Curtain wall

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Glass curtain wall of the Bauhaus Dessau.

Curtain wall is a term used to describe a building façade which does not carry any dead load from the building other than its own dead load. These loads are transferred to the main building structure through connections at floors or columns of the building. A curtain wall is designed to resist air and water infiltration, wind forces acting on the building, seismic forces, and its own dead load forces.

Curtain walls are typically designed with extruded aluminum members, although the first curtain walls were made of steel. The aluminum frame is typically infilled with glass, which provides an architecturally pleasing building, as well as benefits such as daylighting and environmental control. Other common infills include: stone veneer, metal panels, louvers, and operable windows or vents.

Curtain walls differ from storefront systems in that they are designed to span multiple floors, and take into consideration design requirements such as: thermal expansion and contraction; building sway and movement; water diversion; and thermal efficiency for cost-effective heating, cooling, and lighting in the building.

History

Medieval curtain wall

Curtain wall is used to describe the set of walls that surround and protect the interior (bailey) of a medieval castle. These walls are often connected by a series of towers or mural towers to add strength and provide for better defense of the ground outside the castle, and are connected like a curtain draped between these posts. Additional provisions and buildings were often enclosed by such a construction, designed to help a garrison last longer during a siege by enemy forces. Examples of curtain walls as part of castles are at Muchalls Castle, Scotland and Dunstanburgh Castle, England, the latter of which is in a ruined state.

Modern curtain wall

Prior to the mid-20th Century, buildings were constructed with the exterior walls of the building supporting the load of the entire structure. With the advent of the structural concept of shear walls and building cores, the exterior walls of buildings no longer had to support high dead loads and could be designed as much lighter and more open than the brick and steel facades of the past. This gave way to increased use of glass as an exterior façade, and the modern day curtain wall was born.

The first curtain walls were made with steel mullions, and the plate glass was attached to the mullions with asbestos or fiberglass modified glazing compound. Eventually silicone sealants or glazing tape were substituted. Some designs included an outer cap to hold the glass in place and to protect the integrity of the seals. The first curtain wall installed in New York City was this type of construction (see Lever House). Earlier modernist examples are the Bauhaus in Dessau and the Hallidie Building in San Francisco. The 1970's began the widespread use of aluminum extrusions for mullions. Aluminum offers the unique advantage of being able to be easily extruded into nearly any shape required for design and aesthetic purposes. Today, the design complexity and shapes available are nearly limitless. Custom shapes can be designed and manufactured with relative ease.

Similarly, sealing methods and types have evolved over the years, and as a result, today's curtain walls are high performance systems which require little maintenance.

Stick systems

The vast majority of curtain walls are installed long pieces (referred to as *sticks*) between floors vertically and between vertical members horizontally. Framing members may be fabricated in a shop environment, but all installation and glazing is typically performed at the jobsite.

Unitized systems

Unitized curtain walls entail factory fabrication and assembly of panels and may include factory glazing. These completed units are hung on the building structure to form the building enclosure. Unitized curtain wall has the advantages of: speed; lower field installation costs; and quality control within an interior climate controlled environment. The economic benefits are typically realized on large projects or in areas of high field labour rates.

Rainscreen principle

A common feature in curtain wall technology, the rainscreen principle theorizes that equilibrium of air pressure between the outside and inside of the "rainscreen" prevents water penetration into the building itself. For example the glass is captured between an inner and an outer gasket in a space called the glazing rebate. The glazing rebate is ventilated to the exterior so that the pressure on the inner and outer sides of the exterior gasket is the same. When the pressure is equal across this gasket water cannot be drawn through joints or defects in the gasket.

Design

Curtain wall systems must be designed to handle all loads imposed on it as well as keep air and water from penetrating the building envelope.

Loads

The loads imposed on the curtain wall are transferred to the building structure through the anchors which attach the mullions to the building. The building structure needs to be designed and account for these loads.

Dead load

Dead load is defined as the weight of structural elements and the permanent features on the structure. In the case of curtain walls, this load is made up of the weight of the mullions, anchors, and other structural components of the curtain wall, as well as the weight of the infill material. Additional dead loads imposed on the curtain wall, such as sunshades, must be accounted for in the design of the curtain wall components and anchors.

Wind load

Wind load acting on the building is the result of wind blowing on the building. This wind pressure must be resisted by the curtain wall system since it envelopes and protects the building. Wind loads vary greatly throughout the world, with the largest wind loads being near the coast in hurricane-prone regions. Building codes are used to determine the required design wind loads for a specific project location. Often, a wind tunnel study is performed on large or unusually shaped buildings. A scale model of the building and the surrounding vicinity is built and placed in a wind tunnel to determine the wind pressures acting on the structure in question. These studies take into account vortex shedding around corners and the effects of surrounding buildings.

Seismic load

Seismic loads need to be addressed in the design of curtain wall components and anchors. In most situations, the curtain wall is able to naturally withstand seismic and wind induced building sway because of the space provided between the glazing infill and the mullion. In tests, standard curtain wall systems are able to withstand three inches (75 mm) of relative floor movement without glass breakage or water leakage. Anchor design needs to be reviewed, however, since a large floor-to-floor displacement can place high forces on anchors.

Snow load

Snow loads and live loads are not typically an issue in curtain walls, since curtain walls are designed to be vertical or slightly inclined. If the slope of a wall exceeds 20 degrees or so, these loads may need to be considered.

Thermal load

Thermal loads are induced in a curtain wall system because aluminum has a relatively high coefficient of thermal expansion. This means that over the span of a couple of floors, the curtain wall will expand and contract some distance, relative to its length and the temperature differential. This expansion and contraction is accounted for by cutting horizontal mullions slightly short and allowing a space between the horizontal and vertical mullions. In unitized curtain wall, a gap is left between units, which is sealed from air and water penetration by wiper gaskets. Vertically, anchors carrying wind load only (not dead load) are slotted to account for movement. Incidentally, this slot also accounts for live load deflection and creep in the floor slabs of the building structure.

Blast load

Accidental explosions and terrorist threats have brought on increased concern for the fragility of a curtain wall system in relation to blast loads. The bombing of the Alfred P. Murrah Federal Building in Oklahoma City, Oklahoma, has spawned much of the current research and mandates in regards to building response to blast loads. Currently, all new federal buildings in the U.S., and all U.S. embassies built on foreign soil, must have some provision for resistance to bomb blasts.

Since the curtain wall is at the exterior of the building, it becomes the first line of defense in a bomb attack. As such, blast resistant curtain walls must be designed to withstand such forces without compromising the interior of the building to protect its occupants. Since blast loads are very high loads with short durations, the curtain wall response should be analyzed in a dynamic load analysis, with full-scale mock-up testing performed prior to design completion and installation.

Blast resistant glazing consists of laminated glass, which is meant to break but not separate from the mullions. Similar technology is used in hurricane-prone areas for the protection from wind-borne debris.

Infiltration

Air infiltration is the air which passes through the curtain wall from the exterior to the interior of the building. The air is infiltrated through the gaskets, through imperfect joinery between the horizontal and vertical mullions, through weep holes, and through imperfect sealing. The American Architectural Manufacturers Association (AAMA) is the governing body in the U.S. which sets the acceptable levels of air infiltration through a curtain wall. This limit is expressed (in America) in cubic feet per minute per square foot of wall area at a given test pressure. (Currently, most standards cite less than 0.6 CFM/sq ft as acceptable).

Water penetration is defined as any water passing from the exterior of the building through to the interior of the curtain wall system. Sometimes, depending on the building specifications, a small amount of controlled water on the interior is deemed acceptable. To test the ability of a curtain wall to withstand water penetration, a water rack is placed in front a mock-up of the wall with a positive air pressure applied to the wall. This represents a wind driven heavy rain on the wall. Field tests are also performed on installed curtain walls, in which a water hose is sprayed on the wall for a specified time.

Deflection

One of the disadvantages of using aluminum for mullions is that its modulus of elasticity is about one-third that of steel. This translates to three times more deflection in an aluminum mullion compared to the same steel section. Building specifications set deflection limits for perpendicular (wind-induced) and in-plane (dead load-induced) deflections. It is important to note that these deflection limits are not imposed due to strength capacities of the mullions. Rather, they are designed to limit deflection of the glass (which may break under excessive deflection), and to ensure that the glass does not come out of its pocket in the mullion. Deflection limits are also necessary to control movement at the interior of the curtain wall. Building construction may be such that there is a wall located near the mullion, and excessive deflection can cause the mullion to contact the wall and cause damage. Also, if deflection of a wall is quite noticeable, public perception may raise undue concern that the wall is not strong enough.

Deflection limits are typically expressed as the distance between anchor points divided by a constant number. A deflection limit of L/175 is common in curtain wall specifications. Say a given curtain wall is anchored at 12 foot (144 in) floor heights. The allowable deflection would then be 144/175 = 0.823 inches, which means the wall is allowed to deflect inward or outward a maximum of 0.823 inches at the maximum wind pressure.

Deflection in mullions is controlled by different shapes and depths of curtain wall members. The depth of a given curtain wall system is usually controlled by the area moment of inertia required to keep deflection limits under the specification. Another way to limit deflections in a given section is to add steel reinforcement to the inside tube of the mullion. Since steel deflects at 1/3 the rate of aluminum, the steel will absorb much of the system's deflection at a lower cost or smaller depth.

Stress

Contrary to popular belief, stress is not related to deflection; it is a separate criterion in curtain wall design and analysis. For example, the advantage of some curtain wall designs is the ability to span more than one floor (commonly known as twin-span or multi-span, as opposed to single or simple span). Multiple floor spans significantly reduce the required area moment of inertia for a mullion. The stresses in the mullion, however, are significantly increased in a multiple span, giving way for a higher required section modulus (S, expressed in cubic inches) in the mullion.

As mentioned above, the deflection of aluminum is three times greater than an equivalent steel shape under the same load. However, the allowable stress in that same aluminum member may be roughly equivalent to or higher than its steel counterpart. This means that aluminum mullions can be as strong as or stronger than steel members.

Thermal criteria

Relative to other building components, aluminum has a high heat transfer coefficient, meaning that aluminum is a very good conductor of heat. This translates into high heat loss through aluminum curtain wall mullions. There are several ways to compensate for this heat loss, the most common way being the addition of thermal breaks. *Thermal breaks* are barriers between exterior metal and interior metal, usually made of polyvinyl chloride (PVC). These breaks provide a significant decrease in the thermal conductivity of the curtain wall. However, since the thermal break interrupts the aluminum mullion, the overall moment of inertia of the mullion is reduced and must be accounted for in the structural analysis of the system.

Thermal conductivity of the curtain wall system is important because of heat loss through the wall, which affects the heating and cooling costs of the building. On a poorly performing curtain wall, condensation may form on the interior of the mullions. This could cause damage to adjacent interior trim and walls.

Rigid insulation is provided in spandrel areas to provide a higher R-value at these locations.

Infills

Infill refers to the large panels that are inserted into the curtain wall between mullions. Infills are typically glass but may be made up of nearly any exterior building element.

Regardless of the material, infills are typically referred to as *glazing*, and the installer of the infill is referred to as a *glazier*.

Glass

The Mexican hothouse at the Jardin des Plantes, built by Charles Rohault de Fleury from 1834 to 1836, is an early example of metal and glass curtain wall architecture.

By far the most common glazing type, glass can be of an almost infinite combination of color, thickness, and opacity. For commercial construction, the two most common thicknesses are 1/4 inch (6 mm) monolithic and 1 inch (25 mm) insulating glass. Presently, 1/4 inch glass is typically used only in spandrel areas, while insulating glass is used for the rest of the building (sometimes spandrel glass is specified as insulating glass as well). The 1 inch insulation glass is typically made up of two 1/4-inch lites of glass with a 1/2 inch (12 mm) airspace. The air inside is usually atmospheric air, but some inert gases, such as argon, may be used to offer better thermal transmittance values. In residential construction, thicknesses commonly used are 1/8 inch (3 mm) monolithic and 5/8 inch (16 mm) insulating glass. Larger thicknesses are typically employed for buildings or areas with higher thermal, relative humidity, or sound transmission requirements, such as laboratory areas or recording studios.

Glass may be used which is transparent, translucent, or opaque, or in varying degrees thereof. *Transparent* glass usually refers to *vision* glass in a curtain wall. Spandrel or vision glass may also contain translucent glass, which could be for security or aesthetic purposes. *Opaque* glass is used in areas to hide a column or spandrel beam or shear wall behind the curtain wall. Another method of hiding spandrel areas is through *shadow box* construction (providing a dark enclosed space behind the transparent or translucent glass). Shadow box construction creates a perception of depth behind the glass that is sometimes desired.

Stone veneer

Thin blocks (3 to 4 inches (75-100 mm)) of stone can be inset within a curtain wall system to provide architectural flavor. The type of stone used is limited only by the strength of the stone and the ability to manufacture it in the proper shape and size. Common stone types used are: granite; marble; travertine; and limestone. The stone may come in several different finishes, which adds many more options for architects and building owners.

Panels

Metal panels can take various forms including aluminum plate; thin composite panels consisting of two thin aluminum sheets sandwiching a thin plastic interlayer; and panels consisting of metal sheets bonded to rigid insulation, with or without an inner metal sheet to create a sandwich panel. Other opaque panel materials include FRP (fiber-reinforced plastic) and stainless steel.

Louvers

A louver is provided in an area where mechanical equipment located inside the building requires ventilation or fresh air to operate. Curtain wall systems can be adapted to accept most types of louver systems to maintain the same architectural site lines and style while providing the necessary functionality.

Windows and vents

Most curtain wall glazing is fixed, meaning there is no access to the exterior of the building except through doors. However, windows or vents can be glazed into the curtain wall system as well, to provide required ventilation or operable windows. Nearly any window type can be made to fit into a curtain wall system.

Fire safety

Fire safing and smoke seal at gaps between the floors and the back of the curtain wall are essential to slow the passage of fire and combustion gases between floors. Spandrel areas must have non-combustible insulation at the interior face of the curtain wall. Some building codes require the mullion to be wrapped in heat-retarding insulation near the ceiling to prevent the mullions from melting and spreading the fire to the floor above.

Fireman knock-out glazing panels are often required for venting and emergency access from the exterior. Knock-out panels are generally fully tempered glass to allow full fracturing of the panel into small pieces and relatively safe removal from the opening.

Maintenance and repair

Curtain walls and perimeter sealants require maintenance to maximize service life. Perimeter sealants, properly designed and installed, have a typical service life of 10 to 15 years. Removal and replacement of perimeter sealants require meticulous surface preparation and proper detailing.

Aluminum frames are generally painted or anodized. Factory applied fluoropolymer thermoset coatings have good resistance to environmental degradation and require only periodic cleaning. Recoating with an air-dry fluoropolymer coating is possible but requires special surface preparation and is not as durable as the baked-on original coating.

Anodized aluminum frames cannot be "re-anodized" in place, but can be cleaned and protected by proprietary clear coatings to improve appearance and durability.

Exposed glazing seals and gaskets require inspection and maintenance to minimize water penetration, and to limit exposure of frame seals and insulating glass seals to wetting.