A STUDY OF
MONOLITHIC BRICK PAVING
ITS EVOLUTION, CONSTRUCTION AND STRENGTH

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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"On the prepared subgrade
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in the most economical way."

"All operations are carried on within 100 feet of the mixer."

A STUDY OF

MONOLITHIC BRICK PAVING

ITS EVOLUTION, CONSTRUCTION, AND STRENGTH.

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I. EVOLUTION.

The monolithic brick pavement, wherein the wearing course of vitrified paving blocks is united with the concrete foundation, into one rigid slab, is the logical outgrowth of the demand for a permanent pavement, simple and rapid in construction, and costing less than the brick pavements of the sand cushion type. Its production marks a long step forward in the construction of brick roads. In order that the full value and usefulness of this pavement be appreciated, it is necessary to know something of the early types of the brick pavement, and to follow them through their evolution to our present day roads.

Early Types.

The earliest brick roads were constructed of what are now considered common building brick, placed on edge on tarred boards or compacted earth or gravel covered with a layer of sand to smooth over inequalities of the surface. The interstices between the bricks, or the "joints", were filled with sand, and the road opened to traffic immediately. This surface was better than dirt, especially in wet weather, but since there was little or no foundation to distribute and carry the load, these pavements were suited principally for light traffic.

In order, therefore, to provide a better foundation, a layer of brick was placed flatwise on the earth or gravel, a layer of sand or fine gravel on top of this, and upon this bed the wearing surface of brick was laid on edge. This type of surfacing made a more nearly waterproof covering, keeping the earth foundation dryer, and consequently of better bearing capacity.

Since these pavements were made of relatively soft brick, varying somewhat in hardness and toughness, they soon wore to an uneven and bumpy surface. Furthermore, on account of the installation or extension of water, gas, or electric conduits, trenches were excavated in the streets which, by being poorly backfilled, often left humps or depressions in the pavement. In spite of all these defects, many of these old pavements still exist in our cities and towns, as evidence of the long life of this type of pavement.

Introduction of Concrete Foundation.

As the price of cement became lower, concrete began to be introduced as a pavement foundation. At first, the concrete was of a rather poor quality, but it increased in strength and uniformity as its use became more common and equipment for mixing it was improved. Natural cement was at first used, mixed by hand with bank-run gravel, in proportions varying from 1:6 to 1:16, and consequently the concrete varied in strength from that which could be removed with a shovel to that which required a good pick or sledge to break it up.

Mechanical Mixing.

Shortly after concrete became common as a pavement foundation the continuous mechanical mixer was introduced. This was a great improvement over hand mixing, for it delivered the concrete in a continuous stream from the mixer, whence it was wheeled and dumped into place on the road by means of wheelbarrows. The continuous mixer, however, did not prove entirely satisfactory in producing a uniformly proportioned product, and was finally replaced by the common batch mixer.

Origin and Use of Sand Cushion.

The first concrete foundations were rough and uneven. This made it necessary to continue the use of a layer of sand to take up these inequalities and provide a smooth, even, surface upon which to lay the brick. This was the reason for the use of the so-called sand cushion, and was the origin of our sand cushion pavements, the defects of which we believe to have eliminated in the monolithic type.

After Portland cement had become cheap enough to be used in pavements, and the workmen had become skilled in the handling and finishing of concrete, smoother and more even surfaces began to be obtained by various means, principally by the use of the long-handled wood float, until now the better class of work produces foundation surfaces varying not more than half an inch from a straight line. Thus we see the need for the sand cushion (originally two inches thick) decreasing to the vanishing point.

Sand Cushion Working up in Joints.

In placing the wearing surface, the brick were laid by hand in regular courses, and rolled to a smooth, regular surface with a heavy roller. It was in this rolling that the variations in character of the sand cushion became evident. Some sands, if not previously compacted, worked up between the brick, filling the joints from one half to three fourths full. This made little difference if the joints were to be finally filled with sand, but if a higher-class or more expensive form of filler were to be used, it often necessitated the taking up and relaying of the sections so affected. The importance of this became more pronounced as the filler became more rigid.

Kinds of Fillers.

The three forms of fillers used are the sand or granular, the bituminous or plastic, and the cement, or rigid types. Of these the first is the most simple and least expensive. It, however, affords no protection for the edges and corners of the brick, but allows them to become rounded, making the surface of the pavement rough. With the bituminous filler, applied in a hot and quite liquid state, little difference is made whether or not the joints are free from sand. The rigid filler, however, necessitates clean joints the entire depth of the brick; for otherwise serious trouble will be caused later on. As this is the cause of the greater number of pavement failures, it might be well to consider it more in detail.

Grout Filler.

In the cement or "grout" filled pavement, it is essential that the joints be free from sand or other foreign material, and be filled the entire depth of the brick, thus cementing the separate brick into a solid slab. As the temperature rises and falls, the slab must expand and contract. Since the brick are in a solid slab having no allowance made for expansion, this expansion can take place only to a very slight degree, and instead great internal compressive stresses are set up. If the joints are filled solidly, the center of compression will be through the center of the slab, distributing the stress equally over the entire depth of brick. If,

Roor Grouting

The first application did not fill the joints sufficiently. The second was too thick.

Cause

Effect

however, the joints are filled but one inch or less at the top, the stress comes entirely on this small section, and is often enough to shatter the brick or crush the cement filler, destroying the bond, and ultimately subjecting the entire pavement to wear the same as a sand filled pavement. This failure by crushing however, seldom comes in the entire pavement, but rather comes in spots where the grout has been carelessly applied, or of such thick consistency that it failed to penetrate the full depth. More wear is caused at these spots from the hammer-like impact of heavy wheels over the uneven surface, ultimately resulting in ruts or depressions. Again, water penetrates these opened joints and its lubricating qualities combined with the vibration from traffic causes the sand to shift and compact, leaving a hallow space under this part of the slab. As traffic moves over this and adjoining sections, great shearing and tensile stresses are put on the grouted joints, ultimately causing their failure and consequently increasing the

Typical expansion joint failure

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Failure of grout along wheel track adjacent to expansion joint.

area of failure. Wherever expansion joints have been placed, this same action of water seeping in at the joint has caused the failure of the adjoining grouted joints, resulting in bumps, ruts, and crushed brick at each place. This destructive action is often hastened by the freezing and consequent expansion of water in the sand cushion. Still another and often more dangerous occurence is due to faultily filled joints, and is the "blow-up". As the internal stress or pressure due to expansion increases, the resultant pressure, applied through the upper part of the brick slab maintains a great tendency toward upheaval, held down only by the weight of the pavement, since there is nothing in the lower part of the joints to resist. On hot days, this pressure sometimes becomes too great, and the whole pavement at the weak section is thrown up with great force,

Slow Blow-up

Shaded by trees till noon

The next day

not unlike an explosion, throwing brick many feet into the air and endangering everything in the vicinity. It is the elimination of these defects, then, that to a great extent makes the advent of the monolithic form of construction such a forward step in the laying of the brick pavement.

Cement-Sand Bed.

Several years before the introduction of the true monolithic idea, cement mixed with sand (usually proportioned about 1:5), was substituted for the troublesome sand cushion, and was given the title of the cement-sand bed. Where the concrete foundation was finished to a smooth and even surface, the thickness of this cement-sand bed was reduced in many instances to as little as three fourths of an inch. This pavement was a distinct type developed for city streets, and from the start was a great success. Its object was not only to afford a uniform bearing surface for the brick, but since the mixture of cement and sand was converted into a mortar by means of a thorough wetting after the brick were laid and rolled but not grouted, the setting up of this mortar finally formed a rigid bed and overcame many of the defects of the sand cushion. In addition, it effected to a limited extent a union between the brick surfacing and the concrete foundation, thus giving substantially a semi-monolithic beam. The success of this type of pavement on heavy traffic streets has earned for it a very enviable reputation.

Types of Monolithic Pavement.

With the introduction of the monolithic pavement, there began a new era in brick pavement construction. Since the brick were laid immediately upon the fresh concrete base, the problem soon arose as to whether a sufficiently smooth surface could be obtained on the concrete to receive the brick. Two types of the monolithic brick pavement therefore came into use, differing in the method of smoothing the concrete surface. In one is used a thin layer of a dry mix composed of cement and sand proportioned about 1:3, spread directly upon the concrete by means of a double template, and followed by the immediate laying and rolling of the brick. In the other this intermediate layer is omitted and the laying, rolling, and grouting of the brick takes place immediately upon the smooth surface of the concrete, obtained by the judicious use of sliding and tamping templates.

The first type was evolved by Mr. W. T. Blackburn of the Dunn Wire-Cut-Lub Brick Co., and the early pavements were laid under his direction by Mr. A. J. Parrish at Paris, Illinois in 1914. The first of the other type, sometimes known as the Vermilion County or the direct-contact type, was laid near Danville, Illinois, as an experiment upon the suggestion of Mr. Harvey C. Adams of the Danville Brick Co., and Mr. W. W. Marr, State Highway Engineer, in the fall of 1915, and later was developed on the Vermilion County Bond Issue Roads under the direction of Mr. P. C. McArdle, Superintending Engineer.

Experimental Sections.

The experimental sections were laid on a road receiving heavy traffic from coal mines, about two miles west of Danville. It was laid in four sections, as follows: (1) A length of 36 feet using 3-inch brick laid upon a 3-inch base, with 1:3½:6 concrete; (2) A length of 64 feet using a 4-inch brick laid longitudinally upon a 2-inch base; (3) A length of 50 feet using using a 4-inch brick laid transversely upon the same thickness of base; (4) A length of 48 feet using a 4-inch brick laid transversely on a 1-inch base, the concrete being a 1:3½ cement-sand mixture. The pavement was crowned 1½ inches in a width of 15 feet, The concrete was laid just as wet as possible without running at the edges, struck off with a template but not tamped, and the brick laid and grouted immediately.

The fourth section, or the 1-inch base, was placed where it received the most severe test - at the end of a soft gravel road. In the spring when the frost is going out of the ground this gravel road is little better than a series of mudholes,

Gravel road in spring

Experimental sections

from which the traffic bumps up on the pavement, while in the summer the surface of the gravel is above the brick and the traffic drops down upon the edge of the pavement. However, to date none of the work has shown the slightest sign of failure.

II. CONSTRUCTION.

Preliminary Preparation.

The monolithic brick pavement ~~pavement~~ is constructed in a similar manner to any other rigid pavement. After all necessary grading is done, suitable ditches, culverts, catch-basins, and cross-drains provided where necessary, the earth is brought to grade and rolled to a uniform, compact, and even surface with a heavy roller. Upon this prepared subgrade the concrete materials are distributed in the most economical way.

Unloading materials

Distribution of materials

A good 1-inch graded gravel or crushed stone should be used, except for bases less than two inches in thickness, where aggregate well-graded from one half inch down to fine material, or its equivalent in gravel and sand, should be used for the concrete in the proportion of 1:4 or 1:2½:4. For the thicker bases, the proportion of 1:3½:6 produces satisfactory results. Steel forms are set in advance of the mixer and a good line can be maintained with little difficulty. If before placing

Oiling the forms

the concrete, a little low-grade oil is applied to the face of the forms, it will keep them clean and consequently will save much time and labor later on.

Consistency of Concrete.

The concrete used in the base should be of a slightly quakey consistency, dumped directly from the mixer upon the dampened subgrade, spread out between the side forms and struck off to the proper thickness and crown by suitable templates drawn forward by the mixer.

Templates.

In the first type, the template has two steel faces, between which the dry mixture of cement and sand is placed.

The forward face cuts off the concrete, while the rear face, set three sixteenths of an inch higher, allows the dry mix to spread over the concrete in a thin layer, forming a smooth, even surface to receive the brick.

There are several different templates used in obtaining the smooth surface required by the direct-contact type, varying in character and operation with the size of aggregate used, the consistency of concrete desired, and the thickness of base required. Most of these templates have been developed on the four inch base pavements of Vermilion County near Catlin and Hoopeston, while the simplest is in use on the one inch base monolithic pavement construction of Stockland Township, Iroquois County, Illinois.

In the work near Catlin, at first only one template was used. This was made of two 2x10-inch oak planks placed vertically ten inches apart, with suitable cross-bracing between. The lower edge of these planks was cut to a one inch crown and faced with a strip of iron. Rollers were fastened to each of these planks for movement along the forms. This template was not satisfactory, however, for although well weighted down, the concrete often piled up in front as it was being pulled ahead, causing the rear face to rise and leave a high place in the base, which if not removed by a second dragging of the template, caused a wave in the pavement.

In the work at Hoopeston, therefore, an additional template having the crowned faces two feet apart was used. This was supported on the forms by runners three feet long faced with iron curved upward at the front end. This acted as a check on the first template, taking off any high places and filling in the low ones.

Although this was an improvement on the original scheme still it was not altogether satisfactory. When excess concrete piled in front of this second template, the tendency was for its rear face to rise, the same as did the first template. The development of the machine pulled template stopped at this point, owing to financial reasons, and the succeeding work has been carried on by a double template followed by a hand operated sawboard template and finally by a light tamping template, to compact the concrete.

A new steel template has been designed which, although never tried out, should prove satisfactory in solving this template problem. It has three faces placed two feet or more apart, the rear one being tilted backward slightly, so as to smooth down and compact the concrete. This template is pulled along the forms on eight foot runners, projecting a foot or more in front of the front face. Runners are used on the templates instead of rollers in order to eliminate any irregularities in the surface or at the joints of the forms. Rollers drop into any depressions, leaving the concrete with the same contour as the surface of the forms. They also concentrate the weight of the template, tending to make irregularities in the forms, especially at the joints, while the runner distributes this weight over a large area. Instead of having the same crown as the finished pavement, the faces of this new template are crowned one and one half inches in ten feet to allow for more compacting of the concrete and for a greater depth of embedment of the brick, while still maintaining a final crown of one inch.

Where large aggregate is used in the concrete, the crowned tamping template has been employed to good advantage.

Placing and tamping concrete base

This template is made of two 2x10-inch planks placed vertically, between which is placed a 1x6-inch strip extending diagonally upward and outward from each end, and containing at the upper end a handle for moving the template up and down. The bottom edges of these planks are crowned $1\frac{1}{4}$ inches, somewhat similar to the dragging template, and have a 1x10-inch strip nailed to them for a tamping face. The upper part of the planks extends out over the edge of the form, while the lower part is cut in to the width between the forms, the depth of cut being the distance desired between the concrete and the top of the forms. This template is operated with a vertical tamping motion by two men, thus flushing a thin coat of mortar to the surface, upon which the brick are laid.

Laying brick on tamped surface

In the thin-base monolithic paving the dragged template is entirely done away with, using instead a hand-operated saw-board template. This has proved successful for this type of work, very probably on account of the small size of the coarse aggregate, enabling 800 to 1000 lineal feet of 9-foot pavement to be laid in a ten hour day.

Thin base Monolithic Pavement

Setting forms

Striking off concrete

General view

Laying pavement

Brick Laying

Upon the prepared surface of the concrete the brick are laid and rolled to a smooth, even surface with an 800-lb. water-ballast hand roller. Inspection is made at this time, and all

rough, broken, or cracked bricks are removed. The brick are carried on to the pavement with tongs or on short boards called "pallets", and stacked in regular order for laying so that the lugs will all be in one direction and the best face up.

The brick are bedded in the green concrete

Grouting

The brick are grouted immediately after the rolling is completed. The grout is made of equal parts of cement and sand, mixed to a uniform consistency in either a wooden mixing-box or any one of the mechanical grout mixers. The sand is of such size

Wooden mixing box

that it will all pass a number twelve screen. Grout sand of at least this degree of fineness should be used, or much trouble from separation is likely to be experienced.

Use of mechanical mixer

Usually the joints are filled in from two to three applications. The first application of grout should be of a consistency comparable to thin cream or 'light' motor oil. It is applied in such quantity that the joints will be nearly full. The excess on the bricks is then broomed into the joints with a coarse street broom. After most of the settlement has taken place, the second application of grout is made, using a mixture slightly thicker than before, comparable to medium thick cream or to the usual 'heavy' motor oil. Great care should be taken to fill the joints

Second application of grout

completely. If the grout is too thick it will merely bridge over the upper inch of the joints, leaving the lower portions open to the destructive action of water, frost, and pressure due to rise

Second coat of grout applied too thick

in temperature. This coat should be applied with the aid of a 'squeegee' and worked thoroughly into the joints. The material along the edges is made somewhat thinner by sprinkling the sides slightly before applying the second coat, thus insuring a thorough filling along the edges of the pavement. A small amount of grout is left on the pavement at this time to provide for settlement. When it has partially stiffened, the pavement is gone over again with the squeegee aided by a sprinkling can, filling all joints and cleaning the grout off flush with the surface of the brick. All operations should be carried on within 100 feet of the mixer.

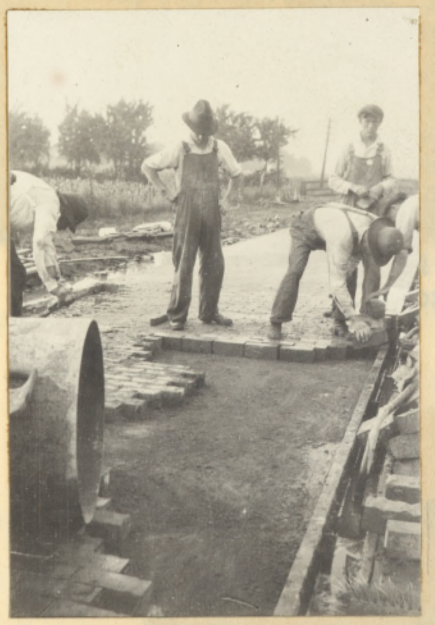
All operations are carried on
within 100 feet of the mixer

When the grout has hardened sufficiently, the pavement should be covered with earth or other materials capable of retaining moisture, and kept wet for at least ten days to allow the concrete and grout to cure properly. All traffic should be kept off for at least three weeks, the earth then removed and the road made ready for traffic.

Expansion joints.

No expansion joints are needed in this pavement, but if desired, thin strips of tarred paper may be placed through the slab at intervals of about 35 feet. These would act as contraction joints, eliminating the danger of contraction cracks forming in a jagged line across the pavement, with the accompanying possibility of having the adjacent bricks loosened by traffic.

With this type of construction, the most important part of the work, so far as obtaining a smooth surface is concerned, is at the mixer and the templates. Intelligent rolling of the brick is a necessity, but if the concrete is not of uniform consistency, almost no amount of work short of taking up the brick and reshaping the concrete will make the pavement smooth. Too



Reshaping concrete base

great emphasis can not be placed upon this detail of the work. The proper operation of the mixer to insure a uniform consistency of concrete is imperative.

Re-surfacing with Monolithic Paving

Re-surfacing old brick pavement

4-inch brick are laid on a smoothing layer of concrete

Quite a difference from the original surface

Contractors Organization

Thick base

Since the most popular width of pavement for country work not demanding a "double track" is ten feet, the general outline for a contractor's organization of crew will be described on this basis. The number of men required for an efficient gang varies somewhat with the thickness of base. Considering the organization for laying a slab composed of 4-inch brick and 4-inch concrete, thirty-two men are required, when using a one-half cubic yard batch mixer. The distribution of the men is as follows: Ahead of the mixer, nine men are needed; one to set and oil the forms, five to wheel sand and stone from the piles to the mixer hopper, and three to help shovel stone. These three helpers may be eliminated if gravel is used since it is much easier to shovel than crushed rock. At the mixer five men are required; one loading cement into the hopper, one operator, who tends the machinery, one fireman, and two concrete shovelers, who distribute the concrete between the forms properly. If the the mixer is heavy and the subgrade sufficiently soft to require board tracks, one man is kept busy moving these boards forward, and either tamping the concrete or supplying dry mix to the template.

In the paving gang proper, thirteen men are employed. Usually the bricksetter is the boss of this gang, which consists of himself; five carriers, who bring the brick from the piles to the pavement; three stackers, who stack the brick in such order that they can be laid in the pavement with the greatest ease and speed, best face up, and lugs to the rear; one starter, who commences each row for the setter; one batter, who cuts the closing bats to correct size to complete each course; one culler or inspector, who turns over or throws out all uneven, cracked or broken brick; and one roller, who operates the 800-lb. hand roller, bedding the brick and securing a smooth even surface on the pavement. His is an important position, for upon him largely depends the smoothness and eveness of the pavement. Three men usually constitute the grout gang, one charging the mixer, another brooming the first coat into the joints, and the third one taking care of the finishing coat with a squeegee. Finally, one man is needed to keep the pavement covered, wet down, and the forms pulled.

In charge of the whole crew, of course, should be a competent foreman. A waterboy is generally required, who does odd jobs and usually ties the empty cement sacks into bundles for returning. This distribution of men will occasionally have to be changed to suit varying conditions, but it is representative of ordinary conditions. With this organization and a good mixer, from 700 to 900 lineal feet of ten foot pavement should constitute a good ten hour day's work.

Thin base

The organization for the one inch base monolithic pavement is quite similar to the foregoing, using about twenty-five men. Ahead of the mixer is the form-setter, three wheelers, one cement man, one fireman and mixer operator. On the other side of the mixer are two men spreading and striking off the concrete, one brick-setter, one starter, one batter, six carriers, two stackers (if brick are carried in by tongs), one inspector, one roller, three men to the grout machine, and one man for pulling forms, covering, and wetting down the pavement. With such an organization under ordinary conditions from 700 to 1000 lineal feet of nine or twn foot pavement can be laid satisfactorily in one ten hour day.

III. STRENGTH

In the preceeding pages, the evolution and improvement of the brick pavement has been outlined; the construction of the modern monolithic type has been followed through its various stages; and the contractors organization on the road described in detail. First-hand information and data dealing with the latter two items have been gained through the writers' connection with the Vermilion County Bond Issue Road construction during the summer of 1916 in the capacity of inspectors under the direction of Mr. P. C. McArdle, Superintending Engineer. The experience thus gained has proved invaluable during the progress of the tests described in the succeeding pages. Actual road conditions have been approximated as nearly as possible in all the work, and the results have been interpreted with these conditions in mind.

In the summer of 1915, when the monolithic form of paving was receiving great attention in and out of the technical press, several slabs were made at the University of Illinois under the direction of Mr. W. T. Blackburn and broken twenty-eight days later in the T. & A. M. Laboratory. From the results of these tests and the flood of inquiries concerning this pavement received by the University, it was decided to continue the investigation of this new type of pavement. The following pages really constitute a progress report on the work as completed to date. The conclusions drawn must therefore be taken as tentative, reasonable, or probable, and consequently must be subject to revision if the subsequent tests so require. The scope of this investigation has been somewhat broad and has included, in addition to slab tests, tests upon all the component materials to determine their character, suitability, strength, and their wear-resisting qualities. From the making and breaking of seventy-two slabs, data has been gathered concerning four general classes of pavements and their component parts, viz:

Classes of Tests

(1) Monolithic brick slabs of the thin dry mortar bed, or "dry mix" type, such as was evolved at Paris, Illinois, and adopted as standard by the Illinois State Highway Department.

(2) Monolithic brick slabs of the "direct contact" type, such as was developed in Vermilion County, in which the brick are laid directly on the green concrete without the interposing of any layer of dry mortar.

(3) Plain grouted brick slabs.

(4) Plain concrete slabs.

a. Concrete base type (1:3:5 mix)

b. Concrete pavement type (1:2:3 mix).

Each of these four general types is represented by several sets which differ in thickness or other details of construction. There are at least three specimens in each set.

Materials

All materials used in the construction of these slabs were commercial products, bought in the open market in quantity and were high grade materials, though not especially selected for this work.

The brick used were Danville Block, provided through the courtesy and generosity of Mr. Harvey C. Adams, President of the Danville Brick Co., of Danville, Illinois. Four inch wire-cut-lug brick were used on all but nine slabs, six of these being made with two inch straight wire cut bricks, and the remaining three with partially repressed blocks having vertical lugs on one side.

The concrete sand and gravel were uniformly well graded washed products from glacial deposits near Covington, Indiana. The gravel graded from one inch to one fourth inch, while the sand varied from one fourth inch down and contained very little foreign material.

Two kinds of sand were used for grout, the first being the concrete sand screened to pass a one eighth inch screen, while the second, now being used exclusively, was a fine, hard silicious sand obtained from the Lincoln Sand and Gravel Co., of Lincoln. Illinois. This latter material will all pass a one-sixteenth inch screen.

Chicago AA Cement was used throughout, being bought in quantity on the open market.

Proportioning and Mixing

All concrete materials were proportioned by volume, but individual batches were made up by weight, calculated from the weights per cubic foot of the dried materials. In accordance with common practice, though not theoretically correct, one sack of cement was considered as one cubic foot. To insure accuracy and uniformity in proportioning, all sand and gravel was oven-dried.

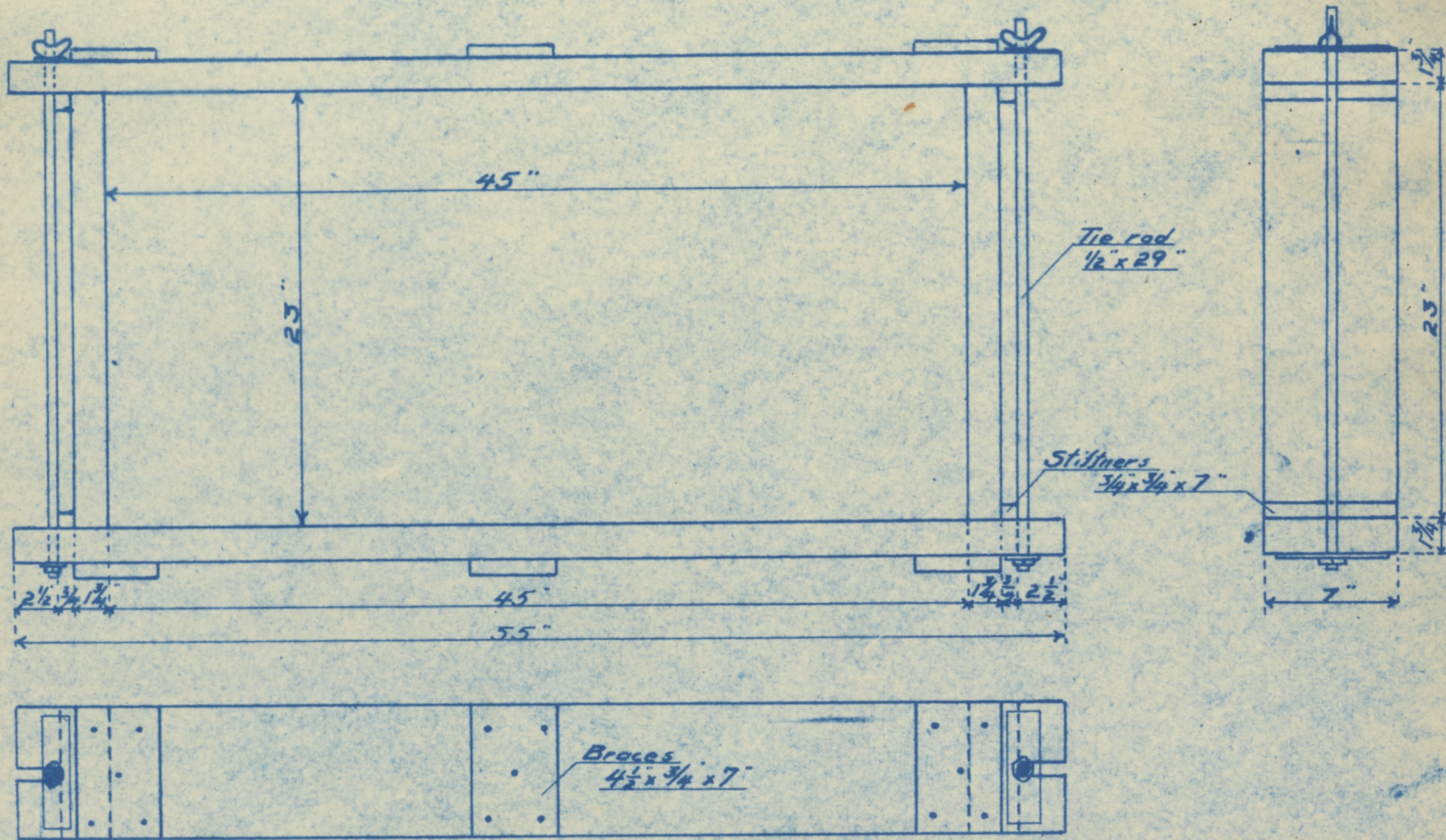
The concrete was thoroughly mixed in a small power-driven batch mixer. At first, the grout was mixed by hand in a pan, but later, after the acquisition of a new mixer, all grout was machine mixed.

Forms

The slabs were made in wooden forms, having inside dimensions of 23 x 45-inches. This held six longitudinal courses of five brick each or eleven transverse courses of two and one half brick each. At first it was not deemed necessary to make these forms of heavy material, for only a small number of tests were anticipated; but as the work progressed, the old forms became warped, and it became necessary to prepare forms more rigid and durable than those first used.

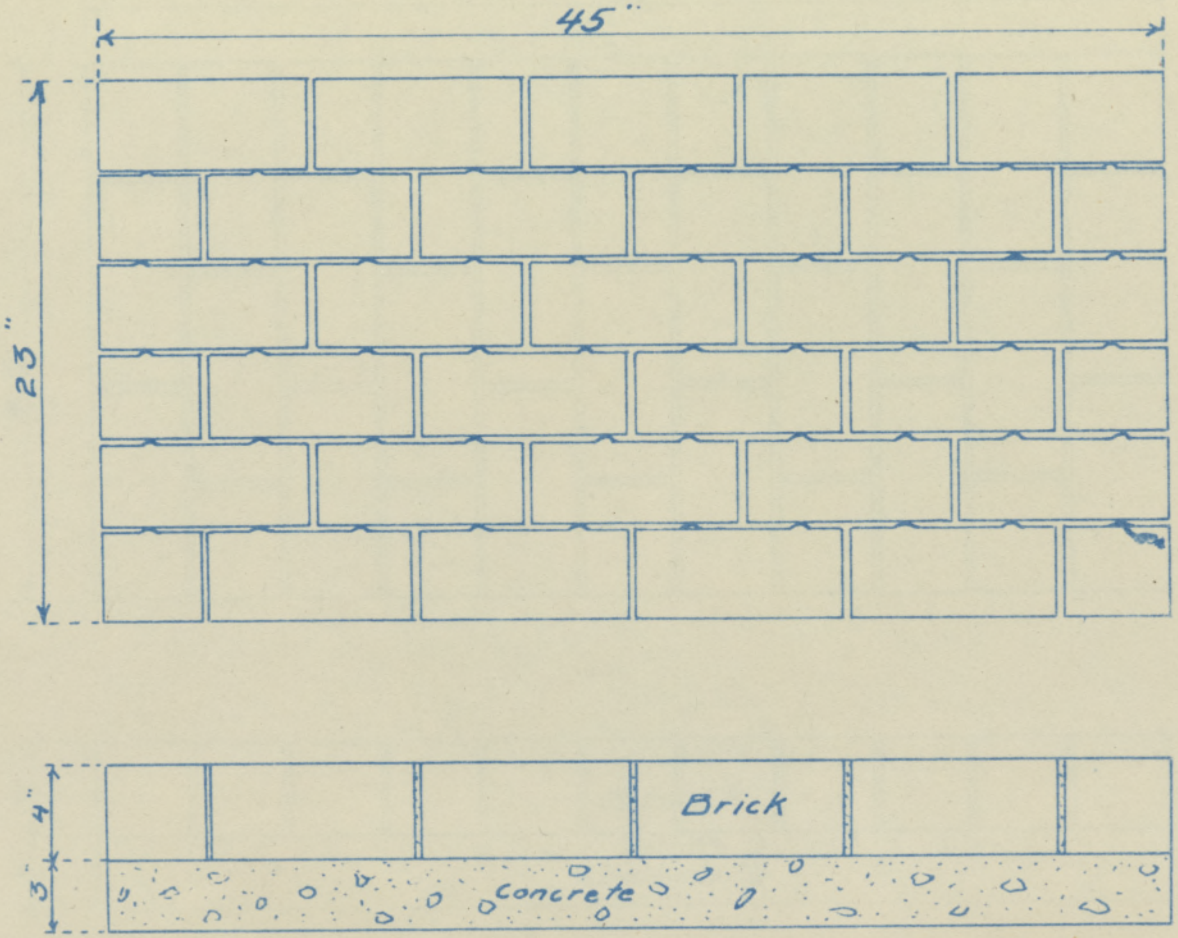
The original forms were made of one-inch pine, six or seven inches wide, nailed together and braced at the ends. The new forms, however, were made of 2 x 7-inch cypress, built in accordance with the plan shown on the accompanying print. Although these are heavier to handle, they are more rigid. The use of tie rods in slots at the ends of the side pieces greatly simplified the work of assembly and removal of the forms. Likewise, the use of guide blocks for the heavy ends insured accurate assembly as well as additional rigidity.

PLAN OF NEW FORMS



Scale: 1 1/2" = 1'-0"

Longitudinal Brick Slab



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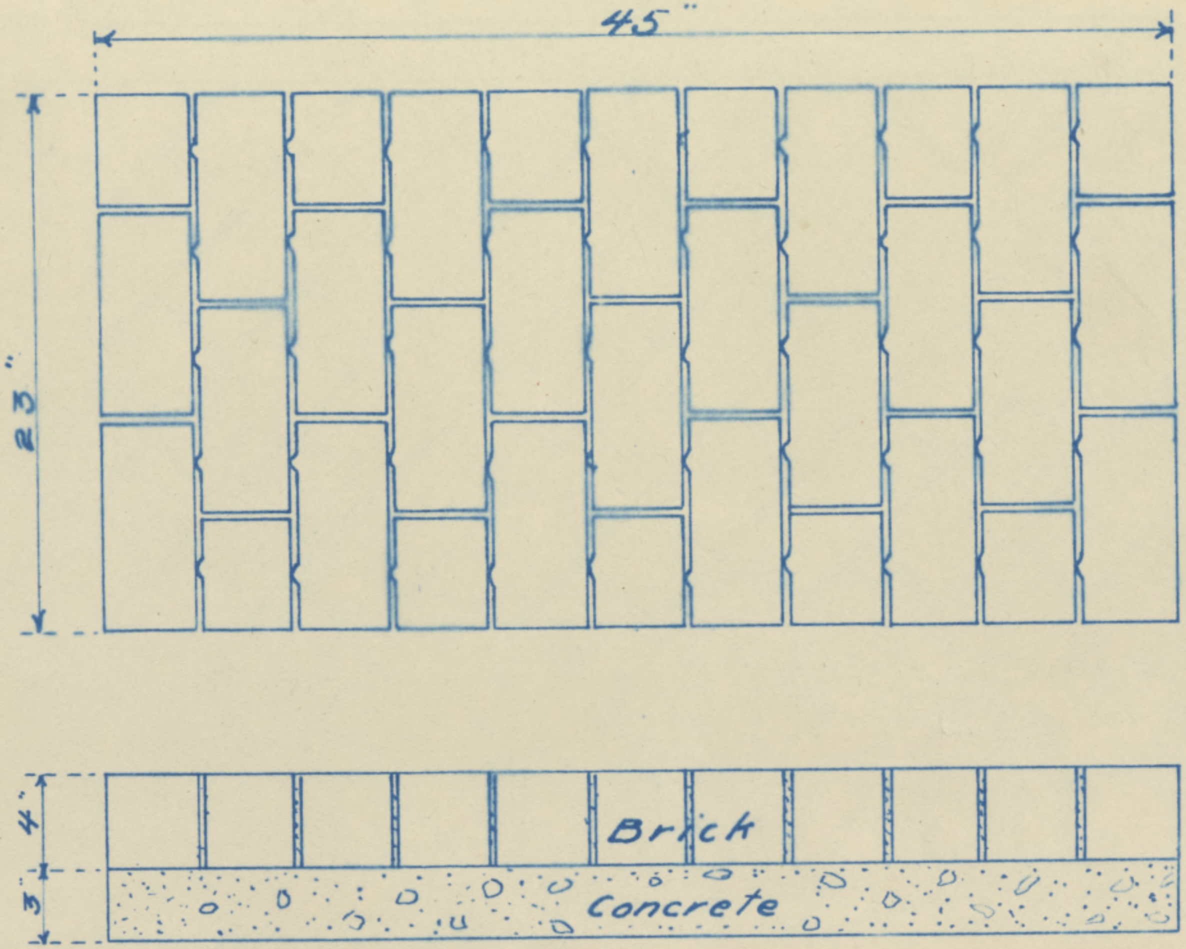
Transverse Brick Slab



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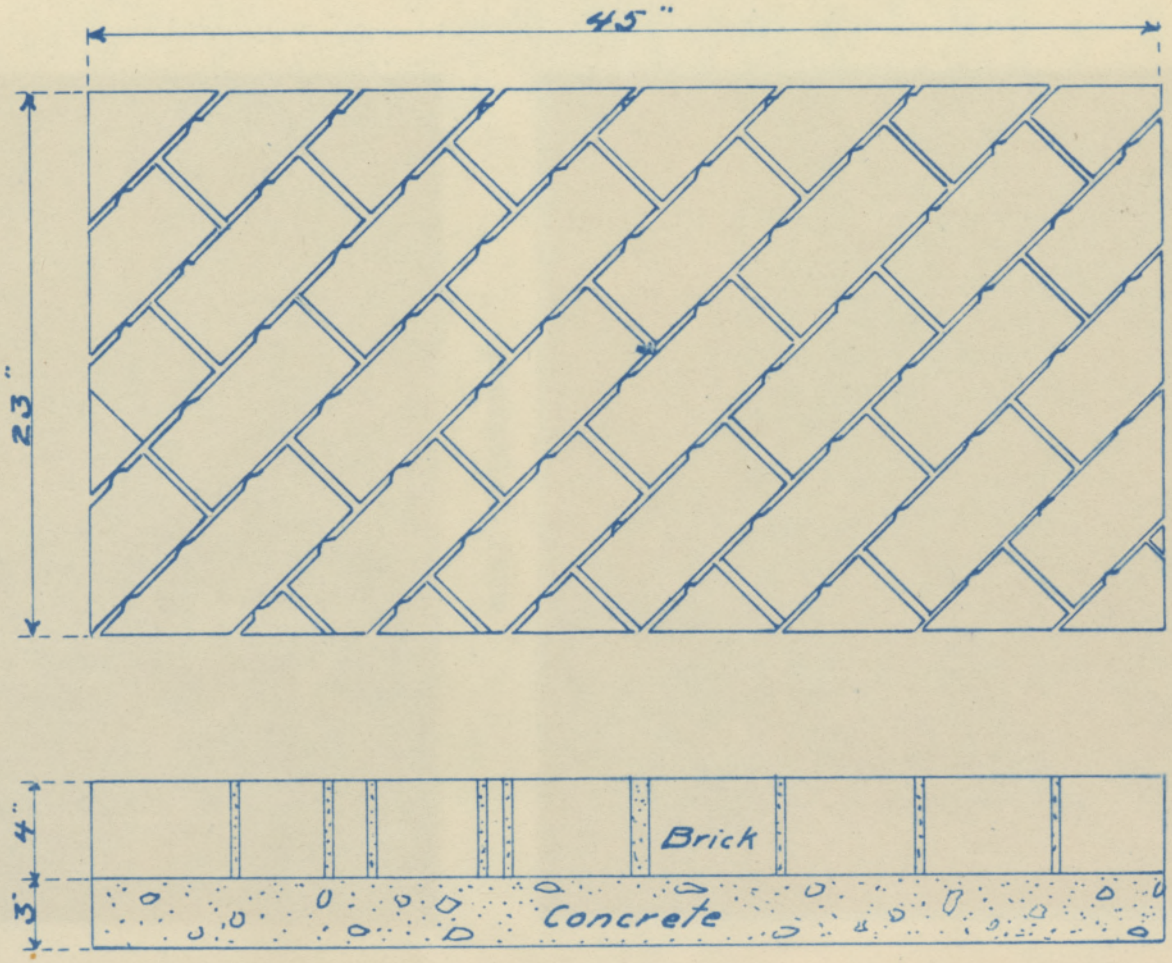
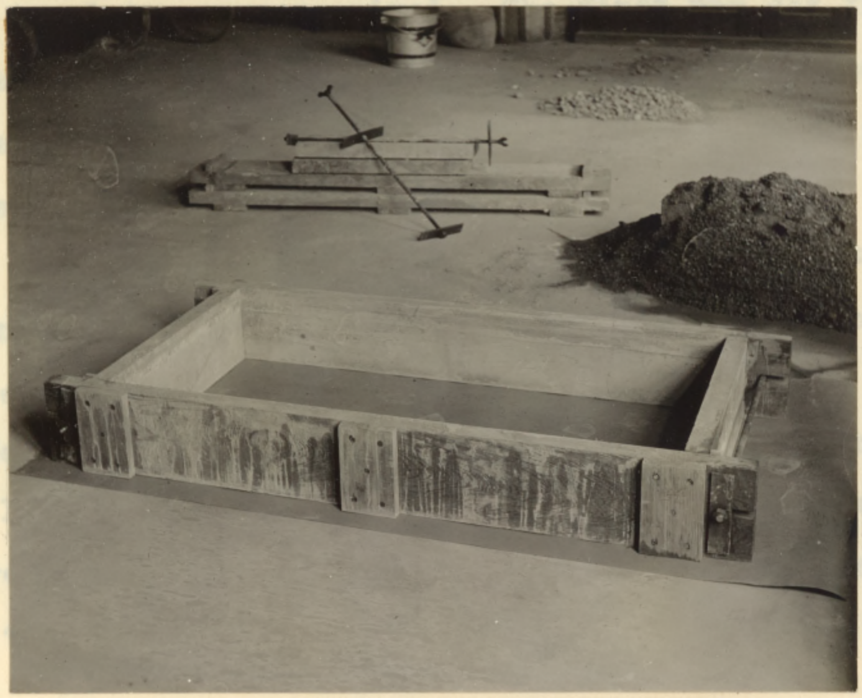
45° Diagonal Brick Slab



Scale: $1\frac{1}{2}$" = 1'-0"

These forms were set on the concrete floor of the laboratory, care being taken to see that the spot selected was level. A layer of heavy building paper was put under each to prevent

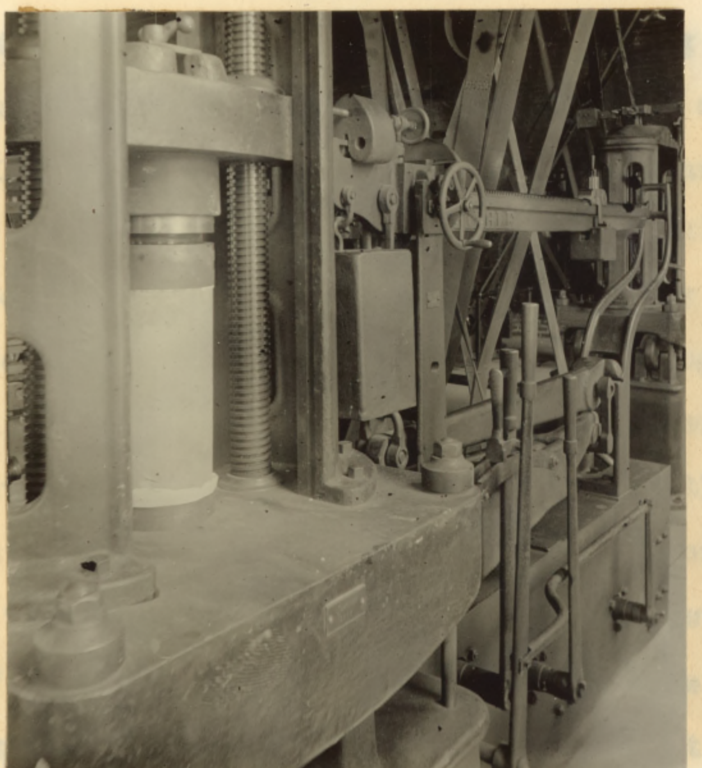


Assembled form

Striking off concrete

the concrete sticking to the floor. After the concrete was deposited and the sides spaded, it was struck off with a wooden template to the desired depth. If a thin layer of dry mix was used, two templates were required. The first was set three-sixteenths of an inch lower than the second and was used simply to cut the concrete to the desired thickness. The dry mix was then spread over the surface and smoothed off with the second template. When the dry mortar was omitted, one template sufficed. This was used both for striking off the concrete and for tamping it to an even surface.

Test cylinders were made at the same time as the concrete base was laid, one cylinder being made for each batch mixed. These were tested at the same age as the slabs, and served as a check on the quality of the concrete.



Cylinder ready for testing

Upon the prepared surface of the concrete the brick were laid by hand, one man laying while another supplied the

Laying brick

brick and bats as needed. At first, when making slabs of the dry mix type, the brick were dipped in a bucket of water and laid directly on the dry bed. It was thought that this would help to set up the dry mix. However, upon breaking these slabs it was noticed that there was a decided tendency for the brick and concrete to separate, especially if in making the test, the pieces fell more than an inch. On examination of the separated bases of several specimens it was noticed that the sand grains were not entirely coated with cement as they should have been. We came to the conclusion, therefore, that the surplus water on the face of the brick had a tendency to wash the cement away from the exposed grains of the dry mix. To test the correctness

Separated slab

Close view of separated base, showing
effect of laying wet brick on dry mix

of this theory, some slabs were made without dipping the brick. These when broken, showed comparatively little signs of separation, and from then on the brick were laid dry. This showed that an intimate mixture of cement and sand, characteristic of concrete could not be obtained in a dry mix, and in addition that the water did cause a separation of the cement from the sand on the surface.

After the brick were laid, they were tamped to a firm bearing and an even surface. For this purpose a light 4 x 4-inch tamper was used, striking on a 1x6-inch board extending over several courses of brick. After this the brick were ready for grouting.

Grouting

The grout was poured on the slabs from a small bucket and worked into the joints by means of a small rubber edged squeegee. Several applications of grout were made, great care being taken to see that all the joints were completely filled. Just before the final set took place, all surplus grout was removed.

Two methods of mixing the grout were employed, - by hand and by machine. A mixer was not available at first, so for the greater part of the first series, the grout had to be mixed by hand. All the ingredients were weighed out, obtaining uniformity in proportioning; but at best it was a rather crude and laborious task to mix a batch of grout by hand and maintain it at the proper consistency. Practice soon lessened this trouble, but until the mixer was obtained it was a rather difficult matter to get the best grout. This difficulty was greater of course, when using the coarse grout sand, and separation was avoided only by constant and vigorous stirring. Machine mixed grout, on the other hand, exhibited this tendency to separate to a much less degree, but even if then the coarse sand were used the grout had to be continually agitated after leaving the mixer. No difficulty whatsoever was experienced while using the fine sand.

While the grout was being applied, nine briquettes were made and allowed to cure under the standard conditions for cement mortar briquettes. Four of these were tested at the end of seven days and the remaining five on the twenty-eighth day. These served as a check on the uniformity of the grout.

Storing

The day after the slabs were made they were covered with about two inches of sand and kept moist until the twenty-sixth day, when they were uncovered and allowed to dry in air preparatory to breaking on the twenty-eighth day. The testing laboratory being located about two blocks away necessitated transportation of the slabs by wagon. Careful observation, however, has not disclosed any evil effects attendant upon this handling.

Curing the slabs

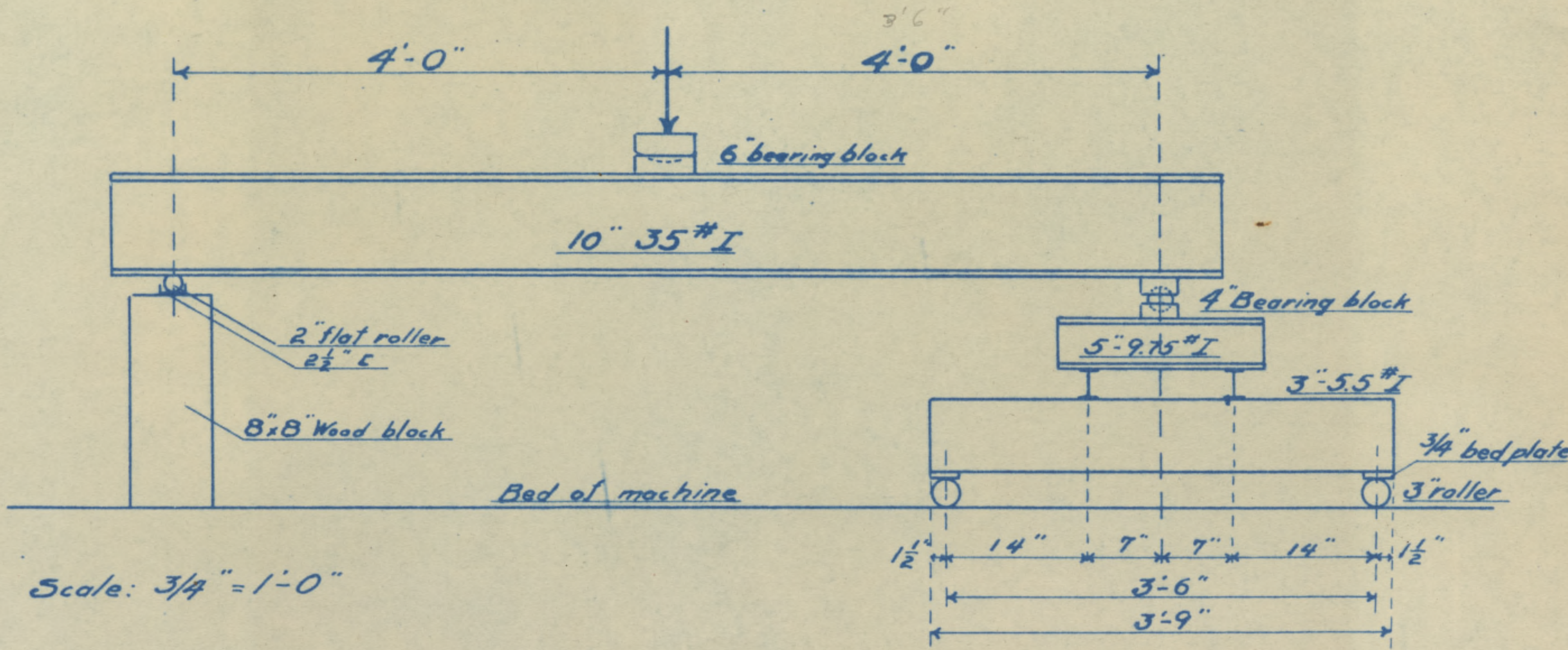
Forms removed preparatory to testing

Testing

The slabs were broken in an Olsen testing machine of 200,000-lb. capacity, applying the load at the rate of 50-lbs. per second. Owing to the fact that the slabs were too wide to go between the screws of the machine, they were placed upon one arm of the machine outside the screws and the load transferred by means of a needle beam. The needle beam was so spaced that the beam reading on the machine was just twice the load applied to the slab. The load was transferred from the needle beam to the slab by means of a bearing block resting on a loading rig of light I-beams. These I-beams concentrated the load at the third points of the span, giving a uniform bending moment over the middle third of the slab. In order to facilitate handling, a complete set of guides, clamps, and templates was devised, which insured quick and accurate setting of the equipment and test specimens. The photographs accompanying this discussion will serve to show the various parts of the equipment ready for the slab to be placed, the load to be applied, a typical broken specimen, and the manner of handling the specimens before and after breaking.

The main bearings were 3-inch cold rolled shafting. On these were placed 3 x $\frac{3}{4}$ -inch bars of cold rolled steel, upon which the slab rested. The free span was 42 inches. All necessary dimensions are shown on the accompanying diagram. In order that complete and true bearing might be obtained, the main bearing plates and loading rig were bedded in plaster of paris.

DIAGRAM SHOWING METHOD OF BREAKING SLABS



Scale: 3/4" = 1'-0"

Equipment ready for Slab to be placed.

Slab ready for Load to be applied

A broken specimen

Method of handling, showing sling used

Exposure after Testing

After breaking, the specimens were placed out of doors with the broken edges uppermost, and exposed to the elements.

Storing slabs after breaking

Extreme conditions were thereby attained, the effects of which are now under observation. Some of the slabs have been exposed for over a year, but as yet the various types have not been exposed sufficiently long to warrant any definite statements concerning their action, except that some of the earlier dry mortar specimens are showing a tendency toward separation. Whether this is due to the manner of construction or to contraction of the concrete, can not be definitely stated.

Problems Met

There were many problems of varying importance to be met in this work. Some of them have been solved, and others are still present. The question which has caused the most discussion is the location of the neutral axis of the slab. No method has been devised as yet to accurately locate its position, but the assumption has been made throughout that it lies in the center of the slab, regardless of the varying thicknesses of base and wearing surface. This assumption may be erroneous, but it appears to be on the safe side, so all calculations have been made for the compound slabs as if they were uniform beams. A possible method of determining the position of the neutral axis is to set at least two sets of metal plugs in the slab, one set on the upper side near the edge, and the other on the lower side, both being set at equal distances from the center, and then take a series of strain gauge measurements as the load is applied. If it is then assumed that sections plane before bending remain plane after bending as in the case of homogeneous beams, and the points obtained plotted and connected, the intersection of these lines should give the location of the neutral axis. Several sets of tests on various thicknesses of slabs would be necessary, but the results obtained should warrant the time spent.

Computation of Data

In considering the data gathered from the tests, the method used in figuring the results must first be explained. For simplicity, all possible factors were reduced to one constant for each thickness of slab, reducing also the chance for error. The various terms and symbols used follow:

L = Total breaking load in pounds.

M = Bending moment in inch pounds, figured by multiplying one half the load by one third the span, or $\frac{1}{2}L \times \frac{42}{3} = 7L$.

d = Thickness of slab in inches.

c = Distance from the surface of the slab to the neutral axis in inches. This was assumed to be in the center of the slab, consequently $c = \frac{1}{2}d$.

b = Width of slab, equals 23 inches.

I = Moment of inertia of a cross section of the slab about the assumed neutral axis. Since the cross-sections were rectangular, $I = \frac{1}{12} bd^3$.

S = Modulus of rupture as computed from the formula $S = \frac{Mc}{I}$.

Example of computations for a 7-inch slab

b = 23"   d = 7"   c = $3\frac{1}{2}$"   M = 7L

$$I = \frac{23 \times 7^3}{12} = \frac{23 \times 343}{12} = 657.42$$

$$S = \frac{Mc}{I} = \frac{7L \times 3.5}{657.42} = \frac{24.5\ L}{657.42} = 0.03737\ L$$

Taking Slab No.A3 as an example, having a breaking load

L = 15,600

$$S = 0.03727 \times 15,600$$

$$= 581$$

All the slabs were figured in the same manner.

IV. INTERPRETATION OF RESULTS

Conditions

When studying these results, or when thinking of monolithic construction, the idea of two separate parts merely stuck together should be avoided. The terms base and wearing surface are misleading, but necessary in order to distinguish the two component materials of a slab. It should be thought of as a solid beam, and to use an illustration taken from the concrete people, "having the large aggregate on the top." If the results are viewed in this manner, many of the features brought out will be more easily understood.

In interpreting the results of these tests we shall endeavor to tie them in with some existing road conditions. For instance, a washout of the subgrade over a considerable distance or else an upheaval of the subgrade over the same distance, the rest of the subgrade remaining normal. When a washout occurs, the pavement slab acts as a continuous beam with the load applied on its upper surface. This sets up a condition of stresses such that at the center of the span the slab is in tension on the under side and compression on the upper, while at the ends these conditions reverse, giving compression in the lower fibers and tension in the upper. If the subgrade heaves because of frost action, these conditions would simply be reversed, Thus we see that it is necessary to study the behavior of the slabs under two conditions of loading, such that the base is in tension and the wearing surface in compression and vice versa.

As it was impossible to make tests on continuous slabs, each of the foregoing sets of stress conditions were studied separately. Various types of construction were tested, and the effect of changing the thickness of base was noted. Tests were also made on separate slabs of each of the component parts of monolithic paving slabs.

Deflection Tests

During some of the first tests an attempt was made to measure the deflection of the slab before rupture. This, however, did not prove feasible, since the deflections were very slight, probably less than two thousandths of an inch on either brick or concrete slabs. The important feature was indicated, however, that the compound slabs deflect the same as those of homogeneous construction. If there were much difference between the modulii of elasticity of the component parts, separation would take place under the loading. As this did not take place, we must conclude that a compound beam may be said to have but one coefficient of deflection.

Transverse Tests

It will be noted that ~~that~~ the slabs with the brick laid transversely are much lower in strength than are those having the brick laid longitudinally, especially when the brick are in tension. This may reasonably be expected, as there is no keying action taking place between the brick, and there is only the tensile bond between the brick surfaces and the grout to resist the bending moment. It is therefore the natural assumption that the slab should always fail transversely. However, such is very seldom the case.

The extreme case of a washout taking place so that the slab is supported only at the two ends, i.e., having the supports exactly transverse to the longitudinal axis of the road, and giving no support along that axis, rarely, if ever, occurs. In most instances the slab is supported along one side as well as at the ends even when a severe washout takes place. The support is almost invariably diagonal at the ends at least, causing a combination of stresses, longitudinal and transverse, which will now be analysed as exhibited in simply supported slabs.

Reason for High Value

The slab has different ultimate strengths in different planes of fracture as shown by these tests, but apparently the coefficient of deflection is the same in all planes. Consequently, any load which will give sufficient deflection to cause transverse rupture must of necessity cause failure longitudinally. Therefore, the higher value of the longitudinal strength helps the transverse section to support the load until the deflection is great enough to cause rupture. The failure must then either take place simultaneously in both directions or along some curve of uniform stress in both directions. This latter case appears the most probable, and seems to be borne out by actual road conditions.

As an illustration of this theory, cases may be pointed out on grouted brick roads where loads sufficiently heavy to cause fracture have come on the pavement along an unsupported edge. In these cases a simple transverse failure did not occur, nor was a rectangular section broken out, but rather a segmental or crescent-shaped piece was broken off.

Heaving Action

The slab is weaker under the action of forces from the under side. That is, if heaving takes place the slab will withstand less than if spanning action took place. Heaving is caused by the freezing of water in the soil, but there is no data as to the intensity of the pressure set up. However, any loads which may come on the wearing surface will serve to neutralize these forces, as does also the weight of the slab. Moreover, one of the functions of a pavement is to keep the subgrade dry. This is attained by the monolithic pavement. So we see that heavy heaving action could only take place under extreme conditions such as a long flood followed by a heavy freeze. Such a condition is so rare that it is not economical to regard it in any ordinary design. Consequently we believe that it is safe to figure the strength of monolithic slabs as if spanning conditions were the maximum.

Diagonal paving

On examination of the accompanying tables it will be noticed that two sets of tests were made in which the brick were laid in courses at 45^0 with the sides of the forms. Both sets were tested with the concrete in tension. The most probable reason for the low modulus of rupture is that there is little keying action and that the bond between the glazed ends of the brick is low. One thing, however, is shown which may be worth noting. That is, the assumption that laying the brick in courses at a 45^0 angle with the line of traffic will increase the strength and resistance to wear is erroneous so far as any increase in strength is concerned.

Comparisons - Sand Cushion Type

Some comparisons may be suggestive and instructive in showing how this new type of pavement compares in strength and economy with the older forms of pavement. For example, consider the old sand cushion type, having a concrete base to carry the load. First compare the thicknesses of base required to carry the same load as 5-inch and 7-inch monolithic slabs. If it is assumed that a 1:3:5 mix is used for this base, which is as rich as is ever used in practice, it will be found that it would take a trifle over 5½ inches of base alone to support the same load as would a 5-inch monolithic pavement. The brick used would be the same in either case, and therefore it would save 4½ inches of concrete to use the 5-inch monolithic; and in addition, in the older type the sand cushion would be an added expense. Assuming a 1½ inch sand cushion, which is usual, it would require six inches more excavation for the sand cushion type than for the monolithic slab of equal strength in order to bring both types to the same elevation. These are facts of economic importance! How much more road could be built with the money saved by eliminating six inches of cut and 4½ inches ofeconcrete over the entire area? It is well worth considering.

If a stronger pavement is desired, consider then the 7-inch monolithic as compared with the sand cushion type. It would take a concrete base 7¼ inches thick to support an equal load, which would result in the saving of 4¾ inches of concrete and 6¼ inches of cut by using the monolithic construction. Is not this well worth while?

There is still another item to be considered in comparing the sand cushion and monolithic forms of paving. In the sand cushion type the base is relied upon to carry all the load, the brick merely serving as a wearing surface. If the surface is thoroughly grouted, which is not always the case, this slab will carry about 5400 lbs. before giving way. From this point on the concrete alone must continue to carry any additional load until its ultimate strength is reached. The pavement, however, has a weak spot where the brick slab has failed, and this spot will grow larger, the brick jarring loose and cobbling under the action of traffic, making the pavement rough and unsatisfactory for motor traffic, although the foundation may still support the load. Such is not the case with the monolithic type. This pavement remains smooth and unbroken until the ultimate loading has been attained. Even after this, the resulting crack is not as bad as in the former case, which occurred much sooner, and there is less danger of cobbling because of the complete bonding of the brick. This is no small advantage, and should be taken into consideration when designing or specifying a new pavement or a country road.

Rumbling

The nuisance of "rumbling" is also done away with if monolithic construction is used. Rumbling is due to the sand cushion shrinking or washing away from the wearing surface. This allows the grouted brick slab to span the space left unfilled and act as a sounding board similar to the head of a drum. The sound of the blows from a horse's hoof or the rattle of a steel-tired wagon is intensified and prolonged, and this noise is commonly termed "rumbling". This is a serious deterant to the construction of the old sand cushion type. It need no longer be feared if a monolithic pavement is laid, for the sand cushion and its many evils have been done away with.

Rapidity of Construction

Further, the monolithic pavement has the advantage in length of time required for construction. The concrete base of the sand cushion type must set at least four days before the wearing surface can be applied. This, if grouted, must also be allowed to cure for several weeks before being opened to traffic. The monolithic type, on the other hand, is constructed and cured as a unit, thus eliminating the time of curing of the concrete base, and the extra time of placing the sand cushion and laying the brick - a saving of fully a week.

After taking all these features into consideration, and giving them their due weight according to both the layman's and the engineer's viewpoint, it will appear that the old sand cushion pavement should not be laid in the future except in cases where other considerations, such as opening the surface for repair work, etc. take precedence over durability and strength, and even here the cement-sand bed is decidedly preferable to the sand cushion if the grout filler is used. If the sand cushion is used a soft joint filler should be employed.

Comparisons - Concrete Road Type

As a further comparison, consider the monolithic slab and a slab of 1:2:3 concrete, such as is commonly employed in concrete roads. The tests show that a 7-inch concrete slab will carry 12,815 lbs. before breaking, while a 7-inch monolithic slab will carry 14,293 lbs. On this basis a 7-inch monolithic slab is as strong as 7.4 inches of solid concrete. The saving in excavation in this case is not enough to be concerned with, but the question of the extra half inch of concrete and the relative wearing qualities of the surface must be considered. Consequently when we see that the monolithic pavement is fully as strong or even stronger than a concrete slab, and in addition has a better and more lasting wearing surface, we come to the conclusion that this new type of pavement is the best that has yet been devised.

DRY MIX TYPE

Description	Slab No.	Thickness in inches: Concrete	Brick	Total	Material in Tension	Total load lbs.	Modulus of Rupture lbs. per sq. in.
Brick laid	A1	3	4	7	Concrete	14225	529
longitudinally	A2	3	4	7	"	13055	486
Concrete 1:3:5	A3	3	4	7	"	15600	581
Average						14293	532±19
Brick laid	B1	3	4	7	"	10490	391 *
transversely	B2	3	4	7	"	11845	442
Concrete 1:3:5	B3	3	4	7	"	9925	45 *
	B4	3	4	7	"	11775	439
	B5	3	4	7	"	13000	485
Average						12207	455±12
Brick laid at	C1	3	4	7	"	10440	389
45° angle	C2	3	4	7	"	10890	406
Concrete 1:3:5	C3	3	4	7	"	13125	489
Average						11485	428±21
Brick laid	D1	2	4	6	"	9165	465
longitudinally	D2	2	4	6	"	10420	529
Concrete 1:3:5	D3	2	4	6	"	10080	511
Average						9888	502±13
Brick laid	E1	3	4	7	Brick	12655	471
longitudinally	E2	3	4	7	"	12730	474
Concrete 1:3:5	E3	3	4	7	"	12130	452
Average						12505	466±5
Brick laid	F1	3	4	7	"	4310	161
transversely	F2	3	4	7	"	4475	167
Concrete 1:3:5	F3	3	4	7	"	4290	160
	F4	3	4	7	"	3200	119 *
Average						4358	163±2
Brick laid at	G1	3	4	7	"	6350	237
45° angle	G2	3	4	7	"	7140	266
Concrete 1:3:5	G3	3	4	7	"	7665	285
Average						7052	263±9
Brick laid	H1	2	4	6	"	10015	588
longitudinally	H2	2	4	6	"	10850	551
Concrete 1:3:5	H3	2	4	6	"	9910	503
Average						10258	521±10
Brick laid	a	$4\frac{3}{16}$	3	$7\frac{3}{16}$	Concrete	13100	465 +
longitudinally	b	$4\frac{1}{4}$	4	$8\frac{1}{4}$	"	21500	580 +
Concrete 1:2:4	c	$7\frac{1}{16}$	0	$7\frac{1}{16}$	"	12500	460 +
Cement-Sand 1:3	d	1	5	5	"	6700	490 +

Note: Results marked * not included in average
" " + obtained on special set of slabs first tested

DIRECT CONTACT TYPE

Description	Slab No.	Thickness in inches			Material in Tension	Total load lbs.	Modulus of Rupture lbs. per sq. in
		Concrete	Brick	Total			
Brick laid	K 1†	3	4	7	Concrete	13035	486
longitudinally	K 2†	3	4	7	"	11875	442
Concrete 1:3:5	K 3†	3	4	7	"	13550	505
Average						12820	478±13
Brick laid	L 1‡	3	4	7	"	11625	433
longitudinally	L 2‡	3	4	7	"	12725	474
Concrete 1:3:5	L 3‡	3	4	7	"	13510	504
Average						12620	470±12
Brick laid	M 1	4	2	6	"	10935	558
longitudinally	M 2	4	2	6	"	10950	559
Concrete 1:3:5	M 3	4	2	6	"	11000	562
Average						10962	560±1
Brick laid	N 1	1	4	5	"	7750	566
longitudinally	N 2	1	4	5	"	7375	539
Concrete 1:2½:4	N 3	1	4	5	"	7075	517
Average						7400	551±11
Brick laid at	O 1	1	4	5	"	5600	409
45° angle	O 2	1	4	5	"	5655	413
Cement-Sand 1:3	O 3	1	4	5	"	4230	309 *
Average						5628	411±2
Brick laid	P 1†	3	4	7	Brick	11265	419
longitudinally	P 2†	3	4	7	"	12175	454
Concrete 1:3:5	P 3†	3	4	7	"	11750	437
Average						11730	437±7
Brick laid	Q 1	4	2	6	"	12500	638
longitudinally	Q 2	4	2	6	"	11120	568
Concrete 1:3:5	Q 3	4	2	6	"	11485	585
Average						11702	584±16
Brick laid	R 1	1	4	5	"	7320	419
longitudinally	R 2	1	4	5	"	7515	454
Concrete 1:2½:4	R 3	1	4	5	"	7600	437
Average						7478	437±7

Note: Results marked * not included in averages
In sets marked † the concrete set 1½ hours
" " " ‡ " " " 5 "

GROUTED BRICK SLABS

Description	Slab No.	Thickness in inches			Material in Tension	Total load lbs.	Modulus of Rupture lbs. per sq. in.
		Concrete	Brick	Total			
Brick laid	S 1	0	4	4	Brick	4150	474 *
longitudinally	S 2	0	4	4	"	5065	578
on half points	S 3	0	4	4	"	5750	657
Average						5407	617 ± 27
Brick laid	T 1	0	4	4	"	5570	636
longitudinally	T 2	0	4	4	"	4115	470 *
on third points	T 3	0	4	4	"	5680	649
Average						5625	642 ± 4
Repressed vertical	U 1	0	4	4	"	5050	577
lug bricks laid	U 2	0	4	4	"	4610	526
longitudinally on	U 3	0	4	4	"	4535	517
half points Av.						4732	540 ± 19
Brick laid	V 1	0	4	4	"	1310	150
transversely	V 2	0	4	4	"	1375	157
on half points	V 3	0	4	4	"	1285	147
Average						1325	151 ± 2

Note: Results marked * not included in average.

PLAIN CONCRETE SLABS

Description	Slab No.	Thickness in inches			Material in Tension	Total load lbs.	Modulus of Rupture lbs. per sq. in.
		Concrete	Brick	Total			
Foundation type	W 1	7	0	7	Concrete	10420	388
Concrete 1:3:5	W 2	7	0	7	"	12850	479
	W 3	7	0	7	"	11935	445
Average						11735	437± 18
~~Foundation type~~ Road type	X 1	7	0	7	"	12045	449
Concrete ~~1:3:5~~ 1:2:3	X 2	7	0	7	"	13625	507
	X 3	7	0	7	"	12775	476
Average						12815	477± 11
Road type	Y 1	6	0	6	"	10065	510
Concrete 1:2:3	Y 2	6	0	6	"	10110	507
	Y 3	6	0	6	"	8360	424 *
Average						10087	509± 1

Note: Results marked * not included in average

TYPICAL FRACTURES

Dry mix type

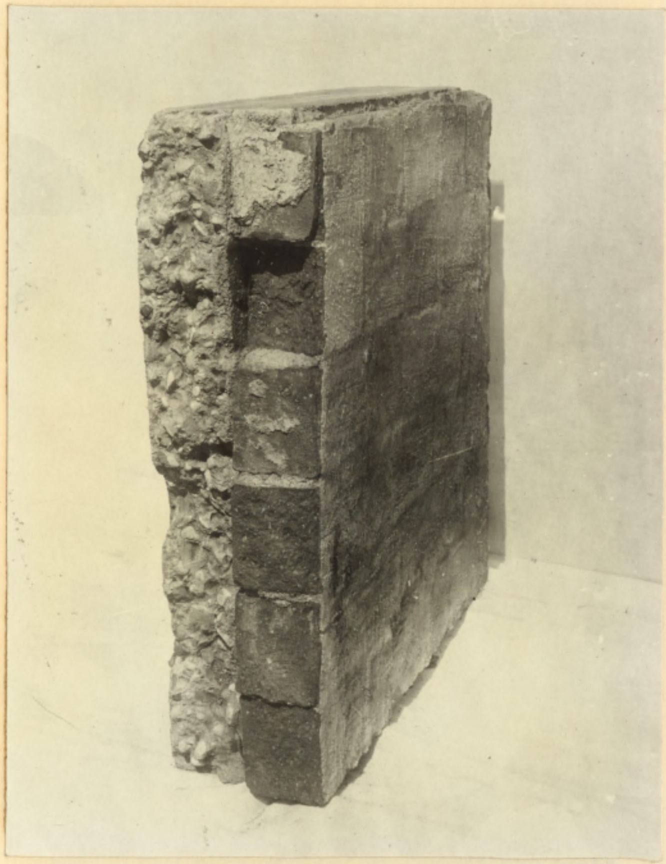
4-inch brick
3-inch concrete

Dry mix type

4-inch brick
3-inches concrete

Dry mix type

4-inch brick
3-inch concrete



Dry mix type

3-inch brick
4-inch concrete

Dry mix type

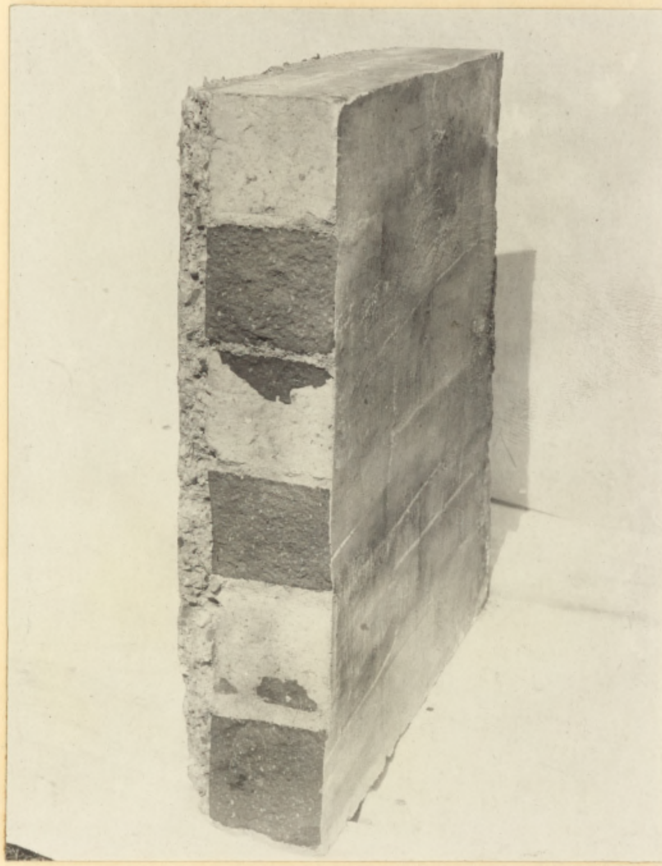
4-inch brick
3-inch concrete

Direct contact type

4-inch brick
3-inch concrete

Direct contact type

2-inch brick
4-inch concrete



Direct contact type

4-inch brick
1-inch concrete

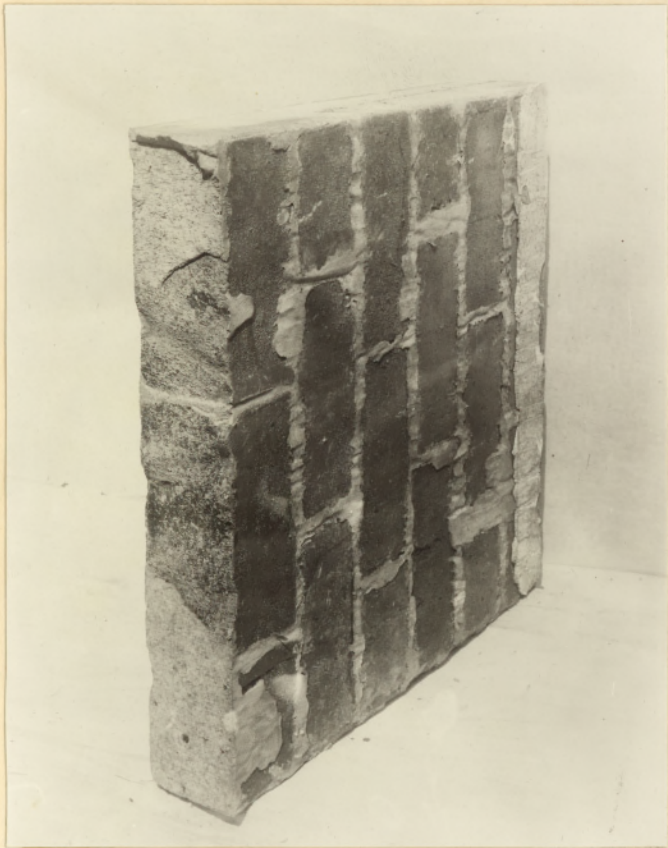
Dry mortar base

4-inch brick
1-inch base (1:3)

4-inch brick

4-inch brick
laid on third points

4-inch semi-repressed brick
Straight vertical lug



4-inch brick

7-inch concrete slab

Shattered brick
Showing strength of grout

"POOR GROUTING"

CHECK TESTS ON MATERIALS

Group	Size of cylinder inches	Concrete cylinders Total load lbs.	Concrete cylinders Strength lbs per sq. in.	Grout Briquettes lbs. per sq. in. 7 day	Grout Briquettes lbs. per sq. in. 28 day
A	8 x 16	100,000	1990		
	"	100,000	1990		
	"	90,000	1790		
Average		96,666	1923		
B	6 x 12	48,610	1724	290	390
	"	53220	1885	410	470
	"	50,550	1790	300	440
	"			350	445
					450
Average		50,793	1796	325	439
C	6 x 12	67620	2390		
	"	71750	2535		
	"	61400	2170		
	"	72470	2560		
Average		68310	2415		
D	8 x 16	114,940	2290		
E	8 x 16	100,000	1990		
	"	100,000	1990		
	"	90,000	1790		
Average		96,666	1923		
F	6 x 12	58,530	2070	375	500
		67,400	2380	350	550
				405	545
				405	525
					525
Average		62,965	2225	384	529
G	6 x 12	67,620	2390		
	"	71,750	2535		
	"	61,400	2170		
	"	72,470	2560		
Average		68,310	2415		
H	8 x 16	114,940	2290		

CHECK TESTS ON MATERIALS

Group	Size of cylinder inches	Concrete cylinders		Grout Briquettes lbs. per sq. in.	
		Total load lbs.	Strength lbs. per sq. in.	7 day	28 day
K	6 x 12	54870	1936	470	635
	"	52680	1860	495	625
	"	58390	2060	505	670
				420	680
					625
Average		55313	1950	472	647
L	6 x 12	57160	2022	315	470
	"	51360	1813	300	555
	"	50880	1800	325	530
				310	510
Average		53133	1880	312	537
M	6 x 12	51150	1822	315	520
	"	46760	1652	295	515
	"	56200	1986	315	560
				270	530
					560
Average		51370	1817	299	537
N	6 x 12	68,070	2407		
	"	58830	2080		
Average		63450	2244		
O		No cylinders			
P	6 x 12	54870	1936	470	635
	"	52680	1860	495	625
	"	58390	2062	505	670
				420	680
					625
Average		55313	1950	472	649
Q	6 x 12	51150	1822	315	520
	"	46760	1652	295	515
	"	56200	1986	315	560
				270	530
					560
Average		51370	1817	299	637
R	6 x 12	68070	2407		
	"	58830	2080		
Average		63450	2244		

CHECK TESTS ON MATERIALS

Group	Size of cylinder inches	Concrete cylinders Total load lbs.	Concrete cylinders Strength lbs. per sq. in.	Grout Briquettes lbs. per sq. in 7 day	Grout Briquettes lbs. per sq. in 28 day
S				555	640
				540	660
				580	600
				585	630
					600
Average				565	626
T				475	635
				435	530
				435	595
				400	600
					650
Average				436	602
U				555	640
				540	660
				580	600
				585	630
					600
Average				565	626
V				555	640
				540	660
				580	600
				585	630
					600
Average				565	626
W	6 x 12	57160	2022		
	"	51360	1813		
		53133	1880		
Average					
X	8 x 16	125150	2490		
	"	150140	2990		
	"	142360	2830		
Average		139217	2770		
X	6 x 12	89510	3170		
Average			2970		
Y	8 x 16	125150	2490		
	"	150140	2990		
	"	142360	2830		
Average		139217	2770		
Y	6 x 12	89510	3170		
Average			2970		