68-015-7772

SKID RESISTANCE OF BITUMINOUS AGGREGATES

GUIDE LINES FOR FUTURE TESTS

BY

ROGER FERVAL

APRIL 25, 1968

68-015-7772

SKID RESISTANCE

OF BITUMINOUS AGGREGATES

GUIDELINES FOR FUTURE TESTS

SUMMARY

The problem of SKID-RESISTANCE has become increasingly critical. Our first basic approach to it was reviewed in the report entitled Dolomite Study (68-003-7760).

The present supplementary report recapitulates the practical elements needed for implementing a program of systematic research and surveillance, including first of all the essential technical equipment.

CONTENTS

Introduction

Our interim report on skid-resistance under the heading of dolomite (Project #7760) concluded that further tests were required in order to develop more adequate specifications.*

The purpose of this report is to put together bibliographic data on the methods used elsewhere in this country and abroad for conducting tests of this kind.

Two main documents were at our disposal, one of them is the Proceedings of the First International Skid Prevention Conference held in Virginia in 1958, the second one is a collection of papers on slipperiness put out by the French Road Research Laboratory under the title of Glissance.

Most students of slipperiness of roadways underline the fact that its complexity is enormous and the number of variables almost endless. It is clear that oversimplification will not be of any help and isolating a single criterion may be misleading. Whatever we do in this field, there will always be an "if" and a "but"; relativity in this subject is queen.

All of the many papers thus published speak about friction coefficients. But there is little mention of polishing and still less of surface texture. The two last mentioned points are the most important, the most critical and also the least advanced in this recent technology.

We are passing by the many discussions on how to measure the coefficient of friction of surface courses in the field, because our own solution for this particular criterion has already been developed.

---

*For ready reference, copies of the two final chapters of the DOLOMITE REPORT are inserted at the end of this study.

Truly, the most important consideration is time; it is not really difficult to obtain a fair initial coefficient of friction; what is difficult is to make it hold out under heavy traffic. Therefore, polishability of the aggregates is the most important consideration and this has to be measured. It is done by measuring the coefficient of friction before and after an operation of accelerated polishing.

As to the surface texture, which holds the key to the solution, no one so far has developed a clear and practical method for defining it. This is the field where the greatest efforts of imagination and experimenting are called for.

Some of the technicians remind us of the need to consider also other incidental angles such as noise and light reflection, and not just friction. The question of noise is a little critical because open surface textures are notoriously more resonant than the smooth ones, as we have seen ourselves when we installed rumble strips with the deliberate purpose of shaking up the driver and sharpening his attention.

While the general aspects of the question have been dealt with in our overall digest of the available literature appended to the dolomite project, it may be useful to bring out what is perhaps the most interesting advice given at the Virginia Conference by the Virginia delegate. He mentioned that the highest standards of skid resistance are needed only in selected, especially dangerous spots such as intersections, bends and some steep gradients. This realistic observation places the question of cost in a practical light. The lengths and surface areas of those peculiar spots are so limited that it is quite possible to treat them in the most effective manner whatever the cost.

My own accumulated observations on this vital subject brought out an unavoidable fact which we have to face at the beginning of our study: In order to avoid skidding we have to create friction, therefore wear; the result has to be accelerated wear of the roadway and of the tires. Saving lives will be expensive, but is this not worth the price?

This aspect of the question should be brought out to the users or drivers: the more absent-minded and lacking in self-control they will be, the higher must be the price they pay, either in lives or in investment in the roadways. Over three hundred years ago the French Prime Minister Mazarin, when he heard of people complaining about taxes, drove into the countryside and found they were singing. He turned around to his advisors and said "ils cantent, donc ils pagaront--they sing, therefore they will pay". Mazarin was Italian born, hence his grammar.

* * * * * * * * * * * * * * *

In attacking once more this subject it may be useful for us to realize that we are far behind many other highway departments and research organizations. This problem, perhaps more than any others, brings out the need for this department to develop an up-to-date and properly equipped and endowed apparatus of study and experimenting in order to really get hold of our most trying problems.

According to a summary Professor Moyer put together for the Virginia meeting, the first road-surface friction tests with the towed trailer method were made as early as 1924 at the Iowa State College. Moyer himself continued this research from 1932 onward. Stinson & Roberts started their series of similar tests in 1933, with special emphasis on the importance of slipperiness on wet surfaces. As far back as 1938 the Oregon Highway Department showed how much higher is the resistance of open textures compared with the dense ones, not forgetting the inconveniences such as the rumble noise and the more frequent surface failures in freezing conditions.

These are just some high spots of the past activity throughout the country: California, Tennessee, General Motors, the Langley Aeronautical Lab., the Bureau of Public Roads, the Michigan Highway Department, the Portland Cement Association with Cornell, all of these and others applied the same towed trailer test methods, confirming the results that had been discovered and widening the field of reference.

Similar experiments were made by using the stopping distance method by the highway departments of Virginia, of Michigan, North Carolina and Mississippi, as well as the Universities of Purdue and Michigan.

Besides these field tests, other tests were run in laboratories with various improvised instruments. This work undoubtedly added to the general knowledge but the findings obtained this way remain less realistic, because it is so difficult to duplicate the actual driving conditions indoors. Among the researchers which applied these methods were the highway departments of Kentucky and California, the Crushed Stone Association, and the Universities of Minnesota, Tennessee, Purdue and Penn State.

The latest "Highway Research in Progress", published by the Highway Research Board, lists 21 projects on skid resistance current in 15 states and 27 such projects in 9 foreign countries, many of them on a considerable scale. The time has come when New Jersey will have to participate in this movement on a more active scale, both with field and laboratory tests. Let the experience of others show us the way.

* * * * * * * * * * * *

A practical way for acquiring a good background on this subject will be to go back to our own files and the assembled Bibliography. In these you will find three essential sources:

1. The first notes on skid resistance are in the original folder (not numbered) put together by Mr. Van Breemen years ago with memoranda by himself and Mr. Reed.

2. Next comes our own folder of negotiations with the Stevens Institute which produced our order for our new skid trailer (#7710).

3. Our dolomite study (#7760). Outside the actual study on the New Hope quarries and some related aggregates, this report is backed up by a very broad and complete summary of all the data available, including the monumental books on the 1958 International Conference on Skid Resistance (see our Library), the French study entitled "Glissance", (see our Library) and various other papers we discovered (two folders).

The present report is a continuation of that one, but this time we are concentrating on the kinds of tests that are necessary and the equipment we will have to acquire to carry them out.

* * * * * * * * * * * * *

It goes without saying that our tests will have to be built around desirable minimum requirements of skid resistance. The latest paper on this subject is the authoritative Report #37 of the National Cooperative Highway Research Program, of which an abridgement follows; only the abridgement not the summary, which is much too long.

A skid number of 37 is recommended as the tentative minimum requirement for pavement friction on main rural highways. This number is that measured with a skid trailer in accordance with ASTM Method E-274 at 40 mph in the most polished track of the road during summer or fall. For high-speed roads, higher skid numbers are explicitly recommended. The recommendations are also expressed by the stopping distance method and with portable testers.

The recommended requirements are based on the normal needs of traffic derived from driver behavior studies, and in close agreement with accident studies. Steps which can be taken and research which is needed to reduce skidding accidents and to improve the skid resistance of pavements are suggested.

A program of further research to improve the basis from which more definitive minimum requirements or standards can be derived is suggested.

Another very interesting source of information on Standards of Skid Resistance for roads is to be found in a British paper which we have extracted from "Road Research 1964" published by the British Ministry of Transports (Pages 56 through 60). Reproductions of the most meaningful passages follow on pages 8, 9, and 10:

Standards of skidding resistance for roads. Two surveys have been carried out to test the validity and practicability of the values of sideway force coefficient required for different conditions of road layout previously suggested.[1,6]

In the first survey the values were tested with the co-operation of a panel of highway engineers, covering six different areas of the country. A selection of 133 typical road sites representing the suggested categories A, B, and C was made by the engineers concerned from roads in Essex, Harrow, Middlesex, Nottinghamshire, Somerset and West Sussex.

To check the proposed values of skidding resistance for the various sites a comparison was made of the measured values of skidding resistance with the accident records for each site. To give a figure of sideway force coefficient likely to be representative of the performance of each site at its lowest, the skidding measurements were made during the summer months. The accident records were assessed using the method described elsewhere[19][20] for comparing frequencies of skidding accidents on short stretches of road.

The results (Fig. 24) showed that, with one exception (a site classified as category C), all the sites with significantly high skidding rates (above the national dry road average) had values of sideway force coefficient below the figure suggested.

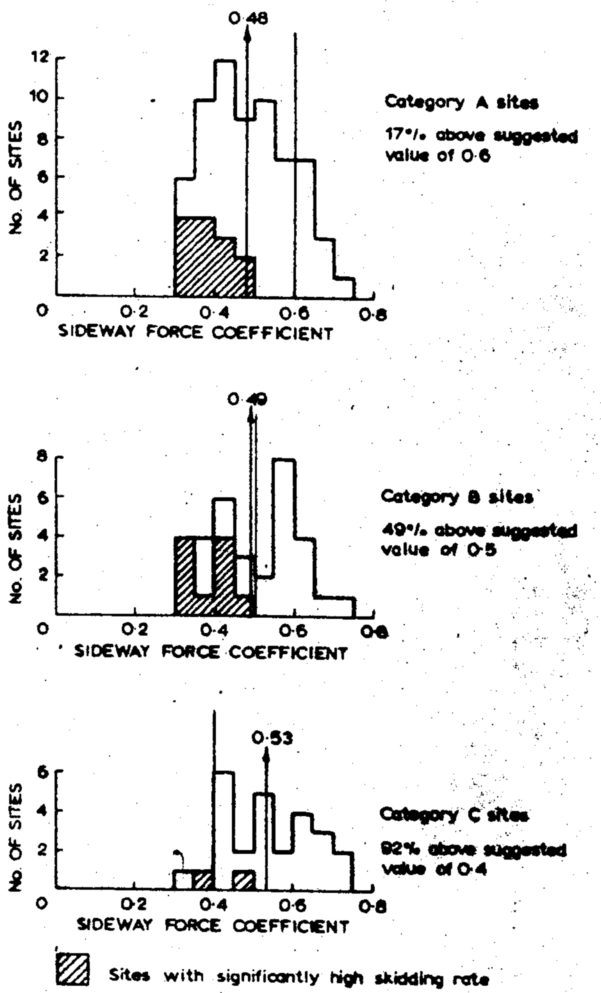


Fig. 24. Distribution of sideway force coefficient at Category A, B and C sites chosen by a panel of highway engineers

The results indicated therefore that the suggested values were of the right order and that at many of the sites which had been selected the suggested values of sideway force coefficient were already being obtained without difficulty. In two counties all the sites were above the suggested standard of skidding resistance and all were free of skidding difficulties.

In the second survey surface treatment was carried out at 38 sites, of which 21 were classified as category A sites, 15 as category B sites and two as category C sites. A check was kept on the skidding resistance and accident records at these sites before and after treatment for a total period of approximately 7 years and sideway force coefficients were measured annually.

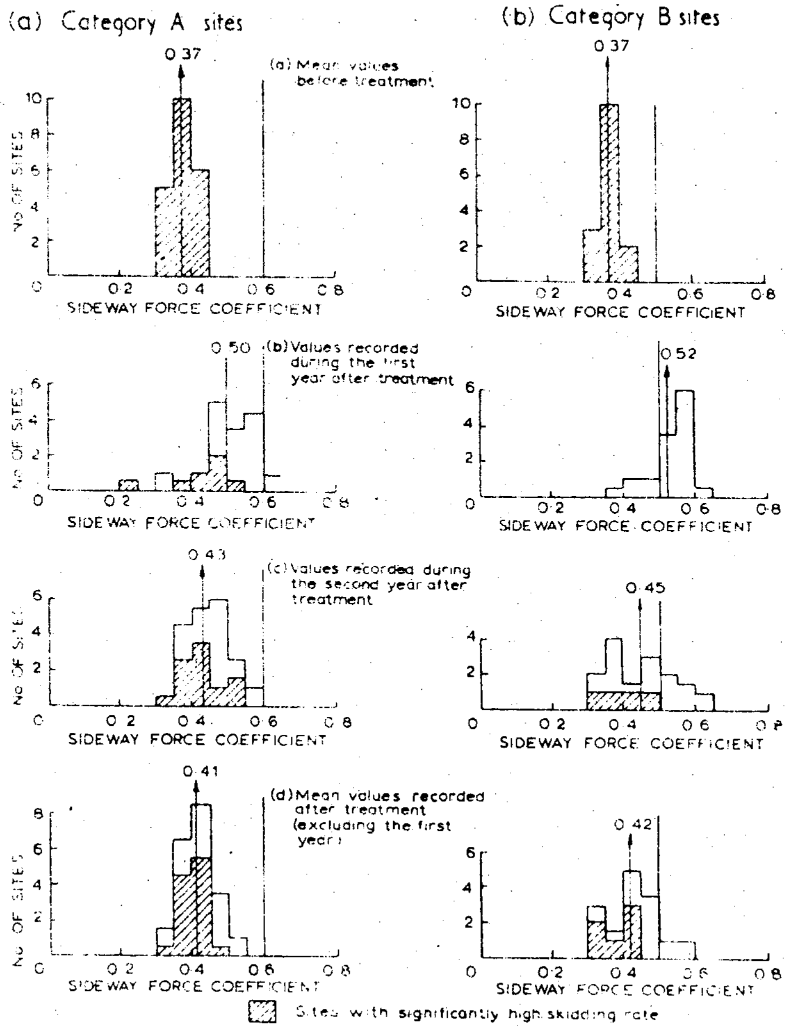


Fig. 25. Distributions of sideway force coefficients at Category A and B sites before and after treatment

Unfortunately at many of the sites the sideway force coefficients were not maintained above the desired values for any appreciable length of time. This is especially true for category A sites, where with one exception the values had fallen below 0·6 within the first year, and in subsequent years the values became even lower, being below 0·5 in all cases. At most of the category B and C sites the sideway force coefficients were above the suggested values of 0·5 and 0·4 respectively in the first year but within about two years the coefficients were generally below these values.

The sideway force coefficients and accident records in periods before and after treatment are compared in Figs. 25 (a) and (b) for category A and B sites respectively. There is no site in category A with a coefficient greater than 0·55 which has a high skidding accident rate (Fig. 25 (a)). Although sites with such high coefficients were rather few, the result tends to suggest that a value of 0·55 should be adequate to ensure freedom from skidding in wet weather in most circumstances. This is supported by evidence in Fig. 24, and a reappraisal of the evidence provided by earlier surveys supports this finding; in studies of nearly 400 skidding black-spots only one such site (a bend on a fast road) was found to have a sideway force coefficient greater than 0·55.

For the category B sites (Fig. 25 (b)) a minimum sideway force coefficient of 0·45 is desirable, although there is little evidence in this survey that values as high as 0·5 are necessary. However, there were a number of sites in the earlier surveys where coefficients between 0·45 and 0·5 were associated with frequent skidding in the wet, so a change in the level of sideway force coefficient for category B does not appear to be justified.

An overall comparison of measurements of sideway force coefficient and percentages of wet-road accidents involving skidding (Table 27) shows that there is a greater risk of skidding in accidents at the category A sites than at the category B sites for coefficients of the same order; this demonstrates the need for higher coefficients at category A sites. Comparison of data for category A sites with those for category B sites suggests that the figure for category A sites should be 0·05 higher.

Table 27

Comparison of skidding resistance and accidents at category A and B sites before and after surface treatment

Site		Before treatment	After treatment
Category A	Mean sideway force coefficient	0·37	0·41
	Percentage of wet-road accidents involving skidding	68	52
Category B	Mean sideway force coefficient	0·37	0·42
	Percentage of wet-road accidents involving skidding	47	28

Some modification to the levels of suggested values of sideway force coefficient recommended for road surfaces in wet weather are therefore desirable. Because of the difficulties of obtaining a sideway force coefficient of 0·6 or greater at category A sites, it appears feasible to lower the minimum value for such sites to 0·55 without appreciably increasing the risk of skidding; an amendment to the table of values is suggested in Table 28. In other respects the definition of category A sites appears to be satisfactory and there seems to be no difficulty in interpreting results of measurements at these sites. For category B sites the level of 0·5 seems to be of the right order and at present there appears no justification for lowering this value.

Table 28

Suggested amendment to table of values of sideway force coefficient

Requirement for category A	
Sideway force coefficient at 30 mile/h	Standard represented
0·55	Generally fulfilling requirements at even the most difficult sites, and making it most unlikely that the road will be the scene of repeated skidding accidents: in exceptional cases a value of 0·6 may be required

The raw materials to be tested of course will be essentially those that are available to us on an economical basis. But it will also be useful to include at least some tests of <u>synthetic aggregates</u> of the kind described and discussed in NCHRP Report #8. A summary of that report is also enclosed at the end of this report (Appendix II).

NA 4/68

American Experience

"Testing in California" by Professor Moyer

Professor Moyer is the ranking, long-standing authority in this matter. After his initial work at the Iowa State College in 1932 he continued his investigations and by 1958 had spent eight years in California testing and measuring both bituminous and portlant cement surfacings on 300 different types, using truck-trailer equipment. He experimented with many types of aggregates; natural sand, crushed and uncrushed gravel, crushed rock from various limestones, granite and basalt. He tried all practical sizes from sand size to crushed rock, 1/4 inch to one inch maximum for seal coats, and 1/2 inch to one inch maximum for plant mixes.

For determining the coefficient of friction he always applied the Coulomb formula, $f=\frac{F}{N}$. For example: for a braking or friction force of 400 pounds and a load on the wheel of 800 pounds, the coefficient of friction $f=\frac{400}{800}$ or 0.5. He considered the method of construction, the type and size of aggregate, the traffic volumes, the age of the road, the weathering effects.

He compared dry and wet conditions, angular and rounded aggregates, excess asphalt surfaces, plant-mixed surfaces and seal coat surfaces, rib tread and smooth tread tires, passing and traffic lanes.

He does not seem to have run systematic tests on the influence of surface texture but he mentions examples of coarse grained granites, 1/4 inch to 3/8 of an inch or 6 to 10 millimeters; these harsh, gritty materials are quite polish resistant and give excellent results. Their crystal structure varies from hard quartz to somewhat softer feldspar and micateous materials, with little polishing.

In the course of these extensive tests Moyer also made notes of other properties namely tire wear, road noise, glare and light reflection.

Zube and Skog of California Highways presented to the 47th HRB meeting of January 1968 a report (#47-21-04) on skid resistance of screenings for seal coats, which includes a method for studying surface texture and particle shape of the screenings, as well as a way of appraising their wear and polish under traffic. But their laboratory polishing machine operates at an unrealistic speed of 2 to 3 mph only.

Indiana Highway Commission

A report dated December 1964 summarizes the testing methods they used over a period of 10 years.

Seventy separate test sites, each 1/10 mile long, were marked off on a test road. All were tested for skid resistance every six months. Each time at the same 30 mph speed, under wet conditions, using the stopping distance method. Both directions and all four lanes were measured, observing the effects of traffic, age and season. The temperatures were recorded.

It is noteworthy that throughout this series they used only the special "Pavement Test Standard Tire" developed by the ASTM Committee E-17 and the Technical Advisory Committee of the Tire and Rim Association.

* * * * * * * *

In the meantime we have received also their report #21 of November 1967, which is a progress report in their skid resistance study. It will be useful to consult it in our library because of the method they have followed in organizing and recording those tests. These were made semi-annually, in the early spring and fall, on their test road, comparing flexible and rigid pavements; each one on a selected spot from among seventy 1/10 mile test sites; 16 sites in the spring, 8 in the fall; 2 skids per site. The dry tests, found to be insignificant, were discontinued.

They again used the pavement test standard tire, on wet roads, at 34.4 mph, in each lane in each direction, using the stopping distance method. It was found that the sand-mix resurfaced flexible surface has shorter stopping distances; for both types the outer lanes have a longer stopping distance, but this difference was more pronounced for the rigid pavements. The flexible type showed pronounced seasonal variations (shorter stopping distances in March than in August). The resurfacing of the flexible pavement made little difference.

Michigan State Highway Department

These tests were run over a period of fourteen months from 1957 to 1958. Over 4,000 skid tests were run on three hundred and thirty six projects over a length of 2,400 miles; this included 193 projects of bituminous aggregates and bituminous concrete.

They generally made 4 to 6 tests per project at representative locations, selected according to the length of the building project. In each case the average of these tests gave them the overall skid resistance level of the project.

They used a two-wheeled trailer. All tests were made on wet surfaces at 40 mph, with only a few at 20 mph, under an aerial temperature of 40 to 90 degrees F. They measured the sliding coefficient of friction on separate lanes, i.e. the traffic lane and the passing lane.

In each case they specified the age of the pavement, using a wear factor according to the following formula: the average daily traffic volume per lane since the construction of the road or section was weighted for percentage of commercial traffic converted to its equivalent number of passenger cars; this was multiplied by 1,000 and by the age of the project in years. For the equivalent number of passenger cars they took the product of the average truck-to-car tire contact area ratio and the truck-to-car weight per unit area ratio. Specifications of some of their bituminous concrete test mixes are shown on the following page.

1. Basic bituminous mixture design:

Coarse aggregate (retained on No. 10 sieve)	50-55 percent
Fine aggregate (passing No. 10, retained on No. 200 sieve)	30-35 percent
Filler (passing No. 200 sieve)	5.5-6 percent
Asphalt cement	5.5 percent
Marshall stability	1500-3000 lb.

2. Revisions in Material Specifications:

	Prior to 1944	1944-1948	Since 1948
Asphalt Cement	Pen. 85-100	Pen. 85-100	Pen. 60-70 or 80-1
Mineral Filler	Limestone dust	Limestone dust	Fly Ash or Limesto dust
Coarse Aggregate	100% pass. 1/2 in. 15-45% pass. No. 4 (Dept. Spec. 26A)	90-100% pass. 1/2 in. 0-25% pass. No. 4 (Dept. Spec. 26A mod.)	90-100% pass. 1/2 10-25% pass. No. 4 0-10% pass. No. 1 (Dept. Spec. 25A)

3. 3BC Fine Aggregate:

Passing No. 4	100 percent
Passing No. 4 retained on No. 10	0-5 percent
Passing No. 10 retained on No. 40	15-35 percent
Passing No. 40 retained on No. 80	30-60 percent
Passing No. 80 retained on No. 200	15-35 percent
Passing No. 200	0-5 percent

New York Department of Transportation

We will pay further attention to their Report #67-3 on skid resistance in our last and concluding chapter on our own requirements for getting hold of the skidding problem.

It is, of all the recent reports I have seen, the clearest and by far the simplest. It's conclusions are exactly those I have reached myself after comparing dozens of studies made by many researchers during the last 10 years. It is the one report each one of us should absorb and use as a practical prototype, of course adapting their methods to our own requirements and our own set-up. The main point is that their pattern of work can be applied by ourselves with the latest methods we know of, without having to experiment from scratch, without having to follow a lot of blind trails. It should enable us to organize our surveillance of the New Jersey road system without delay, refining and improving it as we go.

Two statements taken from the letter of transmittal which goes with the report bring out the essential guidelines.

(a) Measure the permanent coefficient of friction, after the first wearing-in period of the road surface is over: this period will consume approximately 5 million passes.

(b) Satisfactory skid resistance is essentially achieved by the use of larger aggregates with polish resistant properties.

These two points, of course, had been previously discovered by many researchers but had never been brought out with the same clarity and simplicity. It's conciseness, after seven years of consecutive tests, is the greatest virtue of the report, which has only about six pages of text.

At the foot of Page 6 there is a summary of test procedures, using the drag force trailer.

Their essential parameter is bituminous pavements (new, in clean condition without excess asphalt), studying chemistry, polishing, texture and mixture.

They have to admit, as everybody does, that there is a problem of correlation between the measurements of the road testing trailer on the one hand and the British portable pendulum tester for the laboratory, which is not very precise. But the two can be used in a practical manner, keeping their differences in mind.

Purdue University

There the well known researchers were Mr. Shupe of Kansas and Mr. Lounsbury of Indiana. Their motto was: the qualities of roadways are short-lived if they are too easily polished away.

For determining skid resistance, they used a laboratory skid tester, spinning the specimens at 2,500 rpm and forcing a rubber shoe against a wet surface. The results were expressed in RRV (relative resistance value), Kentucky Rock Asphalt being the reference material (a specimen of KRA was taken as equivalent to RRV = 1.00).

In their main polishing tests, they applied mixes with intentionally low asphalt content in order to bring out the effect of the aggregate.

For accelerated wear and polishing tests, the procedure was this: At the start, the initial compaction and particle orientation were achieved by rolling at 140 degrees F; then came the first wear test (coarse wear) with quartz as the abrasive; next the fine-polish test, where the abrasive was limestone filler; finally another rolling coated the aggregate lightly and simulated the seasonal effect.

For each aggregate they mentioned in their notes its identification symbol, its location, megascopic description and petrographic description, as well as the chemical analysis ($CaCO_3$, $MgCO_3$, SiO_2).

In order to demonstrate the effects of surface structure, namely the mixtures of sizes, they showed the composition of the specimens as follows:

The percentage passing the sieve, the percentage retained in the sieve, the gradation number (1 to 5); in this gradation, number 3 was considered a standard specimen, numbers 4 and 5 were more dense, numbers 2 and 3 were more open graded; they showed also the asphalt content in percent of the total weight of the mixture.

They made photographs of the test specimens at the completion of the coarse-wear cycle.

Virginia Highway

They have been very active in this field, in fact at the time of the 1958 International Conference they were in the lead.

In this new series of tests they experimented with:

Twenty-six sources of limestone including dolomites, on 1298 sites

Two sources of siliceous gravel on thirty-four sites

Two sources of trap rocks (diabase) on 115 sites

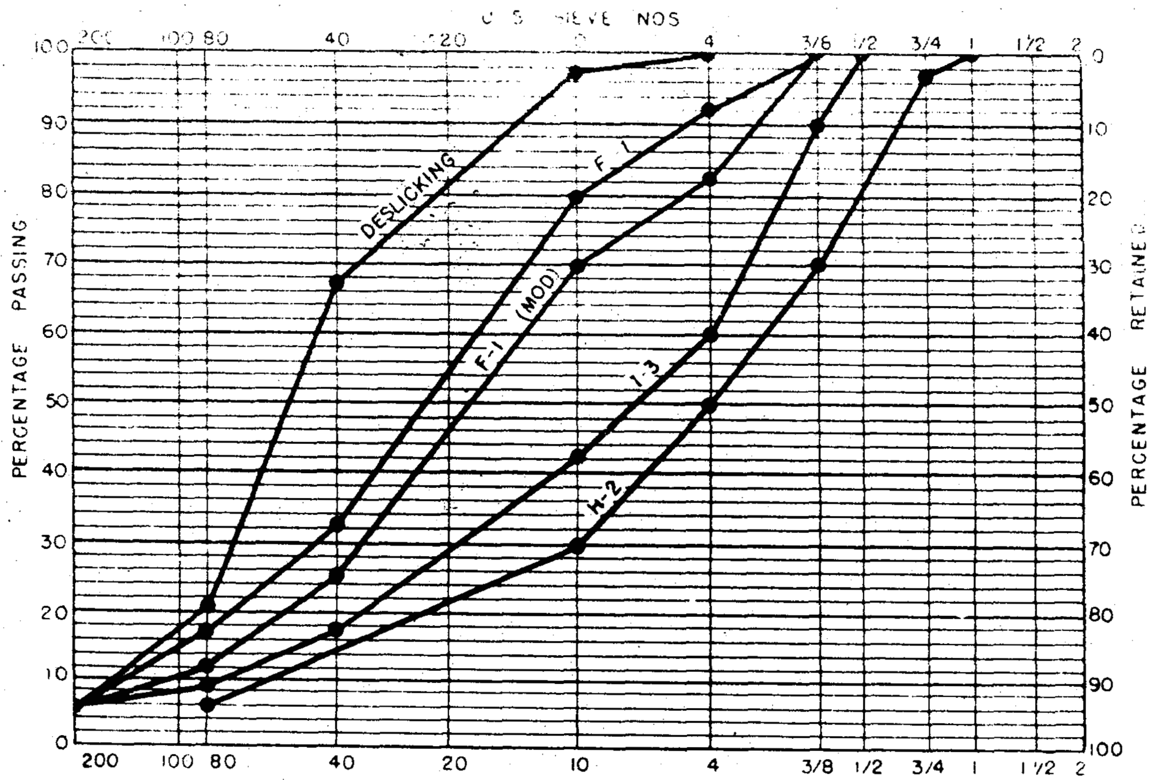
Four sources of granite on 114 sites

Nine sources of coarse sand on 270 sites

Six coarse sands on 106 sites

This effort totals up to nearly 2,000 test sites and some 50 sources of supply. Their investigated mixes are detailed in the two following illustrations.

SIEVE NO	H-2 % PASSING	1-3 % PASSING	F-1 (MOD.) % PASSING	F-1 % PASSING	DESLICKING % PASSING
1"	100				
3/4"	95-100				
1/2"		100			
3/8"	60-80	80-100	100	100	
4	40-60	50-70	75-90	85-100	100
10	20-40	35-50	60-80	65-95	95-100
40		10-25	15-35	20-45	40-95
80	3-10	3-15	5-15	5-30	12-30
200		2-10	2-10	2-10	2-8
APPROX A. C.	5.0 %	6.2 %	7.0 %	7.2 %	8.0 %


U S SIEVE NOS
200
100 80
40
20
10
4
3/8
1/2
3/4
1
1 1/2
2
PERCENTAGE PASSING
PERCENTAGE RETAINED
0
10
20
30
40
50
60
70
80
90
100
DESLICKING
F-1
F-1 (MOD)
I-3
H-2

All these tests were made of course on wet roads; the speed was generally 40 mph. They used the stopping distance method although they found that it is slow and usable only on straight sections of road and level sites. They also used for measuring the coefficient of friction a test trailer borrowed from General Motors.

In each series of tests they measured the friction conditions at various ages of the road, but they gave up their attempt to analyse separately the effects of age and traffic. They noticed, however, that in practically every case the road was at its worst from the standpoint of slipperiness after one year of use and for this they did not offer any explanation. It looks like a process of initial "wearing in".

Of particular interest is their attempt to study the effects of siliceous admixtures to limestones as a practical compromise which would achieve safe results without the complete elimination of limestone. They used fine non-polishing silica sands, gravels, and granite as additives. At first they added only up to 20 or 25 percent, then they tested mixes with a minimum of 50 percent; finally they tried various amounts up to 50 percent, generally 20/25 or 40/50 percent, of the total mix, or else 100 percent of the fine aggregate. They tested them after nine months and 24 months and 48 months.

After this, they tested additions of nonpolishing coarse aggregates in three special test sections, the idea being that after one year of heavy traffic the tires are mostly in contact with the coarse portions of the surface; in these tests up to 50% of the coarse was siliceous gravel or granite, while the fines were still made up to 100% of limestone. They tried these after one year and after three years of use.

In a third series of tests, a different test section was built with 100% of non-polishing aggregates with all-limestone fines. These were tried after six months and after one year.

Finally, in the fourth series, they tried fine silica deslicking mixes in order to simulate the well known Kentucky rock asphalt, so-called, which is a sand-stone. In this series they also treated very thin top courses (8 to 50 psi) with a relatively low asphalt content, in order to see how lower courses could be built entirely of limestones, to be covered with thin non-slippery surfaces. These they tested after three months, one year, and three years. This kind of treatment, of course, would have to be frequently renewed in heavy traffic areas.

EUROPEAN EXPERIENCE

Some Notes From Europe

Most of these notes, but not all of them, are taken from a general paper by C. G. Giles of the British Road Research Laboratory, one of the leaders in this field.

The general concensus is that most roads are skid safe in a dry condition; therefore, all tests of skid-resistance must be made on wet surfaces. From the American movie picture on hydroplaning or acquaplaning, which we have seen, we remember that when the amount of water on the roadway reaches a considerable level, there is practically no more friction and no more adhesion between the tire and the road. In this respect, there is a rather curious note in some Italian paper to the effect that from their findings, heavy flooding is not the most dangerous condition because it washes the road surface clean of mud; therefore, they say that attention should be given to wetting the surface only slightly during the tests.* On the other hand, the Bureau of Public Roads recently awarded the Cornell Aeronautical Laboratory a contract for investigating the phenomenon of hydroplaning.

Many researchers put the emphasis on the sideway components of the vehicle's movements during the process of skidding. They take it for granted that it is not sufficient to measure the coefficient of friction in the longitudinal direction parallel to the center line of the road, but also in the transverse direction.

It goes without saying that there is no such thing as an average coefficient of friction for any road, because wear is uneven and even the shortest bad section of a generally good road can produce bad accidents. Also, the most heavily travelled lanes are not always the most slippery.

* Mr. William Van Breemen remarked in a 1958 report that "pavements are likely to be in their most slippery condition when it first starts to rain."

The skid-resistance of any given spot varies with its age, it also changes with the seasons, being generally lowest in summer. Therefore, no single measurement or series of measurements at any specific time of the year can be taken as defining the permanent condition of the road.

Naturally, the type of traffic is all important in any such test; not only the frequency of passes, but also the average and extreme speeds, and the types of vehicles. One specialist suggested that the most realistic definition of the usage to which a roadway is subjected would be the weight in tons passing per unit of time, instead of simply the number of vehicles. Some students of this problem have complex formulas for integrating truck traffic with the ordinary passenger car traffic, in order to get closer to real wearing conditions.

The type of tire to use in these tests, whether smooth or treaded, is still controversial.

The speed applied during the tests of various kinds, whenever such speeds were being controlled by the researchers, varied but was never high. The general impression is that the most frequent average is close to 30 mph.

No one seemed to give much attention to the bituminous binder, whose type or quality was not thought to have any effect on skid prevention. But, too high percentages of it would weaken the surface and naturally any bleeding could be calamitous.

What the most desirable limit or allowable minimum should be for the coefficient of friction of a wet roadway seems to become more and more a relative concept. They especially seem to realize that conditions of use as well as practical possibilities of control and expenditure would make it undesirable to specify one single figure for all locations. It is rather suggested that different values should be chosen for heavily used city areas where speeds are limited and for country roads with less traffic and higher speeds.

Giles mentioned that in accordance with British tests, u-turns are over 80 times more likely to produce repeated skidding accidents than straight sections of a road, whereas, other types of layouts show other proportions of risk in this order: sharp bends 50 times; steep gradients 13 times; junctions 7 times; slight gradients 4 times; curves in general twice as many times as those of straight sections of the road. The following table is an expression of the British thoughts on practical sideway friction coefficients.

SUGGESTED SIDEWAY FORCE COEFFICIENTS

Category	Type of Site	Sideway force coefficient on the wet surface at 30 mph with a smooth tire
A	'Most difficult sites', such as: 1. Roundabouts. 2. Curves with radius less than 500 ft. on fast derestricted roads. 3. Gradients, 1:20 or steeper, of length greater than 100 yd. 4. Approaches to traffic lights on derestricted roads.	Above 0.6
B	'General requirements', i.e.: Roads and conditions not covered by categories A and C.	Above 0.5
C	'Easy sites', e.g.: Mainly straight roads, with easy gradients and curves and without junctions, and free from any features such as mixed traffic, especially liable to create conditions of emergency.	Above 0.4

Some experts suggest that testing equipment and specialized personnel should be made available to contractors and all concerned.

Another precaution has been recommended, the one of organizing a permanent surveillance system because roadways, especially the heavily travelled ones, undergo a constant evolution. This system should involve not only inspections and sometimes measurements but also the investigation of the causes of all significant accidents. The police should have instructions to look out for signs of skidding and to locate the danger spots with minute precision.

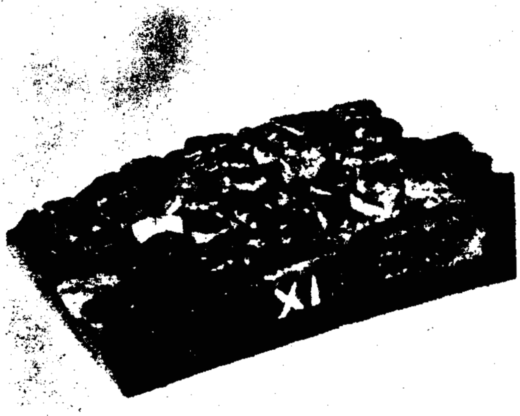
British Research

The Road Research Laboratory of the United Kingdom has built for itself an International reputation second to none. They have even been trail blazers in a number of directions, developing new methods and new kinds of apparatus for constructive solutions.

They developed an apparatus for laboratory measurement of the polishing of aggregates. This accelerated polishing machine is made of a rubber wheel, 15" in diameter, rubbing against "chips" (i.e. aggregate) embedded in mortar, with the use of fine abrasive powders in between. The result is expressed as the "polished stone coefficient".

The two photographs and list of data which follow give more specific information on this machine.

Accelerated polishing machine.



Specimen for accelerated polishing test.

ESSENTIAL DATA OF THE ACCELERATED POLISHING MACHINE

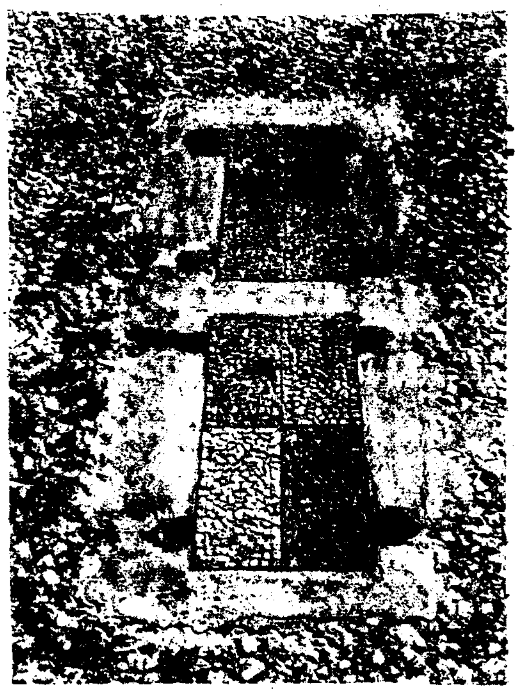
1. Wheel Carrying Specimens	
Diameter	15 in.
Diameter of Outer Surface of the Specimens	16 in.
Width of Stone Surface	1 3/4 in.
Speed	320 r.p.m.
2. Pneumatic Tyre	
Diameter	8 in. nominal
Width	2 in. nominal
Surface	Smooth (untreaded), 60° Dunlop hardness
Inflation Pressure	45 lb/sq. in.
Total Normal Load Between the Pneumatic Tyre and the Stone Specimens	88 lbs.
This is Applied by Means of a Lever Arm with a Ratio of 4 : 1	
3. Means for Feeding Water to [illegible] Specimens at Rates up to	20 g/min
4. Means for Feeding Sand (52 - 100 grade) to the [illegible] at a Rate of	12 g/min
5. Means for Feeding Emery Fl[illegible] (100% Finer than 0.06 m[illegible] 0.002 mm) to the Surfa[illegible] at a Rate of	2 g/min

Further details on this machine will be found in the later chapter on Equipment Required.

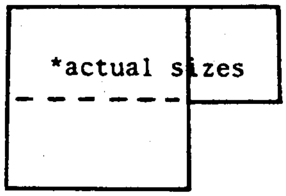
The RRL also made extensive polishing tests on heavily travelled roads selecting straight sections as well as bends, where they inserted test areas of 3/8 of an inch "chippings" embedded in mortar, to check the accuracy of the laboratory tests, in wet, practical field conditions. For these road tests they used their portable skid resistance tester, the coefficient of friction being then called "skid resistance values".

There was a good correlation between laboratory and road. The road tests were repeated at intervals so as to follow the evolution of the project. They watched systematically the relation between skid resistance on the one hand and traffic intensity on the other, having installed the same materials simultaneously at different spots; also age, accounting for traffic accumulations with time in individual spots; furthermore, the influence of weather and the neatness of the road, since dust acts as an abrasive and there is more of it after a rainy period.

Experimental surfacings were laid on a number of roads, each test installation comprising a number of sections with a different type of aggregate in each, as shown in the picture.



For each of them they measured the sideway force coefficient and the polished stone coefficient. The road sections they chose had a traffic between 60,000 tons per day and 1,000 tons per day. They tested half inch and one inch-maximum aggregates*, after they had found that the use of 1/8 inch "chippings" made little difference.



Glissance-French Research

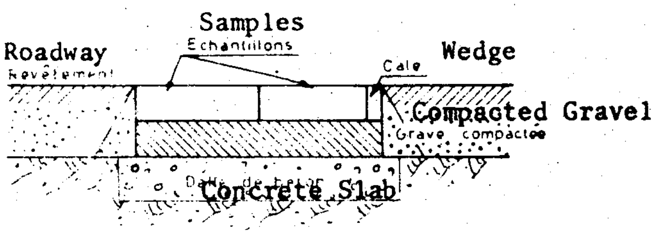
The notes hereafter were selected from a separate brochure on slipperiness in the form of a large collection of specialized papers, put together by the French Government Road Research Laboratory, whose functions are similar to those of the British RRL. In our supplement to the digest of bibliographic material on skid resistance we have covered the results of the French studies. This time we will put together significant information on the types of tests they have made and the details of their methods of measurement.

In the first paper, the only remark concerning us here refers to the small pendulum-type instruments for measuring the coefficient of friction. It is natural that this type of instrument should be used in laboratories; but the authors of this paper mention that their Leroux apparatus as well as the British RRL are also quite useful for field tests with treaded tires at medium speeds, not exceeding some 35 mph. These instruments make it possible to pin-point conveniently the excessively slippery areas on the roadway.

In the third paper, they emphasize the importance of properly selecting the test sites: by using spots of high intensity traffic, the measurements become similar to those of accelerated polishing. This pin-pointing of the test sites is particularly important for sample installations.

Details on the measuring of the gradual polishing of the road's aggregates is of particular importance for our own future research. The French, in this field as in several others, have been inspired by the British methods, those of Mac Lean and Shergold of the RRL. It will be interesting for the reader to compare the notes hereafter with the discussion of the original British methods that we have given in a preceding part of this series.

The French Road Laboratory installed <u>on roadways</u> samples measuring 10x10x30 cm (approx. 4x4x12 in.). These samples can be removed after their planned exposure to traffic and then carefully studied in the laboratory. The little picture shows how test samples are installed in a test road, exposed to regular traffic.



The French also organized accelerated <u>polishing</u> tests <u>in the laboratory</u>. In these tests, rubber from a tire is rubbed against a sample of roadway material, with an abrasive in between. The friction coefficient is repeatedly measured after prearranged cycles of passes. The process looks fast and simple. Different mechanical set-ups have been built in various European countries, the most frequent one being the Manege (or Manage): Samples are mounted on a wheel, between 10 and 20 feet in diameter, and the rubber is mounted on another wheel; in this way, real traffic conditions are approximated, but in a more concentrated and even, therefore, "accelerated" manner. In view of the importance of this type of test for our own purposes we have written for further particulars on how these tests were set-up in various countries.

As to the French version itself, another paper in their book describes it as an adaptation of the British measurement method BS812(1N), using a 42 cm diameter drum which revolves at 320 rpm. Fourteen samples are mounted on the periphery of the drum, in such a way that a fairly even cylindrical surface is produced. Each test sample is prepared in the following way: First, aggregate is dropped into a convenient hollow mould; then, aluminous cement is poured into it, taking care that his binder does not appear on the outer surface of the sample.

A rubber wheel, inflated at 3.16 kg/cm and revolving freely, is applied against the drum with a pressure of 40 kg. During the test, abrasives are inserted between the tire and the samples: during the first three hours, a silicious sand with grain sizes between 0.16 and 0.40 mm; during the three following hours, emery powder of less than 40 u.

At the end of the test, the coefficient of friction is measured with the British pendulum tester. This coefficient then is called "accelerated polishing coefficient", in order to differentiate it from the regular coefficient before polishing.

The French researchers note that this kind of test cannot reproduce the exact wearing conditions encountered on the roads, where some crushing of the road surface occurs, and the nature and quantity of dust vary greatly. They consider a "polishing coefficient" lower than 0.35 as bad, and of over 0.45 as good.

Another paper in the French series deals in more detail with the evaluation of the geometric roughness* of the roadway, which is of paramount importance for effective skid control. The French engineers, who seem to have gathered all the available material produced by other researchers,

*Surface Texture

emphasize the fact that very little headway has been made in this field. From all we have seen ourselves in the many reports we have examined from a number of sources, the methods used so far have all been primitive and not sufficiently significant; the definitions themselves are still quite primitive. The French report reviewed the several approaches known to them in the following series:

Some investigators have spread sand over the test surface and estimated the mean depth of the interstices by measuring the volume of the sand.

Others took an imprint of the road surface after first inking the tops of the protrusions, then pressing a sheet of paper onto them, thus producing a map of the peaks and valleys; in this manner, they determined the area of the valleys or canals for water evacuation, the relative bearing surface of the peaks and the depths of the valleys.

The French Road Laboratory itself has started experimenting with replicas of the test areas using Silastene to make moulds of the roadways. These they intend to analyse for determining the micro-roughness characteristics and their significance for skid control. This promising approach has still to be developed.

The depth and valleys are also studied with the help of a stereographic process developed in England. It is intended to draw an enlarged profile of the hills and dales and measure them. Attempts will be made to define the angularity of the aggregates with the help of this method, which is also used in Denmark and Germany as well as in Russia.

Other methods - optical or electrical - are also under consideration for producing overall evaluations, but have not been used as yet.

Other kinds of processes produce profiles of cross-sections. In one of them, a sample of the top course is sawn; the section is photographed and enlarged for detail study. Micro-profiles of aggregate grains are also prepared in this way. In another method of this group, an instrument drops multiple needles over the test area; the line of the needle tops is photographed, outlining the profile (Texas A&M College has one of these). There is a similar instrument with only one needle, inspired by Russian researchers, presently being perfected by the French laboratory. Finally, an electronic assembly, coupled with the wheel, follows the curves of the profile and reproduces them in greatly amplified form; this very precise industrial process has not been used for road-making purposes as yet, but it seems to be a useful indication.

The results of these various attempts to grasp the nature and practical usefulness of the surface texture differ considerably from one laboratory to the other; no concensus on optimal procedures and characteristics has been worked out as yet and the field remains wide open. The four graphs reproduced hereafter give an idea of the prevailing trends.

The first one represents the relationships between the depth of the roughness, the width of the interstices and the relative bearing surface. The second one combines the coefficient of adhesion (with treaded tires on a dry surface) with the depth of roughness at two different speeds. The third one relates the same two characteristics at 35 mph and smooth tires, but it compares wet and dry conditions. In the fourth one, the coefficient of friction on a wet surface at 35 mph is shown together with the grain sizes of the aggregates.

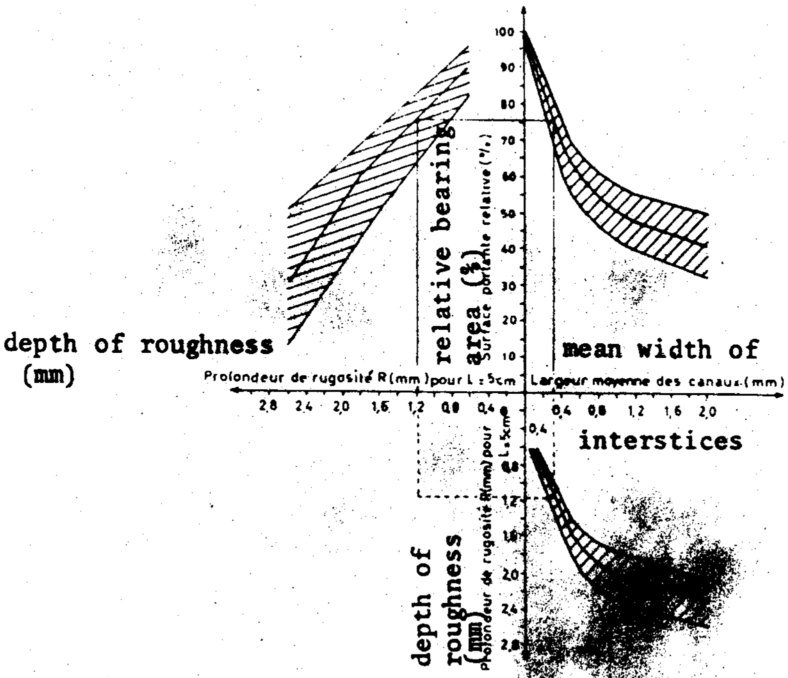
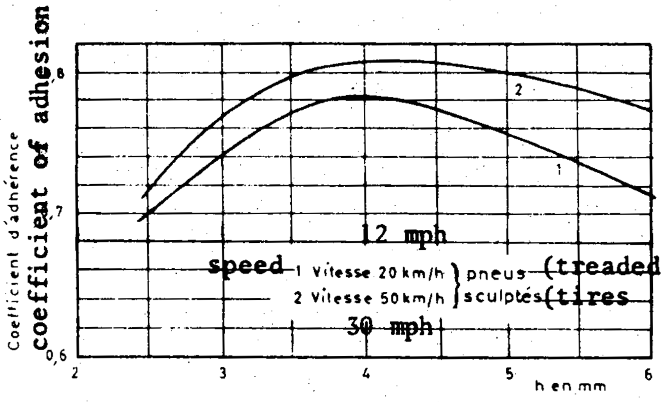
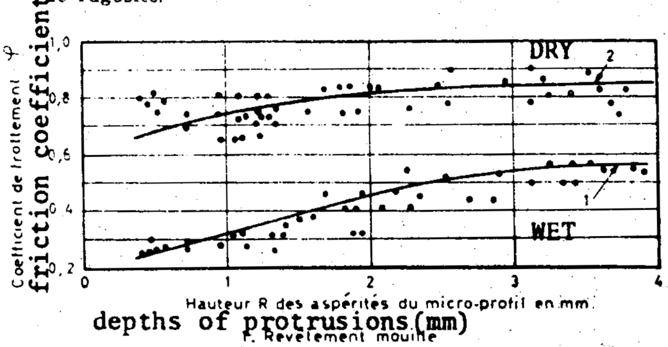


Fig. 5 — Graphique représentant la relation qui existe entre les trois caractéristiques d'état de surface : profondeur de rugosité, surface portante relative et largeur de canaux pour revêtements routiers.

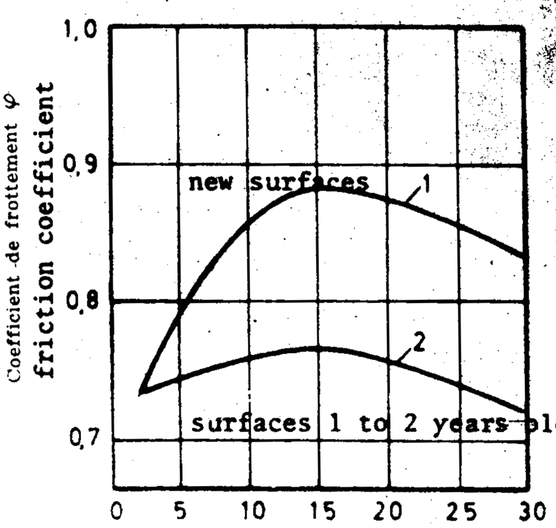


Coefficient d'adhérence en fonction du degré de rugosité.



1. Revêtement mouillé
2. Revêtement sec

Relation entre le coefficient d'adhérence à 60 km/h et la hauteur des aspérités du micro-profil (pneus lisses).



Granulométrie du matériau en mm.
grain sizes (mm)

1. Revêtements neufs
2. Revêtements ayant 1 ou 2 ans de service

Relation entre coefficient de frottement pour une vitesse de 60 km/h sur revêtement mouillé) et les dimensions des gravillons en mm (pneus sculptés).

It seems that the skid resistance grows with roughness up to a certain optimum of the order of 2 to 4 millimeters of grain size. The decrease, past this optimum, may be due to the decrease of the number of surface contact points. Much more research is needed before we know that we really have the problem in hand.

* * * * * * * * * *

The French Road Research Laboratory, which seems to be organized on a very broad and highly scientific basis with considerable attention to theory and mathematics, has sent us a great deal of information including most recently a considerable amount of bibliographical data on the research done all over Europe on polishing machines and polishing tests on special road tracks. They have a large basic running project for the purpose of developing the best possible polishing machine after studying and trying out all the other designs and methods used by others. Unfortunately, as all such research projects, this one will take time, probably more than we can afford to wait. We are sure to be kept informed by them.

Latest British Report

This most recent study by Mrs. Sabey of the RRL reached us after our report had been completed. It's scope is best expressed in the original abstract:

> Past work has indicated that on wet roads the rate of decrease of skidding resistance with speed is largely dependent on the coarseness of the road surface texture. On smooth, fine-grained surfaces the coefficient decreases rapidly with speed, but on coarse-textured surfaces the decrease is much less rapid.
>
> Tests have now been carried out to examine more closely the way in which coefficients decrease with speed up to 80 mile/h and to attempt to find a quantitative measure of surface texture which will indicate the rate of fall in coefficient with speed. Two techniques of measuring texture have been examined: the "sand-patch" method from which a measure of "texture depth" can be obtained, and a new stereophotogrammetric technique which records the surface profile.
>
> A statistical correlation has been obtained between the percentage decrease in coefficient between 30 and 80 mile/h and the texture depth, which measures the coarseness of texture. Recommendations for texture-depth requirements for fast roads are given: to restrict the decrease to less than about 25 per cent, a texture depth of more than 0.025 in. appears necessary. A better correlation with percentage decrease in coefficient is obtained by a measure of the surface profile (the "profile ratio") which takes into account the shape of projections in the surface.

(end of quotation)

For measuring skid resistance they used both their sideway-force machine and their small braking-force trailer, at 30 to 80 mph; with smooth tires, because these are more closely related to the most significant accident risks.

For surface-texture measurements they applied the sand-patch method to obtain texture depth and the stereocamera to obtain surface profiles. With that sand-patch method they actually measure the average depth of the hollows in the surface below the general level of the peaks. This appears to be the method described by the French Laboratory (see Page 38 above, paragraph 2).

The experience of the RRL has shown that at medium speeds the value of the friction coefficient "μ" largely depends on the very-fine-scale texture (micro-structure) of the surface (its small-scale sharp edges), not on the size of the easily visible asperities (macro-structure). The latter becomes important at high speeds.

The proportions of hollows and asperities do not characterize these conditions clearly enough because the effectiveness of the surface roughness - particularly at high speeds - depends on the shape and angularity of the projections. This is why the RRL put to use the new stereophotogrammetric method also described by the French Laboratory (page 38 above, paragraph 5). They assess "the profile ratio", i.e. the ratio of the length of the profile to the length of the baseline.

On bituminous surfaces they made 74 sideway-force tests and 84 braking-force tests. Some of the results appear in the following table:

Site no. A-asphalt ~~C-concrete~~	Measured braking force coefficient at:		Decrease in coefficient between 30 and 80 mile/h		Texture depth (0.001 in)	Profile ratio
	30 mile/h	80 mile/h	Actual decrease	Percentage decrease		
5 A	0.30	0.20	0.10	33	28	1.030
6 A	0.38	0.28	0.10	26	31	1.065
7 A	0.28	0.16	0.12	43	26	1.032
8 A	0.38	0.30	0.08	21	24	—
9 A	0.25	0.15	0.10	40	30	1.034
10 A	0.39	0.27	0.12	31	19	—
11 A	0.27	0.21	0.06	22	24	—
12 A	0.38	0.25	0.13	34	28	1.032

It is interesting to relate the difference of coefficients at the two test speeds with the several texture depths, as well as the profile ratios. For the latter, the higher the figure is the more pronounced will be the desirable irregularity of the profile.

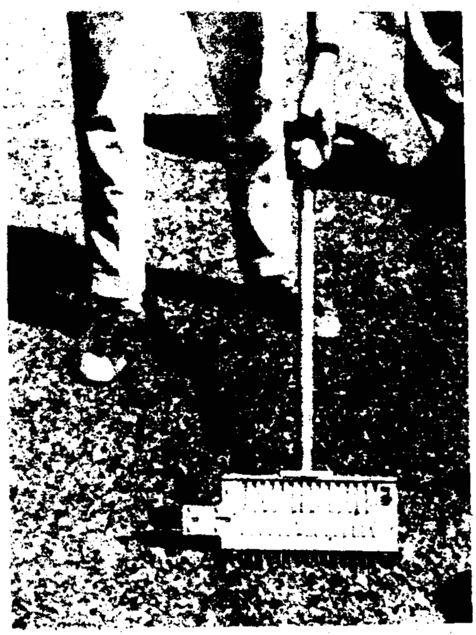
Although this new dual method has not yet passed the experimental stage, it looks like an element of progress worth trying. It has already lead the RRL to two conclusions:

(1) Very large decreases in the μ coefficient between 30 and 80 mph can be expected when the texture depth is less than 0.010", however high μ is at 30 mph.

(2) In order to restrict the decrease of μ to 25% it appears that, on average, texture depths greater than 0.025 inch are desirable. A more complete judgment can be applied if the "profile ratio" is taken into account.

Highway Research Board - National Cooperative Highway Research Program

Their Report #7 of 1964 shows this picture of a texture meter developed by F. H. Scrivner of the Texas Transportation Institute and W. Ronald Hudson of the Texas Highway Department with this comment:



The texture meter developed by Scrivner and Hudson gives a measure of the micro relief of the pavement by means of a series of prongs which gives an indication of the indentations and surface roughness of the pavement. The texture meter was developed primarily for use on flexible pavements, but was also used on other pavements.

The instrument was presented at the January 1964 meeting of the HRB in a paper summarized as follows in the HRB abstract:

Use of the CHLOE profilometer in Texas indicated that this device for measuring road roughness tends to rank pavements having a coarse textured surface too low on the serviceability scale. To offset this tendency, a hand operated device for measuring coarseness of texture was developed, and a term for textural roughness was added to the AASHO Road Test formula for the serviceability index. The coefficient of the new term was evaluated by analysis of the subjective ratings given 43 flexible pavements by a 12-man panel of highway engineers.

Canadian Department of Highways

Report #46 of 1964 on Skid Resistance

A very good and useful synopsis of the entire subject.

Regarding our present preoccupation with testing methods they indicate that for the determination of friction values the first International Skid Prevention Conference gave preference to the coefficient of sliding friction (straight-ahead locked-wheel braking) over the sideways friction. In our above digest of French experience, the same conclusion was found, the argument being that with modern high speeds the prevalence of the forward momentum is overwhelming.

They point out that the correlation of many different methods of measurement has been found difficult, with some concordance but much unevenness. We will have to see how our new skid trailer fits into this picture, so that full comparisons with outside studies remain possible. They give the following description of the British accelerated wear machine:

> The apparatus consists of a pneumatic-tired wheel in contact with another wheel; on the flat periphery of the second wheel small specimens of chipping-sized stones set in cement mortar are mounted. The second wheel is driven by an electric motor, while load is applied to the pneumatic-tired wheel using a lever arm. This apparatus is used to attain traffic-simulated wear of aggregate specimens, in the presence of suitable abrasive powder.

The Canadian list of factors to be considered in the course of testing is useful:

> Tire variables such as size, load, pressure, tread pattern, composition, temperature; braking force variables such as uniformity between wheels, uniformity during application, number of wheels, weight shift; covering on the surface such as oil, dirt, paint, ice, snow, the amount of water; defects such as roughness, ravelling, bleeding, faulted joints, extruded joint seal, rutting, patching; also ambient and pavement temperatures.

- -

In addition to the problems of measurements, the C.D.H. studied other aspects of slipperiness. Their conclusions do not differ substantially from but supplement those we gathered at other sources. Particularly interesting are their data on minimum requirements for safe roadways (P. 27/28), on practice standards adopted outside of New Jersey (P. 28), on actual conditions in numerous locations (P. 29), and on the anti-skid values of aggregates (Canadian page # p. 34/35).

Of the polishing effect of traffic on roadways they find that it is the work of fine abrasive particles found in the road scum which become imbedded in the tire treads.

Concerning the amount of wetting required to reduce the skid resistance of a surface to its minimum value, they have this to report:

> British investigators have found that a 0.025 mm thick water film is sufficient to abruptly reduce the skid resistance of a pavement; further reduction occurs as the film thickness is increased to about 0.5 mm; and additional water apparently has no further effect. According to Italian experience,

very slight wetting is needed only to obtain minimum measurements, such as a 0.06 mm water film on dusty roads. Canadian tests have indicated that about 85-90% of the total reduction is achieved by merely wiping the test surface with a moderately wet cloth, and 94-98% by a water film thickness of 0.1 mm; the minimum value is reached at a film thickness of about 1.0 mm, and the addition of more water results in a slight increase of measured skid resistance. Utilizing a test-car at a speed of 60 mph, American investigators found further reduction in skid resistance on the "too much water" side. Typical measurements were 0.4 at a film thickness of 0.75 mm, 0.2 at 5.0 mm, and 0.15 mm, at 7.5 mm. These results were explained by "tireplaning", a phenomenon which involves the tires skid over the water surface much as skis skim over the surface in aquaplaning. Although, the test results reported in the literature are not in complete agreement, it is obvious that the degree of wetting is to be specified, at least within broad limits, in order to obtain reproducible, and preferably minimum, skid resistance measurements.

For further details, see our research library

International Road Congresses

Rio de Janeiro, 1959 - The following extracts and digests will be of interest:

General Meeting, speech by Dr. A. R. Lee (U.K.):

> I would like now to refer to the note dealing with the skidding resistance of the surface; and in considering skidding resistance of bitumen surfacing, attention must always be given to the tendency of the exposed stone to polish under the action of traffic. This property is the one decisive factor in coated macadam surfacing; in dense surfacings it contributes its effect, together with that of the dense mortar. The test we have developed in Great Britian to measure the polished stone coefficient of any stone gives results that correlate well with the behaviour of the road. When an engineer has a road on which skidding accidents are occurring, the test will tell him whether stone can be used in a given road surfacing which will have less tendency to polish than the stone already there. The use of a better stone will tend to reduce the accidents due to skidding. A test of this kind is essential for helping the engineer to select a stone for use in a surfacing that is required to reduce skidding accidents and we strongly recommend its adoption. The polished stone coefficient is a property of the stone. It can be measured with a satisfactory degree of accuracy and it is constant for each particular stone. It can therefore be used in a specification as a means of defining the property of the stone that is necessary for any particular site. The minimum requirement for any particular site can be assessed by the highway engineer on the basis of the knowledge he will soon acquire when he uses the test. I suggest, Mr. Chairman, that a conclusion should be added to the report that this test be adopted internationally.

Committee on Slipperiness, speech by Mr. Vanneufville (French):

> It is also necessary, I feel, to draw attention to the importance of this problem. It will not have escaped your notice that a perfectly smooth and thoroughly sound road may be more dangerous, if it is slippery, than a road of less satisfactory quality. Consequently, from the point of view of safety, and that is the problem we all have in mind, you have only to consider the number of accidents that occur in every country in the world, to realize that no effort must be spared to ensure road safety.
>
> This consideration clearly demonstrates that the problem of the appearance of the road surfacing is quite as important as the question of the foundations and behaviour of the road.

A good summary was given at the Rio meeting of the 1958 Skid Prevention Conference held in Virginia, which we discussed in our Dolomite report (Project #7760). It was stated in Rio that considerable attention had been paid at the Virginia meeting to the polishing of road stones, a key aspect of the problem. Another point of emphasis was that the correlation between the several friction measuring machines had been found very poor; it had been recognized that such correlation was "a basic factor in the problem of slipperiness which is increasing in seriousness in all countries."

The German delegate, Professor Wehner, insisted on the need for testing the several "wheel tracks", which vary greatly on any road.

Mr. Brudal, the representative from Norway, in relating local experiments, concludes that "a very high coefficient of friction may be obtained when the surface has a somewhat rough-looking texture, and when at the same time each of the stones has a real sand-paper texture. But such surfaces may cause a very high wear of the car tires, especially at high speeds." He also added this comment on grain sizes: "measurements seem to indicate that asphaltic concretes with a good smooth grading curve, containing all particle sizes, as well as coarse sand and fine gravel, are superior to those with a gap-graded aggregate.

Mr. Giles, the prize-winning British specialist, insisted on thoroughness of testing and recording: "Our machines give a continuous record over the entire length of the stretch of road. When we are carrying out tests, it is our practice to quote not only the mean figure, but also the highest value and the lowest value which are found on any stretch; it has the advantage of pinpointing attention on the most slippery stretch of the road. Any variation greater than ±0.1 on either side of the mean value certainly needs attention."

He agreed with the Norwegian delegate on the importance of building not only coarse-scale roughness into the road, but also fine-scale projections. "The critical scale of projections", he said, "is of the order of 0.170 inch (4.31 mm) or less". He recommended to watch the Norwegian experiments that are trying to define more precisely the optimum texture pattern.

On our subject the congress concluded its work with two brief recommendations:

> It is desirable to continue with the studies for the purpose of establishing the minimum coefficient of friction to apply on the projects. The skidding resistance of a road surface is substantially affected by the resistance of the aggregates to polishing under traffic action.

Rome 1964

Sixty-five nations were represented at this recent international meeting with 500 reporters producing 137 technical and economic papers; each of the ten committees issued a general report on its specialized discussions.

The fourth committee, in charge of "surface qualities of pavements", actually functioned as the "technical committee on slipperiness." The original report by J. G. Smith of Great Britian is not itself available, but its discussion brought out some noteworthy remarks.

An excellent correlation was established between the French Leroux apparatus and the pendulum of the British RRL, making it possible to convert the Leroux values into the RRL skid-resistance values, a good agreement was observed between the two scales.

The accelerated polishing test developed in England as B.S. 812, 1960, is regularly carried out also in France, but the value of its findings is interpreted, in each instance, in the light of the specific local conditions:

> It has been found that the geological identification of an aggregate is not sufficient and that it must be supplemented by the determination of its petrographic characteristics under the microscope and by tests of micro-hardness which enable a better understanding of the polishing phenomenon to be obtained, firstly, by considering the difference in the hardness of the constituent minerals which govern the depth of the hollows and, secondly, by examining the distribution of the hard parts and the soft parts.

The French Road Laboratory recommended that efforts be made to advance the knowledge on skid-resistance at high speeds (up to 120 mph) and to develop high skid-resistance surfacings for such speeds.

A British reporter also insisted on the "phenomenal increase" of traffic - in volume, speed and weight; the aggregates therefore polish faster and the danger of skidding grows. The British tests are said to be near perfection. "It is important", they say, "to have a rugous surface with coarse stone protruding upwards, to give good drainage and to avoid acquaplaning. This has been achieved in recent road surfaces in England by superimposing 3/4 inch pre-coated chippings into low stone content asphalt."

Two sets of conclusions were drawn up by two committees of the Rome Congress. While they do not concern the limited object of this report, they are such useful summeries on skid-resistance that we attached them as Appendix III.

E Q U I P M E N T   R E Q U I R E D

by N. J. D. T.

EQUIPMENT REQUIRED BY NEW JERSEY DEPARTMENT OF TRANSPORTATION

It goes without saying that if we can invent new methods and develop new instruments to implement them, so much the better. But as long as we want to save time and get the urgent program underway, the following is a minimum proposal of acquisition of the essential types of equipment developed outside of New Jersey:

I. Friction:

(a) field tests: our Stevens trailer, based on ASTM standards, is expected to become available before long. It will be advisable to formulate a clear relationship between its empirical SN measurements and the scientific coefficient of friction.

The excerpts hereafter describe a calibration machine for skid testers, developed in Sweden, which we may want to consider later on.

(vii) **Sweden**

(1) **Calibration equipment for skidding machines** [illegible]

Calibration equipment designed in ac[illegible] principles is indispensable [illegible] National Swedish Road Research Insti[illegible] equipment whereby known forces can be [illegible] with a test wheel in the same way as the [illegible] forces are applied when testing a road surface. All types of [illegible] vehicles used by the Institute can be calibrated by this equipment.

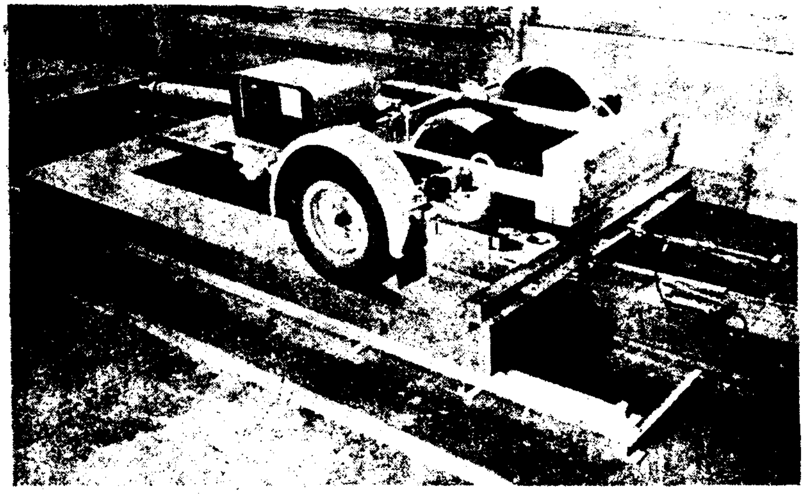


Fig. 2.12. General view of the Swedish calibration machine, seen from the rear. Note the hydraulic jack which moves the small platform.

The equipment (Figs. 2.12, 2.13, 2.14) consists of a horizontally arranged, movable platform. The test vehicle (Skiddometer BV.8 in Figs. 2.12, 2.13 and 2.14) is placed on this platform and the draw bar eye is locked to the platform at the correct level (Fig. 2.12). The test wheel rests on a separate small platform supported on ball bearings (about 30, $1\frac{1}{2}$ in. dia.). The small platform is horizontally anchored to the frame of the equipment by a circular spring dynomometer and fairly long link arm (Fig. 2.14) and stands on a precision weighing-machine, the dial of which is seen in Fig. 2.13. A hydraulic jack is used to move the small platform which in turn moves the test vehicle. This movement causes the test wheel to slip and the corresponding resistance directly transmitted is measured by the spring dynamometer. The dynamometer reading divided by the reading on the weighing-machine is then co-ordinated with the records simultaneously obtained from the test vehicle. By increasing the pressure in the hydraulic jack by suitable steps a complete set of calibration data is obtained.

The advantages which this type of calibration equipment offers are obvious. However, as the test vehicles of the Institute measure the coefficient of friction not only at locked wheel but also at incipient skid, a correction for the varying test wheel radii at different speeds is necessary.

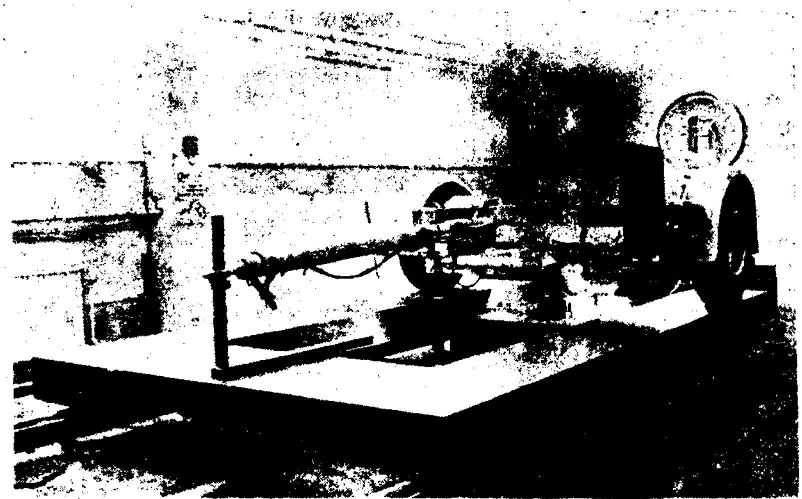


Fig. 2.13. General view of the Swedish calibration machine, seen from the front. Note the dial of the precision weighing machine in the background.

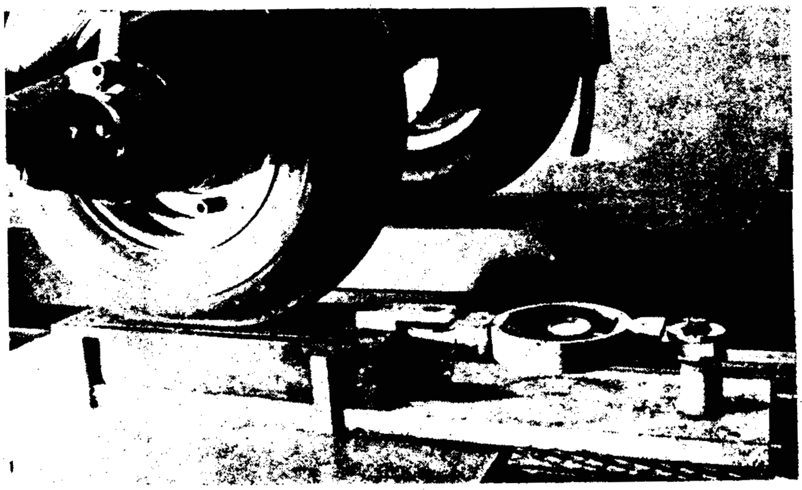


Fig. 2.14. Detail of the device for reading the horizontal force.

(from Report of the Tokyo World Road Congress 1967)

Another interesting device is the gauge for measuring the depth of the water film made in Great Britain (RRL) and easy to adapt.

Measurement of Water Depths

In view of the differences in skidding [illegible] occur at high speed because of variations in the amou[illegible] the road surface, attempts have been made to [illegible] of visual depth gauge which would give a qua[illegible] depth.

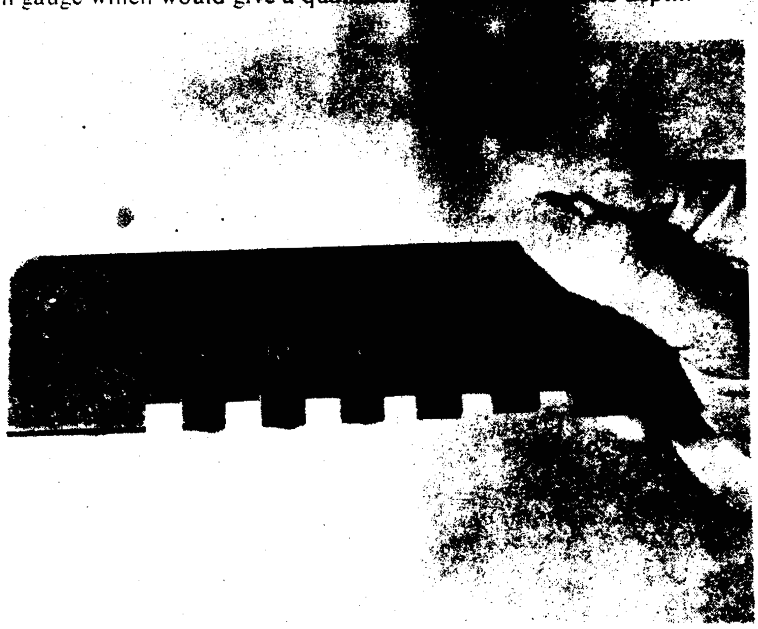


Fig. 5.4. Stepped gauge for measuring depth of water film.

Figs. 5.4 and 5.5 show two simple devices that have been made at the Road Research Laboratory for the purpose. The stepped gauge shown in Plate 5.4 is placed in an upright position on the wetted surface and when it is lifted single drops of water are retained on the steps which have made contact with the water. This simple device is quite reliable on smooth or fine-textured surfaces but is more difficult to use successfully on the rough coarse-textured surfaces. Plate 5.5 shows another gauge using the same principle, but here the set screws can be adjusted individually as required to suit the range of depths that is being used.

A more elaborate means of detecting and recording water depth on runways has been developed* but this could equally be used for road surfaces or test tracks where tests are to be carried out regularly. It consists of a road stud specially cut so that water can pass beneath it. Probes set at different levels allow the depth to be recorded on a meter or, if necessary, on a continuous moving chart.

Fig. 5.5. Adjustable stepped gauge for measuring depth of water film.

(from Report of the Tokyo World Road Congress 1967)

(b) laboratory tests: needed, a static, though portable tester of the pendulum type, or some other kind of instrument serving the same purpose. To be used for systematic friction tests in the laboratory, including the polishing tests; also for field tests for pinpointing danger spots.

The American supplier of the British portable pendulum tester quotes a price of $795 on 9-6-67; delivery 12 days from Chicago warehouse. Copy of their leaflet is enclosed; also other pictures of the same instrument, as used by the State Roads Commission of Maryland. It is in wide used in this country and abroad. A report just arrived from Georgia Highway gives minute details on the handling of field measurements. A cross-section, taken from an ASTM article, is also enclosed.

We have also a copy of the British road note #27 (1964) with instructions for using the British portable pendulum tester. This booklet is one file with the basic documents for this report.

The British pendulum tester can also be supplied with a special slider and scale for monitoring aggregate polish (see Penn-State Report #11 Page 42, paragraph 2). The test team at Penn State University headed by Mr. Kummer has made some modifications which we may or may not consider for our own use. Also see the same Report #11 Pages 1, 2, 3, & 4.

SKID RESISTANCE TESTING

① The portable unit is removed from its carrying case, assembled and levelled.

A pendulum-like testing arm with a special "shoe" on the end is adjusted to the proper height. This is usually so that the shoe comes in contact with the surface to be tested, but not enough to prevent it from passing through an arc.

② The road surface to be tested is then wetted with water as is the rubber slider mounted on the underside of the pendulum shoe. This is to reproduce the condition of rain or wet pavement, the condition most conducive to skidding.

③ Next, the pendulum is released so that it slides across the pavement as it completes its arc. As the pendulum passes through an arc, it carries with it a movable marker which will mark on a scale the highest point in the pendulum arc. The height of the arc is directly affected by the amount of "skidability" inherent in the wetted pavement being tested. The more skidability in the road surface, the higher the arc; the less skidability, the lower the arc. The pointer reading on the scale measures the resistance to skidding of the surface being tested. The scale is graduated from 0 to 150.

Skidding is a contributing factor in a high percentage of automobile and vehicular accidents in this country each year. Most skidding is caused by ice, water or oil slick present on a driving surface. In a good many other instances, however, an extremely smooth or slick road surface can make this condition worse. A new testing device marketed by Soiltest, Incorporated and designed to accurately determine the "skidability" of a road surface is helping road and highway designers and government road agencies make our highways and by-ways safer.

12 days from Chicago

HT-120 PORTABLE SKID-RESISTANCE TESTER

A new portable instrument that measures the skid resistance of surfaces has been introduced by Soiltest, Inc. This new device, called the Portable Skid-Resistant Tester, gives a simple direct reading of the frictional co-efficient between a skidding tire and a road surface. The instrument was developed by the British Road Research Laboratory. The new test instrument consists of a pendulum arm with a spring-loaded rubber slider on the foot of the pendulum. It can be used on both flat roads and those with camber or gradient.

The portable skid-resistant tester is placed on the portion of the road to be tested, levelled, and the height of the center of suspension of the pendulum adjusted by a system of screws to a fixed value which is read on a special gauge. The pendulum is then released from the horizontal position and swings freely until the rubber slider meets the surface being tested. The slider moves over the surface for a fixed distance, slowing the pendulum down. A frictionally-constrained pointer affixed to the pendulum arm measures the highest point in the pendulum arc. The position of the pointer is then read on a measuring arc graduated from 0 to 150. The pointer reading measures the resistance to skidding of the surface being tested.

HT-120 Portable Skid Resistance Tester.
HT-122 Replacement Main Test Slide.

Shipping weight: 86 pounds Net weight: Tester with case, 71 pounds
Tester only, 33 pounds

- 9.201.233.1188

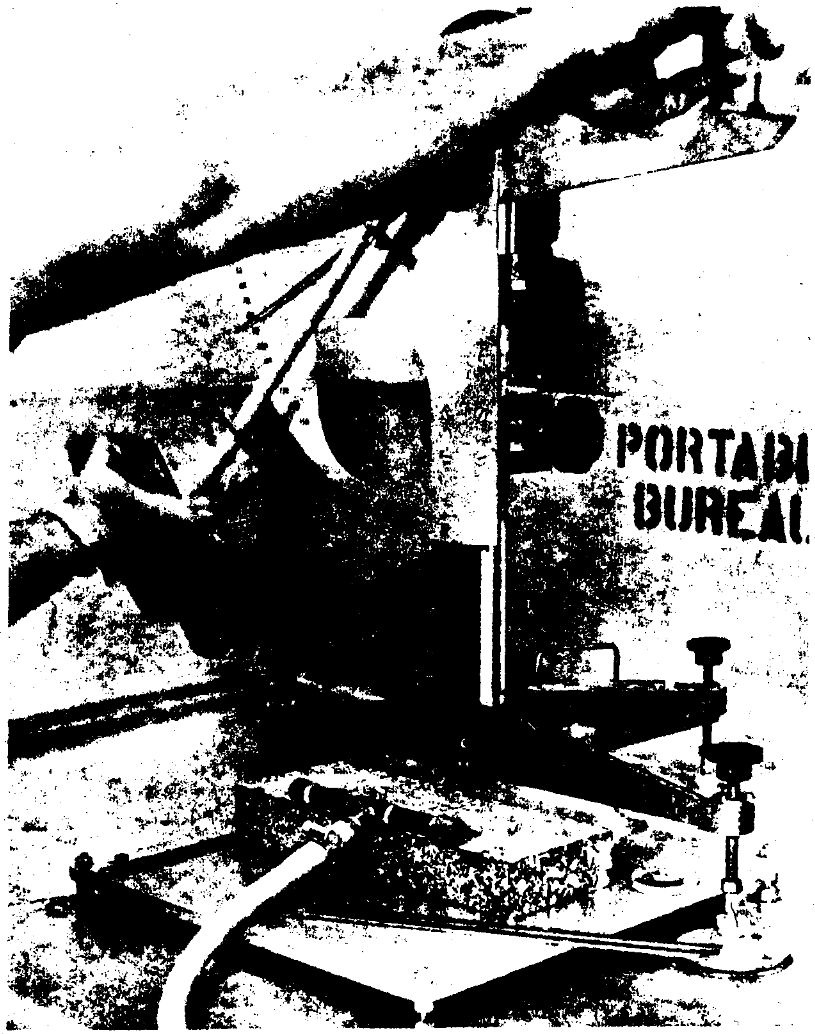
Prices and Specifications are Subject to Change
All prices are F.O.B. Chicago, Illinois. For export shipment add 7% for export packing and inland freight.

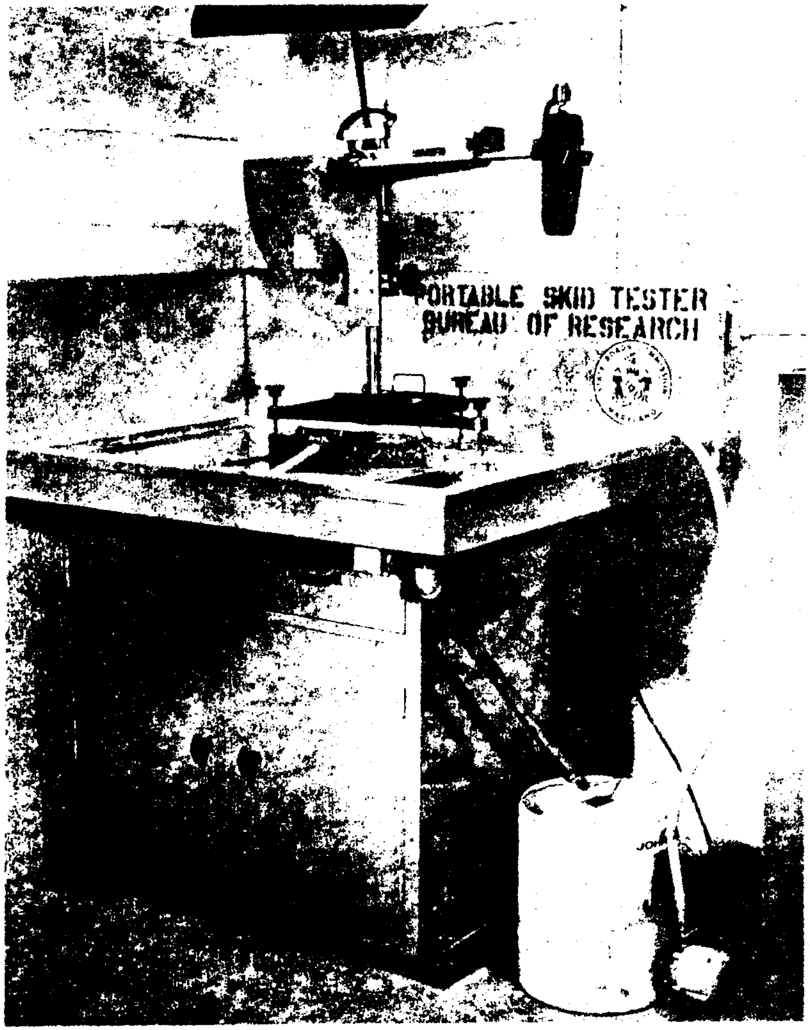
SOILTEST Incorporated

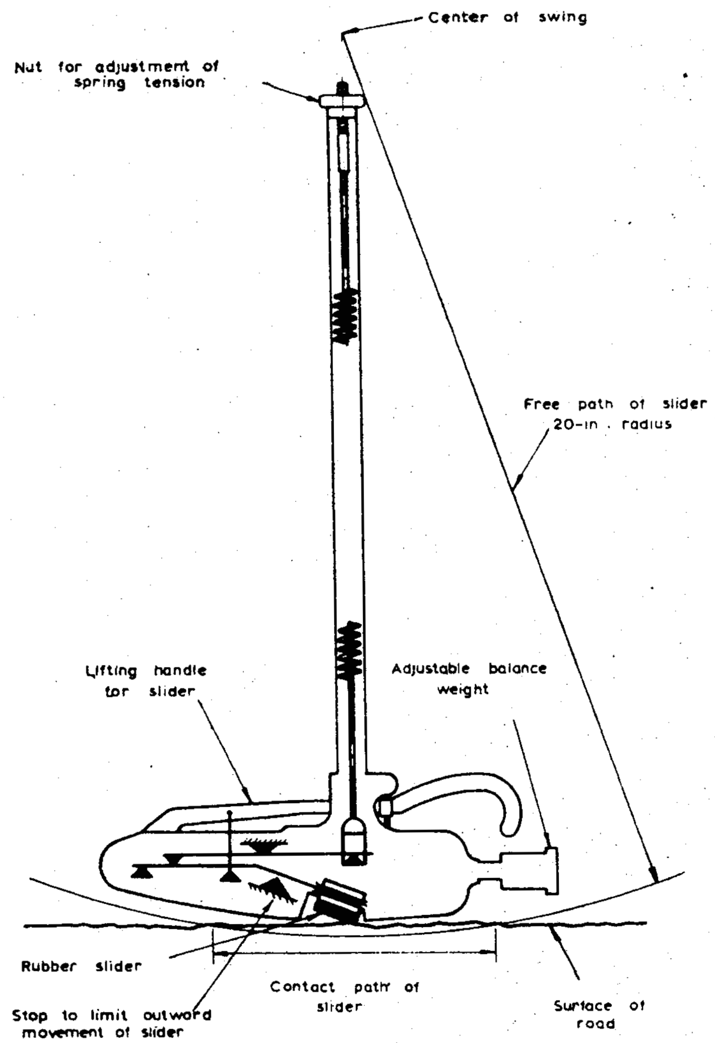
SALES REPRESENTATIVES IN ALL COUNTRIES

SUBSIDIARY CENCO INSTRUMENTS CORP.
4711 WEST NORTH AVENUE, CHICAGO, ILLINOIS 60639, U.S.A.
Telephone: Area Code 312 — 772-6400
Cable: Soiltest Chicago Teletype: 312-222-0663

British Pendulum Tester in use at Maryland Highway







The British RRL Pendulum Tester

From an article in ASTM publication No. 326 of 1959

II. Polishability:

The testing process will use the above-mentioned portable tester for measuring friction before and after polishing, developing first the "skid-resistance value" (the original coefficient of friction), then the "polished-stone coefficient" (the coefficient of friction after polishing). The polishing itself will have to be done by some accelerated polishing apparatus, probably of a drum or wheel type. The general type of equipment for this purpose seems to have been widely agreed upon, but precise details are hard to get. We have written for particulars in order to locate a source of supply, or else obtain sufficient data for making our own machine (or have it made by a qualified shop), with the benefit of outside experience.

In our summary on the French work in the field of skid resistance we have already mentioned the polishing machine they take so much time to develop - too much for us to wait.

Georgia sent us 21 drawings and 5 photos, plus a brief report and letter on the machine they have used themselves. But since they have no assembly drawings and their photographs are not clear enough, their material is not immediately applicable for our purpose.

The picture which follows is taken from Penn State report #11 of July 1966, made in cooperation with the Pennsylvania Department of Highways under the signature of H. W. Kummer. It is the report we mentioned above.

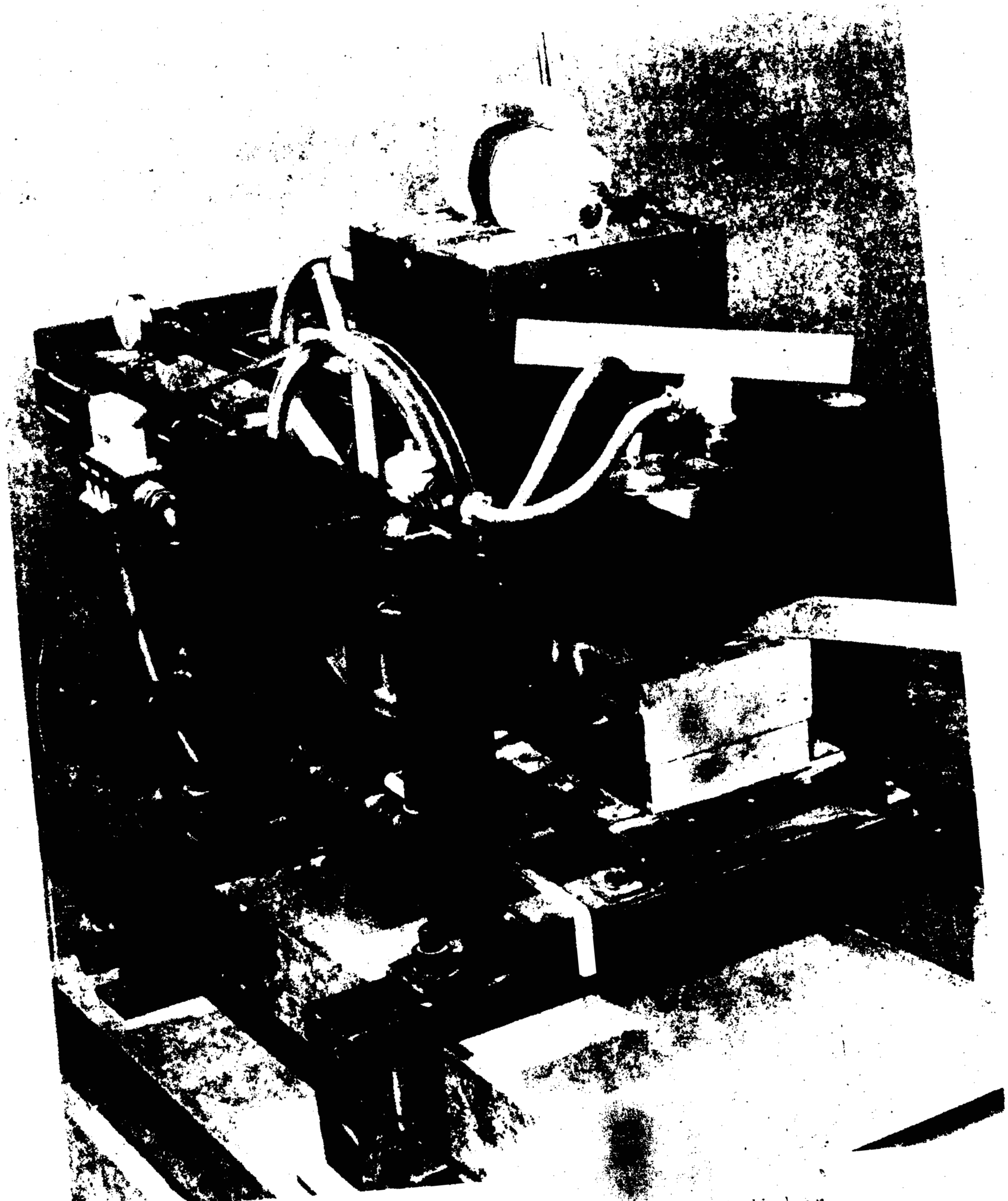


FIG. 28. Reciprocating Pavement Polisher.

(PENN - STATE)

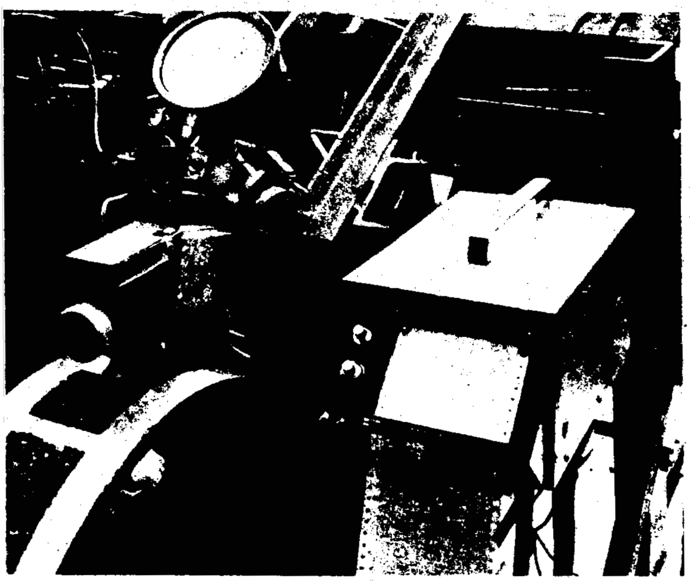


FIG. 29. Rotary Wear Machine, Photo. **(Penn-State)**

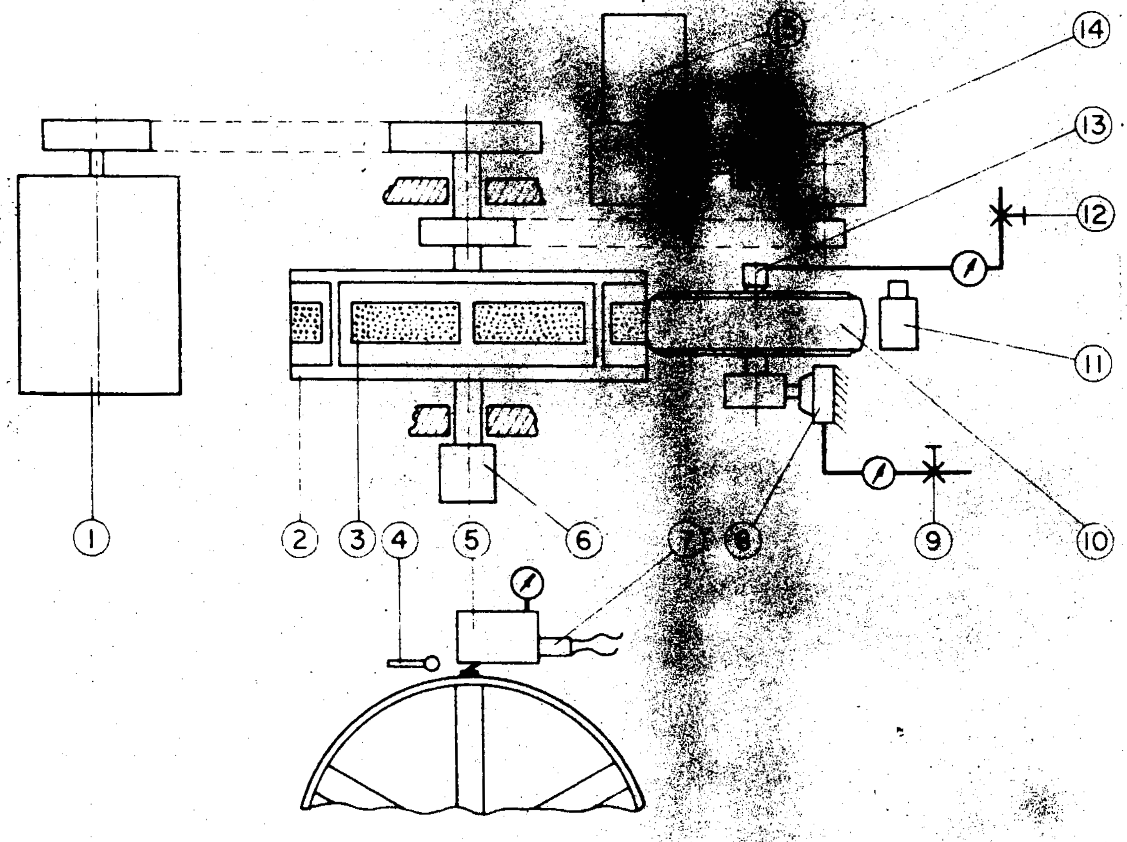


FIG. 30. Rotary Wear Machine, Layout. **(Penn-State)**

The relative motion between the loaded tire tread and pavement provides the mechanism of polishing and wear, and reproduces the actual mechanism due to traffic action on highway pavements. The convex curvature of the drum surface is the only departure from the actual kinematic conditions in the field. The use of a polishing agent is one means of accelerating the wear-polish process, which would normally take years in the field. In the usual application of the test, the test tire has a smooth running band to prevent the breaking and tearing of aggregate caused by profiled tires. A polishing agent is introduced so as to accelerate the polish-wear process. When the coefficient approaches a constant value, the polishing process may be regarded as complete.

One of the latest reports we succeeded in discovering is the one by New York Department of Transportation. It is their #67-3, called Skid Resistance of Bituminous Surfaces, mentioned above. On page 8 appear pictures of their polishing wheel as well as of the British portable tester. As mentioned already, practically everybody in this field of research used that portable tester in spite of it's limitations. The size of those limitations appears on figure 8 which shows the correlation of the BPT and the New York State Skid trailer (40 mph).

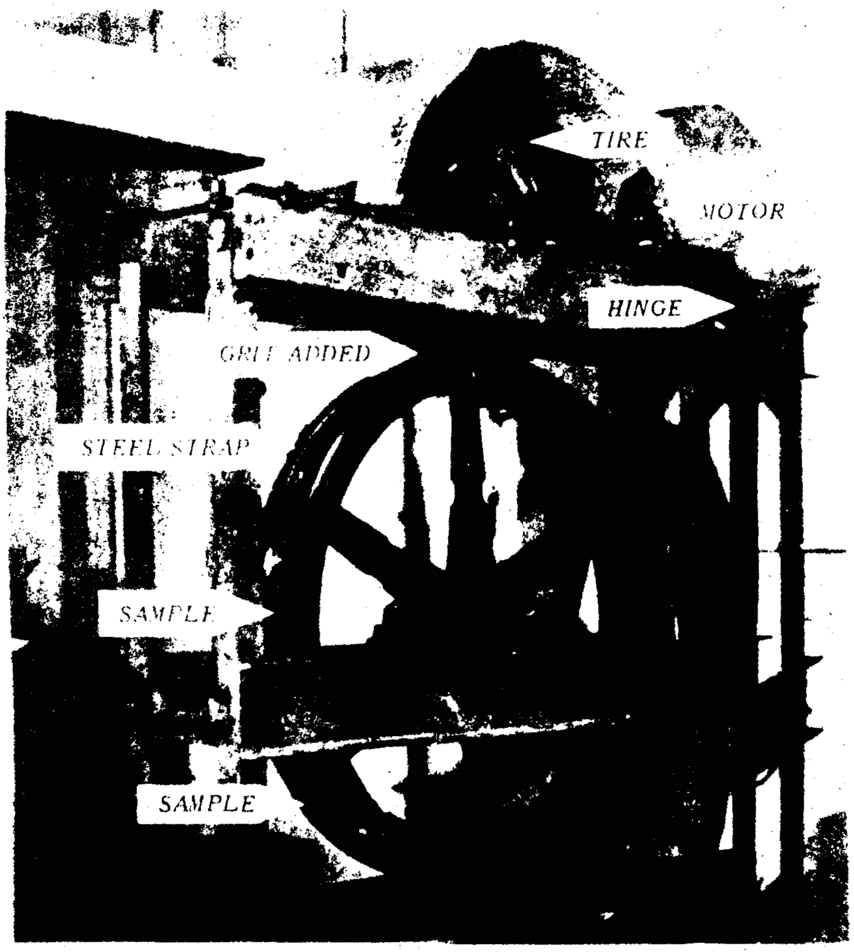


Figure 6. Polishing wheel. (New York State)

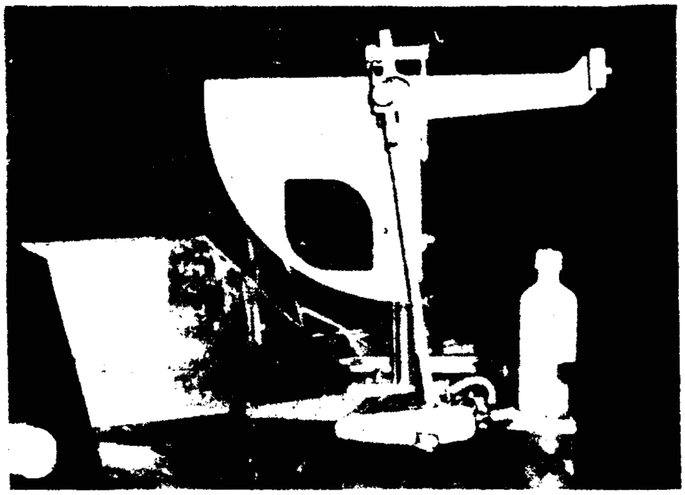


Figure 7. British portable tester.

(New York State)

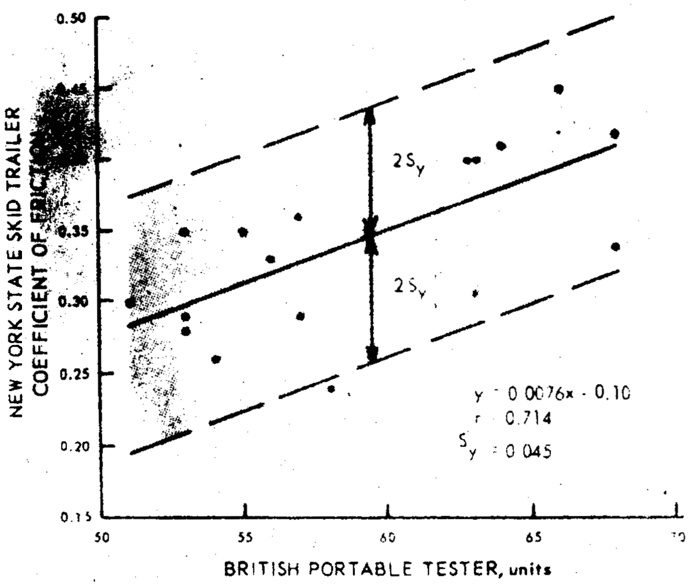
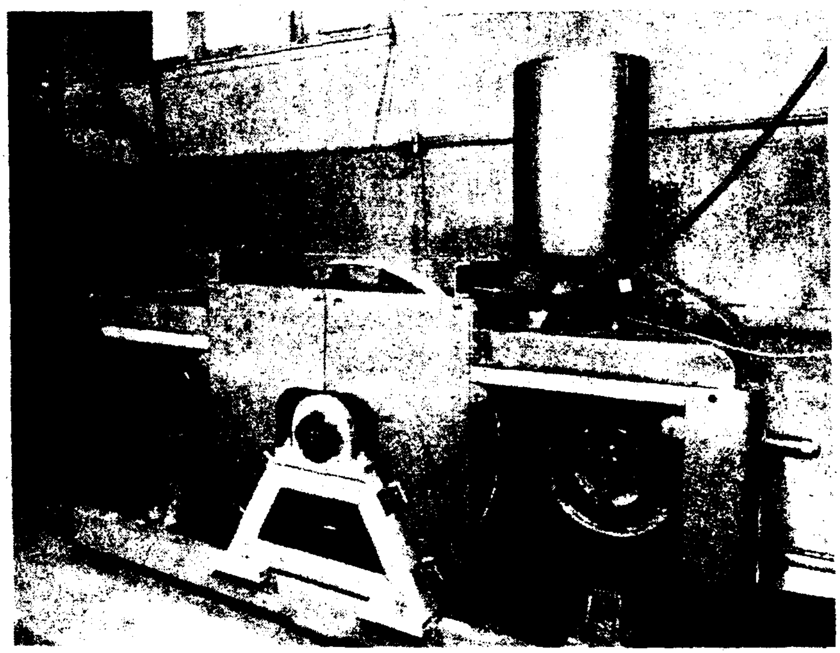


Figure 8. Correlation of British Portable Tester and New York State skid trailer (40 mph).

This leaves us with the British model, which has been in use over there for some ten years and has also been copied or applied in various other countries in Europe. We mentioned it before: on pages 31/32 from the direct British source, on page 37 from French data, and on page 46 via Canada. It is also cited and described in the Belgian Road Research Laboratory's Periodical bulletin called La Technique Routiere which we have in our research library (volume 4, No.1, page 15).

The British "Accelerated wear machine", as they call it, has been briefly described on pages 31 through 32 above. It is shown in the picture and descriptive text that follow. The blue prints have just arrived.



Accelerated-wear machine for research on skidding on concrete roads

PLATE 12

(4) New accelerated wear machine

An accelerated wear machine, in which concrete specimens are attached to a rotating wheel and subjected to wear from two road wheels that are held in contact with the specimens, has been designed and made at the Laboratory. The machine is set so that the road wheels have an angle of scuff with the specimen wheel of 2° and they are tensioned together to give a contact pressure of 55 lb./sq. in. between the road wheels and the specimens. The specimens are first worn and then polished by feeding in an abrasive material between one of the tyres and the specimen surfaces. A natural sand graded between 7 and 14 B.S. mesh sizes is used for wear and is fed in onto the dry specimens for 25 hours after which the blocks are polished for 5 hours by using a fine air floated emery flour powder fed onto the specimens which are wetted. The sand is fed in at a rate of 2,000 gms./hour and the powder at a rate of 250 gms./hour. At various times during test the surface texture depth of the specimens is measured by the sand-patch method and the "skid-resistance" of their surfaces by the portable tester.

Results already obtained from tests carried out with the machine have established that the use of a wire broom is the best of the methods at present available to texture fresh concrete road surfaces.

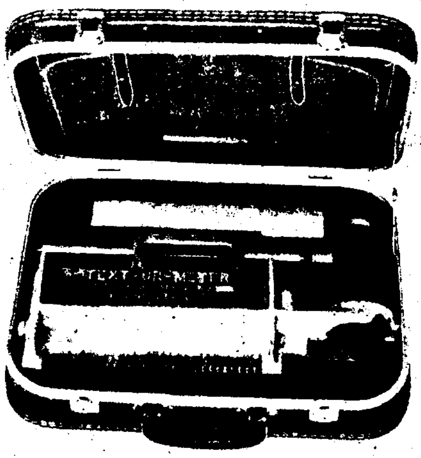
A programme of tests is now in hand to examine further the effect of mix design and the type of aggregate on the life of both wire brushed surfaces and surfaces grooved with specially designed rubber tined units.

(from the Report on the Tokyo World Road Congress 1967)

III. Surface Texture:

The survey made in France (see page 38 above) has brought out the great variety of attempts made for solving this problem, none of which seemed to be practical and up-to-date. The most frequently mentioned system (by the British, the French, and others) for defining and representing surfacr texture is the sand-patch method, a very simple device which anyone can duplicate by his own means; it is both cumbersome and primitive.

But we have ample information on the little texture meter developed in Texas (see page 46 above). It seems to be practical and costs only $650. A photo and a general description follow on the next page:



Cat. No. 870 TEXT-UR-METER (TEXAS)

A HAND OPERATED INSTRUMENT [illegible]ING COARSENESS OF TEXTURE, PARTICULARLY FOR "A MODIFICAT[illegible]HO ROAD SERVICEABILITY INDEX TO INCLUDE SURFACE TEXTUR[illegible] GEOMETRY CONFORMS WITH CITED INSTRUMENT WHEN 15 PR[illegible]USED. CONVERTS EASILY FOR ABOUT 2-1/2 TIMES HIGHER SENSITIV[illegible]H 14 INTERMEDIATE PROBES.

The theory behind it is that the texture of the [illegible] between two points 10-in. apart is related to the additional length of cord abo[illegible]10-in. needed to follow the surface. In practice, the 10-in. space between two fixed reference points is equally divided by 15 spring loaded probes which are free to move vertically in guides. When the fixed reference points contact a surface the intermediate probes move up or down according to the elevation under each one. These movements deflect a cord from its zero straight position, and a dial indicator shows the additional length needed. Sensitivity can be easily increased about 2-[illegible]times by installing the supplied 14 additional probes, as illustrated.

Close correlation between instrument[illegible] is [illegible]ed through close production control and 22 pre-shipment checkings on ele[illegible]rows of typical surface variations covering the operating range of the instru[illegible]

CAT. NO. 870 TEXT-UR-METER - Co[illegible]te with Operating & Service Manual, Dial Indicator, Zeroing & Checking Bar, Extension Handle Assembly and fitted Carrying Case. (See General Specifications [illegible])
Approx. Ship. Wt., 25 lb. $600.00 Each

*Scrivner, F. H. and Hudson, W. R. Paper presented at the 43rd Annual Meeting of Highway Research Board, Washington, D. C., January 13-17, 1964.

GENERAL SPECIFICATIONS - Sturdy and accurately machined aluminum alloy body with cast-in handle which accepts aluminum extension handle for operation from convenient standing position. A dial indicator guard protects the easily read AD Group III jeweled Dial Indicator furnished with revolution counter. Dial reads .001 per division; 100 divisions per revolution; .250-in. total travel. 6 x 11-in. clip-board for test data forms is attached to the body. Highly flexible and stretch resistant cord and ample supply of replacement cord is furnished. Replaceable fixed end reference pins are 10-in. apart and both are 3/16-in. dia. standard hardened, copper plated and blackened dial indicator contact points with 3/16-in. radius of their face. The brass probes are fitted with replaceable hardened, copper plated and blackened steel contact points with a .031-in. point radius. The probe contact points are .625-in. apart when used as a 15 probe unit and .3125 in. apart when used as a 29 probe unit. A dust sealed, rugged molded-fibre 18 x 12 x 5-in. attache case, complete with equipment holding fixtures and removable 5 pocket file, is supplied for transportation and storage. Furnished with zeroing and checking bar of aluminum 3/4x2x12-in. complete with pattern of accurate flat-bottomed holes for over-all checking of the unit. Operating and Service Manual with appended specimen report and current procedure of Texas Transportation Institute is included.

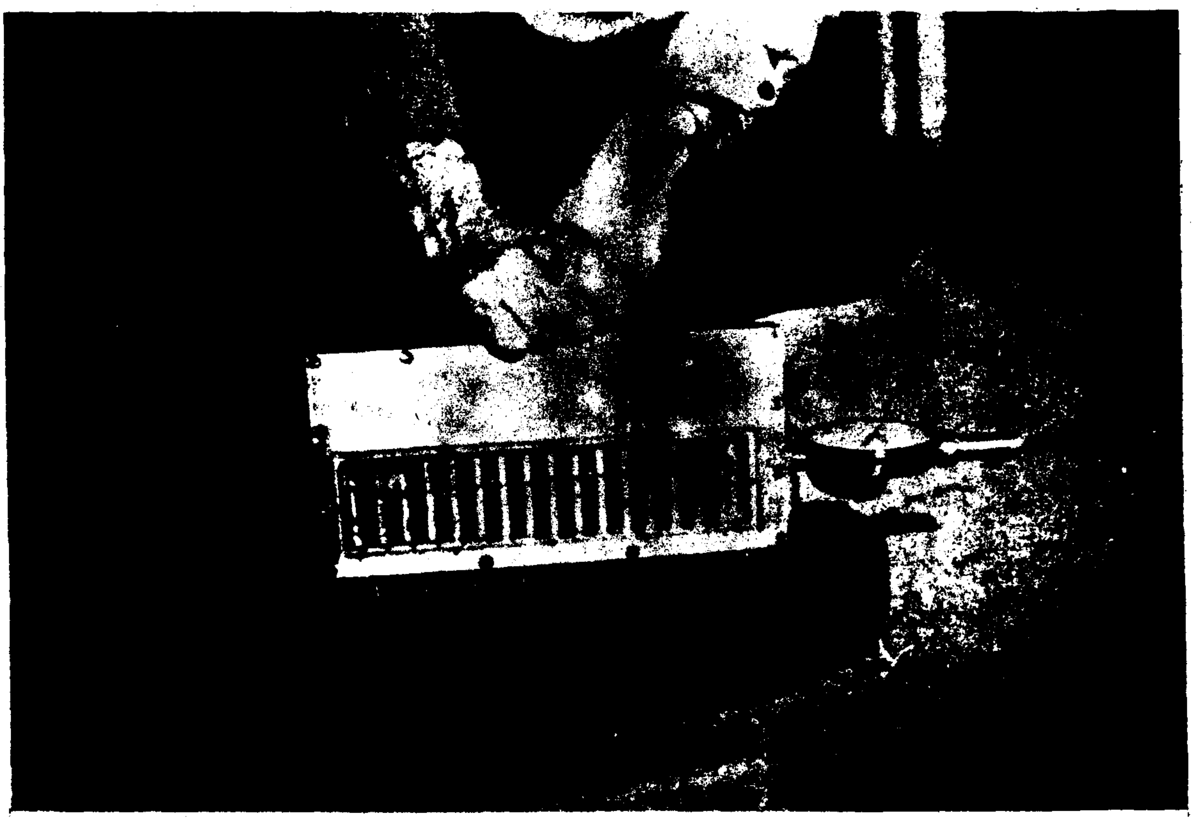


Figure 4. The texturemeter applied to a laboratory specimen of asphaltic concrete. Road surfaces give dial readings ranging from zero to about 100 thousandths of an inch. (Texas)

The larger photo of 870-TEXT-UR-METER is taken from Technical Report No. 1 by the Texas Transportation Institute, dated May 1963. Mr. Huff, Chief Design Engineer of the Texas Highway Department, wrote last October as follows:

> The most effective use of this instrument is to take a large sample of several readings over the surface in question. This sample should be larger on open textured pavements. It is believed that Mr. Scrivner uses approximately 20 readings on penetration or surface treatments. The results are meaningful since small closed textured surfaces (concrete paving) result in low readings and large open textured pavements result in large readings (around 100 thousands of an inch), but the reading of the small, closed-textured surfaces will be less meaningful because of the probe spacing. The instrument should be read as quickly as possible after placement. This is because the "stops" at each end of the probes (and possibly the probes themselves) penetrate into an asphaltic material depending on the viscous properties at the points of contact.

A practical texture camera was developed by the British. Their own description follows, taken from their Road Note No. 27:

A SIMPLE CAMERA UNIT FOR RECORDING ROAD SURFACE TEXTURES

Requirements

Methods of photographing road surfaces have been described elsewhere[2] but the camera units used are not suitable for use by a skidding team. Such a team requires a relatively small unit which can be carried in one piece in a car or light van, is easily transportable from one section to an adjacent section of road, and is quick and easy to operate. The unit described in this Appendix fulfils these requirements and, although some of the high-quality finish of the photographs produced by the more elaborate apparatus is lost, the reproduction obtained is quite satisfactory for record purposes.

Description of apparatus

The camera unit, which is shown in Plate 4, consists of a ¼-plate camera with an alternative 120 roll-film back adapter mounted vertically with its focusing plate 2 ft 10 in. from the road surface, and with a synchronized flash gun mounted within the same housing. The camera used had a 13.5-cm, f4.5 lens, permitting a coverage of 12 in. × 16 in. on the ¼-plate size photograph, or 9 in. × 13 in. on the 120-size negative. To illuminate this area the flash bulb is located midway along one of the longer sides of the box at a distance of 20 in. and 55° from the centre, as indicated in Fig. 2. This position was found by experiment to be the best, having regard to the essential requirement that the overall dimensions of the unit should be as small as possible: the direction of the flash is sufficiently oblique to show up details of surface texture, and the source of the flash sufficiently distant to give reasonably uniform illumination. (Ideally the direction of the incident light should be more oblique, but this requires a much more distant source.[2])

With this arrangement, PF14 flash bulbs were used in combination with a slow panchromatic film or plate, the camera lens being set at an aperture of f16 with a fixed focus. With this setting the depth of focus is about 1½ in., which is sufficient to accommodate unevenness and roughness in the road surface. The flash gun was mounted on a hinged door to facilitate replacement of the flash bulbs. Each photograph can be identified by marking with crayon a traffelyte rule, which is also engraved with a scale in inches: this rule is placed directly on the road surface.

In operation the camera is set on the road surface, the identification rule set in position, a flash bulb inserted in the gun, the camera shutter set, the door closed and the trigger fired. Thus the time taken to obtain a permanent record of the surface, showing all the details of texture and general appearance required, occupies only a few seconds at each site. Standard conditions of illumination ensure a fair comparison between different surfaces. Typical photographs showing the range in texture (taken on PanX 120 film) are those shown in Plate 2. Experience has shown that in wet weather the road may be dried with a sponge and rag and a reasonable photograph still obtained.

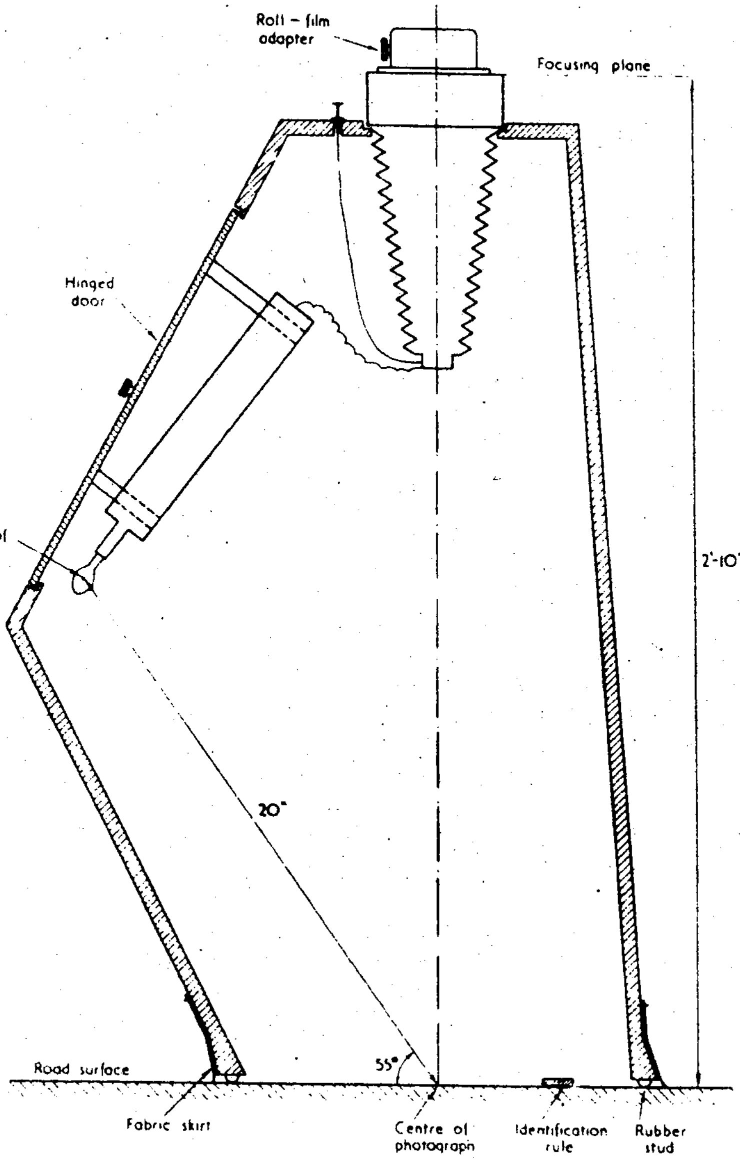
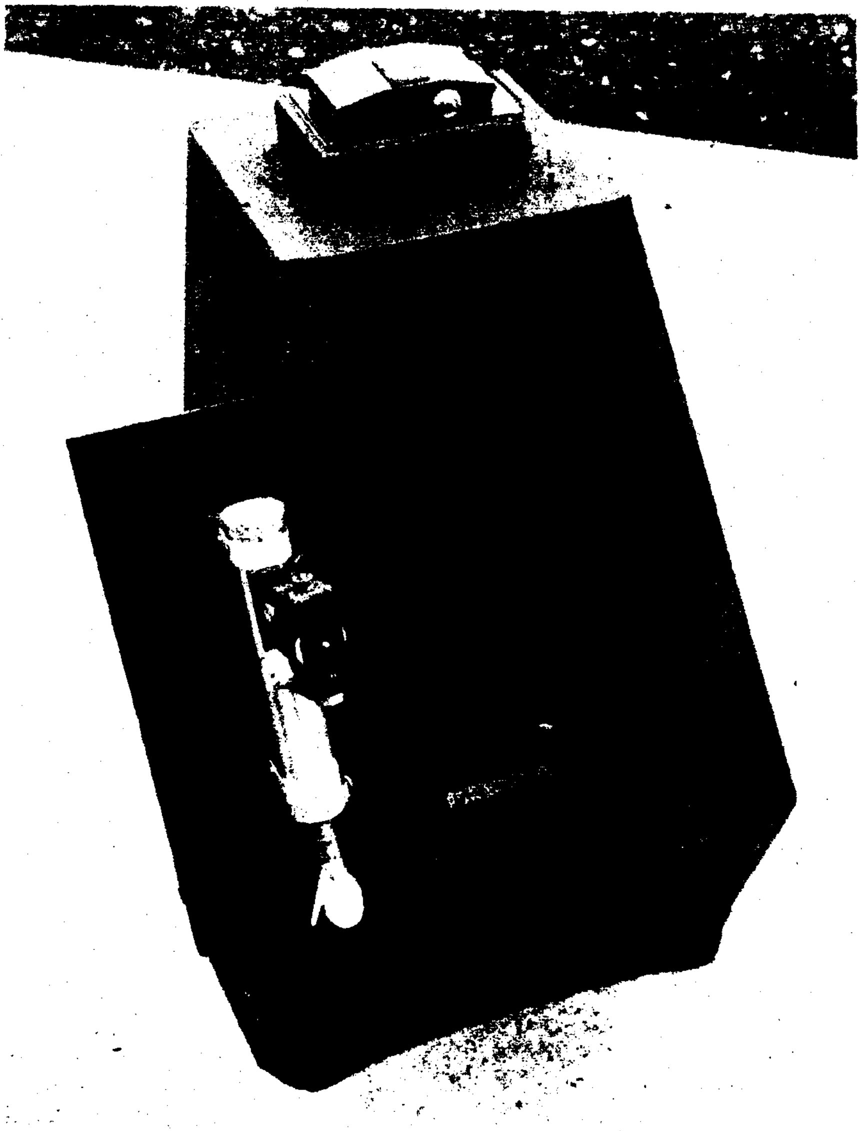


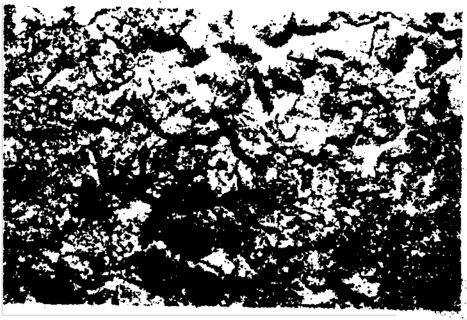
FIG. 2 *Diagrammatic arrangement of surface texture camera box*

(British RRL)



Camera unit for photographing road surfaces, showing flash gun mounted on door

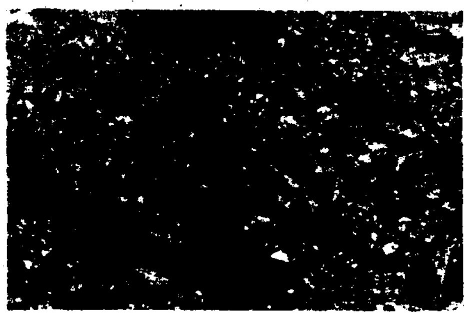
PLATE 4 **(British RRL)**



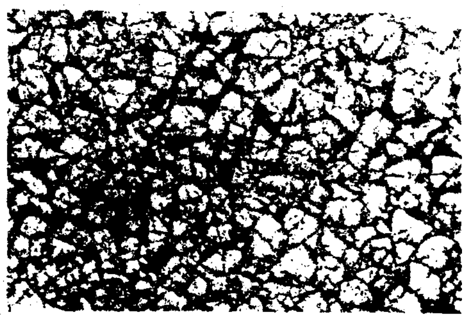
a

b

Rough or open-textured surfaces

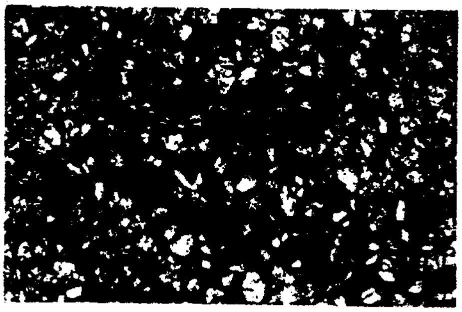


c



d

Medium-textured surfaces



e

f

Smooth or fine-textured surfaces

Typical surfaces having open-, medium- or fine-textured appearance

(Approx ½ size) **(British RRL)**

PLATE 2

There is also the much more involved method of Stereophotogrammetry of textures developed by the British Ministry of Transport. We are reproducing hereafter the text taken from their booklet "Road Research No. 27, 1964", published in 1966:

Measurement of road surface texture. In connexion with studies of surface texture requirements for good skidding resistance, a stereophotogrammetric method which records the surface profile of small areas of road has been developed. The advantage of this method is that it gives a record of the shape of projections in the road, whereas the 'sand-patch' and texture printing methods of recording surface texture do not. Knowledge of the shape or angularity of the projections is important in determining the contribution to friction arising from deformation losses in the rubber of a tyre tread. This stereo method should therefore have particular application in assessing surface texture requirements for high-speed roads.

The camera used for taking the stereophotographs, illustrated in Plate 2 (B), is a single-lens plate camera with a 105-mm focal length lens. Stereopairs are obtained by shifting the camera unit a fixed distance on its base. The lens is at a fixed distance of 30 cm from the road surface and the camera shift is 8 cm. The surface is illuminated by a steady light source and time exposures are made using an aperture of *f*.11. An area of approximately 5 in by 4 in is covered, and the depth of focus of nearly ¾ in ensures that on the majority of road surfaces both hills and valleys are in focus. Stereopairs of two surfaces are shown in Plate 3.

The surface profile is obtained by means of the comparator shown in Plate 4 (A). Measurements are made of the relative heights of successive points at 1/50-in intervals along a line on the surface with the aid of a parallax bar, and readings are recorded on punched tape. Sections of profiles measured from the stereopairs shown are drawn in Fig. 31. These are distorted profiles, the vertical magnification being approximately 2½ times the horizontal, and readings of heights are accurate to approximately 1/100 in. The profiles indicate the larger scale roughness of the road surface, not its microtexture (state of polish); for the latter purpose an accuracy of the order of 1/1000 in would be required.

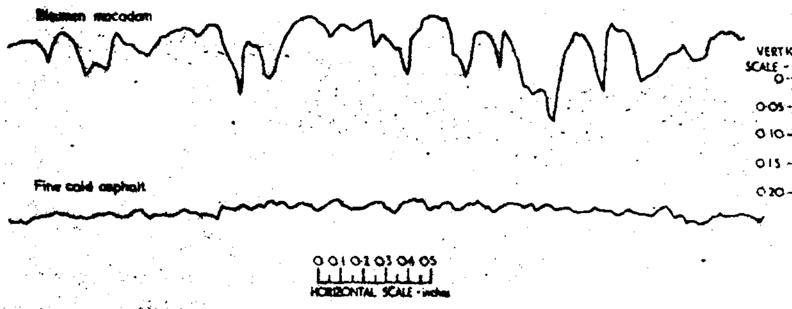


Fig. 31. Profiles obtained from stereophotographs on two surfaces

Different techniques of assessing the profile are being explored; one simple measure, already used, is the ratio of the length of the distorted profile to the length of the baseline. This ratio correlates with the texture depth of the surface measured by the 'sand-patch' techniques (see Fig. 32).

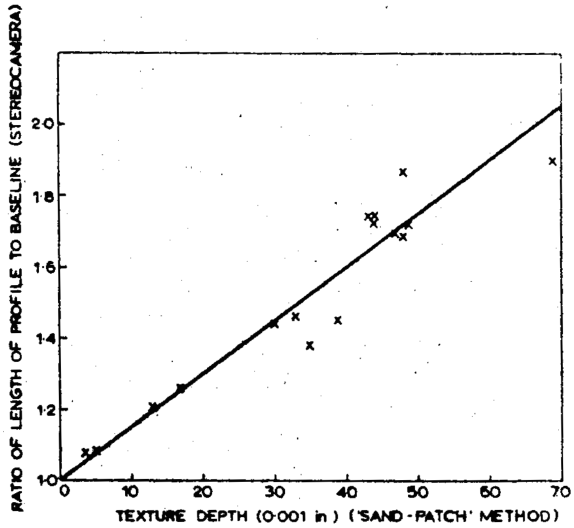
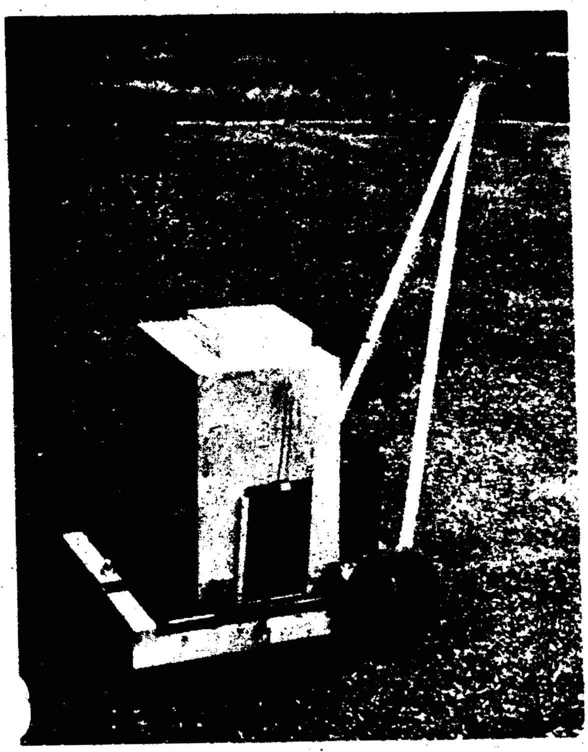


Fig. 32. Comparison of measurements of the ratio of length of profile to baseline obtained with the stereocamera and texture depth measured by the 'sand-patch' method



(B) Camera used for stereo photography of road surfaces
PLATE 2

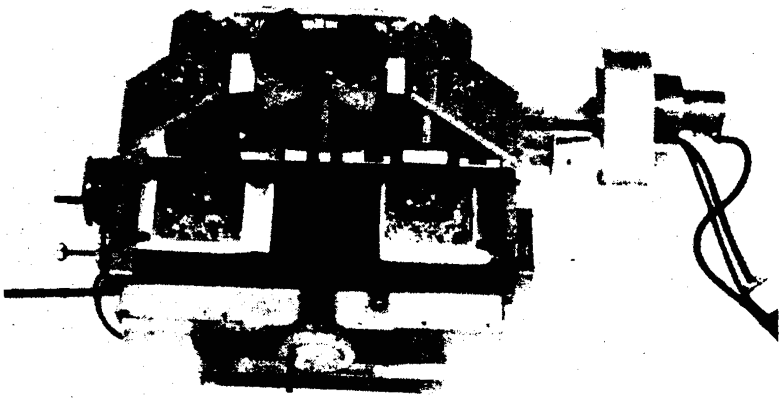
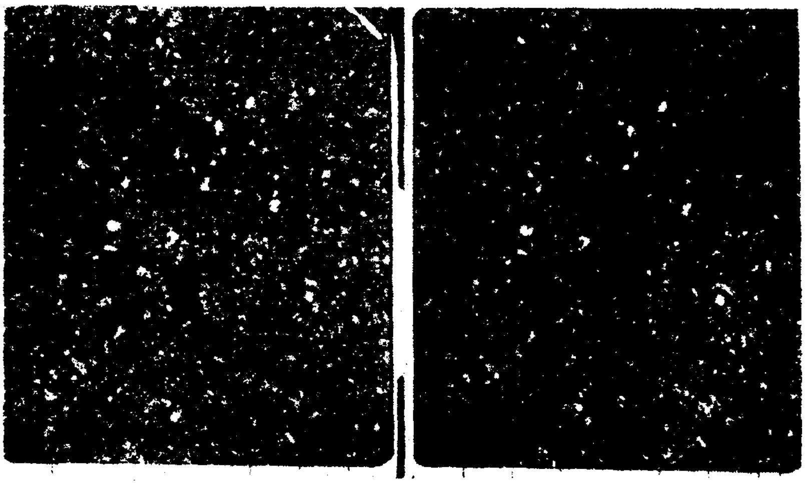


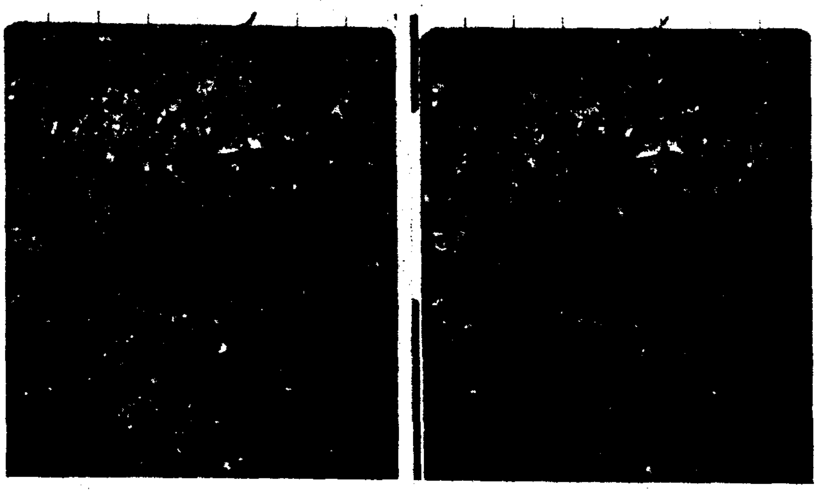
PLATE 4

(A) Comparator for obtaining surface profiles from stereopairs

(all 3 pictures from the British RRL)



(a) Bitumen macadam



(b) Fine cold asphalt

Stereo photographs of two road surfaces

PLATE 3 **(British RRL)**

Also see their RRL report LR 57 of 1967, dealing in depth with this subject (in our library). Even in its country of origin, this method is still in its infancy. The use of it would best be deferred until the time when we have gained more experience in this field, and the British too have refined theirs.

The report on the Tokyo meeting of the World Road Congress in 1967 gives two summaries of German and French methods. They do not differ essentially from those described above.

(iii) **Chief methods used**

(1) **Method used in Germany**

(a) *S[illegible]ce moulding*[1]

Usi[illegible]fusible paste [illegible] a [illegible] flowers of sulphur and graph[illegible] the propo[illegible] negative mould of the road surfa[illegible] To ext[illegible]ch as a liquid mineral oil is use[illegible]

Thi[illegible]gativ[illegible]ould [illegible] the same way to obtain a positiv[illegible] severa[illegible] surface are required.

It i[illegible]ible to [illegible] slici[illegible] mould with parallel vertical cuts, [illegible] profiles o[illegible] sa[illegible] by several successive, thin, horizo[illegible] strips, a diag[illegible] irre[illegible]ities of the surface texture.

Photographs are then [illegible] the pr[illegible]es and enlargements made for closer examination. An analy[illegible] made in the first case applying German Standard DIN 4762. From the characteristic values of the profile and the length of base chosen calculations are made of the maximum depth R, the texture filling factor (indicating the way in which the materials are distributed throughout the heights and hollows), the bearing length (indicating the amount of wear likely, assuming the texture to be uniform).

In the second case, the amount by which the cut surface exceeds in area in relation to the overall surface area is observed and one deduces the capacity of the surface for surface water drainage.

(b) *Method using a profilograph*

Another apparatus was constructed recently consisting of a row of 180 needles, 0·6 mm. in diameter, free to move vertically as they conform to the road surface. The curve formed by the line of needle points which had been raised is photographed to show the profile of the road surface.

This operation which can be carried out very quickly gives results accurate to better than 1 mm.

The results are analysed following the principles laid down in the specification of Standard DIN 4762.

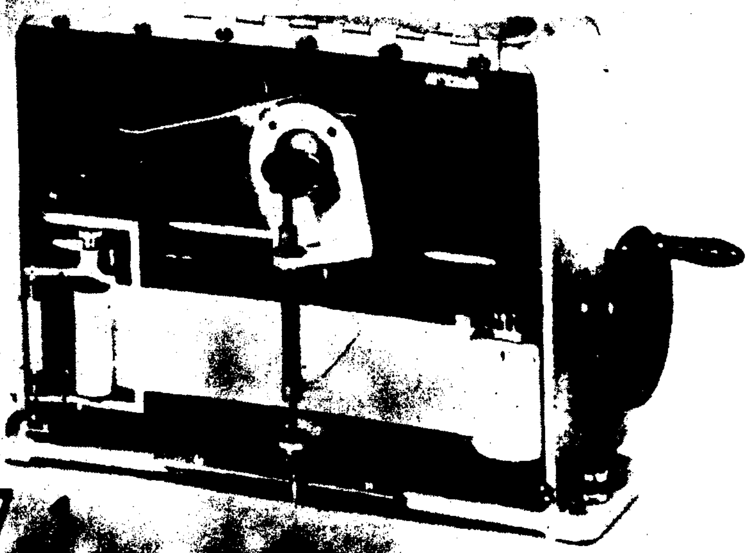
Two series, five each of profiles, are generally made in two perpendicular directions so as to obtain a representative mean value of the surface texture.

(2) Methods used in France

(a) Use of the profilograph[3]

The Central Laboratory of Ponts et Chaussees first of all constructed an apparatus, based on a Soviet model, having a single needle. The principle on which it worked was based on the intermittent contact of a [illegible] needle which moved up or down as it was moved horizontally along the profile of the surface texture undergoing test.

The envelope drawn by the stylo on the wax paper roll that provides a rec[illegible] actual size of a section of the profile of the road.



Fig[illegible] T[illegible] [illegible]cro[illegible] [illegible] Laboratoire Central des Ponts et [illegible]

The analysis of t[illegible] [illegible]en [illegible]rried out in accordance with the method described by [illegible] [illegible]om which for convenience we quote[4]:

on the diagram o[illegible] [illegible]n 100 mm. of length, two lines L and $L_{\rm II}$ are drawn touching [illegible] [illegible]est peak and the lowest hollow. The distance measured [illegible] [illegible]se two lines give the maximum depth R_{100};

The 100 mm. length is divided into two equal lengths of 50 mm. on which the above operation is repeated. This gives the mean value R_{50} of the two R_{50} depths thus obtained:

The operation is repeated to obtain the mean values R_{30}, R_{20}, R_{10}.

In this way a set of values are obtained characterising the rugosity at various steps. The representative curve can then be characterised mathematically very easily.

(b) Use of moulds

In a similar way to what has been done in Germany and Great Britain moulds of the road surface have also been made. By using a material with a silicon base it was possible to dispense with a freeing agent to withdraw the mould (thus giving a mould of greater fidelity) and in particular to get a mould showing the "counter-reliefs". On the other hand, however, the negative mould is too flexible to stand up to direct measurement and a positive mould has to be made.

The methods of analysis which are used are the same as for the German method except that the enlargement is obtained using a profile projector apparatus. This method is accurate to 0·01 mm. (0·004 in.).

Akin to this method which the Centre National de la Recherche Scientifique (C.N.R.S.) developed is one which enables an analysis to be made, by means of replicas, of the surface conditions and their importance to skid resistance. This method giving an accuracy to the order of a micron is now coming into use with some slight changes for certain rocks.

The Tokyo Report Concludes:

Conclusion

(1) With the recent studies showing the great importance of surface texture in determining the skidding resistance of roads at high speeds fresh emphasis has been [illegible] to the study of methods of surface texture measurement not only [illegible] the point of view of research but also with a view to meeting the requirements of the highway engineer.

[illegible] ous t[illegible] have been u[illegible] recording the coarse elements [illegible] surface [illegible] measurement of the very fin[illegible] texture [illegible] ble[illegible]

[illegible] where the t[illegible] satisfactorily its expression as [illegible] numerical quantity [illegible] problem. For example t[illegible] pro[illegible] of the texture come into [illegible] close [illegible] to [illegible] significant role in influenc- [illegible] dding [illegible] the surface.

(4) There remains considerable scope for the development of surface texture measuring devices for practical use on the road.

* *

Without going into more sophisticated or doubtful solutions that would take too much preparatory time, we could very well combine the little British texture camera and the Texas texture meter to obtain for each test site and each test sample visual and measured characteristics. These would enable us to compare the actual surface structure patterns with the real and the desirable resistance characteristics.

RECOMMENDED PROGRAM

With the simple equipment outlined above we should be able to tackle, without delay, the life-saving task of controlling the skid resistance of our roads, also without excessive expenditure and effort. Five thousand dollars were included in September 1967 in the Division's budget request for special equipment to cover the cost of the Pendulum Tester and the polishing machine.

In the meantime we can prepare our logistics, along the lines hereafter:

1. Order the essential equipment and gather the team of men to handle it.

2. Define our skidding performance criteria for bituminous surfaces as well as for the materials to use.

3. Organize our test patterns for pavement diagnosis and remedial prescriptions.

4. Review and test the raw materials available to us on an economical basis.

5. Survey the accident statistics to locate the danger spots, and prepare the program of actual tests.

6. Set up a permanent system of surveillance and control, for the future detection of critical zones.

Excerpts from Dolomite Report (7760) :

R E C O M M E N D A T I O N S

&

B I B L I O G R A P H Y

RECOMMENDATIONS

Until a more advanced investigation of the problem of dolomitic aggregates for bituminous surface courses can be achieved, it would be best for the Department to be guided in its practical operations by the findings of compiled case study data. More specifically, extensive yearly skid test comparisons should be conducted on selected main-line and intersection pavements to aid in the development of suitable interim specifications and achieve desirable pavement skid resistance characteristics.

But the more important approach concerns the farther future, to be prepared through a broader and more refined program of systematic research, involving much more means and equipment then this Division can command at the present time. Here is a first listing of essential items for such a continuing study into the effects of wearing course aggregates on main-line pavements and intersections:

(1) A study in depth of the slipperiness indexes of all bituminous pavements, with the assistance of the skid-testing apparatus being currently designed by the Stevens Institute of Technology. These tests could begin as soon as the apparatus becomes available.

(2) A petrographic analysis of quality control samples from all approved and potential sources, in order to determine if any particular mineral assemblage will produce a more skid-resistant surface. This analysis may also make it possible to forecast behaviour patterns for various aggregates prior to their use in pavements.

The conduction of these analyses in our laboratories would require the purchase of numerous pieces of new equipment for thin-section analyses, X-ray diffractions, etc. An undertaking of this magnitude would require considerable investment in money, time and trained personnel. It might, therefore, be more convenient to have it done by qualified outside agencies.

(3) Investigations into the permeability of various aggregates in order to determine the effects of oil drippings upon the penetrability of the pores and interstices of the materials, thereby creating a continuously lubricated surface which would become slippery with the introduction of water onto its surface.

(4) Analysis of insoluble residues from coarse aggregates in order to determine the percentages of various sand-grained and larger-sized (greater than .05 mm) particles and the distribution of these particles in the residue. We are awaiting further information on this item from the Crushed Stone Association.

(5) It is extremely difficult to analyze traffic accident data with the present system of reporting. The use of new milepost markers throughout the State would be extremely helpful in isolating alledgedly slippery and high-accident areas for the purposes of future investigation.

BIBLIOGRAPHY

As a preparation to this study-in-dolomites, an extensive search was made in a broad field of publications, visualizing the problem against the wider background of national (and some international) experience.

This 90-page digest of some two dozen papers can be made available whenever needed. In the meantime, the condensation which follows will give a ready perspective of the major trends the investigation has brought out.

\- - - - -

The already long history of the struggle against the danger of skidding has entered a new, more decisive phase after the First International Skid Resistance Conference of 1958.

The reason for this upsurge - which had been indeed the driving force behind that conference - is the uninterrupted growth of the problem itself. Its nature was clearly defined in papers published in 1965 by the Pennsylvania Department of Highways and the British Ministry of Transport.

In Pennsylvania, skidding is the primary cause in 35 to 40% of all highway accidents. In Great Britain, 45% of the wet surface accidents involve skidding. Pennsylvania shows that from 1950 to 1960, the average speed of automobile travel has increased by 11%, requiring a 23% increase in the frictional coupling between tire and road; this demand rises proportionally to the square of the speed. At the same time, traffic density on the average mile of road has grown by 48.5% with a like increase in the rate at which the pavement surface is polished.

The Pennsylvania researchers see the roots of the skid-resistance problem in travel speed, the frequency of the vehiculer polishing action, the decrease of the friction coefficient with speed, and the tendency of aggregates to polish.

A particularly significant warning came from Virginia where in three areas, using limestone as the primary aggregate material, the frequency of skidding accidents was almost double that of other areas of that state.

But, as a paper from Kentucky puts it, "an aggregate that is perfect for all situations does not exist. It is therefore necessary to define the requirements of a given situation, then to find a product to fit that situation".

Most researchers realize that the causes for accidents are much more complex than the mere influence of deceleration produced in the vehicle by the pavement surface after brake application. Nonetheless, experience has shown that surface improvement produced sharp reductions of accidents; high accident rates increased as the coefficient of friction decreased.

British investigations led to the conclusion that the number of wet-road skidding accidents could be reduced by 80% by resurfacing the "accident black-spots" with materials containing polish-resistant aggregates.

None of the twenty-nine papers and articles we consulted for the purposes of this study dealt in depth with dolomites as such. They left, however, significant indications on widely scattered simultaneous efforts and on the trends they generate.

Limestones in general come out of many skid-resitance experiments, as a problem. No one suggests to eliminate entirely the use of limestones in roadway surface courses, but there is a general agreement that they are not to be used indiscriminately. A separate article by W. A. Goodwin of the National Highway Research Council suggests that studies and tests will eventually lead to the selective use of limestone in surface mixtures.

A fact that bothered many researchers is that the characteristics of the limestones vary enormously from one quarry to the other. Very few only can be used satisfactorily all by themselves, most of them are too slippery. Some can be rendered "adequate" by blending with skid-resistant fines.

No one has succeeded so far in establishing simple, clear-cut characteristics of limestones that would simplify the selection of the usuable types. Skid resistance seems to be lower in limestones with higher carbonate content ($CaCO_3$). On the other hand, chemical purity promotes lower skid resistance because it produces greater uniformity. Some of the dolomites come out better then the majority of the limestones with low or no magnesium content.

Among the limestones, the relatively best results were obtained on specimens with coarser grain structures and particles of different hardnesses. In most of the papers, the principle of mixed petrology emerges as highly effective. What the experts mean is that a mineral assemblage of greatly varying wear characteristics will abrade unevenly and in this way perpetuate the non-smoothness of the roadway.

Most of the authors insist on this point, including the British who emphasize the need for keeping the road surface in a nonskidding condition by providing an effective composite structure of the aggregates, namely "coarse grains for high speeds and sharpness of grains for low speeds". In order to obtain "a larger grain structure for high speeds", they have used "coated chips rolled into the surface" at the rate of 1 ton per 100 to 130 square yards. Purdue also shows uniformity of texture as a weakness; they favor a crystalline interlocking grain structure as happens in some dolomitic limestones; they also mention dense-graded mixtures in which wear gradually exposes the coarse ingredients.

This principle of surface renewal was also found by Virginia in gneiss, which combines coarseness of grain with inherently uneven hardness, producing differential wear, therefore renewed abrasiveness.

The superiority of silicious sands (the "natural" being somewhat superior to the "crushed"), of trap rock, slag and quarzite for skid resistance seems to be well established, even as an indirect effect: self-generated hard fines roughen-up the pavement under traffic, thus perpetuating its skid resistance. These materials are also useful as a practical palliative in the form of a temporary thin cover of sand-asphalt mix over the existing roadway.

It should be noted, however, that silicious materials, functioning as nonskid admixtures, are useful only in sand-size grains not in very fine form. In other words, hardness alone is not sufficient, differences in hardness do the job. It was also mentioned that additions beyond 50% seem to be unwarranted and that small changes in any mix have little effect.

The optimum grain size of the aggregates is a problem in itself, to which no one has produced a specific solution. A consensus, however, appears to have developed on limiting the maximum dimensions: it is held that too large grain sizes would speed up the polishing process.

No one seemed to think that the type of bitumen used in surface mixtures made any difference. There is, however, the phenomenon of flushing, that is, bleeding of the bituminous binder up onto the surface. Its nature was not clarified, but it did not seem to be related to the skid resistance characteristics of the aggregates.

In most researcher's reports, special attention is given to the "special" spots -- curves and crossings -- where the roadway is subjected to the most intensive polishing action, where therefore a maximum attention has to be given to keeping the coefficient of friction at a safe level.

According to the paper Mr. J. C. Reed of the New Jersey Department of Transportation wrote in 1956, "slipperiness is an elusive subject. If all the variables could be formulated, the problem could be solved. But nothing being all white or all black, the shade of slipperiness as a subject is rather gray. From all the many reports and papers that have been examined on this subject, it is apparent that this shading has not changed much in the last ten years."

****

To sum up the summary, with this specific problem in mind, the papers do not supply any specific guidance on which to base decisions on dolomite. Limestones in general are not eliminated, but it appears clearly that selectiveness plus admixtures are more important with limestones than with most noncarbonates. With regards to this selectiveness, durably skid resistant texture comes out as the most constructive angle; it is obtained by means of deliberately built-in differentiation of grain structure with intentionally uneven wear.

A consensus of outside specialists makes it clear that the essential difficulty is not in the designing of a road surface endowed with an instant skid-resistant character, but in its capacity to stay that way under continuous use. This reasoning points to the avoidance of a monolythic bituminous roadway and to its replacement by a composite course, i.e. a mix combining minerals with appreciable differences in their properties of wear, of polishability and of angularity of grain.

SYNTHETIC AGGREGATES FOR HIGHWAY CONSTRUCTION

By F.F. Fondriest and M.J. Snyder, Battelle Memorial Institute
Columbus, Ohio

Report No. 8 of NCHRP

SUMMARY

Greater activity in highway and other construction has speeded the rate at which high-quality aggregates are consumed. This situation, coupled with an unbalanced geographical distribution of deposits, has created a supply problem in some areas, and many more areas are expected to encounter the problem in the future.

To compensate for the shortage or high cost of aggregates, less commonly used materials, such as shell and scoria, are being substituted in highway construction. Stabilized soils are also being substituted for aggregate in bases and subbases. Another approach to the problem is to use synthetic rather than naturally occurring aggregates.

A study was made to identify existing and potential materials suitable for producing synthetic aggregates, to conceive new methods of producing such aggregates, and to evaluate the present and future prospects for their use in highway construction. A large number of existing and potential synthetic aggregates were identified. Several manufactured or by-product materials, such as lightweight aggregates and blast-furnace slag, currently are used as aggregates; other by-product or waste materials that might be used after minor mechanical processing include a number of ceramic wastes, various industrial slags and clinkers, demolition wastes, and scrap iron or steel. The study considered potential methods for producing new synthetic aggregates — by sintering or fusing such fine-grained natural material as sand, clay, or soil, or such waste materials as steel-furnace dusts or mining wastes; or by chemical or thermochemical processing of mixtures such as those of sand and lime or fly ash and lime.

Synthetic aggregates offer a possible alternative to importing natural aggregates from other areas. The present worth of synthetic aggregates for highway construction thus depends on specific economic factors in the locality suffering an aggregate shortage. In time, when the aggregate shortage becomes more widespread and the importing of natural aggregates becomes too extensive and costly to be a sound practice, synthetic aggregates may provide a feasible solution to the problem. The most significant development for the future is likely to be either the use of job-site materials for making synthetic aggregates in versatile and portable processing equipment or the establishment of a widespread synthetic aggregate industry which processes widely available materials such as clays and shales. Another possibility, the development of new highway systems requiring lesser quantities of aggregates, should not be overlooked.

It is not too early to start planning, developing, and evaluating job-site materials for making synthetic aggregates with versatile and portable processing equipment, and large-scale processing of widely available materials such as clays and shales.

CONCLUSIONS AND RECOMMENDATIONS

As the reader may easily confirm, the progress which has been made since the previous Congress has been characterised by the interest and constant co-operation shown generally by all who are concerned in studies of road slipperiness. This is shown for example by the increasing number of specialists attending the Committee's meetings, and contributing to its work. A second example may be found in the establishment in June, 1960, by the American Society for Testing and Materials (A.S.T.M.) of a special Committee to deal with problems of this kind, known as Committee E-17 (A.S.T.M.).

This increasing scale of action can in some measure be regarded as a reflection of the rather difficult and complicated nature of the skidding problem: a problem of direct interest to the vehicle and tyre designer, to every road user, and even to those concerned with aircraft performance and runways, as well as to the Highway Engineer. As now constituted, the Committee is fortunate to have among its members representatives of these different interests who are able to combine their efforts in order to contribute towards satisfactory technical solutions, where these are to be found, or towards a better understanding of the problems.

Quite a lot remains to be done before the Committee is in a position to discharge the terms of reference for which it was established. Nevertheless, it is pleasing to report that between the previous congress and the present one the co-operation of all the members of the Committee has had a significant effect on various questions important to current practice. It is with this in mind that the Committee has attempted to give the summaries of present knowledge and practice to be found in Sections 2 and 3 of this report. Other more recent developments of practical importance will be found among those described in Section 5. On the other hand the descriptions and discussions in the early part of Section 4 will have been of more direct interest to the specialist in problems of skidding resistance measurement.

From the increasing number of correlation and other tests carried out it is becoming apparent:—

(1) That the principal methods in use for studying the skid-resisting properties of roads can be used successfully to discriminate between surfaces which are satisfactory and those which are undesirably slippery.

(2) In the light of present knowledge there is no clear indication that any one of the alternative methods of measurement is to be preferred to the others. Indeed for the ultimate solution it may be necessary to apply a combination of the different methods of measurements, and also the different test machines, rather than a single one to obtain a complete picture of the "non-skid" properties of a wet surface.

(3) Whatever method of test is used some background data based on a survey of existing roads carried out with the chosen method would seem to be indispensable. A correlation with accident records is especially important. Only with this kind of knowledge can satisfactory standards of skidding resistance be established which are appropriate for the method of test to be employed.

(4) In this connection, the Committee wish to emphasise once more the importance, and the great value to all systematic work on skidding resistance problems, of police accident reports which give for all accidents a clear statement on whether or not skidding occurred, and whether the road surface was dry, wet or icy.

(5) In developing any test method special attention must be given to standardising the tread properties of the test tyres to be employed from the points of view of resilience, hardness and the presence or absence of a pattern. With this in mind, the Committee regards the establishment of a specification for a suitable standard test tyre and for the necessary means of checking these properties as one of its most important and immediate future tasks.

(6) The problem of the best technique for watering the test surface is also still an important one especially where tests are contemplated at speeds of the order of 80 km/h. or more.

(7) [illegible] any type of road construction the essential steps which will result in the production of satisfactorily non-skid roads are:— (1) to choose an aggregate or chippings for the surface layer with a satisfactory reistance to polishing. This can now be done with the help of Laboratory tests for resistance to polishing. (2) to choose the binder content, the proportions of the other constituents of the surfacing, and the laying and finishing technique so that the chosen material will always be exposed in the surface and constitute the main proportion of the surface area throughout the life of the road surface.

(8) Progress has been made in understanding some of the effects of weather and traffic on the skid-resisting properties of wet surfaces. All road surfaces must be expected to show changes in "non-skid" properties when wet throughout their life, but at the present time these can only be followed by direct measurement, rather than predicted by any simple rule based on observations of weather and traffic.

(9) Where systematic testing is carried out, it is strongly recommended that to assist in the interpretation of results regular measurements should also be made on some typical surfaces so that the current pattern of seasonal variations in slipperiness can be followed, and an approximate allowance made for its effects.

(10) Moreover, since the skidding resistance of a surface varies with speed, with tyre properties, with the effects of wear due to differences in the distribution of traffic and so on, it must be recognized that generally speaking its performance can rarely be represented by a single value of coefficient. When test results are presented it is desirable that they include: the value of the mean coefficient; the value of the minimum coefficient, and a guide to its location on the surface tested; a measure of the scatter of results about the mean value (the standard deviation for example); and an indication of the texture of the surface.

(11) Ice and snow bring special problems of slipperiness, and, as far as the Highway Engineer is concerned, such treatments as "gritting", "salting" or "water-sanding" at present appear to offer the only feasible and effective remedial techniques.

Summarising all that has been said in this report, and attempting to forecast the lines which the Committee's future work might follow, the Committee's Chairman who has drawn up these final conclusions, would like to express the opinion that, despite any superficial appearances to the contrary, the increased complications which have been brought to light by recent investigations into the problem of slipperiness do not represent any serious fundamental differences of principle; indeed at the present time the Committee's most important role should be to resist any suggestions of discouragement at some of the complexities of the problem which have been revealed, rather than seeking to act as an arbiter between any opposing points of view; only in the light of further patient and persistent studies is a way likely to be found by which some of the existing points of difficulty can be resolved. In this respect a wide field of study remains open to workers on skidding problems and the Committee looks forward with confidence to the time when their efforts will be crowned with success.

PERMANENT INTERNATIONAL ASSOCIATION OF ROAD CONGRESSES

Secretary-General: 4[illegible], Avenue du Président-Wilson, Paris, 16

XIIth CONGRESS ROME - 1964

Section I : Construction and Maintenance of Roads and Runways

QUESTION IV

Surface Qualities of Roads

4.1. Improvement in the resistance to skidding on various kinds of roads; change under the action of traffic, climate and the age of the road.

4.2. Improvement of the riding qualities of the different types of roads; changes under the action of traffic, climate and the age of the road.

4.3. Progress made in the measurement of resistance to skidding.

4.4. Progress made in the measurement of riding quality.

4.5. Icy roads, analysis of the phenomenon, remedies and palliatives.

GENERAL REPORT

by

J. G. SMITH, M.I.C.E., M.I.Mun.E.,
Chief Highway Engineer, Ministry of Transport.

GREAT BRITAIN

CONCLUSIONS

Dealing with the five parts of the question in order:

4.1. (a) In order to improve resistance to skidding there must be a thorough understanding of the various factors involved. Most countries have therefore laid stress on the systematic accumulation of data from road tests, often on experimentally prepared surfacings.

(b) The influence of time of year is evident from the cyclical variation from minimum resistance in summer rising to a maximum resistance in winter. Tests of skid resistance must not therefore be considered in isolation but in relation to summer conditions (in the Northern hemisphere) when resistance is lowest.

(c) The use of high hysteresis rubber in tyres is an advantage in reducing the risk of skidding on slippery surfaces. Problems however then arise in the dissipation of heat within the tyre.

(d) The main action of traffic is to polish the aggregate and so decrease resistance to skidding although with some surfaces there is erosion of the finer particles in the wheel tracks with increases in rugosity and resistance to skidding. Emphasis is laid by many countries on the need for care in selection of aggregates resistant to polishing and laboratory tests for this purpose have been described.

(e) There are physical and chemical reactions in the surfacings due to weathering and age, particularly in bituminous roads, which increase the rate of erosion of fine particles. The use of Trinidad Lake asphalt and pitch bitumen in Great Britain to promote this is discussed in question 2. The Italian report also emphasises the value of use of materials of different rates of wear.

(f) The influence of increased vehicular speed is chiefly to reduce the resistance to skidding. The rate of reduction can be lessened by maintaining a textured surface. This is of great importance on high speed motorways and on airfields.

(g) The influence of degree of wetting and cleanliness of the surface is evident. Both Germany and Sweden report on this aspect but the driver skids on a road which is not prepared for quantitative tests of this type.

(h) There are interesting reports from Norway on the continued experience of epoxy resin/sand treatment of roads there and from Poland on treatment of airfields that could have applications to road works.

4.2. (a) Evenness of the surface of the roads is a quality of great importance with the increasing mileage of motorways where sustained high speeds occur.

(b) Changes under traffic are attributed to deformation of the surface or base layers. The Belgian report on the construction of concrete roads particularly notes the importance of base layers, efficient construction of joints and relation of reinforcement and spacing of joints.

(c) The influence of poor finishing of the surface contributes materially to unevenness; this is noted in the British report on asphalt surfacings and in the Belgian report on concrete with appropriate recommendations.

4.3. (a) The attention given to research on the factors influencing skidding at high speeds is a marked reflection of the increasing use of motorways.

(b) Most countries report work at speeds of up to 80 km./hr. [50 m.p.h.] with emphasis on experience on airfield work to guide development on roads.

(c) Portable apparatus (pendulum type) is now in general use in France and Great Britain. An interesting comparative test of apparatus is reported by the former and this perhaps could be extended to promote more effective interchange of data between contributing countries. Some work on these lines also is reported from Italy.

(d) The need for standardised conditions of tests (e.g. tyre pressure, resilience and tread pattern, speed, use of clean surfaces etc.) is emphasised by many countries including Germany, Italy and Sweden.

(e) Apparatus is under development in many countries to appreciate conditions [illegible] vehicle speeds now current.

(f) The use of te[illegible]r than physical measurement of friction is suggested in the British use of accident records (often however fortified by measurements) and in the German and British correlations of light reflection and skid resistance.

4.4. (a) The general use of straight edges in measurement of evenness as a determination of riding quality is often tedious. Mobile developments of the straight edge to speed up measurements are in hand and modifications of the American Roughness Indicator are reported by many countries as the basic tool for assessment of riding quality.

(b) The British report describes a multi-wheel straight edge type device to limit discrepancies between a standard straight edge and the two-wheeled mobile variation of this.

(c) There is an interesting reference from Japan to the use of acceleration meters to assess riding comfort.

(d) There is clearly a need for continued development in this field emphasised by the reports from Belgium and Germany as to the difficulties in determining the base for measurement.

4.5. (a) The marked influence of geographical location in the attention given to this work is evident.

(b) Attention is particularly concentrated on the problems of glazed (or black) ice and development of an automatic warning device in France is particularly noted.

(c) There is a concentration of effort on known points of frequent icing illustrated by the German use of permanent signs, in Japan by a permanent de-icing spray installation and in Great Britain by use of electrical heating for positions of danger.

(d) It is agreed generally that grit or sand alone is ineffective under moderate or heavy traffic. The method in general use in North Sweden of sealing in grit with a water spray in freezing conditions is a notable exception.

(e) Where chemical de-icing agents are used there is agreement on the effectiveness of salt and mechanical spreading is described in several reports.

(f) Where salt is used there is agreement on the advantages of pre-salting, the need for effective meteorological forecasts and a considered plan for action in adverse conditions with efficient communications.

PERMANENT INTERNATIONAL ASSOCIATION OF ROAD CONGRESSES

Secretary General, [illegible] avenue du Président-Wilson, Paris, 16

XIIIth CONGRESS TOKYO 1967

REPORT BY TECHNICAL COMMITTEE ON SLIPPERINESS

MEMBERS OF THE COMMITTEE

Chairman:

C. G. GILES (GREAT BRITAIN)

Members:

R. ARIANO (ITALY)
A. DOYEN (BELGIUM)
J. L. ESCARIO (SPAIN)
C. VAN DE FLIERT (NETHERLANDS)
H. GROB (SWITZERLAND)
A. J. HARRIS (GREAT BRITAIN)
G. KULLBERG (SWEDEN)
A. PASQUET (FRANCE)
B. WEHNER (GERMANY)

Experts:

A. J. P. VAN DER BURGH (NETHERLANDS)
P. OUTER (BELGIUM)
M. MACZYNSKI (POLAND)
Y. TCHENG (FRANCE)

Secretary:

J. LUCAS (FRANCE)

Conclusions

At the end of each section of the report a series of conclusions has been given summarising the main points which in the opinion of the Committee emerge from the topics which have been considered. In this section of the Report on the other hand an attempt will be made to bring together the main developments and points of view which in the Committee's opinion merit the special attention of the Congress. These may be summarised as follows:

(1) With the increasing speed of vehicles, problems of skidding resistance at high speeds are assuming much greater importance. These problems are receiving attention in an increasing number of countries and it is clear that they raise a number of new problems and intensify old ones.

(2) One consequence of this work is that it throws new importance on to the surface texture of roads and the pattern and resilience properties of tyre treads.

(3) As a result increasing attention is being given to the study of methods for surface texture measurement and to the development of new equipment for high speed studies.

(4) High speed studies tend to emphasise the numerical differences in coefficient values obtained with a side-slipping wheel, a locked wheel and a wheel braked to give the peak coefficient value. Much more work is needed on the inter-relation of these different coefficient values before a final decision on the optimum test method will be possible.

(5) High speed investigations have also thrown into prominence the important effect of the thickness of the water film on friction values at high speed. This has great practical significance as well as presenting serious problems in the execution and standardisation of measurements at high speeds.

(6) This question of water depth comes into particular prominence in connection with the phenomenon of "aquaplaning" to which increasing attention is now being given. Theoretically this may occur on roads at quite moderate speeds although experiments show that it is in fact rather difficult to produce in practice. Nevertheless it is a very real effect which can, and no doubt does, occur from time to time.

(7) In the preoccupation with high speed studies the fact should not be lost sight of, that good progress is being made in unifying the measurements made at lower speeds, and with the laying down of guide lines for the interpretation of their results. The present report gives details of such developments in connection with locked wheel braking tests and the previous one gave similar information for sideway force tests.

(8) Attention is drawn to the section on "Confidence limits" which must, however, be taken into account in interpreting results of measurements.

(9) The task of standardising test conditions has become more difficult in recent years because of the rapid development in tyre tread composition and properties. Test results illustrating this problem are given in the report and at the present time it would appear that no simple solution offers itself. In its future work the Committee will give further study to this problem.

(10) Finally the development of studded tyres represents an important new approach to the problem of dealing with slipperiness on roads covered with ice and snow. This is particularly so since, when these conditions occur, it is not possible for the highway authorities to provide other remedial measures simultaneously on every section of road. It is hoped that the account of recent research on this subject, which is given in the report, will be of value to highway authorities and others in estimating the usefulness of this development.