HIGHWAY RESEARCH RECORD

Number 171

Studded Tires

3 Reports

Subject Area

26 Pavement Performance
40 Maintenance, General

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Foreword

There has been a phenomenal acceptance of studded tires by individuals in snowbelt states. And sales exceeding 600 million studs annually, coupled with rising prices for tungsten carbide, have resulted in the development of competitive materials such as high alumina ceramic studs. Therefore, it is important that regulatory agencies have information available to assist then in resolving the question of individual preference vs public good in the sale and use of studded tires.

Such agencies will find the papers in this RECORD helpful because fears are allayed in some problem areas and studies of other problem areas are reported. Whitehurst and Easton conclude "studded snow tires . . . appear to perform essentially the same on dry or wet pavement as do similar tires containing no studs," solving a dilemma noted in RECORD 136. Prospective tire purchasers will be interested in Miller's comments on the extended tire and stud life possible if the studs have been correctly seated in a properly designed tire. Yet, they may be concerned to note a marked decrease in effectiveness after only 5000 miles of tire use, reported by Whitehurst and Easton.

Pavement slipperiness is recognized today as a major contribution to accidents. In fact, the new National Highway Safety Agency has placed emphasis on conducting a continuing inventory and evaluation of pavement coefficients for maintenance of pavements and planned program of corrective action for slippery pavements. Findings by Dempster and Bellis that studded tires accelerate the polishing action of conventional tires will be of concern to pavement designers and maintenance engineers. Unfortunately, accelerated test results, reported here and elsewhere, showing high wear rates through abrasive action, erosion and polishing have yet to be confirmed or invalidated by extensive field experience.

It is hoped that continued studies by state agencies and colleges in Illinois, Minnesota, New Jersey and New York will produce answers on disputed points.

Contents

Principles of Winter Tire Studs

W. PETER MILLER, II, Director of Engineering, Studebaker Corp.

The most recent approach to safe winter driving is the studded winter tire, consisting of a number of small rivet-shaped units scientifically arranged in the tread pattern of a tire. Each unit protrudes radially approximately 0.040 to 0.060 in. to provide a gripping action on ice during stopping, traction and cornering.

As the tire wears so should the tire stud. This is a critical factor in the concept. To maintain the required protrusion it is necessary to use a very wear-resistive material. It has been found that tungsten carbide of a specific compound will meet this requirement.

•SINCE the introduction of the studded winter tire in North America, engineers have been increasing their knowledge regarding the related concepts and principles necessary to obtain the results expected of the product. Approximately three years before they became available here, tire studs had been used to improve traction, stopping, and cornering on ice in Scandinavia. Little was known as to why or how these results were obtained. The information available indicated that marked improvements were being obtained over previous methods that integrated a device within the tread pattern of the tire.

This new approach consists of inserting within the tread of the tire a hard metal unit capable of matching the wear rate of the tire itself. Allowing this unit to protrude a specified amount beyond the tread surface creates enough gripping action on ice to improve substantially the stopping, cornering, and traction ability of the vehicle. It is most important to maintain this protrusion during the normal wear cycle of the tire. The hard metal satisfying this requirement is tungsten carbide.

During the 1963-1964 winter season, the first quantity of tungsten carbide tire studs was test-marketed in the United States. Initially it was thought that something so small and simple in appearance could not possibly be complex. However, this is not the case. Many aspects must be considered to obtain maximum results. Neglect of the fundamental principles of studded tires greatly affects their performance.

At present, tungsten carbide is the accepted material for tire studs in both Europe and North America. However, continual research is being conducted by many organizations to find other materials that will function equally well, if not better, as a traction device on ice.

BASIC CONCEPT

Throughout the history of tires there have been many developments in the line of anti-skid devices for winter driving. Many of the approaches were based on various materials being cured in the tread pattern, which would remain flush to the tread surface during the normal life of the tire. The principle involved in this case was a protrusion effect that occurred when the tires were subjected to the forces created by stopping, cornering, and accelerating conditions.

Another development was a hardened steel unit which, when new, protruded beyond the tread surface of the tire to provide the necessary biting action into the ice. However, the rubber would soon outwear the steel, with the result that the steel became

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flush to the tread surface. The advantages present during the protrusion period were much greater than those obtained as the flush condition approached.

The protrusion principle involved in the tire stud as it is known today is primarily a function of the insert. This is one of the most important factors to be considered. As mentioned earlier, when the stud is properly seated in the tread portion of the tire, there must be compatibility between the wear rate of the tire and of the tire stud. If the material of the insert is unable to satisfy this requirement, the principle will not work satisfactorily.

Extensive testing shows that a properly compounded tungsten carbide, one of the hardest materials made by man, has a wear rate which can be controlled to match that of a tire. One basic problem, however, must be taken into consideration: the varying rates of tire wear. The following factors contribute to this wear variance: rubber compound, tread pattern (open or closed design), tire construction (flex rate), type tire (winter, highway or truck), weather conditions, type road surface (new, used, materials) and driving conditions (stops, starts, curves, straight-a-ways, and speeds). Because of these factors, one grade of tungsten carbide alone will not satisfy all the conditions; consequently, several grades are presently being used to satisfy the various requirements. To clarify this point, consider a tire stud with an insert designed to match the wear rate of a first line winter tire. This same tire stud would not match the wear rate of a lesser grade of tire which in many cases differs as much as 5,000 mi in its expected life-span. In such a situation the tire would wear faster than the tire stud. The protuberance of the stud beyond the tread surface would increase. The greater the increase of this distance, the greater the possibility of the tire stud being ejected from the tread pattern. This is due to increased forces which result as the unit contacts the road, leading to a knocking over action rather than its normal radial movement.

The reverse of this would be a fast wearing tire stud placed in a tire that is more resistant to wear. In this case the stud would wear at a faster rate than the tire. Within three to five thousand miles, depending on the wear rate factors, the tire stud would become flush to the tread surface. As the flush condition is approached the effectiveness is reduced. Therefore, it is extremely important to match the proper tungsten carbide grade to the tire. If two winter driving seasons—approximately 10,000 mi or more—are to be obtained from a studded tire, a compatible wear rate between the tire and the tire stud must be maintained.

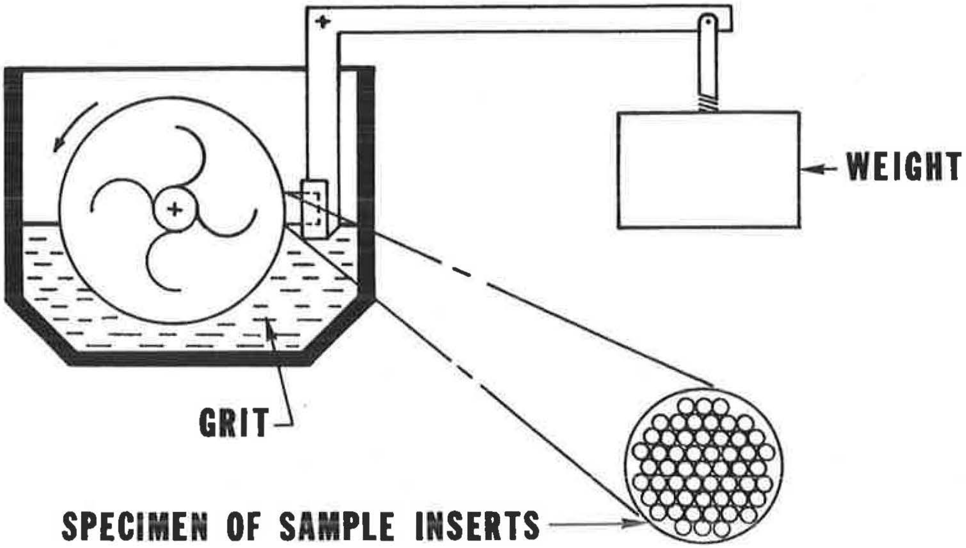

Figure 1. Wear rate tester.

It is necessary to conduct many miles of road testing to establish grades of tungsten carbides. As the results are obtained, they are correlated with a laboratory method of determining the wear rate of the insert. A common procedure uses a Riley Stoker machine (Fig. 1). Here a cluster of inserts is arranged in a 1-in. diameter specimen which, under controlled conditions, is subjected to a rotating wheel in an abrasive grit (1). At the end of the test, the penetration depth of the sample is carefully measured. The deeper the penetration, the less wear resistant the material. The range of penetration depth establishes the wearing grade of the material from which the inserts were manufactured.

Specifications have been established for three grades of tungsten carbide. Two of the three grades are presently being used in the majority of the cases. Quality control procedures are closely followed to insure that the tungsten carbide manufactured meets the proper wear rate requirements.

COMPONENT PARTS OF TIRE STUD

A typical tire stud is made up of two basic parts. The outside part is called the stud body or jacket, and usually consists of one, two or more flanges. Figure 2 shows a single-flange tire stud. The purpose of the flange, or flanges, is to retain the stud in the specially prepared tread of the tire. Figure 3 shows the size of the hole designed into the tread area before insertion and also a single-flange tire stud seated in the tread. Because of the size of the tire stud as compared to the size of the hole, the rubber around the stud exerts compression on the jacket portion, thus retaining the stud in the tire during normal service.

There have been many jacket designs, and a wide range of jacket materials such as plastic, nylon, aluminum, and steel has been used.

When considering the material to be used for the jacket, it is important to investigate the heat transfer properties involved. Under normal driving conditions, tempera-

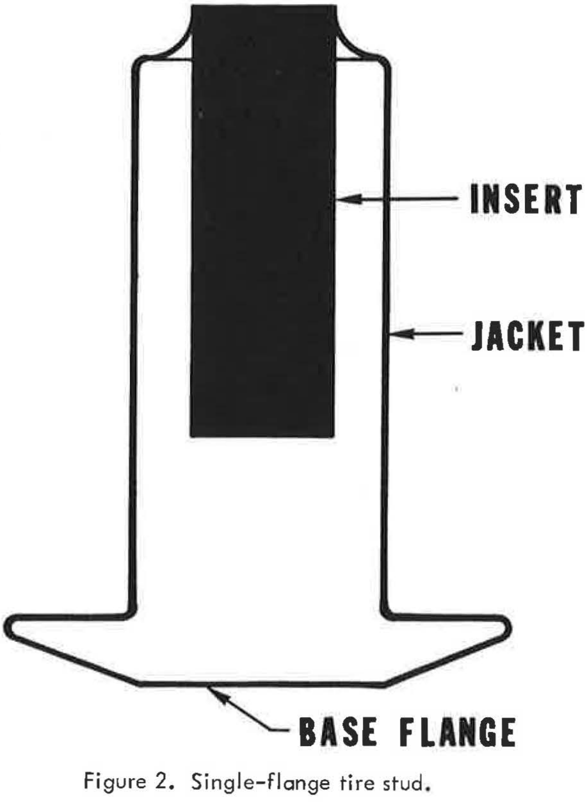

Figure 2. Single-flange tire stud.

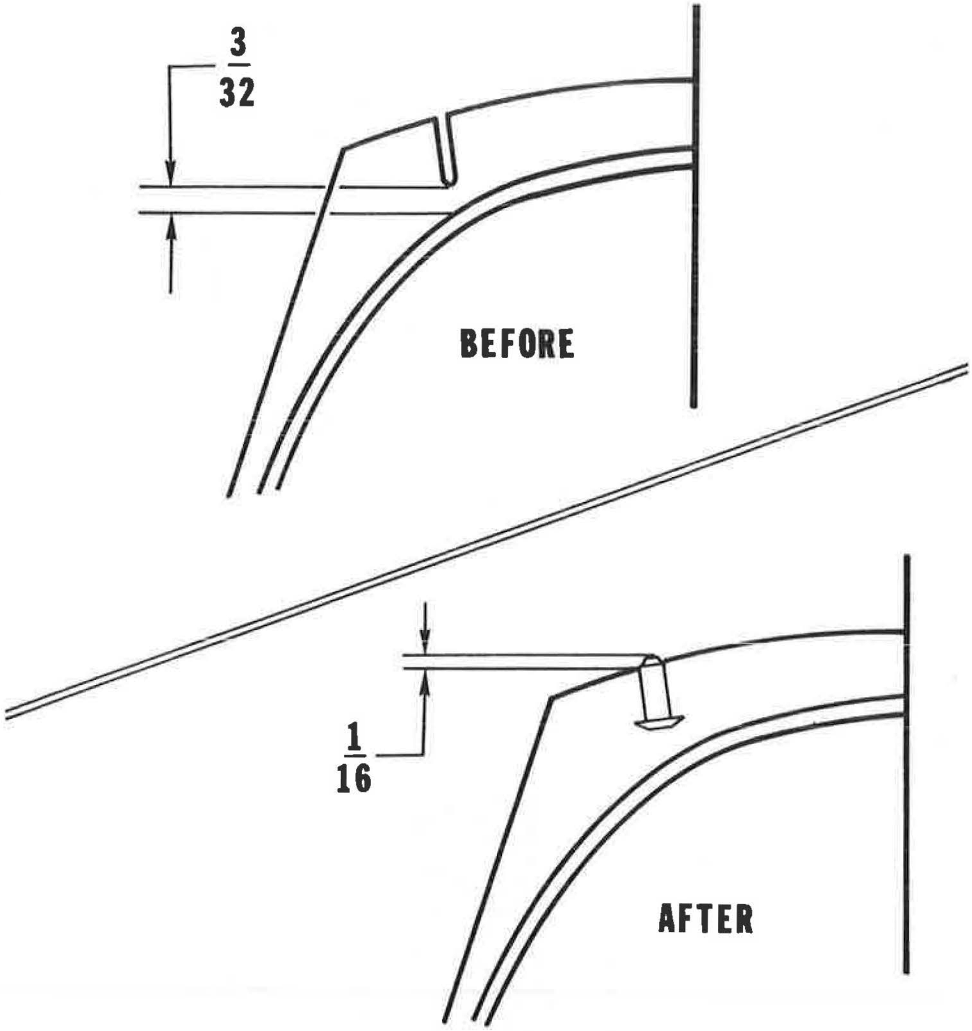

Figure 3. Tire tread before and after insertion of stud.

tures in excess of 400 F have been recorded (2). This heat, if dissipated readily through the jacket, would be detrimental to the rubber in the immediate area, thus affecting the retention of the stud. Consequently, the steel jacket has been very successful in controlling this problem under extreme driving conditions. It absorbs a certain amount of the heat and at the same time dissipates a limited amount of heat to the surrounding rubber. However, the amount dissipated is not enough to affect retention. Also, the termal coefficients of expansion of the two materials, tungsten carbide and steel, are such that under severe conditions the heat generated does not affect the ability of the jacket to retain the insert, providing there is sufficient bond to begin with.

INSERT RETENTION

During the manufacturing process of the winter tire stud, the insert must be securely seated in the jacket. This is a function of the manufacturing process involved in assembling the two component parts. There have been instances in which, during normal service of the studded tire, the insert has been released from the jacket of the stud. When this occurs the result is an inoperable unit. Because of this, many rubber companies have specified that the bond of the insert-to-the-jacket must meet a minimum requirement. Specifically, the force required to dislodge the insert from the jacket must be at least 400 lb. This is usually tested by removing the back portion of the tire stud, thus exposing the insert; force is then applied, with a hardened pin the diameter of the insert, and recorded until the bond is broken.

TIRE STUD LENGTH

It was mentioned previously that tire studs are considered for a wide range of tires. This may include heavy truck, light truck, second and sometimes third line winter designs, highway designs and retreaded tires of the same combinations. This variety requires that various conditions be taken into account when developing the proper length of tire stud to be used for a specific tire.

When engineering a tire stud to a specific tread pattern, a good rule of thumb is to maintain $^3/_{32}$ in. of rubber from the bottom of the base flange to the top of the carcass (Fig. 3), the carcass being that portion which consists of the fabric plys. This cushion of rubber improves the resiliency of the stud and provides sufficient protection against damage to the carcass.

When considering retreaded tires, the $^3/_{32}$-in. rubber gage is the distance between base flange of the tire stud and the buff line above the carcass. Experimentation has established that if the base flange of the tire stud is located directly on the buff line, it will result in a possible separation of the retread portion from the original casing. To prevent this separation, retread engineers have developed a studded tire to accommodate the proper length mold pin. Testing of studded retread tires has given excellent results. There is no effect, whatsoever, on the life or safety of the tire when it is properly studded.

REACTION OF STUDS IN TIRES

We have discussed the various components of the tire stud, including the design concepts that have been applied to the jacket; the reasons for precise control of the insert material; the retention of the insert in the jacket; and the length of the stud vs the particular tire in which it is inserted. Attention will now be directed to the various conditions encountered after the stud has become an integral part of the tire.

The amount of stud protrusion beyond the tread surface of the tire is directly related to the retention of the stud in the tire. Testing has shown that the protrusion should be in the general area of 0.040 to 0.060 in. This is referred to as the optimum operating zone (Fig. 4). Consequently, it has been necessary to develop a length of tire stud that, when seated properly in the tread, has a protrusion in this zone. Because of the various rubber gages and type tires being considered, a wide range of hole depths in the tread pattern is necessary. As a result of this, plus the requirement previously discussed (that of the necessary rubber gage between the base flange and the top of the carcass and/or buff line), the hole in the tire is an established feature requiring studs of different lengths to be designed to meet it. There are roughly five or six standard hole depths to cover all studded winter tires. A complete line of tire stud lengths is available to match these various hole depths.

In developing a stud length to satisfy the protrusion requirement, it is necessary to consider not only the hole depth but the rubber gages as well. It would be a simple matter to add 0.050 in. to the hole depth to obtain a proper stud length for the optimum operating zone; however, this is not the case. As the depth of the hole increases, the length of the tire stud required increases at an increasing rate (Fig. 5). This is primarily due to the various rubber gages involved. As the gages become thicker, an increased settling action occurs during the initial service of the unit, requiring an additional amount to be considered in the overall length of the tire stud.

A typical wear pattern of tire studs shows that studded tires picked at random from production had an average stud protrusion beyond the tread surface of the tire of approximately 0.070 in. In a short time the tire studs settled to a protrusion of 0.040 in. This height represents the stud length/hole depth relation developed by the engineer. The remainder of the curve represents a typical wear pattern over a distance of 8,000

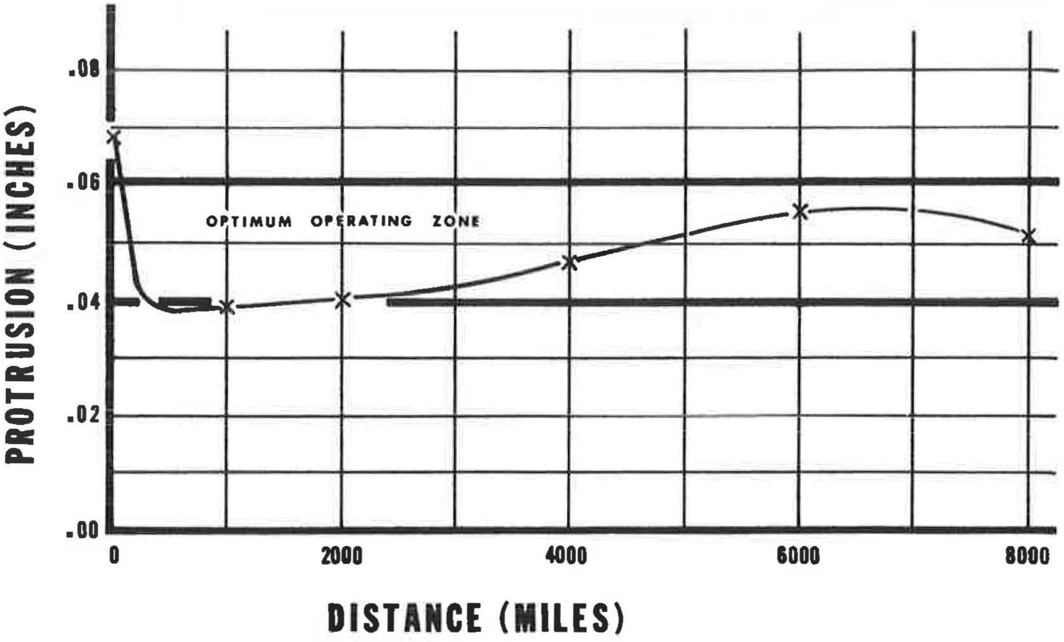

Figure 4. Typical wear pattern, single-flange tire stud.

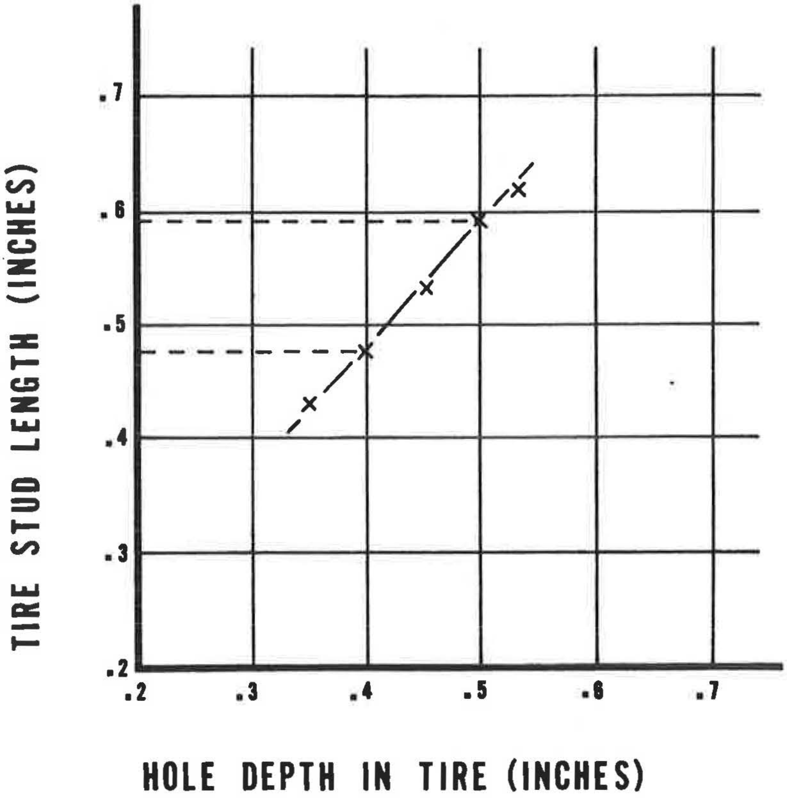

Figure 5. Tire stud length vs hole depth in tire.

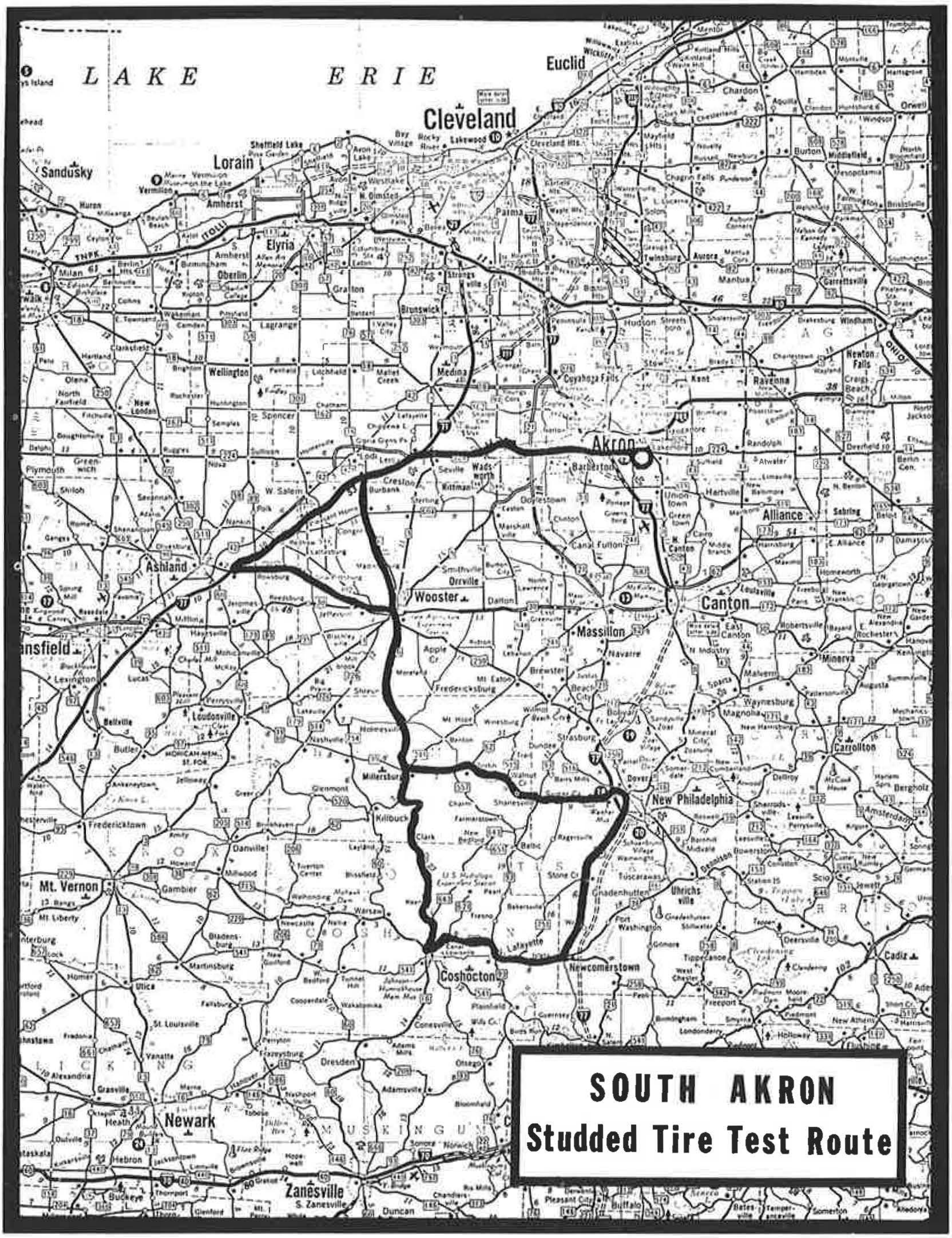
SOUTH AKRON
Studded Tire Test Route
LAKE ERIE
Cleveland
Akron
Canton
Wooster
Ashland
Massillon
New Philadelphia
Coshocton
Newcomerstown
Millersburg
Mansfield
Mt. Vernon
Newark
Zanesville
Lorain
Elyria
Sandusky
Medina
Alliance
Dover
Euclid

Figure 6.

mi, using a test route selected to simulate normal driving conditions. Figure 6 shows the actual test route used. There is a peaking action around 6,000 mi, and then the protrusion begins to taper off. Throughout the entire curve the tire studs remained in the optimum operating zone. There would be very little, if any, difference in the performance of the studded tires at 8,000 mi as compared to 4,000 mi.

BREAK-IN PERIOD

During the initial life of the tire stud a settling action takes place and the rubber begins to envelop the shape of the jacket. Immediately after the insertion, the rubber merely bridges the distance from the flange to the shank of the tire stud (Fig. 7). The retention of the stud in the tire is not at its maximum until the rubber around the stud completely envelops the jacket. Pull tests have required in excess of 60 lb of force to extract the stud from the tire tread.

To insure maximum retention of the tire stud, a break-in period of 50 mi at speeds less than 50 mph is recommended. This will allow the stud to seat itself in the tire properly before being subjected to severe driving conditions. Tests have shown that actual settling of the tire stud to the proper protrusion occurs under 25 mi; however, a distance of 50 mi is recommended for complete adjustment of the surrounding rubber to take place.

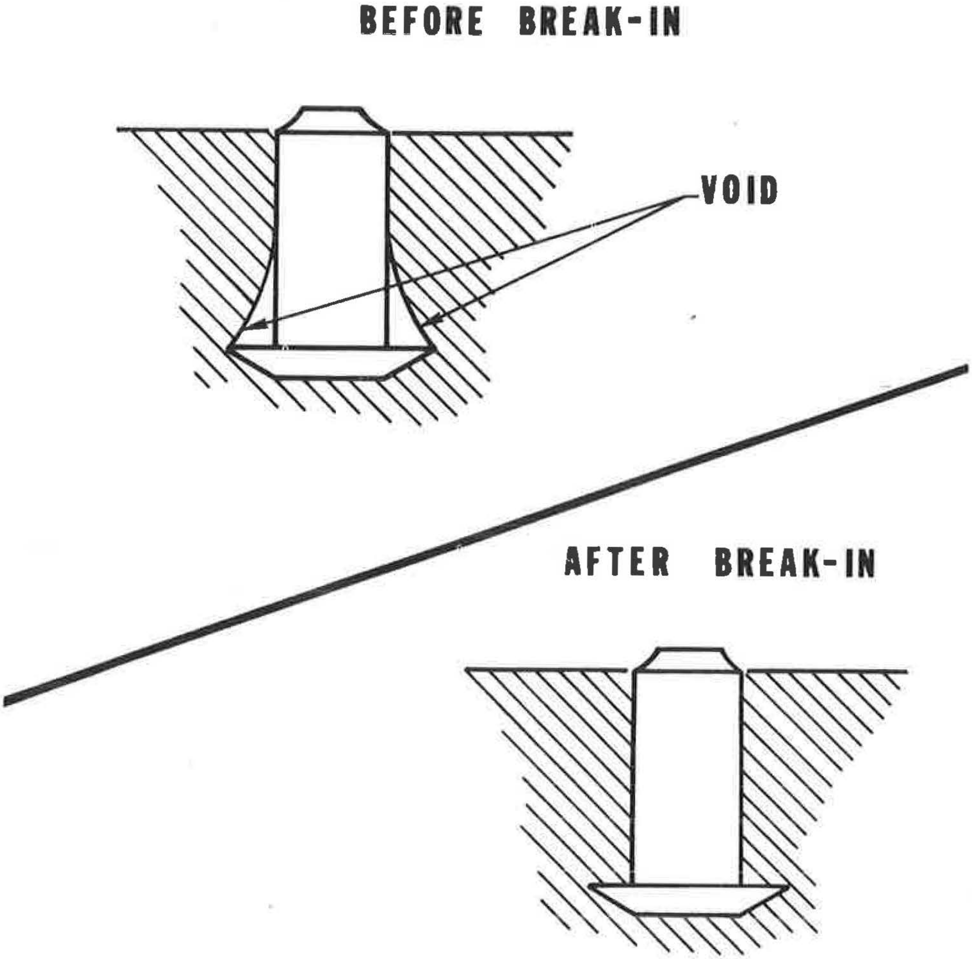

Figure 7. Tire stud before and after break-in period.

PROPER TESTING PROCEDURES

The test route, from which the results of the wear pattern (Fig. 4) were obtained, closely simulated that of normal driving conditions, which would be on either dry or wet pavements cleared of ice and snow. Therefore, wear rate testing was conducted on bare pavements.

To obtain an accurate account of the wear rate of the tungsten carbide or similar material inserts vs that of the tire, it is important to use a proper test route. Exposure of tires to testing on a straight throughway type of condition results in what is termed a slow-wear tire test. That is, the rubber in the tires wears away at a slower rate than it would if subjected to in-town conditions such as stopping, starting, and cornering. Basically, there are test routes that are slow-wear tire tests and test routes that are fast-wear tire tests. Further investigations have shown that the wear rate of the tire stud reacts in exactly the reverse manner. The slow-wear tire test is a fast-wear tire stud test, and a fast-wear tire test is a slow-wear tire stud test. It follows, therefore, that to get a true relationship of the wear rates, the studded tire should be evaluated on a test route consisting of a composite of throughway type driving which is typical on turnpikes, highways, and expressways and in-town type driving which includes stopping, starting and turning. Only under these conditions can the proper wear rate relationship be established. For example, studded tires tested 100

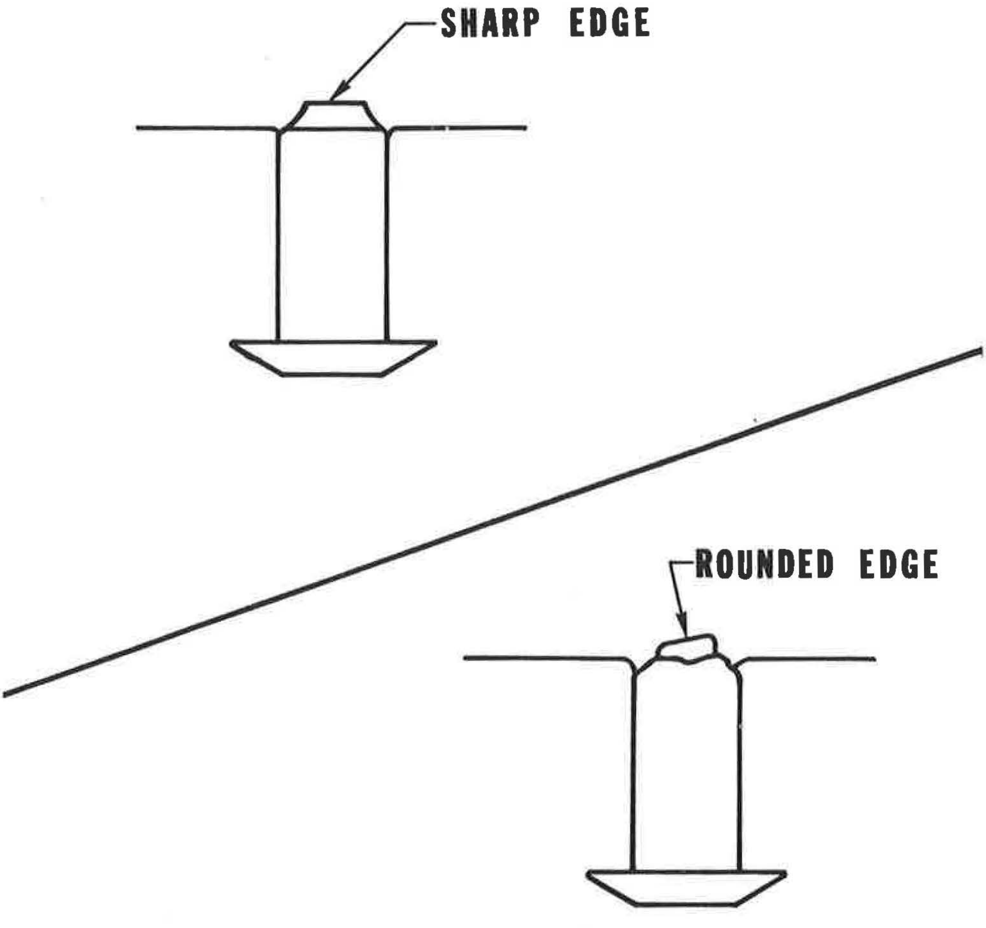

Figure 8. Effect of rounding action on tire stud.

percent of the time on a road such as the Pennsylvania Turnpike would soon have their studs flush to the tread surface.

The tires were subjected to a slow-wear test, and the tire studs subjected to a fast-wear test. After approximately 3,000 to 5,000 mi, the performance of the tire studs on ice is greatly reduced.

PERFORMANCE

In the new condition, tire studs have a squared-off edge at the tip of the insert. As they are subjected to service, a rounding action takes place (Fig. 8). The period of time it takes to have the sharp edges rounded off is a function of several factors including the roads and the driving conditions. This rounding action occurs very quickly in the life of a tire stud, and there is a very slight reduction in performance after the sharp edges are worn off. It stands to reason that a sharp edge could bite into ice much better than a rounded edge. After this initial rounding action takes place, the performance of the studded winter tire remains constant throughout the remainder of its useful life. Later, an angled wear occurs on the insert. The degree of this type of wear pattern is a function of the stability of the stud in the tire.

ROTATION VS RETENTION

When the stud is well within its wear pattern, a direction of wear on the insert is established. Even if the insert wore evenly on all sides, there would still be a possibility of rotation of the unit in the hole, which in turn would have a slight effect on the retention factor. However, inasmuch as the insert wears off at an angle (Fig. 9), its direction throughout its useful life is established. Consequently, organizations such as the American Automobile Association have recommended that when studded winter tires

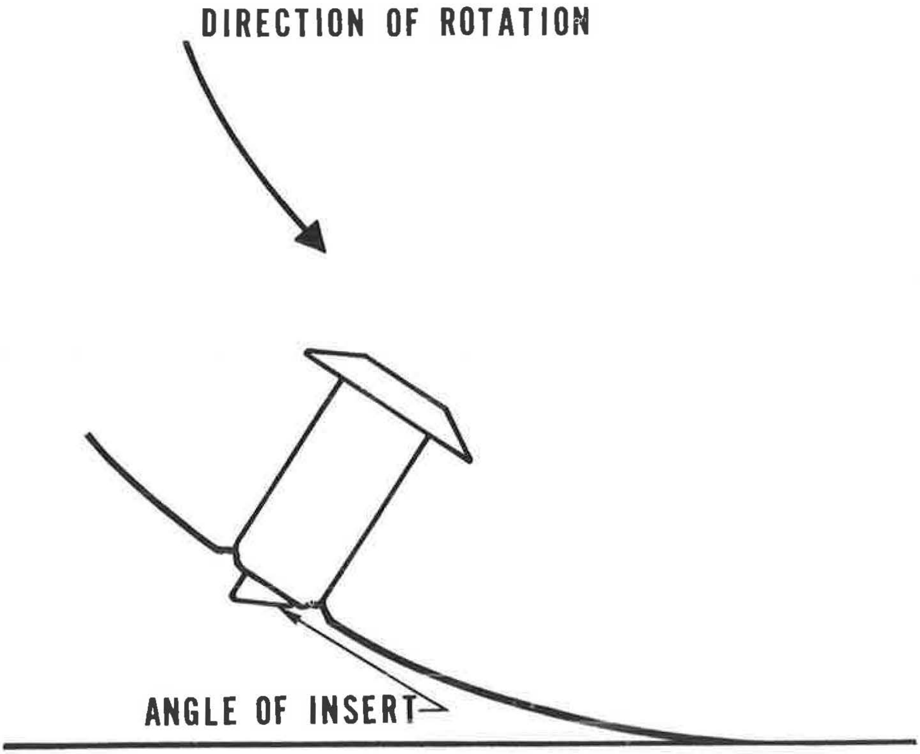

Figure 9. Effect of direction of rotation on angle of insert.

are removed at the end of the season, the direction of rotation be indicated on the tire. This allows the tire to be replaced at the beginning of the next season with the same direction of rotation. If the tire is reversed, the normal angle of wear established by the insert would oppose the wearing forces applied as the insert passes through the contact zone on the pavement; the stud would eventually be forced to rotate 180 deg to reassume its normal wear position, and this could have a slight effect on retention.

When designing a tread pattern for tire studs, it is recommended that a sufficient supporting element of rubber be provided to hold the stud. This will largely eliminate the angle of wear. A rule of thumb would be, the less the support, the greater the wear angle.

ABRASION FACTOR

During service, the studded tire is subjected to road grit and sand which create a wear factor on both the tire stud and the surrounding rubber. Road grit and sand work their way between the material of the jacket and the rubber of the tire. With the stud flexing radially in the tire several times a second at high speeds, the sand and grit act as an abrasive to both the rubber and jacket material. Later, the studs become somewhat loose in the tread as a result of this abrasion. This is a normal reaction, and it occurs faster in certain parts of the country than in others, largely because of the various road compositions involved. Pull tests on loosened studs indicate that there is still sufficient retentive force present to insure adequate retention of the studs in the tire.

When a stud becomes extremely loose it has a tendency to kick over when striking the pavement, thereby escaping the normal wear it received when it was a stable unit. Because of this, the stud protrusion increases until the external forces resulting from striking the road eject the unit. Testing has shown that early ejection results from extremely severe driving conditions, i.e., conditions so severe that elements from the tread pattern of the tire are also thrown. These conditions are very unsafe for both the tire and the tire stud. Under normal driving conditions it is common to obtain 14,000 to 19,000 mi of wear before there is any serious loss of studs. With conditions such as these, the studded tire provides top performance throughout its useful life.

NEW DEVELOPMENTS

Research and development continue the search for an improved method of providing safe driving on ice. Numerous anti-skid devices have already been developed, some more familiar than others, including chains, coils of wire, shredded wire, walnut shells, wire combs, and many others. With the exception of tire chains, which are applied on the outside of the tire when needed, these items are molded into the tread pattern during the curing process of the tire. It is assumed that as the stopping and accelerating forces are applied enough of the material will be exposed to improve the overall performance of the vehicle on ice. Whereas the foregoing devices, with the exception of tire chains, are usually flush with the tread pattern of the tire, the tire stud is applied after the tire is cured and maintains a protrusion throughout its useful life.

Since the introduction of tungsten carbide as a material able to match the wear rate of a winter tire, extensive research has been conducted on high alumina ceramics and on high wear resistant materials such as titanium carbides and molybdenum. These experimental materials are being evaluated on the basis of the protrusion principle.

A primary reason for investigating various wear-resistant materials is the cost and availability of tungsten carbide. Since the acceptance of the winter tire stud, there has been a severe drain on the supply of tungsten carbide and its cost has increased. Therefore, research will continue on similar materials to find one which matches the wear rate of a tire.

New developments have not been restricted to the field of tire studs. A major transition is presently taking place in the tire industry. Several years ago when tire studs were introduced in this country, the tire manufacturers quickly converted existing equipment to provide the necessary locations for inserting studs. Today, practically every rubber company provides from one to three complete lines of tires that can be studded if so desired. Also, the new winter tires being developed are designed to incorporate the tire studding patterns. Previously, this was merely an afterthought of existing tread designs.

A final development is the equipment required to insert the studs in the tire. This continues to be one of the greatest problems from the standpoint of both the manufacturer and the dealer.

Tire studs are inserted after the tire is cured, either at the manufacturing facility or in the local gas station. A wide range of equipment is required to satisfy the various levels. Each year new developments have been introduced to provide the additional speed and efficiency during the inserting process. Although significant advances have been made, there is still much room for improvement.

CONCLUSION

In conclusion, we have seen that the principles involved in a studded winter tire warrant careful consideration if maximum performance of the product is desired. These principles include: (a) the jacket of the tire stud, its design and the materials used; (b) the insert, which consists of a wear-resistant material capable of matching the wear rate of the tire; (c) the bonding of the insert to the jacket; (d) establishing the proper length tire stud; (e) the break-in period; and (f) the driving conditions necessary to result in a typical wear pattern for the studded tire.

All of these must be carefully coordinated to maintain the optimum operating zone, that of 0.040 to 0.060 in. which in turn results in a highly efficient studded winter tire. Early results from the field, in many cases, have shown disregard for one or more of the foregoing principles. For example, the use of a wrong length stud for the tire or failure to follow the proper carbide recommendation would be enough to produce an ineffective studded tire in a very short time. The various manufacturers of studded tires

Figure 10. Shaded areas show states, except Alaska, in which studded auto tires can be used (Jan. 1, 1967).

are attempting to educate the field as quickly as possible. The nature of the learning situation involved and the number of people to be reached have made this a very difficult job. Through the combined efforts of tire and tire stud manufacturers, future availability of a properly studded tire will be obtained as easily as the right spark plug for a car.

In 1964 approximately 3 million tire studs were marketed in the United States and Canada. In 1965 this became 30 million, and by 1966 close to 300 million tire studs were marketed. Figure 10 shows the states, except Alaska, in which studded tires can now be used.

It has been estimated that for the 1966-1967 winter season this figure should be at least double, making a total market of roughly 600 million tire studs. With a growth such as this, it is extremely important to insure that the principles of winter tire studs are known and adhered to. When a driver is informed that he has more than twice the traction and can stop in at least half the distance on ice when using studded winter tires, he must have exactly what it takes to achieve this performance (3).

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An Evaluation of Studded Tire Performance

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A. H. EASTON, Professor of Mechanical and Civil Engineering, University of Wisconsin, and Chairman, National Safety Council Committee on Winter Driving Hazards

•THE National Safety Council Committee on Winter Driving Hazards was established in 1939. One of its responsibilities throughout the years has been to evaluate the performance of devices offered for sale to the public which are advertised to improve vehicle performance under driving conditions involving snow and ice. In attempting to meet this responsibility, the Committee has, with few exceptions, held an annual test program during the midwinter months, usually covering a two-week period. The results of the Committee's investigations are made available annually in the form of an annual report of the Committee, and summaries of the Committee's activities have been published periodically (1-6).

In late 1963, the Committee became aware that tires containing tungsten carbide studs were being offered for sale in the United States in limited numbers. Although it was known that such tires had been used for some time in Europe, few published data were available in this country to indicate the performance which might be expected of such tires as compared with highway tread tires, snow tires, and reinforced tire chains. The Committee decided to include in the 1964 annual testing program a very limited series of tests on studded tires, with the expectation that the results thereof would serve as a basis for the development of a more extensive investigation in the 1965 testing program.

These test programs were carried out, within the limitations imposed by uncontrollable weather conditions. The investigation was not completed in 1965, and an extensive series of studded tire tests was planned for the 1966 program. Although this program was heavily curtailed by adverse weather, a great deal of information was obtained. This paper summarizes the findings of the Committee on Winter Driving Hazards on the basis of three annual test programs involving the performance of studded tires.

TEST SITES AND FACILITIES

The 1964 program was conducted at Gaylord, Mich., during the period from January 20 to January 31. A test course was laid out in the northwest portion of the town and constructed by city crews (Fig. 1). This course provided an ice strip approximately 100 ft wide by 600 ft long, running generally from north to south. Joining the strip near its southern end was a 50-ft wide circular track having an inner radius of 200 ft. Approximately half of the circular track, adjacent to the ice straightaway, was ice and the remainder of the circular track was packed snow. All testing on the straightaway was done from north to south, with a return lane through the adjacent snow covered field provided for test vehicles. Equipment and warm-up trailers were available adjacent to the ice strip.

The dimensions and geometry of the course precluded the use of both the straightaway and circular tracks at the same time. The testing program selected for 1964 was a rather extensive one involving, in addition to the studded tire investigations, studies of braking systems of buses and large trucks. Adverse weather conditions reduced the testing program effectively from two weeks to six days. When the test crews assembled

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Figure 1. Test site at Gaylord, Mich.

Figure 2. Test site at Stevens Point, Wis.

at Gaylord on January 20, the ambient temperature was well above freezing, the ice was melting, and there was a real danger of losing the entire test course. This situation continued through January 25, at which time the weather suddenly became much colder. City crews worked throughout the night flooding the facility, and limited tests were undertaken on January 26. Testing then continued as rapidly as possible through January 31.

The 1965 and 1966 test programs were conducted at Stevens Point, Wis., where a much larger test facility (Fig. 2) was provided and maintained by the city. The facility is adjacent to the Stevens Point Airport. An ice course approximately 200 ft wide by 1000 ft long with suitable packed snow turnarounds at either end was constructed parallel to a packed snow course approximately 120 ft wide by 600 ft long. Nearby was an ice circle having an inside radius of 200 ft and a track width of 50 ft. The straightaway courses again lie in a generally north to south direction. The size of the ice course, however, permits simultaneous testing in both directions. It also permitted, during the 1965 tests, simultaneous operation of passenger cars and skid trailers used in the studded tire evaluation and very large trucks involved in brake system analysis.

The 1965 testing program was scheduled for January 25 through February 5. Testing continued throughout this period. The rate of testing was somewhat curtailed because of extremely cold weather during the first ten days. Although a good snow course had been constructed before the testing period, no new snow fell during the period, and the snow course soon became hard packed, rough, and generally unusable.

The 1966 tests were held at the same site with essentially the same facilities as in 1965. Again, however, the testing program was curtailed to approximately six days because of weather. The course was successfully flooded on February 1 and tests commenced on February 2. The temperature rose steadily from that date until February 7, providing an excellent range of ice surface temperatures for test. On the night of February 7 rain commenced to fall, the temperature continued to rise, and this situation persisted throughout the entire following day. By the morning of February 9, the course had been destroyed for further use during 1966, and the test program was terminated.

No tests were performed on the snow course in 1966. The Stevens Point area was essentially devoid of snow during the test period. It was, in fact, necessary to truck snow into the approaches to the ice course almost daily to prevent the tracking of dirt onto the ice surface.

The data reported herein, therefore, were collected during a total testing period of approximately four weeks spread over the period 1964 to 1966 inclusive.

EQUIPMENT AND TECHNIQUES

This report deals almost entirely with measurements of automobile stopping distance and skid trailer coefficients of friction on glare ice. During each of the three annual test programs three skid trailers were operated by the General Motors Proving Ground, the Portland Cement Association, and the Tennessee Highway Research Program. Descriptions of the trailers and the techniques involved in their use may be found in the appropriate annual reports of the Committee and have been published elsewhere (7).

Stopping distance tests during each of the three years were made with new, current year model Chevrolet sedans. In 1964 and 1965 two such vehicles were used. In 1966 four were available, but only three were used during the testing program. Each stopping distance vehicle was equipped with a fifth wheel which indicated traveling speed to the driver and recorded distance traveled after the brakes were applied. All tests, both stopping distance and skid trailer, were conducted at a speed of 20 mph.

Two questions may appropriately be raised concerning data collected in the manner and over the time interval of those reported herein. The first is whether ice and test conditions were sufficiently comparable to permit data collected in 1964, 1965 and 1966 to be considered together. The second is whether the various test units, particularly the skid trailers, were capable of making identical measurements under identical circumstances.

Since 1963 the committee has stored and used annually a series of tires made from the rubber specified by ASTM designation: E 249-64T (8) for use in the standard test tire, but having a conventional highway tread configuration. These tires were originally used in an effort to learn something of the variation of ice coefficient of friction with temperature, and the effect on ice coefficient of friction of such parameters as ambient temperatures and solar radiation. During the past two years they have been used in an effort to tie together data collected from year to year. Figure 3 shows the results of skid trailer tests performed with these tires during each of the past four years. The regression lines and confidence limits are based on the points representing tests in 1963, 1964 and 1965. All points added as a result of the 1966 tests fall within these confidence limits.

The results of stopping distance tests performed by vehicles on which the same tires were mounted are shown in Figure 4. With one exception, the points added to the figure in 1966 fall within the confidence limits based on the previous three years' work. The exception falls on the lower 95 percent confidence limit.

It is believed, on the basis of the previously described data, that test techniques were comparable from year to year and that data collected during any one of the years under discussion may be properly compared with data collected in any of the other years.

At least a limited attempt was made each year to insure that similar pieces of test equipment obtained similar results under similar conditions. In 1965 a very careful correlation of the three skid trailers was conducted. All three trailers were mounted on the highway tread tires made from ASTM E-17 rubber. A very limited area on the ice surface was marked off, and all tests were made within the limits of that area. The tests were performed by all three trailers within a 15-min time interval while the ice temperature was 5.5 F. The General Motors trailer measured a coefficient of friction of 0.103, the University of Tennessee trailer 0.093, and the PCA trailer 0.097. The tires were then removed from the three trailers and carefully examined. Those mounted

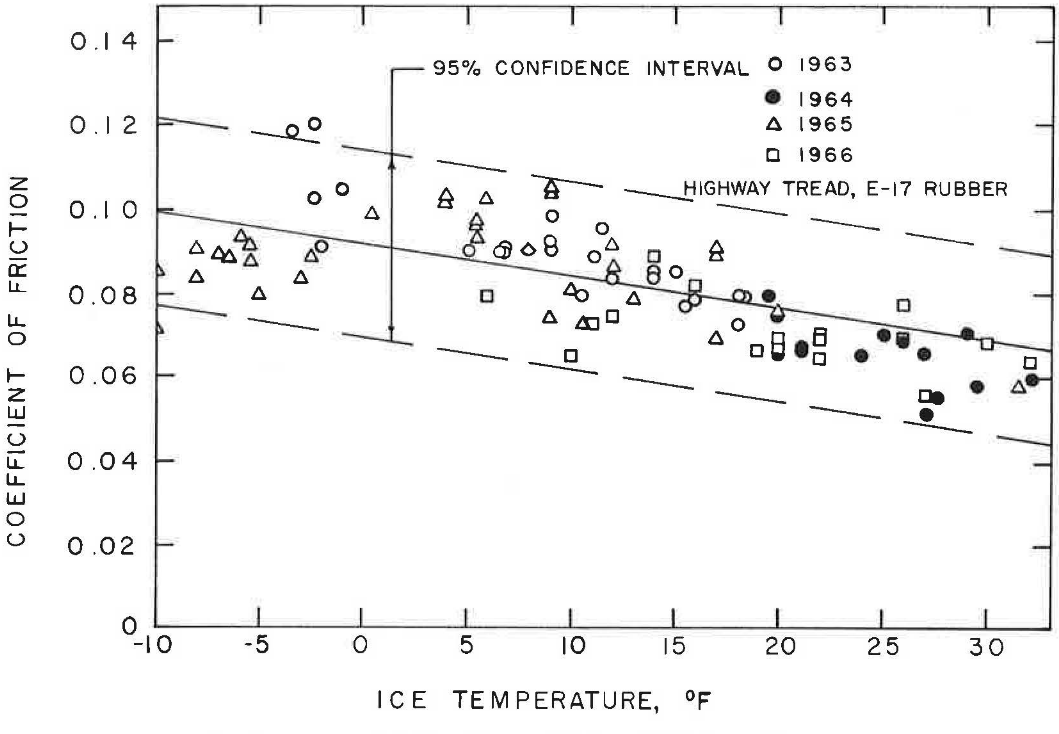

Figure 3. Variation and skid trailer coefficient of friction with temperature.

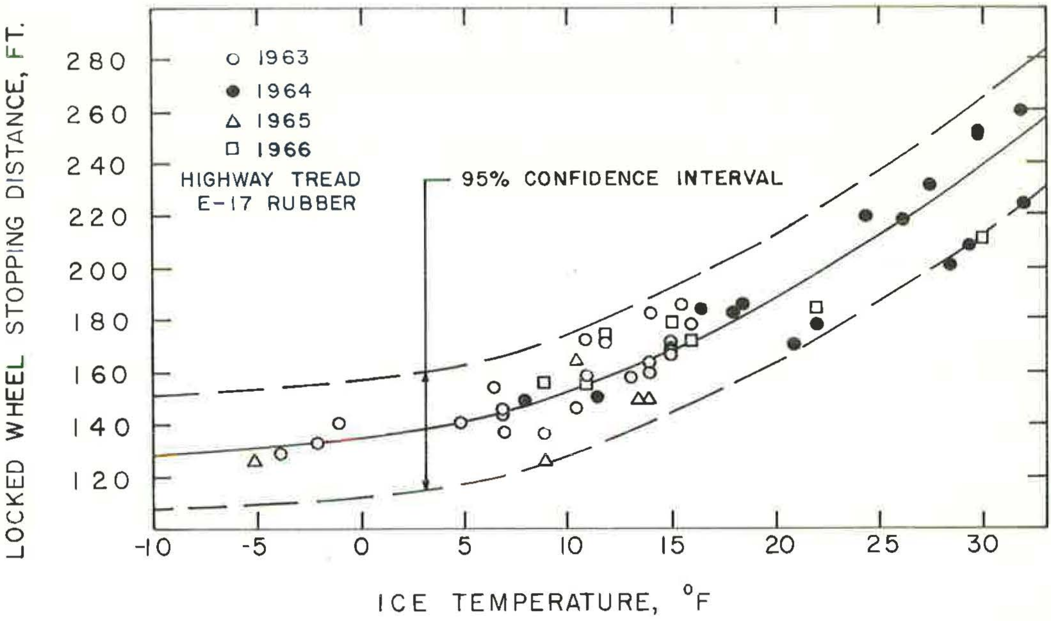

Figure 4. Variation of stopping distance with temperature.

on the PCA and University of Tennessee trailers appeared to be in perfect condition. There were a number of slightly worn spots on the tire which had been mounted on the General Motors trailer. These apparently resulted from previous use of the tire in a few dry pavement tests. Several hours later the tires which had been mounted on the General Motors and University of Tennessee trailers were transposed, and the tests were repeated at an ice temperature of 12 F. In this instance, the General Motors trailer measured a coefficient of friction 0.087 and the UT trailer 0.092. It is believed that this study showed excellent correlation between the three trailers used during these tests and indicates that the trailers are capable of measuring coefficient of friction differences on ice somewhat smaller than 0.01.

No similarly detailed correlation between stopping distance cars was attempted during any of the three years reported. In each case, however, test tires were repeatedly rotated between vehicles and the data collected were analyzed to determine whether any bias appeared to be introduced by any one vehicle. No such bias could be found in any of the three years.

It is believed, therefore, that all skid trailer data may be considered together as one population, and that all stopping distance data may be treated similarly.

TEST RESULTS

Skid Trailer Tests

In 1964, tires were submitted for test by two manufacturers. One manufacturer submitted tires containing a highway tread, a studded highway tread, a snow tread, and a studded snow tread. The other submitted only tires containing a studded snow tread. All tires were in a new condition. The results of skid trailer tests on ice having a temperature of 25 F are given in Table 1. The highway tread and snow tread tires, neither containing studs, performed in an identical manner. The studded highway tires

TABLE 1

SKID TRAILER COEFFICIENTS OF FRICTION AT 25 F ICE TEMPERATURE, 1964

Tire Mfg.	Tire Tread	Coeff.	Improvement Over New (%)	
			Highway Tread	Snow Tread
A	Highway	0.092		
	Snow	0.092		
	Studded snow	0.189	105	105
	Studded highway	0.142	54	54
B	Studded snow	0.145		
A	Highway w/reinforced chains	0.326	254	254

gave coefficients of friction 54 percent greater, and the studded snow tires showed an increase in coefficient of friction of 105 percent. No such comparisons could be made in the case of tires from manufacturer B because only one type was provided.

In 1965, tires were submitted for test by four manufacturers. The first, which submitted tires in the previous year, submitted eight groups of tires, including both new and worn tires having a highway tread, a studded highway tread, a snow tread, and a studded snow tread. The studded highway tread tires contained 76 studs and the studded snow tires 108. All tires designated as worn had been in service for 5000 mi. The second manufacturer again provided only new studded snow tires containing 63 studs. A third manufacturer provided six groups of tires containing both new and worn tires having a highway tread, a snow tread, and a studded snow tread. The studded snow tires contained 72 studs. The fourth manufacturer provided new highway tires, new snow tires, and both new and worn studded snow tires containing 84 studs.

The results of skid trailer tests with each type of tire are given in Table 2. For manufacturer A, studded highway tread tires showed an improvement in coefficient of friction of 63 percent over conventional highway treads, and 36 percent over conventional snow treads. After use for 5000 mi, however, 19 percent of the improvement over highway treads and 86 percent of the increase over snow treads was lost. Studded snow tires containing 108 studs showed an increase of 80 percent over conventional highway tires and 50 percent over conventional snow tires. After 5000 mi of wear, however, 54 percent of the increase over highway treads and 72 percent of the increase over snow treads was lost.

The tires of manufacturer B, being available only in a studded snow tread, provided no comparisons with other similar tires.

The studded snow tires of manufacturer C containing 72 studs per tire showed an increase in coefficient of friction of 70 percent over conventional new highway treads, and 43 percent over conventional new snow treads. After 5000 mi of wear, 71 percent of the increase over new highway tires and 98 percent of the increase over new snow tires was lost.

For the tires submitted by manufacturer D, the coefficient of friction of new studded snow tires containing 84 studs per tire was 93 percent higher than that of new highway tread tires and 84 percent higher than new conventional snow tires. After the tires had been used for 5000 mi, 39 percent of the advantage over new highway treads and 42 percent of the advantage over new snow treads was lost.

For the 1966 tests an effort was made to minimize the number of tire variables by selecting test tires from only one manufacturer. Inquiries were made to tire manufacturers concerning the number of studs being offered for sale in their studded snow tires for 1965-1966, and it was determined that a tire containing 72 studs fell within the range of those on the market, being somewhat below the middle of this range. The manufacturer agreed to make available to the Committee enough tires to test a new highway tread, a new snow tread, and both new and worn studded snow treads with 72 studs.

TABLE 2

SKID TRAILER COEFFICIENTS OF FRICTION AT 25 F ICE TEMPERATURE, 1965

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 3

SKID TRAILER COEFFICIENTS OF FRICTION AT 25 F ICE TEMPERATURE, 1966

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.

In addition, the manufacturer agreed to produce identical snow tread tires containing 48 and 144 studs. The 48-stud tire contained fewer studs than any known to be offered for sale, and the 144-stud tire contained more. These were made available in both a new and a worn condition.

The results of tests on these tires are given in Table 3. The data summarized therein represent results of many more tests than any of those shown for 1964-1965, and of tests made over a wider ice temperature variation than was available in either of those years. Studded snow tires containing 72 and 144 studs performed in an almost identical manner when compared with either new highway or new snow tread tires. Slightly fewer benefits were achieved with the 48-stud snow tires. However, the loss of effectiveness after 5000 mi wear 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.

To provide data concerning the upper level of coefficient of friction of ice, a limited number of tests were run with highway tread tires on which reinforced tire chains had been mounted. Results of these tests are given in Tables 1, 2, and 3. Coefficients so measured ranged from 346 percent higher than that for highway tread tires alone in 1965 to 254 percent higher in 1964. Similar improvements over snow tires alone ranged from 325 percent in 1965 to 235 percent in 1966.

Stopping Distance Tests

All stopping distance tests were performed from 20 mph with new highway tread tires on the front wheels of the vehicle and the indicated test tires on the rear wheels. Only a relatively few stopping distance tests were performed in 1964 and 1965. In some instances, the number performed with a given tire combination was insufficient to warrant reporting; the other results of this test series are given in Table 4. New studded highway tread tires on the rear wheels of the vehicle stopped the vehicle in a distance 14 percent shorter than that required when new conventional snow tires were on the rear wheels, and new studded snow tires reduced the stopping distance, compared to new conventional snow tires, by 28 percent.

Table 5 summarizes the stopping distance test results from 20 mph at an ice temperature of approximately 9 F, in 1965. New snow tires decreased the stopping dis-

TABLE 4

STOPPING DISTANCES FROM 20 MPH AT APPROXIMATELY 28 F ICE TEMPERATURE, 1964

Tire Mfg.	Tire Tread[a]	Condition	Distance (ft)	Improvement Over New (%)	
				Hwy Tread	Snow Tread
A	Snow	New	164	–	–
	Studded snow	New	118	–	28
	Studded hwy	New	141	–	14

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

TABLE 5

STOPPING DISTANCES FROM 20 MPH AT APPROXIMATELY 9 F ICE TEMPERATURE, 1965

Tire Mfg.	Tire Tread[a]	No. Studs	Condition	Stopping Distance (ft)	Improvement Over New (%)		Reduction in Improvement Over New (%)[b]	
					Hwy Tread	Snow Tread	Hwy Tread	Snow Tread
D	Highway	–	New	130	–	–	–	–
	Snow	–	New	109	16	–	–	–
	Studded snow	84	New	95	27	13	–	–
	Studded snow	84	Worn	107	18	2	33	85
	Highway w/reinforced chains	–	New	75	42	31	–	–

[a] Highway tread on front wheels, indicated tread on rear wheels.
[b] After 5000 mi wear.

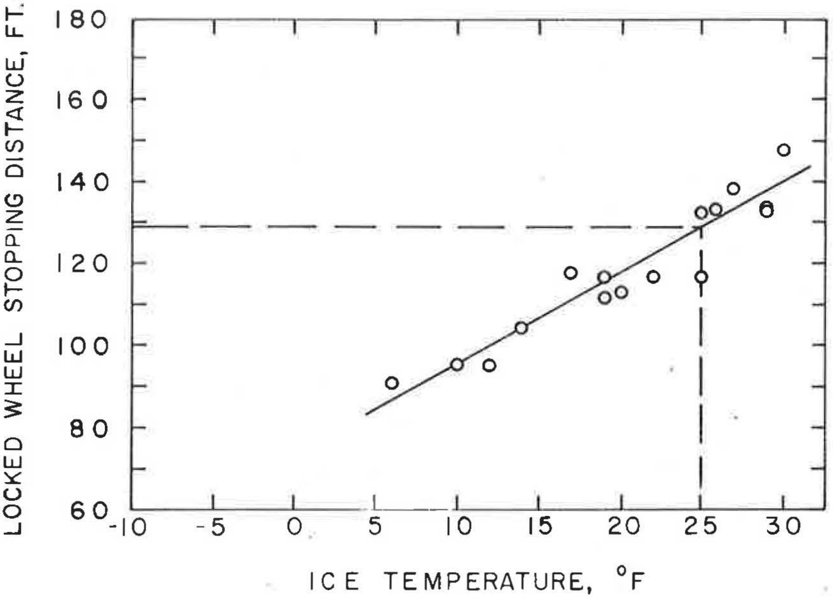

Figure 5. Highway tread on front wheels, snow tread with 72 studs on rear wheels, 1966.

TABLE 6

STOPPING DISTANCES FROM 20 MPH AT 25 F ICE TEMPERATURE, 1966

Tire Mfg.	Tire Tread[a]	No. Studs	Condition	Stopping Distance (ft)	Improvement Over New (%)		Reduction in Improvement Over New (%)[b]	
					Hwy Tread	Snow Tread	Hwy Tread	Snow Tread
C	Highway	-	New	162	-	-	-	-
	Snow	-	New	151	7	-	-	-
	Studded snow	48	New	133	18	12	-	-
	Studded snow	72	New	129	20	15	-	-
	Studded snow	144	New	118	27	22	-	-
	Studded snow	48	Worn	151	7	0	61	100
	Studded snow	72	Worn	143	12	5	40	67
	Studded snow	144	Worn	126	22	17	19	23
	Highway w/reinforced chains	-	New	85	48	44	-	-

[a] Highway tread on front wheels, indicated tread on rear wheels.
[b] After 5000 mi wear.

tance, compared to new highway tread tires, by 16 percent, and new studded snow tires containing 84 studs decreased the distance required by 27 percent. The new studded snow tires stopped the vehicle in a distance 13 percent shorter than new conventional snow tires. However, after the studded snow tires had been used for 5000 mi, 33 percent of the increased effectiveness over new highway tread tires was lost, as was 85 percent of the effectiveness over new snow tread tires.

The Committee generally reports the results of tests on glare ice at an ice temperature of 25 F. Where possible, data collected with each combination of tires are plotted, the least mean square regression equation calculated, and the value at an ice temperature of 25 F taken from the regression line. A typical example of such treatment is shown in Figure 5. All stopping distance tests made in 1965 were performed at much

TABLE 7

TRACTION TEST DATA

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.

lower temperatures. The data in Table 5, being based on an ice temperature of 9 F throughout, show materially shorter distances than would have been the case had an ice temperature of 25 F been available.

The results of stopping distance tests from 20 mph at an ice temperature of 25 F in 1966 are given in Table 6. Average stopping distances for the various tire combinations tested ranged from 162 to 118 ft. New snow tread tires on the rear wheels of the vehicle reduced stopping distance, as compared to new highway tread tires, by 7 percent. Studded snow tires with 48, 72, and 144 studs reduced the stopping distance, as compared to new conventional snow tread tires, by 12, 15, and 22 percent, respectively. The loss in effectiveness of the 48, 72, and 144 stud snow tires after 5000 mi, as compared to new conventional snow tires, was 100, 67, and 23 percent, respectively.

As a further measure of the relative effectiveness of studded tires, a limited number of stopping distance tests were performed with reinforced tire chains mounted on conventional highway tires on the rear wheels of the test vehicles. The average stopping distances under such conditions measured in 1965 were 75 ft and in 1966 85 ft, showing a reduction in stopping distance of 42 to 48 percent.

Traction Tests

In both 1964 and 1965 a limited number of drawbar traction tests were performed by attaching a second vehicle to the test vehicle by means of an instrumented drawbar and measuring the pull in the bar as increasing power was fed to the test vehicle until the wheels began to spin. The load on the bar immediately before spinning is referred to as the break-away traction. The load remaining on the bar after the wheels are spinning is referred to as spinning traction. In 1964 only break-away traction was measured. Both were measured in 1965.

The results of these traction tests are given in Table 7. The limited data available do not permit the drawing of any extensive conclusions. In general, however, snow tread tires exhibited somewhat greater traction than highway tread tires, studded tires exhibited considerably greater traction than identical tires without studs, and worn studded tires exhibited materially less traction than identical new studded tires. The greatest traction was obtained with reinforced chains mounted on highway tread tires.

Truck Tests

In the 1966 test program a few tests were performed using studded tires on a four-wheel drive truck. The results of stopping distance tests with the truck (Fig. 6) reveal

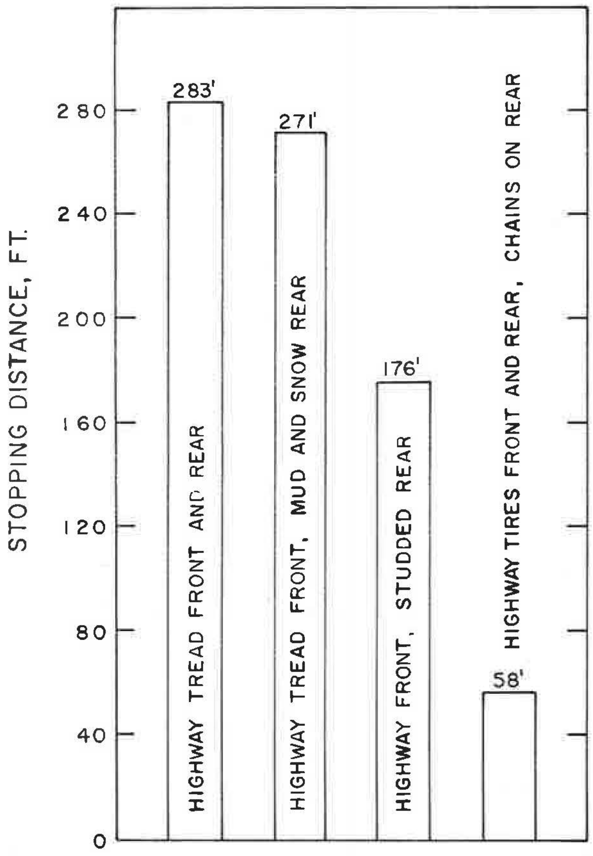

Figure 6. Truck stopping distances on glare ice at 27 F.

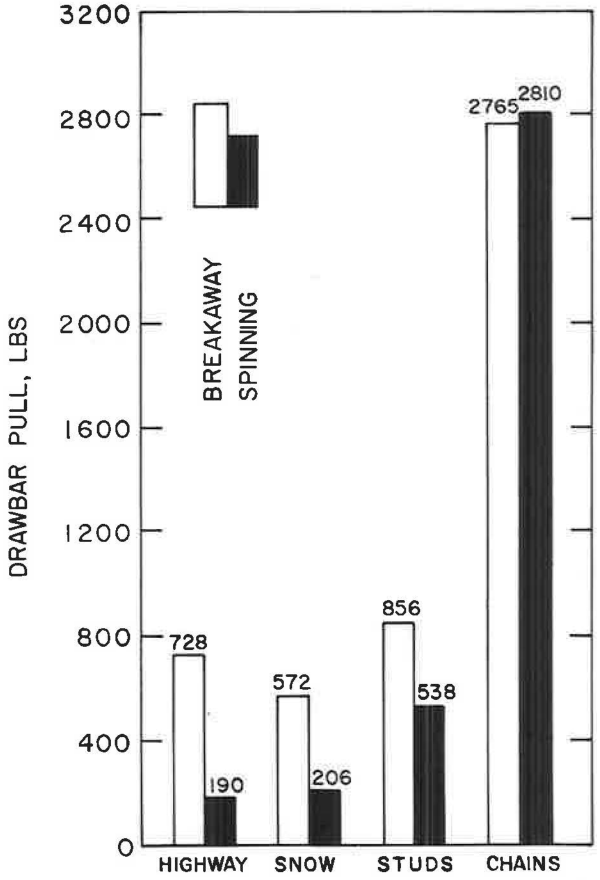

Figure 7. Effect of tire type on truck traction on glare ice at 16 to 19 F.

TABLE 8

DRY AND WET PAVEMENT TESTS

Pavement	Speed (mph)	Snow Tires[a]				72 Studs[a]				144 Studs[a]			
		Stopping Distance (ft)		Trailer Coeff.		Stopping Distance (ft)		Trailer Coeff.		Stopping Distance (ft)		Trailer Coeff.	
		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.

that stopping distances varied from 283 ft when highway tread tires were mounted on all wheels to 58 ft when chains were used in the rear wheels. When studded mud and snow tires were placed on the rear of the truck, the stopping distance was reduced by 35 percent as compared to tests with identical tires having no studs on the rear of the truck.

Results of traction tests with the truck are shown in Figure 7. The break-away traction shown for highway tires does not fit the general pattern established by the rest of the tires tested. This may have resulted from some unusual ice condition at the time of the test. The remainder of the tests fall in a reasonable order. The studded snow tires materially increased both break-away and spinning traction, but by far the greatest traction was obtained when chains were mounted on conventional highway tires.

Wet and Dry Pavement Tests

The Committee is fully aware that when studded tires are placed on a vehicle in the fall and removed in the spring, most of their operation will be on pavement surfaces bare of snow or ice. The Committee felt that at least limited tests should be made on wet and dry pavements in which the performance of studded tires could be compared to that of similar tires containing no studs.

These tests were performed by the Tennessee Highway Research Program in the fall of 1965, using some of the tires which were to be evaluated in the 1966 test program. Comparisons were made between new snow tires and new studded snow tires containing either 72 or 144 studs. Both skid trailer and stopping distance tests were made—in a wet and a dry condition—on two bituminous pavement surfaces, one of which had reasonably high skid resistance and the other somewhat less. Skid trailer tests were also made on a wet portland cement concrete surface. The results of these tests are given in Table 8.

There are essentially no systematic differences between the performance of the snow tires and that of the snow tires with 72 studs. A very limited tendency toward longer stopping distances and lower coefficients of friction at some speeds on some surfaces may be observed in the case of the snow tires with 144 studs (which is a larger number than is now generally available to the public). This tendency is by no means universal for all speeds on all surfaces tested.

CONCLUSIONS

Inasmuch as this report deals with the effectiveness of studded tires, it seems appropriate that conclusions be based only on comparisons of tests of tires which are identical, except for the presence or the absence of studs, to tests of highway tread tires with and without reinforced tire chains. As the data presently available on studded highway tread tires are exceedingly limited, and as the use of such tires by the public appears equally limited, conclusions herein are based on tests of studded snow tread tires and similar snow tread tires without studs.

Subject to the foregoing limitations, the following conclusions are drawn.

1. New studded snow tires increase the coefficient of friction between the tire and glare ice at a temperature of 25 F, as measured by skid trailers at 20 mph, from 43 to 105 percent. When the tires have been driven for 5000 mi, however, from 36 to 98 percent of this increase is lost.
2. New studded snow tires, containing numbers of studs now generally available to the public, mounted on the rear wheels of a passenger car, decrease the stopping distance on glare ice at 25 F from 20 mph by 13 to 28 percent. After the tires have been driven for 5000 mi, 67 to 85 percent of this increased effectiveness is lost.
3. New studded snow tires similarly increase the pulling traction of the vehicle on which they are mounted. After 5000 mi of use, much of the increased traction is lost.
4. Studded tires may be somewhat more effective, in both reducing stopping distance and increasing traction, on trucks than on passenger cars. This is probably a function of the axle weight distribution of the vehicles, with the heavier vehicle having the relatively heavier rear axle load.
5. The effectiveness of studded tires does not appear to be directly related to the number of studs in the tire. It is probably more nearly a function of the number of grooves cut in the ice by the studs. There is limited evidence, however, that tires containing a greater number of studs tend to lose their effectiveness less rapidly than those containing a lesser number.
6. Studded snow tires containing a number of studs now generally available appear to perform essentially the same on dry or wet pavements as similar tires containing no studs.
7. Reinforced tire chains, mounted on conventional highway tread tires, provide materially greater traction and stopping ability than any other devices tested to date.

Finally, a strong precautionary recommendation is made concerning the use of this and other reports dealing with the effectiveness of studded tires or other devices intended to alleviate some of the hazards of winter driving. Statements concerning very

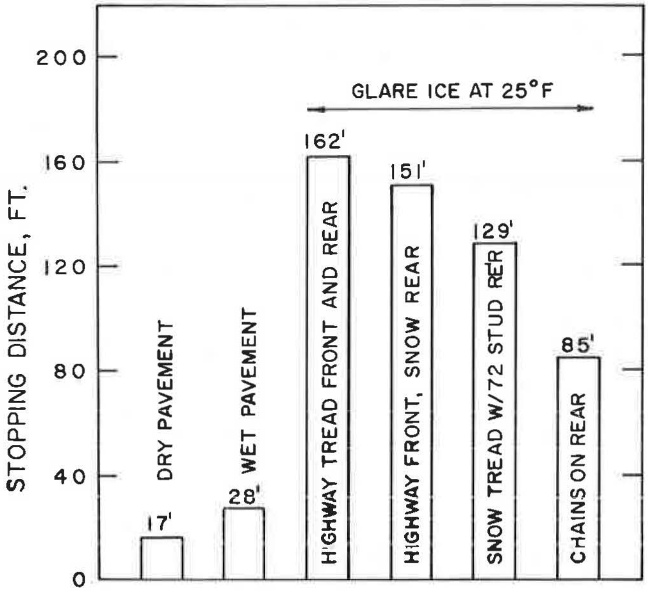

Figure 8. Effect of tires and surface condition on stopping distance.

large percentage increases in the coefficient of friction or tractive ability are impressive. However, when applied to the coefficient of friction or traction on ice, these increases represent large percentages of initially very small numbers. Figure 8 supports this precautionary note. Even with reinforced chains on the rear wheels, a vehicle slides approximately five times as far from 20 mph on ice at 25 F as it would on a dry pavement or three times as far as it would on a wet pavement. With studded snow tires on the rear wheels the vehicle slides approximately 7.5 times as far on ice as on a dry pavement, or 4.6 times as far as on a wet pavement. With conventional highway tires on all wheels, the vehicle slides approximately 9.5 times as far on ice as on a dry pavement, or 5.8 times as far as on a wet pavement. Considerable care should be exercised to assure that the potential user of even the best of the devices currently available is aware that he must still exercise far greater care in driving on ice than he would even on a wet pavement.

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Studded Tire Evaluation in New Jersey

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•THIS REPORT represents an initial comprehensive effort to evaluate the overall effect of allowing studded tires on the New Jersey highway system. A studded tire is herein defined as any conventional or snow tire having embedded in its tread a number of encased tungsten carbide pins, approximately $^3/_{32}$ in. in diameter.

Two major objectives were established for this research effort. The first concerns the measurement of damage to typical New Jersey pavement surfaces due to normal travel, and to panic and abrupt stopping situations, with ordinary passenger vehicles equipped with studded tires. In addition to pavement wear measurements, the accomplishment of this first objective includes an attempt to determine pavement surface skid resistance changes and to compare these changes to values attributed primarily to general rubber tire traffic.

The second objective, as initially established, was to place into application and to evaluate a proposed studded tire acceptance procedure which described a series of tests to be applied to sample tires before acceptance for use on New Jersey highways.

The application of the acceptance procedure immediately proved impractical, and the evaluation of this document actually evolved into a rather broad look at the general performance of studded tires. The principal items of interest in this section of the study include the results of a stud pull-out test, a check for stud loss and an actual extended period of studded tire use on Department vehicles, with a resultant driver questionnaire regarding vehicle performance.

HISTORY

The statutes of New Jersey in effect in 1964 were so written as to exclude the use of tires equipped with studs on the highway system. A portion of the statement excluding such use said "no motor vehicle tire shall be fitted with any block, hobs, studs, or other projections . . . ."

During November 1964 a bill was introduced to the New Jersey legislature, and subsequently passed, which provided the means to allow the use of studded tires on the highway system and which placed the responsibility for the control of this use with the Director of the Division of Motor Vehicles. On June 4, 1965, the State Division of Motor Vehicles issued a regulation indicating the requirements for the legal use of studded tires in New Jersey on passenger vehicles only.

Only provisional approval of studded tires, on an individual tire type basis, was to be effected. In addition, the regulation states that studded tire approval must also have the concurrence of the New Jersey State Highway Department (now New Jersey Department of Transportation).

The following is a select summary of the specific requirements of the regulation promulgated by the Division of Motor Vehicles:

1. Studs may be placed only in new tires in openings molded for that purpose by the tire manufacturer;
2. There must be a minimum of $^1/_8$ in. of rubber between the base of the stud and the body of the tire;

Paper sponsored by Ad Hoc Committee on Studded Tires and presented at the 46th Annual Meeting.

3. The projection of the tungsten carbide tip of the stud shall be not less than 0.04 in. nor more than 0.06 in. from the surface of the tire;
4. Approval will not be granted for tires operating with recommended air pressures greater than 30 psi; and
5. No stud tire shall be used on a public highway earlier than November 1 or later than April 15 of any winter season.

In September 1965, the New Jersey State Highway Department established a committee for the purpose of developing a studded tire acceptance procedure in anticipation of the first winter season (1965-1966) in which studded tires were to be allowed on our highway system. The acceptance procedure was primarily an instrument by which the Department would provide its concurrence to the studded tire approvals of the Division of Motor Vehicles.

Committee activity produced such an acceptance procedure by October 1965, and the Division of Research and Evaluation of the Department began immediate testing of the sample studded tires on hand.

During the period of development of the acceptance procedure, only three sets of sample studded tires that had been submitted for approval had actually been received. This fact to a large degree influenced the content of this procedure, particularly the road test provisions. Ultimately, a total of 53 sets of sample studded tires (106 individual tires), representing a large cross-section of tire manufacturers, were received for testing. This large number rendered the road test provisions of the acceptance procedure impractical.

The specific inclusions of this proposed acceptance procedure were as follows.

1. Record the number, pattern, and type of stud in each tire;
2. Measure stud projections;
3. Apply a tensile force equal to 30 lb on studs to insure their firm seating in the tire;
4. Test the performance of each tire in the general areas of stability, handling, and skid resistance;
5. Measure pavement damage due to studded tire use; and
6. Have each tire tested for durability by subjecting it to 1,000 mi of conventional driving.

Inasmuch as the acceptance procedure soon became obviously impractical, primarily due to the large number of tires submitted for approval, an alternate approach to studded tire evaluation was devised. It was decided that applicable portions of the acceptance procedure were to be applied to the test tires and that efforts in the road test provisions were to be revised. Specifically, studs were counted and recorded in each tire, stud projections were measured, and a stud tension test was applied. As a substitute for our original field tests, it was decided to install the sample studded tires on Department vehicles during their legal period of use. In addition, a driver questionnaire was developed to attempt to evaluate general performance. The principal elements of consideration included in the driver questionnaire were normal acceleration traction, rapid acceleration traction, ability to hold a straight course, control in passing, crossing longitudinal joints, cornering, side-skid resistance, normal stopping, and panic stopping.

Because of the late arrival of the majority of studded tires submitted for approval, and because of the impracticality of the available acceptance procedure, actual concurrence of the State Highway Department with the Division of Motor Vehicles' approval of studded tires did not occur during the initial winter season of use. The Division of Motor Vehicles did provide provisional approval for virtually all of the tires included in our test program. Currently, both agencies are cooperatively attempting to establish the future status of studded tire use in New Jersey.

FIELD TEST PROGRAM

A field testing program was devised to obtain a measure of the pavement damage potentially due to the widespread use of studded tires on conventional passenger vehicles.

The primary objectives of this test program were the determination of the relative magnitudes of pavement surface wear and skid resistance losses. The majority of testing was accomplished at one site on which a test track was established; however, the field data relating ordinary rubber tire passes to actual skid resistance loss were obtained at a variety of road locations throughout the state.

The primary test site was a short section (approximately 300 ft) of pavement constructed at the end of Route 26 in 1955. This pavement will ultimately become part of a direct through route to Route 1; however, this particular portion of the pavement has been barricaded since its completion and has retained the appearance of virtually new pavement construction.

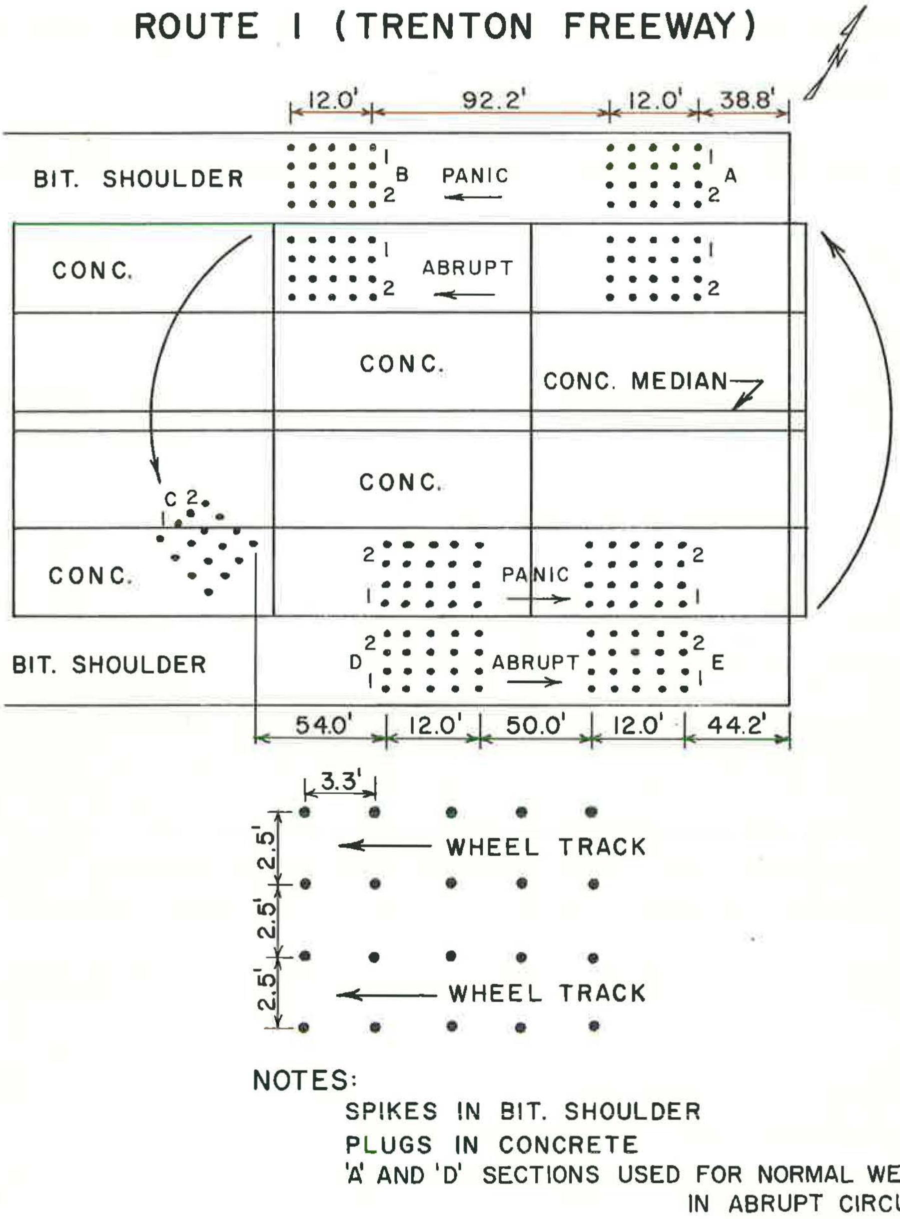

Figure 1. Studded tire test track.

The pavement section selected consists of a portland cement concrete slab design with a burlap drag surface finish, and bituminous concrete shoulder with a medium aggregate bituminous concrete surface similar, although slightly coarser, to that currently used in flexible pavement construction. A ramp composed of cold mix bituminous patching materials was provided to allow traversing of the existing center island, and additional crushed stone layers were placed in the future bridge abutment area to provide a stable base for turning movements. Figure 1 shows a detailed plan of the test site.

Elevation controls were established by placing depressed brass plugs, approximately $^1/_2$ in. in diameter, into the portland cement concrete pavement, and by driving steel railroad spikes into the existing bituminous concrete shoulders, in the pattern shown in Figure 1. Pavement wear measurements were made with a vernier depth gage capable of accomplishing direct readings to $^1/_{1000}$ in. Gage readings were taken at 1-in. intervals along a steel straightedge which spanned a pair of wheelpath control points. The steel straightedge was supported on inverted clamps which, in turn, rested on the brass plug or steel spike control points.

Two independent test circuits were established (Fig. 1). The initial test circuit was used to measure the effect of panic stops at a specific location. The second test circuit was used to measure the effect of abrupt stops and also to provide a measure of wear due to normal travel.

For the purposes of this report, panic stops are defined as stops caused by locking brakes while traveling at a speed sufficient to cause actual vehicle skidding. An abrupt stop is defined as a quick stop which does not involve vehicle skidding. Normal wear of pavement surface was measured at a predetermined location in advance of the abrupt stop locations and just beyond turning movement areas.

Maximum vehicle speed, due to the relatively short stretch of test pavement, was approximately 20 mph. This represents the speed at which the majority of panic stops were initiated. The vehicle used for testing was a 4-door highway sedan, weighing 2,800 lb, with a longitudinal wheelbase length of 116 in. and a width between wheels of 57 in. The vehicle was equipped with studded snow tires on all four wheels for both circuits, except that studded conventional tread tires were used on the two front wheels during the panic stop testing.

A total of 1400 circuits of the test track were completed for the panic stops and 4990 circuits were completed for the abrupt stops and the normal wear sections. Inasmuch as all four wheels had studded tires installed, the normal wear section measurements actually represent 9980 passes of a studded tire.

Graphs representing periodic measurements of pavement wear vs vehicle circuits of the test track were made for abrupt stops (Fig. 2a) and for panic stops (Fig. 2b). Final pavement loss measurements were taken for the normal wear locations and were recorded as 0.032 in. for portland cement concrete and 0.026 in. for the bituminous concrete surfaces. Both normal wear measurements show pavement wear in excess of that obtained at the abrupt wear locations, which can possibly be explained by the fact that the normal wear locations were so located that the test vehicle was in the process of accelerating and/or traveling at a higher speed than when at the abrupt stop location.

The points on the graphs are a composite of recorded measurements and were obtained by averaging the readings of pavement wear at each test site. As mentioned, readings were made across the wheelpath area. These readings were taken at 1-in. intervals and an average value was calculated for each wheelpath cross-section.

These average cross-section reading differences were then totaled considering both positive and negative readings, and the final average for the test section was obtained. The final average is used in plotting the points on the graphs. Each point represents at least 110 measurements made at the test site. Although painted longitudinal guidelines and transverse stopping lines were used to effect vehicle placement control, there was sufficient lateral movement to make it reasonable to summarize all recorded loss measurements.

An attempt to evaluate the effect of turning movements was made on the portland cement pavement immediately beyond the improvised center island ramp; however, the lack of driver ability to maintain a constant course while turning diminished the value of this effort.

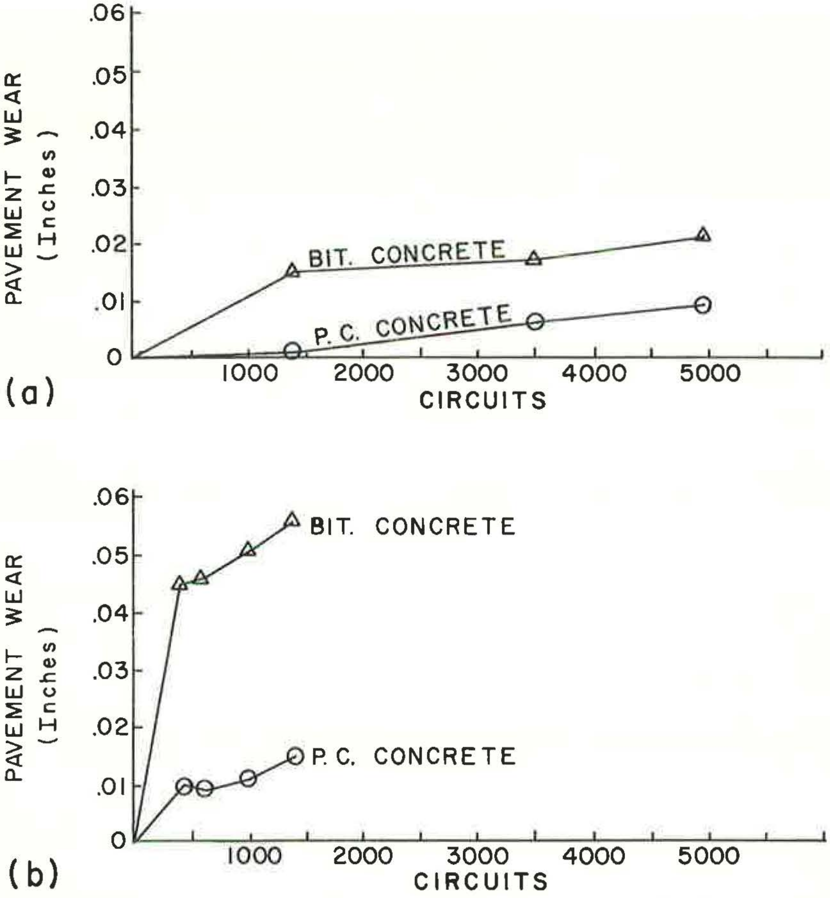

Figure 2. Average pavement surface wear: (a) abrupt stop site and (b) panic stop site.

The following characteristics of pavement surface wear were noted. In general, the pavement wear, abrupt and panic stop curves, and the normal wear values do indicate progressive pavement wear. The observed portland cement concrete pavement wear consisted primarily of loss of burlap drag surface finish which resulted in a smooth mortar surface. The wearing rate of the mortar surface, which has an approximate average thickness of $^3/_{16}$ in., will most likely occur at a diminished rate; however, it appears possible, with even limited studded tire use, to cause coarse aggregate exposure at a highly accelerated rate on major New Jersey routes. The observed bituminous concrete pavement wear also appeared significant. Greater losses were recorded in all phases of measurements, except in the normal wear values. This latter exception may be due to the position of the normal wear section on the test site. The most serious consideration, however, was in the manner in which bituminous concrete pavement wear occurred. The studded tires tended to erode the bituminous-fines matrix, leaving the coarse aggregate highly exposed. In this relatively exposed position the coarse aggregate was noticeably abraded. It also appeared that a decrease in sharpness of original coarse aggregate texture occurred due to the abrading action of the studded tires. This observation of wear is in stark contrast to the general appearance of bituminous concrete surfaces in New Jersey subjected primarily to conventional rubber tire traffic. The type of wear encountered on the bituminous concrete test track is considered the primary cause for the significant loss of skid resistance recorded in this section.

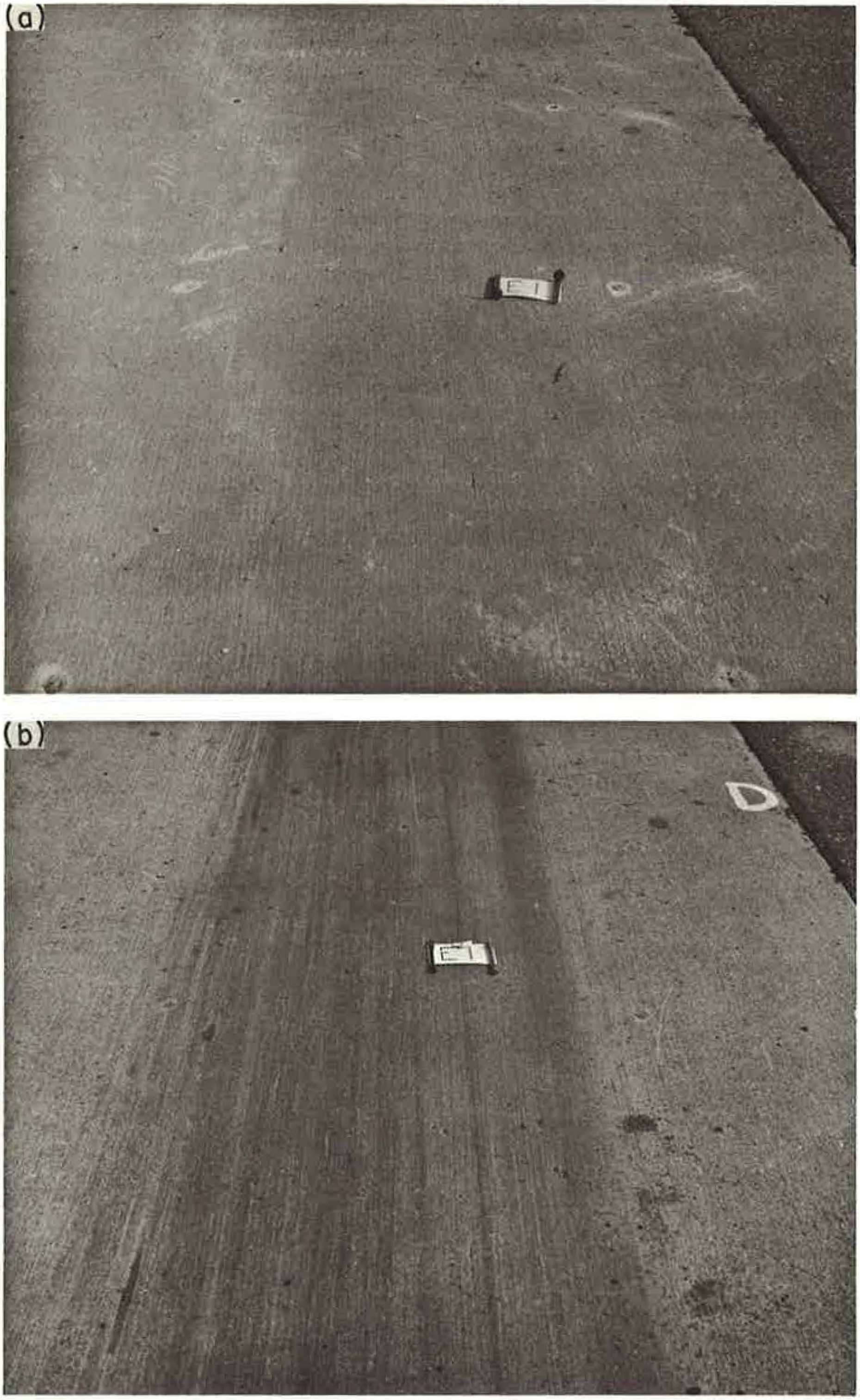

Figure 3. Panic stop site, portland cement: (a) before and (b) after test.

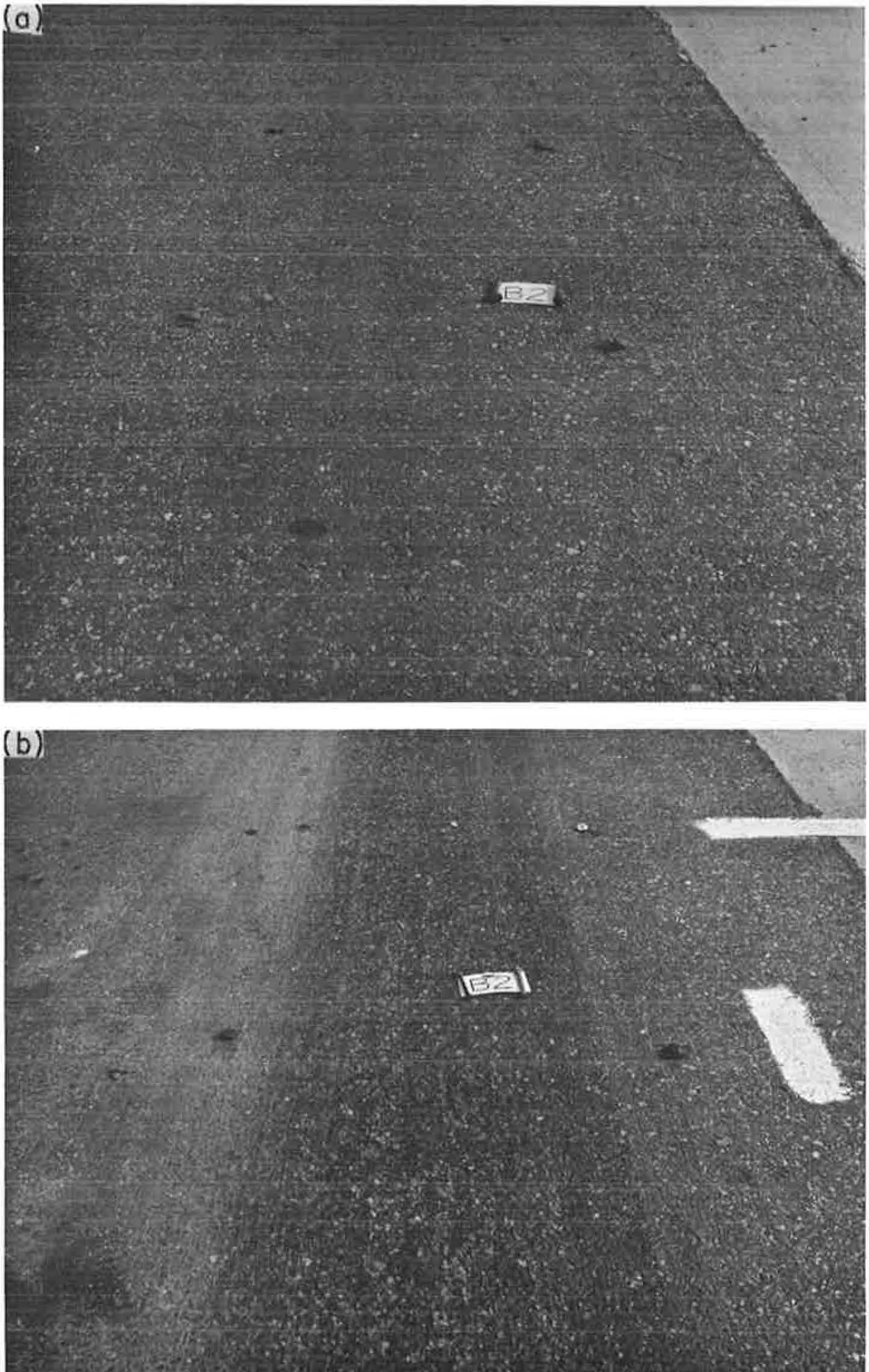

Figure 4. Panic stop site, bituminous concrete: (a) before and (b) after test.

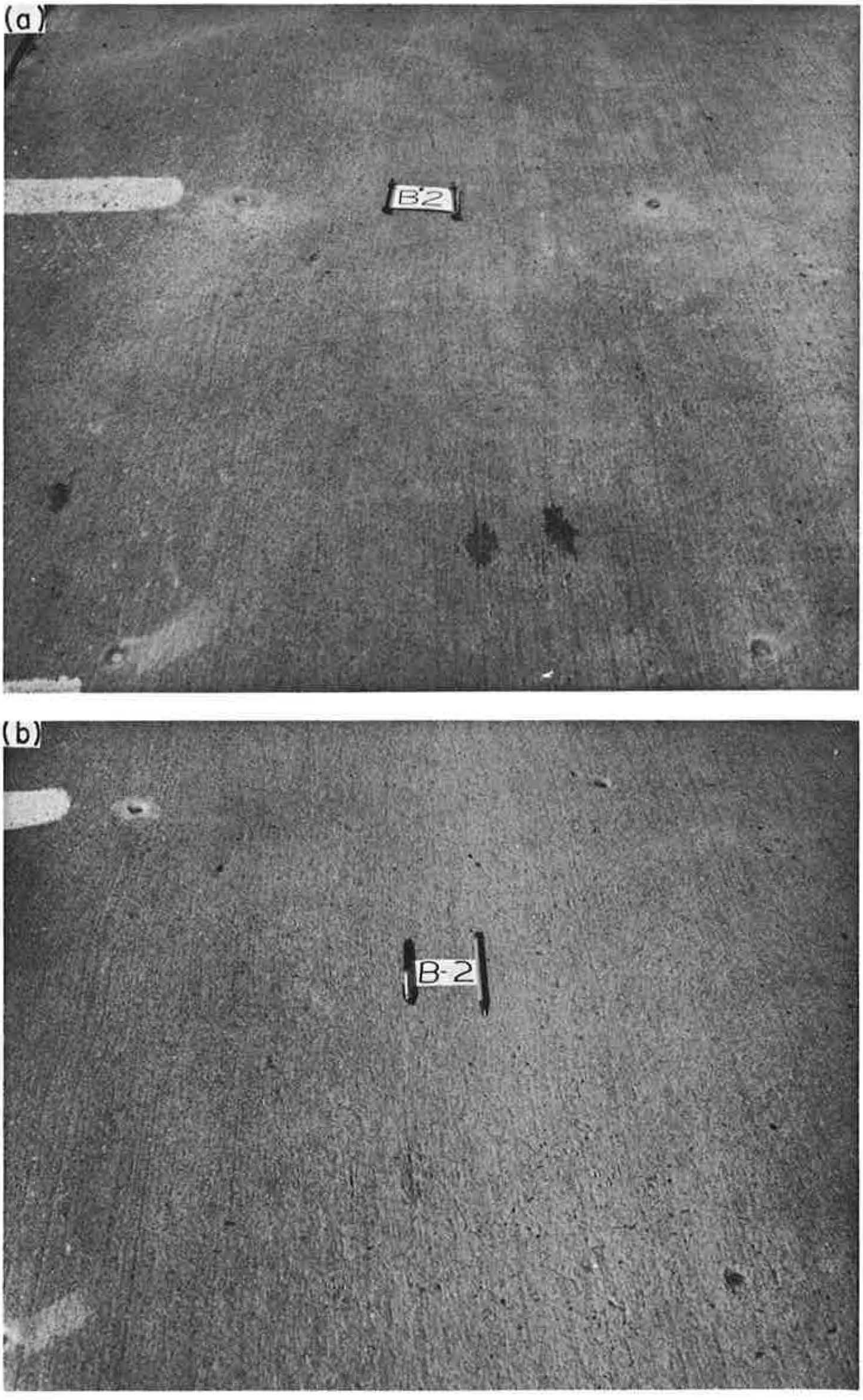

Figure 5. Abrupt stop site, portland cement: (a) before and (b) after test.

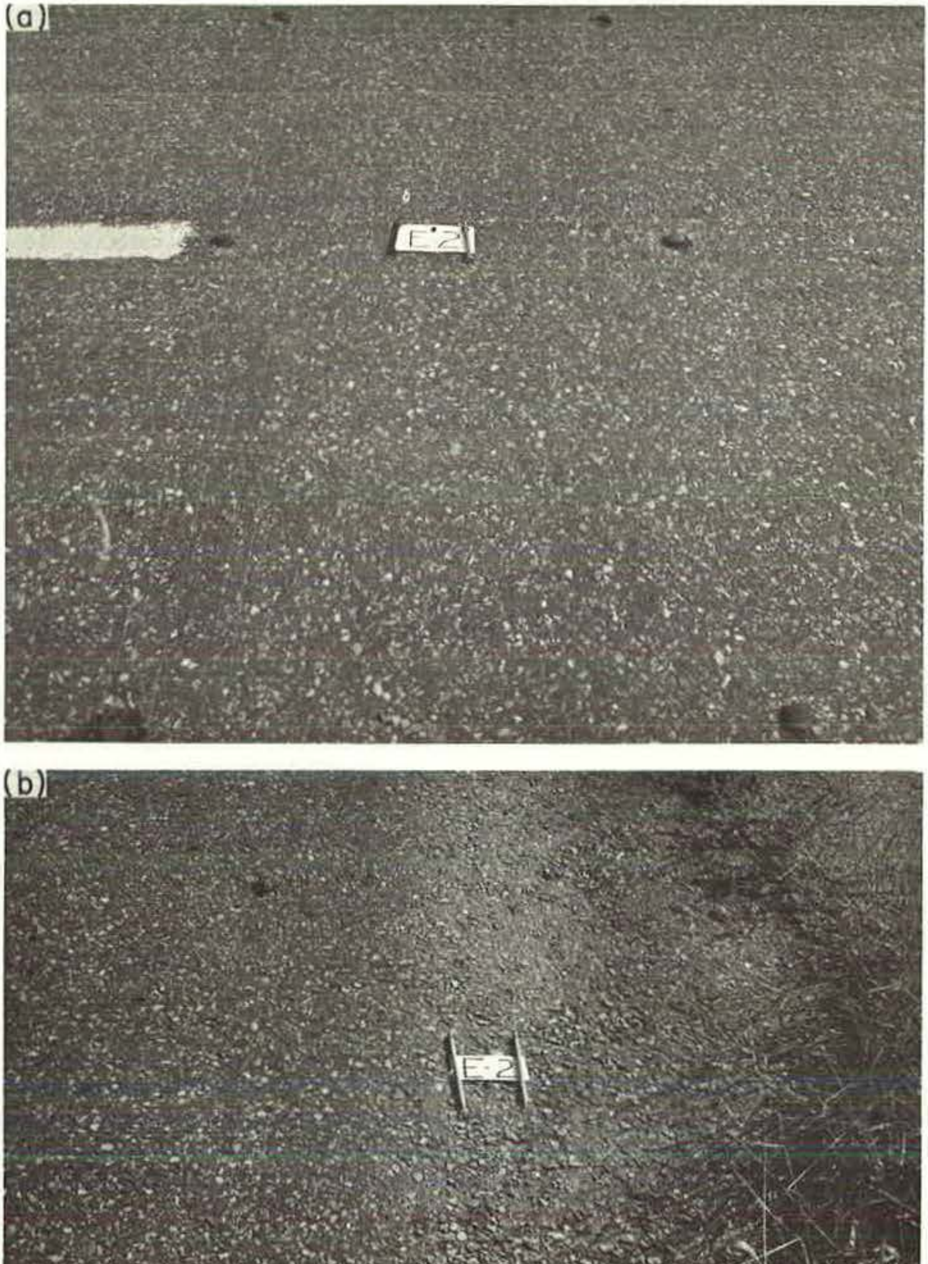

Figure 6. Abrupt stop site, bituminous concrete: (a) before and (b) after test.

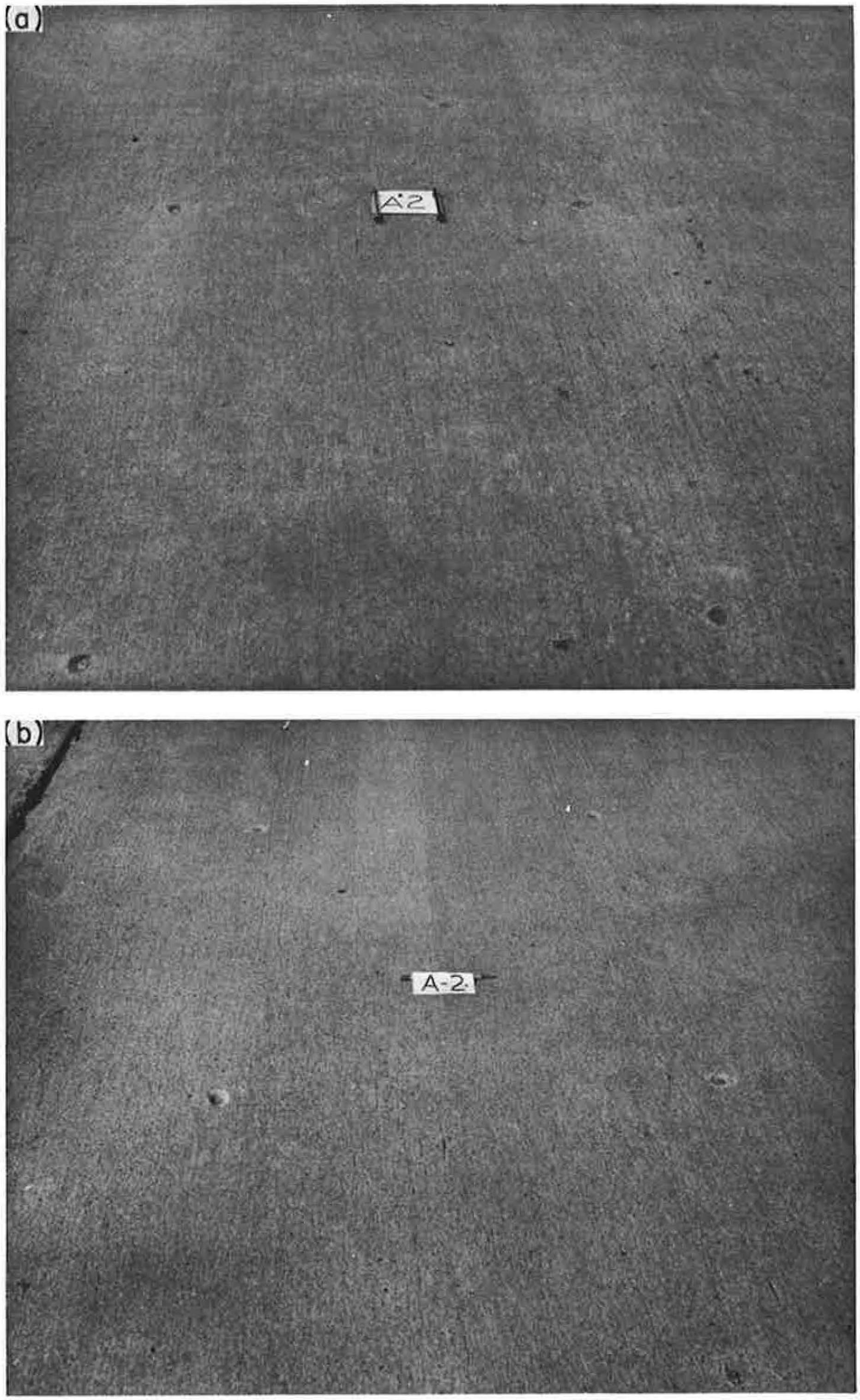

Figure 7. Normal wear site, portland cement: (a) before and (b) after test.

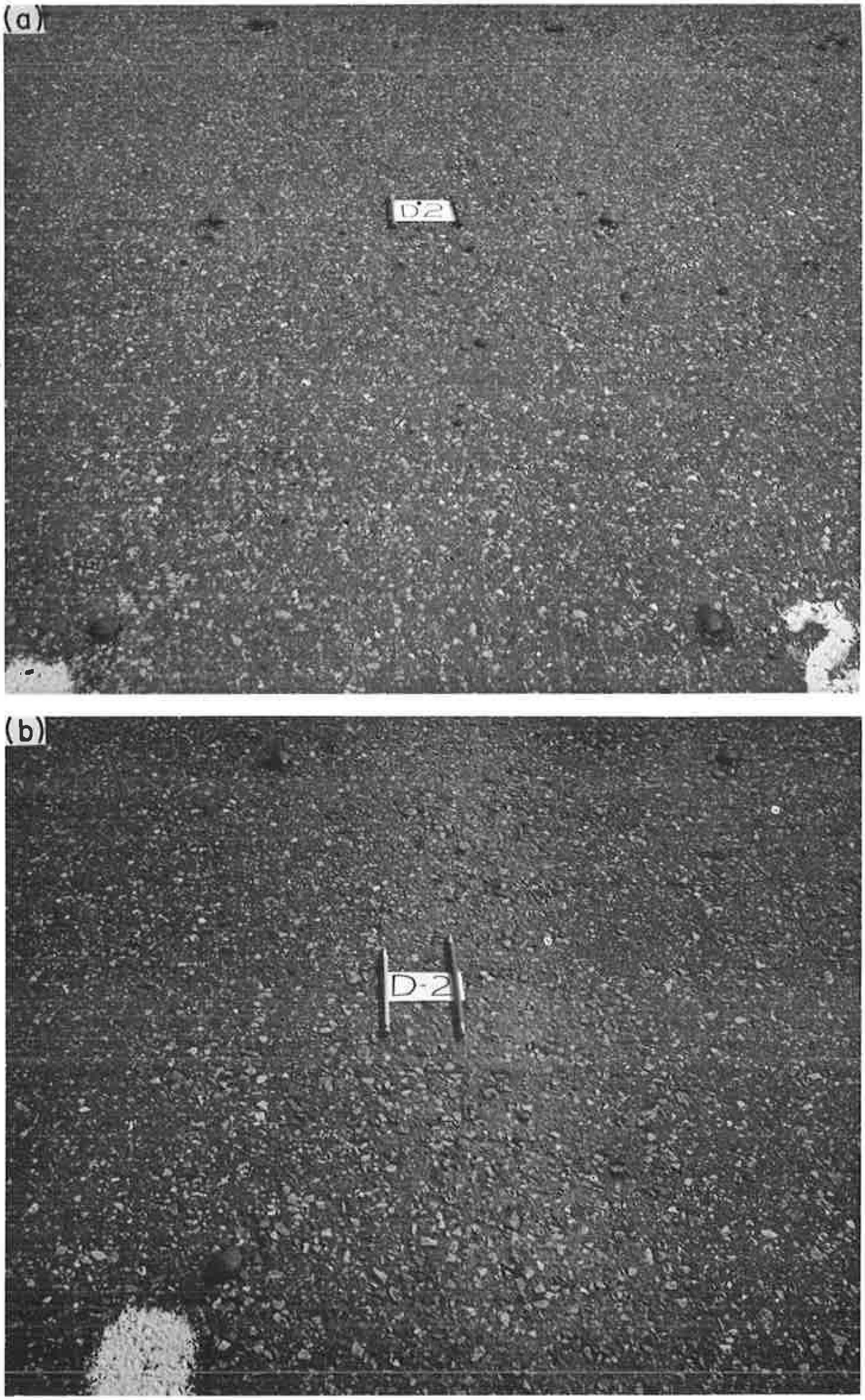

Figure 8. Normal wear site, bituminous concrete: (a) before and (b) after test.

Photographs of test track pavement surfaces, in the before and after condition were made for the panic stop sites (Figs. 3 and 4), for the abrupt stop sites (Figs. 5 and 6), and for the normal wear sites (Figs. 7 and 8) for both the portland cement and bituminous concrete test sections.

The determination of wet pavement skid resistance changes due to the use of studded tires and due to ordinary rubber tire wear was also attempted as part of the overall field test program. Test track skid measurements provided the necessary data regarding studded tire effects on pavement skid resistance. Ordinary rubber tire wear effects on wet pavement skid resistance were also measured on a variety of pavements in service, and graphs indicating loss of skid resistance vs vehicle passes were plotted for both bituminous concrete and portland cement concrete pavements (Fig. 9). No attempt was made to relate vehicle passes to actual wheel passes. Obviously, however, vehicle numbers would have to be multiplied by at least a factor of two to obtain wheel passes.

The following procedure was used to obtain pavement skid resistance data attributable to conventional rubber tires on typical state highways. Twelve locations throughout the state were selected representing routes having low to high accumulative traffic volumes since opening to traffic. Some were on new alignment and some were rehabilitated (widened and resurfaced) routes on existing alignment. The bituminous concrete and portland cement concrete surfaces were equally represented.

Traffic volumes, 2-way AADT, were obtained for each year that these roads were opened to the public, to the present. With the use of these data the accumulated traffic was computed (Table 1). Specific information concerning lane distribution of traffic was lacking for the routes and time intervals involved. On consulting with traffic personnel and reviewing data contained in the 1965 Highway Capacity Manual, it was de-

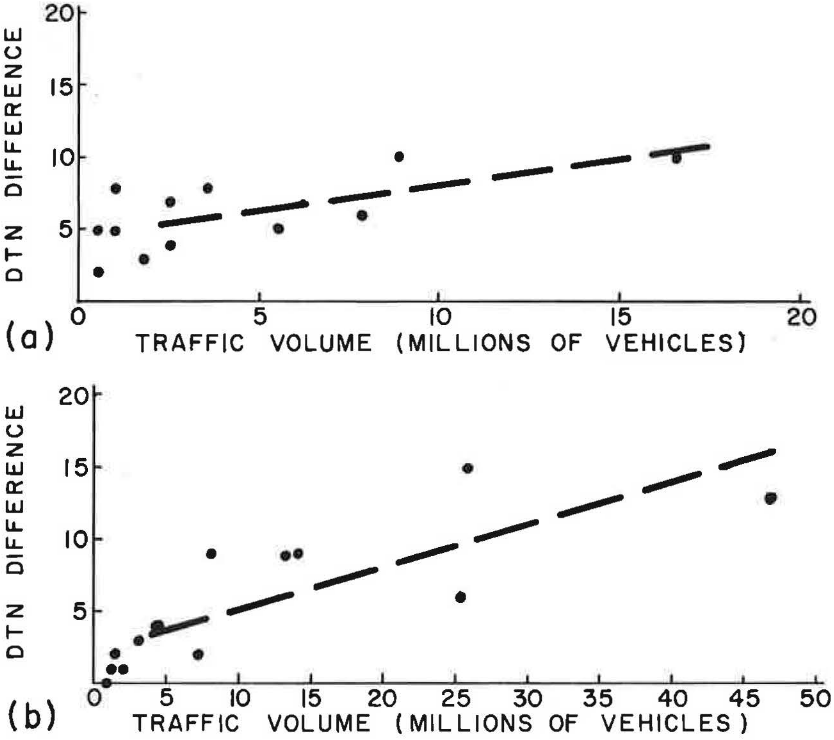

Figure 9. Loss of pavement surface skid resistance: (a) bituminous concrete and (b) portland cement concrete.

TABLE 1

PAVEMENT DATA—SKID RESISTANCE LOSS TESTS

Route	Section	Opened to Traffic	Total Vehicle Passes: Left Lane	Total Vehicle Passes: Center Lane	Total Vehicle Passes: Right Lane
(a) Bituminous Concrete Pavement Surfaces					
129	1A	9-29-61	554,900		1,011,700
9	23A&24A	12-11-65	555,000		1,030,000
80(101)	2B	8-16-63	1,195,000	2,495,000	1,748,000
80	5V	12-11-64	1,714,000	3,567,000	2,497,600
80(101)	2A	4-24-62	3,761,000	7,865,000	5,479,000
1	2	9-26-59	8,883,000		16,476,000
(b) Portland Cement Concrete Pavement Surfaces					
29 Fwy	13F, 14A, &15B	6-23-65	816,000		1,515,000
95(287)	3C	7-1-63	1,400,000	3,000,000[a]	1,950,000
1(26 Ext)	3A	11-30-55	4,335,200		8,051,300
78(102)	2B	10-30-59	7,193,000		13,341,000
29 Fwy	13A	9-6-56	13,960,000		25,936,000
1(26 Ext)	2D	5-24-54	25,255,000		46,920,000

[a] This is a four-lane facility; each of the two central lanes is represented by the volume indicated.

termined reasonable to assume the following: (a) a 50-50 distribution of the reported 2-way AADT; (b) a distribution of the 1-way AADT of 65 percent and 35 percent for the right and left hand lanes respectively for a four-lane facility (two lanes in each direction); (c) a distribution of 32, 46, and 22 percent for the right, center and left lanes respectively for a six-lane facility (three lanes in each direction); and (d) a distribution of 21, 32, 32, and 15 percent for the right, central and left lanes respectively for an eight-lane facility (four lanes in each direction).

A portable skid resistance tester, as manufactured by the Die-A-Matic Corporation, was used to determine the relative skid resistance of the pavement surfaces in the test track area. Sites subjected to testing were those in which the test vehicle was so driven as to produce panic stops, abrupt stops, and normal wear. At each location, four longitudinal test paths were selected for each lane. These four test paths were located approximately 1 ft from the outer limits of each lane, and in the paths traversed by the left and right wheels of the vehicle. Considerable judgment in the application of the foregoing procedure had to be exercised to insure that a portion of pavement denoting virtually no surface wear was tested to afford comparison with wheelpath measurements. All measurements were made in the direction of traffic. Three readings were made at each location and the average of these readings was recorded.

For purposes of comparison, the portable skid resistance tester was also used on the twelve selected in-service pavements essentially following the same procedure as previously outlined with particular care taken to eliminate oil dripping effects from the measurements. Where it appeared obvious that between-lane traffic movements caused surface wear along lane edges, the maximum values were derived from locations having virtual freedom from traffic. The results of these tests are given in Tables 2 and 3 and shown in Figure 9, which plots traffic volumes vs maximum DTN (Drag Tester Number) differences. A least-square line which does not adequately account for initial effects is shown to indicate trend only. No attempt is made to convert the DTN differences to actual coefficient of friction losses; however, it is considered that a DTN difference of 15 units represents a serious loss of surface skid resistance, within the range of the recorded measurements, and that a DTN difference of 3 units represents a meaningful change of skid resistance.

During the selection of the actual sites for testing, a specific effort was made to choose locations which contained only direct traffic patterns relatively unaffected by roadside or geometric conditions. Throughout these tests weathering and other effects

TABLE 2

SKID RESISTANCE MEASUREMENTS

Route	Section	Drag Tester No.						
		Max	Minimum			Difference		
			Left	Center	Right	Left	Center	Right
(a) Bituminous Concrete Pavement Surfaces								
129	1A	35	33	—	30	2	—	5
9	23A&24A	38	33	—	30	5	—	8
80(101)	2B	31	—	27	28	—	4	3
80	5V	40	—	32	33	—	8	7
80(101)	2A	35	—	29	30	—	6	5
1	2	40	30	—	30	10	—	10
(b) Portland Cement Concrete Pavement Surfaces								
29 Fwy	13F, 14A, &15B	34	34	—	32	0	—	2
95(287)	3C	36	35	33	35	1	3	1
1(26 Ext)	3A	38	34	—	29	4	—	9
78(102)	2B	40	38	—	31	2	—	9
29 Fwy	13A	40	31	—	25	9	—	15
1(26 Ext)	2D	40	34	—	27	6	—	13

TABLE 3

SKID RESISTANCE MEASUREMENTS—TEST TRACK

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

occurring to the pavement surface were ignored. This approach was believed reasonable due to the lack of visible effects attributable to causes other than traffic wear.

The results of the skid test track program indicated that wet pavement skid resistance losses due to the use of studded tires were significantly larger in the bituminous concrete sections than in the portland cement concrete sections. The resultant loss in skid resistance in the normal wear bituminous concrete test section was higher than or equal to that recorded for any actual in-service pavement lane having an existence of up to five years and being subjected to in excess of 7,000,000 vehicular passes. However, some of the bituminous concrete pavement surfaces considered also had a tendency to lose skid resistance relatively rapidly although they were subjected to traffic passes considerably in excess of those applied to the test track pavements. The pavement skid resistance losses in the bituminous concrete panic and abrupt stop sites greatly exceeded the observed losses of all actual in-service bituminous concrete pavements tested. The portland cement concrete pavement surface in the normal wear section exhibited a skid resistance loss approximately equal to a similar in-service pavement exposed to use for seven years and subjected to more than 7,000,000 vehicular passes. The abrupt stop test section actually experienced less loss of skid resistance than the normal wear section for portland cement concrete pavement. The skid resistance loss experienced by the pavement surface at the portland cement concrete panic stop site is exceptional and represents a large change in surface qualities.

The significance of the foregoing results, when related to past road performance, is that wet pavement skid resistance losses, as measured by a low and constant speed testing device, occurred at an apparently accelerated rate due to a relatively limited use of studded tires.

ACCEPTANCE PROCEDURE APPLICATION

An acceptance procedure, as briefly described previously in this paper, was developed before the first winter season of studded tire use and was intended to be the primary instrument by which the New Jersey State Highway Department would provide its concurrence to the individual studded tire approvals issued by the Division of Motor Vehicles. The acceptance procedure, as originally devised, soon became obviously impractical, primarily due to the large number of tires ultimately submitted for approval, and was not officially used during the first winter season of studded tire use.

As an alternative to the formal use of the acceptance procedure for studded tire approval, a testing program was established by the Highway Department which incorporated virtually all of the factors of the original acceptance procedure, with the exception that actual tire road test provisions were revised by having the available studded tires placed on the various departmental passenger vehicles in use, and by devising a questionnaire to be filled out by drivers of these vehicles. This approach allowed a rather broad view of the general performance of studded tires, in addition to providing some insight into the validity of the various aspects of the acceptance procedure.

The initial provision of the proposed acceptance procedure involved the recording of the number, pattern of installation, and type of stud in each tire. The number of studs in each tire was carefully recorded soon after receipt, and each tire was subjected to a stud recount after the completion of actual use on a highway vehicle. The number of studs in the various individual test tires ranged from a minimum of 56 to a maximum of 132.

The following listing provides an indication of the number of studs in individual tires submitted for approval:

No. of Tires	Studs/Tire
2	50-59
6	60-69
23	70-79
20	80-89
20	90-99
21	100-109
2	110-119
6	120-129
6	130-139

Many of the tires submitted, some containing over 100 studs, had a large number of additional openings which were able to accommodate more studs. The wide difference in neatness and trueness of stud application varied subjectively from good to poor.

An initial attemp to investigate patterns of stud installation was soon discontinued because most of the specifications were not received with the tires. A few patterns were slightly irregular; however, no stud pattern was considered totally objectionable.

The type of stud used in each tire was relatively consistent in that they were generally of the same size diameter ($^3/_{32}$-in. pin, $^5/_{32}$-in. encasement) and all were encased in metal. A small number of studs were removed from various tires and their average length was approximately $^9/_{16}$ in. A shorter stud length, approximately $^7/_{16}$ in., was extracted from one studded conventional tire set.

At the end of the winter season, the studded tires were removed from the highway department vehicles and mileage and stud loss were recorded. A total of 84 individual tires were used on highway vehicles during this period, and of this number 10 tires had lost studs, totaling from one to as many as nine studs per tire. The tires placed on highway vehicles were snow tires and were only placed, in sets, on the rear wheels of the vehicles. The foregoing data exclude the four sets of studded tires used on the test track vehicle.

The individual mileage recorded for tires placed in general service ranged from a minimum of 946 to a maximum of 10,965 mi. An attempt to relate stud loss with mileage proved fruitless. However, it is possibly significant that a set of two tires having 132 studs per tire, lost nine studs from each tire, and the tire containing 118 studs lost seven studs although the mate to the latter tire, containing 117 studs, did not lose any. The mileage in each of the foregoing cases did not exceed 3,000 mi.

The second principal acceptance procedure test required measuring stud projections from the tire surface. This was accomplished by the use of a machinist's scale, graduated to $^1/_{100}$ in. A random sample of five stud projections was generally measured for each set of studded tires. The specified allowable range of stud projection (0.04 to 0.06 in.) was extremely small and the majority of tires (41 out of 53 sets) contained studs which had projections outside of this range. Stud projection measurements were made only on new tires, before any road use. The maximum range of stud projections recorded, considering all tires, was from 0 to 0.12 in. This same maximum range was also observed on one individual set of tires.

The third element of the proposed acceptance procedure consisted of an effort to insure that studs were firmly seated in the tires. This was accomplished by applying to at least one stud in a tire set an arbitrarily established minimum tensile force of 30 lb. The method used was to grasp the projecting stud with a lockwrench and to exert a radial pull by the additional attachment to the lockwrench of a surveyor's taping scale. The latter element provided the means of force measurement. This stud extraction test was successfully applied to only 29 sets of tires, because in many instances proper gripping of the stud was not possible or the tungsten carbide tip was actually broken. Of the 29 sets of tires successfully tested, only one tire set failed to meet the 30-lb pull requirement. The studs in the failing tire set were fully extracted by a sustained pull of 30 lb. The failing tire set was the only set of conventional treaded tires subjected to testing, and the length of studs placed in this tire was $^7/_{16}$ in., less than the average $^9/_{16}$ in. stud length observed. The foregoing circumstances have further significance in that this particular set of tires was placed on the front two wheels of the vehicle used in the panic stop tests. After a total of 1400 panic stops on both rigid and flexible type pavements, and a total use mileage of 674 mi, this particular set of tires had lost 101 studs out of a total of 157 studs in the new tires. The rear wheels of the panic test vehicle were equipped with studded snow tires which did not lose any studs out of a total of 206 studs. At the conclusion of the panic test program the studs in the conventionally treaded tires protruded excessively.

Subsequent stud extraction tests applied to each tire set indicated that the studs in the conventionally treaded tire could be pulled out with a radial tensile force of only 26 lb, whereas the studs in the snow tires were still firmly embedded. The panic test program was extremely severe, and the front tires of the test vehicle undoubtedly were subjected to greater straining effects. However, the unusual tire performance may support the desirability of having tensile tests applied to studs and may imply that the arbitrarily established 30-lb pull has some significance in relation to stud loss in actual tire performance.

Further comparison is provided by examination of the tires used in the abrupt stop test program, in which both front and rear wheels were equipped with studded snow tires and in which only one stud was lost out of a total of 321 studs in all four tires.

The remaining sections of the proposed acceptance procedure can be grouped and classified as general tire performance considerations. It was the original intent to subject each set of studded tires submitted for approval to a series of road tests which would compare the performance of studded tires to conventional snow tires in the general categories of stability, handling, and skid resistance. In addition, a series of rapid acceleration tests was to be accomplished at a particular site, and pavement ruts caused by studs were to be measured. A final consideration was a durability test in which each set of tires was to be subjected to 1,000 mi of general driving. After such time, the tires were to be checked for stud loss or any other undesirable conditions due to the effects of wear. It was this portion of the proposed acceptance procedure which became impractical when substantial numbers of tires were submitted for approval.

Initial attempts to utilize the proposed acceptance procedure were made at the time when only a few sets of tires were available for testing. Comparative skid resistance tests were made on dry pavements by simply operating similar vehicles at estimated identical speeds, over the same pavement sections, and measuring the resultant skid marks. These rather crude attempts indicated no particular difference in the relative skid resistance, on dry pavements, of vehicles equipped with studded tires as compared to conventional snow tires. Attempts at rapid acceleration were also accomplished; however, the relative lack of power of the test vehicles made this approach virtually impossible.

On reaching agreement regarding the impracticability of the acceptance procedure, an alternate approach was devised which consisted of placing the available studded tires, in sets, on the rear wheels of departmental passenger vehicles for the duration of the winter season and of developing a questionnaire to be completed by the various drivers of these vehicles.

Table 4 gives the principal inclusions of the final questionnaire form and the results of this effort. The items in this admittedly subjective document are believed self-

TABLE 4

STUDDED TIRE PERFORMANCE SUMMARIZATION—QUESTIONNAIRE REPLIES

Operation	Compared With Unstudded Tires	Pavement Conditions			
		Dry	Wet	Snow	Ice
Normal acceleration traction	Not as good	2	6	1	2
	Equal	43	43	16	15
	Better	4	10	26	24
Rapid acceleration traction	Not as good	8	8	—	—
	Equal	33	27	17	14
	Better	5	10	21	21
Ability to hold straight course	Not as good	7	9	1	2
	Equal	36	34	29	20
	Better	4	7	12	19
Control in passing	Not as good	2	8	3	3
	Equal	44	34	25	21
	Better	3	8	14	16
Crossing longitudinal lines	Not as good	2	4	—	—
	Equal	41	34	29	21
	Better	1	5	6	11
Cornering	Not as good	6	9	1	2
	Equal	35	28	25	20
	Better	7	9	16	18
Side skid resistance	Not as good	8	9	1	1
	Equal	33	31	25	20
	Better	6	9	16	20
Normal stop	Not as good	3	3	—	—
	Equal	34	31	23	21
	Better	10	14	18	18
Panic stop	Not as good	6	6	—	1
	Equal	27	21	19	13
	Better	6	12	17	21

explanatory and cover a rather broad area of performance consideration. This approach was intended, at the outset, to be a means of detecting only grossly objectionable characteristics of studded tires, with the realization that innumerable variables were present.

Studded tire use in snow and ice pavement conditions, for purposes of review, are combined because the distinction between these categories was not believed adequately defined to allow proper discrimination. It is evident that a significant majority of questionnaire returns indicate "equal" or "better" performance in snow and ice situations for all categories. In acceleration traction (or straight line driving) the "better" indications outnumbered the "equal" indications; however, for all categories considering side movements and stopping all replies indicate more "equal" than "better" ratings for snow and only two exceptions to this trend for ice conditions. More "better" ratings were given to studded tire performance on ice than to any other category.

Considering questionnaire replies in the dry and wet pavement categories together, there was a more prevalent central tendency resulting in a greater application of the "equal" rating than in the snow or ice condition. The distribution of "not as good" and "better" ratings, for dry and wet categories, was rather even in all but two stopping performance categories. In normal stopping on dry pavements and in both normal and panic stopping on wet pavements, the studded tires were considered to have some apparent advantages. In the categories of rapid acceleration traction, ability to hold a straight course, and side skid resistance the "not as good" ratings outnumbered the "better" ratings in the dry pavement condition. These latter categories were believed interpreted as being related to some form of vehicle stability.

Numerous attempts to relate the various aspects of the proposed acceptance procedure with the results of the questionnaire proved essentially fruitless, except in one possible category. Individual replies regarding four out of eight vehicles, equipped with tires having measured stud projections of 0.09 in. or greater, included some unfavorable ratings, particularly in relation to vehicle stability. Of 17 other vehicles equipped with tires having measured stud projections of from 0.07 to 0.08 in., seven vehicles received some unfavorable ratings. The foregoing remarks pertain to performance on dry or wet pavements only. In the general comments category, 11 returns included additional remarks regarding a higher noise level. One report also indicated that the tires were picking up leaves, and another report indicated hearing a rather sharp pinging sound, after which a stud was lost from a tire. No comments regarding damage of any type due to stud loss were forthcoming, although approximately one-fifth of all tire sets tested exhibited some loss.

In summary, it appears that the studded tire, in fact, has advantages in snow and ice under actual driving conditions, although these advantages do not appear to be necessarily equal in all categories not as pronounced as simple stopping distance testing results on ice might suggest. With regard to studded tire performance on dry and wet pavements, there is reservation regarding their ability to provide overall stability equal to that of conventional rubber tires, particularly when studs have excessive projections. This was an overriding concern on the part of most drivers producing "not as good" ratings.

SUPPLEMENTARY CONSIDERATIONS

It was recognized early in this study that the overall evaluation of studded tire use would require numerous additional considerations beyond the efforts described previously in this report. Of the multitude of relationships possible it was decided that the following additional considerations should be developed further. Initially, an attempt was made by field surveys to establish the incidence of panic stops at high speed signalized intersections. A second effort involved the compilation of pertinent climatological data for two regions of New Jersey for the last three winter seasons. Next, a summarization of traffic accident data regarding skidding and/or same-direction type accidents reported for a 3-yr period was accomplished for a relatively representative cross-section of the New Jersey highway system. In addition to the foregoing, the Maintenance Bureau of the State Highway Department was alerted to the possibility of pavement damage due to studded tires and requested to report same. A review of traffic accidents involving departmental vehicles was made for the 1965-1966 winter season, and a limited survey of retail tire dealers was made to attempt to ascertain the number of studded tires possibly in use during the first winter season.

A series of traffic surveys was accomplished in conjunction with the field test program to project panic stop test track results to potential pavement damage due to panic stops. Four independent sites were selected, each being at a signalized intersection with accompanying jughandle turning provisions. The sites selected were located at various points on Route 1, a four-lane, barrier-divided, land-service highway. Route 1 at the time of the survey had a maximum speed limit of 50 mph and a 1965 2-way AADT of 22,000 vehicles.

The survey was accomplished by counting skidding occurrences in lanes for both passenger and commercial vehicles. The basic criterion used to define a panic stop was that vehicle stops which included skidding, regardless of magnitude of slide, were to be recorded. The surveys were conducted only during daylight hours in essentially dry weather. Pavement surface marks observed on days following surveys indicate that at least an equal amount of skidding occurred during the evening hours. The results of the foregoing survey indicate a potential for pavement damage due to panic stopping at the majority of these sites (Table 5). The locations of the panic stops observed were generally near the entrances to existing jughandles.

A review of climatological data for the past three fall-winter-spring seasons was accomplished for the northeastern and central New Jersey regions. An annual average

TABLE 5

OBSERVED SKIDS (PANIC STOPS)

Location	Passenger Vehicles						Trucks	
	Total Time of Surveys (hr)	Total Count	East Lanes		West Lanes		Total Count	Skids
			Outside Lane	Inside Lane	Outside Lane	Inside Lane		
Route 1 at:								
Bakers Basin Road	20	14,329	7	10	8	11	2905	2
Meadow Road	9	7,640	15	10	8	13	1832	11
Quakerbridge Road	4	3,228	3	6	2	1	699	3
Vicinity of Heineman Electric	7	6,643	15	15	9	6	1418	8

TABLE 6

SAME-DIRECTION AND/OR SKIDDING ACCIDENTS—1962-1964[a]

Month	Monthly Total	Road Conditions		
		Dry	Wet	Ice and/or Snow
Jan.	157	76	40	41
Feb.	150	48	52	50
Mar.	149	93	41	15
April	172	109	63	
May	142	98	44	
June	158	95	63	
July	151	105	46	
Aug.	162	123	39	
Sept.	191	110	81	
Oct.	185	144	41	
Nov.	229	122	107	
Dec.	214	95	67	52
Total	2,060	1,218	684	158

[a]Routes	Sections
130	7E,8D,9D,10D,1A,7C & 9C,10E,7B & 10B,7A
322	3A,11A & 3B
30	14A,2
46	5B & 6A,5A

of 27 days in which snow fell was recorded, and a combined annual average of 49 days was recorded as "snow" and/or "snow-on-ground." An analysis of temperature ranges and other thermal effects indicates that virtually all of the days designated as snow-on-ground would have the potential of causing limited icing of roadways if ice or snow were initially present on the roadway. The problem of frost occurrence on road surfaces was given individual attention; however, it was not believed to add to the 49-day figure. From the preceding data it appears that it is remotely possible that an annual total of approximately 49 days could involve general hazardous conditions. This estimate is considered very high because a multiplicity of effects is present to reduce significantly the actual time of hazardous conditions.

An accident summary for four routes, over a 3-yr period, was compiled with particular regard to the incidence of reported skidding and/or same-direction type accidents (Table 6). The skidding and same-direction accident categories were selected because they were believed most representative of the types of accidents for which studded tires would provide maximum benefits and for which loss of pavement skid resistance would be most detrimental. The maximum number of same-direction and/or skidding accidents occurred during November, a month in which virtually no snow fell during the past three years. December also displayed a high number of similar type accidents; however, the holiday season is believed influential in these statistics. The significant point is that January, February, and March exhibit relatively low recorded numbers of same-direction and/or skidding type accidents. This latter phenomenon may be primarily due to a more cautious driving attitude during these periods. Obviously, the number of same-direction and/or skidding type accidents recorded in New Jersey in conjunction with snow or ice covered pavements is relatively small, representing approximately only 8 percent of the total annual number of similar type accidents.

The Maintenance Bureau of the State Highway Department had been requested to forward recorded instances of pavement damage that could be attributed to studded tire effects. Photographs were provided to pertinent personnel to aid in the recognition of studded tire involvement. No reports of damage were provided for the first winter season of use.

A review of the accident records of the State Highway Department, involving departmental passenger vehicles, for the 1965-1966 winter season showed that two out of 48 vehicles equipped with studded tires (rear wheels only) were involved in accidents, whereas the total number of accidents recorded involving passenger vehicles equipped with conventional or snow tread tires, out of approximately 400 vehicles, was 36.

The actual number of vehicles equipped with studded tires in use on the New Jersey highway system during the first winter season of permitted use is not known. A survey of retail tire dealers indicated that sales of studded tires were relatively low. The most reasonable explanation for this situation is that initial tire approvals occurred immediately before the permitted period of use, a late promotional effort was made, and a relatively large increase in cost ($6 to $10 per tire) occurred.

The additional cost of repair due to the anticipated damages possible from the widespread use of studded tires was also considered. It was believed, however, that this item requires considerable attention before any truly meaningful cost estimate can be made. If the effects at intersections, as related to panic stopping and accelerated starts, is as severe as anticipated, the fact that New Jersey has a total of approximately 1300 signalized intersections in its state highway system would indicate that increased maintenance costs could be incurred.

ANALYSIS

A general analysis of the results of this research makes apparent the fact that the desirability of using studded tires on the New Jersey highway system must still be judged on limited data which are quite subjective in substance and of questionable use in terms of projection. The results of this research, in most instances, cannot be considered definitive; however, it was believed that sufficient insight into the total problem had been achieved to allow a more refined judgment at the present time.

The actual pavement wear, even when studded tires are restricted to use on passenger vehicles, does require serious consideration. It appears that high traffic volumes, containing relatively small percentages of vehicles equipped with studded tires, cause appreciable road wear. The curves developed in the field test program and the normal wear values provided do indicate a slow but progressive wearing effect. The characteristics of this wearing process are not well defined by the amount of testing achieved; however, it appears that the use of studded tires will ultimately require corrective construction in excess of present normal maintenance requirements. An attempt to place a dollar value on this work at this time would be sheer guesswork. One final observation regarding pavement wear is that bituminous concrete construction appears more severely affected by studded tire use than portland cement concrete pavement.

The next consideration is that of loss of skid resistance by pavement surfaces. The major field test observation of detrimental physical effects caused by studded tires is believed to be that concerning new pavement skid resistance loss. The large differences experienced in the panic stop sites and the general loss of skid resistance in the abrupt stop and normal wear sections indicate the possible existence of a serious phenomenon.

Pavement slipperiness is recognized today as a major contributor to accidents, and/or accident severity. Existing research results relate these factors in spite of the complexity of interactions which occur. Skid resistance loss itself is a rather subtle occurrence and is not always readily noticeable to the average motorist. Major efforts are being expended in New Jersey at the present time to develop an improved skid measuring device and ultimately to establish minimum pavement skid characteristic limits.

Caution is necessary, however, in the interpretation of the recorded test track skid resistance losses. Initially, the skid testing device used is subject to the limitations generally attributed to low, constant speed instruments, particularly in their ability to correlate pavement skid resistances at higher vehicle speeds. Also, the test track losses may be considered those of a subjectively rated "excellent" surface being reduced to that of a "good" or "very good" surface. The further reduction to a "poor" surface is not determined by this research effort, nor could the effect of studded tires on a "poor" surface be predicted. In addition, comparisons with actual pavement skid resistance losses involve some material variances and initial construction effects, particularly because the assumed original skid resistance values of the actual pavements were generally lower than those of the original test track surfaces. The fact remains, however, that new pavement skid resistance losses due to studded tire traffic occurred with only a relatively small number of vehicle passes.

The principal concern is not that studded tires would be the direct cause of slippery pavements, but that their effects would cause accelerated initial skid resistance losses and related effects which would allow ordinary traffic to diminish pavement skid resistance at a more rapid rate.

In bituminous concrete pavement, the loss of bituminous materials and very fine aggregates is considered undesirable, as is the abrading effect on the exposed coarse aggregate. The effects of further normal rubber tire traffic is not determined by this research; however, it appears that the coarse aggregate is vulnerable to an accelerated polishing effect.

In portland cement concrete pavement, the initial losses of surface finish and mortar are not necessarily of primary concern in themselves. The fact that progressive pavement wear occurs indicates that the removal of mortar from the pavement surface causes coarse aggregate exposure at a much more rapid rate than that caused by normal rubber tire traffic. New Jersey portland cement concrete pavements have an exceptional record of durability, many being over 30 years old. Also, some of the most slippery pavements in New Jersey are portland cement concrete pavements having a high degree of exposure and protrusion of their constituent coarse aggregates. This condition, however, is not normally achieved for a great many years. The probability that studded tire erosion of the cover and surrounding mortar would cause early exposure of the highly durable coarse aggregates used in New Jersey has been of primary concern.

TABLE 7

SUMMARY OF NEW JERSEY MOTOR VEHICLE ACCIDENTS—1962-1965

Year	Road Conditions		
	Dry	Wet	Ice and/or Snow
(a) Total Accidents			
1962	93,670	25,242	11,298
1963	96,542	28,629	17,017
1964	111,000	38,979	14,847
1965	116,153	39,042	11,948
Total	417,365	131,892	55,110
Percentage	(69.1%)	(21.8%)	(9.1%)
(b) Accidents Involving Injuries			
1962	39,334	13,629	4,260
1963	43,366	12,921	5,869
1964	48,678	17,021	4,373
1965	51,282	17,610	3,705
Total	152,660	61,181	18,207
Percentage	(65.8%)	(26.4%)	(7.8%)
(c) Accidents Involving Fatalities			
1962	613	166	34
1963	671	126	50
1964	731	206	25
1965	778	191	25
Total	2,793	689	134
Percentage	(77.2%)	(19.1%)	(3.7%)

The need for additional information is believed paramount in the area of pavement skid resistance, in relation to studded tire use, particularly for states such as New Jersey in which excessive traffic volumes are encountered and the apparent need for studded tires is relatively slight.

Selected traffic accident statistics for four routes (130, 322, 30, 46) representing a variety of locations provides additional data for analysis. Out of a total of 2,060 reported skidding and/or same-direction type accidents for a 3-yr period (1962-1964) the number of accidents attributable to ice or snow on the road surface was only 158. Although November and December had the largest recorded number of accidents of this type, January, February, and March had a relatively low number of reported similar type accidents. Virtually no snowfall was recorded in November during the past three winter seasons. During the 3-month period from December through February, in which the major portion of the ice and snow in New Jersey occurred, a total of 521 accidents of the skidding and/or same-direction types was recorded for these routes; of these 143 were associated with a snow or ice condition.

A summary of total accidents of all types in New Jersey (Table 7) for the years 1962-1965 indicates a predominance of accidents occurring during dry and wet road conditions, as opposed to accidents occurring on an ice and/or snow covered road surface. Of particular importance are the statistical totals dealing with injuries and fatalities which, regarding wet roads, actually rise in the injury category to 26.4 percent and decline slightly in the fatality category to 19.1 percent of the total injuries and fatalities, respectively. The percentage of injuries reported in accidents on ice and/or snow covered roads actually decreased to 7.8 percent of total injury accidents, and the fatality total on ice and/or snow covered roads decreased sharply to 3.7 percent of all accidents involving fatalities. The foregoing total accident summaries serve to support the use of the specific accident summary which includes accidents involving skidding and/or same-direction accidents (Table 6).

An analysis of the past three winter seasons indicates an annual average of only 27 days in which snow was recorded. Additional analysis indicates a rather remote possibility of generally hazardous driving conditions due to snow or ice on an annual average of 49 days. This figure is considered very high, and its impact greatly reduced, particularly in light of the fact that the majority of hazardous road conditions contemplated would most likely occur in isolated locations and would probably only prevail for a portion of each day. Further, the aggressive snow removal and deicing policies of the State Highway Department and of local agencies would contribute significantly toward reducing the actual time period of hazardous road conditions due to the presence of snow or ice.

The significance of the foregoing is that studded tires are essentially claimed to be beneficial in an iced road situation, yet in New Jersey this beneficial aspect can only be applied to a relatively low percentage of accidents in which studded tires would offer partial advantages, and only for a short time.

Regarding driver questionnaire replies and subsequent commentaries, it is determined that studded tires are effective on a snow and/or ice covered road surface.

However, the fact that approximately 40 percent of the vehicles involved received some individual unfavorable ratings on dry or wet pavements, when using tires with stud projections in excess of the specified maximum protrusion, leaves at least a reasonable doubt concerning the general performance of studded tires on dry and wet pavements compared to ordinary rubber tire performance. Related to this is the necessary concern regarding means of regulating stud insertion procedures, particularly in the light of the large stud projection variances observed in the sample studded tires tested in this program. The foregoing remarks are made regarding the entire sample tire group tested, and are not necessarily true for any individual tire type.

The ability of studded tires to perform in a superior manner on ice and snow covered road surfaces in New Jersey is reduced by the following considerations: (a) the vast majority of accidents occur on dry or wet pavements in New Jersey, and studded tire performance on dry or wet pavements may be inferior to ordinary rubber tire performance in certain characteristics if studs have excessive projections; (b) studded tire use causes an apparent rapid decrease in new pavement normal travel skid resistance; (c) the beneficial period for use of studded tires is very limited in New Jersey; (d) pavement wear can result in increased maintenance costs; and (e) substantial stud loss may occur.

CONCLUSIONS

The principal initial conclusion derived from this research is that the cited advantages of studded tires have bases in fact but that these advantages could be diminished by important disadvantages if unlimited use on passenger vehicles in New Jersey were continued. A plausible extension of the data on hand and the analysis presented indicate that the more immediate benefits of studded tire use in New Jersey are very limited and could likely be outweighed ultimately by the principal disadvantages attached to the potential presence of a less skid resistant and/or more costly system of highway pavement, as well as other important deficiencies.

The limitations of our test data do not warrant final conclusions, nor can the foregoing opinions necessarily be applied to any state other than New Jersey. The validity of the major concern regarding accelerated pavement skid resistance losses in New Jersey must ultimately be proven of actual concern by much further testing. The research described is believed to represent a more comprehensive attempt to evaluate the total effects of studded tire use than that previously provided by much of the available literature. It is also useful in confirming previous observations and highlighting areas of concern which require further and more exhaustive consideration. The major elements of the research described in this paper are being continued for this reason.

Caution is urged once more on the possible applications of the results and conclusions of this study to locations other than New Jersey. Variables of climatic conditions, traffic volumes, accident history, construction materials and methods, as well as other important factors, may prove vastly different in other areas, even in some bordering states. Our research has shown that only comparatively marginal improvements could be anticipated in New Jersey by the introduction of studded tires. Inasmuch as they are convenient and do provide an added measure of winter driving protection, their regulated use in other areas may be entirely justifiable, even in the light of the observed potential disadvantages. A thorough independent analysis by each regulating body is recommended. The comprehensive effort described in this paper is intended to provide an improved indication of true needs, with the best public interest in view.

There is a sincere reluctance to criticize an article which can, selectively, improve highway safety. It is hoped that this work will inspire a cooperative and comprehensive effort by industry and highway representatives to continue to evaluate studded tires and similar products with regard to their overall effects on highway systems.

The common objective remains a total improvement in highway safety for the full range of highway systems and needs.

Discussion

JOSEPH PETER KIGIN, Legislative Assistant, Rubber Manufacturers Association, Washington, D.C.—This discussion was initially motivated by my membership on the HRB's Ad Hoc Committee on Studded Tires. Of greater import, however, is the fact that it represents the concern of studded tire manufacturers over the nature of the paper and its subsequent detrimental effect on the marketability of studded tires. This writer and other industry representatives have objected strenuously to the conclusions of the authors.

The contention of the authors that the report represents a comprehensive research effort to evaluate the potential overall effect of allowing studded tires on the New Jersey highway system is appreciated. However, in turn it is submitted that while the effort was valid, the conclusions to which it gives rise are not necessarily so. These comments are addressed exclusively to the portion of the paper dealing with the areas of pavement damage and skid resistance. The absence of comment on other areas of the paper, however, should not be interpreted as any endorsement of or acquiescence to them.

The damaging effect of studded tires on pavement surfaces and the manner in which their use might alter skid resistance qualities of pavement—two primary areas of the report—were studied under accelerated conditions at a test track of very limited size. During the tests, a passenger vehicle was driven through sustained phases of acceleration and either abrupt or panic-stop conditions. At the end of these tests, observations of pavement damage and skid resistance loss were made and an attempt was made to correlate to actual conditions of motor vehicle usage over New Jersey highways.

This particular attempt at correlation of closed track test data is invalid, because the type of usage to which the studded tires were subjected—acceleration over a short distance and abrupt and panic-stop conditions—does not reflect the type of use which passenger tires will ordinarily encounter at the hands of American motorists.

The tire stud is designed to have a wear rate comparable to the tread rubber of the tire in which it is located. In order to design this comparability, the full range and type of conditions under which the studded tire will be used must be anticipated. This anticipation and subsequent engineering judgments will insure that the stud maintains an optimum degree of protrusion throughout the life of the tire.

The test conditions employed by the authors were such as to defy the established relationship between the stud and the tire and to cause abnormal wear of the tread rubber and excessive protrusion of the stud itself. This excessive protrusion undoubtedly did influence the pavement surface to the degree claimed by the authors. However, seldom, if ever, would the highways be exposed to protrusion of this degree, even under conditions of frequent and extended studded tire usage. In general service, the changes in highway surface as occurred at the New Jersey test site would simply not occur.

The invalidity of both the tests and conclusions of the report were brought to the attention of the authors at the time the report—then proposed—was first received by certain members of the HRB Ad Hoc Committee on Studded Tires.

A photograph of a studded tire that had undergone the tests showed highly abnormal protrusion of the stud. This photograph, originally included in the authors' paper, as made available to a national press medium, was not included in the final paper as published. The protrusion shown in the photograph, which would have developed only under the most extreme conditions, clearly evidenced the invalidity of the testing procedure and the conclusions which it supports.