shrinkage, (b) nullifying the beneficial effect of cement, (c) slow setting and (d) unstable support is reason for the above statement.

In future work, black top soil available for use in a given area, will be inspected and, if necessary, analyzed in the laboratory to insure the use of a material having satisfactory workability as well as textural characteristics. Mixing of two or more materials will be resorted to if necessary. An attempt will be made to hold the organic content between 3 and 6 per cent and sand content as high as 70 to 80 per cent in case of material used in the air type machine Likewise, as coarse a soil as possible containing sufficient fine material and organic matter to give workability and that will produce a minimum of wear upon the pump will be used in the piston type machine

THE DANA AUTOMATIC RECORDING ROUGHOMETER FOR MEASURING HIGHWAY ROUGHNESS

By Homer J Dana, *Assistant Director*

Engineering Experiment Station, State College of Washington

SYNOPSIS

Description of an instrument devised at the Engineering Experiment Station, State College of Washington The essential features are (1) The record paper runs five inches per mile with a faster speed of three inches per one hundred feet available for special roughness study, (2) A pencil operated through a pantograph system connected to a front wheel gives a continuous visible picture of the roughness of the road surface, (3) An automatic stamping device prints the mileage on the record every half mile or oftener as required, (4) The same stamping device prints the integrated roughness along with the mileage

During the past nine years, the Engineering Experiment Station of the State College of Washington has carried forward continuously certain studies in the field of Highway Research

The first was a determination of the relative tire wear on various kinds of highway surfaces Tire wear was measured on smooth and on rough surfaces and the excess wear on the latter was determined [1]

The second study was an outgrowth of the first Rough roads were observed frequently to be washboarded, and therefore an attempt was made to determine the cause and to discover the possible control, of washboards [2]

[1] Fifth Annual Proceedings, Highway Research Board, p 30 Bulletins 16, 17, 18, Eng Exp Sta State College of Washington

[2] Ninth Annual Proceedings, Highway Research Board, p 186 Bulletin 31, Eng Exp Sta State College of Washington

The third study was, again, a natural outgrowth of the preceding work. Even casual observation shows that a good road is relatively smooth and a poor road is usually rough. Elimination of roughness,

Figure 1. The Dana Automatic Recording Roughometer

then, is of primary concern. Therefore, in accord with the premise that "One can best master a problem only when one can measure it," work was directed toward measuring highway roughness.

A successful highway roughness meter, or roughometer, would need to meet three requirements:

1 It must be rapidly and easily manipulated, preferably requiring only one man to operate it Since car reactions were the ultimate interest, such a measuring instrument would logically be attached to a car.
2 It must provide a permanent record of the roughness curve, and of the integrated roughness, and should include distance intervals plainly indicated
3 It must be as nearly automatic as possible, requiring only the minimum of attention from the operator, thus eliminating possibility of personal error

A survey of present equipment in use showed nothing that would meet these requirements The roughometers being used by the U S Bureau of Public Roads and by some of the state highway departments, such as Oregon and California, consist of an indicating roughness meter, and a separate odometer Readings are taken at desired intervals and recorded by an observer

Therefore, no recording roughometer being available, one was designed and built by the Engineering Experiment Station of the State College of Washington Following is a description of the various features of this instrument·

The *Dana Automatic Roughometer* was built to use a standard plain record paper $6\frac{9}{16}$ inches wide, such as can be bought from Remington Rand supply stores If desired, a semi-translucent paper for blue printing can be prepared by cutting a roll of profile paper to the desired width This also has the advantage that the cross section lines furnish a scale right on the record The top of the roughometer is $6\frac{5}{8}$ inches wide by approximately 10 inches long, forming a table over which the record paper moves At one end is located the curve drawing pencil and the stamping mechanism, and the paper travels under these first before crossing the table This exposes to view about eight inches of completed record on which notations can be made by the operator, of landmarks, speed of test, character of road surface, etc The record drive mechanism is linked to the speedometer drive through a variable gear train, thus providing several record scales per mile These range from one to five inches per mile A special high-speed drive can be thrown into gear instantly at will by the operator This provides a record scale of 3 inches per 100 feet, but it is expected to change this to 2 inches per 100 feet, in order to afford an even multiple of the inch for easy reference in scaling the record An automatic reel rewinds the finished record as it leaves the instrument

The record pencil is linked through a pantograph system to the hub of the right front wheel The resulting curve is a picture of the movement of this wheel only, with respect to the car body This method of attachment to the hub reduces the influence of the other front wheel to a minimum. Differences of opinion exists as to which wheel should

make the record—the right wheel is apt to encounter loose material at the edge of the road, and edge breaks, while the left wheel would record the smoother center of the road

The recording pencil employs the feeding mechanism of an Eversharp pencil which permits the use of any grade lead desired Occasional attention is required to screw down the lead Provision is made for adjusting the weight of the pencil against the record, and even for lifting it from the record entirely

The pantograph ratio controlling the pencil is made adjustable so that the roughness curve of a smooth road can be amplified more than is desirable on a rough road. This adjustment, however, does not affect the integrated total roughness as it is stamped on the record

The same gear train, through which the speedometer drive is linked to the record, is extended to drive the stamping odometer This odometer advances by increments of one-tenth mile, but it is expected to increase this to one-hundredth mile This will provide more accurate rating of short sections of highway. The drive to the odometer is also linked through a dog and ratchet to lift the stamps and drop them automatically for stamping Stamping can also be done by hand at any time such as when entering and when leaving a test section of highway

A second number stamp is linked to the axle through an integrator which adds up the vertical travel of the axle with respect to the car body This gives a measure of the roughness of the road surface The total integrated roughness is stamped simultaneously with the mileage every half mile

CONCLUSIONS

We do not claim that our idea of a roughometer is new, but we do claim originality in the feature of the automatic recording of the mileage and of the accumulated roughness along with the roughness curve

We furthermore point out the advantage of a permanent record, easily and quickly obtained, and which can be filed for future reference and for comparison with subsequent records to show the effect of age, of frost, and of traffic, on a given surface

DISCUSSION

ON

THE DANA AUTOMATIC RECORDING ROUGHOMETER

MR L W. TELLER, *U. S. Bureau of Public Roads* This paper is of particular interest to me because of the study which we, in the Bureau of Public Roads, have been giving to the question of determining the relative roughness of road surfaces for the past seven or eight years

Mr. Dana has set up certain criteria which he believes any instrument or device must be able to meet if it is to be successful for "measuring

highway roughness" and states that up to the time the instrument, which has just been described, was designed there was no instrument which would meet the requirements which he has listed in his paper I should like to discuss briefly our experience with this problem particularly with respect to these requirements

With the first of these there can be no argument

The thought of using the deflection of a vehicle spring as a measure of road roughness dates back many years and is the basis for the design of such instruments as the Vialog by the New York State Highway Department and the relative roughness indicator by the Bureau of Public Roads It seems like a fundamentally sound idea but there is one trouble with it The car becomes an essential part of the instrument The result is that all of the individual characteristics of the particular vehicle to which the measuring instrument is attached become characteristics of the road roughness measuring device Such vehicle factors as tire size, tire inflation pressure, spring condition, spring lubrication, shackle action, shock absorber characteristics, speed, load, etc , affect the magnitude of the spring deflections obtained with a particular vehicle and road When two vehicles are used the problem is further complicated and the intercomparison of the data obtained with them is impossible without frequent cross-calibration of the two units With due attention to all of the factors, such as those mentioned, and with a device which will accurately record the spring deflections in some readily usable form, it is possible to consistently arrive at the same result for a given road surface within reasonably close limits With two vehicles so equipped, while the magnitude of the deflection obtained with one over a given road may be quite different from that obtained with the other, a group of surfaces of different degrees of roughness will be arranged in the same order by either Thus it appears to us that an instrument which makes use of the vehicle on which it is mounted has one vital defect which limits its usefulness With due care and one unit good relative data may be obtained but these data can be compared with those obtained with another vehicle only when the two units have been driven together over a large number of road surfaces of varying degrees of roughness and a relation definitely established One solution of this difficulty which seems to present possibilities is the use of a special vehicle capable of standardization in all of its parts The Bureau has been making some study of this possibility but as yet the result can not be predicted The problem is involved and presents many difficulties

To us in the Bureau who have worked on this problem, it has never seemed necessary or even desirable to have a graphic record of the spring deflections If the horizontal scale of such a record is small the individual spring deflections are lost in the overlapping of lines while, with a large horizontal scale, the records become very bulky and in either case the interpretation of such a graph is tedious and difficult. The Vialog,

previously mentioned, had this feature but in the relative roughness indicator this type of recording mechanism was purposely avoided in order to give a small, simple device which would give directly in inches per mile the spring deflection of the vehicle These data are easily recorded and readily compared with those obtained in other tests The Bureau has recently built a counter which gives the number of spring deflections which exceed certain magnitudes and this device is being studied in conjunction with the relative roughness indicator

The fourth requirement listed, that the instrument must be as nearly automatic as possible, is certainly desirable However, an operator or observer is necessary for the operation of any such instrument and so long as he does not have too much mechanism to adjust and keep in operation, he will have ample time to take such notes as may be required in the normal operation of an instrument of the type of the relative roughness indicator

There is another matter which is not mentioned by Mr Dana but with which he is doubtless familiar If the recording mechanism (of whatever type) is to accurately record a reversing motion such as spring deflection, lost motion must be eliminated from the system and the fewer the number of gear teeth, levers, links and other mechanical features needed to produce the result the nearer this can be attained On the smoother pavements of today and particularly with vehicles equipped with low pressure tires the spring movements are small and lost motion in the recording mechanism may introduce a serious error

The principal weakness in all of these devices at the present time, as I see it, is that they must be used in conjunction with a vehicle which is quite incapable of being standardized For this reason no specification for surface smoothness can make use of them nor can an engineer in one state compare his data with those of another in some other state They have their uses and when used with a full knowledge of their limitations, data of real value can be obtained with them They do not measure highway roughness, they indicate the relative roughness of roadway surfaces

MR GEORGE E MARTIN, *Consulting Engineer of The Barrett Co* I think there is a very important point in the last sentence of Mr Teller's discussion These instruments indicate relative roughness of road surfaces That is especially true of the relative roughness indicator or roughometer That instrument can be run over two surface treated roads, for example—one in which a small size cover is used, and another in which a large size cover is used, and widely varying readings of the roughness will be obtained, whereas so far as riding quality is concerned, one road is just as smooth as the other The instrument measures surface texture or surface roughness in addition to the roughness of the road Only the latter quality is of importance to the person riding in the vehicle.

MR. C B BRYANT, *Materials Engineer, Maryland State Roads Commission* The State Roads Commission of Maryland has been using a roughometer of the type designed by the Bureau of Public Roads for several years, and has observed the various difficulties, particularly those noted by Mr Teller In the discussion this morning of these instruments, there is apparent the effort to develop a perfect instrument and it is the implication that until such perfection is reached, such instruments have little value I am afraid that some engineers, who are not acquainted with roughometers or other instruments doing the same work, may lose sight of their value, even in their imperfect condition Regardless of whether or not the instruments are theoretically correct, they unquestionably give comparative information as to road roughness and this, is being used to develop a spirit of competition between contractors and highway department engineers and inspectors, which will result in better riding qualities of completed roads In Maryland, we get out an occasional bulletin to all of the men in our employ and also to all contractors, giving the results of various projects A keen competitive spirit has been aroused in this way, and our figures show that the riding qualities of our new construction have been markedly improved during the several years that this scheme has been followed