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PRECAST PANEL WALL ASSEMBLIES

by

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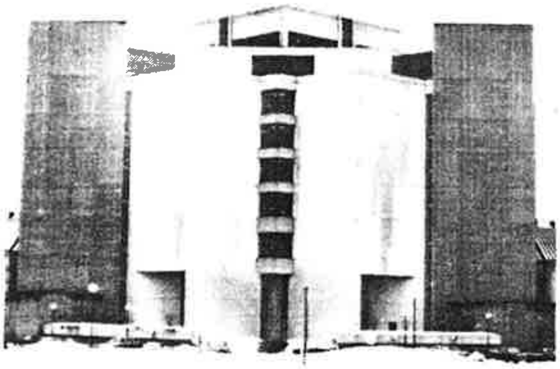
FOREWORD

While this paper does not have all of the detailed examples which were discussed at the Building Science Forum '82, the essence and content of the presentation is the same. Emphasis has been placed on the control of rain penetration and condensation in conventional precast concrete wall assemblies. While the Forum presentation was delivered and debated by M. Rousseau the paper that follows is a joint effort by M.Z. Rousseau and R.L. Quirouette. Questions and answers on this topic from the forum discussion periods are included in the last section of this proceeding.

AIR LEAKAGE AND CONDENSATION IN CONVENTIONAL PRECAST WALL ASSEMBLIES

INTRODUCTION



The appearance of frost and ice on the exterior surface of a precast concrete cladding is a clear sign of a design performance failure. The quantity of water involved in the freeze/thaw pattern which appears in Figure 1 could not have resulted from rain penetration or from the transfer of inside humidity to the outside by diffusion alone. Evidence and analysis point to air leakage as the primary cause of this particular phenomenon.

In a 1961 Canadian Building Digest, A.G. Wilson wrote: "One of the most important aspects of air leakage in relation to the performance of Canadian buildings is the extent to which it is responsible for serious condensation problems. Unfortunately this is largely unrecognized in the design and construction of many buildings, and even when failures develop the source of moisture is often incorrectly identified".[1]

Over the past 20 years, the operation and characteristics of the indoor environment of public buildings have changed somewhat. Buildings are now humidified to a higher level than in the past and building pressurization has also increased, primarily to maintain a neutral pressure at the lobby level of most public buildings. Moreover, buildings are better insulated than in the past, which means that exterior cladding materials may be subjected to greater swings in temperature, increasing the potential for interstitial wall condensation. In addition, the occupants of buildings have become less and less tolerant of the temperature changes that occur within building spaces and comfort-related problems are appearing with greater frequency. A lack of airtightness, even in modern buildings, is likely to be the most frequent and yet most misunderstood design problem with conventional precast wall assemblies. This paper focusses on the control of air leakage and its importance to preventing condensation in or on the walls and to minimizing rain penetration problems.

Precast Concrete Wall Assemblies

The term "precast concrete panel" is used to describe products made of concrete under controlled conditions, either in a permanent factory or in a temporary casting yard on the construction site, and erected as finished materials as the structure goes up. In Canada, precast concrete walls are used mostly as curtain wall units directly supported by the structure of the building.

There are a variety of precast concrete panel exterior wall systems and these are grouped under two basic systems; one, a single-wythe precast concrete panel, used as a cladding and combined with an inner wall, is termed the conventional precast wall assembly. The second type is the precast sandwich panel wall, which comprises precast units, insulation and vapour barrier, all built in the factory and erected on the building as a complete wall element. The performance of the sandwich panel wall system is not discussed in this paper.

The conventional precast wall assembly is unique as an exterior wall because of two factors: the sequence of construction and the presence of large anchors. The most common sequence of construction for a conventional precast wall is to install the concrete panels on the structure first, and then to build the inner wall or "the wall behind the wall". This contrasts with the traditional methods in which walls are usually built from the inside out.

The anchor of a conventional precast panel constitutes a sizeable element which often must penetrate through many layers of the inner wall to be anchored to the floor or column. A good understanding of the characteristics of a conventional precast wall assembly and its effect on the whole enclosure system is vital to designers and builders who intend to provide a building with the best airtightness and the most weatherproof performance achievable.

PERFORMANCE OF CONVENTIONAL PRECAST WALL SYSTEMS

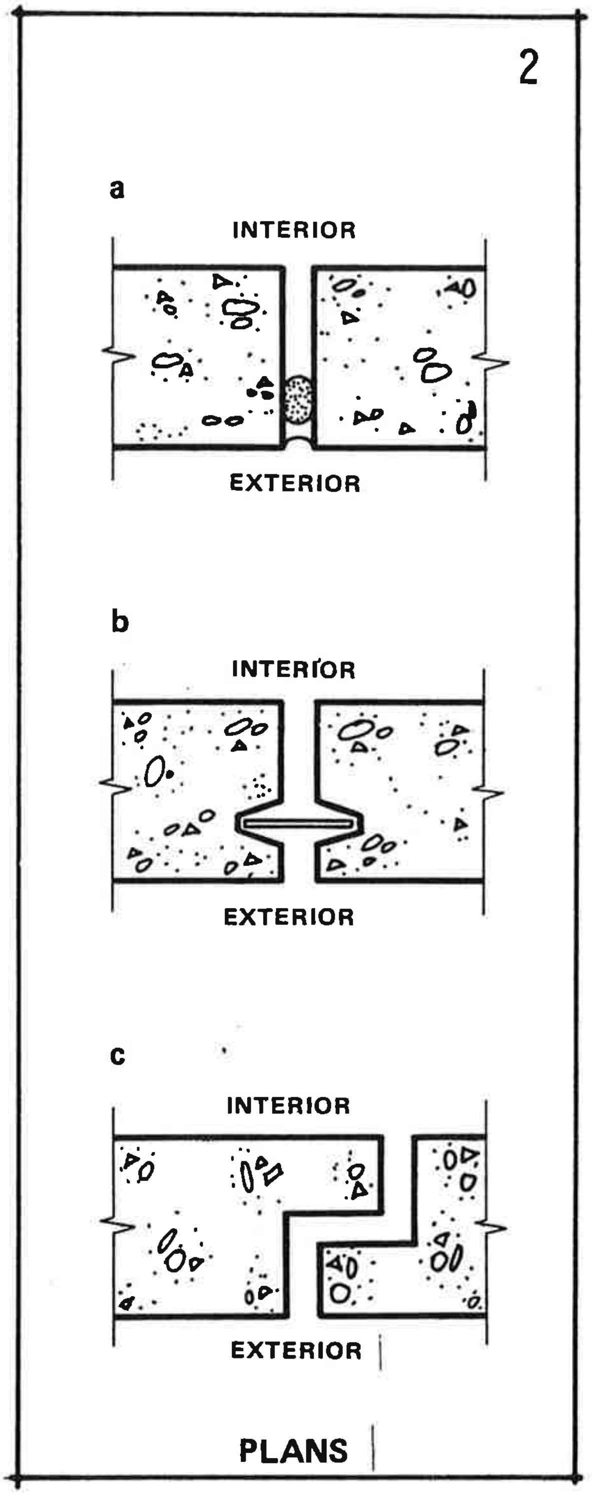
The performance of precast concrete wall systems is examined from two points of view; control of rain penetration and control of condensation in and on the wall.

Rain Penetration

There are four primary ways for rain to penetrate a wall; by capillary action, by gravity flow, through the kinetic energy of rain, and by an air transport through the wall. There are design and construction responses to each of these four mechanisms.

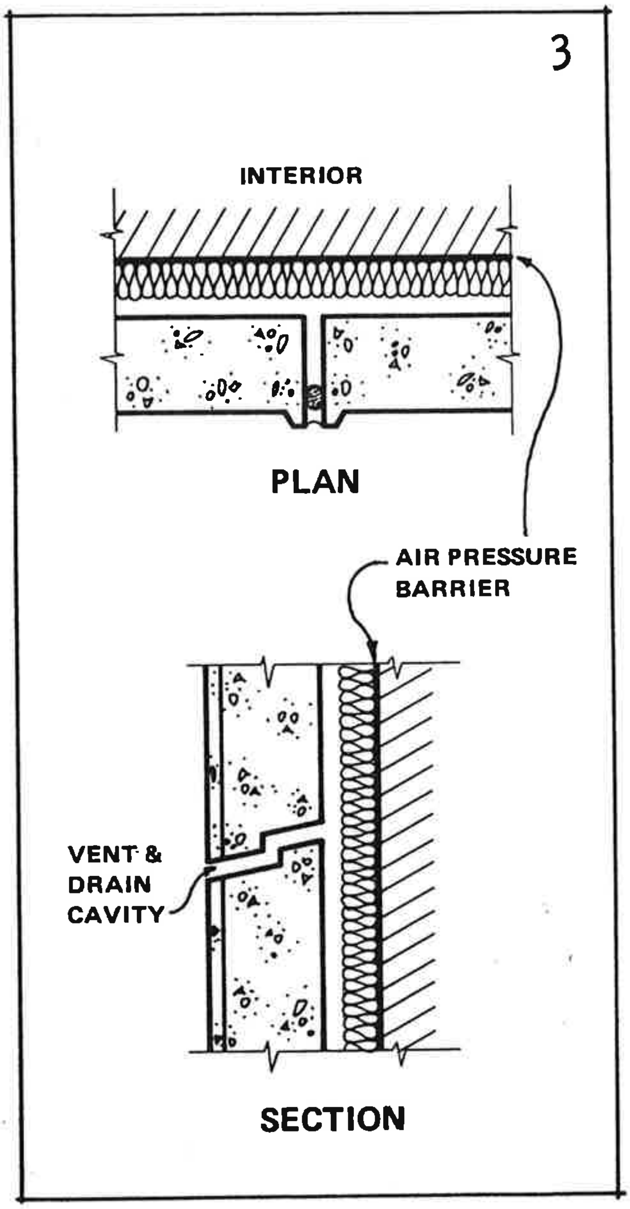
To prevent the entry of rain by capillary action, it is best to introduce a large air gap in the joint between the concrete panel and the cladding in order to prevent wetted materials from touching other materials inside the cavity. The provision of drips and grooves in the horizontal joints between panels limits the inward migration of water by capillary action.

To prevent rain penetration by gravity flow, the general principle is to slope all horizontal joints and interfaces to the outside so that water which accumulates in a cavity may drain to the outside surface of the building. A slope of 20° or so should be used or better, a vertical overlap between the panels to form positive drips on the bottom edge of the cladding panel.



The kinetic energy of rain is simply that energy which will drive a raindrop horizontally through an opening or crack to the inside of a wall surface. In order to control or reduce the entry of rain by this mechanism, a deflector must be designed for the joint (Figure 2). The common practice is to create a deflector out of caulking material and apply it to the outside joint (2a), to insert strips in the grooves of the joint to create a baffle (2b), or to create a labyrinth intrinsic to the shape of the panel edges (2c).

When the wind induces a positive air pressure difference across the cladding, and the inner wall system is not airtight, air may infiltrate into the cracks and openings of the cladding joints. If the facade is wet, the air will transport water to the inside of the wall, and perhaps to the inside of the building. To reduce the entry of rain by this mechanism, the rain screen principle may be applied to the design of the exterior wall. The rain screen system tends to reduce the air pressure difference between the two sides of the cladding, thus reducing the forces that move water to the inside of the wall. To obtain an air pressure equalization across the cladding, there must be an air pressure barrier somewhere behind the cladding which will carry the full wind pressure load (Figure 3). Thus when the wind blows against a building facade, the pressure of the wind will enter the cavity, causing the cladding to become pressure-equalized. The application of the rain screen principle must also consider compartmentalization over the facade of a building. This is the process of dividing the inner



cavity both horizontally and vertically, to create isolated cells. This is to reduce the range of air pressure differences acting on each cell, to enhance the rain screen operation.

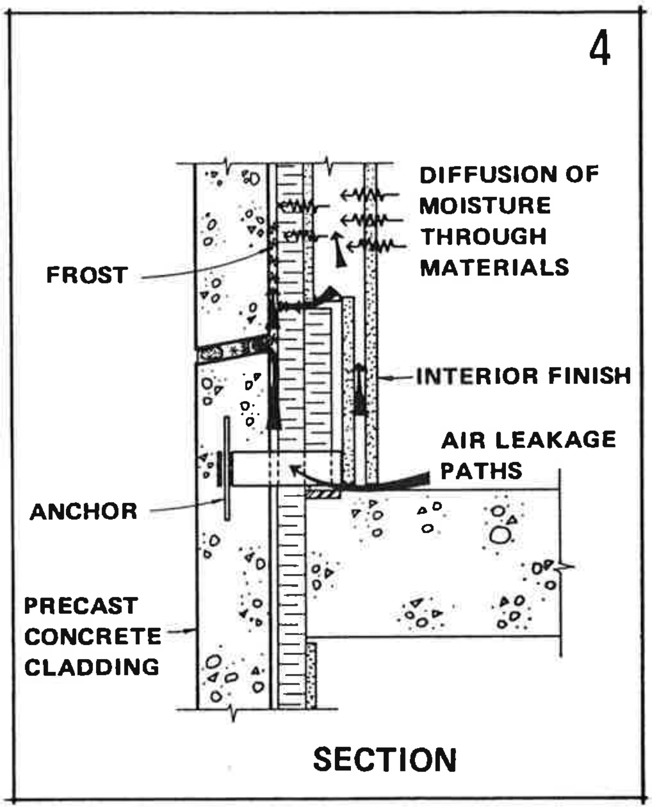
Though the rain screen principle is known by the building industry, it is generally thought to require only a vented cavity behind the cladding. In practice, however, the cavity must be bounded by a rigid interior air barrier and the need for better airtightness in the wall cannot be overemphasized.

Condensation in the Wall Cavity

Icicles and frost at cladding joints are frequently the result of repeated thawing and freezing of water that originally accumulated as condensation in a wall cavity. For this phenomenon to occur, the indoor air of the building must be humid, there must be a significant temperature difference between the inside air and the outside environment, and there must be a leakage path. Since humid air can only hold a fixed amount of water vapour at a particular temperature, a drop in temperature reduces the capacity of the air to hold water vapour. When humid air cools and gives up some of its moisture in the form of frost or water droplets, it is then said to have reached its dew point temperature. When the surface on which this condensation occurs is below freezing, the condensation may accumulate as frost. Then, through a temperature cycle, frost builds up and melts; this may result in water penetration inside the building, or in icicles, particularly around the outside joints.

MOISTURE TRANSFER THROUGH WALLS

There are two independent mechanisms by which moisture can move from the inside of the building to the outside (Figure 4). One mechanism is called diffusion, a process whereby moisture migrates through the building materials. This is a slow process, dependent upon the physical properties of the building materials and the difference in absolute humidity of the air on either side of these



materials. Moisture will migrate from a high water vapour concentration environment to a low one. The property of a material which controls the rate of migration of water vapour by diffusion is termed water vapour permeability. Materials having a low permeability to water vapour diffusion have vapour barrier qualities.

The rate of diffusion of water vapour through building materials, and hence through exterior walls, is reduced by installing a vapour barrier in the wall assembly. Such materials as polyethylene, aluminum foil, glass and metals are excellent vapour barriers.

The other mechanism is transport of moisture-laden air through cracks, holes and openings. The flow of moist warm air to the outside of a building is caused by an air pressure difference acting across an opening or a crack. This air pressure difference is caused by any or all of the following primary forces: wind, stack effect, or mechanical ventilation.

Air leakage is a complex problem and requires a design approach other than the one used to design a vapour barrier. This barrier has been termed an air pressure barrier. In general, air leakage rather than diffusion of water vapour is the major cause of moisture transfer across an enclosure.

The Air Leakage Problem

Two conditions are necessary to cause an air flow across a wall assembly: an air pressure difference across the wall and some openings for air to flow through. The air pressure difference may be induced by wind effects, stack effect and the operation of a mechanical ventilation system. These conditions often combine to create a high air pressure difference across the wall assembly; this acts either to draw outside air in or to push inside air out.

Control of the air pressure difference across the wall would be ideal but is not practical. Therefore, the design and construction of the exterior wall must minimize the number of openings and holes that appear in the building envelope. These holes and openings may occur during the construction process, from the aging of the building, or from the effects of a peak air pressure load on the wall.

The Air Pressure Barrier

To control air leakage, the air pressure difference must be resisted, and to this end, a continuous juxtaposition of building materials capable of withstanding the air pressure difference is required. This requires that the materials used to prevent air leakage (the air pressure barrier) must be structurally adequate, of low air porosity and assembled in such a way that continuity is maintained over the whole building enclosure.

Materials that may function as an air pressure barrier include: gypsum board, plywood, hardboard, a stiff metal panel, a concrete panel, and even a flexible membrane, provided it is supported on both sides. An air pressure barrier may also act as a vapour barrier, as in the case of a metal sheeting, glass, or concrete panels, because of their low water vapour permeability. Gypsum board backed with an aluminum foil may be suitable as an air pressure barrier and a vapour barrier. The aluminum foil is the vapour barrier and the gypsum board may be part of the air pressure barrier system. On the other hand, materials such as aluminum foil or plastic film, which are excellent vapour barriers, do not provide enough structural stiffness to function as air pressure barriers.

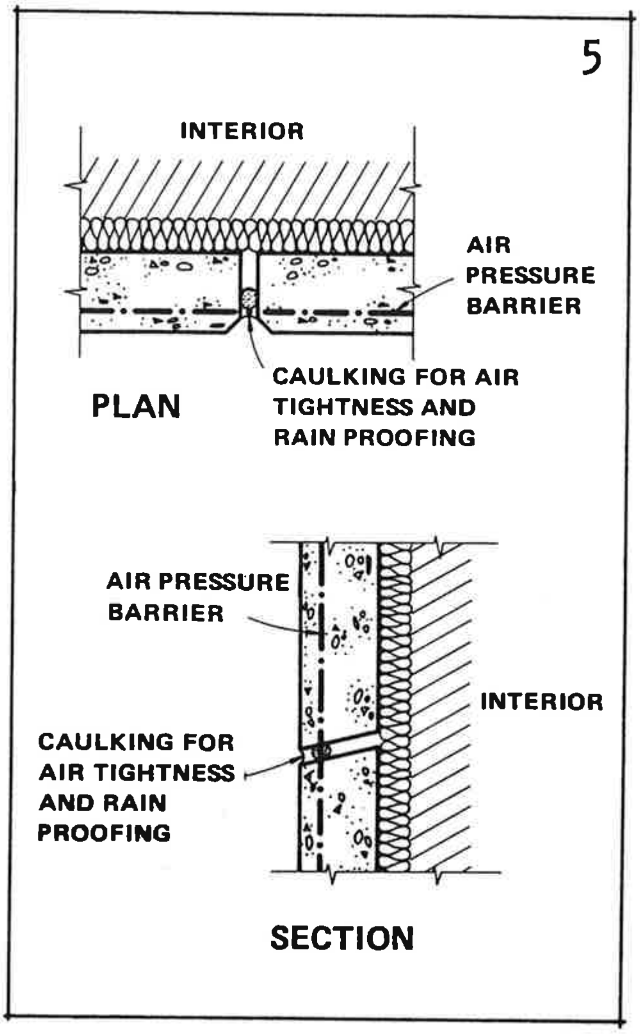
Joints between the elements of an air pressure barrier must be sealed with a material capable of withstanding the air pressure difference. The material chosen must also have the right characteristics. For instance, if a porous material is chosen to close the gaps between the gypsum board, it may act only as a filter. On the other hand, a non-porous material which has poor adhesion or mechanical strength could be blown out of the cavity.

BASIC DESIGN METHODS

In the evolution of the design and construction of the conventional precast panel wall assembly, several design methods have been used to achieve the performance requirements mentioned above. These can be grouped into three basic methods which have been developed by the industry since the introduction of the precast panel wall system. Each method represents a measure of success in performance but each is also subject to certain types of failure. These methods began with the one-stage joint concept, also known as the face seal method, and have evolved towards what is termed a three-stage joint system.

The Face Seal Method

The face seal method consists of caulking all exterior vertical and horizontal joints in a conventional precast wall assembly, in order to make the facade airtight and rainproof (Figure 5). This is based upon the assumption that the concrete panels are structurally



strong and therefore constitute the best wall enclosure material to hold the air pressure difference and to prevent rain penetration.

The face seal method performs well for a short period of time compared to the life of the building; that is for three, and maybe up to five years. However, the caulking compounds used to seal the joints of the concrete panels deteriorate rapidly because of exposure to solar radiation, water, and freeze/thaw cycles. Because of their location, the sealants are subjected to the greatest range of temperature variations, and consequently to the greatest differential movement. While this system has proven itself as a viable approach, it has a high maintenance factor. Even though the face seal method provides unsatisfactory long-term performance for airtightness and rain control, it is still very popular with designers and builders because the 'one wall design myth' makes it necessary to avoid creating any suspicious holes in the cladding, and to seal them carefully to prevent leaks.

The Two-Stage Seal Method

With the two-stage seal method, the airtightness of the wall and rain penetration are controlled by two different seals, located on the inner and outer edges of the concrete panel joints (Figure 6). The outer seal is also referred to as the rain deflector and the inner seal as the primary air pressure seal. In contrast to the one-stage joint, the outer seal is not relied upon to provide both functions.

The two-stage joint is an improvement over the face seal method because the air pressure seal is no longer exposed to water and ultraviolet radiation. Nevertheless some stresses are still induced from thermal movements of the panels and the unavoidable movements of the structure itself. (The durability, and therefore the long-term performance, of the air seal joint is still a concern. Durability is not an inherent property of any material; it is achieved by protecting the material from most of the factors that cause deterioration.

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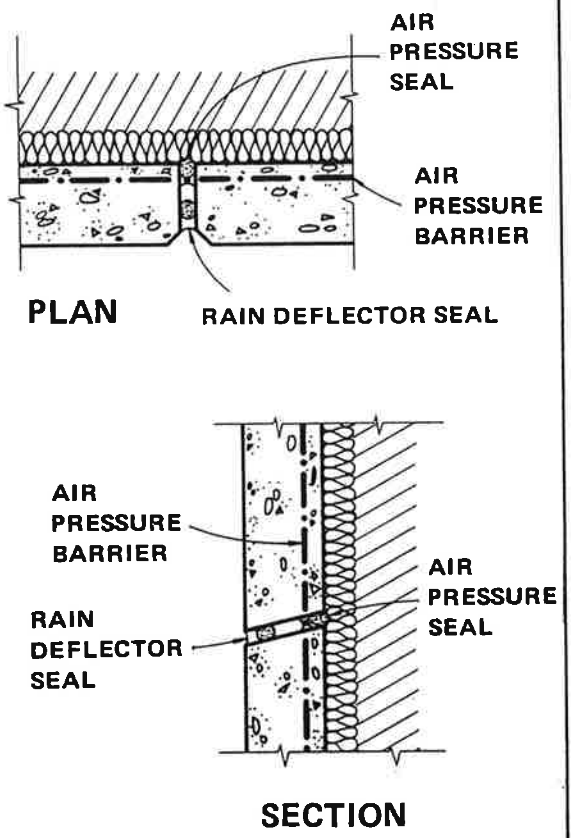

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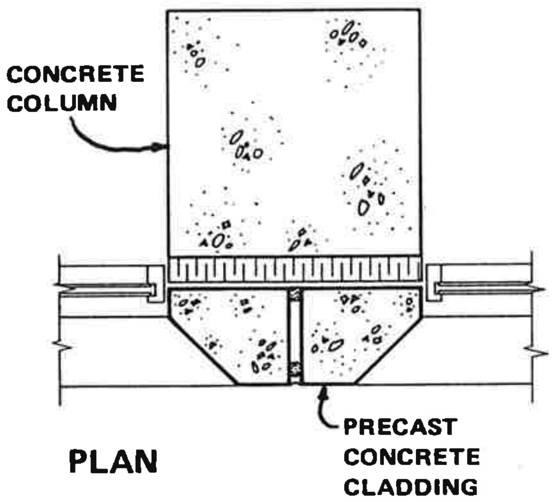


Durability is thus a matter of design rather than the quality of the material.)

More important is whether or not the primary air seal can withstand long-term air pressure differences without creeping out of the joint. This problem has not been addressed by the industry, particularly the material suppliers, as yet.

The design of the wall assembly also has an impact on the performance of the air pressure seal. For instance, it is quite difficult for the builder to quality control the continuity of the air seal when the panel joint is located on a column (Figure 7), or when it must cross a floor slab and the configuration of the panel is too deep to reach the inside edge of the panel joint.

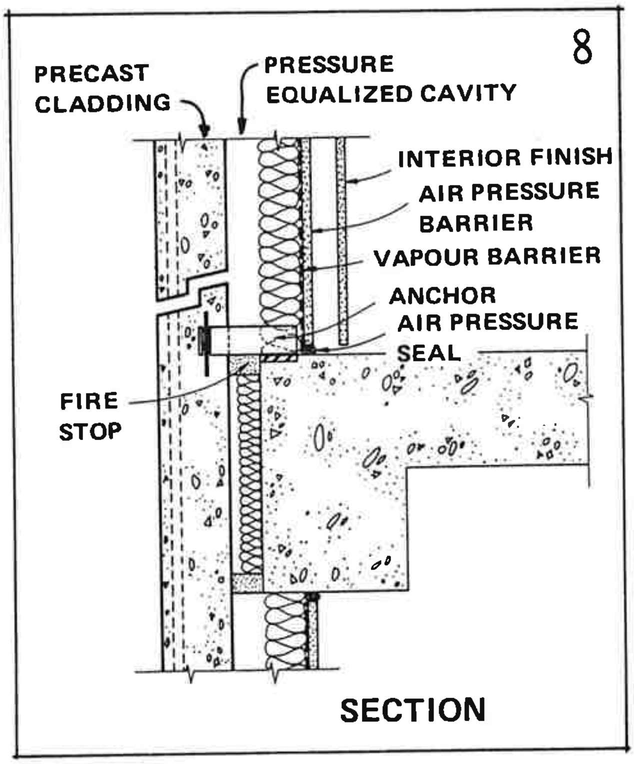
Concrete cladding using a two-stage or face seal method is generally combined with a wall behind a wall; no attempt is made to achieve airtightness because the cladding is supposed to be airtight. This design is generally used with walls for which no air space is provided behind the cladding. In this case the insulation is in direct contact with the concrete panels and the rain screen principle is applied to the joint system only. This system does not provide any drainage path for water that penetrates through the wall.

However, with this approach there is a further potential problem associated with the buildup of condensation in the walls. The concrete panel which is located on the cold side of the insulation may act as a vapour barrier on the wrong side. Moisture going into the wall cavity, either by diffusion or by air movement into a wall behind the inside finish, may condense at the back of the panel or within its joints.

The Airtight Wall Behind the Wall

A more recent approach to the design of exterior walls using conventional precast is to create an airtight surface elsewhere than within the cladding, that is, in the inner wall. There are two important advantages to this method. One is that the air pressure barrier can now be located on the warm side of a wall, thereby providing thermal stability to the air pressure seal joint and further reducing the number of induced stresses caused by temperature changes. The second advantage is that the rain screen principle may now be applied to the whole outside surface of the conventional precast panels, instead of only the joints, as in the two-stage method. But for the wall to function properly, the design must include an air pressure barrier within the wall, behind the cladding. The cavity thus created between the precast and the inner wall must also have an appropriate compartmentalization plan, both vertically and horizontally, over the facade of the building.

Let us consider an example. Assuming that a conventional precast wall panel is installed first in the usual manner, an inner wall is then built in one of several ways (Figure 8); perhaps a steel stud frame, filled with batt insulation held in place by a wire tie system and an inside layer of gypsum, may be constructed using the gypsum board as the primary air pressure barrier. A vapour barrier is then installed, if required, behind the gypsum board on the warm side of the insulation. A second furring bar is then installed over the first layer of gypsum, and a finish layer installed to create a service cavity, if required. An air space is created behind the cladding between an outside sheeting and the precast panel. This cavity is then connected to the outside by means of open horizontal joints, which should be sloped to drain any water that accumulates to the outside. It would be desirable for the concrete panel edges to be shaped to act as vertical deflectors, thus eliminating the need for any sealant treatment of the exterior facade. This may eliminate entirely the need to maintain sealants on the outside of a building. However, even with this wall design approach there are some difficulties to be overcome; the primary ones require



an appropriate flashing, which must bridge the cavity from the precast cladding to the inner air barrier. The second design difficulty and challenge is to ensure that precast panel anchors do not penetrate excessively to the inside of the building, or that the continuity of the primary air pressure barrier is maintained, regardless of its location in the wall behind the wall.

The design of this third system requires careful thought to the structural property of airtightness because failure to achieve it can create just as many problems as in the one- and two-stage joint approaches.

CONCLUSION

The one-stage joint is the simplest way to provide an airtight facade but the durability of the primary face seal is short-lived and requires frequent maintenance.

The two-stage joint promises longer durability because the air pressure barrier seal is hidden and better protected against solar radiation and direct wetting from rain. However, it is still not enough to get long-term performance because the air pressure barrier is subjected to various thermal stresses and movements of the cladding components, and if it needs maintenance it is more difficult to access and to repair.

The one- and two-stage joint methods are often designed such that insulation is applied directly to the back of the precast element. This poses a problem if sufficient moisture diffuses into these cavities; it may accumulate behind the precast panel face, between it and the insulation, and eventually melt back to the inside. In such cases an interior vapour barrier must be provided which has considerably lower permeance than the concrete element on the outside of the insulation.

The three-stage joint, or wall-behind-the-wall system, looks more difficult to apply because it is not part of a traditional method and requires the cooperation of numerous participants in the construction team to assemble. However, if proper consideration is given to the design and construction of this type of system, it promises to be one of the better long-term solutions to the performance of conventional precast wall assemblies.

REFERENCE

1. A.G. Wilson, Air Leakage in Buildings. Canadian Building Digest 23, Division of Building Research, National Research Council of Canada, Ottawa, 1961.