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Field Testing of Pressure-Equalized Rain Screen Walls

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ABSTRACT: One approach to controlling rain penetration into walls is to design them using the pressure-equalized rain screen principle. This design minimizes the wind pressure difference across the exterior cladding (rain screen), thus reducing the predominant force that drives rain into the wall. A pressure-equalized rain screen wall is essentially a cavity wall with sufficient venting in the cladding to enable the cavity pressure to equalize to the exterior pressure. Additional design requirements include an effective air barrier system on the inside of the cavity and horizontal and vertical baffles to form compartments within the cavity. Two buildings with vented cladding were monitored for pressure equalization. Successful pressure equalization was confirmed with a well-vented precast concrete wall system. On the other hand, the cavity pressure of a poorly vented masonry wall system did not equalize with the exterior pressure, with the result that much of the wind pressure was taken by the cladding. While the initial cost of a pressure-equalized rain screen design may be higher, it can be recovered through lower maintenance costs and a modest reduction in the design wind load for the cladding.

KEY WORDS: cavity wall, pressure-equalize, rain penetration, wind load, cladding, masonry, precast concrete, rain screen

Rain Penetration of Walls

Excess water is the key factor in most cases of deterioration of walls or wall materials; one source of this water is rain. It follows that the control of rain penetration is an important objective in the design of walls. Besides causing damage to building fabrics, rain penetration can reduce usable rental space of buildings, affect the appearance of the facade, and be a significant consumer of time and money for the owner/manager.

When rain gets into a wall, the natural tendency is to look for holes in the outside face of the wall, the cladding. Since water will not get in without a passageway, one may try to eliminate any holes, openings, small cracks, pores, and poorly bonded interfaces in the cladding. This approach to controlling rain penetration is commonly referred to as the face seal approach. However, face-sealed walls require frequent maintenance during their life since sealants deteriorate because of direct exposure to outside climate (sun, rain, pollution, freeze-thaw cycles) and because of differential thermal movement of the cladding.

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Pressure-Equalized Rain Screen Principle

In fact, holes alone are not sufficient to cause rain penetration; there must be some force to drive water into the wall. The forces contributing to rain penetration are capillary action, gravity, momentum of rain drops, and air pressure difference. The most complete approach to controlling these forces is the pressure-equalized rain screen principle. The pressure-equalized rain screen wall is often confused with the cavity wall, a design that ignores control of the air pressure difference acting across the cladding.

Control of the first three forces is usually well understood. Indeed, to control capillary action, a discontinuity in the wall behind the cladding is frequently introduced in the form of a cavity. To control the momentum of rain drops, a deflector (not airtight or watertight) can be installed over holes and openings. To control water entry to the cavity by gravity forces, the cavity should be drained to the outside. And what is required to control air pressure difference across the cladding?

Control of Air Pressure Difference

Air pressure difference across the cladding is the most significant force driving rain into a wall. Wind produces the largest air pressure difference, although mechanical ventilation and stack effect can also contribute to it in the absence of an effective air barrier system. Air pressure difference across the cladding can be eliminated by equalizing the air pressure in a cavity behind the cladding (rain screen) to the exterior pressure, hence the name pressure-equalized rain screen. This implies the presence of certain features in the wall: an effective air barrier system, a compartmented cavity, and large venting area of the cladding relative to the leakage area through the air barrier system and to the volume of the cavity.

Air Barrier System—To eliminate airflow through the wall, there must be a continuous air barrier system on the inside of the cavity. This air barrier system must be rigid, primarily to resist wind load with little deflection and also to avoid fluctuations of the cavity volume. The latter will cause pumping of air (and rain) into the cavity and reduce the potential for pressure equalization.

Compartments—Spatial variations in wind pressure over the height and geometry of the facade can produce lateral airflow within the cavity. This lateral airflow in the cavity reduces the potential for pressure equalization across the cladding. To minimize lateral airflow, the cavity should be divided into compartments. The range of pressure variations across the outer surface of each compartment is then reduced, and the likelihood of pressure equalization of each cavity compartment with adjacent exterior pressure is increased. Since wind pressure is usually more uniform nearer the center of the facade than the edge, compartments can be larger in the center and should be smaller near the corners.

Venting area—In theory, a single small hole is sufficient to admit the external pressure into a perfectly rigid and airtight chamber. In practice, the cavity will not be completely airtight because of leakiness of the air barrier system and compartment baffles. In order to achieve pressure equalization across the cladding, the venting area of the cladding must be substantially larger than the leakage area of the air barrier system. Latta [1] has suggested that a ratio of cladding venting area to air barrier leakage area of 10 to 1 will be effective at providing pressure equalization. Since other considerations (e.g., control of exfiltration) [2] dictate that the air barrier system be as tight as possible, this ratio could be achieved

first by decreasing the leakiness of the air barrier system and then by increasing the venting area in the cladding.

Application of the Concept—Two Examples

To assess the effectiveness of pressure equalization achieved with walls designed to be pressure-equalized, two buildings were monitored for 18 months. Pairs of pressure taps were installed in each building—one of each pair was installed in a wall cavity with the second installed on the exterior of the wall. Each pressure tap was referenced to the pressure inside the building so that pressure differences were measured across the air barrier system and across the wall. The pressure difference across the cladding was determined from the difference between the two measurements. A weather station, which included a wind vane and anemometer mounted on a mast, was installed on the roof of each building. Data were monitored 30 times per second and recorded for 30 min following a high-speed wind event.

Building A

Construction—Building A is a 27-story, general-use office building located in the downtown area of a large city in eastern Canada [3]. It is in the wake of other buildings for winds from all orientations except the northwest. The walls, which are of precast concrete sandwich panel construction, are illustrated in Fig. 1. The inner layer of concrete acts as the air barrier while the outer layer acts as the rain screen. The panel cavity is sealed laterally and vertically from adjacent panels. It is vented by a 15-mm-wide opening located at the bottom of the panel and extending the width of the panel, and by a similar opening located above the window. Panels are joined with a two-stage joint, leaky on the outside and tight on the inside.

Instrumentation—Twelve panels on the 24th floor of the building were instrumented with pairs of pressure taps. Eleven panels were installed on the northern half of the floor on the west, north, and east walls; the twelfth was on the center of the south wall. Wind speed and direction were monitored 18 m above the roof, 138 m above the ground.

Cladding Vent Area to Air Barrier Leakage Area Ratio—A static pressure test conducted across a panel showed that essentially all of the pressure drop across the panel occurred over the interior precast concrete element, the air barrier. This result indicates that the ratio of vent area to air barrier leakage area is greater than 10 to 1 [4].

Pressure Equalization—Under wind loading, cavity pressure usually equalled external pressure and the pressure difference across the cladding was small (Fig. 2). When averaged over several seconds, the largest sustained loads recorded on the cladding were no more than ± 50 to 60 Pa. Occasionally, however, the changes in external pressure were so rapid that the cavity pressure was unable to follow and equalization was not immediately achieved (Fig. 3). This situation occurred primarily under negative wind loading. Forty-one events were recorded in which the pressure difference on the cladding was greater than 150 Pa. Thirty-nine of these were generated by negative wind gusts. In all cases the loads lasted less than a second.

Comments—The performance of the system is quite adequate for rain penetration control since, for the part, cavity pressure equalizes to external pressure under positive wind loading. While negative wind loading does not contribute to rain penetration, it will exert

FIG. 1—Detail of precast sandwich panel of Building A.

a structural load on the cladding if pressure equalization does not occur quickly enough. In the case illustrated in Fig. 3, the instantaneous load on the cladding is 45% of the load on the panel. The maximum wind speed recorded during the 18-month monitoring period was equivalent to about 60% of the design pressure for cladding (with a 1 in 10 probability of occurrence). Since 18 months is not a long time relative to the life of the building, a worse case could occur. Wind tunnel tests conducted on a model of the building [5] indicated that the cladding could be designed for 70% of the design load.

FIG. 2—Response of cavity of Building A to positive gust wind pressure.

Building B

Construction—Building B is a three-story, special-use office building located in a small city in western Canada. The terrain is relatively open to the southwest with suburban terrain in the other directions. The walls are constructed of insulated 152-mm steel studs with fibrous insulation between the studs and a brick veneer cladding (Fig. 4). The steel studs are faced on both sides with 12.7-mm gypsum board, with polyethylene vapor barrier beneath the inner gypsum board. The polyethylene vapor barrier is also intended to provide the “plane of airtightness” for the air barrier system.

Architectural details result in a cavity that is irregular in shape, varying in depth from 30 to 330 mm (Fig. 5). Closed cell foam installed in the 30-mm space between the window bays divides the cavity into compartments that are six window bays wide. The cavity is vented through louvered inserts installed in place of mortar joints at three levels; six inserts, two per level, are installed in each window bay. The inserts are approximately 13 mm wide by 60 mm high but only 50% open, giving an estimated net venting area of 0.01 m² per compartment. Examination of the drawings for the building indicates that the flashing detail above the window may provide additional venting of the compartment.

Instrumentation—Ten cavities on the second floor were instrumented with pairs of external and cavity pressure taps (in fact two external pressure taps were installed but they recorded essentially the same value). Six of the instrumented locations were located on the west

FIG. 3—Response of cavity of Building A to negative gust wind pressure.

FIG. 4—Section through cavity of Building B.

FIG. 5—Geometry of cavity for three window bays of Building B. Note that the cavity was typically six window bays wide.

facade, the direction of the prevailing winds. Wind speed and direction were monitored 14 m above the roof, 31 m above the ground.

Cladding Vent Area to Air Barrier Leakage Area Ratio—A static pressure test conducted across a cavity showed that 70% of the pressure drop across the wall occurred at the steel stud assembly. From this result, the ratio of venting area to leakage area was estimated to be about 2 to 1 [4].

Pressure Equalization—The effectiveness (or lack thereof) of the venting is demonstrated when a wall is under wind pressure loading. In this building under positive loading (Fig. 6), the cavity pressure follows the external pressure but never equals it. In this case, the brick veneer carries about 64% of the instantaneous load across the wall and about 55% of the load when averaged over 4 min. While total pressure equalization is not achieved, the

FIG. 6—Response of cavity of Building B to positive gust wind pressure.

pressure difference across the cladding is reduced. When a negative gust load is considered (Fig. 7), the rapid change in external pressure is again not followed by the cavity pressure and, in this case, about 90% of the instantaneous total load appears across the cladding.

Comments—The static pressure test indicated that the venting area is small relative to the leakage of the air barrier system. Although the ratio could be improved by increasing the venting area, this would also increase exfiltration of moist, indoor air with a corresponding increase in potential for condensation in cold weather. As mentioned, loading on the cladding that was 90% of the total wall load was recorded under negative wind pressures. The maximum wind speed recorded during the monitoring period was about 75% of the local design pressure for cladding (with a 1 in 10 probability of occurrence). For this building, the cladding should be designed for 100% of the design wind load.

Design Considerations

There are major differences between face seal walls, cavity walls, and pressure-equalized rain screen walls. The differences lie in their design, performance, maintenance, durability, and distribution of wind loads between the cladding and air barrier system. When designing a wall, it is important to understand the implications for wind load resistance and control of air leakage as well as control of rain penetration.

FIG. 7—Response of cavity of Building B to negative gust wind pressure.

System Design Features

The following features must be included in a wall designed on the pressure-equalized rain screen principle:

1. Cavity.
2. Air barrier.
3. Compartments in the cavity.
4. Venting.

Cavity—A cavity must be located to the interior of the cladding (rain screen). The volume of the cavity should be minimized since this will reduce the amount of airflow required to produce pressure equalization and thus improve the speed of pressure equalization. This latter point is important since rain may be entrained in the air and introduced into the cavity in this manner.

Air Barrier System—There must be an effective air barrier system at the interior surface of the cavity to control air leakage, both infiltration and exfiltration, through the wall. Since the air barrier system is expected to withstand pressure differences created by stack effect, mechanical ventilation, and especially wind, it must be designed to take this load and transfer it to the structure of the building. It should be a rigid assembly of materials with low air permeability, made continuous over the building enclosure. The rigidity of the air barrier

system helps also to maintain a constant cavity volume, without which rapid pressure equalization is difficult to achieve. To gain in pressure-equalization response of the cladding, increasing the venting area in the cladding can be more advantageous than increasing the rigidity of the air barrier beyond the needs dictated by the wind loading [4].

Compartments—To control lateral flow of air behind the cladding, the cavity must be compartmented with baffles. The baffles must be capable of resisting the differences in air pressure at the vents on either side of them. Baffles at corners are crucial, being subjected to the highest pressure differentials. The size of the compartments should be based on the spatial variation of pressures likely to be experienced. Twenty-five years ago, Garden [6] offered the following guidelines for the location of baffles:

1. No more than 1.2 m (4 ft) on center in a 6-m (20-ft)-wide zone around the perimeter of walls.
2. 3 to 6 m (10 to 20 ft) on center in both directions over the central portion.

These are still reasonable figures to aim for.

Venting area—The venting area should be at least ten times greater than the effective leakage area of the air barrier system. Drainage holes commonly found in brick work are not usually frequent enough to do the job and are often blocked with mortar droppings or debris. Also, the permeability of masonry cladding will not be effective in equalizing rapid pressure fluctuations and should not be counted on as venting. Vents should be at least 10 mm wide to avoid bridging by water through surface tension. They should preferably be located at the bottom of the cavity so that they may drain the cavity, should any water get in, and thus act as a second line of defense against rain penetration.

Testing

Laboratory testing of a wall mock-up can provide useful information to predict the performance of a given pressure-equalized rain screen design. The optimum cladding vent area for the leakage of a given air barrier system can be determined using steady-state, or preferably dynamic, wind loading simulation on a as-constructed wall mock-up. The effectiveness of the air barrier system to control air leakage and to resist design wind loads can be assessed in such testing. Finally, boundary layer wind tunnel testing can provide an estimate of the wind loads expected on a building, especially high-rise buildings located in built-up urban areas.

Besides Rain Control

The application of the pressure-equalized rain screen principle not only reduces rain penetration, but also wind loads on the cladding. Indeed, pressure equalization across the cladding is the basic objective. However, the cladding for a properly vented and compartmented wall should still be designed to carry some percentage of the design wind load. For example, laboratory testing indicated that the cladding of Building A should be designed for 70% of the design wind load. The air barrier system, on the other hand, will be subjected to the total wind load for all but the shortest gusts and should be designed accordingly.

Compared to other techniques, the application of the pressure-equalized rain screen principle requires more attention, detailing, and care from the designer and builder. On the other hand, a pressure-equalized wall is likely to require less maintenance and therefore

less attention from the building owner and manager during the service life of the building. The advantages of long-term performance of such a wall should more than justify the initial effort. Further support for this view can be found in Refs 7, 8, and 9.

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