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A STUDY OF THE LIME MORTAR BRICKWORK OF A 26-YEAR-OLD HOUSE

by

P.T. Hodgins and T. Ritchie

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PREFACE

An exceptional opportunity was afforded during the demolition of a brick residence in Ottawa to make careful field observations and to obtain samples for subsequent laboratory study. The results of these studies are now reported.

The fact that the brick masonry had been laid up with lime mortar made it particularly interesting since it was possible to obtain samples upon which measurements could be made of the bond strength attained after 26 years. The Division is particularly indebted to Mr. Merkley for suggesting the study and for the information provided about the house which had been his family home.

Ottawa
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N.B. Hutcheon
Assistant Director

A STUDY OF THE LIME MORTAR BRICKWORK

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An opportunity to study the properties of brickwork which had been made with lime mortar and exposed to the weather for twenty-six years was afforded when the Federal District Commission, in connection with park development, demolished a brick house in April, 1958 on Ottawa's Riverside Drive. The house had been occupied by the Merkley family, and it was Mr. Hugh Merkley, Vice-President of the Ottawa Brick and Terra Cotta Co. Ltd., who brought it to the attention of the Division of Building Research for possible study, and who supplied valuable information on its construction.

Mr. Merkley said that in the autumn of 1931, his father had built the house of bricks and structural tile manufactured by the brick company which he operated at that time. The mortar for the masonry had been prepared from lime and sand, in a large pit dug on the property, the lime having been slaked from quicklime several months before it was used.

Several visits were made to the building before and during the demolition, and samples were obtained of the materials which had been used. These included many large pieces of the brickwork facing of the building which were cut, in the laboratory, to suitable size for use in tests. These tests included determinations of the tensile and compressive strengths of the brickwork and of its resistance to moisture penetration, as well as measurements of properties of the individual bricks and the mortar.

Description of the House

The house shown in Fig. 1, was a large, two-story structure with over-all dimensions about 36 by 30 feet. An overhanging roof which extended between 2 and 3 feet beyond the walls afforded good protection to the walls.

Rough-textured bricks of various dark shades of red and brown and some almost black in colour were used to face the walls above the foundation. The foundation walls were finished with similar bricks but with smooth faces.

The brick facing above the foundation was bonded to a backing of structural clay tile about 8 inches thick; plaster had been applied directly to the tile to form the inside finish of the wall. The brickwork was laid in a bond pattern consisting of 5 courses of stretchers (bricks laid end-to-end) between the courses of headers (bricks laid end-out to bond to the back-up). During construction the brickwork had been back-plastered and a space which had been left between the bricks and the tiles was filled with sawdust insulation. The structural tiles were T-shaped and interlocked vertically, the stems of the T's pointing inward and outward in the alternate courses. The over-all wall thickness was about 13 inches. The manner of construction of the walls is shown in Fig. 2.

The foundation walls were similar in construction, with the addition of an interior brick finish. They consisted therefore, of brick, tile and brick with an over-all thickness of 16 or 17 inches.

The mortar of the brick veneer of the walls was light yellow and, according to Mr. Merkley, a colouring material had been added during its preparation. The mortar used in the back-up masonry, however, was very light grey and apparently contained no colouring matter. All mortar joints exposed to the weather had been tooled to a concave shape.

The brickwork of the house appeared to be in excellent condition. The bricks and mortar gave no indication of weathering decay. The east wall and part of the north, of apparently sound brickwork, are shown in Fig. 3.

The brickwork over the windows was carried on steel angles, the deflection of which apparently had caused cracks in the brickwork at the corners of the windows.

A separate garage was constructed of the same materials as the house, but had a flat roof surrounded by a low parapet wall. The parapet wall was capped with cast-in-place concrete; the brickwork immediately below was in poor condition, the mortar having come away from the joints in many places. The east wall of the garage is shown in Fig. 4.

The difference between the conditions of the upper parts of the garage walls and of the walls of the house was very striking. It seemed to correspond to the different degrees of protection afforded to the brickwork by the contrasting roof structures. It was not ascertained, whether, in the case of the garage walls, proper flashings had been installed between the parapet and the roof to protect the masonry.

In spite of the good condition of the brickwork of the house, when the bricks and mortar were taken apart, it was noted that faulty bricklaying techniques had frequently resulted in incompletely filled and unbonded joints. This observation also applied to the garage. Almost all the vertical joints between the ends of stretcher-course bricks were incompletely filled. The same was true of the vertical joints of the soldier course which girdled the house at the top of the foundation. These joints were probably purposely underfilled to facilitate the alignment of the bricks. The resulting brickwork was admirable in appearance but its value may have been marred by the poor contact between bricks and mortar.

In the buildings studied, not only were the unfilled areas of the joints of course lacking in any strength, but also there was often a lack of intimate contact between the brick and mortar in the immediate surroundings. Many of the cavities in unfilled joints harboured insects and other small life. A number of cocoons were found in one such shelter.

Figures 5a and 5b illustrate unfilled vertical joints of both stretcher and soldier courses. Figure 5a also shows, at left, a fairly well filled end joint of a stretcher course, which was not pressed together sufficiently for the mortar to enter the depressions of the textured surface of one brick.

Mortar joints are left unfilled for several reasons, the main one probably being that less effort is required to push bricks into mortar beds having empty centres. The mortar at the edges of the joints is allowed to squeeze inward as well as outward, thus reducing the net areas of mortar placed under pressure. A second reason, important in regard to vertical joints, is that the trowel and materials are conveniently handled so that often only a little mortar is dabbed onto the areas to be joined. A third reason may also be that the workmen try to save mortar.

Properties of the Bricks

The facing bricks used in both the house and the garage had been formed without core holes by the stiff-mud extrusion process. They had been finished in three different surface textures, smooth, vertically scored and wire-cut.

The greater part of the wall area of the house was composed of the wire-cut bricks. Those of the foundation and of the soldier courses over the windows, however, were smooth-faced while those of some other parts of the trim were vertically scored.

The bricks varied widely in colour but were mainly shades of red and brown; some, however, were almost entirely black. Most were multi-coloured as the result of a "flashing" treatment involving a change of kiln atmosphere during the burning process. Examples of the bricks are shown in Fig. 6; their mortar-covered faces have been removed by means of a diamond saw.

Bricks of types other than those used in the face of the wall had been employed occasionally in the backing, especially around windows and doors where the large tiles could not be fitted. Here, dry-press bricks and some unusual bricks, extruded in a direction parallel to their length, had been used. One variety of the latter had a single, wide, longitudinal core-hole, while another had two circular longitudinal holes (Fig. 2).

Nineteen samples of bricks from the faces of the buildings were prepared for certain standard tests, including measurements of initial rate of absorption, absorption by 24-hour immersion and absorption by immersion in boiling water for five hours. The properties of saturation coefficient, bulk density and porosity of the bricks were calculated from the results of these tests.

In the test for initial rate of absorption the brick was dried and weighed, then placed with its bedding surface in 1/8-inch of water for one minute. The brick was removed and reweighed to determine the moisture absorbed. In the immersion tests the absorption or amount of water taken up by the brick was expressed as a percentage of the dry weight. The saturation coefficient was calculated as the ratio of the amounts of water absorbed by the brick in the 24-hour test and in the 5-hour boiling test.

In the determination of bulk density, which is the ratio of dry weight to volume, the saturated brick sample was weighed in air and in water; the difference between these values indicated the volume of water displaced by the sample, i.e., the volume of the sample itself.

Porosity was determined as the ratio of pore or void volume to the total volume of the brick, expressed as a percentage. The amount of water absorbed during the 5-hour boiling test was taken to indicate the pore volume; the total volume had previously been determined for the bulk density measurements.

Specific gravity of the solids of the brick is the ratio of the dry weight to the net volume of the solids. The latter was determined by the subtraction of the pore volume from the total volume. Both of these values had been previously determined.

Since mortar was adhering to the surfaces of the samples, it was considered necessary, before the initial rate of absorption test, to cut off the bedding surface of the brick and to make the test on the clean surface thus obtained. Some new bricks treated similarly, however, increased slightly in initial rate of absorption. The results of the tests for this property, therefore, may be only approximate.

The properties of the bricks are shown in Table I. The samples are arranged in order of ascending values of initial rate of absorption.

Fifteen other bricks were used for tests of compressive strength, the test being made on half-bricks capped on the upper and lower surfaces with plaster of paris as required in standard test methods. The strength varied from 5240 psi to 10,350 psi, with an average value of 7015 psi. The relationship of these figures to those of brick and mortar assemblages will be shown later.

There was no indication that the facing bricks had deteriorated as a result of weathering. According to the present specifications of the C.S.A. and A.S.T.M., all the bricks tested would be classified as Grade SW. This Grade is described in C.S.A. specification A82.1-1954 as "Brick intended for use where a high degree of resistance to frost action is desired and the exposure is such that the brick may be frozen when permeated with water."

Mortar Properties

The mortar was a straight lime and sand composition with some yellow pigment added for aesthetic reasons. A partial chemical analysis (Table II) of two mortar samples taken from a single joint in the west wall of the house, was performed by E.C. Goodhue of the Division of Applied Chemistry, National Research Council. One sample was taken near the face of the wall, the other about eight inches in from the surface.

The extent of carbonation of the lime (CaO) and magnesia (MgO), if these are taken together, is calculated as 63.3 and 59.2 per cent for samples Nos. 1 and 2 respectively. If it is considered that the lime alone is carbonated, these figures become 92.8 and 88.2 per cent.

The possibility was considered of some non-carbonated lime and magnesia occurring as sulphates. A sulphate analysis however, performed on two other mortar samples indicated the presence of only a small fraction of one per cent of SO_3. The determination did indicate that more sulphate occurred in the exterior than in the interior mortar. This may be the result of the exposure of the exterior mortar to the atmosphere which may also have caused a difference in its carbonate content.

There is a possibility that some of the remaining lime and magnesia were present in the form of silicates but no determinations were made.

Samples of the sand were recovered from the mortar by means of baths of dilute hydrochloric acid, which dissolved the cementing material. The sand samples were then tested for particle-size gradation and for specific gravity. The results are probably only approximate since the acid could have attacked some of the components of the sand. Also, in the procedure adopted all the very fine suspended matter could not be retained during the frequent changes of the acid solutions needed to leach all the lime from the mortar. Samples of the mortar used with the structural clay tiles within the wall and of the yellow-pigmented mortar used in the facing brickwork were leached separately to obtain two separate sand samples for subsequent tests.

The particle-size grading curves of the sands are shown in Fig. 7 which also indicates, for the purpose of comparison, the limits imposed by A.S.T.M. specification C144-52T on the grading curves for acceptable mortar sands.

The grading curves of the two samples do not differ greatly from one another; probably the same sand was used for both mortars.

The sand, of specific gravity 2.64, was evidently from a natural deposit and had been derived from rocks of igneous origin. It was composed largely of quartz grains; another common constituent was feldspar. Some dark mineral grains and flakes of mica were also discernible to the eye.

During the recovery of the sand for the determination of the grading curves, it was found that the two mortar samples contained, by weight, 72.5 and 70.4 per cent of sand. These values agree closely with those in Table II. The mortar-mix proportions by volume could not be determined from the information available.

Tests were performed to determine the compressive strength and modulus of elasticity (E, Young's modulus) of the mortar and to determine its bulk density, specific gravity and void content. The high content of gross voids in the mortar probably influenced greatly its strength and modulus of elasticity. The samples used in the determinations of density may have been affected by the boiling treatment used in the test.

The compressive strength tests on mortar cubes will be discussed fully; it can be stated, however, that strengths of approximately 200 to 400 psi were recorded on several 2-inch cubes of mortar while one cube, of a smaller and non-standard size, yielded a strength of 700 psi.

In the modulus of elasticity tests, the stress-strain relationships of six mortar prisms were plotted. All the plotted lines curved from the outset, indicating that in this material stress is not proportional to strain. A unit stress of 180 psi was taken arbitrarily as the useful limit of the strength of the mortar, and E values were calculated on this basis. These values ranged from 382,000 psi to 754,000 psi, the average figure being approximately 590,700 psi.

The compression of the mortar prisms was continued to failure, so that additional compressive strength records were obtained. In these tests the ultimate compressive values ranged from 235 psi to 567 psi, with an average value of 445 psi. These figures are higher than those for the 2-inch cubes; no explanation can be advanced to account for this.

Some of the mortar cubes and prisms are shown in Fig. 8. Two serious flaws in the largest cube are evident; it contains a large amount of unmixed lime which is badly cracked and a long, thin void. Similar flaws were common since the mortar had not been prepared for test purposes; they undoubtedly contributed to low compressive strengths and E values.

The compressed faces of the prisms were shellacked and then plastered; the plaster caps after having hardened were filed flat and paralleled as shown for good bedding in the testing machine jaws.

The following values for the properties of the mortar were obtained by methods similar to those used in the tests on the bricks:

Bulk density = 1.74 gm/cc or 108.6 lb/cu ft.
Specific gravity (solids only) = 2.65
Porosity (void volume/total volume x 100%) = 34.4%

An interesting phenomenon was noticed regarding many of the mortar joints, in which a singular ridge and trough pattern stood out in relief on the surface of the mortar when it was separated from the brick. The patterns resembled the etched wood grain of a weathered flat-sawn board. They were revealed even when the joints were broken apart but were particularly clear when the diamond saw was used to separate the brick from the mortar. In the latter case the patterns were apparently etched from the sawing plane by the high-speed spray of cooling water thrown off by the whirling blade.

The patterns are illustrated in Figs. 9a and 9b; the upper photograph shows the mortar in two broken joints, while the lower demonstrates how the patterns were revealed by sawing.

The ridges and troughs tended to follow the longitudinal direction of the mortar bed; considerable wavering from the straight line, however, and even complete reversals of direction were not unusual. The ridges moved in smooth curves, and any reversal of direction was accomplished by a rather sweeping turn.

It is believed that the waverings of the lines of the mortar patterns resulted from local changes of conditions along their lengths and that the greater the change of conditions the greater was the resulting deviation from the "normal" straight line. Variations in the character of the mortar, of the bricks, of their mutual bond, or of their exposure to the air and to weathering all could have constituted such changes of conditions.

Observation indicated in fact, that these variations were responsible for many of the deflections noted. Between many of the solider-course bricks used in the decorative window and doorway lintels, for example, the mortar beds contained patterns in which the ridges and troughs reversed their direction completely at the end of the beds exposed to the air. This phenomenon is illustrated in Fig. 9a. It should be remembered that the back (inside) surfaces of the bricks were exposed to the air in the cavity within the walls.

Several patterned mortar beds from the regular stretcher courses showed a disturbance in the pattern from the effects of contact with the vertical joints at the ends of the bricks. This disturbance is illustrated in Fig. 10 where the mortar intersects vertical joints at both ends of a brick. Frequently the vertical joints were not completely filled with mortar; therefore, they may have given moisture and the atmosphere easy access to these joints, with the observed results.

One possible explanation of the mortar patterns is that they resulted from carbonation of the lime during cycling conditions of wet and dry, or perhaps of heat and cold. The process may have worked continuously and progressively inward through the mortar joints from all exposed faces, or under some conditions, even in the reverse direction (i.e., from the center outward).

The time interval represented by one ridge-and-trough interval in the mortar has not been determined. If such a determination could be made, however, it might be an excellent opportunity to measure the length of time required for the carbonation of a lime mortar joint.

Compressive Strength Tests

A series of tests was made to determine the compressive strengths of various mortar cubes, individual brick samples and brick and mortar assemblages. The mortar cubes approximating the 2-inch standard size were cut from samples taken from the tile back-up where large openings had been filled with mortar. The compressive strength test for individual brick samples was made on half-bricks, capped on the top and bottom surfaces with plaster of paris as required by C.S.A. and A.S.T.M. specifications. Many of the large pieces of brickwork were also cut up in the laboratory to obtain brick and mortar combinations of various shapes.

Some of these last samples consisted of two, three and four half-bricks, with mortar joints between, capped in the same way as were the individual half-brick samples.

Other specimens consisting of three whole bricks and two mortar joints were also obtained as well as some of similar dimensions but with a vertical joint in the middle course.

The results of the tests are shown in Fig. 11. The average, maximum and minimum compressive-strength values are listed for the various types of samples. A compressive load was applied to the brick-and-mortar combinations and to the individual bricks at a rate of 30,000 lb/min and to the mortar cubes at 1200 lb/min.

The strength of the individual cubes of mortar was very low compared to that of the bricks, but when the compression test was made on combinations of brick and mortar, the failure seemed to occur by cracking or shearing-off of surfaces of one or more of the bricks, damage to the mortar apparently being relatively slight. Two of the samples are shown after test in Fig. 12.

In order to investigate the influence of the height of the sample without changing the number of mortar joints, two of the half-brick couplets were sliced through both bricks so that their total height was reduced to that of a single normal brick. The resulting samples, therefore, consisted of a mortar joint sandwiched between two brick wafers, the over-all size and shape being equivalent to that of a half-brick. Their compressive strengths were 4590 and 3690 psi, the average being 4140 psi compared with an average of 3555 psi for the regular-size half-brick couplets.

Since the reduced half-brick couplets were the same size as the half-brick samples, the two types could be compared to determine the influence of the mortar joint. The reduced couplets averaged 4140 psi in compressive strength, while the half-bricks averaged 7015 psi.

A similar study was made on two samples consisting of a pair of half-bricks put together one above the other without mortar but with their contact surfaces ground flat and smooth. These samples had compressive strengths of 7650 and 6820 psi, with an average value of 7235 psi.

It appears that the height of such compressive test samples had a relatively insignificant effect on their strength but that the nature of any discontinuities, such as joints, was quite important. This was because the half-brick couplets with mortar joints were considerably weaker than those with ground joints, while the latter were equal in strength to ordinary single half-bricks.

These tests shed new light on the observation that in compressive tests on brick masonry it is the bricks which show the apparent damage, while the mortar joints may seem unharmed. Actually, the mortar probably yields at the unconfined edges of the joints and concentrates severe stresses in certain parts of the bricks.

Differences in compressive strength were noted between samples containing, on the one hand, well-filled mortar joints and on the other, joints with large voids which the bricklayer had produced by furrowing the mortar bed with his trowel. In the tests of samples consisting of a pair of half-bricks with a mortar joint, for example, two specimens which had joints containing large voids yielded unit strengths of 2960 and 3475 psi, while two others with well-filled joints tested at 3780 and 4000 psi.

Mortar Joint Bond Strength Tests

The ultimate strengths of 45 mortar joints were obtained in a series of bond strength tests by means of an apparatus which placed the joints in tension. Many panels of masonry of various sizes, shapes and brick arrangements were used in the tests. All the joints investigated had been made with yellow-pigmented lime mortar and were usually well bonded although inferior workmanship, which is discussed later, had resulted in some cases in unbonded areas within individual joints or, more often, in complete lack of bond.

Most of the masonry panels tested were obtained from slabs of the brick veneer pried from the faces of the house and garage by the wrecking contractor's men. A few slabs were specially removed from the walls so that fragile masonry such as that of a decorative soldier course could be sampled without mishap. Almost without exception, the masonry samples survived transportation by jeep or truck for several miles over rather rough roads.

A requirement of the tensile-testing apparatus (as of the moisture-penetration test apparatus to be mentioned later) was that the test panels be of a regular rectangular outline, one brick-length in breadth (roughly 8 inches) and one brick-width in thickness (about $3\frac{3}{4}$ inches); the maximum number of horizontal joints in any test panel was limited to four by the dimensions of the apparatus. Panels of this description were cut in the laboratory from the slabs brought from the field. In some cases it was necessary to remove parging (back plastering) mortar; the panels were then allowed to dry thoroughly.

The panels were tested in the first type of bond-strength apparatus described in a DBR Report under preparation. This apparatus gripped two adjoining bricks and applied and measured the tensile force necessary to break the intervening joint. The joint's unit strength could then be calculated in pounds per square inch of gross joint area.

In a few cases the unit strength in terms of the net area of mortar actually bonded to both bricks was also calculated; this indicated the strength which could theoretically have been attained had the joint been completely bonded. In many cases the bonding was complete and thus the two unit strengths mentioned were the same.

The unit tensile bond strengths of the 45 mortar joints are given in Table III. It should be remembered that the selection of samples may have been unintentionally biased since many weak or unbonded joints may not have survived rough handling and would not appear in these results. The average strength of all 45 joints was 18.0 psi based on gross area; that of the 29 soldier-course joints was 18.6 psi while that of the 16 stretcher-course joints was 16.9 psi.

The net-area unit bond strength values of only 8 joints were calculated; it can be suggested, however, that the average net-area strength of all the joints would have exceeded 20 psi.

No significance can be attached to the different distributions of the strength values for soldier- and stretcher-course joints. Certain unusual conditions may have affected the test results; for example, an eccentric loading effect must have occurred when one edge of any joint was not bonded and a "thin edge of the wedge" stress concentration probably existed at the limits of any cracks and unbonded planes within the mortar.

Moisture Penetration Tests

The resistance of the brickwork to moisture penetration was assessed by applying air pressure against the face of a small panel of the brickwork while water was being sprayed on the surface to form a continuous film. In this way the panel was subjected to conditions which might arise in a heavy wind-driven rain.

The apparatus used in the tests has been described in DBR Internal Report 160. The test panel was mounted in a frame, sealed in place by sponge plastic, and then the frame was bolted to an air pressure chamber. A water-spray pipe, placed near the top of the panel played small streams of water on the brick to spread over the surface in a film. The water which did not enter the masonry was drained from the bottom of the chamber.

The air pressure valve was carefully regulated to maintain an air pressure difference across the panel of 2 inches of water (approximately equivalent to a wind speed of 50 miles per hour). The tests were continued for 24 hours.

The five panels tested were 8 inches in length, 4 or 5 courses high and about 4 inches thick. Two of them which had been obtained from the soldier-course brickwork were tested with the joints horizontal, rather than vertical as they had been originally constructed. One of these last panels contained five bricks, the other four.

The three remaining panels had been cut from the regular stretcher-course brickwork and contained vertical joints in some courses. The bricks of these panels were rough-faced, whereas those of the two soldier-course panels were smooth-faced. With one exception, all of the panels tested were parged; in some cases, however, the coverage of the parging was not complete.

The results of the tests are shown in Figure 13. In all cases moisture penetrated to the backs of the panels within the 24 hours of test; the time required for this varied from a few seconds to over an hour. One of the samples was relatively tight in the test having only a small area of dampness on the back after 24 hours of test, and no free water. Other samples allowed measurable amounts of moisture penetration, the rate of leakage through the panel varying from $\frac{1}{4}$ ml to about 30 ml per minute. In some cases several hours were required before free water started to leak from the back of the panel.

Two of the three stretcher-course panels suffered moisture penetration first at the vertical joints, which, as mentioned earlier, were often incompletely filled with mortar. The parging did not appear to influence appreciably the tightness of the wall since a completely parged panel performed indifferently, while the best performance was that of the panel which had no parging.

Summary

The purpose of this report has been to record the properties of the lime mortar brickwork of a house and garage built in the autumn of 1931 and demolished in the spring of 1958 after exposure to the Ottawa weather for over 26 years.

The brickwork of the house, which had a widely-overhanging roof, was judged to have performed well both structurally and with respect to weather resistance and durability during its years of service. The brickwork of the garage was similar to that of the house but had not had the same roof protection; it showed serious decay in certain areas. The great influence of the design of a building upon its performance was made clear by these observations.

Despite the fine outward appearance of the brickwork of the house, faulty bricklaying techniques had been used in its construction with the result that many joints had been incompletely filled with mortar and others had been improperly bonded. The imperfections, however, apparently had not caused deterioration or other difficulty.

The compressive strength values determined for the brickwork (bricks and mortar combined) proved to be within the range of 2,000 to 4,000 psi. Large voids in the mortar joints of certain brickwork specimens considerably reduced their strengths in comparison with similar samples free of such voids. The taller specimens yielded lower strengths than did the shorter ones, presumably because some of their individual components were free to move without the immediate restraint of the steel jaws of the testing machine. Another reason may have been that the higher samples had greater opportunities to be weakened by the presence of voids. Even the weakest brickwork was many times stronger than its mortar component taken alone; the strongest brickwork, however, had only half the strength of typical individual bricks.

An interesting pattern, appearing as systems of ridges and troughs, was observed in the mortar of some joints of the brickwork in both the house and the garage. The pattern was attributed to the effects of cyclical changes in conditions affecting the lime mortar during its gradual carbonation.

The bond strength and moisture penetration measurements yielded particularly variable results. A certain degree of variation can always be expected from brickwork even after the most carefully standardized preparation in the laboratory, but it was considered that the values measured in this study had been seriously affected by variations in properties of the bricks and by the rather haphazard bricklaying techniques which had resulted in the inclusion of many large voids, cracks and open passages in the masonry.

The maximum measured bond-strength values approached 50 psi. The joint of the highest strength was that which occurred between the two bricks having the lowest values of initial rate of absorption of those measured (brick samples 1 and 2, Table I). This observation bears out the findings of other studies that, in general, bricks of relatively low initial rates of absorption have favourable bonding characteristics.

All of the brickwork panels tested for moisture penetration showed some leakage under simulated conditions of heavy wind-driven rain. Parging was found to be ineffective in stopping this leakage; the most moisture-tight panel tested was free of any such coating.

The variability of the results recorded in this report illustrates the difficulty of forecasting accurately the properties of brick masonry as erected in normal practice. The difficulty is greatly aggravated by uncertainty regarding the quality of the workmanship to be expected on the job.

TABLE I

BRICK PROPERTIES

Sample	Type of Face	Initial Rate of Absorption (gm/min/30 sq in.)	Absorption (% Dry Weight) by 24-hr Immersion	by 5-hr Boil	Saturation Coefficient	Bulk Density (gm/cc)	Porosity (%)	Specific Gravity of Solids
1	Smooth	7.6	4.4	7.1	0.62	2.20	15.6	2.61
2	"	8.3	4.3	7.0	0.62	2.22	15.4	2.62
3	"	8.8	4.4	7.0	0.62	2.21	15.5	2.62
4	"	11.3	5.0	7.6	0.66	2.19	16.7	2.63
5	"	13.2	4.9	7.4	0.66	2.21	16.3	2.64
6	"	14.8	6.0	8.8	0.68	2.14	18.9	2.64
7	"	19.6	6.8	9.4	0.72	2.12	20.0	2.65
8	Rough	22.8	3.6	6.2	0.58	2.22	13.8	2.57
9	"	24.6	6.2	8.6	0.72	2.15	18.6	2.64
10	"	28.3	5.0	7.5	0.66	2.18	16.5	2.61
11	"	28.8	5.9	9.4	0.71	2.17	18.0	2.65
12	"	29.6	4.2	7.0	0.59	2.19	15.4	2.59
13	"	29.8	6.5	8.7	0.75	2.16	18.8	2.65
14	"	31.9	4.7	5.8	0.80	2.21	10.2	2.62
15	"	33.7	7.9	10.0	0.79	2.11	21.0	2.67
16	Smooth	37.8	8.5	11.2	0.76	2.05	23.0	2.66
17	Rough	42.5	6.0	8.9	0.68	2.11	18.8	2.60
18	"	50.2	5.9	9.0	0.66	2.12	19.0	2.61
19	"	50.8	6.1	8.9	0.68	2.11	18.9	2.60

TABLE II

CHEMICAL ANALYSIS OF THE MORTAR

	Sample No. 1 (West Wall Exterior) (%)	Sample No. 2 (West Wall Interior) (%)
Insoluble matter	70.80	71.54
SiO_2 (from insol.)	48.39	48.47
CaO	13.42	13.35
MgO	4.50	4.71
CO_2	9.78	9.26
(Undetermined)	(1.50)	(1.14)

TABLE III

MORTAR JOINT BOND STRENGTHS

Unit Tensile Bond Strength (psi)		Joint Location	
Gross Area	Net Area	Between Soldiers	Between Stretchers
1.4	15.0	X	
4.3		X	
4.8			X
5.6	16.8		X
5.6			X
6.8			X
6.9			X
7.4		X	
8.6			X
8.9		X	
8.9			X
9.0			X
9.4		X	
9.6	17.4	X	
10.0			X
10.5		X	
10.8		X	
11.8		X	
12.2			X
12.4		X	
13.3		X	
15.7		X	
16.6		X	
16.8		X	
17.8			X
18.5			X
18.8		X	
19.3	21.4		X
19.3		X	
20.2		X	
20.3	33.8	X	
20.7		X	
20.9	31.4	X	
22.4		X	
22.7		X	
24.1		X	
27.0		X	
28.2		X	
30.7		X	
31.3	39.1	X	
38.2		X	
40.3			X
45.7		X	
46.7			X
48.7	48.7		X

Figure 1 The Merkley house (west wall)

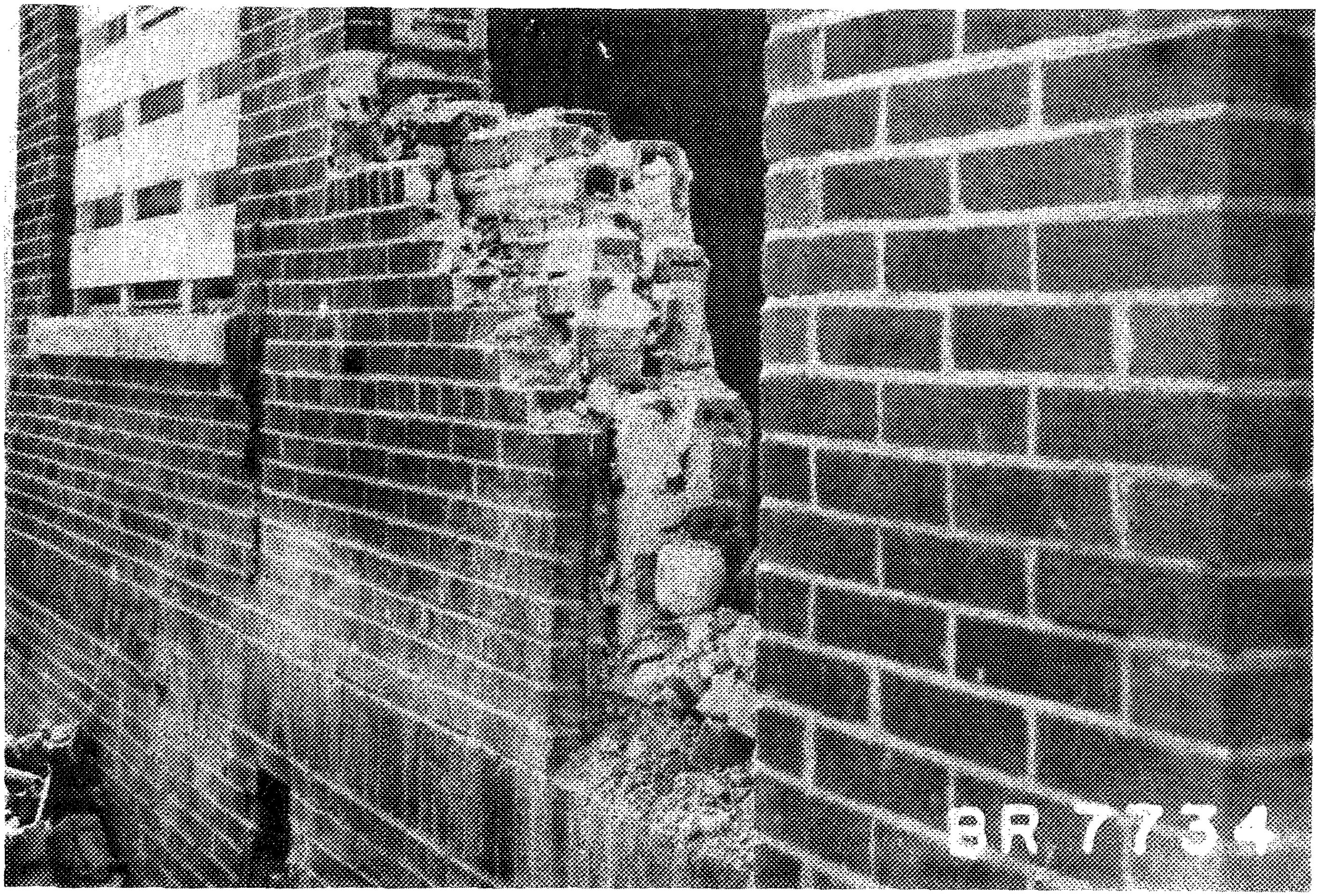


Figure 2 Wall construction details

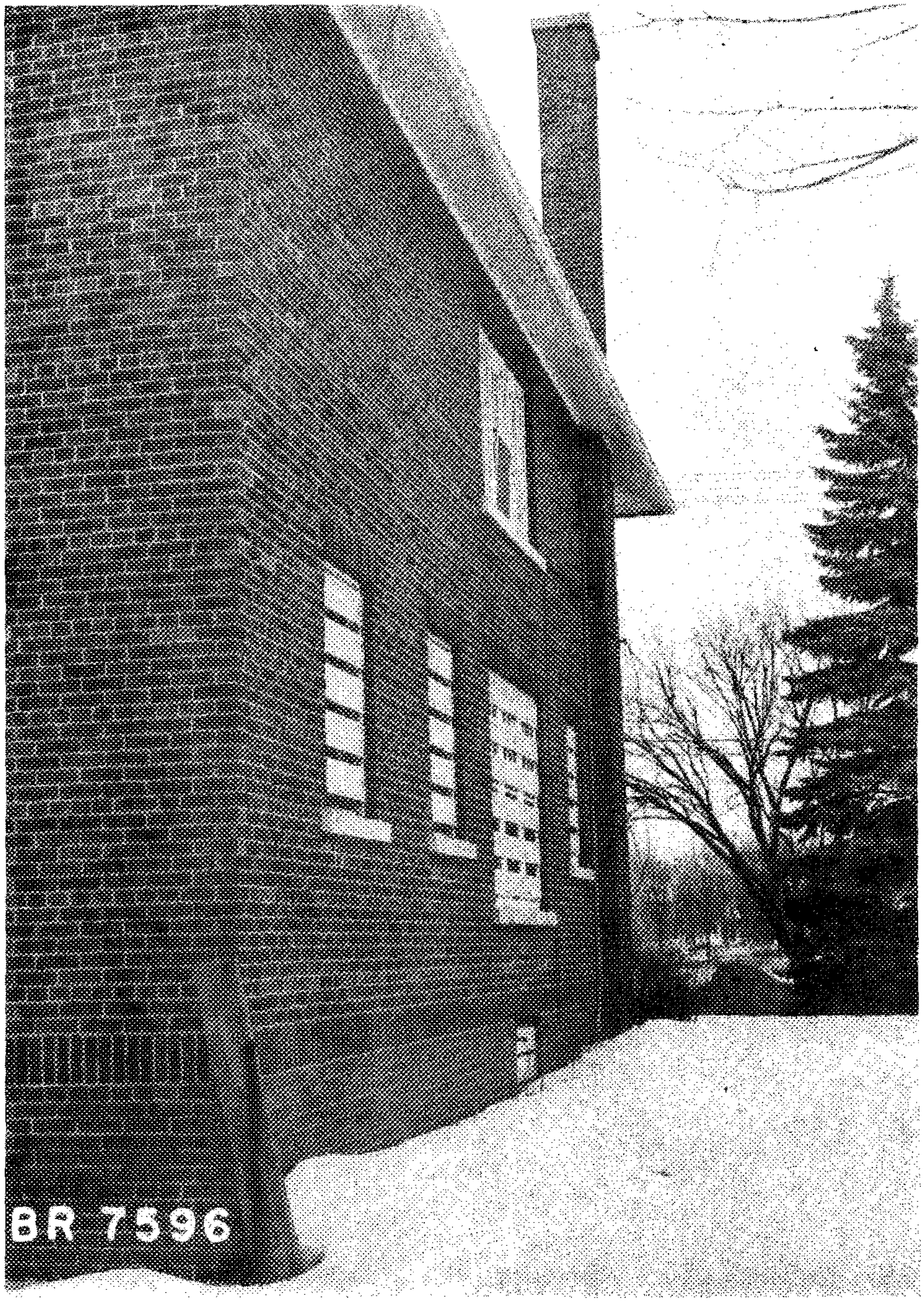


Figure 3   East and south walls

Figure 4 East wall of the garage

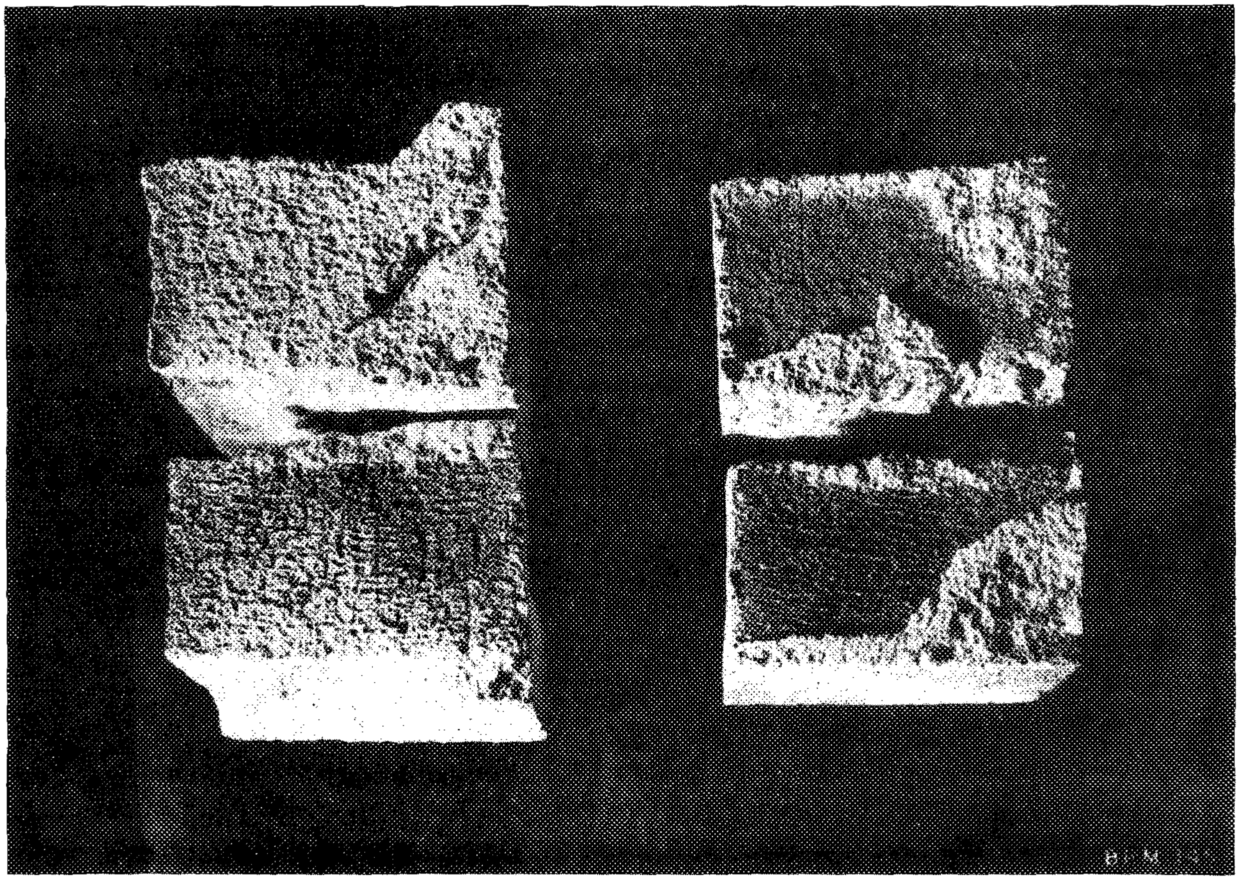


Figure 5a   Mortar-brick unbonded areas

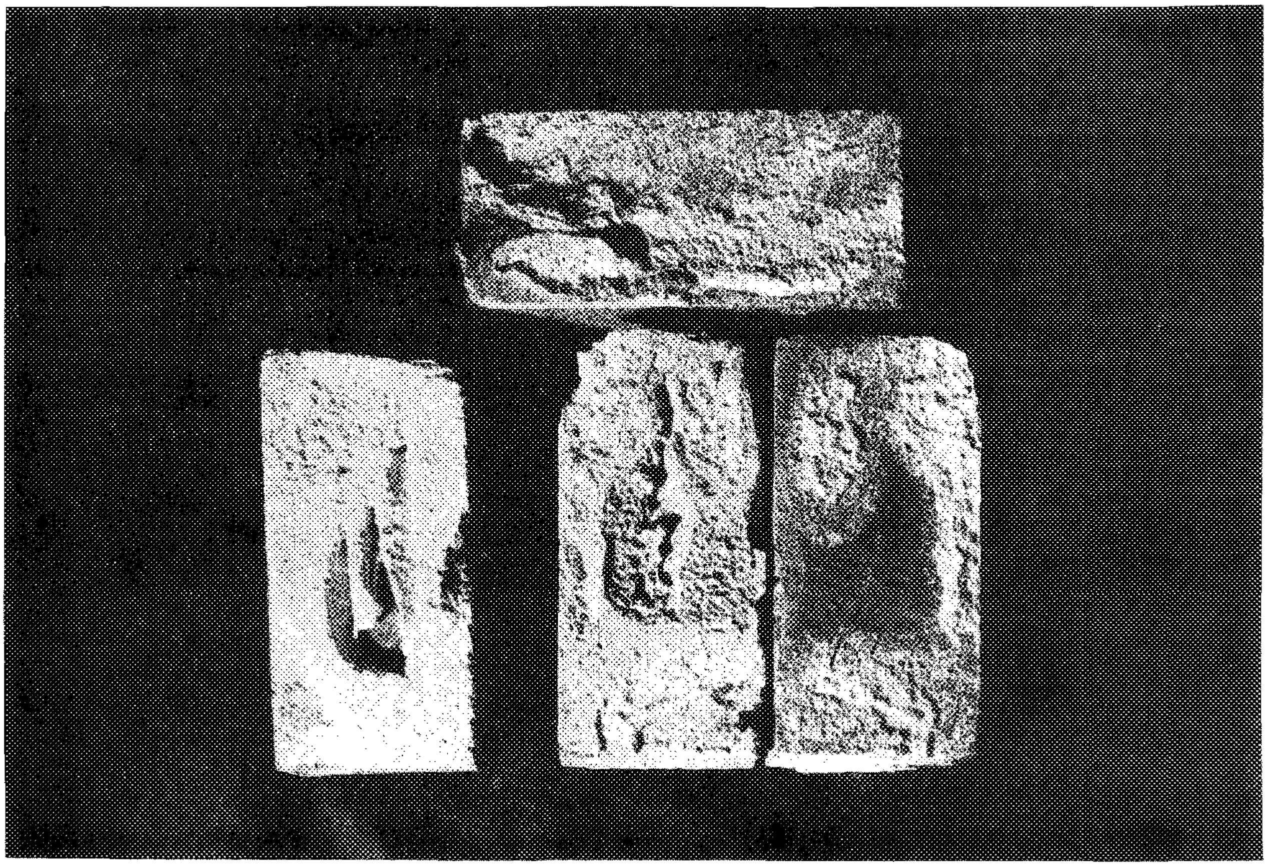


Figure 5b Unfilled vertical joints of soldier and stretcher courses

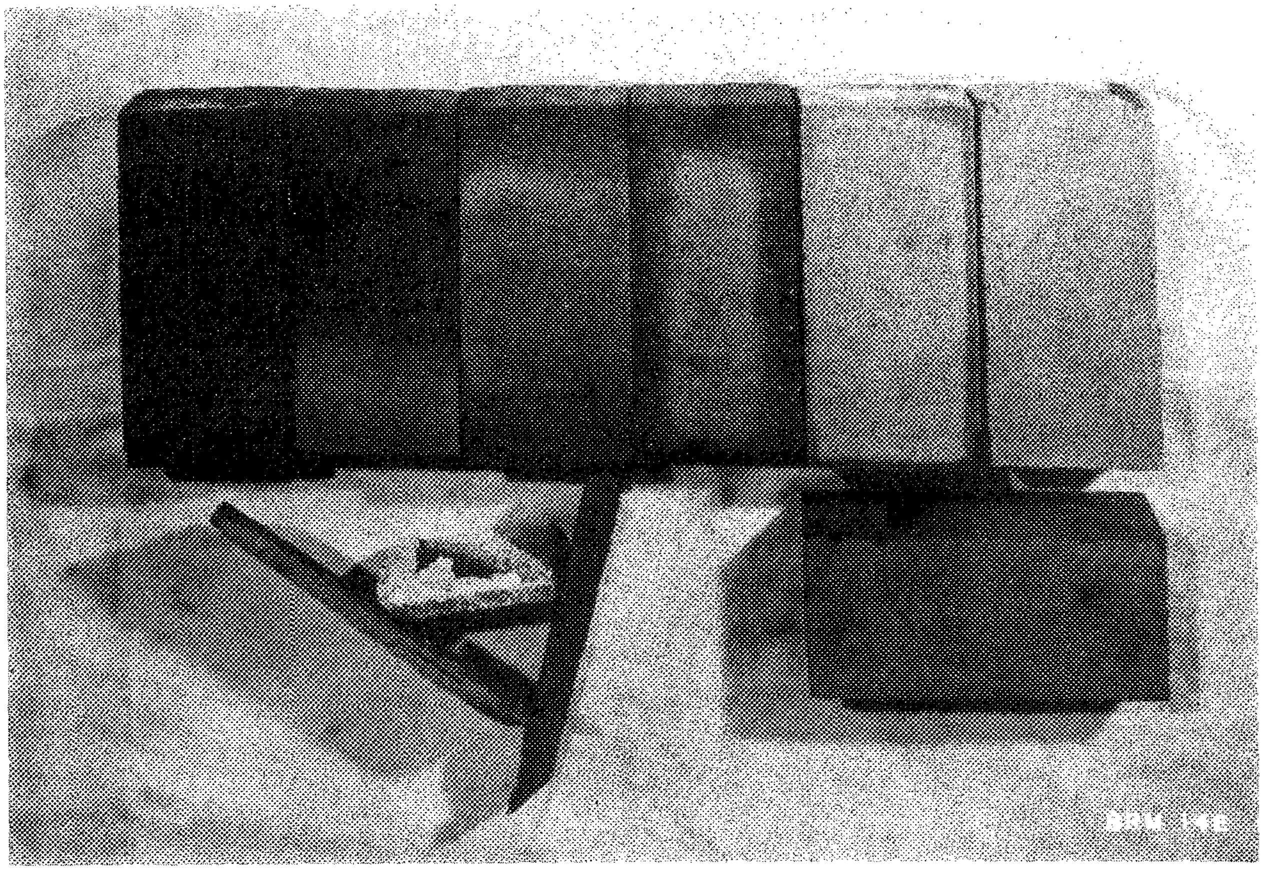


Figure 6   Samples of the bricks

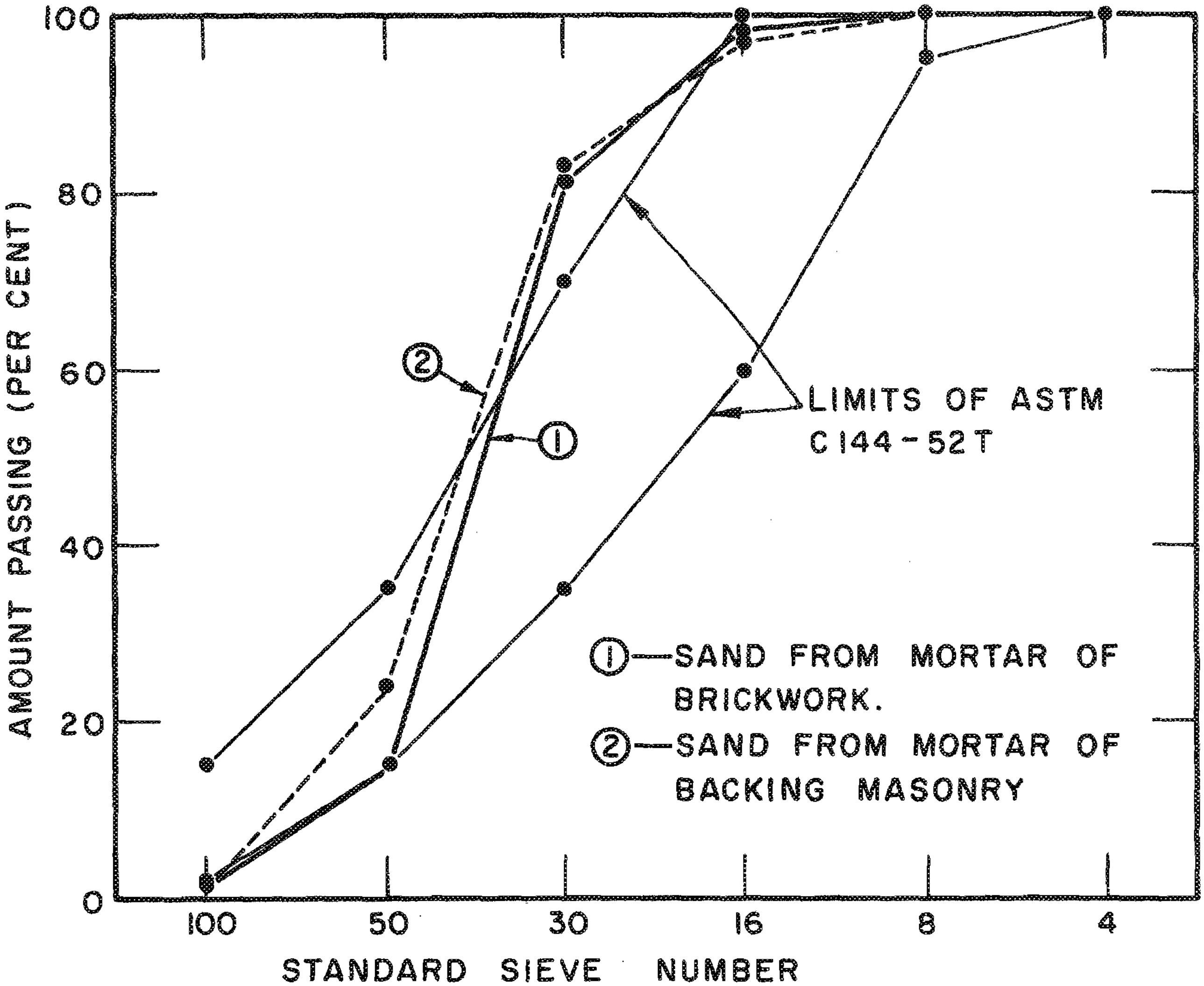


FIGURE 7

PARTICLE-SIZE GRADING CURVES FOR SANDS FROM MORTAR OF MERKLEY HOUSE, OTTAWA.

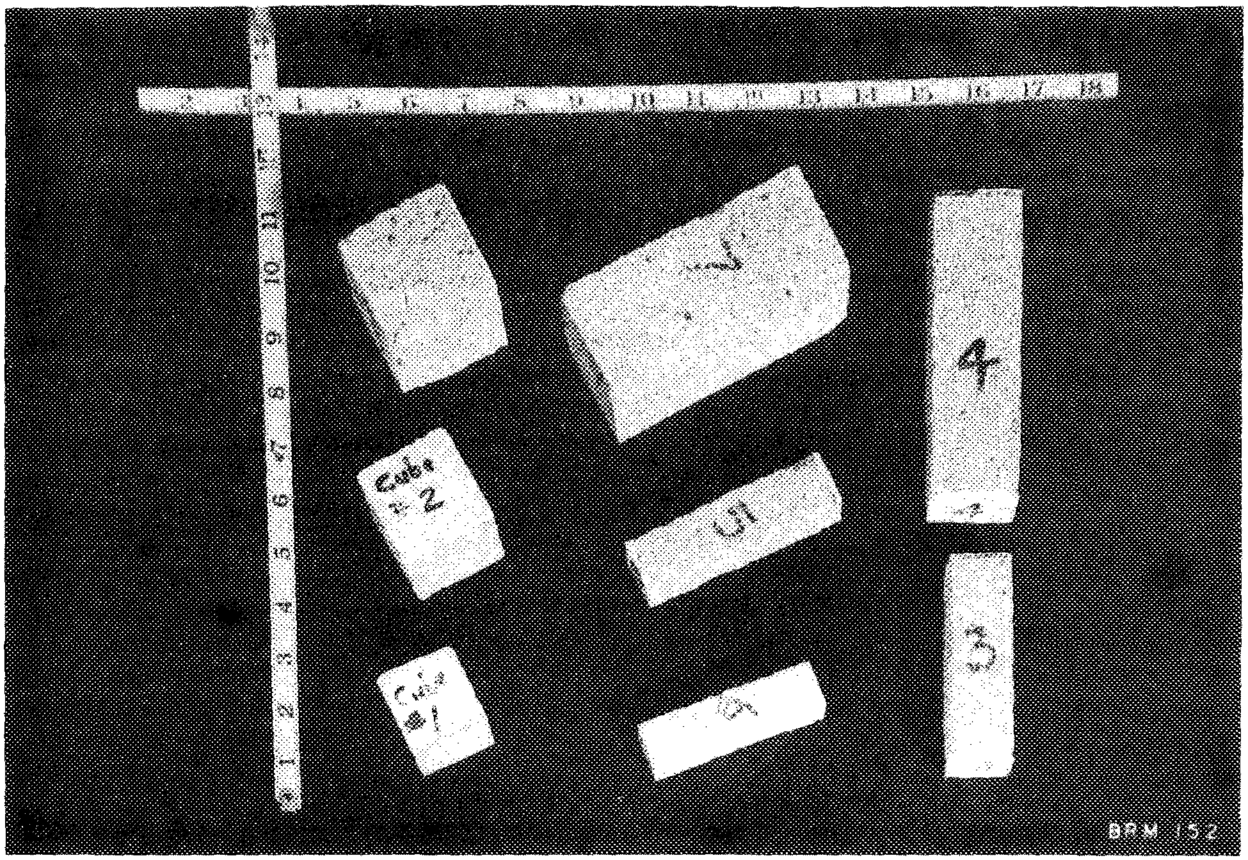


Figure 8 Mortar samples

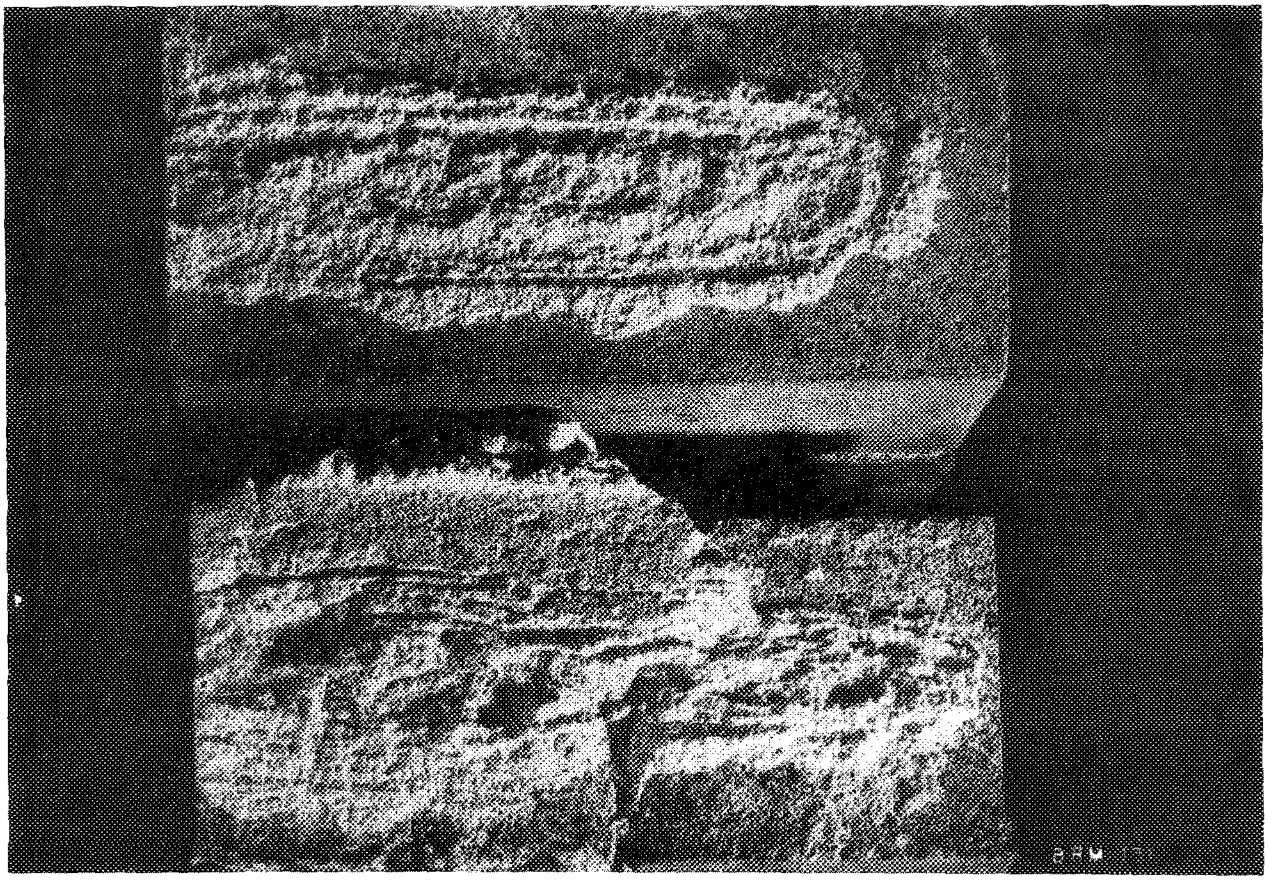


Figure 9a   Patterns in mortar (two broken joints)

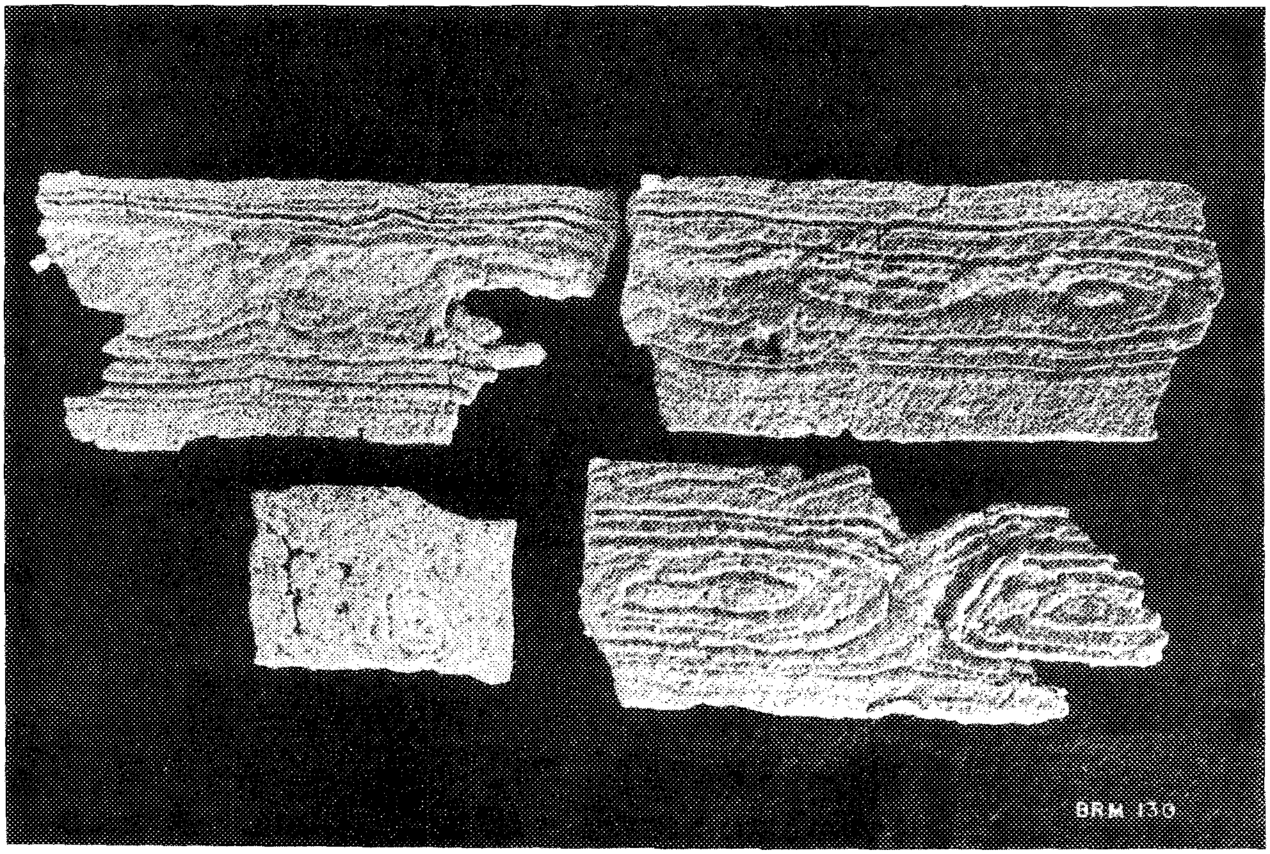


Figure 9b   Patterns in mortar (revealed by sawing)

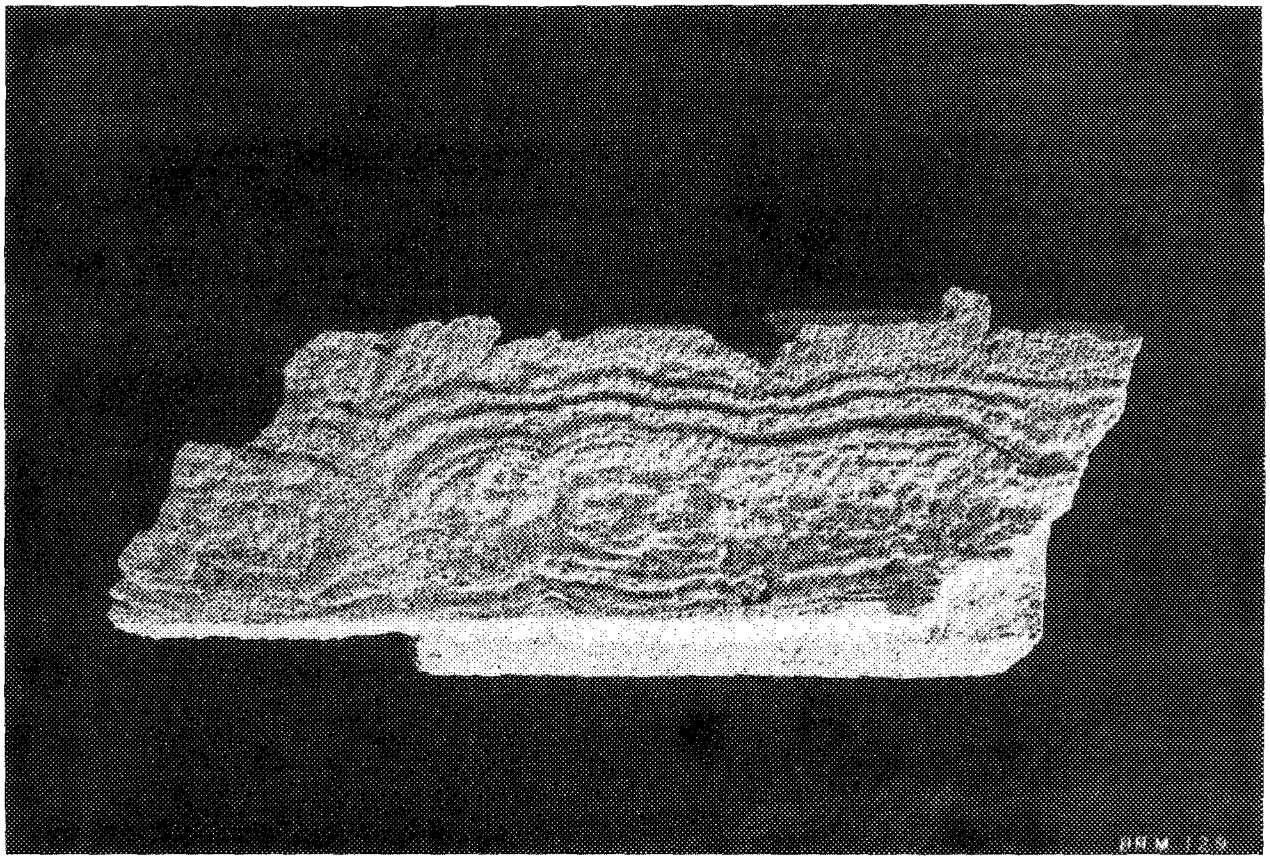
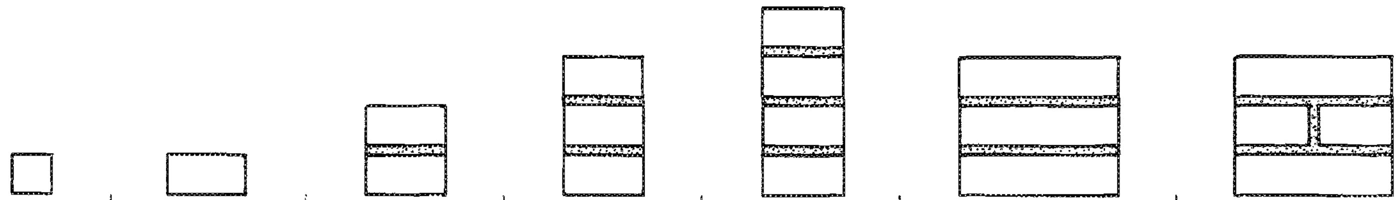


Figure 10   Mortar patterns



	2" MORTAR CUBE	HALF BRICK	2 HALF BRICKS & MORTAR JOINT	3 HALF BRICKS	4 HALF BRICKS	3 FULL BRICKS & 2 MORTAR JOINTS	2 FULL BRICKS & 2 HALF BRICKS
AVERAGE COMPRESSIVE STRENGTH P.S.I.	345	7015	3555	2650	2500	3110	2935
MAXIMUM P.S.I.	430	10350	4000	3040	2845	3295	3210
MINIMUM P.S.I.	195	5240	2960	2250	2105	2820	2665
NUMBER OF SAMPLES	7	15	4	4	3	3	2

FIGURE 11 TYPES OF SAMPLES TESTED FOR COMPRESSIVE STRENGTH.

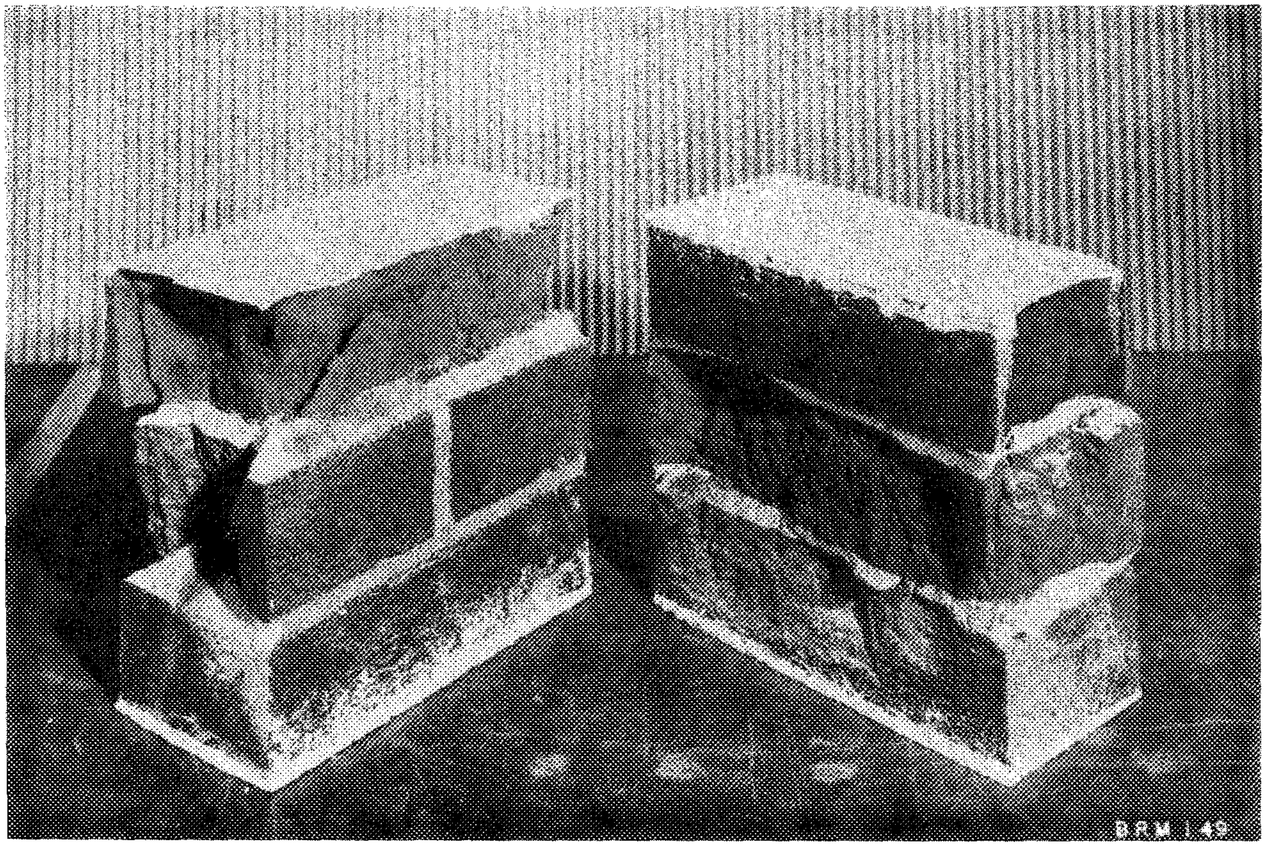
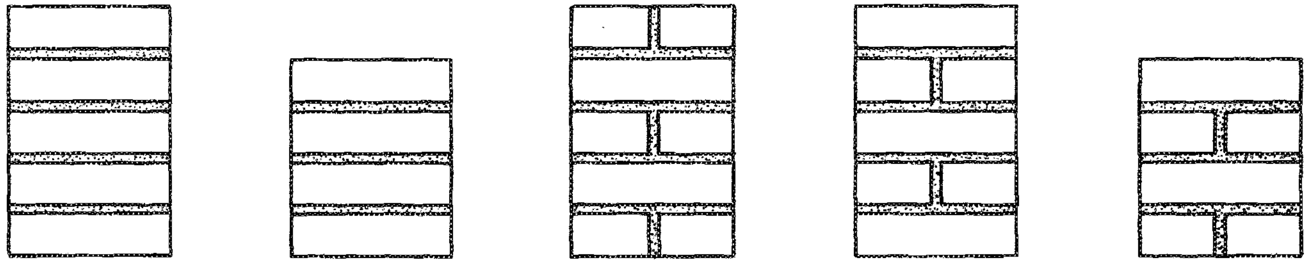


Figure 12   Samples after compressive strength test



	SMOOTH-FACE BRICK	SMOOTH-FACE BRICK	ROUGH-FACE BRICK	ROUGH-FACE BRICK	ROUGH-FACE BRICK
TIME TAKEN FOR DAMPNESS TO PENETRATE	11 MIN	IMMEDIATE (a)	IMMEDIATE (b)	IMMEDIATE (c)	1 HR 40 MIN
MAX. RATE OF LEAKAGE (ML. PER MIN. FROM BACK OF PANEL)	0	31 (d)	5	1/3	1/4

NOTES:

(a) BOTTOM JOINT IMMEDIATELY DAMP, OTHER JOINTS DRY FOR 1 HOUR.

(b) IMMEDIATE DAMPNESS BEHIND MIDDLE VERTICAL JOINT.

(c) IMMEDIATE DAMPNESS BEHIND TOP VERTICAL JOINT, OTHER DAMP SPOTS IN FIRST 3 MIN OF TEST.

(d) MOST OF LEAKAGE FROM BOTTOM JOINT, OTHER JOINTS RELATIVELY TIGHT.

FIGURE 13 PANELS TESTED FOR RAIN PENETRATION