Fig. 1.—Dorry Hardness Machine.

Fig. 2.—Details of Dorry Hardness Machine.

The Physical Testing of Rock for Road Building—I*

The Methods Used and the Results Obtained

By Albert T. Goldbeck and Frank H. Jackson, Jr.

THE study of the physical and chemical properties of road materials by means of laboratory tests has been carried on in a more or less desultory fashion for over 30 years. Quite recently, however, the development of more systematic and greatly improved methods for testing, with a consequent augmented accumulation of data, has given the results obtained a much more practical significance than formerly.

the establishment of laboratories in many technical institutions, both in this country and abroad, as well as in the various State highway commissions.

agency of laboratory tests on the relative worth of the materials which he proposes to use in road construction, and it is the object of this bulletin to describe these tests as now practiced and to interpret their results.

AGENCIES DESTRUCTIVE OF ROADS.

The surface of a road is subject to deterioration due to the effects of (a) mechanical, (b) chemical, and (c) physical agencies whose disintegrating action may be more or less combated by proper construction and maintenance with carefully selected materials. The individual stones in a macadam road are bound together by finer particles and rock powder, and the ideal condition is that in which there is always just enough dust existing to cement these stones together tightly.

(a) *Mechanical Agencies.*—The action of traffic on a road surface is purely mechanical. The severe impact of horses' feet tends to disturb the individual stones by loosening the binding material. At the same

Fig. 3.—Page Impact Testing Machine.

In December, 1900, the United States Government, because of the growing importance of the problem of testing road materials, established a laboratory in the Bureau of Chemistry of the Department of Agriculture, under the direction of Mr. Page. This laboratory was transferred in 1905 to the Office of Public Roads, where its present organization was developed.

The present general interest in the necessity for good road construction has resulted, quite recently, in

* Office of Public Roads, Bulletin 44.

Fig. 4.—Details of Page Impact Testing Machine.

The fact that a large number of samples are submitted for investigation and reported on annually by these laboratories is good evidence of the value of the information received by the road engineer through the

Fig. 5.—Method of Drilling Core from Rock Sample With Diamond Core Drill.

time the stones are subjected to an abrasive action which grinds away their surfaces. The fine material thus created is partly carried away by the wind and partly washed away by the rain, while part is retained

Fig. 6.—Details of Core Drill.

on the road under favorable conditions to form new cementing or binding material. Should there be more fine material formed by abrasion than is carried away by the wind and rain, the road becomes dusty and muddy; whereas if too little fine material is formed to cement the particles of rock together, the road disintegrates because of raveling.

Automobile traffic exerts a severe shearing action on the road surface which loosens the individual stones, but fails to supply, by abrasion, enough additional fine material to compensate for that lost in the clouds of dust raised by this class of traffic. As a consequence, plain macadam construction raveling when subjected to considerable fast moving automobile traffic.

(b) *Chemical Agencies.*—Since all rain and surface water contains carbonic acid in amount sufficient to dissolve carbonates of lime and iron, there is some disintegration from this source. The humus acid derived from animal and vegetable decay likewise renders soluble certain of the rock-forming materials containing magnesia, potash, soda, lime, iron, and silica. However, investigations have shown the deterioration of road surfaces from this source to be negligible.

(c) *Physical Agencies.*—Although it is probable that rock used in road making is very little affected by the action of frost, the action of repeated freezing and thawing on the body of the road is considerable. This is particularly true in the event of poor drainage, because the absorptive power of the roadbed is in general quite high, even though the absorption of the rocks used is low. The materials loosened up by the heaving action of the frost are carried away, to the detriment of the road, by the mechanical action of wind and rain.

NECESSARY PHYSICAL AND MECHANICAL QUALITIES OF ROAD MATERIALS.

The action of mechanical agents is by far more severe in causing the destruction of a road than either chemical or physical agents, and the ability of a rock to withstand mechanical destruction is of great influence in judging its value as a road-making material.

A road-building rock must have three very essential characteristics, i. e., it must be (a) hard and (b) tough, and (c) it must have good cementing or binding power.

(a) By the hardness of a road material is meant its ability to resist the abrasive action of traffic in causing displacement of the surface particles by friction.

(b) The toughness of a rock is a measure of its ability to resist rupture due to the impact of traffic.

(c) The cementing or binding power of a rock determines how firmly the individual stones will be cemented together by the rock powder formed through the action of traffic.

PHYSICAL TESTS OF ROAD MATERIALS.

To determine the above three characteristics essential for a good road material, as well as to investigate other minor physical features, the following tests are made at this office: (1) Hardness; (2) toughness; (3) resistance to wear; (4) cementing value; (5) specific gravity; and (6) absorption.

¹ Logan Waller Page in Report of Mass. Highway Commission, 1900.

HARDNESS TEST.

The test for the hardness of rock, i. e., the resistance of its surface particles to displacement by abrasion, as determined in the Dorry machine, was developed in the French School of Bridges and Roads, and is used with slight modifications at the present day.

Dorry Machine.

The Dorry machine (see Figs. 1 and 2) consists of a circular steel disk *A*, revolving in a horizontal plane about the vertical shaft *B*, which is driven from the pulley *C* by means of the bevel gear *D*. The cylindrical rock core *E*, 25 millimeters in diameter, is cut from a specimen of rock with a diamond core drill, and the test piece is held perpendicularly against a revolving cast-steel disk under a constant pressure of 1,250 grammes, while standard quartz sand, between 30 and 40 mesh, is fed on the disk to act as the abrasive agent. The machine used is arranged to hold two core pieces so that two tests can be run simultaneously. At the end of 1,000 revolutions the loss in weight is determined and the test repeated with the specimen reversed. The average loss in weight computed from the two runs is used in determining the hardness of the rock. In the earlier work the loss in length was determined from measurements taken before and after each run, and the average loss expressed in millimeters per 1,000 revolutions subtracted from 20 was given as representing the hardness of the specimen. The arbitrary constant 20 was selected with a view to giving the results of this test about the same range of variation as the French coefficient of wear described later under the abrasion test. It has been found, however, that the hardest rocks lose only about 2 millimeters per 1,000 revolutions, while some of the softer varieties lose considerably more than 20 millimeters, thus giving rise to negative values in the results of the test. In order to avoid this, the following method of expressing the hardness has been adopted:

$$\text{Hardness} = H = 20 - \frac{1}{3} W,$$

where *W* = loss in grammes per 1,000 revolutions.

The results of numerous tests which have been made with the above machine will appear in our next issue.

TOUGHNESS TEST.

As applied to road materials, toughness is understood to mean ability to resist fracture due to impact. To be resistant to the severe pounding action of traffic

Fig. 8.—Details of Grinding Lap.

on the roadway, road material, it will be recognized, should possess the quality of toughness to a high degree. The method of testing the toughness of rock, as used in its present form, was developed by Logan W. Page.

Page Impact Machine.

The Page impact machine (see Figs. 3 and 4) consists of a 2-kilogramme hammer *N*, which is guided by two vertical rods *J*. The upper end of the hammer has

a small cone set in it, which fits snugly into a concentric electromagnet, and this is attached to the lower side of a cross-head *M*, which slides freely on the guide rods *J*. This crosshead is provided with a slot on its rear side through which a sprocket chain *S* passes, and this sprocket chain is supported on the sprocket wheels, which are attached to castings at the top *I* and near the base *H* of the machine. The lower sprocket wheel is directly connected by a worm gear to an electric motor *G*. The sprocket chain is provided with two small lugs *X*, which, when the chain is being driven by the motor, engage a spring bolt attachment which projects inward on either side of the slot on the cross-

Fig. 7.—Details of Diamond Saw.

head *M*. This raises the crosshead until tripped by a rod projecting downward from an upper crosshead *L*. When this takes place, the crosshead *M*, which holds the electromagnet, falls until it comes in contact with the hammer *N*. The electromagnet is supplied with current from the circuit running the motor. This current is conveyed through two small conducting rods running parallel to the guide rods, both of which are insulated from the rest of the machine. The current passes from one of these conductor rods through a small carbon brush to a make and break attachment on the upper crosshead *L*, thence down one of the guide rods, through the electromagnet, and back to the other conductor rod.

When the crosshead *M* is raised by the lugs on the sprocket chain and the current turned on the magnet, the hammer is lifted until the crosshead *M* comes in contact with the make and break on the crosshead *L*, and thus releases the hammer, which falls, striking a plunger *O*. This plunger is made of armor-piercing steel, with the maximum temper at its lower end, which is spherical in shape. The test piece rests on a counter anvil *W* of hard steel, while the plunger rests on its upper surface, which is tangent to it at its center point.

It will be observed that the blow, as delivered through a spherical-end plunger approximates as nearly as practicable the blows of traffic. Besides this, it has the further advantage of not requiring great exactness in getting the two bearing surfaces of the test piece parallel, as the entire load is applied at one point of the upper surface.

The upper crosshead *L* is raised through any desired height by means of the long, revolving screw *K*, which is geared at its lower end to a dial *Q*, on which the height of the make and break attachment and, therefore the height of the hammer drop may be read directly. By means of the revolving dial and screw the height of the crosshead may be adjusted, by very close approximation, to within one millimeter.

In order to prevent the crosshead *M*, which holds the electromagnet, from striking too hard a blow on the hammer when falling, a dashpot was first used, but it has been found that a few drops of cylinder oil on the lower end of the guide rods completely eliminated this difficulty.

The test consists of a 1-centimeter fall of the hammer for the first blow, and an increased fall of 1 centimeter for each succeeding blow, until failure of the test piece occurs. The number of blows required to cause failure is used to represent the toughness.

The impact test was adopted by the American Society for Testing Materials on August 15th, 1908.

Core Drill.

(For preparing rock core.)

Specimens for the hardness and toughness test are prepared by drilling a core from the sample of each to be tested. The core drill shown in Fig. 6 consists of a steel core tube *A*, carrying at its lower end the brass ring *B*, containing eight carbon points, spaced as shown,