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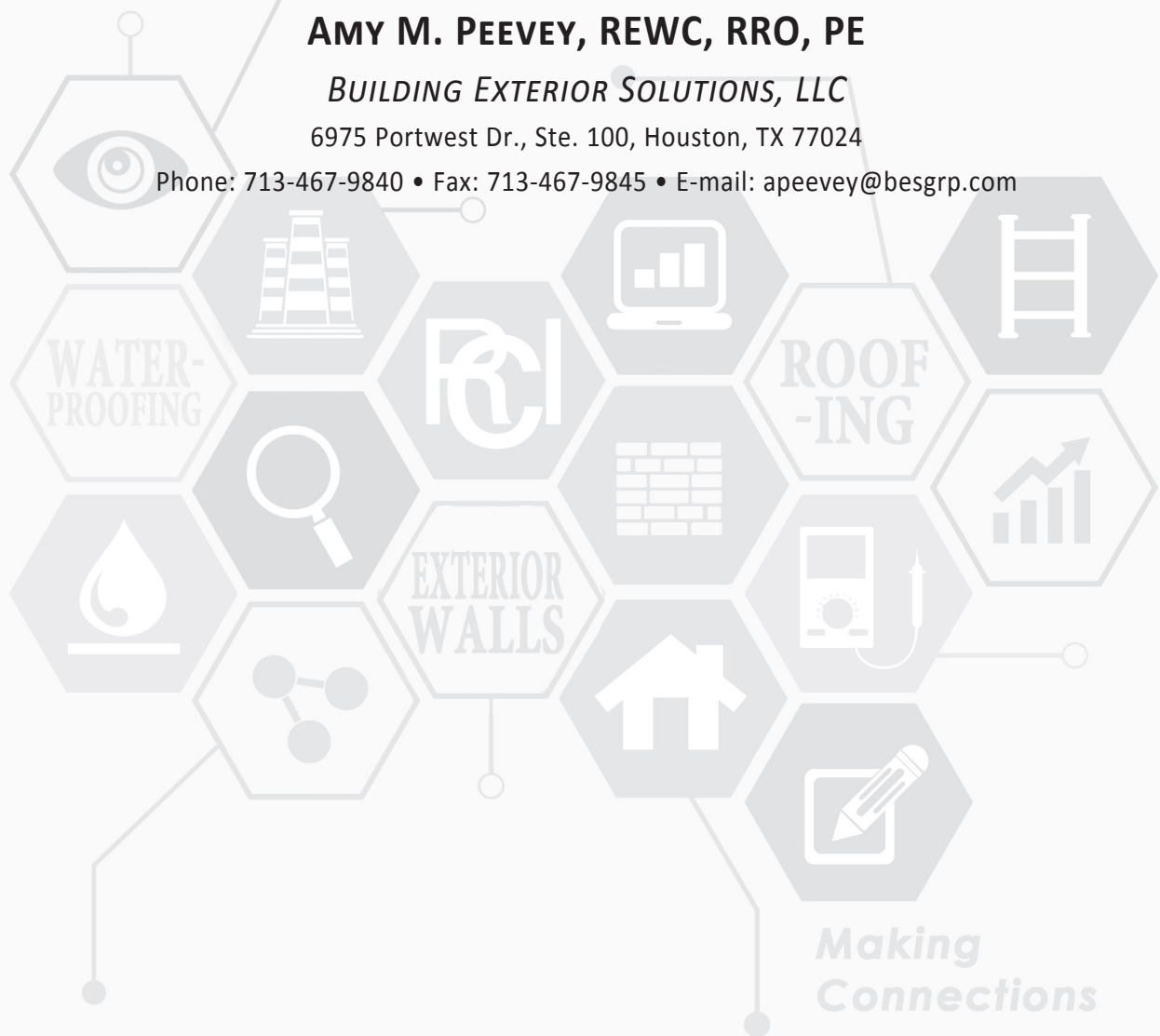
CURTAIN WALL LABORATORY MOCK-UP TESTING: THE WHO, WHAT, WHEN, WHY, AND HOW

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ABSTRACT

Curtain wall preconstruction laboratory mock-up testing is often omitted or inappropriately utilized for many new construction projects. This intermediate presentation/paper will assist designers, owners/developers, and contractors with understanding preconstruction curtain wall laboratory mock-up testing. Specifically, case studies will be presented illustrating how to 1) determine when laboratory testing should be incorporated into a project, 2) evaluate the qualifications and requirements for the testing facility, 3) develop an appropriate testing scope, and 4) incorporate requirements determined from the laboratory mock-up test into the project construction. To supplement the topics presented, case studies will be utilized from the author's experience.

SPEAKER

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INTRODUCTION

Curtain wall systems remain one of the more prevalent exterior wall systems of modern building construction. When used, these systems typically comprise a large portion of the building envelope cost. As such, there are many curtain wall decisions made early during project conception without the specialized expertise of a consultant or the subcontractor performing the work. These decisions, such as the use of “custom” systems, often inadvertently lead to the use of unproven systems with undesirable performance. Even if the design team includes procedures to confirm system performance, such as delegated design submittals and preconstruction testing, these procedures are often not properly specified, performed, or incorporated into the project.

This paper discusses curtain wall preconstruction laboratory testing to assist designers, owners/developers, and contractors with the proper specification and performance of preconstruction laboratory testing. Specifically, identification of when to perform preconstruction testing, qualifications and requirements for the testing facility, mock-up specimen, testing scope, and mock-up installation requirements will be discussed. Additionally, case studies of laboratory mock-up testing will be utilized to illustrate the topics discussed, as well as lessons learned from the author’s experience over the past 15 years.

THE WHEN AND WHY OF PERFORMING TESTING

Laboratory mock-up testing provides an opportunity to determine the efficacy of the exterior wall design, fabrication, sequencing, constructability, aesthetics, and performance of individual exterior wall systems and integration between systems. It affords the opportunity to address construction problems prior to assembly on the building where remediation can be extremely difficult, costly, and lead to significant impacts on the project aesthetics, schedule, and budget.

For many projects where the design

can accommodate standard manufactured curtain wall systems, preconstruction laboratory testing is often not required. For these projects, manufacturers’ third-party laboratory testing of their standard system indicates that it has been tested to meet or exceed the specified performance requirements for the project. However, careful consideration of the test specimen(s) should be performed to ensure that it is representative of the project-specific system.

Specifically, when evaluating the system’s structural performance, the test specimen must have framing profiles, joinery and framing connections, system depth, etc. that are equal to that for the project; and the mullion spans, insulated glazing sizes, etc. must be equal to or larger than that for the project.

When evaluating the system’s air infiltration and water-penetration performance, the means of glazing such as structural silicone, mechanically captured, inside glazed vs. outside glazing, etc. must be equivalent to that specified for the project. Another example where a manufacturer’s standard laboratory test report may be used in lieu of preconstruction laboratory testing is for thermal requirements. When evaluating the thermal performance, the test specimen frame type and profile must be equal, the framed openings must be equal or smaller, and the glazing must be equal to or inferior in thermal performance to that for the project in order to certify that the system meets the specified requirements.

However, if the third-party laboratory test specimens, test procedures, test parameters, etc. are not representative of the project-specific conditions and performance requirements, if systems are combined to create a new hybrid system; if new elements such as sunshades or vertical fins are incorporated; if a system is custom-designed for the project; or if there are project requirements for which a system has not been tested (e.g., blast resistance, hurricane impact, sound transmission, seismic resistance, etc.) then the standard manufacturer third-party preconstruction laboratory testing is not representative of the actual proj-

ect conditions and requirements. For these conditions, preconstruction laboratory testing is required to ensure that the proposed system can meet the specified performance requirements.

Many times, it is justified to extrapolate the structural performance of a system through engineering analysis and modeling. However, while a modified system can be modeled and the modifications validated structurally by means of a delegated design, the assumptions that serve the basis of the design require verification. Further, a delegated design cannot assure air infiltration, water penetration, thermal performance, etc. of significantly modified systems. Therefore, the extrapolation with engineering analysis should only be performed for a small percentage of the curtain wall where an existing system has been certified to meet the majority of the higher load requirements and will only require reinforcement to meet higher wind loads at “hot spots” or at longer spans. Otherwise, project-specific preconstruction laboratory testing is warranted to certify the system performance and confirm that the modeling and associated assumptions are accurate.

Additionally, the prefabrication process can play a significant impact on the system performance. Many systems originally intended for field-assembly are modified by installers, so that portions or entire components are prefabricated to expedite installation and reduce construction schedules. However, these modifications are often not part of the manufacturer’s standard installation instructions and have typically not been incorporated into the manufacturer’s third-party laboratory testing for a standard system. As a result, the performance of these modifications has not been confirmed, nor is the impact on the performance and maintenance of the system understood. Therefore, depending on the extent of modification, a preconstruction laboratory test may be warranted or, at a minimum, performance of a preconstruction field test should be performed prior to wholesale installation of these modified systems.

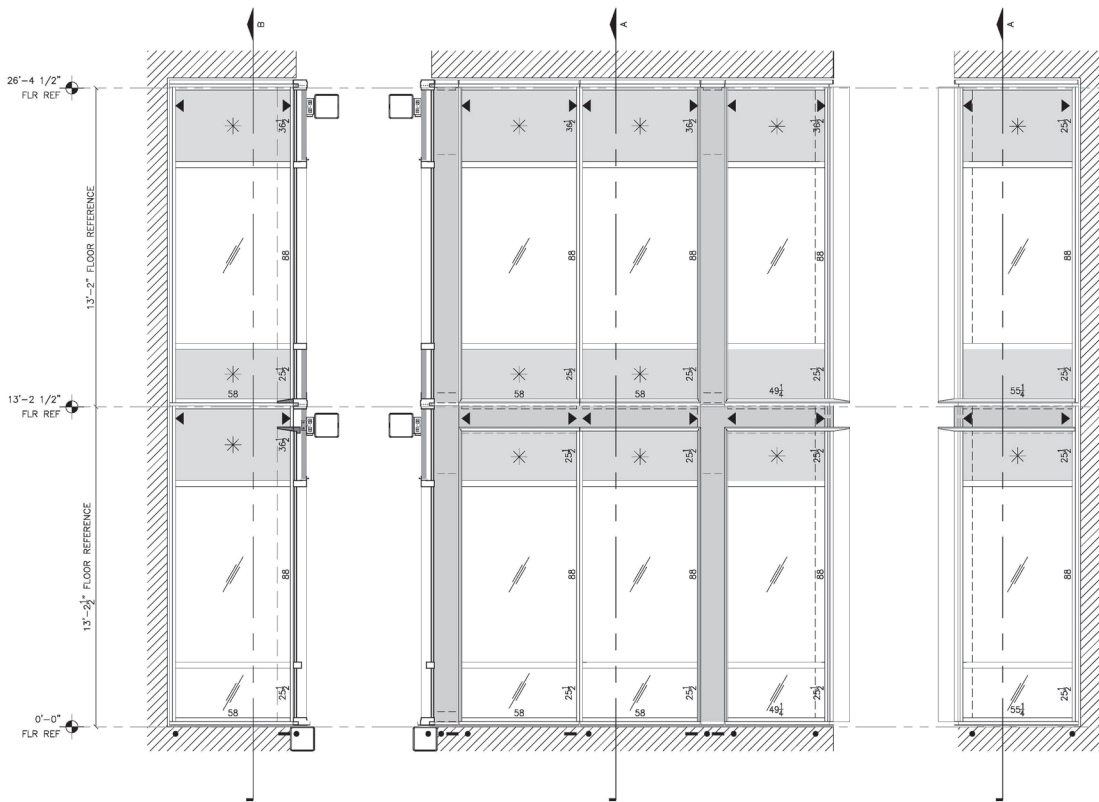


Figure 1A – Mock-up elevation for a Class-A office building in The Woodlands, Texas.

ing indicated, as documented according to ASTM E548, *Standard Guide for General Criteria Used for Evaluating Laboratory Competence*. ASTM E329 defines the minimum requirements and qualifications of the laboratory personnel, as well as the technical requirements for the testing equipment. ASTM E548 provides guidance on evaluating the expertise of testing laboratories.

In addition to utilizing a qualified laboratory, the laboratory should be independent, with no affiliations with the manufacturer, installer, or other project team members. One means

While the main purpose of performing the preconstruction laboratory testing is to evaluate the performance of the system(s), aesthetic considerations can also be addressed within the mock-up test specimen. It is common practice to have different glazing types or architectural finishes provided within the test specimen for the designer's consideration. Also, repaired conditions may be incorporated so that the designer can develop acceptance thresholds for various exterior wall cladding system repairs anticipated during the construction process.

of ensuring a laboratory meets the qualifications (as well as independent, third-party requirements) is to utilize an AAMA-certified laboratory. Utilizing an AAMA-certified laboratory ensures that the laboratory has the means and resources to perform the AAMA and ASTM testing and is an independent party (no affiliation with manufacturers) so that the project team is assured they can properly perform the testing in an unbiased manner.

During construction of the mock-up test specimen, a test laboratory representative, the installer's foreman and installation crew, general contractor, consultant, and designer should be present. Observations of the mock-up installation by these representatives should be conducted to ensure that the systems are being installed in accordance with the manufacturer's installation instructions, as well as the design intent. The owner's representative, general contractor, installer's foreman, consultant, designer, and test laboratory representative should all be present during all testing of the mock-up, including pre-testing and retesting, if any. These project team members should be those designated for the project construction phase. Typically,

Who Should Perform and Be Involved With Testing

Laboratory mock-up testing is a large project investment. Gleaning the benefits of this endeavor is only as valuable as the data generated. Therefore, it is critical to utilize a qualified and independent laboratory testing agency. The laboratory selected should be qualified according to ASTM E329, *Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection*, for test-

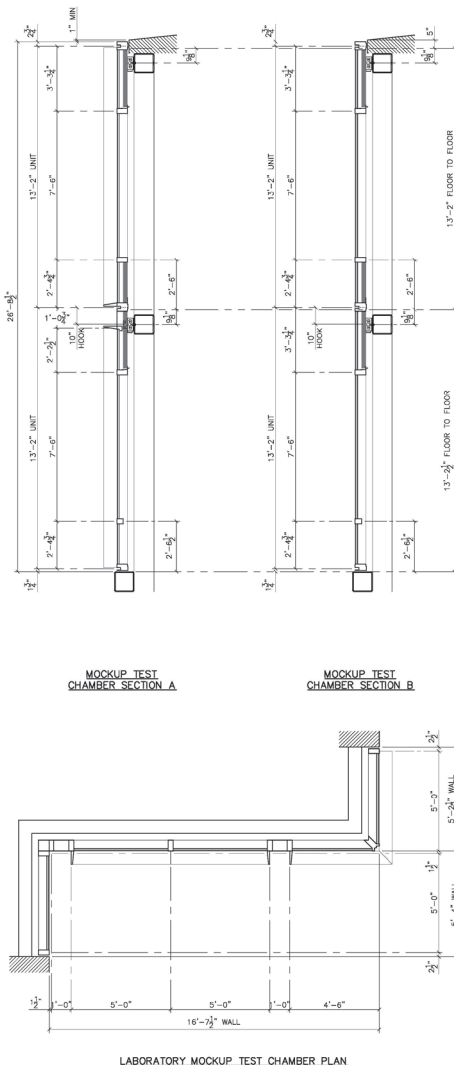


Figure 1B – Mock-up sections for a Class-A office building in The Woodlands, Texas.

a large amount of information is collected regarding the required prefabrication process, installation procedures, and integration of the exterior wall components during the mock-up test specimen installation and testing. The presence of project-designated team members will help ensure that this knowledge is properly incorporated into the project submittals and field installation so that the system(s) perform properly in the field.

What Is the Scope of the Test Specimen and Testing?

Laboratory mock-ups are to be full-sized and representative of the actual project conditions including the exterior wall systems that comprise the building cladding. The mock-up elements are to be of accurate size, orientation, and configuration, including their means of cladding attachment and integration between systems. ASTM E2099, *Standard Practice for the Specification and Evaluation of Preconstruction Laboratory Mock-ups of Exterior Wall Systems*, and AAMA 501, *Methods of Tests for Exterior Walls*, provide insight into the scope, size, and testing for exterior wall mock-ups. These standards should be utilized and referenced in the specification of preconstruction laboratory mock-up testing. ASTM E2099 provides minimum parameters that include interior and exterior corners, at least one floor in height or one repetition of the cladding design that bypasses a floor line (whichever is greater), and at least three bays in width. *Figures 1A and 1B* illustrate a mock-up size, configuration, and components that meet the ASTM E2099 parameters.

Another consideration that may be included is to simulate the transport and erection process of prefabricated units as a part of the mock-up test specimen. Specifically, if a fabrication facility requires long transport, shipping transport, or other transport of prefabricated components that may impact the prefabricated work and related performance, then the units fabricated for the mock-up should undergo the same transport procedures so that the process (storage, crating, lifting, vibration, transport loads, etc.) can be vetted as a part of the preconstruction laboratory mock-up testing. Or if the erection process may result in loading of the units that is outside the typical performance requirements, such as the potential torqueing of twin-span units

(units that are two stories in height) during erection, then the project-specific erection process should be incorporated as a part of the mock-up installation. Ultimately, the actual extent of the preconstruction laboratory mock-up test specimen and testing scope is left to the specifier, installer, testing laboratory, and other project team members.

As a general rule, the author recommends following the parameters outlined in ASTM E2099 for the specimen size and that the configuration of the mock-up be representative of a majority of the actual project conditions. However, specific features that may be performance concerns (such as bump-outs, overhangs, large projecting shading elements, cantilevered parapets, or soffit conditions, etc.) may also be incorporated so that they can be studied and their performance verified. Incorporation of these elements and their impact on the overall mock-up performance should be heavily considered. Finally, it should be noted that the laboratory chamber size might restrict the size of the mock-up, as well as the mock-up components. Some test laboratories may have head clearance, load capacity, or accessibility issues for crane access for heavier cladding components such as precast panels. Therefore, the proposed testing laboratory should be consulted prior to finalizing the mock-up size and scope.

The purpose of testing the laboratory mock-up is to confirm the performance of the exterior wall system's air infiltration, water penetration, and structural performance, as well as other requirements. Therefore, at a minimum, testing for the air, water, and structural requirements should be incorporated into the testing sequence. AAMA 501, *Methods of Test for Exterior Walls*, provides a testing sequence that includes associated performance tests, as well as optional testing for other performance characteristics. Optional additional testing can be performed to evaluate the thermal performance, condensation resistance, seismic performance, acoustical performance, etc. The specifier should review the performance requirements and corresponding testing to develop an appropriate testing scope and test parameters for the project.

To define the system parameters, the specified performance requirements are utilized. For the mock-up air infiltration and

water penetration resistance pressures, the specified pressures are used. However, it isn't always so straightforward when establishing the structural test pressures. For structural testing, the positive and negative test pressures should be representative of the higher wind pressures for the building cladding, yet not necessarily the "hot spots" where the design can be extrapolated in the delegated design. As a general rule, the author recommends that the structural test pressures be the highest pressure representative of 95% of the cladding area.

Once the test scope and parameters are determined, the sequencing of the testing must be established. AAMA 501 provides guidance on the testing sequence and ASTM E2099 outlines a specific testing sequence for testing, including optional testing that may be performed.

One element essential to the long-term performance of curtain wall systems is the performance of the curtain wall after reglazing. Curtain wall systems will require replacement of units from damage or performance issues throughout the life of the building. Therefore, the manufacturer's reglaze procedure should be tested to confirm that it is able to meet the air infiltration, water penetration, and structural performance requirements. As such, the author highly recommends incorporation of a reglazed insulated glass unit into the mock-up testing scope. It should be noted that reglazing of units that are structural silicone-glazed and then weather-sealed at the face will impact the overall test schedule, as the weather seal will need to sufficiently cure prior to performance of the testing.

How to Incorporate Into the Project

The preconstruction laboratory mock-up process takes a significant amount of time; therefore, the project schedule should include sufficient lead time to allow for preparation, construction, and testing of the mock-up. Initially, to coordinate the mock-up construction and confirm it meets the specifier's intent, mock-up shop drawings should be generated. ASTM E2099 provides guidance regarding the information to be conveyed in the mock-up shop drawings, which entails dimensioned elevations and plans with details sufficient to illustrate the mock-up construction. The author recommends the following additional general requirements. First, the shop



Figure 2 – Stick-framed curtain wall mock-up.

drawings should be a coordinated set from each installer representing their scope of work and how it is integrated with adjacent systems. Next, testing should be performed in the presence of the specifier, contractor, installer, laboratory, and owner's representative, and the results of testing should be documented by the laboratory. Finally, after testing is completed, any modifications to the mock-up components should be documented into as-built shop drawings and incorporated into the project.

Additionally, there are several other recommended provisions that can be incorporated that will assist with maximizing the benefit of performing a preconstruction laboratory mock-up testing. These include the inclusion of mock-up submittals, a preconstruction mock-up meeting, key personnel requirements, and provisions for extra materials. To ensure that the pre-fabrication and field installation procedures utilized for the mock-up meet the project requirements, the author recommends that these procedures be submitted prior to erection of the mock-up. If test failures occur, then

are transferred to project personnel performing and supervising the actual work, the key personnel supervising and performing the mock-up construction are to be the same as that for the project. Finally, because mock-up failures result in expensive delays due to repairs and laboratory personnel availability, the author recommends that extra materials be on hand at the mock-up site, should repairs be required after a failure occurs.

CASE STUDY #1

In 2013, a 20-story, high-rise, concrete-framed Class-A office building located in the Galleria area of Houston, Texas, was constructed with the exterior walls consisting of aluminum-framed glass curtain wall. The office building included a two-story ground-floor lobby and eight parking decks at the lower floors with 12 floors of office space at the upper floors. The owner/developer negotiated a contract price with the curtain wall installer for a "custom" unitized curtain wall system at a significant savings without the involvement of a project building envelope

these procedures can be reviewed and revised accordingly. The final procedures generated after successful mock-up performance are to be those utilized for the project. Additionally, shop and field quality control and assurance procedures can be submitted so that their effectiveness can be reviewed during mock-up construction. To ensure that sequencing, constructability, compatibility, and other construction installation issues are vetted, the author recommends the performance of a preconstruction mock-up meeting. As previously indicated, to ensure that the lessons learned during mock-up construction and testing

consultant. The custom system was to be designed by the manufacturer to meet the project requirements, including the incorporation of large sunshades and cantilevered conditions at the entry-level soffit and roof parapet condition. Additionally, the proposed custom system's extrusions were to be fabricated in China, partially assembled in South America, and then glazed in the United States.

Once construction was underway and the consultant was integrated into the construction phase, the consultant expressed concerns regarding the custom system. Of significant concern was that the system had not undergone laboratory testing to certify that its performance could meet the project requirements and confirm the basis of the engineering assumptions and modeling of the curtain wall design. Additionally, the procurement of the components and prefabrication process for the unitized system was of concern. Materials fabricated in China do not have the same American processes and standards to confirm they meet the specified requirements. Prefabrication and shipping of unglazed units present concerns regarding potential damage to joinery seals and components during shipping. In addition, quality assurance and quality control concerns were expressed, as the prefabrication process would be difficult to monitor at such a long distance. The consultant recommended that the custom system be fabricated and glazed locally and undergo preconstruction laboratory testing to certify its performance. However, the installer and general contractor indicated that the initial project schedule would not allow for the testing without resulting in delays, as well as adding significant cost to the project.

During discussions with the project team regarding incorporation of the recommended preconstruction testing, the manufacturer indicated that testing could be performed in South America. However, it was quickly determined that the facility in South America was not an accredited facility and was only capable of performing air infiltration and water penetration testing. Further, partial and/or full fabrication in South America did not address the consultant's shipping or quality assurance and quality control concerns. Eventually, the installer agreed to fabricating and glazing locally and assured the general contractor and owner/developer that it would maintain the initial schedule while

Figure 4 – Outside corner of unitized curtain wall mock-up.



Figure 3 – Unitized curtain wall mock-up.



assuming the risk of proceeding with fabrication, though testing could potentially require necessary modifications to the system in order to meet the performance requirements.

It was determined that two mock-ups would be performed: one for the two-story entry stick-framed curtain wall, and one for the unitized curtain wall of the tower. An agreement was made to utilize an accredited laboratory in Texas. The installer proposed the configuration of the two test specimens: a two-story, two-unit-wide mock-up specimen for the stick-framed curtain wall (Figure 2), and a two-story, three-unit wide with a single-unit outside corner return (Figures 3 and 4) for the unitized curtain wall. Further, the soffit and parapet cantilever conditions were incorporated into the installer’s proposed unitized mock-up configuration (Figure 5). Both mock-up configurations were accepted by the project team.

The installer proceeded with final engineering for the mock-up and the building, as well as the subsequent shipment and fabrication of the curtain wall components at the installer’s plant in Texas. Initially, the mock-up units were prefabricated, and then the building units were prefabricated, starting with the lower floors. The consultant conducted plant visits to observe the process and confirm that quality assurance and control provisions were

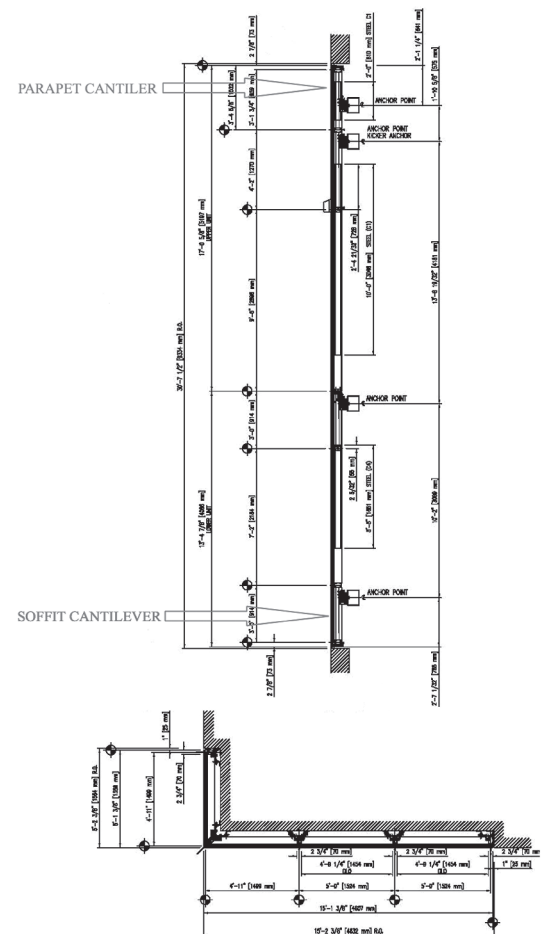


Figure 5 – Section through unitized mock-up.



Figure 6 – Reglazing of unitized mock-up.

in place. Once the mock-up units were fabricated, they were sent to the testing laboratory and were erected onto the test chamber.

The consultant required that one of the insulated glass units (IGUs) be deglazed and reglazed within the unitized mock-up specimen (*Figure 6*) to confirm the performance of the custom system’s reglaze procedure. During the deglazing and reglazing process, it was determined that the reglaze procedure was inadequate because it omitted ripping of the pressure plate to allow clearance for the IGU installation, and also because it required additional joinery and zone plug sealant repairs as a result of deglazing. The consultant, installer, and manufacturer worked together to create a new reglaze procedure that accurately reflected the reglaze requirements to ensure that replacement of units would still meet the project requirements.

The preconstruction laboratory test scope included air infiltration, water infiltration (dynamic and static), and structural testing of the stick-framed and unitized curtain wall specimens, as well as testing of the window washer tie-back buttons on the unitized curtain wall. Both the stick-framed and the unitized curtain wall met the air infiltration testing requirements. Water intrusion was observed at the perimeter joint conditions during initial water testing of the unitized curtain wall. For the stick-framed curtain wall, deformation of the stick-framed mullions at the anchors (*Figures 7 and 8*) was observed during structural testing. For the unitized system, excessive structural deflection of the unitized two-piece intermediate mullions (*Figures 9 and 10*) was observed. As a result, both systems failed to meet the structural performance requirements. Subsequently, structural testing was suspended and the remainder of the testing was canceled.

For the stick-framed curtain wall, it was determined that the single-trunk “T” mullion anchors resulted in excessive bearing pressure on the aluminum mullion interior wall, resulting in deformation of the mullion. The anchors were replaced with standard two-trunk “T” brackets to distribute the bearing between the anchors and the mullions so that it did not exceed the allowable aluminum-bearing strength. Once the structural issues were mitigated, static water testing was performed and water intrusion was observed. The water intrusion was subsequently repaired, and the specimen was able to pass the remainder of the testing, meeting the specified performance requirements.

However, testing of the unitized system was not as straightforward. The deflections recorded during structural testing of the unitized system were not representative of the behavior modeled by the curtain wall engineer responsible for the del-

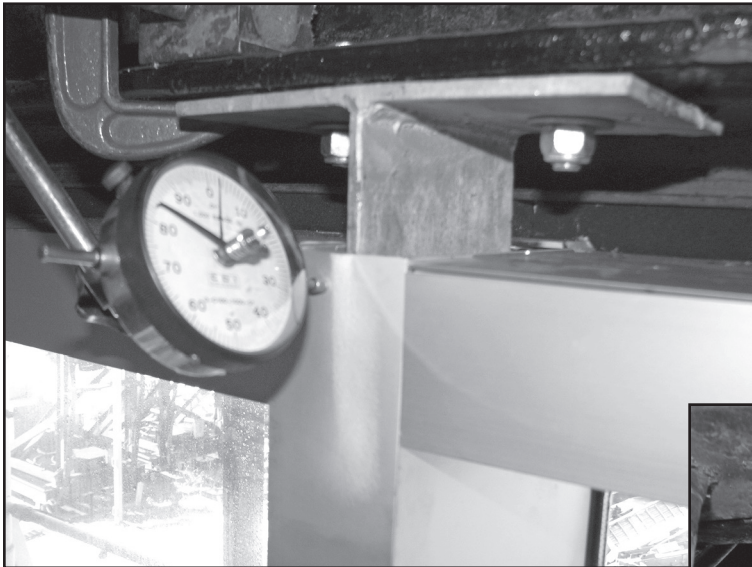


Figure 7 – Structural failure at mullion connection of stick-framed curtain wall.

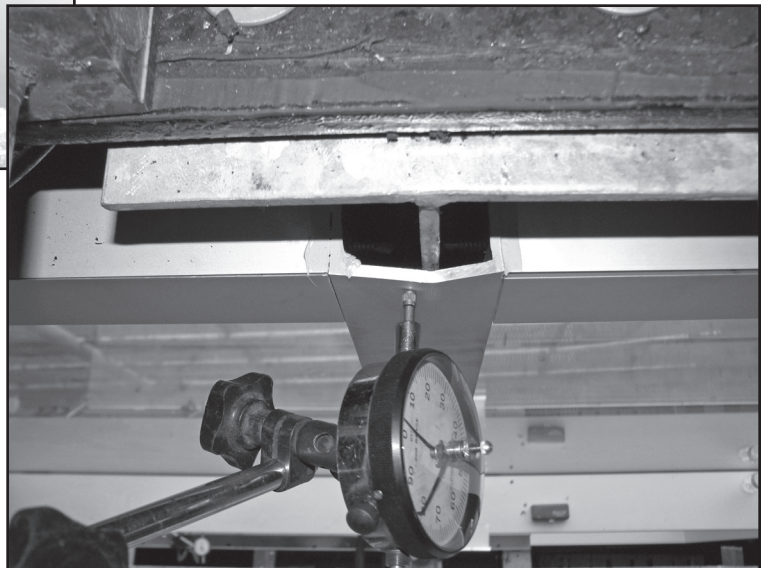


Figure 8 – Structural failure at mullion connection of stick-framed curtain wall.

egated design. This was of particular concern, as not only was the curtain wall experiencing excessive deflection that was partially deglazing units and causing rolling of the intermediate two-piece mullions, but the engineer's assumptions for structural modeling of the curtain wall system did not appear to be accurate. As a result, the custom unitized curtain wall design was in question.

Initially, rotation of the anchor clips was suspected as the cause of the abnormal behavior. However, adjustments to the anchors did not mitigate the excessive deflections during subsequent retesting, and displacement at the anchors was observed (Figures 11 and 12). In addition, the unitized curtain wall was disassembled so that steel reinforcing could be incorporated. However, additional retesting continued to result in excessive deflections of the intermediate mullions, which continued even after the maximum amount of reinforcing was incorporated at the intermediate mullion conditions.

After multiple rounds of testing, the curtain wall engineer was unable to reconcile the calculation model with the actual behavior observed during testing. Therefore, in order to certify the performance of the unitized curtain wall for the lower floors where the units had already been fabricated, it was determined that a separate mock-up would be constructed that was representative of a typical two-story unitized configuration (Figure 13). This mock-up was tested, and while it experienced multiple water penetration failures due to poor stack joint, joinery, and gasket seals, it was able to meet the



Figure 9 – Partial deglazing of vision unit due to excessive deflection of two-piece mullion for unitized curtain wall.



Figure 10 – Rolling of two-piece intermediate mullions and partial deglazing of IGU following negative-pressure structural testing.

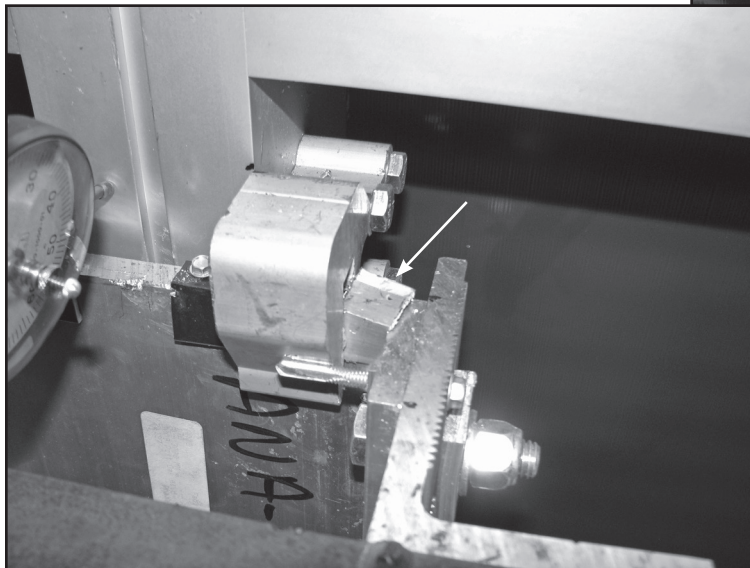


Figure 11 – Shim added at unitized curtain wall anchor bracket assembly.

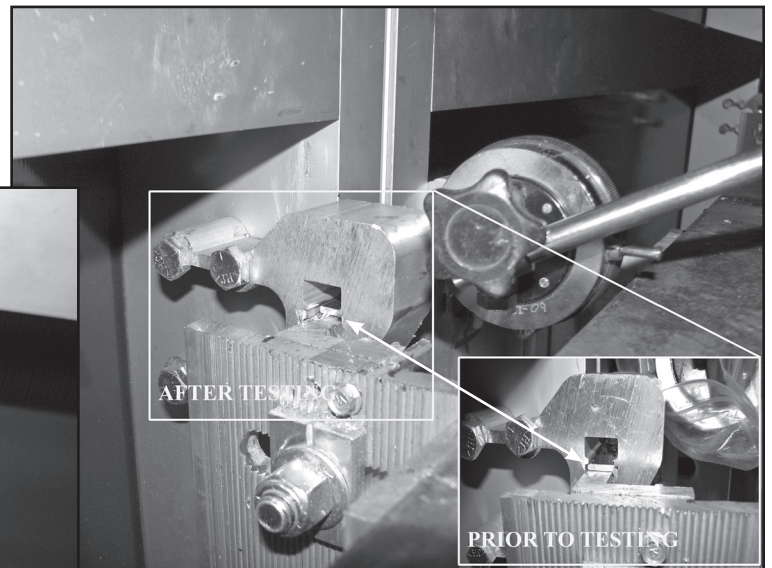


Figure 12 – Displaced shim following structural testing at negative pressure.



Figure 13 – Two-story unitized mock-up of typical floor spans.



Figure 14 – Glazing breakage during 150% negative structural load testing.

structural performance requirements. So, despite the ongoing structural failure of the original unitized curtain wall, installation on the building proceeded at the lower floors, as the third mock-up was able to confirm that the system was able to meet the structural requirements for standard floors.

Meanwhile, additional testing of the original unitized mock-up was performed with modified anchors and maximum reinforcement of the intermediate mullions. This testing yielded breakage of the glazing when tested at 150% negative structural load (Figure 14). The failure was attributed to displacement of the horizontal stack assembly (Figure 15).

Following the mock-up testing, it was determined that the mock-up configuration with two cantilevered conditions at each end with only an intermediate twin-span condition was not representative of any condition of the actual project. While the deflections of the fully reinforced intermediate mullions at the taller upper floors adjacent to the parapet condition still exceeded the requirements, it was determined that the mock-up configuration resulted in significantly higher deflections than representative for the project and that the fully reinforced mullions at the upper floors was acceptable.

Another asset gained from preconstruction laboratory testing that was gained was the requirement to incorporate the unitized system's reglaze procedure. During installation of a portion of the unitized curtain wall that included fritted insulated glass units, it was determined that the low-E coating was omitted from the fritted units. As a result, a few hundred preglazed unitized IGUs had to be removed and replaced. The revised reglaze procedure was utilized for these replacements, and field-pressurized chamber water testing was performed to confirm successful performance.

CASE STUDY #2

In 2014, a 12-story, high-rise, concrete-framed Class-A office building located in Houston, Texas, was constructed with the exterior walls consisting of aluminum-framed glass curtain wall (Figure 16). As with Case Study #1, the owner/developer negotiated a contract price with a curtain wall installer for a "custom" unitized curtain wall system at a significant savings without the involvement of a building envelope consultant on the project. The custom system was to be designed by the installer to meet the project requirements, including the incorporation of glazed granite panels within the unitized system. This time, consideration for a preconstruction laboratory mock-up was included within the installer's scope and the project schedule.

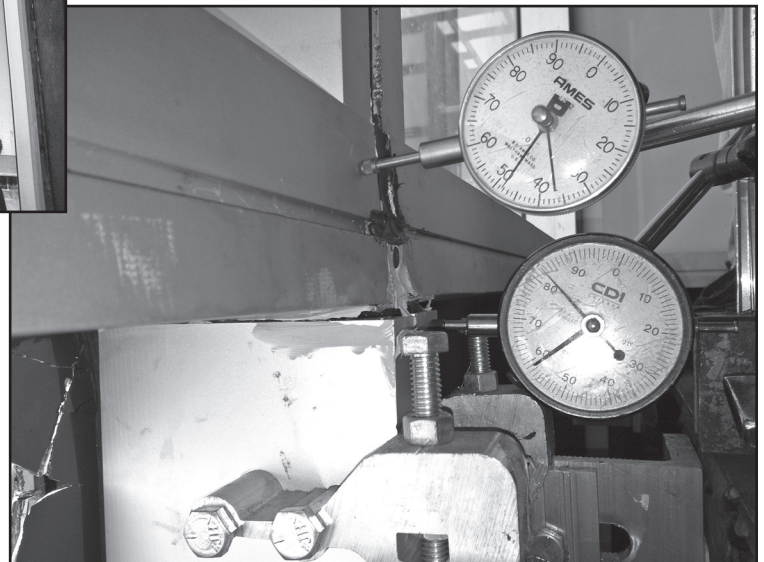


Figure 15 – Displaced unitized curtain wall horizontal stack assembly.



Figure 16 – Case Study #2—a 12-story commercial office building.

Figure 17 – Unitized mock-up of Case Study #2.



It was determined that the mock-up configuration would be two stories in height and three units wide, with a single-unit outside corner return (Figure 17). The preconstruction laboratory test scope included air infiltration, water infiltration (dynamic and static), and structural testing of the unitized curtain wall specimen, as well as testing of the window washer stabilization anchorage. Specifically, the testing sequence was as follows: static water testing, dynamic water testing, structural testing at +100%, static water testing, structural testing at +150%, and window-washer stabilization anchor testing.

During initial testing, excessive air infiltration was observed, and testing was suspended. No water testing was performed, as failed air testing would typically yield water penetration during water testing. However, to confirm that there were not structural performance issues with the mock-up, preliminary testing of 50 and 100% structural at



Figure 18 – Air exfiltration observed with smoke bomb and pressurized chamber.



Figure 19 – Air exfiltration observed with smoke bomb and pressurized chamber.

Figure 20 – Extended mullion end cap.

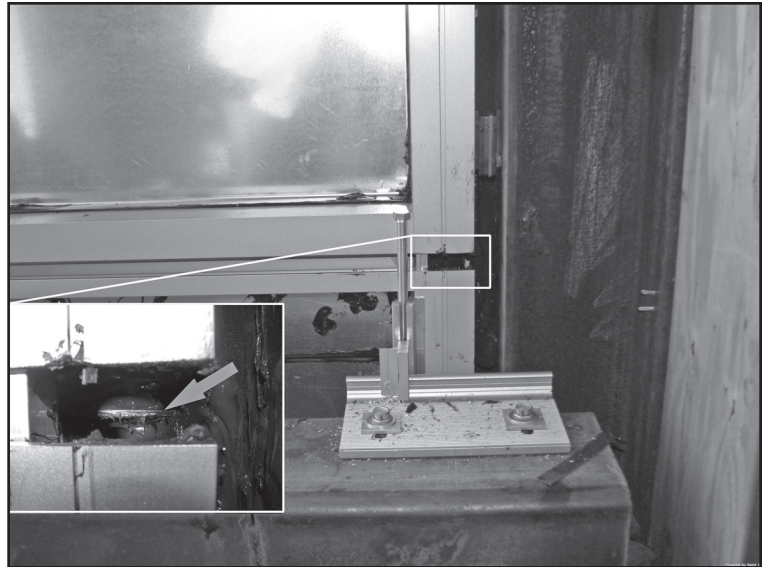
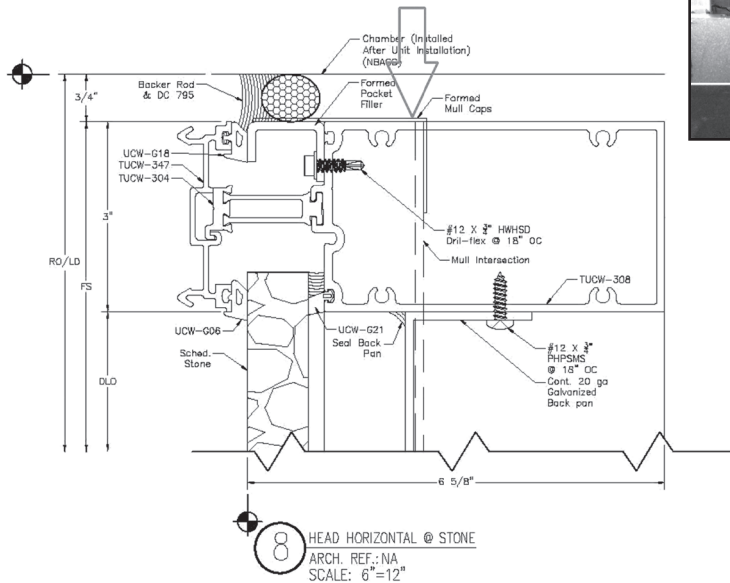


Figure 21 – Section at extended mullion end cap.



positive and negative pressures was conducted. No excessive deflections or structural performance issues were identified.

Additionally, the source of the air leakage was investigated with a smoke pen and a smoke bomb while negatively pressurizing the chamber (Figures 18 and 19). Air infiltration was observed at each mullion head, stack joint, and sill condition. Specifically, it was determined that air was passing up and over the stack joint vertical receiver (aka “chicken head”) inside the overlying hollow two-piece mullions. Additionally, the mullion end caps were not of sufficient depth to encapsulate the back of the glazing pocket, allowing air infiltration at each end of the unit mullions.

Repairs were made to the test specimen, which included the installation of deeper mullion end caps (Figures 20 and 21) at the head and sill of each mullion, as well as the installation of sealant at the interior pocket at the stack joint condition within each mullion (Figures 22A and 22B). Testing was repeated, and the system met the air infiltration and water penetration performance requirements, as well as the structural requirements.

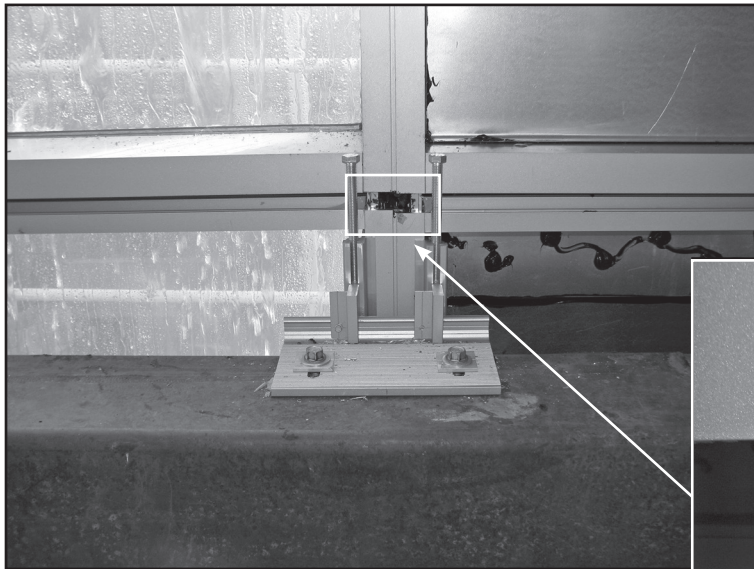


Figure 22A – Additional seal at hollow two-piece mullion stack joint condition.



Figure 22B – Close-up of additional seal at hollow two-piece mullion stack joint condition.



Figure 23 – Stick-framed mock-up of Case Study #3.

CASE STUDY #3

During 2007 and 2008, a 14-story, high-rise, concrete-framed Class-A office building located in Houston, Texas, was constructed with the exterior walls consisting of aluminum-framed glass curtain wall. As with Case Studies #1 and #2, a “custom” curtain wall system was selected for the project; however, the system was stick-framed and not unitized. The custom system was to be designed by the installer to meet the project requirements, including the incorporation of sunshades. Consideration for a preconstruction laboratory mock-up was included



Figure 26 – Rectangular weepholes at base sill track.

Figure 27 – Modified weepholes at other intermediate horizontal mullions.



within the installer’s scope and the project schedule.

It was determined that the mock-up configuration would be two stories in height and three units wide (Figure 23). The preconstruction laboratory test scope included air infiltration, water infiltration (dynamic and static), and structural testing of the curtain wall specimen, as well as testing of the window-washer stabilization anchors. Specifically, the testing sequence was as follows: static water testing, dynamic water testing, structural testing at +100%, static water testing, structural testing at +150%, and window-washer stabilization anchor testing.

During initial static water-penetration testing, water intrusion was observed at several locations. Through field-nozzle testing (used to isolate the location of the water penetration) with the pressurized chamber and visual observation of the

curtain wall installation, three installation issues were identified as contributing to water infiltration. These sources were modified glazing stops, modified weep holes, and installation sequencing.

A large source of water intrusion was the premature termination of the interior glazing stops (Figure 24) or discontinuity of the glazing stops at curtain wall mullion anchor locations (Figure 25). The glazing stops were replaced with continuous glazing stops that terminated within ¼ inch of the glazing corner conditions.

Another source was determined to be weep holes that were modified in size and profile from that indicated in the shop drawings along the sill condition. Rectangular slotted weeps, in lieu of circular weeps, were observed (Figures 26 and 27). These weeps allowed more water into the system than could be managed and evac-



Figure 24 – Prematurely terminated interior glazing stop.



Figure 25 – Discontinuous interior glazing stop at mullion anchor.



Figure 28 – Alignment plate at the face of the splice joint prohibiting proper field sealant installation.

uated to the exterior, resulting in overflow at the back of the glazing pocket along the sill condition.

Finally, the alignment plate at the mullion splice along the face of the left mullion prohibited proper field adhesion of the splice sealant (Figure 28). Therefore, the field installation procedure was modified so that the alignment plates were removed during installation to permit adequate field-sealant installation. The alignment plates were then reinstalled with cap-sealed fasteners.

CLOSING

While preconstruction laboratory testing adds additional cost and schedule impacts for new construction projects, it is often necessary to ensure that the proposed system(s) meet the project performance requirements. If cost and schedule take precedence, then the designer should incor-

porate curtain wall systems that have been tested by a third-party laboratory as a basis of design. When specifying these systems, the designer must carefully review the product test reports to ensure that the tested specimen is representative of the project and meets the desired performance requirements.

However, deviations from the basis of design system—such as custom or hybrid systems, incorporation of new components, or laboratory test reports with specimens that are not representative of the project—will require preconstruction laboratory testing for a project. Also, preconstruction laboratory testing is often desired to confirm that the detailing of the transitions between exterior wall systems meet the specified structural, air infiltration, and water penetration requirements. Finally, evaluation of different glazing types and other aesthetic considerations is desired in support of performing project-specific preconstruction laboratory testing.

When it is determined that preconstruction laboratory testing is to be performed, then only a qualified and independent laboratory should perform the testing. Certification programs such as those by AAMA are a means of ensuring that unbiased parties properly perform the testing. During construction of the mock-up and performance of testing, at a minimum, project-dedicated representatives from the owner, designer, consultant, general contractor, and installer should be present to help ensure that lessons learned during testing will be properly incorporated into the project.

Prior to testing, the scope of the test specimen must be developed. The scope of the mock-up should indicate what is to be tested and what testing is to be performed. The mock-up test specimen should incorporate full-sized exterior wall elements that

are representative of the project conditions. At a minimum, the air infiltration, water penetration, and structural performance should be tested. The scope of the mock-up test specimen and the testing performed should be coordinated with the testing laboratory and the project team members. Additionally, the author strongly suggests that the transport and erection procedures, as well as incorporation of a reglazed insulated glass unit, be considered as a part of the mock-up test specimen to ensure that these procedures do not negatively impact the system's performance requirements.

Sufficient time for the construction and testing of the mock-up test specimen should be provided within the project schedule to ensure completion of testing prior to prefabrication of exterior wall components and field installation. The schedule should include provisions for retesting, if necessary. Further, to maximize the benefit of preconstruction laboratory mock-up testing, mock-up submittals, a preconstruction mock-up meeting, key personnel participation requirements, and provisions for extra materials should be included.

The case studies presented highlight the need for testing of curtain wall systems. Had preconstruction laboratory mock-up testing not been performed for these projects, the results could have been catastrophic. These case studies present considerations for preconstruction laboratory mock-up testing scope and importance of incorporating the provisions indicated within this paper. When properly specified and performed, preconstruction laboratory mock-up testing can ensure proper performance of the system(s), as well as proactively resolve issues prior to construction, thereby mitigating the potential for costly and time-consuming repairs during or after construction. 