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BUILDING LOADS IMPOSED BY MONO AND BI-FOLD DOORS

Post-frame buildings are frequently used to store and maintain equipment of various types. The size of post-frame buildings and the openings in those buildings have increased as the articles and equipment housed in post-frame structures has increased in size. Heated structures demanded doors that can be insulated and properly sealed to minimize heat loss. Finally, our customers are demanding the convenience provided by automated doors. Bi-fold and the newer hydraulic mono-fold doors address the need for large, insulated, automated doors in post-frame structures.

Mono and bi-fold doors load post-frame structures in unique ways. Wind pressure flows both vertically and horizontally. Gravity acting on the open door induces a couple in the jamb columns. The door's large size results in large forces imposed on the building into which they are installed. The quick start and stop made possible by hydraulics can result in significant dynamic effects. It is critical we understand the structural impact of these doors so we can design the building to safely resist the imposed forces.

This article will discuss generalized mono and bi-fold doors. There are many manufacturers of these doors. Each door system has unique characteristics that could impact specific load paths. The designer must understand the specifics of the door being used and adjust the loading and design procedures appropriately.

Definitions

Bi-fold door — a door composed of two rigid leaves with horizontal hinge lines located at the door top and the door mid-line. The door is opened by pulling the bottom of the door toward the top with cables or straps that are wound around a motorized winding device. This shortens the distance between the top and bottom of the doorframe and causes the center of the door to push out away from the building. The door is supported at the top via hinges attached to the building and at the bottom with rollers that roll up the jamb columns. Typically bi-fold doors have trusses that span across the door at the bottom of the lower leaf, and near the center hinge point of the lower and upper leaves. The trusses can be located either inside the building (typical) or exterior to the door. The trusses carry wind load to the jamb columns when the door is closed and distribute dead load to the door edge when the door is open.

Mono-fold door — a door composed of a single rigid leaf. The door is supported at the top via a frame and hinges attached to the building. The door includes an integral frame to which a large hydraulic ram is attached at each doorjamb. The bottom of the door leaf is forced to pivot away from the building by extending the hydraulic cylinders, opening the door. Mono-fold doors have a truss located near the bottom of the door. The truss carries wind load to the jamb columns when the door is closed and distributes dead load to the door edge when the door is open.

Construction

The door slabs of mono and bi-fold doors are typically similar in construction. Structural steel tubes are welded together to form a rectangular frame. Often lighter tubes, cold-formed shapes, or even 2x_ wood elements span between the primary structural tubes and act as secondary framing. The same corrugated steel cladding used to sheath the building is attached to the secondary framing. The steel cladding is the weathering surface. The steel cladding also provides shear strength, effectively turning the door slab into a diaphragm. Diaphragm action makes the door slab nearly rigid in plane. However, the door slab is relatively flexible out of plane.

Bi-fold doors rely on the building for support. The upper hinges are bolted directly to the building. Rollers located at the lower corners of the door roll directly on an angle attached to the jamb columns. The door is latched to the jamb column near the center hinge when the door is closed.

Mono-fold doors, despite occasional claims to the contrary, also depend on the building for support. Mono-fold doors typically include a tube steel perimeter frame that attaches to the building framing which forms the door opening. The perimeter frame can support the door vertically if it bears directly on a concrete foundation. The perimeter frame does absorb and redistribute eccentric forces generated by the hydraulic ram. However, the perimeter frame is typically not rigid or strong enough to resist the force couple resulting from the open door or the closed door under wind suction. The jamb columns and building framing are required to provide the strength and rigidity for global door stability.

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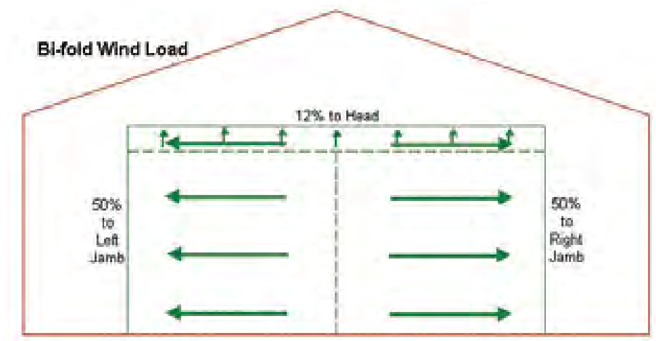

Door Loads

Bi-fold Door — Wind Load

Bi-fold doors typically are large enough that it is appropriate to use MWFRS wind pressures when designing the framing required to support bi-fold doors. The actual door is designed by the door manufacturer.

Wind pressure applied to a bi-fold door is transferred through the sheathing to horizontal and vertical frames. The door acts as a two-way slab spanning both vertically and horizontally. Typically bi-fold doors have trusses that span across the door at the bottom of the lower leaf and near the center hinge point of the lower and upper leaves. The wind trusses can be located either inside the building (typical) or exterior to the door. The exterior design is sometimes used on very large doors. Several bi-fold door suppliers indicate that roughly 1/8 of the total wind on the door moves vertically and is resisted by the building header system. The remaining 7/8 of the wind load is transferred to the jamb columns via the previously described wind trusses. Since most of the wind load applied to a bi-fold door is transferred to the door jamb columns and the load is imposed at several points over the door height it is straight forward and slightly conservative to simply add half the door width to the tributary area of the jamb column for the height of the door. The wind imposed on the door will be modeled as a uniform line load when designing the jamb column. The same load distribution strategy can be used for both wind suction and pressure.

- Wind pressure for half the door width is applied as a line load to the jamb column.
- 1/8 of the total wind load on the door is applied as a line load to the door header.

NOTE: The wind pressure distribution prescribed above is slightly conservative in that 12 percent of the wind at the top of the door is applied twice, once to the head and again to the adjacent jambs.

Bi-fold doors are latched to the door jambs just below the hinge point. The latches hold the door closed under suction loads. The latches apply point loads to the jamb column. However, it is simpler and conservative to distribute the suction pressure to the surrounding framing in a manner similar to that used for the pressure load case. Since suction forces rarely control jamb column design this simplifying distribution method will have little impact on design results.

Bi-Fold Door — Operation Loads

A bi-fold door is a simple machine. Two half-height, full width panels are

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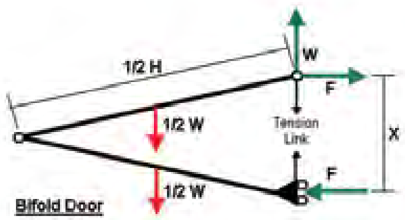


hinged together at the centerline and hinged to the building at the top. Tension straps located intermittently across the door width are wrapped around drums. The straps form the third side of a triangle. As they are wound, that side of the triangle shortens, the bottom door panel rolls up the jamb columns and the door opens. When a bi-fold door is stationary, the entire assembly can be assumed to be a rigid body.

The door weight can usually be assumed to be 6 psf for unlined un-insulated doors and 8 psf for lined insulated doors.

When the door is closed the door hangs from the upper hinges. Much of the door dead load is transferred via diaphragm action of the door slabs to the exterior hinge points and then to the supporting jamb columns. Though diaphragm action of the door slabs will distribute the dead load toward the jambs, this is not typically acknowledged in the design process. Rather, the entire weight of the door is applied as a uniform line load to the head assembly. This is conservative and accounts for loads that will be transmitted to the head assembly as the door opens.

Each jamb column must be designed to support half the dead weight of the door applied at the elevation of the upper hinge.

As the door opens the weight of the door begins to move away from the building wall. This causes eccentricity in the rigid body door assembly. This eccentricity causes the door to want to pull out of the door opening. A force couple develops to counter this force. The eccentric dead load and the resisting force couple are at the maximum when the door is fully open.

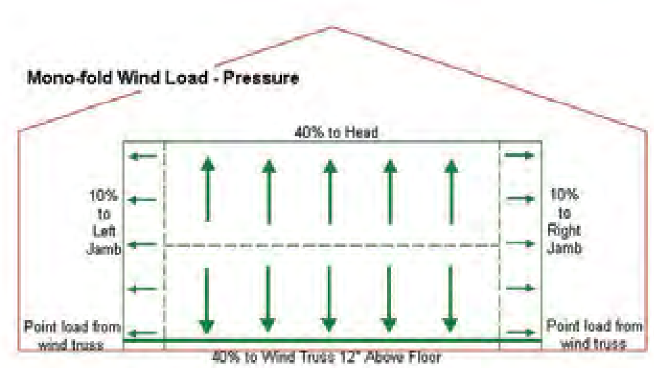
Eccentric couple = W x H/4
Resisting couple = F x X
W = door weight (lbs) = 6 psf x width (ft) x height (ft)
(Use 8 psf if the door is lined)
H = door height (ft) (Not opening height. Distance from floor to hinge line.)
X = distance from hinge line to rollers (Roller location in the fully open position is typically top of door opening but can be lower with some specialty door assemblies.)
F = Force of resisting couple
Solving: F = WH / 4X

The force couple is shared equally by both jamb columns. Each jamb also supports half the dead weight of the door.

Mono-fold Door — Wind Load

Similar to bifold doors, MWFRS pressures will be used when designing the framing required to support mono-fold doors.

Positive and negative wind load applied to a mono-fold door is transferred through the sheathing to light horizontal tubes that act as girts. The light tubes frame into heavy vertical tube framing. The vertical framing is spaced roughly 10 feet on-center. The vertical frames transfer the load down to the wind truss located at the bottom of the door and up to the header attached to the building frame located at the top of the door opening. Mono-fold doors require special load cases for wind pressure and suction forces.

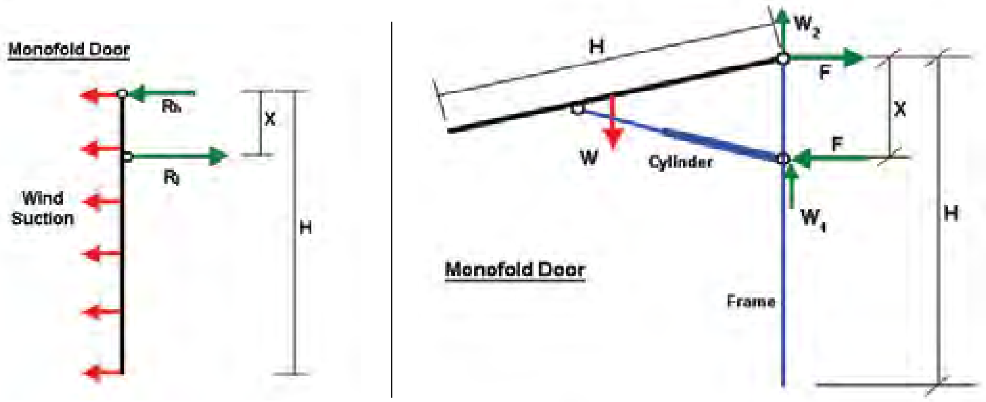


Wind pressure forces the entire door and frame into the building framing. Force transfer readily occurs through bearing at the door head and jambs. For wind pressure a line load from 10 percent of the door width is applied to each jamb column. A point load from the wind header is applied 12 inches above finished floor. The point load at each jamb is equal to 1/5 the total wind load on the door. The remaining load is applied as a line load to the header at the top of the door opening. Most or all of the header load is transferred via bracing to the roof and ceiling diaphragm.

When *wind suction* is applied to a mono-fold door it pulls away from the building. The door will open unless latched to the building frame. Mono-fold doors are typically "latched" by locking the hydraulic rams. The door is stationary when the door is closed and "latched." The door assembly can be treated as a rigid body when it is stationary. The doorframe is attached to the building frame along both jambs and across the head. This is an indeterminate structure since it is essentially a beam on an elastic foundation. Replacing the distributed reaction at each jamb with a resultant force simplifies the problem such that the equations of statics are sufficient for solution. The problem now becomes where is the resultant?

The shape of the distributed reaction along the jamb is dependent on the relative stiffness of the doorframe and the jamb column as well as the location of the cylinder to frame attachment. The stiffness of the tube steel doorframe is typically only a small fraction of the stiffness of the jamb column. Hence the distributed reaction concentrates near the ram attachment. Experience has shown satisfactory building performance when the building is designed with the jamb column resultant located at the ram attachment point. The designer can evaluate the appropriate location of the jamb resultant for specific door cases. The ram to doorframe / jamb column attachment point is a reasonable starting point.

Cane bolts located at the bottom edge of the door can be used in lieu of the locked ram latching system. Suction wind load is simply split between the head and the sill in this case. Assume locked ram latching unless otherwise specified by the door supplier and the owner is aware they must be engaged during high wind events.



Eccentric couple = W x H/2
Resisting couple = F x X

W = door dead load
H = door height
X = vertical distance from the hinge line to the hydraulic ram attachment points
F = Force of resisting couple

Solving: F = W H / 2 X

Rh = horizontal reaction @ head
Rj = horizontal reaction @ jamb
S = wind suction pressure
w = door width
H = door height
X = vertical location of jamb reaction
Summing moment about head
$S \times w \times H^2/2 = R_j \times X$
Summing forces in the X direction
$(S \times w \times H) + R_h = R_j$

½ R_h and ½ R_j are applied to each jamb column under the suction wind case. Half of door weight is included on each jamb under dead load.

Mono-fold Door — Operation Loads

When a mono-fold door is stationary, the entire assembly consisting of the frame, door leaf and hydraulic cylinders can be assumed to be a rigid body. The door weight can be assumed to be 6 psf for unlined doors and 8 psf for lined doors.

When the door is closed the door hangs from the hinges. The door dead load is transferred via diaphragm action of the door leaf to the exterior hinge points and then to the vertical frames that are lagged to the jamb column. Again, it is common practice to ignore dead load redistribution via diaphragm action and apply the entire dead weight of the door as a uniform line load to the head framing system.

As the door opens the weight of the door begins to move away from the building wall. This causes eccentricity in the rigid body door assembly. This eccentricity causes the door to want to pull out of the door opening. A force couple develops to counter this rotational force. The eccentric dead load and the resisting force couple are at maximum when the door is fully open.

The cylinder is a pin ended axial link. Hence the resultant of W_1 and **F** must align with the cylinder axis. The cylinder force can be calculated directly if system geometry is well known. However, it is not common in actual practice to know the precise orientation of the cylinder. Fortunately, the horizontal component of the cylinder force **F** can be calculated if the vertical location of the cylinder to frame attachment is known. This is done by summing moments about the upper hinge. It can also be observed that the door weight **W** is equal to the sum of W_1 and W_2. It is common practice to apply the full door weight to the jamb columns at the upper hinge elevation despite the fact that a portion of the door weight is supported by the cylinder and the door frame may transfer some load to the foundation if present. This practice eliminates the need to calculate W_1. The need

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for information about cylinder orientation is thus avoided.

The above ignores the contribution of the vertical doorframe in distributing the hydraulic ram force. The argument for making this assumption here is the same as that made in the wind suction case. The stiffness of the jamb column is typically several times that of the doorframe. Hence the jamb column will attract the bulk of the force from the resisting couple at a location near the cylinder attachment.

Mono-fold doors can impose significant dynamic effects. These have been ignored in the loading procedure outlined above. It is believed that the redundancy resulting from ignoring the steel door frame and the energy absorptive characteristics of wood construction allow dynamic effects to be safely ignored. Even so, use of soft start/stop technology in the hydraulic circuit as a means of minimizing dynamic effects is highly recommended.

Building Design

The building, jamb columns, bracing and connections must be designed to safely absorb the forces produced by mono and bi-fold doors when they are included in the structure. Building design is beyond the scope of this article. Suffice to say, the forces generated by large doors can be significant. A competent post-frame design professional should be engaged to ensure a successful project.

Conclusion

Mono and bi-fold doors load the buildings into which they are installed in unique ways. The large sizes of these doors mean the loads can be very large, easily controlling the design of door framing elements. The above discussion provides a rational framework for determining the forces imposed by mono and bi-fold doors. Sizing building components and connections based on the resulting forces have resulted in several buildings that have performed well.

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