Bulletin No. 329

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

ORGANIZATION, EQUIPMENT, AND OPERATION

OF THE

STRUCTURAL-MATERIALS TESTING LABORATORIES AT ST. LOUIS, MO.

BY

RICHARD L. HUMPHREY

WITH PREFACE BY

JOSEPH A. HOLMES

IN CHARGE OF TECHNOLOGIC BRANCH

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PREFACE.

By Joseph A. Holmes.

The authority for the investigations described in this report is embraced in the following item of the bill making appropriations for the sundry civil expenses of the Government for the fiscal years 1906 and 1907, as follows:

For the continuation of the investigation of structural materials belonging to or for the use of the United States, such as stone, clays, cement, and so forth, under the supervision of the Director of the United States Geological Survey, to be immediately available, one hundred thousand dollars.

As illustrating the magnitude of the work which may be affected by these investigations, it may be stated that the expenditures of the Federal Government for building and construction work now approximate $30,000,000 per annum, while the expenditures of the country at large for similar purposes are in excess of $1,000,000,000 per annum.

It was with a view to reducing the cost and improving the quality of the materials used in this building and construction work that Congress was asked to provide for the investigations of structural materials now under way. In order that this work might be done in such a manner as to best meet the needs of the Government in this respect, an advisory board was organized, on which were placed by the President the chiefs of each of the Government bureaus having in charge important building and construction work, viz, the Chief Engineer of the Isthmian Canal; the Chief Engineer of the Reclamation Service; the Supervising Architect of the Treasury Department; the Chief of the Bureau of Ordnance of the Army; the Chief of the Bureau of Steam Engineering of the Navy; and representatives of the Corps of Engineers of the Army and of the Bureau of Yards and Docks of the Navy; and in order that these investigations thus conducted for the use of the Government might be satisfactory to the engineers of the country, and also of service in meeting the needs of the general public wherein they agree with the needs of the Government, representatives of the national engineering and allied organizations were similarly brought into consultation as members of this advisory board. The members of this board connected with the Government service were asked to submit recommendations as to the investigations which were specially needed in connection with the construction work under their supervision; and the plans covering each investigation were submitted to and approved by the members of this board before the work was undertaken.

Engineers and architects, in drawing up plans and specifications for building and construction work, usually prescribe quantities of materials considerably in excess of the quantities which theoretically would be considered necessary for the purpose if exact knowledge concerning the properties, behavior, and permanence of the materials to be used were available; and it is fair to estimate that if the investigations under way can supply this information, they may be instrumental in reducing the cost of the construction work of the Government as much as 10 per cent on its present estimates.

As a result of several conferences among the representatives of the Government bureaus having in charge this construction work, it was decided that in view of the convenience and economy with which concrete might be more largely used in this work, and the lack of exact knowledge concerning its real properties and behavior and especially its strength and permanence under different conditions, concrete, reinforced concrete, and the constituent materials available for making it should receive a large share of attention in connection with the investigations provided for by Congress.

The importance of this work was further emphasized by the fact that a large quantity of this material might be needed in connection with the construction work of the Isthmian Canal, the Reclamation Service, the Corps of Engineers of the Army, and the Supervising Architect's Office. At that time attention was further called to the fact that inasmuch as a considerable period of time (from two to three years) would elapse in the investigations of concrete before any one series of tests could be completed—owing to the changes that concrete might undergo during periods of seasoning—these investigations should be begun immediately and pushed vigorously in order that the results might be available at the earliest practicable date for important construction work then being planned by these several branches of the Government service.

For the reasons above outlined, during the last two years the larger part of the appropriation for the investigations of structural materials has been devoted to an investigation of the character and distribution of the constituent materials available for concrete construction at centers where these materials were to be needed by the Government; the character and properties of the concrete and reinforced concrete made from these materials; such general properties of concrete as its strength, porosity, permanence, and fire-resisting qualities; the more efficient methods of reinforcing concrete for different purposes; and the behavior of concrete and reinforced concrete under different treatment with salt or fresh water, acids, electric currents, fire, etc.

The general plan of operations in these investigations involves (1) the obtaining of information concerning the nature and extent of the deposits of sand, gravel, and stone which appear to be available for the purpose of making concrete at or near the centers where Government building and construction work are to be undertaken; (2) the collection of samples, ranging from a few tons to a carload in quantity, of these sands, gravels, or stone which would be representative of the larger deposits available for actual use, and the shipment of these samples to the central laboratory at St. Louis; (3) the testing of these materials, not only by chemical and physical examination of the materials themselves, but also by mixing them with a typical cement and using these mixtures in the making of blocks, beams, etc., of concrete and reinforced concrete under a variety of conditions; (4) the testing of the steel used in making the reinforced-concrete masses; (5) the seasoning of these masses for different periods of time, under a variety of conditions; and (6) the testing of these masses from time to time in such manner as to determine their different properties and their suitability for different classes of building and construction work.

Perhaps the controlling reasons for asking that the Federal Government provide for these general investigations are the following: (1) The building and construction work of the Government greatly exceeds that of any State, corporation, or individual. (2) This work by the Government, being done in all parts of the country under many different conditions, calls for the solution of a far larger number and variety of general problems than may be called for in connection with the work of any State, corporation, or individual; and therefore the information which is in this way gained for the use of the Government, and which it pays the Government to obtain for use in its own work alone, is of value to the States, municipalities, and the whole people of the country in connection with their own building and construction work; provided that the results of the investigations are published in such a way as to become available for the use of the general public. (3) The investigations conducted by the Government are presumably disinterested, there being no other interest to be served than the acquirement of facts for public use; and in view of the varied conditions under which these results are to be used, and the ease with which the Federal Government can obtain results of similar investigations in foreign countries, this Government work should be and presumably is conducted with sufficient thoroughness and on a sufficiently comprehensive plan to make the results also valuable for the use of the general public. (4) There is less occasion for duplication when these investigations are conducted by the Federal Government, because of this thoroughness and comprehensiveness. If this work were done by the States, municipalities, or individuals, each for its own purposes, there would be an extensive and unnecessary duplication in labor, cost, and time. The above statement applies only to these general investigations of structural materials. In addition to these, many special tests of local materials will naturally be desired by each State or municipality or private individual; and such tests, having only a local application, of course should be made or paid for by the State or persons concerned.

As an illustration of the thoroughness with which those in charge have endeavored to conduct the investigations called for in connection with this testing of the materials to be used by the Government, the fact may be mentioned that during the two fiscal years ending June 30, 1907, the number of tests and determinations made aggregated 35,500; also that in certain investigations of plain and reinforced concrete made in connection with the work of the Supervising Architect of the Treasury Department, more than 1,000 concrete beams (each 13 feet by 8 by 11 inches) have been made, representing different types of mixtures, reinforcement, etc. These beams are now being tested at intervals to determine the varied conditions in their makeup and the effects of age and seasoning.

Another of the numerous series of investigations, still under way, for the Supervising Architect's Office, is that in relation to the fire-resisting qualities of the materials needed for use in the construction of the public buildings—a work which requires the testing of many materials under many different conditions. As illustrating the importance of this investigation in relation to the general public, attention may be called to the fact that the fire losses in the United States, including not only property destroyed, but maintenance of fire departments, payment of insurance premiums, so-called curative agencies, and other incidentals, amounted to over $500,000,000 in 1906, or over 80 per cent of the value of the total new building construction. This is equivalent to an annual tax of over $6 per capita. By comparison, in six of the larger European countries the fire losses average only 33 cents per capita, and this in spite of the fact that the appliances and facilities for fighting fires in the United States are greatly superior to those in European countries. This discrepancy in the fire losses is due to the more extended use in other countries of building materials which are more or less fireproof.

The first report issued by the structural-materials division (Bulletin No. 324) related to the effects of the San Francisco earthquake and fire on buildings and materials. The present report embraces a statement of the organization and equipment of the division. The next will relate to the studies of the constituent materials (sands, gravels, stone, and cement) used in the construction of concrete masses, samples of these materials having been collected in different parts of the country and examined in connection with this general investigation.

Other reports now ready for publication will embrace the results of other lines of investigation in relation to concrete and to reinforced-concrete masses made of these materials mixed with the typical Portland cement described in this report.

In connection with the taking up of any new line of investigation, much time is necessarily required for the preliminary work of procuring equipment, training experts to conduct the investigations, determining the exact methods which are to be employed, and bringing the establishment to a high degree of efficiency. This having been accomplished at the structural-materials laboratories, the work should hereafter go forward rapidly and in a satisfactory manner. There is serious need, however, of additional equipment for testing larger masses of material, for investigating clays and clay products, and for testing the fire-resisting properties of materials.

ORGANIZATION, EQUIPMENT, AND OPERATION OF THE STRUCTURAL-MATERIALS TESTING LABORATORIES AT ST. LOUIS, MO.

By Richard L. Humphrey.

INTRODUCTION.

HISTORICAL SKETCH.

The investigation of structural materials now being conducted at the structural-materials testing laboratories in Forest Park, St. Louis, Mo., had its inception at the Louisiana Purchase Exposition in 1904 in the collective Portland cement exhibit and model testing laboratory of the Association of American Portland Cement Manufacturers, the purpose of which was to exploit the growth and magnitude of the American Portland cement industry, the many uses of cement, and the equipment and method for testing cement proposed by the special committee of the American Society of Civil Engineers. This exhibit was under the direct supervision of Mr. Richard L. Humphrey.

The exhibit building served as a working illustration of reinforced-concrete construction until its completion, September 1, 1904. The exhibit comprised: (1) A collection of raw materials from which Portland cement is manufactured, together with samples of this material taken in various stages of manufacture; (2) a collection of various sands, gravels, cinders, broken stone, and metal used in concrete construction, together with photographs and models of concrete and reinforced-concrete structures in all parts of the world; (3) a library of books and files of the various technical journals devoted to cement mortar and concrete; (4) a completely equipped model testing laboratory; (5) a collection of machines for mixing and molding concrete; and (6) a collection showing the many forms in which concrete is used.

The laboratory was in operation until December 15, 1904. During this period the laboratory work was confined to illustrating the proper methods for testing cement and to investigations of the comparative value of a few sands, gravels, and broken stones used in cement mortars and concretes in some of the principal cities of the country. Outside exhibits of full-size beams, floors, columns, pipes, railroad ties, fence posts, burial vaults, and building blocks were made by several construction companies, and at the close of the exposition some of these structures were tested to destruction.

Shortly after the close of the exposition the buildings occupied by the exhibit became the property of the city of St. Louis and the equipment of the laboratory was purchased by Mr. R. W. Lesley, and presented to the University of Pennsylvania. Before the equipment was moved, however, an earnest appeal was made to Congress for funds to continue the work under Government supervision.

About 100 yards west of the cement exhibit was located the fuel-testing plant of the United States Geological Survey. The investigation of fuels during the exposition was carried on under an appropriation of $60,000 made by Congress in April, 1904, and was under the direct supervision of Mr. Joseph A. Holmes, in charge of the technologic branch. The valuable results obtained in the cement laboratory and the great need of more reliable information concerning the various structural materials suggested the advisability of having these investigations carried on by the Government. Accordingly, when the Director of the United States Geological Survey asked Congress for an appropriation for the continuance of the investigation of fuels he also asked for a small appropriation for the continuation of the work begun by the Association of American Portland Cement Manufacturers. In the spring of 1905 the sum of $12,500 was made available for this purpose, with the understanding that heat, light, and power were to be supplied from the fuel-testing plant. The work was placed under the direction of Mr. Joseph A. Holmes, Mr. Richard L. Humphrey being appointed in immediate charge of the structural-materials testing laboratories.

Upon the passage of the bill appropriating funds for the continuation of the work it was arranged, through the courtesy of Mr. R. W. Lesley and Dr. Edgar Marburg, professor of civil engineering, University of Pennsylvania, that the equipment might be retained by the Geological Survey. Permission was also granted by the city of St. Louis to continue the work in Forest Park.

NATIONAL ADVISORY BOARD ON FUELS AND STRUCTURAL MATERIALS.

ORGANIZATION.

In order that the money available for this work might be so expended as to secure the most efficient results, it was thought desirable to create an advisory board composed of members appointed by the various national societies directly interested, to whom could be referred the scope to be covered by the investigations and the methods to be used, and from whom could be obtained a critical opinion of the results. Accordingly an invitation was extended by the Secretary of the Interior, with the indorsement of the Secretary of Agriculture, to the various national societies, requesting that the president or some other representative of each society be appointed to serve on the national advisory board for the investigation of fuels and structural materials.

In response to this invitation a meeting was held in Washington, D. C., June 3, 1905, in the office of the Director of the United States Geological Survey. Later the personnel of this board was slightly changed, and in March, 1906, the members received direct appointments from President Theodore Roosevelt. In addition, a representative was appointed from each of the several Government bureaus interested in the investigations.

PERSONNEL.

The original advisory board consisted of the following representatives of the various national societies and Government bureaus.

The American Institute of Mining Engineers: John Hays Hammond, past president, New York; Robert W. Hunt (Robert W. Hunt & Co., testing engineers, Chicago, Pittsburg, and New York), Chicago, Ill.; B. F. Bush, manager and vice president, Western Coal and Mining Company, St. Louis, Mo.

The American Institute of Electrical Engineers: Francis B. Crocker, professor of electrical engineering, Columbia University, New York; Henry C. Stott, superintendent of motive power, Interborough Rapid Transit Company, New York.

The American Society of Civil Engineers: C. C. Schneider, past president, chairman committee on concrete and reinforced concrete, Philadelphia, Pa.; George S. Webster, chairman committee on uniform tests of cement, city engineer, Philadelphia, Pa.

The American Society of Mechanical Engineers: W. F. M. Goss, dean of the School of Engineering, University of Illinois, Urbana, Ill; George H. Barrus, steam engineer, Boston, Mass.; P. W. Gates, Chicago, Ill.

The American Society for Testing Materials: Charles B. Dudley, president, Altoona, Pa.; Robert W. Lesley, vice president, Philadelphia, Pa.

The American Institute of Architects: George B. Post, past president, New York; William S. Eames, past president, St. Louis, Mo.

The American Railway Engineering and Maintenance of Way Association: H. G. Kelley, past president, Minneapolis, Minn.; Julius Kruttschnitt, director of maintenance and operation Union Pacific Railroad, Chicago, Ill.; Hunter McDonald, past president, chief engineer Nashville, Chattanooga and St. Louis Railroad, Nashville, Tenn.

The American Railway Master Mechanics' Association: J. F. Deems, general superintendent of motive power, New York Central lines, New York; A. W. Gibbs, general superintendent of motive power, Pennsylvania Railroad, Altoona, Pa.

The American Foundrymen's Association: Richard Moldenke, secretary, Watchung, N. J.

The Association of American Portland Cement Manufacturers: John B. Lober, president, Philadelphia, Pa.

The Geological Society of America: Samuel Calvin, professor of geology, University of Iowa, Iowa City, Iowa; I. C. White, State geologist, Morgantown, W. Va.

The Iron and Steel Institute: Julian Kennedy, metallurgical engineer, Pittsburg, Pa.; C. S. Robinson, vice president, Youngstown Sheet and Tube Company, Youngstown, Ohio.

The National Association of Cement Users: Richard L. Humphrey, president, Philadelphia, Pa.

The National Board of Fire Underwriters: Chas. A. Hexamer, chairman board of consulting experts, Philadelphia, Pa.

The National Fire Protective Association: E. U. Crosby, Philadelphia, Pa.

The National Brick Manufacturers' Association: John W. Sibley, treasurer, Sibley-Menge Press Brick Company, Birmingham, Ala.; William D. Gates, American Terra Cotta and Ceramic Company, Chicago, Ill.

The National Lumber Manufacturers' Association: Nelson W. McLeod, past president, St. Louis, Mo.; John L. Kaul, president Southern Lumber Manufacturers' Association, Birmingham, Ala.

The Corps of Engineers, U. S. Army: Lieut. Col. William L. Marshall, New York.

The Isthmian Canal Commission: Lieut. Col. O. H. Ernst, Washington, D. C.

The Bureau of Yards and Docks, U. S. Navy: Lieut. Frank T. Chambers, civil engineer, Washington, D. C.

The Supervising Architect's Office, United States Treasury Department: James K. Taylor, Supervising Architect, Washington, D. C.

The Reclamation Service, United States Interior Department: F. H. Newell, Director, Washington, D. C.

Since the first meeting the following additional appointments have been made:

The American Institute of Mining Engineers: E. V. D'Invilliers, mining engineer, Philadelphia, Pa.

The National Lumber Manufacturers' Association: William Irvine, president, Chippewa Falls, Wis.

The Bureau of Ordnance, U. S. Army: Gen William Crozier, chief, Washington, D. C.

The Bureau of Steam Engineering, U. S. Navy: Admiral Charles W. Rae, chief, Washington, D. C.

The Isthmian Canal Commission: John F. Stevens, chief engineer, Washington, D. C.; Lieut. Col. George W. Goethals, Washington, D. C.

The following members of the board have resigned:

Mr. Nelson W. McLeod, Lieut. Col. O. H. Ernst, John F. Stevens.

The purpose of this board is to further the work and to render it of the broadest possible application by bringing to bear upon the investigation the advice and suggestions of a widely representative body. It was formally organized in Washington, D. C., March 31, 1906, with Dr. Charles B. Dudley as president and Mr. Richard L. Humphrey as secretary. This board also acts in an advisory capacity toward the Forest Service.

JOINT COMMITTEE ON CONCRETE AND REINFORCED CONCRETE.

ORGANIZATION.

The members of the special committees on concrete and reinforced concrete of the American Society of Civil Engineers, the American Society for Testing Materials, the American Railway Engineering and Maintenance of Way Association, and the Association of American Portland Cement Manufacturers met at Atlantic City, N. J., on June 17, 1904. Mr. C. C. Schneider was elected temporary chairman, and Prof. A. N. Talbot was elected temporary secretary. The proposed plan of action of the special committee of the American Society of Civil Engineers was outlined, involving the appointment of subcommittees on plan and scope, on tests, and on ways and means. It was voted that the other committees present should cooperate with the special committee of the American Society of Civil Engineers, and that the work should be carried on under a common organization to be known as the joint committee on concrete and reinforced concrete. Mr. C. C. Schneider and Mr. J. W. Schaub, as chairman and secretary, respectively, of the committee of the American Society of Civil Engineers, were made chairman and secretary of the joint committee. Mr. Emil Swensson was elected vice chairman, and upon the resignation of Mr. Schaub Mr. Richard L. Humphrey was elected secretary.

PERSONNEL.

The present members of the joint committee and of the various subcommittees are as follows:

OFFICERS.

Chairman: C. C. Schneider.
Vice chairman: Emil Swensson.
Secretary: Richard L. Humphrey.

MEMBERS.

American Society of Civil Engineers (special committee on concrete and reinforced concrete):

Greiner, J. E., assistant chief engineer, Baltimore and Ohio Railroad, Baltimore, Md.
Hatt, W. K., professor of civil engineering, Purdue University, Lafayette, Ind.
Hoff, Olaf, vice president Butler Brothers, Hoff & Co., New York, N. Y.
Humphrey, Richard L., consulting engineer, Philadelphia, Pa.
Lesley, R. W., president American Cement Company, Philadelphia, Pa.
Schaub, J. W., consulting engineer, Chicago, Ill.
Schneider, C. C., consulting engineer, Philadelphia, Pa.
Swensson, Emil, consulting engineer, Pittsburg, Pa.
Talbot, A. N., professor of sanitary engineering, University of Illinois, Urbana, Ill.
Worcester, J. R., consulting engineer, Boston, Mass.

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American Society for Testing Materials (committee on reinforced concrete):
- Fuller, William B., consulting engineer, New York, N. Y.
- Heidenreich, E. Lee, consulting engineer, New York, N. Y.
- Humphrey, Richard L., consulting engineer, Philadelphia, Pa.
- Johnson, Albert L., consulting engineer, St. Louis, Mo.
- Lanza, Gaetano, professor of theoretical and applied mechanics, Massachusetts Institute of Technology, Boston, Mass.
- Lesley, R. W., president American Cement Company, Philadelphia, Pa.
- Marburg, Edgar, professor of civil engineering, University of Pennsylvania, Philadelphia, Pa.
- Mills, Chas. M., principal assistant engineer Philadelphia Rapid Transit Company, Philadelphia, Pa.
- Moisseiff, Leon S., assistant engineer department of bridges, New York, N. Y.
- Quimby, Henry H., assistant engineer of bridges, bureau of surveys, Philadelphia, Pa.
- Taylor, W. P., engineer in charge of testing laboratory, Philadelphia, Pa.
- Thompson, Sanford E., consulting engineer, Newton Highlands, Mass.
- Turneaure, F. E., dean of College of Mechanics and Engineering, University of Wisconsin, Madison, Wis.
- Wagner, Samuel Tobias, assistant engineer Philadelphia and Reading Railroad, Philadelphia, Pa.
- Webster, George S., chief engineer bureau of surveys, Philadelphia, Pa.

American Railway Engineering and Maintenance of Way Association (subcommittee on reinforced concrete):
- Boynton, C. W., chief inspector Universal Portland Cement Company, Chicago, Ill.
- Cunningham, A. O., chief engineer Wabash Railroad, St. Louis, Mo.
- Moore, C. H., engineer of grade crossings, Erie Railroad, New York, N. Y.
- Scribner, Gilbert H., jr., contracting engineer, Chicago, Ill.
- Swain, George F., professor of civil engineering, Massachusetts Institute of Technology, Boston, Mass.

Association of American Portland Cement Manufacturers (committee on concrete and steel concrete):
- Fraser, Norman D., president Chicago Portland Cement Company, Chicago, Ill.
- Griffiths, R. E., vice president American Cement Company, Philadelphia, Pa.
- Hagar, Edward M., president Universal Portland Cement Company, Chicago, Ill.
- Newberry, Spencer B., manager Sandusky Portland Cement Company, Sandusky, Ohio.

STANDING SUBCOMMITTEES.

SUBCOMMITTEE ON WAYS AND MEANS.

R. W. Lesley, chairman.
J. E. Greiner.
Olaf Hoff.
A. L. Johnson.
A. O. Cunningham.
Edward M. Hagar.

SUBCOMMITTEE ON TESTS.

Richard L. Humphrey, chairman.
A. N. Talbot.
W. K. Hatt.
Olaf Hoff.
Spencer B. Newberry.

SPECIAL SUBCOMMITTEES.

HISTORY.

To collate existing literature and results of previous investigations.

J. R. Worcester, chairman.
R. W. Lesley.
F. E. Turneaure.
George F. Swain.
R. E. Griffiths.

CONCRETE.

(a) Study of aggregates, proportions, and mixing.

Sanford E. Thompson, chairman.
William B. Fuller.
W. P. Taylor.
Olaf Hoff.
George S. Webster.
C. H. Moore.

(b) Physical characteristics, waterproofing, etc.

A. O. Cunningham, chairman.
E. Lee Heidenreich.
Sanford E. Thompson.
Samuel Tobias Wagner.
C. W. Boynton.

(c) Strength and elastic properties.

J. E. Greiner, chairman.
Charles M. Mills.
W. P. Taylor.
George S. Webster.
Gilbert H. Scribner, jr.

BEAMS.

(a) Simple beams.

F. E. Turneaure, chairman.
J. E. Greiner.
C. C. Schneider.
J. R. Worcester.
A. O. Cunningham.

(b) T-beams, floor slabs, etc.

Samuel Tobias Wagner, chairman.
J. W. Schaub.
E. Lee Heidenreich.
Gaetano Lanza.
C. H. Moore.

COLUMNS.

Gaetano Lanza, chairman.
William B. Fuller.
Edgar Marburg.
Leon S. Moisseiff.
Henry H. Quimby.

FIRE-RESISTING QUALITIES.

C. W. Boynton, chairman.
C. C. Schneider.
A. L. Johnson.
Norman D. Fraser.
Edward M. Hagar.

FAILURES OF CONCRETE STRUCTURES.

Emil Swensson, chairman.
J. W. Schaub.
A. L. Johnson.
Gilbert H. Scribner, jr.
George F. Swain.

ARCHES.

Henry H. Quimby, chairman.
Emil Swensson.
Edgar Marburg.
Charles M. Mills.
Leon S. Moisseiff.

COOPERATION BETWEEN NATIONAL ADVISORY BOARD AND JOINT COMMITTEE.

The national advisory board at its first meeting discussed and revised the tentative programme adopted for the continuation of the work begun during the exposition. In addition to the study of the properties of concrete and reinforced concrete, this programme provided for an examination of the constituent materials of concrete, including the collection of representative samples of crushed stone, gravel, sand, slag, cinders, etc., from all parts of the country, and the testing of these samples to determine their relative value for mortar and concrete.

In view of the similarity of the investigations outlined by the joint committee, and those about to be started by the Geological Survey, there was discussed at a meeting of the joint committee in Cleveland, Ohio, June, 1905, the advisability of joint cooperation. At a meeting a few days later in Atlantic City, N. J., Mr. Joseph A. Holmes, representing the Director of the Geological Survey, submitted a basis of cooperation providing for the execution of this work by the Geological Survey, either in its laboratories at St. Louis or in other laboratories which possess the requisite facilities, under the general direction of the joint committee. This plan of cooperation was mutually agreed to and the subcommittee on tests was instructed to cooperate with the Geological Survey in accordance with this understanding.

On December 14, 1905, the subcommittee on tests submitted a revised programme of tests, which was amended and adopted by the joint committee. This programme was approved by the national advisory board March 31, 1906, and now constitutes the working outline for these investigations.

FUNDS.

The first appropriation by Congress for the investigation of structural materials amounted to $12,500, of which $5,000 was available until June 30, 1905, and $7,500 until June 30, 1906.

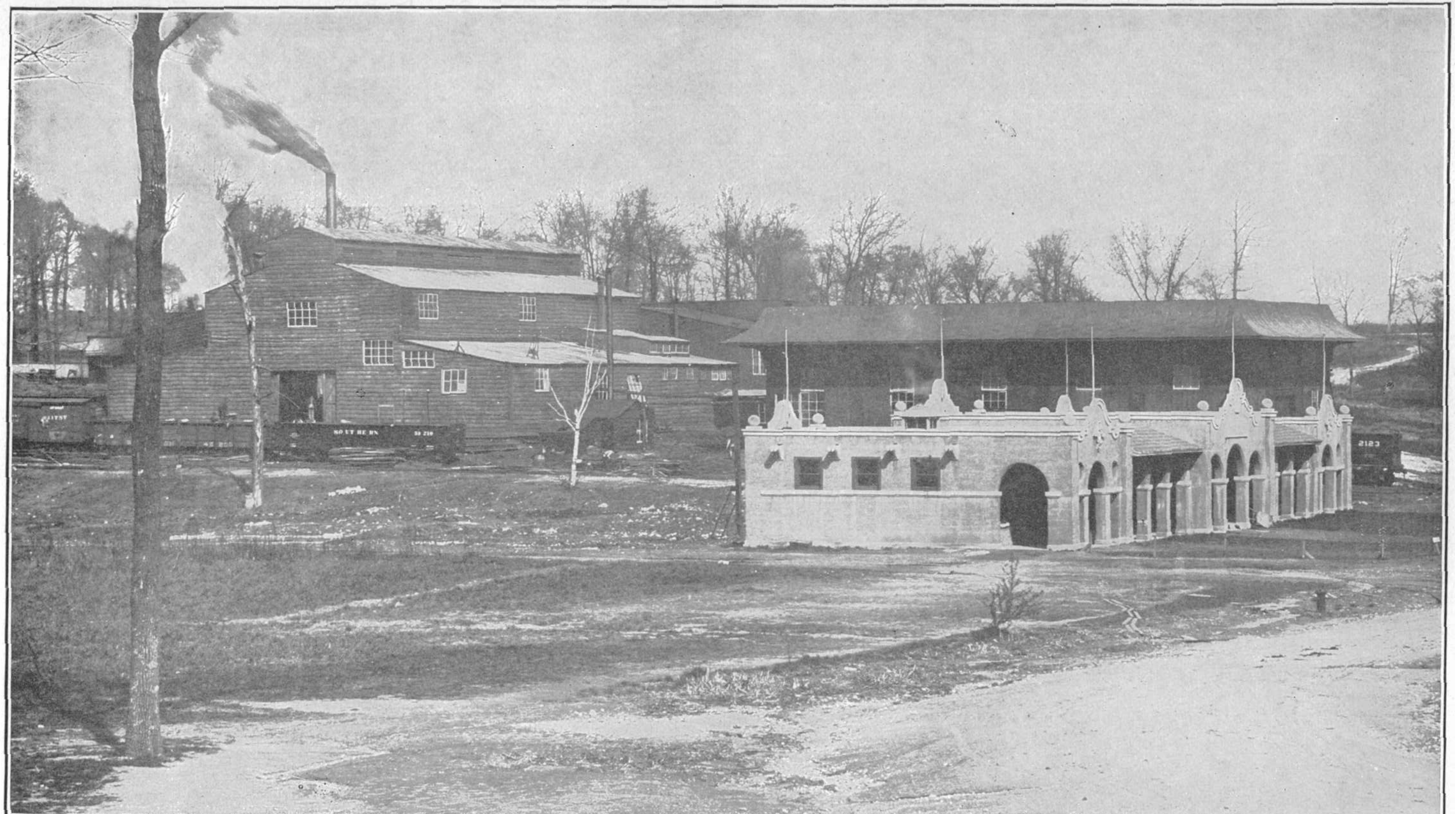
Some months before the close of the fiscal year ending June 30, 1906, this small appropriation of $12,500 for the work at the structural-materials testing laboratories became exhausted, and the work was nearly at a standstill until a new appropriation of $100,000 became available July 1, 1906. With this increased appropriation the work was greatly extended, new equipment purchased, and two large buildings, used during the exposition by the department of mines and metallurgy, were occupied for testing purposes.

Another appropriation of $100,000 for the fiscal year July 1, 1907, to June 30, 1908, insures the continuance of the work which is now being conducted as described in the following pages.

STRUCTURAL-MATERIALS DIVISION.

ORGANIZATION.

The investigation of structural materials assigned to a division of the technologic branch of the United States Geological Survey is under the general supervision of Mr. Joseph A. Holmes, expert in charge, with Mr. Herbert M. Wilson as chief engineer, and is under the direct supervision of Mr. Richard L. Humphrey, engineer in charge.



GENERAL VIEW OF BUILDINGS OCCUPIED BY STRUCTURAL-MATERIALS TESTING LABORATORIES.

Office and constituent-materials laboratory in foreground.

The organization of the structural-materials division comprises the following sections:

- Administrative.
- Metallurgical.
- Editorial.
- Computing.
- Drafting.
- Field.
- Constituent materials.
- Beam.
- Tension and shear.
- Slab.
- Column.
- Building block.
- Permeability.
- Chemical.
- Photographic.

BUILDINGS.

The structural-materials testing laboratories, located in Forest Park, St. Louis, Mo. (Pl. I and fig. 1), occupy the cement and foundry

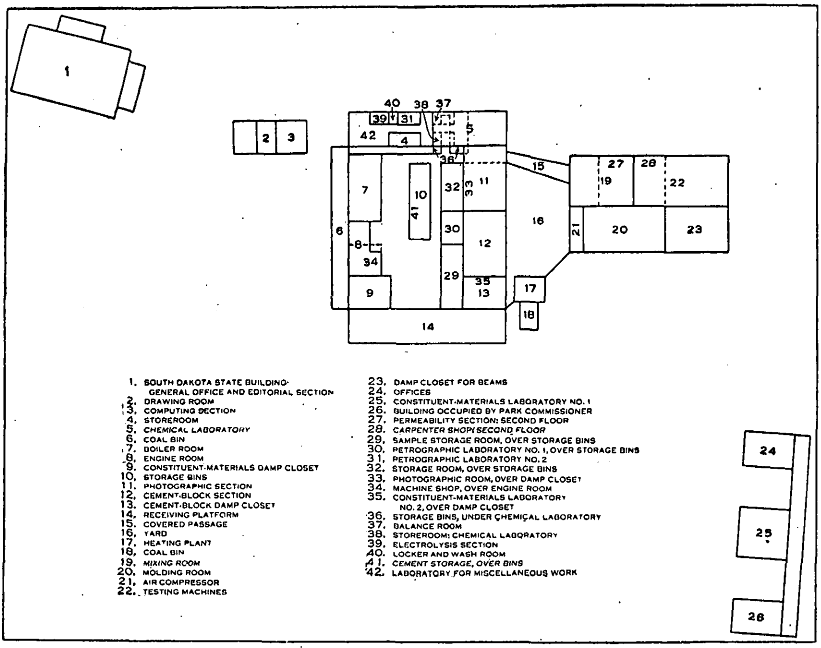


FIG. 1.—General plan of buildings occupied by structural-materials testing laboratories in Forest Park, St. Louis, Mo.

buildings and the metal pavilion of the Louisiana Purchase Exposition. The cement building is constructed entirely of reinforced concrete and was built by the Association of American Portland Cement Manufacturers. It consists of three pavilions, separated by intermediate courts, and connected across the front by a continuous loggia. The central pavilion is 30 feet square and is used by the constituent-materials section; that on the right is used as a general office; that on the left is used by the park commission of the city of St. Louis, by whose courtesy these laboratories are permitted to remain in Forest Park.

The metal pavilion, 60 by 100 feet, is used by the beam, the permeability, the shear and tension, and the column sections, and by the carpenter shop and the steel-cutting plant. In order to put this building into proper condition for use it was necessary to replace the original glass sides with wooden sheathing and to lay a concrete floor. In addition, a ceiling at a 12-foot elevation was built, affording a second story of the full size of the building. Partitions were erected dividing the building into four rooms, which are used for mixing, molding, storing, and testing beams, columns, and shear and tension test pieces.

The foundry originally consisted of a steel skeleton having a roof of corrugated iron and sides of wire netting. Up to February, 1907, this building was used by the fuel-testing plant for testing coke, and when these tests were finished it was sheathed with wood, a new roof was built, and it now houses the building-block, the petrographic, and the photographic sections and a portion of the constituent-materials section. It also contains 25 bins, each of one car capacity, for storing material; a workshop equipped with a machine lathe, drill press, and emery grinder; a blacksmith shop, and the necessary power equipment for the entire plant.

Power was furnished by the fuel-testing plant until its removal to the Jamestown Exposition at Norfolk, Va., in April, 1907. The one-story annex to one end of the foundry is occupied by the chemical and electrolysis laboratory. In addition to these buildings a one-story frame building contains the computing and drafting sections.

EQUIPMENT.

The greater part of the equipment of the model cement-testing laboratory of the Association of American Portland Cement Manufacturers was loaned for some time, through the courtesy of Mr. R. W. Lesley and Dr. Edgar Marburg, and was subsequently purchased by the Geological Survey. The remainder of the equipment which had been loaned for exhibition purposes was afterwards purchased from the manufacturers at very low prices.

In a large number of instances the manufacturers, recognizing the importance of the investigations being carried on at the laboratories, and desiring to be of some assistance, have supplied equipment for the purpose at greatly reduced prices, in some cases at less than cost.

In addition to the equipment loaned to or purchased by the Geological Survey, a small amount of equipment belonging to the United States Reclamation Service has been used.

In the following list of the more important items of equipment it was deemed inadvisable to include the smaller pieces of apparatus, as these are mentioned in connection with the work of the different sections. Half-tone reproductions of photographs of only a portion of the apparatus are shown in the following pages. The list of the principal equipment follows:

One 600,000-pound, motor-driven, automatic, Universal four-screw testing machine, manufactured by Tinius Olsen & Co., Philadelphia. This machine has a full equipment of tools for making tests of columns up to 30-foot lengths, transverse tests on beams up to 25-foot span, and tests for tensile strength for specimens up to 24 feet in length, with an elongation of 25 per cent.

One 200,000-pound, motor-driven, automatic, Universal four-screw testing machine, manufactured by Tinius Olsen & Co., Philadelphia. This machine has a full equipment of tools for making compression and tension tests up to 4 feet in length and transverse tests on beams up to 10-foot span.

One 200,000-pound, motor-driven, automatic, Universal four-screw testing machine, manufactured by Tinius Olsen & Co., Philadelphia. This machine also has a full equipment of tools for making tension and compression tests up to 4 feet in length and transverse tests on beams up to 20-foot span.

One 200,000-pound, motor-driven, automatic, Universal four-screw testing machine, manufactured by Tinius Olsen & Co., Philadelphia. This machine was furnished by the Reclamation Service, and has a full equipment of tools for making tension and compression tests up to 4 feet in length and transverse tests on beams up to 20-foot span.

One 200,000-pound, motor-driven, automatic, three-screw testing machine, manufactured by Tinius Olsen & Co., Philadelphia. This machine has a full equipment of tools for making compression and tension tests up to 4 feet in length and transverse tests on beams up to 20-foot span.

One 100,000-pound, motor-driven, automatic, Universal three-screw testing machine manufactured by Tinius Olsen & Co., Philadelphia. This machine has a full equipment of tools for making tension and compression tests and transverse tests on beams up to 16-foot span.

One 40,000-pound, hydraulic, hand-driven, compression machine, manufactured by the Falkenau-Sinclair Company, Philadelphia. This machine is designed for testing small test pieces in compression, and was furnished by the Reclamation Service.

One 50,000-pound, hydraulic, hand-driven testing machine, very kindly loaned by Tinius Olsen & Co., Philadelphia.

One 2,000-pound, long-lever, tensile testing machine for cement, manufactured by Tinius Olsen & Co., Philadelphia.

One 2,000-pound, automatic shot, short-lever, tensile testing machine for cement, manufactured by Tinius Olsen & Co., Philadelphia.

One 2,000-pound, automatic shot, short-lever, tensile testing machine for cement, manufactured by the Fairbanks Company, New York.

One motor-driven torsion machine for testing wire, manufactured by Tinius Olsen & Co., Philadelphia, and furnished by the Reclamation Service.

One hand-driven, 10,000-pound tension machine for testing wire, and also adapted for making transverse tests on small specimens, manufactured by Tinius Olsen & Co., Philadelphia, and supplied by the Reclamation Service.

One set of tools for making shear tests on concrete cylinders 6 inches in diameter and 24 inches long, together with 12 cast-iron molds. The apparatus is adapted for shearing out sections 2, 4, 6, 8, 10, or 12 inches in length.

One one-half cubic yard capacity concrete cubical mixer, mounted on skids, manufactured by the Municipal Engineering and Contracting Company, Chicago. This mixer was very generously loaned by the manufacturers during the first year's work in the laboratories, and was afterwards purchased from them at a very low price.

One 1 cubic yard capacity cubical concrete mixer, with automatic charging hopper mounted on skids; and one motor-driven one-half cubic yard capacity cubical concrete mixer, with an automatic charging hopper mounted on skids. These mixers were manufactured by the Municipal Engineering and Contracting Company, and very generously sold by them for an amount much lower than the market price.

Five hollow concrete block machines manufactured and very kindly loaned by the American Hydraulic Stone Company, Denver, Colo.; the Miracle Pressed Stone Company, Minneapolis, Minn.; the P. B. Miles Manufacturing Company, Jackson, Mich.; the Dykema Company, Grand Rapids, Mich.; and the Century Machine Company, Jackson, Mich. These machines, representing different types, were selected by a committee of the Concrete Block Machine Manufacturers' Association.

Six steel molds, with 90 extra interchangeable bottoms for 8 by 11 inches by 13-foot beams, also adjustable for 6-, 8-, and 10-foot beams.

Seventy-two cast-iron molds for cylindrical test pieces 8 inches in diameter and 16 inches long, 12 of which were furnished by the Reclamation Service.

Twenty-four cast-iron molds for 6-inch cubes, 12 of which were also furnished by the Reclamation Service.

Sixty-three single brass molds for transverse specimens of cement 1 by 1 inch in cross section and 13 inches long; 10 of these molds were furnished by the Reclamation Service.

Eighteen 3-gang and 18 5-gang standard brass briquet molds. Eight of the 3-gang and 10 of the 5-gang molds were furnished by the Reclamation Service.

Twenty 3-gang 2-inch cube molds of brass. Fourteen of the 2-inch cube molds were furnished by the Reclamation Service.

Four cubic-foot measures.

One hundred and eighty cement storage cans of galvanized iron, 24 inches in diameter and 29½ inches high.

Three hundred tin storage cans, 6⅛ inches in diameter, 6¾ inches high, with a 4-inch diameter screw top.

One complete accelerated-test apparatus for cement, including a copper tank, metal-frame support, and constant-level bottle.

One 5-gallon still.

One water bath of heavy copper.

One 4-inch diameter electrical hot plate.

One 12-inch diameter electrical hot plate.

One 10-horsepower American standard feed-water heater.

Two soapstone moist closets, 43¾ by 24 by 18 inches.

Nine soapstone tanks, 7 feet long and 30 inches wide, eight of which are 6 inches and one 30 inches deep, inside measure. These tanks are arranged in tiers of three each, on steel frames, and piped for running water. Two tiers were manufactured by Stambach & Love, Philadelphia, and one by Cahill, Swift & Co., St. Louis.

Two standard mixing tables with glass tops.

Two sets standard brass sieves 8 inches in diameter, having 10, 20, 30, 40, 50, 80, 100, and 200 meshes per linear inch.

Two automatic sifting machines, one belt driven and the other motor driven, manufactured by Howard & Morse, Brooklyn, N. Y.

Three analytical balances.

Five Troemner scales, two No. 7, two No. 293, and two No. 80; the No. 7 scale being furnished by the Reclamation Service.

Five movable platform scales.

Three hand trucks.

One steel carriage for raising and moving concrete beams. This consists of an 8-inch channel, supported by steel legs 15 feet long, the bottom flange of which serves as a track for two 1-ton trolleys with roller bearings, bearing differential hoists.

One air compressor with a complete outfit of air tampers and tools, generously loaned by the Ingersoll-Rand Drill Company, New York.

One complete outfit for preparing cubes of stone, consisting of a gang saw, band saw, slicing machine, and polishing table.

Four compressometers.
Two extensometers.
Four beam deformeters.
Four slip of rod apparatus.
Three Thatcher computing machines.
Two Draper recording thermometers.
One Bristol recording thermometer.
One muffle furnace.
Two gas furnaces.
One gas generator for chemical laboratory.
One Buffalo portable forge.
Two lever jacks.
One Lodge & Shipley machine lathe.
One 70-horsepower horizontal tubular boiler.
One 74-horsepower Habercorn slide-valve engine.
One Worthington fire pump.
One Westinghouse dynamo.

In addition to the above equipment all the divisions of the laboratories have a complete equipment of smaller apparatus, and facilities for making the tests covered by the investigations.

ACKNOWLEDGMENT OF DONATIONS.

The extent and importance of the investigations of structural materials being conducted by the United States Geological Survey are such that in order to procure the needed information in a reasonable time, it is necessary to make the available appropriations cover as much work as possible. These appropriations are relatively small in comparison with the amount of work to be done, and it is extremely desirable that all persons interested in this work should accord it their hearty support as far as possible. The results of these investigations will be of great value not only to the Government, but to the public at large, especially engineers, architects, contractors, manufacturers, and all others who manufacture or use structural materials. The help which has been received up to the present time has made it possible to devote to the investigations a large amount of money that otherwise would have been spent in defraying transportation charges for materials and men, and for purchasing the materials with which to conduct the investigations. In most cases it has been simply necessary to make known the needs of these laboratories for materials or transportation; in a few cases material has been especially solicited, and in almost every case the reply has been a generous compliance with the request.

Railroads have aided in the work by transporting the materials and the employees of the laboratories free of charge. Special acknowledgments are made to those lines and to certain Portland cement manufacturers, collectively and individually; also to the Municipal Engineering and Contracting Company, the Hydrex Felt Engineering Company, the Concrete Block Machine Manufacturers'

Association, the Underwriters' Laboratories of Chicago, the Illinois Steel Company, the Carnegie Steel Company, and the Ingersoll-Rand Drill Company.

Acknowledgment is due the Union Sand and Material Company, of St. Louis, Mo., for donations of material as well as for courtesies extended and for service in delivering material by teams for use in these laboratories.

The tests that are being made require large quantities of cement, sand, gravel, stone, and steel, and up to the present time these have been contributed generously and promptly upon request. For donations of Portland cement acknowledgments are made to the following companies:

Alpha Portland Cement Co., Easton, Pa.
American Cement Co., Egypt, Pa.
Atlas Portland Cement Co., Hannibal, Mo.
Bonneville Portland Cement Co., Siegfried, Pa.
Chicago Portland Cement Co., Oglesby, Ill.
Coplay Cement Manufacturing Co., Coplay, Pa.
Dexter Portland Cement Co., Nazareth, Pa.
Edison Portland Cement Co., Stewartsville, N. J.
German-American Portland Cement Co., La Salle, Ill.
Iola Portland Cement Co., Iola, Kans.
Lehigh Portland Cement Co., Mitchell, Ind.
Lawrence Cement Co., Siegfried, Pa.
Northampton Portland Cement Co., Stockerstown, Pa.
Omega Portland Cement Co., Jonesville, Mich.
Peerless Portland Cement Co., Union City, Mich.
Penn Allen Portland Cement Co., Bath, Pa.
Pennsylvania Cement Co., Bath, Pa.
Phoenix Cement Co., Nazareth, Pa.
Sandusky Portland Cement Co., Syracuse, Ind.
St. Louis Portland Cement Co., St. Louis, Mo.
Universal Portland Cement Co., Chicago, Ill.
Virginia Portland Cement Co., Fordwick, Va.
Vulcanite Portland Cement Co., Vulcanite, N. J.
Western Portland Cement Co., Yankton, S. Dak.
Whitehall Portland Cement Co., Cementon, Pa.
Wolverine Portland Cement Co., Coldwater, Mich.

For contributions of steel bars acknowledgments are made to the Illinois Steel Company and to the Carnegie Steel Company. For donations of sand, gravel, and crushed stone in carload lots acknowledgments are made to the following:

Carmichael, Wm. R., Williamsport, Ind.
Casper-Stolle Construction Co., East St. Louis, Ill.
Chicago Crushed Stone Co., Chicago, Ill.
East St. Louis Stone Co., East St. Louis, Ill.
Fruin-Bambrick Construction Co., St. Louis, Mo.
Grafton Quarry Co., Grafton, Ill.
McLaughlin-Mateer Co., Kankakee, Ill.
Ozark Red Granite Co., St. Louis, Mo.
Reliance Quarry Co., Alton, Ill.
Rickey, C. A., Louisville, Nebr.
Schneider Granite Co., St. Louis, Mo.
Union Sand and Material Co., St. Louis, Mo.
United Railways of St. Louis.

For courtesies extended and facilities afforded in investigating the various deposits of sand, stone, and gravel, forming a part of the field work of these laboratories, acknowledgments are made to the following:

American Sand and Gravel Co., Chicago, Ill.
American Smelting and Refining Co., Omaha, Nebr.
Andrew & Hoertz, Louisville, Ky.
Atwood-Davis Sand Co., Beloit, Wis.
Bambrick-Bates Construction Co., St. Louis, Mo.
Beloit Concrete Stone Co., Beloit, Wis.
Biesanz Stone Co., Minnesota City, Minn.
Big Rock Stone and Construction Co., Little Rock, Ark.
Buckeye Dredging Co., Columbus, Ohio.
Bull Frog Mining Co., Joplin, Mo.
Carey Construction Co., Cleveland, Ohio.
Casparis Stone Co., Columbus, Ohio.
Chicago, Milwaukee and St. Paul Railroad.
Chilton, Chas., Ottumwa, Iowa.
City of Madison, Madison, Wis.
Cleveland Builders Supply Co., Cleveland, Ohio.
Clifton Sand and Gravel Co., Vicksburg, Miss.
Cobb, H. H. & L. D., Fort Worth, Tex.
Coughlan, T. R., Mankato, Minn.
Darragh Bros., Marble Falls, Tex.
Eagle Point Lime Works, Dubuque, Iowa.
Fleming & Co., Cincinnati, Ohio.
Glencoe Lime and Cement Co., St. Louis, Mo.
Granby Zinc and Mining Co., Joplin, Mo.
Greene, J. A., Stone City, Iowa.
Greenleaf Stone Co., Greenleaf, Wis.
Hillsboro Stone Co., Hillsboro, Ohio.
Horton Stone and Milling Co., Springfield, Mo.
Houston and Texas Central Railroad, Houston, Tex.
Hydraulic Pressed Brick Co., St. Louis, Mo.
Jahuke Navigation Co., New Orleans, La.
Jarrett Construction Co., Sibley, La.
Kelley Sand and Fuel Co., Burlington, Iowa.
Laclede Fire Brick Co., St. Louis, Mo.
La Crosse Stone Co., La Crosse, Wis.
Lake Shore Stone Co., Milwaukee, Wis.
Lauer, Jacob, St. Paul, Minn.
Lauterdale, J. W., Millican, Tex.
Le Claire Stone Co., Bettendorf, Iowa.
Little, C. H., & Co., Detroit, Mich.
Louisiana Railway and Navigation Co., Colfax, La.
Loveland Stone and Gravel Co., Loveland, Ohio.
McTernan & Halpin Construction Co., Kansas City, Mo.
Merchants Ice and Coal Co., St. Louis, Mo.
Miami Sand and Gravel Co., Loveland, Ohio.
Mineral Supply Co., Minneapolis, Minn.
Missouri Pacific Railway, Little Rock, Ark.
Mitchell Fire Clay Co., St. Louis, Mo.
Missouri, Kansas and Texas Railway, Osage, Okla.
Moores, Cooney Co., Cincinnati, Ohio.
Moorman, E. S., Baton Rouge, La.
Mound City Gravel Co., St. Louis, Mo.
New Union Sand Co., St. Louis, Mo.
Norton, C. E., Ottumwa, Iowa.
Ohio and Michigan Gravel and Sand Co., Toledo, Ohio.
Ohio River Sand Co., Louisville, Ky.
Ousley, Dr. J. D., Denison, Tex.
Perkinson Bros., St. Louis, Mo.
Rucker Stone Co., Greenfield, Ohio.
St. Joseph Lead Co., Hoffman, Mo.
St. Joseph Street Construction Co., St. Joseph, Mo.
Samuels & Holmes, Kansas City, Mo.
Scullin-Gallagher Iron and Steel Co., St. Louis, Mo.
Sheehan, J. P., Austin, Tex.
Shreveport Sand and Concrete Co., Shreveport, La.
Sibley Quarry Co., Sibley, Mich.
Southern Hydraulic Stone Co., Galveston, Tex.
Stewart-Peck Sand Co., Kansas City, Mo.
Storey Bros., Milwaukee, Wis.
Toledo Stone and Glass Sand Co., Toledo, Ohio.
Ware, R. J., & Sons, Cincinnati, Ohio.

PROGRAMME FOR INVESTIGATION OF CONCRETE AND REINFORCED CONCRETE.

ORIGIN OF THE PLAN.

In October, 1904, the joint committee, in session at the Louisiana Purchase Exposition, St. Louis, Mo., adopted a programme of the tests necessary to procure the information desired in the preparation of a report on concrete and reinforced concrete, together with suggestions for putting the same into effect. The plan proposed that the subcommittee on tests should arrange for the cooperation of the joint committee with those schools of technology having adequate facilities for making the tests desired, and also arrange to supervise these tests so as to insure the proper accuracy and correlation of work. Materials of uniform and satisfactory quality were to be furnished to the different institutions, and methods of testing were to be outlined so as to standardize them as far as practicable. The inspection of the preparation of the test pieces and testing of the same by an experienced assistant was to be maintained, in order that the sources of error arising from the investigation of closely related problems at scattered laboratories might be reduced to a minimum. Funds to defray the cost of the material and the expense of efficient inspection were to be raised by a subcommittee on ways and means.

In response to an invitation issued by the subcommittee on tests in behalf of the joint committee, the following technical institutions expressed a willingness to cooperate in the work: Case School of Applied Science, Columbia University, Cornell University, Harvard University, Massachusetts Institute of Technology, Ohio State University, Purdue University, State University of Iowa, University of Illinois, University of Minnesota, University of Pennsylvania, and University of Wisconsin. The investigations assigned by the subcommittee on tests were conducted at these institutions during the same college year (1904–5) by advanced students or members of the instruction staff. Since arrangements for investigative work by students in nearly all such institutions necessitate the completion of any series of tests by at least the last of May of each year, the time available proved insufficient for making needed arrangements and providing materials sufficiently in advance to permit the completion of the requisite tests. This rendered impossible the thorough organization that was desired in the first year's work.

DETAILS OF THE PLAN.

I. EXAMINATION AND CLASSIFICATION OF CONSTITUENT MATERIALS.

A. *Examination of deposit.*—Sands, gravels, stones, gravel and stone screenings (¼-inch screen), slags, cinders, etc., are to be collected by a special representative of the testing laboratory sent out for that purpose. The deposit from which the samples are collected is to be examined to determine the extent and natur of the material.

B. *Physical tests in the laboratory.*—The laboratory tests are to include the examinations and determinations indicated below:

1. Mineralogical examination.
2. Specific gravity.
3. Weight per cubic foot.
4. Sifting (granulometric composition).
5. Percentage of silt and character of same.
6. Percentage of voids.
7. Character of stone as to percentage of absorption, porosity, permeability, compressive strength, and behavior under treatment.

C. *Chemical analysis.*—Analyses are to be made to determine the composition and character of the stone, silt, etc., used in tests.

II. TESTS AND CLASSIFICATION OF MORTARS MADE WITH TYPICAL PORTLAND CEMENT AND SAND, GRAVEL, AND STONE SCREENINGS (¼-INCH SCREEN).

A. *Proportions and conditions.*—Proportions to be stated by weight and volume. The unit of volume for cement is 100 pounds per cubic foot. The typical Portland cement is to be prepared by thoroughly mixing a number of brands, each of which must meet the following requirements:

Specific gravity, not less than 3.10.

Fineness, residue not more than 8 per cent on No. 100 nor 25 per cent on No. 200 sieve.

Time of setting: Initial set, not less than 30 minutes; hard set, not less than 1 hour nor more than 10 hours.

Tensile strength:

	Pounds.
1. Neat—	
24 hours in moist air	175
7 days (1 day in moist air, 6 days in water)	500
28 days (1 day in moist air, 27 days in water)	600
2. One part cement, three parts standard sand—	
7 days (1 day in moist air, 6 days in water)	175
28 days (1 day in moist air, 27 days in water)	250

Constancy of volume: Pats of neat cement 3 inches in diameter, one-half inch thick at center, tapering to a thin edge, shall be kept in moist air for a period of 24 hours. A pat is kept in air at normal temperature and observed at intervals for at least 28 days. Another pat is kept in water maintained as near 70° F. as practicable and observed at intervals for at least 28 days. A third pat is exposed in an atmosphere of steam above boiling water in a loosely closed vessel for 5 hours. These pats must remain firm and hard and show no signs of distortion, checking, cracking, or disfiguration.

The cement shall not contain more than 1.75 per cent anhydrous sulphuric acid nor more than 4 per cent magnesium oxide.

A test of the neat cement must be made with each mortar series for comparison of the quality of the typical Portland cement.

B. *Physical tests in laboratory.*—The laboratory tests include the following determinations, those designated as items 1 to 10 being each made at the ages of 7, 28, 90, 180, and 360 days:

1. Tensile strength with one part cement to varying percentages of material.
2. Compressive strength with one part cement to varying percentages of material.
3. Transverse strength with one part cement to varying percentages of material.
4. Shearing strength with one part cement to varying percentages of material.
5. Tensile strength with cement, material sifted to one size.
6. Compressive strength with cement, material sifted to one size.
7. Transverse strength with cement, material sifted to one size.

8. Shearing strength with cement, material sifted to one size.
9. Modulus of elasticity in compression of different mixtures as to proportion and size of aggregate.
10. Modulus of elasticity in tension of different mixtures as to proportion and size of aggregate.
11. Yield in mortar.
12. Porosity.
13. Permeability.
14. Volumetric changes in setting.
15. Absorption.
16. Methods of waterproofing.
17. Freezing tests.
18. Coefficient of expansion.
19. Effect of oil: (*a*) On hardening mortar; (*b*) on hardened mortar.
20. Effect of sea water.

III. TESTS AND CLASSIFICATION OF CONCRETE MADE WITH TYPICAL PORTLAND CEMENT AND STONE, STONE AND GRAVEL SCREENINGS, GRAVEL, SAND, CINDER, SLAG, ETC.

A. *Proportions and conditions.*—Proportions to be stated by weight and volume. Unit of volume for cement, 100 pounds per cubic foot.

B. *Physical tests in laboratory.*—The laboratory tests include the following determinations, those designated as items 1 to 6 being each made at the ages of 30, 90, 180, and 360 days:

1. Tensile strength with different mixtures as to proportion and size of the aggregate.
2. Compressive strength of different mixtures as to proportion and size of aggregate.
3. Transverse strength of different mixtures as to proportion and size of aggregate.
4. Shearing strength with different mixtures as to proportion and size of aggregate.
5. Modulus of elasticity in compression of different mixtures as to proportion and size of aggregate.
6. Modulus of elasticity in tension of different mixtures as to proportion and size of aggregate.
7. Character of crushed stone used: (*a*) Weight per cubic foot; (*b*) size; (*c*) percentage of voids; (*d*) percentage of silt.
8. Weight per cubic foot, uncrushed.
9. Yield.
10. Absorption.
11. Porosity.
12. Permeability.
13. Methods of waterproofing.
14. Protective influence against corrosion of metal.
15. Fire-resisting qualities: (*a*) Effect of heat on hardening concrete; (*b*) effect of heat on hardened concrete; (*c*) thickness necessary for proper insulation.
16. Freezing tests.
17. Volumetric changes.
18. Effect of vibration and of applied stress (impact): (*a*) On hardening of plain and reinforced concrete; (*b*) on hardened plain and reinforced concrete.
19. Adhesion of concrete to metal under varying conditions, for varying periods, up to at least three years: (*a*) Effect of shape; (*b*) effect of embedded length; (*c*) effect of various kinds of loading; (*d*) effect of chemical action; (*e*) relative value of surface adhesive resistance and grip.
20. Effect of oils: (*a*) On hardening concrete; (*b*) on hardened concrete.
21. Coefficient of expansion.
22. Effect of sea water.

C. *Full-size tests.*—The laboratory tests of full-size beams, building blocks, and bricks include the following:

1. Beams of various spans, sections, and compositions.

2. Building blocks and bricks, as to (*a*) compressive strength, wet and dry mixtures; (*b*) transverse strength, wet and dry mixtures; (*c*) shearing strength, wet and dry mixtures; (*d*) absorption, wet and dry mixtures; (*e*) permeability; (*f*) methods of waterproofing; (*g*) effect of accelerating the hardening of concrete blocks by means of live steam, etc.; (*h*) fire-resisting qualities; (*i*) efflorescence.

IV. TESTS OF REINFORCED CONCRETE.

A. *Beams.*—Tests of beams to include determinations of—

1. Effect of amount of reinforcement.
2. Effect of character of reinforcement.
3. Effect of form, size, and position of reinforcing bars.
4. Effect of initial stress in reinforcement.
5. Effect of different manners of loading.
6. Methods of providing for diagonal stresses.
7. Effect of variation in section, such as trapezoidal, T-shaped, etc.
8. Effect of variation in length and depth.
9. Effect of restraining the ends.
10. Effect of repetitive loading.

B. *Columns.*—Tests of columns to include determinations of—

1. Effect of amount of reinforcement.
2. Effect of disposition of reinforcement: (*a*) Longitudinal; (*b*) hooped; (*c*) combination of (*a*) and (*b*).
3. Effect of form, size, and position of reinforcement.
4. Effect of character and eccentricity of loading.
5. Effect of variation in section, such as square, round, and rectangular.
6. Effect of fixing the ends.

C. *Slabs.*—Tests to be made of slabs—

1. Supported at two or four edges.
2. Fixed at two or four edges.
3. Use of expanded metal, wires, etc.
4. Effect of concentration of load.
5. Variation in per cent of reinforcement.
6. Variation in span and thickness.

D. *Arches.*—Tests to be made of forms and features of arches as follows:

1. Continuous ring.
2. Hinged.
3. Voussoirs.
4. Shape.
5. Span and rise.

WORK AT TECHNOLOGICAL INSTITUTIONS.

In connection with the work at the laboratories it has been deemed desirable by the national advisory board and the joint committee on concrete and reinforced concrete to invite the cooperation of those technological institutions possessing proper facilities for carrying on investigations comprising, in part, tests in which the methods of execution are still open to formulation and which involve general phenomena. In addition to this, it was thought desirable for this laboratory to act in an advisory capacity to any laboratory desiring to conduct investigations along these lines. Among the topics which are available for such investigations may be mentioned—

1. Shearing: Comparison of methods.
2. Modulus of elasticity: Comparison of methods.
3. Protective influence of concrete against corrosion.
4. Fire-resisting qualities of concrete.
5. Methods of waterproofing.
6. Coefficient of expansion.

7. Effect of vibration and applied stress.
8. Adhesion of concrete to metal.
9. Reinforced-concrete beams: (*a*) Effect of different manners of loading; (*b*) methods of providing for diagonal stresses; (*c*) effect of variation in section; (*d*) effect of restraining ends; (*e*) amount and character of reinforcement.
10. Reinforced-concrete columns: Method of testing.

SEQUENCE OF TESTS.

It is evident that the investigations embraced in the foregoing programme will cover a number of years, and it is therefore the aim of the United States Geological Survey to investigate first those questions which will yield information most urgently needed in constructive work by the different branches of the Government, the policy being to work continuously upon as many of the problems as the facilities and appropriation will permit.

As the investigation progresses it may be found necessary to do considerable experimental work in determining the proper methods to be followed, the sources of error to be guarded against, and the probable causes of given phenomena, and the programme may therefore be varied according to conditions.

SUMMARY.

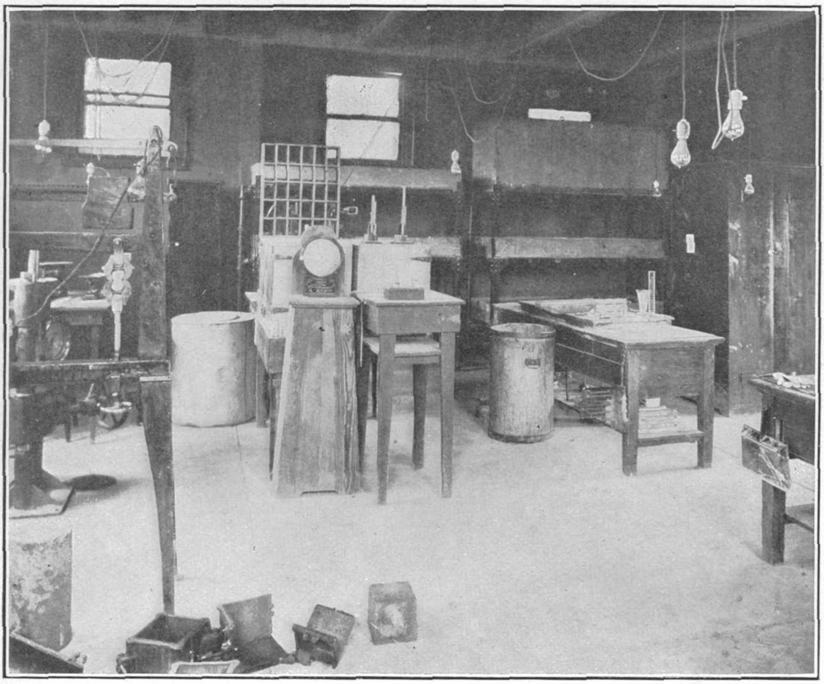
In the following pages the character of the investigations being conducted at the laboratories is presented, together with a description of the apparatus and methods of testing, methods of computing, and forms used for recording the results, the work of each section being separately described.

The methods of testing are given in some detail without, however, any reference to the investigations which led up to their adoption. These investigations often entailed a series of comparative tests between a number of different methods. No change of method is made without a thorough series of tests on identical material by both the old and the proposed method, not only to determine the relative advantages and disadvantages of the two methods, but also to have an equation between the results obtained by both methods by which, should the new method be adopted, the results obtained by the old method would be comparable with those obtained by the new.

The theories underlying the methods of testing are not touched upon except in one instance. The methods used in testing beams are somewhat different from those used by other investigators, hence the theories underlying the methods used at these laboratories are explained.

The methods used in transforming the data obtained at the testing machines into form for publication are not treated in detail, an outline[a] only being given.

[a] See Form B (p. 24) and footnote relating thereto (p. 23).



A

B

INTERIOR VIEWS OF CONSTITUENT-MATERIALS LABORATORY.

It is the policy to present only the results of the tests, eliminating all statements of opinion or theories concerning them. Occasionally in bulletins on a particular phase of a subject curves will be drawn showing graphically certain relations, such as the variation of strength with age or the variation of deformation with increasing stress. Attention will also be called to points of interest or some unusual feature in the results.

CONSTITUENT-MATERIALS SECTION.

OUTLINE OF INVESTIGATIONS.

Nature of the work.—All the sand, stone, gravel, and other materials which are used in the investigations being carried on by the division are tested for their quality in this section.

In addition a series of investigations are under way covering the determination of the relative value of the various sands, gravels, cinders, crushed stone, and other constituent materials used in cement mortars and concretes.

For these investigations there is used a typical Portland cement, obtained by thoroughly intermixing a large number of standard brands of Portland cement. In the earlier stages of these investigations, it was the practice to test each brand separately, and also each mixture of these brands. It was found that the difference between the result obtained for the mixture and the average of the results of the individual brands was so slight as to be negligible for all practical purposes. It is the practice now, however, to test the various brands in order to ascertain whether the cement meets the requirements for a typical cement contained in the programme for these investigations (p. 17). The cement obtained by mixing several brands, here referred to as a typical cement, is mixed in large quantities at a time and sealed in air-tight galvanized cans of about 800 pounds capacity.

Laboratories.—Interior views of the constituent-materials laboratories are shown in Pl. II. A briquet is shown in the clips of the long-lever testing machine at the left in *A*, and the soapstone immersion tanks are shown in the background. The glass-top mixing tables are shown in the foreground of *B*. This view also shows the 200,000-pound Olsen testing machine at the left, the long-lever cement-testing machine and the hydraulic hand-operated compression-testing machine in the center, and the moist closet at the right.

Register numbers.—Each sample of material as it is received at the laboratories is given a register number, a record of which is made and filed in a card index. The sample is subsequently known by this register number, which is so chosen that it indicates the nature of the material. For example, each material is designated by the first and last letters of its name; thus, Ct. for cement, Sd. for sand, Gl. for gravel, Cr. for cinder, Sg. for slag, and Se. for stone. The first sample of the cement was called Ct. 1, the next Ct. 2, etc. When the mix is made it is given a single number and each sample taken from that mix is given a subsequent number; thus the second mix was called Ct. 133, and the first sample from that mix Ct. 133–1, etc.

PHYSICAL TESTS OF CEMENT.

All the cement used at the laboratories is subjected to the following physical tests: (1) Specific gravity. (2) Fineness. (3) Time of setting. (4) Tensile, compressive, and transverse strength, neat and with three parts Ottawa sand. (5) Percentage of water for normal consistency. (6) Soundness.

The methods recommended by the special committee on uniform tests of cement of the American Society of Civil Engineers are used in making these tests.

The specific gravity is determined upon untreated, dried, and ignited samples. A large series of special tests have been made to determine the relative merits of the different forms of apparatus; the Le Chatelier apparatus, however, is the standard for routine work.

The time of both initial and hard set is determined both by means of the Gilmore wires and by the Vicat needle apparatus. The latter apparatus, however, is the standard for all tests. The temperatures of the air and of the water are recorded on Draper automatic recording thermometers, which record covers a period of one week.

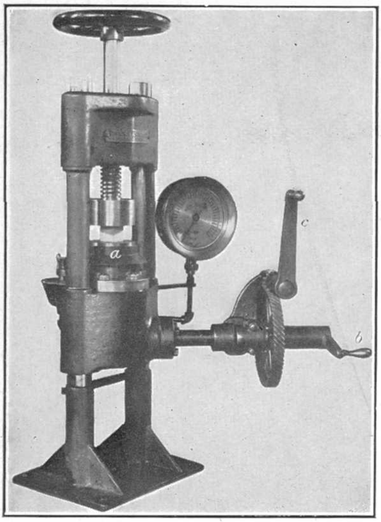
The accelerated testing apparatus for making tests for soundness is illustrated in Pl. III, *B*. The test consists in maintaining the pats in an atmosphere of steam over boiling water for five hours.

The percentage of water for normal consistency is determined with the Vicat needle apparatus. The test for fineness is made by sifting the cement through the No. 100 and No. 200 sieves, using a special sifting apparatus made by Howard & Morse, which is capable of holding nine sieves at one time.

STRENGTH TESTS OF NEAT CEMENT AND OTTAWA SAND MORTAR.

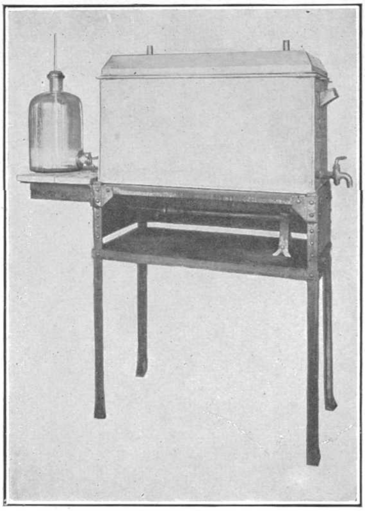
The neat cement is tested for tensile, compressive, and transverse strength at ages of 1, 7, 28, 90, 180, and 360 days, and a parallel series of tests is made of 1:3 mortar, using standard Ottawa sand for all ages except one day. Three test pieces are broken for each age.

Tension briquets are approximately 1 inch square at the smallest section; in order to get accurate results the least dimensions are carefully measured at the time of testing and the actual unit stress

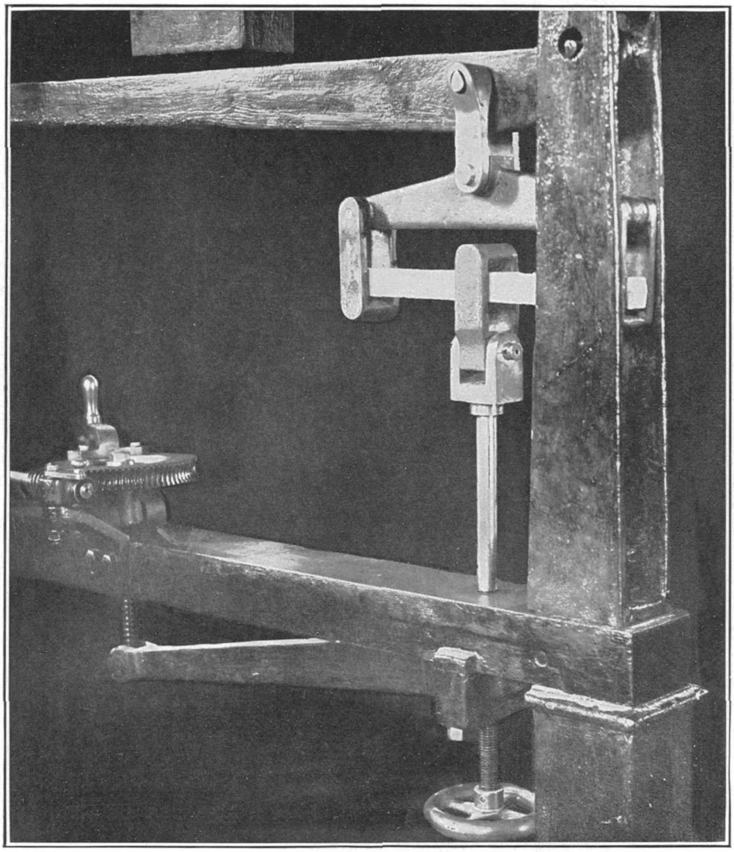


A. 40,000-POUND HYDRAULIC HAND-POWER COMPRESSION MACHINE.

(See explanation in text, p. 30.)



B. ACCELERATED TEST APPARATUS FOR SOUNDNESS TESTS OF CEMENT.



C. ATTACHMENT FOR TESTING SHORT TRANSVERSE TEST PIECES ON OLSEN LONG-LEVER CEMENT-TESTING MACHINE.

is computed. The briquet molds are of the 5- and 3-gang type and are made of brass (Pl. II, *A*).

Compression test pieces are 2-inch cubes, the molds being of the 3-gang type. The mortar cubes are tested in the 40,000-pound hydraulic hand-operated compression machine shown in Pl. III, *A*, in which *a* is a ball-and-socket bearing and *b* and *c* are handles that give fast and slow motions, respectively. A cube is shown in the machine just above *a*. The stronger neat cubes are tested in the 200,000-pound testing machine.

Transverse test pieces are 1 inch square in cross section and 13 inches in length; they are tested on a span of 12 inches. The transverse molds are of the individual type. The transverse specimens are usually tested on the machine shown at the left of the center in Pl. II, *A*, but can be tested in the briquet machine by means of the apparatus illustrated in Pl. III, *C*.

The test pieces are stored in the moist closet for twenty-four hours, and are then placed under water, in the immersion tanks, until tested. The water in the immersion tanks is kept constantly running and heated when necessary in order to maintain a constant temperature of about 70° F.

The order of testing is regulated by a filing system with cards 6 by 4 inches in size which have blanks for data, as shown in Form A.

Form A. { UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. } MOLDING CARD.

Date .... Test .... Reg. No............... Field No...................
Mold test pieces as follows:

Neat with .....per cent; mark, ...	1:4 with .....per cent; mark, ...B....
1:3 with........per cent; mark, ...A....	1:3 one size...per cent; mark, ...C....

Take all temperatures and date neat test pieces.
Temperatures: Tanks......°F.; moist closet, ...°F.; air in lab. ......°F.; mixing water, ...°F.
Remarks.—...
Operator's signature: .... Approved: ....

When a sample of neat cement, for example, is molded into test pieces, a card is made out for each group of three, and the date upon which the group will be tested is placed at the top of the card. The cards are then filed in the order of the dates. Calendar guide cards are used, dividing the months into three parts. Each morning the cards bearing the date of that day are removed from the front of the file, and the test pieces indicated on them are tested that day. In this way the cards are kept moving toward the front of the file and reach the front on the day when the test pieces whose register numbers they bear are to be tested.

The results of these physical determinations are entered upon Form B[a] for filing at the laboratory, and are subsequently copied into tables for publication.

[a] Forms B to R, inclusive, are condensed in the pages of this bulletin, in connection with the subject-matter to which they severally relate, for the purpose of showing in detail how the results of the various tests are recorded. In practice, each form is printed on a sheet of paper 8 by 10½ inches in size.

Form B. UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. CEMENT REPORT.

Station.. Approved..
Register No............ Brand.. Sp. gr.....
Residue on No. 100 sieve...................per cent; on No. 200 sieve.............................per cent.
Time initial set..........hr.,...........min. Hard set..........hr.,..........min. Method............
Pat test in air, 70° F ....
Pat test in water, 70° F..
Pat test in steam, 5 hours..
Pat test in water, 180° F..
Water used: Neat......per cent; 1:3......per cent. Kind of sand used in 1:3........................

Temperature at mixing.
- Neat: Tension—water.....° F.; air.....° F. Compression—water.....° F.; air.... ° F. Flexure—water.....° F.; air.....° F. Pats—water.............° F.; air.....° F.
- 1:3..: Tension—water.....° F.; air.....° F. Compression—water.....° F.; air.....° F. Flexure—water.....° F.; air.....° F.

Age (days).		Tensile strength.		Compressive strength.		Transverse strength.		
		Pounds per square inch.	Av.	Pounds per square inch.	Av.	Center load in pounds.	Av.	Mod.
Neat	1							
	7							
	28							
	90							
	180							
	360							
1:3	7							
	28							
	90							
	180							
	360							

Remarks.— ....

SAND, STONE, GRAVEL, AND OTHER AGGREGATES.

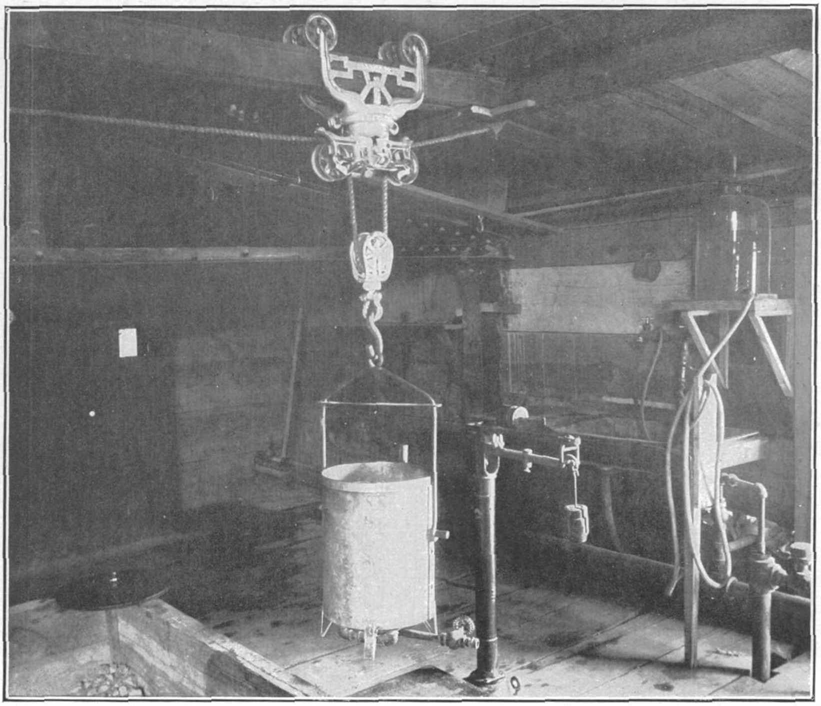
PHYSICAL TESTS MADE.

Samples of sand, stone, gravel, cinders, etc., are collected by a geologist who makes a complete report on the location, extent, and geological formation of the source of the supply, the methods of preparing the material for the market, the market supplied, the output, etc. In the case of broken stone and gravel he collects samples of crusher or pit-run screenings below one-fourth inch, and pieces of stone about 1 cubic foot in size. The physical tests made upon this material are as follows:

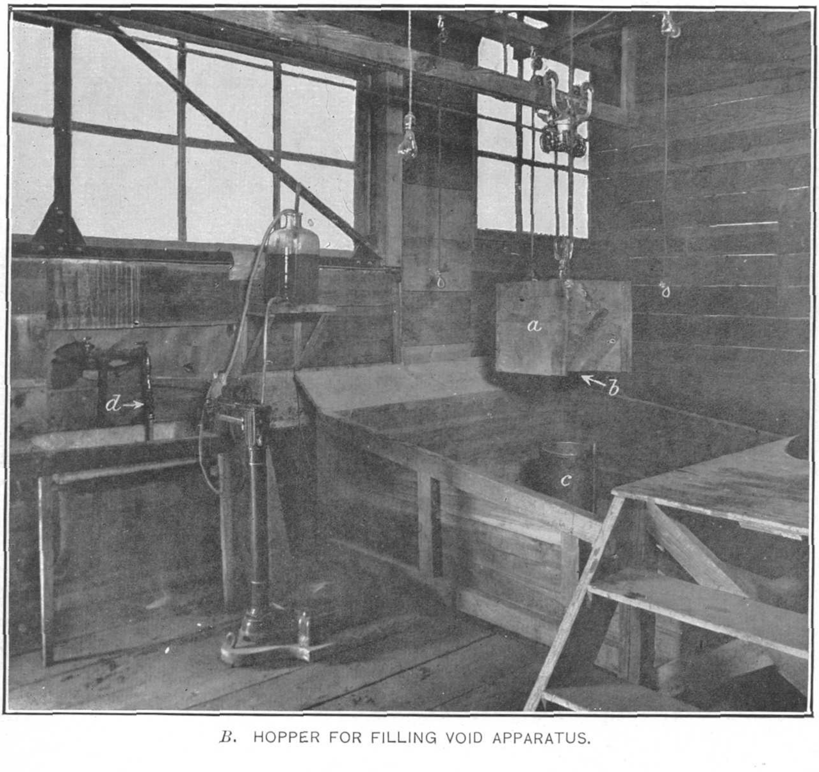
Percentage of voids; percentage of moisture; weight per cubic foot; percentage of absorption; specific gravity; percentage of silt; granulometric analysis; strength and density tests of mortar; strength, modulus of elasticity in compression, and density tests of concrete.

PERCENTAGE OF VOIDS.

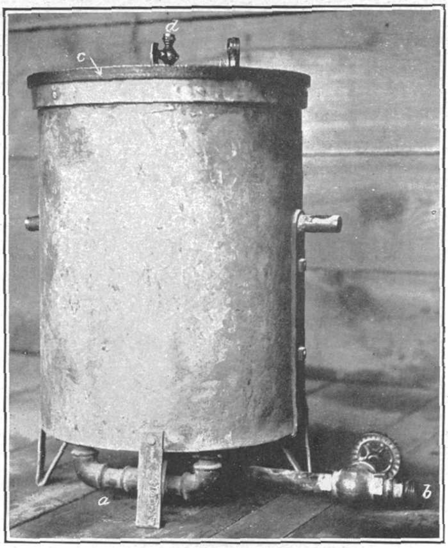
Apparatus.—The apparatus shown in Pl. V, *A*, consists of a heavy galvanized-iron cylinder 12 inches in diameter and 15 inches high, inside dimensions. The pipe *a* admits water through four 1-inch apertures in the bottom of the vessel, the inlets being fitted on the inside with perforated porcelain disks which prevent fine material



A. METHOD OF HANDLING VOID APPARATUS.

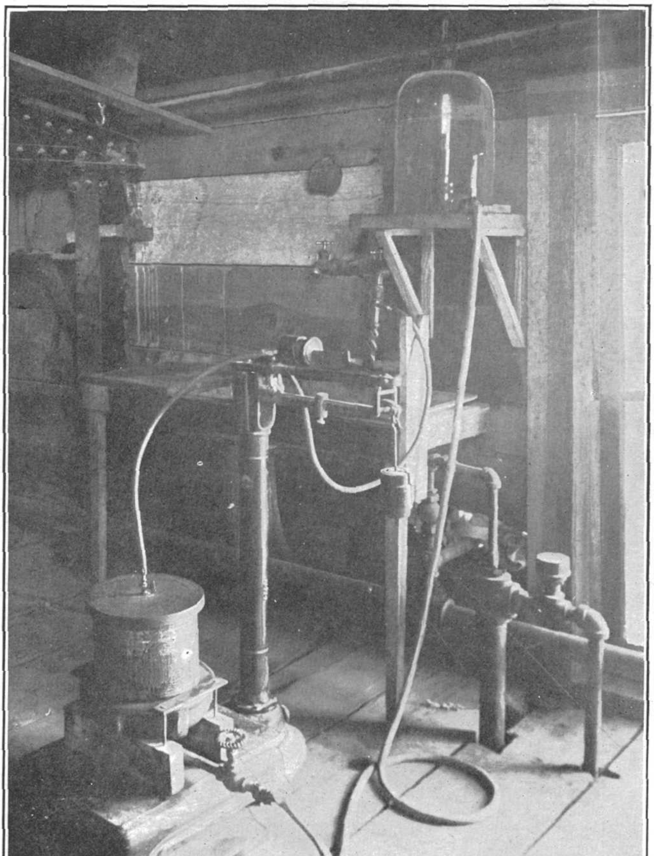


B. HOPPER FOR FILLING VOID APPARATUS.



A. APPARATUS FOR DETERMINING PERCENTAGE OF VOIDS.

(See explanation in text, pp. 24–25.)



B. APPARATUS AND CONNECTIONS FOR MAKING VOID TEST ON "ONE-SIZE" MATERIAL.

placed in the vessel from dropping down into the pipe. The pipe *b* is connected by a rubber hose to a 5-gallon water bottle. The lid *c* is of cast iron and is ground to an air-tight fit. The small cock *d* is connected by a rubber tube to a Richards air pump (shown at *d*, Pl. IV, *B*, and at *b*, Pl. VI, *A*), which is attached to a water faucet. Pl. IV, *B*, shows the apparatus for filling the cylinder, with the water bottle, the air pump *d*, and the scales in place. The material is placed in the hopper *a* and runs through the opening at *b* into the cylinder *c*.

Method.—A sample of the material is dried to constant weight, thus incidentally obtaining the percentage of moisture contained in the material as received. The dry material is placed in the hopper (*a*, Pl. IV, *B*), which is raised so that its bottom is 24 inches above the center of the cylinder. The aperture *b* is opened to such an extent that the material will fill the cylinder in about one minute. The material is allowed to fill the cylinder to overflowing and is struck off level with a straightedge. The cylinder is then transferred to the scales by means of the overhead trolley (Pl. IV, *A*) and its weight with contents is ascertained and recorded. The tube from the water bottle is next attached to the pipe beneath the cylinder and the tube from the pump is attached to the valve in the lid, which is carefully put in place. The air is exhausted from the cylinder by means of the air pump (*d*, Pl. IV, *B*), and the water is allowed to flow in slowly from below until it approaches the top, when the cover is removed and the water brought to the top of the vessel. The water is allowed to flow into the voids at such a rate that it reaches the top in about one hour. The weight of the vessel is taken after the voids are filled with water.

The percentage of voids in the large material and in the screenings and sand is determined in the same way except that a smaller cylinder is used for the material sifted to one size. This cylinder has only one hole in the bottom for the introduction of the water. The smaller cylinder is used because the material of a given size is often insufficient to fill the larger one (shown in Pl. V, *A*). Pl. V, *B*, shows the test on large-sized material under way.

Computations.—The volume and weight of the vessel and the weight of water required to fill the pipes beneath the vessel are known. The quantities measured and recorded during the tests are (1) the weight of the vessel full of dry material, (2) the weight of the vessel full of material and water, (3) the weight of a portion of the surface-dried sand after the test, and (4) the weight of the thoroughly dried sand after the test.

The percentage of voids is obtained by correcting the measured volume of water for that filling the pipes and absorbed by the material, dividing by the volume of the vessel and multiplying the result by 100.

The percentage of voids is also obtained by dividing the weight per cubic foot of the dried sample by the product of the specific gravity of this material and the weight of a cubic foot of water.

PERCENTAGE OF MOISTURE.

Method.—The weight of water introduced into the cylinder is corrected for the absorption of water by the stone, which is determined by weighing a portion of the material after surface drying and again after thoroughly drying it over a hot plate.

Computations.—The percentage of moisture is found by dividing the difference in weight between an ordinary sample before and after drying by the weight of the dry material and multiplying by 100.

WEIGHT PER CUBIC FOOT.

The weight per cubic foot of the material is found by taking the difference between the weight of the empty vessel and the weight of the vessel full of dry material and dividing by the volume of the vessel.

PERCENTAGE OF ABSORPTION.

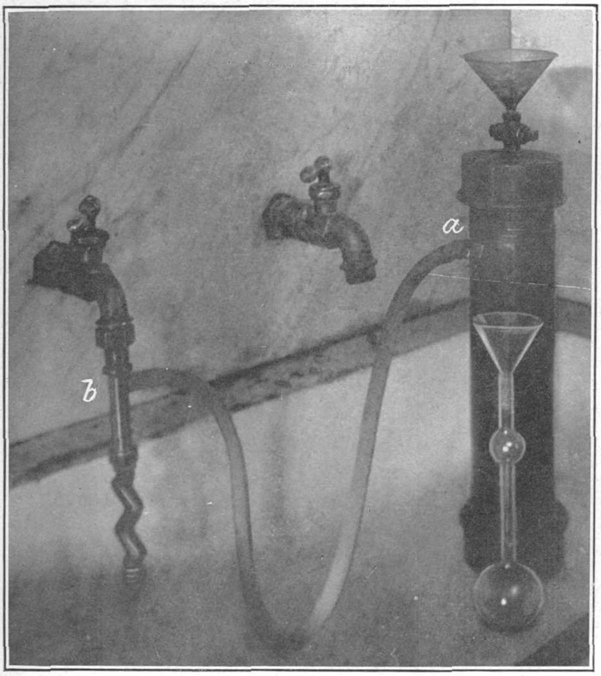
Method.—The sample used for the absorption test, taken from the material in the void apparatus, is obtained by spreading the material out and selecting small portions from several different parts of the mass.

Computations.—The unit absorption, or the weight in pounds of water absorbed per pound of dry material, is the difference between the weight of the surface-dried material after the test and of the thoroughly dried material divided by the weight of the thoroughly dried material.

SPECIFIC GRAVITY.

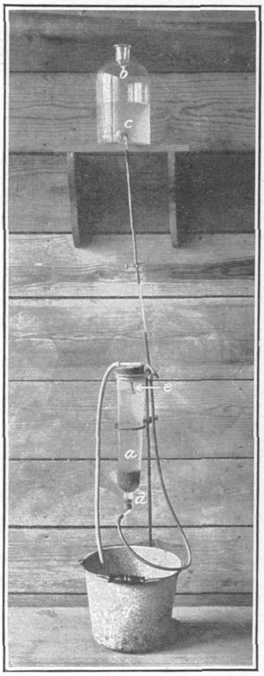
METHOD USED WITH LARGE MATERIAL.

Apparatus.—Pl. VI, *C*, shows the apparatus used in determining the specific gravity of large material. The cylinder (*a*) is the same as that used for making the void test on "one-size" material. It is made from an 8-inch wrought-iron pipe 8½ inches long; the cap at the bottom has a 1-inch opening in the center fitted with pipe and valve (shown at *b*) and is protected from the materials placed in the cylinder by a No. 50 wire-gauze screen. This pipe is connected by rubber tubing to an aspirator bottle containing clean water. The valve in the lid is connected to the Richards air pump (shown at *c*). The lid is of cast iron and is grooved to fit the top of the cylinder. A rubber gasket is placed in the groove, making an air-tight joint. The tin vessel (*d*) is arranged to hang from the arm of the balance (*e*), so that its weight may be determined when it is immersed in water.



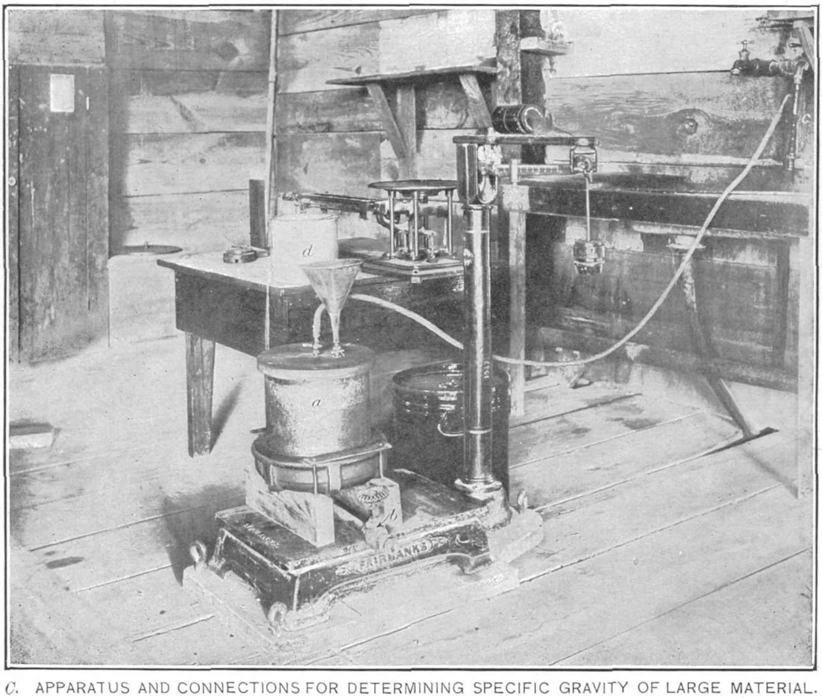
A. APPARATUS AND CONNECTIONS FOR DETERMINING SPECIFIC GRAVITY OF SAND AND SCREENINGS.

(See explanation in text, pp. 25, 27.)



B. APPARATUS FOR REMOVING SILT FROM STONE SCREENINGS.

(See explanation in text, p. 28.)



C. APPARATUS AND CONNECTIONS FOR DETERMINING SPECIFIC GRAVITY OF LARGE MATERIAL.

(See explanation in text, p. 26.)

Method.—A 1,500-gram sample, dried to constant weight, is placed in the tin bucket, which is then placed in the iron cylinder; the cast-iron lid is put in place and the air exhausted. The water is then slowly admitted until the stone is covered, when the lid is removed. The stone is allowed to soak for one-half hour (the average time of the immersion of material in the void test); the bucket is removed and hung on the arm of the balance (*e*), so that it is immersed in the water contained in the vessel (*f*), and the weight of the immersed tin bucket and contained material is measured.

The amount of water absorbed is measured by weighing the material after surface drying with a towel and again after drying it to constant weight over a hot plate. The original dry weight is used in determining the loss of weight in water and the final dry weight in determining the unit absorption. The original dry weight is used because small particles are apt to be lost during the surface drying.

Computations.—The quantities measured and recorded are (1) the weight of the original dry stone, (2) the weight of the stone and tin vessel suspended in air and (3) in water, (4) the weight of the surface-dried stone after the test, and (5) the weight of the thoroughly dried stone after the test. All these weights are in grams. The difference between the last two weights gives the weight of water absorbed, and the weight of the original dry stone divided by the loss of weight of the stone in water corrected for absorption gives the specific gravity.

METHOD USED WITH MATERIAL THAT PASSES THE ONE-FOURTH INCH SCREEN.

Apparatus.—With screened material a 3-inch wrought-iron pipe, 12 inches long, shown in Pl. VI, *A*, is used. It is permanently capped at the bottom and has a removable screw cap at the top. The valve at *a* is connected with the air pump, and water is admitted through the funnel and the stopcock in the top. A glass flask with a long neck graduated to one-fifth of a cubic centimeter is used to hold the material. The Le Chatelier specific-gravity bottle (Pl. VI, *A*) may be used.

Method.—About 55 grams of the material, dried to constant weight, is put in the flask and weighed. The flask is then placed in the cylinder and the air exhausted, after which water is admitted to the flask through the funnel. The vacuum prevents foaming when limestone is used and also approximates the condition under which the voids are measured. When the material is entirely covered with water, the flask is removed from the cylinder and allowed to stand one-half hour. Its weight is then taken and the volume read on the neck of the flask. Owing to the delicacy of this test the temperatures of air and water must be controlled. The amount of water absorbed is determined by weighing the material after surface drying with blotters and filter paper, and again when dry.

Computations.—The weight in grams of the flask is known and the following quantities are measured and recorded, the weights being in grams and the volumes in cubic centimeters: (1) Weight of flask and sand; (2) weight of flask, sand, and water; (3) weight of surface-dried sand; (4) weight of dry sand; (5) volume of sand and water, read on the neck of the flask.

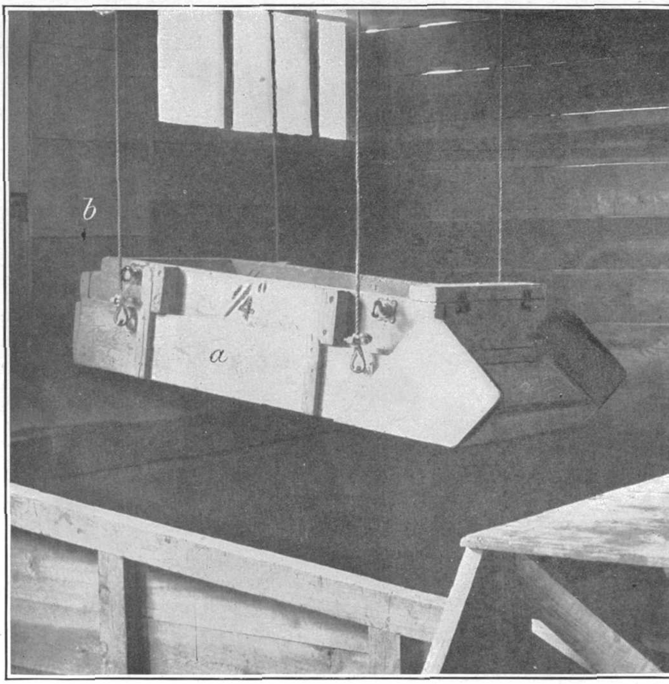
From these data the original weight in grams of the dry sand, the weight in grams of water absorbed per gram of dry sand, and the total weight in grams of water absorbed are computed. The difference between the volume of the sand and water read on the neck of the flask and the volume of the water in cubic centimeters in the flask corrected for absorption gives the volume of the sand in cubic centimeters. Finally, the ratio between the weight in grams and the volume in cubic centimeters of the dry sand gives the specific gravity.

PERCENTAGE OF SILT.

Apparatus.—The apparatus used in this determination is shown in Pl. VI, *B*. The glass percolator (*a*) is 13 inches long, with an upper inside diameter of 3 inches and a lower inside diameter of 2½ inches. The vessel (*b*) is placed with its outlet (*c*) 3 feet above the top of the percolator. The opening (*d*) at the bottom of the percolator is one-half inch in diameter, and is fitted with a perforated porcelain disk to prevent the passage of the material placed in the vessel. The glass tube (*e*) is placed with its lower end 10 inches above the surface of the material.

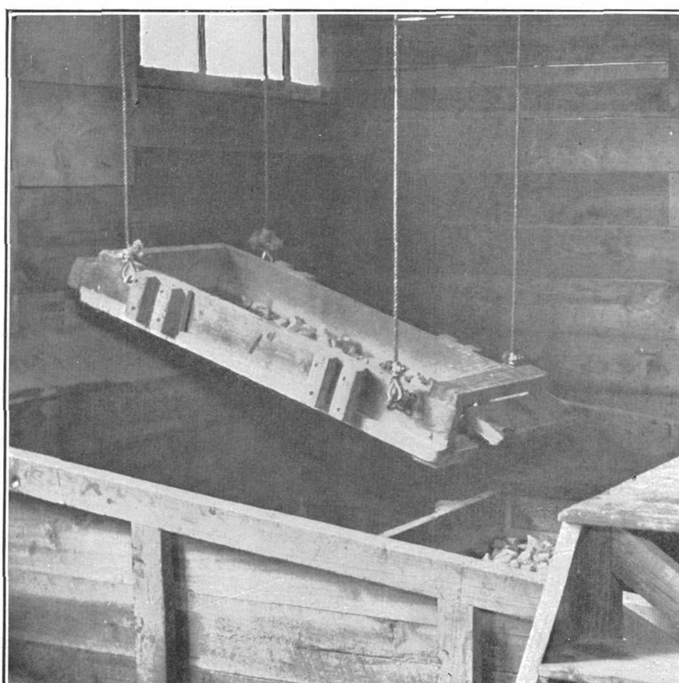
Method.—The vessel (*b*) and the percolator (*a*) are filled with clean water, and a 100- to 200-gram sample, depending upon the probable amount of silt present, is put in the latter. The upper stopper of the percolator is put in place, and the current of water is started. The silt is carried by the current of water over into the vessel *f*. The flow of water is continued until the effluent is clear, when the upper stopper is removed, the material stirred, and the current again started. This operation is repeated until the effluent is clear immediately after the material is stirred. The water containing the silt is evaporated on a water bath, when the silt is scraped and brushed onto a watch glass and permitted to remain uncovered until it attains the temperature of the room so that it will be under the same conditions as the original sample. It is then weighed. The silt thus obtained is chemically analyzed.

Computations.—The percentage of silt is the weight of the silt divided by the weight of the material placed in the percolator and multiplied by 100.



A. BUMPING SCREEN FOR MAKING GRANULOMETRIC ANALYSIS.

(See explanation in text, p. 29.)



B. METHOD OF FILLING ONE SCREEN WITH MATERIAL RETAINED ON ANOTHER.

GRANULOMETRIC ANALYSIS.

Apparatus.—Two sets of screens are used for the granulometric analysis; one for material larger than one-fourth inch and one for smaller material. The set of large-mesh screens (openings $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{3}{4}$, and 2 inches) are 2 feet wide, 4 feet long, and 6 inches deep, and are provided with hooks at the corners by which they may be suspended by ropes passing through pulleys at the ceiling (Pl. VII). A shallow wooden box (*a*, Pl. VII, *A*) fits beneath each of the two finest screens so that material passing these screens will be caught in the box with the loss of as little fine material as possible. When the material has been placed upon the screen, the latter is raised to a convenient height by means of the ropes and is repeatedly pulled out about 18 inches from the post at *b* and released, so as to bump against the post. The impact violently jars the screen and aids the material in passing through.

The set of smaller-mesh screens (openings 10, 20, 30, 40, 50, 80, 100, and 200 to the linear inch) are brass circular hand sieves, 8 inches in diameter, and fit one upon another, each set being provided with a cover and a bottom pan. A Howard & Morse power sifter is used, which gives the nest of sieves a rotary motion, violently reversed after a part revolution, and at the same time a vertical bumping motion.

Method.—A 100-pound sample is dried to such a degree that it will not clog the screens. It is placed upon the $\frac{1}{4}$-inch screen and the material passing is reserved. That portion remaining on the screen is then run onto the screen of next larger mesh (Pl. VII, *B*) and the operation repeated. Each sifting is continued until the material ceases to pass through the sieve. The material passing each screen is weighed. A 500-gram sample is then taken from the material that passes the $\frac{1}{4}$-inch screen and is placed upon the upper of the nest of small sieves and sifted for fifteen minutes, when the residue on each sieve and the material passing the No. 200 sieve are weighed.

Computations.—The percentages recorded represent the residues on each of the fine and the coarse sieves, and are given in terms of the weight of the original sample.

TESTS OF MORTAR.

DESCRIPTION.

The sand and screenings received at the laboratories are made into mortar, using different proportions and sizes of material. This mortar is then investigated as to tensile, compressive, and transverse strength, and as to density. Should the material contain particles larger than one-fourth inch, these are removed by the use of a $\frac{1}{4}$-inch screen. The mortars are made with one part typical Portland cement in proportions of 1: 3 and 1: 4, and in addition a 1: 3 mortar is made from sand screened to one size between Nos. 30 and 40 sieves and from stone screenings sifted to one size between Nos. 10 and 20 sieves. These mortars are molded into tensile briquets, 2-inch cubes, and transverse test pieces of 1-inch cross section 13 inches long.

STRENGTH TESTS.

Apparatus.—An improved Fairbanks shot machine is used for the tension tests, and a 40,000-pound capacity oil-pressure hand-operated machine, shown in Pl. III, *A* (p. 22), is used for the compression tests. The transverse tests are made either on the 10,000-pound wire tester, which is fitted with transverse tools, or on a long-lever 2,000-pound Tinius Olsen & Co. machine with a special bearing made by the same company, as shown in Pl. III, *C*. When transverse specimens are being tested, the heavy counterpoise is replaced by a light wooden one loaded with shot. This requires a greater movement of the poise to balance the same load, and thus permits the small loads sustained by the beams to be more accurately measured than with the original counterpoise.

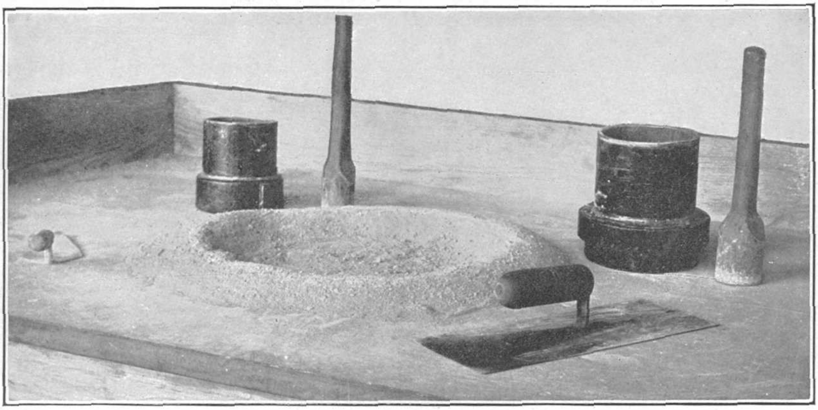
Methods.—The methods recommended by the special committee on uniform methods of the American Society of Civil Engineers are used in the mixing and molding. The test pieces are placed in the testing machine upon their sides (with reference to the position in which they are molded).

Computations.—The only computations necessary are those for obtaining the unit strengths from the gross loads read at the machine and the averages of the three tests in each case.

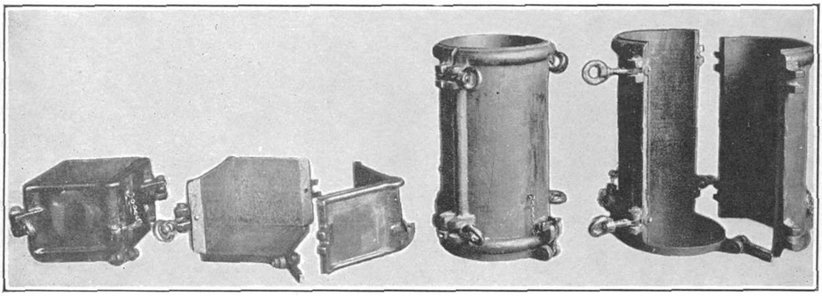
DENSITY TESTS.

Apparatus.—The implements used in the density tests are shown in Pl. VIII, *A*. Two sizes of molds are used in order to determine which size gives the more uniform results. After this has been decided, it is proposed to abandon the one giving the less consistent results. The molds are sections of wrought-iron pipe capped at one end. One is 3½ inches in diameter and 4½ inches deep, while the other is 4½ inches in diameter and 5½ inches deep, inside dimensions. The diameter of the tamper head is one-half the diameter of the cylinder in each case, so that when the tamper is moved around the inner circumference of the cylinder and kept in contact with the mold the entire surface of the mortar in the cylinder will be tamped. The table top is of slate.

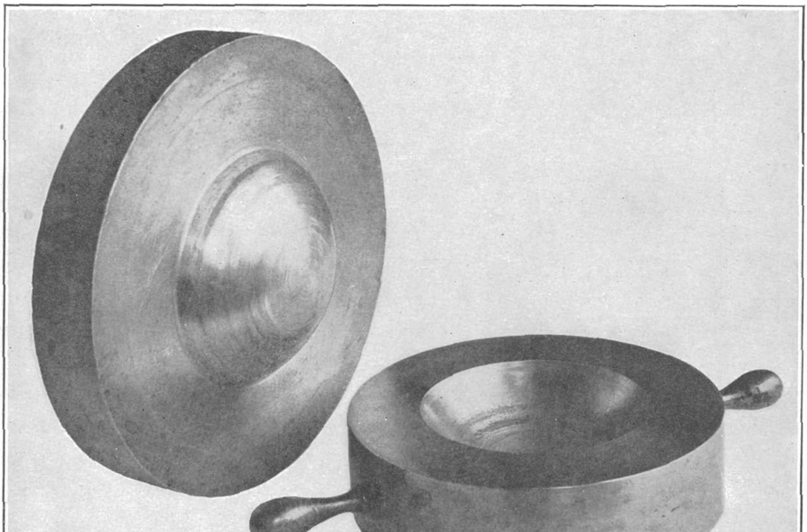
Method.—The required proportions of the dry material are carefully weighed out, and water is added to form a normal consistency. The



A. IMPLEMENTS USED IN MAKING DENSITY TESTS OF MORTARS.



B. CAST-IRON CUBE AND CYLINDER MOLDS.



C. SPHERICAL BEARING BLOCKS FOR COMPRESSION TESTS.

mixing is continued for two minutes and the mortar placed in the molds in layers about 1 inch thick and thoroughly and uniformly tamped. The top surface is troweled off even with the top of the mold and allowed to stand one-half hour. The weight of the full mold is then taken. The amount of shrinkage of the mortar from the top of the mold is measured by a steel rule.

Computations.—The weight of each ingredient in the mixture multiplied by the ratio of the weight of the mortar in the mold to the total weight of the mixture gives the weight of the cement and sand entering the cylinder. The absolute volume of the sand and cement in the molds is computed by dividing their weights in grams by the respective specific gravities. The sum of these absolute volumes is then divided by the volume of mortar in the cylinder, and thus the density obtained.

The values are recorded on Form C.

Form C. { UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. } MORTAR REPORT.

Station... Approved: ....

Sand reg. No........ Cement reg. No. .... For parallel cement tests, see Cement report on.........

.... sand passed through No. .... sieve and retained on No. .... sieve.

Proportions of mortar by weight, ...; by volume,....... Water used ....per cent.

Temperature at mixing. {Tension—water......° F.; air......° F. Compression—water......° F.; air......° F. Flexure—water......° F.; air......° F. Shear—water.............° F.; air......° F.}

Age (days).	Tensile strength.		Compressive strength.	
	Pounds per square inch.	Av.	Pounds per square inch.	Av.
7				
28				
90				
180				
360				

Age (days).	Transverse strength.			Shearing strength.	
	Total center load in pounds.	Av.	Mod.	Pounds per square inch.	Av.
7					
28					
90					
180					
360					

Remarks.—...

TESTS OF CONCRETE.

DESCRIPTION.

The large material, crusher-run stone, pit-run gravel, etc., is made into concrete with typical Portland cement, using different proportions, and the concrete investigated as to its compressive strength, its modulus of elasticity, and its density.

The large material, first, has all the ¼-inch material screened out and is then made into the following concretes:

(1) Using Meramec River sand in proportions of 1:3:6, 1:2:4, in such amounts that the cement is 10 per cent in excess of the amount required to fill the voids in the sand and the mortar 10 per cent in excess of the amount required to fill the voids in the stone, and in proportions which will produce the greatest density as determined by the yield test, when the cement is first one-ninth and second one-sixth of the total aggregate. Meramec sand is a bar sand of excellent and uniform quality, donated by a company operating on the Meramec River near St. Louis, Mo.

(2) Using the ¼-inch screenings in place of the sand in proportions of 1:3:6, 1:2:4, and in the proportion producing the maximum densities, as with the Meramec sand. The concrete is mixed in a one-half cubic yard Chicago cube mixer. This mixer is equipped with a charging hopper and a direct-connected motor. Water is supplied from a barrel which rests on a platform scale, so that the amount of water used may be weighed. The barrel is fed from a faucet and discharges through a quick-closing faucet into a large funnel. The water passes from the funnel to the mixer through a 2-inch hose. The concrete is molded into cylinders 8 inches in diameter and 16 inches long and into 6-inch cubes. Both cylinders and cubes are tested for compressive strength, and on the cylinders the modulus of elasticity is also determined. The cubes and cylinders are tested at 28, 90, 180, and 360 days, three similar pieces being tested at each age.

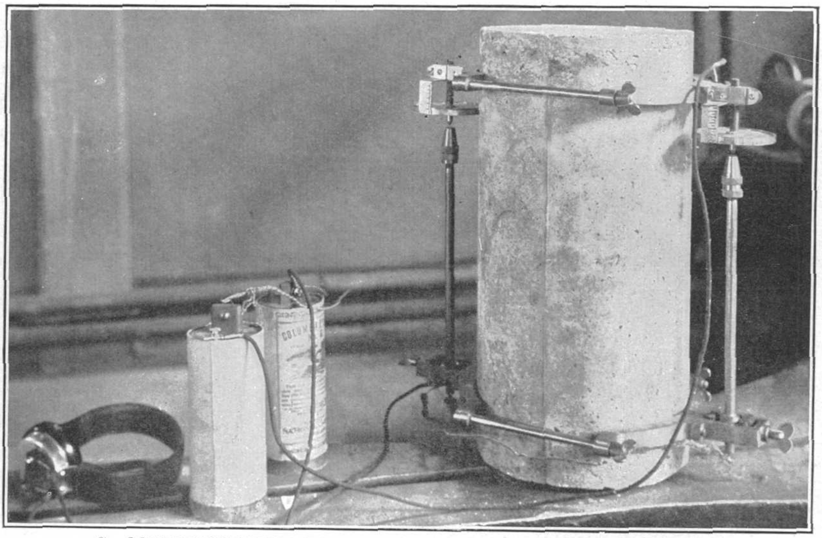
STRENGTH TESTS.

Apparatus.—The cube and cylinder molds are shown in Pl. VIII, *B*. They are of cast iron, with the inner surfaces machined. The clamp screws are of brass. In testing the cylinders and cubes, a 12-inch spherical bearing block (shown in Pl. VIII, *C*) is used to give a uniform distribution of the load.

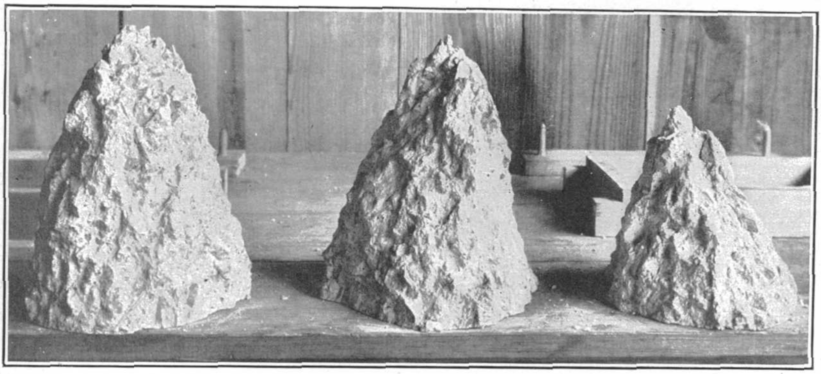
Method.—(a) Molding: The concrete is made of medium consistency (see description of consistencies under "Beam section," pp. 49–50), and the tamping is done by hand in 3-inch layers, using tampers 3½ by 1¼ inches at the ends and weighing 12½ pounds each. The greatest care is exercised to insure the uniform tamping of all test pieces. The cylinders and cubes are permitted to remain in the molds for twenty-four hours; then they are placed in a moist room. This room is lined with waterproof paper, and either steam or water may be sprayed into the air from a number of spraying nozzles at the ceiling. The specimens are sprinkled with water at regular eight-hour intervals. (b) Testing: The cubes are centered in the testing machine on a spherical bearing block and bedded top and bottom with asbestos

A. TYPICAL FAILURE OF CONCRETE CYLINDER.

B. FAILURE OF CONCRETE CYLINDER—RUPTURE THROUGH AGGREGATE.



C. COMPRESSOMETERS FOR MEASURING DEFORMATIONS OF CYLINDERS.



D. TYPICAL CONES FORMED BY RUPTURE OF CONCRETE CYLINDERS.

board one-eighth inch thick (Pl. X, *A*, p. 48). The testing of the cylinders is described under the next heading.

MODULUS OF ELASTICITY IN COMPRESSION.

Apparatus.—The compressometer used in measuring the vertical deformations of the cylinders during testing is shown in Pl. IX, *C*. The gage length is exactly 12 inches. The micrometers measure to one ten-thousandth inch, and the contact is read by listening for the making and breaking of the electric circuit in the usual telephone operator's receivers (shown at the left in Pl. IX, *C*), which are held to the ears of the operator by clamps.

Method.—The ends of the cylinders are smoothed off with plaster of Paris at right angles to the axes a short time before testing. This insures an even distribution of the breaking load over the ends. For this purpose a rigid table is used, the top of which is horizontal and consists of a heavy piece of plate glass about 1 foot square. After the glass has been oiled, plaster of Paris is spread on it about one-fourth inch thick, into which, before it sets, the cylinder is forced, so that all but a layer about one-sixteenth to one-eighth inch thick is squeezed out. The sides of the cylinder are made vertical by means of a spirit level. After the plaster at one end has set, the other end is treated in the same way. The cylinders thus prepared are placed in the testing machine without further bedding.

The load is applied continuously at a speed of about one-fortieth inch per minute, and readings of the gross deformations are taken at 5,000-pound intervals or at about 100 pounds per square inch. The load at first crack, the ultimate load, and the appearance of the ruptured cylinder are recorded, the latter in the form of a sketch. In Pl. IX, *A* and *B*, are shown typical forms of failure. In the example shown in *B* the rupture has occurred by shearing through the aggregate. Pl. IX, *D*, shows three typical cones from broken cylinders.

DENSITY TESTS.

Apparatus.—The tests for density of concrete are made in cylinder molds of wrought-iron pipe similar to those used for the determination of the density of cement mortar, except that they are 8 inches in diameter and 9 inches long, or 10 inches in diameter and 12 inches long.

Method.—The test is made in the same manner as that for density of mortar. In the series of tests now under way the proportions of cement and large and small aggregates are varied in order to obtain the mixture that will produce concrete with the greatest density. The ratio between the cement and the total aggregate is kept constant (1:9), while the ratio between the small and large aggregate is varied.

In another series about to be started this ratio of cement to total aggregate will be 1:6. Four or five trials are usually sufficient to determine the proportions giving a concrete of the greatest density.

The results of these tests are recorded on Form D.

Form D. { UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. } COMPRESSION CYLINDER. REGISTER REPORT.

Station.. Approved:..
Cylinder No. .... Date made............................ Date tested.......................................
Dimensions: Diameter..................in., length..................in., area..............sq. in.
Concrete: Proportions {by vol.......... by wt.......... Kind of aggregate.................................... Characteristics of specimen..................................
Storage.. Manner of testing..................................

Form E is the log sheet upon which the micrometer readings in tests of modulus of elasticity are recorded, and Form F is used at the time of molding the test pieces. A record is made in the batch report of the basis upon which the proportioning was done, whether by volume, maximum density, or percentage of voids.

Form E. { UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. } LOG SHEET.

Station.. Approved..
No........... Date..........................
Observers.. Calculators..

Applied load.			Total deformation.		Average of A and B.	Unit deformation.	Unit stress per square inch.	Remarks.
	A	B	A	B				
						Inches.	*Pounds.*	
....	....	....	....	....	....	....	....	
....	....	....	....	....	....	....	....	

Form F. { UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. } BATCH REPORT.

Station.. Approved..
Batch No.......... Date mixed.............. Manner of mixing..
Proportions (a) by weight........................ (b) by loose volume..

Material.	Reg. No.	Weight (pounds).			Per cent.
		Actual.	Per cubic foot.		
Cement..........	....	....	....	Water in terms of dry materials........	....
Sand..........	....	....	....	Moisture in sand........	....
Stone..........	....	....	....	Moisture in stone........	....
....	....	....	....	Moisture in gravel........	....
				Moisture in cinders........	....
Water..........	....	....	....	Time of adding water........	

Time of placing in molds...... Batch used in specimens No...... Corresponding reports No......
Remarks.—..

Computations.—The proportions by weight entered on the batch report are determined from the weight per cubic foot of the material and the weight of the moisture contained in it and correspond to the proportions by volume.

The percentage of water added in the mixer plus the percentage of moisture contained in the material is found in terms of the dry material.

Densities are calculated in the same way as for the sand mortar, except that in this case there are three ingredients instead of two.

The initial modulus of elasticity is determined from the slope of the tangent drawn at the origin of a curve whose abscissas are the average unit deformations obtained from the micrometer readings on either side of the cylinder and whose ordinates are the unit stresses.

Forms G, H, I, and J are used for recording the results of these physical tests.

Form G. { UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. } SAND REPORT.

Station.................................... Approved ....

	Granulometric analysis.
Reg. No........ Kind of sand...... Specific gravity......	Weight analyzed........grams.
Weight per cubic foot {(a) Loose and moist............pounds.	Retained on sieve— Per cent.
(b) Loose and dried............pounds.	No. 10 (wire......)...............
Shape of grains	20 (wire......)...............
Voids {(a) Passing $\frac{1}{4}$-in. sieve.......................per cent.	30 (wire......)...............
(b) Screened to...........size.................per cent.	40 (wire......)...............
Moisture by weight in terms of dry material ....per cent.	50 (wire......)...............
Amount and character of silt....................................	80 (wire......)...............
	100 (wire......)...............
Yield { Volume of mortar / Volume of sand = ... Reg. No. of silt............	200 (wire......)...............
	Passing sieve No. 200...............

Remarks.—..

Form H. { UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. } STONE REPORT.

	Granulometric analysis:
Station...................... Approved........................	Weight analyzed.........pounds.
Reg. No............ Kind of stone...... Specific gravity.......	Retained on screen— Per cent.
General shape of pieces..	2-inch................ ......
Weight per cubic foot: Pounds.	$1\frac{3}{4}$-inch................ ......
(a) Crusher run....................................	$1\frac{1}{2}$-inch................ ......
(b) Solid and dry....................................	$1\frac{1}{4}$-inch................ ......
(c) Passing $\frac{1}{4}$-inch sieve....................................	1-inch................ ......
Voids: Per cent.	$\frac{3}{4}$-inch................ ......
(a) Crusher run....................................	$\frac{1}{2}$-inch................ ......
(b) Passing $\frac{1}{4}$-inch sieve....................................	$\frac{1}{4}$-inch................ ......
(c) Screened to..............size....................	Passing $\frac{1}{4}$-inch screen..... ......
Yield { Volume of mortar / Volume of screenings =....................................	Retained on sieve—
Absorption:	No. 10................ ......
(a) Crushed material {24 hours........................	20................ ......
48 hours........................	30................ ......
(b) Solid material {24 hours........................	40................ ......
48 hours........................	50................ ......
Moisture....................................	80................ ......
Compressive strength of....inch cube cylinder....pounds per	100................ ......
square inch.	200................ ......
Silt: Reg. No.......... Amount......... Kind........	Passing No. 200 sieve ....

Remarks.- ....

Form I. UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. SPECIFIC GRAVITY AND ABSORPTION REPORT.

Operator............ Date......... Reg. No....... Field No....... Test No....... Flask marks.....

	Grams.		Grams.
Weight of water, screenings, and specific gravity flask	....	Weight of pan and thoroughly dried screenings	....
Weight of screenings and specific gravity flask	....	Weight of pan	....
Weight of specific gravity flask	....	Weight of water absorbed	....
Weight of water	....	Weight of dry screenings in pan	....
Weight of screenings in flask	....	Water absorbed per gram of screenings	....
Weight of pan and air-dried screenings	....	Total weight of water absorbed by screenings in flask	....

Reading of water level: Temperature............; 15° C....................; Corrected for calibration.; Corrected for absorption.

Volume of screenings..............................

Specific gravity $\left\{\frac{\text{Weight of screenings}}{\text{Volume of screenings}}\right.$ = ...

Water admitted..............................

Reading taken..............................

Form J. UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. VOIDS REPORT.

Operator .... Date.......... Reg. No. .... Field No. .... Test No. ....

Weight of void can plus material plus water	....	Weight of water (W)	....
Weight of void can plus material	....	Volume of void can	....
Weight of void can	....	Moisture per pound of material (m)	....
Weight of material (M)	....	Absorption per pound of material (a)	....

Effective weight of material = M (1 − m) = ...

Weight per cubic foot of material $= \frac{\text{Effective weight of material}}{\text{Volume of void can}} =$ ....

Effective weight of water, W − a M = ...

Percentage of voids $= \frac{\text{Effective weight of water}}{62.355 \times \text{volume of void can}} =$ ....

Computed voids: Volume $= \frac{\text{Weight per cubic foot}}{\text{Specific gravity} \times 62.355} =$ ....

Percentage of voids = 1 − volume ....

Time elapsed in charging void can: With material ....; With water ....

Approximate voids, ignoring absorption.............................. ....

Moisture:		Absorption:	
Weight of pan	....	Weight of pan	....
Weight of pan and material	....	Weight of pan and material	....

TESTS OF STONE.

Apparatus.—The large blocks of stone sent in by the field geologist, having been roughly dressed by hammer and chisel, are sawed into cubes by the gang saw (Pl. XI, *C*, p. 50) and finally ground to exactly 2 inches on an edge by rapidly revolving horizontal cast-iron disks about 18 inches in diameter.

Methods.—The position in which the blocks were bedded in the quarry is indicated on the stone by the collector and this mark is transferred to the finished cubes. Half of the cubes sawed out of the blocks are then crushed with the bedding plane perpendicular and the other half with it parallel to the direction of application of the load.

Previous to the strength tests the cubes are placed in a pan containing one-half inch of water, and their increase in weight measured at the end of twenty-four hours. The water is permitted to flow gently through the pan and is maintained at a constant level by an outlet placed one-half inch above the bottom of the pan. From these data the percentage of absorption is obtained. The weight per cubic foot and the specific gravity are also determined.

BEAM SECTION.

OUTLINE OF INVESTIGATIONS.

NATURE OF THE WORK.

The principal work in the beam section consists in the making and testing of plain and reinforced concrete beams. The beams are made of different consistencies, different aggregates, and, in the case of the reinforced beams, of different percentages of steel; the beams are tested at different ages. In addition to making and testing beams, the beam section also makes and tests cylinders and cubes formed of concrete like that used in the beams. Each rod used in the reinforced beams is tested in the beam section and all the materials that are used in the concrete are tested in the constituent-materials section. This gives a complete report of all the properties of the material used and makes it possible to study the effect of different properties on the strength of concrete beams.

The first schedule of tests (now under way) in the beam section is given in the accompanying table (p. 38). All the beams, cylinders, cubes, and bond test pieces outlined in this table have been made, and some of the 360-day test pieces have been tested.

Outline of first three series of beam tests.

Series.	Concrete.				Number of test pieces.				Round bars of mild steel 33,000.				Variables.
	Mortar.		Aggregate.	Consistency.	Beams.	Cylinders.	Cubes.	Bond.	Per cent.	Diameter (inches).	Number of bars.		
	1.	2.	4.								In beam.	Tested.	
1.	Standard cement.	Meramec River sand.	Granite.	Very wet.	12	12	12	.....	.....	.....	.....	.....	Aggregate and consistency.
			Limestone.		12	12	12	.....	.....	.....	.....	.....	
			Gravel.		12	12	12	.....	.....	.....	.....	.....	
			Cinders.		12	12	12	.....	.....	.....	.....	.....	
			Granite.	Medium.	12	24	24	.....	.....	.....	.....	.....	
			Limestone.		12	24	24	.....	.....	.....	.....	.....	
			Gravel.		12	24	24	.....	.....	.....	.....	.....	
			Cinders.		12	24	24	.....	.....	.....	.....	.....	
			Granite.	Dry.	12	12	12	.....	.....	.....	.....	.....	
			Limestone.		12	12	12	.....	.....	.....	.....	.....	
			Gravel.		12	12	12	.....	.....	.....	.....	.....	
			Cinders.		12	12	12	.....	.....	.....	.....	.....	
Total					144	192	192	.....	.....	.....	.....	.....	
A.[a]	Standard cement.	Meramec River sand.	Granite.	3 consistencies for each aggregate.	.....	36	.....	.....	.....	.....	.....	.....	Aggregate. Consistency. Proportion.
			Limestone.		.....	36	.....	.....	.....	.....	.....	.....	
			Gravel.		.....	36	.....	.....	.....	.....	.....	.....	
			Cinders.		.....	36	.....	.....	.....	.....	.....	.....	
Total					.....	144	.....	.....	.....	.....	.....	.....	
2.	Standard cement.	Meramec River sand.	One set each with gravel, limestone, granite, and cinders.	Medium.	48	48	48	One set of 12 for each aggregate.	0.49	½	2	96	Aggregate and percentage of steel.
					48	48	48		.74	½	3	144	
					48	48	48		.98	½	4	192	
					48	48	48		1.24	½	5	240	
					48	48	48		1.47	½	6	288	
					48	48	48		1.72	½	7	336	
					48	48	48		1.96	½	8	384	
Total					336	336	336	48	.....	.....	.....	1,680	
3.	Standard cement.	Meramec River sand.	Limestone.	Medium.	12	12	12	One set of 12 for each size of bar.	0.49	¼	8	96	Percentage and diameter of steel.
					12	12	12		.98	¼	16	192	
					12	12	12		1.10	¾	2	24	
					12	12	12		.98	1	1	12	
					12	12	12		1.65	¾	3	36	
					12	12	12		1.53	1¼	1	12	
					12	12	12		2.21	¾	4	48	
					12	12	12		1.96	1	2	24	
Total					96	96	96	48	.....	.....	.....	444	
Grand total					576	768	768	96	.....	.....	.....	2,124	

[a] Theoretical proportions.

Remarks.—Three test pieces identical in composition to be tested at each of the following ages: 30, 90, 180, and 360 days. Three cylinders of each aggregate, theoretically proportioned, to be tested at each of above ages. Three cylinders and three cubes of each aggregate for medium consistency to be tested at each of above ages. Mild steel.—One coupon to be tested from each bar.

The above outline of the first three series covers the following parts of the general programme (pp. 16–19): Section III.—B, items 2 and 5; C, item 1. Section IV.—A, items 1, 2, and 3.

The proposed schedule of beam tests is given in the table on pages 40–47.

This schedule is only tentative, the object of these tests being to determine the maximum strength of a beam—that is, to determine the amount and character of reinforcement necessary to cause failure by compression in the upper fibers. Many of these tests have been arranged on assumptions which may not be true and which may therefore necessitate a change in the series.

Beam schedule

Series.	Tests.		Concrete.[a]		Beams (all 8 inches wide and 11 inches deep, except as noted — series 11 and 22).		Number of test pieces.			
							Bond pieces—		Beams and cylinders—	
	Number (3 for each age).	Age in days.	Aggregate, 1 set each with—	Proportions.	Span (feet).	Depth to lower layer of steel.	For series.	Of each.	Of each for series.	Of each.
4	9	2 7 14	Gravel, granite, cinders, limestone.	1:2:4	12	10	....	b 9	......	36 36 36
Total							36	....	108	......
				1:1½:3	......	......	......	......	......	12 12 12
5	6	28 91	Gravel, limestone	1:3:6	12	10	....	c 6	......	12 12 12
				1:4:8	......	......	......	......	......	12 12 12
Total							36	....	108	......
6	6	28 91	Gravel, limestone	1:2:4	12	10	....	b 6	......	12 12 12
Total							12	....	36	......
				One set each with 1:2:4 and 1:3:6.	6	......	......	......	......	24 24 24
7	6	28 91	Gravel, limestone		8	10	....	c 6	......	24 24 24
					10	......	......	......	......	24 24 24
Total							24	....	216	......

[a] All mortar to be of standard cement and Meramec River sand, and of medium consistency except in the case of 12 out of the 18 cylinders and plain beams of series 20. Six of these 12 for each shape are to be of "dry" consistency, and the others "wet."

proposed for 1907.

Steel.						Reinforcement.		Variables.	Remarks.
		Number of bars.							
Size (inches).	Per cent.	In beam.	Tested.	Elastic limit (thousands).	Kind of bar.	Rods.	Stirrups.		
½	0.98	4	144	35 to 40	Round....	....	....	Age; aggregate; per cent.	
½	1.47	6	216						
½	1.96	8	288						
.....	.....	...	648	....	....	....	....	....	
1	1.95	2	24	35 to 40	Round....	....	....	Age; aggregate; per cent.	The percentage of reinforcement given in this series is only tentative. The expectation is that with one of these percentages for each proportion the compressive strength of the concrete will be developed if it can be done for this span, without diagonal reinforcement.
1	2.94	3	36						
1	3.92	4	48						
1	1.95	2	24						
1	2.94	3	36						
1	3.92	4	48						
1	1.95	2	24						
1	2.94	3	36						
1	3.92	4	48						
.....	.....	...	324	....	....	....	....	....	
1	1.95	2	24	65 to 75	Round....	....	....	Age; aggregate; per cent.	
1	2.94	3	36						
1	3.92	4	48						
.....	.....	...	108	....	....	....	....	....	
1	0.97	1	24	35 to 40	Round....	....	....	Age; span; aggregate; per cent.	One percentage to be computed for each span to develop the bond resistance of the concrete; one percentage to be taken above and one below this computed percentage in order to fix this point more definitely.
1	1.95	2	48						
1	2.94	3	72						
1	0.97	1	24						
1	1.95	2	48						
1	2.94	3	72						
1	0.97	1	24						
1	1.95	2	48						
1	2.94	3	72						
.....	.....	...	432	....	....	....	....	....	

b For each aggregate.
c For each aggregate and each proportion.

Beam schedule proposed

Series.	Tests.		Concrete.		Beams (all 8 inches wide and 11 inches deep, except as noted in series 11 and 22).		Number of test pieces.			
	Number (3 for each age).	Age in days.	Aggregate, 1 set each with—	Proportions.	Span (feet).	Depth to lower layer of steel.	Bond pieces— For series.	Bond pieces— Of each.	Beams and cylinders— Of each for series.	Beams and cylinders— Of each.
8	6	28 91	Gravel, limestone	1:2:4	6	10	....	*a* 6	.....	12 12 12 12 12 12 12 12 12 12 12 12 12 12 12
Total	.....	.....	.....	.....	.....	.....	....	....	180	.....
9	3	28	Gravel, limestone	1:2:4	6	10	....	*b* 3	.....	6 6 6 6 6 6 6 6 6 6 6 6
Total	.....	.....	.....	.....	.....	.....	24	....	72	.....
10	3	28	Gravel, limestone	1:2:4	6	10	....	6	.....	6
Total	.....	.....	.....	.....	.....	.....	6	....	6	.....
11	3	28	Gravel, limestone	1:2:4	12	20 22 18 20 22 18	....	*b* 3	.....	6 6 6 6 6 6
Total	.....	.....	.....	.....	.....	.....	12	....	36	.....

a For each aggregate and each size of rod.

for 1907—Continued.

Steel.						Reinforcement.		Variables.	Remarks.
Size (inches).	Per cent.	Number of bars. In beam.	Number of bars. Tested.	Elastic limit (thousands).	Kind of bar.	Rods.	Stirrups.		
Will depend on results of tests in series 7.				50 to 60	Round.	Bent up, as shown at *A* (fig. 2); at least 2 rods carried through.	None	Age; aggregate; per cent and method of reinforcement.	Fig. 2, to which reference is made under "Reinforcement," is on page 48.
						All carried through.	½-inch rod stirrups spaced uniformly, as shown at *A* and *B* (fig. 2), to points *a*, as follows: 6 in. 4 in. 6 in. 4 in.		
These columns can not be completed (see remarks).				50 to 60	Square deformed. Square twisted. Hexagonal twisted. Symmetrical deformed.	None	½-inch round; 6 inches or less apart.	Aggregate; kind and per cent of reinforcement.	Steel: 3 percentages below that which developed compression strength in series 8; the reduction to be in proportion to the elastic limit.
Per cent same as that which developed compressive strength in series 9.				50 to 60	Square deformed.	None	½-inch	Aggregate.	Square deformed stirrups 6 inches or less apart.
See remarks.				35 to 40	Round	Same per cent as in series 8.	½-inch	Aggregate; depth; kind and per cent of reinforcement.	Stirrups as in series 10. Same percentage of horizontal and diagonal reinforcement as 6-foot beam that failed by compression in series 10 for deformed and in series 8 for plain bars; depth fixed by $\frac{d}{L}$ for 6-foot beams; same area of steel for all depths.
				50 to 60	Deformed.	None.			

b For each aggregate and each kind of bar.

Beam schedule proposed

Series.	Tests.		Concrete.		Beams (all 8 inches wide and 11 inches deep, except as noted in series 11 and 22).		Number of test pieces.			
							Bond pieces—		Beams and cylinders—	
	Number (3 for each age).	Age in days.	Aggregate, 1 set each with—	Proportions.	Span (feet).	Depth to lower layer of steel.	For series.	Of each.	Of each for series.	Of each.
12	3	28	Limestone	1:2:4	12	10	....	a 3	......	3 3 3 3 3
Total	......	......	......	......	......	......	6	....	15	......
13	3	28	Limestone	1:2:4	6	10	....	3	......	3 3 3 3 3
Total	......	......	......	......	......	......	3	....	15	......
14	3	28	Limestone	1:2:4	12	10	....	3	......	3
Total	......	......	......	......	......	......	3	....	3	......
15	3	28	Limestone	1:2:4	12	10	....	3	......	3
Total	......	......	......	......	......	......	3	....	3	......
16	3	28	Limestone	1:2:4	12	10	....	3	......	3
Total	......	......	......	......	......	......	3	....	3	......
17	3	28	Limestone	1:2:4	6	10	....	3	......	3
Total	......	......	......	......	......	......	3	....	3	......
18	6	28 91	Gravel, limestone	1:2:4	12	10	....	b 6	......	12 12 12 12
Total	......	......	......	......	......	......	48	....	48	......
19	6	28 91	Gravel, limestone	1:2:4	6	10	....	b 6	......	12 12 12 12
Total	......	......	......	......	......	......	48	....	48	......

a For ½-inch rods; same for bottom rods.

for 1907—Continued.

Steel.						Reinforcement.		Variables.	Remarks.
Size (inches).	Per cent.	Number of bars. In beam.	Number of bars. Tested.	Elastic limit (thousands).	Kind of bar.	Rods.	Stirrups.		
Same as that which developed compressive strength in series 17.				50 to 60	See remarks.	Same as in series 11..		Kind of bar: Bottom, square; top, deformed. Reinforcement in compression side of beams, as shown at *C, D, E, F, G*, fig. 2 (p. 48).	
See remarks.				50 to 60	Round....	Method of anchoring rods as shown at *H*, fig. 2 (p. 48). Per cent of reinforcement the lowest that caused failure in compression for deformed bars having high elastic limit concentrated in few bars in series 10.			
½	1.96	8	24	35 to 40	Round....	Deformation as shown at *J*, fig. 2 (p. 48).			
½	1.96	8	24	35 to 40	Round....	To destroy tensile stress in concrete, insert pieces of oiled tin at 4-inch intervals as shown at *K*, fig. 2 (p. 48).			
½	98	4	12	35 to 40	Round....	Variable: Effect of arching concrete and anchoring rods, as shown at *L*, fig. 2 (p. 48).			
Per cent same as that which developed compressive strength in series 8.				50 to 60	Round....	Diagonal rods as at *b* in *M*, fig. 2 (p. 48); angle of bend in rods variable. Spacing of ½-inch stirrups same as for maximum strength in series 8.			
½ 2 x ¼ 1¼ x 3/16 ¾	1.25 1.25 1.17 1.41	4 2 4 2	48 24 48 24	35 to 40	Square.... Flat...... ....do.... Square....	....	....	Age; aggregate; kind of reinforcement.	Test of flats and squares, two sizes each: Square, ½-inch and ¾-inch; flat, 1¼ by 3/16-inch and 2 by ¼-inch.
½ 2 x ¼ 1¼ x 3/16 ¾	1.25 1.25 1.17 1.41	4 2 4 2	48 24 48 24	35 to 40	Square.... Flat...... ....do.... Square....	....	....	Age; aggregate; kind of reinforcement.	Do.

b For each aggregate and each size of rod.

Beam schedule proposed

Series.	Tests.		Concrete.		Beams (all 8 inches wide and 11 inches deep, except as noted in series 11 and 22).		Number of test pieces.			
							Bond pieces—		Beams and cylinders—	
	Number (3 for each age).	Age in days.	Aggregate, 1 set each with—	Proportions.	Span (feet).	Depth to lower layer of steel.	For series.	Of each.	Of each for series.	Of each.
20	6	28 91	Limestone	1:2:4	12	.....	.....	.....	.....	6 6 6
Total	.....	.....	.....	.....	.....	.....	.....	.....	18	.....
21	6	28 91	Gravel, limestone	1:2:4	12	.....	.....	a 6	.....	12 12 12
Total	.....	.....	.....	.....	.....	.....	36	.....	36	.....
22	3	28	Gravel, limestone	1:2:4	6	15 20 15 20	.....	b 3	.....	6 6 6 6
Total	.....	.....	.....	.....	.....	.....	18	.....	24	.....
Grand total	.....	.....	.....	.....	.....	.....	.....	.....	978	.....

a For each aggregate and each variation in method.

for 1907—Continued.

Steel.						Reinforcement.		Variables.	Remarks.
Size (inches).	Per cent.	Number of bars. In beam.	Number of bars. Tested.	Elastic limit (thousands).	Kind of bar.	Rods.	Stirrups.		
Plain beams...				....	....	....	....	Age; consistency.	To be made in wooden molds.
....				....	....	....	....	....	
Steel same as that which developed compressive strength in series 11. Age, aggregate, and method of molding and molds to be variable: (1) Wooden molds to be used under conditions of actual outside practice; (2) steel molds to be used under laboratory conditions, but uniform with (1) as to time; (3) steel molds to be used by outside workmen for comparison of workmanship.									
....				....	....			....	
Initial percentage of reinforcement same as in series 10.				50 to 60	Square deformed; see remarks.			Aggregate; depth per cent and number of rods in reinforcement.	½-inch stirrups spaced at 6 inches. First set of rods with number constant; second set per cent constant; diameter changing.
....				....	....			....	
....				....	....			....	

[b] For each aggregate and each size of rod.

MIXING.

Apparatus.—The concrete used in the beam section is mixed in a 1 cubic yard Chicago cube mixer (Pl. X, *B*). This mixer is equipped with a charging hopper (shown at the left of view) and is geared to a motor (shown at the right). When the concrete is thoroughly mixed the machine dumps it on the floor through the discharging end.

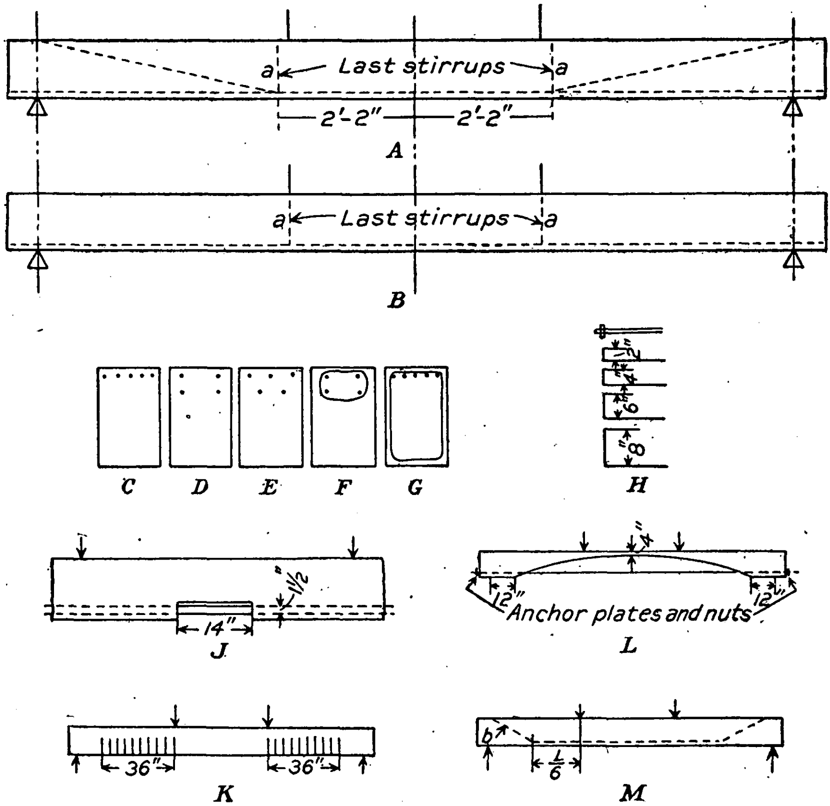
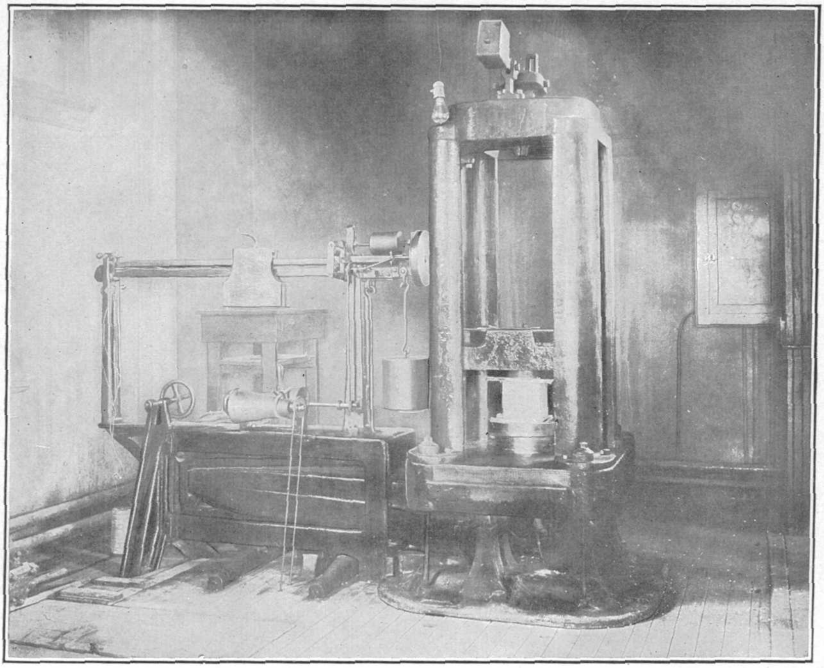
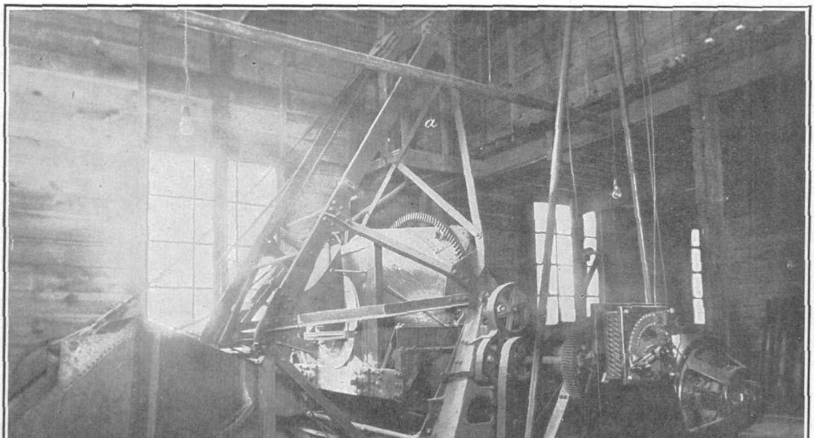


FIG. 2.—Diagrams showing details of reinforcement of beams (see tabular schedule, pp. 43, 45). *A*, Detail of bent-up rods (series 8); *B*, detail of spacing of stirrups (series 8); *C-G*, reinforcement of compressive side of beam—the spirals in *F* and *G* have a pitch of 4 inches (series 12); *H*, method of anchoring rods, whether with nut or bent up at end (series 13); *J*, direct measurements of deformation in steel (series 14); *K*, method of inserting pieces of oiled tin (series 15); *L*, detail of concrete arch and anchoring rods (series 16); *M*, angle of bend in rod (series 17).

Proportioning.—The proportions of ingredients entering into the concrete are referred to by volume of the loose, dry material. A record is also made of the proportions by weight. The weight per cubic foot of the dry material is determined in the constituent-materials section. Tests are made each morning to determine the correction which must be made in the weights of the material used during the day on account of the contained moisture. The weight of cement is assumed at 100 pounds per cubic foot.



A. 200,000-POUND COMPRESSION MACHINE.



B. CONCRETE MIXER, CHARGING END. CAPACITY, 1 CUBIC YARD.

a, Scales for weighing water.

The ingredients are weighed in wheelbarrows on a platform scale situated between the material bins and the mixer. The water is weighed in a barrel on scales and supplied to the mixer in the same manner as previously described for the constituent-materials section (p. 32). Three different consistencies of concrete are used. The percentage of water required to bring each combination of aggregates to the three consistencies, stated as "wet," "medium," and "damp," described below, was determined by trial before the series was started. The percentage of water in terms of the dry material for each consistency and for each aggregate is kept constant throughout the series, but the actual amount of water added in the mixer varies from day to day with the varying percentage of moisture in the aggregates. The same form is used for the batch report as in the constituent-materials section. (Form F, p. 34.)

Wet concrete.—The concrete of "wet" consistency appears smooth and behaves like a viscous liquid in the mixer. It is carried with the mixer in the direction of motion but slides back from the ascending surface of the metal without being carried far enough over to drop back. This sliding causes the top surface of the lower part of the mass to work under to the bottom against the surface of the mixer. When "wet concrete" is dumped on the floor it stands in a very low pile, the sides assuming a slope of about 30° with the edge rounded against the floor. The mass has a smooth appearance, neither voids nor individual stones being visible. When deposited in the molds it is impossible to compact it by tamping, and it splashes under the rapid strokes of the pneumatic tamper. Water appears on the surface immediately upon being placed in the molds, and a finished beam is covered with from one-fourth to one-half inch of water.

Medium concrete.—Concrete of "medium" consistency appears almost as smooth as that of "wet" consistency but is more lumpy. As the mixer turns, the sliding action noticed with the "wet" consistency is accompanied by the dropping back of lumps from the ascending side of the cube. The lower edge of that portion of the material which slides does not turn smoothly under the body of the mass, as is the case with the "wet" consistency, but rolls in a more or less lumpy condition. When dumped on the floor the pile stands at a slope of about 45° and the surface is lumpy. No voids are apparent on the surface, and the individual stones stand out distinctly; a granular coating of sand mortar is visible on the surface of the aggregate. This concrete is also incompressible under the tamper, as the material rises on all sides of the instrument, but there is no splashing. No water collects on the top of the finished beam, but the surface is sleek and easy to finish with a trowel.

Damp concrete.—Concrete of "damp" consistency is decidedly granular in the mixer, and the tendency to lump is not so great as with the "medium" concrete. The material dropping from the top of the mixer falls mostly as individual stones and particles of mortar. While the material when dumped on the floor stands at the same angle as the "medium" concrete, it has a decidedly different appearance. It is granular, has large voids, and the mortar coating on each stone is clearly visible. No water shows at any point. The term "damp earth" applies well, at least to the mortar. When tamped the material offers considerable resistance.

The top of the finished beam is only damp, not enough water flushing to the surface to permit troweling except with difficulty.

Method.—When the desired weight of dry material has been ascertained, it is put into the mixer, which is turned two minutes before any water is added. The proper amount of water is then added and the batch is mixed for three minutes more. The mixer dumps the concrete on the floor, and the portion to be used in the beams is shoveled into wheelbarrows and wheeled to the molding room, about 50 feet away. The cylinders, cubes, and bond test pieces are molded in the mixing room, the concrete for these being shoveled directly into the molds from the floor. Two beams, two cylinders, and two cubes are molded from each batch.

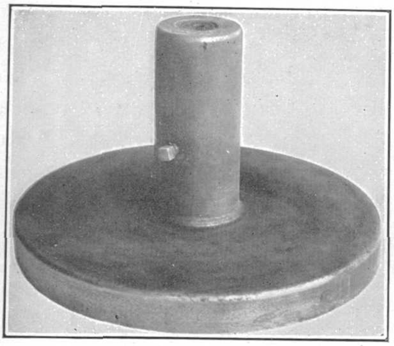
MOLDING.

The molds used for the cylinders and cubes are the same as those used in the constituent-materials section (Pl. VIII, *B*). The concrete cubes are 6 inches on a side, and the cylinders are 8 inches in diameter and 16 inches long.

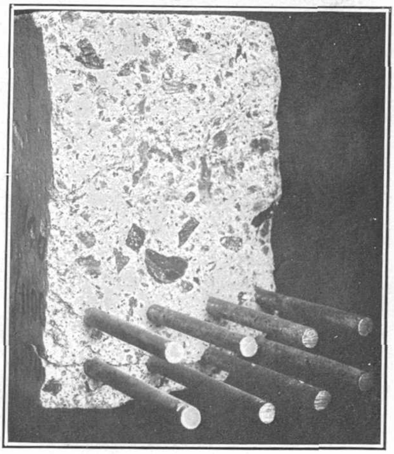
The bond test pieces are cylinders 8 inches in diameter and of varying length, the shorter lengths being used for small rods.

The bond test pieces are molded in cylinder molds in which are placed closely fitting cylindrical wooden blocks of sufficient thickness to make the test pieces the proper length when finished flush with the top of the mold. At the center of the top surface of the blocks is a socket about one-fourth inch deep, to receive the lower end of the rod, which is to be embedded in the cylinder. The machined casting shown in Pl. XI, *A*, is used to surface the top of the test piece and to make the rod perpendicular to the top of the test piece. The bore of the stem can be altered to accommodate different-sized rods by introducing brass bushings of various interior diameters.

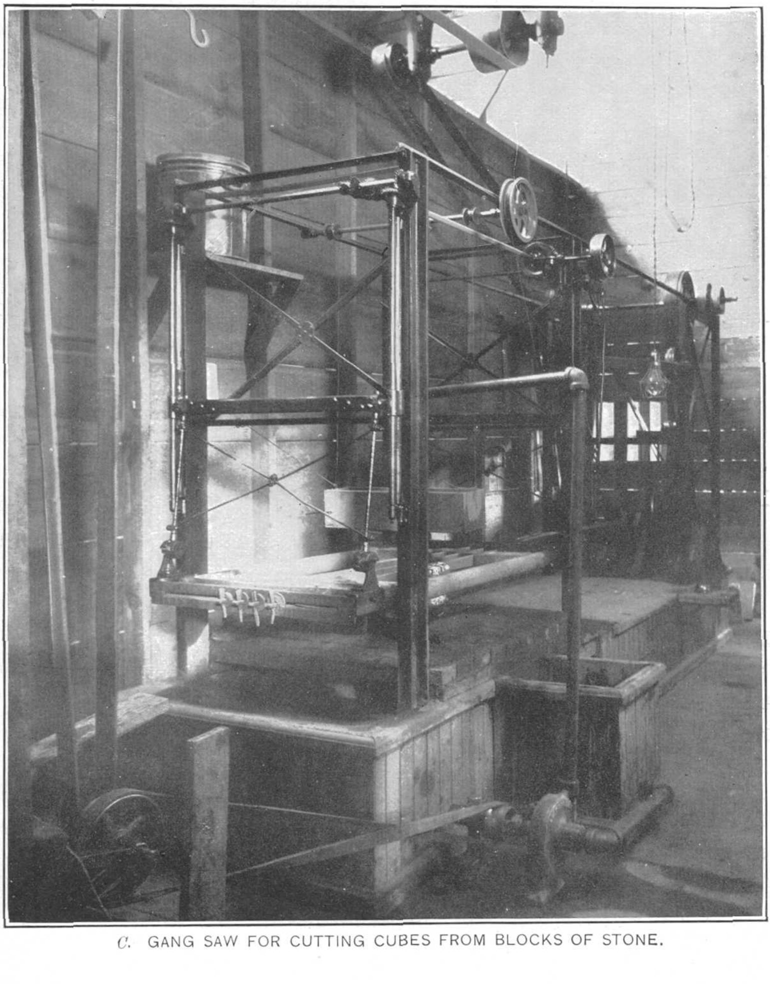
The thickness of the block used for each kind of concrete and size of rod is varied so that the length of embedment for each test piece will be such that the rod will be pulled out of the concrete before it is stressed to its elastic limit. The lower end of the rod is placed in the socket in the center of the wooden block and held in a vertical position



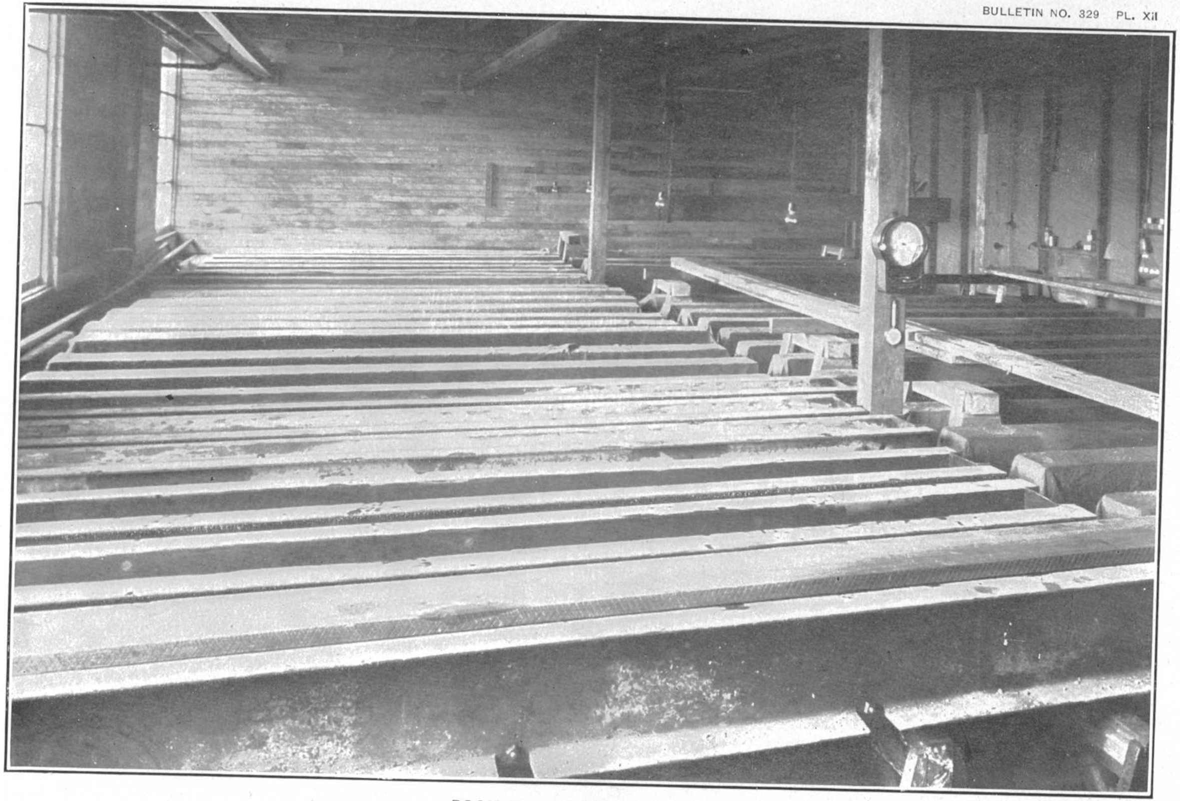
A. APPARATUS FOR FINISHING TOP OF BOND-TEST SPECIMENS.



B. BEAM SELECTED AT RANDOM TO SHOW ACCURACY OF ROD SPACING.



C. GANG SAW FOR CUTTING CUBES FROM BLOCKS OF STONE.



ROOM FOR MOLDING BEAMS.

Three empty molds in the foreground.

by hand while the concrete is tamped around it. The concrete is brought somewhat above the top of the mold; then the casting shown in Pl. XI, *A*, its surface having been oiled, is slipped down over the rod and twirled about on the surface of the concrete. After the concrete has set the casting is removed, leaving the upper surface of the test piece as a smooth plane perpendicular to the rod. The test pieces are stored in the moist room.

The molding room is shown in Pl. XII. Three empty molds used in forming the beams are shown in the foreground. Each mold makes a beam 8 inches wide, 11 inches deep, and 13 feet long, and consists of five sections of steel channel bolted together. The two side channels and the two pieces closing the ends are placed with their flanges outward. The channel forming the bottom is placed with its flanges turned down. At the points where the beams are supported in moving them the webs of the bottom channels are cut away for a width of $1\frac{9}{16}$ inches. When the beam is being molded this slot is closed by a filler. When the beam is ready to be moved this filler is driven out and a slightly narrower piece which projects $1\frac{1}{4}$ inches beyond each side of the beam is substituted. A stirrup hanging from the chain blocks is hooked under these projecting ends. When the concrete is ready to be placed in the molds their inside surfaces are coated with oil.

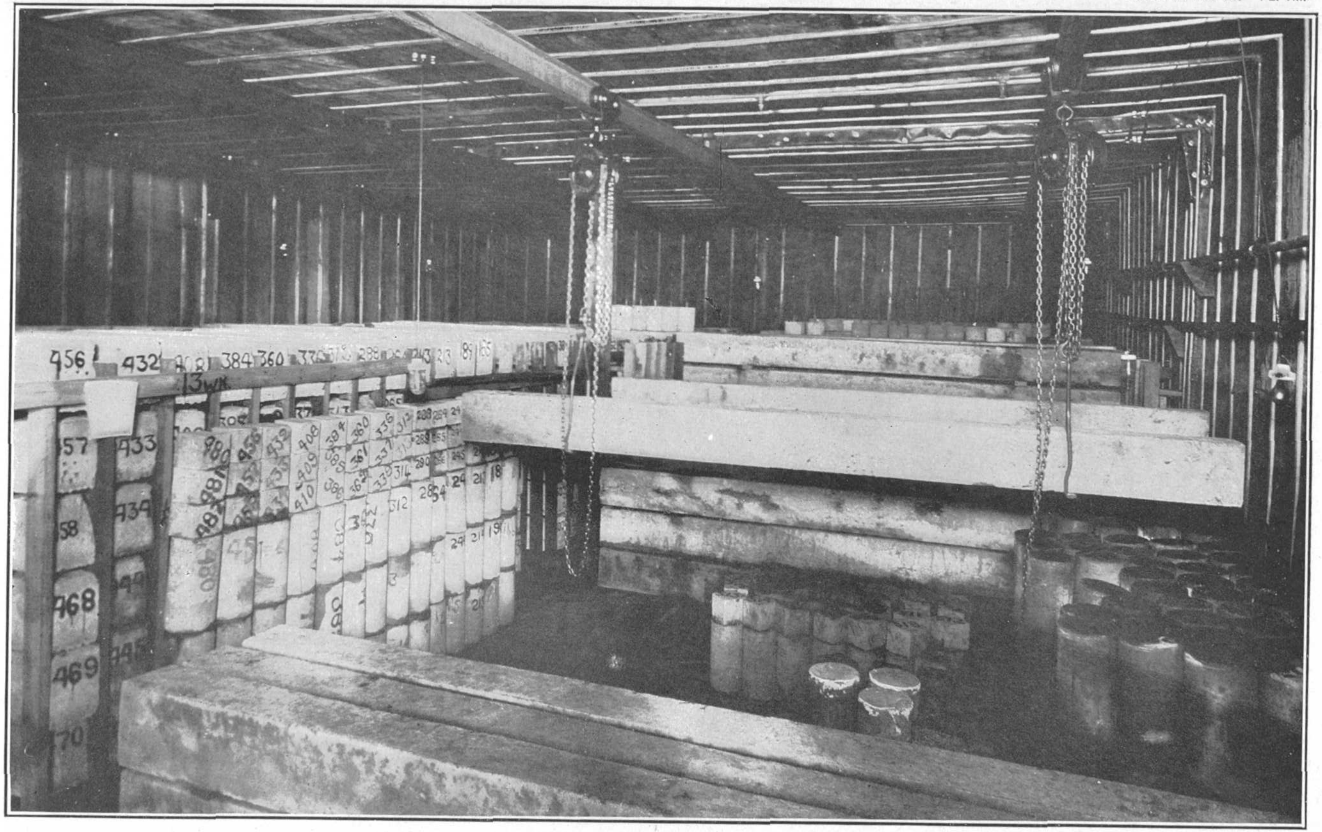
In molding the plain beams the concrete is deposited in three layers of approximately equal thickness and the layers are tamped by hand. Each layer is tamped three times with an iron tamper weighing $13\frac{3}{4}$ pounds and having a rectangular face, $1\frac{1}{4}$ by $3\frac{1}{2}$ inches. The following sequence of steps is strictly followed: Beginning at one end of one side of the beam the tamper is moved its own width at each stroke until it arrives at the opposite side. It is then moved forward and worked back across the beam. In this way every part of a layer, after the first tamping, has been struck once. This operation is then repeated. After each layer has been tamped twice the concrete is spaded back from the sides of the mold, the attempt being to reach down to the bottom at each spading. With the dry mix, however, it was found impossible to force the spade to the bottom after the top layer had been tamped. After each spading the layer is tamped a third time to force the concrete back against the sides of the mold. The tops of all beams are troweled to as smooth a surface as possible with a large bricklayer's trowel.

In molding reinforced-concrete beams two methods are used, depending upon whether the steel is placed in one or in two layers. All the reinforced beams are tamped with a pneumatic tool working under 60-pound pressure and having a 3-inch by $\frac{3}{4}$-inch rectangular head. The method of tamping described above for the plain beams is followed, except that each layer, after the first, is tamped but once before spading and once after. When the rods are in one layer their centers are placed 1 inch from the bottom, except for 1-inch and 1¼-inch rods, for which a distance of 1¼ inches was used. Sufficient concrete is placed in the bottom of the mold to bring the surface of the layer a little above the center of the rods. After this layer has been tamped twice the rods are laid upon it and held the proper distance apart and from the sides of the mold by slotted wooden templets. The rods are then tapped down into the concrete to the required depth; the distance down from the top being gaged by means of a T-shaped templet, the arms of which rest on the sides of the mold and the end of the leg on the rods. The concrete is then placed in three equal layers, tamped and spaded as described above, and the top troweled smooth. With those beams reinforced with two layers of rods the manner of placing the first layer of concrete and the bottom layer of rods is identical with that followed when there is but one layer of steel. When the lower rods have been placed a layer of concrete is added of such thickness that, when tamped, its surface comes about to the depth of the center of the upper layer of rods, which are placed 2½ inches from the bottom of the beam. This layer of rods is then placed in the same manner as the first layer. The concrete in the remainder of the beam is placed in three layers in the usual manner and the top troweled. The accuracy with which the rods are spaced may be seen in Pl. XI, *B*, which shows a beam selected at random and cut open after testing.

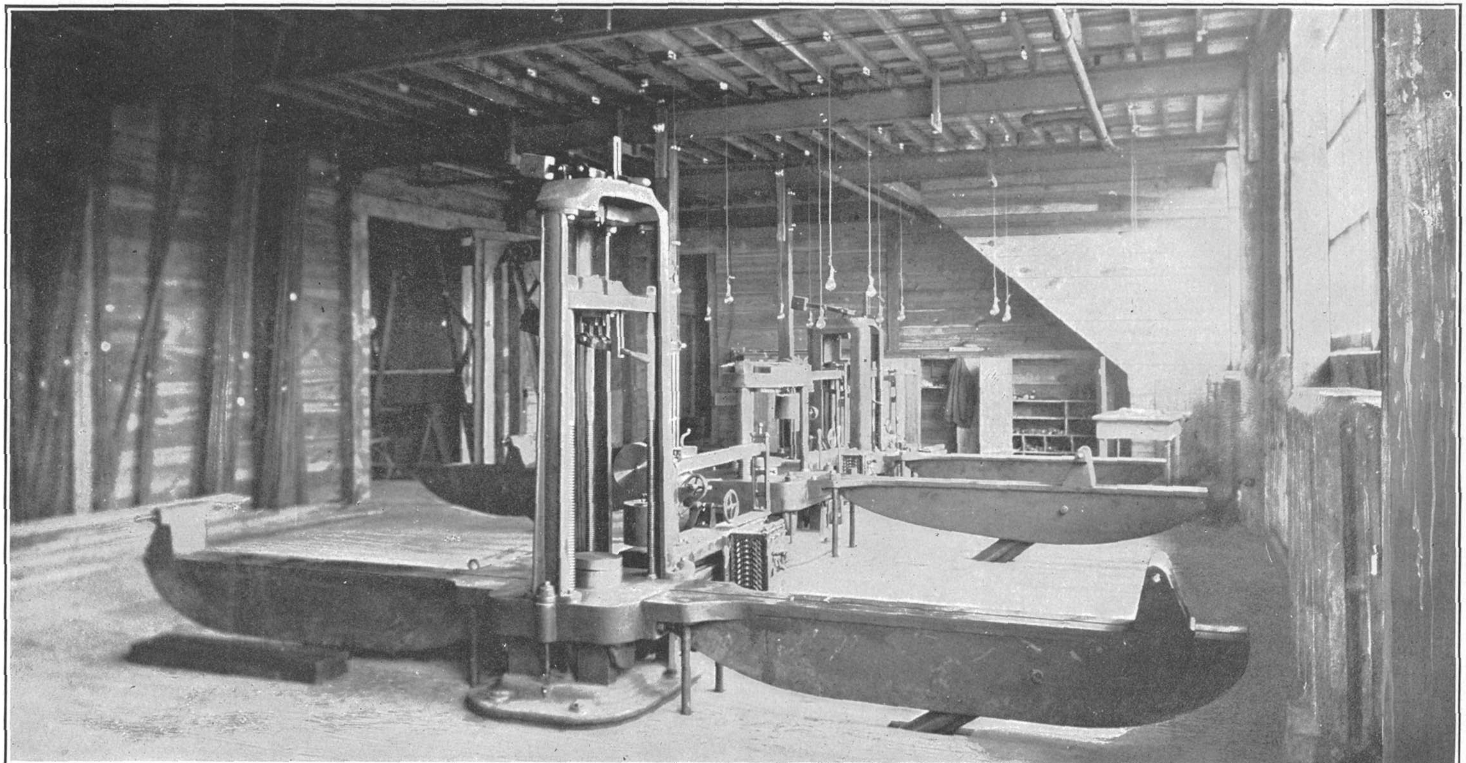
Three beams are molded in succession; the first three are molded on the floor and over these wooden horses are placed upon which to support another set of three beams. The molds are allowed to remain on the beams for twenty-four hours. The sides and ends are then removed for use in molding other beams. The beams remain on the bottom channels until lack of room on the molding floor makes it necessary to move them into the moist room. With the present accommodations the time that the beams are permitted to remain on the molding floor ranges from twelve to sixteen days. When the side channels are removed the beams are covered with burlap, which is kept wet by sprinkling with a hose at regular eight-hour intervals.

STORAGE.

When it becomes necessary to move the beams they are lifted from the bottom channels, as described, by means of hoists. The 4-wheeled trolleys run on the bottom flanges of I beams that traverse the ceilings of the molding and storage rooms. A smooth motion, free from jolting, is obtained by the use of Yale & Towne triple-chain blocks. The tracks are spaced such a distance apart that a



INTERIOR VIEW OF MOIST ROOM FOR STORAGE OF TEST PIECES.



INTERIOR VIEW OF TESTING ROOM, BEAM SECTION.

13-foot beam will be supported at those points which will cause a minimum bending moment.

An interior view of the moist room for storing beams, cylinders, cubes, and bond test pieces is shown in Pl. XIII. A 13-foot beam, supported by the trolleys, is shown at the right. The cylinders are piled three high with three cubes at the top. The beams are piled six high and the piles are prevented from toppling over by the wooden racks shown at the left. Each beam rests on two small timbers placed at the points that give the smallest bending moment. The register numbers of the test pieces may be seen. Either steam or water may be sprayed into the moist room from the ordinary type of fire sprinklers near the ceiling. At the present time water is sprinkled in fine spray over the test pieces at regular eight-hour intervals.

The waterproofing of this room for the purpose of making it steam tight was done without cost to the laboratories under the supervision of a representative of the Hydrex Felt and Engineering Company, through the courtesy of the manager, Mr. Edward De Knight.

Both the molding and storage rooms have self-registering thermometers giving a seven days' continuous record, and the moist room is equipped with a hygroscope for determining the percentage of moisture in the air.

Each day the beams that are to be tested are raised by means of the chain hoists, moved out into the molding room, and placed upon two trestles or upon the floor, whence they are taken to the testing room.

BEAM TESTING.

APPARATUS.

The testing room is equipped with one 3-screw 100,000-pound testing machine, one 4-screw 200,000-pound testing machine, and one 3-screw 200,000-pound testing machine, as shown in Pl. XIV. A 600,000-pound machine for testing columns and large beams is being installed in this room. The machine ordinarily used for testing beams is shown in the center.

The beams are raised and carried to the testing machine by means of a steel carriage shown in Pl. XVI, *B*. The carriage is pushed along the floor end first over the extension arm of the testing machine and one end of the beam is lowered to a dolly and rolled into place on the testing table. The beams are tested on a 12-foot span. The load is applied to the beams at the third points; that is, 4 feet from the ends and 4 feet apart. The apparatus through which the load is transmitted to the beams at two points consists of a steel box girder 4 feet long by 6 inches deep, built of two 6-inch channels and a ½-inch by 8-inch cover plate, top and bottom.

The curved inner surface of the castings are somewhat more than semicylindrical, so that the rollers, while permitted to bear on the beam and turn freely with any motion of its upper surface, will remain in place when the steel girder is raised above the beam.

The load is transmitted from the machine head to the steel girder through a spherical bearing block (*a*, Pl. XV, *B*) from the girder to the beam through two cylindrical rollers (*b*), which bear upon steel blocks (*c*) bedded with plaster of Paris upon the top of the beam. The upper surfaces of these blocks are cylindrical surfaces whose axes are parallel to the length of the beam.

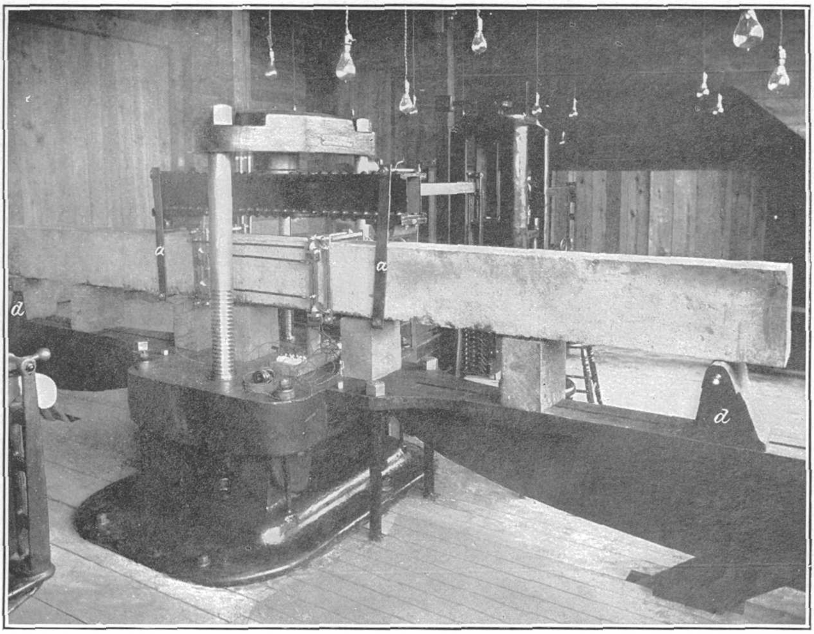
PLAIN-CONCRETE BEAMS.

The testing machine is balanced with the poise at zero before the beam is placed in the machine; when the beam has been placed on the supports, its weight is read on the scale beam and is recorded.

After the weight of the beam has been found, two sets of deformeters are placed on the beam, one having a gage length of 29¼ inches, with contact points 10 inches apart vertically, and the other a gage length of 24 inches, with contact points 5¾ inches apart vertically.

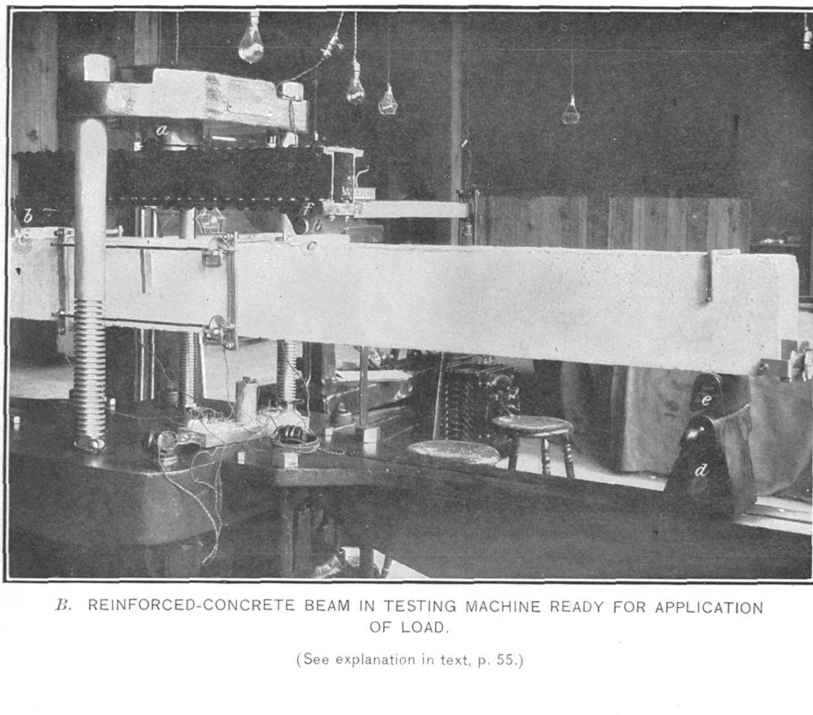
A plain-concrete beam in place in the testing machine, with its deformeters adjusted ready for testing, is shown in Pl. XV, *A*. The supports for the beams are shown at *d*, *d*. These blocks have cylindrical tops and have a slight outward motion, so that they may move outward to accommodate the lengthening at the bottom of the beam.

In several preliminary tests it was found that plain beams four weeks old failed under a total load but a few hundred pounds greater than their own weight, and therefore, if tested by the usual method of supporting them at their ends and applying two equal loads at the third points, but a few readings from which to interpret the test were obtained. On this account it was thought advisable to get a reading of the micrometers when the total deformations throughout the gage lengths are zero. A table was prepared showing the necessary amounts by which the reactions must be decreased for beams of different weights in order to make the total deformations throughout the gage lengths equal to zero. The uplift to decrease the reactions is applied at the third points of the beam by means of the stirrups marked *a* in Pl. XV, *A*. The head of the machine is raised so that the stirrups pull up on the beam until the support afforded the beam by the stirrups is sufficient to reduce the reactions at the ends of the 12-foot span to the value taken from the table. The micrometers are then read and the head of the machine is lowered until the beam rests freely on the 12-foot span, when the stirrups are removed and the micrometers on the deformeters are again read. The load is then applied through the box girder and readings of the micrometers



A. PLAIN-CONCRETE BEAM IN TESTING MACHINE, WITH DEFORMETERS IN PLACE AND STIRRUPS FOR SUPPORTING BEAM AT THIRD POINTS.

(See explanation in text, p. 54.)



B. REINFORCED-CONCRETE BEAM IN TESTING MACHINE READY FOR APPLICATION OF LOAD.

(See explanation in text, p. 55.)

are taken for every 200 to 1,000 pounds of applied load. This method is used in order to obtain a complete record of the deformations, since in this way it is possible to take readings from the point of zero deformations instead of only for the applied loads. Readings are taken up to the point of failure, blocks being so arranged under the beam, as shown in Pl. XV, A, that it can not drop more than one-half inch at failure, thus never endangering the deformeters.

After the beam breaks the larger of the two portions is tested on as great a span as its length will permit. The load is applied in the same way as with the long beams, the load points being each 2 feet from the center of the span. No attempt is made to suspend the beam for zero deformations, and only the outside set of deformeters is used. The beam deformeters are of two types; that shown in Pl. XV, *A*, attached to a beam, is of the electric contact type, the contact being noted by means of head-band telephone receivers; there is also another set used in which the indicator of the dial is moved by the movement of the rod.

In Pl. XV, *A*, the micrometers on the outside set of deformeters are shown at the right; those on the inside set are shown at the left. In some recent tests the inside deformeters have been omitted, their only use having been to confirm the theory of the conservation of plane sections.

The vertical deflections of unreinforced concrete beams are so slight that they are not recorded. Form K is used for recording the results of the tests of both full-length and short-length beams. The values entered are subsequently copied into tables for publication. All necessary computations for reducing the results to comparable figures are made by the computing division.

Form K. { UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. } TEST OF PLAIN BEAM.

Beam Reg. No. ...... Lab. No. ...... Length of beam, ... feet...... inches. Age, ... days. Gage length, ... inches. Contact points spaced .... inches apart. Weight of beam, ... pounds. Weight of corresponding ...... -foot beam, ... pounds. Cross section at center, ... inches wide by ...... inches deep; bd² .... Span, ... feet ...... inches. For character of concrete and corresponding test pieces see Batch report Bm ....

Deformeter No. .... Weight of deformeter, ... pounds. Load applied at ,...... Maximum applied load exclusive of weight of deformeters, ... pounds. Beam broke ...... feet ...... inches from center. Unit elongation of lower fiber for weight of beam and attachments ......; modulus of rupture, ...; distance of neutral axis from top, ... inches.

Beam brought from damp closet at ......; placed on supports at ......; test started at ......, time ......; test completed at ......; time ......; sheet given to office at ......, time ......; delay ......, due to ....

Remarks.—..

REINFORCED BEAMS.

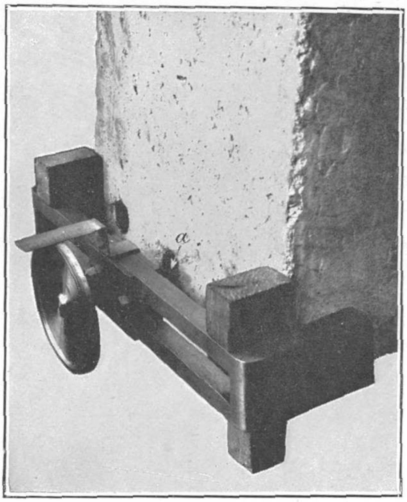
A reinforced-concrete beam in the testing machine ready for testing is shown in Pl. XV, *B*. The support shown at *d* is the same as that used for plain beams.

Addition of the part *e* gives a rocking motion perpendicular to the length of the beam. This insures an even distribution of the reaction over the width of the beam and also permits the lower part of the beam to elongate without restraint.

The test is started by supporting the beam at the third points to get zero deformations; only one set of deformeters is used. The gage length is 29¼ inches, and the lower contact point is 1 inch above the bottom of the beam, except when the reinforcing rods are 1 inch or 1¼ inches in diameter, when the lower contact points are 1¼ inches from the bottom of the beam. The upper contact points are one-half inch below the top of the beam in all cases.

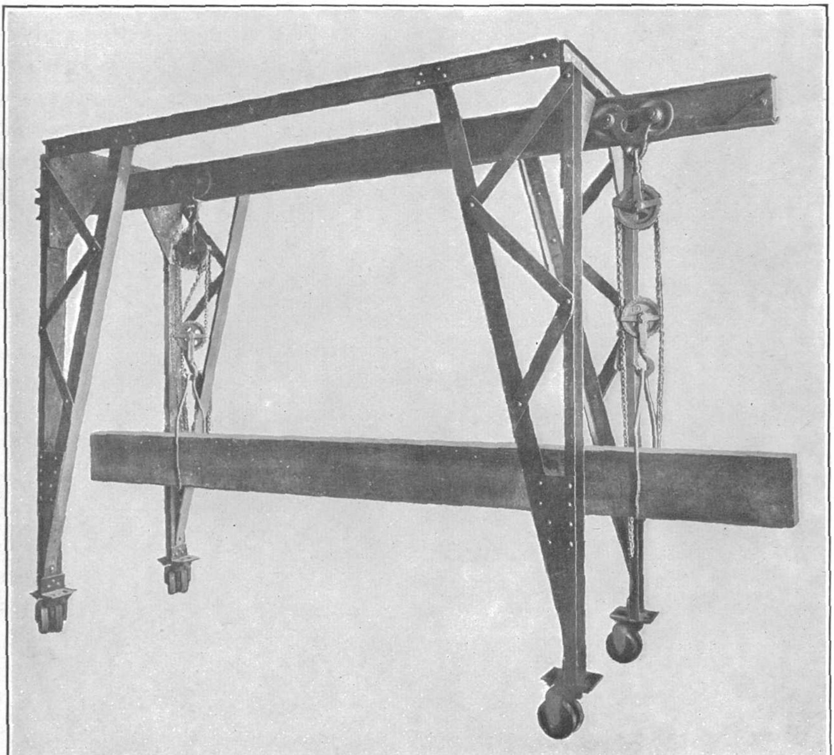
For the purpose of reading vertical deflections a steel piano wire is stretched tight from end to end of the beam and hangs from two clamps, being supported at each end by a projection near the bottom of the clamp directly over the supports. One of these clamps is shown in Pl. XV, *B*. Near the center of the span a steel scale is fastened to the side of the beam directly behind the piano wire, and the deflections are read on this scale. In order to avoid parallax a mirror is fastened beside the scale.

After readings are taken at zero total deformations in the gage length and when the beam rests under its own weight the load is applied in increments which vary with the amount of reinforcement in such a way that as large a number of points as possible is obtained where there is an abrupt change of direction of the load-deformation curve. The first three increments in all cases are 1,000 pounds, after which they are usually 500 pounds each up to a total load of about 7,000 pounds. Between these limits it has been found the cracking of the concrete brings about a sharp change in the direction of the curve. Increments of 1,000 pounds are used from about 7,000 pounds up to nearly the maximum, after which 500-pound increments are again used. Great care is taken to discover the first crack and to locate and trace all the cracks that appear throughout the test. Three men examine one surface of the beam very carefully with reading glasses after each 1,000-pound increment of load. The directions of the cracks and the highest points to which they reach before they become invisible through the reading glasses are marked with a pencil on the concrete and the applied load on the beam is marked at the top of each crack. When the test is completed these pencil marks and numbers are painted on the concrete and the beams are photographed in sets of three. These photographs, two of which are shown in Pl. XVII, *a*, *b*, form chronological charts of the development of the cracks, giving their position, shape, and extent for each load. With the 28-day-old beams this method was strictly followed for each individual beam, but when three beams identical in construction and 28 days old failed by tension in the steel, it was safe to assume that the corresponding older



A. ATTACHMENT AND MICROMETER FOR MEASURING SLIP OF RODS.

a, End of rod.



B. STEEL CARRIAGE FOR HANDLING BEAMS.

METHOD OF RECORDING CHARACTER OF REINFORCED-CONCRETE BEAM FAILURES.

a, *c*, Typical failures by steel reaching elastic limit; *b*, typical failure by diagonal tension and stripping of rods.

beams would fail in the same manner, since the gain in strength of the concrete rendered it less likely to fail. Consequently, when the older beams were tested, the cracks were marked out for the increments of 1,000 pounds for the first beam only of each set of three. The other two were tested to failure; at the maximum load the cracks were marked out as before. A group of three beams treated in this manner is shown in Pl. XVII, *c*, the bottom beam being the one first tested.

Slipping of the rods with reference to the adjacent concrete at the ends of the beam is determined by means of a micrometer reading to one ten-thousandth of an inch, shown at the extreme right end of the beam illustrated in Pls. XV, *B*, and XVI, *A*. The micrometer is clamped to the end of the beam, from which a small portion of concrete has been removed, exposing the end of one of the reinforcing rods. The micrometer screw is adjusted to touch the end of the exposed rod. No electric contact is used with the micrometer since the least slipping of the rods may be detected by touch. This same instrument is used to detect the slipping of the rods in the bond tests.

Form L is used for recording the results of the tests on reinforced concrete beams.

Form L. { UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. } REINFORCED BEAM TEST.

Beam Reg. No. .... Lab. No. .... Age ...... days. Gage length ...... inches. Contact points spaced ...... inches apart. Weight of beam ...... pounds. Length of beam ...... feet ...... inches. Span ...... feet ...... inches. Cross section at center ...... inches by ...... inches. Rods: Number........; size......; kind...... Reg. No. of steel...... For distribution of steel, see diagram No.... For information regarding concrete and corresponding test pieces, see Batch report Bm....

Deformeter No. .... Weight of deformeter ...... pounds. Load applied at .... Applied load at first observed crack ...... pounds. Position of crack ...... feet ...... inches from center. Maximum applied load ...... pounds. Position of failure crack ...... feet ...... inches from center. Development of cracks observed ...... Deflection of center .... Character of failure ....

Beam brought from damp closet at ......; test started at ......, time ......; test completed at ......, time ......; sheet given to office at ......, time ......; delay ......, due to......

COMPUTATIONS.

The forms of batch report for both the plain and reinforced beams (Form F, p. 40) are identical except that for the reinforced beams the number, size, position, and form of rods are also given. For these beams the percentage of reinforcement is computed and the yielding point of the steel is found from tests on short pieces cut from the reinforcing rods before being placed in the beams.

In order to make clear the methods used in obtaining some of these values a short statement of the theory will be given.

The method of finding the necessary decrease in the reactions in order that the total deformation within the gage length will be zero will be given first. This method is used in order to obtain a greater number of readings of the micrometers during the test and therefore more points on the deformation–bending moment curves.

When a beam rests freely on supports, the upper and lower fibers are deformed on account of the bending moment due to the weight of the beam. When the supports are at the ends of the beam, the upper fibers are shortened and the lower fibers are lengthened. For equal moduli of elasticity in tension and compression, which are constant for concrete for small loads, the deformation at any point of the beam is proportional to the bending moment at that point,

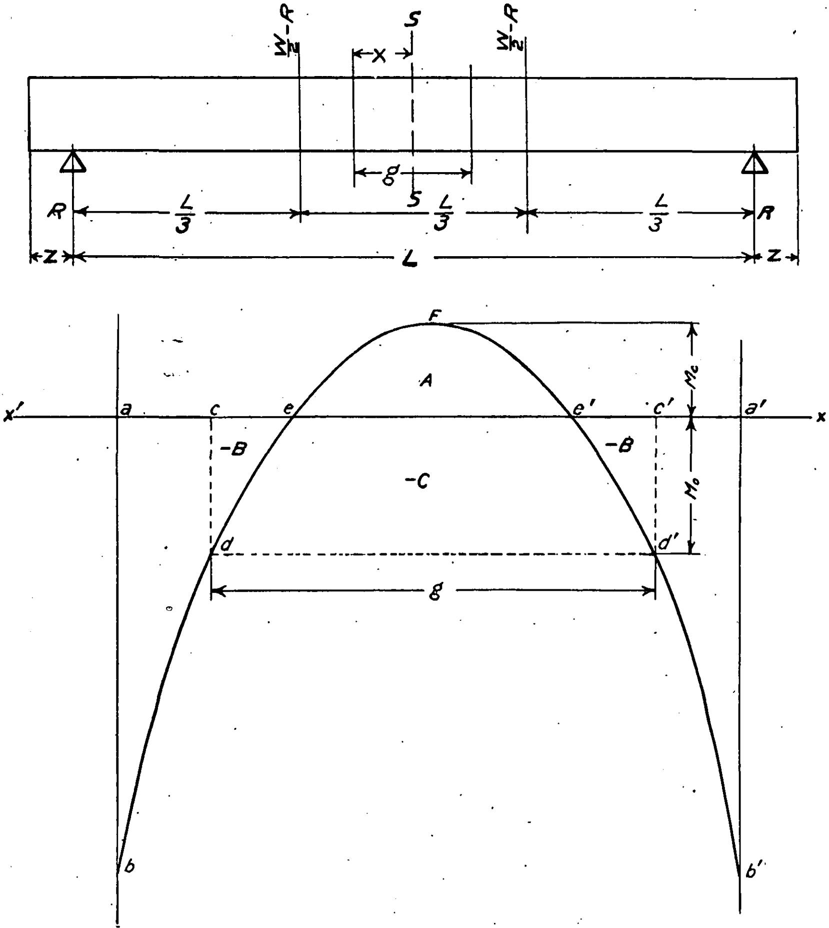


FIG. 3.—Diagrams illustrating method for computation of concrete beams. Upper diagram: Notation used. Lower diagram: Curve of bending moment within gage length (beam supported at third points).

and the total deformation over any length of the beam is proportional to the area of the bending-moment diagram over that length. Therefore when the total positive bending-moment area in the gage length of the deformeters equals the total negative bending-moment area in the gage length, the net total deformation in that length is zero, and both the upper and lower fibers of the beam have the same length as when unstressed. For a particular reaction at the ends of the beam the positive bending-moment area in the gage length is equal to the negative bending-moment area. In order to get this reaction, the beams are supported at the third points by stirrups suspended from the head of the machine. As the stirrups take more and more of the weight of the beam the end reactions become smaller and smaller and the character of the bending-moment diagram within the gage length changes until the desired condition is reached.

The method of finding the required reactions for total zero deformations within the gage length in terms of the weight of the beam and other known quantities (fig. 3) is as follows:

Let L = distance between the supports.

g = gage length of deformeters.

Z = overhang of beam at each end.

$\frac{L}{3}$ = distance from each support to force exerted by each stirrup.

W = total weight of beam.

$\frac{W}{2}-R$ = force exerted by each stirrup at a distance of $\frac{L}{3}$ from the supports.

R = each reaction at end.

SS = any vertical section within the gage length at a distance, X, from one of the gage points.

M_x = bending moment at section SS.

M_o = bending moment at deformeters, where $X=0$.

M_c = bending moment at center of beam, where $X=\frac{g}{2}$.

m = constant bending moment over the gage length due to the weight of all attachments, such as bearing blocks under the load points and the deformeters. This weight is applied outside of the gage length and equally on each side of the center of the beam.

The bending moment at section SS, considering forces to the left only, is as follows:

$$M_x=R\left(\frac{L}{2}-\frac{g}{2}+X\right)+\left(\frac{W}{2}-R\right)\left(\frac{L}{6}-\frac{g}{2}+X\right)-\frac{W}{2(L+2Z)}\left(\frac{L}{2}+Z-\frac{g}{2}+X\right)^2+m.$$

Reducing to a simpler form gives:

$$M_x=\frac{RL}{3}-\frac{W}{4}\left(\frac{L}{6}+Z\right)-\frac{W}{4\left(\frac{L}{2}+Z\right)}\left(\frac{g}{2}-X\right)^2+m.$$

The bending moment at the end of the gage length ($X=0$) is as follows:

$$M_o=\frac{RL}{3}-\frac{W}{4}\left(\frac{L}{6}+Z\right)-\frac{Wg^2}{16\left(\frac{L}{2}+Z\right)}+m.$$

The bending moment at the center of the gage length $\left(X=\frac{g}{2}\right)$ is as follows:

$$M_c=\frac{RL}{3}-\frac{W}{4}\left(\frac{L}{6}+Z\right)+m.$$

The moment diagram between the third points when there is both positive and negative bending moment in the gage length is shown in fig. 3, in which xx′ is the horizontal axis of the moment diagram. The curve d, e, e′, d′ is a parabola, and crosses the axis at two points, viz, at e and at e′, between the ends of the deformeters. Then in the gage length c c′ there is negative bending moment from c to e and from e′ to c′, and positive bending moment from e to e′. The dotted lines c d, c′ d′, and d d′ are drawn for the purpose of demonstration. Then the distance M_c represents the bending moment at the center of the gage length, and M_o represents the bending moment at the end of the gage length. The negative bending-moment areas within the gage length are c d e and c′ d′ e′, each being represented by $-B$. The positive bending moment area within the gage length is e F e′, and is represented by A.

The condition that the positive bending-moment area is equal to the negative bending-moment area is represented by the equation: $A=-2B$.

Adding the quantity $-C$ to both sides of the equation gives: $A+(-C)=-2B-C$.

The first part of this equation is the area included between the horizontal line d d′, and the parabola d F d′, that is:

$$A+(-C)=\frac{2}{3}g\left[M_c+(-M_o)\right]$$

The second part of the equation is equal to the area of the rectangle d c c′ d′, that is:

$$-2B-C=-g\,M_o.$$

Therefore $$\frac{2}{3}g\,[M_c+(-M_o)]=-gM_o.$$

Whence $2M_c=-M_o$.

Substituting the values of M_o and M_c as found above gives—

$$+\frac{2RL}{3}-\frac{2W}{4}\left(\frac{L}{6}+Z\right)+2m=-\frac{RL}{3}+\frac{W}{4}\left(\frac{L}{6}+Z\right)+\frac{Wg^2}{16\left(\frac{L}{2}+Z\right)}-m.$$

Whence $$RL=\frac{3W}{4}\left(\frac{L}{6}+Z\right)+\frac{Wg^2}{16\left(\frac{L}{2}+Z\right)}-3m$$

and $$R=\frac{3W}{4L}\left(\frac{L}{6}+Z\right)+\frac{Wg^2}{16L\left(\frac{L}{2}+Z\right)}-\frac{3m}{L}.$$

In almost all the beams tested at the laboratories L, Z, g, and m are constant.

It only remains to find W and to compute R. A table has been computed by the above formula for all the usual values of W, and the corresponding values of R in any case can be read directly from the table.

Form K (p. 55) is used for reporting the results of the tests on plain concrete beams.

The breaking load consists of the applied load together with the weight of the beam plus the deformeters. The total load is read directly from the scale arm of the machine when the beam fails, while the applied load is the total load less the weight of the beam and deformeters, which are found at the beginning of the test.

After the loads have been found the bending moment is computed and the value of the arbitrary term $\frac{M}{bd^2}$ is found for purposes of plotting. The term $\frac{M}{bd^2}$ at the center for the breaking load is obtained by the usual calculation, considering the weight of the beam between the supports and the 6-inch overhang at each end as a uniform load and considering the weight of the deformeters as two loads concentrated at the ends of the gage length.

The quantities recorded for unit elongation of the lower fiber for weight of beam, together with the weight of all attachments, are the micrometer readings (1) when the beam is partly suspended so as to cause zero total deformations in the gage length, and (2) when the beam rests under its own load plus that of the deformeters.

The computations involved are the subtraction of these two micrometer readings, the averaging of the differences obtained on opposite sides of the beam, and the correction of this average so that it will represent the elongation of the lower fiber instead of that of the fiber upon which the deformeter was clamped. This last computation is made upon the basis that the elongation varies uniformly as the distance from the neutral axis or upon the usual assumption of the conservation of plane sections. The reading of the two sets of deformeters verifies this assumption.

The unit deformation is then obtained by using the parabolic formula, except in cases where the bending moment due to the applied load is so great in comparison to that due to the weight of the beam that the error due to dividing by the gage length is less than the probable error in reading the deformeters. The correction by use of the parabolic formula is based upon the assumption that the total deformation of any fiber is proportional to the product of the bending moment and the length of the fiber, or, in other words, to the bending-moment area included in the length of the fiber. This is represented in fig. 4, in which M_g is the bending moment at the end

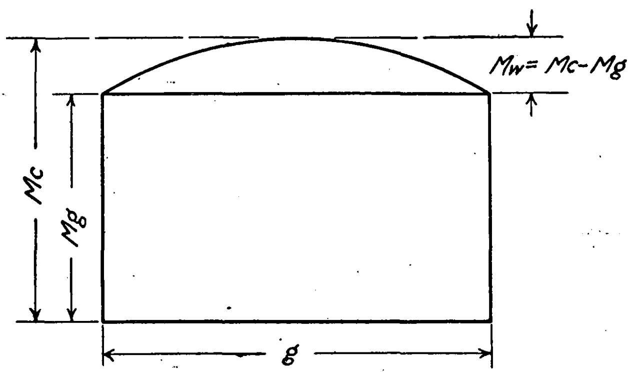


FIG. 4.—Diagram illustrating bending moment between gage points.

of the gage length and M_c is that at the center of the gage length, the difference being M_w. The area (A) in the diagram is equal to $A = g\ (M_g + \frac{2}{3} M_w)$. Dividing this area by the greatest M_c gives a new gage length which, were the bending moment constant over it and equal to M_c would give the same total deformation which was measured. Dividing this deformation by the new gage length gives the unit deformation where the bending moment is greatest. The final deformeter values are calculated from the load and the micrometer readings at the last full set of micrometer readings before the maximum load was reached.

The percentage of the distance of the neutral axis from the top of the beam is assumed to be equal to the deformation of the top fiber multiplied by 100 and divided by the sum of the top and bottom deformations.

The modulus of rupture is calculated by means of the formula $S = \frac{Mc}{I}$, the value of M at the center of the span being used.

The short sections of the plain beams are not suspended for zero deformations in the gage length, and therefore the deformations calculated for these are those due to the applied load only.

Form L (p. 57) is used for reporting the results of the tests of reinforced concrete beams.

The percentages of steel recorded in the batch report are given in terms of the section of concrete above a line drawn through the centers of the rods, the lower layer being taken when there is more than one layer.

The position of the neutral axis is calculated as in the plain beams, except that instead of using the deformation of the lower fiber, the deformation of the steel is used, thus obtaining the percentage of the depth below the top in terms of the distance from the top of the beam to the center of the lower layer of rods. The position of the neutral axis is calculated for several loads up to the maximum, and curves are drawn in order to show the variation in the position with the increase in the load.

The values under this general heading are obtained from the load, deformations, and deflections at the last full set of micrometer readings before the maximum load. After the location of the neutral axis has been found, the final deformeter values at the top of the beam are corrected so as to give the deformations at the extreme top. It should be noted that the lower micrometers are clamped directly over the steel, and therefore no correction of the micrometer readings is necessary to allow for the fact that the fiber whose elongation is required is not the fiber upon which the micrometers are clamped.

All the calculations made for the plain beams are repeated here except the one giving the modulus of rupture, for which a special formula must be used. The maximum values are obtained from the load, lower micrometer readings, and deflections when the beam has reached its maximum resistance, or from the last full set of deformeter readings before failure.

TESTS OF CYLINDERS AND CUBES.

Method.—A cylinder and a cube are made from the same batch of concrete from which each beam is molded, and all are tamped by hand with a tamper weighing 7 pounds and having a circular face $3\frac{1}{2}$ inches in diameter. The same molds (shown in Pl. VIII, *B*, p. 30) are used for these specimens as for those tested in the constituent-materials section. The method of testing is also the same (pp. 31–36). The compressometers for measuring the deformations of the cylinders are shown in Pl. IX, *C* (p. 32). The micrometers used on these compressometers measure directly to $\frac{1}{10000}$ inch. Form M is used for recording the results of tests.

Form M. { UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORY. } CYLINDER TEST.

Cylinder reg. No. .... Lab. No. .... Gage length, ... inches. Diameter, ... inches. Length, ... inches. Weight, ... pounds. Area, ... square inches. Volume, ... cubic inches; ...... cubic feet. Weight, ... pounds per cubic foot. Ultimate load, ... pounds. Ultimate strength, ... pounds per square inch. Initial coefficient of elasticity, ... Range of linear value, ... pounds per square inch. Probable ultimate unit deformation, ... Bedding in machine, ... For character of concrete and corresponding test piece see Batch report Bm ....

Cylinders and cubes brought from damp closet at ......; weighing, measuring, and capping finished at ......, time ......; test of cylinders started at ......; test of cylinders completed at ......, time ......; sheet handed to office at ......, time ......; delay, ..., due to ......

Remarks.—..

Computations.—The compressive strengths of the cubes and the cylinders are calculated in pounds per square inch. For the cylinders the modulus of elasticity is determined by drawing a curve showing the values at different loads. A tangent to the curve at or near its origin is assumed to represent the initial modulus of elasticity.

BOND TEST PIECES.

Method.—The schedule of bond tests is shown in the table on pages 40–47. A bond test piece in the machine ready for testing is shown in Pl. XVIII, *B*. The concrete cylinder is placed on top of the machine with the embedded rod projecting downward. The lower end of the rod is gripped in the jaws of the machine. The lower surface of the concrete cylinder is embedded in plaster of Paris on a ½-inch plate with a hole in its center one-sixteenth inch greater in diameter than the rod which passes through it. The instrument for measuring the slip of the rod is shown at the top of the test piece in the figure. During the test the micrometer and load are read at intervals of about 500 pounds until the slip of the rod amounts to about one-tenth inch. The load in all cases is applied continuously until failure. The bond pieces are tested at the ages of 30, 90, 180, and 360 days.

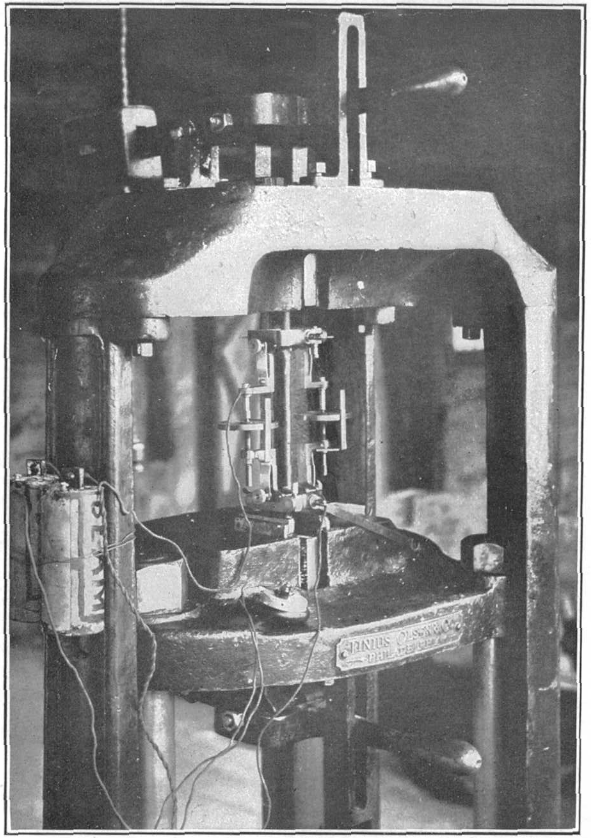
Computations.—Form N is used for recording results of the bond tests.

Form N. { UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. } BOND TEST.

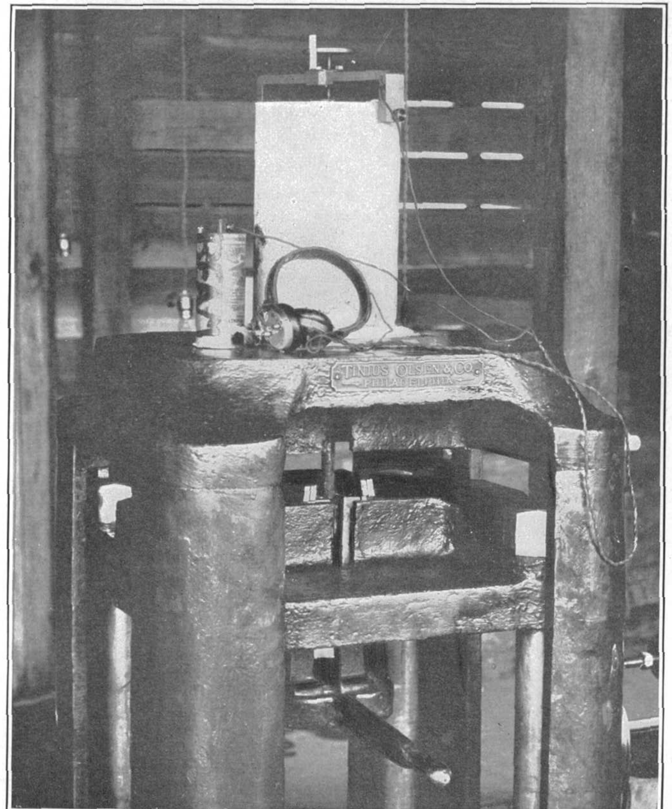
Bond reg. No. .... Lab. No. .... Diameter of embedded rod, ... inches. Embedded length of rod, ... inches. Embedded surface, ... square inches. Reg. No. of rod .... Elastic limit, ... pounds per square inch. Yield point, ... pounds per square inch. Load at first slip, ... pounds. Unit bond stress at first slip, ... pounds per square inch. Maximum load, ... pounds. Maximum unit bond stress, ... pounds per square inch. Unit stress in steel at first slip, ... pounds. Unit stress in steel at maximum load, ... pounds. Condition of surface of embedded steel, ... Condition of surface of steel when pulled from concrete, ... For character and proportions of concrete see Batch report Bm .... Bedding of test piece ....

Remarks.—..

The unit bond at any load is found by dividing the load by the surface area of the rod in contact with the concrete.



A. HENNING STEEL EXTENSOMETER FOR MEASURING ELONGATION OF STEEL.



B. METHOD OF MAKING BOND TEST.

Micrometer at top for measuring slip of rods.

TESTS OF STEEL.

Method.—As may be seen in the tables (pp. 38, 40–47), every rod used for reinforcement is tested. The tests include the determination of the yielding point as seen from the drop of the beam, the elastic limit obtained by the divider method, and the ultimate strength, elongation, reduction of area, and breaking strength. The elastic limit is determined on a gage length of 8 inches, one point of the dividers resting in a punch mark and the other marking on chalk rubbed on the surface of the test piece. The elongation is measured on the gage length of 8 inches. In addition to the above, the modulus of elasticity is determined on every tenth bar, using the Henning extensometer with electric contact. The percentage of carbon, phosphorus, and sulphur in every bar is determined in the chemical laboratory.

A view of the steel ready for testing is shown in Pl. XVIII, *A*.

Computations.—A record of steel tests is kept on a log sheet similar to Form E (p. 34). After the computations have been made the results are entered in Form O. The unit stresses at different loads are calculated by dividing the gross load by the area of the test piece.

The percentage elongation in 8 inches and the reduction of area at fracture are also calculated.

The modulus of elasticity is determined by dividing any unit stress below the elastic limit by the unit elongation at that stress. The elongations as obtained by the two micrometers on either side of the test piece are averaged and divided by the gage length to obtain the unit elongation.

Form O. { UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. } STEEL REPORT.

Station...... Reg. No...... Approved......

Kind of bar	......	Unit stress, pounds per square inch. (a) At elastic limit	......
Marks on bar and coupon	......	Unit stress, pounds per square inch. (b) At yield point	......
Dimensions, inches	......	Unit stress, pounds per square inch. (c) At maximum load	......
Area, square inches	......	Unit stress, pounds per square inch. (d) At breaking load	......
Cold bend test	......	Per cent elongation in 8 inches	......
Load in pounds. (a) At elastic limit	......	Diameter of neck in inches	......
Load in pounds. (b) At yield point	......	Per cent reduction in area	......
Load in pounds. (c) At maximum load	......	Character of fracture	......
Load in pounds. (d) At breaking load	......	Condition of surface	......

Remarks.—..........

SHEAR AND TENSION SECTION.

OUTLINE OF INVESTIGATIONS.

Shear.—A schedule of the tests on the strength of concrete in shear is given in the subjoined table (p. 67). The test pieces are cylinders 6 inches in diameter and 18 inches long. The molds are similar to those for making the regular compression cylinders, differing only in size. The testing apparatus is operated between the heads of the Universal testing machine, and the three cutting tools are arranged to shear out a section ranging from 12 to 2 inches in thickness. Only the top half of the 2-inch piece is used. The 4- and 6-inch pieces can be used with the bottom piece so as to incase the whole section. The object of these bottom pieces is to prevent any bending action in the test piece for the larger sizes. The results thus far obtained seem to indicate that this precaution is unnecessary. Pl. XIX, *A*, shows a

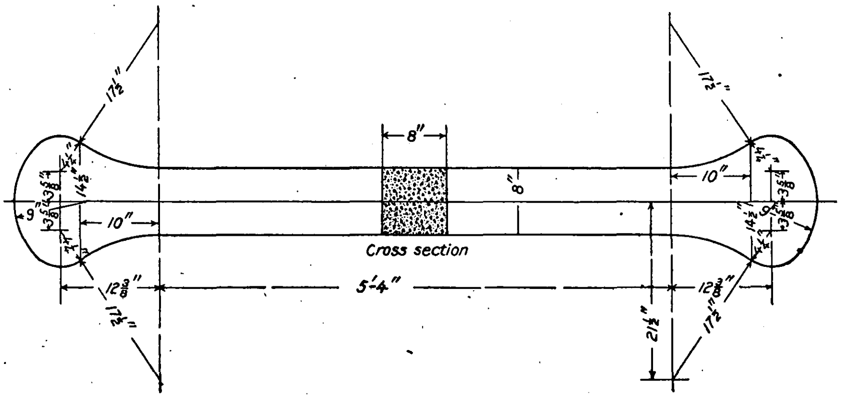
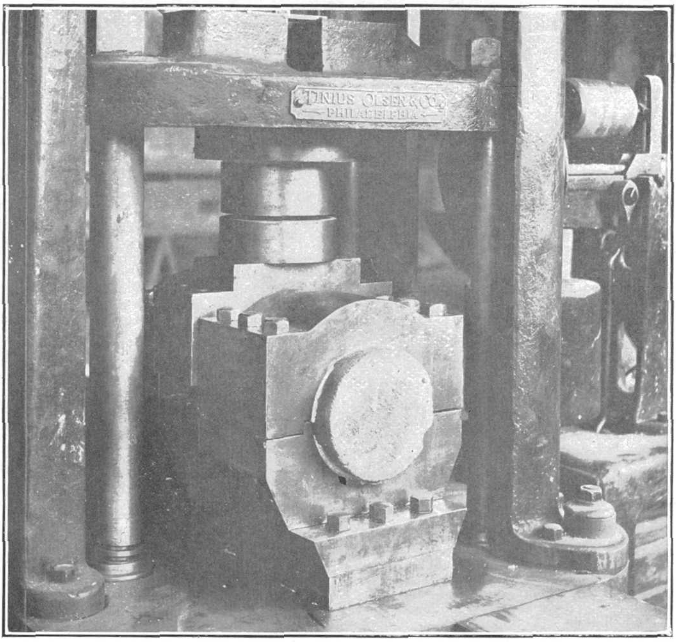


FIG. 5.—Specimen for concrete tension tests.

test piece in the machine ready for testing. The diameter of the bearing surfaces is 6¼ inches and the ⅛-inch space between the test piece and the castings is filled with plaster of Paris. A spherical bearing block is placed on the top of the cutting tool. The bed plate is slotted so that the end support of the cylindrical test piece may be adjusted for any width of cutting tool.

Tension.—A schedule for determining the modulus of elasticity and strength of concrete in tension is shown in the table (p. 67). The test pieces will be of the flat dumb-bell shape, about 8 feet long over all, having a stem 8 by 8 inches in cross section. One of these test pieces is shown in fig. 5, and the grip or apparatus for testing it is shown in fig. 6. The grip is constructed by bending an 8-inch channel so as to inclose the head of the test piece and to bear against the inner surfaces of the head. The two sides of the channel are kept from spreading apart by plates extending from side to side. One of the plates is riveted to the flanges of the channel; the other is held



A. SHEAR SPECIMEN IN MACHINE READY FOR TEST.

B. INTERIOR VIEW OF STORAGE ROOM, BUILDING-BLOCK SECTION.

by bolts so that it can be taken off for the purpose of placing and removing the test piece.

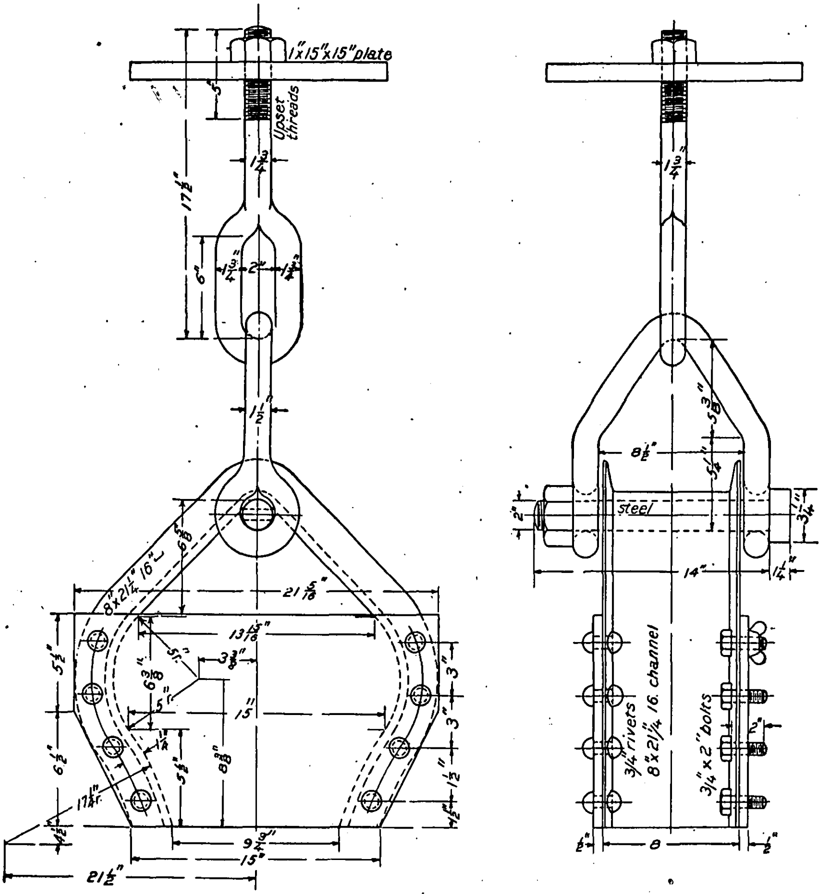


FIG. 6.—Apparatus for concrete tension tests.

Shear and tension tests proposed for 1907.

Test.	Form of specimen.	Concrete (proportions by volume). Cement (1).	Sand (2).	Aggregate (4).	Variables.	Age when tested (days).	Number of pieces.
Shear:							
Series No. 1.	6-inch cylinder {18, 24} inches long.	Standard.	Meramec River.	Limestone; gravel; cinders.	Consistency, and length to be sheared.	28	81
Series No. 2.[a]	6-inch cylinder 18 inches long.	Standard.	Meramec River.	Gravel; cinders; granite.	Consistency,[b] and age when tested.	28, 90 180, 360	84
Tension...	Dumb-bell shape; uniform, 8 by 8-inch section; 5 feet long.	Standard.	Meramec River.	Gravel; cinders; granite.	Consistency,[b] and age when tested.	28, 90 180, 360	84

[a] Length to be sheared to be determined from series 1.
[b] Only one consistency used for granite specimens.

MIXING, MOLDING, AND STORAGE.

The specimens for the shear and tension tests are mixed, molded, and stored under the same conditions as in the case of beams (pp. 48–53).

COMPUTATIONS.

The unit shearing stress is found by dividing one-half the shearing load by the area of a vertical section of the test piece. For the tension tests the dimensions of the section and the distance of the break from the center will be given, besides a complete record of the usual information regarding the making of the test pieces. The unit strength and the initial modulus of elasticity will be calculated from the results.

A series of parallel tests will be made, including a cylinder for compression tests, so that values for a particular lot of concrete will be obtained, giving the strength in shear, in tension, and in compression, and also the modulus of elasticity for tension and for compression. In the report a complete record will be given of all the materials used in making the test pieces, together with a record of the conditions governing the making, storing, and testing.

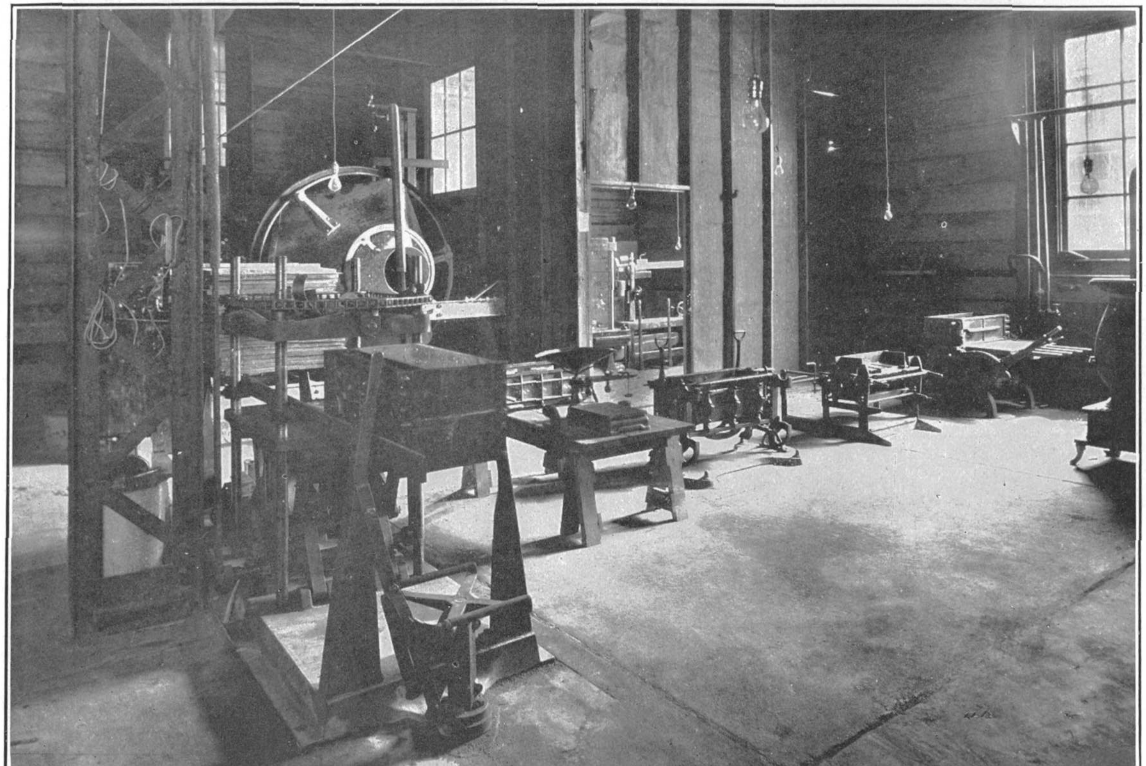
BUILDING-BLOCK SECTION.

OUTLINE OF INVESTIGATIONS.

In the building-block section an extensive series of investigations on the properties of building blocks is under way. Five different types of building blocks are used. They are made up of different proportions and different aggregates and are tested at different ages. With each series of blocks a set of cylinders 8 inches in diameter and 16 inches in length are made, and these are stored under the same conditions as the blocks. The blocks are subjected to strength tests in cross bending and compression, and to fire tests to determine what aggregates and proportions offer the greatest resistance to fire.

A large number of mortar blocks have been made and many of these have been tested. The schedule of tests now under way comprises the manufacture on five different types of block, mixed in proportion of 1 part typical Portland cement to 2, 4, and 8 parts Meramec River sand, and of damp, medium, and wet consistencies. The strength tests cover periods of 28, 90, 180, and 360 days. This series necessitates the making and testing of 720 blocks and 360 cylinders.

In the case of blocks made of concrete, which include aggregates of limestone, gravel, granite, and cinders, proportions of 1:2:4, 1:2:5, and 1:3:6 are used. For convenience in handling, all volumes are reduced to weight and all materials are charged into the mixer by weight.



INTERIOR VIEW OF THE MIXING AND MOLDING AND THE TESTING ROOMS, BUILDING-BLOCK SECTION.

The consistencies which are indicated by the terms damp, medium, and wet are defined as follows: (1) In damp consistency the per cent of water used gives the driest mixture which can be used in all five types of block machines; (2) medium consistency is halfway between the damp and the wet consistencies; (3) in wet consistency the per cent of water used gives the wettest mixture which can be used.

The five cement-block machines which are in use were loaned to the laboratories under an arrangement made by a committee of the United Concrete Block Machine Manufacturers' Association, through the courtesies of the following companies: American Hydraulic Stone Company, Denver, Colo.; Miracle Pressed Stone Company, Minneapolis, Minn.; P. B. Miles Manufacturing Company, Jackson, Mich.; Dykema Company, Grand Rapids, Mich.; Century Machine Company, Jackson, Mich. These machines are shown in Pl. XX.

PROGRAMME OF INVESTIGATIONS.

The programme that has been adopted as a suggested outline covering all the investigations of mortar and concrete blocks is as follows:

I. VARIABLES IN THE MANUFACTURE OF BLOCKS UNDER INVESTIGATION.

A. *Type of wall block—all plain face and standard ends:*

1. With facing.
    - *a.* One-piece wall block.
        - (1) Hollow block.
            - (a) Down face.
                - x. Single air space.
                - y. Double air space.
            - (b) Side face.
                - x. Single air space.
                - y. Double air space.
        - (2) Solid block.
            - (a) Down face.
            - (b) Side face.
    - *b.* Two-piece wall block.
        - (1) With metallic bond.
        - (2) Without metallic bond.
2. Without facing.
    - *a.* One-piece wall block.
        - (1) Hollow block.
            - (a) Down face.
                - x. Single air space.
                - y. Double air space.
            - (b) Side face.
                - x. Single air space.
                - y. Double air space.

A. *Type of wall block—all plain face and standard ends*—Continued.

2. Without facing—Continued.
    - *a.* One-piece wall block—Continued.
        - (2) Solid block.
            - (a) Down face.
            - (b) Side face.
    - *b.* Two-piece wall block.
        - (1) With metallic bond.
        - (2) Without metallic bond.

B. *Materials used:*

1. Cement, typical Portland.
2. Aggregate.
    - *a.* Single.
        - (1) Sand.
        - (2) Limestone.
        - (3) Granite.
        - (4) Gravel.
        - (5) Cinder.
    - *b.* Double, consisting of sand and—
        - (1) Limestone.
        - (2) Granite.
        - (3) Gravel.
        - (4) Cinder.

I. VARIABLES IN THE MANUFACTURE OF BLOCKS UNDER INVESTIGATION—continued.

C. *Dimensions of specimen:*
1. Outside.
   - *a.* 8 by 8 by 16 inches.
   - *b.* 9 by 12 by 24 inches.
2. Web—1½ to 3 inches.
3. Air space—30 to 33⅓ per cent.

D. *Consistency:*
1. Damp.
2. Medium.
3. Wet.

E. *Proportions:*
1. Mortar.
   - *a.* 1:2.
   - *b.* 1:4.
   - *c.* 1:8
   - *d.* Balanced proportions for waterproofing.
2. Concrete.
   - *a.* 1:2:4.
   - *b.* 1:2:5.
   - *c.* 1:3:6.
   - *d.* Balanced proportions for waterproofing.

F. *Process of manufacture:*
1. Mixing.
   - *a.* Hand.
   - *b.* Machine.
2. Molding.
   - *a.* Wet mixture—cast in molds in which test pieces remain until hard set.
     - (1) Sand molds.
       - (a) Poured without vibration.
       - (b) Poured with vibration.
     - (2) Metal molds.
       - (a) Poured without vibration.
       - (b) Poured with vibration.

F. *Process of manufacture*—Continued.
2. Molding—Continued.
   - *b.* Damp and medium mixtures—cast in molds from which specimens are removed before hard set.
     - (1) Hand tamped.
     - (2) Power tamped.
       - (a) Air.
       - (b) Mechanical.
         - x. Single application.
         - y. Repeated application.

G. *Curing:*
1. Natural.
   - *a.* Air.
   - *b.* Air and sprinkling.
2. Artificial.
   - *a.* Submerging.
   - *b.* Steam.
     - (1) Low pressure.
       - (a) With CO_2.
       - (b) Without CO_2.
     - (2) High pressure.
       - (a) With CO_2.
       - (b) Without CO_2.

H. *Aging:*
1. Blocks that are fired.
2. Blocks that are not fired.
   - *a.* 4 weeks.
   - *b.* 13 weeks.
   - *c.* 26 weeks.
   - *d.* 52 weeks.

J. *Use of waterproofing compounds:*
1. Applied to surface.
2. Added to material.
   - *a.* Body.
   - *b.* Facing.

II. PROPERTIES TO BE INVESTIGATED.

A. *Strength:*
1. Transverse.
   - *a.* Type.
   - *b.* Material used.
   - *c.* Dimensions of specimens.
   - *d.* Consistency.
   - *e.* Proportions.
   - *f.* Process of manufacture.
   - *g.* Curing.
   - *h.* Aging.
   - *j.* Use of waterproofing compounds.

A. *Strength*—Continued.
2. Compression.
   - *a.* Type.
   - *b.* Material used.
   - *c.* Dimensions of specimens.
   - *d.* Consistency.
   - *e.* Proportions.
   - *f.* Process of manufacture.
   - *g.* Curing.
   - *h.* Aging.
   - *j.* Use of waterproofing compounds.

II. PROPERTIES TO BE INVESTIGATED—continued.

A. *Strength*—Continued.

3. Shearing.
   - *a*. Type.
   - *b*. Material used.
   - *c*. Dimensions of specimens.
   - *d*. Consistency.
   - *e*. Proportions.
   - *f*. Process of manufacture.
   - *g*. Curing.
   - *h*. Aging.
   - *j*. Use of waterproofing compounds.

B. *Permeability:*
   - *a*. Type.
     - (1) Block.
     - (2) Special test piece.
   - *b*. Material used.
   - *c*. Dimension of specimens.
   - *d*. Consistency.
   - *e*. Proportions.
   - *f*. Process of manufacture.
   - *g*. Curing.
   - *h*. Aging.
   - *j*. Use of waterproofing compounds.

C. *Absorption:*
   - *a*. Type.
   - *b*. Material used.
   - *c*. Dimensions.
   - *d*. Consistency.
   - *e*. Proportions.
   - *f*. Process of manufacture.
   - *g*. Curing.
   - *h*. Aging.
   - *j*. Use of waterproofing compounds.

D. *Efflorescence:*
   - *a*. Type.
   - *b*. Material used.
   - *c*. Dimensions of specimens.
   - *d*. Consistency.
   - *e*. Proportions.
   - *f*. Process of manufacture.
   - *g*. Curing.
   - *h*. Aging.
   - *j*. Use of waterproofing compounds.

E. *Fire-resisting properties:*

1. Fired and cooled in air.
   - *a*. Type.
   - *b*. Material used.
   - *c*. Dimensions of specimens.
   - *d*. Consistency.
   - *e*. Proportions.
   - *f*. Process of manufacture.
   - *g*. Curing.
   - *h*. Aging.
   - *j*. Use of waterproofing compounds.
2. Cooled by spraying with water.
   - *a*. Type.
   - *b*. Material.
   - *c*. Dimensions of specimens.
   - *d*. Consistency.
   - *e*. Proportions.
   - *f*. Process of manufacture.
   - *g*. Curing.
   - *h*. Aging.
   - *j*. Use of waterproofing compounds.

MIXING AND MOLDING.

Method.—The mixing is performed in the same manner as described under "Beam section" (pp. 48–50). The mortar entering the blocks that have been made has been so dry that the forms could be removed as soon as the tamping was completed. Two men are employed in molding the blocks—one to shovel the material into the molds and one to tamp. The concrete is put in the molds in 3-inch layers and tamped with a hand or pneumatic tamper, care being taken to tamp all the blocks in the same manner and the same length of time.

As soon as the tamping is finished, the sides of the forms are removed and the block is weighed and placed in the moist storage room. The weight of the blocks in any one batch is not permitted to vary more than 1 per cent. After the sides of the molds are removed the blocks are allowed to remain on the bottom for sixty hours. At the end of this time they are marked and piled in the order in which they are to be tested.

Apparatus.—All the mortar and concrete used in the tests are mixed in a one-half cubic yard Chicago cube mixer, which is mounted on skids and is motor driven. The discharging end of the mixer appears in the background at the left in Pl. XX, which shows the mixing and molding room. Through the open doorway near the center of the picture can be seen the testing room. The water used is weighed in the barrel resting on the platform scales, the process being similar to that described under "Constituent-materials section" (p. 32).

STORAGE.

One of the moist rooms for the storage of blocks and cylinders is shown in Pl. XIX, *B*. There are two of these rooms, which are lined with moisture-proof paper and furnished with water and steam sprinklers near the ceiling. The specimens are sprinkled at regular intervals of eight hours. The five different types of blocks and corresponding cylinders may be seen in Pl. XIX, *B*.

STRENGTH TESTS.

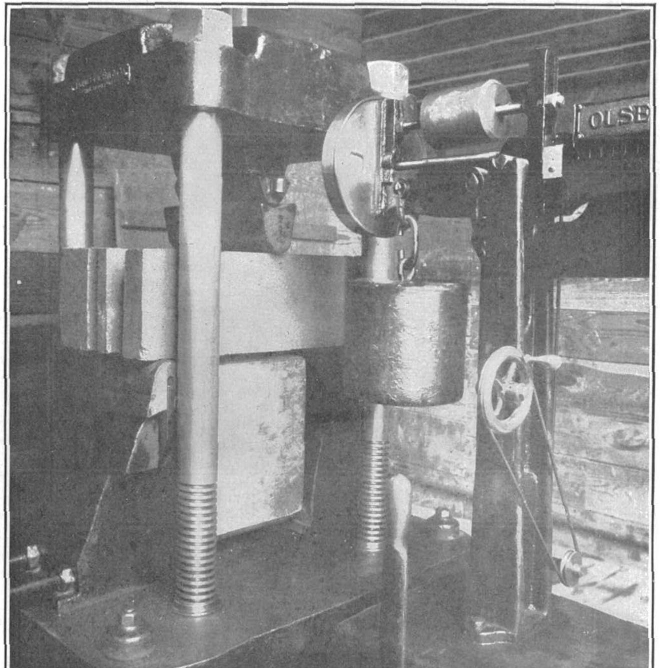
Apparatus.—The strength tests of the blocks and corresponding cylinders are made on a 200,000-pound 4-screw motor-driven testing machine, a portion of which will be seen through the doorway in Pl. XX.

The blocks are first tested for transverse strength on a span of 20 inches, the load being applied at the center of the span. Pl. XXI, *A*, shows a building block in the testing machine ready for application of the load. An isometric drawing of each block is given to the operator and the position of the break is sketched upon the drawing, the distance of the break from one end of the block being measured and recorded on the drawing.

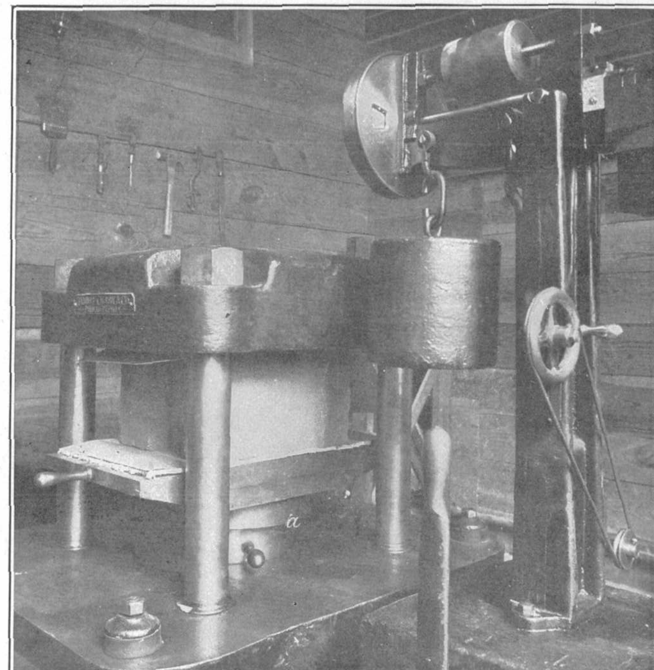
The two pieces of the block resulting from the transverse test are placed in the testing machine one at a time and tested for compressive strength. A half block ready for testing is shown in place in the testing machine in Pl. XXI, *B*. The top and bottom of the block are bedded with thick sheets of asbestos, and the spherical bearing block (*a*) assures an even distribution of the load.

Before these halves are tested, the top and bottom surfaces of each are traced, full size, on large sheets of paper for the purpose of getting the least area subjected to compressive stress. The load at the first crack and the breaking load are recorded.

The ends of the cylinders are smoothed off with plaster of Paris and are tested as described under "Constituent-materials section" (pp.



A. BUILDING BLOCK IN MACHINE READY FOR TRANSVERSE TEST.



B. ONE-HALF OF BUILDING BLOCK IN MACHINE READY FOR COMPRESSION TEST.

31–36). The load at the first crack, the ultimate load, and compressometer readings for increasing loads are recorded.

Forms and computations.—The results of the preceding tests are entered on Form P.

Form P. { UNITED STATES GEOLOGICAL SURVEY, STRUCTURAL-MATERIALS TESTING LABORATORIES. } BLOCK TESTS.

Station.. Approved:..

Description of block.. Age ...... days.

Breadth ...... inches. Depth ...... inches. Length ...... inches. Span ...... inches.

TRANSVERSE STRENGTH.

Reg. No.	Previous treatment.	Breaking load (pounds).	Manner of failure.	Mod.	Date of test.
....	....	....	....	....	....
....	....	....	....	....	....

COMPRESSIVE STRENGTH.

Reg. No.	Previous treatment.	Crushing area (square inches).	Crushing load (pounds).	Compressive strength (pounds per square inch).	Date of test.
....	....	....	....	....	....
....	....	....	....	....	....

The modulus of rupture is computed by means of the formula $S=\frac{M_c}{I}$, substituting for M and I their values at the center of the block. The unit compressive strength of each half is found by dividing the greatest load by the least area of the piece tested. The area is found by using a planimeter on the outline sketched just before the test.

FIRE TESTS.

Outline of investigations.—A preliminary series of investigations of the fire-resisting qualities of structural materials has been inaugurated in connection with the work of the building-block section. These investigations comprise tests upon the various types and kinds of blocks of concrete, and the various building stones, burned clay, cement, sand-lime brick, and terra cotta found in the vicinity of Chicago. Portions of the plain concrete beams after testing have been sent to Chicago with the cement building blocks, while the other materials have been purchased in Chicago. The tests on panels of terra cotta have included the tile used for fireproofing and partition work and for ornamental work. In the case of terra-cotta tile partition panel tests have been made on both the plastered and unplastered tile. These tests have all been completed and are being gotten into shape for publication.

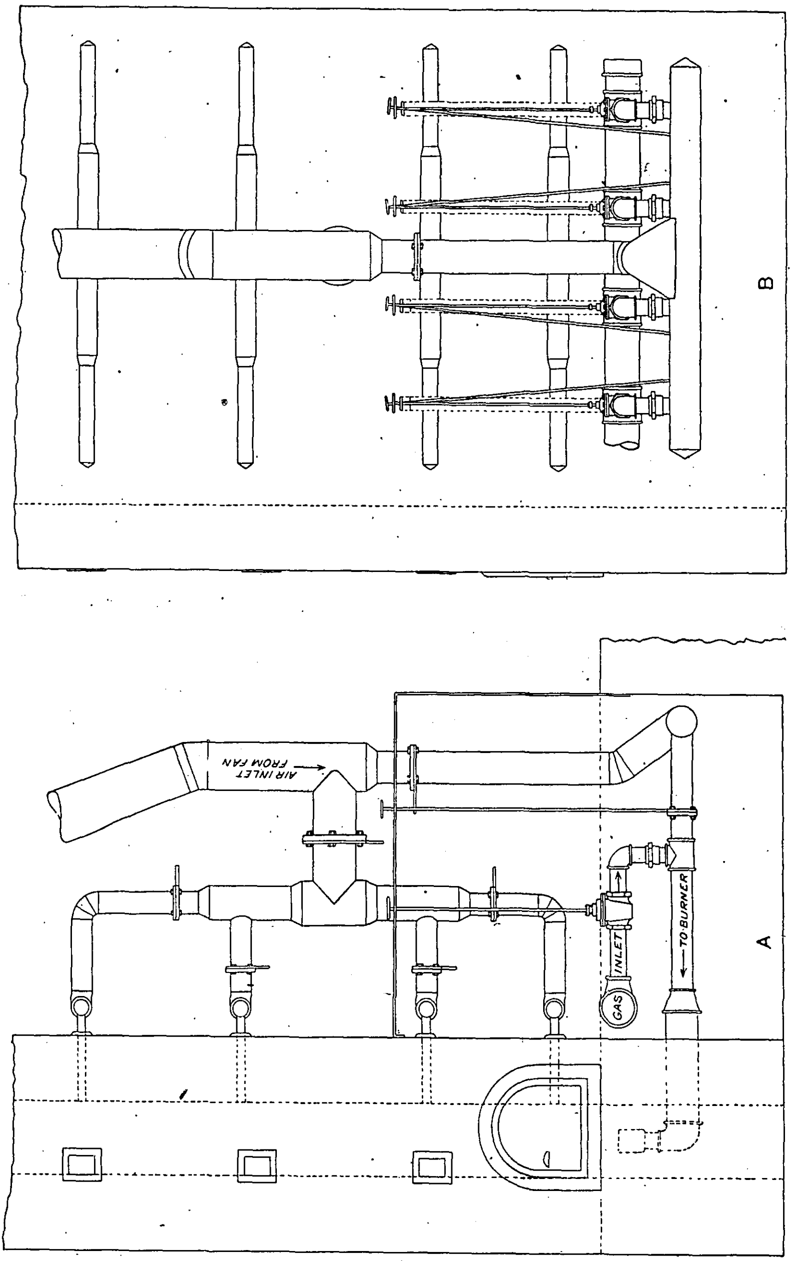
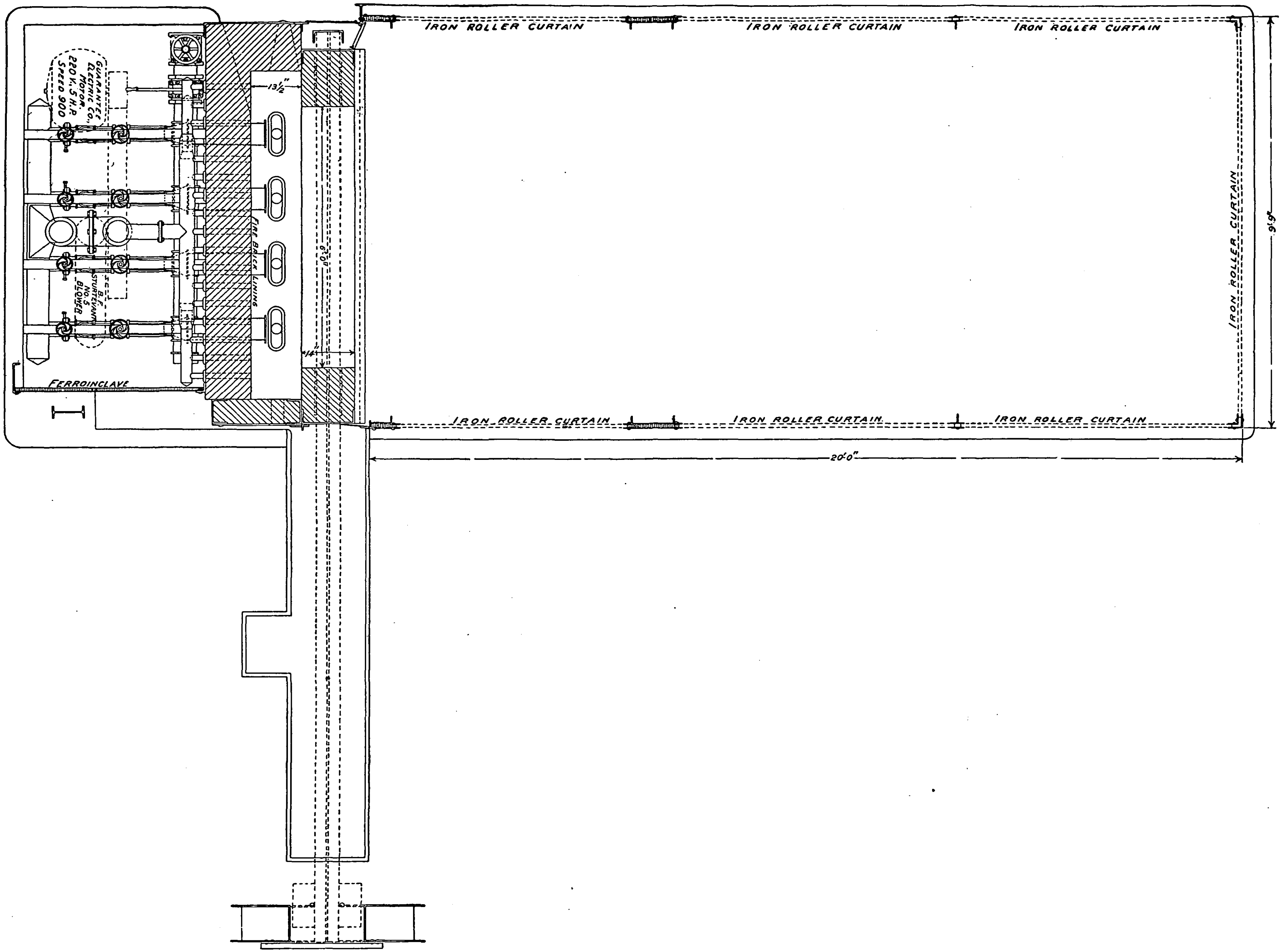
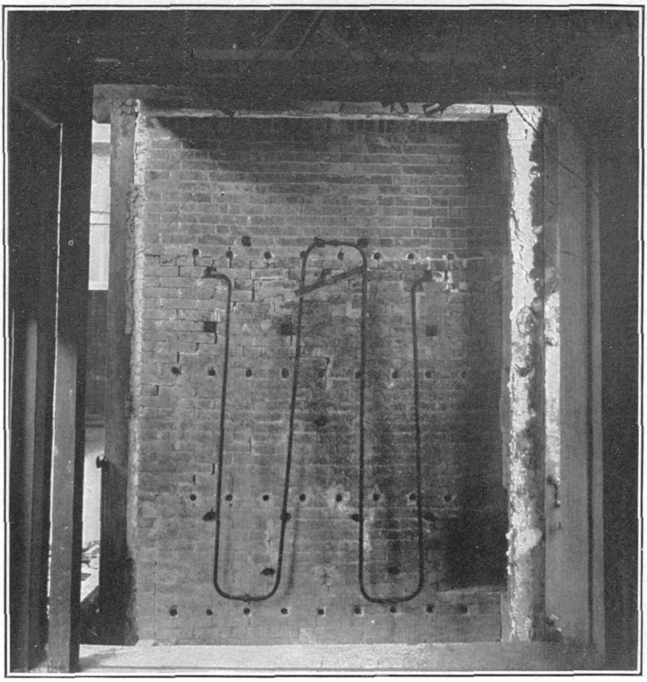


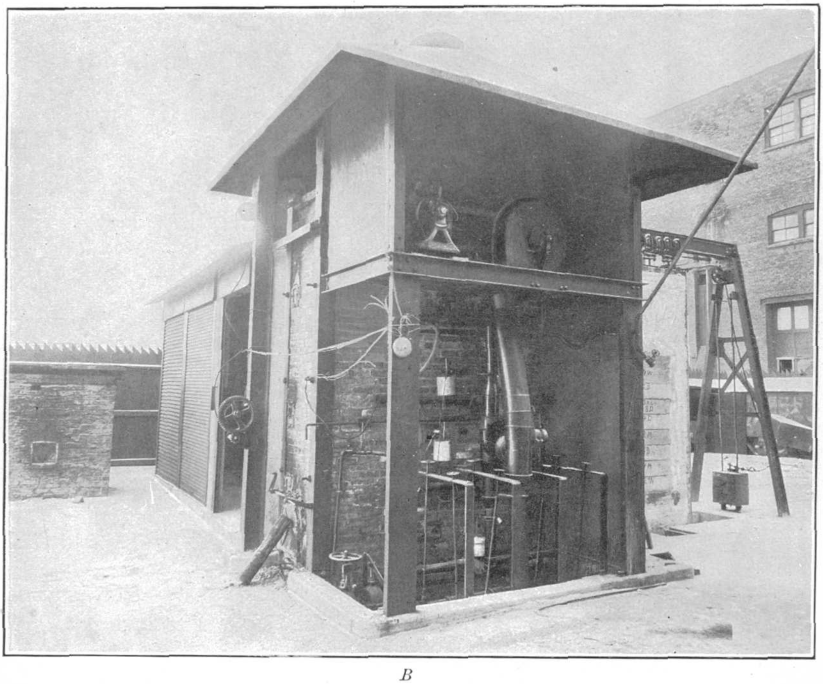
FIG. 7.—Fire-test furnace of the Underwriters' Laboratories, Chicago, Ill. A, Side elevation, showing piping; B, rear elevation, showing piping.



SECTIONAL PLAN OF FIRE-TEST FURNACE, UNDERWRITERS' LABORATORIES, CHICAGO, ILL.



A



B

HEATING CHAMBER, UNDERWRITERS' LABORATORIES, CHICAGO, ILL.

A, Interior view, showing water pyrometer; *B*, General view, showing regulating apparatus for gas and air.

Methods.—The cement blocks tested were made at the laboratories at St. Louis and were stored there in the moist room until about two weeks before they were to be tested, when they were packed in straw in a refrigerator car and, in the case of a batch shipped during the winter, live steam was injected into the car, which was then sealed. Upon reaching Chicago the blocks were removed to the Underwriters' Laboratories and stored in a warm, dry room until tested. The length of this storage was from two to ten days.

This preliminary series of fire tests is being made in the fire-test furnace of the Underwriters' Laboratories in Chicago, a sectional plan of which is shown in Pl. XXII, and elevations of which are shown in fig. 7. Pl. XXIII, *B*, shows a general view of the heating chamber. The valves for regulating the supply of gas and air are shown in the foreground. The motor and fan for the air blast are located in the compartment above the valves. The door through which the gas is lighted and the isinglass peepholes for observing the progress of the tests are shown at the left of the chamber.

The test pieces are laid with fire clay in the opening in the steel-frame, fire-brick-lined hanging door shown in Pl. XXIV, *A*. When the fire clay has hardened, the rolling door is drawn into the furnace by means of a winch, shown at the left of the chamber in Pl. XXIII, *B*. The door is held in place in the chamber by means of a latch. When the test is completed, the latch releases the door and it is quickly drawn out of the chamber by means of the weight shown near the ground at the right in Pl. XXIII, *B*, and at the left in Pl. XXIV, *A*. When the blocks have been placed in the opening, the door has the appearance shown in Pl. XXIV, *A*. The door is drawn into the chamber, so that it is about 2 feet from the burners. A view of the interior of the fire chamber, showing the burner wall, is shown in Pl. XXIII, *A*, and at the right in Pl. XXIV, *A*. Gas is admitted through holes below the floor level. The openings in the brick wall are for the purpose of admitting air to the fire chamber. The piping shown on the face of the wall is a water pyrometer.

The door is fired for two hours, the temperature being kept as nearly uniform over the door as the adjustment of the furnace permits, or within about a 5 per cent variation. The temperature is brought to 925° C. in about thirty minutes, and is maintained at that point one and one-half hours longer.

The temperature of the heating chamber is determined by means of four thermocouples placed symmetrically 6 inches from the back wall of the heating chamber. The temperature of the face of the test pieces is determined by means of six thermocouples symmetrically placed on the face of the blocks, against which the flames impinge. These thermocouples are laid in fire-clay tubes in the joints, with the points one-sixteenth inch back of the face of the wall, these ends being protected from the direct heat by a coating of fire clay. Readings on all ten couples are taken at intervals of ten minutes by means of an Englehardt galvanometer.

Five thermometers are hung on the back of the wall for the purpose of determining the rate of heat transmission. The bulbs are held against the blocks by covering them with fire clay, which prevents the cooling effects of air currents.

After the door has been subjected to the heat for two hours the gas is turned off and the door is removed from the chamber. In some of the tests the blocks are allowed to cool slowly in air, and in others they are cooled suddenly by water.

The quenching test consists in directing a stream of water against the hot blocks. The door can be run out of the furnace and the water applied in about thirty or forty seconds after the gas has been turned off. The stream is played for five minutes through a $\frac{7}{8}$-inch nozzle at a distance of 20 feet from the door and at a pressure of 50 pounds per square inch. (See Pl. XXIV, *B*.)

After the blocks tested in the recent series were sufficiently cool they were removed to the Armour Institute, and, by the courtesy of Prof. R. Burnham, in charge, they were tested for transverse and compressive strength, using the same methods as those used at the laboratories in St. Louis.

Form Q is used for recording the results of the fire tests.

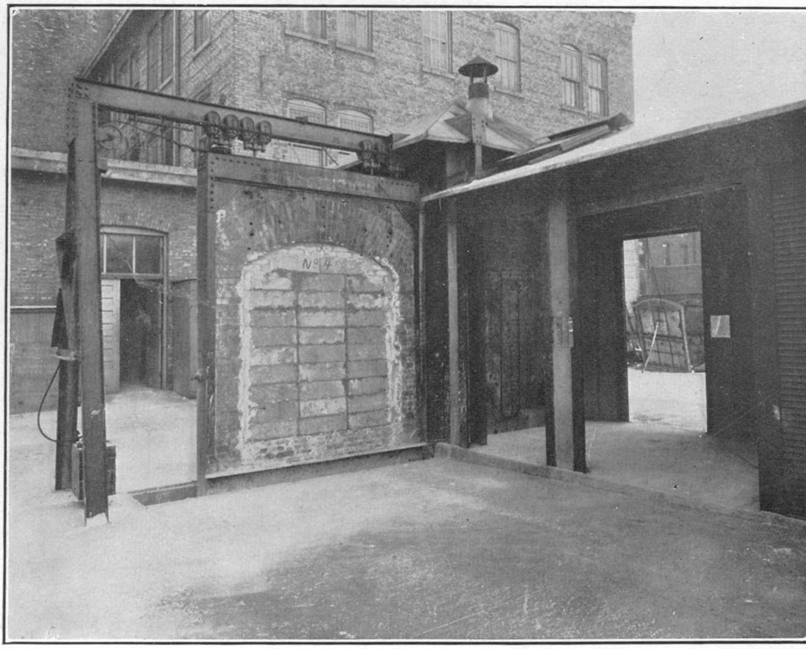
Form Q. { UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. } FIRE TEST.

Station....... Reg. No........ Approved:....... Date....... Duration....... Manner of cooling......
Arrangement of blocks in furnace..........
Condition of blocks after the test..........

Time.	Temp. (°C.)	Temperature observations (to include both faces).
....	....	....
....	....	....
....	....	Max. temperature..........
....	....	Water test....... minimum at...... pound per square-inch pressure.

PERMEABILITY SECTION.

Outline of investigations.—The programme for the permeability investigations includes a preliminary series for the purpose of determining the best method of procedure. The subsequent series covers tests on cement mortars and concretes—those treated with waterproofing coatings and those in which different kinds of waterproofing compounds have been incorporated. Different mixtures, consistencies, and thicknesses are used and the specimens are tested at different ages. Tests will be made on specimens treated with



A. FIRE DOOR FILLED WITH BUILDING BLOCKS READY FOR TEST.

B. APPLICATION OF WATER JET TO TEST PANEL AFTER FIRE TREATMENT.

all the available waterproofings, including powders and liquids for incorporation in the mixture and also for exterior application.

In addition, 2-inch cubes of mortar and concrete will be made and tested for porosity in order to find the relation between porosity and permeability.

Apparatus.—The apparatus for these tests is shown in Pl. XXV and fig. 8.

The arrangement for holding the test piece and the can for catching the water that passes through it are shown in Pl. XXV, *A*. The piece of apparatus shown at the right is placed on top and that next is placed on the bottom of the test piece, with rubber washers between each cap and the test piece. A test piece is shown just to the right of the can. A cross section of the apparatus for holding the test piece, with a test piece in it, is shown in fig. 8. The water is applied to the top of the test piece through the pipe *C;* the distance *Y* is the height of the test piece, and *A* shows the position of the rubber washers at the top and at the bottom of the test piece. The water that passes through the test piece is measured, being caught in the can *B* attached to the bottom of the casting that holds the test piece.

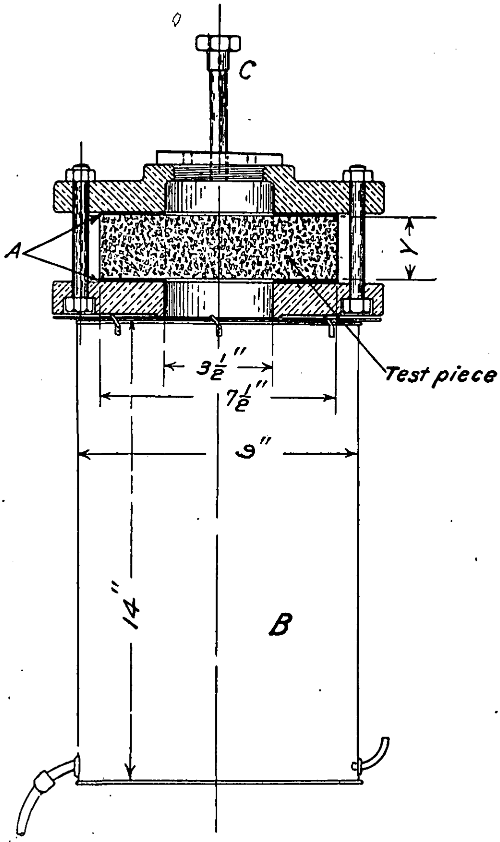


FIG. 8.—Cross section of apparatus for holding permeability test pieces.

A view of the room used for this work, with two permeability tests under way, is shown in Pl. XXV, *B*. Twelve tests can be carried on at once. A diagram of the apparatus, with pipe connections, is shown in fig. 9.

The water passes through the filter *A* and into the tank *B*, from which it is fed to the test pieces attached at the pipe connections. Tank *D* is connected to the air compressor on the floor below and is used to equalize the variable pressure of the compressor. The air is introduced above the water tank *B* at the point *E*. The pressure of the water is read at gage *F*, and of the air at gage *G*. The molds for the test pieces are short sections of iron pipe of 7½ inches internal diameter and of varying lengths.

Method.—The mortars and concretes used in the permeability tests are mixed on a glass-top table. The material is firmly pressed into the mold by hand, the object being to do as little tamping as possible in order to prevent the flushing of cement to the surface. The top of the test piece is smoothed off level with the top of the mold by the use of a 10-inch flat trowel, and is then scraped rough at the surface so that it will have the same characteristics as the interior.

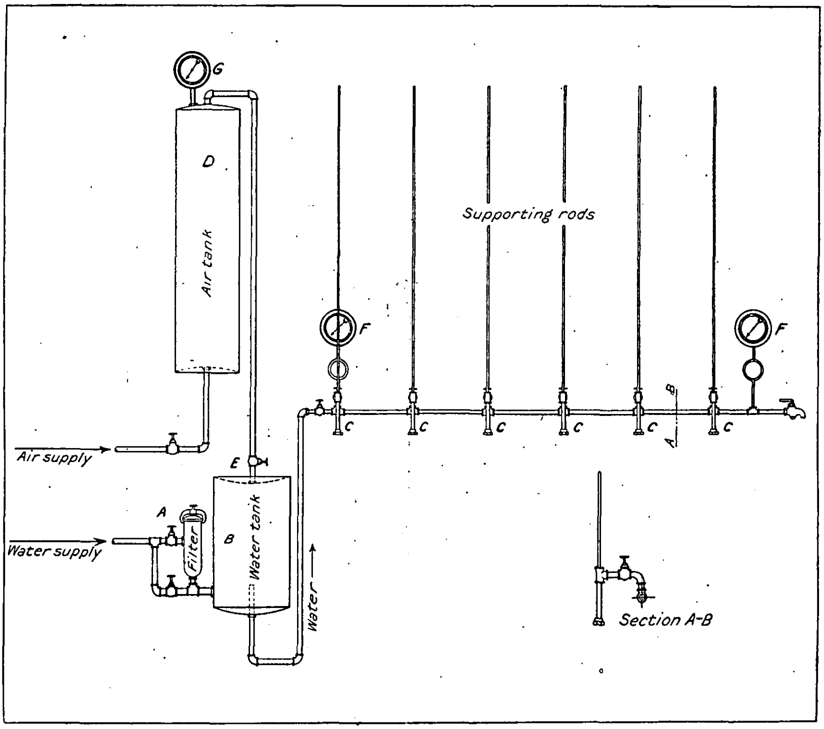
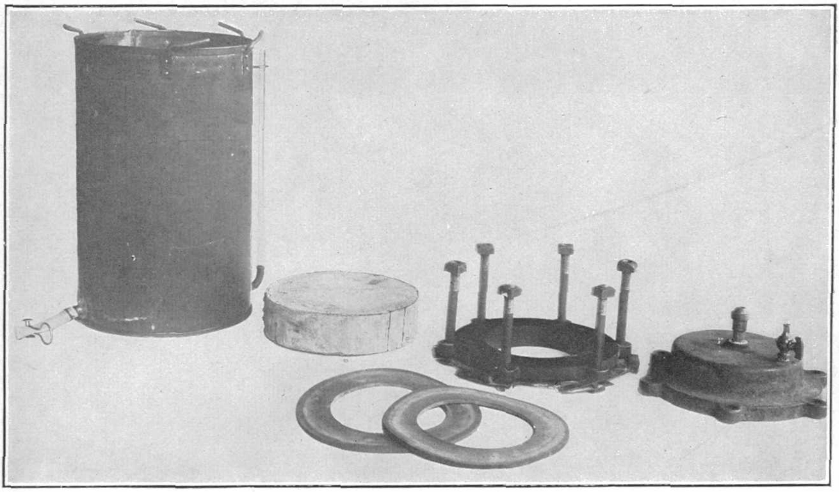


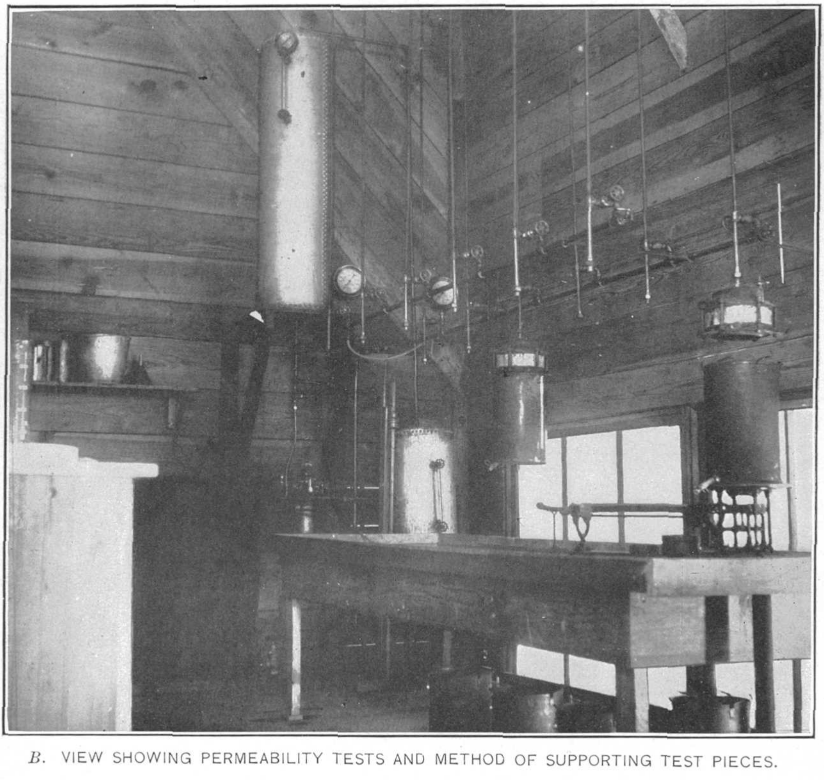
FIG. 9.—Diagram of permeability apparatus and connections.

The test pieces are stored in a moist room of the block section until ready for testing.

The test pieces are placed in water for forty-eight hours before being tested. Annular spaces at the outer edges of both the top and bottom surfaces are painted with a rubber waterproofing paint, leaving a circular area 5 inches in diameter in the center of the specimen in its original condition. Rubber washers are placed over the waterproofing and the specimen is securely fastened in the holder. The apparatus is then attached to the unions (*C*, fig. 8) and the water is turned on. In the present series a pressure of 20 pounds per square inch is maintained. Higher pressures are to be used in the subsequent series.



A. PERMEABILITY APPARATUS.



B. VIEW SHOWING PERMEABILITY TESTS AND METHOD OF SUPPORTING TEST PIECES.

Readings are taken at regular intervals of the amount of water passing through in one minute. The flow of water through the test piece diminishes as the test progresses and readings are accordingly taken at longer intervals until the flow of water becomes constant.

In testing the 2-inch cubes for absorption they are weighed after being thoroughly dried in a gas oven at 100° C. They are then placed in water for twenty-four hours and again weighed. The difference in weight is the absorption.

Forms.—The forms used for recording results of tests give the usual information concerning register number, consistency, etc., also the kind of waterproofing used, the thickness of the specimen, the weight of water absorbed, and the weight of water passing.

CHEMICAL SECTION.

OUTLINE OF INVESTIGATIONS.

The chemical laboratory is equipped with every facility for making the analyses which are required in the course of the investigations of structural materials. In addition to its work in connection with the structural-materials division the laboratory has been making a large number of analyses of cement-making materials (limestone, shales, etc.), for the Reclamation Service.

An annex to the main laboratory communicates with a combustion room, a sampling and storage room, a balance room, and an office. The equipment is very complete and comprises analytic balances, pulp balance, copper still, electric stirring apparatus, gas retainer, carbon dioxide apparatus, oxyhydrogen blast lamps, muffles, and an ample supply of platinum, nickel, and glassware.

ANALYSES OF CONSTITUENT MATERIALS.

CEMENT.

In the analysis of cement the methods recommended by the committee on uniformity in the analysis of materials for the Portland cement industry of the New York section of the Society for Chemical Industry are used, with the following exceptions: In the analysis of cements the silica is not purified by treating with HFl and H_2SO_4. The precipitated iron and aluminum hydrates are dissolved in dilute HNO_3 instead of in dilute HCl; the ignited CaO is also precipitated from a HNO_3 solution the second time. Lastly, the SiO_2 is not determined in the ignited Fe_2O_3 and Al_2O_3.

SILT AND OTHER MATERIALS.

METHODS.

The methods used in the analysis of silt and other materials are those described in Bulletin No. 305 of the United States Geological

Survey, on the analysis of silicate and carbonate rocks, prepared by Dr. W. F. Hillebrand, with the following exceptions:

Moisture at 100° C.—A 1-gram sample of the silt is weighed out upon a small watch glass. It is heated for two hours at 105° C. in an air oven and is weighed after being allowed to cool in a desiccator. The loss in weight is checked by another heating for one hour in the oven.

Silica.—SiO_2 is usually not treated with HFl and H_2SO_4 to determine the Fe_2O_3 and Al_2O_3 which is invariably present; at the same time the Fe_2O_3 and Al_2O_3 are not evaporated with H_2SO_4 after the bisulphate fusion to determine the SiO_2 present in them. In the greater number of cases these two errors about counterbalance one another. The ferric oxide (Fe_2O_3) and alumina (Al_2O_3) are precipitated with ammonia, washed with hot water containing 20 grams ammonium nitrate per liter, dissolved in nitric acid, and reprecipitated. The Fe_2O_3 is reduced by zinc and not by hydrogen sulphide.

Manganese oxide.—MnO is determined by precipitating the hydrated MnO_2 with bromine water in the filtrate from the iron and alumina, filtering, igniting, and weighing as Mn_3O_4.

Total moisture.—One gram of the material is weighed out into a porcelain boat and placed in a piece of hard-glass combustion tube, which is contained in a combustion furnace of the ordinary type. This is preceded by a U-tube, one arm of which is filled with $CaCl_2$ and the other with soda lime; this is preceded by a bubble tube filled with H_2SO_4, and is followed by a U-tube filled with $CaCl_2$, which is followed by another of the same, serving as a safety tube. About five of the burners are lighted under the boat and the total H_2O driven out of the material. The H_2O is drawn through the tube by a current of air and is caught in the U-tube containing $CaCl_2$. The increase in weight of this gives the total H_2O—from which is subtracted the moisture—giving the H_2O above 100°. Necessarily the combustion tube must be heated and the whole train freed in this way from H_2O before the boat with the material has been inserted.

Carbon in organic matter.—One gram of the material is placed in the small beaker and 60 cubic centimeters H_2O and 10 cubic centimeters HCl added and warmed. The mixture is then filtered through a perforated platinum boat containing a mat of ignited asbestos. The boat is then dried at 100° and placed in a combustion tube contained in a 16-burner combustion furnace. This is preceded by a U-tube, one arm of which is filled with $CaCl_2$ and the other with soda lime, which is preceded by an absorption bulb filled with 1.20 specific gravity KOH and this preceded by a second combustion tube contained in a second furnace. This second tube can be connected either with a U-tube filled with $CaCl_2$ and soda lime, preceded by a KOH bulb filled with 1.20 specific gravity KOH, or with an oxygen holder. The combustion tube in the first furnace is filled as follows: About 3 inches from one end (which becomes the posterior end in the furnace) is placed a plug of asbestos followed by 5 or 6 inches of coarse granulated CuO, then by 3 inches of ignited lead chromate and a second plug of asbestos, and the whole finally followed by a roll of silver foil about 1½ inches long. The second tube is filled in the same way except that about twice as much CuO is used and the silver foil is omitted. After the first tube there is placed a bubble tube filled with acid ($AgSO_4$) to catch any HCl not washed out of the boat. This is followed by a U-tube filled with $CaCl_2$, then an absorption bulb filled with 1.20 specific gravity KOH, to which is connected a $CaCl_2$ drying tube, and the whole is followed by a guard U-tube filled with $CaCl_2$. With all the burners in the furnace turned on full except the one at each end, a current of oxygen is drawn through the train for twenty minutes, then air is drawn through for ten minutes. The absorption KOH bulb following the first furnace with its connected $CaCl_2$ tube is then weighed. The increase in weight is equal to the CO_2 and this multiplied by 0.2727 gives C.

Necessarily, before placing the boat in the furnace, oxygen must be passed through it and all C burned completely out of it, a condition which is attained when there is no further increase in the weight of the absorption bulb.

SUMMARY.

The above methods apply equally well to shales, to clays, and to all high SiO_2 rock—also to limestone, but in this case only about 1 or 2 grams of the mixed carbonate of potassium and sodium are needed in the fusion.

Form R is used for recording the analyses.

Form R. { UNITED STATES GEOLOGICAL SURVEY. STRUCTURAL-MATERIALS TESTING LABORATORIES. } CHEMICAL ANALYSES.

Station....... Reg. No........ Approved:......
Date....... Method of treatment of sample.................................. Moisture......per cent.

Rocks—cement.				Steel.	
Ultimate analysis.		Rational analysis.			
	Per cent.		Per cent.		Per cent.
Silica (SiO_2)........	....	Free silica........	....	Total carbon (C)........	....
Alumina (Al_2O_3)........	....	Clay substance........	....		
Ferric oxide (Fe_2O_3)........	....	Feldspathic substance.	....	Combined carbon........	....
Manganese oxide (MnO)........	....		....		
Lime (CaO)........	....	Ignition loss........	....	....	....
Magnesia (MgO)........	....	....	....	Graphitic carbon........	....
Sulphuric anhydride (SO_3)........	....	....	....	....	....
Phosphoric oxide (P_2O_5)........	....	....	....	Phosphorus (P)........	....
Alkalies { Soda (Na_2O)........	....	....	....	....	....
Alkalies { Potassa (K_2O)........	....	....	....	Sulphur (S)........	....
Water at 100° C........	....	....	....	....	....
Water above 100° C........	....	....	....	Manganese (Mn)........	....
Carbon dioxide (CO_2)........	....	....	....	....	....
Ignition loss........	....	....	....	Silicon (Si)........	....
Total........	....	Total........	....		

Remarks.—..

ANALYSIS OF STEEL.

All the steel used in the reinforced beams is analyzed. The percentages of carbon, phosphorus, and sulphur are determined by the usual methods and are recorded.

Carbon is determined by solution of steel in potassium cupric-chloride filtration and combustion of the residue. (Blair's "The Chemical Analysis of Iron," 6th ed., pp. 156–166.)

Phosphorus is determined by the volumetric method proposed by the subcommittee on methods of the International Steel Standard Committee of the United States. (Blair, pp. 92–104.)

Sulphur is determined by evolution as hydrogen sulphide and absorption in ammoniacal solution of hydrogen peroxide. (Blair, pp. 60–65.)

INVESTIGATIONS OF COLUMNS AND FLOOR SLABS.

A comprehensive series of tests is being inaugurated to investigate the properties of both plain and reinforced concrete columns ranging in length from 10 to 30 feet and in section from 8 to 12 inches.

A series of tests is being put into execution to investigate the properties of concrete slabs reenforced with steel of 10-foot span. The column tests have been delayed awaiting the arrival of the 600,000-pound testing machine, the installation of which will make it possible to proceed.

THE EFFECT OF ELECTROLYSIS AND SEA WATER ON CEMENT MORTARS AND CONCRETES.

In connection with the work of the laboratory at Norfolk, Va., there is being conducted a series of investigations covering (1) the effect of electrolysis on cement mortars and concretes, and (2) the effect of sea water on these materials. In this latter series of experiments test pieces are being made with sea water and immersed in sea water, made with fresh water and immersed in sea water, and a parallel series made with and immersed in fresh water. A series of parallel experiments will be carried on in St. Louis as to the effect of electrolysis on cement mortars and concretes. The cages in which these test pieces are stored are located at the end of what is known as the commercial pier, which extends about 1,500 feet from the shore, near the grounds of the Jamestown Exposition. The use of this pier has been obtained through the courtesy of the local authorities.

PROGRESS OF THE WORK.

PRELIMINARY WORK.

The appropriation for the first year's work amounted to $12,500, of which $5,000 was carried by the general deficiency bill and was available until June 30, 1905, and the balance, $7,500, was available until June 30, 1906.

The appropriation was made for the purpose of continuing the investigations started during the period of the Louisiana Purchase Exposition, and it was expected that light, heat, and power would be furnished by the fuel-testing division, which would considerably increase the funds available for actual testing work. During that year the work consisted principally of the investigations of the constituent materials of cement mortars and concretes, the work being carried on in the cement building now used by the constituent-materials section.

Late in the fall of 1905 the metal pavilion was occupied and was used for several months as a temporary storage house for the materials used in the investigations then pending. The funds for the work, however, were so small that it was necessary to reduce the force of men employed on this work in the spring of 1906, which brought it practically to a standstill until the new appropriation of $100,000 became available for the fiscal year beginning July 1, 1906. After this date the work was again taken up and greatly extended; the beam, building-block, and computing sections and a chemical laboratory were organized, and new equipment was purchased and installed.

PRESENT WORK.

During the fiscal year 1905–6 the work at the laboratories was greatly hampered by the removal of the buildings which formed a part of the Louisiana Purchase Exposition, which work extended through 1906 and well into 1907, and rendered it difficult to repair the buildings and to install the apparatus required in making the tests. This necessary work, however, was accomplished during the summer and fall of 1906, so that the work of the new divisions was well under way early in 1907.

During the fall of 1906 and the first half of 1907 many test pieces have been made and tested. Those made prior to July, 1907, aggregate 35,200, while the number of tests and determinations which have been made amount to 35,500.

The approximate number of test specimens made and tested is divided among the various sections as follows:

Constituent-materials section.—In the constituent-materials section there have been made 5,750 transverse specimens 1 by 1 by 13 inches; 8,700 two-inch cubes; 12,550 tensile briquets of 1-inch cross section; 870 cylinders 8 inches in diameter and 16 inches long; and 710 six-inch cubes. Of these there have been tested 3,650 transverse test pieces; 6,740 two-inch cubes, 540 six-inch cubes; 9,750 tensile briquets, and 600 cylinders. In addition to the above about 10,000 physical determinations of specific gravity, time of setting, soundness, mechanical analysis, etc., have been made.

Beam section.—In the beam section there have been made approximately 600 beams of plain and reinforced concrete, 8 inches wide, 11 inches deep, and 13 feet long; 600 six-inch cubes; 800 cylinders 8 inches in diameter and 16 inches long; and 110 bond specimens 8 inches in diameter and of varying lengths. Of these, there have been tested 290 beams, 280 cubes, 390 cylinders, and 40 bond test pieces. In addition to these about 2,500 steel tests have been made, and the modulus of elasticity has been determined on 250 of these.

Building-block section.—About 1,600 building blocks of standard size and 400 cylinders 8 inches in diameter and 16 inches long have been made, and of these 1,150 blocks and 200 cylinders have been tested.

Chemical section.—About 550 chemical analyses have been made.

FUTURE WORK.

The appropriation of $100,000 available for the fiscal year beginning July 1, 1907, insures a continuance of the work. Many new series, some of which have been outlined in this report, have been begun and will be continued during the coming year.

In addition to the work at these laboratories many tests are being made at technological institutions in cooperation with the United States Geological Survey, among which may be mentioned Columbia University, the University of Illinois, Purdue University, and the University of Wisconsin, the purpose of this cooperative work being to avoid all unnecessary duplication in work or unnecessary expenditures for equipment the temporary use of which could be obtained elsewhere.

The results of the tests are being rapidly worked up into reports for publication, which will be issued in bulletin form, each treating of a particular phase of the work at the structural-materials laboratories.

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