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**Publisher's version / Version de l'éditeur:**
https://doi.org/10.4224/20338120
*Building Practice Note, 1979-10*

ISSN 0701-5216

# BUILDING PRACTICE NOTE

RAIN PENETRATION AND DESIGN DETAIL FOR MASONRY WALLS



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Ottawa, October 1979

NO 17

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Even with the careful selection of a masonry wall system, compatible and durable materials, and excellent workmanship during construction, wind-driven rain will inevitably penetrate a masonry wall. The problem can be minimized and controlled by good design detail.

There is ample field evidence to illustrate the contribution of inadequate design detail to rain penetration problems. When these problems arise the masonry contractor points to the absence of design detail in the plans and specifications, whereas the designer responds by suggesting that proper detailing is a part of "good practice" and is the responsibility of the contractor.The forthcoming publication by the Canadian Standards Association of the Standard on Masonry Construction for Buildings will doubtless help to clarify the situation.

It should be recognized that the modern job superintendent is not the "Master Builder" of yester-year, with his all-encompassing knowledge of materials, engineering and trade practice. The continual appearance of a multiplicity of new materials, mechanical equipment and design patterns make it impossible to acquire an over-all expertise. It is therefore incumbent on all members of the construction team to ensure that the ground rules and limitations of their particular area of concern are fully understood by the other members of the team. No design can compensate for inferior materials and poor workmanship, likewise quality materials and good workmanship cannot compensate for poor design. All partners must work together to ensure satisfactory performance.

An in-depth discussion of design detail would be long and involved. The purpose of this Note is to indicate briefly some of the factors and problem areas that should be of concern. Readers wishing to pursue the subject in more detail are directed to the list of References at the end of this Note.

## Effect of Exposure

The design of any building should reflect the exposure conditions to which it will be subjected. The severity of the rain penetration of masonry walls depends on the amount of rain falling and the strength of the wind pushing it against the wall. A rational assessment of the probability of rain penetration requires an involved and lengthy study of hourly weather records over an extended period of time. As a practical alternative designers are referred to information available in recent publications. Supplement No. 1 of the National Building Code of Canada[1] contains data on rainfall intensity and wind pressures for selected Canadian locations. The

Driving Rain Map of Canada[2] combines mean wind speed and annual rainfall, and clearly illustrates the variable conditions that can occur in Canada. Severe exposures are indicated for the Avalon Peninsula of Newfoundland on the East Coast and for part of Vancouver Island and some other islands off the West Coast, with a moderate exposure for other coastal areas and a generally sheltered exposure for the inland areas of Canada.

In another approach, the potential for rain penetration of the wall is judged by a numerical index based on hourly wind speeds and directional effect during rain storms of minimum duration of twelve hours. Data for twelve Canadian cities is shown in Table I, taken from "A Wall Penetration Map of Canada,"[3] where the information is also presented in map form. Again the variable conditions occurring in Canada are indicated. The heaviest rains in Victoria and Vancouver are accompanied by winds from the southeast and east directions. At Halifax heavy rains are accompanied by wind from the east, but other Atlantic coastal areas have severe exposures from almost every direction.

The designer should note that these publications do not give the complete story. On the East Coast, rain storms occur frequently during the winter months and are often associated with rapid freeze-thaw cycling, which can accelerate deterioration in masonry mortar joints making them more vulnerable to rain penetration. Finally, it should be remembered that the exposure for an individual site can vary significantly from the average for the area due to the effect of local geography and surrounding buildings on the direction and intensity of the wind pattern.

## Cracking

In addition to water and a force to propel it, the third essential factor in rain penetration is an opening in the wall. Openings or leakage paths are inevitably provided by cracking, which can result from foundation settlement, but are more often caused by differential movement within the wall itself. Masonry walls are dynamic structures, as the various component materials respond to changes in moisture content, temperature, plastic flow, and vibrations in mechanical equipment in the building. The problem is complicated by the fact that different materials respond to these changes in different ways. These differences are illustrated by the responses of concrete and clay units - a popular combination in composite masonry walls. Both expand and contract in response to temperature changes, but the dimensional change in the concrete units is greater than that in the clay units. However concrete units undergo initial drying shrinkage while clay units undergo a slow irreversible expansion, of smaller but significant magnitude, under the influence of moisture. Concrete is also subject to plastic flow or creep under sustained loading. Thus the movement in concrete units is greater than, and generally opposite to, that in clay units. Similarly other materials have their own peculiar movement characteristics. Modern masonry walls, containing high strength mortars, are also relatively thin and brittle, and lack the potential for accommodating movement that was an inherent characteristic of thicker masonry walls laid up with high lime mortar.

Cracking occurs when the stresses created by wall movements exceed the tensile strength of the masonry. The designer can control these stresses and minimize the incidence of cracking by the use of bond breaks, flexible anchorage and control joints. Judicious use of these tools requires an intimate knowledge of the movement characteristics of the materials to be used. This information is available in masonry handbooks.[4,5]

## Bond Breaks and Flexible Anchorage

Masonry walls are usually placed on concrete foundations. If the walls are of clay bricks and the bottom wythe is "fastened" to the foundation wall with a strong mortar, with no concession to the opposing dimensional movement of the two materials, the result will be the inevitable foundation corner cracking so frequently seen. In other instances shrinkage cracks, which sometimes occur in the foundation or basement wall, can extend up into the masonry wall. These problems can be minimized by the use of a bond break between the foundation and the masonry wall which can be achieved by placing a layer of building paper under the bottom wythe of bricks.

Another problem that occurs at the wall-foundation interface is basement leakage, which is the result of rain penetrating the masonry veneer, draining to the bottom and running down the inside of the basement wall in the absence of proper flashing that should have intercepted and drained it to the outside. The problem can be eliminated by providing a "brick check" at the top of the concrete foundation wall. A simple method of doing this involves placing a two-by-four stud horizontally against the formwork to form an inset on the exterior side of the top of the wall when the concrete is poured. After the wall has cured, the two-by-four is removed and the bottom wythe of bricks is laid in the brick check with a proper flashing detail.

Masonry walls tied rigidly to skeletal frames often crack because of differential movement between the two components. These movements can be controlled by the use of flexible anchors that will allow the frame and the wall to move independently, within certain limits, without one restraining the other.

## Control Joints

Masonry "purists" use the term "expansion" joints for clay masonry (because clay units expand) and the term "control" joints for concrete masonry (to control cracking due to shrinkage). In this discussion the term "control" joints covers all types of masonry. A control joint is a separation built into a wall at locations where stresses otherwise may be expected to cause cracking.

There is no standard formula for the location of control joints. Each building must be analysed on its own. Procedures for such analyses and methods of forming control joints are described in masonry handbooks.[4,5] Vertical control joints for concrete masonry[6] are used to break up long stretches of wall or to separate changes in height or thickness, at return angles in "L," "T" or "U"-shaped buildings, at abutment of wall and columns, and at one or both sides of wall openings. Control joints are also used to break up excessively long runs in clay masonry walls[7] and at other vulnerable areas such as the juncture at wall offsets and T-junctions in cavity walls.

It is also important to consider the need for horizontal control joints in high-rise buildings. Absence of these joints in such buildings with reinforced concrete frames and exterior clay brick wythes supported on angle irons at spandrel levels has caused problems.[8,9] The combined effect of drying shrinkage and plastic flow can cause the concrete frame to shrink, and in the absence of a control joint between the bottom of the angle iron and the top wythe of the brick panel below it, cracking and/or buckling can occur.

Control joints must be rain resistant and should be designed to permit unrestrained movement of adjacent wall areas. Control joints in the concrete inner wythe of a solid or rigidly tied composite wall should extend through the exterior wythe. This is not necessary if flexible wall ties are used. One of the prerequisites for good joint design is a knowledge of the properties of the sealants that will be used. Just as there are variations in the properties of masonry units, there are also variations in the properties of sealants.[10,11] Movement capability and durability are most important and should influence the design of the joint.

## Bond Beams and Joint Reinforcement

Bond beams and horizontal joint reinforcement can also be used to control cracking. Bond beams, constructed with masonry units filled with concrete or grout and reinforced with embedded steel, provide extra strength and stiffness for masonry walls. They are usually located above and/or below wall openings and in other vulnerable locations. Joint reinforcement, using steel rods or a specially built reinforcing web, is embedded in horizontal mortar joints at different intervals depending on length, height and number of openings in the wall.

## Flashing

In areas of severe exposure, designers are encouraged to design the most rain resistant wall possible and then make provision for controlling the water that will inevitably penetrate the wall. Good flashing detail is essential in reaching these objectives.

Flashing[12] is required wherever the masonry is vulnerable to rain penetration. There are two types of flashing - external and internal. The purpose of external flashing is to prevent water from entering the wall, while internal flashing is intended to intercept water that has entered the wall and direct it back to the exterior.

External flashings are used on parapets, projections and recesses, and intersections of the masonry wall and flat surfaces such as a roof. In the last instance they consist of two members, the base flashing which is attached to the covering of the flat surface (roof membrane) and turned up against the masonry, and the counter flashing which is built into the vertical surface (mortar joint) and turned down over the base flashing.

Internal or concealed flashings are built into the masonry wall. The flashing must extend through the exterior wythe and ideally should be turned down to form a drip to throw water clear of the wall. However this is generally not acceptable for aesthetic reasons, and most through-wall flashings are terminated at the front edge of the exterior surface of the mortar joint. These concealed flashings set in tooled mortar joints make the installation of weep holes mandatory in order to permit water to drain from the wall. Internal flashings are required at the base of cavity walls, under window sills, at heads of openings, spandrel beams, and other vulnerable areas.

Feedback on problems of rain penetration has identified several problem areas. In buildings with infill masonry walls, base-wall flashing often terminates at the columns. It should be carried around the columns, and if this is not done the ends of the flashing should be turned up. Flashings should also be well lapped where they join together. Failure to take these measures has resulted in water running off the ends of the flashing, down the columns, and eventually penetrating the inner wythe at the first vulnerable spot. Serious leakage problems have also been traced to inadequate flashing details around metal windows and doors where the problem is complicated by differential movement between the masonry and the metal components. Architectural detail in the form of projections over doors and windows, once a common feature on buildings, is helpful in diverting water away from these openings.

Sills, capping stones and chimney caps should be constructed with a drip, the purpose of which is to keep water off the wall. If they are monolithic the use of flashing under them is not necessary in areas of moderate exposure. But flashing is essential under sills in which there are joints, because inevitably the mortar will crack and/or disappear, leaving a clear path for water to enter the wall in the absence of flashing.

## Flashing Materials

Although it is not the intent of this Note to discuss materials it is necessary to comment briefly on flashing materials because unfortunately their final selection is often based on price or ease of application rather than durability and performance. The replacement of inadequate or deteriorated flashing can be very difficult and very costly.

Flashing materials[12] include sheet metals, bituminous membranes, plastics and combination materials. Sheet copper has an excellent performance record and is most durable. It is also the most expensive. Stainless steel is also a superior material but its composition must be known because different compositions have varying degrees of resistance to corrosion. Zinc, aluminum and lead are other sheet metals used for flashing but all are susceptible to some degree of corrosion when in contact with fresh mortar and require some degree of protection (such as a bituminous coating).

Bituminous felt and combination materials are used in certain locations as low cost substitutes for the sheet metals for internal flashings. They are less durable and are sometimes punctured by the masonry units.

In recent years a variety of plastic flashings have been used extensively. The better plastics are tough, resilient and corrosion resistant. They are very pliable and easy to install, which is a major reason for their popularity. Field reports indicate that their pliability is also the cause of problems due to the difficulty of installing them with a positive slope to the exterior. "Wrinkling" of the plastic can impede the flow of water from the wall system and in some instances has resulted in water backing up and penetrating the interior wythe.

The use of inferior flashing materials for dollar savings is false economy. The amount of flashing on a masonry building is a small item in comparison to its total cost, and the amount of money saved by using an inappropriate material is not appreciable. It is particularly important to use top quality materials in severe weather exposure areas.

## Weep Holes

Walls with internal flashings must be drained to the outside, which is achieved by providing weep holes at 24-in. intervals, in head joints in the brick wythe above the flashing. Weep holes are made by omitting the mortar from the vertical joint or by installing one of a number of available metal drains. If weep holes are not provided water may be trapped inside the wall.

## Conclusion

Good design detail can be a positive factor in the control of rain penetration of masonry walls. The development of an effective design detail requires an accurate understanding of (1) the environment to which the proposed building will be exposed and (2) the properties of the materials that will be used in its construction. Architectural detail that will direct water away from vulnerable areas is desirable. Quality flashing materials and good workmanship are essential in translating good design detail to optimum field performance.

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## TABLE I

## ANNUAL WALL PENETRATION FOR SELECTED CANADIAN LOCATIONS

(in units of 100 $km^2/h$)

| STATION | PERIOD | N | NE | E | SE | S | SW | W | NW |
|---|---|---|---|---|---|---|---|---|---|
| Victoria, B.C. | 1953-1972 | 3 | 23 | 34 | 611 | 0 | 13 | 24 | 15 |
| Vancouver, B.C. | 1953-1972 | 0 | 191 | 972 | 218 | 0 | 0 | 6 | 10 |
| Calgary, Alta. | 1953-1972 | 246 | 15 | 26 | 26 | 0 | 0 | 41 | 377 |
| Winnipeg, Man. | 1953-1972 | 302 | 208 | 114 | 85 | 0 | 0 | 34 | 81 |
| Toronto, Ont. | 1953-1972 | 124 | 88 | 229 | 50 | 0 | 5 | 1 | 21 |
| Montreal, Que. | 1953-1972 | 141 | 399 | 44 | 151 | 0 | 78 | 37 | 16 |
| Quebec City, Que. | 1957-1966 | 13 | 959 | 761 | 0 | 0 | 70 | 50 | 0 |
| Halifax, N.S. | 1953-1972 | 327 | 947 | 1474 | 226 | 0 | 103 | 15 | 35 |
| Sydney, N.S. | 1953-1972 | 642 | 423 | 918 | 753 | 0 | 243 | 1 | 90 |
| St. John's, Nfld. | 1953-1972 | 1403 | 1350 | 815 | 749 | 0 | 696 | 127 | 528 |