Moisture penetration of solid facing brick walls

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Authors: P. Jonell and T. Möller.

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PREFACE

Rain penetration of brickwork, and of other types of unit masonry, is a problem which has been encountered in many areas of Canada, especially in the Atlantic provinces. The Division of Building Research has been studying this problem, and the general problem of weathering of masonry materials, by reference to the extensive literature of such studies, by observations of the performance of masonry buildings in many regions of Canada, and by laboratory studies of masonry materials.

The weather resistance of unit masonry has been shown to depend on many factors. It requires the use not only of individually durable units and mortar, but also of units and mortar which can be combined to form an integral assembly. If this is not achieved, serious troubles may occur in masonry, even if the materials themselves are highly durable.

This translation of Swedish studies on moisture penetration of brick walls, which has been prepared as a part of this Division's continuing studies of the problem, should be of interest to those who are concerned with the weather resistance of masonry walls.

The Division of Building Research wishes to record its thanks to Mr. H.A.G. Nathan of the Translations Section, National Research Council, for translating this article.

Ottawa,
July 1956

R.F. Legget,
Director.

MOISTURE PENETRATION OF SOLID FACING BRICK WALLS

Among the construction engineering problems associated with the building of solid brick walls the question of the wall's impermeability to water occupies a dominating position, especially in regions with windy and rainy climate, where the difficulties in this respect have always been fully realized. Various means were tried to overcome the disadvantages associated with moisture penetration.

In England, therefore, the building of solid brick walls has been abandoned to a great extent in favour of so-called cavity walls, i.e., the separation of the facing brick wall from the backing by an interspace. At the west coast of Norway, where weather conditions are severe from the moisture point of view, it has been suggested that the building of solid facing brick walls be discontinued. These measures are indeed effective "remedies" but unfortunately do not contribute towards a solution to the problem of the ability of solid brick walls to withstand rain.

In the states of the U.S.A. bordering the Atlantic it is not unusual for wind-driven rains to last more than three days, at a mean precipitation of between 1 and 2 mm, per hour. Therefore, there has been every reason for investigating the factors affecting a wall's capability of resisting the penetration of rain. Moreover these investigations have been carried out on a scale far beyond anything undertaken elsewhere.

In Sweden the climate of the west coast is the chief reason for the attention being paid to the problem.

No studies of the problem worth mentioning have been made in the past, although damage due to moisture of the type indicated is by no means uncommon. This may perhaps be explained by the moderate extent of the construction engineering research being carried on and by the fact that the moisture which does occur is relatively mild and could well be regarded merely as an inevitable and quite harmless inconvenience. However, moisture damage is becoming more common as time goes on, and owing to the very heavy and very extensive damage which occurred in the years following the last war the problem has now become urgent.

Buildings damaged by moisture in the Göteborg district were inspected at the end of 1949 and the beginning of 1950. The tour of inspection lasted several days and was conducted by Professor Hjalmar Granholm together with officials from the Public Works Department. Although this inspection produced good results from many points of view, it was nevertheless impossible to determine the direct causes of the damage merely by studying the damage itself. Instead, full-scale laboratory tests of both material and walls are needed.

Tests for Leaks in Brick Walls

Such an investigation was carried out by the Building Research Institute of Chalmers Tekniska Högskola, chiefly during the year 1951.

For this purpose outdoor test walls (115 × 115 cm.) were erected having a thickness of 1½ brick, except in a few cases. The walls were built of two different types of facing brick, the one being porous, yellow, and showing a high degree of water suction (type I) and the other a hard burnt brick showing a very slight degree of suction (type II). Another wall (no.18) was built of red facing bricks (type III). Red brick (type IV) was used as the lining brick in all cases.

The properties of the different brick types have been listed in Table I.

Table I

Brick type	Wt. by vol. of brick material	Water abs. in % of dry wt. in 24 hr.	Water suction from the flat side during 1 min.
I	1.70 kgm./cu. dm.	19	115 gm.
II	1.98 "	8	30 "
III	1.98 "	9	70 "
IV	1.60 "	21	100 "

The numerical values given are mean values from five tests.

The water absorption was determined by leaving the completely dried brick submerged in water for 24 hours, whereas the water suction was determined by immersing 3 mm. of the flat side of the brick in water for one minute.

In order to determine the extent to which the care taken by the bricklayers affects the permeability of the wall to water, two performance ratings were set up as a means of classifying this factor. Performance B corresponds roughly to the kind of work done on building sites in Göteborg. Performance A was intended to be of a higher quality; the bricklayers were to make sure that all the joints were grouted.

In all the cases except one the mortar used was mixed and activated in the institute where the investigations were carried on. The test wall in which this mortar was not used was jointed with mortar from a plant.

After the walls had been erected they were allowed to set for three weeks, after which the test proper began. With the aid of a perforated pipe placed at the top in front, the wall was kept covered with a thin layer of running water. This spraying of the front surfaces was continued for at least 24 hours. The backs of the walls were coated with lime paint, which changes colour distinctly when it becomes wet, i.e., it darkens. By marking the wet portions on the backs of the walls at suitable time intervals an indication of the rate at which the water penetrates the wall is obtained.

The different kinds of brick and mortar mentioned above were combined in many different ways. In certain test walls the bricks were moistened before being laid. Since the walls were built in two different ways (i.e., some in the ordinary way and some with great care), the entire series of tests covered approximately 30 different walls.

For the sake of clarity, only 18 walls are discussed in detail below. The other walls showed a similar behaviour in every respect.

The composition of the mortars used is given in Table II.

Table II

Designation	Composition in parts by volume			Comments
	Cement	Lime	Sand	
A	1	½	4.5	
B	1	2	9	
C	1	½	4.5	0.01% Vinsol
D	1	½	5	
E	1	1	7	

The composition of the different test walls and the way in which they were built (A or B) are shown in Table III.

Table III

No. of test wall	Type of facing brick	Brick condition at laying	Mortar	Performance rating	Comments
1	II	dry	B	A	
2	I	wet	B	A	
3	I	dry	lime mortar	A	From mortar plant
4	I	dry	B	A	
5	II	wet lining	B	A	Only lining brick wet
6	I	dry	A	A	
7	I	dry	A	B	
8	II	wet lining	A	A	Only lining brick wet
9	I	dry	B	B	
10	II	dry	C	A	
11	I	wetted when wall was built	A	A	
12	I	wet	C	A	
13	I	dry	A	A	
14	II	wet lining	D	A	Only lining brick wet
15					
16	II	dry	C	A	Halsingborg facing bricks used as lining bricks
17	I	wet	E	A	
18	III	wet	E	A	

The lines defining the wet spots in the lime colour were drawn every half hour. The farther these lines are apart the greater the permeability of the wall to water. In order to express the watertightness of the walls numerically, measurements were made to determine the extent to which the backs of the walls had become wet after 1, 2 and 3 hours.

These values are shown in the diagrams of Figs. 2a and b.

These diagrams show the spreading of the penetrating moisture during the first three hours after the sprinkling with water began. The numbers on the curves refer to the numbers of the test walls according to Table III.

If these lines are studied it is found that their position with respect to one another is difficult to explain. The fact that one wall is more permeable to water than another frequantly cannot be attributed to differences in the bricks or mortar. However, there is some difference between porous bricks (type I) and hard burnt bricks (type II). The extent of the moisture penetration after two hours of spraying is shown in Fig. 3 for the two types of brick. Apparently the porous brick is decidedly inferior to the hard burnt. On the average, 32% of the back of the porous brick is wet after two hours of spraying compared with 17% in the case of hard burnt brick. The porous brick has a greater suction capacity for the water penetrating through cracks and expanding the joints, thus temporarily preventing the water from penetrating through to the back. Therefore, if the above comparison is accepted, the walls of porous brick must have had a greater number of cracks.

The irregularities in the curves in Fig. 2 must be due to the bricklaying itself. The performance was not first-class with respect to watertightness. The quality of the work varied at random from wall to wall and no apparent difference between performance rating A and B could be established.

The test walls were built by apprentices leaving the Göteborg school for bricklayers. By current bricklaying standards their work was good. However, it proved difficult to make them modify the bricklaying technique they had been taught. Therefore, one test wall (no. 18) was built by two men who had no previous experience whatever in bricklaying. The work was performed in such a way that all the joints were properly filled with mortar. This wall was sprayed with water for 48 hours without penetration (cf. Fig. 4). None of the other walls resisted penetration longer than 30 minutes. It might perhaps be contended that a different facing brick (type III) was used for wall 18 from that used for the other walls, and that this is probably the reason for the good result. However, in other similar tests it was found that the brick in question did not have any special properties with respect to watertightness but occupied an intermediate position between brick type I and that of type II. This is also evident from Table I.

The investigation reported here and the majority of American papers show that the work quality is unquestionably the most important factor in making masonry moisture-proof. However, it would be unfair to put the blame for all moisture damage on the bricklayer. Unsuitable material may render the building of watertight walls difficult or even impossible.

Brick Properties

Investigations carried out in this connection have stressed the importance of the fact that the suction of water by the brick has certain advantages. As mentioned above, from the moisture point of view the porous brick sucking in water is decidedly inferior to the more hard burnt, watertight brick. This is due chiefly to the fact that the porous brick sucks in water from the mortar so rapidly that the latter becomes unworkable as soon as it comes into contact with the brick. The mortar does not retain its semifluid consistency long enough to fill up the open joints. Therefore, it is much more difficult to build watertight walls with dry bricks sucking up water. The strong suction property of the brick may also result in depriving the mortar closest to the brick of some of the water required for setting. This renders the hardening and setting of the mortar more difficult and the strength attained by the mortar will be lower. The risk of cracks in the joints between mortar and brick thus increases.

There are at present no rules prescribing the water absorbing and water suction requirements of facing bricks.

Consequently there are now facing bricks which suck in more water than a normal lining brick. No doubt, at present much more porous bricks, capable of greater suction, are used than say 50 years ago, a trend which should be arrested.

Many investigations, particularly in the U.S.A., showed that facing bricks should have a suction power of between 10 and 30 gm. on being immersed to 3 mm. of their flat side in water for one minute. If the suction is greater, this will result in the disadvantages mentioned above. In order to determine to what extent the common types of Swedish facing brick satisfy this requirement, most of the bricks made in Sweden at present were investigated. In this investigation the water absorption was determined partly according to American recommendations and partly by complete immersion in water. In all the tests the bricks were first dried in a heating chamber for 24 hours at a temperature of slightly more than 100°C. The water absorption was determined by weighing before and after the soaking.

The result can be seen in the diagrams shown in Fig. 5a and b.

Apparently only one or two types of brick have the qualities which a facing brick must have to ensure dry masonry.

The study of similar measurements of facing bricks commonly used in the U.S.A. shows that a great many more hard burnt facing bricks and fewer facing bricks having too high suction capacity are being used in the U.S.A.

Almost all Swedish facing bricks should be moistened before use in order to reduce suction to a suitable rate, i.e., to between 10 and 30 gm., as pointed out above.

The method of moistening the bricks before they are used for building walls is by no means new. Especially in Russia and Poland this method is quite common. In Sweden it seems to be absolutely unknown, and in large sections of the building trade any suggestion of moistening the brick is almost taken as a joke, while covering brick piles at all times so as to protect them from rain is taken for granted. On the other hand, it is well know that it is necessary, or at any rate very useful, to moisten masonry, and normally all other surfaces, before applying the plaster.

The objection made against the moistening of bricks is that this frequently injures the hands of the bricklayers. This danger is great, of course, if the bricks are dripping wet on delivery to the bricklayer; the skin of their hands would thus be softened by the water and would wear off, forming sores. In view of this it is perhaps unsuitable to moisten the bricks directly before they are laid by dipping each individual brick in a bucket of water Instead the bricks should be moistened the day before they are laid so that the water sucked in has an opportunity to spread in the bricks. Despite moistening, the surface of the brick gets relatively dry. This would not be so hard on the hands of the bricklayer. The time for soaking should be adapted to each individual type of brick.

In order to avoid damage owing to moisture in walls of solid facing bricks because of the climate of Sweden's west coast, either soaking of the bricks should be prescribed throughout or bricks having a smaller capacity for sucking up water should be used. A facing brick is at present appraised merely by its compressive strength and resistance to frost. Important as these properties may be, they are nevertheless not directly related to the suitability of the brick from the moisture point of view. In this respect certain standards should be drawn up and observed.

However, a wall does not consist exclusively of brick. The properties of the required mortar are at least equally important.

<u>A Number of Considerations Regarding Mortar</u>

For exposed facing walls a mortar containing more cement than lime should preferably be used. Mortar consisting entirely of lime is not suitable here. However, in seeking to make the mortar as watertight as possible care must be taken to see that its plasticity is not adversely affected. Otherwise, the bricklayer will find it more difficult to fill the joints, and the final result will be much less satisfactory. This is one of the reasons why cement mortar is frequently viewed with suspicion.

When cement is used in the mixing of mortar, either by hand or in a concrete mixer, the mortar obtained is much less workable than that containing fat slaked lime instead of cement. Therefore, when in the past, with quite justified intention of producing a watertight mortar, most of the lime was replaced by cement, a less workable mortar was obtained. The result was a greater number of unfilled joints and cracks in the masonry, although the quality of the work remained the same. Thus the finished wall was inferior to one built with the more plastic lime mortar, even though the latter is not nearly as watertight as cement mortar. In order to improve the plasticity of cement mortar, the cement content was frequently increased above normal. As a result, shrinkage of the mortar could frequently be observed and a large number of cracks were obtained.

Since high-speed mortar mixers (activators) are now in use, it is possible to produce a cement mortar, i.e., a watertight mortar, which also shows adequate plasticity. In the mixer the mortar is beaten at high speed (approximately 8m./sec.). By mixing the mortar with a chemical agent the plasticity can be improved still further. For example, a suitable substance for admixture is 0.005% Vinsol calculated per weight of the cement in the mortar. Such an aerated mortar, i.e., with air-entraining agent, is being produced and used at a number of building sites in Göteborg, and everywhere the bricklayers have expressed their satisfaction with this mortar.

A disadvantage in using mortar from the plant is the fact that it can only be delivered in large quantities and thus must be stored for a relatively long time before it is used. Mortar produced exclusively from slaked lime and sand is not adversely affected when it is stored for some time. The evaporated water can be replaced without inconvenience. However, for mortar containing cement this method is entirely unsuitable. The addition of water increases the shrinkage of the mortar here and reduces its strength. Old cement mortar must be thrown away. If the mortar is mixed in a high-speed mixer at the building site, a first-class mortar, satisfying the highest demands from both an engineering and constructional standpoint, is obtained. Furthermore, this mortar is always fresh when the bricklayer receives it.

The range of grain sizes of the sand should be adapted to the rules of the booklet "Modern Putsteknik" (Modern Plaster Technique) issued by the Swedish Cement Association. The sand should not contain grains larger than 2 or 3 millimetres. This is an important point, for otherwise the adhesive power of the mortar would deteriorate considerably.

If the mortar has the proper consistency and the suction of the brick is right, then after being laid and picked up again the bottom surface of the brick should be entirely coated with mortar.

The properties of a number of different mortars were investigated in this respect. It is clear that even an unworkable mortar will firmly adhere to a brick if the latter is vigorously pressed and rubbed against the mortar. In order to obtain comparable values, the mortar had to be applied on the bricks in the same way and with the same force in the various tests. This was brought about in the following manner. An open metal box was partially filled with mortar. The brick was placed on the box like a lid. Then the box and brick together were turned upside down so that the brick was at the bottom. The box was removed and the brick turned over again so that most of the mortar loosened and dropped off. The adhesive power of the mortar was determined according to the area of the brick still covered with mortar.

The measuring arrangement and a number of results obtained from the investigation are shown in Figs. 6 - 8.

The looser the mortar the greater will be its adhesive power. Therefore, all the comparisons of the different mortars were made with respect to consistency. A mortar, which had the following composition in parts by volume: cement 1, lime powder 1 and sand 6, and which had been activated with an air-entraining agent, was found to be the best of all the mortars investigated. If a watertight wall is desired it is essential that the mortar should moisten readily and adhere firmly to the brick over its entire surface. Incomplete adhesion will result in cracks between mortar and brick, thus facilitating penetration of rain into the masonry.

Importance of the Bricklayer's Performance

It must indeed be emphasized that moistening the bricks or using hard burnt facing bricks merely increases the possibility of watertight masonry being built by the bricklayer. If the quality of the work is not absolutely first-class and some of the joints are not grouted properly, the choice of the material will make little difference. This is clearly evident from the test walls.

Here the quality of the work was not as high as it should have been for erecting a watertight wall, although from the point of view of strength and aesthetics it was satisfactory. Some of the test walls were built of high-grade, hard burnt brick and some of bricks having very high suction power. Furthermore, the quality of the mortar varied from very watertight mortar with a high cement content to lime mortar. Hence great differences in water-tightness of the different walls might have been expected. However, tests showed that the differences were not appreciable. A wall of hard burnt brick and mortar of good quality was virtually as permeable to water as one built of dry brick with great suction power and a poor quality mortar. However, this behaviour does not contradict what has been said above concerning the importance of the brick and mortar properties. It merely shows that the performance is the determining factor. Differences in quality of the material become apparent and important only when the work is first class in every respect.

Concerning the technique applied by the bricklayer, there are a number of details which should be changed. The vertical joints are more difficult to grout than the horizontal. If a stretcher is to be laid, for example, the bricklayer usually places a dab of mortar on the wall as shown in Fig. 9a. He then attempts to grout the open vertical joint by putting on a dab of mortar (cf. Fig. 9b), and forcing this down into the joint with the edge of the trowel. The joint can never be completely filled in this manner, in any case not if the brick has great suction power or if the mortar is stiff, as is usually the case. Therefore, the mortar for grouting the joints should be quite loose, but not so loose that the brick will squeeze the mortar out of the joint by reason of its weight. It was found that activated mortar, even though it has a very loose consistency, has good bearing capacity compared with a non-activated mortar of the same consistency. This is associated with the gel structure, which is formed in the mortar during activation. Therefore, activated mortar may be looser than non-activated. This is an advantage, as stated above.

The technique outlined above should be changed. The amount of mortar applied should be just sufficient to cover the vertical sides of the adjoining brick (Fig. 9c). Adhesion to the horizontal mortar joint is now easily obtained at the upper side of the brick (Fig. 9d), and when this technique is applied the bricks will form a tightly packed structure.

The Effect of Capillarity

From what has been said so far it may easily be concluded that cracks in the joints and unfilled joints are the major cause of moisture damage in brick walls. However, the role which capillary moisture movement plays in this connection must not be overlooked. To be sure, moisture damage due to the former reason is more noticeable and frequently causes greater discomfort to the people living in the house, but in the long run, and particularly from the landlord's point of view, damage of the latter type is quite as serious.

When the face of a brick wall is battered by rain the water is rapidly sucked up by the bricks. The rate at which this takes place is shown by the curves in Fig. 10, relating to the water absorption of a number of different facing bricks. A comparison with the water absorption values of bricks which had been completely submerged in water for 24 hours (Fig. 5a) shows that after 15 minutes the two most porous bricks had absorbed approximately 90% of the saturation quantity and the most watertight brick approximately 55%. Water absorbed by capillary action in a brick wall exposed to rain does not show as moisture on the inside of the wall chiefly for two reasons. The first of these is simply that the initial fast rate of water absorption of dry masonry decreases rapidly as the pores of the material are filled (Fig. 10). As a result, and in view of the large amounts of water which a brick with strong capillary attraction can absorb, exceptionally long periods of heavy rain are required for the masonry to become saturated. Until this is the case there is no possibility of free moisture appearing on the inside of the wall; for, the capillary forces responsible for the rapid movement of moisture in the brick are equally effective in keeping it there. Not until the brick becomes saturated will the conditions for the water to leave the wall in liquid form have been created. However, as soon as the brick is saturated the capillary movement of moisture ceases, and the only force which could drive the water through the wall would be a possible difference in pressure between the outside and inside of the wall. It is clear that the amounts of water which can be transported in this way are exceedingly small.

The other, and perhaps the chief reason why the capillarity does not normally become evident as moisture penetration is the fact that the water in walls thicker than one brick must pass through at least one mortar joint in order to reach the inside of the wall. This joint offers resistance to the capillary movement of water, particularly if the joint is filled with a tight mortar.

It is possible to build a watertight wall even of very porous brick with great suction power, for example by using brick type I, provided, of course, the wall is so thick (1 1/2 bricks or thicker) that the water must pass through one mortar joint at least in order to penetrate the wall. If the mortar is sufficiently tight no water can pass from the outer rain-soaked bricks to the inner ones. This can easily be proved by a simple experiment. Two highly porous bricks with great suction power are laid side by side. After the mortar had set for the required time, the two bricks with the mortar joint were placed one above the other in approximately two centimetres of water. The water was then sucked in by the lower brick, which rapidly became saturated up to the mortar joint. When a mortar with high cement content (1 : 1 : 7) was used it was found that it was very difficult for the water to penetrate through the mortar joint up into the upper brick.

Normally the capillary moisture movement through the mortar joint and up into the upper brick is so slight that this brick is not noticeably moistened no matter how long it remains in water. The water evaporates from the upper brick as fast as it is sucked in.

This simple test clearly shows that it is possible to build a solid brick wall which is very resistant to penetration of rain, provided that each brick is embedded in tight mortar and no cracks are found in the joint.

A large number of test specimens were made, each consisting of two bricks joined together at their side faces. All the specimens were made of the same type of brick. The mortar in the joints varied with respect to both the cement content in the binder and total amount of binder. The mortar which was the "leanest" and had the lowest cement content was a normal lime-cement mortar (1 cement : 2 lime : 12 sand). The fattiest mortar, i.e., that with the highest cement content, had the following composition in parts by volume: 1 cement : 1 lime : 6 sand. One of the bricks in the test specimen was provided with a metal collar (cf. Fig. 11), and the water was sprinkled on the surface thus shielded. The brick which was directly sprinkled with water became completely soaked through in a very short time, whereas the movement of water through the mortar joint took place so slowly that the penetration of the water into the second brick could be observed as a clearly marked moisture front.

As expected, the result of the investigation showed that both a high binder content and a high cement content in the binder affects the tightness of the joint favourably. The extreme case in the present investigation is shown in Fig. 12. The white lines show the position of the moisture front at the number of hours after the beginning of the test indicated on the respective lines. Apparently the fatty mortar with a high cement content is very much tighter, it might even be called completely tight.

What has been said about the importance of the capillarity for the moisture penetration does not affect any of the views given on the conditions for obtaining watertight masonry. The investigation just described shows clearly that as long as the bricks are laid in a satisfactory way and the joints are well grouted with a tight and strong mortar, the more or less marked tendency of the brick for capillary action will scarcely become evident.

Summary

The present report is an attempt at appraising the factors which affect the watertightness of solid masonry. A lively discussion of this problem is at present in progress between representatives of different sections of the building trade. The representatives of the bricklayers have constantly maintained that when masonry built with poorly grouted joints is exposed to moisture penetration the incompletely filled joints are not to any appreciable extent responsible for the resulting damage. However, this is a complete misconception. The bricklayers should be made to realize that the watertightness of a facing brick wall depends above all on the quality of their work.

Bricklaying practices should be subjected to a critical scrutiny. Any shortcomings in these practices or unsuitable methods should be exposed, and the results thus obtained should be made known to those concerned by proper explanation. Our trade schools, in particular, have a chance of achieving something here.

However, the entire responsibility for the performance should not be placed on the bricklayer. In order to make it possible for him to carry out satisfactory work with a reasonable amount of labour the materials must of course be of high quality.

It is essential that the suction power of the brick be just right. Practically all Swedish facing bricks on the market at present have too great a suction power. Either the brick industry should concentrate on producing a more hard burnt brick with less suction power, or the contractors should see that the brick is soaked in plenty of time before the work begins so as to have the right suction on being laid. The brick standards should include specifications regarding the suction of facing bricks.

The consistency of the mortar should be such that it enables all the joints to be filled completely. The mortar should also have adequate adhesive power so that the joint will be strong and, above all, watertight after the mortar has set. A mortar with comparatively high cement content will have optimum adhesive power, tightness and strength. In order to give this mortar a loose consistency without sacrificing plasticity (cohesion), the mortar should be mixed in a special high-speed mixer.

Furthermore, the plasticity of the mortar can be improved by any of the chemical air-entraining agents found on the market at present (e.g. Vinsol resin, Darex).

Because the cement sets so rapidly, cement mortar should be used almost immediately after it has been mixed. For this reason mortar should preferably be mixed at the building site. This also facilitates determination of the amount to be mixed. Adding water to old cement mortar is highly objectionable and this practice should be prohibited.

The composition of the mortar should be determined by a competent person and his directions must be scrupulously observed at the building site. The frequently practised "intuitive" method of mixing mortar must be considered particularly unsuitable. If chemical air-entraining agents are used it is particularly important that the dosage be carefully checked.

In brief, the rules for building watertight masonry may be given as follows:

1. All the joints should be grouted completely; each brick should be surrounded by an unbroken watertight layer of mortar.

2. The brick should have a water suction of between 10 and 30 gm. when one of its flat sides is immersed 3 mm. in water for one minute. More porous facing bricks must be soaked.

3. A mortar, which has a high cement content and which is mixed in a mixer at the building site, should be used. A suitable mixture, in parts by volume, is as follows: 1 cement + 1 lime + 6 - 7 sand or 1 cement + 1/2 lime + 4.5 - 5 sand.

Fig. 1

Photograph of a test wall (no. 9) taken from behind. The coat of white lime inexorably reveals the poorly filled joints. The lines drawn indicate the spreading of the moisture spots at ½-hour intervals. Note that the initial penetration is confined to the joints.

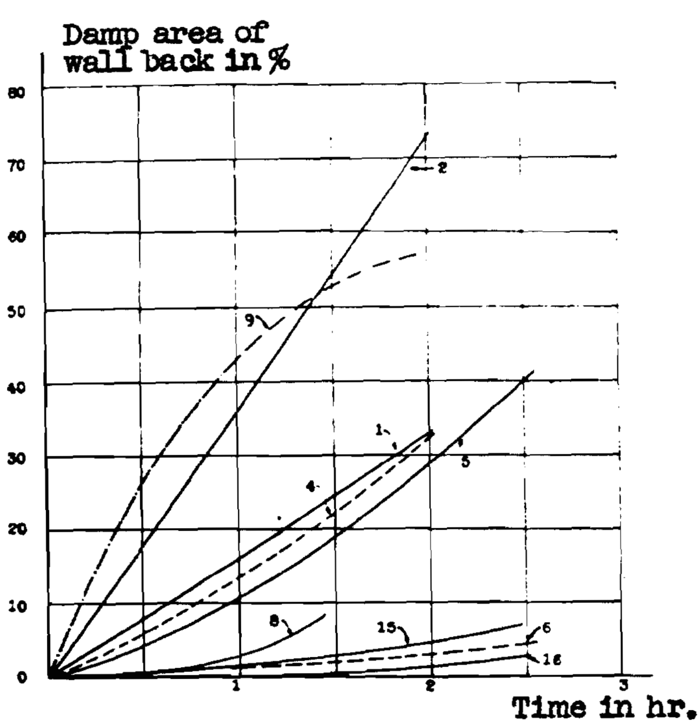


Fig. 2a

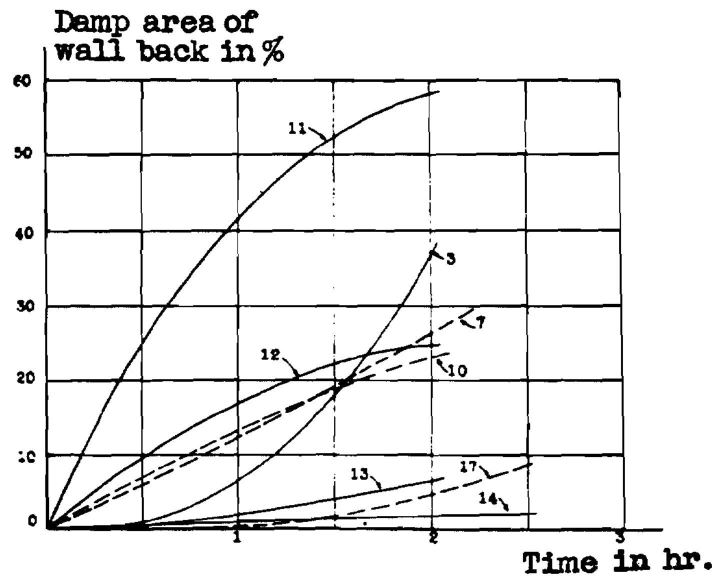


Fig. 2b

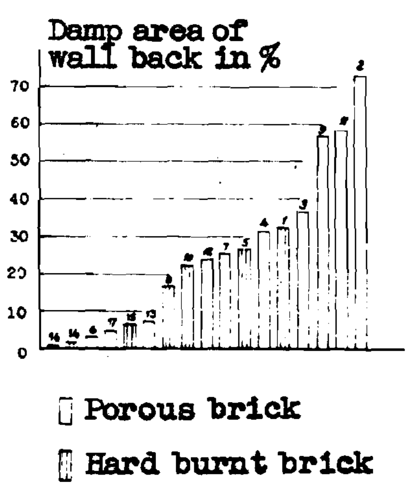


Fig. 3

Spreading of the penetrated moisture after two hours of spraying with water. The numbers on top of the piles indicate the numbers of the respective walls. Apparently the extent of spreading is considerable, but it may be pointed out that walls of porous brick are decidedly inferior to those of hard burnt brick.

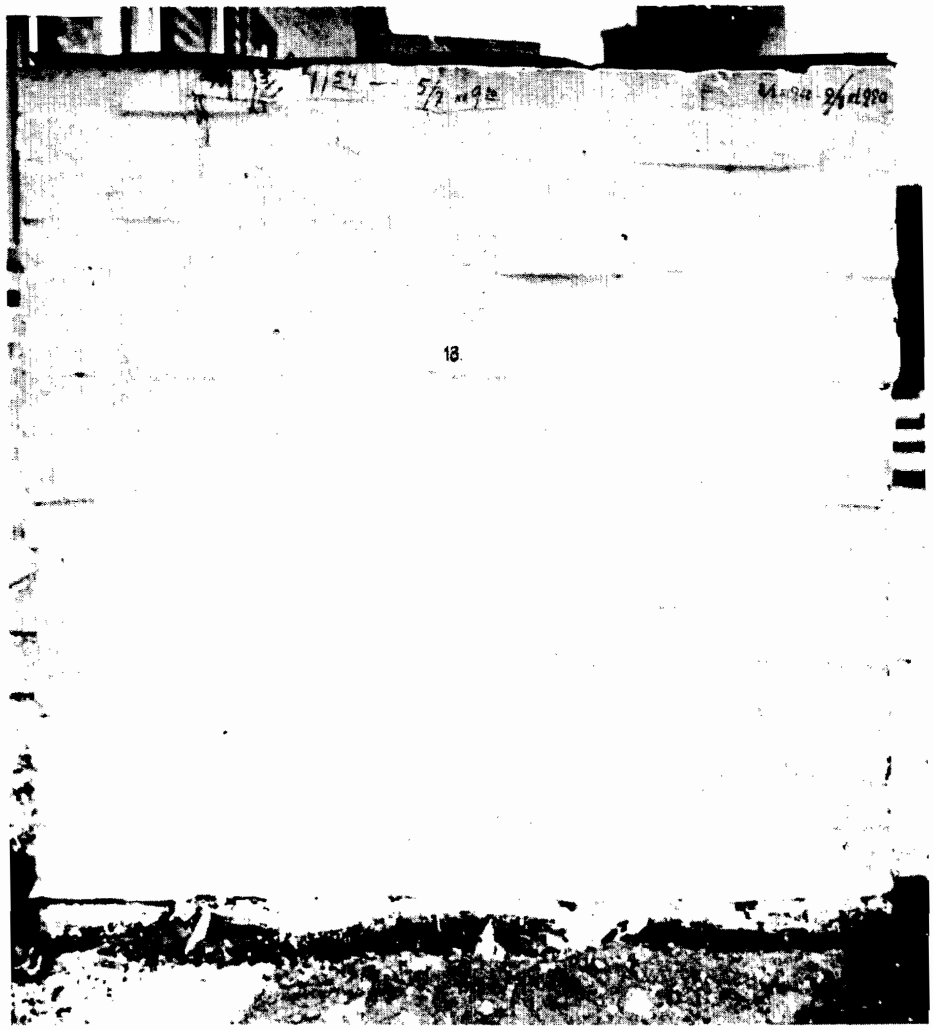
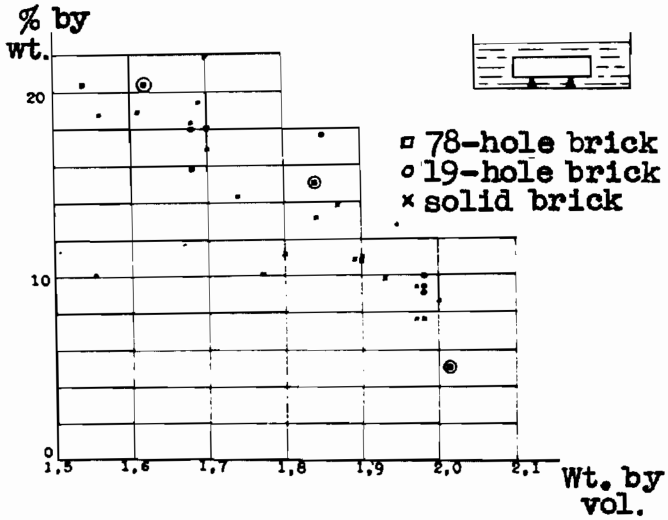


Fig. 4

Fig. 5a

Water absorption of different Swedish facing bricks which were dry before they were completely submerged in water for 24 hr. The importance of the weight by volume for the water absorption is clearly evident even though no direct relationship can be established because of the extensive spreading. For the bricks marked by rings determination of the water absorption was carried out continuously during the first 15 min. after immersion in water. The results of these measurements are shown in Fig. 10.



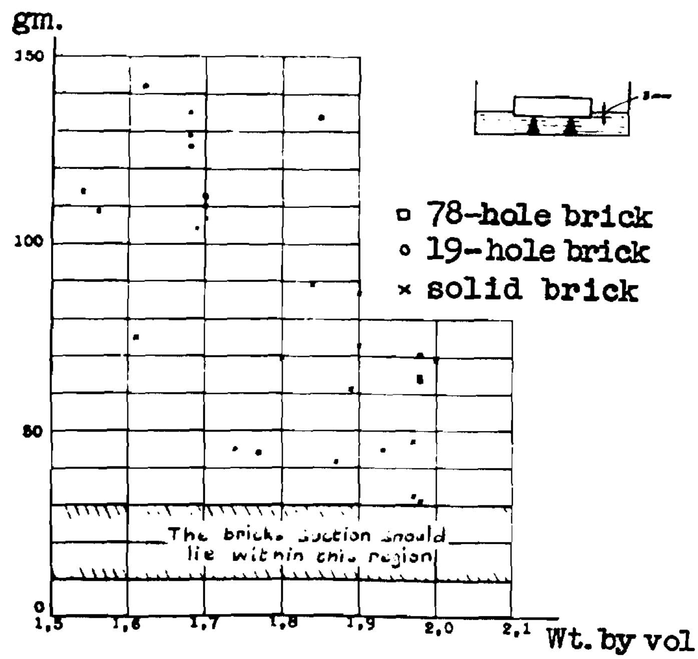


Fig. 5b

The water suction of different Swedish facing bricks determined by means of an American method as the amount of water which a dry brick sucks in during 1 min. on being immersed in water to 3 mm. of its flat side. Only two of approximately 30 different bricks tested should be approved and then only with hesitation.

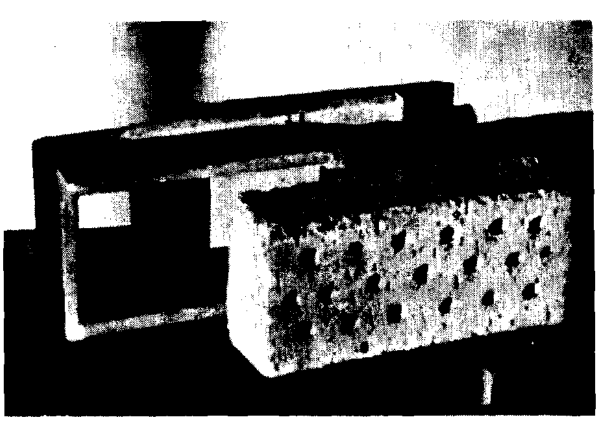


Fig. 6

Photograph showing the simple arrangement used for determining the adhesive power of different brick mortars.

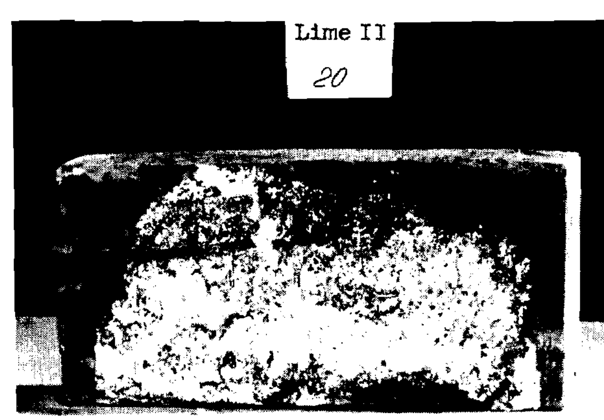


Fig. 7

Adhesion test with lime mortar obtained from a brick mortar plant. The consistency of the mortar was 20 according to the mo-meter.

Fig. 8

The same test as in Fig. 7, carried out with activated cement mortar (1 : 1 : 6), also having a consistency of 20 (mo-meter). Figs. 7 and 8 show the great difference in adhesive power of the two mortars. It can also be seen that the cohesion of the activated cement mortar is far superior.

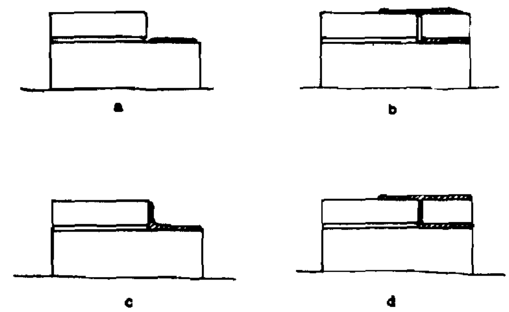


Fig. 9

Two different ways of laying bricks, the normal way (a and b) and a suggested way (c and d).

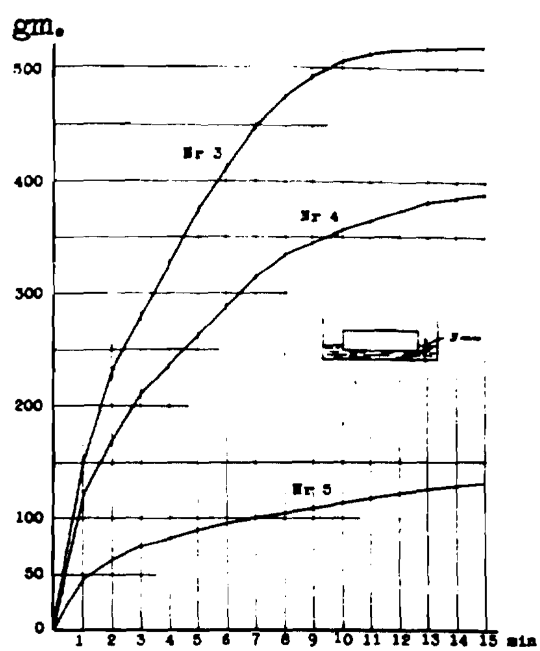


Fig. 10

Water absorption of some facing bricks as a function of time. The inset illustrates the arrangement of the bricks. The volume weights of the bricks tested were 1.6, 1.85 and 2, and the weights were 2.73, 2.78 and 2.97 kgm. for tests no. 3, 4 and 5 respectively.

Fig. 11

Experimental set-up for determining the watertightness of mortar. The surfaces shielded with metal collars were sprinkled with water by a nozzle placed in front of the bricks.

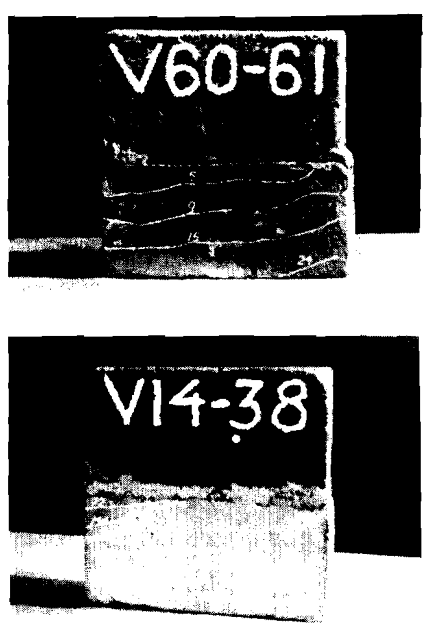


Fig. 12

Test specimens for determining the watertightness of mortar after the end of the test. The upper test was carried out with ordinary lime cement mortar (1:2:12) and the lower with a fattier mortar having a higher cement content (1:1:6). The lines drawn show the position of the moisture front after the number of hours given by the values on the respective lines. No comment required.