HIGHWAY RESEARCH BOARD

Bulletin No. 27

Road Surface Properties

REPORT OF COMMITTEE
AND
PAPER ON RUBBER IN
BITUMINOUS PAVEMENT

1950

Presented at the
Twenty-Ninth Annual Meeting

HIGHWAY RESEARCH BOARD

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HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH
NATIONAL RESEARCH COUNCIL

Washington 25, D. C.
September 1950

DEPARTMENT OF HIGHWAY DESIGN

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COMMITTEE ON ANTISKID PROPERTIES OF ROAD SURFACES[1]

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[1] The name of this Committee has now been changed to the Committee on ''Road Surface Properties Related to Vehicle Performance''.

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REPORT OF COMMITTEE ON ANTISKID PROPERTIES OF ROAD SURFACES

The Committee on Antiskid Properties of Road Surfaces was reorganized with a new chairman and several new members just prior to the 28th Annual Meeting of the Highway Research Board. During the 28th Meeting the Committee met and set up certain objectives. These objectives and the research program of the Committee were expanded during 1949 as the result of new developments and research in road surfaces of special interest to the Committee. In this report the objectives of the Committee will be outlined together with a statement of the expanded research program and the progress made thus far in the proposed research program.

While skid resistance is one of the most important properties of road surfaces, there are at least six other factors relating to road surfaces which are closely related to skid resistance, to which the highway engineer should give special attention in the design, construction, and maintenance of highways for the safe and economical operation of modern high speed traffic. These six factors are: road roughness, tire wear, tractive resistance, noise, glare and light reflection and electrostatic properties. In the reports given by Committee members during the past twelve years, some notable researches in road roughness, tire wear and tractive resistance have been presented at the annual meetings. No reports of research in road and tire noise, glare and light reflection and electrostatic properties of various types of road surfaces have been given. The lack of reports is an indication of the need for research on these topics.

It should be realized at the outset that it is not possible to build road surfaces which will provide the best possible performance for all of the above conditions. Thus, a surface which is highly skid resistant is almost certain to be an abrasive surface which contributes to a high rate of tire wear. Conversely, the lowest tire wear is obtained on surfaces which are slippery when wet. Also, road surfaces which provide high skid resistance frequently will have excellent light reflecting qualities for night driving, but they may have a coarse open surface texture which causes a "roaring" tire noise, especially at high speeds. This roaring or rumbling tire and road noise is a source of considerable annoyance and irritation to drivers and passengers in cars so affected and may be an important contributing factor in traffic accidents

The public judges a road largely by its smoothness or riding quality. The braking performance, tractive resistance, safety and economy of operation of all vehicles is improved when road surfaces are built with a uniformly smooth surface. Periodic measurements of surface smoothness (or roughness) provide a definite test of the excellence of the design standards and of the construction and maintenance methods used to meet the traffic requirements for a given road in a given location. Highway engineers can profit in many ways by a study of road roughness, not only as a measure of the public acceptability of a given road, but also as a measure of the progressive failure of the road due to heavy vehicles, pavement pumping, frost action, differential heaving, and other traffic and road factors.

It does not appear logical to direct the attention of highway engineers to only one property of road surfaces, however important it may be, when there are other important properties to be considered, and to be correlated in rating road surfaces and in establishing the best possible standards for the design, construction and maintenance of road surfaces. Accordingly, it is proposed that the scope of activity and the objectives of the Committee be enlarged and that its name be changed to "Road Surface Properties Related to Vehicle Performance".

OBJECTIVES OF THE COMMITTEE

On the basis of its enlarged scope the objectives of the Committee, briefly stated, now are:

1. To assemble researches in the measurement of skid resistance, road roughness, tire wear, tractive resistance, noise, glare and light reflection, and electrostatic properties in relation to various types of road surfaces and to determine where additional researches are needed.
2. To encourage organizations, and persons fitted to do so, to conduct needed researches on subjects relating to the study of the above-named subjects, which will lead to the development of uniform standards of measurement and a rating system for each of these factors which may be used in establishing acceptable standards of design, construction and maintenance of the surfaces of various types of roads.
3. To coordinate and bring to the attention of highway engineers and highway users results of researches which will lead to the establishment of acceptable road surface standards based upon the rating system as proposed by the Committee and thus provide greater safety, economy and comfort in the operation of motor vehicles or road surfaces built to these standards.
4. It is recognized that with the enlarged scope of activity of the Committee, its membership should be increased if satisfactory progress in meeting its objectives is to be achieved.

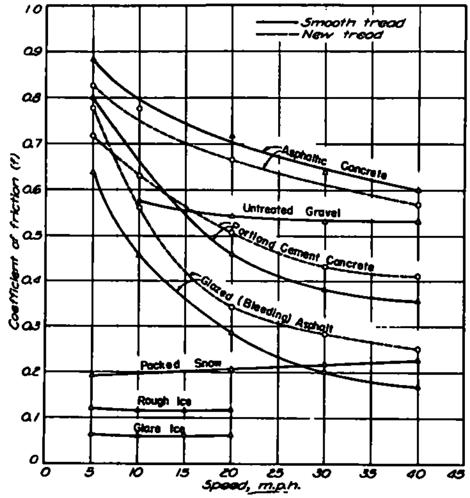

Figure 1. Coefficients of Friction for new Tread and Smooth Tread Tires on Various Types of Road Surfaces in Wet Condition

DISCUSSION OF RESEARCH ON SKID RESISTANCE, ROAD ROUGHNESS AND RELATED PROPERTIES OF ROAD SURFACES

In the following discussion, a brief review of the research on skid resistance, road roughness and related properties of road surfaces will be given. Test proposals for measuring various properties and for establishing standards of measurement and standards of design, construction and maintenance will also be discussed.

Skid Resistance - The earliest reports of research on skid resistance of rubber tires on various road surfaces which gave a true indication of the many variable factors which influence tire and road friction, especially the hazardous slippery condition of certain road surfaces when wet, were given at the Annual Meeting of the Highway Research Board in 1933 by R. A. Moyer, covering the work at Iowa State College, and by Stinson and Roberts, covering the work at Ohio State University.

The most important findings in these two researches are fairly well summarized in Figure 1. In this figure, the slipperiness of typical road surfaces on which tests were run by Moyer is shown in terms of the coefficients of friction at various vehicle speeds from 5 to 40 mph. for new tires with a non-skid tread pattern, and for smooth tread tires. A significant fact uncovered by this study was that the coefficients of friction for all slippery surfaces, except those covered with snow or ice, were fairly high at low speeds, but dropped sharply as the speeds of the test vehicle were increased. Thus, at a speed of 5 mph. the coefficients for the glazed asphalt surface when wet were in the range of 0. 8 to 0 6, but at speeds of 30 to 40 mph., the coefficients for new tread tires dropped to values below 0. 3 and for smooth tread tires to values below 0. 2, which is in the range obtained on ice and snow, surfaces known by all drivers to be extremely slippery. The seriousness of the hazard created by this characteristic of slippery road surfaces, for which the coefficients of friction decrease with an increase in speed, becomes more apparent when attention is directed to the fact that the friction requirements for such driving operations as acceleration and braking increase approximately as the square of the speed.

In these early tests it was found that the type of tire tread had important bearing on the coefficients of friction. Thus, smooth tread tires developed much lower coefficients on slippery, wet surfaces than tires with a non-skid tread pattern, as shown in Figure 1 for the glazed asphalt surface. On coarse grained surfaces, such as the asphaltic concrete in Figure 1, and on rockchip treated surfaces with an open texture, the coefficients for the smooth tires were higher than for the tires with a non-skid tread pattern. This led to the squeegee theory, which provides a logical explanation for the effectiveness of various tread patterns to develop the measured skid resistance on various types of road surfaces.

All of the research in 1933, and the field observations and studies which have been made since that time, clearly show that skid resistance can be built into road surfaces of any type, that slippery roads exist because of improper construction and inadequate maintenance, and that any road can be made skid-resistant and kept in that condition. Thus, it seems fair to state that a "Slippery Road" sign is a confession of faulty construction and upkeep It is to be regretted that many highway departments still depend on "Slippery Road" signs to warn drivers of a danger which is entirely unnecessary.

An important objective of our Committee is to bring to the attention of highway engineers the extremely dangerous conditions which may exist on highways and city streets where no attention is given to skid resistance measurements and to the correction of slippery road conditions. This is a matter of increasing importance today, because driving speeds are higher than at any time in the past, car registrations are greater (as are the number of cars with smooth tires), and since the end of the war there has been an increased use of asphalt for seal coats and for resurfacing, without adequate controls to prevent over-sealing. Oversealing (the use of excessive amounts of asphalt) is the most common cause of asphaltic type surfaces being slippery when wet.

Skid Resistance Measurements in Virginia - At the Annual Meeting of the Highway Research Board in 1947, Messrs. Shelburne and Sheppe presented a report on "Skid Resistance Measurements of Virginia Pavements". In this report, published by the Board as Research Report No. 5-B, a relatively simple and inexpensive method of making skid resistance measurements was described. It consisted of stopping distance or braking tests which were made with a light weight car using an electrically actuated detonator connected to the brake pedal which fired chalk at the pavement to determine the point at which braking started. Tests were run on dry and wet surfaces at speeds of 10, 20, 30, and 40 mph.

All of the pavements tested in the dry condition were found to have equally satisfactory skid resistance at all of the test speeds. The design standard for braking adopted by the AASHO was used in these tests. It provided for a max. stopping distance of 113 ft. for a speed of 40 mph. This corresponds to a coefficient of friction of not less than 0. 47 at 40 mph. Twenty-seven of the 32 surfaces tested wet were considered to have satisfactory skid resistance. Three surfaces found to be unsafe were rebuilt or resurfaced to provide the necessary skid resistance. Tests made on one surface after the non-skid treatment, showed that the stopping distance on this surface when wet was reduced from 222 to 94 ft. at 40 mph. This large reduction in stopping distance is an indication of the value of the tests and the improvements which can be made on surfaces which need non-skid treatment.

The Committee recommends that State highway departments and cities adopt the method of making skid resistance measurements used in Virginia as a simple and reliable procedure.

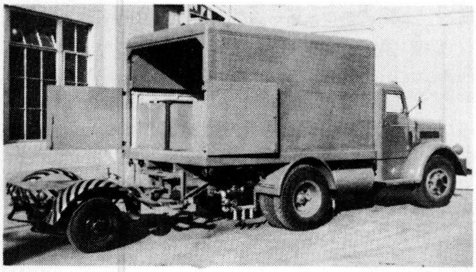

Figure 2. FWD Truck and Trailer Used in Skid Tests

University of California Skid Tests - During the past year, a research project was started at the University of California under the direction of the Chairman of this Committee in which it was proposed to make a study of all properties of road surfaces in California, including skid resistance, which have a bearing on the economy, safety and comfort in the operation of motor vehicles.

In California methods of road surface construction have been developed by the Division of Highways which differ from the methods used in the middlewest and east. The materials used are not always of the same type as the materials used in roads for which published results of skid resistance are available. In the construction of light weight bridge floors, California has adopted an open grid steel decking design. Today there are conflicting reports concerning the skid resistance of this type of bridge floor when wet, largely because measurements of the skid resistance of the various types of open grid steel decking have not been made. From the above it is evident that there is ample justification for a program of tests to measure the skid resistance of roads and bridge floors in California.

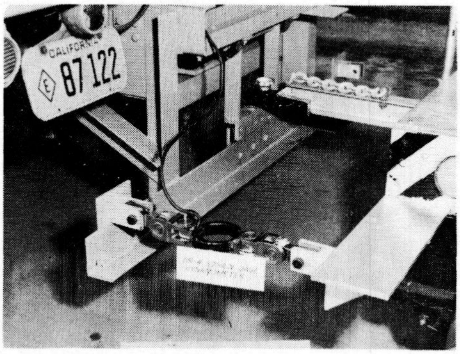

Figure 3. Close-up of Dynamometer under Trailer Hitch

In this testing program, we will measure the skid resistance of various surfaces by the towing-trailer method and in certain locations by the stopping distance method used in Virginia. The towing-trailer method has the advantage that the tests can be run at various uniform speeds, thereby causing a minimum of interference with traffic. This is an important consideration when tests are to be made on heavily traveled roads such as those in California.

In the towing-trailer method, a two-wheel trailer equipped with electric brakes is used. The tow truck is a powerful FWD truck, which can be operated with the brakes applied on one trailer wheel at speeds up to 50 mph. In the body of the truck, there are two large water tanks with a capacity of 170 gal. each. An instrument panel and two work tables have been mounted on the tanks for the various instruments and controls required to measure the braking forces, speed, time and temperature in the braking tests. The water is pumped from the tank to the spray nozzles which are placed in a line directly ahead of each trailer wheel to wet a narrow path on the pavement to be tested. The brakes are applied on only one trailer wheel at a time, since, if the brakes of both wheels were applied at the same time, the drawbar pull required to tow the trailer would be so great that tests could be made only at relatively low speeds. These tests will be made at uniform speeds ranging from 10 to 50 mph. The max. braking force at each speed will be measured with an SR-4 strain gage dynamometer and a magnetic type direct-inking oscillograph.

The truck and trailer with the dynamometer in place is shown in Figure 2. A close-up view of the dynamometer and trailer hitch is shown in Figure 3. The strain analyzer, the two-channel oscillograph recorder, the dynamometer and the speed indicator used in obtaining a record of the braking forces at various speeds are shown in Figure 4.

In the calibration of the dynamometer, it was found that the braking forces can be measured to an accuracy of + or - 2 percent for forces up to 2,000 lb. The most important item in the operation of the direct-inking oscillograph shown in Figure 4 is the magnetic pen motor which provides a uniform response for the maximum recommended amplitude of the pen swing up to a frequency of 70 cycles per sec., which is higher frequency than is required for these tests. The electric brakes on the trailer are operated by an observer in the body of the truck. An Ohmite rheostat is used for accurate control of the braking force, and an electric brake controller is used for quick application. With these controls the maximum braking force can be measured for both the skid-impending (rolling wheel) condition and the locked or sliding wheel condition.

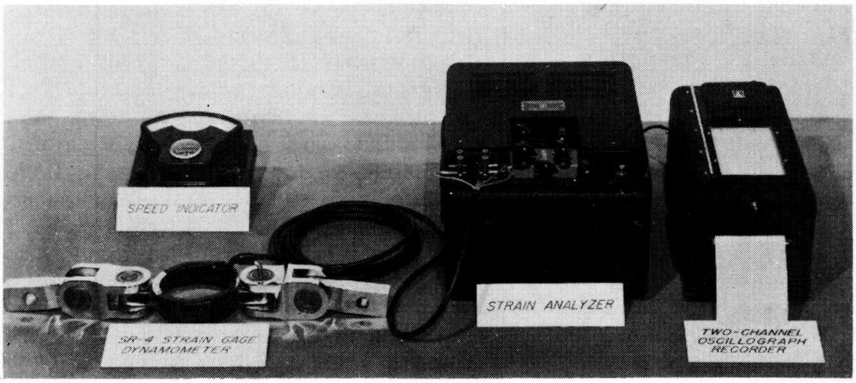

Figure 4. Equipment Used in Measuring Braking Forces and Speed in Skid Tests

In the body of the truck a gasoline motor generator has been installed to provide a 110-volt 60-cycle current with a capacity of 7.5 KVA required to operate the oscillograph, the water pump, lights, fans, and other small items of 110-volt AC equipment.

All of the equipment for these tests has been designed to make possible more accurate measurement of skid resistance and braking forces under various conditions than was possible with any equipment or test procedures previously used by the Chairman in this type of research.

Rubber-Asphalt Test Roads - During the past year test roads were built in Ohio, Texas, and Virginia in which powdered rubber was incorporated in various types of bituminous road construction. By the addition of rubber, it is claimed that the skid resistance and durability of bituminous surfaces will be improved and that they will be less susceptible to temperature change.

Three members of our Committee, Messrs. Allen and Evans of Ohio and Mr. Shelburne of Virginia have taken an active part in these experiments. Reports of this new development in road construction were given at the 1949 Committee meeting by Shelburne and Allen. A paper on the Virginia experiments by Shelburne and Sheppe is included in this Bulletin.

ROAD ROUGHNESS

Road roughness has for many years been recognized by highway engineers as an important factor in the construction of all types of surfaced roads. The use of a long straightedge has been and still is the most widely used method to check surface roughness during the construction of surfaced roads. Since this method does not automatically provide a record of road roughness, and is much too slow for making road roughness surveys, various machines have been developed to speed up the work and to provide automatically a record of the roughness for any desired length of pavement.

The early machines had various defects, the most serious of which was that the results obtained with the different machines were not comparable. In an attempt to overcome the defects of the early machines, the Bureau of Public Roads built the "Road Roughness Indicator" which was described in a paper presented at the Annual Meeting of the Highway Research Board in 1940. This machine provides a quick dependable method of measuring road roughness. It is so designed that it can be exactly duplicated and, to this extent, it is standardizable. Plans for building the BPR Roughness Indicator can be obtained from the Bureau of Public Roads.

Duplicate models of the BPR Road Roughness Indicator were built at Iowa State College and by the Virginia Department of Highways. Extensive tests were made with the Indicator on roads in the middlewest and in Virginia yielding highly satisfactory results. The Indicator built at Iowa State College was acquired during the past year by the University of California. It was completely overhauled and is now being used for making road roughness measurements of various road surfaces in California.

The BPR Road Roughness Indicator is a single-wheel trailer which is towed by a car or light truck (Fig. 5). A detailed description of the Indicator is given in a paper by J. A. Buchanan and A. L. Catudal, entitled "Standardizable Equipment for Evaluating Road Surface Roughness", published in the 1940 Proceedings of the Highway Research Board. Briefly stated, this machine measures the irregularities in the road surface which are transmitted through a standard tire to the axle of the wheel. The vertical movements of the axle are transmitted by a wire cable to a double-acting ball clutch integrator which in turn transmits the accumulated vertical movements in in. to an electric counter mounted on a board in the tow car. A similar electric counter records the revolutions of the trailer wheel and thus provides an accurate measure of the travel distance. The roughness tests have been standardized at a speed of 20 mph. and the measurements are recorded on a data sheet by an observer for each half mile and at the end of the project. The data are summarized by expressing the roughness of each section of road in terms of a standard unit known as the Roughness Index (RI), which is the roughness in in. per mi.

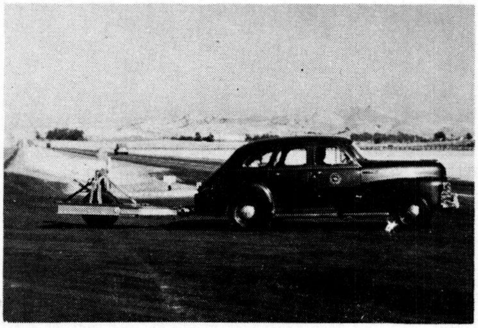

Figure 5. Road Roughness Indicator and Tow Car

Experience in the use of the BPR Indicator thus far has led to the adoption of the following tentative standards for evaluating road surface roughness of rural highways:

ROUGHNESS INDEX (in. per mi.)	RIDING QUALITIES
Below 100	Excellent
100 - 150	Good
150 - 200	Fair
Above 200	Rough

On city streets, where speeds do not exceed 35 mph., the above values can be increased 25 percent for each of the four ratings in riding quality.

The California University Road Roughness Oscillograph Recorder - A criticism of the BPR Indicator has been that, in providing the accumulated values of road roughness for a given section of road, it does not give an indication of the type of roughness. Thus, a concrete pavement may have faulting at joints, or it may be badly warped at the joints, while the rest of the pavement may be exceptionally smooth. The roughness values for such a pavement are not likely to be sufficiently higher than those for a concrete pavement without these defects to clearly indicate the poor riding qualities of such a pavement. To obviate this criticism, a special device was developed at the University of California which makes it possible to obtain a graphical record of the road roughness as measured by the BPR Roughness Indicator. This device is attached to the top of the frame of the Indicator (Fig. 6). It consists of a bridge circuit formed by a potentiometer and two precision resistors. A steel tape is attached to the axle of the trailer wheel and to a pulley on the shaft connecting with the potentiometer. A clock spring is used to maintain sufficient tension in the tape so that it follows accurately the vertical movements of the axle and the tire as it rolls over various irregularities on the road surface. The vertical movements of the axle are transmitted to a two-channel direct-inking oscillograph mounted in the tow car. This oscillograph is the same type of unit previously described in this report as being used in the University of

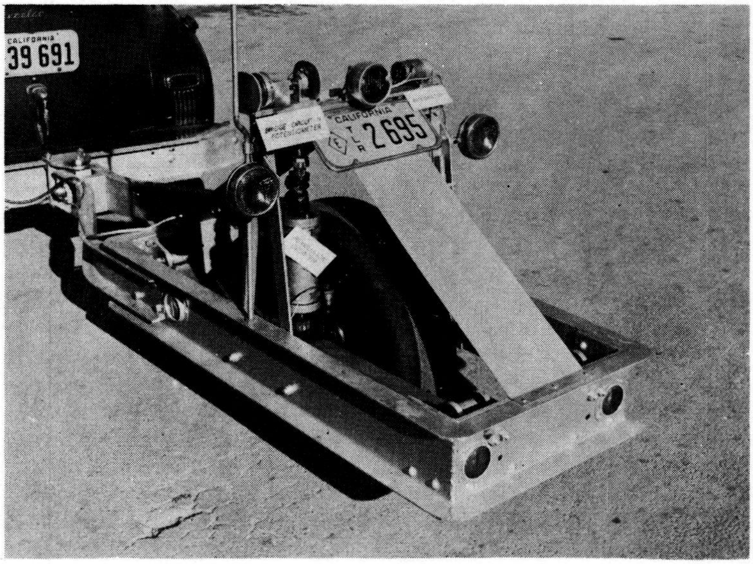

Figure 6. Close-up of Road Roughness Indicator

California skid resistance tests.

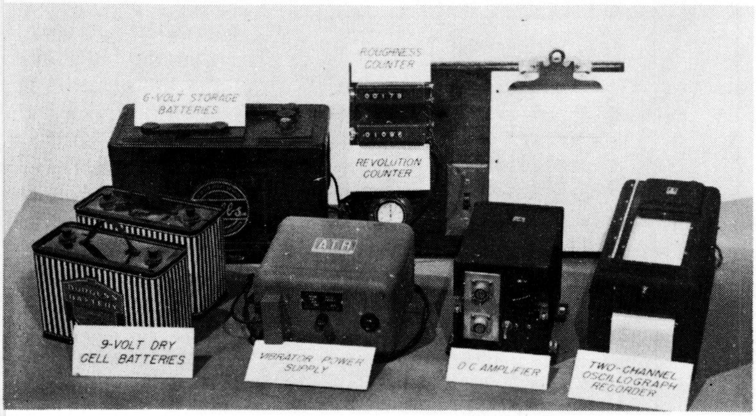

Figure 7. Equipment Used in Obtaining Oscillograph Records and Integrated Values of Road Roughness

The various items of equipment in the tow car required to obtain the oscillograph records of road roughness and the magnetic counters used as standard equipment in this test, are shown in Figure 7. Two six-volt storage batteries are required to provide the current for the vibrator power supply unit and for the DC amplifier unit. The two 9-volt dry cell batteries are connected in series to provide 18 volts to feed the bridge on the trailer. The unbalance from the bridge, developed by the vertical movement of the trailer axle, is transmitted to the DC amplifier and then to the oscillograph recorder. The vibrator power supply changes the 6-volt DC to 110-volt AC required for the motor used to drive the oscillograph chart paper. The DC single-stage amplifier also has a vibration power supply unit to convert the 6-volt DC from the storage battery to 110-volt AC required to operate the oscillograph pen motor.

The revolution counter is tied in with the oscillograph recorder by a direct connection to the pen motor, except that a potentiometer is included in the circuit to reduce the high induced voltage across the pen motor terminals developed by the revolution counter at the break in contact.

The oscillograph is equipped to operate at three paper speeds - 5, 25, and 125 mm. per sec. The best records thus far have been obtained at the medium speed of 25 mm. (1 in.) per sec. when operating the car and trailer at the standard roughness test speed of 20 mph. For these speeds of paper and car, the horizontal scale of the record on the paper is 1 in. = 30 ft. The equipment was designed to provide a vertical scale on the paper of 1 in. = 2 in. These scales are sufficiently large to give the desired detail and accuracy in the record without requiring an excessive amount of paper.

Typical oscillograph records obtained for various concrete and bituminous pavements and for certain special test conditions are shown in Figures 8, 9, and 10. The roughness index (RI) values for the half-mile sections on which these records were obtained are also shown on the records.

The oscillograph record at the top of Figure 8 shows the remarkable smoothness of a section of concrete pavement on US 40 in California on the Fairfield By-pass where the roughness index over a half-mile section was found to be 56 in. per mi. According to the published records of road roughness with the BPR Indicator this is by far the smoothest section of concrete pavement on record. The previous low value for concrete pavements was 78 in. per mi.

obtained on a pavement in Missouri in tests reported in the 1942 Highway Research Board Proceedings.

The low value of 56 in. per mi. was obtained on a section of pavement built with continuous reinforcement with no transverse joints. The omission of transverse joints, however, was not the only reason for the low roughness of this section of pavement as is evident from the low index of 64 in. per mi. obtained on the concrete pavement with construction joints spaced 15 ft. on centers on the Oakland Freeway, for which an oscillograph record is shown in Figure 8.

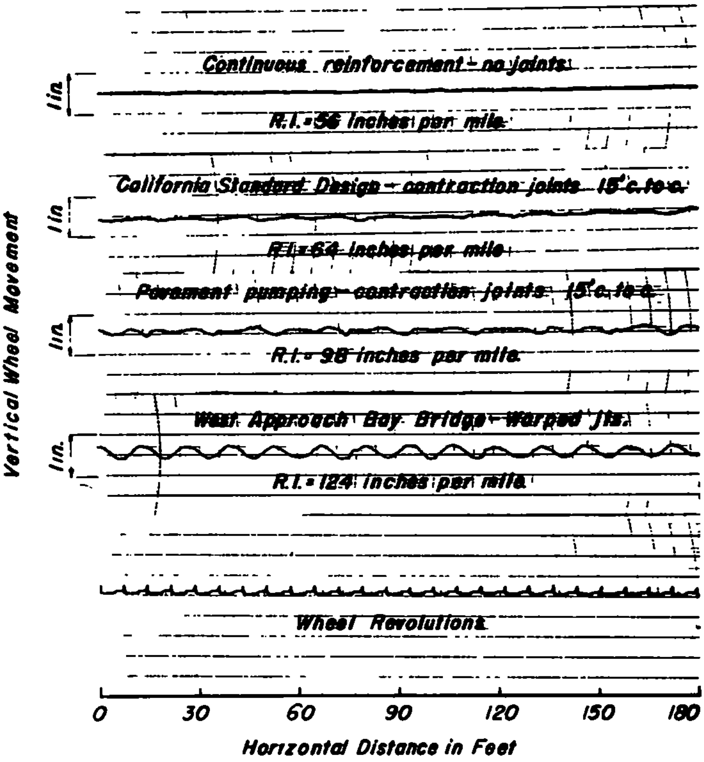

Figure 8. Roughness Oscillograph Records for Concrete Pavements

Tests with the BPR Roughness Indicator on more than 50 mi. of concrete pavement in California gave consistently low values. It was apparent that with such low values the California Division of Highways had developed a method of finishing concrete pavements which is superior to methods used in the other States where roughness tests with the BPR Indicator had been run Observations of the concrete paving operations on the Oakland Freeway indicated that the key to building smooth concrete surfaces was largely in the skillful use of the Johnson Finisher developed in California about 15 years ago. Credit for developing high standards of surface smoothness in California should also go to Mr. F. N Hveem, Materials and Research Engineer and to Mr Earl Withycombe, Construction Engineer, both of the Division of Highways, who have been checking road roughness and keeping extensive records of road roughness of the pavements built in California for more than ten years.

The third oscillograph record in Figure 8 shows an oscillogram taken on a section of two-lane concrete pavement subject to pumping on US 40 south of

Fairfield, California The faulting at the joints spaced 15 ft. on centers is clearly evident in this record. The roughness index of 98 in. per mi. appears to be considerably higher than for the smooth pavements shown in Figure 8, yet according to the tentative standards of roughness using the BPR Indicator, this pavement would be given a high rating. Careful examination of the oscillogram for this pavement indicates that the pavement is smooth between joints, and that it is only the faulting at the joints due to pavement pumping which has raised the roughness index to 98 in. per mi.

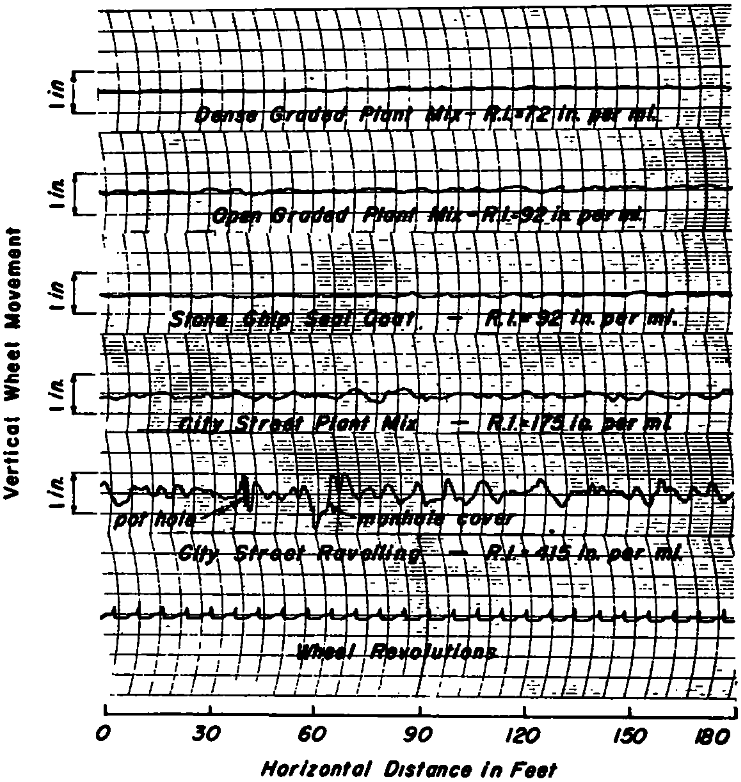

Figure 9. Roughness Oscillograph Records for Bituminous Pavements

The oscillogram for the concrete pavement on the west approach to the San Francisco - Oakland Bay Bridge provided an interesting record, since this pavement also has a smooth surface finish but it is badly warped at the joints spaced 15 ft. on centers. The roughness index for this section was found to be 124 in. per mi., which, according to the tentative standards, would indicate that this pavement has good riding qualities. Actually the surface has a smooth surface finish and it is only the warped joints which give it the index of 124 in. per mi., an above average value for concrete pavements. For this case, the oscillogram gives a better indication of the riding quality of this pavement than the roughness index, because it shows the smooth sine wave produced on this type road surface, which is responsible for the rythmic bouncing ride experienced when driving passenger cars over it at speeds above 35 mph.

Typical oscillograph records of the roughness of bituminous pavements are shown in Figure 9. While the values of road roughness are higher for the bituminous pavements than for the concrete pavements, the oscillograms for the top three surfaces clearly indicate that these surfaces are remarkably smooth. The value of 72 in per mi. obtained for the dense graded plant mix surface on the East Shore Freeway, which carries very heavy truck traffic, is evidence of excellent bituminous pavement design and construction. While these values for the roughness of bituminous pavements are low, it is significant that in 1948 Mr. Shelburne reported a minimum value of 62 in. per mi. for a bituminous concrete pavement in Virginia. In searching for an explanation for the low roughness values obtained on bituminous pavements in California and in Virginia, it is believed that the answer lies in the use of plant mix materials and a well-designed asphalt pavement finishing machine. Of course, bituminous pavements require a stable base, a well-designed mix, proper compaction, preferably with a three-axle roller, and every step in the plant and placing operations must be carefully controlled to obtain the extremely smooth surfaces which the results of these tests indicate are being built in Virginia and California

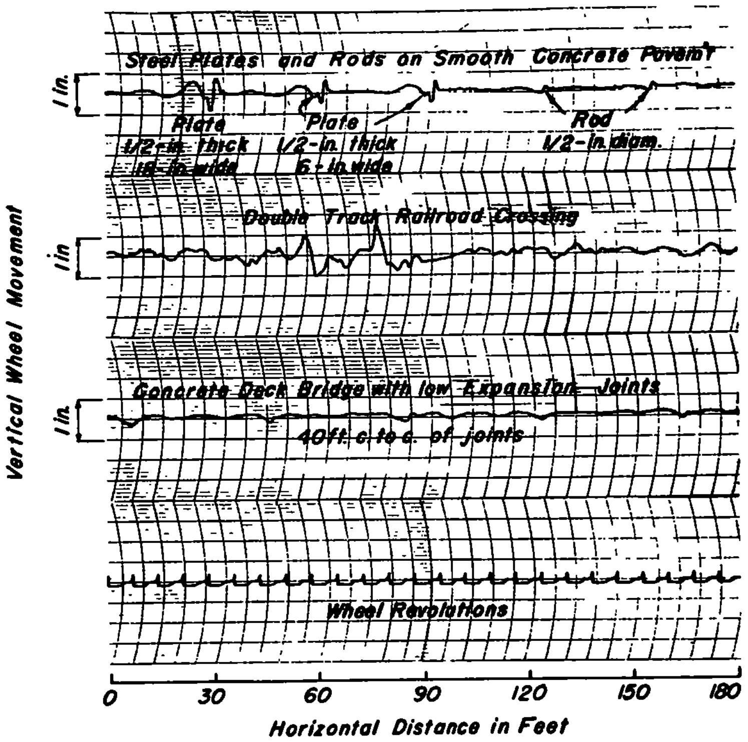

Figure 10. Roughness Oscillograph Records for Special Conditions

The oscillograph records for the city streets shown in Figure 9 are fairly typical of the roughness of city streets where the construction and maintenance methods do not measure up to the high standards required by State highway departments. While it is true that, since the speeds are slower on city streets than on rural highways, it is not necessary to have as high a standard of road roughness for city streets as for rural highways; nevertheless, when the roughness of a city street reaches the high value of 415 in. per mi. shown in Figure 9, it should be evident that such a street is due for reconstruction or resurfacing. It may be worth mentioning in this connection that one of the best methods which engineers can use for rating road surfaces is in terms of the roughness index Such a rating plan should be very useful in establishing priorities for resurfacing city streets when combined with traffic counts for the streets under consideration.

The three roughness oscillograph records for the special conditions in Figure 10 clearly show the action of the tire and the spring suspension of the BPR Roughness Indicator as it rolls over steel rods and plates of known dimensions, a railroad crossing and a concrete deck bridge. It should be noted that the 1/2-in. diameter rod causes only a ripple in the surfaces as the tire rolls over it, since the wheel rises only about 0. 2 in. when it strikes the rod. There is no indication of a bouncing or vibrating effect after it strikes the rod, which is evidence of the excellent damping action of the dash pots. Since the rise of the wheel is less than half of the thickness of the rod, it is evident that the tire is deformed by the rod and thus contributes to the damping action. When the tire rolls over the 6-in. plates, it is deformed only slightly and is raised almost the full 1/2-in. thickness of the plates. When the tire drops off the end of the plates, it deforms by an amount almost equal to the thickness of the plates. This is followed by a single bounce which is immediately damped out by the dash pots.

The oscillogram obtained when the Indicator crossed a double track railroad crossing shown in Figure 10, gives an indication of the action of the trailer for a condition which is fairly typical of the road roughness at railroad crossings. The oscillogram obtained on the concrete deck bridge shows the action of the trailer as it passed over some low transverse contraction-expansion joints with a 40 ft. spacing. At each joint there were two steel plates six in wide with a groove approximately one-half in wide between the plates. The pattern obtained in this oscillogram gave a clear indication of this particular surface condition and thus gave added support to the accuracy of the records obtained with this equipment.

STUDY OF TIRE WEAR, TRACTIVE RESISTANCE, NOISE, GLARE AND LIGHT REFLECTION ON VARIOUS ROAD SURFACES

The Committee recognizes that tire wear, tractive resistance, noise, glare and light reflection are important road surface factors which deserve careful study and that the results of such studies should be correlated with the results of studies of skid resistance and road roughness. In view of the research now being conducted by various members of the Committee and that which other persons or organizations may be encouraged to do as a result of this report, the prospects appear very favorable for some excellent reports covering all properties of road surface at future annual meetings.

ACKNOWLEDGMENTS

In the research at the University of California described in this paper, the Chairman has been ably assisted by Messrs. Gale Ahlborn, John R. Jones, Louis Possner and John Shupe in the construction of test equipment and in running the road roughness tests. Mr. J. R. Hall, Electronics Engineer and Mr. R. G. Newcomb, Senior Laboratory Mechanic, designed and built the SR-4 strain gage dynamometer, the road roughness recorder equipment, and certain other items of test equipment.

The Chairman also wishes to acknowledge the cooperation of the Division of Highways in helping to arrange for running the tests on new sections of pavement and Mr. Earl Withycombe, Construction Engineer, for his suggestions and interest in conducting the road roughness tests.

FIELD EXPERIMENTS WITH POWDERED RUBBER IN BITUMINOUS ROAD CONSTRUCTION

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SYNOPSIS

Information concerning foreign experiments with rubber in bituminous road surfaces indicates that such combinations may have merit. It is claimed that the addition of small percentages of rubber results in a more durable mixture - one that is less susceptible to temperature change, thereby having less tendency to bleed or shove at high temperatures or to crack at low temperatures. Resistance to skidding is also said to be improved.

This report describes three field experiments with powdered rubber built during the summer of 1949 by the Virginia Department of Highways on Route 250 west of Richmond. In Section 1 powdered natural rubber was incorporated in the bituminous concrete sand asphalt wearing surface. Section 2 was a similar surface to which reclaimed powdered rubber was added. The third section was a seal treatment with cut-back asphalt (RC-2) to which natural powdered rubber was added and mixed in the distributor prior to application. Identical sections (1-C, 2-C, and 3-C) without rubber were constructed adjacent to the experimental ones for purposes of comparison. Sections 1 and 1-C were constructed in May, 1949 and the remaining ones in September, 1949.

Complete records were secured at the time of construction concerning materials, quantities, procedures, temperatures, workability, etc. Follow-up studies since construction included visual observations, road roughness measurements, and skid tests. Since Section 1 and 1-C were constructed earlier, more data are available on their performance, particularly as related to skid resistance.

At this time little, if any, difference can be noted between comparable sections with and without rubber. Road roughness measurements made on Sections 1 and 1-C shortly after construction indicated no significant differences between the two sections that could be attributed to the use of rubber. In both sections, however, the outside lanes which carry the majority of traffic were considerably rougher than the inside or passing lane.

Two series of skid tests have been conducted on Sections 1 and 1-C - one immediately after construction (May, 1949), and the other six months later (November, 1949). Only one test series has been performed on the remaining sections. These were made in November, 1949.

Resistance of the surface to skidding was determined by the stopping distance method. All surfaces including the control sections were found to have satisfactory resistance to skidding, both in a dry and in a wet condition. Stopping distances on Section 2, containing reclaimed rubber, were practically identical with those on the control section (2-C). The seal treatment (Section 3), including natural powdered rubber, indicated a slight beneficial effect since the stopping distance on the wet surfaces at 40 mph. was about 3 ft. shorter than on Section 3-C. It is possible that slight surface texture variations may at least partially account for the difference. Additional tests at later dates will have to be made for further evaluations.

Skid results on the older sections (1 and 1-C) in a wet condition appear to be more significant. Results are summarized below:

	STOPPING DISTANCE (FT.)			
Speed (mph.)	10	20	30	40
	IMMEDIATELY AFTER CONSTRUCTION			
Section 1-C, *Plain*	4.9	21.3	49.9	93.7
Section 1, *with natural rubber*	5.1	21.1	49.1	87.9
Difference	-0.2	0.2	0.8	5.8
	SIX MONTHS AFTER CONSTRUCTION			
Section 1-C, *Plain*	6.0	25.5	57.0	101.2
Section 1, *with natural rubber*	5.1	22.6	49.2	87.5
Difference	-0.9	2.9	7.8	13.7

From the data it appears that the incorporation of natural rubber in the bituminous concrete (F-1 sand asphalt) resulted in a slight difference in stopping distance at the time of construction, particularly at higher speeds. After six months, greater differences in stopping distances on wet pavements were found between the section containing natural rubber and the one without it. On the rubber section (1), stopping distances for the two test series were practically identical; however, on the plain section (1-C) they had increased considerably during the six-month period.

While conclusions cannot be drawn at this early date regarding improvement in durability characteristics, small percentages of natural rubber may be beneficial in minimizing the change in resistance to skidding to bituminous plant mix sand asphalt surfaces when wet. In order for such mixtures to be generally accepted they must not only show improved performance but also prove economical to the user.

REVIEW OF PREVIOUS WORK

Experiments with rubber-asphalt mixtures have been conducted for several years in other countries, principally by the Dutch in Holland and the East Indies. The first published report of results of a systematic investigation into the changes produced by the addition of rubber to asphalt was published by Van Heurn and Begheyn (*1*)[1] in 1934. In 1931 Fol and Bijl (*2*) reported some experiments conducted for the Technical Department of the International Rubber Association. This work was continued in 1933, by Plazier (*3*) who used unvulcanized powdered rubber instead of latex rubber solutions or vulcanized rubber (such as ground automobile tires) which were used in most of the earlier investigations. Mixtures with varying percentages of rubber were made by stirring the required amount of rubber powder into the melted bitumen and heating for one hour to about 150 deg. C. It was found that the addition of a small amount of rubber made the asphalt less susceptible to temperature changes and therefore less likely to bleed in summer or crack in winter.

Several methods of constructing rubber asphalt pavements were employed in these experimental projects. A premixed material was used in a light surface course at the rate of 10 to 13 lb. per sq. yd. Seal treatments consisted of applying the rubber-asphalt mixture on the surface, covering with aggregate and rolling lightly. Other surfaces constructed were asphaltic concrete carpets containing rubber powder throughout their entire thickness.

Dr. F. T. Bokma (*4*) reviews the status of experimental work in his paper "Rubber in the Construction of Roads". He states that between the years 1935 - 1940, some 30 test areas were constructed by the Rubber Foundation in collaboration with government institutions. Of these areas, many in both Holland and the East Indies were destroyed as a result of inundation or fighting during the recent war. However, of the remaining areas, the rubber-asphalt section performed much better than the control section with a life of 8 to 10 yr. where only a thin surface dressing was used over coarse asphaltic concrete. Where rubber was used throughout the entire thickness of asphaltic concrete mixtures there was very little difference between these sections and the controls, so that a period longer than 10 yr. is necessary to determine the effects of adding rubber-powder. Dr. Bokma also found that the use of small percentages of rubber in asphaltic mixtures increased the skid resistance of the surface and reduced maintenance costs.

Rubber has been used in the United States in rubber-asphalt compounds for sealing joints in concrete pavement for several years. However, to the writers' knowledge, it was not used in surface courses until the summer of 1948 when the city of Akron, Ohio (*5*) constructed a street using a mixture of powdered synthetic rubber with the

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[1] Italicized figures in parentheses refer to list of references at the end of the paper.

asphalt. In this work the asphalt was heated to approximately 300 deg. F. and the rubber powder slowly sifted in with agitation and mixed for two hours. Rubber was added in the amount of 5 and 7.5 percent by weight of the asphalt. A bituminous concrete surface was constructed using a 1-1/2-in. binder course over which was placed a 1-1/2 in. surface course containing rubber. This plant-mixed surface course is much thicker than was used in most of the Dutch experiments and a longer period may be required to evaluate it.

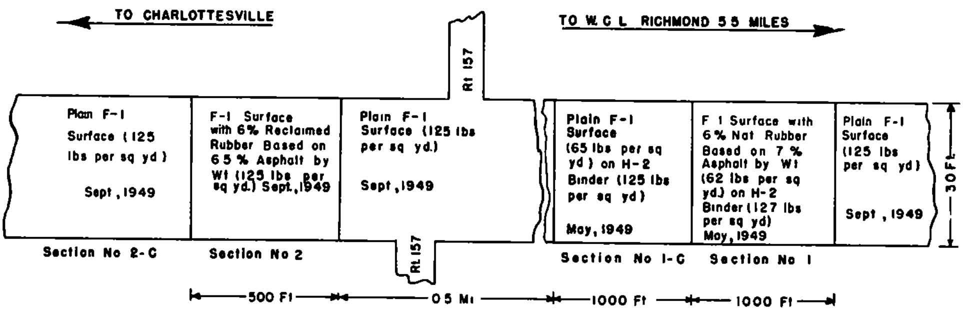

Figure 1. Field Experiments with Rubber in Bituminous Plant Mix, Route 250, Henrico County

Theories have been advanced regarding what actually happens when powdered rubber is incorporated with asphalt. It is reported that a study of photomicrographs indicates that homogenous solutions do not result, since particles of rubber can be distinctly seen in the mixture. Some investigators speculate that the lighter oily constitutents of the asphalt are slowly absorbed by the rubber, causing it to swell, and that this process can be hastened by heating The writers have no data on this subject; however, prior to the initiation of the field experiments some exploratory tests were conducted in the laboratory by the Division of Tests (6) to determine if various percentages of natural rubber powder affected standard test results of asphalts. Accordingly, various percentages of rubber were mixed with 85-100 and 200-300 penetration grade asphalts (AP-3 and AP-00, Va. Spec.) and tested for penetration, softening point, ductility, specific gravity and flow. These tests indicated that blending temperatures were critical and that best results were obtained at a temperature range of from 170 to 190 deg. C. (340 to 375 deg. F.). At lower temperatures uniform results were not secured and at higher temperatures decomposition of the rubber was noted For mixes blended (from 0 to 15 percent rubber) within this temperature range the penetration, ductility and flow decreased and the softening point increased with increasing amounts of rubber The addition of rubber powder to the two grades produced parallel results which indicate that comparable effects could be expected with intermediate grade asphalts

CONSTRUCTION OF FIELD SECTIONS

Originally it was proposed to construct experimental sections containing natural, synthetic and reclaimed rubber; however, since synthetic rubber was not available, only natural and reclaimed rubber were used. Most foreign experiments were reported to have been constructed by hand methods It was believed that if these experiments were to be of maximum value they should be built by machine methods. It was, therefore, decided to construct a section 1,000 ft. in length using a binder course and a bituminous concrete (F-1 sand asphalt) wearing surface, in which a small percentage of powdered natural rubber had been incorporated at the plant. Otherwise, this bituminous concrete was to be designed and constructed in accordance with our standard procedures. Adjacent to this section was constructed a control section identical in every respect except that no rubber was added These sections are identified in Figure 1 as 1 (experimental) and 1-C (control). Section 2, in which reclaimed rubber was incorporated and 2-C, without rubber, were constructed later in the season as part of a large project (Fig. 1).

Realizing that several years might be necessary before any decided differences in performance might be apparent between the sections containing rubber and the control sections, it was decided to try the natural rubber in a seal treatment. The life of such surfaces is much less than that of the bituminous concrete and such treatments are usually rather critical as to weather conditions and control of quantities. Often seal treatments bleed excessively. The location of this (Section 3) and the control (Section 3-C) is shown in Figure 2. Design and construction details follow for each of the three experiments.

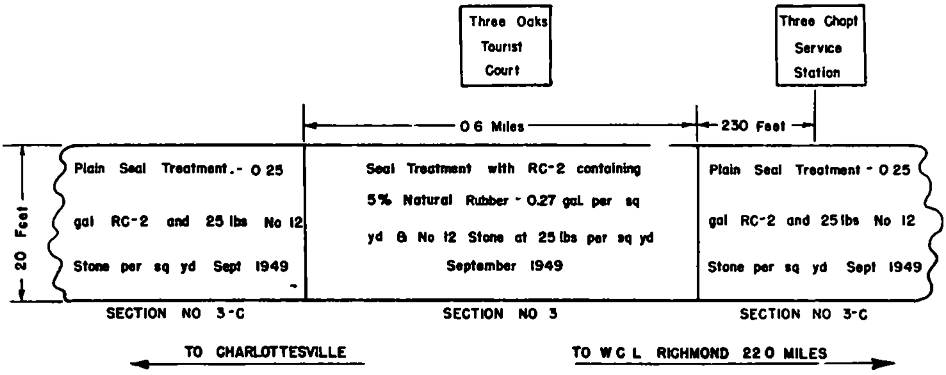

Figure 2. Field Experiments with Rubber in Bituminous Seal Treatment, Route 250, Goochland County

Sections 1 and 1-C - Sections 1 and 1-C constructed of Type F-1 sand asphalt are located on US Route 250 about 5 5 mi. west of Richmond, Virginia. The road is 30 ft. in width with a macadam base and old plant-mix surface. The average 24-hr traffic volume for the year ending June 30, 1949 was 3,135 vehicles, 768 of which were trucks and buses.

The aggregate (3/8-in. max. size) selected for this section was a 50-50 mixture of natural sand and granite screenings. The percentage of asphalt (85-100 pen grade) required was determined by the surface area method and checked by density and stability tests. It was found that 7 percent asphalt gave a satisfactory mix Based on the grading of the aggregates and the above tests, Dr. F. T Bokma, who furnished technical advice on the use of rubber, recommended a rubber content of 6 percent by weight of asphalt, or 0.42 percent by weight of the total mix. This rubber powder was predominately between the 20 and 80 mesh sieves. Only 2.3 percent was retained on the No. 20 and 4.9 percent passed the No. 80 sieve. The mix was set for 7.0 percent asphalt, 0.42 percent powdered rubber and 92.58 percent aggregate.

The mix was produced in a "Simplicity" plant of the stationary pug mill type Rubber powder for each batch was weighed and placed in a bag from which it was dumped into the pug mill along with the dry aggregate which had been heated to 300 to 325 deg. F. After mixing the aggregate and rubber for 15 sec., the asphalt (heated to 215 deg. F.)

was added and mixing continued for an additional 45 sec. It was attempted to produce the mixture with a temperature of 260 deg. F., but due to break down of equipment and delays there was considerable variation.

The existing surface was cleaned and a tack coat of AP-3 asphalt (85-100 penetration) was applied at the rate of 0.065 gal. per sq. yd. This was followed by a bituminous concrete binder course (H-2) applied at 127.5 lb. per sq. yd (Fig. 3). As soon as the binder course was completed in each lane of Section 1 it was covered immediately with the bituminous concrete (F-1, sand asphalt) wearing surface containing rubber (Fig. 4). An attempt was made to lay the wearing course as thin as possible. Average amounts were 62.5 and 65.5 lb. per sq. yd. for Sections 1 and 1-C, respectively. Both courses were placed with a Barber-Greene paver and rolled with 7 - and 12-ton tandem rollers.

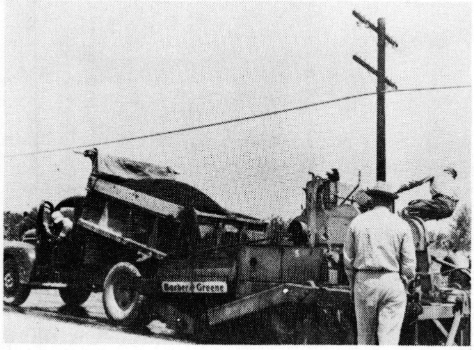

Figure 3. Laying H-2 Binder Course with Barber-Greene Paver Prior to Placing Type F-1 Rubber-Asphalt Surface - Note asphalt tack coat on pavement ahead of paver.

Sections 2 and 2-C - Section 2, 500 ft. in length, was constructed of Type F-1 sand asphalt containing reclaimed rubber. It is located about 0.5 mi. west of Section 1. The old pavement was also a macadam road which had an old plant-mix surface. For the year ending June 30, 1949 it carried an average 24-hr. traffic volume of 2,919 vehicles, 746 of which were trucks and buses.

On this project, the aggregate (3/8-in. max. size) was a mixture of 2/3 natural sand and 1/3 crushed gravel. As the rubber-asphalt section was only a small part of a large project, the mix had been designed and a considerable amount of material placed before the section containing rubber was constructed. An asphalt (AP-3) content of 6.5 percent had been found to be the most desirable for the aggregates being used. Since the grading of this aggregate was about the same as the aggregate used in Section 1, a rubber content of 6 percent by weight of asphalt was used. The reclaimed rubber was much coarser than the natural rubber. It was predominately between the 10 and 40 mesh sieves. Only 0.2 percent was retained on the No. 10 and 6.0 percent passed the No. 40 sieve.

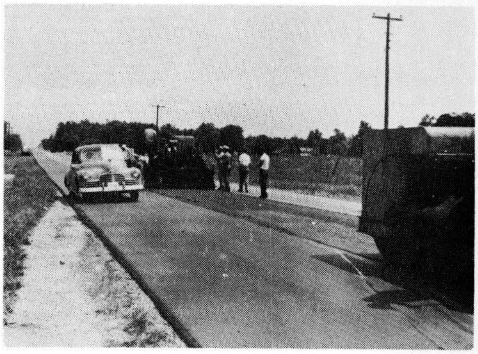

Figure 4. Placing Type F-1 Surface Containing Natural Rubber with Barber-Greene Paver - Note slight ''pulling'' of uncompacted surface. Picture shows completed westbound lane and eastbound lane where binder course has not been applied.

This mix was also produced in a "Simplicity" plant of the stationary pug mill type. Rubber was weighed, added to the hot dry aggregate and mixed as described for Section 1. However, in order to produce the mix with a temperature of 275 to 285 deg. F. the asphalt was heated to about 270 deg. F.

After the surface of the road was

cleaned, a tack coat of 0.059 gal. per sq yd. of AP-3 was applied. Since no binder course was used on this project the F-1 mixture containing reclaimed rubber was placed on the tack coat at the rate of 124.7 lb. per sq. yd. The regular F-1 surface course (without rubber) on either end of the section containing rubber was designated as Section 2-C (control section). These mixtures were placed with an Adnun paver (Fig. 5) and rolled with 8-and 10-ton tandem rollers.

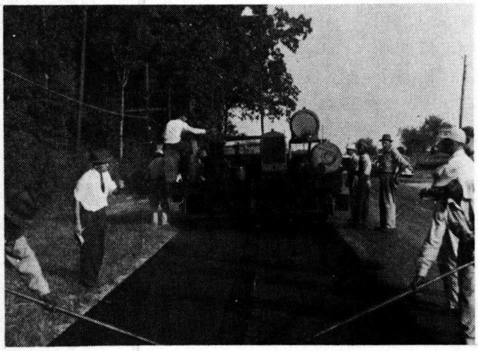

Figure 5. Placing Type F-1 Surface Containing Reclaimed Rubber with Adnun Paver - Note absence of ''pulling'' in uncompacted material.

Sections 3 and 3-C - Section 3 which is 0.6 mi. in length is on US Route 250, about 22 mi. west of Richmond. It consists of a seal treatment of cut-back asphalt (RC-2) containing natural rubber and No. 12 stone chips placed on a 20-ft. macadam road that had an old broom-drag surface treatment. The average 24-hr. traffic volume for the year ending June 30, 1949 was 1,500 vehicles, 423 of which were trucks and buses.

Approximately 600 gal. of cut-back asphalt (RC-2) was placed in a 1,000 gal. distributor and heated to 180 deg. F. Powdered natural rubber in the amount of 5 percent by weight was slowly added and agitated (Fig. 6) until thoroughly mixed. Two mixings of powdered rubber and cut-back asphalt were necessary for each lane. While the rubber mixed with the asphalt readily, the operation required considerable time so that progress of the work was retarded.

When the rubber was uniformly mixed with the asphalt, it was applied on the road at the rate of 0.27 gal. per sq. yd. (Fig. 7) and covered with about 25 lb. per sq. yd. of No. 12 crushed stone (3/8-in. -No. 8). The stone was then rolled with a 7-1/2-ton tandem roller followed by a rubber-tired roller. When rolling was completed the treatment was allowed to cure for a minimum of 1-1/2 hr. before it was opened to traffic. Again, this section was a part of a large project and the regular surface without rubber was used for a control section (3-C).

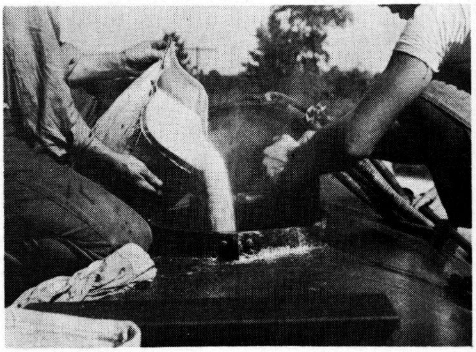

Figure 6. Mixing Powdered Natural Rubber with Asphalt (RC-2) in Distributor - The rubber was added slowly, stirred with a paddle and agitated by the distributor.

OBSERVATIONS AND RECORDS DURING CONSTRUCTION

During the construction, the temperature and workability of the various F-1 mixes were carefully observed and recorded. Temperature of the material was taken at the plant when it was being weighed and again on the road when the material was placed in the paver. There was considerable variation in temperatures between different loads of material and between different batches in the same load. This variation was attributed to failure of equipment, or other delays which caused the aggregate to remain in the drier for a longer period than usual, and in some cases to aggregate being put through the drier too rapidly. Some temperatures at the plant were probably low due to removal of the thermometer from the mix before max. temperature had been recorded.

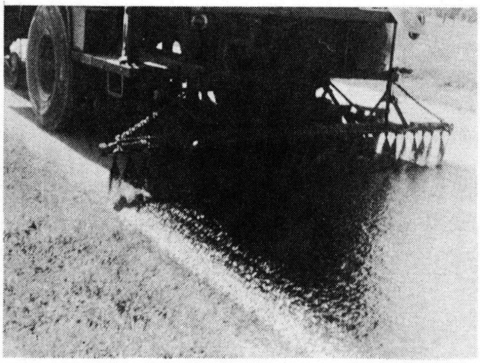

Figure 7. Applying Mixture of Powdered Natural Rubber and Asphalt (RC-2) with Powder Distributor - Note that no difficulty was experienced with clogging of the nozzles.

On Sections 1 and 1-C temperatures recorded at the plant averaged 250 deg. F. and on the road 248 deg. F. The average recorded from Sections 2 and 2-C were 272 deg. F. at the plant, and 276 deg. F. at the paver.

The type F-1 mix containing natural rubber was placed very readily with the Barber-Greene paver. It was found, however, that in order to prevent "pulling", the machine had to be operated slower (8 ft. per min.) with rubber than without (12 ft. per min.). An attempt was made to place the rubber-asphalt mixture at the rate of 50 lb. per sq. yd. instead of the 62.5 lb. obtained. It is believed that with a smoother binder, trained operators, and a machine in good adjustment it would be feasible to place this material at rates as low as 50 lb. per sq. yd.

With the type F-1 mix containing reclaimed rubber, no difficulty was encountered in placing the material with the Adnun paver. There was very little "pulling" in evidence with the reclaimed rubber. Immediately after rolling, particles of rubber were visible above the compacted surface; however, most of these particles appeared to be whipped off under traffic.

The rollers worked equally well on both materials. Good compaction was obtained with little or no pushing in front of the roller. There was no delay in rolling the sections containing rubber and while the surface was new it appeared to scar less under traffic than the surface without rubber.

On Section 3, where natural rubber was mixed with (RC-2) in the distributor, it was necessary to add the rubber slowly, stir with a paddle and agitate the asphalt with the distributor. When it was thoroughly stirred the rubber mixed readily with the asphalt. The volume of the asphalt was increased about 10 percent by the addition of 5 percent of rubber by weight.

The power distributor applied the rubber-asphalt mixture without difficulty. Even distribution of the material on the road was obtained with no clogging of the nozzles that could be attributed to the presence of the rubber.

Many photographs were taken during the construction of each section. In addition, moving pictures were made during construction and while performing skid-resistance tests on Section 1. These pictures show many construction details that will be of value in future studies.

FOLLOW-UP STUDIES

Since construction, follow-up studies of the experiments have included visual observations, road roughness measurements, and skid tests.

Visual Observations - Visual inspections of each section are made frequently, but to date, there has been no noticeable difference in appearance between the sections containing rubber and their respective control sections, except as previously described for Section 2 and 2-C. These inspections will be continued and complete performance surveys made when pronounced differences are apparent.

Road-Roughness Tests - Road-roughness measurements were made on Sections 1 and 1-C in June 1949, with the single-wheel type of road roughness indicator designed by the Bureau of Public Roads (7). The section containing natural rubber with an average roughness index of 98 in. per mi. was slightly rougher than the control section which had an average roughness index of 92 in. per mi. This difference is small, and since considerable difficulty was experienced in keeping the paver properly adjusted, it is believed that differences in roughness may have resulted from operation of equipment rather than from the presence or absence of rubber in the mix. It was found that a greater difference existed between the outside lanes and the inside or passing lane. For example, the outside lanes averaged 103 in. per mi. and the center lane 79 in. per mi.

Figure 8. Skid Tests on Sand Asphalt Surface - Note mark on pavement and dust from chalk bullet fired by detonator as wheels were locked.

The other sections have not been tested for riding qualities; however, it is planned to make these measurements as soon as possible.

Skid Resistance Tests - One of the benefits claimed for the use of powdered rubber in asphalt mixtures is improvement in skid resistance of the surface. In order to evaluate this quality, skid resistance tests (8) have been made on each section. Results shown in Table 1 are the average of two or more tests made at each speed for each surface condition. The individual measurements checked very closely with repeat tests under the same conditions.

Skid resistance tests (Fig. 8) were made on Sections 1 and 1-C in May, soon after completion. At that time, with the surface wet at 40 mph., an average stopping distance of 93.7 ft. was measured on the plain surface and 87.9 ft. was measured on the F-1 surface containing natural rubber. The difference of 5.8 ft. in favor of the mix containing rubber indicates that natural rubber in F-1 mixes tends to improve skid resistance of the surface at early ages.

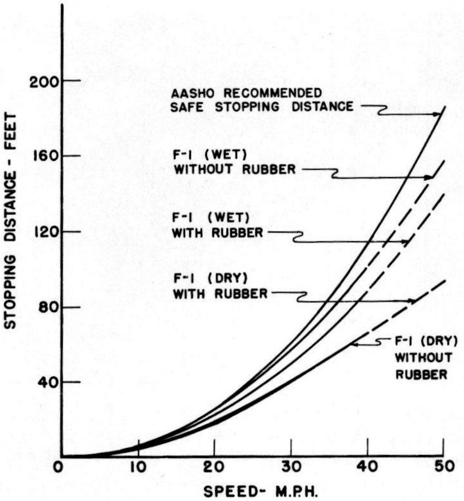

Figure 9. Skid Test Results on Bituminous Concrete (Type F-1) Surfaces with and without Natural Rubber (Six Months After Construction)

Sections 1 and 1-C were again tested for skid resistance in November, 1949. These tests at 40 mph. on wet surfaces gave an average stopping distance of 101.2 ft. on the plain section and 87.5 ft. on the one containing natural rubber. Results of these tests are shown graphically in Figure 9 in comparison with the AASHO recommended max. safe stopping

TABLE 1

SKID RESISTANCE MEASUREMENTS

Section Number	Surface Condition Speed - mph.	Dry								Wet								Date Tested
		10		20		30		40		10		20		30		40		
		S	f	S	f	S	f	S	f	S	f	S	f	S	f	S	f	
		Bituminous Concrete, Sand Asphalt (F-1)																
1-C	Without Natural Rubber	4.8	0.69	18.2	0.73	37.4	0.80	63.4	0.84	4.9	0.68	21.3	0.63	49.9	0.60	93.7	0.55	May 1949
1	With Natural Rubber	3.7	0.90	17.2	0.78	38.9	0.77	60.7	0.88	5.1	0.65	21.1	0.63	49.1	0.61	87.9	0.61	May 1949
	Difference in S	1.1		1.0		-1.5		2.7		-0.2		0.2		0.8		5.8		
1-C	Without Natural Rubber	4.5	0.74	19.6	0.68	40.1	0.75	65.9	0.81	6.0	0.56	25.5	0.52	57.0	0.53	101.2	0.53	November 1949
1	With Natural Rubber	4.2	0.79	18.6	0.72	40.2	0.75	66.6	0.80	5.1	0.66	22.6	0.59	49.2	0.61	87.5	0.61	November 1949
	Difference in S	0.3		1.0		-0.1		-0.7		0.9		2.9		7.8		13.7		
2-C	Without Reclaimed Rubber	4.5	0.74	18.3	0.73	40.1	0.75	64.7	0.82	5.3	0.63	22.6	0.59	49.8	0.60	88.2	0.60	November 1949
2	With Reclaimed Rubber	4.4	0.76	18.6	0.72	40.5	0.74	67.9	0.78	5.4	0.62	21.5	0.62	48.8	0.61	88.5	0.60	November 1949
	Difference in S	0.1		-0.3		-0.4		-3.2		-0.1		1.1		1.0		-0.3		
		Seal Treatment																
3-C	Without Natural Rubber	5.0	0.67	20.4	0.65	44.2	0.68	73.5	0.72	5.9	0.56	24.3	0.55	55.0	0.55	93.1	0.57	November 1949
3	With Natural Rubber	4.2	0.79	19.3	0.69	41.0	0.73	71.7	0.74	5.6	0.60	24.0	0.54	53.0	0.57	90.0	0.59	November 1949
	Difference in S	0.8		1.1		3.2		1.8		0.3		0.3		2.0		3.1		

S = stopping distance in feet

f = average coefficient of friction, as determined from $f = \frac{v^2}{30S}$ where

v = velocity in mph

Note Each stopping distance value is the average of two or more determinations distances. It will be noted that even for the wet surface without rubber, the stopping distance is well below the recommended max. safe stopping distance of 113 ft. at 40 mph. The above tests show that while the skid resistance of the section containing natural rubber remained the same six months after construction, there was an increase in stopping distance on the plain section.

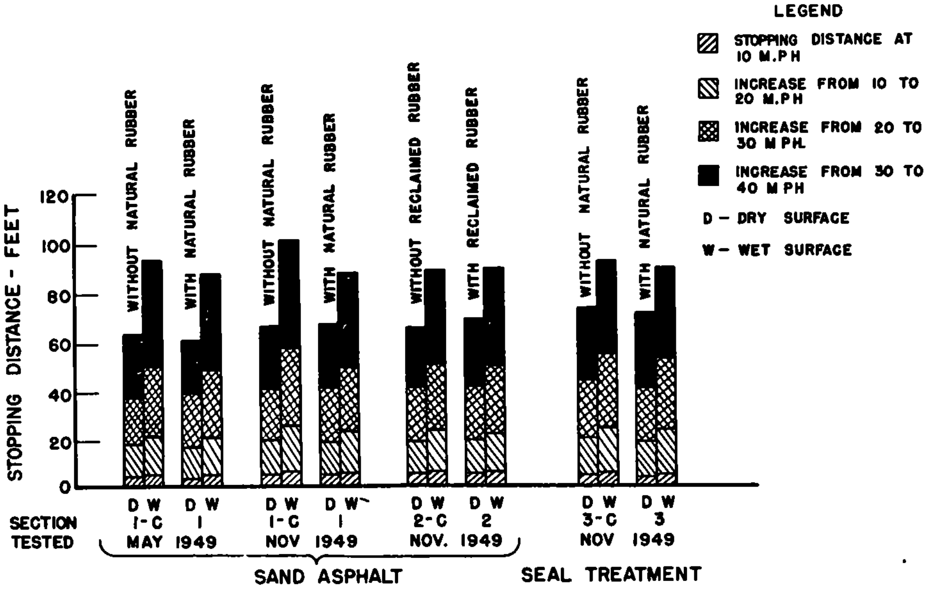

Figure 10. Skid Resistance Measurements

Results of skid resistance tests at 40 mph. on Sections 2 and 2-C gave an average stopping distance of 88.5 ft. on a wet F-1 surface containing reclaimed rubber, and 88.2 ft. on a wet F-1 surface without rubber. These results indicate that, at the time the tests were conducted, the reclaimed rubber had not been effective in improving skid resistance of this F-1 surface.

Skid resistance tests on Section 3 at 40 mph. with the surface in a wet condition gave a stopping distance of 90.0 ft. on the seal treatment containing natural rubber and 93.1 ft. on the seal treatment without rubber. The difference of 3.1 ft. in stopping distance is small and may have been affected by the surface texture which is rather harsh. Tests will have to be conducted over a longer period of time to evaluate any improvement due to rubber in this type of surface.

Figure 10 shows skid tests results to date. It will be noted that all surfaces tested have good skid resistance even in a wet condition and are well below the max. safe stopping distance as recommended by the AASHO. With the surfaces dry, stopping distances for the various F-1 surfaces are very close together. On the seal treatment, there is very little difference between the stopping distance for the sections with and without rubber. Since results of a large number of tests on surfaces of various types show that all pavement surfaces in Virginia have good skid resistance in a dry condition, only results of tests on wet surfaces at 40 mph. are used to evaluate their skid resistance.

SUMMARY OF RESULTS

While definite conclusions regarding the economics and durability of sand-asphalt (F-1) bituminous plant mixes and seal treatments to which small percentages of natural or reclaimed powdered rubber have been added cannot be made at this early date, the following tentative conclusions may be drawn:

1. It is feasible to incorporate small percentages of natural or reclaimed powdered rubber in sand-asphalt (F-1) mixes at the plant and in the manner followed in these experiments. Also, no difficulty was encountered in adding a small percentage of powdered natural rubber to asphalt cut-back (RC-2) and applying it with a distributor. No method was devised to determine the distribution of the rubber throughout the mix, and consequently no data are available on this feature.
2. It was found to be practical to lay such a mixture with Barber-Greene and Adnun pavers. With the equipment available, however, the thinnest rate of application that could be applied successfully was approximately 60 lb. per sq. yd. It was further found that with the natural rubber in the mixture, the max. speed of the Barber-Greene paver for good results was about 8 ft. per min., while without the rubber a speed of 12 ft. per min. could be maintained with equally good results. Reclaimed rubber in the mixture did not affect the results obtained with the Adnun paver.
3. No difference in appearance has been observed between the sections with natural rubber and the ones without. The surface containing reclaimed rubber showed particles of rubber standing above the compacted surface when rolling was completed.
4. Since the natural and reclaimed powdered rubber was furnished gratis to the Department, no information is available concerning added costs for these materials.
5. Immediately after construction, measurements of resistance to skidding indicated that in a wet condition the section of F-1 sand asphalt with natural powdered rubber had slightly better resistance to skidding than the control section. In a dry condition there was very little difference between the stopping distance on the sections with and without natural rubber. Similar tests six months later, on the wet surface, showed an increase in stopping distance for the control section, but no change in the skid resistance of the rubber-asphalt surface.
6. After two months there is no indication that the reclaimed rubber has been effective in improving skid resistance of type F-1 sand asphalt. Skid resistance measurements on the section with reclaimed rubber were about the same as those for the control section.
7. A slight difference in stopping distances on a seal treatment with and without natural rubber was indicated in favor of the rubber section, two months after construction.
8. The outside lanes which carry the majority of traffic were found to be rougher than the inside or passing lane; however, no differences were found in the riding qualities of Sections 1 and 1-C that could be attributed to the presence or absence of rubber in the mix.
9. Based upon experience with similar sand-asphalt mixes not containing powdered rubber, it is believed that several years will be required before decided differences in performance on these sections may be apparent. It is believed that where small percentages of powdered rubber are incorporated with the asphalt and applied in conjunction with a seal treatment, an evaluation of the effectiveness of the rubber-asphalt combination may be possible at a much earlier date.

In conclusion it is suggested that comprehensive laboratory research be conducted to determine fundamental properties of rubber-asphalt mixtures.

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