Precast Concrete Construction: From Pitfalls to High Performance

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ABSTRACT

Over the past few decades, the use of glass and glazing on our high-rise buildings has increased dramatically. More recently, as a result of increased industry recognition of the importance of energy efficiency, the trend is towards more energy-efficient glazing systems. However, there are instances of implementation of new technology that have resulted in premature and costly failures. Several case studies will be used to show and explain the variety of problems that can occur with glass and glazing after installation. We will offer designers risk reduction recommendations to avoid the most common causes of failures.

SPEAKER

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BRIAN HUBBS has over 20 years’ experience as a consultant practicing exclusively in the field of building science. Recognized by his peers as being a practical building science engineer and researcher who consistently delivers innovative solutions, Brian has a unique blend of theoretical and hands-on knowledge gained from completing hundreds of building enclosure investigations and rehabilitation projects, as well as from design consulting and construction review of building enclosures for new buildings.
**ABSTRACT**

Precast concrete has long been an established architectural cladding system for buildings of all sizes and shapes. Precast concrete allows for unique architectural shapes and textures and has a long track record of good durability and performance. In recent years, most cladding systems have evolved to be more energy-efficient through the integration of high-performance air barriers, rain screen moisture management design, and thermal breaks at anchors for continuous insulation. However, conventional precast has remained virtually unchanged in the past 50 years. The high cost, coupled with relatively poor thermal, air, and water leakage performance, often makes conventional precast uncompetitive when compared to modern cladding systems.

By changing the sequence of construction, it is possible to create high-performance and energy-efficient rain screen systems using conventional precast panels; however, this increases the overall cost. Advances in precast ties and anchors allow insulated precast sandwich panels to be made and installed like a window wall system on high-rise buildings. At the same time, advances in forming technology make the addition of custom patterns and textures cost-effective. These panels can be installed quickly, have continuous insulation, and incorporate rain screen cladding design and detailing. With attention to the economics of precast at the design stage, it is possible to install these complete systems at a cost that is less than most other cladding and window assemblies.

Through a number of case studies, the author will discuss shortcomings, failures, successes, and lessons learned when dealing with precast concrete cladding systems, as well as insight for potential future improvements.

**INTRODUCTION**

In order to understand the basic science behind the performance of concrete as a building envelope material, five distinct types of concrete wall assemblies have been identified for comparison in this paper: cast-in-place concrete, precast concrete cladding, tilt-up concrete panels, thin-shell sandwich panels, and true rain screen precast panels. With the exception of the true rain screen panels, all of the concrete wall assemblies listed above are considered mass walls.

**Rain Penetration Control Strategy**

The rain penetration control strategy of a mass wall is to absorb any rainwater that penetrates the face and store the water until it is able to dry. To have an effective system, the mass wall must be able to store enough water so that it will always be able to dry before the water reaches the inside of the wall and infiltrates into the interior space. Factors affecting the rain penetration performance of mass walls include storage capacity, exterior finish, joint detailing, crack control, and amount of wetting.

**Thermal Performance**

Thermal performance of conventional mass concrete walls is typically not ideal. In concrete buildings, slabs act as large thermal bridges at each floor. This can lead to high energy costs, cold spots inside the building, and increased condensation potential. The one benefit of mass walls in regard to thermal performance is their large thermal mass, which means a large amount of energy is required to change the temperature. Once the mass wall is at a desired temperature, it will stay relatively consistent, even when other elements around it are changing more rapidly; and as a result, heating and cooling requirements can be significantly decreased by exposing the thermal mass to the conditioned space (as seen in Figure 1).

In practice, this means that concrete mass walls that have a substantial portion of their mass inside the insulation layer (such as sandwich panels) can expect up to a 7% increase in energy savings compared to conventional precast systems.

**Cast-In-Place Concrete**

Cast-in-place concrete walls use the mass wall rain penetration strategy of absorbing water until it is given a chance to dry. Since this concrete is integral with the building structure, it is likely to crack when the building undergoes movements as a result of settlement, thermal expansion and contraction, and live and/or environmental loads throughout its life. As a result, joint and crack control is critical to successful performance. In standard cast-in-place concrete walls, all of the thermal mass is outside the insulation, and any water penetration to the interior of the building is unable to drain back to the exterior of the building. Water infiltration through cast-in-place concrete enclosures is a common occurrence at cracks, tie holes, and interfaces with other enclosure systems (Figure 2).
Precast Concrete Cladding

Conventional precast concrete cladding utilizes a mass wall rain penetration control strategy with a heavy emphasis placed on joints between panels. Since the panels are mounted onto the main structure of the building rather than being an integral structural component, they can be attached using anchors that are able to move and rack independently of the building. As a result, it is less likely that panels will experience uncontrolled cracking. The thermal mass for this wall system is also on the exterior, unconditioned face.

Tilt-Up Concrete Panels

Tilt-up concrete panels also use the mass wall rain penetration control strategy. The use of sandwich panels with insulation between two layers of concrete is common in tilt-up applications. This allows for half of the thermal mass to be inside the conditioned space, leading to more efficient-energy performance, while the interior concrete wythe serves as an interior vapor retarder.

Performance Enhancers for Face-Sealed Precast

It is common for builders to install performance enhancers in conjunction with face-sealed precast to promote drainage within the wall. During numerous investigations, the author has observed metal drainage gutters in the capillary break between the back of the precast panel and the metal studs to direct water ingress back to the exterior at window heads and though joints, sometimes incorporating unconventional construction materials as shown in Figure 3.

While this gutter system can be effective in promoting drainage, it is not the best solution to the problem of leakage at joints and cracks. Often, high humidity, created by drainage water or leakage around the gutter system, will cause damage to the interior finishes and result in costly rehabilitation work.

Precast Joints

Joints between precast panels are crucial in order to maintain a waterproof and airtight system. Since sealants inevitably will fail over time, it is recommended to use two stage joints for redundancy. The interior sealant joint is the air and moisture barrier, which is continuous down the entire height of the wall. The exterior sealant joint is the water-shedding surface. To make the two stage joint systems work effectively, periodic gaps in the primary face seal, in conjunction with ramping of the top of the joint, should be provided for drainage and venting (Figure 4).

Ramping of the joint at the base of the wall is also required to ensure that water is not directed straight downwards into the building.

Current State of Precast

The lack of redundancy for water penetration resistance, combined with the thermal bridging and weight, often make precast a less desirable choice when compared with high-performance exterior insulated rain screen systems such as masonry or metal panel. Interfaces between precast panels and other building enclosure elements are also often difficult to detail and...
require a lot of attention in design and construction. To solve these issues with conventional precast, it is useful to look at other enclosure systems used in high-rise construction to see if there is a more efficient method of installing precast in today's high-rise buildings.

Mass-storage rain control can only hold so much water before it passes through, or even worse, finds its way inside through a crack. Therefore, in order to make precast concrete a viable wall system in today's high-rise construction industry, it is desirable to use a redundant, drained system that easily interfaces with modern window and curtain wall systems.

The following case studies will showcase the author's experience assisting in the evolution of several unconventional precast concrete cladding systems. Lessons learned in the case studies were used to develop a model precast system that is economical, fast to install, and aesthetically variable.

**CASE STUDY 1**
*Rain Screen Precast Outside and in Sequence*

The first precast, concrete-clad building discussed in this paper is a 32-story, multiunit residential building in Portland, Oregon. The design called for concrete framing with post-tension slabs, aluminum window wall, and precast concrete cladding, which was to be installed like unitized curtain wall, where precast concrete panels are stacked as individual units and supported at each floor line (Figure 5).

The three fundamental requirements for the precast concrete panel system were exterior insulation, self-adhered weather barrier, and the ability to act as a rain screen wall system. To achieve these requirements, the precast panels incorporated a self-adhered air/moisture/vapor weather barrier membrane over exterior sheathing and insulation on the exterior. Drainage for the weather barrier was to be provided by through-wall flashing at each floor line and by ramping of two stage joints between panels. Originally, a conventional inside-to-outside construction sequence was planned, which involves installing the layers of the wall assembly sequentially, starting with the studs and moving outwards to the exterior finish. However, constructability and cost issues made it necessary to build the wall system from outside to inside. This reversal of sequence required a prefabricated, panelized, interior wall assembly (Figure 6) and bolted connections for mounting the precast panels in order to avoid welding near the self-adhered membrane.

Although continuity of thermal, water, vapor, and air barriers was achievable with this inside-out panelized approach, blind sealing at the interior was required to ensure this continuity. As a result, significant quality assurance and control (QA/QC) efforts were required, resulting in a slower and more costly installation than was originally anticipated by the construction team.

**CASE STUDY 2**
*Precast Sandwich Panels on High-Rise, Installed Like Curtain Wall*

Case Study 2 is a high-rise building in Seattle, Washington, where the desired masonry finish was achieved by casting the thin brick into the face of the precast sandwich panels (Figure 7).
The precast panel-to-slab edge details were based on curtain wall detailing with some minor modifications. The thickness of a precast sandwich panel allowed for the interior concrete wythe to sit on the slab below, reducing the required anchor size. Silicone sealant and extrusions ramping downwards of spray foam were used as through-wall flashing and at the panel head and sill for the interior air seal.

Corner and slab details required pre-manufactured flashing boots (Figure 8) and Dow 123 preformed silicone extrusions to maintain a continuous air and water seal around the entire perimeter of the building.

Some of the more difficult interfaces, such as the jamb conditions between precast panel and curtain wall, had to be worked out in the field rather than in the design stage, which is to be expected when working with a completely new system. Regular QA/QC testing was necessary to check air and moisture seals and was crucial in discovering areas that needed attention. Overall, the cladding system was found to be quick to install and economical by the design and construction team.

**CASE STUDY 3**

**Rain Screen Precast – Proper Sequence**

The third case study is a three-story hospital building in Sechelt, BC, which featured large precast panels. The wall design (as suggested by the author) was precast concrete over mineral wool over self-adhered membrane; however, this design was changed during construction. Instead, spray-applied polyurethane foam (SPF) was used as the insulation, air barrier, and water barrier, instead of mineral wool and self-adhered membrane. Even though the potential for cracking of foam and compatibility issues with welding were raised, the plan, moving into the construction phase, was to proceed with SPF.

Following the proper enclosure construction sequence of building interior to exterior, the precast concrete cladding was the last wall component put onto the building. The panels were attached to anchors protruding from the edge of the slabs and welded into place (Figure 9). Joints in the panels were sealed with silicone sealant and allowed to vent and drain at the bottom of the wall.

While installation of the precast cladding was performed without issues, ultimately the SPF created difficulties. Erection of the precast panels and welding of precast panel anchors damaged the foam, and natural shrinkage of the foam resulted in it pulling away from metal girts and window frames, creating discontinuities in the air and moisture barrier. Because of this,
multiple repairs were necessary to maintain a continuous air and water barrier. This precast system was relatively costly due to the complex panel shapes, but was easy to install and is expected to perform well in its highly exposed marine environment.

**CASE STUDIES 4 AND 5**

**Precast Sandwich Panels on High-Rise Installed Like Window Wall**

The final two case studies discussed in this paper represent a culmination of the author's knowledge of innovation in precast concrete cladding systems, borrowing successes and lessons learned from past projects. The highlighted project at the University of British Columbia (*Figure 10*) is a high-rise university residence with unique and challenging design requirements, including the following: effective R-15 insulation cladding, textured concrete cladding with randomly shifting panels and colors, high-performance air and moisture management strategy, similar installation cost to window wall ($40-50/sq. ft.), short construction schedule, durable lifecycle, and LEED Gold status.

This set of requirements was unattainable with conventional precast systems in this region. In order to achieve the design requirements, the team had to rethink the way precast cladding is designed, manufactured, and installed. To meet the project requirements, insulated precast sandwich panels were utilized. The fundamental idea behind the precast system designed for this project was to make the precast panels act, interface, and look like the adjacent window wall units. This allows the window wall mounting angle to be run continuously around the perimeter of the building and allow for substitution of window wall units and precast panels at desired locations.

While mock-ups are recommended and required in nearly every new construction project, with an entirely new system being developed for this building, concept mock-ups were even more important than usual. Through-wall flashing details for the panels were modelled in 3-D and then mocked-up using metal flashing, silicone, and foil-faced, self-adhered membrane to select the preferred method (*Figure 11*).

For the connection device to hold the two precast wythes of the sandwich panel together, metal, carbon fiber, and fiber composite ties were considered. Ultimately, fiberglass composite ties were chosen due to their superior energy efficiency (*Figure 12*).

Since these precast panels act as a screened wall assembly with no drain space, a concern was raised about the need for a drain mat. Heat and moisture transiency analysis software (WUFI) was used to show that the panels would have no issues with drainage; however, the insulation panels were grooved to promote additional drainage, which satisfied all parties. Extruded polystyrene (XPS) insulation at a thickness of 3 inches was selected as the insulating material, providing an effective R-value of 16.

With the enclosure design substantially completed, the next phase was fabrication of these unique precast concrete panels (*Figure 13*). The first step in this process is to prepare the formwork for the required panel dimensions. Next, the exterior wythe steel mesh is placed, and concrete is poured to the required thickness of 3 inches. An XPS board with ties on both sides is then placed onto the plastic concrete and vibrated into place, and vertical concrete returns are poured monolithically with the exterior wythe.
The interior wythe is prepared with a galvanized mesh and mounting embeds before the concrete is placed to complete the sandwich panel. Completed panels are then steam cured in accordance with the Canadian Standards Association, and once stripped from the form, can be sealed. However, the author advises against sealing precast concrete in the factory, as the concrete should be sealed in-situ after fully curing and pressure washing.

The installation of these precast sandwich panels (Figures 14 and 15) was straightforward, with larger mounting angles installed over the window wall angle. Two mounting angles corresponded to the location of two embeds on the bottom of the interior wythe, and the panels were easily dropped into place. Quality assurance smoke testing during construction revealed that mounting bolts were not airtight and required sealant around the head. The interior only required paint finishing, providing construction cost savings along with life cycle cost savings, due to the durability of concrete rather than drywall in a university residence setting.

Many lessons were learned throughout the duration of the project. Since the details for panels and window wall are so similar, it is feasible and even beneficial to have one contractor install all of the building-
critical sealant and membrane seals, as was the case for this project. Speed of assembly was found to be very rapid, and crews were able to install 20 to 25 panels per day using portable cranes and temporary outriggers.

Installing precast sandwich panels like window-wall is a new concept for the precast manufacturers involved; therefore, training and education is required for both manufacturers and installers. Parties involved must be aware of the intricacies of the system in order to accurately provide a bid and minimize potentially troubling disconnects in knowledge. A specialized structural engineer should be used for analysis due to the unique nature of the work and to prevent expensive, ultra-conservative designs. The completed project is shown in Figure 16.

THE NEXT STEP – WINDOW WALL-STYLE PRECAST SANDWICH PANELS

Based on the successes and the exposure gained from working on the buildings at the University of British Columbia, the author was approached by another architect looking to use the same style of panel in order to achieve a bamboo-like cladding pattern (Figure 17).

This project will have sandwich panels of different sizes and nonuniform width running in front of the window wall units. The building design initially had over 30 different panel sizes. In the previous project, it was discovered that one of the largest cost factors is the number of distinct panel sizes. Curve analysis and rendering software (RHINO) was used to optimize the panel layout to 17 unique panels while still meeting the required look (Figure 18).

The overall cost of the precast concrete sandwich panel system was less than the conventional window wall ($50/sq. ft.), which was one of the primary design objectives. The use of precast concrete sandwich panels installed like window wall (Figure 19) met all of the design parameters for this building and allowed it to be completed on time and on budget.

OVERALL BUILDING THERMAL VALUES

Using insulated precast concrete sandwich panels is an economic, easy-to-install, and thermally efficient solution for the
building envelope. However, when analyzing a building for thermal performance, the building as a whole must be evaluated. Due to the inverse addition of R-values, the component with the lowest R-value in a system will have a dominant effect on the overall effective building R-value, even if it exists at a relatively low percentage of building surface. In practice, windows will always be the most vulnerable areas in a building’s thermal performance, and improving these assemblies will greatly increase the overall performance. The comparison of an R-2 window wall to an R-6 window wall is shown in Figure 20. This graphically shows the dominant effect that windows have on the effective thermal resistance of the building and reinforces the drive for better windows on our buildings.

REFERENCES
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