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The Design of Pressure-Equalized Rainscreen Walls

Introduction

The control of rain-water penetration through walls can be provided by methods ranging from the "face-seal" approach to the "pressure-equalized rainscreen" approach. In the last two decades designers have been moving away from the face-seal approach, favouring pressure-equalized rainscreen (PER) technology. The main problems posed by the use of "face-seal" wall construction are the poor durability of some sealant materials when exposed to a harsh northern climate and the effects of the premature failure of these face-seal materials on the wall's ability to handle moisture loads. This reduced capability of the wall results in moisture penetration into the wall and its subsequent deterioration.

Pressure-equalized rainscreen technology represents the most complete design approach to control rain-water penetration. The technology evolved from the "cavity-wall" design approach that was first introduced to reduce water penetration through masonry walls. Designers have difficulty in designing PER walls because design guidelines are currently very limited. A literature review conducted by the National Research Council (NRC) in 1992 has shown that the available guidelines are not comprehensive and that those that do exist are mainly qualitative, established by means of trial and error. The guidelines that originated from scientific research are based on static theory and may not be sufficient to design a wall capable of controlling rain-water penetration under wind-driven rain conditions. In light of the designer's dilemma, a collaborative research project has been initiated by NRC to develop performance evaluation procedures and systematic design guidelines for PER walls.

Design Approaches

Face Seal

The face-seal approach was prevalent in building design until a few decades ago. This approach consists of sealing the exterior wall cladding to control air leakage and water penetration. When load-bearing exterior walls gave way to veneer or curtain walls, and both comfort standards and the mechanical ability to provide this comfort became available, some aspects of face-seal walls which had protected them from functional failure in northern climates were lost. Massive masonry was no longer available to soak up water penetrating from the exterior; nor were people willing to put up with cold interiors and the energy loss of the uninsulated wall which, coincidentally, moderated the temperature extremes of the wall materials. The new, thin, non-absorbent face-seal walls of the 1950s and 1960s, exposed to outdoor temperatures (due to being insulated on the interior) reacted quickly to changes in temperature and solar radiation, thus imposing large stresses on the joints between components. Materials used to seal the joints could not withstand these stresses for long, with the result that the joints opened up, allowing water and air to penetrate the wall.

The face-seal approach is still used in modern exterior walls to provide the required air-leakage and water-penetration control. Given that the sealing materials are exposed to harsh weathering conditions, they require frequent maintenance to sustain the performance of the exterior wall.

Drained Cavity

The cavity-wall design approach addresses only some of the forces that contribute to rain-water penetration, e.g. capillary action and raindrop momentum. A cavity wall consists of two layers of material separated by an empty cavity (Figure 1). The outer layer is the

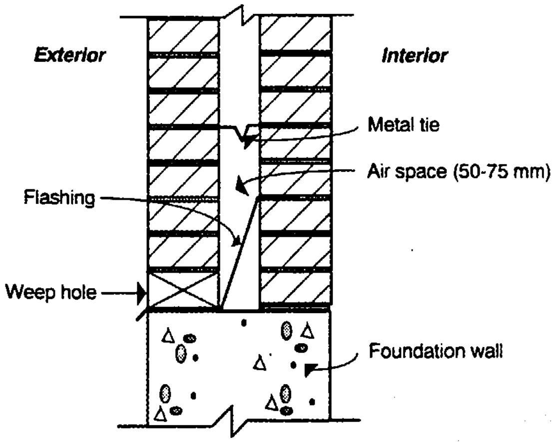

Figure 1. Typical "drained cavity" wall section

time. The effective area of the vent holes must be sized relative to the air leakage of the air-barrier system and to the volume of the chamber. Under dynamic wind conditions, the stiffness of the rainscreen and the air-barrier system will affect the volume of the chamber. This must be taken into account in designing the venting requirements.

When designing the features of a PER wall to achieve pressure equalization at all times, it is important to distinguish between static and dynamic air-pressure loads since the wall does not respond the same way to both. Air-pressure differences across the wall induced by mechanical ventilation and stack effect are static pressure loads, i.e. loads that are relatively constant over time. Wind gusts, however, induce dynamic pressures on walls, i.e. pressure that varies with time and location. The implication of dynamic pressure loads on the pressure-equalization performance of PER walls is explained in detail in the paper "Pressure Equalization and the Control of Rainwater Penetration under Dynamic Wind Loading," Construction Canada, March 1994. (Please note, this article is included in the Seminar Handout.)

IRC Research Project

The Institute for Research in Construction (IRC) of NRC has initiated a collaborative research project to develop design guidelines for pressure-equalized rainscreen walls through computer modelling, experimental studies and consultation with industry. The experimental research is jointly sponsored by Canada Mortgage and Housing Corporation (CMHC). Several wall-system manufacturers are contributing to the project by providing test specimens and advice on practical details of construction.

Several wall systems, representing common types of wall construction in Canada, were identified for the experimental studies. To date, the following test-specimens have been evaluated using IRC's unique dynamic wall-testing facility: Four EIFS walls, two precast concrete panels and a brick-veneer wall. The IRC facility is capable of simulating air-pressure dynamics typically experienced by a building envelope system in the field.

A numerical model applying the techniques of Computational Fluid Dynamics (CFD) is under development to predict the performance of PER walls. The data obtained from the experimental evaluations are being used to validate the model. Once validated, the model will be used to develop a better understanding of the dynamic pressure behaviour of walls by determining the effect on their pressure-equalization performance of parameters such as height, width and depth of the chamber, size and geometry of the venting, and leakage of the air-barrier system.

Research Findings

EIFS wall The first two EIFS test specimens had identical cross-sections but different vent details (Figure 3). The pressure-equalization chamber was approximately 63 mm deep, 1 120 mm wide and 2 270 mm high and completely filled with high-density (approximately 120 kg/m^3) mineral fiber insulation (MFI). The venting was located at the bottom of the chamber and extended over its whole width. In one specimen, the vent consisted of a thin sheet of steel with 29 holes of 12.7 mm in diameter punched along its length (vent area of 0.0037 m^2). In the other specimen, the vent consisted of a 25 mm-wide open strip covered with reinforcing mesh (vent area of 0.0294 m^2).

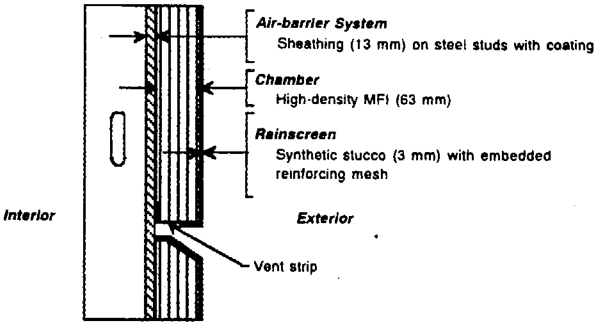

Figure 3. Vertical section of EIFS wall test specimens (specimens 1 and 2)

The test results indicated unacceptable pressure-equalization performance for both of these test specimens. The pressure equalization across the rainscreen deteriorated as the frequency of the driving dynamic pressure increased. There was no difference in the pressure-equalization response of the cavities under different loading conditions. The pressure difference across the rainscreen increased as the distance from the vent increased. The lack of a dynamic pressure response of the chamber was a consequence of the air-flow resistance of the high-density mineral wool insulation.

The third and fourth test specimens were identical in size and materials to the first two but their insulation layout and vent configuration differed (Figure 4). The

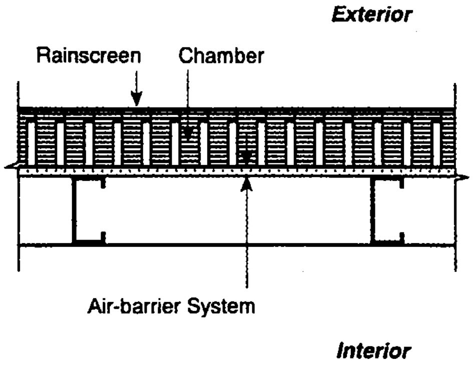

Figure 4. Horizontal section of EIFS wall test specimens (specimens 3 and 4)

cavity consisted of boards of MFI insulation of approximately 63 mm by 150 mm by 2 400 mm installed vertically and spaced 12 mm apart in one specimen and 6 mm in the other. The spacing of the insulation boards created air channels from bottom to top in the chamber. These channels were open to the outside at the bottom of the specimen, creating a vent opening of identical cross-section to that of the air channels.

The test results indicated adequate dynamic pressure response over the range of frequencies tested for the chamber with the 12 mm channels. Some delay was observed in the dynamic pressure response for the chamber with 6 mm air channels at the higher frequencies tested. The delay was attributed to the increased air-flow resistance of the 6 mm channels. No significant difference in the dynamic pressure response was observed over the height and width of either specimen.

Precast Concrete Panel The two precast concrete test specimens were 2 400 mm high by 1 190 mm wide. Each specimen consisted of a 100 mm thick precast concrete inner slab which acted as the air-barrier system, 50 mm of extruded polystyrene insulation, a 13 mm cavity, and a 64 mm precast concrete outer slab which acted as the rainscreen (Figure 5). The inner and outer slabs were connected by two vertical stainless steel trusses located 610 mm apart. In one specimen (specimen 3), the chamber was an open air space which extended over the height and width of the specimen. In the other specimen (specimen 4), the chamber was formed using a 13 mm thick geosynthetic (a dimpled plastic sheet with a geotextile bonded to the dimples) which also extended over the height and width of the specimen.

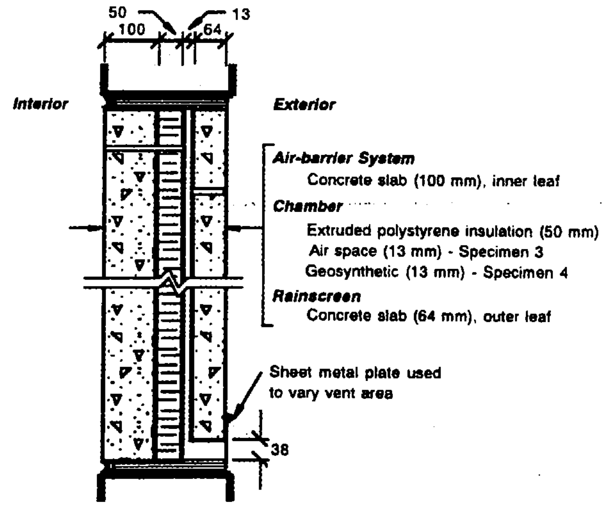

Figure 5. Vertical section of precast panel test specimens

The specimens were tested for various air-leakage (0.0015 to 0.240 L/s/m^2 at 75 Pa) and chamber-venting (0.0001 to 0.0007 m^2) characteristics. The air leakage of the specimens was obtained by drilling 6 mm diameter holes at the top of the air-barrier system. The venting was obtained with 12.7 mm diameter holes located at the bottom of the rainscreen. The flexibility of both the air barrier and the rainscreen was determined to be in the range of 0.05 to 0.15 mm/kPa.

The test results indicated no significant differences between the two test specimens with respect to pressure-equalization performance. The following effects were also noted:

- The pressure difference across the rainscreen increased when:
  - the air-barrier leakage increased;
  - the rainscreen venting decreased;
  - the frequency of the driving dynamic pressure increased.
- The pressure difference across the rainscreen changed negligibly with the height of the specimen.
- The dynamic pressure response of the chamber was directly proportional to the amplitude of the applied pressure difference. For example, if the amplitude of the driving pressure difference doubled, the amplitude of the rainscreen pressure difference doubled.

To study the water-leakage control of the test specimen, a defect consisting of a horizontal saw-cut with a net opening, 5 mm high by 64 mm wide, was made in the rainscreen. Water-leakage control was evaluated under both static and dynamic pressure conditions while spraying water on the wall at a constant rate. The following effects were observed:

- With a leaky air-barrier system and no venting, i.e. a face-seal approach, one third of the available water passed through the defect with no pressure difference and most of the available water passed through the defect with a static pressure difference of 100 Pa.
- With a perfect air-barrier system and no venting, i.e. a drained cavity approach, a dynamic pressure difference across the specimen forced about two thirds of the available water through the defect.
- With a perfect air-barrier system and adequate venting for pressure equalization, i.e. a PER approach, a dynamic pressure difference across the specimen forced about one third of the available water through the defect.
- Air-entrained water is not a problem if the design of the vent is such that it does not become filled with water. This emphasizes the importance of properly designed drip and vent details.

Figure 6 summarizes the rate of water-penetration into the chamber measured for various configurations of cavity venting and air-barrier leakage. Water penetration into the chamber under pressure differences is much reduced by an effective PER wall design.

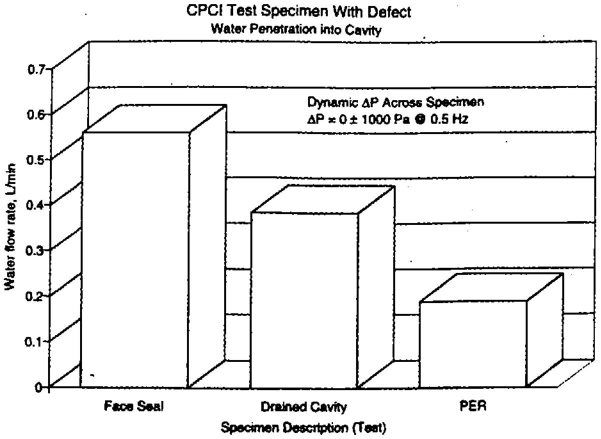

Figure 6. Water-flow rate measured through the defect under dynamic pressure differences

Brick-Veneer Wall The brick-veneer test specimen measured 2 400 mm x 2 400 mm. The back-up wall consisted of a 38 mm x 89 mm (2" x 4") wood frame with an airtight 13 mm plywood exterior sheathing (Figure 7). The equalization chamber of the test specimen was 25 mm deep. The brick veneer (rainscreen) and the back-up wall (air-barrier system) were not coupled, in order to study the dynamic pressure response of a variable chamber volume. The flexibility of the back-up wall was in the order of 5.5 mm/kPa at the center of the wall.

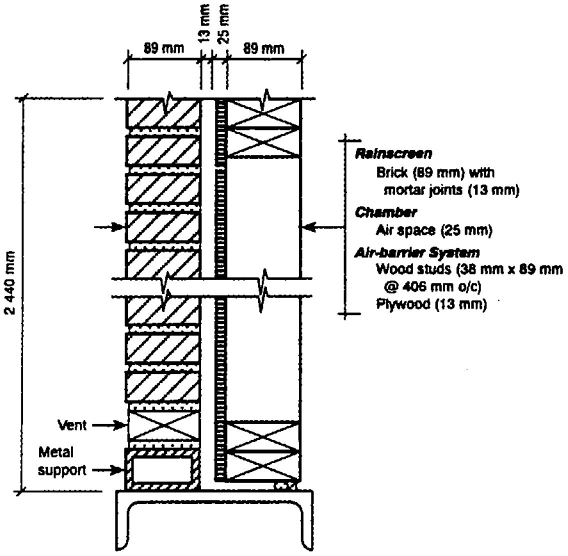

Figure 7. Vertical section of brick-veneer wall test specimen

The preliminary test results indicated that 8 head joints of venting were not sufficient to achieve dynamic pressure equalization across the rainscreen even with a perfect air-barrier system. The following effects were observed:

- The pressure difference across the rainscreen increased under the following conditions:
  - the rainscreen venting decreased;
  - the frequency of the driving dynamic pressure increased.
- Pressure difference across the rainscreen changed negligibly with the height of the specimen.
- The dynamic pressure response of the cavity was directly proportional to the amplitude of the applied pressure difference.

Implications for Designers and Builders

The application of the pressure-equalized rainscreen technology to a wall requires more attention and care in both detailing and construction on the part of the designer and the builder respectively. The additional expense and complexity in designing and building a performing PER wall will benefit the owner/manager by requiring less maintenance during its service life.

A PER wall is more tolerant of common construction defects than either a cavity wall or a face-seal wall. However, to benefit from this advantage, the air-barrier system, the chamber and the rainscreen of the PER wall must be designed systematically to control air and rain-water flow. To help in the design process the following preliminary design guidance is provided.

Air-Barrier System

The inner layer of the wall must contain an effective air-barrier system. An air-leakage rate of not more than 0.2 $L/s/m^2$ at a pressure difference of 75 Pa has been proposed by the Canadian Construction Materials Centre (CCMC) in a technical guide for air-barrier systems. In addition, the air-barrier system must be designed to withstand the pressure loads induced by mechanical ventilation, stack effect and wind. And, of course, the plane of airtightness of the air-barrier system must be continuous throughout the wall assembly.

Pressure-Equalization Chamber

Because of the sharp pressure gradients that occur at corners and tops of buildings, the chamber compartments should be no more than 1 200 mm wide in a

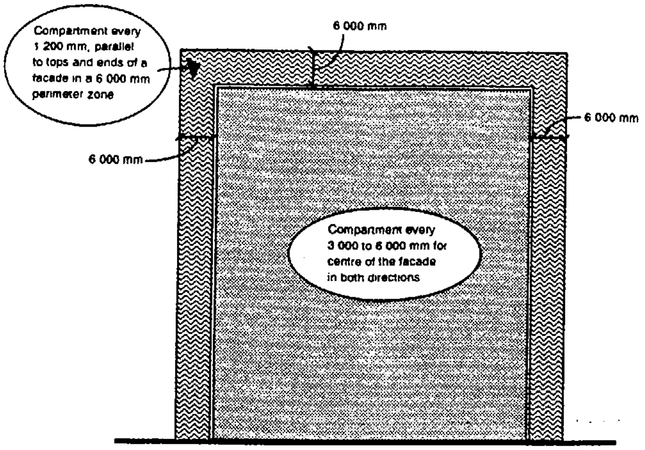

Figure 8. *Compartmentation over a flat facade due to wind-pressure variations*

zone 6 000 mm wide around the sides and top of each of the walls (see Figure 8). Compartments can be 3 000 mm to 6 000 mm wide over the central portion of the wall. (The compartment height should not exceed 6 000 mm because of the spatial variation of the pressure over the height of the building.) At ground level, chamber compartments no more than one storey high are preferable. The compartment delimiters should be airtight to prevent lateral air flow between compartments. Each compartment must contain a proper flashing to drain incidental water that finds its way into the equalization chamber.

The precast concrete panel test results suggest that geosynthetics could provide excellent material for the equalization chamber since they are sufficiently open to allow air movement within the chamber and thus to achieve pressure equalization across the rainscreen. Note that the vapour permeance of the geosynthetic material may have to be considered in the design of the wall for condensation control.

Rainscreen

The preliminary test results indicate that for water-penetration control due to pressure differences, adequate pressure equalization may be defined as less than 25 Pa across the rainscreen at any time. The dynamic pressure response of rigid compartments was directly proportional to the amplitude of the applied pressure difference. This means that most PER walls only need to be evaluated under one amplitude in order to establish their pressure-equalization characteristics.

The vent holes do not need to be uniformly distributed over the width of the chamber compartment as long as the holes are not further than 3 000 mm from the vertical delimiters of the compartment. All vent holes should be at the bottom of the compartments so that they can be used as drainage holes. They should be located along the same horizontal line to avoid any pressure difference over the height of the compartment that might induce air flow and water penetration within the cavity. The vent holes should be a minimum of 10 mm and provided with appropriate drips to prevent bridging by water which would result in the penetration of water into the cavity. Raindrop momentum should be controlled with appropriate shielding of the vent.

The minimum total vent size per compartment should be determined from the following guidelines:

- The effective area of the vent holes has to be sized relative to the leakage of the air-barrier system and to the volume of the pressure-equalization cavity. The limited experimental and modelling studies that have been carried out indicate that the vent area should be at least 40 times that of the air-leakage area of the air-barrier system.
- A chamber volume to vent area ratio of at most 50 m should be acceptable for PER walls that are similar to the precast concrete panel tested with respect to stiffness, chamber geometry and airtightness. This ratio should apply to any such wall with similar chamber compartments that extends up to 6 000 mm both horizontally and vertically. For a variable chamber volume such as that of the flexible brick-veneer wall tested, the preliminary results indicate that a chamber volume to vent area ratio as low as 25 m will be required. This demonstrates the importance of designing a rigid air-barrier system and supporting structure to achieve adequate pressure equalization with limited venting.

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