Dynamic Issues Drive Curtain Wall Design

By Ken Brenden

Today's curtain wall is a complex, integrated system composed of framing members, sash, glazing, spandrel panels, fasteners, and sealants that must accommodate a wide variety of forces, both static and dynamic.

The principal static force acting upon a curtain wall is, of course, gravity. However, because of the relatively light weight of materials used in curtain walls, this "dead load" is a force of secondary significance, rarely imposing any serious design problems beyond ensuring that the horizontal members can support the weight of large glazing infills without excessive deflection or twisting. Therefore, in terms of structural design considerations, the requirements of stiffness rather than strength usually govern.

Live Loads and Provision for Movement

Of primary concern are the dynamic *live loads*, chief among them wind, thermal expansion and, in some areas, seismic movement.

The wall's anchorage to the building frame must be designed with due regard to these dynamic forces, which can cause substantial movements at many of the joints between its parts. Joint design thus becomes the key to accommodating these movements without jeopardizing the wall's integrity and weather tightness.

Joint configurations used in curtain wall design are typically of three types:

- Butt joint, in which the edges of two components meet in the same plane.
- Lap joint, which permits relative over-sliding movement of the joining parts.
- A combination of these two forms, such as the "Surround" or glazing type joint used at the periphery of glass or panels. This is the most common type.

Wind Loading

Chief among the environmentally-imposed live loads are lateral wind forces. On the taller structures in particular, the structural properties of framing members and panels, as well as the thickness of glass, are determined by maximum wind loads. Winds also contribute to the movement of the wall, affecting joint seals and wall anchorage.

Designing to accommodate these forces is a routine procedure, provided that the nature and magnitude of the wind loads are known. This is not a trivial task for high-rise structures, however, despite the straightforward methodology and handy availability of references for wind loads such as ASCE-7-02 and AAMA TIR-A11-04. That is because the nature and intensity of such loads are affected by the height and geometry of the building, as well as by surrounding structures or natural topography.

Often too little significance is attached to negative wind loading (suction forces) acting on the wall, which can be augmented by internal building pressures due to air conditioning. On high-rise buildings, these negative pressures usually reach a maximum near exterior corners, where they may be more than twice as great as any positive load. This negative loading is why windows are more likely to blow out of a high-rise building during an extreme wind event, rather than collapse inward.

ASCE 7-02 was developed based on the effect of winds on rectangular buildings; however, the vast majority of buildings are not perfect rectangles. Especially for tall and/or irregularly shaped buildings, it is best to have a boundary layer wind tunnel (BLWT) study performed on a scale model of the building.

Thermal Expansion

A representative maximum range of U.S. ambient temperature is about 120°F. Metal surface temperatures, however, vary over a much wider range – typically 150°F and in some locales as much as 200°F. This can translate into thermal expansion of ¼ to 5/16 inches in a ten-foot length of aluminum. A sheet of glass alongside the aluminum will expand by less than half as much due to aluminum's relatively high coefficient of expansion.

This disparity causes relative movement that must be accommodated without causing undue stress on glass, curtain wall joints, anchors, joint seals or structural elements.

Seismic Loads and Interstory Drift

Although wind is the principal actor in dynamic loading, seismic loading is also a major consideration in several areas of the U.S. While both can cause interstory drift, or racking – defined as relative horizontal movement between adjacent stories of a multi-story building – seismic action is by far the greater concern.

Seismic events cause similar building movements, as do major wind events. In the latter, the top of the framing will move inward at the top of the story on the windward side of the building and outward on the leeward side. It will move laterally in the plane of the wall on sides parallel to the wind, tending to force the framing out of square as the building tries to "lean" with the wind. (Note that some negative wind loading will also occur on the parallel sides.) In seismic events, the same sort of movements occur in relation to the direction of ground motion. System designs must take into account all of these motions.

Seismic design has evolved from a force-based approach (expected load multiplied by an appropriate safety factor) to one of calculated deformations. The ultimate goal is to keep the structure from collapsing in major earthquakes, while accepting some damage as a result of different earthquake magnitudes. The designer must strike a balance with respect to seismic design based on function, cost and probability of damage. Guidelines are published in the 1997 NEHRP *Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*.

AAMA has published test methods 501.4-00, *Recommended Static Test Method for Evaluating Curtain Wall and Storefront Systems Subjected to Seismic and Wind Induced Interstory Drifts*, and AAMA 501.6-01, *Recommended Dynamic Test Method for Determining the Seismic Drift Causing Glass Fallout from a Wall System*, that compliment one another for use in laboratory evaluation of curtain wall performance when subjected to specified horizontal displacements. AAMA 501.4 testing should, in general, be considered whenever the calculated interstory drift in the primary structural system exceeds 0.005 times the story height. AAMA 501.6 testing helps determine the amount of drift that causes glass fallout from a curtain wall or storefront (indicated by "$\Delta_{fallout}$").

Design Considerations to Accommodate Movement

Tolerances

Because curtain wall construction involves covering a field-constructed skeleton with a factory-made skin, much of the detailing work may be done by the manufacturer rather than by the architect/engineer. Also, the design must consider that curtain wall systems connect to many other parts of the buildings, involving the work of numerous trades. Significant deviations from true alignment in the building frame are generally not correctable by field cutting, fitting and patching. All of these factors converge to require careful attention to manufacturing and installation variances, with the resulting tolerance stack-ups still capable of providing the clearances necessary to accommodate building movement due to in-service live loads. Most successful curtain walls are the result of a team effort, with the architect/engineer, contractor, and fabricator pooling their knowledge and talents to produce an attractive, efficient and practicable design.

Tolerances and clearances may be closely related, but the two terms are often confused. A tolerance is a permissible amount of deviation from a specified or nominal dimension. A clearance is a space or distance purposely provided between adjacent parts (e.g., between the building frame and the curtain wall) to allow for movements or anticipated size variations, to provide working space, or for other reasons.

Glass-holding members must be erected so they provide glass openings that are within certain tolerances for squareness, corner offset and bow. For example, it is generally recommended that the difference between the measured lengths of the diagonals should not exceed ⅛-inch.

Wall Anchorage

For the most part, rare instances of curtain wall failure or excessive deformations have been due to faulty anchorage details.

Anchors must, of course, have the hardness, yield and tensile strength to accommodate the weight of the wall itself, as well as the dynamic forces imposed by wind loads, while accommodating fabrication and construction tolerances and allowing for thermal movement. Locking devices must be employed to prevent loosening or turning out due to thermal expansion and contraction cycles, building movements or wind-induced vibration.

Exposure, metal type and coatings are important considerations due to galvanic action that occurs when dissimilar metals become wet from rain or condensation which can cause corrosion, especially in harsh environments such as seacoast locations. Industry guidelines, such as AAMA TIR A9-91, specify the optimum metal combinations, as well as the data necessary to select fasteners for curtain wall framing members and components, and for anchoring the curtain wall to the building structure.

Joint Sealant

Sealants represent a very small part of the wall cost, but often play a major role in its performance.

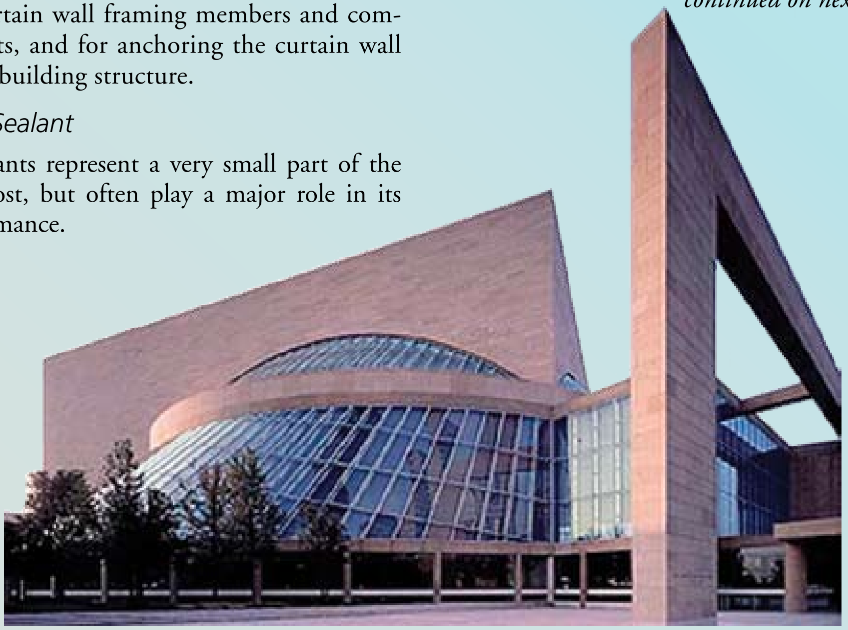
Joint sealant performance is dependent on the design of the joints, the proper selection of sealant materials and proper application. Whether the joints are "working joints," designed to accommodate movement, or "non-working joints," secured by fasteners, some kind of seal is usually required. It is particularly important that the size of the sealant joint take into account the maximum thermal expansion and contraction, as well as building movements that will affect the joint.

The most critical properties of a sealant are its adhesive strength and cohesive strength. Unless the sealant adheres securely and continuously to the substrate, it will fail when subjected to tensile stress. In many cases, depending on the substrate material, a primer may be required to promote the bonding action. Clearly, cohesive strength is equally important. A material that lacks the strength to "hold itself together" under repeated stress cannot provide a suitable seal. Also important are the sealant's recovery ability after deformation, modulus of elasticity, and durability under the effects of weathering. In addition, sealants must be chemically compatible with other compounds, substrates and wall cleaning solutions.

The type of joint dictates much of the sealant selection. In a butt joint (in which the sealant is subjected to tensile and compressive stresses) the critical factor is joint width. In lap joints (where the sealant is subjected primarily to shear stress), it is the thickness of the sealant that is critical.

Sealant compounds vary considerably in the amount of extension and compression movement they can withstand before failure. The following performance classifications are reflected in current federal specifications and ASTM standards.

continued on next page



• Low Performance Sealants or "Caulks." These are sealants having minimum movement capability through their useful life in relatively stable joints. Rarely used in curtain walls, it was the failure of such products when used in some of the early large curtain walls that, in fact, led to the development of the higher performance sealants.
• Medium Performance Sealants. Medium performance sealants are those having a predicted cyclic movement capability of ±5% to ±12.5% through their useful life. Their use is normally confined to non-working joints and those working joints where relatively small movement is expected.
• High Performance Sealants. Class B High performance sealants are those which have a predicted cyclic movement capability of ±12.5% to ±25% through- out their useful service life.Those with the higher capability, able to accommodate ±12.5% to ±50% maximum cycle movement, are designated as Class A.

Deflection of Glass-Supporting Frame Members

The rigidity of the framing members that support the glass affects the amount of flexure the glass panel will experience under load. The more the frame deflects under the load, the more stress is placed on the glass and the greater the likelihood of breakage.

The typical design convention is to limit frame member deflection to maximum of L/175 of the unsupported (clear) span length (L), when subjected to design loads. Certain sealants may require a lower deflection ratio than L/175, as will the need to limit movement to accommodate the properties and location of interior finishes or to prevent disengagement of applied snap covers or trim. Lower deflections usually require the use of heavier frame cross-sections or reinforcements, which has visual impact.▪

AAMA References

The design professional will find the following material useful when approaching the design of a curtain wall system:

• Aluminum Curtain Wall Design Guide Manual (AAMA CW-DG-1-96)

• Metal Curtain Wall Manual (AAMA MCWM-1-89)

• Joint Sealants (AAMA JS-91)

• Glass and Glazing (AAMA GAG-1-97)

• Structural Properties of Glass (AAMA CW-12-84)

• Metal Curtain Wall Fasteners (AAMA TIR A9-91 and the 2000 Addendum)

• Design Windloads for Buildings and Boundary Layer Wind Tunnel Testing (AAMA CW-11-85)

• Maximum Allowable Deflection of Framing Systems for Building Cladding Components at design Wind Loads (AAMA TIR A11-04)

• Installation of Aluminum Curtain Walls (AAMA CWG-1-89)

• Recommended Static Test Method for Evaluating Curtain Wall and Storefront Systems Subjected to Seismic and Wind Induced Interestory Drift (AAMA 501.4-00) and Recommended Dynamic Test Method for Determining the Seismic Drift Causing Glass Fallout from a Wall System (AAMA 501.6-01) (combined document)

These publications may be obtained online by visiting the "Publication Store" at **www.aamanet.org**.

Ken Brenden possesses more than 30 years of window and curtain wall experience in manufacturing, testing, engineering and designing. He serves as the Code and Industry Affairs Manager for the American Architectural Manufacturers Association (AAMA), a trade association of approximately 275 manufacturers of architectural, commercial and residential fenestration products and components.