CAST-IN-PLACE CONCRETE CLADDING; IS IT ALL ITS CRACKED UP TO BE?

RDH Building Engineering Limited     RDH Building Engineering Limited

ABSTRACT

The lower mainland of British Columbia has recently undergone a residential building boom, which has contributed to the increased cost of both housing and construction. One result has been that cast-in-place concrete walls have been regaining popularity in BC, as well as in other areas of the Pacific Northwest, largely because of their lower cost and the perception of improved durability. This trend is counter to another trend which, since the mid 90’s, has been the utilization of rainscreen wall assemblies to manage rainwater on mid to high rise buildings.

In contrast to uninsulated mass masonry walls, there is actually very little information available regarding the performance of insulated, cast-in-place concrete wall assemblies. Also, over the past few years there have been numerous design and construction changes especially in regard to air tightness, insulation, interior relative humidity, use of exterior coatings, and availability of experienced trades. In combination these factors can adversely affect both the short and long-term performance of these wall assemblies.

The paper summarizes the results of a study of the performance of cast-in-place concrete cladding assemblies in coastal British Columbia. This study was the product of a research project funded by Canada Mortgage and Housing Corporation (CMHC) and the Homeowner Protection Office (HPO). The purpose of the study was to identify the reasons why older buildings with similar wall assemblies have performed well, and what strategies for design and construction are required in order to address the code-related and other requirements for newer buildings. The paper also examines the forensic analysis of several buildings as case studies. On these buildings moisture infiltration through cast in place concrete walls had resulted in warranty claims, or in some cases significant remedial work. Physical testing was used to highlight the cause of the problems and how they could have been prevented. In many cases utilizing the recommendations outlined in the study would have prevented the problems.

INTRODUCTION

Cast-in-place concrete construction has become an increasingly popular form of construction for mid and high-rise residential buildings in British Columbia. Cast-in-place concrete walls (Figure 1) are initially cost effective since they combine the functions of a structural element and an exterior wall assembly. Concrete also provides great flexibility and simplicity in building design.

While offering many advantages from a design and construction perspective, cast-in-place concrete construction also brings challenges. Compared with buildings constructed in the past, today’s cast-in-place concrete buildings are more complex in terms of building form and interface details. In addition, today’s buildings place a greater emphasis on air tightness and mechanical ventilation.
These new complexities mean that close attention needs to be paid to moisture management strategies to avoid both rainwater penetration and interior moisture related problems such as deterioration, fungal growth and staining. Poured in place wall assemblies also have a relatively poor effective thermal performance when compared to exterior insulated rainscreen wall assemblies and this needs to be considered at the conceptual design stage in the context of sustainable design. In addition, while the thermal performance is generally sufficient to allow adequate performance in the costal areas of British Columbia it may not be a good choice for other parts of Canada with colder climates. This paper summarizes the results of a study using several examples from case studies to emphasize the importance of effective design and construction practices for exposed cast-in-place concrete walls.

**METHODOLOGY**

The study was based on the following information:

- A survey and investigation of four older buildings and five new construction projects.
- Hygrothermal analysis of several insulation, vapour retarder, and coating combinations using WUFI™,
- Thermal analysis of the overall wall and key thermal bridging locations such as steel studs, slab bypass, and projecting eyebrows using Therm. The results are also compared to a modern rainscreen wall assembly,
- Knowledge obtained during review of construction drawings and methods with local trades, construction managers and architects during the design and construction of several high-rise buildings in Vancouver, British Columbia.

**DISCUSSION**

The success of a cast-in-place concrete wall clearly involves achieving many performance objectives. The control of heat, air and moisture flows (both vapour and rain) are important, and the wall assembly must also be durable, constructible and maintainable.

Rain penetration control should be considered a priority performance criterion. Achieving this objective is not easy, particularly in the B.C. coastal climate. Many of the other objectives can be achieved in a variety of ways, and relatively easily, once the rain penetration control strategy is defined.

Building form has a profound impact on the risk of water penetration since it impacts the amount of wetting that can occur on a wall, as well as the extent to which problematic details occur. Choices made with respect to building form determine how dependent rain penetration control performance is on the quality of the design and construction of
details. Building form that minimizes the potential for cracking, wetting (Photo 2) and the extent of uncompressed construction joints provides a lower risk of water penetration. Figure 2 shows a classification of different building form variables according to the overall risk of water penetration. In general overhangs reduce the time of wetting and the amount of water contacting cracks, while mixing load bearing columns with upstand curbs under windows increases the complexity of the interfaces and the amount and severity of cracking.

**Two Lines of Water Penetration Resistance**

Cast-in-place concrete walls do not have the redundancy inherent in rainscreen wall assemblies, and therefore can not provide the same level of long term water penetration resistance. However, it is possible to achieve adequate performance, provided that two lines of resistance to water penetration are provided. The first line of water penetration resistance for a concrete wall is the face of the concrete, which is made more water resistant through the use of a coating. The second line of resistance is created by the concrete itself, since it has sufficient thickness and impermeability to restrict the inward movement of water. Some moisture can be absorbed into the concrete and later dry to the exterior as weather conditions permit. For portions of the cast-in-place concrete wall area that are free of cracks and joints, the key variables for effective water penetration control are, therefore, the properties of the coating once it is installed on the concrete and the water resistive characteristics of the concrete material.

![Figure 2 - Risk of Cracking, Wetting and Associated Water Infiltration](image)

The real challenge with respect to water penetration control for cast-in-place concrete walls is in achieving a second line of resistance at cracks, penetrations, construction joints and control joints in the concrete. At these locations the coating will not bridge any significant cracks in a durable manner. Cracks or joints essentially represent a hole through the concrete. Gravity, pressure gradients created by the wind and capillary forces can all act to drive water through these holes to the building interior.

**Sources of Water Penetration**

Cracks at unanticipated locations, construction joints and control joints are the most common sources of water penetration through exterior concrete walls. Design considerations for joints include:

- Design of building form to limit horizontal length of concrete walls thereby limiting the need for control joints.
- Building form and geometry to prevent initiation of cracks, for example, re-entrant corners and similar discontinuities should be avoided.
- Spacing of control joints to minimize shrinkage and cracking between the joints.
• Appropriate detailing is required to prevent migration of water through construction and control joints. This detailing includes the use of waterstops and other joint sealants to provide two layers of resistance to water leakage.

• Form tie holes, pipe runs and honeycombed concrete are also common locations of water movement through concrete. These should be filled with crystalline grout from the interior to improve resistance to water infiltration and hydraulic cement from the exterior to reduce the risk of efflorescence and paint delamination. All significant cracks that appear should be routed and sealed like construction joints on the exterior, especially if they are subject to ongoing movement. Interior cracks can be routed and sealed with crystalline grout or injected with urethane or epoxy in the interior provided they are static.

Test for Water Tightness
Testing of the concrete for water tightness during construction can be relatively easy to undertake. Simply wetting the uncoated concrete wall for several hours from the exterior (pressure differential not usually required) will often provide an indicator of the water tightness of cracks, tie holes and construction joints. This type of testing should be undertaken prior to closing in the walls on the interior so that locations of leaks can be readily identified and addressed. The windows should be installed prior to the testing. The results from the concrete testing should be correlated with the results of the pressurized window and window interface testing to ensure that all known leakage paths are identified.

Other Heat, Air and Moisture Control Functions
Primary air tightness is readily achieved in cast-in-place concrete walls by the concrete itself and by continuity of air tightness at joints, penetrations and interfaces. Hygrothermal modeling of these wall assemblies indicates that vapour diffusion control is important both for inward and outward acting vapour drives. The modeling shows that walls incorporating a layer of polystyrene insulation (XPS) or spray-in-place polyurethane foam immediately adjacent to the inside surface of the concrete will have the least overall risk for condensation moisture problems related to vapour diffusion, air movement and thermal bridging. Not only does this insulation layer provide an effective balance for inward and outward acting vapour drives, it also eliminates the potential for air-leakage related condensation (interior air movement into a space created between the concrete and the internal stud wall), convective looping, and provides a relatively continuous thermal insulation layer within the wall to reduce the impact of the highly conductive steel studs.

The overall thermal resistance provided by the insulating layers in cast-in-place concrete wall assemblies is reduced by thermal bridging caused by intersecting concrete walls and floor slabs, penetrations, vents and possibly by the interior steel stud framing. The effects of thermal bridging generally make cast-in-place concrete walls much less energy efficient than walls that are continuously insulated from the exterior.

It is clearly beneficial to detail penetrations and interfaces within wall assemblies with thermal breaks between the concrete and other thermally conductive building components, such as steel studs and window frames.

Critical Features & Details
Several features and details are critical in cast-in-place concrete buildings with respect to water penetration control. These include construction joints, control joints, planter curbs and parapets, window interface details and surface runoff control features. Examples of these features and details are illustrated below.
**Construction and Control Joints**

Two lines of defense should be provided at all construction and control joints. An example of how this can be achieved is shown in the adjacent figure.

1. Storage capability of concrete wall (second line of defense)
2. Concrete slab
3. Storage capability of concrete wall or column (second line of defense)
4. Vertical crack control joint created in monolithic concrete pour of an upstand wall under the window opening and the adjacent full height wall
5. Horizontal construction joint between walls and floor slab
6. Caulked joint in reglet at joints on exterior of concrete surfaces (first line of defense)
7. Coating on wall (first line of defense)
8. Bentonite strip at construction joint (second line of defense)
9. Crystalline drypack in reglet and crystalline slurry at construction joint (second line of defense)
10. Crystalline drypack in reglet at vertical control joint (second line of defense)

**Figure 3 – Redundant Water Seals at Construction and Control Joints**

**Planters, Curbs and Parapet Walls**

It is quite common in the industry for planter curbs and parapets on waterproofed horizontal surfaces to be constructed using one of the following methods:

1. Casting a curb directly to the concrete with the waterproofing membrane brought up both sides and terminated slightly below the top of the landscaping (Figure 4a) or,

2. Installing the curb directly over a prestripping of the waterproofing membrane. Once the concrete has cured the field membrane is applied and spliced onto the prestripping membrane (Figure 4b).

**Figure 4a – Planter Curb Method 1 – Commonly Used - Not Recommended**

**Figure 4b, Planter Curb Method 2 – Commonly Used - Not Recommended**

Both of these installation methods have significant drawbacks. In method 1, any cracks in the concrete curb will allow water to flow directly to the interior, and the identification of these leak paths will be very difficult. In method 2, the reinforcing steel penetration is at a level where it will be frequently (if not continually) exposed to water. In addition, the membrane cannot be maintained or repaired near the
curb without necessitating the complete removal of the concrete curb. This problem is often compounded, because the membrane is often damaged at this location during construction. The lack of roof dividers and the inability to visually review the membrane under the curbs makes it very difficult to locate and repair leakage in this system.

A much better method of installing a planter curb is to treat it like a roof parapet and bring the waterproofing membrane up and over the top of the curb. Precast or cast-in-place concrete can be installed to provide an exposed concrete finish and protect the membrane as shown in Methods 3 and 4.

**Planter Curb Method 3 – Best Performance:**
1. Removable precast concrete or metal flashing protects the membrane and facilitates membrane maintenance and replacement.
2. Membrane continuous up and over curb – no membrane terminations.

**Planter Curb Method 4 – Good Compromise:**
1. Curb cast in two pours, with membrane continuous up and over lower curb.
2. Water entering cracks in top curb flows to exterior.
3. Reinforcing steel penetrations always above water ponding level.
4. Membrane can be maintained and replaced without bottom curb removal.
5. Membrane pre-stripping on sides of curb is coated over when main field membrane is installed repairing any construction damage.
6. Waterproofing areas are divided by sub curbs making the location and repair of leaks much easier and faster.
7. Gap in bottom curb can be left for drainage and sprinkler or electrical services eliminating complex membrane penetrations.

**Balcony Interface**

The control of water run-off to avoid concentrated flow over potentially sensitive areas is essential in order to ensure successful performance of the building enclosure. Examples of these conditions include upstand wall saddle interfaces, window sill / jamb interfaces, and balcony saddle interfaces with adjacent walls. One of the simplest strategies to minimize risk of water penetration related problems is to divert water flow away from potentially sensitive areas and to ensure waterproof membranes are turned up at all wall interfaces and lapped over vertical surfaces where water flow is expected (Figure 5).
**Figure 5 - Surface Runoff Features**

Avoiding concentrated runoff and having water drip free of the building face are good water management features:

2. Cricket at wall to balcony interface to direct balcony runoff water away from wall.
3. Drip edge on balcony slab so that water drips free of slab rather than along underside.

**Window Interface**

Continuity of barriers at interfaces is critical to successful performance. Key features of a good window sill detail include:

1. Sub-sill drainage.
2. Exposed top surface of concrete protected and waterproofed.
3. Connection of window to membrane on metal angle, and the metal angle–sealant–concrete joint provides continuity of the air barrier and moisture barrier.
4. Adequate backing for membrane flashing
5. Adequate insulation, thermal breaks, heat sink angles, and proper placement within the assembly to manage condensation on the interior surfaces.
Window installation methods 1 and 2 shown above are appropriate for the coastal climate of BC. For installation method 2 at winter design temperatures (-7°C), the interior RH level must be maintained below 45% RH for the system to manage condensation. At typical winter temperatures around 0°C interior temperatures must be maintained below 54% RH. For colder climates the window must be moved back into the stud opening using installation method 1 until adequate surface temperatures can be achieved.

**Concrete Properties**

Concrete is the common material in all the wall assemblies under consideration for this study. Its behaviour as a material has a profound impact on the performance of the wall assembly as a whole. It is also unlike most other materials in the wall assembly in that it is a mixture of constituent materials that are mixed together at the building site to create the material. Control of the location and frequency of cracking and construction joints is the most important element for water penetration control. This requires the involvement of the architect, structural designer, contractors, concrete supplier and building enclosure consultant. Mix design, rebar placement, waterstop selection and placement, and coating selection require input from many different parties involved in the project and can have a significant impact on the overall water penetration resistance of the concrete. Finally, construction quality control during the placement, vibration and curing of the concrete is essential to ensure that finished concrete will be able to resist water penetration in the main field of the wall.

**Coating Materials**

The most common method of reducing permeability of the surface of the concrete is through the addition of a coating. Since concrete, by its nature, is porous and minor amounts of moisture are anticipated to exist behind the face, the coating must be able to allow this moisture to dry back to the exterior when conditions permit. A wide range of performance characteristics must be considered in selecting a coating. A summary of these considerations is provided in Table 1.

![Figure 6c - Temperature Isotherm for Window Installation Method 2](image)

<table>
<thead>
<tr>
<th>Property</th>
<th>Acrylic Latex Paint</th>
<th>Acrylic Latex Elastomeric</th>
<th>Silicone Elastomeric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (mil)</td>
<td>2-3</td>
<td>10-20</td>
<td>10</td>
</tr>
<tr>
<td>Crack Bridging</td>
<td>Poor</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Elasticity</td>
<td>Poor</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Recoats Before Complete Removal Required</td>
<td>5</td>
<td>2-3</td>
<td>5</td>
</tr>
<tr>
<td>Water Penetration Resistance</td>
<td>Poor</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Vapour Permeability</td>
<td>Good</td>
<td>Poor</td>
<td>Excellent</td>
</tr>
<tr>
<td>Relative Cost</td>
<td>1</td>
<td>2</td>
<td>2.2</td>
</tr>
<tr>
<td>Life Expectancy (Years)</td>
<td>2-5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Abrasion Resistance</td>
<td>Good</td>
<td>Good</td>
<td>Poor to fair</td>
</tr>
<tr>
<td>Surface Preparation/ Ease of Application</td>
<td>Easy</td>
<td>Easy</td>
<td>Difficult</td>
</tr>
<tr>
<td>UV Stability</td>
<td>Poor</td>
<td>Poor</td>
<td>Excellent</td>
</tr>
<tr>
<td>Ease of Cleaning</td>
<td>Moderately Difficult</td>
<td>Moderately Difficult</td>
<td>Very Difficult</td>
</tr>
</tbody>
</table>

As is shown in Figure 7, all the walls demonstrate an overall drying trend from the initial conditions and approach acceptable concrete moisture content levels. However, the concrete moisture content of the coated walls is generally lower than the moisture content of uncoated walls, indicating that the reduction in rain absorption outweighs the reduction in diffusive drying potential. Note that with the
higher permeance silicone coating the concrete moisture content is significantly lower, indicating that it offers a superior balance between restricting absorption while allowing drying.

Based on the WUFI modeling results, the addition of coating appears to be beneficial not only for limiting water penetration at hairline cracks, but also to maintain lower concrete moisture content levels.

![Concrete Moisture Content](image)

**Figure 7** - Concrete moisture content for wall W3 with No Coating (NC), Silicone Elastomeric (SE) and Acrylic Elastomeric (AE) exterior coatings. Water content shown in units of kilograms per cubic meter

**Below Grade Concrete Elements**

The exterior environmental conditions are quite different for below grade cast-in-place concrete elements and, therefore, require a special application of this technology. The interior space may be occupied living space or unoccupied space such as a parking garage. The exterior side of the wall experiences more moderate temperature swings than above grade, but may be subjected to longer periods of wetting and hydrostatic pressure.

Assuring performance of below grade cast-in-place concrete elements has some similarities and some very key differences to above grade cast-in-place concrete walls. For example, the requirements for concrete mix design, construction and control joint waterproofing, and crack control are generally the same for both types of walls. The key difference in strategy reflects the different moisture loads including the possible presence of hydrostatic pressure. Much more robust assemblies and details need to be used when hydrostatic pressure exists. An example of typical below grade moisture control strategies for concrete walls under different loads is provided in Table 2.

**Maintenance and Renewals**

It is important to design assemblies and systems that are reasonably maintainable. For example, relying solely on a concealed waterstop within the concrete for water tightness can be problematic when the waterstop nears the end of its service life. If an exterior sealant is used in conjunction with an internal water stop then the primary water shedding element can be easily reviewed and maintained as required. The above grade concrete, and the associated coating and sealant materials will require annual maintenance and renewals work over the service life of the building. The maintenance and renewals plan should therefore focus on provisions for inspection, cleaning, maintenance, repair and renewal of the coating and sealants. Later in the service life of the walls, it may be necessary to undertake more
significant inspection and repair work such as sounding of the concrete surfaces, and repair of deteriorated concrete. Provided that the building has been designed and constructed with an adequate moisture control strategy, with readily maintainable components, regular maintenance can prevent water ingress and associated deterioration from occurring.

**Table 2 - Example of Below Grade Moisture Control Strategies for Concrete Walls**

<table>
<thead>
<tr>
<th></th>
<th>Walls</th>
<th>Slab on Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exterior</td>
<td>Moisture Barrier</td>
</tr>
<tr>
<td>No Hydrostatic Pressure Unoccupied/Unfinished</td>
<td>Yes</td>
<td>Dampproofing</td>
</tr>
<tr>
<td>No Hydrostatic Pressure Occupied/Finished</td>
<td>Yes</td>
<td>Waterproofing</td>
</tr>
<tr>
<td>Hydrostatic Pressure Unoccupied/Unfinished Low permeable Soils (Clay)</td>
<td>No</td>
<td>Waterproofing Fully Bonded to Concrete</td>
</tr>
<tr>
<td>Hydrostatic Pressure Occupied/Finished Low permeable Soils</td>
<td>No</td>
<td>Waterproofing Fully Bonded to Concrete</td>
</tr>
<tr>
<td>Hydrostatic Pressure Unoccupied/Unfinished High Permeable Soils (Sand)</td>
<td>No</td>
<td>Waterproofing Fully Bonded to Concrete</td>
</tr>
<tr>
<td>Hydrostatic Pressure Occupied/Finished High permeable Soils</td>
<td>No</td>
<td>Waterproofing Fully Bonded to Concrete</td>
</tr>
</tbody>
</table>

**CONCLUSIONS/RECOMMENDATIONS**

- Design the building so that the basic form, size, and features minimize uncontrolled cracking. If uncertain, then introduce a control joint.
- Provide some overhang protection wherever possible especially where control joints are required.
- Provide two lines of defense in the water penetration control strategy for all construction and control joints.
- Provide two lines of defense for monolithic concrete areas (field portion) through the use of coatings in combination with the concrete itself.
- Place extruded polystyrene or spray-in-place urethane foam insulation against the interior surface of the concrete (in addition to any insulation placed in the stud space) to reduce potential for condensation and improve overall thermal performance.
• Window frames and other components that pass from the exterior to the interior should not be placed in intimate contact with concrete (avoid thermal bridging).

• Continuity of critical barriers (thermal, moisture and air tightness in particular) should be maintained at all interfaces and penetration details.

• Confirm water penetration resistance of walls by testing of the wall assembly prior to closing in from the interior.

• All non-vertical concrete surfaces should be protected with waterproofing and/or metal flashing.

• Membranes should terminate on a vertical surface and the top edge should be protected.

• Place concrete curbs so that membranes are accessible for maintenance and renewals.

• Control surface runoff with drip edges, crickets and diverters.

• Review heat, air and moisture control functions for the cast-in-place concrete elements at the design and construction stages with a qualified person (e.g. consultant) having appropriate experience and qualifications.

• Include provisions for coatings and sealants in maintenance and renewals plans.

• Waterproofing should be designed and constructed using details that allow maintenance and repair of the membrane system without the requirement for concrete removal and do not rely on the exposed concrete for any part of the waterproofing system other than for mechanical damage and UV protection of the membrane.
CASE STUDY 1

<table>
<thead>
<tr>
<th>Background</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age:</strong> 13 years</td>
<td></td>
</tr>
<tr>
<td><strong>Height:</strong> 27 stories</td>
<td></td>
</tr>
<tr>
<td><strong>Occupancy:</strong> Residential above commercial</td>
<td></td>
</tr>
<tr>
<td><strong>Wall Construction:</strong></td>
<td></td>
</tr>
<tr>
<td>6” cast-in-place concrete</td>
<td></td>
</tr>
<tr>
<td>2 ½” steel studs (with a 1/2” gap between the steel studs and the concrete)</td>
<td></td>
</tr>
<tr>
<td>2 ½” rigid polystyrene insulation</td>
<td></td>
</tr>
<tr>
<td>6 mil poly vapour retarder</td>
<td></td>
</tr>
<tr>
<td>gypsum board</td>
<td></td>
</tr>
<tr>
<td>interior paint</td>
<td></td>
</tr>
<tr>
<td><strong>Problems:</strong></td>
<td></td>
</tr>
<tr>
<td>• None reported</td>
<td></td>
</tr>
</tbody>
</table>

The exterior walls consist primarily of cast-in-place concrete with the east elevation partially clad in EIFS. The concrete elements are generally restricted to columns and upstand walls under aluminum punched windows. The concrete was sandblasted but not sacked or coated as part of the original construction (Photo CS1). A condition assessment of the building was completed in 2002. Although the condition assessment scope of work included the roofs and at-grade assemblies, the focus of this case study is on the findings related to the cast-in-place concrete walls and windows.

Performance observations made from the exterior included the following:

- The sealant joint at the window perimeters had failed adhesively at many locations (Photo CS2).
- Cold joints in the cast-in-place concrete walls at floor levels and below window jambs were not sealed. Efflorescence and staining was noted at joints throughout the building (Photo CS2).
- Dark staining due to concentrated run-off was visible at several locations.
Performance observations made from the interior included the following:

- Condensation was occurring on window and curtain wall framing in some suites leading to damage at wood window sills as well as wall and ceiling finishes and carpet tack strips.

- Interior openings revealed mold present on the exterior face of the interior gypsum board at some locations, most notably in areas of wall below window jambs (Photo CS3). This is likely occurring due to leakage at cold joint or window perimeter.

- Ventilation was provided though bathroom and kitchen fans with no humidistat controls and fresh air intake provided either through the exterior walls and windows or under suite entry doors. There was a continuous hallway pressurization system.

**CASE STUDY 2**

<table>
<thead>
<tr>
<th>BACKGROUND</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age:</strong></td>
</tr>
<tr>
<td><strong>Height:</strong></td>
</tr>
<tr>
<td><strong>Occupancy:</strong></td>
</tr>
<tr>
<td><strong>Wall Construction:</strong></td>
</tr>
<tr>
<td>• Exterior Acrylic Paint</td>
</tr>
<tr>
<td>• 6” cast-in-place concrete</td>
</tr>
<tr>
<td>• 4” steel studs (with a 1/2” gap between the steel studs and the concrete)</td>
</tr>
<tr>
<td>• Fiberglass batt insulation</td>
</tr>
<tr>
<td>• 6 mil poly vapour retarder</td>
</tr>
<tr>
<td>• gypsum board</td>
</tr>
<tr>
<td>• interior paint</td>
</tr>
<tr>
<td><strong>Problems:</strong></td>
</tr>
<tr>
<td>• 20% of survey respondents reported condensation and mold issues</td>
</tr>
</tbody>
</table>

A condition assessment of the building was completed in 2006. The exterior concrete walls at this building were designed and constructed without overhangs, and upstand curbs were cast integrally with the concrete columns (Photo CS4). Crack control joints were not utilized at the interface between the structural columns and the non-load bearing upstand curbs under the windows. This design has the highest risk of cracks occurring in areas where there is no secondary line of defense for water ingress (Figure 2e). The building is exhibiting a very high incidence of uncontrolled cracking in the concrete (Figure 8, Photos CS5,6,7). Water testing of the cracks indicates that some of the cracks are allowing active leakage into the wall assembly. Corrosion staining and spalling also indicate that water leakage through cracks in the concrete is reaching the reinforcing steel.
Roofing and waterproofing details have been performed as per Method 1 (Figure 4a) for curbs and parapets. The waterproofing membrane has been terminated below the top of the pavers (Photo CS11) and in some cases below flowing water (Photo CS8). Cracking has occurred through the exposed concrete at curbs (Photo CS13), walls and parapets (Photo CS9) and water is infiltrating the cracks and getting behind the waterproofing membrane (Photo CS10,12).
CASE STUDY 3

BACKGROUND
Age: < 5 Years
Height: High Rise
Occupancy: Residential
Wall Construction:
- Exterior Acrylic Paint
- 6” cast-in-place concrete
- 4” steel studs (with a 1/2” gap between the steel studs and the concrete)
- Fiberglass batt insulation
- 6 mil poly vapour retarder
- gypsum board
- interior paint

Problems:
Numerous reports of water infiltration, condensation and mold/mildew issues

A condition assessment of the building was completed in 2006. Test openings and observations made from the interior of the building revealed damage to interior wall components and finishes (Photos CS15, 16). Active water leakage into the wall assembly was observed during testing (Photo CS17). Corrosion staining and spalling also indicate that water leakage through cracks in the concrete is reaching the reinforcing steel. The exterior concrete walls at this building were designed and constructed without overhangs, and upstand curbs were cast integrally with the concrete columns (Photo CS15). This design has the highest risk of cracking and associated water leakage (Figure 2e). Architectural reveals were cast into the concrete, however, they were not located at locations where cracking would be expected (Photo CS18). Vertical crack control joints, construction joints and waterstops were not installed. The building is exhibiting a high incidence of uncontrolled cracking particularly at floor slabs and windows (Photos CS19,20,21,22.)

Waterproofing membranes at balcony and eyebrows were terminated short of the slab edge in many areas and no end dams or saddle flashing details were used at terminations with the wall assembly (Photo CS23). Cracking and associated water leakage in these locations has delaminated the weatherproof membrane in numerous areas.

Numerous areas were observed where sealant has failed adhesively to the concrete and cracks through the exterior coating are allowing water infiltration.

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CASE STUDY CONCLUSIONS

- Casting structural columns monolithically with non load bearing upstand curbs for punched windows increases the risk of unanticipated concrete cracking.

- Cracking that occurs through the exterior coating and concrete in areas where there is no waterstop in the concrete to provide a second line of defense is more likely to result in water penetration to the interior.

- Waterproofing membranes that are sealed to the sides of exposed concrete curbs and parapets are at an increased risk for water penetration. Cracks will occur in the concrete and allowing water to enter behind the waterproofing membrane. This problem is compounded if waterproofing membranes are terminated below finished surfaces where water tends to flow.

- Condensation can occur due to the poor thermal performance characteristics of the walls and windows in combination with a poor suite ventilation system.

- Lack of regular maintenance will result in water penetration at some locations.

- Concentrated run-off can result in significant staining and increased potential for water penetration.
REFERENCES

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v  ACI 224R, “Control of Cracking in Concrete Structures”, Manual of Concrete Practice, American Concrete Institute, Detroit, MI 2003. ACI 224.1R

vi  “Causes, Evaluation and Repair of Cracks in Concrete Structures,” ibid. ACI 504R

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viii ACI 201.2R, “Guide to Durable Concrete,” ibid