Innovative Structurally Glazed Curtain Wall at the New Vancouver Convention Centre: Design and Construction Challenges

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ABSTRACT

The Vancouver Convention Centre and Expansion Project (VCCEP) was a project undertaken to more than triple the size of the existing Vancouver Convention and Exhibition Centre. The new VCCEP building is located in downtown Vancouver and is built over land and water, overlooking the Burrard Inlet. It is approximately 102,000 m^2 (1.1 million ft^2), and its construction started in the fall of 2004 and took almost five years to complete.

The primary vertical building envelope element for the VCCEP consists of curtain wall glazing. Of the two types of curtain wall systems used on the project, the primary system is a structurally glazed curtain wall (SGCW). This system is an innovative, custom designed and built unitized curtain wall that includes aluminum horizontal mullions, structurally glazed glass fins as vertical mullions, and exterior or interior trusses that support wind load. Sag rods transfer dead loads from the trusses to the building structure.

This paper discusses the development of the SGCW from the architectural concept design to the finalized details, including the specifications, procurement, and cost of the architectural element from a thermal perspective. The paper provides select design details, including the slab-to-curtain-wall connection, and a typical head deflection joint. The findings of the laboratory testing of a curtain wall mock-up are presented, as are the ensuing recommendations for plant and site quality control. Despite the rigorous mock-up testing, a number of field tests failed. The test findings are discussed, as are challenges faced during construction with respect to building envelope integrity.

INTRODUCTION

The construction of the new Vancouver Convention Centre Expansion Project (VCCEP), which began in 2004, was undertaken to add roughly 102,000 m^2 (1.1 million ft^2) of additional floor space to the existing Vancouver Convention and Exhibition Centre. The new building, now called Vancouver Convention Centre West, was completed in April 2009.

The vast majority of vertical building envelope elements consist of curtain walls. A conventional "stick frame" curtain wall is found mainly at the retail spaces at the level of the east, north, and west bikeways as well as at the south exhibition hall level. The remainder and majority of the curtain wall system—called the *structurally glazed curtain wall* (SGCW)—is an innovative, custom designed and built unitized curtain wall that includes aluminum horizontal mullions, structurally glazed glass fins as vertical mullions, and exterior or interior trusses that serve to support wind loads. Sag rods transfer dead loads from the trusses to the building structure. The design challenge in the use of unconventional elements such as glass fins and trusses lays in ensuring that the system as a whole meets the requirements under structural wind loading and seismic racking as well as for air and water leakage control, particularly given that a significant proportion of the structural sealant is field applied. This paper discusses the design development of the SGCW from the architectural concept design to the finalized details, including the specifications and procurement. In the design process, the cost of the architectural element from a thermal perspective was considered for the building, for

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which LEED® Platinum certification has been achieved. Select SGCW details are shown, such as slab-to-curtain-wall connections and a typical head deflection joint. The findings of the SGCW mock-up laboratory testing are presented, as are the ensuing recommendations for plant and site quality control. Despite adherence to the mock-up report recommendations, a number of field tests failed. These tests' findings, as well as the challenges faced during construction with respect to building envelope integrity, are discussed.

DESIGN DEVELOPMENT AND SPECIFICATIONS

The site of the new Vancouver Convention Centre West building is one of the best in the city: the building faces Burrard Inlet and North Vancouver to the north, Stanley Park to the northwest, and the downtown cityscape on other elevations. One of the principal architectural design intents of the vertical envelope was to offer uninterrupted views of these beautiful vistas, and also to integrate the new building into its setting. The design team achieved the concept of visual openness by minimizing the visual impact of vertical elements. Specifically, low-iron vertical glass mullions were used rather than traditional aluminum mullions. The clarity of the low-iron glass renders the mullions nearly unnoticeable.

The design team maximized the size of the insulated glazing units (IGUs) to optimize the perception of visual openness. Structural design issues included the spacing of the mullions and their positions with respect to the IGUs. A structural engineer determined the spacing of the glass mullions required to stiffen the IGUs and to ensure acceptable deflection under wind load. The end result achieves the design intent of visual openness but also obscures the line of the vertical black structural silicone sealant. The design team also decided to extend the 19 mm (3/4 in.) thick mullions past the face of the IGUs in order to limit solar heat gain at the west elevation. For consistency and uniformity, this concept was carried out on all building elevations. In the end, however, because the mullions are low-iron glass and typically extend only 100 mm (4 in.) past the face of the IGUs, their impact on limiting solar gains is expected to be insignificant.

Another structural issue explored at the preliminary design stage included the structural support for the SGCW. The high vertical floor-to-floor spans necessitated a mid-span horizontal mullion to carry lateral loads and ensure IGU deflections were within acceptable limits. Trusses provided lateral support for these mullions. The trusses, located either to the outside or the inside of the curtain wall, were supported by columns and hung from sag rods suspended from the roof (Figures 1 and 2). Aluminum was used for the trusses rather than steel, as the crisp edge and finish of the aluminum integrates well with that of the horizontal mullions. The issue of rainwater management was raised as a concern with respect to the exterior trusses. As it turns out, field testing revealed difficulties in ensuring a seal at the horizontal mullions supported with exterior trusses. In addition, the design team decided to pull the glass fin's shoe back from the face of the horizontal mullion and to reduce the thickness of the shoe sealant. These modifications refined the detail and provided the glass fin its desired prominence.

The design team was also concerned about sound control due to the close proximity of float planes in the harbor. The design was revised for optimum IGU configuration to reduce the sound transmission. Available literature on acoustical testing was reviewed and, from this, the thicknesses of the IGU inner glass lites and of the air space were established. Acoustical performance was achieved using an IGU with an outer lite of 13 mm laminated glass with low-e coating, a 24 mm air space, and an inner lite of 6 mm glass. In addition, an acoustical consultant was brought in to review the effect of the vertical glass mullions.

With respect to the curtain wall system, the construction manager drove the idea of a unitized curtain wall rather than a "stick built" system to accelerate the construction schedule, given that a unitized system is in large part pre-fabricated and requires less field labor. The use of a unitized system also tends to raise the quality of the final product and requires less field storage, a benefit on the project site.

Based on the conceptual design, the specifications went further and provided technical requirements with respect to the curtain wall design, its performance, and field testing requirements. The specifications required that the project's curtain wall systems be thermally broken (except for the glass fins) and required pressure-equalized rainscreen glazing systems, including IGUs with a low-e coating on surface no. 2 (the inner surface of the IGU outer glass pane). The specifications mandated rainwater penetration control for all exterior wall systems in the building, including the curtain walls, when

Figure 1 *East elevation of the new Vancouver Convention Centre West building, showing the SGCW trusses on the inside of the curtain wall, supported by interior columns.*

Figure 2 *South elevation of the new Vancouver Convention Centre West building, showing the SGCW trusses on the outside of the curtain wall, supported by exterior columns. Note the exterior trusses and sag rods.*

subjected to a positive air pressure difference of 718 Pa (15 psf) in accordance with *ASTM E331, the Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference* (ASTM 2000a), and air leakage control for fixed components to a maximum of 0.55 m^3/h·m (0.10 cfm/ft) of crack length when exposed to 75 Pa (1.6 psf) of positive pressure, as per *ASTM E283, the Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors under Specified Pressure Differences Across the Specimen* (ASTM 2004). For glazed systems, centre-of-glass winter requirements called for U-factors less or equal to 1.70 W/m^2·K (0.3 Btu/h·ft^2·°F) and a solar heat gain coefficient of 0.39. The curtain wall's design required the prevention of condensation on any plane inboard of the air barrier under –5°C outdoor as well as 21°C indoor temperatures, 50% indoor relative humidity, and a minimum temperature index of 58% [temperature index, TI, is defined as TI = $(Ts - Te)/(Ti - Te)$, where Ts is the inner surface temperature and Te and Ti are the outdoor and indoor ambient temperatures, respectively]. The specifications also mandated requirements for thermal movement and acoustical performance. A more detailed discussion is beyond the scope of this paper.

The project specifications called for field testing for water penetration resistance and air leakage, as well as sealant adhesion performance; however, air leakage testing was not undertaken, given the low consequence of air leakage and the good air leakage results obtained in the laboratory testing, as described later. Field testing was also required to verify the quality of the structural silicone sealant. The specifications mandated a minimum of six SGCW structural silicone sealant tests on each of the four building elevations, to be done in accordance with *ASTM C1521, Standard Practice for Evaluating Adhesion of Installed Weatherproofing Sealant Joints* (ASTM 2002a). Details on the SGCW field testing are given later in this paper.

While the vertical glass mullions provide a characteristic architectural feature, their presence creates a thermal bridge. Thermal bridging is typically a building envelope concern because of heat loss and moisture-induced issues resulting from condensation formation. The design team discussed extensively various methods to avoid thermal bridging of the vertical mullions while maintaining the visual effect. Providing separate interior and exterior mullions that were independently supported but supported the IGUs was investigated but proved cost-prohibitive. In the final analysis, because the large glass surface area created the need for sufficient ventilation for condensation control, and because of the building's inherent low moisture loads, the design team determined that the risk of condensations on the glass fins was minimal.

The design team was concerned with the whole-building energy consumption, particularly given the goal to apply for LEED® Platinum certification for the project and to seek "Energy and Atmosphere" credits (USGBC 2009). During the conceptual design stage, the team evaluated the impact of the thermal performance of the SGCW on the building's overall energy consumption. Parametric evaluations of the thermal performance of SGCW elements, including the horizontal aluminum mullions, the vertical glass fins, and the IGUs, were conducted by others using THERM (LBNL 2005).

Details on the SGCW configuration include a standard IGU consisting of a 6 mm low-iron outer lite of float glass with a low-e coating on surface no. 2, a 13 mm air space, and a 6 mm low-iron inner lite of float glass. The percentage of vision area to total area ranges widely depending on the panel

configuration, but it is roughly 96% for a typical panel. Modeling was done using a typical panel size rather than the National Fenestration Rating Council standard size. The overall U-factor of the curtain wall was determined to be 1.87 $m^2 \cdot K$ (0.33 $Btu/h \cdot ft^2 \cdot °F$) based on an area-weighted U-factor calculation of curtain wall elements for a typical panel. For comparison purposes, this is roughly the same overall system U-factor for a conventional captured glazed aluminum curtain wall with a similar percentage vision area, total area of 95%, and an IGU that includes a low-e coating. This may be surprising but may be attributed to the low conductivity of the glass used for the fins relative to aluminum, even when used in thermally broken mullions.

The project's mechanical engineers carried out whole-building energy modeling, looking at the effect of varying the IGU properties on the whole-building energy consumption. The engineers determined that, despite the glazing area covered by the SGCW and its relatively high U-factor, the overall energy consumption was insensitive to the curtain wall's thermal performance. This insensitivity is attributed to the building's large volumes and high ventilation rates as well as relatively high internal heat loads such as people, lighting, and equipment. The mechanical engineers' whole-building energy simulations also took into account the daylight sensors that are located within the building perimeter zones and control roller blinds and, hence, solar gains.

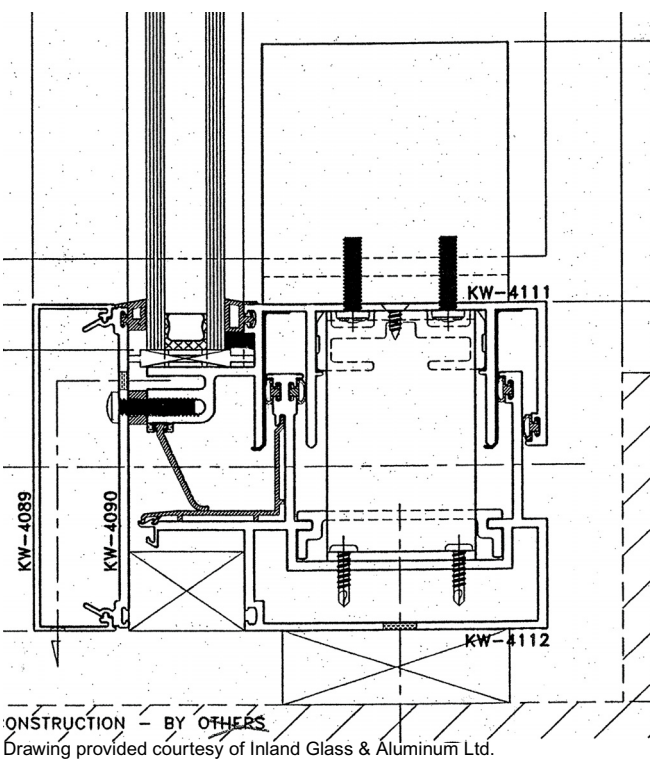
DRAWING DETAILS

The design of the innovative SGCW is best understood by a review of the drawing details. The dead load of the curtain wall is designed to be supported by the building's floor slabs. The interior and exterior trusses provide lateral support. These are themselves supported by columns and by stainless steel sag rods, which carry the loads to the building structure. At some locations, the curtain wall "sits" on a step in the suspended slab (Figure 3), while at other locations, the curtain wall's horizontal mullions are supported by an aluminum member fastened into a steel plate cast into the face of the slab (Figures 4 and 5). The horizontal mullions between the floors are supported by an interior truss (Figure 6) or an exterior truss (Figure 7). These trusses are essentially supported by columns; between the columns, they are hung from the roof deck via solid stainless-steel rods.

At the head of the curtain wall, the vertical deflection of the slabs and of the roof above is accommodated by a deflection joint. Figure 8 shows the SGCW head at typical locations where the curtain wall is expected to be exposed to the elements.

Figure 9 shows a typical vertical mullion connection to the curtain wall sill. Butt joints in the horizontal mullions are sealed as shown in Figure 10.

Issues arising from nontypical conditions are discussed later in the paper.



Drawing provided courtesy of Inland Glass & Aluminum Ltd.

Figure 3 *SGCW sill detail, where the horizontal mullion sits at a step in the slab.*

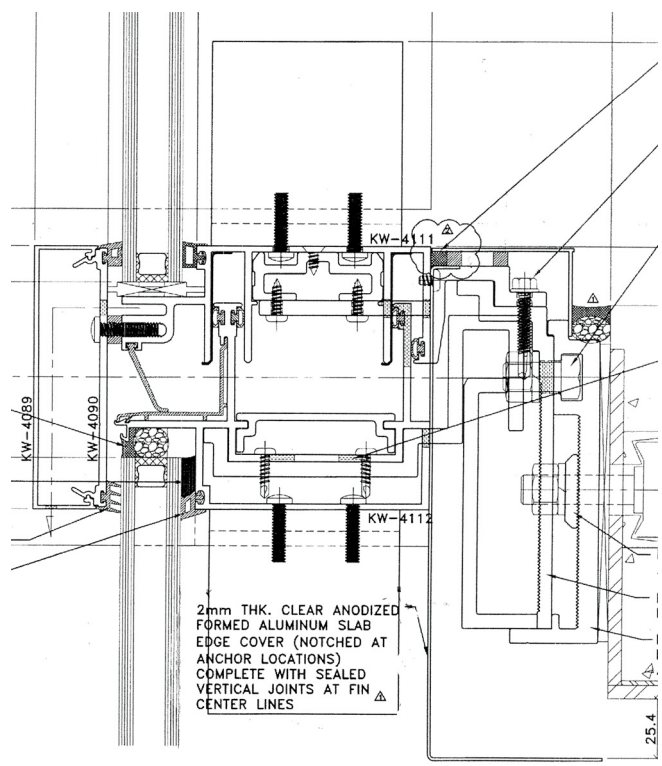


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Figure 4 *Horizontal mullion support at a slab overhang. A continuous aluminum extrusion provides the air seal between the mullion and the slab edge.*

Figure 5 *Horizontal mullion at the slab edge, showing the structural support at the slab edge.*

CURTAIN WALL LABORATORY TESTING

Two SGCW mock-ups were tested at a laboratory facility in Miami, Florida. The first mock-up addressed a curtain wall outside corner where the mid-slab horizontal mullion is supported by an exterior truss. The second mock-up consisted of an outside corner assembly with an interior truss, where one of the two faces is sloped and the other is vertical. This configuration is found on the building's north elevation. Both elevations on each mock-up consisted of three by three lites.

Methodology

The testing sequence for each of the two mock-ups was performed as per project specifications and is summarized as follows.

1. **Air Leakage Test.** The volume of air leakage at a set pressure was measured and compared to specification. The testing was conducted in accordance with ASTM

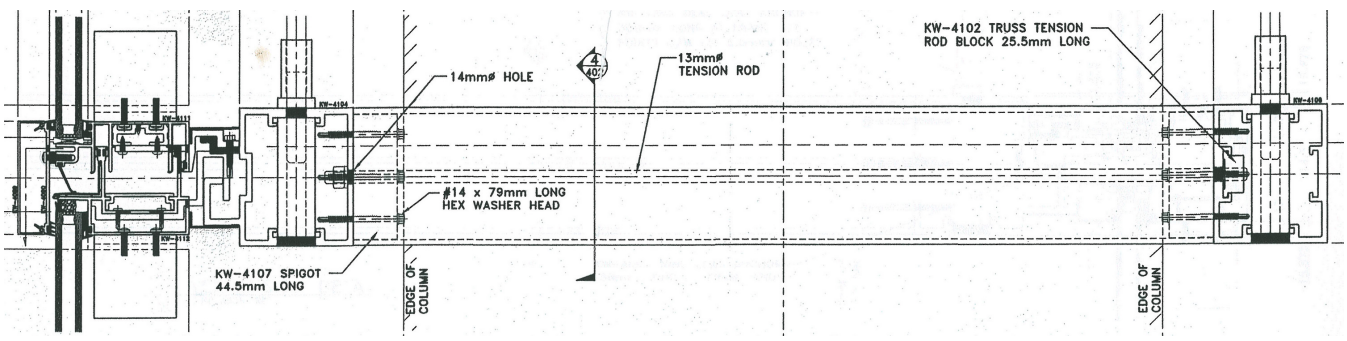

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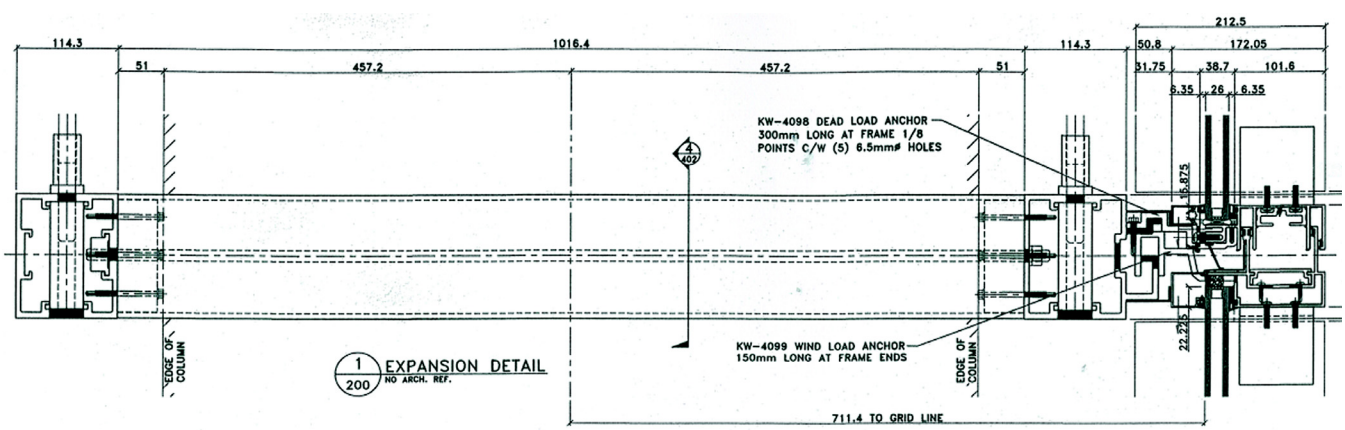
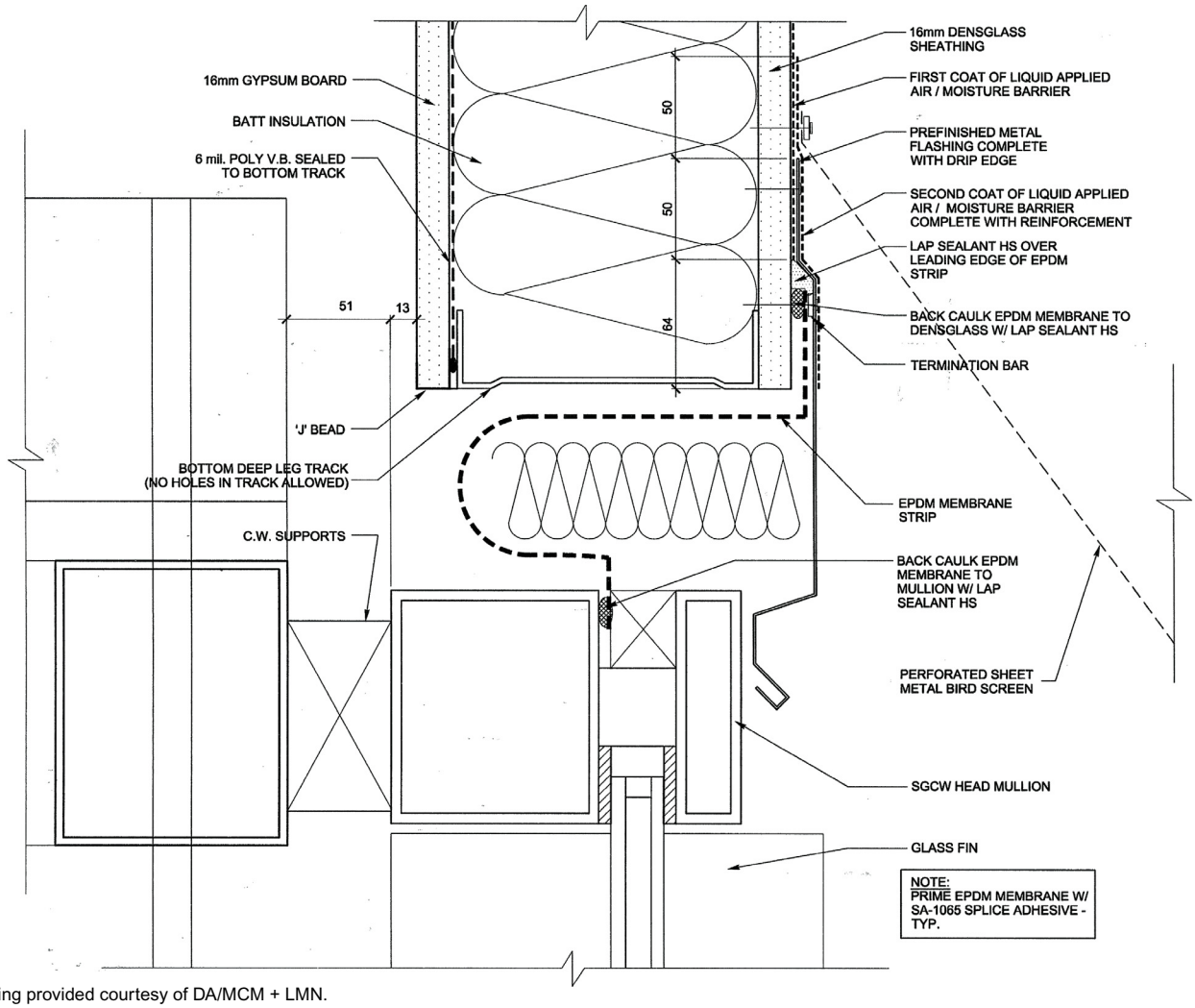
Figure 6 *SGCW configuration with an interior truss.*



Drawing provided courtesy of Inland Glass & Aluminum Ltd.

Figure 7 *SGCW configuration with an exterior truss.*



Drawing provided courtesy of DA/MCM + LMN.

Figure 8 *Deflection joint at the head of the SGCW, used typically at exposed locations.*

Figure 9 *SGCW jamb-to-sill connection, showing the vertical glass mullion, the supporting "shoe," and the butt joint of the horizontal mullion.*

Figure 10 *Horizontal mullion butt joint, showing the black polyvinyl chloride watershed element.*

E283 (ASTM 2004). The specified maximum allowable air leakage was 0.55 m^3/h·m (0.10 cfm/ft).

2. **Static Water Leakage Test.** Each mock-up was subjected to a calibrated water spray and an air pressure difference of 700 Pa for 15 minutes to determine its water penetration resistance. This test was conducted in accordance with ASTM E331 (ASTM 2000a).
3. **Dynamic Water Leakage Test.** Each mock-up was subjected to a water spray and the propeller wash of an airplane engine to simulate a buffeting high speed wind to see if it the mock-up assembly leaked at the test condition, as per *AAMA 501.1, Standard Test Method for Water Penetration of Windows, Curtain Walls and Doors Using Dynamic Pressure* (AAMA 2005).
4. **Structural Wind Load Test.** The mock-ups were subjected to inward and outward pressures matching the calculated wind load, 1530 Pa (32 psf) for the building in its climate. To pass, the elastic deflection of the structural components (glass mullions and trusses) must be within the specified limits (L/175) and there can be no significant permanent deformation. This test was conducted according to *ASTM E330, Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference* (ASTM 2002b).
5. Repeat of the **air leakage test** to see if the stress from the previous structural test impacted the assemblies
6. Repeat of the **static water leakage test** to see if the stress from the previous structural test impacted the assemblies.
7. **Seismic Racking Test.** As per *AAMA 501.4, Recommended Static Test Method for Evaluating Curtain Wall and Storefront Systems Subjected to Seismic and Wind Induced Interstory Drifts* (AAMA 2000), the centre floor or truss connection of the mock-up was jacked sideways in each direction by the amount calculated to be the distortion of the building frame in a design seismic event (20 mm).
8. Repeat of the **air leakage test** to see if the stress from the previous seismic racking test impacted the assemblies.
9. Repeat of the **static water leakage test** to see if the stress from the previous seismic racking test impacted the assemblies.
10. **Structural Safety Factor Test.** Each mock-up was subjected to 150% of the design wind pressure used in the structural wind load test. To pass, there cannot be failure of structural components, but permanent deformation is acceptable.
11. **150% Seismic Racking Test.** The centre floor or truss connection of the mock-up was jacked sideways in each direction by the amount calculated to be 150% of the distortion of the building frame in a design seismic event (30 mm).

Laboratory Mock-Up Test Results

Both curtain wall mock-ups passed the air leakage test. The air leakage tests repeated after the structural wind load tests were also successful.

Water ingress was noted at three locations during the static water leakage testing:

1. Water was noted on the sill of horizontal mullions (Figure 11). The testing team traced the water ingress to defects where the sill heel bead connected to the vertical butt glazing bead. The location and geometry of this connection made it a challenge to seal and/or visually detect a defect. This occurred at three locations in the first mock-up and at two in the second mock-up.
2. Water was noted at the head of the glazing where the field-applied glazing seal ran around the "shoe" that support the glass mullion.
3. Water was noted at a small defect in the factory-applied structural silicone butt seal between the IGU and the glass mullion on a corner of the first mock-up.

Repairs of the sealant at the various locations, followed by successful static and dynamic water penetration resistance testing, demonstrated that the leaks could be corrected in the field.

Both the structural wind load and the seismic racking tests were successful. However, a problem occurred with the structural safety factor test of the second mock-up assembly. During the outward pressure test, a noise was heard and the wall "jerked" as the pressure passed the 1900 Pa (40 psf) level. The pressure was increased to the planned 2250 Pa (47 psf) level and held there for the prescribed amount of time with no apparent structural failure. The seismic racking testing was then successfully completed. The investigation after the test revealed failure of the weld attaching one of the truss anchors to the simulated corner column of the building. The field-applied weld was noted

Figure 11 *Water ingress observed during laboratory static water penetration resistance testing.*

to be of poor quality, which may have been due, in part, to the difficulty in accessing the weld location. The presence of a second truss anchor at the second column prevented a disastrous failure during the test. The failed weld was re-done, and the structural safety factor and 150% seismic racking tests were repeated, both of which passed.

Recommendations Ensuing from Laboratory Testing

The location and geometry of the factory-sealed transition between the heel bead on the horizontal joint and the vertical butt glazed joints (failure 1 from the laboratory testing) rendered it difficult to seal the transition and to visually detect a defect. Because a visual review would not likely be sufficient to demonstrate success, the testing team recommended that quality control procedures in the fabrication plant include a simple panel or joint test that could demonstrate air- and watertightness. The fact that the curtain wall was a unitized system permitted such a test. The recommendation included the following testing:

- 100% first 10 panels,
- 10% on the next 100, and
- 2% of the balance.
- For every failure, two additional panels should be tested.

In addition, every tested panel should be identified and documented.

The investigation of failure 3 from the laboratory testing revealed that the sealant had been installed by means of a dual bead (two sealant beads on either side of a closed cell foam backer rod), in accordance with the shop drawings. The glazing contractor recommended that the dual bead be replaced by a solid bead. The team also felt that a solid joint might be necessary to provide the necessary glass-to-sealant surface area contact for structural load resistance.

To address the anchor weld failure, the testing team agreed that review of the field welds should be conducted by a qualified inspector. Also, modifying the anchor connection to facilitate access to the weld location was suggested.

QUALITY CONTROL DURING PLANT FABRICATION AND PROCUREMENT

A quality control audit of the glazing contractor plant and that of the subcontractor responsible for plant production of curtain wall components was performed. Both plants are housed in the same facility. The reviewed processes included procurement and receiving, storage, fabricating, testing, and shipping.

The plants' new automated inventory control system was noteworthy; the system uses a bar-coding system to track stock material prior to and after cutting. The system enables the users to track activity completion and the locations of components. The new tracking system was in the process of being implemented and therefore not fully functional at the time of the plant audit.

Of interest to the audit team was also the SGCW panel assembly and testing process. Each individual SGCW panel included the IGU, a portion of the head and sill horizontal mullion, one glass vertical mullion, and its respective head and sill "shoe."

For each panel, the glass mullion was sealed to the IGU in the shop with a two-component structural silicone sealant. The team reviewed documentation of testing of the two-part structural silicone sealant for conformance with the sealant manufacturer's requirements, including butterfly and snap time tests. Butterfly testing was performed to ensure that the two-component dispensing equipment was adequately mixing the sealant base and the curing agent, while the snap test helped determine that the mixing ratio was correct and whether the sealant was curing properly. Both tests were conducted at each pump start-up or when either the base or the curing agent containers were changed.

While water leakage testing of panels was not being conducted at the time of the plant visit, the glazing contractor provided documentation on previous test results, which appeared to be in conformance with the recommendations made following the laboratory testing.

During assembly, a production status sheet was affixed to each panel and identified the personnel, date, and components of the work installed. Final inspection was required and controlled by three signatures before any component could be shipped.

FIELD WATER PENETRATION RESISTANCE TESTING

The project specifications called for field testing for water penetration resistance of the SGCW in accordance with *ASTM E1105, Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform or Cyclic Static Air Pressure Difference* (ASTM 2000b), at an air pressure difference of 718 Pa (15 psf). The specifications required three water penetration tests of the SGCW equipped with an interior truss and three more with an exterior truss.

All water penetration testing was conducted by an independent testing agency. An interior chamber, consisting of a polyethylene sheet supported by a wood frame, served to create the required air pressure difference. The chambers were installed from the middle of an upper panel to the middle of a lower panel and spanned horizontally from the inside of one fin to the inside of the adjacent panel's far fin, capturing the two panels' common fin. The water penetration test locations, the test results, and the remediation measures are summarized in Table 1. All three tests performed on the curtain wall with an interior truss—designated in Table 1 as tests 1, 2 and 3—passed. However, similar success was not met with the exterior truss system.

Table 1. Summary of SGCW Water Penetration Resistance Testing Results

Test #	Test Result	Suspected Cause and Remediation
	Interior Truss	
1	Pass	—
2	Pass	—
3	Pass	—
	Exterior Truss	
4	Fail – small amount of water ingress at underside of horizontal mullion butt joint.	Suspected residual construction moisture. Retest without exterior water spray.
4a	Fail – same as test 4.	"Dry out" system and retest.
4b	Fail – same as test 4.	Investigate source of leak, repair, and retest.
4c	Fail – same as test 4.	Suspected residual moisture from previous test failure. "Dry out" system and retest.
4d	Pass	—
5	Pass within chamber; interior aesthetic seal complete. Failure adjacent to chamber; breach in the air/moisture seal visible.	Investigate source of leak, repair, and retest.
5a	Pass	—
6	Fail – significant water ingress at underside of horizontal mullion butt joint connection to shoe.	Suspected breach in silicone air/moisture seal at butt joint caused by cutting interior aesthetic seal. Investigate, repair, and retest.
6a	Pass	—

The first water penetration test (test 4) conducted on the system supported by an exterior truss failed. Water ingress was noted at the underside of the horizontal mullion butt joint (Figure 12). Given the high air pressure difference applied and the small amount of water ingress, the water was suspected to have been trapped within the system during construction. To test this theory, the test was repeated (test 4a), this time without applying any water, and the test failed again. The glazing contractor then dried out the system by depressurizing the interior chamber until no water ingress was observed. However, upon another retest (test 4b), it failed again at the same location, indicating that "construction moisture" was not the sole moisture source. We observed water migrating through a pinhole in the sealant applied on the interior face of the horizontal mullion's butt joint. This observation prompted a recommendation to remove or cut this sealant prior to performing the next tests, since this sealant was purely aesthetic and its presence prevented visualization of water migration past the line of watertightness. The structural silicone sealant at the butt joint was repaired from the exterior, and a retest was conducted (test 4c). A few drops of water ingress were noted once again, at the same location. The glazing contractor suspected residual moisture from the previous test. He dried out the system once again and conducted a smoke test to verify the airtightness of the system. Upon completion of these checks, testing was repeated (test 4d) and passed.

The same curtain wall system was tested at a different location (test 5). Upon application of the water spray, leaks occurred at the curtain-wall-head-to-truss connection on either side of the test chamber (Figure 13). However, no water ingress was noted at the same joint located within the test chamber. We noted that the horizontal mullion joint between the two panels had no interior caulked seal at the leak locations but that the seal was complete at the joint within the chamber. When the testing team reviewed the location of the leak from outside using a scissor lift, a breach in the air/moisture seal

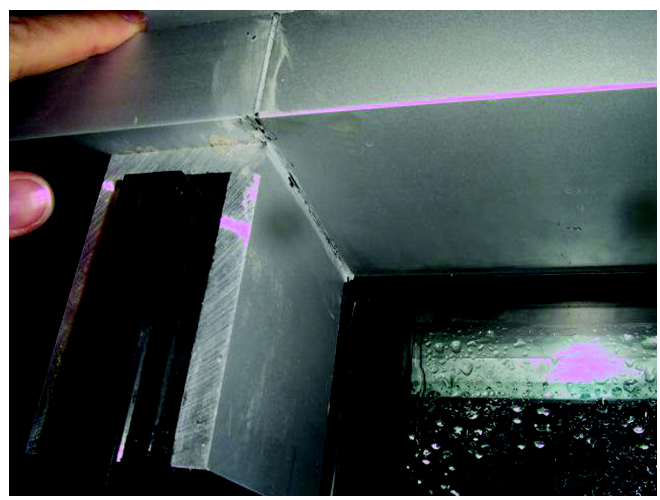


Figure 12 *Sealed butt joint in the horizontal mullion from which water penetration was noted during field testing.*

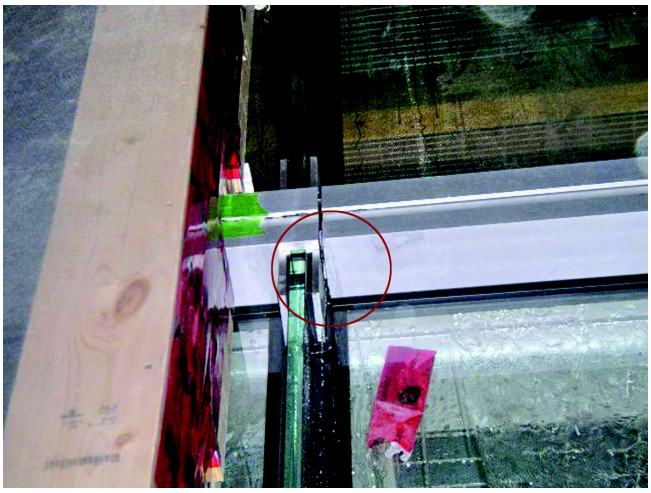


Figure 13 *Unexpected water ingress at a butt joint in the horizontal mullion located adjacent to the test chamber.*

was noted. Calling this test a failure was arguable. While the failures did not occur within the test area, the leaks were unexpected, as they occurred at areas where the moisture seal was expected to be complete. The glazing contractor investigated the leaks and conducted the repairs. The contractor suggested that the interior gasket at the sill of the curtain wall be removed at the jamb connection and silicone sealant be injected. The repairs complete, the curtain wall was retested (test 5b) and passed. It was agreed that the failure of test 5 was likely a systemic problem for the SGCW with exterior truss and that the contractor would need to apply the same repair method to all similar joints.

A third and last SGCW location was tested (test 6) after implementing the systemic repairs recommended from the previous test failures (see for example, tests 4b and 5). We also noted the interior seal at the horizontal mullions' butt connection to be complete; however, as with the other locations, the testing agency cut the seal so that any water ingress into the system could be visualized. A significant amount of water ingress was noted coming through the connection between the horizontal mullion and the shoe of the fin. The air/moisture seal was subsequently resealed, and a retest was conducted (test 6b). The retest passed.

Interestingly, the failures experienced in the laboratory testing did not reoccur during the field testing, perhaps because of the contractor's diligence at these known vulnerable points. The exterior truss proved to be the key to the issues noted in the testing of the SGCW. The presence of the truss made access to the horizontal mullion's butt joint difficult, resulting in deficiencies in the field-applied silicone air/moisture seal at this location. The testing revealed the need for consistent and careful workmanship at these joints.

FIELD REVIEW AND CONSTRUCTION CHALLENGES

Field Testing of the Structural Silicone Sealant

As was the water penetration resistance testing, field testing of the structural silicone sealant was a project requirement. Testing was focused on the field-applied sealant, which, because of its depth, was installed in a two-stage process: the glazing contractor installed a backer rod in the joint and a two-component structural silicone sealant from the interior. When this sealant was sufficiently cured, the backer rod was removed from the exterior, and a compatible single-component structural silicone sealant was applied. The single-component sealant was required for the exterior because of access limitations and the weight of the two-component dispensing equipment. We conducted field testing following ASTM C1521 (ASTM 2002a) using the destructive tail procedure and the sealant manufacturer's guidelines. The testing's purpose is to ensure the sealant's adhesion to the substrates (the IGU and the glass fin) and to check for proper mixing of the two-part sealant and the presence of any air bubbles. The manufacturer requires a positive test result by cohesive failure rather than adhesion failure. All sealant tests passed.

SGCW Sill at Level 1 West Terrace

The tie-in between the sill of the SGCW and the west terrace waterproofing membrane became an issue during construction for two reasons: 1) the difficulty of providing a watertight seal at the transition and 2) the risk of rainwater ingress at this particular detail. At this location, the curtain wall's horizontal mullion sits on a recess in the slab such that the top surface of the mullion is flush with the main floor slab (Figure 3). Early in the project, we identified the position of the mullion with respect the exterior slab to pose a risk with respect to the control of rainwater ingress. Nevertheless, the design was maintained due to the design team's desire for maximum visual openness and because a significant portion of the west elevation is protected by a large roof overhang. In addition, the consequence of incidental water ingress onto the recess in the concrete slab was deemed unimportant. The construction team entertained a couple of different waterproofing materials to tie in the exterior terrace's hot rubberized asphalt waterproofing membrane to the curtain wall, including a self-adhesive modified bitumen (SBS) sheet, which could easily be integrated with the terrace's hot rubberized asphalt membrane, and hot rubberized asphalt reinforced with a butyl sheet. Both methods have their drawbacks: the self-adhesive modified bitumen membrane is more prone to leaks at membrane laps, and a great degree of care is required to apply hot rubberized asphalt onto the curtain wall shoulder and only onto the shoulder. In the end, the hot rubber option was chosen by the waterproofing contractor. However, neither he, the waterproofing membrane manufacturer, nor the glazing contractor accepted liability for any future leaks at the transition.

SGCW Sill at Level 2 North Terrace

Another SGCW construction issue arose at the second-level north terrace, where the sill of the SGCW interfaced with the terrace's parapet. These two meet at a 90° angle. The detail is complicated by the fact that the top surface of the parapet, which covers the head of the SGCW below, was higher than the curtain wall sill (Figure 14). The parapet was redesigned and rebuilt to reduce its height by cutting back the curtain wall head's extrusion. However, the curtain wall head's height could not be sufficiently reduced to permit the tie-in of the parapet's modified bitumen waterproofing membrane to the SGCW sill's shoulder. The roofing contractor proceeded to seal the parapet's membrane to the SGCW sill's PVC watershed (Figure 15). However, the compatibility of the membrane and the watershed was an issue: we noted lack of adhesion between these two during a field review. The roofing contractor subsequently cut back the modified bitumen membrane and attempted to tie in the PVC and the modified bitumen membrane with a proprietary liquid-applied polyurethane membrane compatible with the modified bitumen membrane, but he encountered a similar adhesion issue with the watershed. Different options were considered, including cutting back the PVC watershed at the parapet and adhering the modified bitumen membrane to the exposed aluminum extrusion beneath the watershed; however, the glazing contractor was reluctant to pursue this option as it created a risk of moisture ingress at the butt joints in the horizontal mullion. In the end, after successful on-site qualitative adhesion testing, hot rubberized asphalt was successfully applied as a transition membrane between the modified bitumen and the PVC watershed, as shown in Figure 15.

Figure 14 *Terrace parapet connection to the SGCW sill during construction. Note the SGCW head extrusion at the parapet, which prevented a proper tie-in to the SGCW sill.*

SGCW Sill-to-Bulkhead Transition Beneath East Escalator

At the building's east elevation, there is a bulkhead located beneath an escalator that serves as an environmental separation (Figure 16). Where the bulkhead meets the sill of the SGCW, the construction challenge lay in the need to provide a transition that allowed continuity of the air, moisture, and vapor barrier systems; allowed access to the inside face of the IGUs for cleaning purposes; and was aesthetically pleasing. At the same time, the transition was complicated by the structural steel supporting the SGCW sill and the aluminum bar grating beneath the bulkhead.

The construction team dismissed the original design detail (see Figure 17) because the presence of the steel

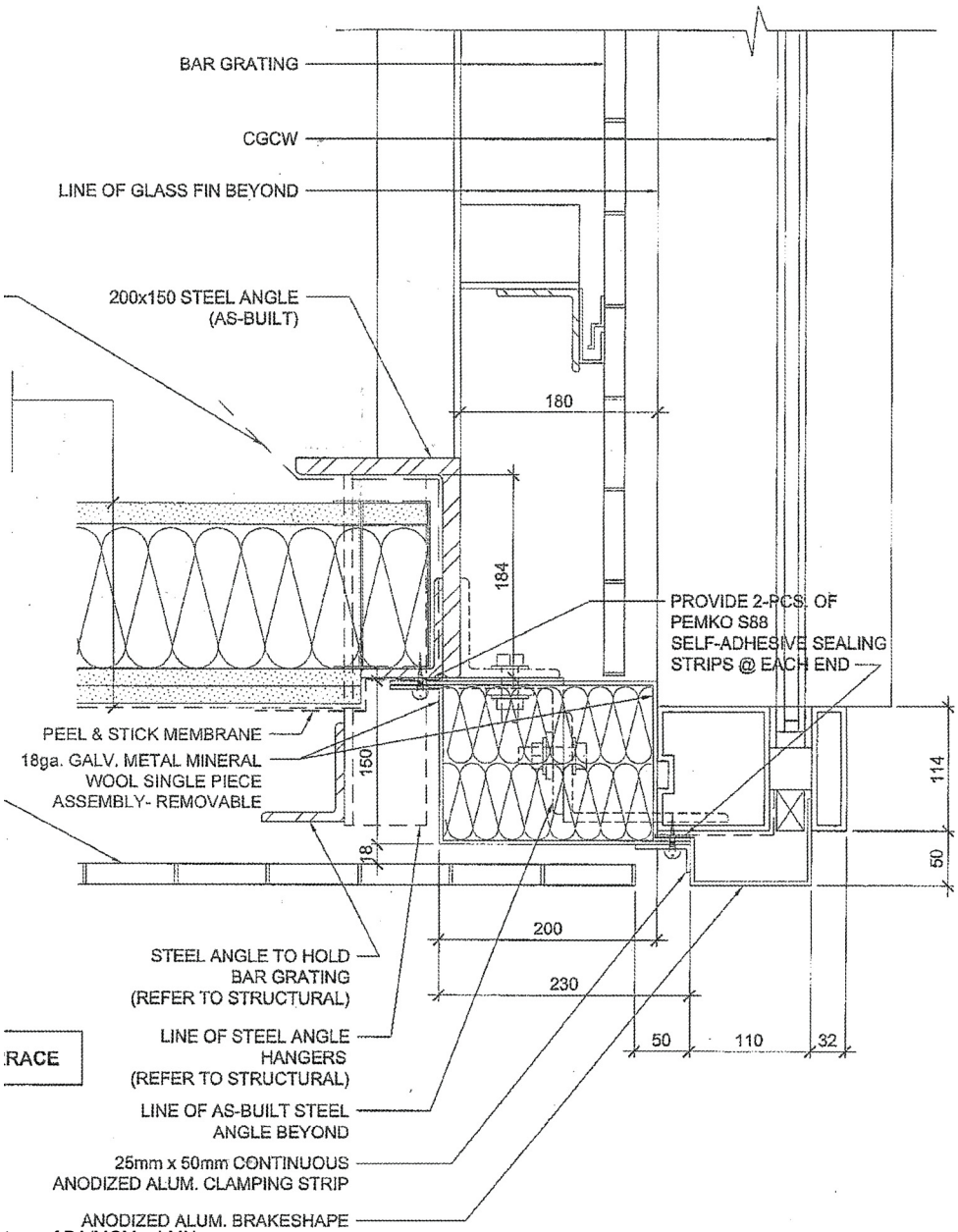
Figure 15 *Once the SGCW head extrusion was cut back, the parapet construction was completed and continuity of the waterproofing was achieved.*

Figure 16 *Bulkhead serving as an environmental separator below the escalator required a tie-in to the SGCW sill for envelope integrity.*

supporting the SGCW sill, and the as-built position of the steel supporting the bar grating, interfered with the 18 gauge galvanized metal breakshapes serving to bridge the SGCW sill and the bulkhead. The final design consisted of replacing the inner breakshape with a strip of EPDM membrane sealed and mechanically fixed to the bulkhead with a termination bar; at the mullion, the EPDM membrane is sealed with a gasket and covered with a breakshape, which doubles as a termination bar (Figure 18). The use of a gasket at the mullion connection permits removal of the EPDM membrane. Note that the configuration of the removable black breakshapes was modified by the contractor during construction.

Transition of SGCW Sill-to-Floor-Slab at Building Expansion Joint

At the east and north elevations, the edge of the level 1 floor slab hangs over exterior space. At these locations, the air seal between the SGCW sill and the floor slab is maintained using aluminum extrusions that bridge the gap between the SGCW horizontal mullion and the concrete slab (Figure 4 and detail BB of Figure 19). Here, the extrusions also serve as smoke seals. The construction team raised a concern about the continuity of these seals at the north elevation, where the SGCW meets the building's north-south expansion joint. The



Drawing provided courtesy of DA/MCM + LMN.

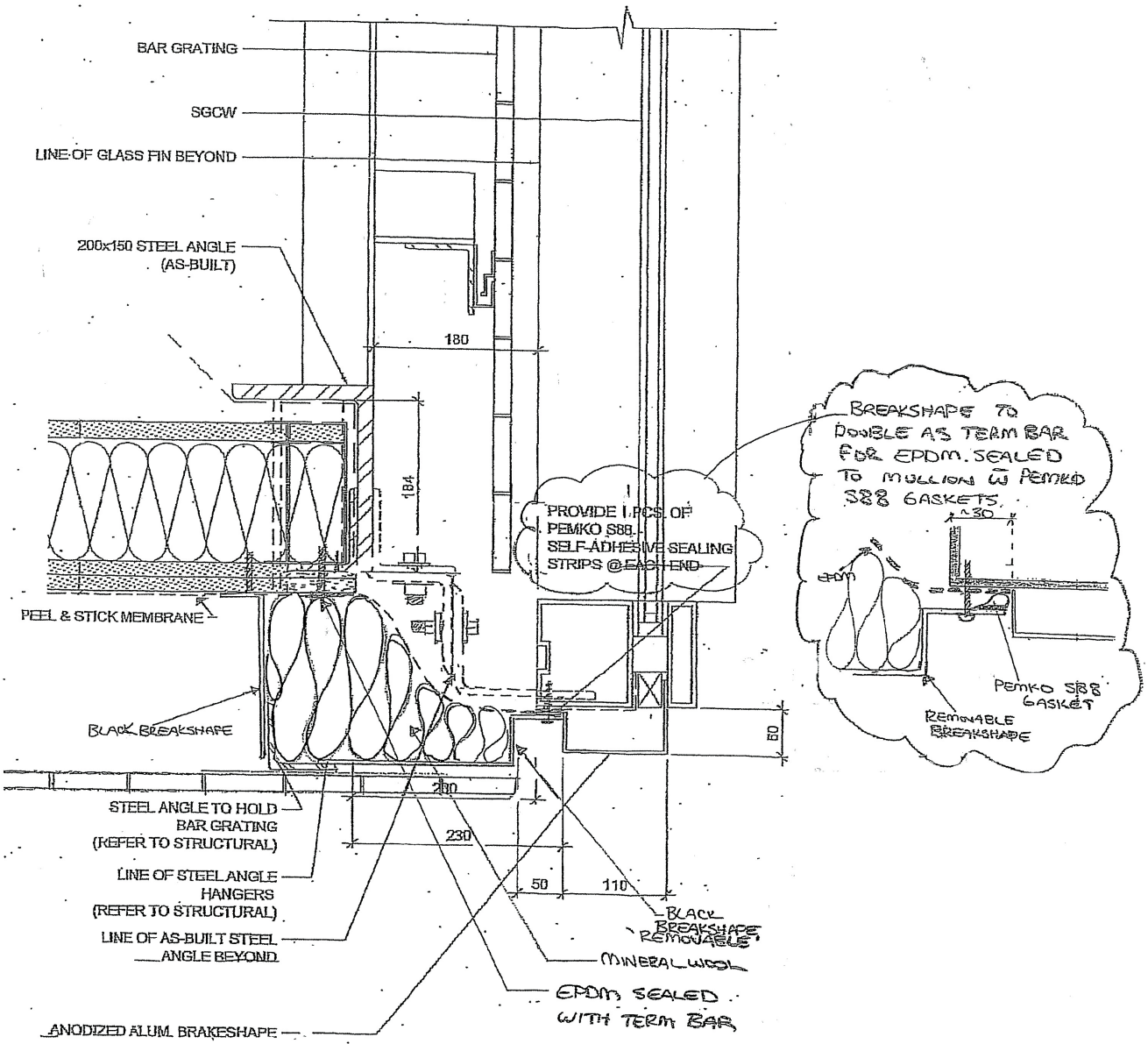
Figure 17 *Original architectural detail showing the use of metal breakshapes to tie in the bulkhead to the SGCW sill.*

three-dimensional detail is complicated by the presence of Halfen supports for the SGCW at the slab edge on either side of the expansion joint.

The vertical air/moisture/vapor barrier is maintained at the expansion joint through the SGCW using a pre-formed sheet-type silicone extrusion, which returns horizontally at the SGCW sill to meet the floor slab's air/moisture/vapor barrier membrane. On either side of the expansion joint and extending horizontally past the Halfen supports, the design and construction teams decided to use the same silicone extrusion membrane and carry it from the face of the curtain wall sill shoulder to the underside of the slab (detail AA of Figure 19). For continuity of the seal from one configuration to the other, the silicone extrusion was returned up and sealed to the back side of the horizontal mullion and the face of the slab, as shown in detail BB of Figure 19. In addition, to reduce convection within the horizontal mullions themselves, spray polyurethane foam was applied within the horizontal mullion at the transition between the two configurations.

DEFLECTION OF SLOPED INSULATED GLAZING UNITS

During construction, the construction team expressed concerns of excessive deflection of the sloped curtain wall's



Drawing provided courtesy of DA/MCM + LMN.

Figure 18 *Revised architectural detail showing the as-built location of the bar-grating structural support, and the use of a flexible EPDM membrane for envelope continuity.*

IGUs due to their own self-weight. The IGUs, which are approximately 3.5 m (12.5 ft) high, slope inward from top to bottom. As was described in an earlier section, each unitized panel includes a jamb where the structural silicone seal is factory applied. The issue arises at the joint for the field-applied sealant. To prevent excessive deflection of the IGU, the glazing contractor devised a custom clip that, fastened to the glass fin, held the IGU in the proper position while the application of the structural silicone sealant was completed. When the sealant cured sufficiently, the clip was removed, and the sealant installation was completed.

SUMMARY AND CONCLUSION

A signature building envelope system of the new Vancouver Convention Centre West building is the innovative unitized structurally glazed curtain wall (SGCW). The design team's principal intent consisted of offering to the occupants views of the building's surrounds. This was achieved with the use of low-iron glass fins instead of traditional aluminum vertical mullions. Maximizing the size of the insulated glazing units also contributed toward the visual openness of the SGCW. Structural considerations included the use of interior and exterior aluminum horizontal trusses to laterally support the curtain wall at mid-floor height. The trusses themselves were supported by interior or exterior columns and stainless-steel sag rods suspended from the roof.

Two typical curtain wall sections were tested at a laboratory facility to verify the SGCW's ability to meet the required air, water, and structural performance requirements. As a result of the mock-up testing, plant and field personnel were

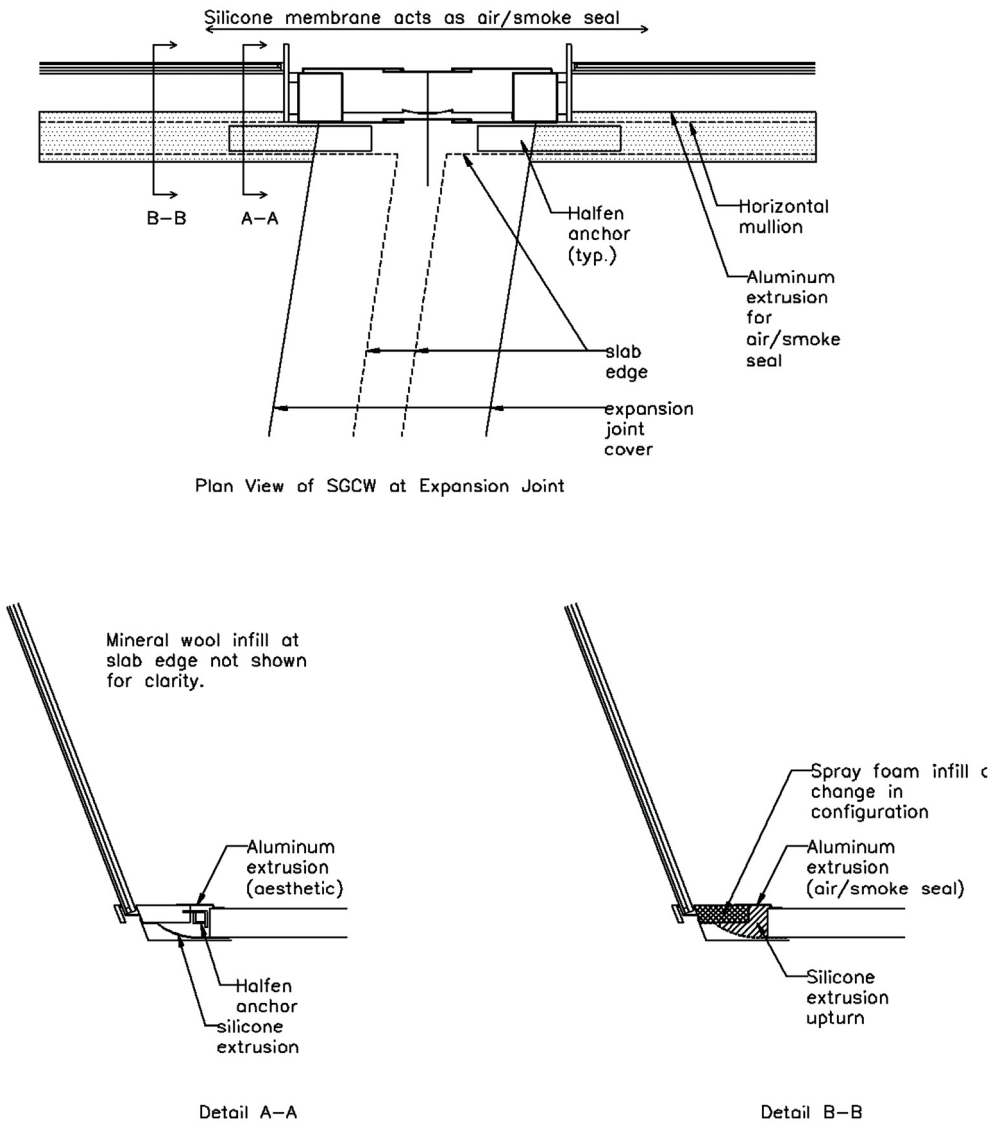


Figure 19 *SGCW sill horizontal mullion connection at the building's expansion joint and beyond. Note that at the expansion joint proper, the silicone extrusion membrane is sealed to the floor expansion joint membrane.*

aware of the system's weaknesses and were able to avoid them. Three weak points noted during laboratory water penetration testing included the transition of the IGU sill's heel bead and the vertical mullion sealant butt joint; the head of the glazing, where the field-applied glazing seal ran around the "shoe" that supports the glass mullion; and the factory-applied structural silicone butt seal between the IGU and the glass mullion at a corner. The use of a single thicker sealant bead was recommended over a dual bead with a backer rod to ensure a better seal and provide a larger bonding surface area for structural purposes. Failure of a structural nature was also noted during the mock-up testing, which lead to a recommendation for field review of field truss anchor welds. Subsequent to the laboratory testing, plant quality control measures were established that included a testing protocol for the unitized panels to ensure air- and watertightness. Defects noted during the lab testing were not reproduced in the field during the site testing. Instead, the field water penetration testing revealed a different weakness: the intersection of the vertical fin's shoe and the horizontal mullion for the exterior truss system. The field testing showed the need for systemic repairs at this location as well as the need to remove any interior aesthetic sealant bead that would otherwise prevent visualization of water ingress into the system past the plane of watertightness.

The building construction highlighted challenges that could be of interest in future projects. For instance, the lack of a curb beneath the curtain wall sill and the west terrace created a greater risk of water ingress and difficulties with respect to providing a watertight seal at the transition. Another challenge occurred at the level 2 north terrace, where the SGCW sill met the terrace's parapet at 90 degrees. The height of the parapet (and the curtain wall head below) prevented a proper tie-in to the SGCW sill's shoulder, which required a field modification to the curtain wall head, redesign and reconstruction of the parapet at the transition, and field testing to ensure adhesion of different waterproofing products. A further interesting issue was the method taken by the glazing contractor to avoid excessive deflection of the large IGUs at the north-sloped SGCW system.

Overall, the significant effort and collaboration of the design team, project manager, building envelope consultant, and glazing contractor led to a quality product, a successful project, and lessons learned for future projects.

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