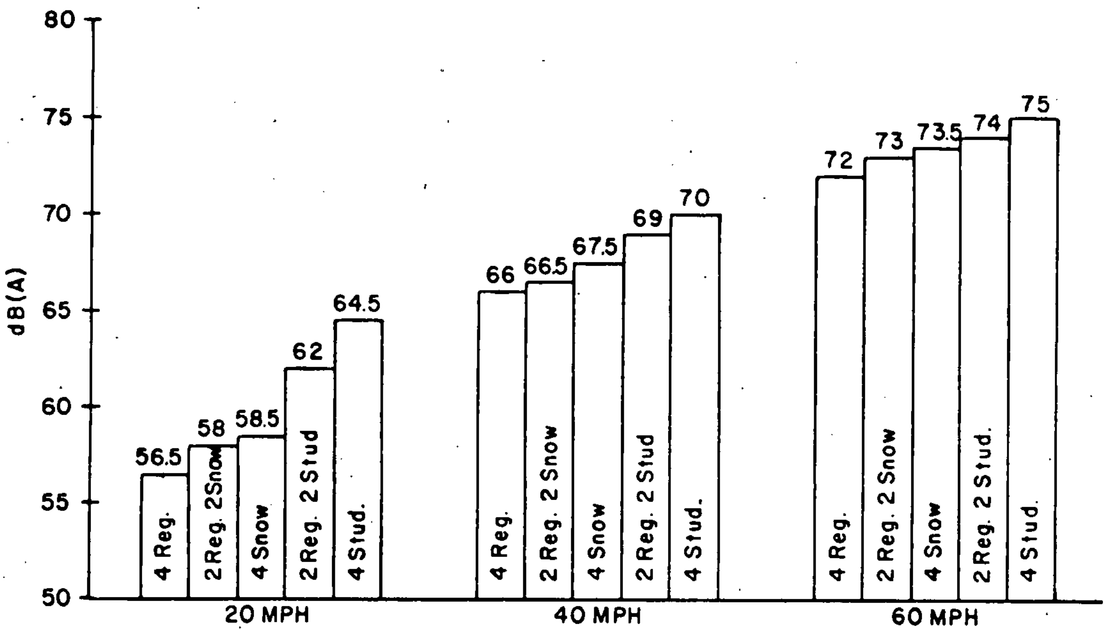


Figure 18. Noise-intensity tests 50 ft (15 m) from source (Connecticut) (30).

and primary routes in that state would be required because of premature wear due to studded tires (*37*).

Minnesota's 1971 study (*34*) estimated that the continued use of studded snow tires would generate additional annual pavement maintenance expenditures gradually increasing them to $12.6 million by 1980. A part of this cost was estimated to be the additional cost on new construction caused by the use of special materials to provide wear-resistant surfaces as new highways are constructed. This information is given in Table 24.

Benefits to the user in increased mobility have not been quantified for studded tire use. Studies have been made by a number of states to evaluate mobility benefits as a basis for determining the appropriate expenditure level for snow and ice control. Obviously, there is a significant relationship between the snow and ice control program, the use of studded tires, and the mobility/cost effect of each, or some combination of both.

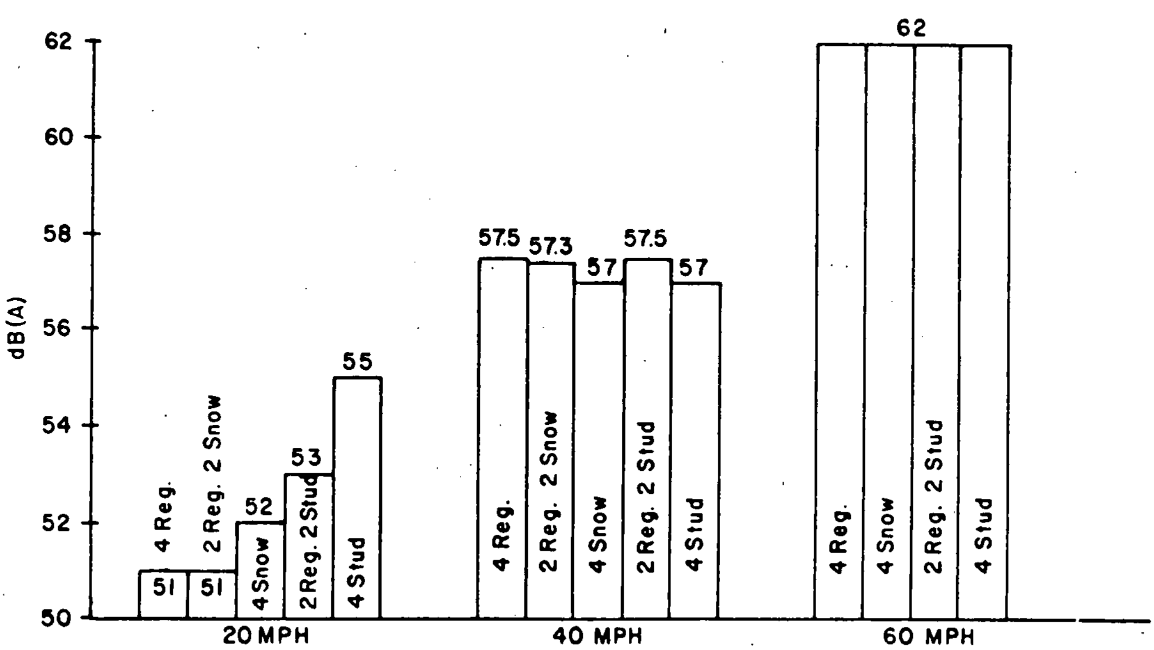


Figure 19. Noise-intensity tests 100 ft (30 m) from source (Connecticut) (30).

TABLE 23

ANTICIPATED ADDITIONAL RESURFACING COSTS ON PENNSYLVANIA HIGHWAYS (*36*)

Year	Additional Construction Funds Required	*Annual Invested Funds Required
1	-	38,390,702
2	-	38,390,702
3	-	38,390,702
4	909,540	38,390,702
5	992,612	38,182,417
6	14,162,730	38,005,732
7	12,000,048	35,966,299
8	25,086,752	34,526,293
9	-	31,992,531
10	69,810,674	31,992,531
11	7,209,272	26,686,920
12	48,779,152	26,203,899
13	2,084,446	23,325,929
14	-	23,215,453
15	50,406,984	23,215,453
16	174,472,145	21,047,953
17	2,533,713	14,243,539
18	31,111,250	14,154,859
19	100,962,433	13,159,299
20	-	10,231,388
21	129,209,623	10,231,388
22	37,094,528	7,001,147
23	1,082,077	6,147,973
24	115,930,661	6,125,249
25	217,920,327	3,922,566
Total	$1,041,758,967	$593,141,626

*From formula $N = S\frac{r}{(1+r)^n - 1}$, where

N = amount invested each year
r = interest rate (6%)
n = number of years compounded
S = amount needed at year of resurfacing

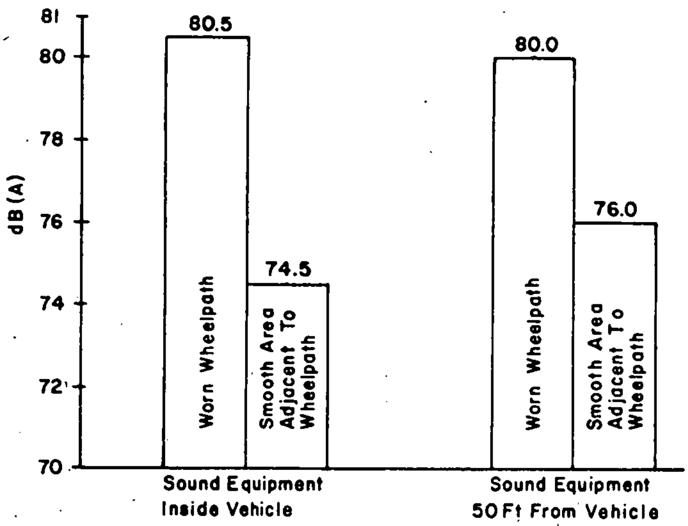


Figure 20. Noise intensity from worn wheelpaths (Connecticut) (30).

TABLE 24

ESTIMATED ADDITIONAL MINNESOTA STATE HIGHWAY EXPENDITURES FOR DAMAGE REPAIR FROM STUDDED TIRES (*34*)

Year	Pavement Overlay Cost	Bridge Deck Repair Cost	Additional New Construction Cost	Total
1973	$ 680,000	$ 120,000	$ 2,050,000	$ 2,850,000
1974	160,000	60,000	2,130,000	2,350,000
1975	680,000	580,000	2,210,000	3,470,000
1976	2,720,000	280,000	2,300,000	5,300,000
1977	2,710,000	1,340,000	2,390,000	6,440,000
1978	5,170,000	1,180,000	2,490,000	8,840,000
1979	10,200,000	580,000	2,590,000	13,370,000
1980	7,790,000	2,120,000	2,690,000	12,600,000
Total	$30,110,000	$ 6,260,000	$18,850,000	$55,220,000

Safety benefits or losses related to studded tires have been considered, as indicated in the earlier discussions of the Minnesota, Ontario, and Winnipeg studies of accidents. Quantitative analyses of the economic value of safety effects would be difficult to develop and defend, however, because of the great number of variables affecting safety in addition to the presence or absence of studded tires.

Alternative strategy costs to provide safety and mobility could include a number of available alternatives as well as potential alternatives under technological development. The range would include existing or new snow- and ice-removal techniques, various forms of studless tires for snow and ice travel, existing or new types of tire chains, and other traction-aid devices, and even other modes of transportation and communication. Although reports on studies of such alternatives have not been reported in conjunction with studded tire use, many ongoing transportation studies and equipment development efforts may yield applicable, reliable data for such analyses in the future.

CHAPTER FIVE

CONCLUSIONS

In summarizing and evaluating the available information on the effects of studded tires, few concise, well-documented conclusions can be drawn. Instead, the reviewer is faced with an extensive set of data some of which is inconclusive or conflicting in results and much of which is based on changing conditions of studded tire design and use.

Out of this review, however, several sets of information can be assembled that lead to general if not precise conclusions.

1. With respect to the first-generation studs (i.e., circa 1962 stud design), it appears to be well demonstrated that:
   (a) Tires with such studs, even when used only on rear wheels, provide improvement in vehicle-stopping capability on ice.
   (b) When used on the drive wheels of the vehicle, studs provide improvement in driving traction on ice and improvement in recovery of control after loss of such control during a transient maneuver on ice.
   (c) Studs provide no improvement in sustained cornering capability on ice unless used on all four wheels, a practice that is not common in the United States.
   (d) Use of studs by a significant number of motorists in a given area of high-traffic volumes results in undesirable and expensive pavement wear.
   (e) Use of studs on pavements not covered with ice and snow (whether wet or dry) appears to cause reduction in vehicle-stopping capability under some circumstances. Data on the degree of such reduction varies.

2. With respect to the second-generation studs, introduced into the United States market in the winter of 1970-1971 and sold exclusively by all major United States manufacturers in the winter of 1971-1972 (which suggests that essentially all studs now in use are of this class), the following performance is reported *as compared to the older studs:*
   (a) Reduction in effectiveness of such studs on vehicle performance capabilities on ice is in the order of 15 percent.
   (b) Reduction in pavement wear of new studs mounted in bias snow tires may be as high as 30 percent to 50 percent; however, this is still many times the wear rate of unstudded tires.
   (c) Reduction in pavement wear by new studs mounted in radial tires, now becoming more prevalent, may be somewhat greater.

3. When translating observed improvements in vehicle capabilities into observable safety performance of the vehicle, the record is less clear and agreement less widespread. This is understandable in view of the complexity of the large number of variables affecting any accident. Those studies that have been made have been generally inconclusive. There is little evidence of any reduction in accidents resulting from use of studded tires or an increase in accidents following banning of studded tires.

4. In considering a driver's exposure to weather and roadway conditions that require winter driving traction aids, a variety of measures have been reported. A realistic appraisal, provided by Minnesota, suggests that studded tires could be potentially helpful for about 10 percent to 15 percent winter travel. This proportion would be lower in climates less severe than that of Minnesota.

5. The possibility of other hazards to traffic resulting from road wear caused by studded tires presents a number of concerns that have been widely expressed. The same circumstances that make difficult the assessment of safety achievements make difficult the assessment of the degree and effect of such hazards, and much less effort has been devoted to their study. The concerns expressed include:
   (a) Hydroplaning.
   (b) Splash.
   (c) Loss of pavement markings.
   (d) Vehicle displacement due to channelization.
   (e) Noise, vibration, and vehicle degradation due to pavement roughness.
   (f) Destruction of skid-resistant surfaces and pavement grooving.

Thus, there appears to be potentially conflicting objectives contributing to the controversy over the use of studded tires. In the first instance, there is the apparent objective of the highway user—mobility and safety for vehicle operations under adverse weather conditions. The highway user has confirmed his desire for this objective by his willingness to pay a premium price to have studs fixed in his tires and by his support (and often demand) for costly winter snow- and ice-control programs on the highways he uses.

On the other hand, the highway user also desires safe roadway conditions during periods when the roadway is free of ice or packed snow. To the user, this means a pavement free of roadway ruts and all the attendant problems associated with them. As the taxpayer providing the principal support for the highway system, he also requires that this level of service be provided at a minimum cost for both new construction and for maintenance and operation.

The fundamental question is whether or not *both* of these objectives can be achieved in a practical, economically feasible way—and specifically with the use of studded tires. The final answer to this question is not found in the studies and research that constitute the present state of the art. The introduction and rapid acceptance of the studded tire in the United States took place before the evolution of the present generation of controlled-protrusion studs. Consequently, the vehicle performance and pavement wear studies that constitute a majority of the data on this issue are based on an obsolete studded tire design.

Newer designs for studded tires and studless tires claim reduced pavement wear and good performance on snow and ice. It remains for these characteristics to be proved (i.e., that the performance is better than regular snow tires and the pavement wear is acceptable).

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APPENDIX A

STUDDED SNOW TIRE REGULATIONS (MARYLAND)

STATE OF MARYLAND

DEPARTMENT OF TRANSPORTATION

MOTOR VEHICLE ADMINISTRATION

ADOPTED RULE AND REGULATION
(Effective Date: January 1, 1974)

AGENCY RULE
11.02.10 - RULES GOVERNING VEHICLE EQUIPMENT

Paragraph
.21 REGULATION OF STUDDED SNOW TIRES

A. The purpose of this rule is to regulate the sale and use of studded snow tires in Maryland and to establish standards for tire studs pursuant to the authority contained in Sections 12-102 and 12-405.2 of Article 66-1/2 (A.C. of Md.).

B. "Tire Stud" as used in this Chapter shall mean a pin made of a material having a hardness factor approximating tungsten carbide surrounded by a casing equipped with a flanging arrangement designed to retain the assembly into pre-molded holes in the tire tread surface.

.22 SALE AND USE OF STUDDED SNOW TIRES

A. On and after July 1, 1974, no person shall sell, offer for sale, install or distribute in this State any tire stud or any snow tire equipped with tire studs unless the tire studs are of a type approved by the Administrator and the installation of tire studs into the tire complies with the provisions of this Chapter.

B. On and after July 1, 1974, no person shall operate, attempt to operate or cause to be operated upon the highways of this State any vehicle equipped with studded tires unless the tire studs are of a type approved by the Administrator.

C. Vehicles equipped with studded snow tires may be operated upon the highways of this State only between the dates of October 15 of a year and April 15 of the succeeding year. The operation of any vehicle equipped with studded snow tires upon the highways of this State between the dates of April 15 and October 15 shall be deemed a violation of this regulation.

D. No vehicle having a registered gross weight of more than 10,000 lbs. shall be operated upon the highways of this State at any time when equipped with studded snow tires except school buses and authorized emergency vehicles may be equipped with studded snow tires during the times specified in sub-paragraph C above.

.23 TIRE STUD STANDARDS

A. Tire studs shall be constructed to employ a pin or core and a casing in such a manner as to regulate the protrusion of the tire stud beyond the tread surface of the tire. Tire stud pins or cores shall be constructed of a material with sufficient hardness characteristics to be effective in providing traction on hardpacked snow and ice. Tire studs shall be designed for maximum retention qualities when inserted in pre-molded holes in the tire tread surface.

B. Tire studs shall be designed to regulate protrusion under all conditions of loading to a minimum of 1/32 inch (.031") and a maximum of 2/32 inch (.062"). Tire stud diameters shall be limited to between .062" and .125" for the pin or core and between .187" and .250" for the casing.

C. Each Tire Stud Manufacturer, prior to the sale,offer for sale, installation or distribution of any tire stud for use in this State, shall make application to the Administrator for approval of the tire stud to be sold, offered for sale, installed or distributed. The application shall be accompanied by samples of the tire stud and such data as may be required to demonstrate compliance with the provisions of this Chapter.

D. The maximum number of tire studs permitted to be installed into a tire shall be according to tire size and shall be calculated on the basis that the combined cross sectional area of the stud assemblies shall not exceed 1-1/4% (.0125 of the total area of the tread surface, but in no event shall the number of tire studs installed exceed 150 per tire.

APPENDIX B

SPECIFICATIONS FOR CONTROLLED-PROTRUSION TIRE STUDS

CONTROLLED PROTRUSION

KENNAMETAL KENGRIP

Controlled Protrusion® Tire Stud Specifications

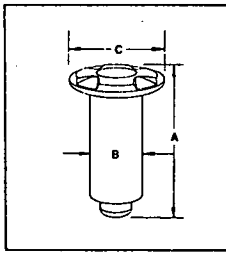
We certify that Kengrip Controlled Protrusion tire studs are manufactured to Tire Stud Manufacturers Institute (TSMI) specifications for compliance with existing state standards for dimensions and protrusion.

(Name) [illegible]

(Title) Technical Director

Specification details are as follows:

Dimensions

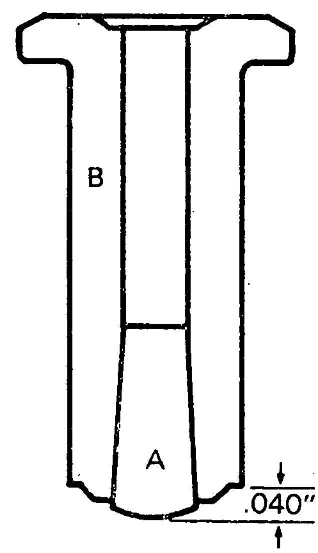


Kengrip Tire Stud Dimension				Tire Hole Dimension		
TSMI (color code)	A	B	C	Hole Dia.	Actual Hole Depth	Nearest 32nd to Hole Depth
*13 (Gold)	.470	.200	.335	3/32	.405	13/32
**15 (Blue)	.520	.200	.335	3/32	.465	15/32
***16 (Silver)	.585	.200	.335	3/32	.505	16/32
****17 (Red)	.615	.200	.350	3/32	.550	17/32

* Replaces 13-2-470 13-3-470 *** Replaces 16-2-585 16-3-585
** Replaces 15-2-520 15-3-520 **** Replaces 17-2-615 17-3-615

Construction

The Kengrip CP tire stud is a two-component device which consists of (A) a long-wearing pin made of high-quality Kennametal carbide fitted into (B) a sintered metal jacket. Both the pin and the jacket bore have close tolerance (±.010") tapers designed to retain the pin securely in place, yet permit the pin to be driven deeper into the jacket as road pressures increase.



Controlled protrusion

When properly installed, the Kengrip CP tire stud has an installation protrusion of approximately .040". At this protrusion level, pressure from the road on the pin is balanced by the resistance of the stud jacket to pin movement. As mileage accumulates and the tire tread begins to wear, stud protrusion increases because the hard carbide pin wears at a much slower rate than tire rubber. The relatively soft stud jacket wears at the same rate as the tire tread. When stud protrusion reaches approximately .050" to .060", the dynamic pressure from the road on the pin becomes greater than the resistance of the jacket to pin movement and the pin is forced back into the jacket until the dynamic forces are again in balance. This occurs when the protrusion level once again achieves the installation level of approximately .040".

Typical cross sectional area specifications

Nominal car size	Tire Data		Tire Stud Data		
	Nominal size	Typical tread surface area (sq. in.)	Typical maximum number of studs	Typical cross sectional area (sq. in.)	Percent of tread surface area
Compact	B78x13	250	96	.0314	1.25
Intermediate	F78x14	270	96	.0314	1.10
Full size	H78x15	312	96	.0314	1.00

Safety effectiveness references

1. Highway Safety Foundation Field Test of Kengrip CP Tire Stud Protrusion Characteristics, December 1971.

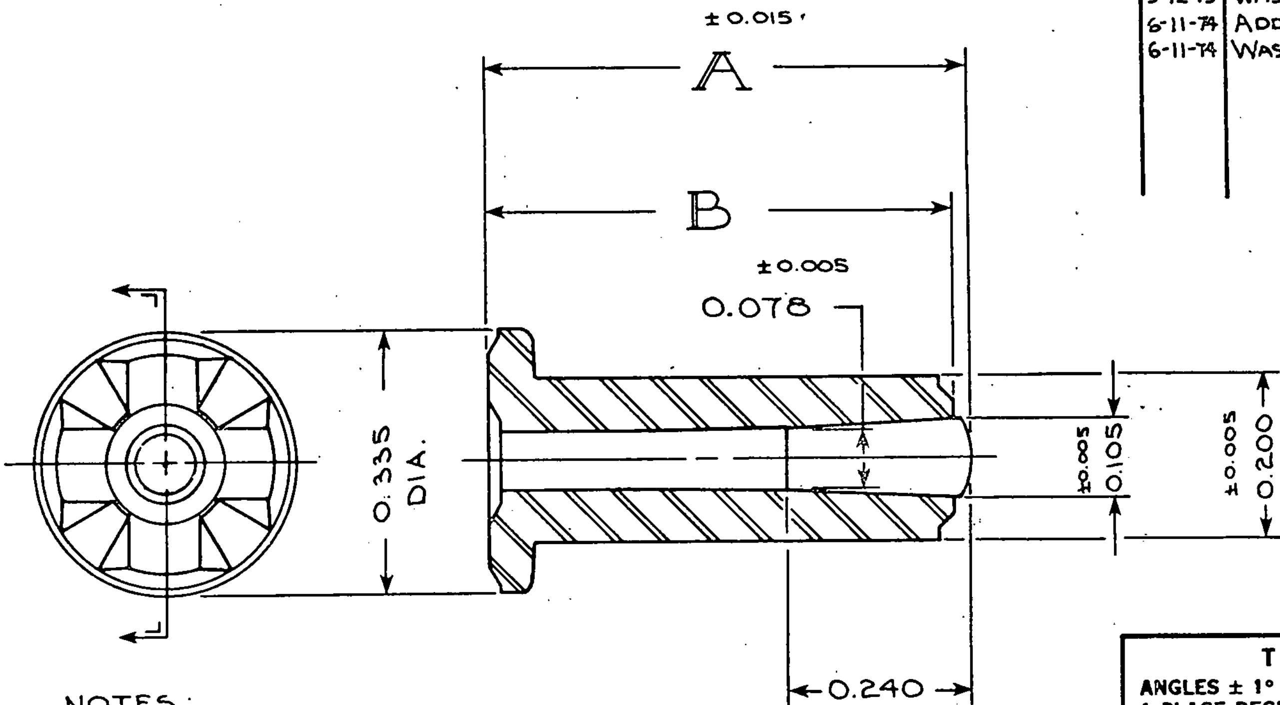
2. Kenneth Perchonok, *Safety Effectiveness of Studded Tires*. Calspan Corp. (Cornell Aeronautical Laboratory, Inc.) Report No. VJ-2915-V-2, September, 1971.

3. E. A. Whitehurst, *Report on Skid Tests Performed for the Kengrip Division, Kennametal Inc., January 7 and 19, 1974.*

4. E. A. Whitehurst, *Report on Skid Tests Performed for the Kengrip Division, Kennametal Inc., Mars, Pennsylvania, November 10, 11, 1971.*

5. *Photogrammetric Measurement of Concrete and Asphaltic Pavement Wear in Metropolitan Winnipeg*, report of a joint project by Western Photogrammetry Limited, Underwood McLellan and Associates Limited, and the Metropolitan Corporation of Greater Winnipeg, December, 1971.

DATE	REVISION	BY
3-12-73	WAS 1972 KENGRIP ①	GAB
6-11-74	ADDED NO. 17 STUD ②	DM
6-11-74	WAS 1973 KENGRIP ③	D.M.



NOTES:

1. TOLERANCE FOR ALL DIMENSIONS ± 0.010 EXCEPT WHERE SHOWN.
2. TREAD HOLE DIA. FOR ALL SIZES - 3/32

HOLE DEPTH IN TREAD, NOMINAL IN 32 No's.

A - DIMENSION

SIZE	B	HOLE DEPTH	COLOR	
17 - 615	.595	.550	RED	
16 - 585	.565	.505	SILVER	
15 - 520	.500	.465	BLUE	
13 - 470	.450	.405	GOLD	

②

TOLERANCES

ANGLES ± 1°
1 PLACE DECIMALS ± 0.050
2 PLACE DECIMALS ± 0.010
3 PLACE DECIMALS ± 0.005
ALL DIM. IN INCHES

UNLESS SPECIFIED OTHERWISE

KENNAMETAL

Customer's Name

①③ 1974 KENGRIP

Cust. Dwg. No.

SHEET OF

Date 12/7/71

Dwn. by RM

Ch'd by EWH

DWG. NO. SR-156-R2

APPENDIX C

FEDERAL HIGHWAY ADMINISTRATION STUDDED-TIRE POLICY

U. S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

SUBJECT	FHWA BULLETIN
STUDDED TIRE POLICY	August 27, 1974

Today I have written to the Governor of each State transmitting the results of recent studies of the effects of the use of studded tires. A copy of that letter is attached. It contains what should now be considered the Federal Highway Administration policy concerning the use of studded tires.

Regional and Division Office staffs should make available to State highway departments any reports, studies or other data pertaining to the effects of the use of studded tires on the highway and on the traveling public involved. A recent film produced by the Alaska Department of Highways summarizes the findings of research relating to studded tires and has been furnished to the northern Regions. This film will be furnished to the remainder of the Regions as copies become available. This film and others, such as those previously produced by the Washington State Highway Commission and the Canada Safety Council, are available for use by the States in their efforts in controlling the use of studded tires. As additional information comes to our attention, we will furnish it to you.

Norbert T. Tiemann
Federal Highway Administrator

Attachment

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
WASHINGTON, D.C. 20590

OFFICE OF THE ADMINISTRATOR

IN REPLY REFER TO:
HNG-23

The studded tire issue has been a very controversial matter for several years. Claims and counterclaims are made by both proponents and opponents of the studs. Because of the concern by highway agencies responsible for highway operations and maintenance, we recently made a review of available studies relating to the use of studded tires. The conclusion reached by this review is that the adverse effects on the safety of our highways outweigh any present and foreseeable future benefits. I consider it appropriate for the Federal Highway Administration to make its position known and have issued the following policy statement.

> "Available information indicates that there is no net safety benefit to be derived from the use of present studded tires. This fact, coupled with the excessive wear and physical damage to the roadway surfaces, provides a sound basis for precluding the continued permissive use of a convenience feature which is effective for relatively short periods of time. This warrants State and local consideration of efforts to ban or limit the use of studded tires."

A copy of a summary of reported effects is enclosed for your information and use. As additional information comes to our attention, we will make it available to you for your consideration and use.

Sincerely yours,

Norbert T. Tiemann
Federal Highway Administrator

Enclosure

EFFECTS OF STUDDED TIRES USED ON HIGHWAYS
FEDERAL HIGHWAY ADMINISTRATION
JULY 1974

STATEMENT OF POLICY

"Available information indicates that there is no net safety benefit to be derived from the use of present studded tires. This fact, coupled with the excessive wear and physical damage to the roadway surfaces provides a sound basis for precluding the continued permissive use of a convenience feature which is effective for relatively short periods of time. This warrants State and local consideration of efforts to ban or limit the use of studded tires which cause more pavement wear than normal treaded tires."

The above statement of policy was determined after careful review and analysis of all available reports, studies and other data pertaining to the effects of the use of studded tires on the physical highway and on the traveling public involved. The features of highway safety, driver convenience and pavement deterioration have been under intensive study not only in the United States, but also in Canada and northern European countries. Following are brief statements of the "effects" as found in the total data available. For each, the specific reference or source document is shown by number, as on the final reference sheet.

REPORTED ADVERSE EFFECTS OF STUDDED TIRES

1. Rutting - Various State studies clearly and conclusively show that studded tires cause significant pavement wear and rutting in the wheel paths.[1, 2, 3]

2. Hydroplaning - Resultant wheel path ruts sufficiently deep to hold water during wet and rainy weather can cause vehicle hydroplaning and subsequent loss of vehicle control.[4, 5]

3. Slippery Pavements - During freezing weather snow plows are unable to remove ice and snow which accumulates in the rutted wheel paths. A hazardous driving condition results.[4, 5, 6]

4. Pavement Markings - Rapid deterioration of pavement markings by wear due to studded tires results in unsafe vehicle operation conditions.[1]

5. Erratic Vehicle Placement - Drivers tend to avoid driving in troughs created by the studded tires. This nonuniform off-center placement of vehicles in the lane can increase the risk of running off the pavement with a subsequent loss of control or collisions with vehicles traveling in other lanes.[6, 7]

6. Increased Stopping Distances - The use of studded tires increases stopping distances up to 27 percent on bare wet concrete pavement.[8]

7. Elimination of Skid Resistant Surfaces - Studded tires cause significant pavement wear which eliminates surface textures for skid resistance which have carefully been built into the pavement. Grooves sawed in concrete pavement have been worn completely down in as short a time as 2 to 3 years.[1, 9, 10, 19]

8. Increased Traffic Noise - Studies show an increase in traffic noise levels of the magnitude of one and one-half times on stud roughened pavements as compared with normal pavement.[11, 19]

9. Increased Splash and Spray - The ponding of water in the wheel path ruts causes greater wheel splash with a resultant loss of vision and associated hazards.[12]

10. Overdriving - The use of studded tires creates a false sense of security for a driver. The small margin of braking benefit offered by studs on seldom occurring glare ice conditions are nullified when the overconfident driver increases his speed by 5 mph or more during these periods. It is also significant that during dry pavement conditions, the driver tends to drive at normal highway speed without considering the reduced traction available to him.[7, 13]

11. Increased Repair Costs - Several highway organizations have estimated 12 million or more dollars annual repair costs due to studded tire wear in each of their States. It normally is not practical to "fill" the worn ruts, instead the whole lane or pavement must be overlayed. Since the highest wear is associated with the highest traffic volumes, the repair problem is compounded both in difficulty of repair and in an increase in accidents related to repair activities.[6, 14, 15]

REPORTED BENEFITS OF STUDDED TIRES

1. Decreased Stopping Distance - On glare ice conditions studded tires do decrease the vehicle stopping distance. These glare ice conditions on highways normally occur about 1 percent of the time in the northern States. Sanding the ice is still the most effective method of reducing stopping distances.[8, 16, 17]

2. Better Steering - Some steering benefits result on glare ice when studded tires are used on all four wheels. (Studded tire use in the United States is nearly exclusively on the rear wheels.)[8, 16]

3. Better Traction - Better traction results from the use of studded tires during glare ice conditions, but research shows that reinforced steel chains are even more effective.[8, 18]

4. Convenience - The inplace feature of studded tires does provide a greater convenience to the driver when compared to the applying of chains when needed.

CONCLUSION

The above analysis indicates that the adverse effects of studded tires both in regard to safety and cost far outweigh the beneficial aspects.

REFERENCES

1. Smith and Schonfeld, "Pavement Wear Due to Studded Tires and the Economic Consequences in Ontario," Highway Research Record, No. 331, 1970.

2. "The Effects of Studded Tires," Minnesota Research Summary Report, March 1971.

3. Christman, "The Performance and Effect of Studded Tires," Connecticut Department of Transportation, 1972.

4. Smith and Schonfeld, "Thoughts on Tolerable Pavement Wear," Ministry of Transportation and Communication Report No. RR. 179.

5. Proceedings of the International Research Symposium on Pavement Wear, June 1972, Norwegian Road Research Laboratory, Oslo, Norway, July 1973.

6. Creswell, Dunlap and Green, "Effects of Studded Tires on Highway Safety Non Winter Driving Conditions," National Cooperative Highway Research Program Project 1-13(2), Final Report, July 1973.

7. "Studded Tire Study Report," Alaska, 1973.

8. Smith, Ewens and Clough, "Effectiveness of Studded Tires," Report on research conducted for Canada Safety Council by Damas and Smith, Ltd., June 1970.

9. Chamberlain and Amsler, "Pilot Field Study of Concrete Pavement Texturing Methods," New York State Department of Transportation, Special Report No. 5 and Highway Research Report 389, 1972.

10. Krukar and Cook, "Studded Tire Pavement Wear Reduction and Repair - Phase II," Washington State University, July 1973.

11. Preus, C. K., "After Studs in Minnesota," Highway Research Record No. 477, 1973.

12. Gunderman, "First-hand Experience with Water Hazard Caused by Studded Tires," Highway Research News, No. 52, 1973.

13. Farley, "Studded Tires: Risk-Benefit for Whom?" American Society for Testing Materials News, Materials Research and Standards Magazine, September 1972.

14. Rice, "A Summary of Estimated Pavement Maintenance Costs for Four States," Proceedings of the International Research Symposium on Pavement Wear, June 1972, Norwegian Road Research Laboratory, Oslo, Norway, July 1973.

15. Normand, "National Report from Canada," Proceedings of the International Research Symposium on Pavement Wear, June 1972, Norwegian Road Research Laboratory, Oslo, Norway, July 1973.

16. Smith and Clough, "Effectiveness of Tires Under Winter Driving Conditions," Highway Research Record No. 418, 1972.

17. Smith P., "Winter Accident Experience in Ontario With and Without Studded Tires," Ministry of Transportation and Communication Report No. 183, Ontario, November 1972.

18. Whitehurst and Easton, "An Evaluation of Studded Tire Performance," Highway Research Record No. 171, 1967.

19. Christman, "The Performance and Effect of Studded Tires," Report 2, Connecticut Department of Transportation, January 1974.

APPENDIX D

REGULATION AND FEES FOR TIRE STUDS (UTAH)

41.6.150. Tires which are prohibited - Regulatory powers of state road commission - Special permits for studs - Fees. - (a), (b) * * * [Same as parent volume.]

(c) No tire on a vehicle moved on a highway shall have on its periphery any block, stud, flange, cleat, or spike or any other protuberances of any material other than rubber which project beyond the tread of the traction surface of the tire, except as otherwise provided in this section. The state road commission may by regulation permit the use of tires on a vehicle having protuberances other than rubber when it concludes that they will not damage the highway significantly, or constitute a hazard to life, health or property. Notwithstanding anything to the contrary contained in this section or in any such regulation, it is permissible to use on a vehicle tires with protuberances consisting of tungsten carbide studs during the periods of October fifteenth through December thirty-first and January first through March thirty-first of each year if the tungsten carbide studs shall not project beyond the tread of the traction surface of the tire more than .050 inches; but tires bearing these tungsten carbide studs shall not be used at any time on a vehicle with a maximum gross weight in excess of 9,000 pounds unless the vehicle is an emergency vehicle or school bus, an emergency vehicle or school bus being allowed to use tires bearing these studs during these periods, provided that a fee of one cent per stud when studs are sold in bulk or $1 per tire when sold with tire be imposed on the wholesaler or distributor, to be paid by him on all tire studs sold by him to Utah outlets. This fee shall accrue to the highway construction and maintenance fund; 50% shall be distributed to the B and C road funds of cities and counties. It shall be permissible to use farm machinery with tires having protuberances which will not injure the highway, and also it shall be permissible to use tire chains of reasonable proportions upon any vehicle when required for safety because of snow, ice, or other conditions tending to cause a vehicle to skid.

APPENDIX E

TRACTION DEVICES (MICHIGAN)

DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

TRACTION DEVICES

Filed with Secretary of State,

These rules take effect 15 days after filing with the Secretary of State

(By authority conferred upon the department by section 710 of Act No. 300 of the Public Acts of 1949, as amended, being section 257.710 of the Michigan Compiled Laws.)

R 247.171. Definitions.

Rule 1. (1) "Reference standard studded tire" means size E 78-14 four-ply, bias construction tubeless snow tire containing 90 studs (Kennametal Class III [16-3-585]) fixed in 6 rows around the tire with 15 studs in each row. This reference tire was chosen because it was that used in the wear tests reported in "Laboratory Evaluation of Pavement Damage Caused by Studded Tires, Salt, and Abrasive Sand," Final Report, American Oil Company, Project 6128, May 1971.

(2) "Bias construction tire" means a pneumatic tire in which the ply cords extending to the beads are laid at alternate angles substantially less than 90 degrees to the centerline of the tread.

(3) "Northern Lower Peninsula" means all counties whose southern boundaries are as far or farther north than the southern boundary of Missaukee county.

R 247.172. Applicability.

Rule 2. (1) These rules apply to all public streets and highways in this state.

(2) These rules do not prevent the application of any other statute or local ordinance which is more restrictive than these rules. Traction devices shall not be used pursuant to these rules unless there is compliance with other laws and ordinances.

R 247.173. Restrictions on use.

Rule 3. After March 31, 1975, a vehicle or special mobile equipment shall not be operated on the public streets or highways of this state on metal or plastic track or on tires which are equipped with metal that comes in contact with the surface of the road or which have a partial contact of metal or plastic with the surface of the road, except as provided in section 710 of Act No. 300 of the Public Acts of 1949, as amended, being section 257.710 of the Michigan Compiled Laws or unless the device meets the requirements set forth in these rules.

R 247.174. Use of traction devices.

Rule 4. Studs or other traction devices shall not be used unless they wear either concrete or asphalt pavements, typical of those in this state, at a rate not to exceed 25 percent of the reference standard studded tire.

R 247.175. Seasonal restrictions.

Rule 5. Traction devices permitted under these rules may be used only between November 15 and April 1 of the succeeding year except in the Upper Peninsula and the Northern Lower Peninsula, where, because of extreme winter snow and ice conditions, they may be used between October 1 and May 1 of the succeeding year.

These rules were prepared by:
Michigan Department of State Highways and Transportation
Testing and Research Division
February 3, 1975

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

Rep. No.	*Title*
—*	A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research—Intermediate Report (Proj. 4-3(2)), 81 p., $1.80
1	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8), 56 p., $2.80
2	An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1), 19 p., $1.80
2A	Guidelines for Satellite Studies of Pavement Performance, 85 p.+9 figs., 26 tables, 4 app., $3.00
3	Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Proj. 3-5), 36 p., $1.60
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5	Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3), 48 p., $2.00
6	Means of Locating and Communicating with Disabled Vehicles—Interim Report (Proj. 3-4), 56 p. $3.20
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11	Effect of Control Devices on Traffic Operations—Interim Report (Proj. 3-6), 107 p., $5.80
12	Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Proj. 4-3(1)), 47 p., $3.00
13	Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report (Proj. 2-5), 43 p., $2.80
14	Density and Moisture Content Measurements by Nuclear Methods—Interim Report (Proj. 10-5), 32 p., $3.00
15	Identification of Concrete Aggregates Exhibiting Frost Susceptibility—Interim Report (Proj. 4-3(2)), 66 p., $4.00
16	Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals (Proj. 6-3), 21 p., $1.60
17	Development of Guidelines for Practical and Realistic Construction Specifications (Proj. 10-1), 109 p., $6.00
18	Community Consequences of Highway Improvement (Proj. 2-2), 37 p., $2.80
19	Economical and Effective Deicing Agents for Use on Highway Structures (Proj. 6-1), 19 p., $1.20

* Highway Research Board Special Report 80.

Rep. No.	*Title*
20	Economic Study of Roadway Lighting (Proj. 5-4), 77 p., $3.20
21	Detecting Variations in Load-Carrying Capacity of Flexible Pavements (Proj. 1-5), 30 p., $1.40
22	Factors Influencing Flexible Pavement Performance (Proj. 1-3(2)), 69 p., $2.60
23	Methods for Reducing Corrosion of Reinforcing Steel (Proj. 6-4), 22 p., $1.40
24	Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants (Proj. 7-1), 116 p., $5.20
25	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (Proj. 10-7), 48 p., $2.00
26	Development of Uniform Procedures for Establishing Construction Equipment Rental Rates (Proj. 13-1), 33 p., $1.60
27	Physical Factors Influencing Resistance of Concrete to Deicing Agents (Proj. 6-5), 41 p., $2.00
28	Surveillance Methods and Ways and Means of Communicating with Drivers (Proj. 3-2), 66 p., $2.60
29	Digital-Computer-Controlled Traffic Signal System for a Small City (Proj. 3-2), 82 p., $4.00
30	Extension of AASHO Road Test Performance Concepts (Proj. 1-4(2)), 33 p., $1.60
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48	Factors and Trends in Trip Lengths (Proj. 7-4), 70 p., $3.20
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Rep. No.	*Title*
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Rep. No.	*Title*
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