FORMATION OF WASHBOARDS IN GRAVEL HIGHWAYS

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INTRODUCTION

Highway transportation in the United States is becoming more important and more popular each year. In many places where the traffic will warrant the expenditure, hard surface roads have been built Whether or not a cement concrete or bituminous type road is built in a given locality is determined partly by the traffic need for such a road, and partly by the financial conditions and the political situation of that region as well In places where hard surface roads for one reason or another cannot be built, and traffic warrants an improved road, it has been customary to surface the road with gravel or crushed rock with which a small amount of clay is mixed for binder This is a type of surface commonly found in the Pacific Northwest There are thousands of miles of such highway in use throughout the United States with many additional miles being added each year

A crushed rock or gravel type surface when in good condition gives excellent service for both passenger and trucking traffic However, as the volume of traffic reaches one thousand or more cars per day, such a surface quickly develops into what is commonly called "washboards" This phenomenon is also known as rhythmic corrugations, ripples, chatter bumps, etc

The presence of "washboards" in gravel or crushed rock highways has proven to be a serious problem in many ways For one thing, it increases the hazard of driving in that cars cannot be so well controlled over such highways at high speeds The severe treatment endured by the tires and running gear of the car tend to shorten the life of those parts materially. In the case of trucks, a badly washboarded highway tends to limit the maximum possible load which the springs can carry. On account of these problems, the highway maintenance engineers have continuously sought means whereby they could either eliminate or materially diminish the formation of "washboards" in gravel highways Their efforts have been directed primarily toward the treatment of the road surface, and this has been only partly successful. By the use of intensive maintenance such as frequent planing and blading of the gravel surface, they have been able to limit the depth to which "washboards" will form. However, the fact that the road surface is being continuously stirred and pulverized by the maintenance equipment has augmented what has popularly been called the "dust menace" of driving. For these reasons and in the interests of economy it is desirable if possible to learn if there may not be some other way of combating the "washboard" menace than by means of an intensive maintenance program

With this situation in mind, the Engineering Experiment Station of the State College of Washington a number of years ago undertook a study of the cause and prevention of "washboards" in gravel highways. In 1926, a car was equipped with a recording mechanism which recorded on paper the relative motion of a car axle with respect to the body of the same car when traveling over "washboarded" roads Extensive tests were made at different speeds over several different "washboarded" highways Tests were also conducted on perfectly smooth roads on which has been placed a bump or a single depression This made it possible to analyze the entire history of a single road shock. It was soon apparent that in the making of these tests there were other factors besides the bumps on the road surface which were entering into the test record One of these especially was the lurch of the car body from side to side During the summer of 1927, a small laboratory apparatus was developed which embodied the characteristics of a car and on which tests could be made without the introduction of disturbing influences other than those being studied All cars possess the characteristics of sprung and unsprung weight The car body, which is carried on the springs is the "sprung weight" The car axle together with the hubs, brakes, and wheels constitute the "unsprung weight" This "unsprung weight" however, is somewhat cushioned by the air in the tires By means of the above mentioned laboratory apparatus, careful analysis was made of the relative motion of the different parts of a car when subjected to "washboard" shocks at different speeds. The results of these tests were published in Engineering Bulletin No. 19.

In order to verify, the conclusions in the above report, during the following summer of 1928 a test track was built on the State College campus for carrying on further "washboard" tests. This track was built 175 feet in diameter and banked for a normal speed of 20 miles per hour The surface of the track was given a gravel topping according to standard highway specifications except that it was only about five inches thick. A model T Ford touring car, used for the test, was equipped with 3½-inch high pressure tires, at fifty-five pounds air pressure and driven at 20 miles per hour. "Washboards" could be formed on the gravel surface of the test track in 100 trips When equipped with Houdaille hydraulic shock absorbers, the formation of "washboards" was found to be much slower In fact, it was not possible to make satisfactory "washboards" on the test track with this combination When balloon tires were substituted without shock absorbers, it was found impossible to make "washboards" on the test track even though the test was continued until the road was virtually worn out

While the above tests all contributed to the fund of information on the subject of "washboards," it was felt that further tests should be conducted on a straight highway This would more nearly duplicate the conditions which exist on the public highways, and results from such tests would be more readily accepted by engineers and others interested in highway maintenance

OBJECTS OF TESTS

The result of the foregoing tests and experiments would seem to indicate that there is a possibility of solving the "washboard" problem in so far as it can be solved not by attacking it from a maintenance standpoint but by controlling the conditions and characteristics inherent in the car itself If this were possible, then at least part of the present objectionable and expensive method of continuously loosening the road surface would be eliminated A reduction of this maintenance program would save substantial amounts of maintenance money, which could be otherwise devoted to improving the highways With these things in mind, the problem was laid before the State Highway Department of Washington Later, with their cooperation, a stretch of gravel road was chosen and prepared for further tests during the summer of 1929

IDEAL CONDITIONS FOR TESTS

During the long dry summers which are characteristic of eastern and central Washington, road surfaces become more or less thoroughly dried out The dry clay binder which is a part of the gravel and crushed rock highways found in this section loses its cementing value under the force of heavy automobile traffic. The continued impact of automobile tires tends to loosen and move this gravel surface into successive bumps and hollows If this gravel is restored to a smooth surface by means of a drag or grader, an equal amount of traffic will again restore the "washboard" condition For this reason, the dry summer weather of Eastern Washington makes it possible to duplicate conditions and repeat tests with fair uniformity of results.

DESCRIPTION OF TEST ROAD

Out of several sites under consideration, one was chosen which is located about twelve miles southwest of Spokane This road was a part of the original highway between Spokane and Cheney before the new concrete road was built It runs east and west on the east side of the concrete highway and ¼ mile north of Four Lakes, Washington The road is level throughout its length except for a short section which has a grade of from three to five per cent There are two long easy curves The surface appears to be of screened material from a glacial gravel deposit, and it is estimated that 85 per cent of this loose material on the road would pass a ⅜ inch screen The sand is quartz with practically no basalt present During the season of the spring rains, the State Highway department went over this road with a grader and left it perfectly smooth Under the normal light traffic (10 to 15 cars per day), the surface became hard and smooth During the following dry weather, a grader was again used to plane the surface leaving about two inches of loose material on a perfectly smooth hard base

CONDUCTING TESTS

Preliminary to each test, this loose material was brought to the center of the road and spread evenly a little wider than the width of a car The drag used (see Figures 1 and 2) consisted of four angle-irons rigidly welded to cross-bars and dragged behind the car at about sixty degrees angle to the line of travel After going over the road with the drag in one direction, the angle of the drag was reversed on the return trip This tended to eliminate "drag ripples" and left the road surface practically smooth and free of any bumps or depressions See Figures 3 and 4

After a test had been completed, "washboards" would be present at various places on the road. See Figure 5. Owing to the light traffic, the test car was driven forth and back in the same track, thus

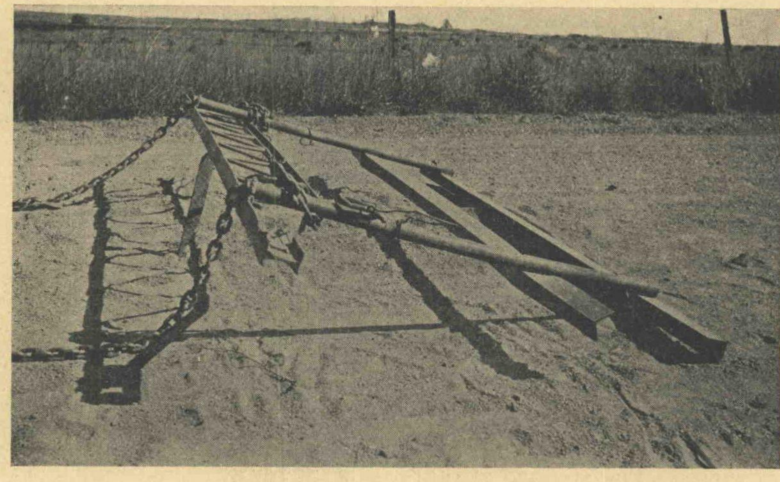

Figure 1. The Road Drag Used to Prepare the Test Road for the "Washboard" Tests, the Drag is Shown Lifted from the Road Surface to Reveal the Four "Edges"

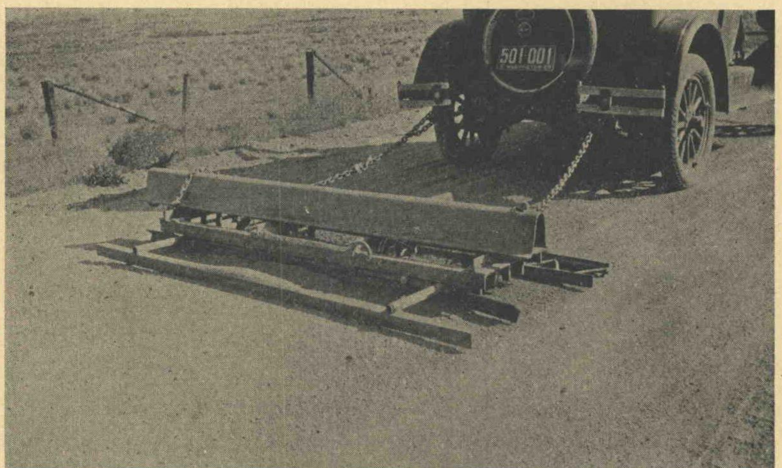

Figure 2. The Road Drag Fully Weighted and Attached Behind Test Car, as Shown, the Blades of the Drag Make an Angle of from 50° to 60° to the Line of Travel

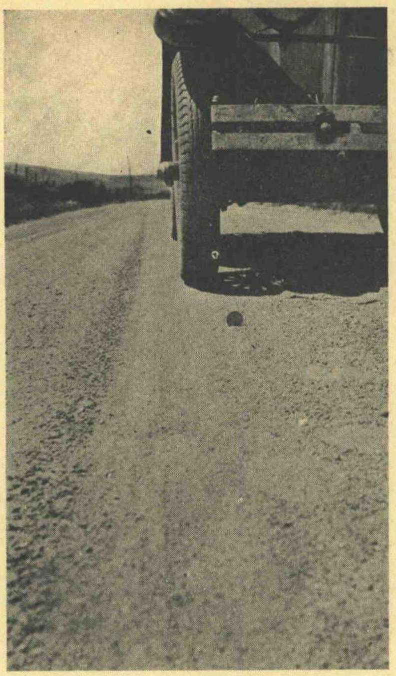

Figure 3. View of Test Road on the 25 M. P. H. Section During Test with Balloon Tires

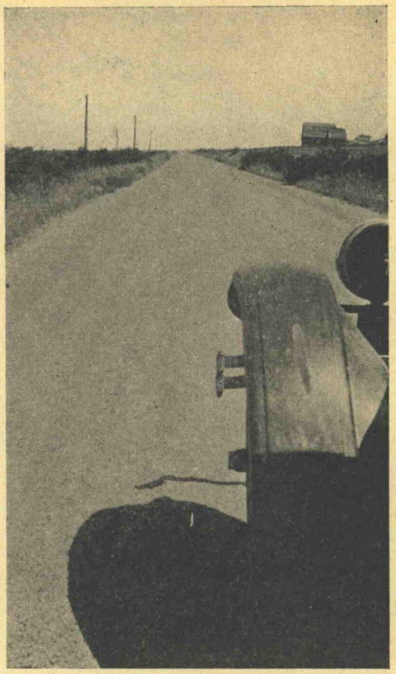

Figure 4. Note the Smooth Surface of Gravel Packed by the Balloon Tires. No Evidence of Washboards Here.

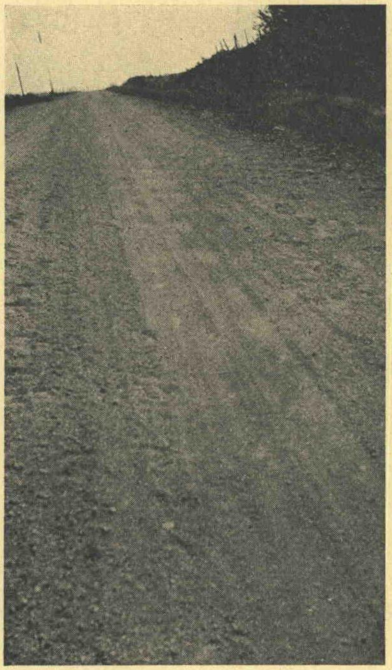

Figure 5. "Washboards" as Developed on the 35 M. P. H. Section, Using High Pressure Tires

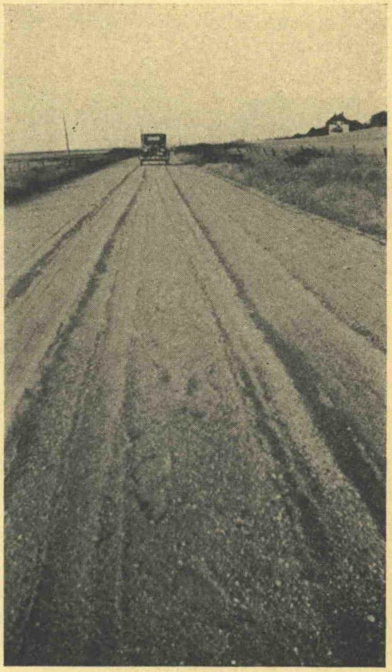

Figure 6. Showing the Progress of the Test in the Loose Gravel on the 40 M. P. H. Section, Using Balloon Tires

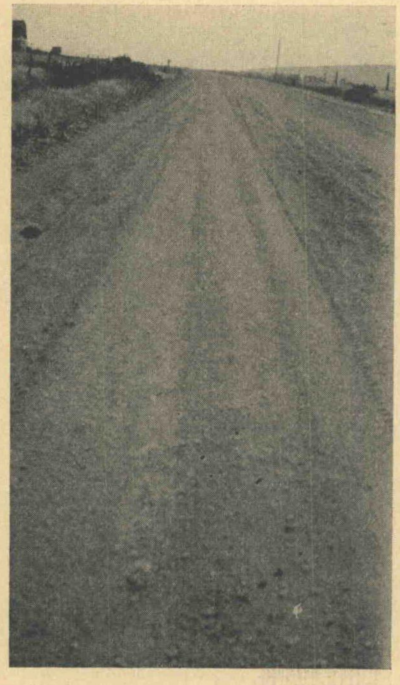

Figure 7. View on the 40 M. P. H. Section Showing the Gravel Smoothed and Compacted by Balloon Tires

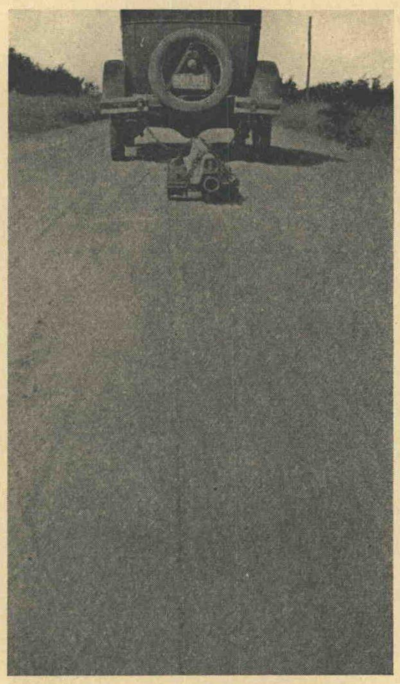

Figure 8. The Weighted Scarifier in Action. Note That It Has Thoroughly Loosened the Compacted Gravel

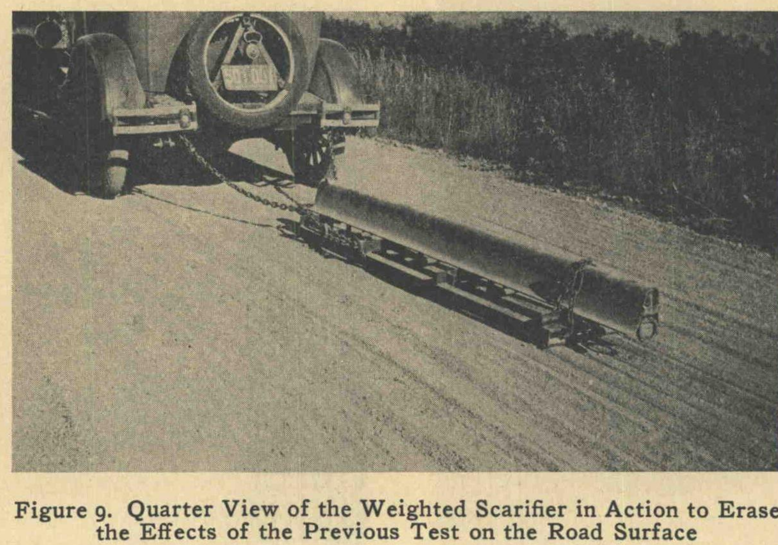

Figure 9. Quarter View of the Weighted Scarifier in Action to Erase the Effects of the Previous Test on the Road Surface

concentrating all the travel on the center of the road. See Figures 6 and 7. In order to thoroughly erase the influences of any previous test, the road was scarified before it was dragged. The scarifier consisted of a steel frame about eighteen inches wide and four feet long. See Figures 8, 9, 10. Four rows of teeth were arranged equi-distant along the length of this frame. Successive rows of teeth were staggered with the preceding rows. While this scarifier was not heavy enough to actually tear up the hard surface of the road, it thoroughly loosened the gravel which the car had packed into "washboard" shape during the previous test. Thus after scarifying and dragging

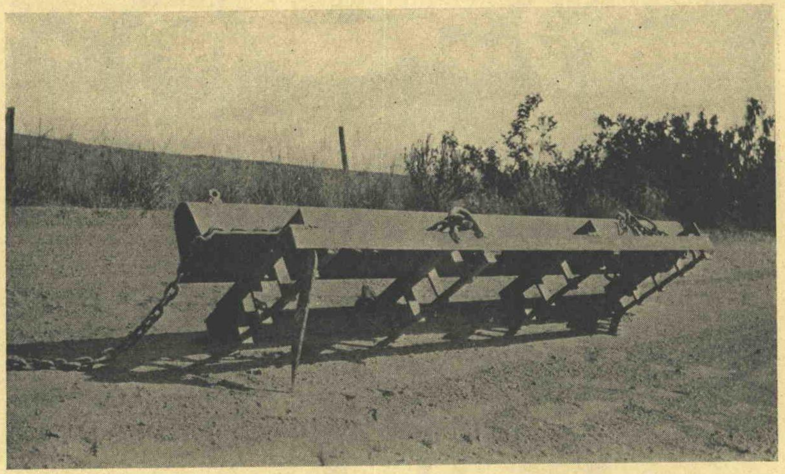

Figure 10. Scarifier Raised from the Road Surface to Show the Four Rows of Teeth. Each Row Is Staggered with the Preceding Row. View Shows Teeth Nearly Worn Out

the surfaces for a new test, it was reasonably certain that the results would not be influenced by what had taken place previously.

DESCRIPTION OF TEST CAR

It was deemed desirable that the car for these tests should be of medium size and weight. The car chosen was a 1927 Chevrolet Coach of 103 inch wheel base and weighing 2620 pounds with driver. Figures 11 and 12. Two sets of wheels were provided. On one set were mounted balloon tires, size 29 by 4.40 inch and operated at 34 pounds air pressure. On the other set of wheels were mounted high pressure tires, size 30 by 3½ inch and operated at 55 pounds air pressure. The car was equipped with a new set of Two-Way hydraulic shock absorbers. Figure 13.

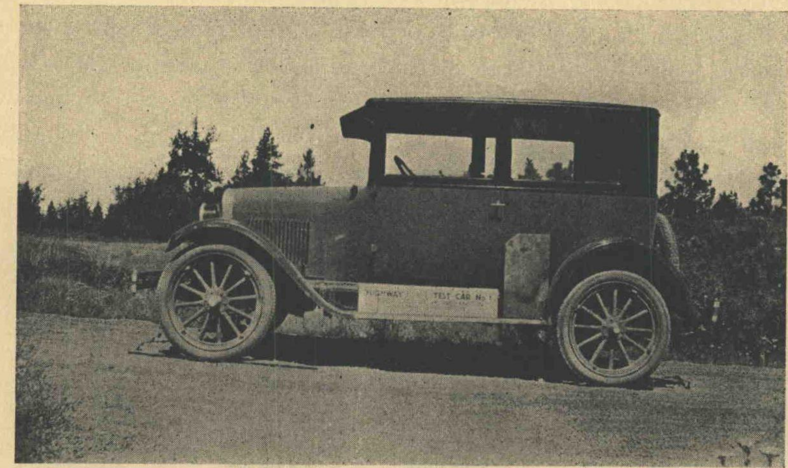

Figure 11. View of Highway Washboard Test Car of the Engineering Experiment Station, Car Is Shown with High Pressure Tires.

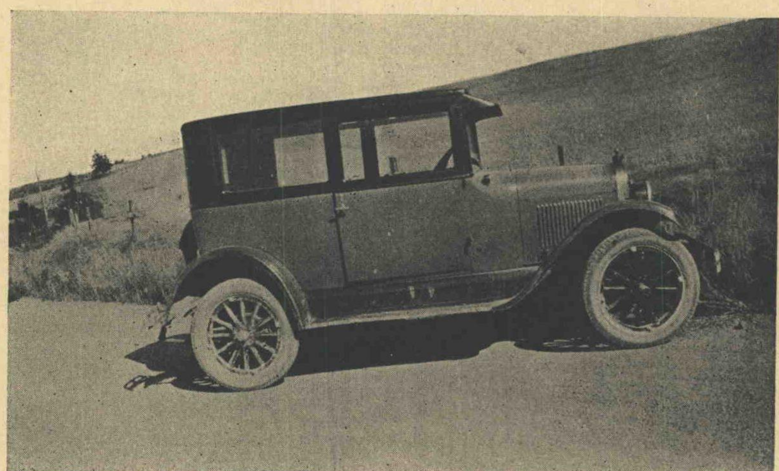

Figure 12. View of Test Car Equipped with Balloon Tires. Separate Wheels Were Provided for the Two Types of Tires

DESCRIPTION OF TESTS

The test road which was 1.4 miles long was divided into five sections On the section at one end of the road a speed of 25 miles per hour was maintained in either direction. On the adjacent section, the speed was raised to, and maintained at, 35 miles per hour On the next section, at 40 miles per hour, on the next section, at 30 miles per hour; and on the other end section, at 25 miles per hour At each end of the track, a short section was reserved for decelerating prior to turning around and for accelerating again to 25 miles per hour. Also between adjacent sections, it was necessary to reserve a short distance for accelerating or decelerating for the speed in the next section. Thus when the test was completed comparative results were shown at four different speeds.

At the beginning of the test, several days were spent in learning how to develop and control the desired conditions For instance, it was found that dragging must be done at a speed not exceeding three to four miles per hour. Otherwise, the drag would jump and chatter leaving a rough surface. It was also found that unless the angle of the drag to the line of travel was reversed each time over the road, a series of drag ripples would result which would seriously influence the results of the tests Repeated tests were made during these first days until it was felt that the conditions were understood and could be controlled and duplicated at will. This made it possible to put the track in the same shape for each successive test Furthermore, it was discovered that the formation of "washboards" as far as comparative tests were concerned need not progress to the extreme conditions found on average gravel highways In other words, a stopping point for the tests was determined upon in which the "washboards" were perhaps not more than $\frac{1}{8}$ of an inch deep, and had not dug into the hard road surface They consisted entirely of the loose gravel placed and packed in more or less uniformly spaced shallow ridges and hollows At this stage of their formation, the "washboards" were plainly visible to a driver in a car, and the distance between successive ridges could readily be marked and measured.

The driver of the test car was constantly on the alert during the progress of the test to observe the first appearance and location of "washboards." Note was made of the time of occurrence and the section of the road on which "washboards" first appeared. As might be predicted, they first appeared on the highest speed section, and were last to appear on the lowest speed section Furthermore, it was observed that the average length of "washboards" varied according to the speed of travel on that section

RESULTS OF TESTS

Table I shows the summarized results of the tests on high and low pressure tires with and without shock absorbers

TABLE I

FORMATION OF WASHBOARDS AS RELATED TO SPEED OF TRAVEL ON TEST TRACK, 1929

Test No	Type tire	Shock absorbers	Trips to make "washboards" 25 M P H	30 M P H	35 M P H	40 M P H
1	High Pressure	No	100	91	36	36
2	High Pressure	No	No results			
3	High Pressure	No	137	79	71	65
6	High Pressure	No	146	76	60	50
5	High Pressure	Yes	No W B at 290	230	153	230
7	High Pressure	Yes	188	188	105	92
9	High Pressure	Yes	No W B at 350	220	126	110
4	Low Pressure	No	No W B up to 360 trips			
8	Low Pressure	Yes	No W B up to 570 trips			

It will be noted that Two-Way hydraulic shock absorbers were used on the 1929 tests These shock absorbers, Figure 13, were installed and used with the original factory adjustment which gives slight resistance to compression and considerable resistance to recoil While tests could have been made with other adjustments of the shock absorbers it was felt that other means could be devised for determining the optimum adjustment without spending the days and weeks necessary to conduct the road tests. In Table II are shown the average lengths of the washboards as measured on the different speed sections of the test track. In Figures 14, 15, 16, and 17 are shown some typical washboards found on other highways during the summer of 1929 They average about 1 inch in depth In Figure 18 are shown the curves giving the information contained in Table I.

CONCLUSIONS

From Table I it will be seen that speed of travel bears a definite relation to the rapidity with which "washboards" are formed by high pressure tires Furthermore, the addition of one type of shock absorber at least has a retarding effect on the formation of "washboards" and would seem to prevent their formation at low speeds It

Figure 13. View Showing Installation of Two-Way Hydraulic Shock Absorbers on the Test Car. The Car Was Equipped with a Set of Four Shock Absorbers

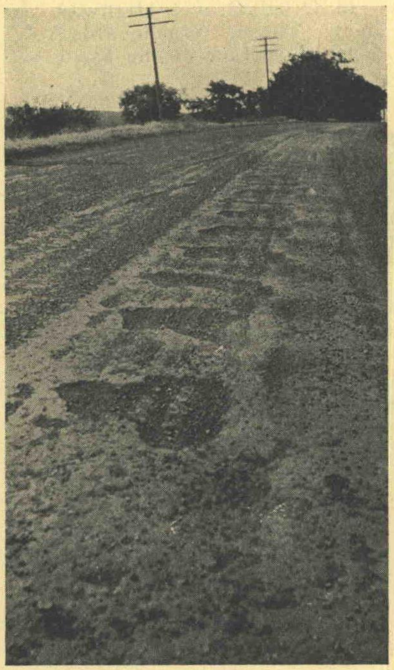

Figure 14. View of "Washboarded" Section of Gravel Highway Which Had Been Treated with Light Oil to Lay the Dust. Surface of Road Was Fairly Smooth and Hard. View Taken about Three Weeks after Application of Oil

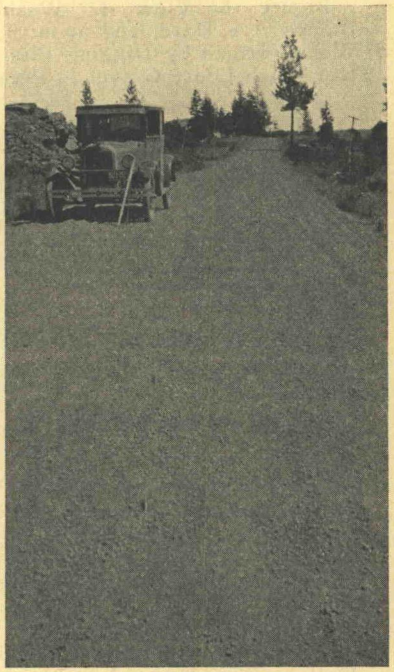

Figure 15. "Washboards" Formed in Dry Loose Gravel. Base Was Hard and Nearly Smooth, with Humps Formed of Fine and Coarse Material More or Less Compacted Into Shape but Still Loose and Easily Moved

Figure 16. View of "Washboards" in Oiled Gravel Highway, Bumps Are Hard, and about 1 Inch Deep. These "Washboards" Were Formed by Digging Pits Into the Hard Surface of the Road. Not Much Loose Gravel Is Present

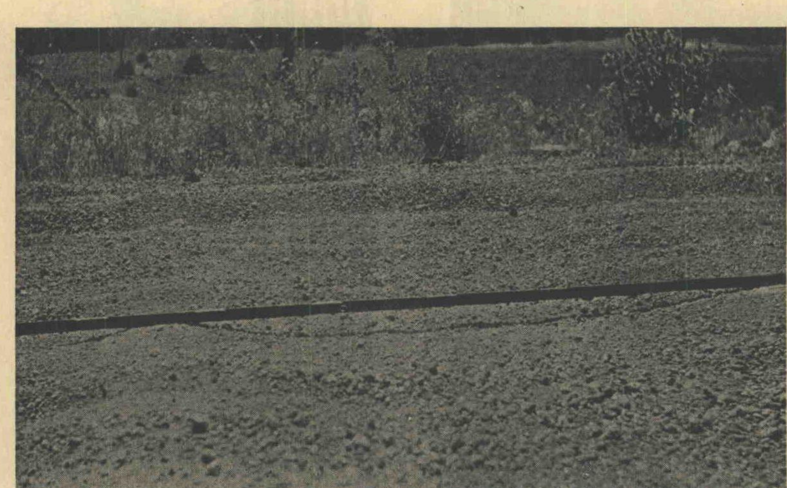

Figure 17. "Washboards" in Dry Loose Gravel. The Bumps Are of Loose Material Which Can Be Scuffed Away with the Foot. The Hollows Are about 1 Inch Deep

will be noted that in these tests, balloon tires did not make " washboards " even after prolonged operation on the test track. Whether or not, balloon tires would promote or retard their formation on an already, deeply " washboarded " highway is a question yet to be answered. Likewise, the comparative effectiveness of different types of snubbers and shock absorbers is still to be determined.

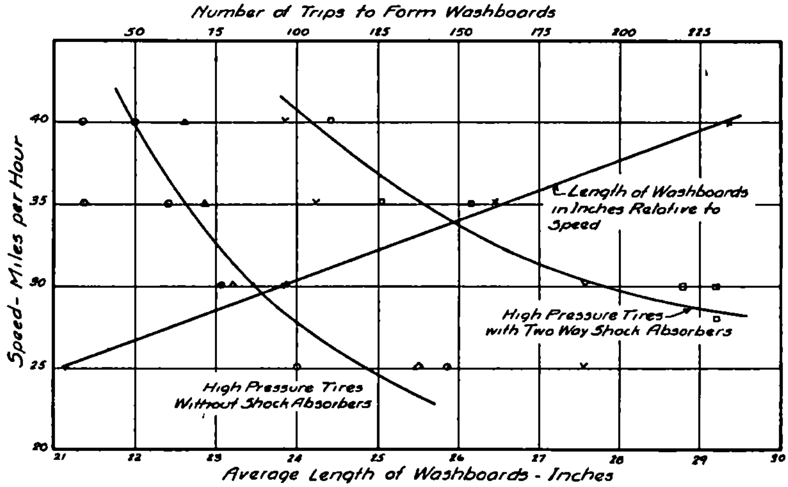

Figure 18 Formation of Washboards as Related to Speed. Chevrolet Coach with 30 x 3.5 Inch Tires at 55 Pounds Pressure and 29 x 4 4 Inch Tires at 34 Pounds Pressure No Washboards Could Be Made with Low Pressure Tires Either with or without Shock Absorbers in 360 and 570 Trips

From Table II it will be noted that the average length of " wash-

TABLE II

CHARACTERISTICS OF WASHBOARDS MADE ON TEST TRACK, 1929

Speed M P H	Average length of W B in inches	Number W B passed per sec
25	21 14	20 8
30	23 83	22 1
35	26 47	23 3
40	29 32	24 0

boards " in the different speed sections varies somewhat according to the speed of travel of the car used in the tests. If the movement of the wheels and axles had corresponded with the free movement of a weighted spring, then the third column would have shown one constant value as the rate of vibration regardless of speed of travel of the car The actual vibrations as computed from the average length of the " washboards " and the speed at which they were formed gives values ranging from 20 8 to 24 0 vibrations per second This indicates that the speed of travel of the car introduces certain factors which cause the wheels and axles to vibrate at a rate other than their "natural period"

While the percentage of high pressure tires on passenger cars has greatly diminished and is at present very small, the percentage of trucks on the highways is constantly increasing Truck tires are, at present, essentially of the high pressure type, although a very few trucks are using what is known as the truck type balloon It is hoped that subsequent tests in the laboratory and on the highway will yield definite information as to how much the behavior of the car or truck wheel can be controlled with reference to its propensity for making "washboards" We are encouraged to believe that some type of snubber or shock absorber applied to the high pressure type of tires will not only contribute to the easier riding quality of the vehicle thus equipped but will serve to greatly diminish the expense of surface maintenance Such an accomplishment would point the way to a possible saving in maintenance money in the State of Washington alone of thousands of dollars per year

STUDY OF TEST CAR

In order to more correctly interpret the results of the tests described, an intensive study was made of the behavior of the test car itself

In the car was mounted a rotating cylinder, geared to the speedometer drive, and carrying a blank paper record. Two pencils were arranged to record on the rotating cylinder, the relative motion between the front and rear axles and the car body. Motion was conveyed to these pencils by means of steel piano wire run over pulleys and attached as near as possible to the right hand wheels The wire was attached to the pivot pin on the right front axle and to the brake housing on the right rear axle, both points of attachment being about the same distance from the plane of the tire.

With the above equipment, the test car was driven over a relatively smooth and hard gravel highway, at one point of which had been placed a rounded artificial bump 6 inches wide and 1½ inches high. This was placed in the path of the right hand wheels only Records were made of the relative motion of the axles with respect to the car body at 20, 25, 30, 35 and 40 miles per hour, using high pressure tires, and low pressure tires, both with and without two-way hydraulic shock absorbers. These records are shown in Figures 19, 20, 21 and 22.

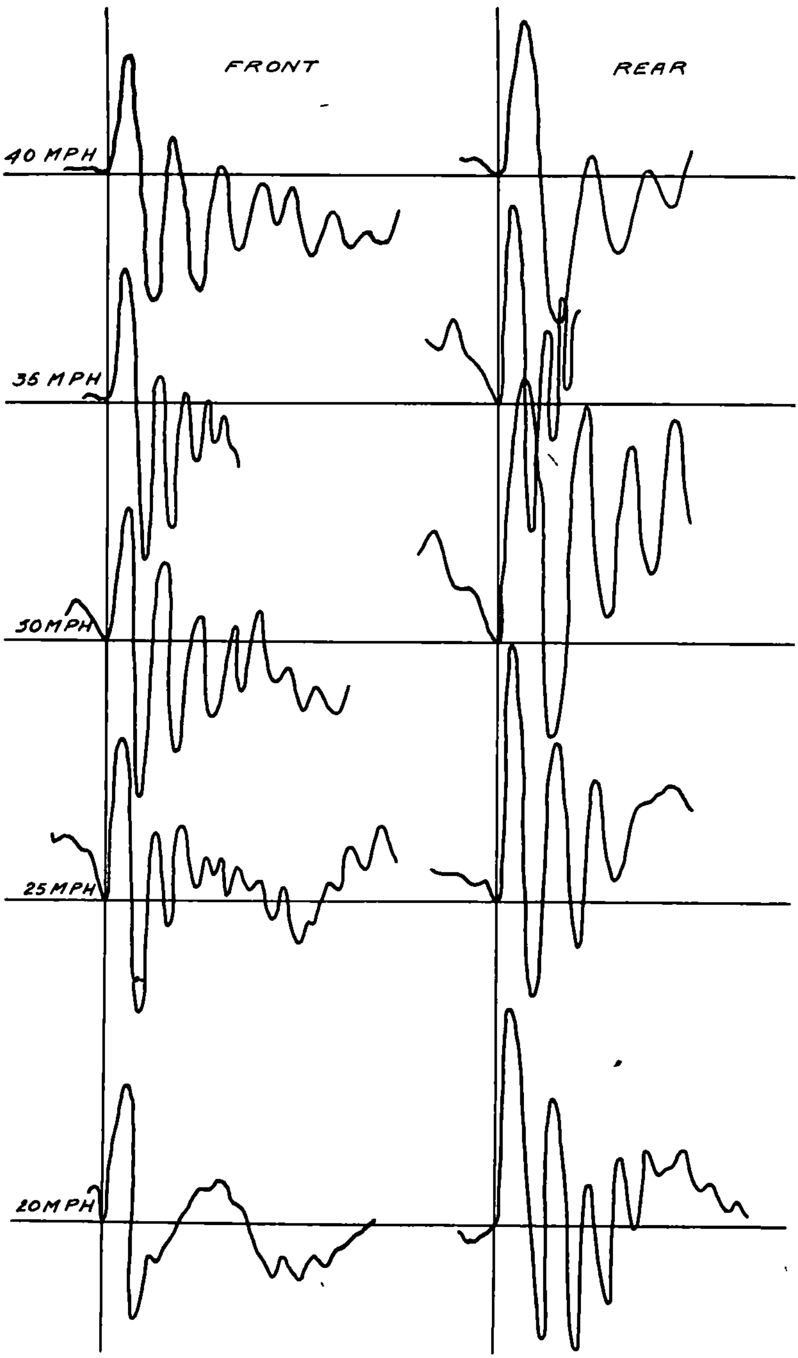

Figure 19 High Pressure Tires—No Shock Absorbers

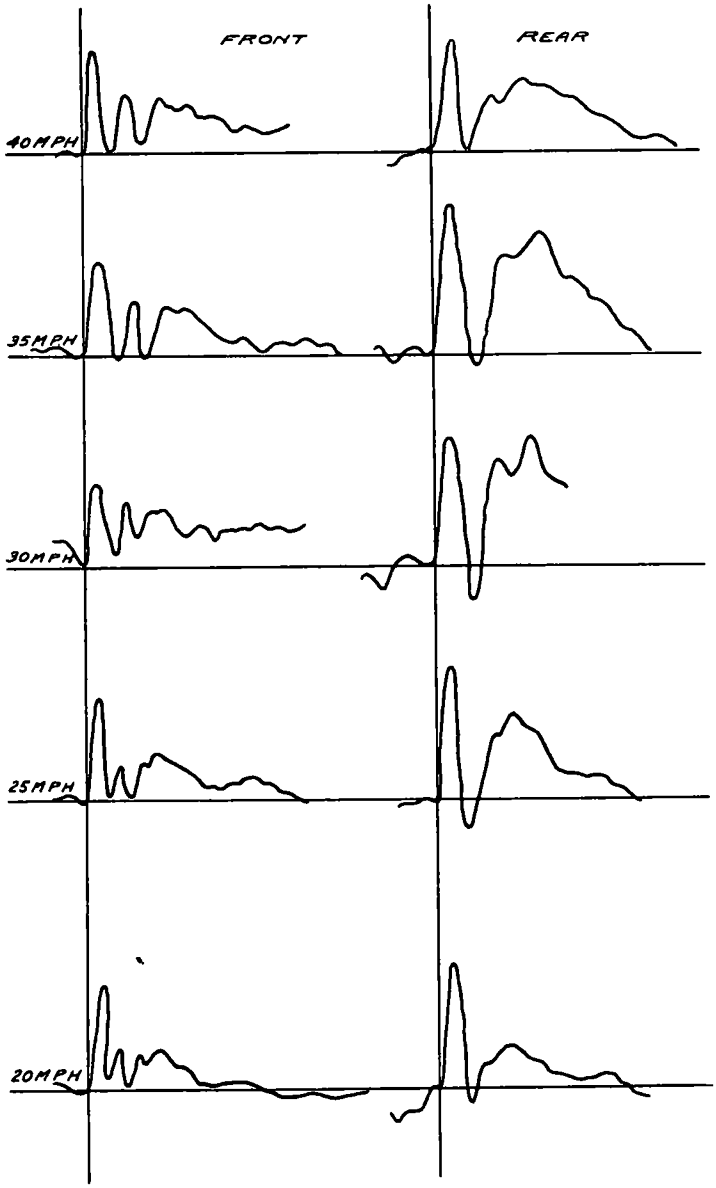

Figure 20. High Pressure Tires—Shock Absorbers

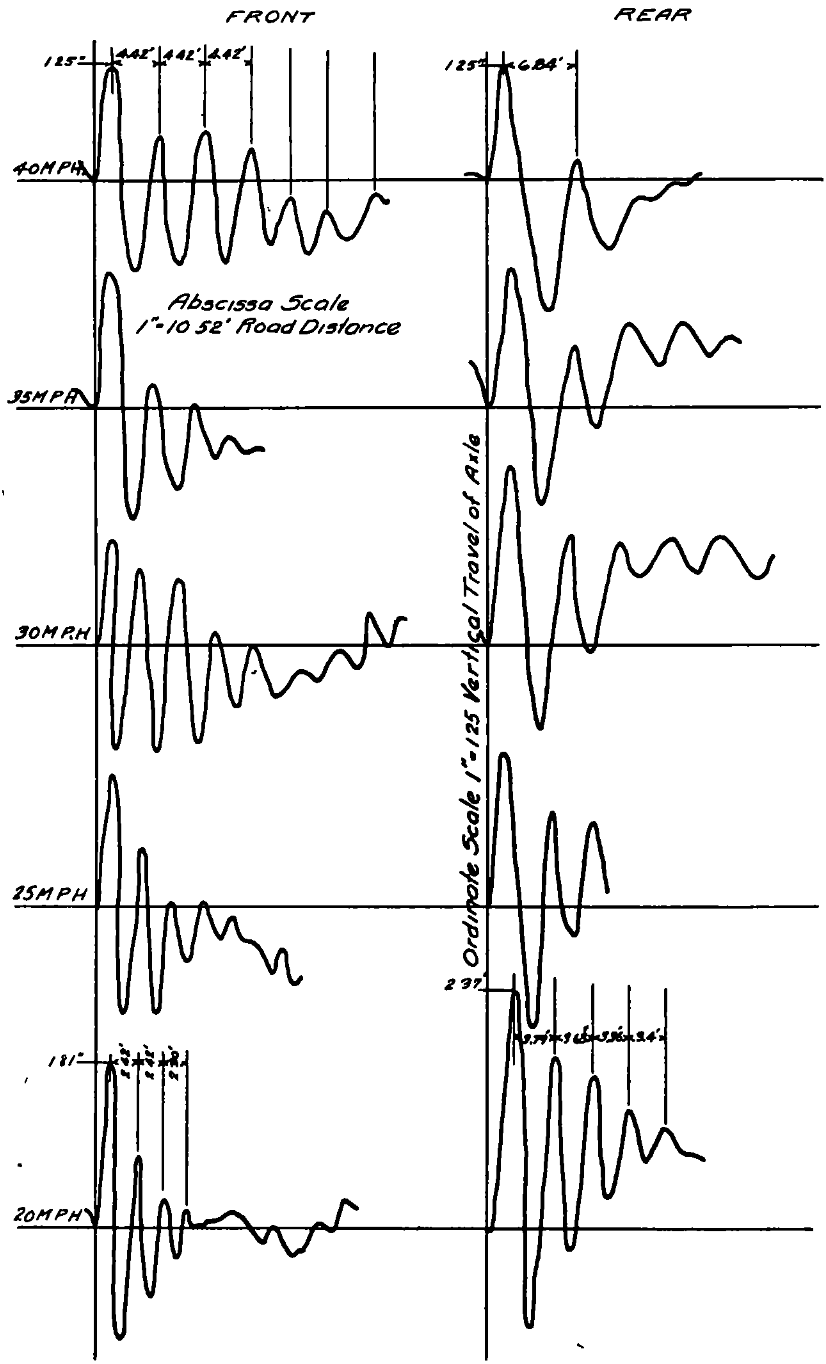

Figure 21. Balloon Tires—No Shock Absorbers

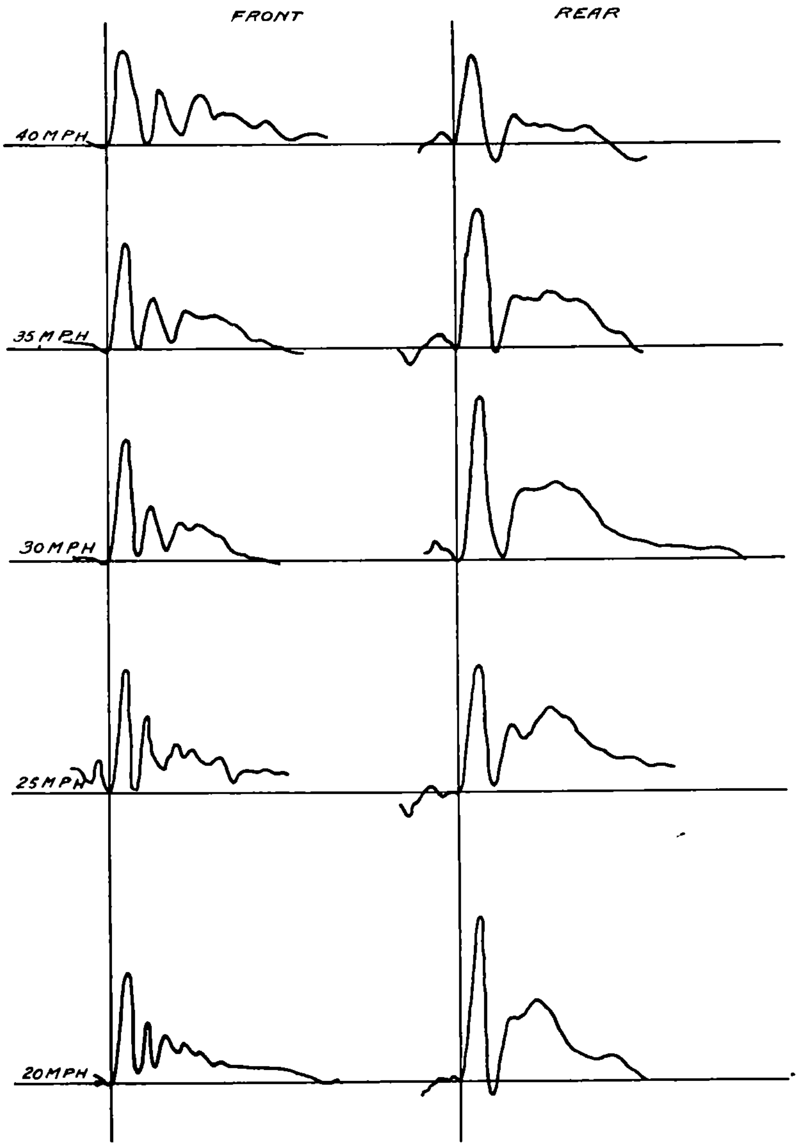

Figure 22 Balloon Tires—Shock Absorbers

ANALYSIS OF RECORDS

A general inspection of these records reveals that the use of shock absorbers either with high pressure tires or with balloon tires not only quickly damps out the axle vibrations but also reduces their amplitude of vibration This means that the tire itself probably takes more of the shock due to the fact that the retarded recoil of the springs by the snubber action of the shock absorbers causes the car body to ride "lower" with reference to its axles on "washboarded" roads This undoubtedly is one of the things which influence the increasing of the rate of vibration of the axles with an increase of speed of the car, as indicated in Table II

The records also show that the rate of vibration is higher for the front axle than for the rear axle. For instance, in Figure 21, at 40 M P H the rate of vibration beginning with the first recoil is calculated to be 13 25 per second for the front axle and 3 57 per second for the rear axle The amplitude with respect to the car body of the first vibration of the axle upward after striking the obstruction is 1.25 inches front and 1 25 inches rear at 40 M P H This amplitude increases with decrease of speed showing that the tire probably absorbs more of the road shock at high speeds

Also, from Figure 21, at 20 M P H the rate of vibration is 12 2 per second for the front axle and approximately 7 9 per second for the rear. The amplitude with respect to the car body of the first vibration of the axle upward after striking the obstruction is 1 81 inches front and 2 57 inches rear at 20 M P H

From the above it will be noted that the apparent distance between impacts of the tire on the road surface after striking the single obstruction exceeds the average length shown for corresponding speeds in Table II

In this connection, consider in Figure 23, the action of the axles of the test car traveling at 20 M P H. over a "washboarded" highway where the average length of the "washboards" is found by measurement to be 23 9 inches. Neither the front axle nor the rear axle are oscillating in step with the "washboards" being traveled over, although both are not far from synchronism. Where the car is traveling at 30 M. P H. (Figure 23) the front axle is shown to be oscillating practically in synchronism with the "washboards" and the curve is remarkably regular. On the other hand, the rear axle is oscillating more or less independently of the "washboards" and at a slower rate.

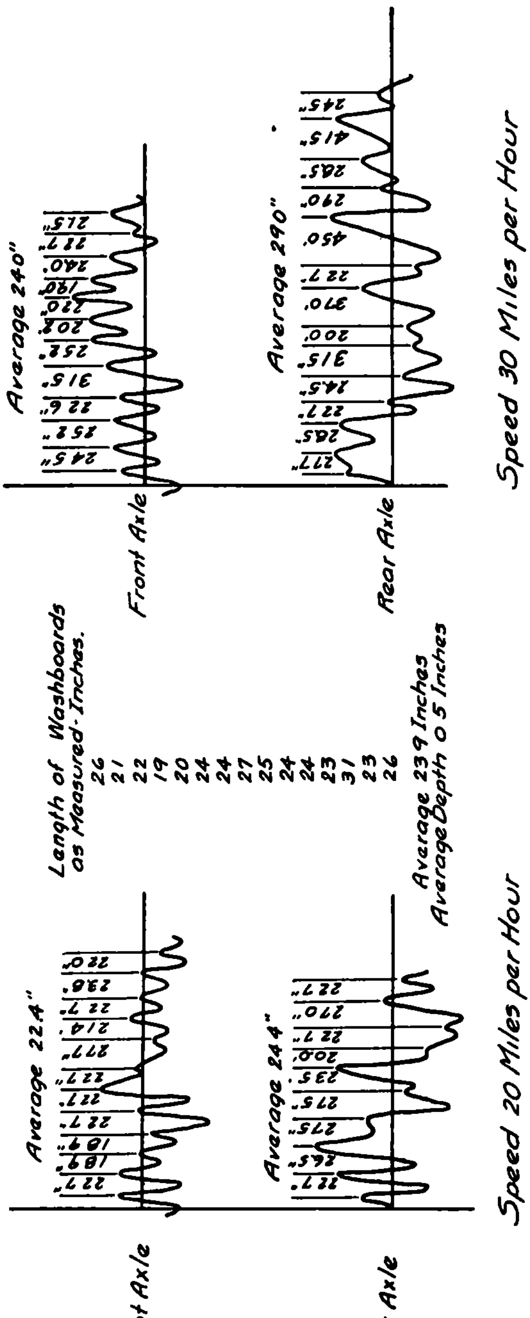

Figure 23. Test Car Driven Over a "Washboarded" Road at Two Speeds. High Pressure Tires with Shock Absorbers. Not on Test Track

When the axle vibration does correspond with a "washboard," then the reaction is indicated by a peak in the curve higher than the average.

From the information secured thus far, it would appear that the average length of the "washboards," formed on each section of the test track as shown in Table II, must represent a compromise between, or a combination of, the separate forces exerted on the road surface by the two vibrating axles of the car, and therefore does not correspond to the natural period of either. This indicates that further study is necessary in order to fully understand the relation between cause and effect

OUTLINE OF FURTHER STUDIES

The data thus far secured seem to indicate that there are a number of questions relative to the prevention of "washboards" which are yet to be answered For instance, will balloon tires driven over a badly "washboarded" highway tend to build up or tear down the existing "washboards?" Will the addition of shock absorbers to a balloon tire equipped car change the answer to the above question?

The results of previous tests indicate that high pressure tires are far more distructive of gravel road surfaces then are balloon tires Since high pressure tires on passenger cars are fast disappearing, our attention is necessarily directed toward high pressure tires on trucks This type of traffic is rapidly increasing both in weight and numbers Much of the stage traffic would be classed with trucks as regards the high pressure tires. The question is, what is the relative effect of this type of traffic upon the highways considering the load per square inch tire contact with the road surface and the customary speed of travel?

In the light of the tests just concluded, at least one particular type of shock absorber (when applied to a passenger car) serves to delay the formation of "washboards" on gravel highways.

The question is, what type of shock absorber is most efficient in the prevention of "washboards"? Furthermore, to what extent can the formation of "washboards" be controlled by the application of such shock absorbers to trucks and stages equipped with high pressure tires? And again, is it possible that a more efficient type of shock absorber can be developed which will not only give riding comfort, but will be more effective in the prevention of "washboards"?

These and other kindred questions have presented themselves in the course of this investigation and the Engineering Experiment Station proposes a continued study of this problem which will ultimately embrace all of the questions mentioned above. This will involve an intensive laboratory study of the inherent characteristics of different cars, to be followed by extensive tests on certain standard gravel highway surfaces As rapidly as time and finances will permit it is proposed to carry this problem to completion