Vol. 6, Part 4 August, 1923 Number 35

BULLETIN

OF THE

NATIONAL RESEARCH COUNCIL

APPARATUS USED IN HIGHWAY RESEARCH PROJECTS IN THE UNITED STATES

Results of Census

By

Advisory Board on Highway Research, Division of Engineering, National Research Council, in Cooperation with the Bureau of Public Roads, United States Department of Agriculture

By

C. A. HOGENTOGLER
Highway Engineer, Bureau of Public Roads

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APPARATUS USED IN HIGHWAY RESEARCH PRODUCTS IN THE UNITED STATES

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Highway Engineer, Bureau of Public Roads

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FOREWORD

After considerable time and effort have been expended in the development of a special instrument or device for highway research, it is often found by trial to be unsuited for the accomplishment of desired results, and must either be remodeled or discarded entirely. The same type of instrumental difficulty is many times encountered by different investigators working on similar problems. While the expenditure for salaries and materials in the development of unsatisfactory devices may be very small, the delay in securing data is unfortunate. Researches into the effects of unknown forces are necessarily accompanied by delays and disappointments, which, however, can be minimized by knowledge of the experience of fellow-workers.

The purpose of this report on Highway Research Apparatus is to assist in establishing a fund of common knowledge on the part of investigators of similar problems. The intention is not to set forth the advantages or disadvantages of the various devices, nor to give the degree of success attained in their use, but rather to describe only the principle and construction of each device and the purpose for which it was designed. For seekers after additional information, the names of organizations and individuals who have had experience with the various devices and instruments are given.

Detailed descriptions of standard laboratory equipment are not given. Apparatus for determining such factors as influence the design of motor vehicles have not been listed, since, by agreement between the Committee on Economic Theory of Highway Improvement of the Advisory Board on Highway Research and the Society of Automotive Engineers, all research of this character has been delegated to the latter organization.

The information on highway research apparatus was secured from questionnaires sent to all investigators listed in National Research Council Bulletin No. 21, Results of Census of Highway Research Projects in the United States. Notification of the existence of apparatus not listed in this circular will be appreciated.

The organization and activities of the Advisory Board on Highway Research are described in National Research Council Bulletin Number 32, entitled Proceedings of the Second Annual Meeting of the Advisory Board on Highway Research, Division of Engineering, National Research Council.

William Kendrick Hatt,
Director, Advisory Board.

APPARATUS USED IN HIGHWAY RESEARCH INVESTIGATIONS IN THE UNITED STATES

Apparatus is arranged alphabetically by states, the District of Columbia being treated as a state.

GROUP I. APPARATUS USED IN INVESTIGATIONS IN THE FIELD OF ECONOMIC THEORY

1. Determination of Character and Intensity of Traffic.

District of Columbia: U. S. Bureau of Public Roads.

TRAFFIC CENSUS TABULATING CARDS

On these cards can be recorded, in the field, details of both passenger and truck service, concerning type and condition of car and equipment, number of passengers, origin and destination, mileage,

PASSENGER CARS

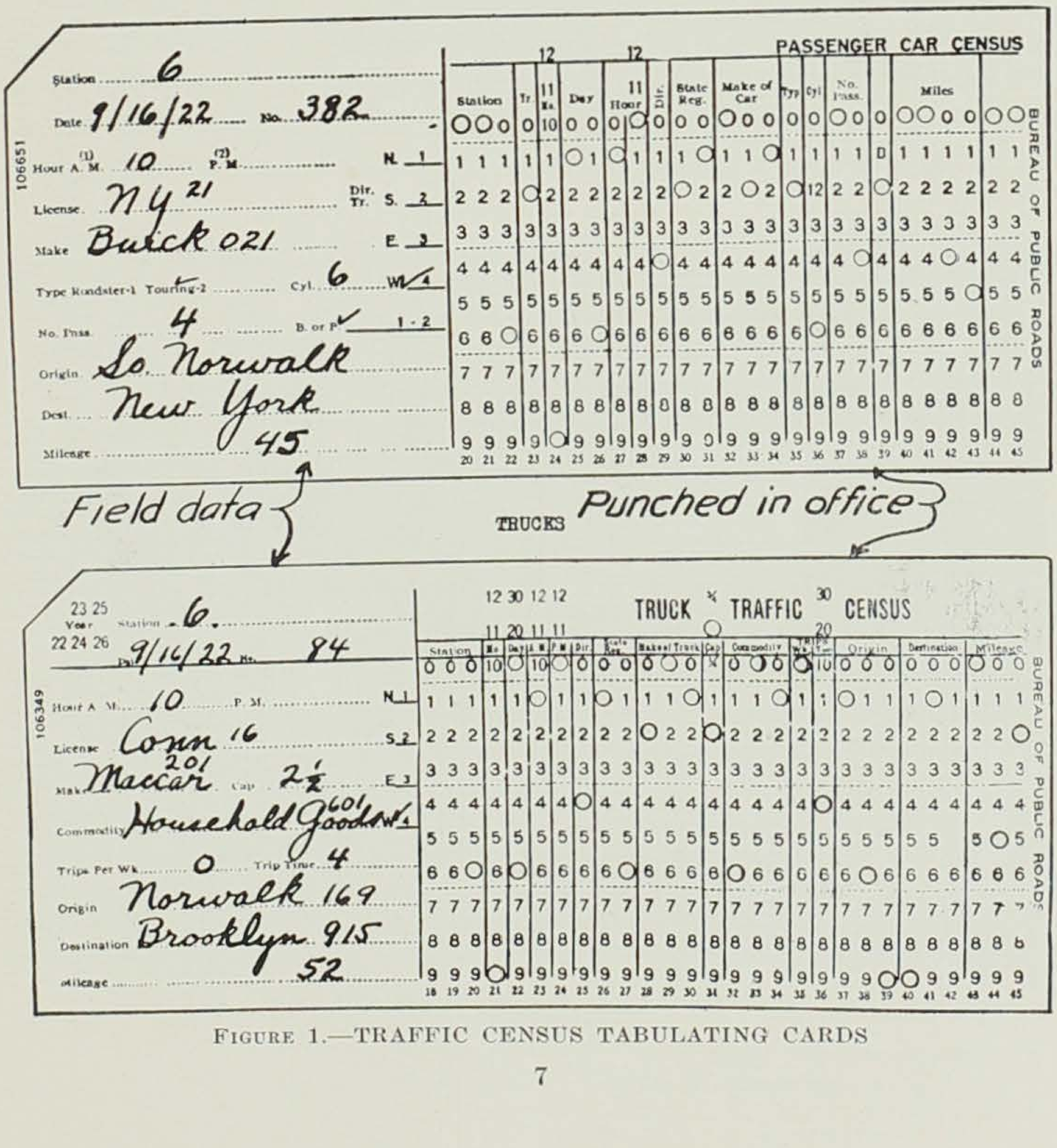

FIGURE 1.—TRAFFIC CENSUS TABULATING CARDS

pleasure or business; and, in the case of trucks, additional information as to the commodity carried and weights on both front and rear axles. One card is used for each unit of traffic. Information secured in the field is recorded on the left side of the card, as shown in the accompanying illustration (Figure 1), after which the cards are sent to the U. S. Bureau of Public Roads, Washington, D. C., where the information indicated by code figures is punched on the right side. Compilation of the data is accomplished by means of special tabulating machines.

Used by State Highway Departments of California, Connecticut, and Massachusetts in traffic studies.

Designed by U. S. Bureau of Public Roads.

AUTOMATIC SCALE AND TRAFFIC COUNTER

This apparatus, Figure 2, consists essentially of a steel trough 10 feet long, containing a piece of fire hose 9 feet long by 2 inches in diameter, on which rests a plunger attached to a platform, over which traffic passes. As shown in the sectional drawing, Figure 3, the trough is made of two 6-inch channels (A) connected to a base ¾-inch by 14-inch plate (B), and the plunger consists of a 6-inch

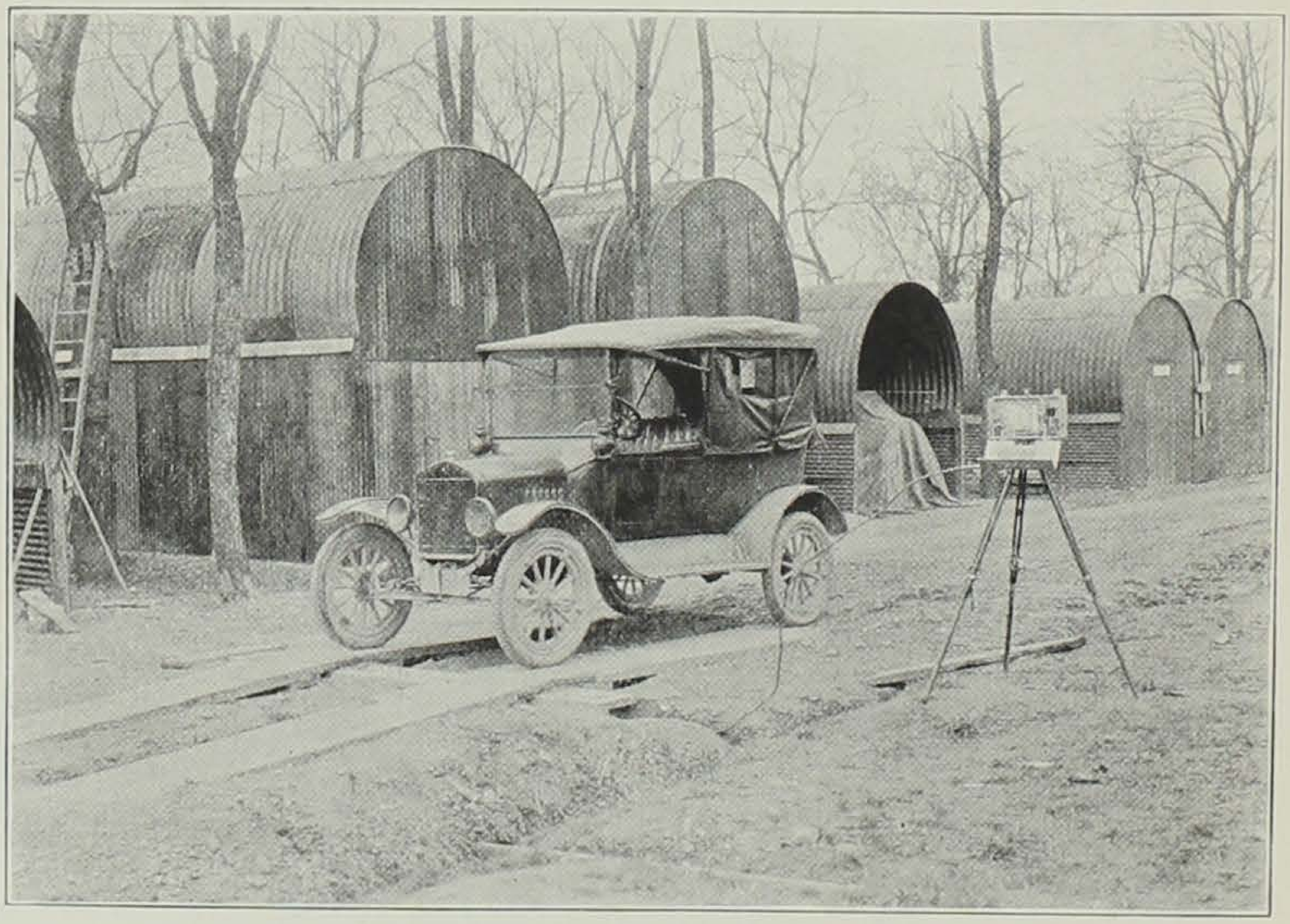

FIGURE 2.—AUTOMATIC SCALE AND TRAFFIC COUNTER, ARLINGTON EXPERIMENTAL FARM

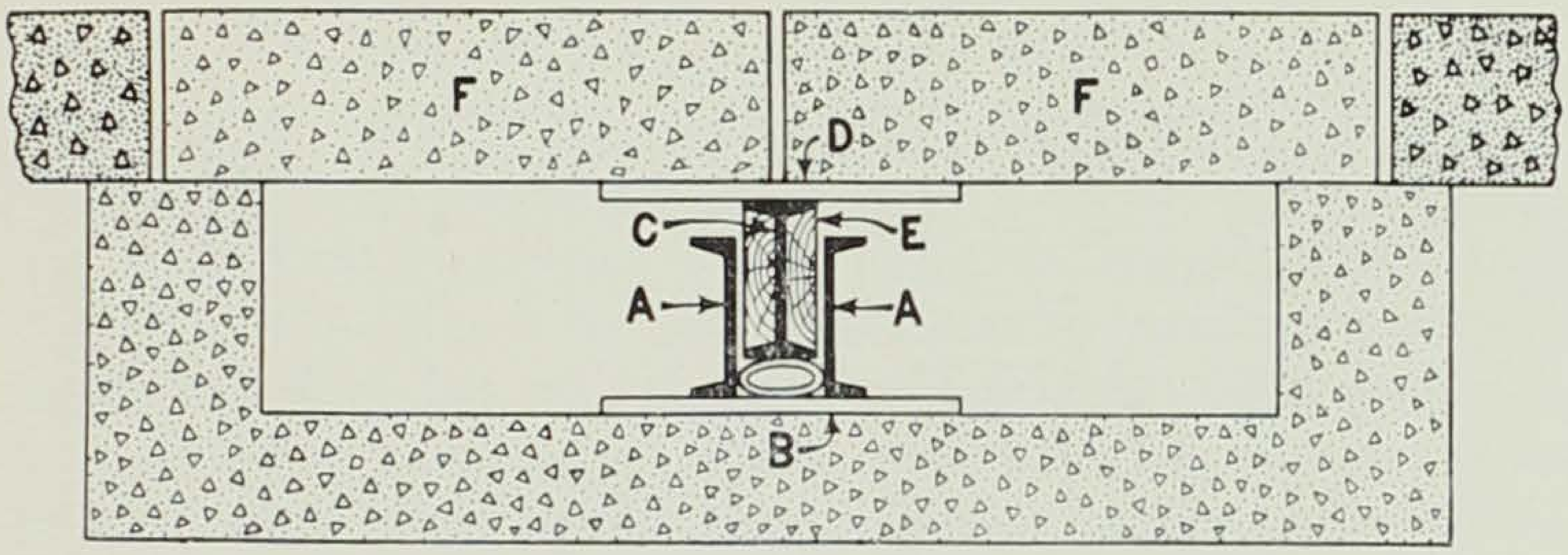

FIGURE 3.—ARRANGEMENT OF TRAFFIC COUNTER IN A ROAD

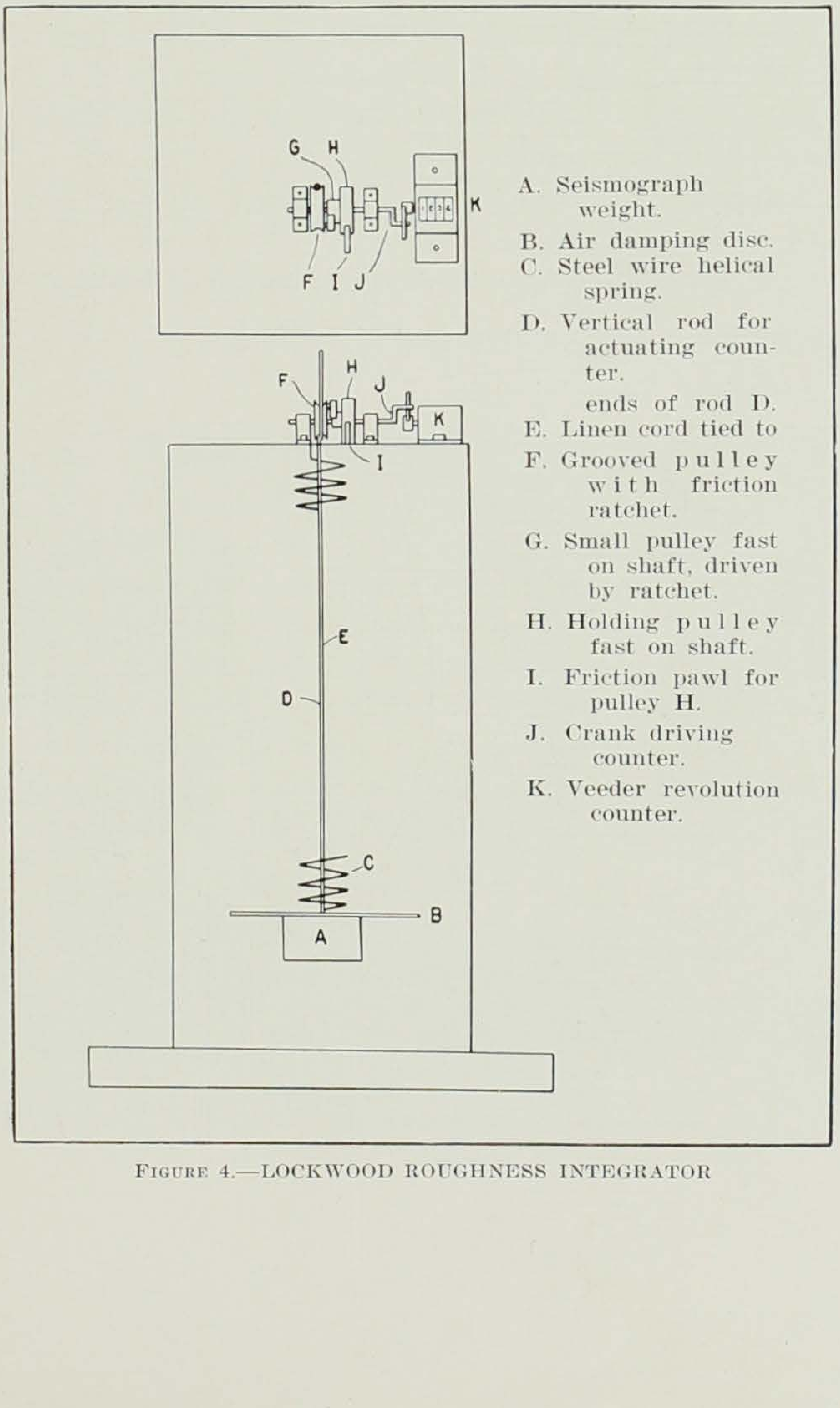

FIGURE 4.—LOCKWOOD ROUGHNESS INTEGRATOR

I-beam (C) attached to a ¾-inch by 14-inch plate (D). Wooden guides (E) bolted to the I-beam prevent horizontal movement of the plunger. The trough is set in a concrete box so that the top of the platform is approximately flush with the bottom of the road surface. Traffic passes over concrete slabs (F), which rest on the plunger. The hose, filled with heavy oil, is sealed at one end, while at the other it is connected to a recording device[1] by means of a flexible tube. A record of pressures exerted on the oil in the hose is thus secured. The recording paper is automatically moved forward a short distance every time a pressure is recorded. The weights of the front and rear wheels, as well as the number of vehicles passing, are recorded. The passage of 4,800 traffic units can be recorded on one roll of paper. Before being used on a road, the apparatus is calibrated with static loads.

The apparatus installed in the Washington-Baltimore boulevard is used for traffic counts.

Developed and constructed by the U. S. Bureau of Public Roads.

2. Determination of Operating Cost of Vehicles.

Connecticut: Yale University.

LOCKWOOD ROUGHNESS INTEGRATOR

The device, shown diagramically in Figure 4, consists of a seismograph weight (A) suspended by a steel wire helical spring (C). A rod connected to the weight is so arranged that its movement in one direction only is recorded by a Veeder revolution counter (K), to which the motion is transmitted by means of specially designed pulleys and shafts. When attached to any part of a motor vehicle, it registers the summation of vertical movements which occur during any definite period of operation. The result is expressed in amount of vertical variation per unit of horizontal distance traversed by the vehicle.

Used for determining relative roughness of various road and street surfaces in Connecticut.

Developed by E. H. Lockwood, Yale University.

District of Columbia: U. S. Bureau of Public Roads.

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[1] In this instrument the recording device is a trainagraph manufactured by the American Steam Gage & Valve Manufacturing Company, Boston, Mass.

TRACTOGRAPH

This apparatus consists essentially of a spring so mounted on the tongue of a wagon that it receives the force of the pull exerted by the horses on the doubletrees. The variation in traction as indicated by change in spring length is recorded on paper carried by a cylinder. The paper movement is proportional to the distance traveled by the wagon. Calibration of the apparatus consists of determining spring compressions which accompany definite pressures.

Used first in a road exhibit at the Cotton States and International Exposition in Atlanta, Ga., in 1895. Later employed in investigations on the effect of different types of surfaces, as well as different tire widths on the force required to move definite loads.

Developed by U. S. Office of Road Inquiry. See Bulletin No. 20, U. S. Department of Agriculture, Office of Road Inquiry, Tractive Tests, by Samuel T. Neely.

RECORDING DYNAMOMETER, WAGON TYPE

The dynamometer (Figure 5) is suspended rigidly from the bed of the wagon. Two coil springs, through which the power is trans-

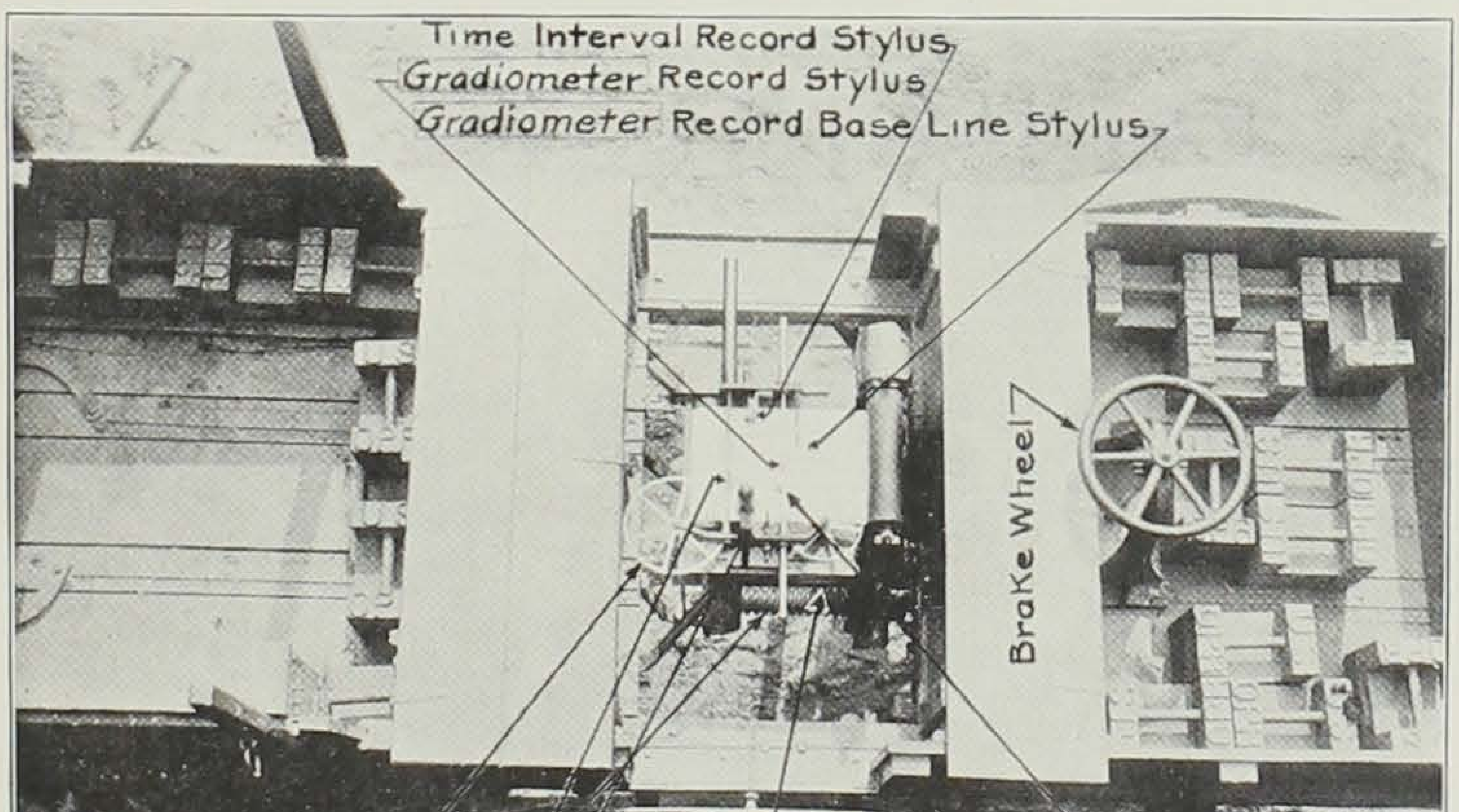


FIGURE 5.—RECORDING DYNAMOMETER, WAGON TYPE

mitted, are in the line of draft from the tongue. The tongue slides freely in roller-bearing guides, and is attached to the traction rod of the dynamometer. As this traction rod is moved forward by the pull on the tongue, the springs are compressed an amount corresponding to the draft exerted. This compression is transmitted through a rack and gear to a ribbon wheel, and, through a steel ribbon, permits the record point to be moved by a coil spring which is in tension. The record points are brass styli, mounted so as to allow slight vertical movement, with constant pressure on the record paper. By this arrangement of rack, gear, ribbon wheel, and spring, all effects of vibration are eliminated without decreasing the accuracy of the mechanism. Sensitized paper, 10 inches wide and some hundred yards in length, is fed through rolls driven by a sprocket-wheel on the hub of one of the rear wheels of the wagon. An odometer, interposed in the gearing, shows the distance traveled. The ratio of paper movement to road travel is 1:264; 240 inches of record representing one mile of road distance.

The machine is equipped with a recording gradiometer of the pendulum type, which approximately determines grades, and also a time-interval clock, which records 15-second intervals. For location of natural landmarks, fractions of miles traveled, etc., a hand-operated fixed-number stamp is used, the explanatory notation being recorded by the observer. The draft on towed vehicles can be obtained by reversing the dynamometer.

The wagon is equipped with eight sets of wheels, ranging from 1⅝ to 6 inches of tire width. The brake on the wagon is under control of the observer. Variation in load is obtained by the use of 100-pound weights.

Used for determining the efficiency of street-cleaning apparatus, percentage of improvement of post-road projects, effect of width of tires, and resistance of various road surfaces to traction on steel-tired wheels.

Designed by Kansas State Agricultural College. Modified and adapted by U. S. Bureau of Public Roads.

Constructed by Studebaker Wagon Co. and U. S. Bureau of Public Roads.

TORSION DYNAMOMETER, AUTOMOBILE TYPE

The torsion dynamometer (Figure 6), installed on the propeller shaft of a motor vehicle, is enclosed in an oil-tight casing, supported by the torque rods of the car or truck. Universal joint connections

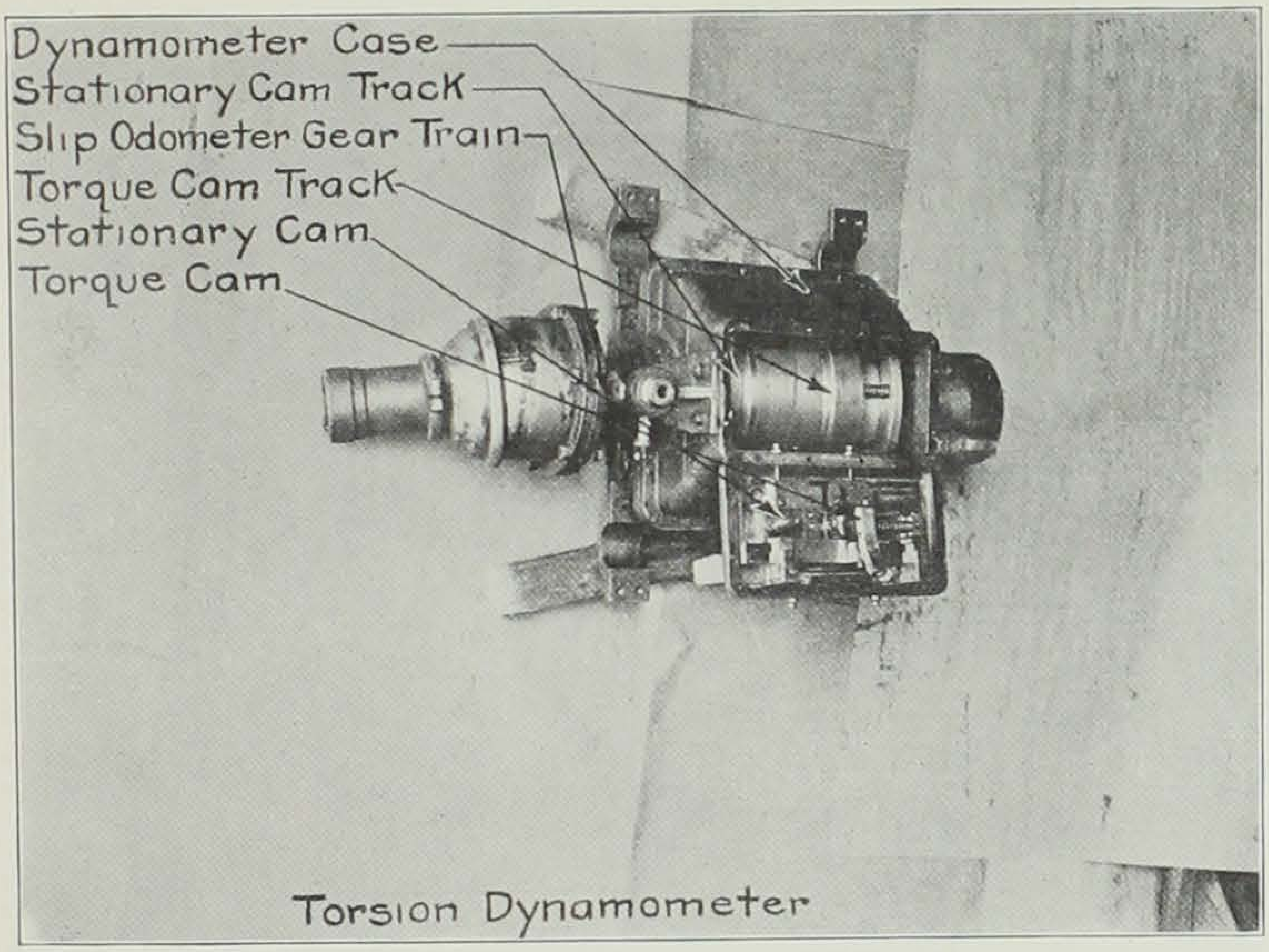


FIGURE 6

with the propeller shaft and the differential housing prevent misalignment of the apparatus.

The dynamometer consists of two flanged couplings, connected by a spiral spring. The face of the front coupling, which carries an annular cam track, has two helical surfaces 180 degrees apart, which are reversed to two helical surfaces on a sliding collar attached to the rear flange coupling. An annular cam track carried by this sliding collar translates, by means of a rack and pinion and a freely revolving shaft, the distortion of the spiral spring to the torque record stylus.

The recording apparatus (Figure 7) consists essentially of two sets of rolls driven by a flexible shaft geared to the front wheel. Surface-coated paper, 10 inches wide and some hundred yards in length, is used. The ratio of paper movement to road travel is 1:264; 240 inches of record representing a torque record of one mile of road distance.

Two odometers are used, one being attached to the front wheel gearing and the other to the propeller shaft in front of the torsion dynamometer. The slippage of the rear wheels is shown by difference in odometer readings.

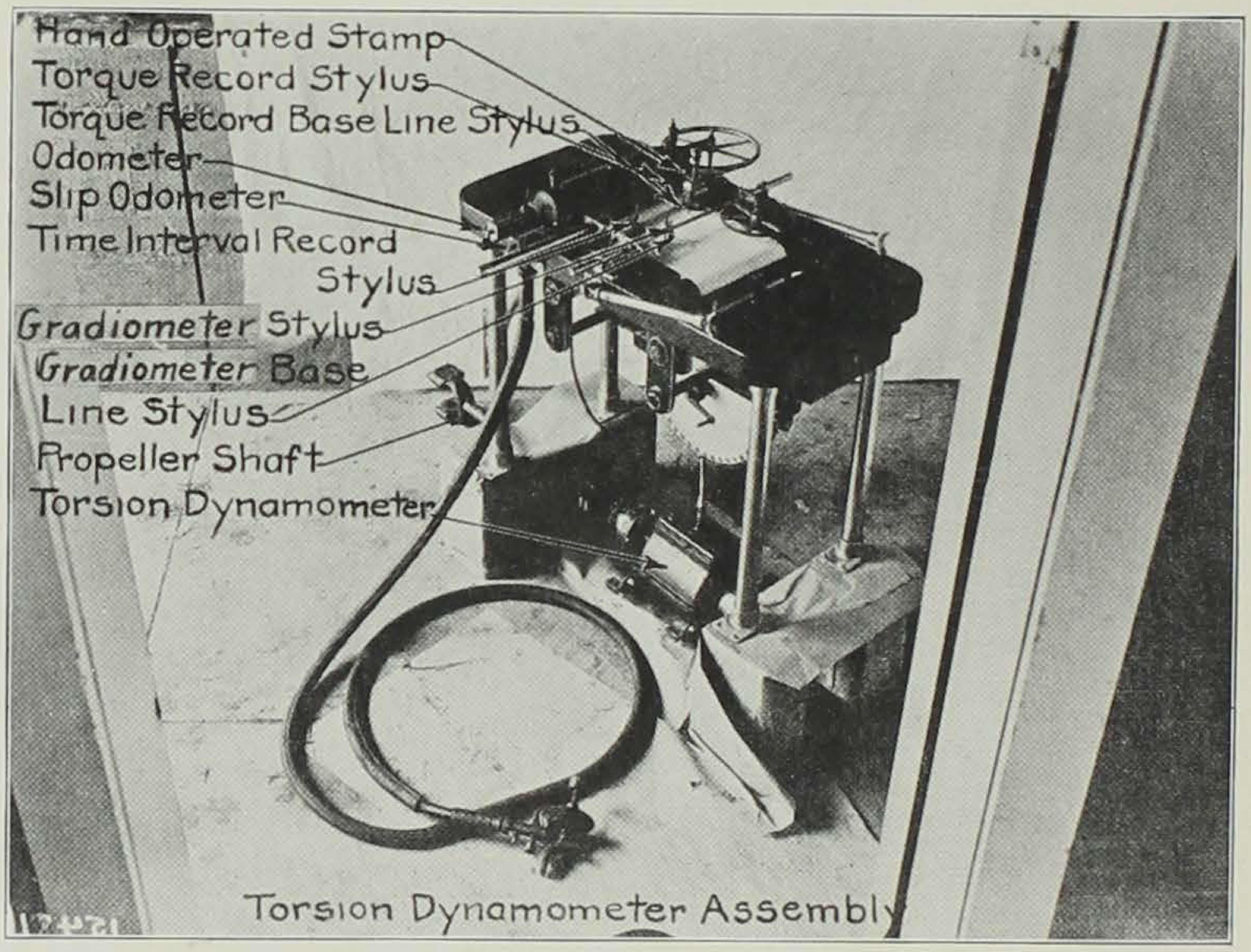


FIGURE 7.—TORSION DYNAMOMETER RECORDING APPARATUS

The machine is equipped with a recording gradiometer of the pendulum type, which approximately determines grades, and also with a time-interval clock which records 15-second intervals. For location of natural landmarks, fractions of miles traveled, etc., a hand-operated fixed-number stamp is used, the explanatory notation being recorded by the observer.

Contemplated use in determining resistance of various road surfaces to traction of rubber-tired, self-propelling vehicles.

Designed and constructed by the U. S. Bureau of Public Roads.

PROFILOMETER FOR MEASURING ROUGHNESS OF ROAD SURFACES

The apparatus (Figure 8) consists of a straight edge (A) or track 24 feet long, and a recording device (B) which, when drawn over the track, records accurately and autographically the profile of the pavement beneath. The track, as used on the Bates road in Illinois, is supported by three bicycle wheels, and consists of two wooden trusses 24 feet long by 20 inches high with a 3-inch space between them. Four turnscrews (C), two at each end, permit leveling the track at each set-up, while a piano wire under constant tension, stretched from end to end, gives a datum for detecting any sag in the track.

The recording apparatus consists of an American strainagraph[2], whose pen arm is connected by a rod with a brass wheel (D) resting on the pavement surface. This allows surface irregularities passed over by the small wheel to be traced on the recording paper. The instrument, which is mounted on a wooden platform carried by four wheels, each $2\frac{1}{2}$ inches in diameter and 2 inches wide, is kept aligned by two guide wheels, which run in the 3-inch space between the trusses.

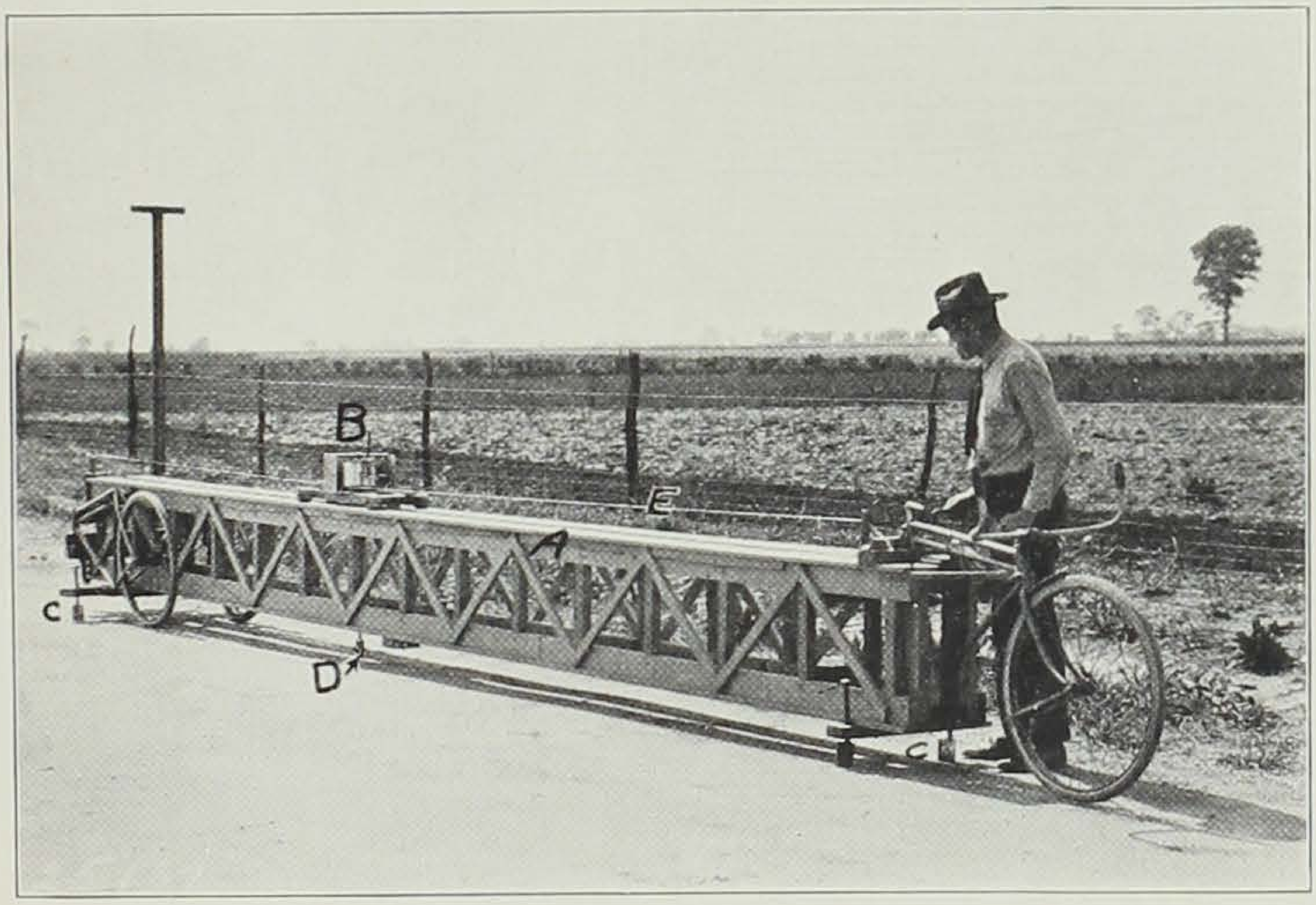


FIGURE 8.—PROFILOMETER

For drawing the recording device over the track, a wire cable attached to each end of the platform and passing over a pulley at each end of the trusses is used. The pulley at one end is operated by a crank.

The summation of the vertical ordinates of the surface profile is obtained by means of a special attachment consisting of a fiber strip $\frac{1}{2}$ inch wide by 6 inches long, which receives the pen arm

[2] The American strainagraph, manufactured by the American Steam Gage & Valve Manufacturing Company, Boston, Mass., was used by the U. S. Shipping Board in investigations of stresses in concrete ships.

movement and operates against the recording wheel of a planimeter in such a way that the upward movement only is recorded. A pen actuated by an electric magnet records every tenth revolution of the planimeter wheel. The summation of vertical ordinates divided by the length of the surface passed over gives an average ordinate, which can be considered a roughness factor of the particular surface.

The rolls carrying the recording paper are driven by a pulley, which, by contact with a cord (E) fastened at each end of the track, is caused to revolve as the platform moves along the track. Thus, the paper on which the record is made moves a distance proportional to that traversed by the wheel on the pavement surface. The ratio of paper length to observed surface distance is about 1:10.

Used in co-operation with Illinois Division of Highways on the Bates experimental road, in an investigation of the roughness of pavement surfaces.

Designed by the U. S. Bureau of Public Roads, and constructed at Bureau of Tests, Illinois Division of Highways.

PROFILOMETER USED IN THE ARLINGTON, VIRGINIA, EXPERIMENTS

In this device (Figure 9), a modification of the one used in the Bates road tests, the recording apparatus (A) rides on an angle iron (B), one end of which is fastened to a frame supported by two wheels (C), which move over the inner concrete curb of the circular track, while the other end is fastened to a steel frame truck on four wheels (D) carried by the two iron rails of the concrete wear test track. The entire frame riding on the six wheels is so trussed as to be perfectly rigid. The profile of any transverse section of the roadway is secured by moving the recording apparatus along the angle iron (B), while that of any longitudinal section is secured by moving the entire frame along the tracks. As in the Bates road instrument, the record length is proportional to the length of pavement surface traveled by the small wheel. The summation of vertical ordinates is given by an integrating attachment.

Used to measure variation in profile of road surfaces, in connection with an investigation of the shoving and waving of bituminous surfaces, at the Arlington Experimental Farm, Arlington, Virginia. For description of use see "What the Arlington Investigations Are Showing," a paper presented by A. T. Goldbeck before the annual meeting of the American Road Builders' Association, Chicago, Illinois, January 16, 1923.

Constructed by the U. S. Bureau of Public Roads.

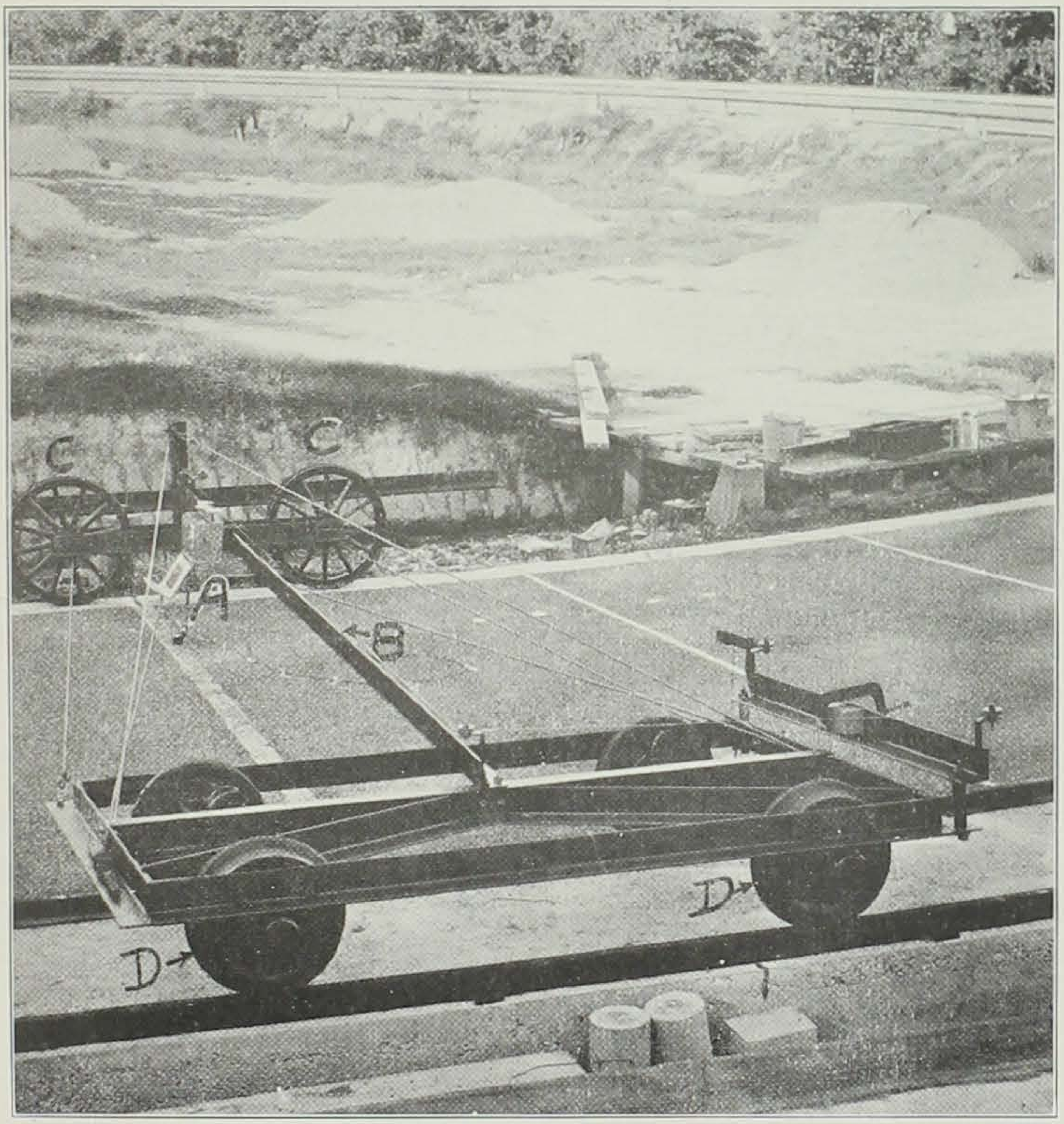


FIGURE 9.—PROFILOMETER USED IN INVESTIGATIONS AT THE ARLINGTON EXPERIMENTAL FARM

ACCELEROMETER FOR STUDYING THE EFFECT OF ROUGHNESS OF ROAD ON MOVING MOTOR TRUCK WHEELS

This device, shown in Figure 10, consists of the recording part and case of an American strainagraph, to the pen arm (A) of which is attached a rod (B) supporting a weight (C) suspended between two compression springs (D). By means of three steel rods, it is attached directly to the rear axle of a motor truck. The recording paper moves a distance proportional to that passed over by the motor wheel, the roll carrying the paper being driven by a speedometer cable (F) and a small rubber-tired wheel (G), which is rotated by contact with the rim of a rear wheel (H) of the truck. By moving

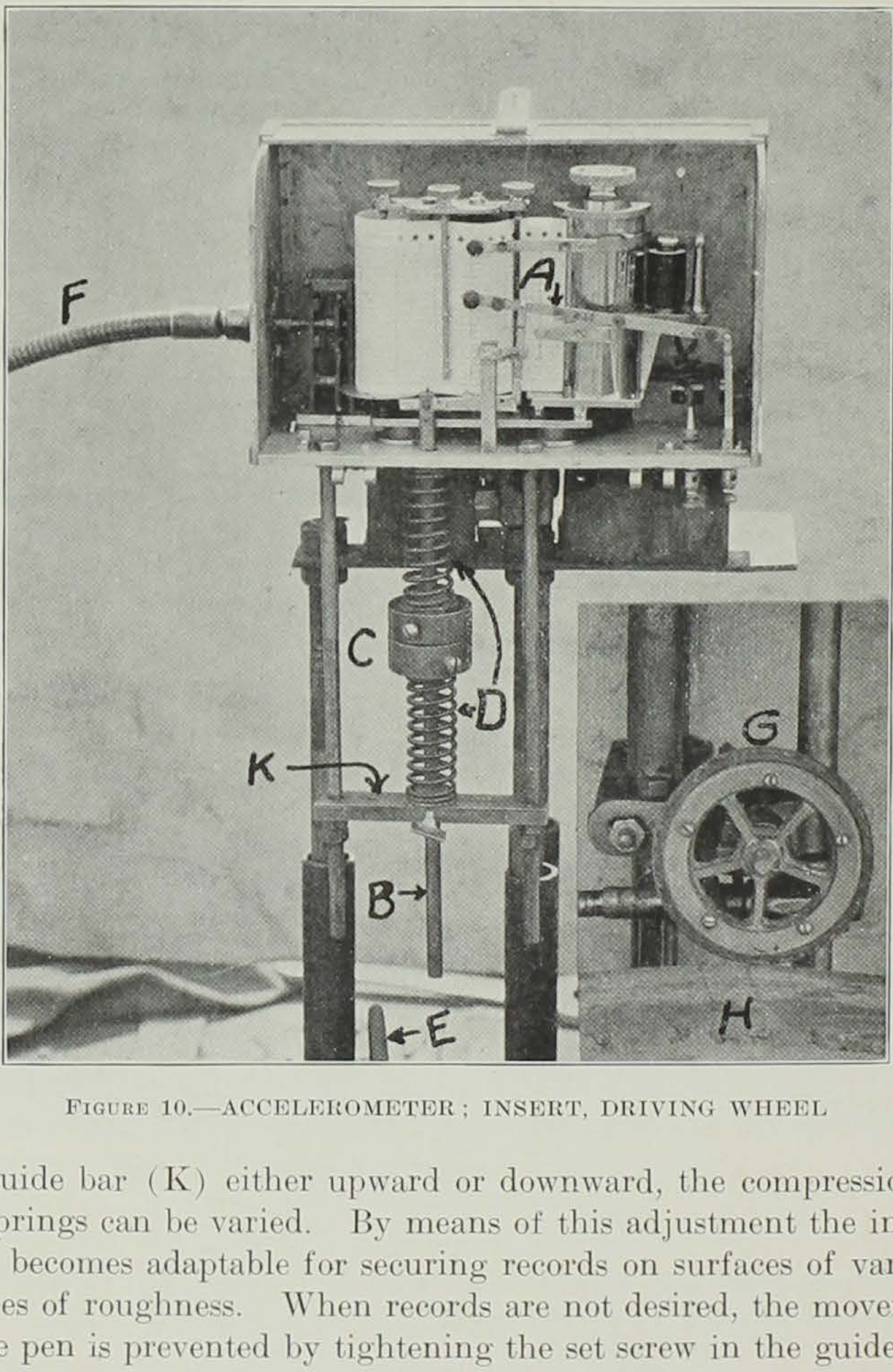


FIGURE 10.—ACCELEROMETER; INSERT, DRIVING WHEEL

the guide bar (K) either upward or downward, the compression of the springs can be varied. By means of this adjustment the instrument becomes adaptable for securing records on surfaces of varying degrees of roughness. When records are not desired, the movement of the pen is prevented by tightening the set screw in the guide bar, and the paper movement is stopped by raising the driving wheel by means of a small rod, the top of which (E) is shown at the bottom of the illustration.

The theory of this device is simple. The record will be a straight line unless the weight in the instrument changes its position with respect to the axle. Any vertical acceleration, however, will cause the weight and consequently the pen to vary from a straight line. The greater the acceleration the greater will be the variation from a straight line. This variation is a measure of the force which causes it, and the force corresponding to any particular variation can be determined by calibrating the springs. Knowing this force, and the mass of the wheel and axle, it will be possible to compute the corresponding impact.

Used in co-operation with the Illinois Division of Highways on the Bates experimental road in an investigation of the effect of road surface irregularities on motor truck wheels.

Devised by the U. S. Bureau of Public Roads, and constructed at the Bureau of Tests, Illinois Division of Highways, Springfield, Illinois.

Iowa: Experiment Station, Iowa State College.

DAVIDSON DYNAMOMETER

This apparatus is a spring-type dynamometer equipped with a recording device that plots a curve showing the variation in draw-bar pull and mechanically integrates the area under the curve.

Designed by Prof. J. B. Davidson, Department of Agricultural Engineering, Iowa State College.

First used on tractive resistance investigations carried on under the direction of Professor Davidson in California and Iowa on experiments of the draft of implements and tractive resistance of vehicles. The instrument has been in factory production for several years.

GULLEY DYNAMOMETER

This apparatus consists of a pressure cylinder which is attached to the draw bar between the towing vehicle and the one under test, and a recording device which plots a curve of the draw-bar pull. The connection between the pressure cylinder and the recording mechanism is a flexible pressure tube. It was thought that the column of oil in the tube and pressure cylinder would serve to damp out some of the impact effects.

For descriptions and use of the Davidson and Gulley dynamometers see Bulletin 64, Iowa State College of Agriculture and Mechanical Arts, "Resistance to the Translation of Motor Vehicles," by T. R. Agg.

FLOWMETER FOR MEASURING FUEL CONSUMPTION OF MOTOR VEHICLES

The flowmeter is in principle a piezometer so arranged as to have a constant pressure head. The velocity head, which varies with the

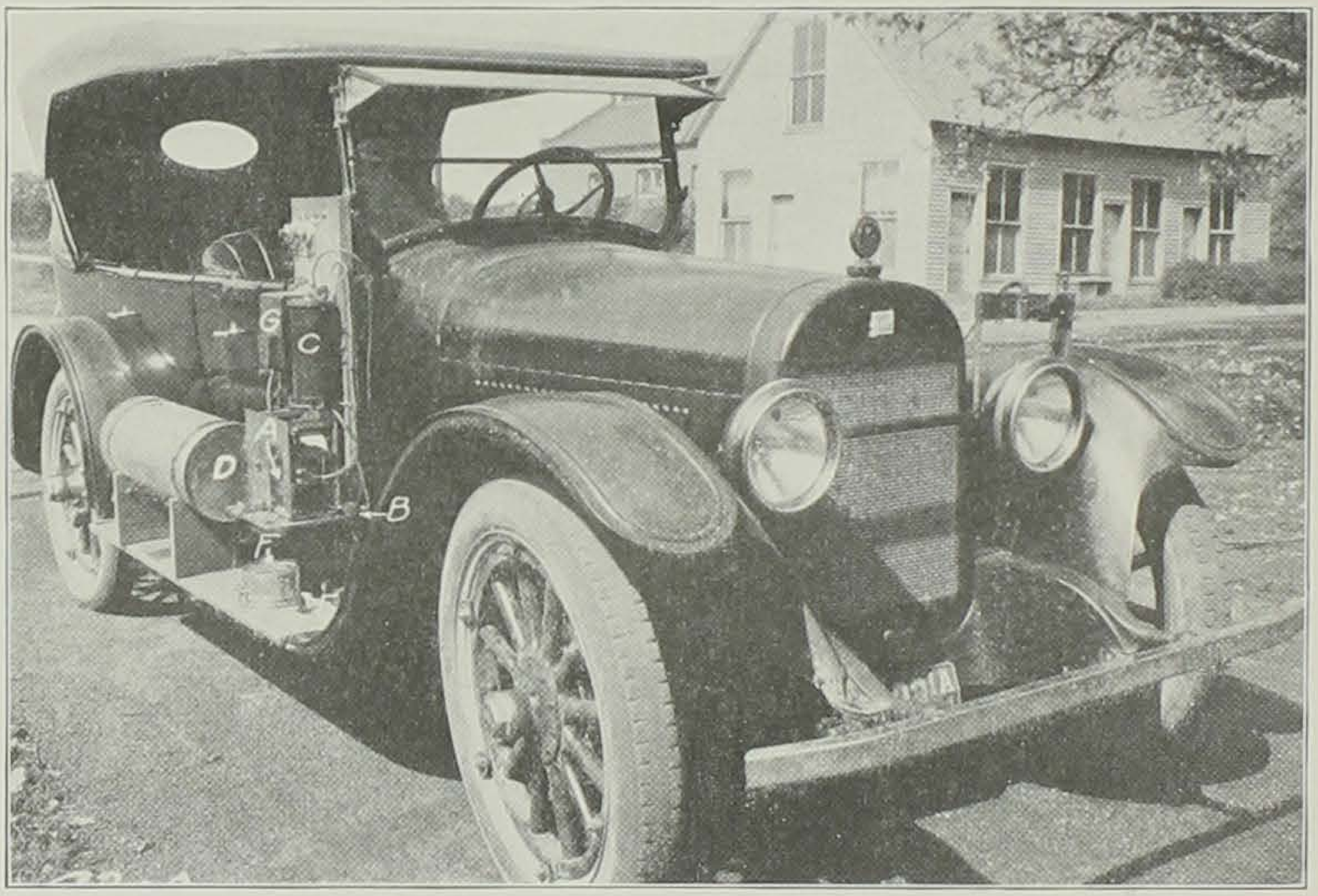


FIGURE 11.—FLOWMETER

quantity of gasoline flowing, is measured by means of a calibrated diaphragm, the movement of which is recorded by an electric spark punching holes in the recording paper.

In Figure 11 the diaphragm is shown at A and the needle valve at B. The vacuum tank at C is used to give nearly constant head and the spare tank at D affords a check on the records. The spare tank may be dispensed with in most cases and connection made to the supply tank on the vehicle. The cable of a taximeter drive (E) is used to operate the paper rolls, and F is a clock arranged to close a circuit momentarily and punch a hole in the paper every ten seconds. The distance between the time marks on the record paper is proportional to the vehicle speed and furnishes the data for a speed curve for the run. A spark coil (G) provides the high-tension current for punching the record paper.

The pilot tube shown over the head-light on the car is connected to an air-speed indicator on the instrument board of the car, and enables the observer to eliminate records which may have been influenced by the wind. The paper upon which the records are made is drawn through the recording device by means of rollers geared to the front wheel of the vehicle, so that the paper travel bears a fixed ratio to the wheel travel. For passenger vehicles the paper moves approximately ½ inch per 100 feet of vehicle travel. For trucks the paper travel is somewhat less.

In using the meter, the paper travel is first determined by calibration runs over a measured course. The needle valve is then set so as to give a record about 1½ inches high when the vehicle is operating so as to use the maximum amount of gasoline. The meter is then calibrated and is ready for use.

There are two sources of error in the instrument, both of which are small: (*a*) errors caused by fluctuations of the flow of gasoline, due to the operation of the float valve in the carburetor; (*b*) variations of the pressure head, due to the fluctuations of the gasoline level in the vacuum tank. The accuracy of the meter has been tested in various ways, and for ordinary operating conditions the maximum error is about 5 per cent and the average error about 2 per cent.

Used in investigations of resistance to the translation of motor vehicles, Iowa State College.

Designed and constructed by the Engineering Experiment Station, Iowa State College, Ames, Iowa.

See "Economic Theory of Highway Grades," by T. R. Agg, Engineering News-Record, Vol. 90, No. 2, Jan. 11, 1923.

SPACE-TIME RECORDER

The instrument consists of a paper feed that moves the paper along at a fixed ratio to the distance the vehicle travels and a pen line to indicate time intervals. The paper feed is driven by a speedometer cable connected to a gear on the front wheel. The time line is broken every one-half second by a pen actuated by a clock mechanism.

The acceleration can be computed accurately from the ratio of distance of paper travel to time.

Used in investigations of resistance to the translation of motor vehicles, Iowa State College.

Designed and constructed by Engineering Experiment Station, Iowa State College, Ames, Iowa.

See Bulletin 64, Iowa State College of Agriculture and Mechanical Arts, "Resistance to the Translation of Motor Vehicles," by T. R. Agg.

Massachusetts: Quartermaster Tractive Resistance of Roads Research, Massachusetts Institute of Technology, Cambridge, Massachusetts.

WIMPERIS ACCELEROMETER WITH LOCOMOTIVE RECORDING ATTACHMENT

The recording attachment consists of a tripod to facilitate mounting the instrument in a vehicle, with dry-cell battery and recording device properly attached. The rolls which feed the adding machine paper over the accelerometer needle are driven by the vehicle's speedometer cable. Both half-second time intervals and instantaneous needle positions are recorded by electric sparks, which perforate the paper. This gives speed for the time-distance relation, and also a value for checking the accuracy of the gross, level-road tractive resistance for coasting vehicles, as indicated by the accelerometer needle.

Used November, 1921, to May, 1922, in Connecticut and Massachusetts by the Quartermaster Tractive Resistance of Roads Research Party.

See "Application of Power to Road Transport," by H. E. Wimperis, in S. A. E. Journal for 1921, pages 30–36.

The Wimperis accelerometer is manufactured by Elliott Brothers, London, England, and the recording device by the Locomobile Company, Bridgeport, Conn.

MASSACHUSETTS TRACTIVE RESISTANCE RECORDER

This apparatus consists of a mercury accelerometer, with an automatic recording device. Record is made by electric spark perforation of record paper. The instrument registers gross, level-road tractive resistance on level or inclined profiles, also speed (by time-distance relation) and other pertinent data. It is readily adaptable to use with a hydrostatic-pressure dynamometer for towing tests. Provision has been made for the addition of such other data records as may be found desirable.

The Massachusetts tractive resistance recorder is the property of the Department of Public Works, Commonwealth of Massachusetts, and is now loaned to the University of Michigan for the use of the University and the Michigan State Highway Department.

Used in the summer of 1922 at Massachusetts Institute of Technology, and in the vicinity of Boston, Massachusetts.

Adapted from the liquid accelerometer idea of the Bureau of Standards, and the electric recording idea of the Locomobile Company to the problem of this research party by Mr. William O. Tait, Automotive Engineer, Bureau of Public Roads, and Major Mark L. Ireland, Q. M. C., U. S. A., Director of Research.

Pamphlet description (typewritten) filed with Department of Public Works, Commonwealth of Massachusetts, Bureau of Public Roads, Q. M. C., U. S. A., Massachusetts Institute of Technology, Yale University, and Harvard University.

Constructed by Quartermaster Tractive Resistance of Roads Research Party at Massachusetts Institute of Technology.

DRAW-BAR PULL DYNAMOMETER

The instrument consists essentially of a piston and cylinder filled with 600 W. transmission oil and connected with an indicating and pressure gage by flexible metal tubing. The apparatus is so connected between the towing and the towed vehicles that the tension between the two is indicated by the recorded oil pressure.

Used in Michigan State Highway Department investigations of truck performance on grades.

For detailed description, see report of above investigations in University Bulletin, New Series, Vol. XXIV, No. 19, Nov. 4, 1922, College of Engineering, Proceedings of the Eighth Annual Conference on Highway Engineering, held at the University of Michigan, February 13–17, 1922.

GROUP II. APPARATUS USED IN INVESTIGATIONS OF THE STRUCTURAL DESIGN OF ROADS

1. Subgrade Investigations.

District of Columbia: U. S. Bureau of Public Roads.

BEARING POWER DETERMINATOR (STATIC LOAD)

This device (Figure 12) for determining the supporting value of soils when subjected to static loads, consists essentially of a brass cylinder (A) and footing (B) so arranged with a tripod that, while vertical movement is allowed, all horizontal movement of the top of the device is eliminated. The loading agency, shot, which is fed into the funnel shown on the top of the tripod, flows through an orifice at a constant rate of speed. The rate of flow of shot is determined by calibration of the orifice. Deformation of the soil under the footing, indicated by the vertical movement of the plunger, is measured by an Ames dial, shown just above the tripod head. Knowing the time of flow of shot, the vertical movement of the plunger, and the area of the footing, the depth of soil penetration for a definite pressure is easily computed.

Used in experiments at the Arlington Experimental Farm, Arlington, Virginia, by the U. S. Bureau of Public Roads.

Designed and constructed by the U. S. Bureau of Public Roads.

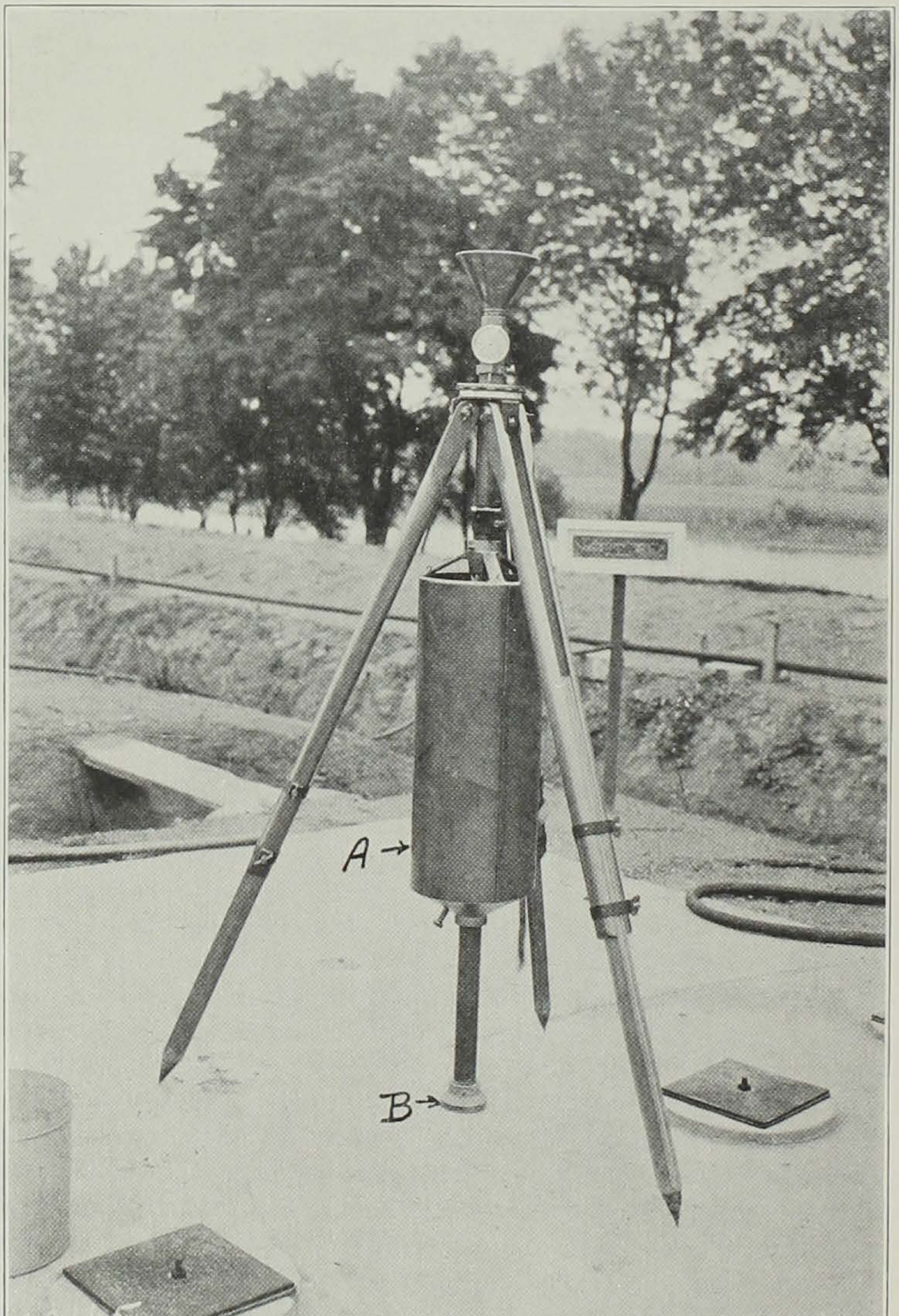


FIGURE 12.—BEARING POWER DETERMINATOR (STATIC LOAD)

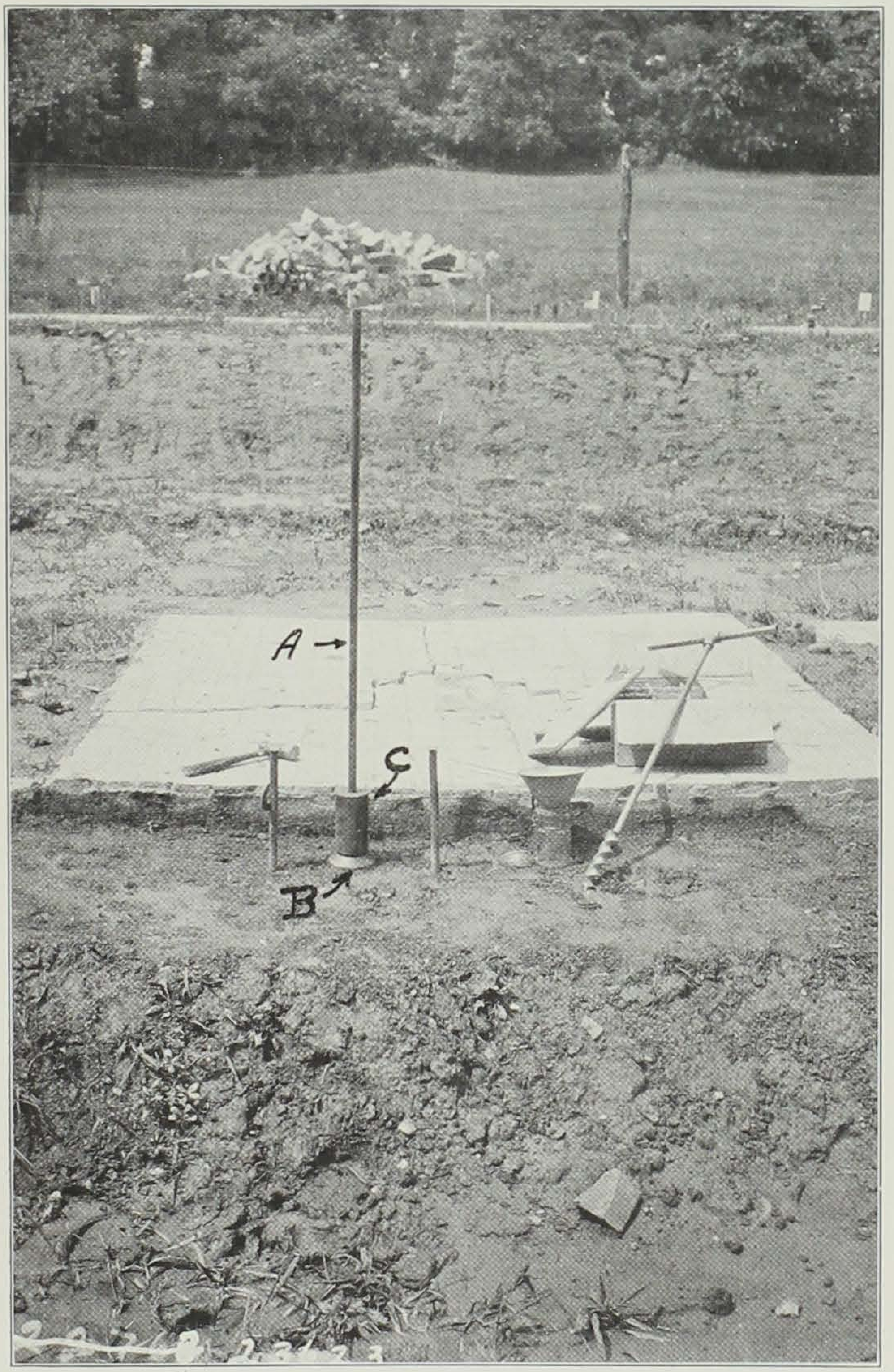


FIGURE 13.—BEARING POWER DETERMINATOR (IMPACT)

BEARING POWER DETERMINATOR (IMPACT)

This device (Figure 13) for determining the resistance of soils to impact, consists essentially of a rod (A) and a footing (B) and a steel cylinder (C), fitted loosely on a rod so that it can be dropped from any height. The footing has an area of about 7 square inches and the cylinder weighs 10 pounds. The difference in the elevation of the rod, before and after a given number of drops of the cylinder from a definite height, is the deformation of the soil. This difference is measured by means of an engineer's scale.

Used in studies of comparative supporting values of subgrades in the Arlington experiments and the Bates road tests.

See Public Roads, Vol. 4, Nos. 5 and 6, September and October, 1921.

Designed by U. S. Bureau of Public Roads.

SUBGRADE CYLINDER FOR DETERMINING SEPARATION BETWEEN SUBGRADE AND SURFACE

This device (Figure 14), which is a modification of the Illinois Subgrade Testing Cylinder (see below), consists of a brass cylinder (A) and plug (B), which can be placed in the pavement during construction, and an Ames dial (C), having a special stem. A thin brass flange (D) is soldered on the bottom of the cylinder to facilitate placement in the pavement during construction. The bottom of the plug is flush with the flange. To measure the separation between the surface and subgrade, the brass plug is removed from the cylinder and the dial is set in its place.

Used in tests of warping of concrete slabs and second series of impact tests at Arlington Experimental Farm, Arlington, Virginia, by the U. S. Bureau of Public Roads.

Adapted by the U. S. Bureau of Public Roads.

SOIL PRESSURE CELL (FOR MEASURING PRESSURES OF SOILS AND OTHER GRANULAR MATERIALS)

Principles of pressure measurement with this instrument depend upon: (1) The equilibration of the soil pressure with air pressure within a small cell buried at the point where it is desired to determine the pressure; (2) the detection of the instant of equilibration by the breaking of electrical contact within the cell; (3) the measurement of the air pressure within the cell at the instant of equilibration by the use of a sensitive gage.

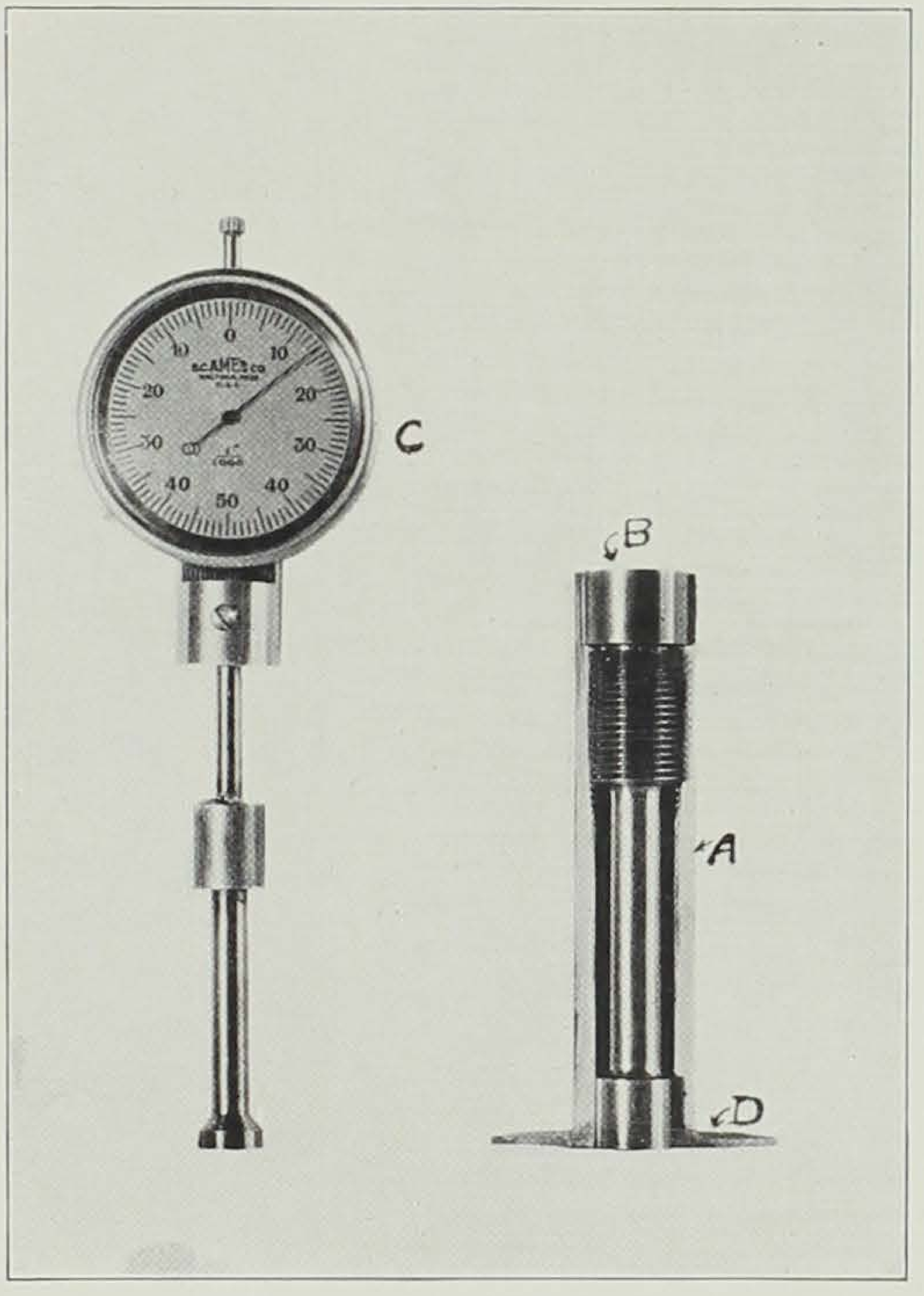
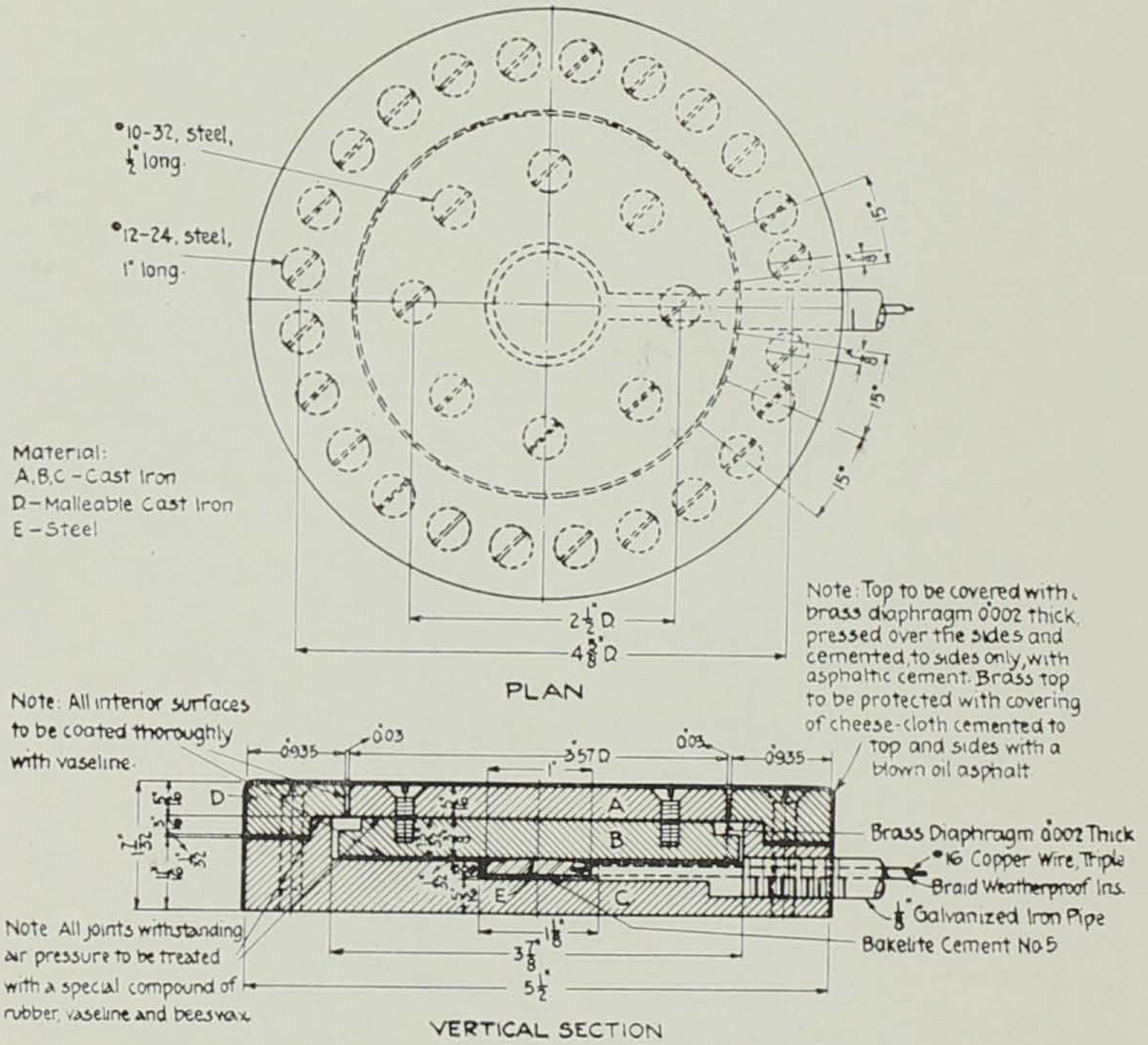


FIGURE 14.—SUBGRADE TESTING CYLINDER

A cross section of the cell as it is used at present is presented in Figure 15, and its construction is shown plainly without further description. When in operation, the movable side of the cell (plan view in Figure 15) is placed in contact with the earth fill in the direction necessary to give the desired component of pressure, horizontal, vertical, or oblique. The ⅛ inch pipe containing an insulated wire is led to any convenient accessible place for taking the measurements. The cell may be at any distance from the pressure recording instrument. When the internal pressure caused by air entering the cell through the pipe just exceeds the soil pressure, contact is broken between B and E. This fact is shown immediately by the extinguishing of a small electric light, and the operator at the indicating instrument at once notes the pressure on the pressure gage. This, for practical purposes, equals the soil pressure.



DIAPHRAGM CELL FOR DETERMINING SOIL PRESSURE

U. S. OFFICE OF PUBLIC ROADS AND RURAL ENG'G.

SCALE FULL SIZE

FIGURE 15

The indicating instrument (Figure 16) can be placed in any desired and convenient position, its air and electrical connection being so arranged that but a few seconds are required to shift from one cell to another. A compressed air tank, which may be filled with air by means of a hand pump, is shown at the bottom of the containing box. It is fitted with a rough gage for recording its approximate pressure. Two accurate standard pressure test gages are placed in the line leading to the pressure cell buried in the fill. These appear just above the air tank. One is graduated from 0 to 30 pounds by increments of 0.2 pound; the other reads up to 100 pounds in increments of 1 pound. A dry cell, a switch, and an electric light are the only electrical equipment required. Necessary

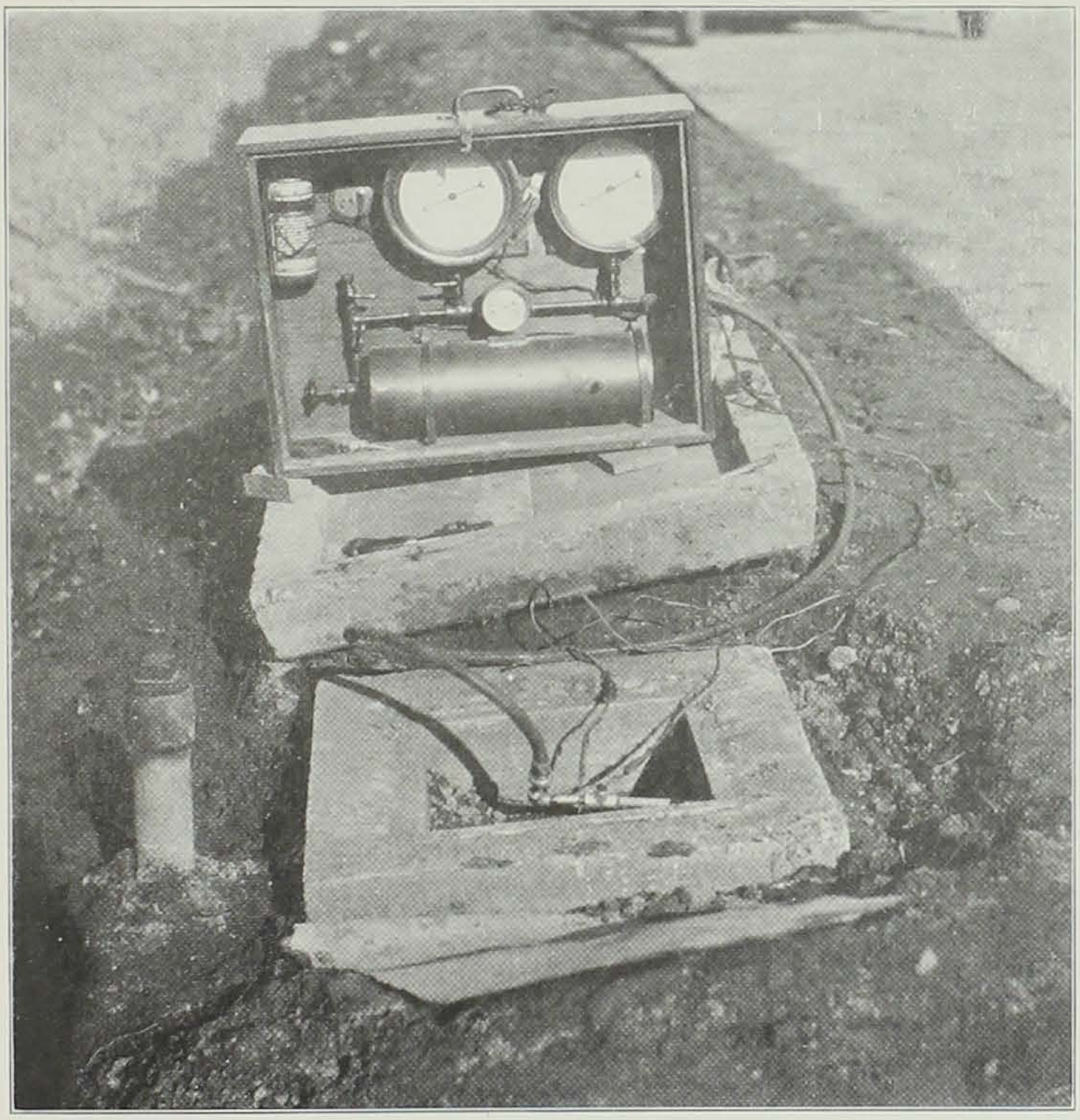


FIGURE 16.—APPARATUS FOR READING PRESSURE ON SOIL PRESSURE CELLS

valves are placed in the air line to enable the operator properly to control the pressure within the pressure cell.

Used for measuring soil pressure against bridge abutments and retaining walls; in pressure distribution experiments, and for obtaining subgrade pressures under experimental roads at Camp Humphreys, Virginia; Bates, Illinois; and Pittsburg, California.

Designed and constructed by U. S. Bureau of Public Roads.

See "An Apparatus for Determining Soil Pressure," by A. T. Goldbeck and E. B. Smith, A. S. T. M. Proceedings, 1916, and "Distribution of Pressures Through Earth Fills," by A. T. Goldbeck, A. S. T. M. Proceedings, 1917.

APPARATUS FOR PRODUCING VIBRATIONS ON SUBGRADES

The soil vibrator (Figure 17), consists essentially of a plunger carried by a lever, whose one end is fastened to a steel frame, while the other end is raised and dropped by a cam motor driven through a system of gears and pulleys. The plunger, which is equipped with a rubber footing, can be adjusted for any desired height of fall.

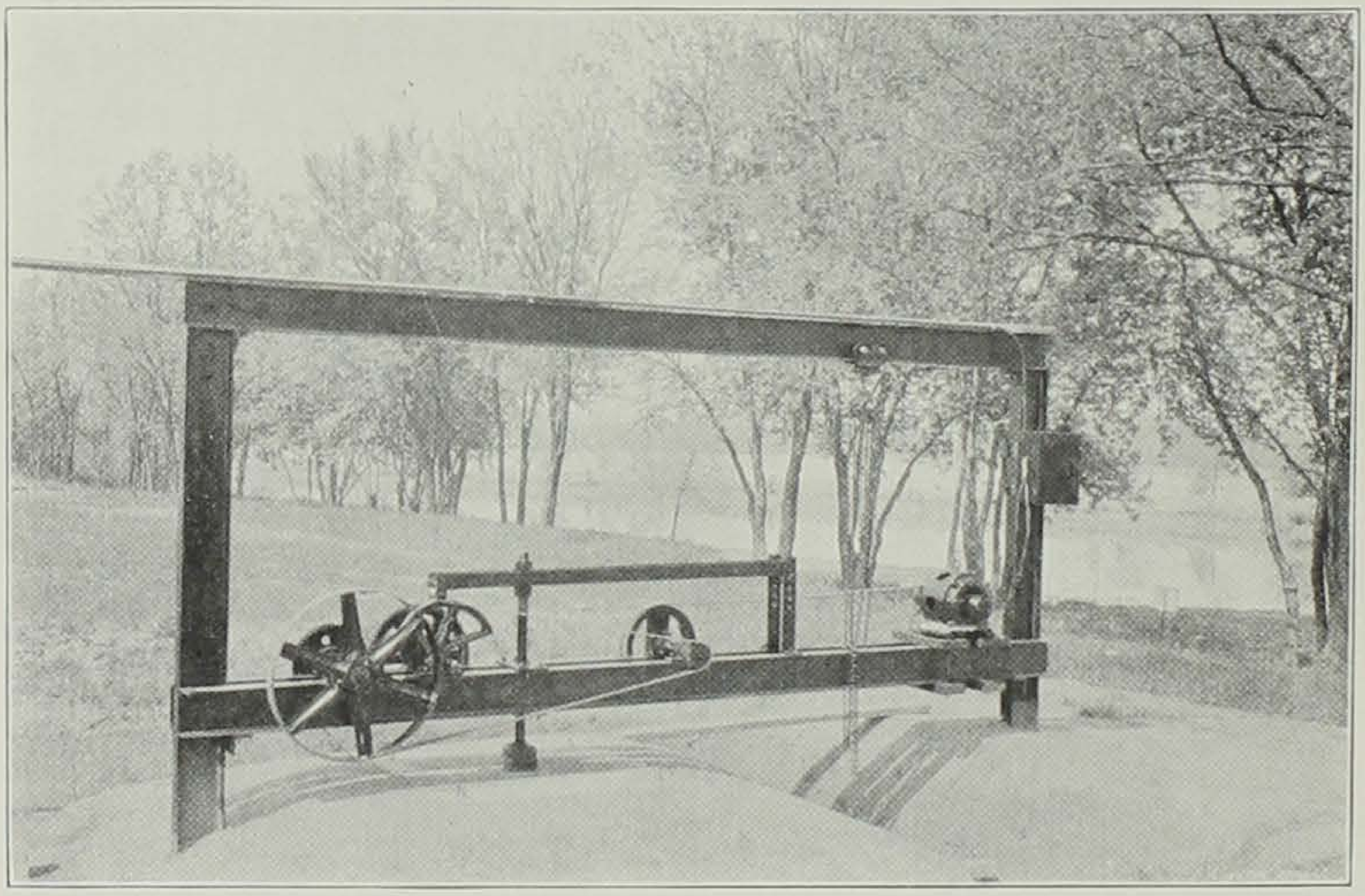


FIGURE 17.—SOIL VIBRATOR

The intensity of the plunger blow is determined by an accelerometer. Both slab and subgrade are caused to vibrate by the dropping of the plunger.

Used to determine the increase in capillary moisture in the subgrade, due to vibration of the slab and subgrade, in subgrade investigations, Arlington Experimental Farm, Arlington, Virginia.

Designed and constructed by the U. S. Bureau of Public Roads.

APPARATUS FOR DETERMINING SUBGRADE TEMPERATURES

The apparatus for determining subgrade temperature, shown diagrammatically in Figure 18, consists of (1) thermo couples, (2) mercury contact panel, (3) constant temperature unit, and (4) potentiometer. The thermo couples consist of two wires, copper and constantan (60% Cn.—40% Ni.) soldered together and inserted in glass tubes, which are sealed with paraffin throughout their entire length to prevent leakage of electricity or water. The leads from the tubes are enclosed in rubber tubing of sufficient length to reach above the surface. The tubes are sealed with sealing wax. The mercury contact panel consists of a number of small cups, so arranged that electrical contact with them can be made. The cups are filled with mercury. The constant temperature unit consists of a commercial vacuum flask, in which is inserted a glass tube containing about 1 inch of mercury. The copper wire of each thermo couple is connected to one of the small cups in the contact panel. The constantan wires of the thermo couple are connected to the constantan lead, whose one end is inserted in the mercury in the constant temperature unit. A copper wire inserted in the same mercury is connected to one of the leads of the potentiometer. To the other lead of the potentiometer is connected a copper wire having a bare point. The difference in temperature between the constant temperature unit and the thermo couples is indicated by the resistance required to sustain constant potential in the system. Observation for temperature of any thermo couple is made by inserting the bare end of the copper wire attached to the potentiometer into the mercury cup, to which is attached a copper wire leading to the respective thermo couple, and reading the resistance necessary for maintaining constant potential. All wires exposed to the atmosphere are protected by a coating of shellac.

Used to determine temperatures in slabs and at various depths in the subgrade beneath, at the Arlington Experimental Farm, Arlington, Virginia.

Adapted to this use by the U. S. Bureau of Public Roads.

Illinois: Illinois Division of Highways.

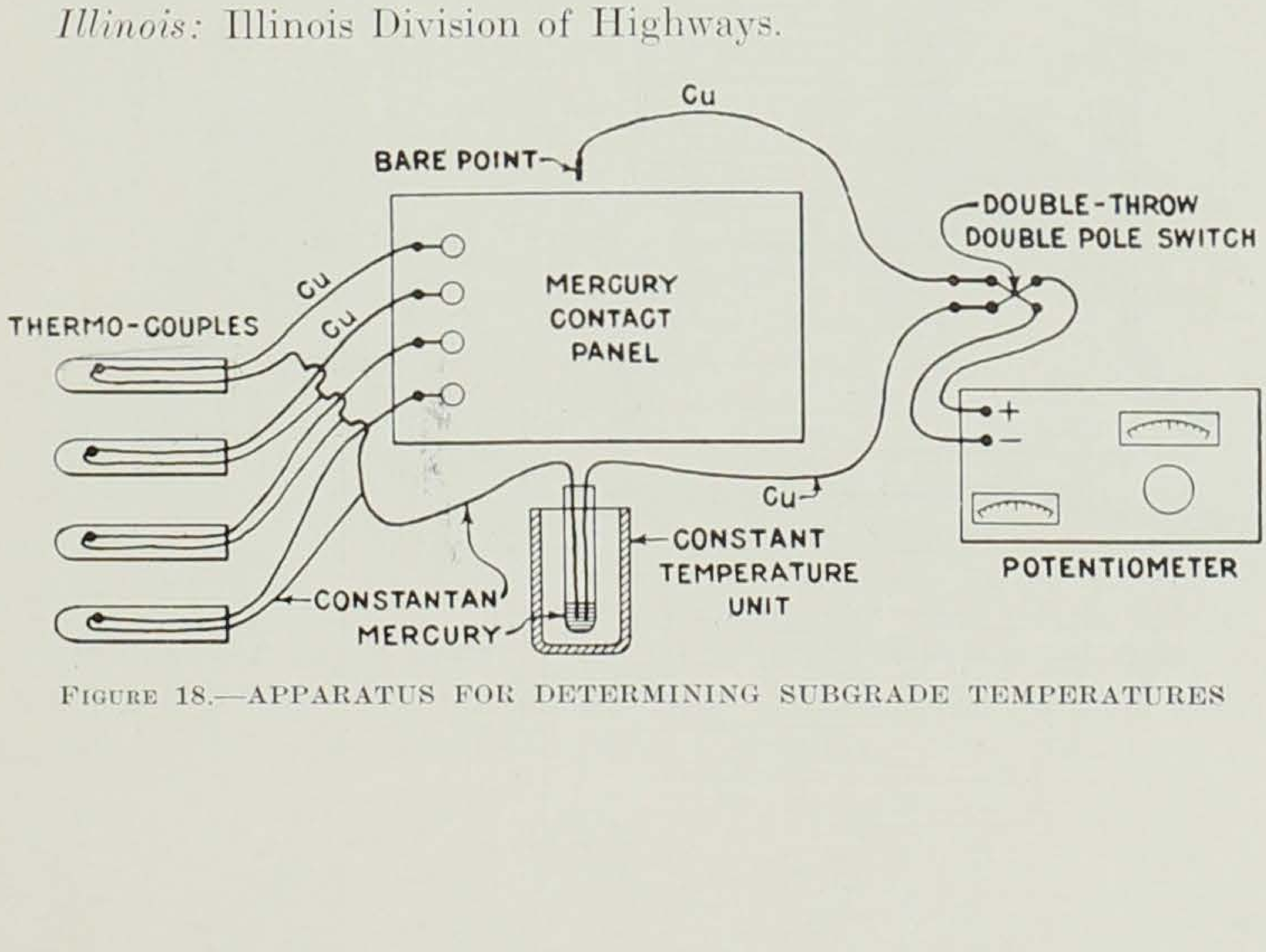


FIGURE 18.—APPARATUS FOR DETERMINING SUBGRADE TEMPERATURES

STATIC-LOAD BEARING POWER DETERMINATOR

The static-load bearing power determinator (Figure 19), consists of a three-legged, iron-pipe frame, carrying a Toledo Automatic Hanging Scale, from which is suspended a pail containing about 30 pounds of shot. The load is applied to the subgrade by means of a steel rod, terminating in a brass shoe. This rod supports a pan, which receives the shot from the pail. A thumbscrew in the frame enables the operator to control the rod movement, which is measured by an Ames dial. An initial reading is taken, with the shoe resting on the subgrade without any load, after which the shot is released and readings are taken for total loads of 10, 20, and 30 pounds. Additional readings are then taken for two minutes at intervals of

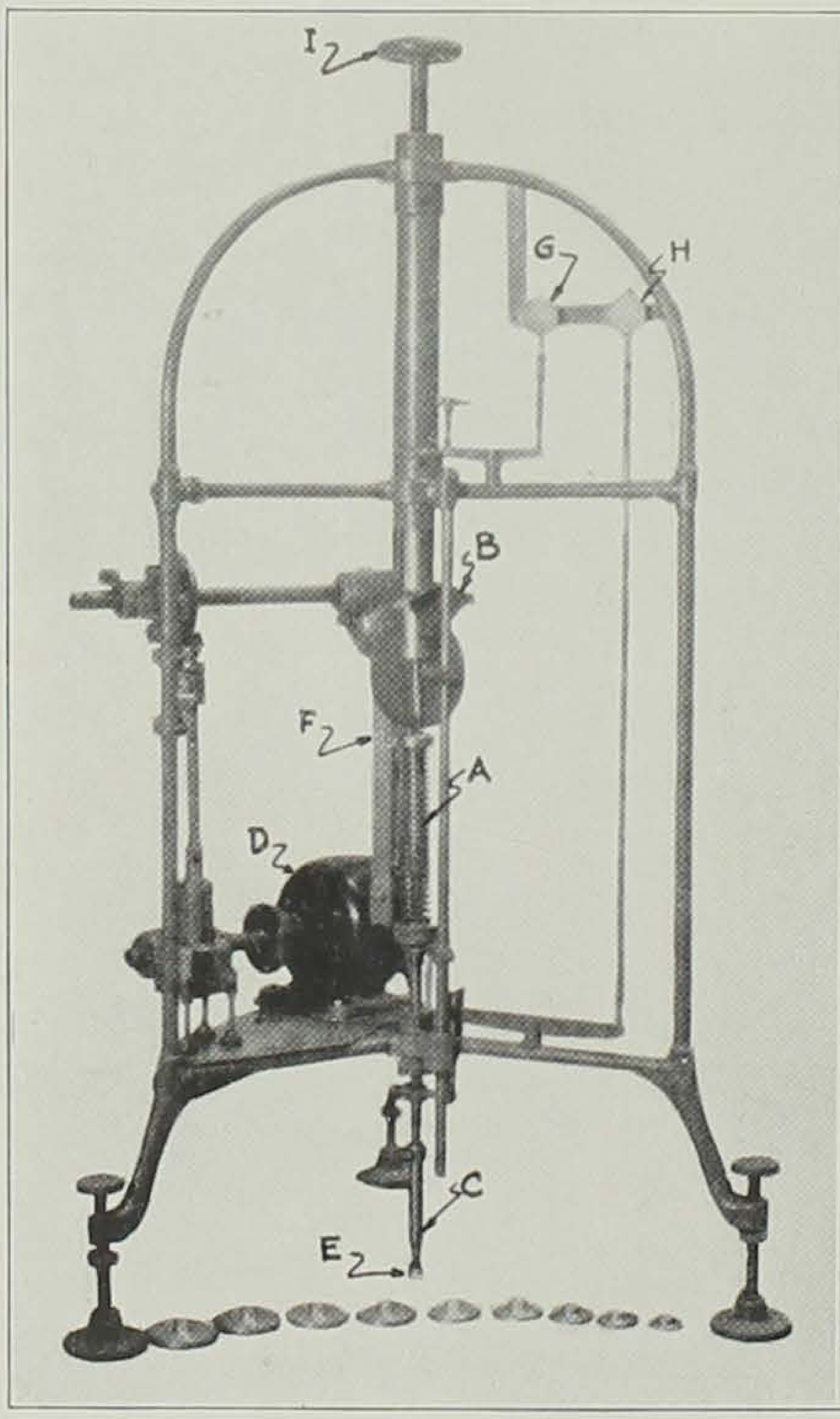


FIGURE 20.—ILLINOIS REPEATED-LOAD BEARING POWER DETERMINATOR

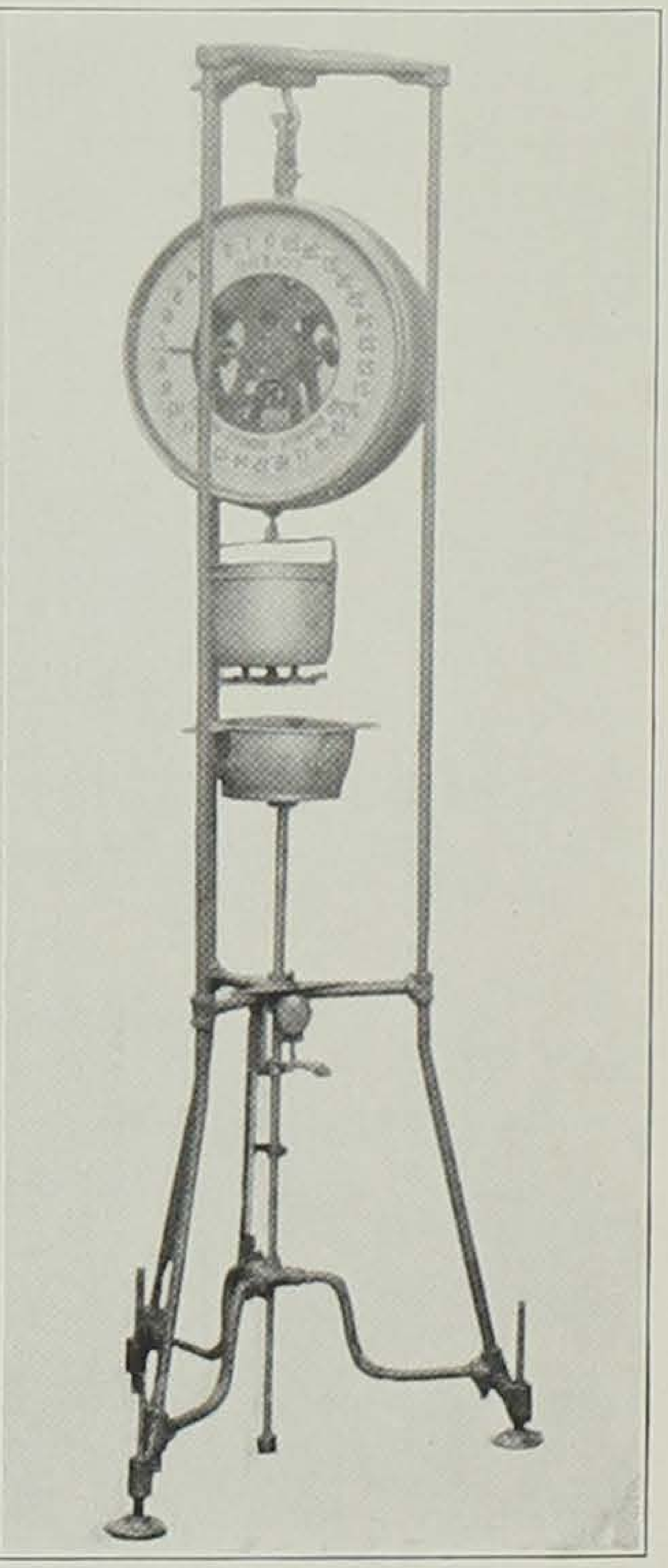


FIGURE 19.—ILLINOIS STATIC-LOAD BEARING POWER DETERMINATOR

thirty seconds under the 30-pound load. The load is then removed and the upward movement of the rod is measured.

Used in 1920 and 1921, during the construction of the Bates experimental road in the study of the relative supporting values of the subgrade under various sections of the road.

Designed by Clifford Older, Chief Highway Engineer, Illinois Division of Highways, and B. H. Piepmier, former Engineer of Construction, Illinois Division of Highways.

Described in "Preliminary Report on Bates Road Tests," by Clifford Older and H. F. Clemmer, Public Roads, Vol. 4, No. 5, September, 1921.

Constructed by Illinois Division of Highways.

ILLINOIS REPEATED-LOAD BEARING POWER DETERMINATOR

The repeated-load bearing power determinator (Figure 20), consists mainly of a pipe frame, in which is mounted a spring (A) for producing pressure; a cam (B), which varies this pressure; a plunger (C), which transmits the pressure to the soil; a one-sixth horsepower D. C. motor (D), which drives the cam at a constant speed of six revolutions per minute; a footing (E), which is attached to the bottom of the plunger and distributes the pressure to the soil (footings of different areas are shown at the bottom of the machine in the illustration); a scale (F) upon which the pressure desired is set; an Ames dial (H), which registers the action of the soil under repeated loads; a wheel (I) which lowers the cam action; and a second Ames dial (G), which registers the vertical movement of this section.

The object of this instrument is to subject the soil to such pressure as might be expected under a road slab during the passage of vehicles. By use of the cam the pressure is increased gradually from zero to maximum, and then decreased to zero. This is similar to the pressure exerted at any point in the subgrade as a moving vehicle passes over a rigid slab. The time of application of load with this apparatus is such as would be expected from a vehicle traveling over a 7-inch concrete surface at the rate of about 15 miles per hour. By changing the spring pressure, the magnitude of the load can be made similar to that which would occur under any thickness of slab. The effect of area of contact upon soil deformations caused by constant pressure intensity can be determined by use of shoes of different footings.

Used in 1921–22 on the Bates Experimental Road, and also in studies of subgrades in various parts of Illinois.

Designed by Clifford Older, Chief Highway Engineer, H. F. Clemmer, Engineer of Tests, and A. C. Benkleman, Assistant Engineer of Tests.

See "New Device for Testing Subgrade Bearing Power," by H. F. Clemmer, Engineering News-Record, September 15, 1921.

Constructed by Bureau of Tests, Illinois Division of Highways.

ILLINOIS SUBGRADE TESTING CYLINDER

The subgrade testing cylinder (Figure 21), consists of a 1¾ by 1½-inch black iron reducer (A), a short length of 1½-inch black iron pipe (B), a special 1¾-inch black iron plug (C), a special 1½-inch brass bearing plug (D), a short sleeve of 1¼-inch black iron pipe (E), and a 1¼ by 1½-inch brass disc (F). Plug (C) is flush with the surface of the concrete, and the disc (F) rests freely on

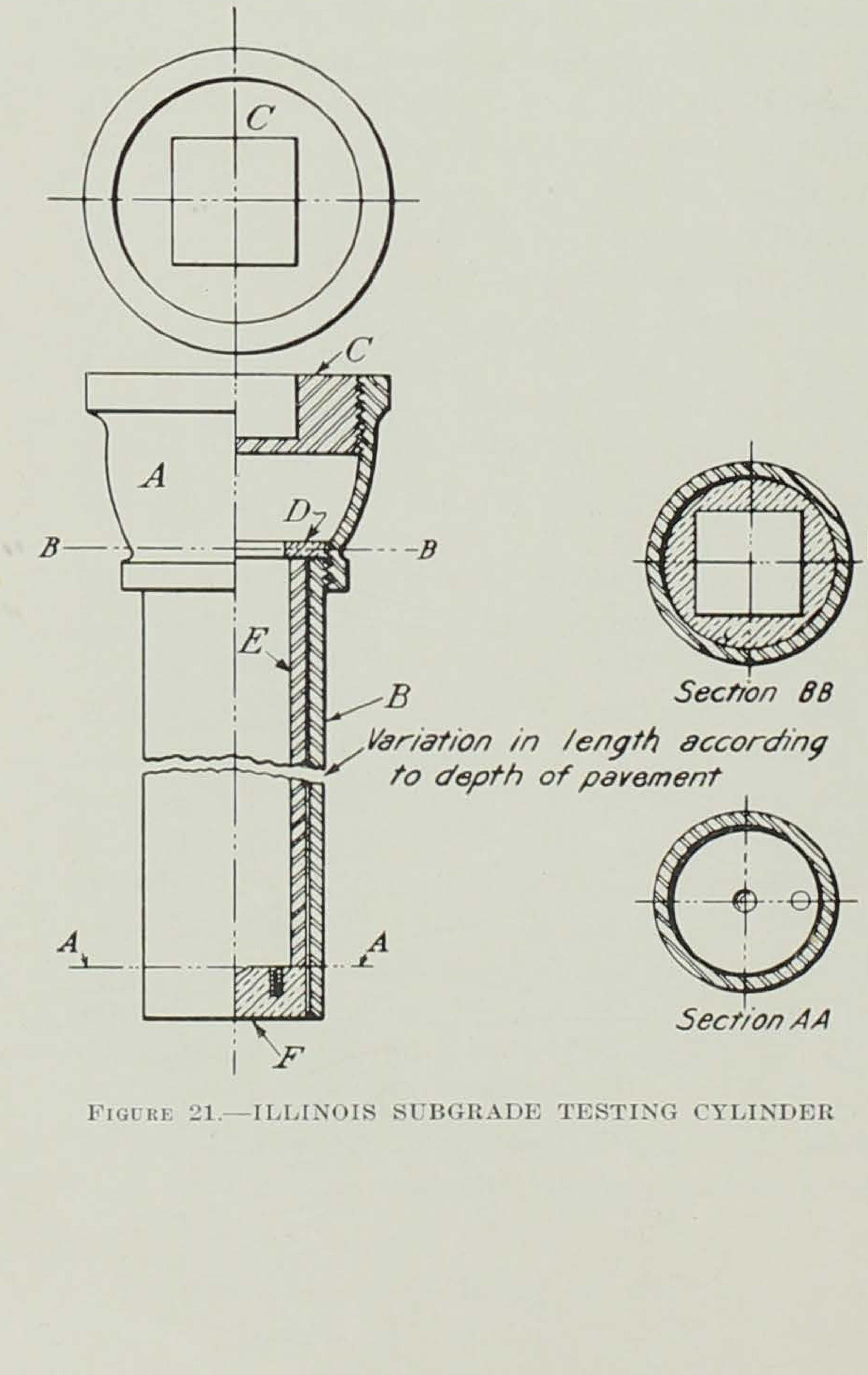


FIGURE 21.—ILLINOIS SUBGRADE TESTING CYLINDER

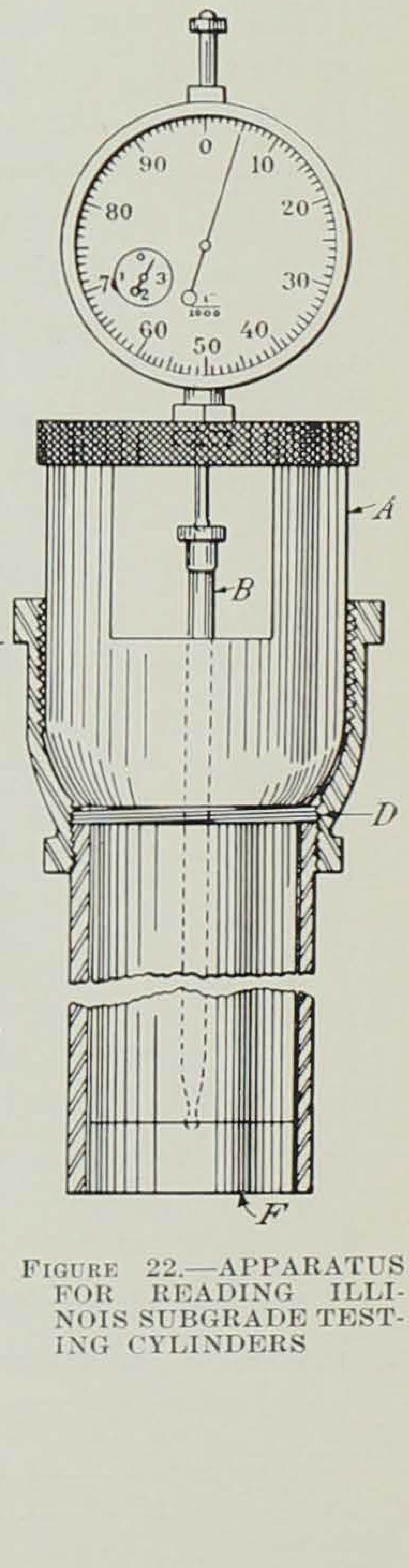


FIGURE 22.—APPARATUS FOR READING ILLINOIS SUBGRADE TESTING CYLINDERS

the subgrade. The length of the pipe (B) and the sleeve (E) varies with the depth of the pavement in which the tester is placed. An Ames dial arranged in a special apparatus (Figure 22), is used for reading these testers. The support (A) into which the Ames dial is screwed, sits snugly against the brass plug (D). The plunger of the Ames dial rests on the rod (B), which fits in a small circular depression in the center of the disc.

The subgrade tester can be used for various purposes. With the special reading apparatus, separation between the subgrade and surface can be measured. By using the disc (F) as a footing for the static load determinator, the supporting value of the subgrade can be determined. By removing the brass bearing plug (D), and the disc (F), access is had for securing soil samples for the determination of moisture content or study of other properties.

Used in 1921–22 on Bates Experimental Road.

Designed by Clifford Older, Chief Highway Engineer, Illinois Division of Highways, H. F. Clemmer, Engineer of Tests, Illinois Division of Highways, A. E. Stoddard, Assistant Engineer of Tests, Illinois Division of Highways.

Described in Engineering News-Record, June 30, 1921.

Constructed by Bureau of Tests, Illinois Division of Highways.

2. Investigations of Road Surface, Structures and Appurtenances.

District of Columbia: U. S. Bureau of Public Roads.

WEAR TESTING MACHINE

As shown in Figure 23, the wear-testing machine consists of five cast-iron wheels, 48 inches in diameter by 2 inches wide, and each weighing 1,000 pounds, thus giving a unit wheel load of 500 pounds per inch width of tire. The wheels are mounted inside a channel-iron frame in such a way that each wheel, independently of the others, is free to move up and down, and thus adjust itself to any inequalities or depressions in the pavement.

It was designed to approximate the effect of action produced by heavily-loaded, steel-tired trailers or horse-drawn vehicles.

Used to produce wear on pavement sections in U. S. Bureau of Public Roads Wear Test on Pavement Sections, Arlington Experimental Farm, Arlington, Virginia. The machine was pulled back and forth over the test sections by means of an endless steel cable driven by a 30-horsepower gasoline engine, and traveled at the rate of five miles per hour.

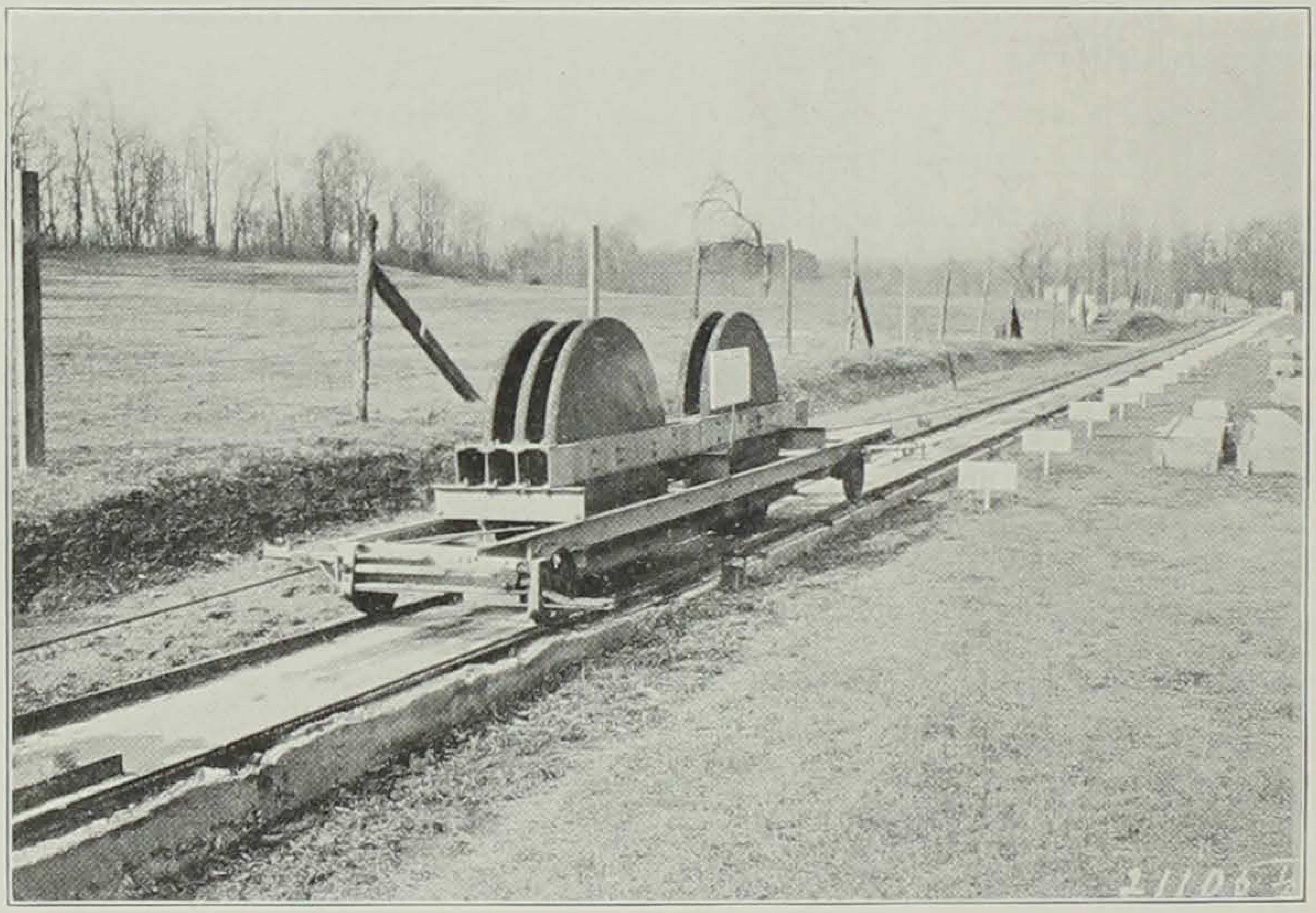


Figure 23.—Wear Testing Machine

Designed and constructed by the U. S. Bureau of Public Roads.

See "Report of Wear Tests on Pavement Sections," by F. H. Jackson and C. A. Hogentogler, Public Roads, Vol. 4, No. 2, June, 1921.

ABRASION APPARATUS

As shown in Figure 24, the abrasion machine consists of two wear-producing wheels, A and B, so arranged in a steel-frame, 4-wheel truck that the position of the wheels on the axles can be changed and the wheel loads can be varied. The wheel (B) through which the power is applied for propelling the apparatus, simulates the action of the rear wheel of a motor vehicle, while the wheel (A), which moves freely, corresponds to a front wheel. The apparatus is driven by an electric motor to which the power is supplied by means of a third rail and plow.

Used in investigations of wear of different types of concrete surfaces, Arlington Experimental Farm, Arlington, Virginia, by the U. S. Bureau of Public Roads.

Designed and constructed by the U. S. Bureau of Public Roads.

See "What the Arlington Investigations Are Showing," paper presented by A. T. Goldbeck at the annual meeting of the American Road Builders' Association, Chicago, Illinois, January 16, 1923.

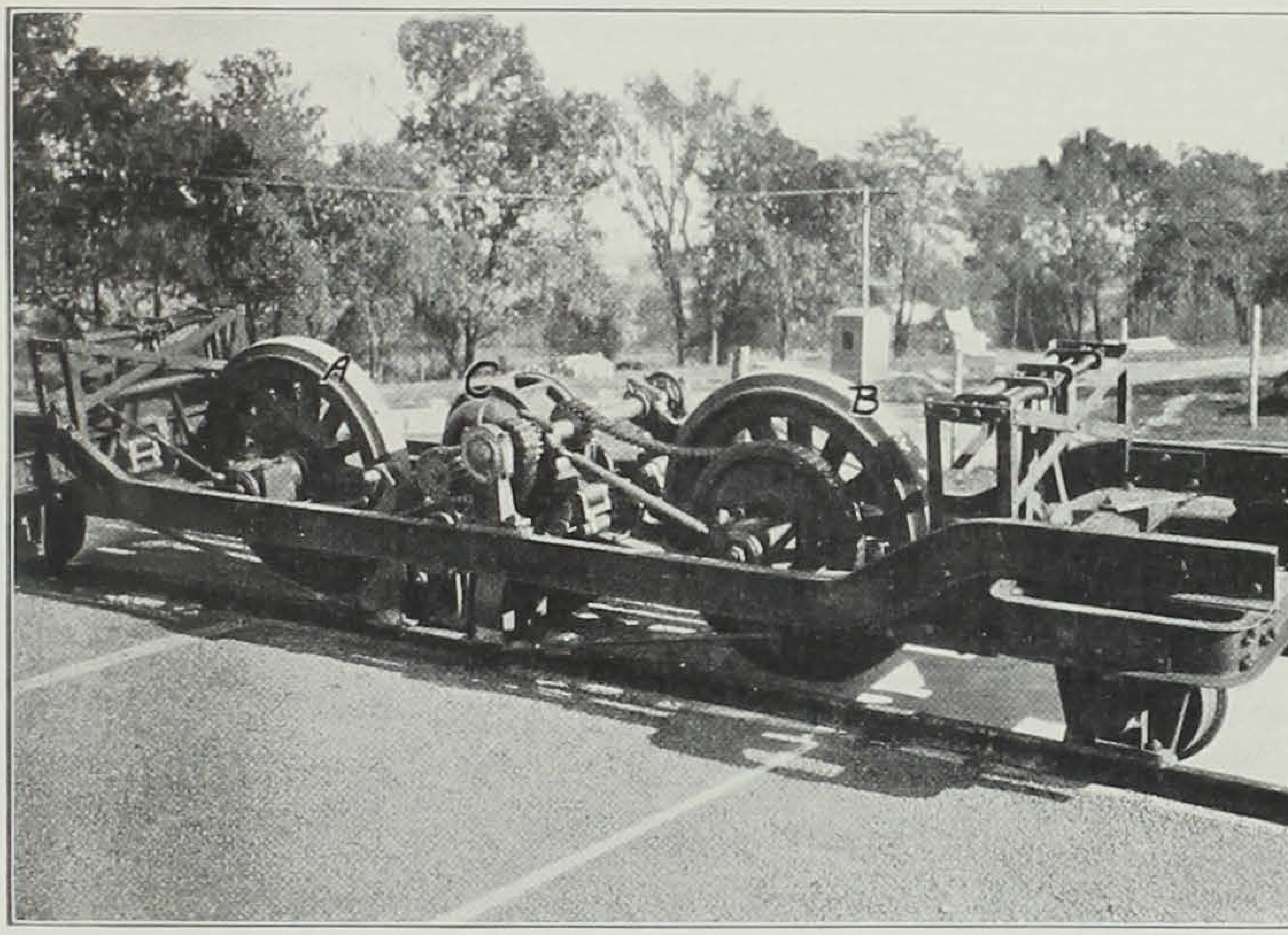


FIGURE 24.—ABRASION APPARATUS

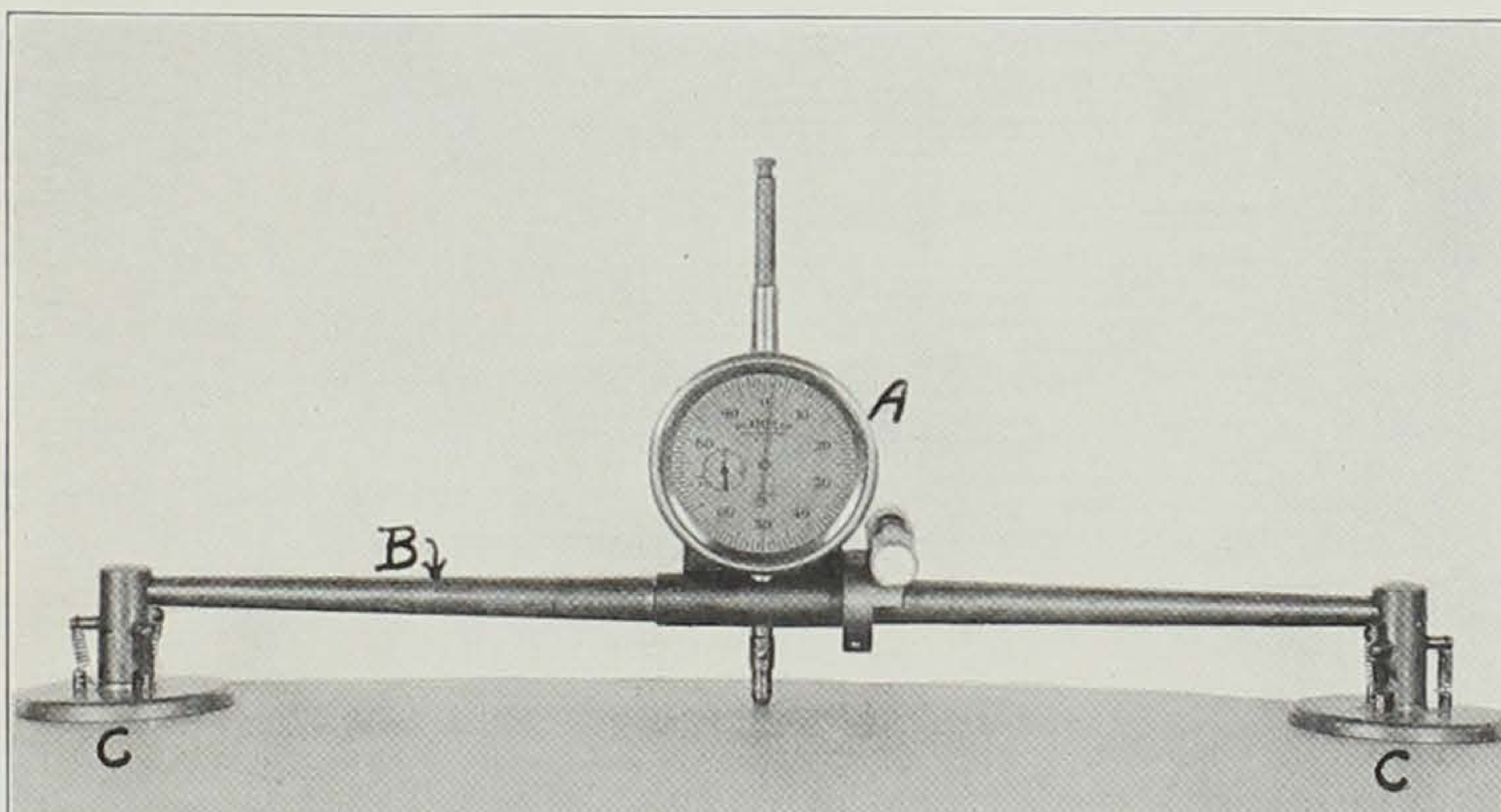


FIGURE 25.—WEAR MEASURING INSTRUMENT

WEAR MEASURING INSTRUMENT

The device, as shown in Figure 25, consists of an Ames dial (A) mounted on a brass beam (B) supported at each end by a swivel footing (C). The footings rest on the pavement surface and the dial plunger rests on a datum, which consists of a brass plug in a small brass cylinder set in the pavement surface. Between observations, the brass plug, which is about ½ inch below the top of the pavement, is protected by cotton waste and putty placed above it in the cylinder whose top edge is flush with the surface. The wear of the surface is indicated by the difference in dial readings in successive observations.

Used in investigation of wear of different types of concrete surfaces, Arlington Experimental Farm, Arlington, Virginia, and by the U. S. Bureau of Public Roads in co-operation with the Delaware State Highway Department, to determine surface wear of concrete roads.

Designed and constructed by the U. S. Bureau of Public Roads.

SLAB IMPACT MACHINE

This apparatus consists of a loaded box riding on a 5½-ton spring, which in turn is supported by a loaded frame or plunger on the bottom of which is a section of double 2 by 6 inches solid-rubber tire. The box and plunger, representing the sprung and unsprung weights, respectively, can be so loaded as to represent a truck of any size or load. By means of a motor, gears, and cam, the plunger or unsprung weight carrying the spring and sprung weight, can be lifted and dropped from any height so that the effect produced approximates that of a motor-truck wheel dropping from one level to another, dropping into a hole or falling to the pavement after striking an obstruction.

Used to test pavement sections in impact tests of the U. S. Bureau of Public Roads, Arlington Experimental Farm, Arlington, Virginia.

Designed and constructed by the U. S. Bureau of Public Roads.

See "Impact Tests on Pavement Sections," by C. A. Hogentogler, Public Roads, Vols. 6 and 7, October and November, 1921.

PORTABLE IMPACT MACHINE

This machine consists, as shown in Figure 26, of a motor-truck wheel supported in a heavy frame which in turn is carried on a heavy, motor-truck spring. This constitutes the unsprung weight and is supported in a vertical motion by means of cams carried on the outside, supporting, angle-iron frame. The apparatus is electrically driven. The height of the drop of the truck wheel can be varied from 0 to 6 inches and the rate of application of load from 6 to 10 drops per minute. By varying the spring pressure and using suitable wheels and weights, a range of impacts from 0 to those which would be expected from the heaviest of motor trucks, can be obtained.

Used to test pavement sections by the U. S. Bureau of Public Roads, Arlington Experimental Farm, Arlington, Virginia.

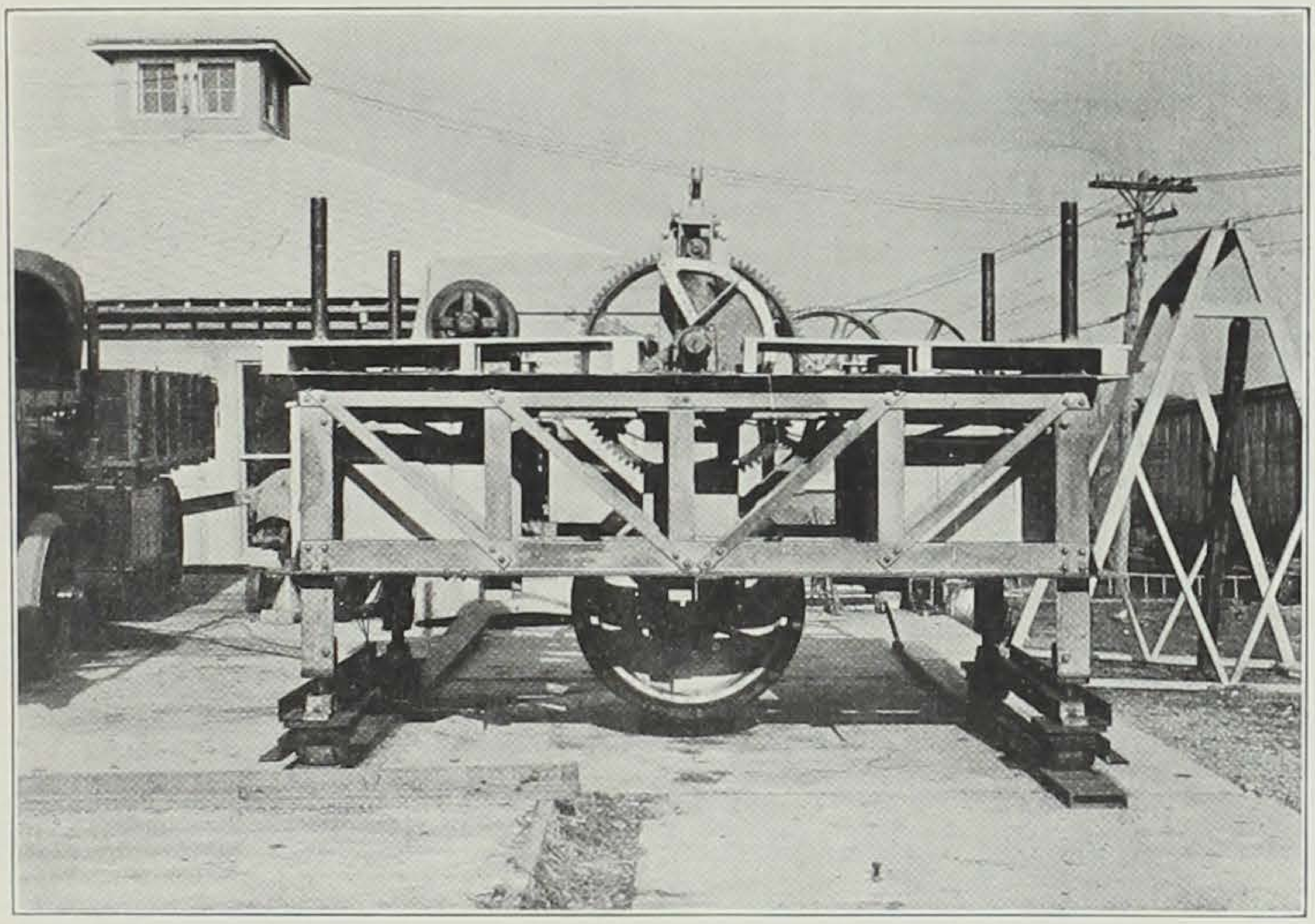


FIGURE 26.—PORTABLE IMPACT MACHINE

Designed and constructed by the U. S. Bureau of Public Roads.

See "What the Arlington Investigations Are Showing," paper presented by A. T. Goldbeck at the annual meeting of the American Road Builders' Association, Chicago, Illinois, January 16, 1923.

SPACE-TIME RECORDER

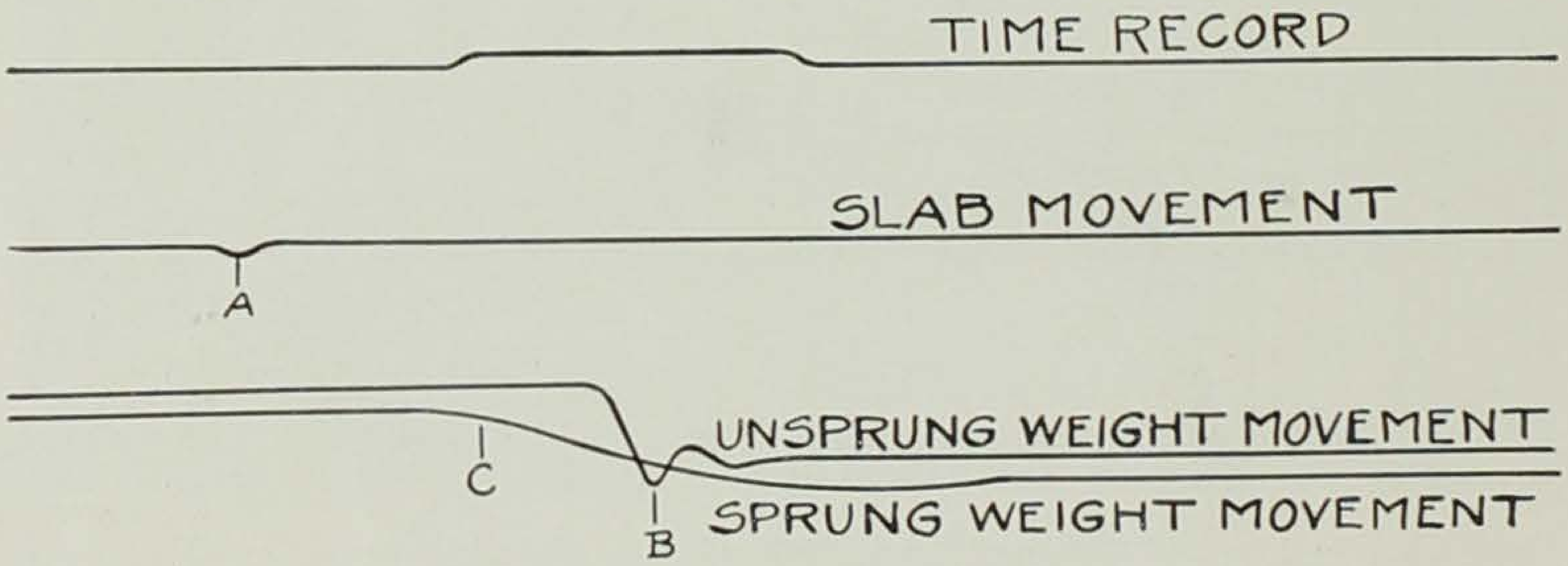
This apparatus, which was attached to the first impact machine, consists of a revolving drum 5 inches in diameter over which is drawn a band of siliconized paper. Three brass points resting against this paper and connected by means of a ¼-inch square steel rod to the respective parts, record the vertical movements of the sprung and unsprung weights as well as the deflections of the test slabs under impacts. A fourth brass point actuated by an electric magnet, records the time in seconds. An enlarged record secured from one drop of the plunger of the impact machine is shown in Figure 27. The slab deflection as shown at A occurs when the unsprung weight has reached its lowest position at B, while the position of the sprung weight at the same time is shown at C.

An improved form of the space-time recorder was attached to the second impact machine. Besides having modifications in the mechanical details, this apparatus was electrically driven, and the time was recorded every .03 of a second.

Used to measure impacts delivered by the impact machine, Arlington Experimental Farm, Arlington, Virginia.

Designed and constructed by the U. S. Bureau of Public Roads.

For complete details of apparatus and methods of computing impact force from space-time curves, see "Impact on Pavement Section," by C. A. Hogentogler, Public Roads, Vol. 4, No. 6, October, 1921, and "Measurement of Impact," by E. B. Smith, Proceedings of the A. S. T. M., 1921.



AUTOGRAPHIC RECORD OF $\frac{7}{8}$ INCH DROP OF PLUNGER OF IMPACT MACHINE.

FIGURE 27

ACCELEROMETER FOR MEASURING IMPACT FORCES

This device, shown in Figure 28, consists of a metal frame supporting a flat steel spring (A) attached to which is a small weight or plunger (B). Any vertical acceleration to which the instrument is subjected is accompanied by a corresponding deflection of the spring. This deflection is measured in the following manner: The bottom of the plunger (B) is triangular in shape and rests in a triangular space in the frame of the apparatus. The sides of the triangular base and the triangular space are not parallel, and are separated by two steel rollers (C). As the plunger moves downward during the sprung deflection, the rollers held by small spiral springs follow the movement and prevent the plunger from returning to its

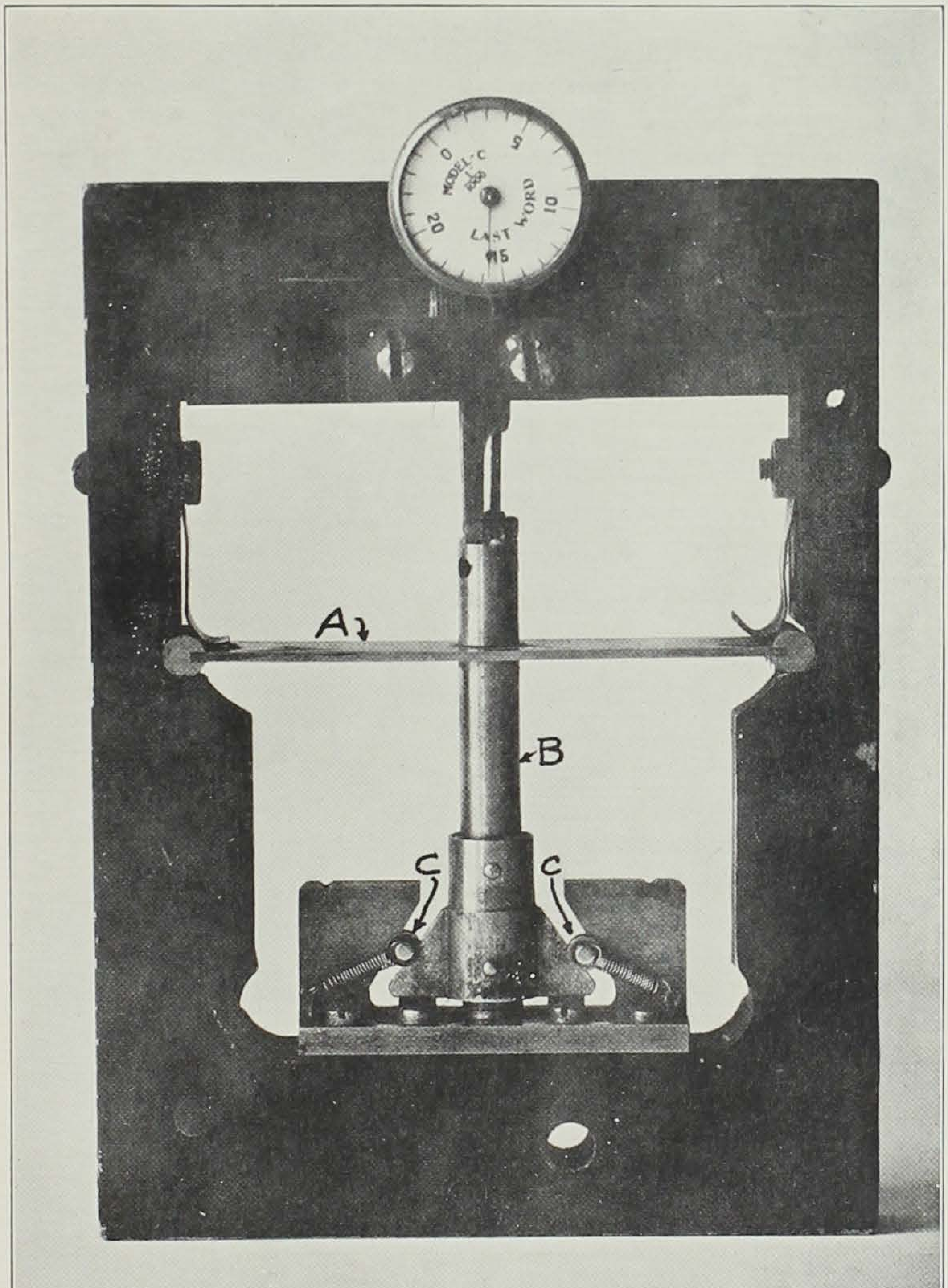


FIGURE 28.—ACCELEROMETER

original position. A Last Word dial is attached to the top of the frame with its stem resting on top of the plunger; thus the difference in elevation of the plunger before and after an impact occurs, is measured by the dial and represents the spring deflection. After properly calibrating the instrument, accelerations can be easily computed from the dial readings.

The instrument has been used to measure impacts delivered by the portable impact machine (see B, Figure 33) at the Arlington Experimental Farm, Arlington, Virginia. If it is attached to a truck running over a road, it will record the maximum acceleration which occurred during the operation.

Designed and constructed by the U. S. Bureau of Public Roads.

MIRROR ACCELEROMETER FOR MEASURING IMPACT FORCES

This device, shown in Figure 29, is a modification of the one described above. The spring (A) and the small weight (B) are similar to those used in the first instrument, but for measuring the deflection a ray of light is used instead of the dial. A light ray from the lamp (E) passing through a lens (F) and striking a mirror pivoted at D, is reflected on the ground glass (G) shown at the top of the frame. Any movement of the plunger (B) causes a slight rotation of the mirror and changes the position of the ray of light reflected on the ground glass. A small brake (C), resting against the mirror, holds the mirror in its position of maximum rotation until the measurement of the movement of the light ray on the ground glass can be secured. To facilitate this measurement, the ground glass has a scale cut on it. After the proper calibration, the acceleration can easily be determined from the distance which the light ray moves on the ground glass.

Used at the Arlington Experimental Farm, Arlington, Virginia, and in studies of the effect of roughness of different types of road surfaces.

Designed and constructed by the U. S. Bureau of Public Roads.

APPARATUS FOR MEASURING IMPACT BY USE OF SMALL COPPER CYLINDERS

This apparatus consists of a jack set in a concrete foundation in such a manner that the top of the jack is flush with the surrounding surface, as shown in Figure 30. Small copper cylinders, ½ inch in diameter by ½ inch high, having previously received special heat treatment to insure uniformity, are deformed in the jack by blows received on its top from moving motor-truck wheels. The force of the impact blow in each case is considered as equivalent to the weight in pounds which, applied statically, would cause the same deformation. By using different heights of drop and wedges and blocks on top of the jack, the effects of holes in the road surface, as well as of

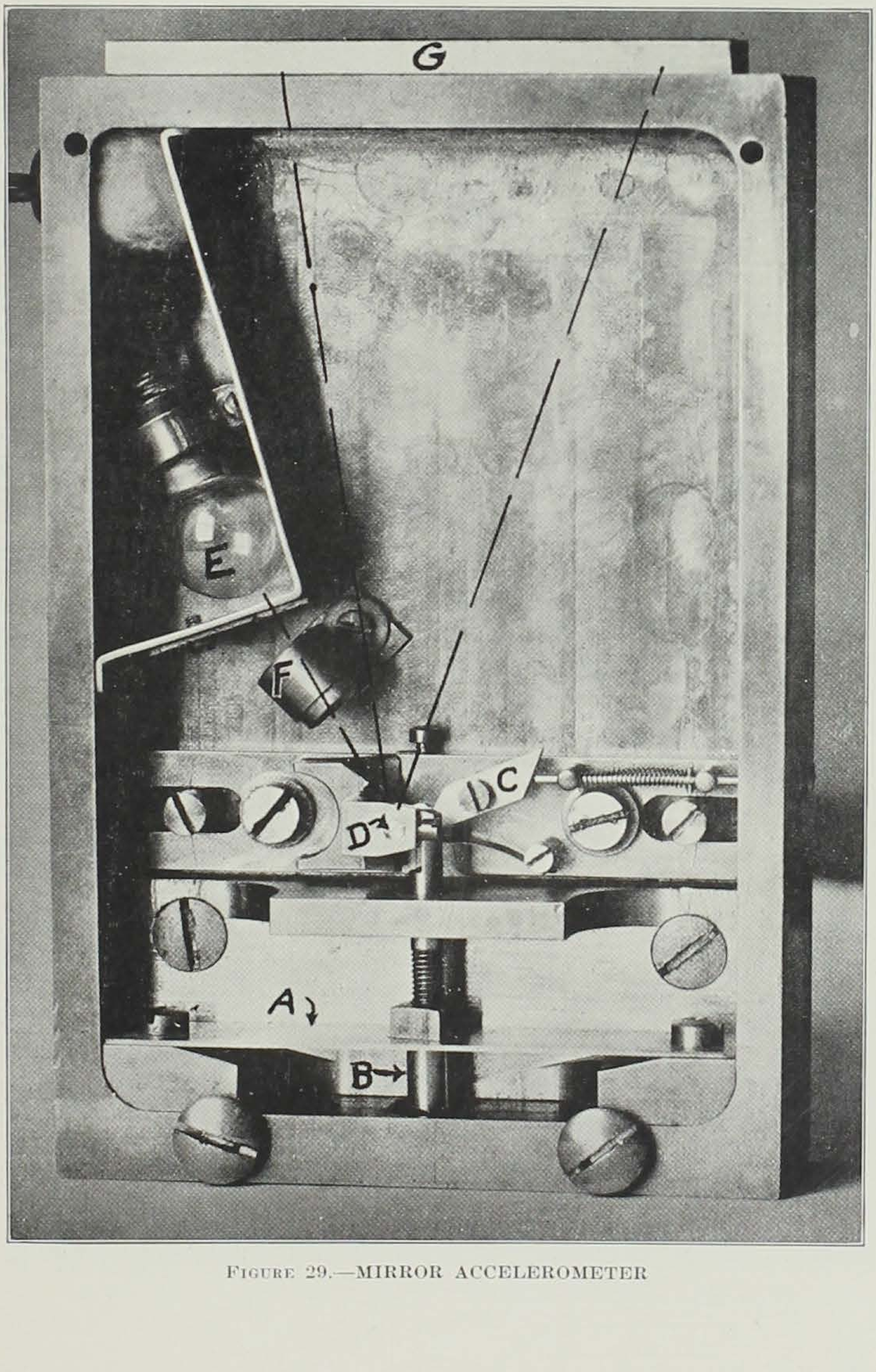


FIGURE 29.—MIRROR ACCELEROMETER

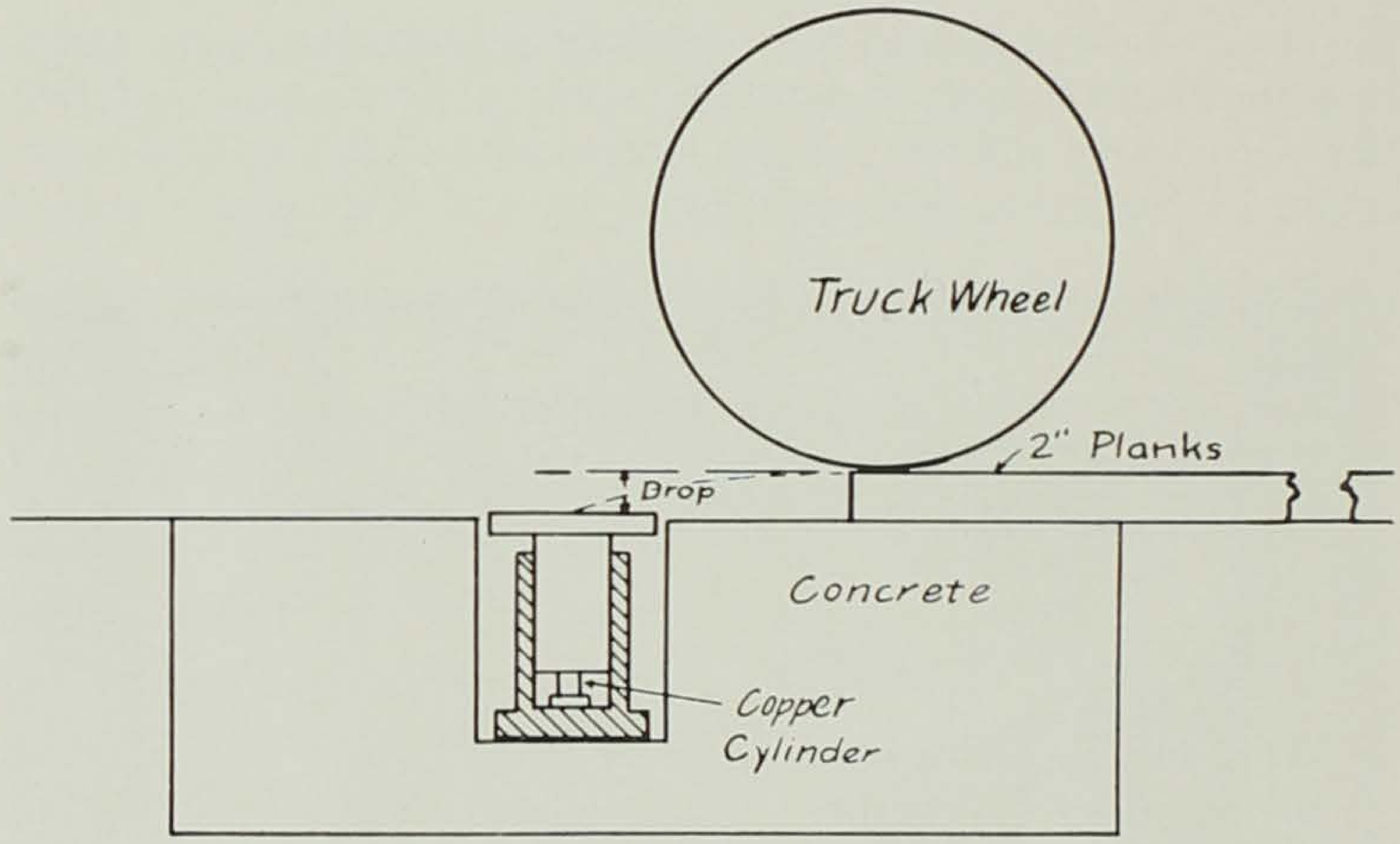


FIGURE 30.—APPARATUS FOR MEASURING IMPACTS BY USE OF SMALL COPPER CYLINDERS

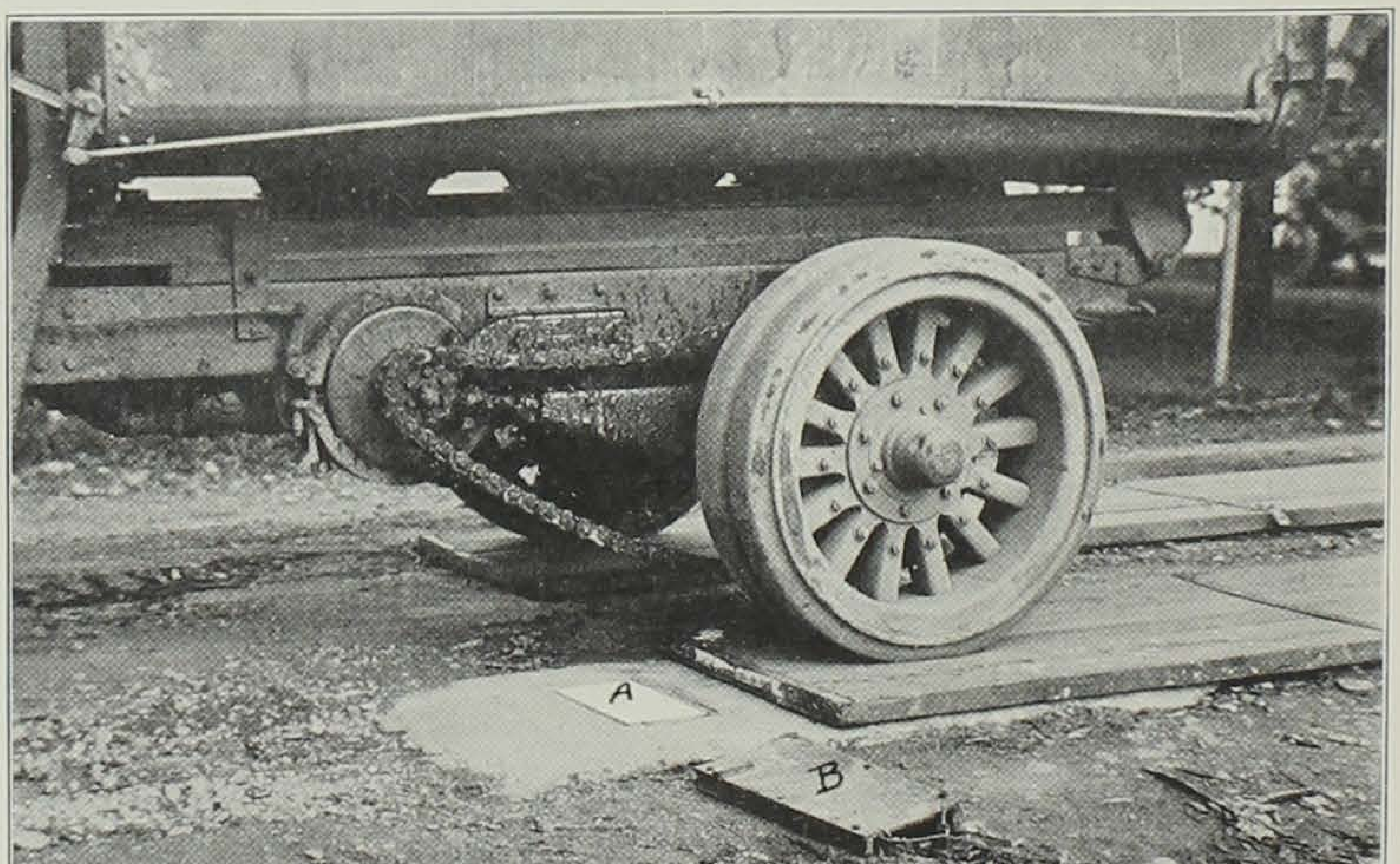


FIGURE 31.—MEASURING IMPACT OF REAR MOTOR TRUCK WHEELS

obstructions, have been simulated. Figure 31 shows the top of the jack (A) about to receive the blow from the truck wheel. The small piece of channel iron (B), with wire attached, spans the top of the jack during the passage of the front wheel, and is withdrawn to allow the blow of the rear wheel to be measured.

Used at Arlington Experimental Farm in impact tests of motor-truck wheels.

Adapted by the U. S. Bureau of Public Roads from method employed by the U. S. Army to determine force of explosives in guns.

See "Motor Truck Impact Tests of the Bureau of Public Roads," by E. B. Smith, Public Roads, Vol. 3, No. 35, Vol. 4, No. 8, March and December, 1921.

ADAPTATION OF KREUGER METHOD FOR MEASURING IMPACT

The apparatus consists of a jack, Figure 32, containing a chrome-nickel block with a flat surface against which rests a chrome-nickel block with a spherical surface. The area of contact between the two surfaces is dependent upon the force exerted upon the top of the jack. By calibration in a testing machine the load causing different

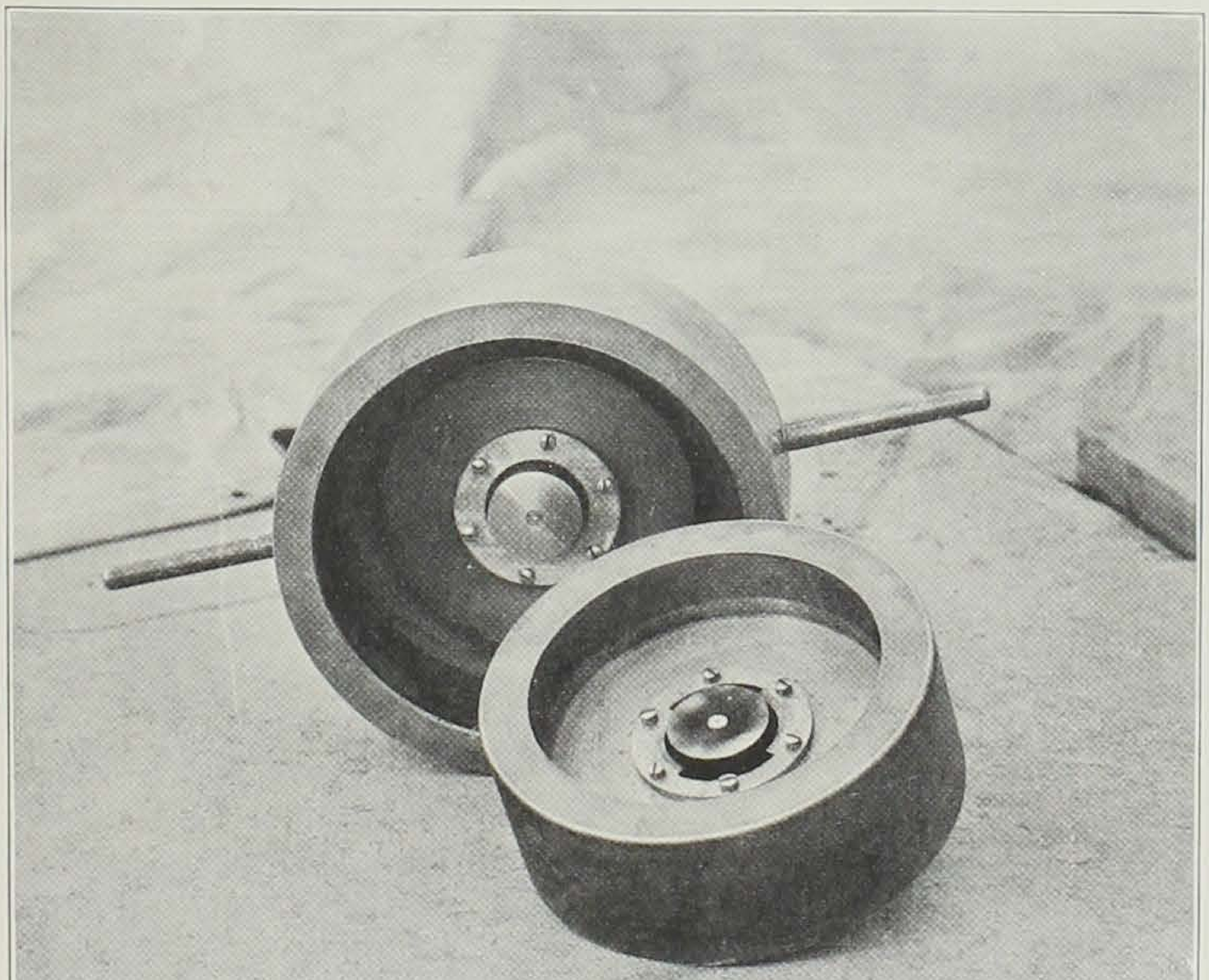


FIGURE 32.—ADAPTATION OF KREUGER METHOD FOR MEASURING IMPACT

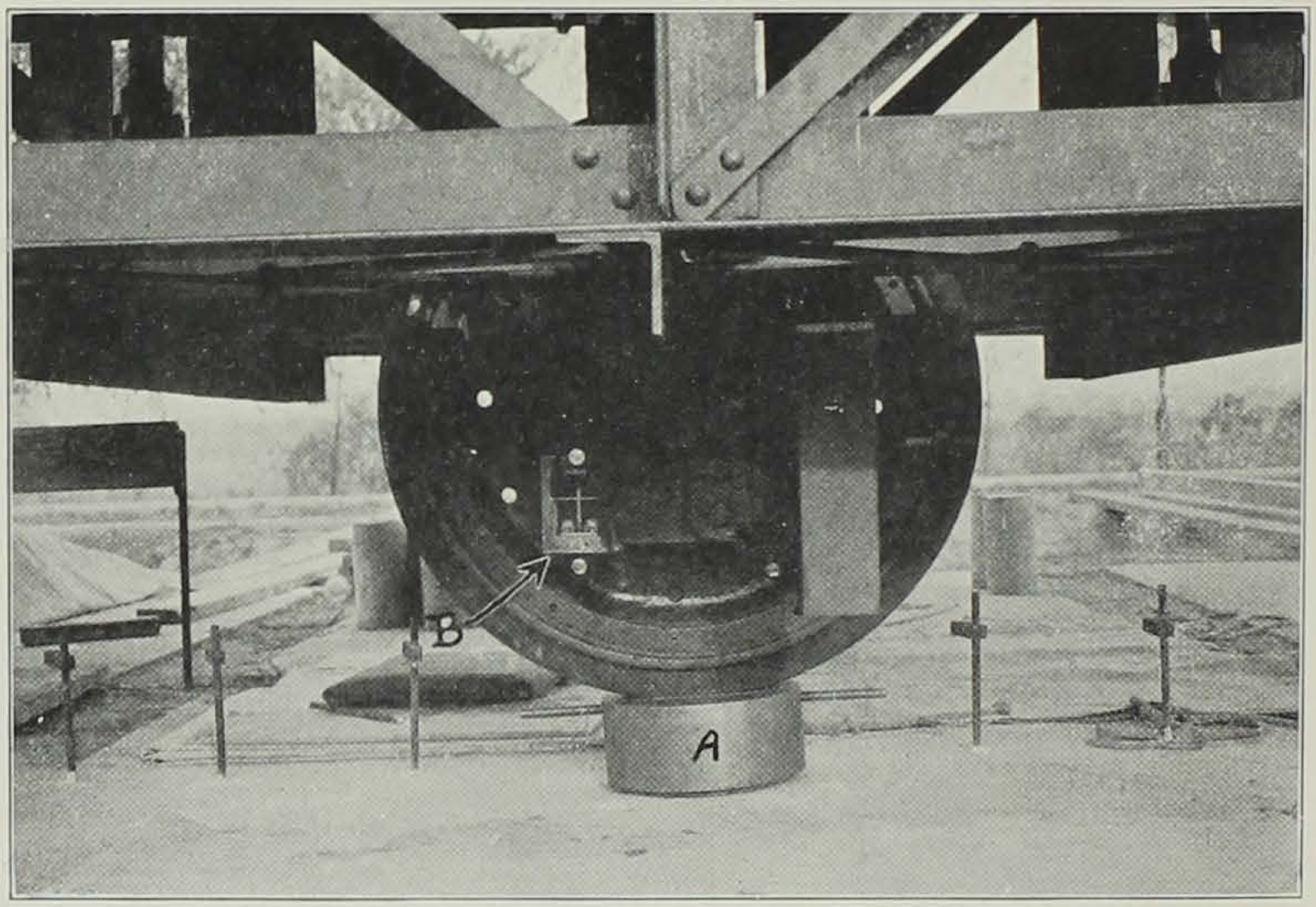


FIGURE 33.—MEASURING IMPACTS BY THE KREUGER METHOD

areas of contact is obtained and a curve showing the relation of load to contact is drawn. For the purpose of obtaining a record of the area of contact between the two blocks, the face of the one having the flat surface is smoked so that after the contact the area is plainly marked on the highly polished steel. From the calibration curve the force which caused a given area is easily ascertained. Figure 33 shows the jack (A) receiving a blow from the impact machine, while Figure 32 shows the impression made on the flat surface by its contact with the spherical block. The size of the blocks is such that no permanent deformation occurs under the forces to which they are subjected.

Used to determine the force of impacts delivered in the second series of impact tests at Arlington Experimental Farm, Arlington, Virginia.

See "Methods for Measuring and Calculating the Magnitude of Forces with Particular Regard to Impact Forces," by Professor Kreuger in Translations No. 2, Engineering and Science Academy, Stockholm, 1921.

INDICATOR FOR MEASURING VERTICAL MOVEMENT OF ROAD SLABS

The device (Figure 34) for measuring vertical movement of pavement edges, due to either warping or load, consists of a pointer ar-

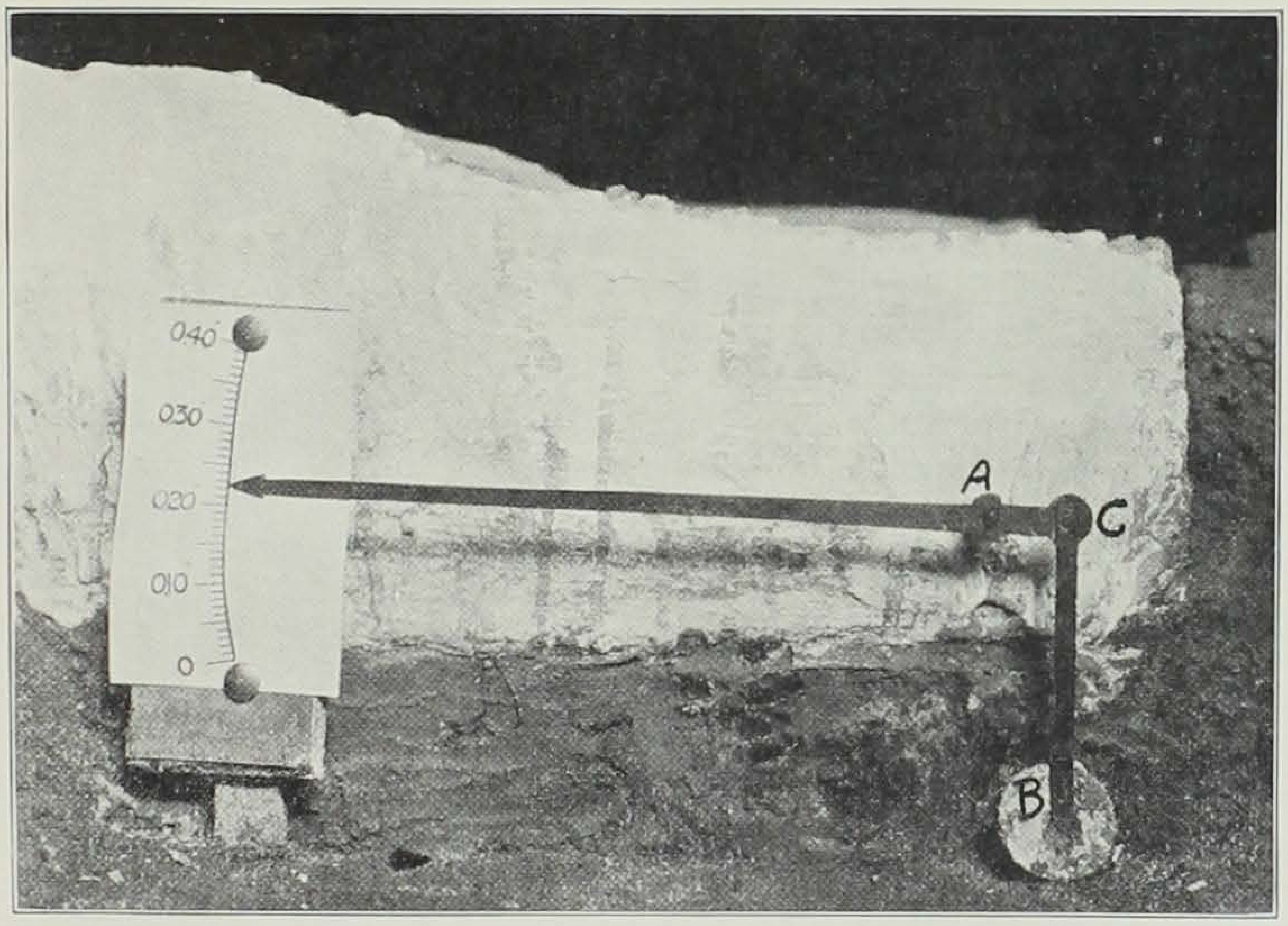


FIGURE 34.—INDICATOR FOR MEASURING VERTICAL MOVEMENT OF ROAD SLABS

ranged as a lever with one center (A) in the concrete and the other (B) in the subgrade. The movement at the free end of the pointer is ten times that of the end which receives the movement of the slab. The scale is increased by 10 so that the movement, as indicated on the scale, is the same as received by C or the actual movement of the slab with respect to the subgrade.

Used in making observations of warping of 18 by 30 feet concrete road slab at Arlington Experimental Farm, Arlington, Virginia.

Modification of the card scheme[2] used by the Illinois Division of Highways on the Bates Experimental Road.

Constructed by the U. S. Bureau of Public Roads.

ADAPTATION OF STRAINAGRAPH FOR RECORDING DEFLECTIONS OF ROAD SLABS

The strainagraph, set up as shown in Figure 35, records the vertical movement of road slabs due to warping. The movement of the corner of the slab is transmitted to the mechanism of the instrument by means of a rod (A) which is shown resting on the corner. The

[2] "Paving Slab and Subgrade Studies in Illinois," by Clifford Older, Engineering News-Record, January 12, 1922, page 81.

recording mechanism is driven by an electric motor so geared that an 8-day continuous record is secured on 50 feet of record paper.

Used at Arlington Experimental Farm, Arlington, Virginia, in the study of warping of road slabs.

Adapted by the U. S. Bureau of Public Roads.

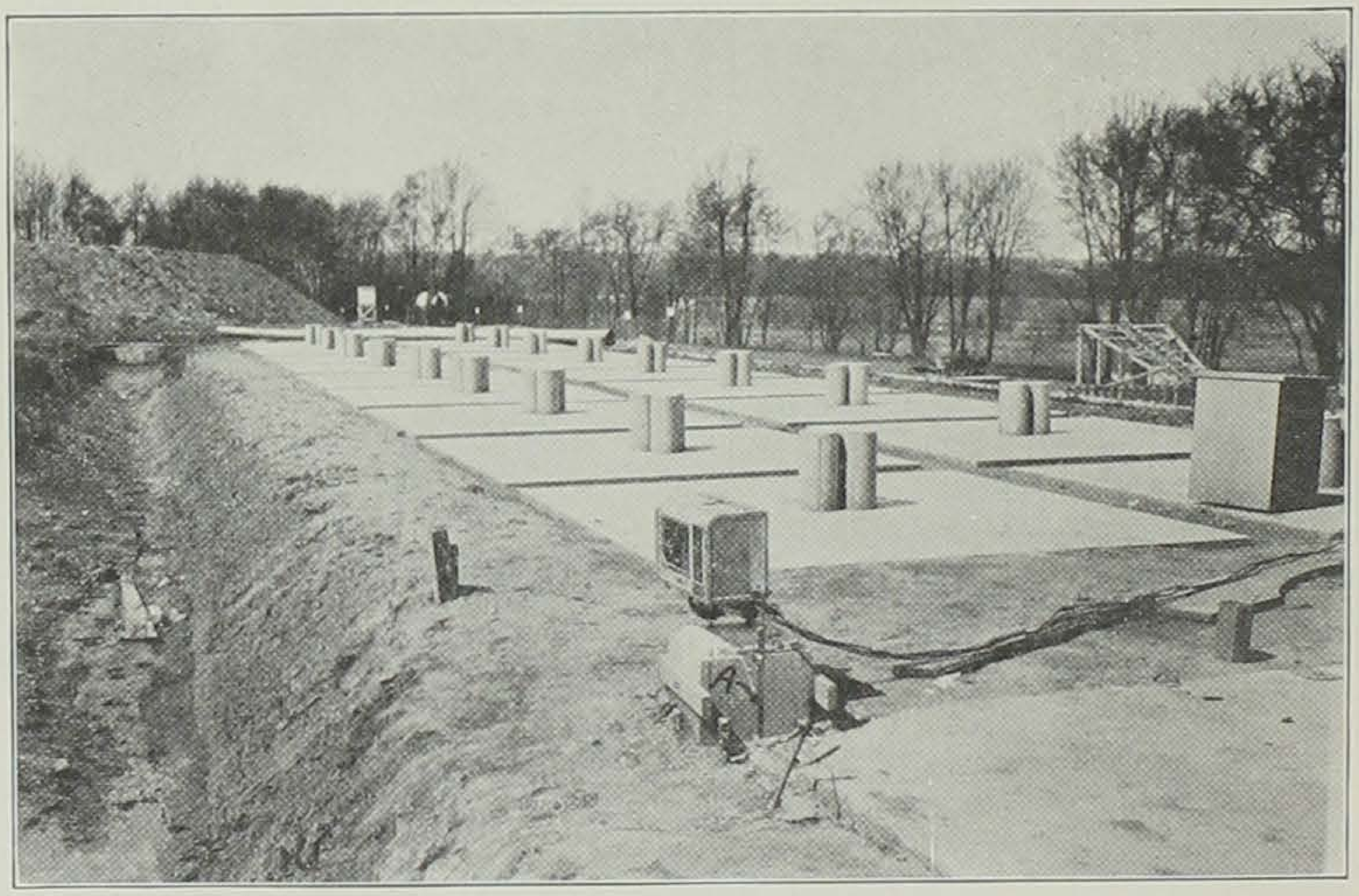


FIGURE 35.—RECORDING DEFLECTION OF ROAD SLAB WITH STRAINAGRAPH

APPARATUS FOR RECORDING AUTOGRAPHICALLY THE VERTICAL MOVEMENT OF PAVEMENT SLABS CAUSED BY WARPING OR LOADING

The apparatus, shown in Figure 36, consists of a motor-driven mechanism which draws a band of paper over a smooth board fastened to supports driven into the ground. The face of the board is parallel to the side face of the pavement surface. The highly-magnified, vertical movements of 20 points, 1 foot apart, on the side of the pavement surface, are recorded on the moving paper by as many pen points which are actuated by levers connecting them with the pavement. From these curves the shape of the side edge, and consequently an indication of stress existing therein, can be secured for any time and for any position of a motor-truck wheel. Used in the study of deflections of road slabs on the Columbia Pike Experimental Road, Arlington County, Virginia.

Designed and constructed by the U. S. Bureau of Public Roads.

See "What the Arlington Investigations Are Showing," paper presented by A. T. Goldbeck at the annual meeting of the American Road Builders' Association, Chicago, Illinois, January 16, 1923.

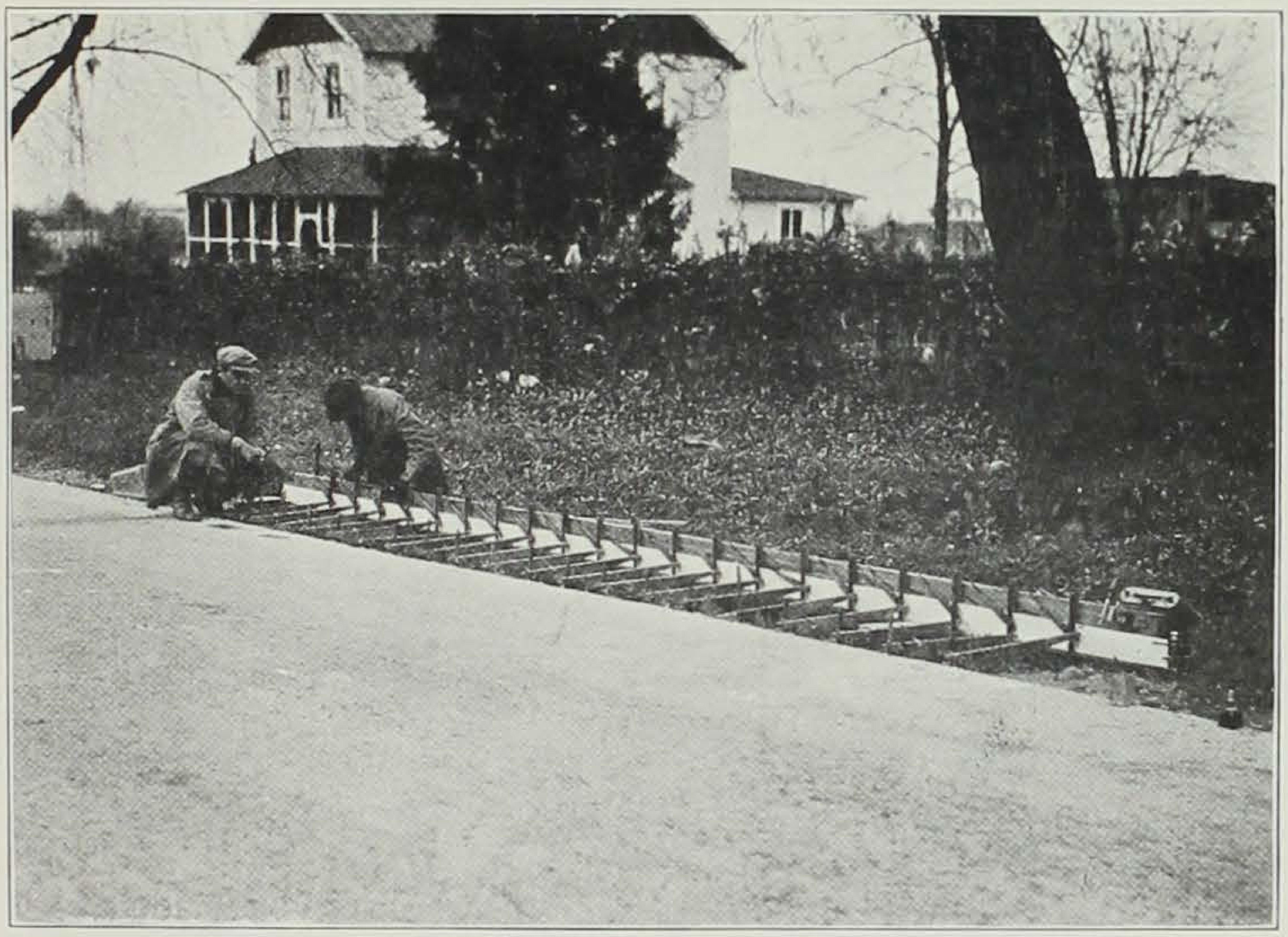


FIGURE 36.—APPARATUS FOR RECORDING AUTOGRAPHICALLY THE VERTICAL MOVEMENT OF PAVEMENT SLABS

STRAIN GAGE FOR DETERMINING MAXIMUM FIBRE DEFORMATION

This instrument is a modification of a similar device used by the Ohio State University. It consists of a distance bar to one end of which is attached a contact point; the other end rests against a small steel block in a steel cylinder. Spring pressure applied through a small plug causes sufficient friction to prevent free movement of the small steel block. In making an observation with this device, the gage points are set on the specimen, and the initial reading of the position of the block with respect to the end of the cylinder is made by means of the Ames dial, after which the load is applied. Any shortening of the distance between gage points is shown by an equal movement of the block. The final reading is taken with the Ames dial, the difference between the two readings indicating the fiber compression. To prevent movement of the block due to pressure of the dial stem during readings, it is held fixed in place by means of a set screw.

Used in the study of impact on highway bridges, co-operative research project carried on by the Iowa State Highway Commission, Iowa Experiment Station, and U. S. Bureau of Public Roads.

See Bulletin No. 63, Iowa State College of Agriculture and Mechanic Arts, "Preliminary Impact Studies, Skunk River Bridge on Lincoln Highway Near Ames, Iowa," by Almon H. Fuller.

TEN-FOOT MICROMETER STRAIN GAGE

This instrument consists essentially of two measuring tubes, one steel, one brass, supported so they cannot bend, and provided with rounded tips against which measurements are made with micrometer screws. By means of micrometer measurements, corrected to constant temperature, changes of length between plugs set in the concrete road are obtained.

The measuring tubes are supported at frequent intervals by brass discs fastened within a brass casing 2 inches in diameter. This casing extends the full length of the instrument and is surrounded and supported at intervals by another casing 3 inches in diameter. At the ends of this outer casing are two collars which rest in the supporting blocks. These blocks are provided with pins whose conical ends fit into holes drilled in bronze plugs set in the road during its construction. One end-supporting block is provided with flat-ended contact pins and the block at the other end of the instrument carries micrometer screws. Adjusting screws are provided merely to support the instrument on the road when not in use. Fiber collars are provided merely for protection when the tube is detached from the end-supporting block.

Knowing the coefficients of expansion of these tubes, obtained by calibration, the difference in the micrometer readings furnishes a mean of obtaining the temperature of the bars. This temperature can then be used in correcting the micrometer measurements to a standard temperature. Thermometers are inserted in the 2-inch casing at the ends of the instrument. The mean of these end temperature readings, as a rule, approaches within 1° C. of the temperature obtained from the micrometer readings.

Used in studies of expansion and contraction of concrete.

Designed and constructed by the U. S. Bureau of Public Roads.

For detail of its use, see U. S. Department of Agriculture Bulletin No. 532, "Expansion and Contraction of Concrete and Concrete Roads," by A. T. Goldbeck and F. H. Jackson, Jr., October 13, 1917.

GRAPHIC STRAIN GAGE

As shown in the diagrammatic sketch, Figure 37, and photograph, Figure 38, the graphic strain gage consists essentially of a short piece of brass (A) and a longer piece (B) connected by a piece of spring steel (H) which acts as a hinge around which the two pieces of brass rotate as permitted by the small space between them. Since the steel-spring connection (H) is set off the center line of the two pieces of brass, any pressure exerted on the ends of the brass piece will cause this rotation. Any change in overall length between the two contact points, K and L, set on the center line, causes rotation of the parts, this rotation being proportional to the change in length. The

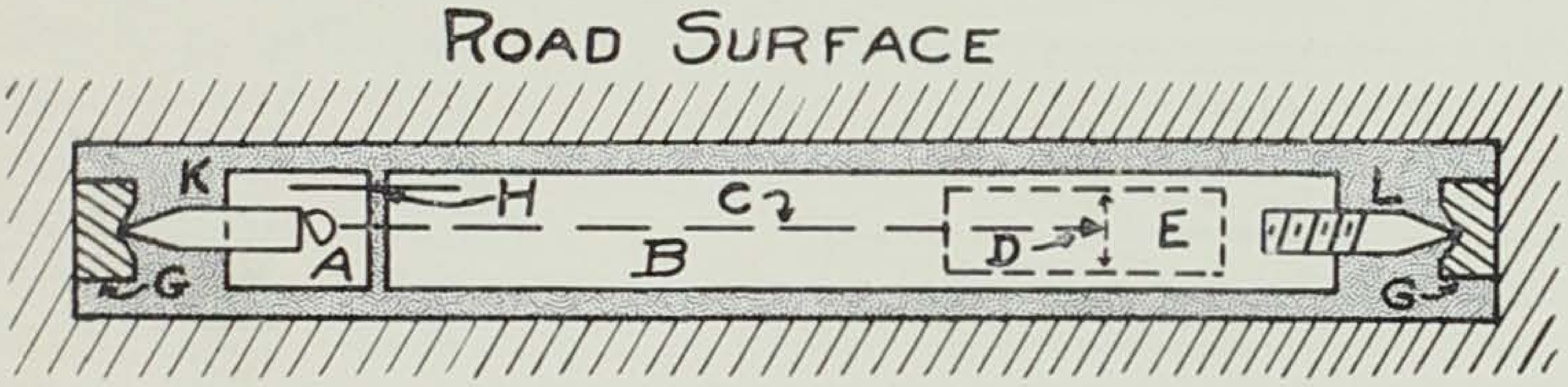


FIGURE 37.—DIAGRAMMATIC SKETCH OF GRAPHIC STRAIN GAGE

lever (C) attached to the small piece of brass (A) permits magnification of the movement of rotation or change of length between contacts. A record of the movement is accomplished by a point D in the free end of the lever moving over the surface of a small piece of

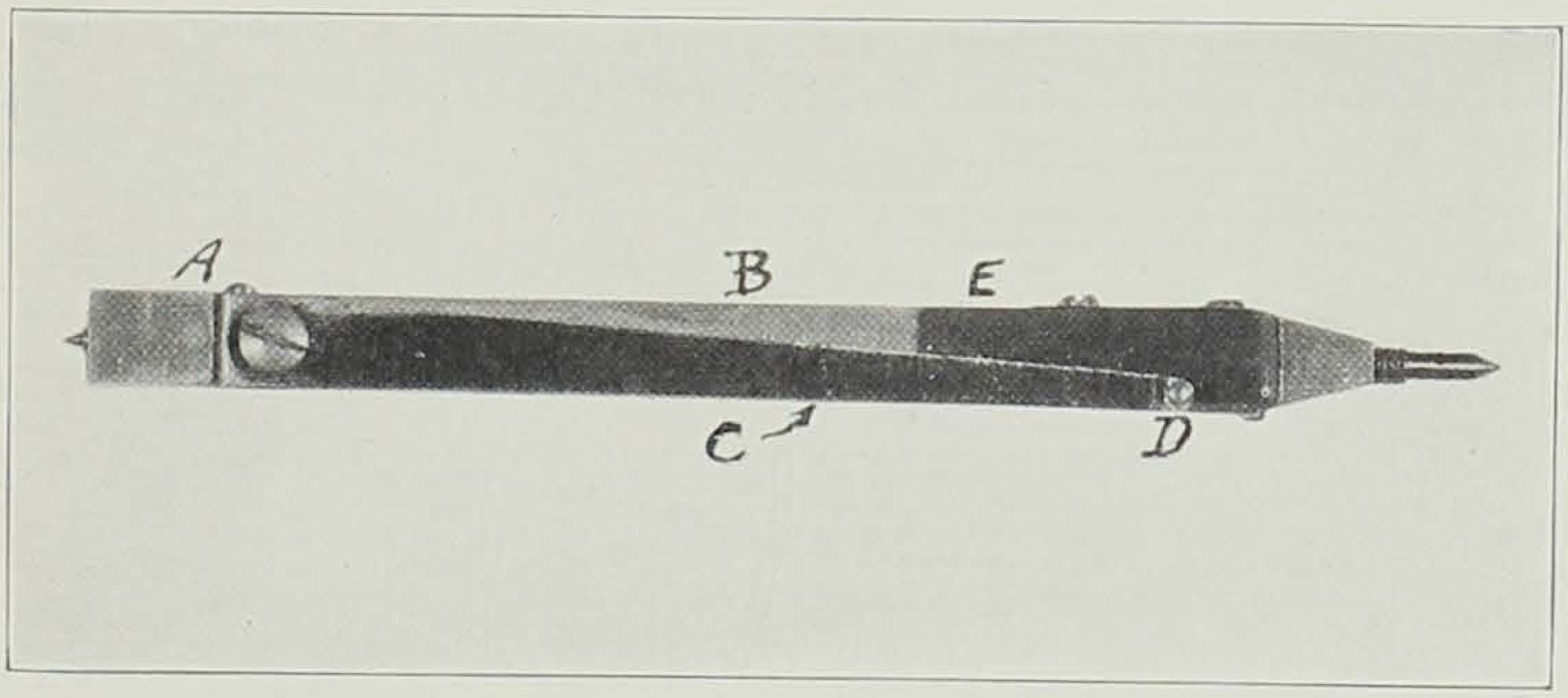


FIGURE 38.—GRAPHIC STRAIN GAGE

glass (E) which has been previously smoked, and which is held fixed on the point D. The devices are so small that they can be inserted, as shown in F, into pavement surfaces in slots ¾ by ¾ by 6 inches in size.

To make an observation, a slot of given dimension is cut in the surface of the road, small brass bearing plugs (G) are then set in plaster of Paris in the ends of the slot cut in the road surface, after which the strain gage is placed in position and adjusted to proper length by turning the contact point (L) until the indicator point is brought to the center of the small smoked glass E. After this position of D is attained, the piece of glass is moved a short distance so that a datum line is made on the record. A load is now applied and the record of both tension and compression occurring in the fiber is noted. Any compression shortens the overall length and causes D to move upward from the datum line, and any tension is shown below the datum line. A number of records can be secured in one piece of glass by simply moving it a slight distance after each load application.

After an observation has been made, the smoked glass record is removed from the strain gage and coated with a film of varnish, filed away, and later, by means of a microscope, is used for determining the fiber deformation.

Motor wheels can pass directly over these instruments which are protected by a thin cover plate. A number of them properly calibrated in various positions in the road slab, allows the determination of the direction, magnitude, and character of stress occurring with any type of moving or static load.

Used in the study of deformation and stress in road slabs on the Columbia Pike Experimental Road, Alexandria County, Virginia.

Designed and constructed by the U. S. Bureau of Public Roads.

See paper by A. T. Goldbeck, "What the Arlington Experiments Have Shown," presented before the American Road Builders' Association, Chicago, Illinois, January 16, 1923.

PHOTOGRAPHIC STRAIN GAGE (FOR MEASURING IMPACT STRESSES IN BRIDGES AND OTHER STRUCTURES)

The optical principle and essential features of this strain gage are shown diagrammatically in Figure 39. A and B are the two gage points of the instrument, A being the movable gage point, pivoted as shown and operating a mirror at its upper end. A light is focused by means of a small lens on the mirror and is reflected back to the scale S. In operation any slight movement of the gage point A will rock the small mirror about its pivot, thus deflecting the beam of light along the scale, magnifying very greatly the maximum movement at A. By this means of magnification it will be seen that there are only two mechanical moving parts, namely, the gage point with its extension and the mirror on its pivot, and since the movement in either case is extremely small, they respond readily with very little inertia. The greater part of the magnification is attained by the reflection of the beam of light by the various mirror positions, and

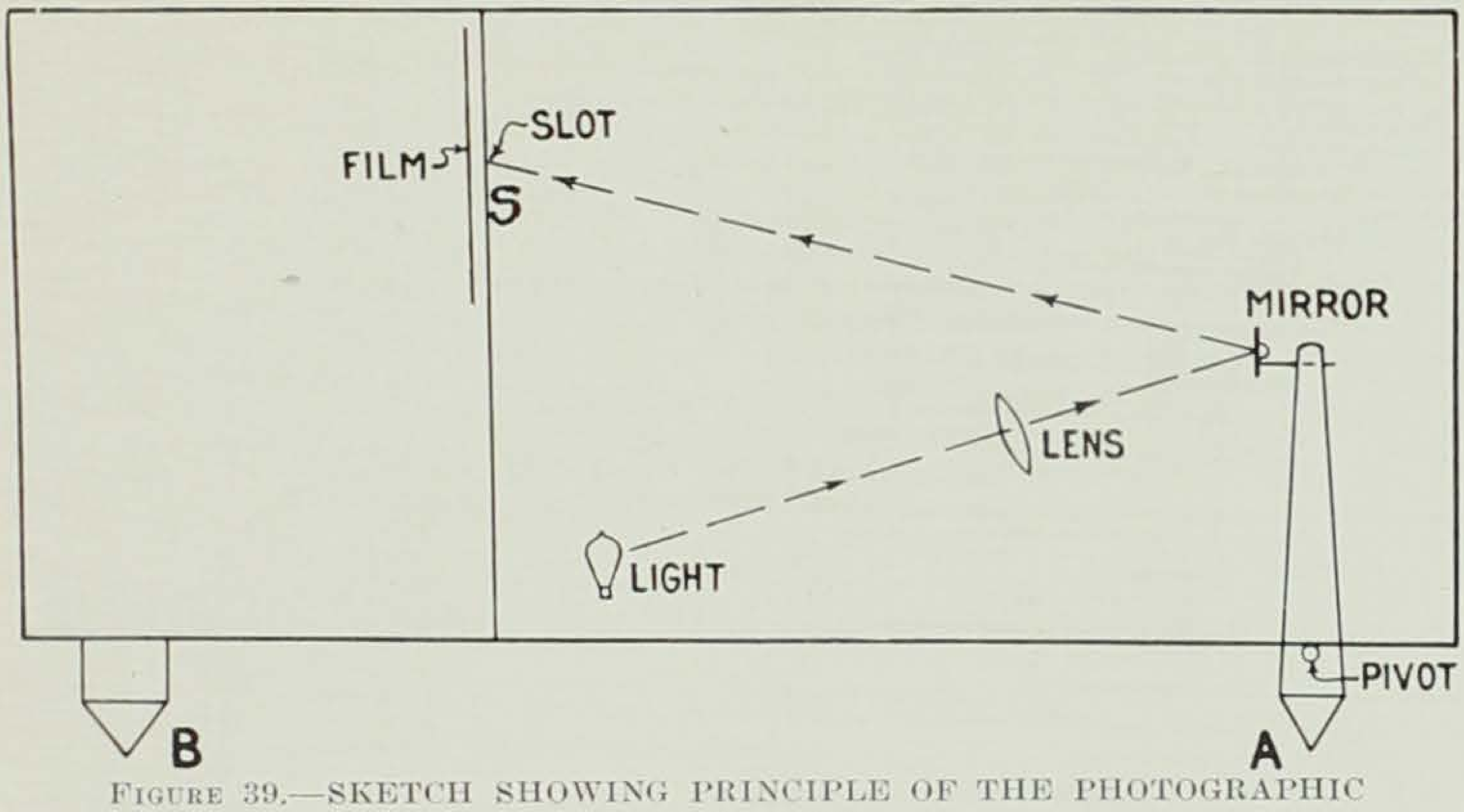


FIGURE 39.—SKETCH SHOWING PRINCIPLE OF THE PHOTOGRAPHIC STRAIN GAGE

this takes place with no inertia, consequently there can be no lag or over-travel. To make the instrument recording, a photographic film is so placed as to receive the record of the beam of light focused on a slot near the scale S.

A photograph of the actual instrument is shown in Figure 40, L being a small electric light bulb the filament of which is focused

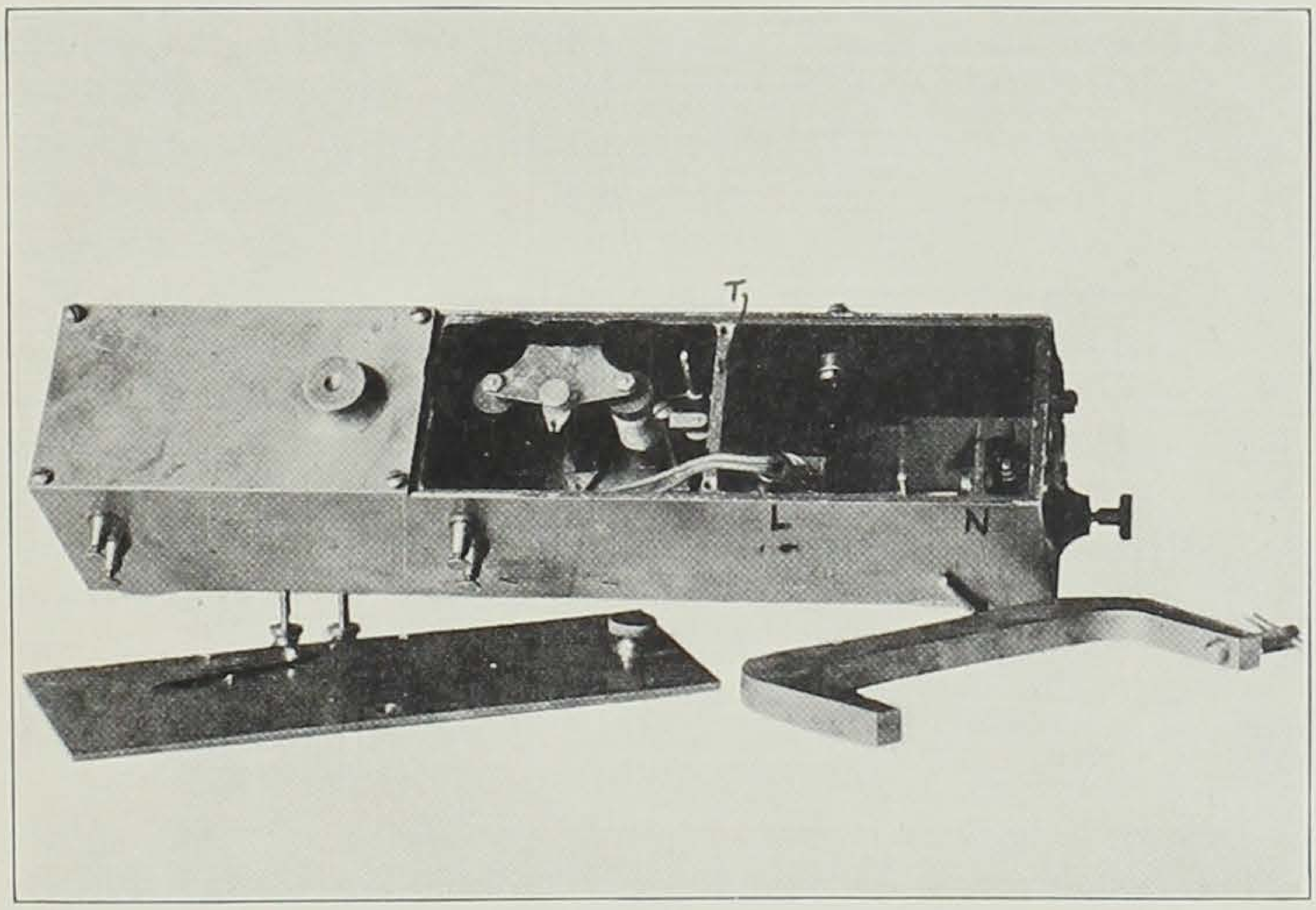


FIGURE 40.—PHOTOGRAPHIC STRAIN GAGE

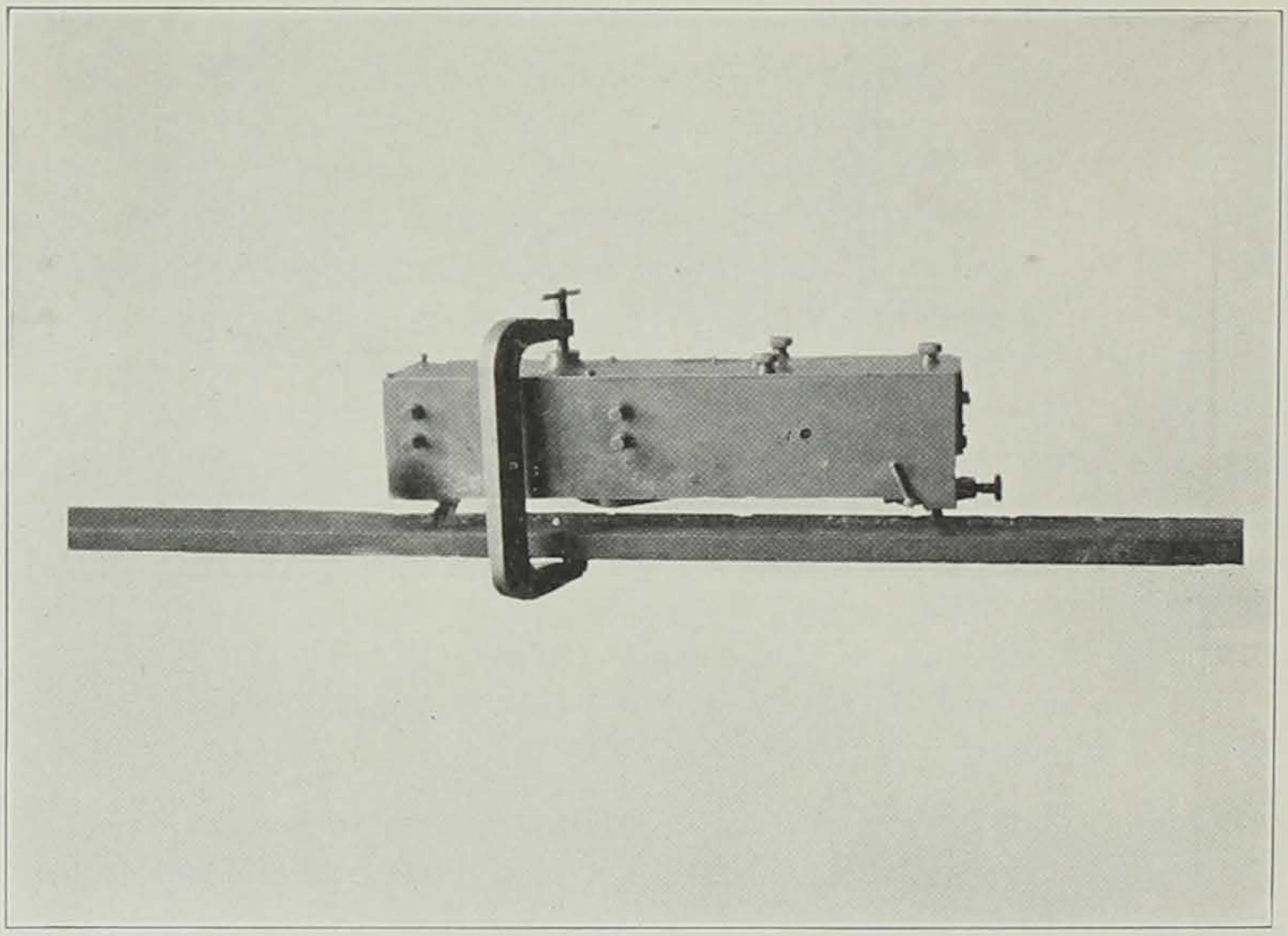


FIGURE 41.—PHOTOGRAPHIC STRAIN GAGE ATTACHED TO BRIDGE MEMBER DURING TEST

through the lens on to the small mirror at N. The image of this filament is reflected back across the vertical slot located in the partition of the instrument at T. A roll of film is caused to pass this slot and receive the record. In the closed end of the box is a small electric motor whose speed is reduced through a worm gear and which serves as the driving power for the film. The motor and the electric lamp are operated from a 12-volt storage battery. Figure 41 shows the instrument attached to a member in test. At the right end is the movable gage point which has a sliding longitudinal adjustment by means of the right hand thumb screw shown. At the left end are three gage points, the two outside gage points being of the same length and about 1/16 inch longer than the middle gage point. For use on flat surfaces, this provides a more stable and secure attachment for the instrument, but in case of narrow plates and bars and round rods, the center gage point is used.

Used in investigations of impact on highway bridges, Engineering Experiment Station, Iowa State College of Agriculture and Mechanic Arts, Ames, Iowa.

Designed and constructed by the U. S. Bureau of Public Roads.

See "Preliminary Report on Impact Studies on the Skunk River Bridge, on the Lincoln Highway, Near Ames, Iowa," by Almon H. Fuller, Proceedings A. S. C. E., March, 1923.

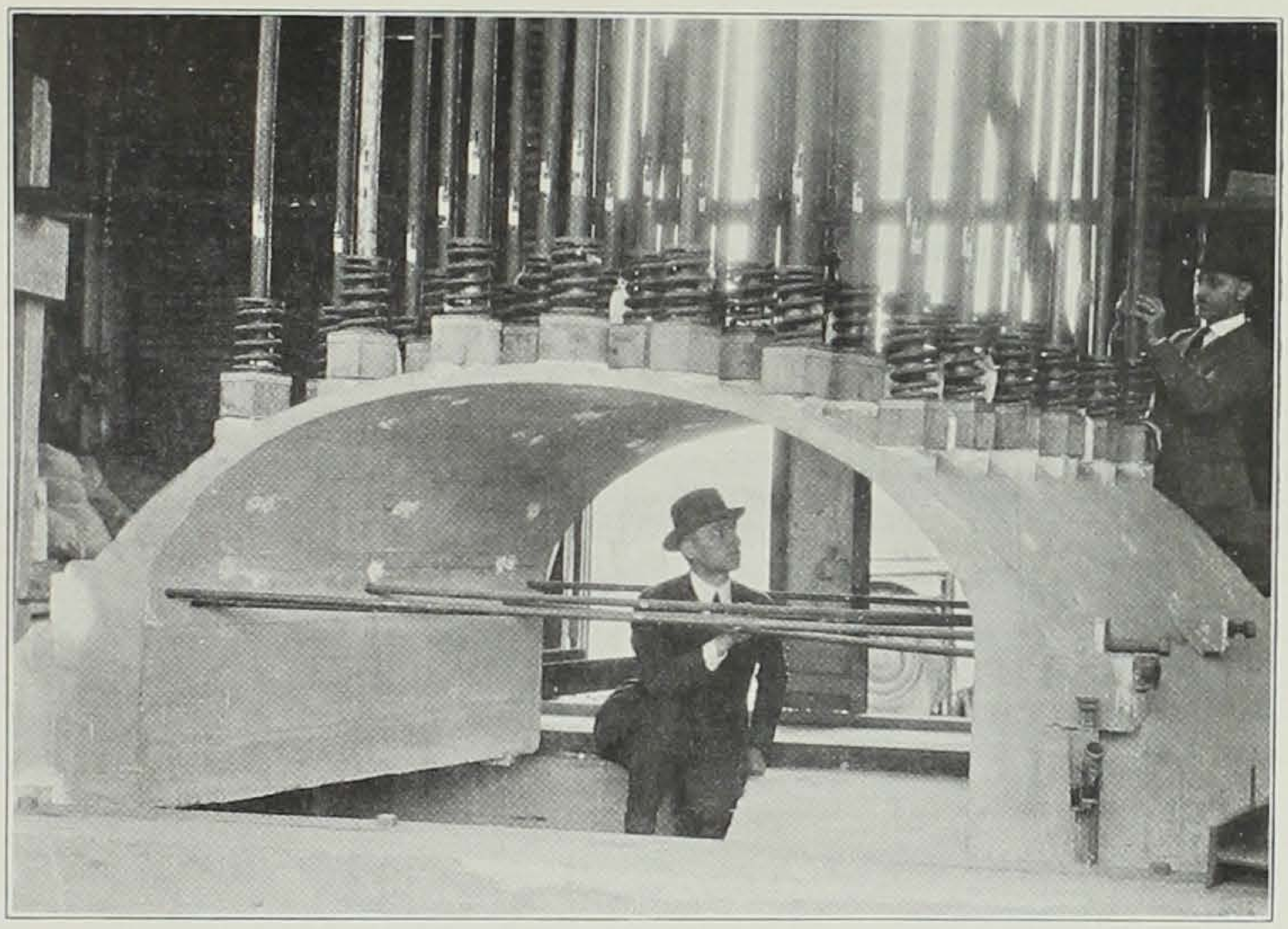


FIGURE 42.—TEST OF SKEW ARCH

APPARATUS FOR TESTING SMALL-SIZE SKEW ARCHES

As shown in Figure 42, the loads are applied to the test specimens by means of a number of springs placed at different points. The compression of each spring can be varied by turning an adjusting nut on top of the spring bearing rod. The applied load is determined by measurement of the deformation of the previously calibrated springs.

The deformation of fibers of the arch is measured by strain gages and the thrusts on the abutments are determined by use of special adaptations of the Kreuger measuring device.

Used in test of small skew arches, Arlington Experimental Farm, Arlington, Virginia.

Designed and constructed by the U. S. Bureau of Public Roads.

APPARATUS FOR TESTING BEAMS IN THE FIELD

As shown by diagram and photograph, Figures 43 and 44, the apparatus consists of a steel I-beam grillage carrying angle-iron knife edges spaced 6 feet apart on which the beam is placed. A load is applied through a wooden beam 6 inches square and 13 feet long. This is removable to facilitate the placing of the specimen. In test-

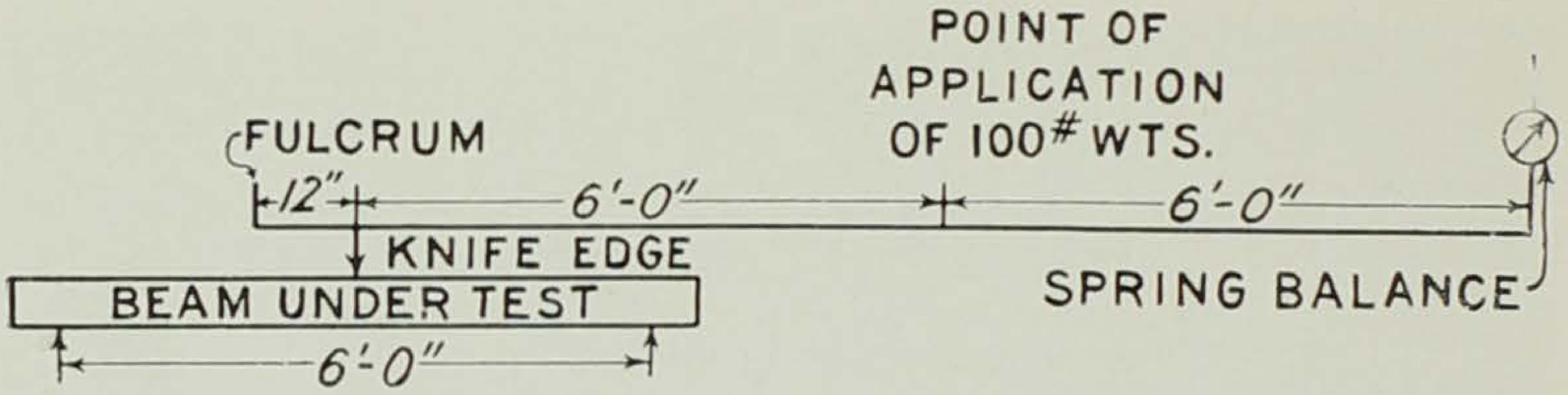


FIGURE 43.—SKETCH SHOWING PRINCIPLE OF BEAM TESTING APPARATUS

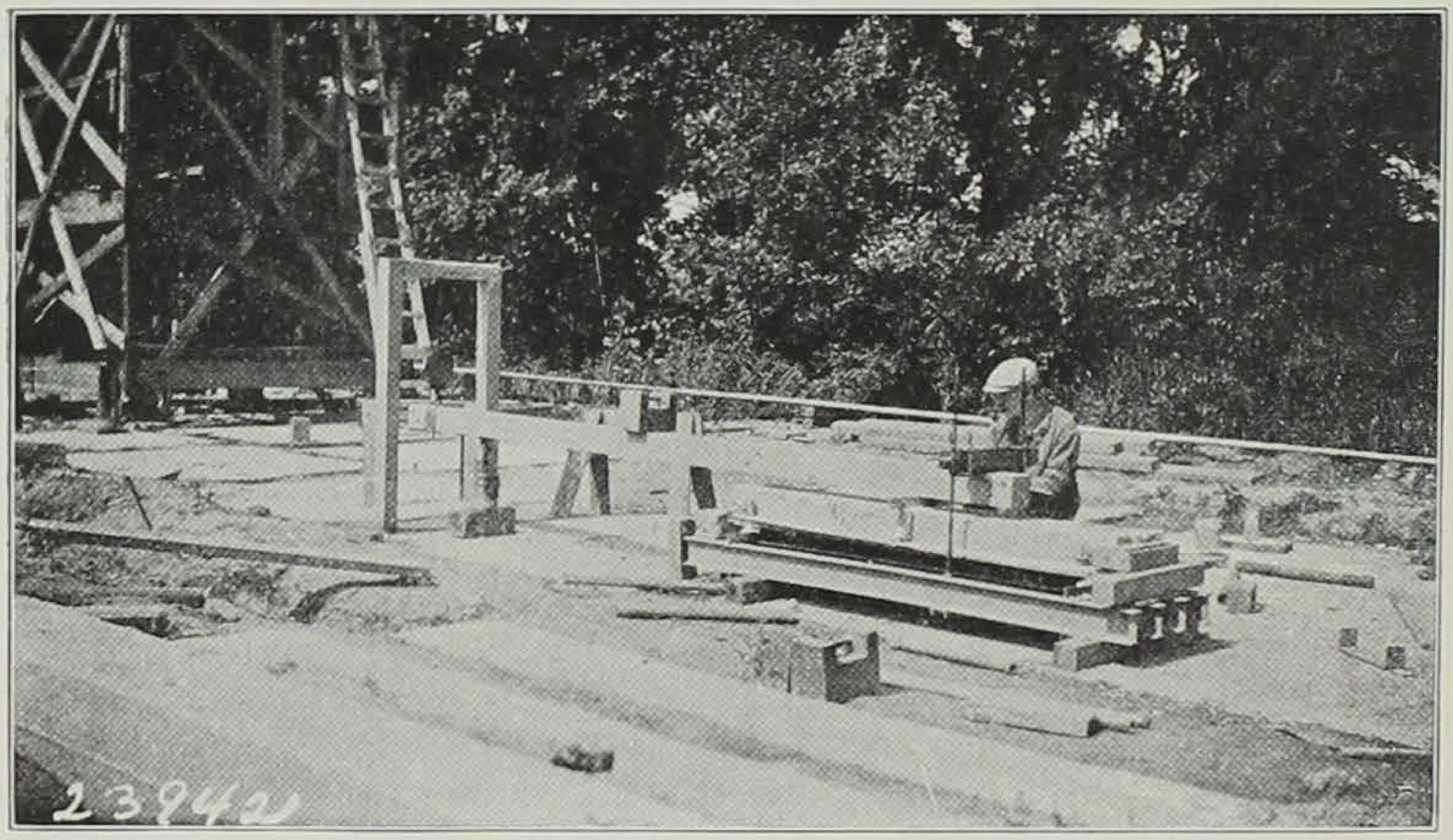


FIGURE 44.—BEAM TESTING APPARATUS

ing the specimen the beam is placed in position, one end supported by the angle iron resting on the specimen, and the other end hung on a spring balance held up by a turnbuckle on a ½-inch diameter steel rod fixed at the top. Proper contact is then made at the fulcrum and the load is applied by lowering the end of the beam at the spring balance by means of the turnbuckle. The load is computed by the reduction in the support of the free end of the beam as indicated by the spring balance. When the weight of the beam is insufficient to break the specimen, one-hundred-pound weights are placed in the middle of the beam.

Deflection of the specimen under test is measured by Ames dials independently mounted on each side of the apparatus bearing against supports attached along the neutral axis of the specimen.

Used in impact tests at Arlington, first series, to test beams 13 inches wide by 7 feet long, representing various types of pavements.

Designed and constructed by the U. S. Bureau of Public Roads.

See "Impact Tests on Pavement Sections," by C. A. Hogentogler, Public Roads, Vol. 4, Nos. 6 and 7, October and November, 1921.

Illinois: Illinois Division of Highways, Springfield, Illinois.

STRAIN GAGE FOR MEASURING FIBRE DEFORMATION IN CONCRETE SLABS SUBJECTED TO STATIC LOADS

This instrument (Figure 45) is sensitive to the one hundred-thousandth of an inch with the use of a ten-thousandth-inch Ames dial. The true surface fiber elongation causes an exaggerated move-

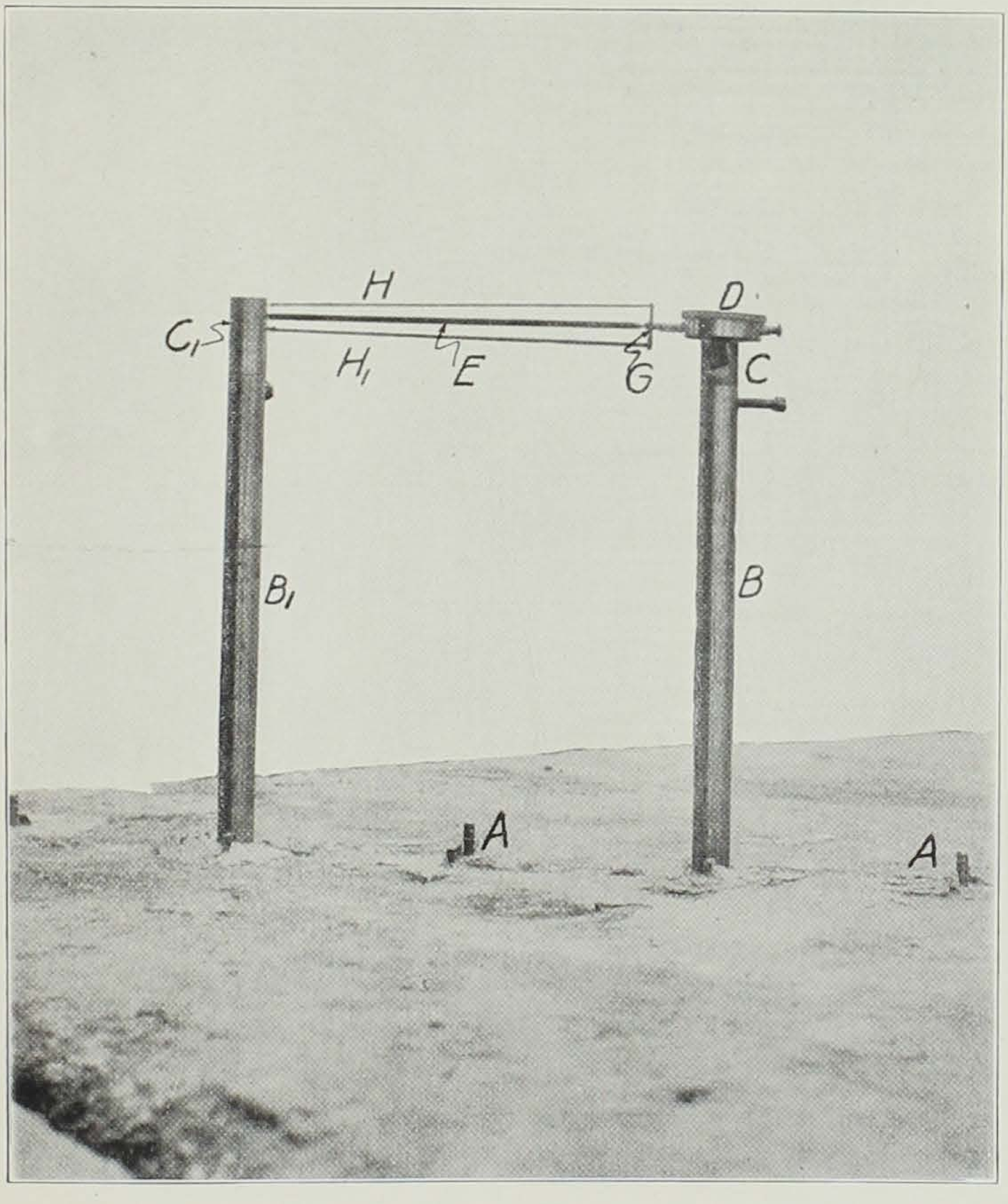


FIGURE 45.—ILLINOIS STRAIN GAGE

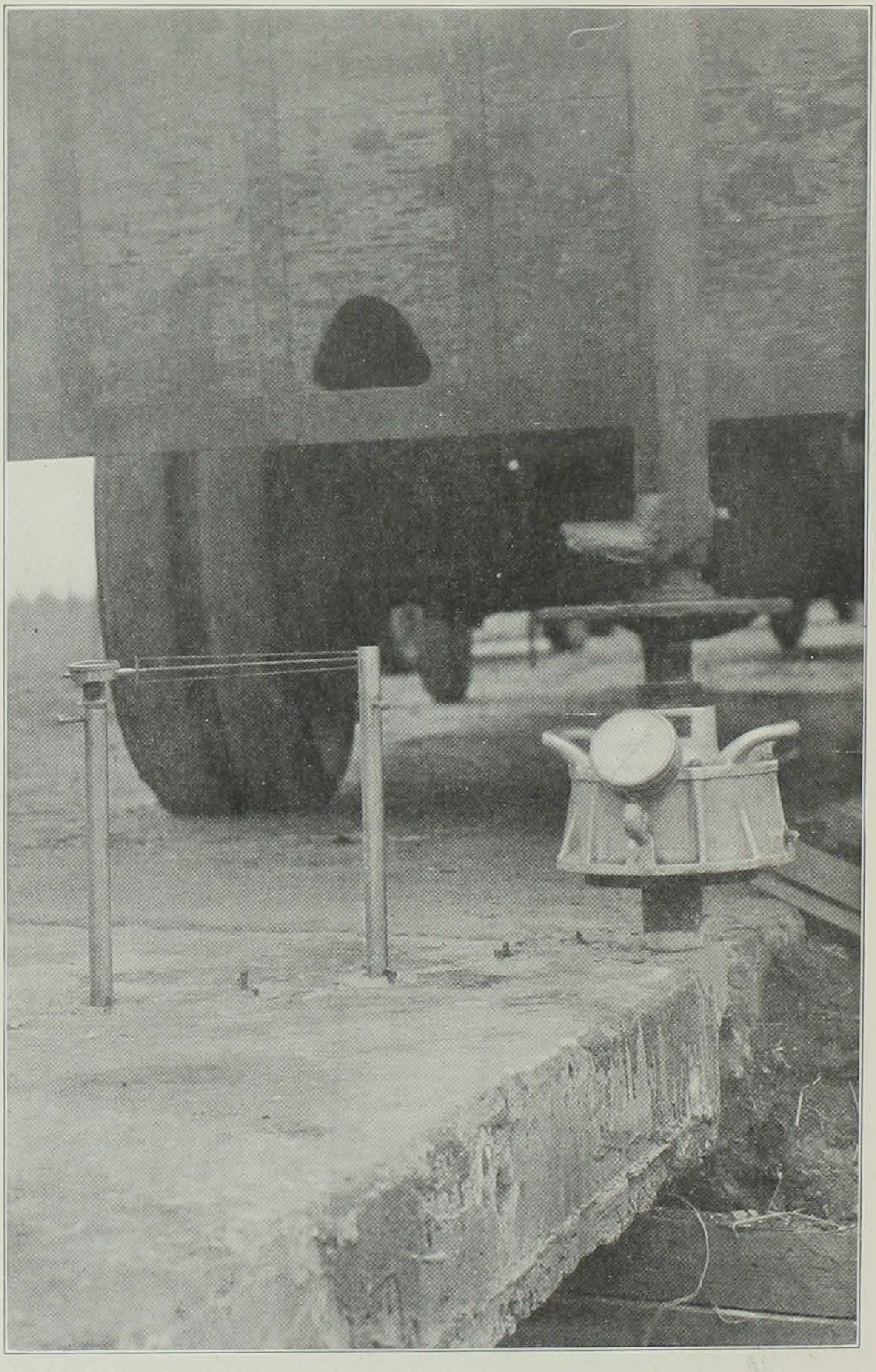


FIGURE 46.—MEASURING FIBER DEFORMATION WITH ILLINOIS STRAIN GAGE

ment dependent upon the length of the extension posts. A shows plugs set in the slab. B and B_1 are extension posts which screw on plugs. C is an adjustable head which holds dial (D). C_1 is also an adjustable head drilled out to receive pointed rod (E). The dial stem head is drilled to receive the other end of rod (E). By means of arm (G) fastened to dial stem and two rubber bands (H and H_1), the dial stem has positive action according to the movement between the posts. By varying the length of rod (E) accurate readings can be taken at distances as short as 4 inches.

Figure 46 shows the instrument used to measure deformation of fiber along the diagonal when a load is applied to the corner of the road slab.

Used 1922-23 in a study of stresses in slabs on the Bates Experimental Road.

Designed by H. F. Clemmer, Engineer of Tests, Illinois Division of Highways, and A. C. Benkleman, Assistant Engineer of Tests, Illinois Division of Highways.

Iowa: Experiment Station, Iowa State College of Agriculture and Mechanic Arts, Ames, Iowa.

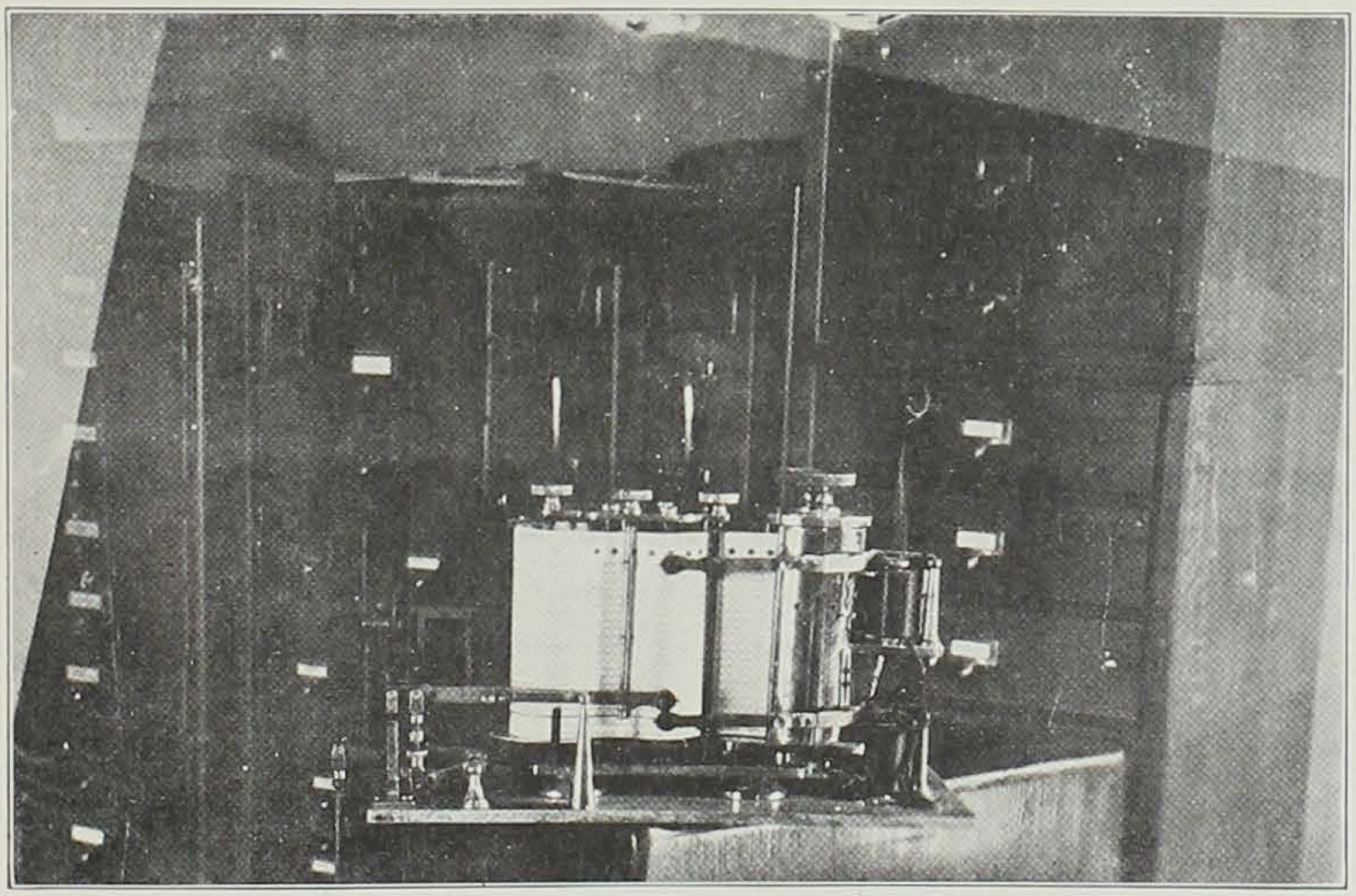


FIGURE 47.—STRAINAGRAPH MEASURING CULVERT IMPACT

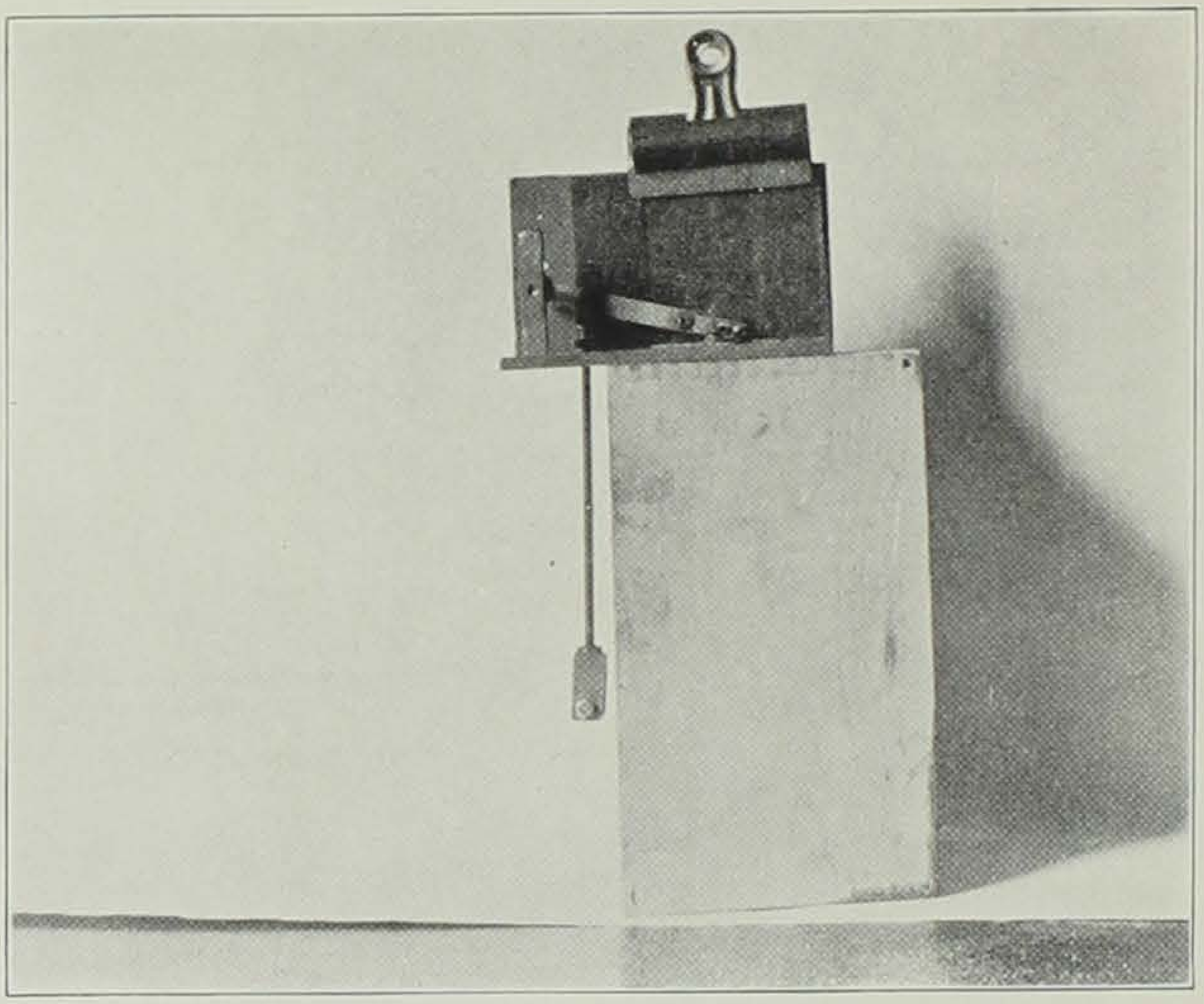


FIGURE 48.—SMOKED GLASS RECORDING DEVICE FOR MEASURING CULVERT IMPACT

ADAPTATION OF STRAINAGRAPH FOR MEASURING CULVERT IMPACT

The strainagraph, shown in Figure 47, is so arranged that the upper pen records the position of the test truck as registered by the space measuring instrument (see below). The middle pen records the elongation of spring due to impact effects which balance the beam of the platform scale. The lower pen records time in seconds, and is actuated by impulses through a pendulum clock.

When the culvert is covered with a comparatively thin fill, the device shown in Figure 48 is used to measure the impact. It consists essentially of a smoked glass plate on which is recorded the movement of a needle point fitted in the end of a lever. This device is used in place of the middle pen described above. The glass plate is held in position by a paper clamp.

The instrument was used for recording the impact data in the culvert investigations at the Iowa State College, Ames, Iowa.

SPACE MEASURING INSTRUMENT

This instrument, as shown in Figure 49, consists of a drum wound with brass wire which is fed off and on the drum evenly through a screw gear feed. The instrument is placed upon the ground with

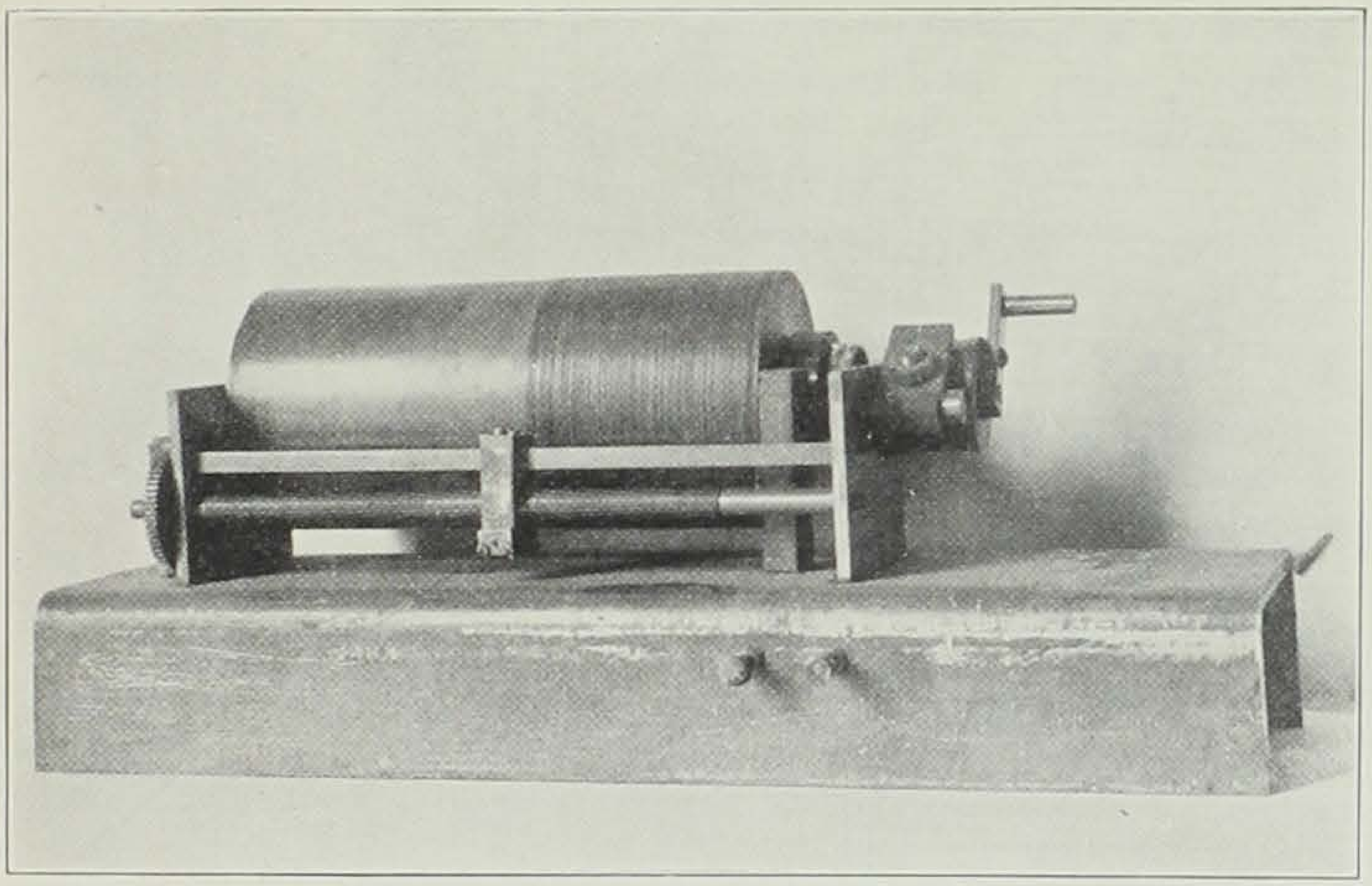


FIGURE 49.—SPACE MEASURING INSTRUMENT

the free end of the wire attached to the rear end of the truck. As the truck moves forward, the drums are rotated at the rate of one revolution for every 2-foot movement of the truck. At each revolution an electric circuit is closed, sending an impulse to the recording apparatus.

Used in connection with the culvert investigations, Iowa State College, Ames, Iowa.

The following instruments are listed as being used in the study of impact on highway bridges, a co-operative research project carried on by the Iowa State Highway Commission, Iowa Engineering Experiment Station, and the U. S. Bureau of Public Roads. From Bulletin 63, Iowa State College of Agriculture and Mechanic Arts, "Preliminary Impact Studies, Skunk River Bridge on the Lincoln Highway Near Ames, Iowa," by Almon H. Fuller.

DIRECT READING WEST EXTENSOMETER

This instrument consists of two yokes about 20 inches apart, held together by a constant-distance bar connected (with necessary freedom of motion) to the center of each yoke. The forked end of each yoke is fastened to the bridge member by means of two hardened screws. The movement, due to the deformation of the member, is transmitted to the other ends of the yokes where it is read directly by means of a Last Word dial.

The West extensometer was developed in the instrument shop of the Department of Civil Engineering, at Lafayette College, by M. L. West, mechanician, under the direction of Almon H. Fuller.

TURNEAURE EXTENSOMETER

This apparatus, which has been used extensively for measuring impact in railway bridges, is described in full in "Transactions of the American Society of Civil Engineers," Vol. XLI (1899), page 412, and in "Proceedings of the American Railway Engineering Association," Vol. 12 (1911), part 3, pages 185 to 202.

STREMMATOGRAPH (RECORDING AND SMOKED GLASS DISCS)

These instruments were developed for measuring the stress in railroad rails by a special committee of the A. S. C. E. to report on stresses in railroad tracks, and are described in the transactions of the American Society of Civil Engineers, Vol. LXXXII (1918), page 1224.

BUREAU OF PUBLIC ROADS PHOTOGRAPHIC MIRROR EXTENSOMETER

Described under Bureau of Public Roads.

BUREAU OF PUBLIC ROADS STRAIN GAGE FOR MEASURING MAXIMUM FIBRE COMPRESSION

Described under Bureau of Public Roads.

OHIO STATE UNIVERSITY MAXIMUM COMPRESSION INSTRUMENT (LOANED BY C. T. MORRIS, OHIO STATE UNIVERSITY)

COMBINATION INSTRUMENT ARRANGED BY USING THE STREMMATOGRAPH SMOKED GLASS DISCS ON A FORM OF THE WEST EXTENSOMETER

WEST STRAIN GAGE

BERRY STRAIN GAGE

Minnesota: State Highway Department.

TILE TESTING MACHINE

This machine, Figure 50, was designed with the idea of producing a portable machine which could be used on the job for testing tile. It is so constructed that it can readily be taken apart and placed in a car so that it can be moved from one job to another. It is essentially nothing more than a small press made out of channel iron and

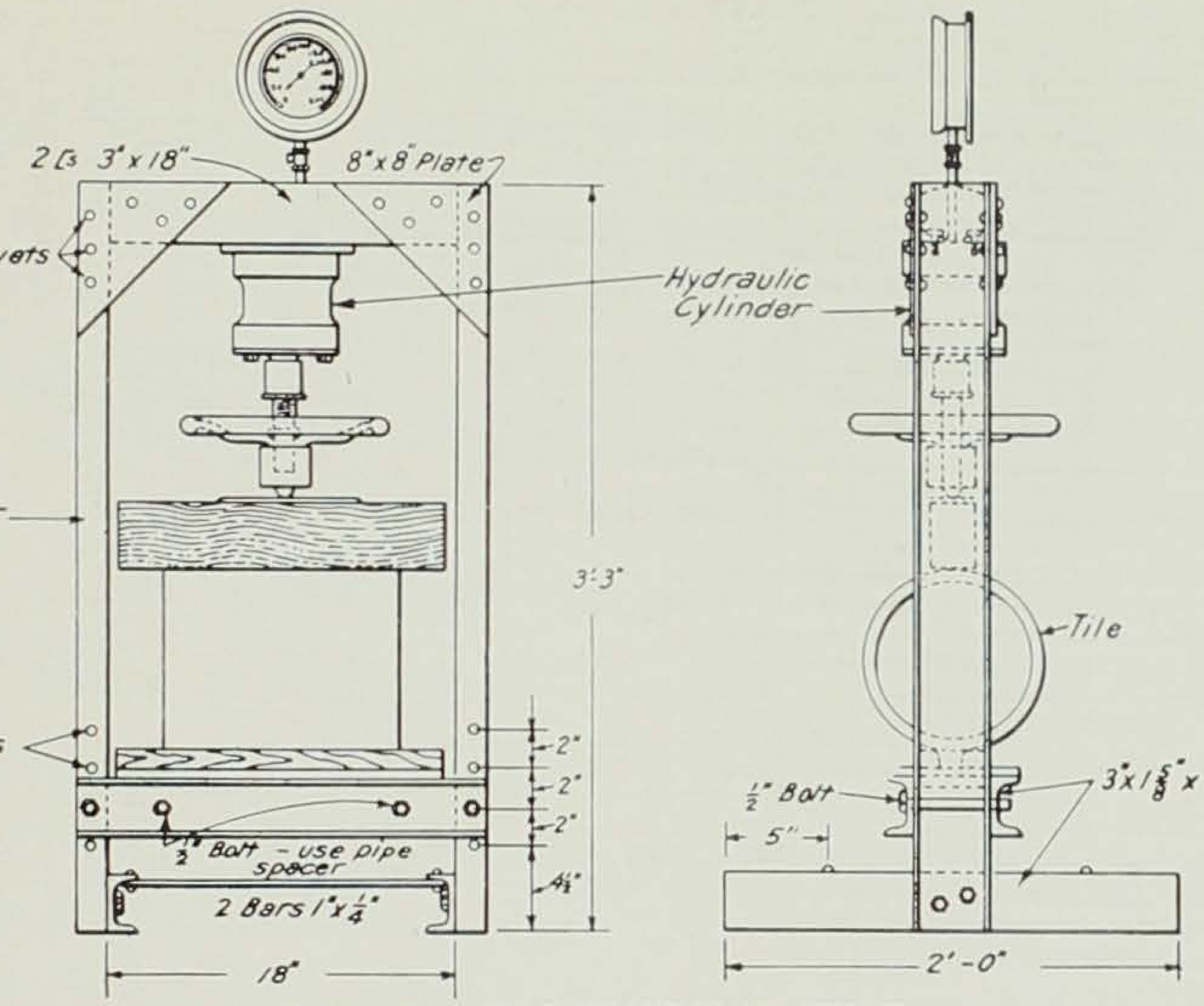


FIGURE 50.—TILE TESTING MACHINE

provided with a hydraulic cylinder and a pressure gage for measuring the load required to break the tile.

Used for field testing of tile.

Designed and constructed by the Minnesota State Highway Department.

GROUP III. APPARATUS USED IN INVESTIGATIONS OF MATERIALS

1. Subgrade Materials.

District of Columbia: U. S. Bureau of Public Roads.

APPARATUS FOR DETERMINING COMPARATIVE BEARING VALUE OF SOILS

This apparatus, as shown in Figure 51, consists of a container for holding the soil to be tested, a bearing block through which pressure is applied, an Ames dial for indicating the deformation of the soil, a counter-weight, system of levers, spring balance supporting the container for Ottawa sand, and a funnel and tube through which the load is applied. After the soil has been properly prepared and placed in the container, the bearing block, whose area is one square inch, is placed upon it, after which, by means of an adjusting screw, the

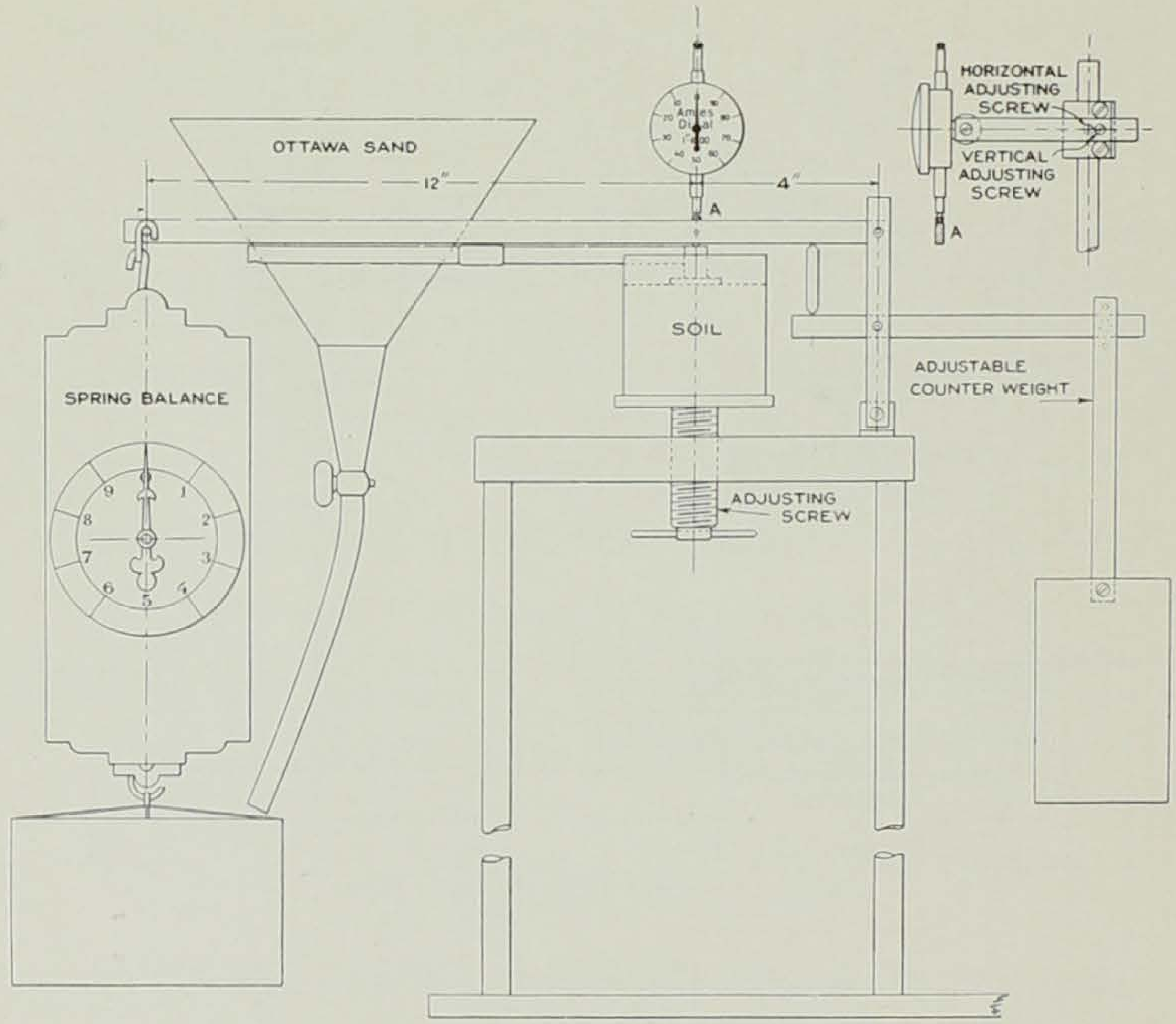


FIGURE 51.—APPARATUS FOR DETERMINING COMPARATIVE BEARING VALUE OF SOILS

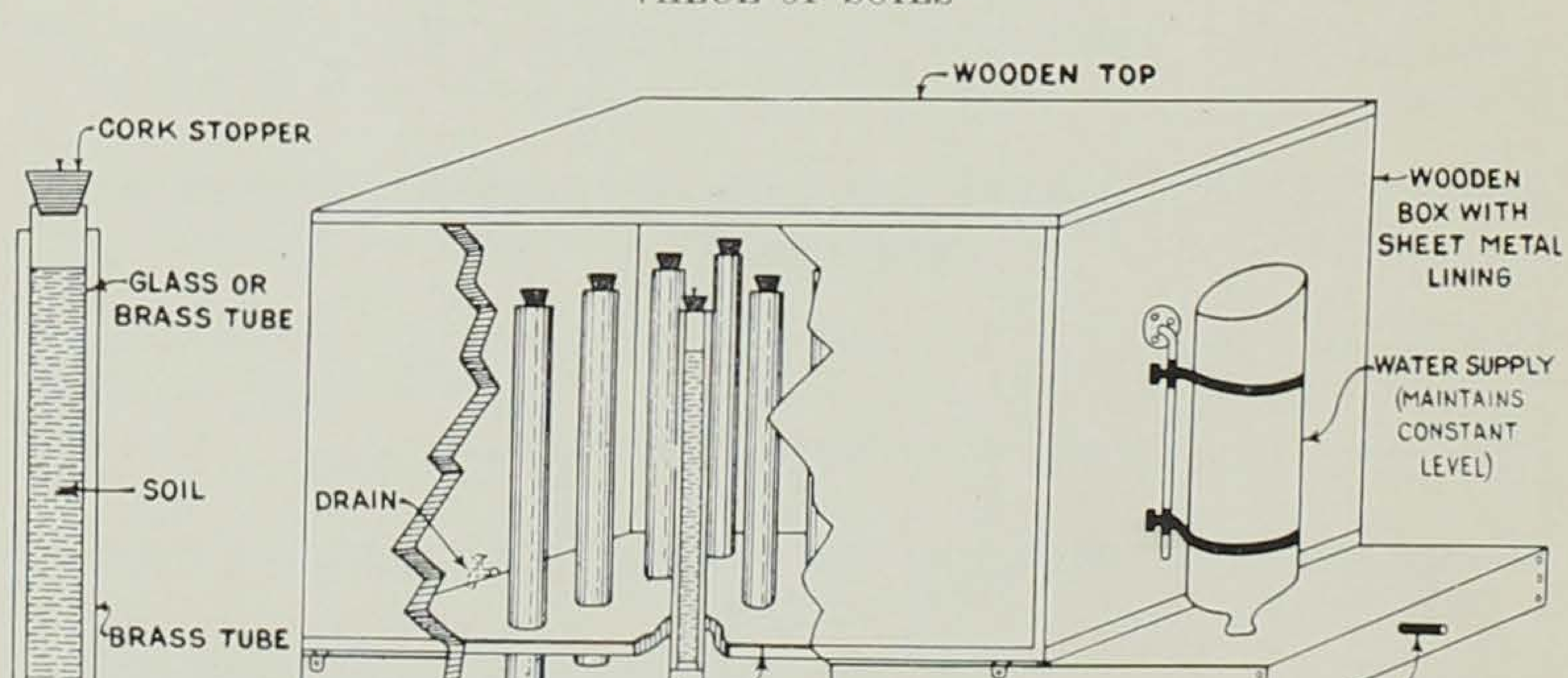


FIGURE 52.—APPARATUS FOR DETERMINING CAPILLARITY OF SOILS

container is raised vertically until the horizontal beam against which the top of the bearing block rests is raised 0.1 inch. The sand for applying the load is now released, and simultaneous readings of load and deformation are made for 0.1-pound increments, the maximum penetration being 0.2 of an inch. The ratio of the lever arms is such that the load readings obtained from the spring balance must be multiplied by four. For comparative purposes the bearing value of the soil is taken at that load in pounds per square inch required to produce a penetration of .1 inch.

ADAPTATION OF CENTRIFUGE FOR DETERMINING MECHANICAL ANALYSIS OF SOILS

APPARATUS FOR DETERMINING MOISTURE EQUIVALENT OF SOILS

APPARATUS FOR DETERMINING SLAKING VALUE

APPARATUS FOR DETERMINING CAPILLARITY OF SOILS

The factors given consideration in the development of this apparatus were:

(1) Simulation, in so far as practical, of the conditions characteristic in subgrade soils in the field to allow of a possible practical interpretation of the results obtained.

(2) Temperature regulation within certain limits.

(3) Accessibility of samples under test, to permit removal for observation, weighing, etc., with minimum amount of interference with the operation, and with the sample.

As shown in Figure 52, it consists of a sheet-metal lined, wooden box (A) supported over a water reservoir (B), and is so constructed as to permit simultaneous operation of a number of samples. Hollow, brass tubes (T) which are permanently set in the base of box (A) which rests upon the bottom of the reservoir (B).

These tubes, which to some extent act as auxiliary supports for box A, serve as protective jackets for and permit easy access to the soil tubes (T) inserted in them. The soil sample tubes are supported by wire strands (W) fitted in each brass tube (T), a short distance above the bottom. The wire supports are placed so that the bottoms of the soil tubes are immersed in the water which is permitted to enter the perforated brass tubes.

While in operation the tops of the tubes containing the soil sample are closed to prevent evaporation or condensation moisture. The bottom of each soil tube is covered with a cap of cheesecloth which confines the soil.

Depending upon the temperature desired, the box (A) is filled to a height just below the top of the protecting tubes (T), with water, ice, ice and salt, or similar material. The temperature of the water in the supply basin is arbitrary with the observer. In endeavoring to duplicate field conditions, it is preferable to so choose the reservoir temperature which corresponds to the temperature-depth relation in the particular subgrade.

The following determinations can be made with this apparatus:

(1) Capillary moisture contents at various temperatures.

(2) Effect of temperature change upon capillary moisture content.

(3) Effect upon the capillary moisture of difference in temperature between the soil column and the moisture supply.

The relative effect of seasonal subgrade temperature conditions upon the capillary moisture can be determined. The effect in winter when the temperature increases with depth of subgrade can be studied, and its effect in spring and summer when the temperature depth relation is more or less reversed.

Used in subgrade experiments at Arlington Experimental Farm, Arlington, Virginia.

Designed and constructed by the U. S. Bureau of Public Roads.

APPARATUS FOR DETERMINING WATER CAPACITY

APPARATUS FOR DETERMINING VOLUMETRIC SHRINKAGE

DYE ADSORPTION TUBE

The apparatus, as shown in Figure 53, consists of an adsorption tube (A), 25 cc. graduate (B), separatory funnel (C), and transfer funnel (D).

The adsorption tube (A) should measure about 6 inches by ½ inch inside diameter, and should be drawn at the lower end for a distance of 1 inch to a straight stem having ⅛-inch inside diameter. The tube is closed by a small disc or filter paper held in place by a ground glass stopper tube which should enclose the end of the stem for a distance of ¼ inch.

The separatory funnel (C) should have a capacity of 10 cc. and should be provided with a 3 mm. opening in the stop cock to allow the free passage of sand passing a 10-mesh screen.

Used to determine the dye adsorption properties of soils.

Evolved in the U. S. Bureau of Public Roads.

See Proceedings, American Society for Testing Materials, Vol. 22. Part II (1922), pp. 344-347.

Manufactured by Bausch & Lomb Optical Company, Rochester. New York.

The apparatus and methods used by the U. S. Bureau of Public Roads in determination of the physical properties of subgrade materials are described in detail in a paper entitled "Physical Properties of Subgrade Materials," presented by J. R. Boyd, before the A. S. T. M., Atlantic City, New Jersey, June 26-30, 1922.

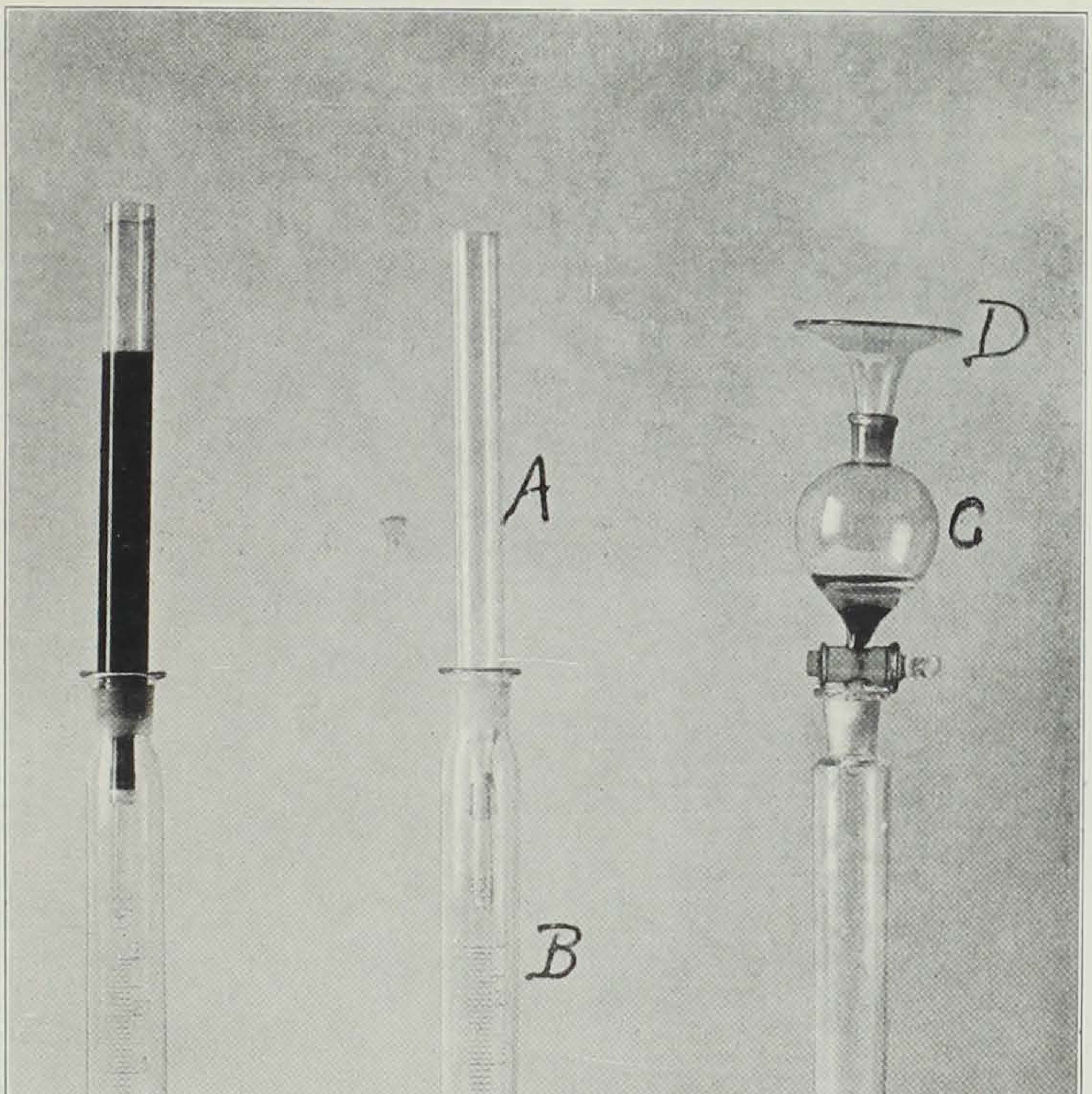


FIGURE 53.—DYE ADSORPTION TUBE

ULTRA MICROSCOPE CELL

The cell, Figure 54, consists of a small circular opening about 4 mm. in diameter and varying in depth from .025 mm. to .05 mm. and having a perfectly plain surface surrounded by an overflow trough about .10 mm. deep and 1 mm. wide. This cell is cut in a high grade optical object glass from 1.75 mm. to 2.25 mm. in thickness.

Used to count colloidal particles in liquids.

Devised in the U. S. Bureau of Public Roads.

See paper by E. C. E. Lord, entitled "Ultra-Microscopic Examination of Disperse Colloids in Bituminous Road Materials," Journal of Agricultural Research, Vol. XVII, No. 4, July 15, 1919.

FIGURE 54.—ULTRA MICROSCOPIC CELL

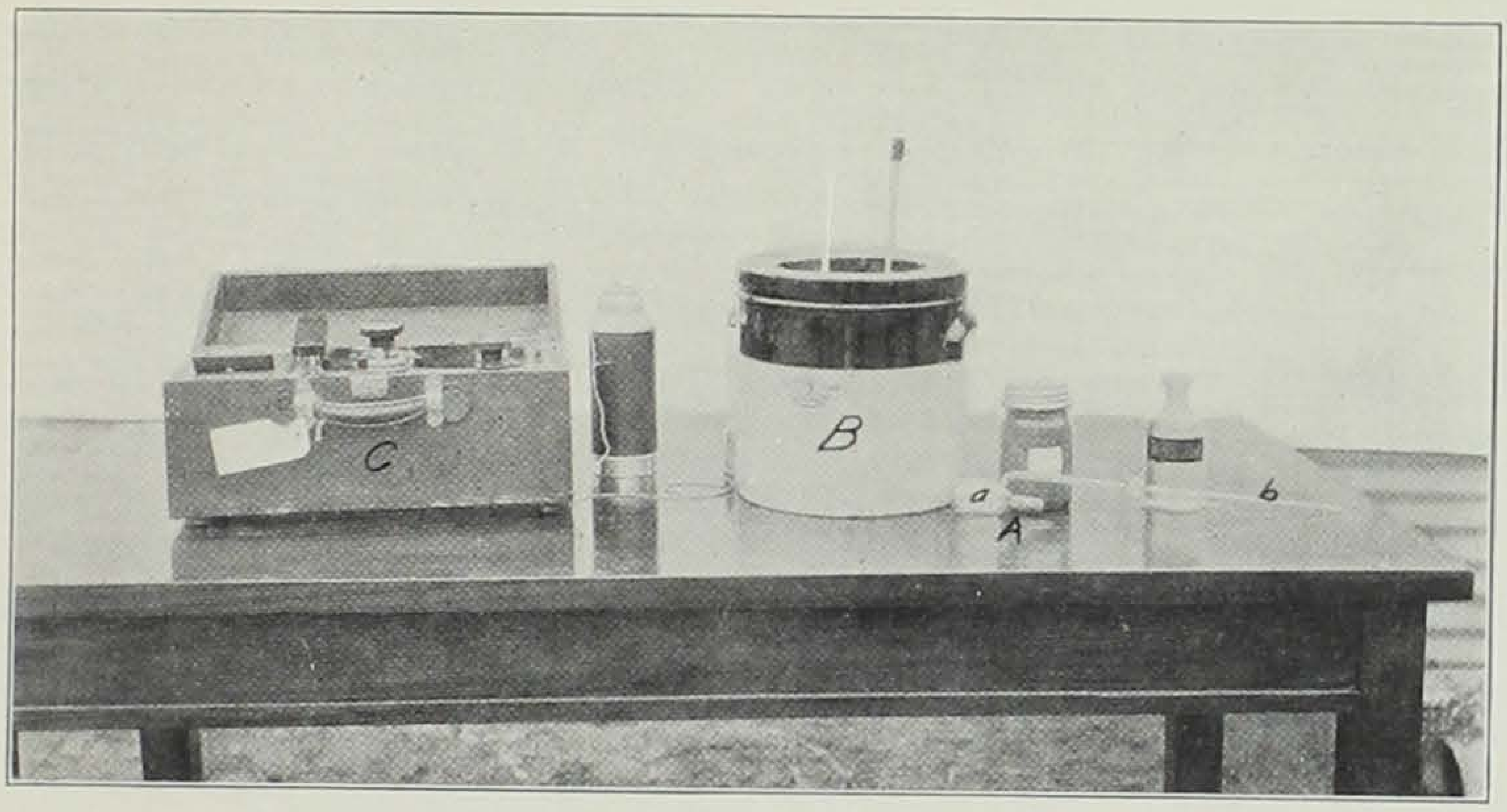


FIGURE 55.—DILATOMETER FOR MEASURING EXPANSION OF FROZEN SOIL SAMPLES

DILATOMETER FOR MEASURING EXPANSION OF FROZEN SOIL SAMPLES

This apparatus (Figure 55) consists of two parts, a dilatometer and a bath. The dilatometer (A) consists of a glass bulb (*a*) in which the soil is placed, and a graduated glass stem (*b*) on which the expansion can be read to .025 cc. A thermo couple inserted through a cork stopper serves to measure the soil temperature and also to mix the soil thoroughly. A coating of paraffin forms water-tight connection with the mouth of the bulb.

The bath (B) consists of two earthenware jars placed one inside of the other. The jars have capacities of three gallons and one gallon, respectively. The space between the two jars is filled with hair, the upper part of which is waterproofed by a paraffin seal. The cooling agency is a mi ture of crushed ice and salt.

The soil temperature is measured accurately to a 0.1 degree by the potentiometer.

Used at Arlington Experimental Farm, Arlington, Virginia, in subgrade investigations.

Devised by U. S. Bureau of Public Roads.

North Carolina: University of North Carolina, Chapel Hill, North Carolina.

CAPILLARY EXPERIMENT BOX

This device consists of a water-proof box 12 by 4 by 3 feet with water storage tank and an under drainage system. The soil to be tested is placed in the box and water is introduced from a storage tank to the under drainage system. The height of rise of the water is determined by an electric apparatus. The lines of vertical tap holes for determining the percentage of moisture at various elevations are in the sides of the box.

Used in the study of subgrade soils, at the University of North Carolina, in co-operation with the North Carolina State Highway Commission.

Developed by H. F. Janda, University of North Carolina.

Constructed by the University of North Carolina Construction Department.

2. Road Surface Materials.

District of Columbia: U. S. Bureau of Public Roads.

MODIFICATION IN DESIGN OF FLOW TABLE

In this modified form of the flow table, Figure 56 (see Bureau of Standards below), a single cast-iron pedestal is used to support the table instead of an angle-iron frame. Due to the possibility of the angle-iron frame being somewhat flexible and thereby possibly influencing the test results, it was thought advisable to substitute an

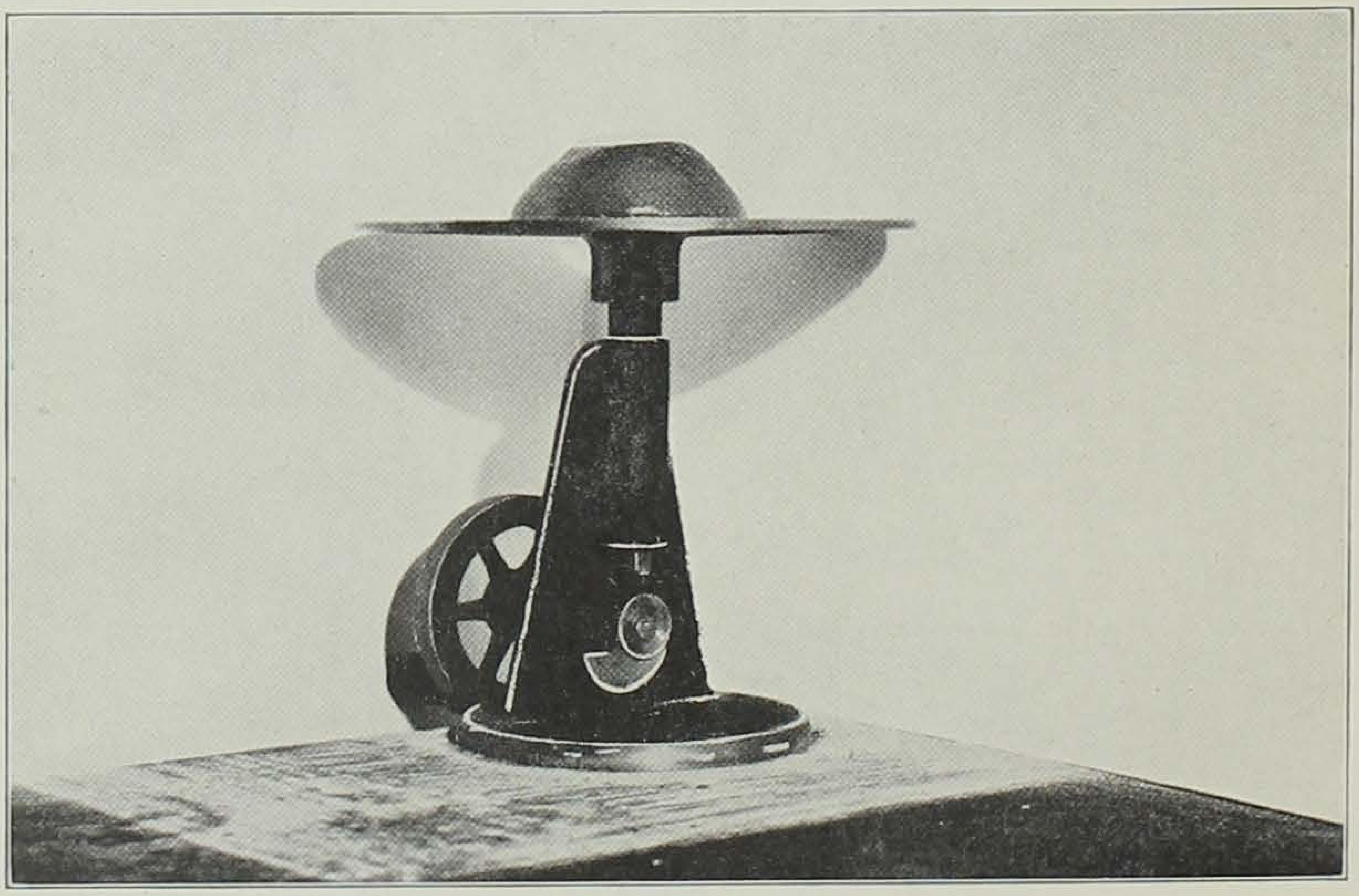


FIGURE 56.—FLOW TABLE USED BY U. S. BUREAU OF PUBLIC ROADS

absolutely rigid cast-iron base. In this type of base the table falls directly on top of the pedestal instead of upon the center of an angle-iron beam in the original design. Likewise a cast brass top is used instead of the old style tin-covered wood top.

Used in the Bureau of Public Roads investigation of consistency of concrete.

CROSS LINE MICROMETER SCALE

The scale is cut in optical glass and inserted in the eye piece of a petrographic microscope. It consists of a 1-centimeter square field divided into 100 square millimeters, one of these small areas being one per cent of the whole field occupied by a mineral.

Used to determine the volumetric percentage of minerals in thin sections of rock.

Devised in the U. S. Bureau of Public Roads.

See "Relation of Mineral Composition and Rock Structures to the Physical Properties of Road Materials," by E. C. E. Lord, U. S. Department of Agriculture Bulletin No. 348.

Manufactured by Bausch & Lomb Optical Company, Rochester, New York.

IMPACT DEVICE FOR TESTING GRAVEL IN THE FIELD

This apparatus, as shown in Figure 57, consists of two 2½-inch steel balls (A and B). The lower ball is fastened rigidly to a cast-iron anvil (C) measuring 5 inches in diameter by 1¾ inches high. The upper ball (A) is free to fall between three ⅜-inch guide rods. An adjustable stop (D), provided with a clamping nut, slides in one of the guide rods. Fastened rigidly to the upper ball is a ⅜-inch rod (E) graduated in inches, which passes through a hole in the plate supported on top of the three guide rods.

The hammer, consisting of the upper ball and the graduated rod, weighs exactly 1,200 g., while the remainder of the apparatus weighs exactly 6 kg., so that the ratio of the weight of the hammer to the weight of the anvil is 1 to 5.

The operation of the test is extremely simple. The fragment to be tested is held firmly on the lower ball between the thumb and first finger of the right hand so that its smallest diameter is vertical. The upper ball is then allowed to rest on the test specimen and the stop adjusted at the height of the fall desired, measured in inches directly on the rod. The top is then clamped in position, the upper ball raised until in contact with it and allowed to fall upon the specimen.

A very little practice will make an operator adept in holding the specimen in place without difficulty. It is possible also in almost

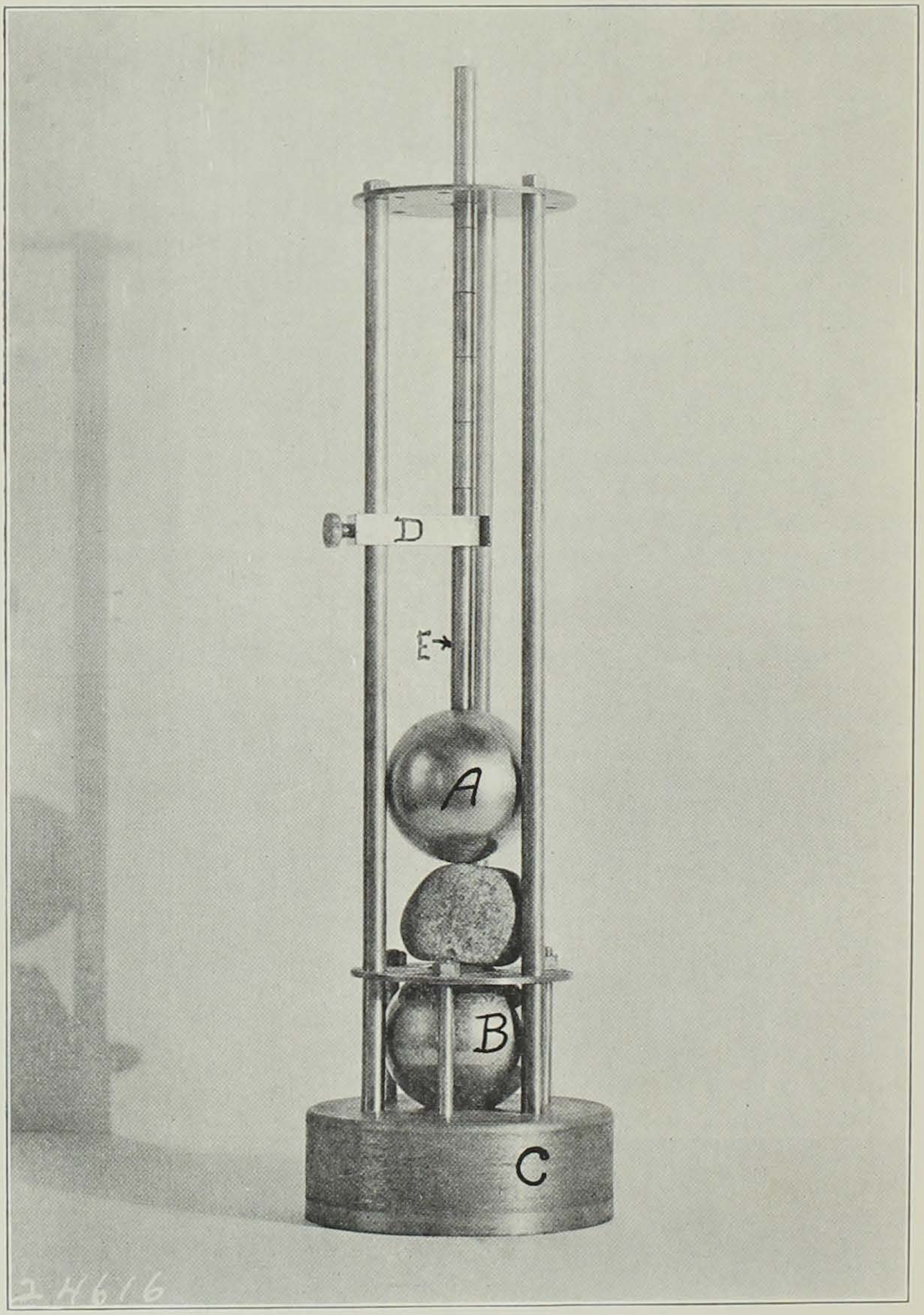


FIGURE 57.—DEVICE FOR TESTING GRAVEL IN THE FIELD

every case to secure a reasonably firm bearing on the lower ball. This may be done by trying the specimen in various positions, allowing the ball to drop in each case from a very small height, say ¼ inch, and noting the effect.

For full description and use of this apparatus see paper entitled "An Impact Test for Gravel," presented by F. H. Jackson before the American Society for Testing Materials, Atlantic City, New Jersey, June 26-30, 1922.

Designed in the U. S. Bureau of Public Roads.

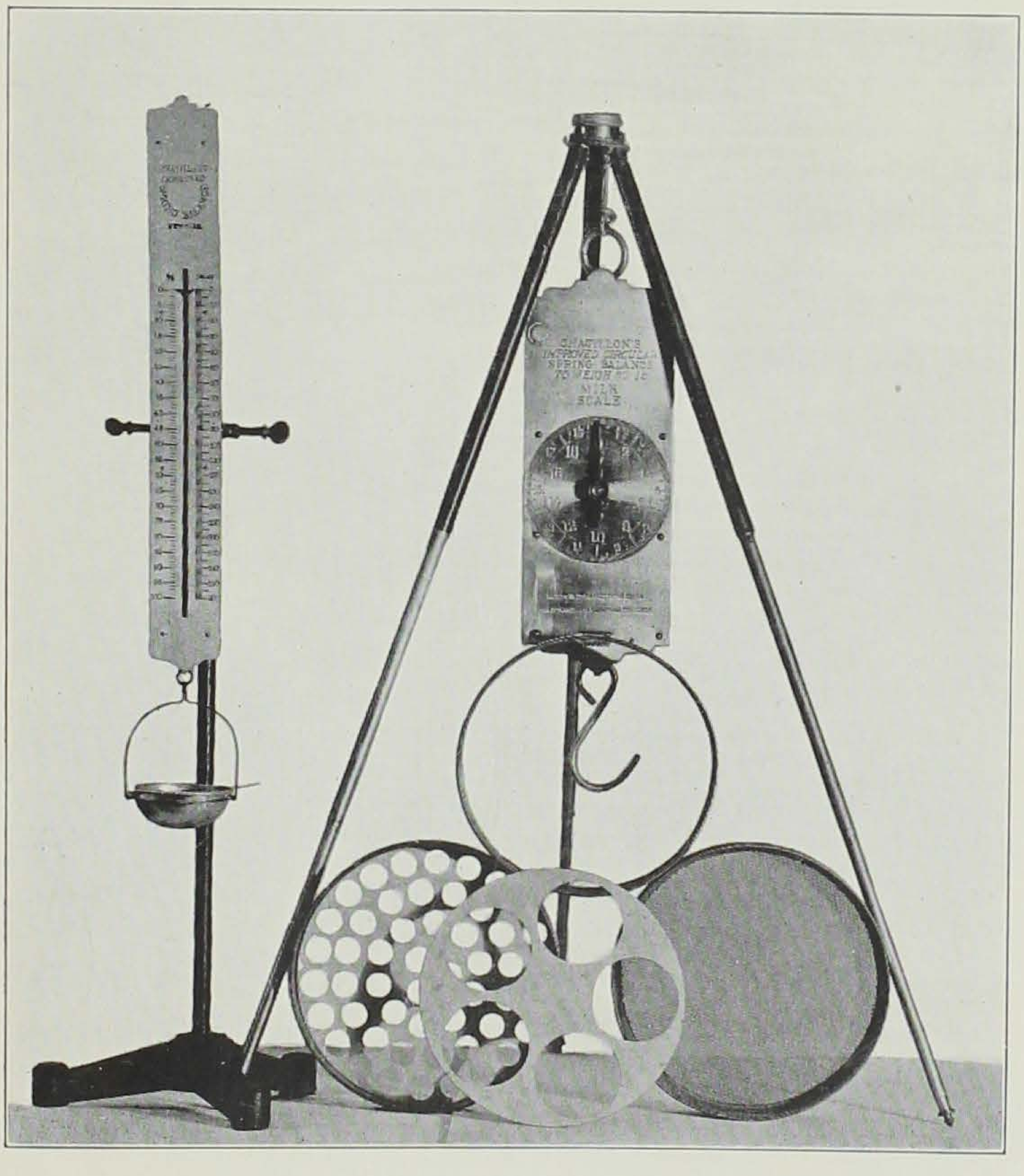


FIGURE 58.—INTERCHANGEABLE TESTING SIEVES

INTERCHANGEABLE TESTING SIEVES

As shown in Figure 58, this apparatus consists essentially of a set of rimless screens and sieves, the screens being thin, galvanized circular plates with circular perforations of various diameters and the sieves being circular brass rings, upon each of which wire mesh of the desired size has been soldered. To assemble a sieve of any desired mesh ready for use, two brass rims of such diameters that one just fits inside of the other, are used. The larger rim has a shoulder formed on the inside upon which the sieve plate rests. A rubber gasket is placed upon the top of the sieve plate to prevent fine material from escaping and the upper ring is inserted and held securely against the gasket by means of three stiff springs. For sizes ¼ inch and larger, the galvanized iron plates are used. These require no rubber gaskets. By this device it is possible to carry enough sieves and screens to make a complete mechanical analysis and still have the package occupy practically the same space as one old style laboratory sieve. For weighing aggregates, two spring-balances are used, one, a milk scale of 30 pounds capacity for coarse aggregates, and the other, a fine spring balance of 200 grams capacity for fine aggregates.

Used in field and plant inspection of aggregates.

Developed by the U. S. Bureau of Public Roads.

PORTABLE CALYX CORE DRILL OUTFIT

The arrangement of this apparatus, Figure 59, is such that the power for driving the drill is secured from the motor of the truck on which it is carried.

Used for securing samples of road surfaces in various cities and states.

Details of power transmission evolved by the U. S. Bureau of Public Roads.

Calyx Core Drill manufactured by Ingersoll-Rand Company, New York, New York.

DIAMOND POINTED TOOL FOR FACING THE ENDS OF STONE CYLINDERS

The diamond pointed tools are manufactured commercially and are similar to the tools used by automobile manufacturers for cylinder grinding. A diamond about ⅛ inch in diameter is used.

Used for preparing plane end surfaces on cylinders of stone which are to be tested in compression. It has been found by experiment

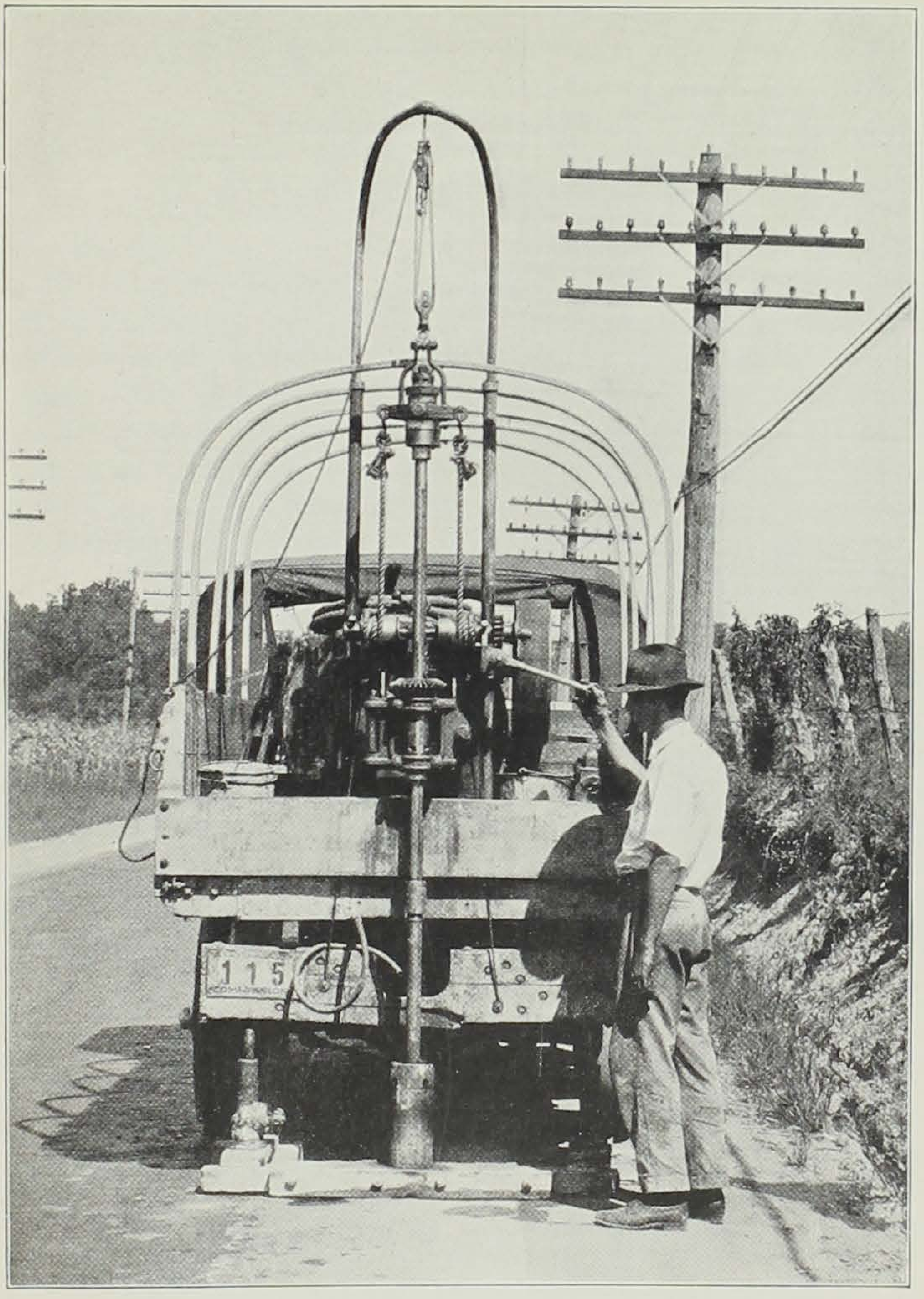


FIGURE 59.—CALYX CORE DRILL ARRANGED ON MOTOR TRUCK

that much higher crushing strengths are obtained when the ends of specimens are plane and in direct contact with bearing surfaces of the testing machine than when any form of capping is used.

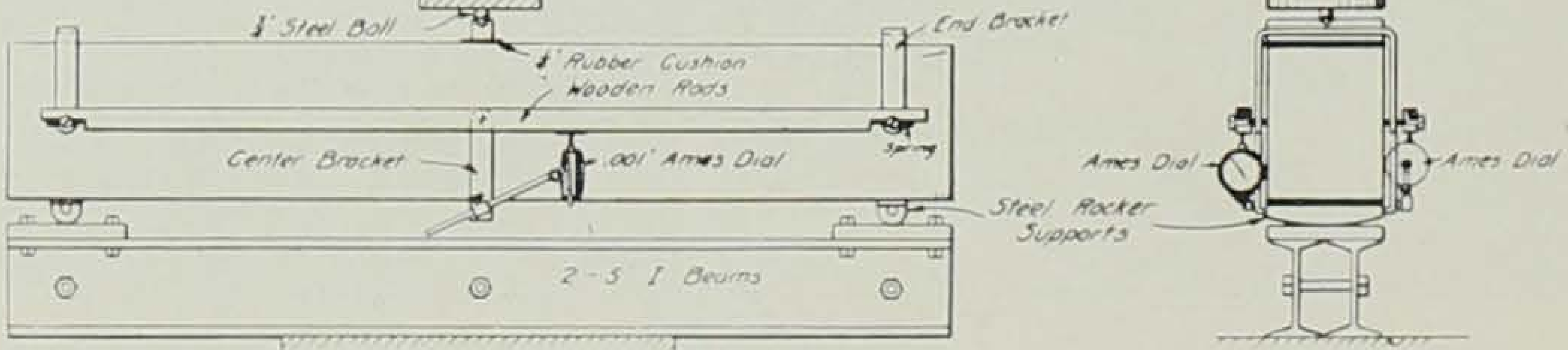
The specimen is mounted in an ordinary lathe and accurately centered so that the axis of the specimen exactly coincides with the axis of rotation of the lathe. After turning one end of the cylinder to a plane surface by means of the diamond point, the specimen is reversed in the lathe and the process repeated.

Adapted by the U. S. Bureau of Public Roads.

APPARATUS FOR TESTING BEAMS

The apparatus, as shown in Figure 60, consists of specially designed rockers having a uniform bearing against the bottom surface of the beam, and a rocker adjustment on the supporting plates. The rockers are placed under the ends of the beam. The plates are fastened to the flanges of two I-beams at such distance that the centers of the supporting rockers are 42 inches apart. The load is applied through a ¾-inch steel ball resting on a 1-inch square steel bar about 7 inches in length. To secure a more uniform application of load, a ¼-inch rubber pad is placed between the steel bar and the beam.

Special apparatus is used to measure the deflection of beams under test. This measuring device consists essentially of three U-shaped brackets of strap iron fastened to the neutral axis on each side of the beam with pointed set-screws. Two are placed directly over the end supports with the third fastened on the neutral axis at the center of the span directly under the load. This center bracket supports two Ames dials measuring to .001 inch, one on each side of the beam. Supported horizontally by the set-screws of the end brackets are two wooden bars (one on each side of the beam) against which the plungers of the Ames dials make contact. To increase



DEFLECTION MEASURING APPARATUS
CIRCULAR TRACK BEAM TESTS

FIGURE 60

the strength of the spring action of the plunger a rubber band is placed around the dial case and over the end of the plunger.

Used to test 6 by 8 by 48 inch beam specimens from the circular track, Arlington Experimental Farm, Arlington, Virginia.

Devised by the U. S. Bureau of Public Roads.

TWO-RING, TWO-DIAL COMPRESSOMETER

This compressometer (Figure 61), is of the two-ring type, supporting two Ames dials on the upper ring and two adjustable rods on the lower ring. The bronze rings are 1 inch square in cross section, and 7 inches inside diameter. These rings have two fixed steel points and one adjustable point. The points project inside the ring and have a 45° taper, which is blunt enough to prevent

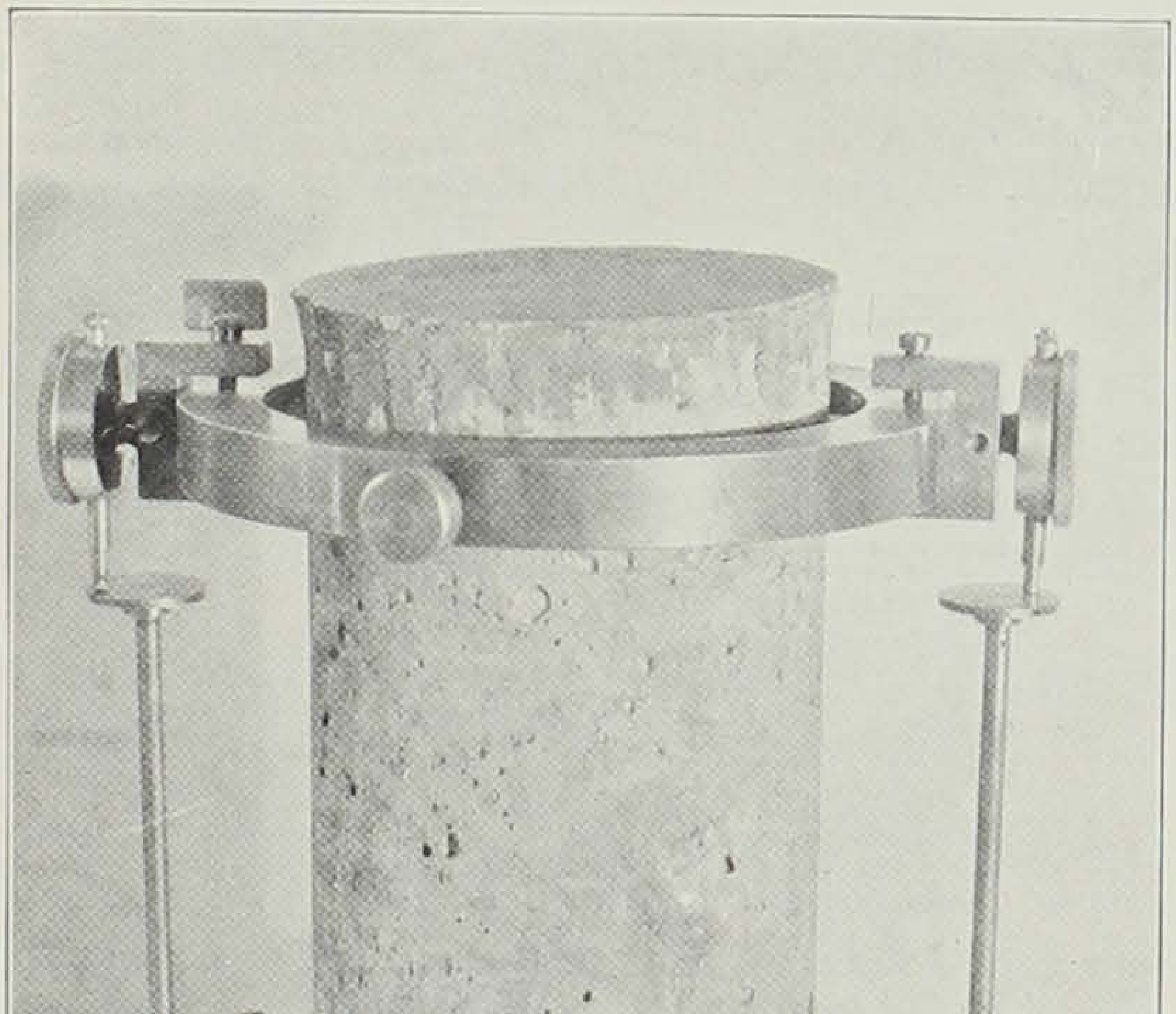


FIGURE 61.—TWO-RING TWO-DIAL COMPRESSOMETER

spalling the concrete. The points are case-hardened and set 120° apart. The adjustable point is a ⅜-inch diameter screw having 24 threads per inch. A very smooth and a close fit was secured between the threads of the screw and those in the ring. The size and weight of the rings accomplished two purposes. First, tightening the single screw of each ring until it was supported by the specimen. Second, the stiffness of the rings themselves prevents such warping as may be caused by the expansion of the cylinder under load. This was one of the main causes of error found when using the other instruments.

The upper ring supports two Ames dials, reading to .0001 inch, clamped diametrically opposite to each other to secure average deformation readings in cases of eccentric loading. The plungers of these dials rest upon the flat discs fastened to rods, which are adjustable in the clamps that are fastened to the lower ring. This arrangement allows the rings to be placed at such position on the cylinder that good support can be obtained and any convenient gage length used.

The gage length used in these tests varied from 8 to 10 inches, usually about 9 inches. As the dials permitted direct readings to .0001 inch, and it was possible to estimate tenths of a division, a unit deformation of .00001 inch per inch could be noticed. Movement of the dials occurred when the unit load did not exceed 40 pounds per square inch.

Evolved in the U. S. Bureau of Public Roads.

MODIFICATION OF THE OVERFLOW APPARATUS FOR DETERMINATION OF SPECIFIC GRAVITY OF AGGREGATES

The apparatus consists of a cylindrical glass of dimensions to accommodate a funnel of 12½-cm. diameter and depth of 15 cm. The funnel is covered by a lid and has a large inclined stem 5 cm. in diameter. A 1½-cm. hole cut 3 cm. from the top of the jar for the insertion of a special overflow tube, with a small siphon starting through capillarity of the liquid in the siphon. The object of this tube (Figure 62), is to secure a sharp cut-off and sensitive start of the flow of the liquid. For material having a large amount of dust, a deeper jar and an extended funnel stem may be used. The object of the funnel is to reduce inclusion of the air, splashing and flotation of the fine materials.

Used for determination of apparent specific gravity of mixed coarse and fine aggregates, particularly as extracted from bituminous mixtures.

Devised in the U. S. Bureau of Public Roads.

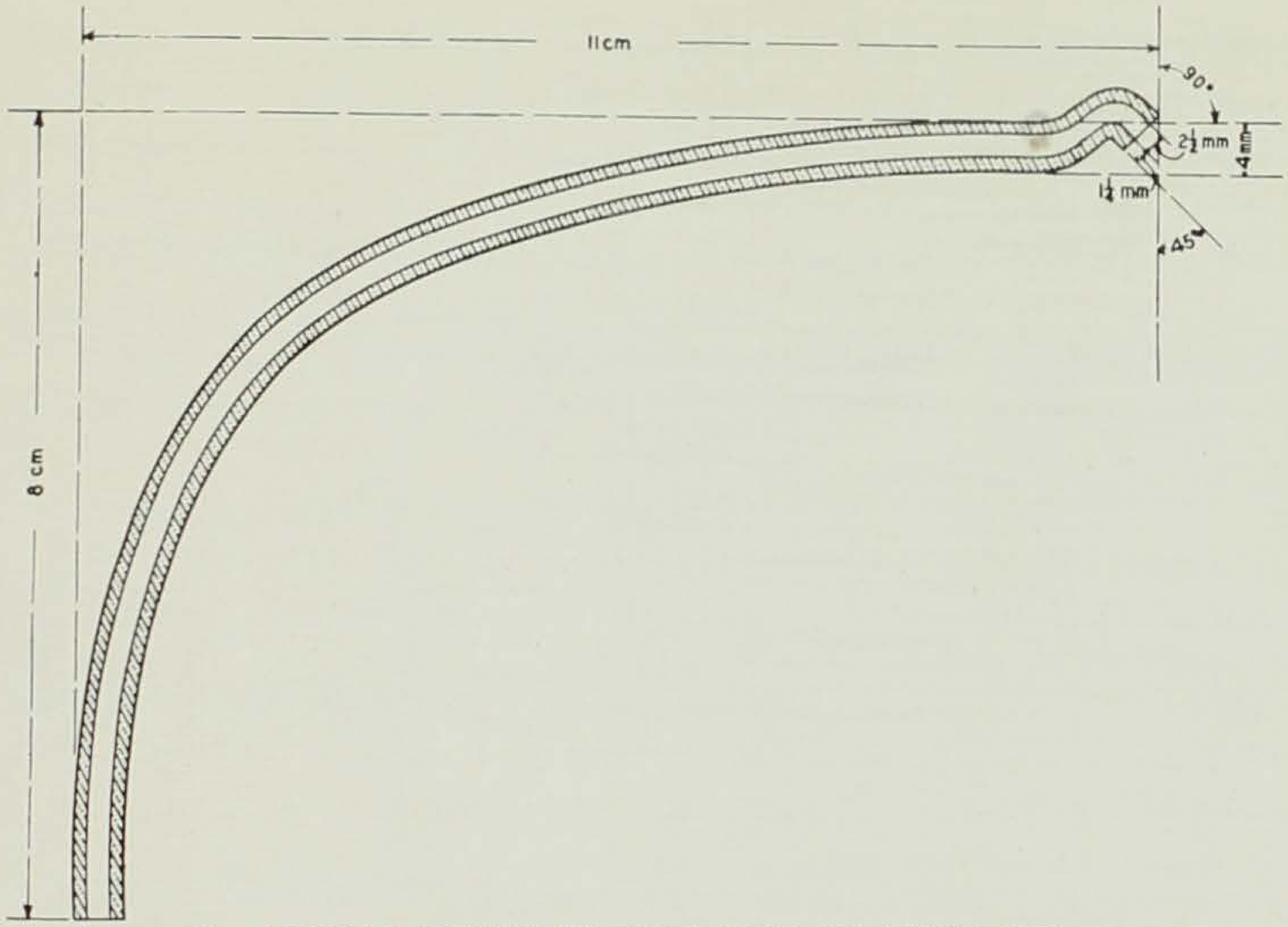


FIGURE 62.—SPECIAL OVERFLOW TUBE USED IN DETERMINATION OF SPECIFIC GRAVITY OF AGGREGATES

ELECTRICALLY HEATED MOLD FOR FORMING ASPHALTIC MIXTURE SPECIMENS

SAMPLER FOR ASPHALT PAVEMENTS

SPECIAL ADHESION CLIP FOR TESTING BITUMINOUS MATERIALS

District of Columbia: U. S. Bureau of Standards.

FLOW TABLE

This apparatus consists of a metal-covered table-top, which can be raised vertically by means of a cam working at the end of a vertical post, to which the top is attached. The height of drop can be adjusted by means of a bolt at the lower end of the shaft. A mass of concrete or mortar is molded at the center of the table in a sheet-metal mold, which has the shape of a hollow frustrum of a cone. For aggregates up to 2 inches maximum size, this mold has a height of 6 inches, and upper and lower diameters of 8 inches and 12 inches, respectively. Smaller aggregates are made up in smaller quantities, and a mold having a height of 3 inches and upper and lower diameters of 4 inches and 6 inches, is used. The mass of concrete is tamped just sufficiently to fill the form completely, the form is withdrawn and the table top is dropped fifteen times through a distance of ½ inch. The mass flattens and usually spreads concentrically. Two diameters at right angles to each other are measured, the long and short, if difference is apparent, by means of a self-reading caliper, which is so graduated that the sum of the two readings is the value for flowability. This may also be calculated by dividing the new diameter by the old and multiplying by 100.

The apparatus is used to determine the consistency or flowability of concrete.

The determination of consistency of concrete by measurement of the spread of a cylinder when dropped through different heights is described in a paper by Cloyd M. Chaplin, entitled "Method and Apparatus for Determining Consistency," published in the Proceedings of the American Society for Testing Materials, Vol. 13, 1913.

Designed and constructed by the U. S. Bureau of Standards.

For full description of the flow table and method of its use, see "Concrete Consistency Measured by Flow Table; New Apparatus Devised at Bureau of Standards Gives Accurate Measure of Flowability or Workability of Concrete," by G. M. Williams, Engineering News-Record, May 27, 1920, page 1044.

Indiana: Purdue University.

FATIGUE TESTING MACHINE FOR CEMENT MORTAR AND CONCRETE

The machine shown in Figure 63 is a mechanical device for studying the fatigue of small cement mortar and concrete beams. The frame of the machine consists mainly of 4-inch I-beams and brace rods. Mounted at the top of the frame is a ½-horsepower electric motor, drive gears and cam shaft. Connected to the cam shaft is a revolution counter and four eccentric cams, which operate the rocker arms. The concrete beams are firmly clamped in an upright position to the base of the machine by means of angle irons, and each beam supports a 4-inch I-beam, which is firmly clamped to it by similar angle irons. The machine is so constructed that movement of the rocker arms by the eccentric cams applies the load of the metal baskets and hangers alternately on the ends of the supported I-beams. This action reverses the stresses in the concrete beams periodically and causes the fatiguing action.

Devised by W. K. Hatt, Professor of Civil Engineering.

Used in Testing Materials, Laboratory, Purdue University, during 1922–23.

Designed by Engineering Experiment Station of Purdue University and U. S. Bureau of Public Roads.

See report by W. K. Hatt, Proceedings of American Concrete Institute, 1922.

Constructed by the Horat Machine Company, Lafayette, Indiana.

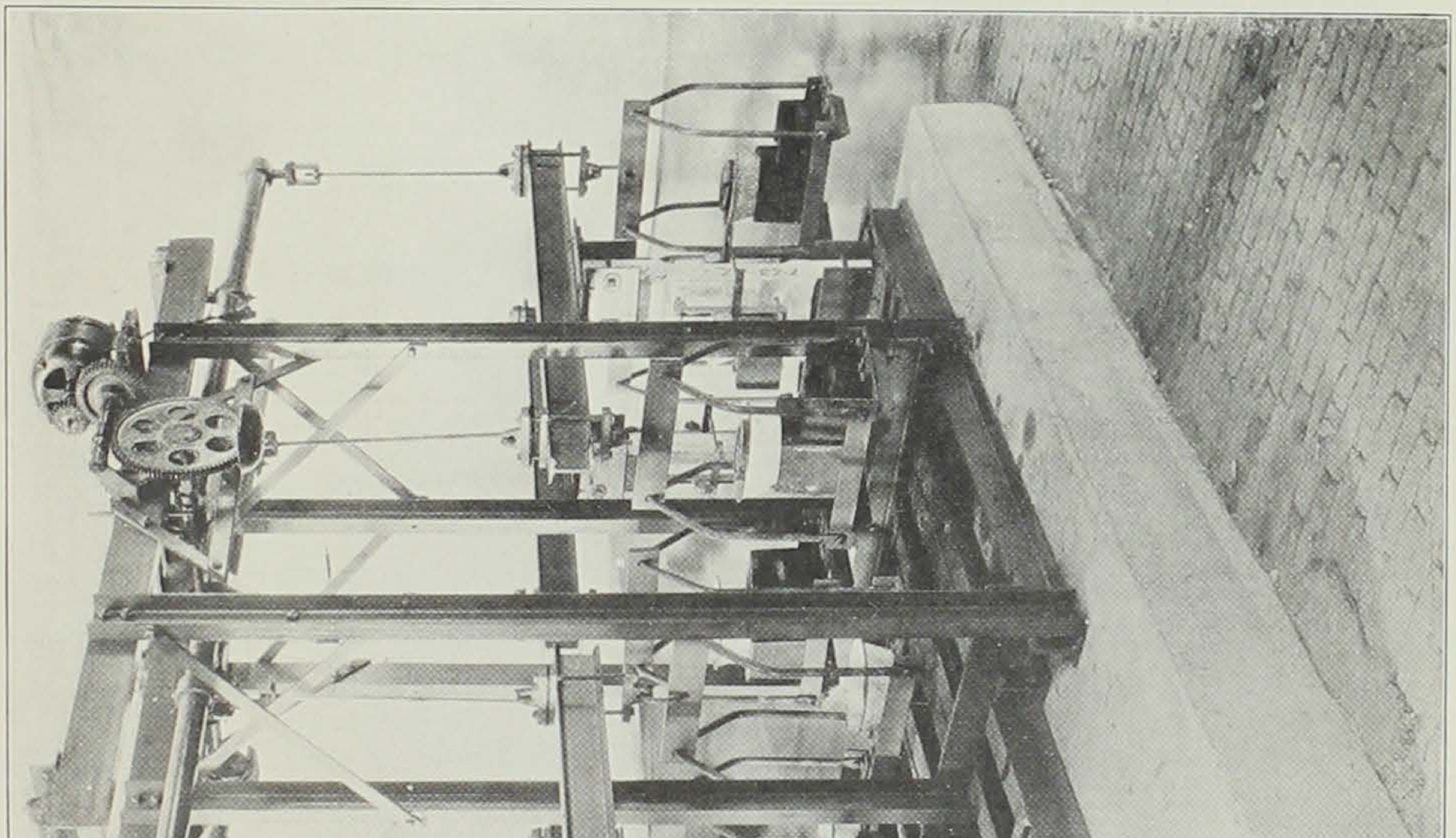


FIGURE 63.—FATIGUE TESTING MACHINE, PURDUE UNIVERSITY

BALL TEST FOR SURFACE STRENGTH OF CEMENT MORTAR AND CONCRETE

A standard steel ball ½ inch in diameter is placed on the surface of a mortar slab, which is 36 by 15 by 4 inches thick. A steel plate, 2 by 2 by 4½ inches thick, with a hole approximately ½ inch in diameter, is placed over the ball, which, therefore, projects half its diameter from the surface of the steel plate. The slab, ball, and the plate, as shown in Figure 64, are placed on the platform of a testing machine, and the load then applied on the projecting ball. This load is increased until the ball penetrates the surface of the mortar slab to one-half of its diameter, whereupon the testing head of the testing machine comes in contact with the surface of the steel plate. The resistance suddenly increases and throws up the scale beam, which is a fairly good indication that the ball has penetrated the slab to one-half of its depth.

Devised by W. K. Hatt, Professor of Civil Engineering.

Used in Testing Materials Laboratory, Purdue University. 1922–23.

Adapted by Engineering Experiment Station, Purdue University, and U. S. Bureau of Public Roads.

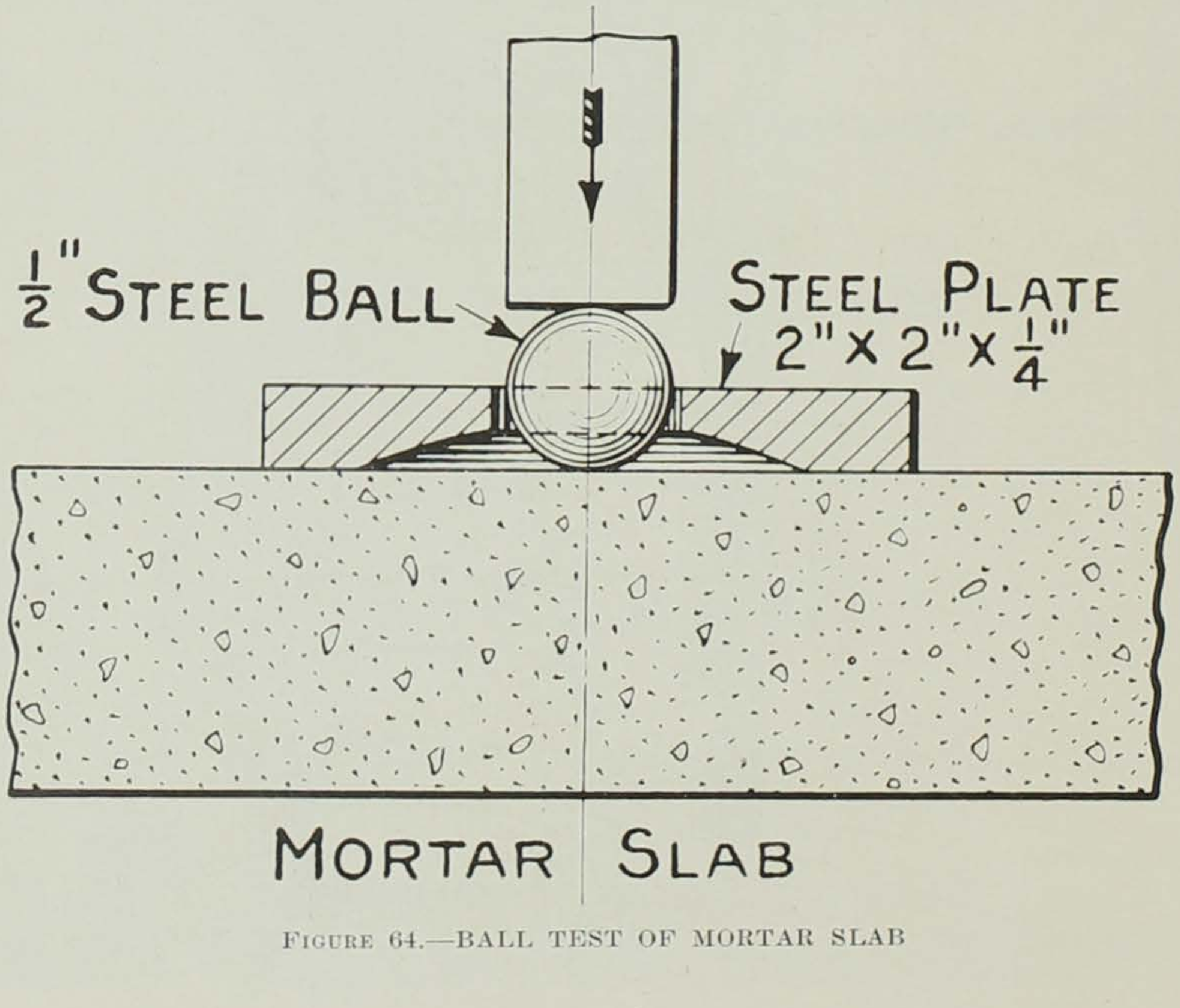


FIGURE 64.—BALL TEST OF MORTAR SLAB

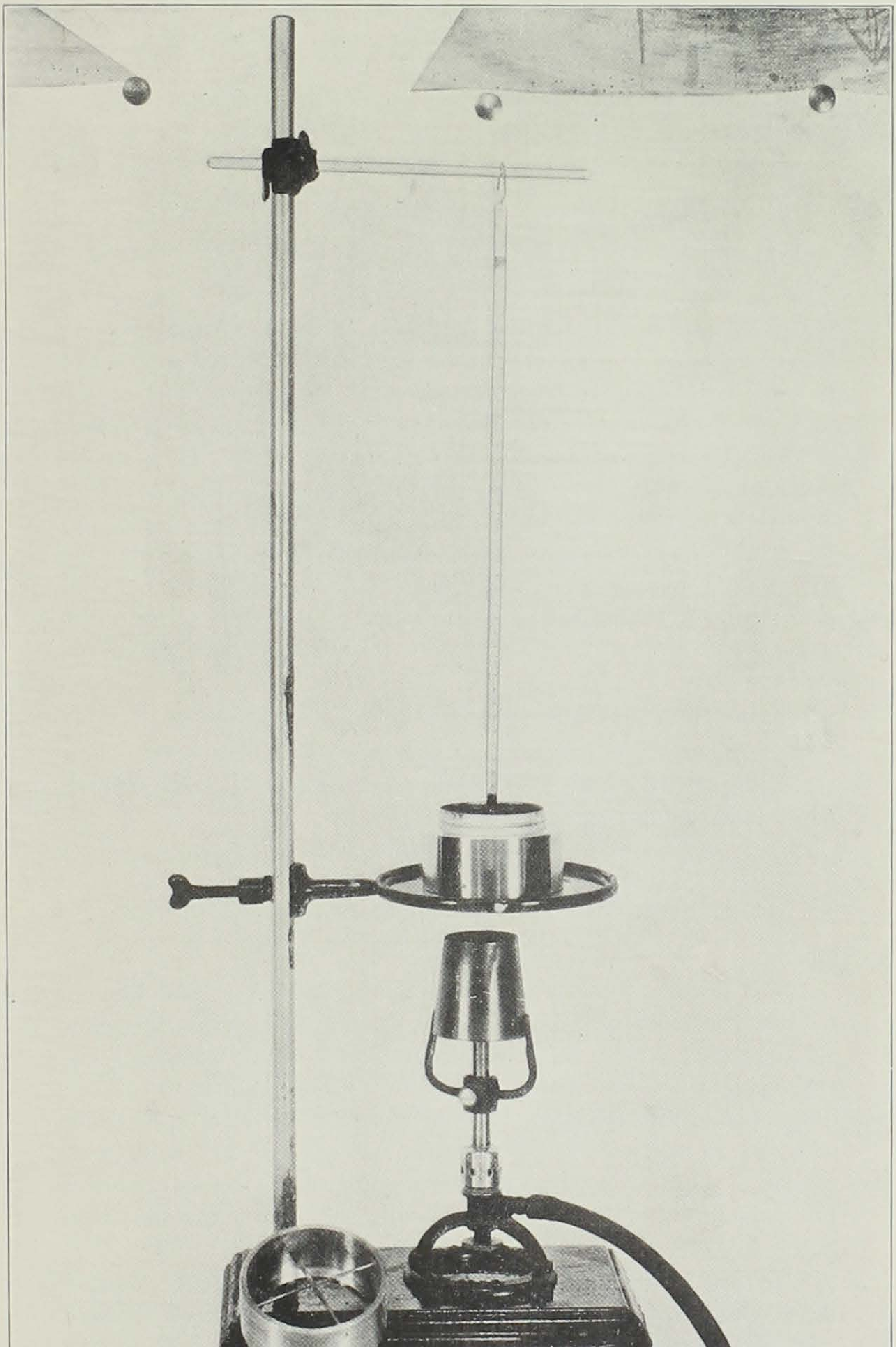


FIGURE 65.—AIR BATH FOR MAKING ANALYSIS OF ROAD OILS

See report by W. K. Hatt, American Concrete Institute Proceedings, 1922.

Constructed by Purdue University, Lafayette, Indiana.

Illinois: Illinois Division of Highways.

AIR BATH FOR MAKING ANALYSIS OF ROAD OILS

The apparatus (Figure 65), which is made of ⅛-inch brass, is designed so that the box containing the oil is immersed to a depth of 1 inch through an opening 1/32 inch larger than the outside diameter of the sample box. A free air space of ¼ inch is provided on the bottom of the box, and at least ½ inch of free air space on the sides below the opening.

The air bath prevents uneven heating of the road oil sample, and also it permits the desired temperature to be reached more quickly and to be more easily controlled than with the sand bath. In all cases uniform results were obtained having a slightly higher percentage of solid residue without any noticeable deposit of cooked residue.

Used by Bureau of Tests, Illinois Division of Highways.

Designed by H. F. Clemmer, Engineer of Tests, Illinois Division of Highways, H. C. Helmle, Assistant Engineer of Tests, Illinois Division of Highways.

Constructed by Bureau of Tests, Illinois Division of Highways.

MODIFICATION OF DEAN & STARK APPARATUS FOR THE DETERMINATION OF WATER IN PETROLEUM

The "distilling tube receiver" in this apparatus as sold by jobbers, is graduated in 0.5 cc. It was decided to have the first four cubic centimeters of the receiver graduated to 0.1 cc., and the remaining six cubic centimeters in the usual manner of 0.5 cc. This change was advisable for two reasons; the volume of water collected in testing road oils seldom exceeds 4.0 cc.; a 50-gram sample of road oil is used, and, as the error in the determination is multiplied by two, the errors in reading the volume should be reduced to a minimum.

The total length of the graduated tube (Figure 66), is increased four centimeters, but it causes no inconvenience in running the test.

Used in Illinois Division of Highways laboratory.

Modified by H. F. Clemmer, Engineer of Tests; A. E. Stoddard, Assistant Engineer of Tests; W. J. Merrill, Assistant Engineer of Tests.

Manufactured by Rascher & Betzold, Chicago, Illinois.

Maine: University of Maine.

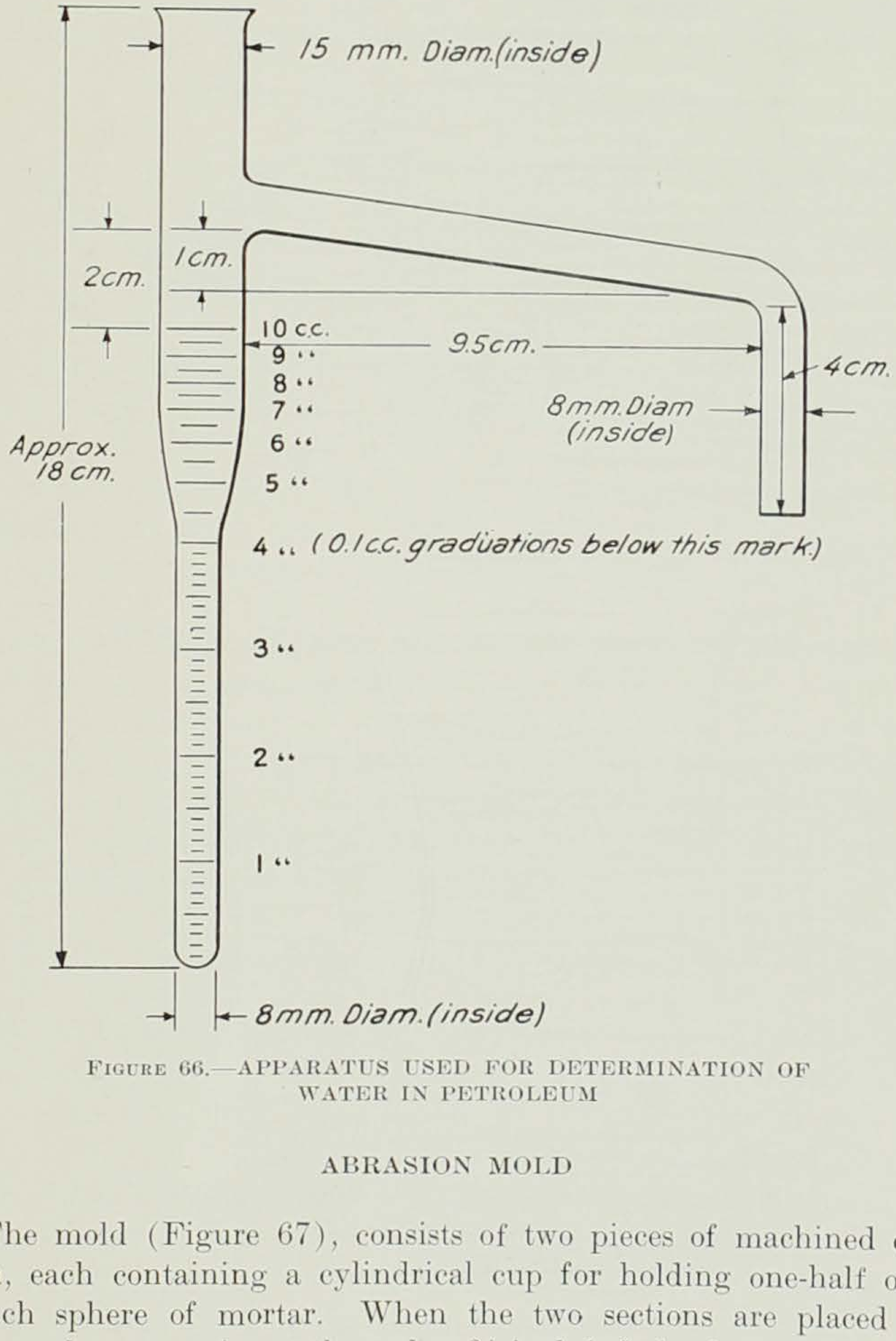


FIGURE 66.—APPARATUS USED FOR DETERMINATION OF WATER IN PETROLEUM

ABRASION MOLD

The mold (Figure 67), consists of two pieces of machined cast iron, each containing a cylindrical cup for holding one-half of a 2-inch sphere of mortar. When the two sections are placed together, the mortar is put through a $\frac{3}{4}$-inch hole in the top plate and tamped with a $\frac{1}{2}$-inch rod. The top of the sphere is given its

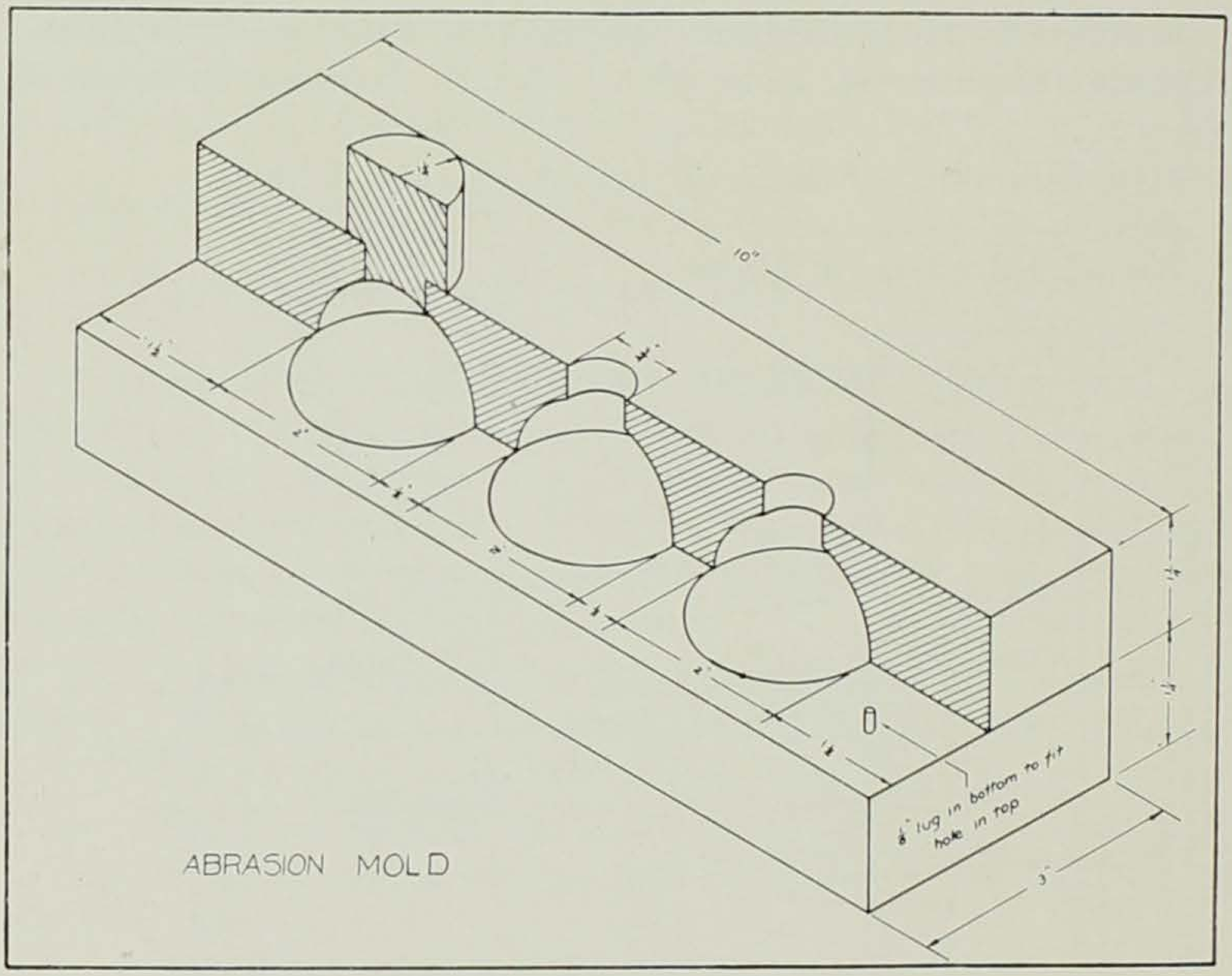


FIGURE 67

final rounding by means of a concave plug that is driven in to just the proper depth. Three spheres of mortar are cast at one time. After handling in moist air for 24 hours, the specimens are removed and placed in water for a longer curing period.

Used in abrasion test for mortar.

Designed by H. Walter Leavitt, Testing Engineer, University of Maine, College of Technology, and Maine State Highway Commission.

Constructed by University of Maine Machine Shops.

Minnesota: University of Minnesota and Minnesota State Highway Department.

SHALE TESTING APPARATUS

This apparatus consists of two galvanized iron pans, about 9 by 12 by 6 inches, and another container made out of 10-mesh sieves. This third container is constructed so as to fit inside of the galvanized iron container.

In making a shale separation, the galvanized iron container is filled with a saturated solution of zinc chloride. The rock to be tested is placed in the mesh container, which is in turn placed in the zinc chloride solution. The rock is then agitated, and the shale will rise to the top and float. The shale can then be skimmed off and the percentage of shale determined.

Used in laboratory and field tests for shale.

Devised by the Minnesota Highway Department.

Pennsylvania: State Highway Department.

ELECTRICALLY HEATED STEEL MOLDS

In these molds are compressed bituminous mixture specimens, which are to be used in tests of density, toughness, deformation, and absorption. The required weight of the heated bituminous mixture is used in order to obtain a cylinder of the desired height under a specified load. Figure 68 shows the 1¼-inch mold prior to wrapping with a resistance wire and insulation, and Figure 69 shows the 4-inch mold, with electrical equipment ready to be placed in the testing machine. By use of the resistance wire and lamp black, uniform temperatures of 100° to 475° F. may be maintained in the mold.

Designed and constructed by the Pennsylvania State Highway Department.

See report of Sub-committee No. 4 of the American Association of State Highway Officials, 1922.

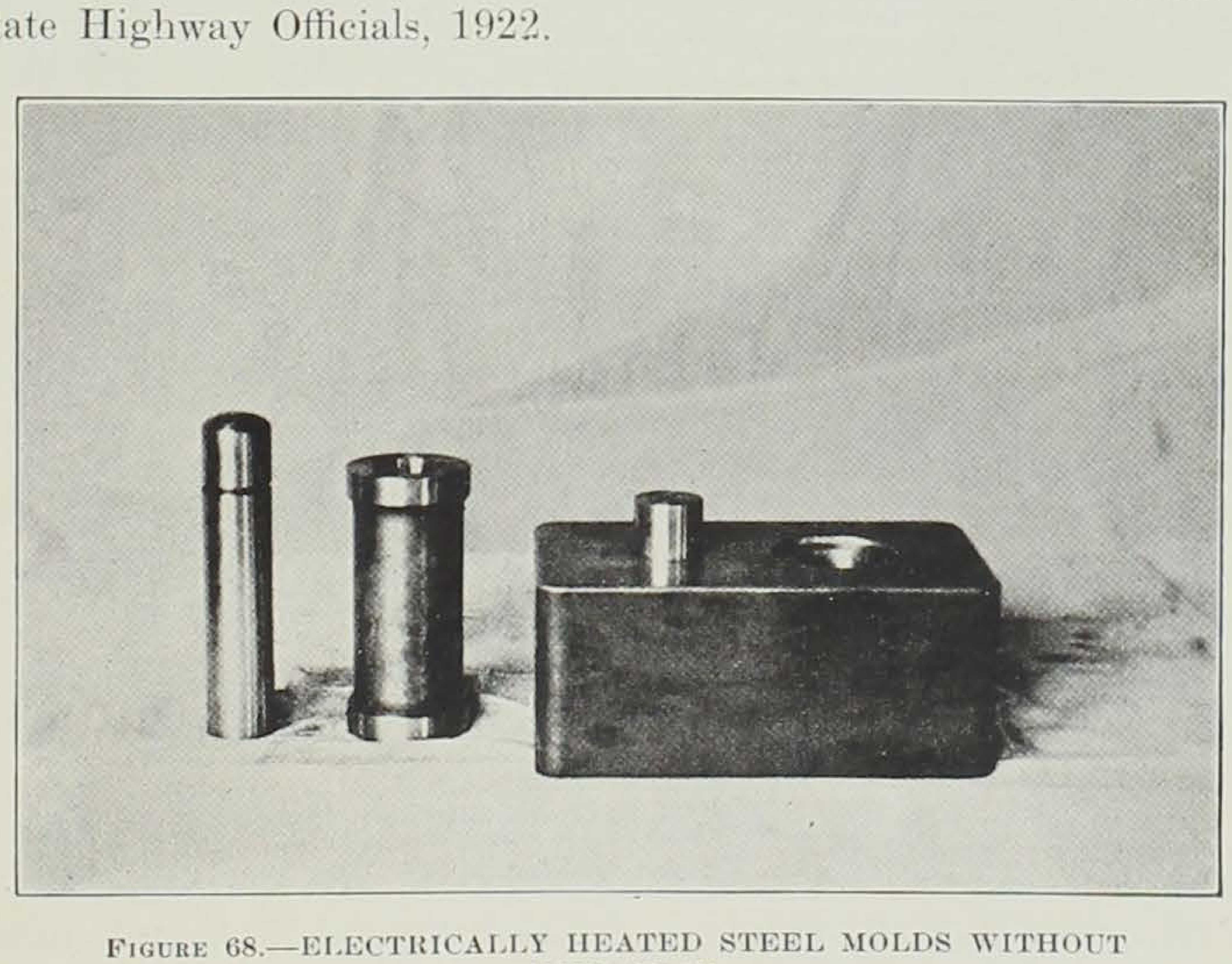


FIGURE 68.—ELECTRICALLY HEATED STEEL MOLDS WITHOUT INSULATION

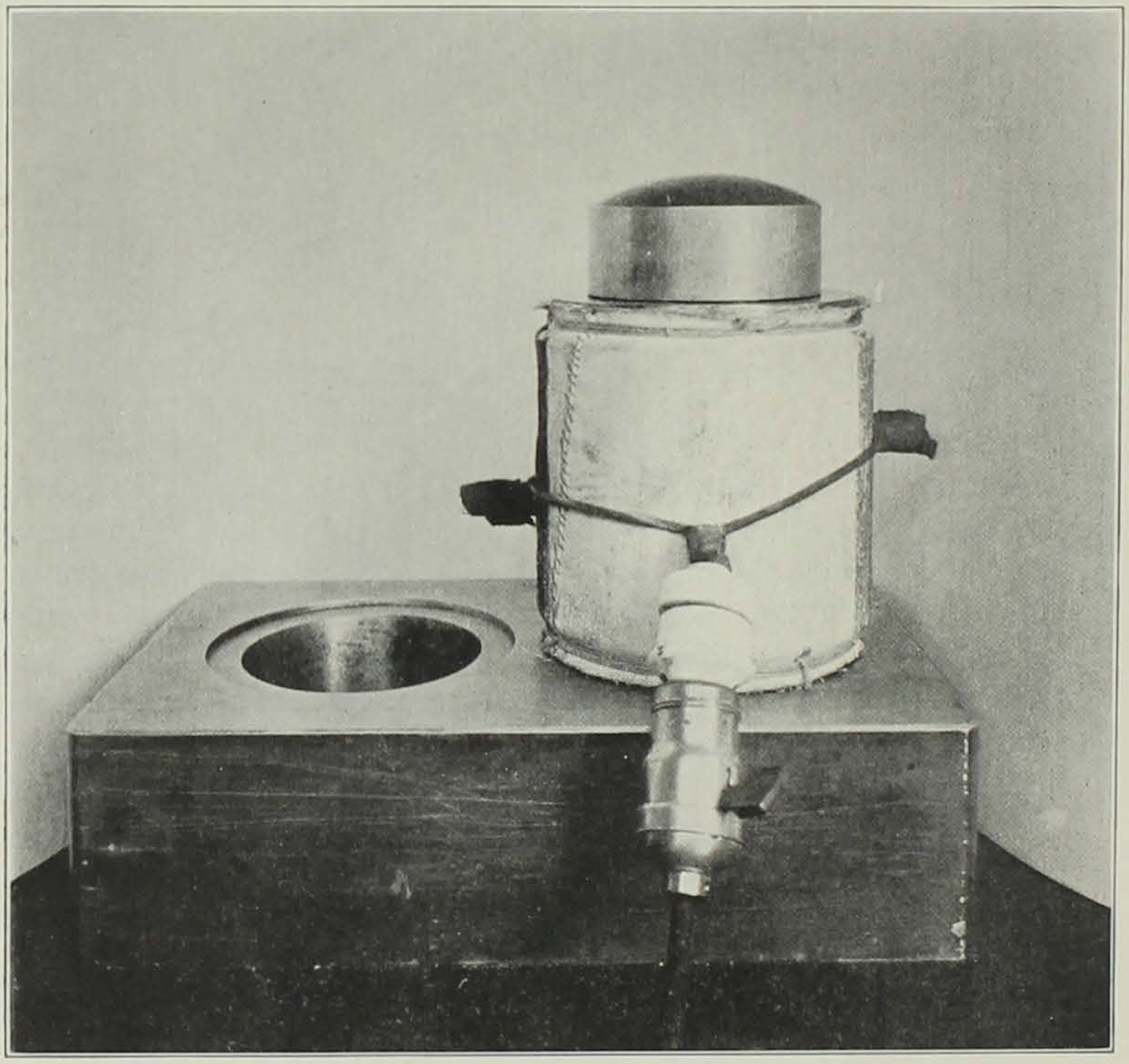


FIGURE 69.—ELECTRICALLY HEATED STEEL MOLD WITH INSULATION

IMPACT MACHINE FOR WEAR TEST ON CONCRETE

The impact machine consists of a head, which is lifted and dropped by a cam. The concrete specimen to be tested is revolved by the mechanism which drives the cam. Eight or nine hardened steel points, with which the head is fitted, are permitted by springs to adjust themselves when they come into contact with high spots on test specimens. The cam can be adjusted for any desired height of fall.

Used for wear tests on the surface of concrete cubes, cylinders, or samples taken from roads. Any size or shape of sample can be fitted in the specimen holder.

Designed by H. S. Mattimore and F. H. Rood when with the New York State Highway Commission.

See paper by H. S. Mattimore, entitled "Impact Tests on Concrete to Regulate Coarse and Fine Aggregate Qualities and Mixes for Highways," Proceedings A. S. T. M., Vol. XX, 1920, Part 11, p. 266.

SLOTTED CYLINDER FOR DEVAL ABRASION MACHINE

The slotted cylinder is similar to the regular cylinder for the Deval abrasion machine. It has 20 slots, equally spaced around the top of the cylinder, and 20 slots around the bottom, to remove the dust as fast as it forms. These slots are 1/16 inch wide on the inside, and about 1/8 inch wide on the outside of the cylinder. This cylinder is especially valuable in determining the relative value of soft aggregates, particularly those showing a loss of 8 per cent or more, in the standard cylinder. It is also used in abrasion tests of gravel.

Designed by H. S. Mattimore when with the New York State Highway Commission.

Described with photograph, Proceedings American Society for Testing Materials, Vol. XVIII, Part 11, 426-428 (1918).

STONE BREAKING MACHINE FOR DEVAL ABRASION TEST

This machine is built on the lines of a letter press. The frame, which is constructed of 4-inch channels, contains an opening about 12 inches square. A knife edge is fitted into the center of the bottom of the frame and one directly above it at the end of the movable screw. A large hand wheel (24 inches in diameter), at the top of the screw gives the required leverage to break the stone.

With this machine it is possible to break a sample of stone into cubical pieces ready for the abrasion test in ten minutes. It is also possible to secure 5 kilograms, consisting of 50 pieces, from a sample weighing about 5,500 grams, from a stone breaking like granite paving block.

Modified letter press first used by the New York State Geologist. Later improved by R. S. Greenman, New York State Engineers Office, and again by H. S. Mattimore, Pennsylvania State Highway Department.

Described in A. S. T. M. Proceedings, Vol. XX, 1920, p. 291.

Wisconsin: University of Wisconsin and State Highway Commission.

RATTLER FOR TESTING ABRASIVE RESISTANCE OF CONCRETE

The accompanying photograph, Figure 70, shows the adaptation of a standard paving brick rattler to rattler tests of 4½ by 8 by 19½-

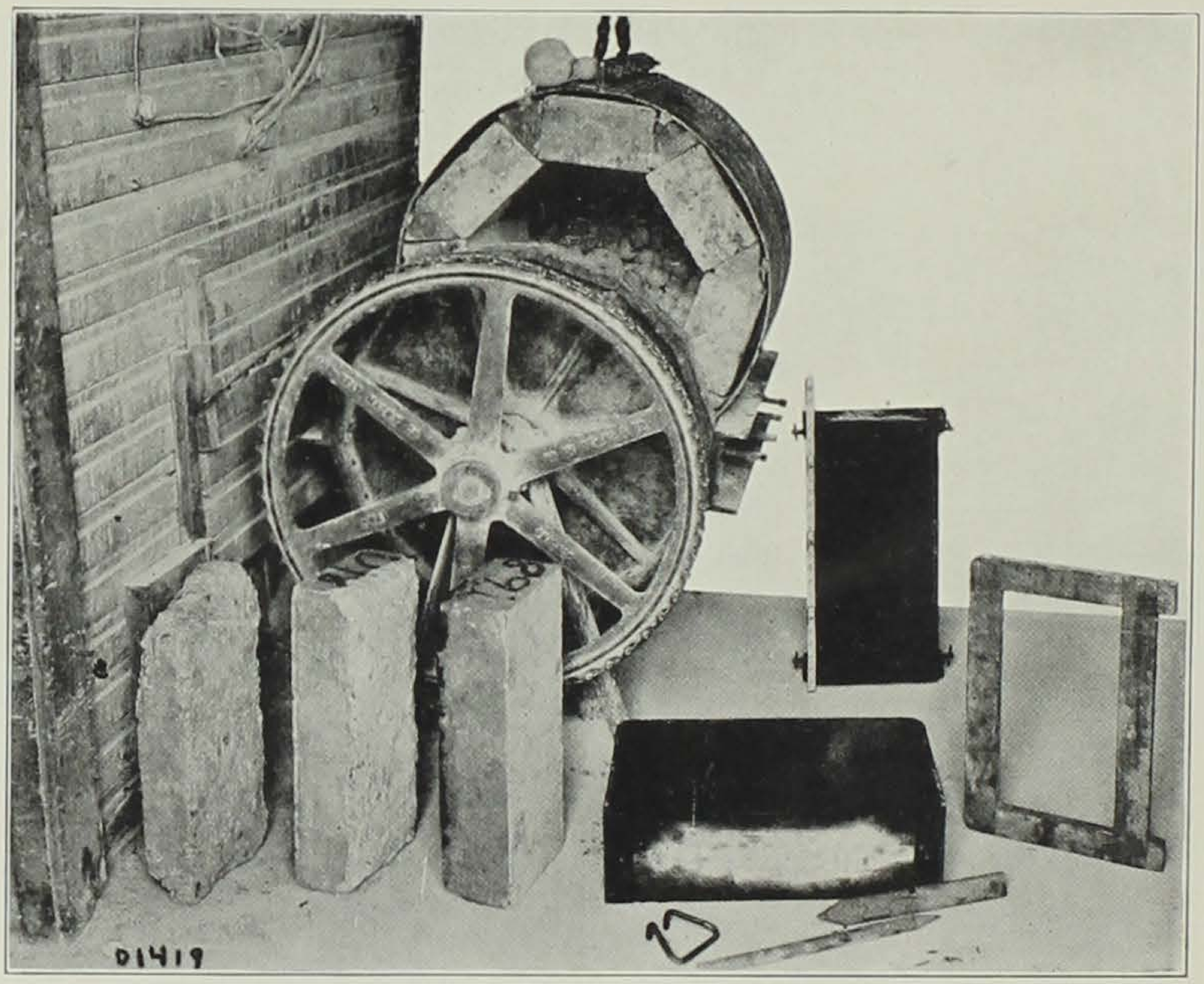


FIGURE 70.—RATTLER FOR TESTING ABRASIVE RESISTANCE OF CONCRETE

inch concrete slabs. Six concrete slabs and one wooden slab, called a "dummy," are held by two tire-like soft steel bands 1/4 inch thick, in the form of a hollow heptagon. The spaces between the slabs are filled with triangular wooden blocks, wedged in place. The wooden dummy is provided with a steel face and two longitudinal slots, approximately 1/2 inch wide and 16 inches long. These slots emit the dust and small pebbles which accumulate during the test. The charge, which is standard for the paving rattler test, consists of 150 pounds of small cast iron shot and 50 pounds of large cast iron shot. After the specimens and charge are securely clamped in the machine, the drum is given 1,800 revolutions in a clockwise direction, and 1,800 in a counter-clockwise direction. The loss in weight during the test, the character of the surface, and the evidence of fracture in aggregate and in slab as a whole, are the criteria by which the suitability of the concrete is judged. The cast iron mold, with wooden scale beside it, illustrates the type used for making specimens in the laboratory. The pressed steel mold with wooden side, shown in the lower right foreground, is used in fabricating slabs in roads, the wooden side being set adjacent to the side form of the road. The top edge of the form is placed about one-half inch below the road surface, and the slab is marked off from the road after all operations have been completed by means of the wooden template shown at the right.

Used in the Mechanics Laboratory at the University of Wisconsin; also in the laboratory and to some extent in the field work of the Wisconsin State Highway Commission.

Designed in Mechanics Department, University of Wisconsin.

Constructed by the mechanician of the College of Engineering, University of Wisconsin.

Wyoming: State Highway Department.

IMMERSION TANK—DAMP CLOSET

This device, in which concrete briquettes are cured, was developed as a result of the investigators' inability to properly cure in still water because of the alkali in the water. If the specimens were stored in still water, the alkali crystalized on them, and, since continual evaporation increased this condition, running water was necessary. And also, since water supply pipes ran through much of the building before being available in the laboratory, the water varied considerably in temperature from time to time. This device aids in securing uniform temperatures.

Used by the Wyoming State Highway Department.

Adapted by the Wyoming State Highway Department, W. A. Norris, Testing Engineer.

Constructed by the R. Hardesty Manufacturing Company, Denver, Colorado.

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