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NORWEGIAN TEST METHODS FOR RAIN PENETRATION THROUGH MASONRY WALLS

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SYNOPSIS

The Norwegian Building Research Inst. has developed methods for laboratory testing ot masonry walls, in which wall panels are exposed to artificial rain and a pressure difference. Laboratory results have been compared with results from test houses and field experience to determine the validity of the laboratory results.

Available knowledge on how water moves into a building material is not sufficient for calculating the results of the movements. The only possible means of gaining knowledge on rain penetration are practical experience, the use of test houses, and full-scale laboratory experiments. Rain penetration is a serious problem in Norway. It is therefore natural that the Norwegian Building Research Inst. (NBRI) has developed certain test methods for rain penetration, and has taken part in the work of the Working Commission on Rain Penetration of the International Council for Building Research, Studies and Documentation (CIB).

The Norwegian test methods have been developed on the basis of experience collected during the research (**1**)[2] of the Norwegian Building Research Inst. and discussions in the above mentioned commission. NBRI uses the definition of rain penetration adopted by the CIB Working Commission on Rain Penetration: "By rain penetration is meant the penetration of rain water into a wall either through the surface of the wall, or through leakage at windows or similar installations. It is not necessary that the water penetrates so far that it is discernible on the inside of the wall."

THE MECHANISM OF RAIN PENETRATION

The Norwegian test methods for masonry walls are based on the following interpretation of what happens when rain water hits a masonry wall.

When rain water hits a wall surface, the water is first sucked into the wall material. If the rain continues faster than the suction, the water starts to run down the wall, forming a film of water which is thicker on the lower part of a building than on the upper part. This film of water forms a bridge over the unavoidable small cracks in the masonry wall. Wind acting on the wall forms a pressure difference over the water film. By this pressure difference the film of water is forced into the wall. Rain penetration seems to occur and be important in cracks between 0.1 and

[1] The Norwegian Building Research Inst., Oslo, Norway.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper.

4 to 5 mm wide. The wind pressure is added to capillary suction. The latter seems to be important for openings smaller than 0.5 mm.

When a wall is filled with water, only a slight pressure difference is sufficient to make the water discernible on the inside of the wall. Factors to be considered in rain penetration are the properties of the wall, the amount of water hitting the wall, and the wind pressure over the wall. The wall is dried out again by evaporation of water from the surface. The speed of evaporation is dependent on climatic conditions (wind, temperature, moisture content in the air) and heat loss through the wall.

The intensity of driving rain on a given surface determines whether a water film will be formed and the thickness of that film. The amount of water striking the wall during a longer period (minus the evaporation from the wall surface) determines in certain cases the amount of water collected in the wall.

Wind pressure is determined by the velocity of the wind, the shape of the building, and the orientation and exposure conditions of the building. Figure 1 shows the relation between wind and pressure. In general, the pressure difference over the wall will not be quite as high, but may become considerably higher when conditions are unfavorable. The local pressure can be several times the quoted values.

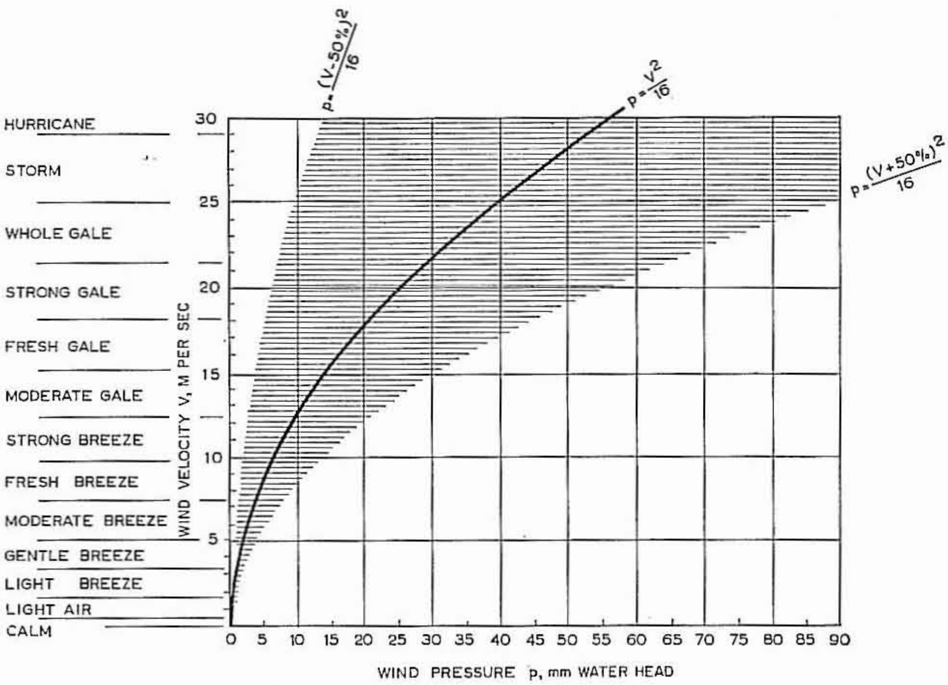

FIG. 1.—Relationship Between Wind Velocity and Wind Pressure.

In Norway, as in most other countries, few observations on driving rain intensity are available (1). These were made by Professor Holmgren in Trondheim. During three months the maximum intensity of driving rain was: in 10 min 1.1 liters per sq m; in 30 min 3.0 liters per sq m;

and in 60 min 4.5 liters per sq m. These observations were noted at a free weather station.[3] The actual onslaught on buildings, however, is very different from conditions at a free weather station. Little is known about the distribution on a real building. Some members of the CIB Working Commission are doing measurements on actual onslaught on buildings, and knowledge is slowly being collected.[4]

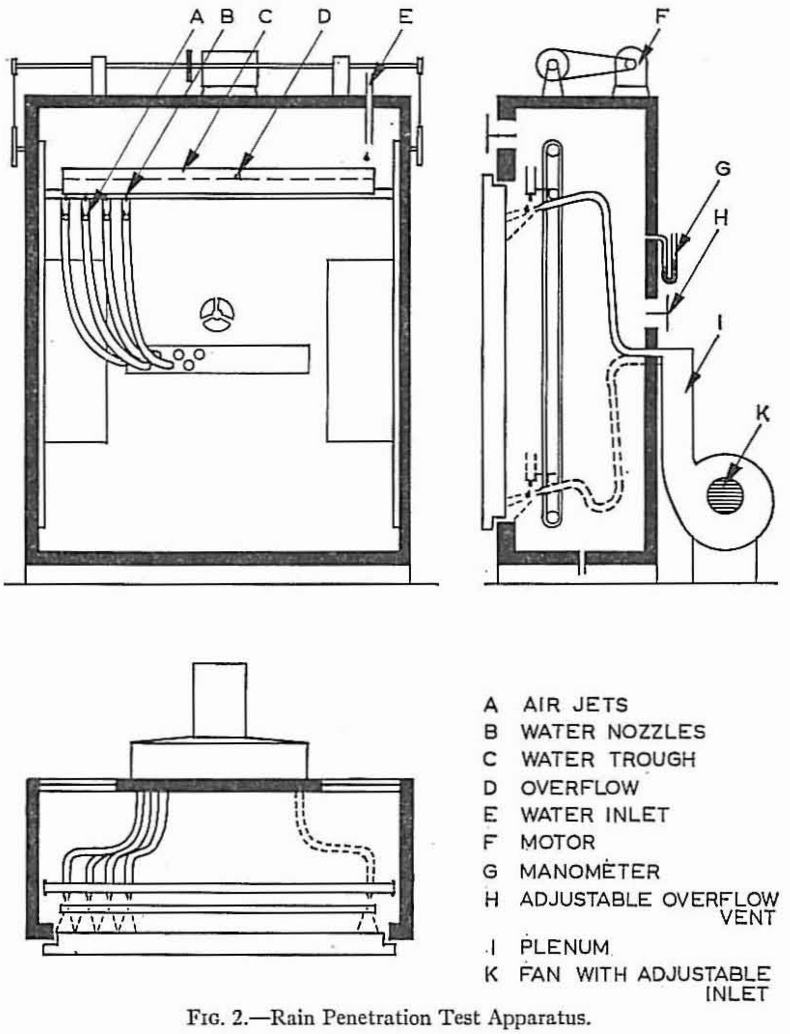

FIG. 2.—Rain Penetration Test Apparatus.

The amount of driving rain on a wall from the most exposed direction in the most exposed place in Norway is 1715

[3] Determined with apparatus recommended by the International Council of Building Research Working Commission on Rain Penetration, originally constructed by Professor Holmgren.

[4] Apparatus recommended by the CIB Working Commission on Rain Penetration is also used. The apparatus was constructed by Mr. Croiset, Centre Scientifique et Technique du Bâtiment, France.

mm per sq m per yr; more than 1000 mm is frequently found along the west coast of Norway. Moreover, the rain is usually distributed throughout the year, often allowing the wall only short periods for drying out. In more sheltered areas in eastern Norway, the onslaught is only a few hundred millimeters.

Onslaught on a specific building seems to be determined as much by the amount of exposure of the site and the height of the building as by the climatic differences between different parts of the country.

TEST METHODS

Tests on rain penetration through masonry walls have been carried out by the NBRI for more than 12 years. The work in this field, however, has been far from continuous and has actually consisted of several research projects with different scopes, presenting a large variety of separate problems. These differences in scope and the new knowledge gradually accumulated through laboratory tests and field experiences have, during the years, led to several changes in research procedure and test apparatuses. In this paper, such methods will be described as are currently in use at the NBRI.

Laboratory Tests:

At present the laboratory has two test chambers for artificial wind-driven rain. As the main principles of design and manner of action are rather similar for the two apparatuses, it should be sufficient to describe only the larger one. A schematic diagram of this apparatus is shown in Fig. 2.

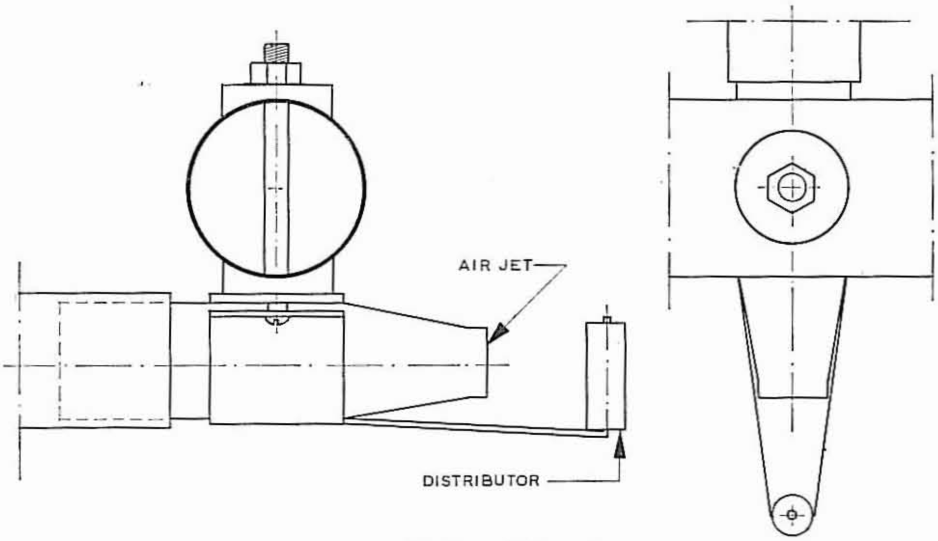

FIG. 3.—Air-Jet with Air and Water Distributor.

The apparatus was originally designed for investigations of framed timber walls. The size of the test area was 185 by 185 cm to accommodate such walls. By using masking frames smaller masonry panels can be fit into the test opening. The test chamber is made of wood lined with metal, and is fairly but not absolutely airtight.

The air necessary for building up a

pressure difference and driving the rain drops is supplied by a centrifugal fan outside the chamber. The fan is connected directly to a plenum from which 16 flexible hoses lead the air inside to separate air jets. These jets are attached to the under side of a horizontal axle parallel to the panel, with the outlets pointing toward the test opening. Supported by the same axle and parallel to it is mounted a water trough with 16 nozzles. Each nozzle is placed at the bottom of the trough exactly above the outlet of an air jet. By means of an overflow, the water is kept at a constant level in the trough.

Drops of water with an approximate diameter of 5 mm are formed by the nozzles. When these drops fall into the concentrated air stream from the jets, they split into a large number of droplets of varying sizes and are blown against the test panel. To secure an even distribution of air and water on the exposed side of the panel, the air jets are given the special form shown in Fig. 3. By changing the size of the nozzles and the water level in the trough, the amount of rain supplied to the test panel can be varied from 0 to 20 liters per sq m per hr.

The air jets can be adjusted to any desired angle in the horizontal and vertical projection, thus forcing the simulated driving rain in the desired direction. Normally, however, the rain angle is 30 deg downward from the horizontal. The pressure drop across the panel can be varied from 0 to approximately 150 kg per sq m. Correspondingly the velocity of the rain drops can be regulated by an adjustable air inlet on the fan and by variable overflow vents in the chamber.

If the air jets are kept in a permanent position, only a horizontal band across the panel with a width of about 25 cm will catch the direct rain spray. If a uniform distribution of drops over the height is desired, the air jets must be made movable. The axle carrying the whole spray equipment is, therefore, mobile and motor-driven. When the motor is switched on, the jets and the water trough travel up and down at a constant rate of one complete cycle every 25 sec. The spray equipment can also be kept at any desired level to give extra load on a specific part of the wall.

Three different types of investigations are at present carried out at the laboratory in connection with masonry walls: tests with small jointed panels, tests with small panels without joints, and tests with larger walls.

Tests with Small Jointed Panels.—For the first type of investigation the panel size is 60 by 120 cm (occasionally 50 by 100 cm), with wall thickness varying from 10 to 25 cm. Only compact walls are tested in this way, and materials used have been brick, hollow concrete block, light-weight aggregate block, and cellular concrete block. The panels are usually built by a professional bricklayer under conditions as standardized as possible. They are then stored in the laboratory for 28 days, and during this time the sides, top, and bottom of the panels are given a water- and vapor-tight surface treatment. Usually four panels are tested at the same time in the two rain apparatuses, the total test time for one series being 46 hr. The following exposure program is used:

1. A wetting period of 5 hr. The amount of simulated rain is 10 liters per sq m per hr and the pressure difference is 75 kg per sq m. The spray equipment is kept stationary at the top of the panel.

2. A drying period of 5 hr. During this period no rain is used and a strong dry air current is directed along the exterior surface of the wall.

3. Continual exposure for 36 hr with the same setup, the same amount of rain, and the same pressure difference as in step No. 1.

The wall panels are weighed to ±50 g just before and just after the test, and specimen is cut up in horizontal and vertical sections and the water penetration into joints and blocks is recorded. Figure 4 shows a typical example of an observation sheet for a test panel made of lightweight aggregate concrete blocks.

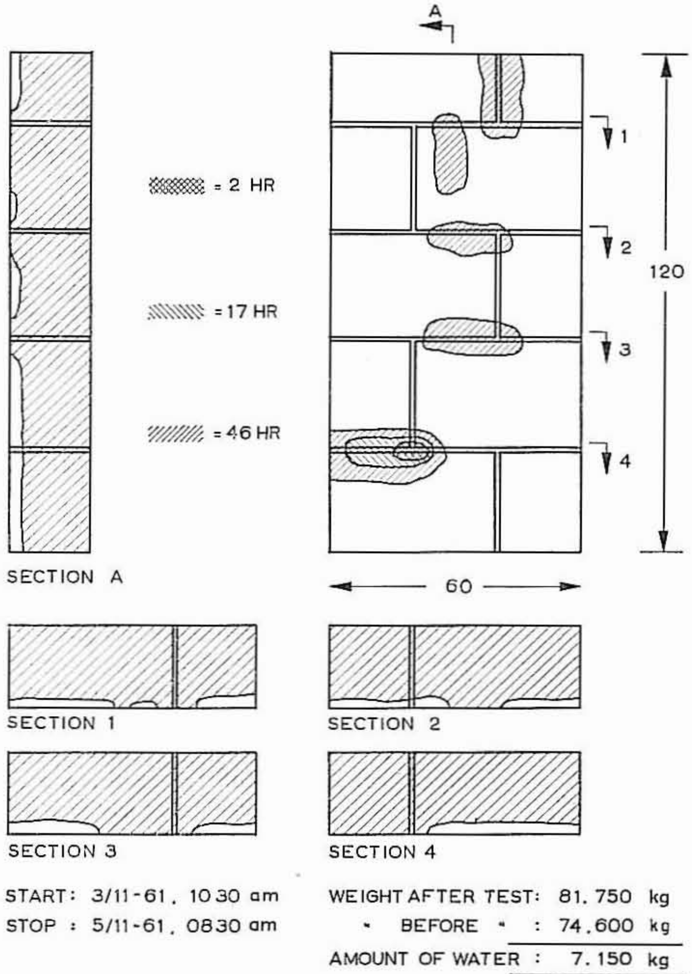

FIG. 4.—Typical Test Results for Small Jointed Panel.

the amount of water which has penetrated into the specimen is thus determined. During the test the whitewashed back of the panel is closely observed and all damp spots are recorded. When the test is finished, the

The two initial periods of the test, the wetting and drying cycle, are usually of less importance than the final 36-hr exposure. If, however, the block material or the coating used has a large drying shrinkage, small cracks may be formed during the second period. This is, of course, very important and should justify the extra 10 hr testing time, especially as the present schedule makes it possible to finish a complete test series every second day.

Several objections may be raised against the test procedure, the most serious being that the results are not easily reproduced. The main reason for this is that holes, openings, and cracks in the joints have a tendency to dominate the test picture. Such defects in workmanship can very seldom be completely avoided, and they are most certainly not reproducible. When the panel is coated, however, the effect of the joints is considerably reduced. It has also been objected that the panels are too small to be really representative of an actual wall. This may be true, but the NBRI strongly feels that even very large test walls might have much of the same weakness, due to the joint effect. The 60 by 120-cm panel is cheap, easy to handle, and handy to test. One single test wall with an exposure area of 185 by 185 cm will cost more in time and money than a large number of the small panels, and will give less reliable results.

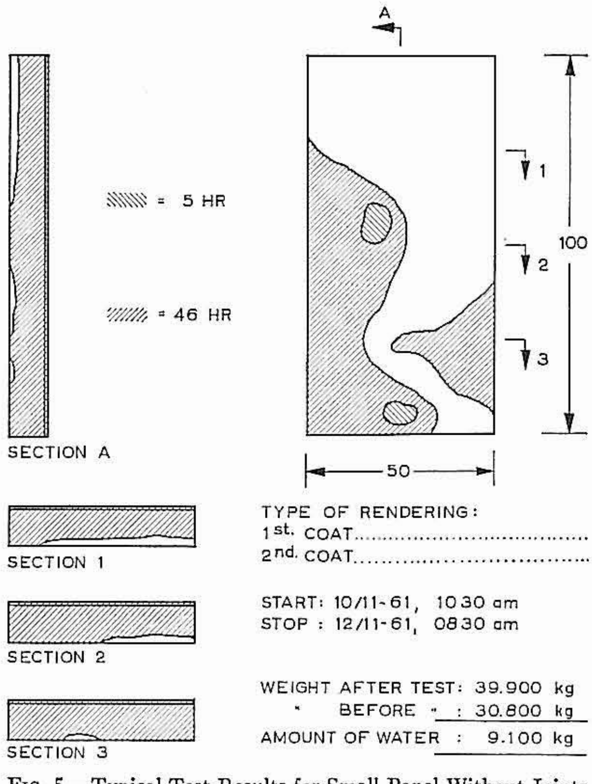

FIG. 5.—Typical Test Results for Small Panel Without Joints.

A third objection is that the amount of water used during the test is too small compared with actual rainfall. This is also true. Ten liters per sq m per hr corresponds fairly well to the maximum amount of *direct* onslaught on a wall in western Norway but does not take into account the large amounts of water which flow down from the upper part of a wall to the lower parts. The fact is, however, that the amount of water is rather unimportant in the Norwegian tests. Our severe climate requires that the wall material—or at least the coating—should have a very low rate of suction. Even 10 liters per sq m per hr will practically always give a continuous water film on the whole wall surface and a large surplus of water at the bottom of the wall.

Tests with Small Panels Without Joints.—Small panels without joints are exclusively used for the testing of coatings. The backing material is 50 by 100-cm slabs of cellular concrete 10 cm thick and 500 kg per cu m bulk weight. Very strict requirements are put on the moisture content, suction, and airtightness of these slabs, and also on the workmanship when the coating is applied. The test method and exposure program are exactly the same as for the jointed panels. Figure 5 shows a typical example of test results.

This test method is, of course, of special interest in a country like Norway, where the great majority of masonry walls are coated. At the same time cellular concrete and similar materials are used to a very large extent and this calls for coatings with a high degree of raintightness. Several hundred tests have been carried out according to this procedure, and the results have often had a decisive influence on the evaluation of new types of coatings by the building authorities and the building industry.

Tests with Larger Panels.—Tests with larger panels have so far been carried out only in connection with brick cavity walls. The size of the panel is approximately 75 by 195 cm, each of the two leaves is half a brick in thickness, and the cavity is 10 cm deep. The outer and inner leaves are built separately, and usually one inner leaf can be used in connection with several outer leaves. Figure 6 shows the construction of an outer leaf. The wall is built on a steel beam and during transportation it is held together with tension rods. Steel binders are placed in the usual number of points and also serve to obtain the correct distance between the two leaves during mounting.

Figure 7 shows details of the mounted panel. The critical problem is to obtain sufficient tightness in all junctions, as the performance of the test wall is completely dependent on a correct pressure drop across the two leaves. Experience from the panels so far tested seems to indicate that this is possible only if the greatest care is taken. To secure an airtight connection between the two leaves, a strong plastic sheet is glued in asphalt all around the cavity. This has the additional advantage that it is possible to inspect inside the outer leaf in those cases where cavity insulation is not used.

The tests with cavity walls have been intended to advance basic knowledge on rain penetration through such walls. Consequently no strict test program has been followed, but the influence of several different variables has been investigated. Among these are the connection between total pressure difference and water penetration, the influence of one or more open vertical joints, different types of surface treatment on the outer leaf, and the behavior of insulation materials when water penetrates into the cavity.

Test Houses:

The NBRI has continued the research work of Bugge and Holmgren (6) which was started in the Norwegian Technical University, in Trondheim, as early as 1919. Several years ago, however, the original small test huts were replaced by one large house, the wall laboratory. This house, situated at the western brink of the University Hill, is 3.5 by 29 m. One of the long walls faces east and the other faces west. In each of

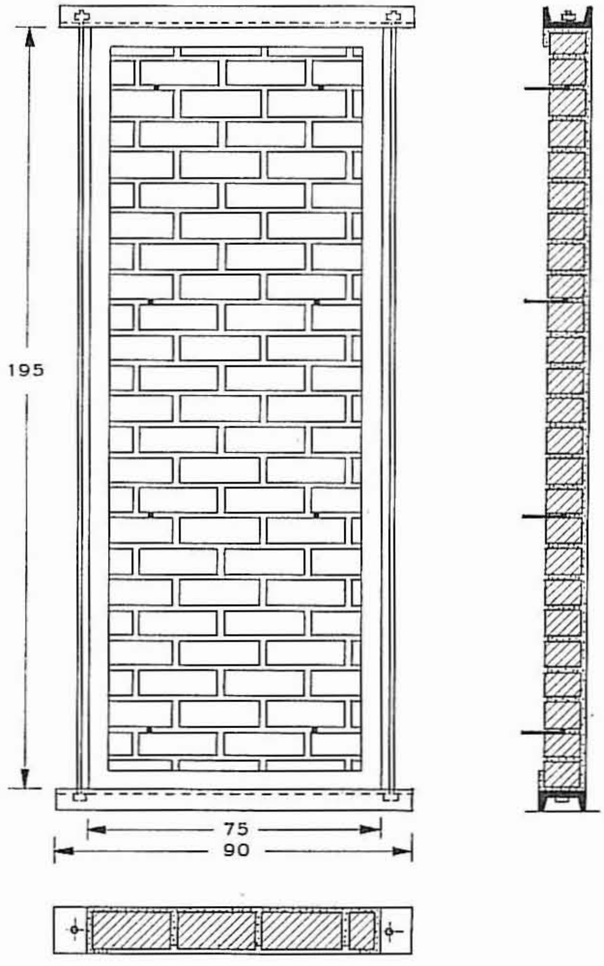

FIG. 6.—Outer Leaf for Cavity Wall Test.

these walls 18 interchangeable test panels are installed, each panel being 140 by 300 cm (Fig. 8).

The primary purpose of the test house, as for the test huts, is to establish practical heat transmittance coefficient values, U, for different types of wall constructions. Almost equally important, however, is the study of rain penetration through the wall panels, and the test house is very well suited for such investigations. West is, by far, the most exposed direction in Trondheim, with approximately 55 per cent of the total amount of wind-driven rain, while less than 5 per cent comes from the east. The site of the test house is also far more exposed than the average Trondheim area. By building duplicate test panels facing west and east, the changes in moisture content for exposed and unexposed walls can be studied. In close connection with the test house, a small meteorological station has been built where daily observations of driving rain, vertical precipitation, and temperature are made.

So far, walls of hollow concrete blocks, cellular concrete blocks and elements, lightweight aggregate blocks, and brick have been tested. At the same time several variable factors have been investigated, including changes in joint width, different ways of applying the joint mortar, variations in the construc-

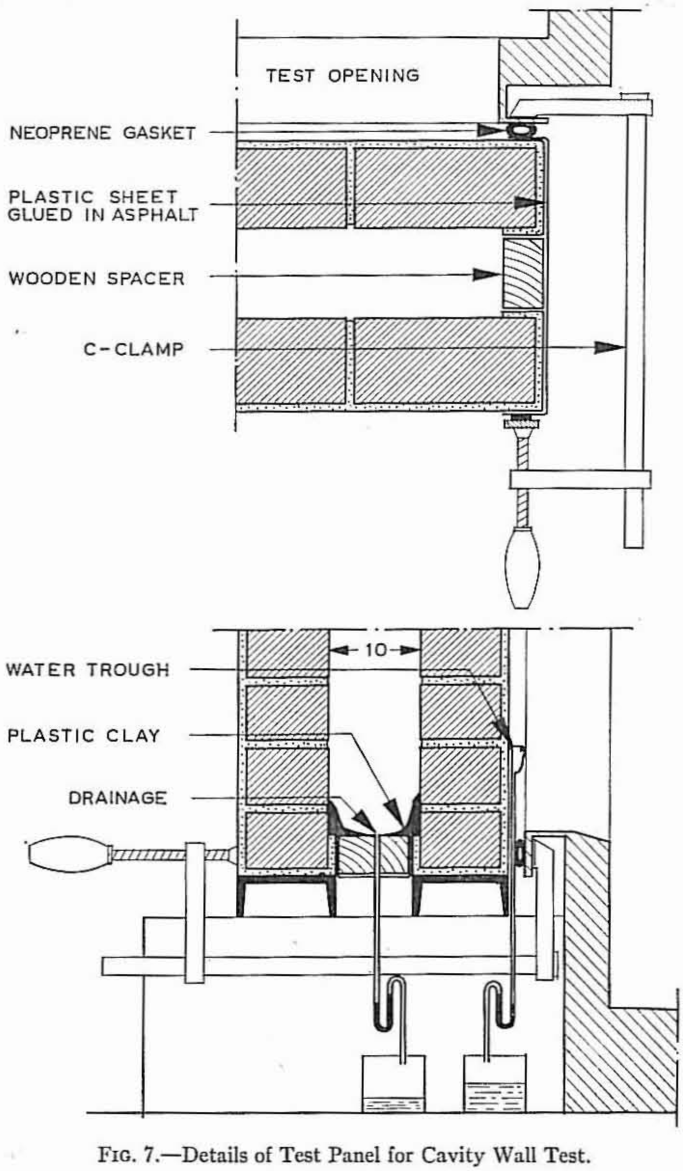

FIG. 7.—Details of Test Panel for Cavity Wall Test.

tion of cavity walls, types and mix proportions of the coating mortar, and the influence of ventilated sheathing.

The period of investigation has varied between 2 and 5 yr, but a few of the panels are as old as 8 yr. At least twice a year the moisture content of the wall material is determined by drying out and weighing drilled-out cores, removed bricks, and samples of cavity insulation. For the solid walls not only the total amount of moisture is measured but also the moisture gradient through the walls. In addition, the continual measurements of U-values might also give added information about sudden changes in moisture content. The insides of the panels are inspected every day and all visible penetration is recorded. The outsides are inspected minutely several times a year and all changes in appearance such as cracks, efflorescence, and discoloration are recorded.

During testing time, the indoor climate of the test house has been kept comparatively constant, with the relative humidity varying between 40 and 50 per cent and with a temperature of 20 C. For certain investigations it has been desirable to increase the relative humidity in certain parts of the test house. This is possible since the house is divided into "cells," each comprising two panels facing east and two facing west.

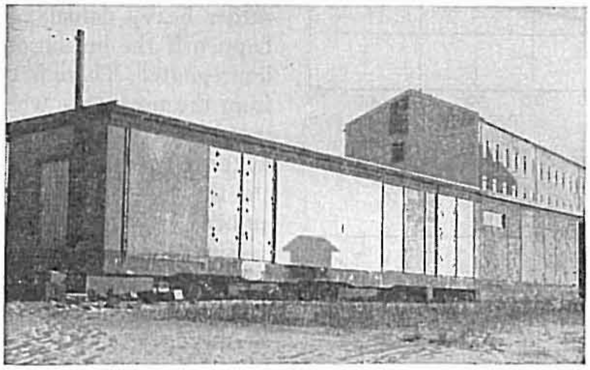

FIG. 8.—West Wall of Test House.

FIELD EXPERIENCE AND TEST RESULTS

The difficulties in designing reliable test methods for rain penetration through masonry walls are both great and many. This is due partly to the large variety and difference in wall material, mortar, and workmanship. The main problem, however, seems to be that masonry in the laboratory is built and stored at conditions rather unlike those on most building sites. Consequently all laboratory tests, if they are to have any value, must be compared with experience gained from real structures in varying climates. The NBRI has tried to follow this line of investigation, and some of the main results are given below.

Field experience, test houses, and laboratory tests agree that in a climate like Norway's, the pressure difference is by far the most dangerous climatic factor in connection with rain penetration through masonry. Even with rather porous wall materials, penetration will occur mainly through joints. Figure 4 is a typical example of this. In some cases, especially where hollow concrete blocks and lightweight concrete blocks are used, shrinkage cracks permit the water to enter. In this respect, the laboratory tests usually fail. The laboratory tests are also rather unreliable in connection with penetration caused by insufficiently filled joints or lack of bond between mortar and block or brick.

The tests with brick cavity walls have given results which are in excellent agreement with the experience from test houses and existing buildings.

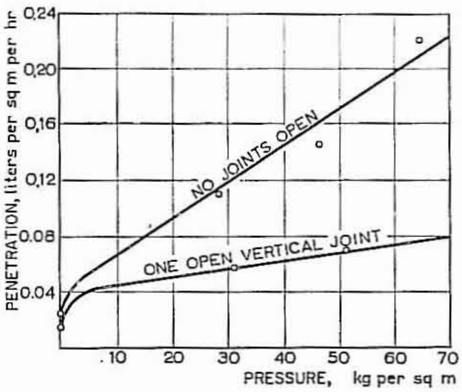

FIG. 9.—Influence of an Open Joint on Penetration.

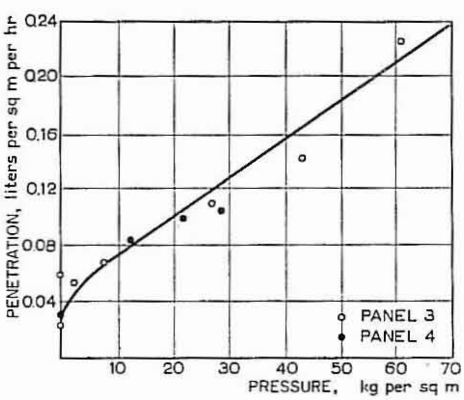

FIG. 10.—Relationship Between Water Penetration and Pressure Drop Across Outer Leaf.

Figure 9 shows, for example, the penetration through an outer leaf with and without one of the vertical joints left open. Figure 10 gives the relationship found between penetration and pressure difference over the outer leaf. Corresponding results, at least fundamentally, have been obtained from the test house and from walls inspected in different parts of Norway. It seems to be established that in such walls some penetration into the cavity will usually take place. The amount of water will increase very much with the pressure drop across the outer leaf, and a certain ventilation of the cavity, therefore, is advisable. If the cavity is empty or filled with properly impregnated insulation material, the water will follow the inside of the outer leaf and can be drained out at the bottom without harm. Obstacles bridging the cavity—for instance, mortar waste—can divert the water to the inner leaf and cause rather heavy damage. The same might happen if the insulation material is not impregnated. There is even one example from the test house where the insulation material (vermiculite) absorbed so much water that it settled in the bottom of the cavity, leaving the upper part quite empty.

Even the coating test with unjointed panels gives good agreement with practice. This is only true, however, as long as the coating is carried out according to good workmanship. The test also fails to give any information about the behavior of the coating when it ages. A rain test on a coating is always combined with measurements of bond strength and water vapor transmission.

SUMMARY

Based on laboratory, test house, and field experience, the Norwegian Building Research Inst. has developed an interpretation of what happens when wind-driven rain hits a wall surface and water penetrates into the wall.

One of the main findings is that in a climate like Norway's, pressure drop is by far the most dangerous climatic factor in connection with rain penetra-

tion. This is valid even with walls from rather porous material, as here also the penetration mainly occurs through joints. For cavity walls a direct correlation between pressure drop over the outer leaf and rain penetration has been established. On this basis certain test methods have been developed. Invaluable for the results achieved has been the exchange of experience established through the CIB Working Commission on Rain Penetration.

REFERENCES

(1) Sven D. Svendsen, "Driving Rain," Norwegian Building Research Inst., *Report No. 20*, Oslo, 1955 (out of print).

(2) Mads Gedde Myrre, "The Influence of Climate on Well-Insulated Brick Walls," Norwegian Building Research Inst., *Reprint No. 35*, Oslo, 1959 (out of print).

(3) Annanias Tveit, "Investigation of Heat Transmittance in Walls," Norwegian Building Research Inst., *Reprint No. 38*, Oslo, 1959.

(4) Annanias Tveit, "Heat Transmission Through Test Walls of Autoclaved Cellular Concrete," Norwegian Building Research Inst., *Reprint No. 68*, Oslo, 1962.

(5) Sven D. Svendsen, "Tightness Against Wind and Driving Rain," Norwegian Building Research Inst., *Reprint No. 71*, Oslo, 1961.

(6) J. C. Holmgren, "Fuktighetsforhold i vegger (Moisture Conditions in Walls)," reprint from "Varme," Copenhagen (1939–1940).