Practical Solutions

solutions for the practicing structural engineer

Perforated Masonry Walls

Part 1: Load Distributions

By David T. Biggs, P.E., S.E.

Engineers who design masonry walls are faced with decisions as to how to reinforce around openings. While many textbooks discuss the design of shear walls with openings, most do not address the design of walls with openings when subjected to out-of-plane lateral loads. This article provides some analysis tips for designing flexural masonry walls with perforations. While there is no set procedure for load distribution for perforated walls, what follows is one engineer's method.

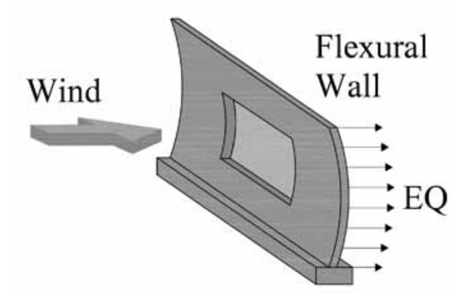

Figure 1: Out-of-plane loading.

Flexural Walls

Figure 1 shows a portion of a wall with an opening undergoing out-of-plane bending. Dependent upon the load combination, the lateral load is applied as either a wind (W) or a seismic force (EQ).

Load distribution around an opening can be determined either by hand methods or by computer techniques. Traditionally, structural engineers have used only hand methods. With the availability of computer software dedicated to designing masonry elements and general purpose finite element method (FEM) programs, computer solutions are possible. Recently, masonry-specific software based on FEM has made the analysis and design task less daunting.

Hand Methods

The load distribution is determined based upon the type of opening. *Figure 2* shows a wall segment with both a personnel door and an overhead door, assumed to be simply supported at the roof level and pinned at the foundation. This represents a non-loadbearing wall area isolated by control joints 30-feet, 8-inches apart.

The personnel door is attached to the wall at its hinges and the door latch, both on the jambs. By code, the door swings out. There is generally a doorstop at the top. Therefore, lateral load applied to the exterior of the door (pressure) is primarily distributed to the jambs, the doorstop at the top, and the threshold at the bottom. Under a suction load, the doorstop and threshold are not effective and all loads are taken by the jambs at the hinges and the door lock. For analysis, all loads are assumed to be transferred to the jambs. The lateral load on the wall above the opening is distributed similarly. *Figure 3 (page 28),* shows the lateral distribution for the personnel door.

Axial load above the wall is also distributed to the jambs through the header over the opening or by arching action. Include roof loads if the wall is a bearing wall. The header can be masonry, structural steel or precast concrete. *Figure 4 (page 28)* shows the axial

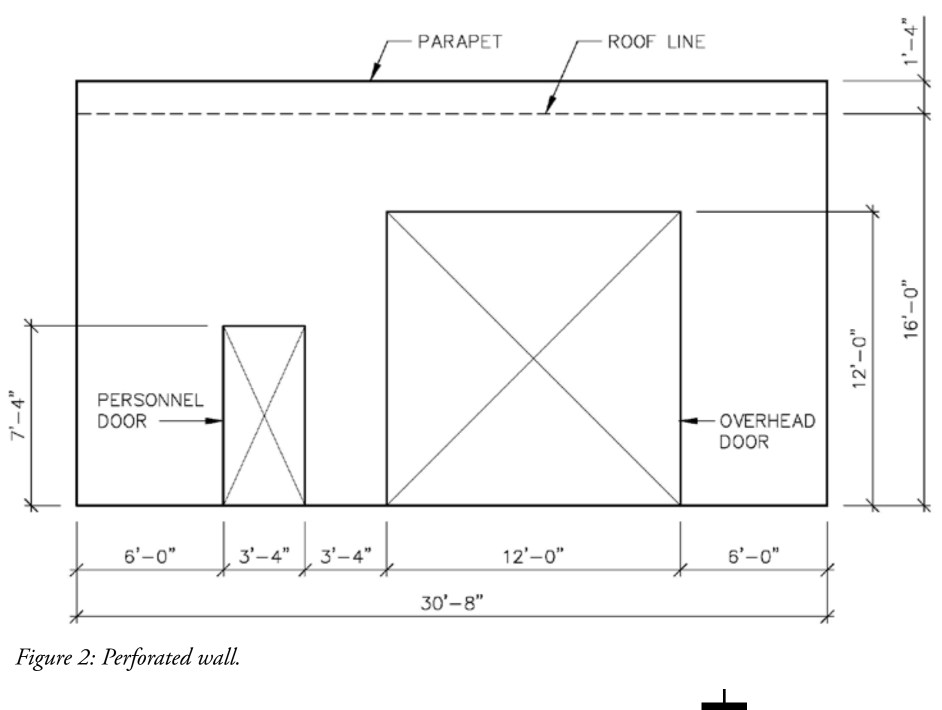

Figure 2: Perforated wall.

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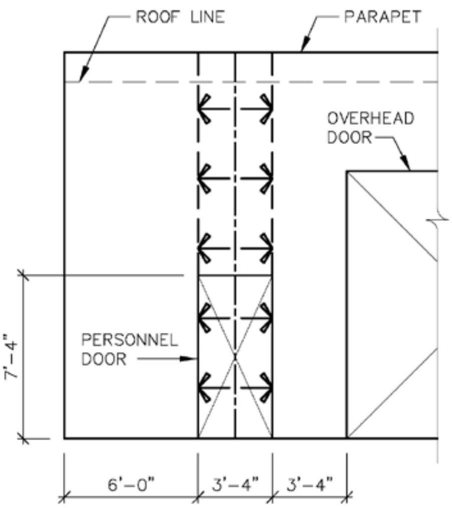

Figure 3: Load distribution at personnel door.

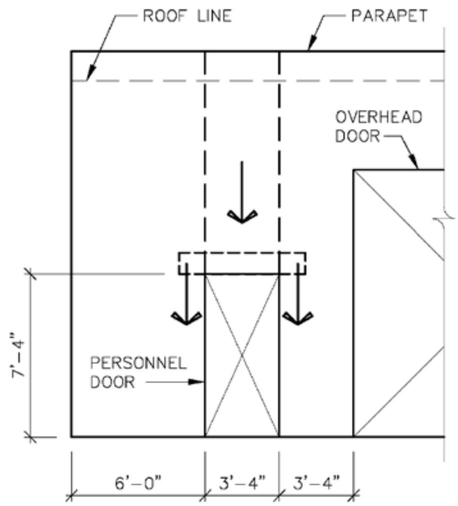

Figure 4: Axial load distribution.

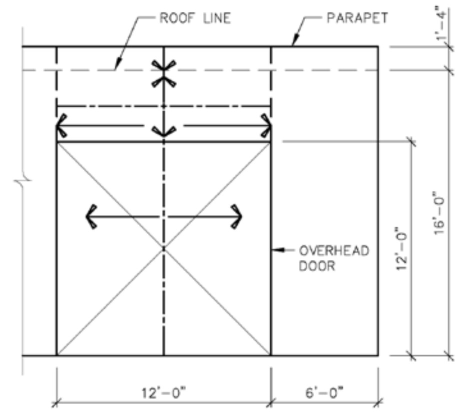

Figure 5: Lateral load distribution at overhead door.

load distribution from the wall. If the wall were loadbearing, the tributary roof load would be included.

An overhead door is generally supported at the head of the door and guided along tracks at the jambs. It generally does not have a recessed bottom track. Many engineers distribute the loads, either pressure or suction, to (a) just the jambs, or (b) a combination of the jambs and head. The appropriate method is dependent upon which element you are designing. If the jambs are the elements to be designed, use (a). If the header is the element to be designed, use (b).

For this example, the jambs are designed so 50 percent of the lateral load on the door will be distributed to each jamb. As an exercise later, you can also redistribute the loads and design the header for combined vertical and lateral loads.

The lateral load on the wall area above the overhead door is distributed to the jamb areas based upon the aspect ratio of the masonry area. For a wall area with a short vertical span as shown in *Figure 5*, the loads distribute to the roof and the header. The header then distributes the loads to the jambs. The vertical load distribution is similar to the personnel door.

For a wall area above an overhead door with a large vertical span in comparison with the header span, the lateral loads distribute similar to that shown in *Figure 3*. For vertical spans where the aspect ratio (vertical span to horizontal span) is closer to one, plate theory can be used to distribute the loads to the roof, header, and jambs. Two analyses may be performed with one distributing all the loads to the jambs and the other distributing a portion to the header so as to provide a conservative design for each.

For a window opening (*Figure 6*), the distribution could be to just the jambs for short windows (length), and to just the head and sill for long windows. The aspect ratio of the wall areas above and below the window will dictate how the loads distribute. Again, two analyses may be required, one to maximize the load on the jambs for their design and one to design the header and window sill. The axial load over the window is distributed similar to *Figure 4*.

Design

Based upon the load distribution, we are now ready to design the masonry. First we'll look at a solid strip of wall, and then the 3-foot, 4-inch pier area between the doors in *Figure 2* using 2006 *International Building Code* (IBC) for loads and the 2005 MSJC (ACI 530/ASCE 5/TMS 402) referenced masonry standard.

For this example, the design assumptions are:

1) The CMU is 12-inch CMU. Assumed wall weight = 63 psf (NCMA TEK 14-13A using 125 pcf units and grout at 48 inches on center). For lateral load effects on the wall, it is better to underestimate the expected weight because the weight, compensates for the flexural tension.
2) Type S mortar.
3) f'_m = 2000 psi ; E_m = modulus of elasticity = 900 f'_m = 1.8 x 10^6 psi.
4) Grade 60 reinforcement. E_s = modulus of elasticity = 29 x 10^6 psi.
5) Modular ratio = n = E_s/E_m = 16.1.
6) Lateral load = 30 psf (assumed component and cladding wind load). If designing for seismic, base the lateral loads on a higher estimated wall weight than is used for the vertical loads to be conservative.

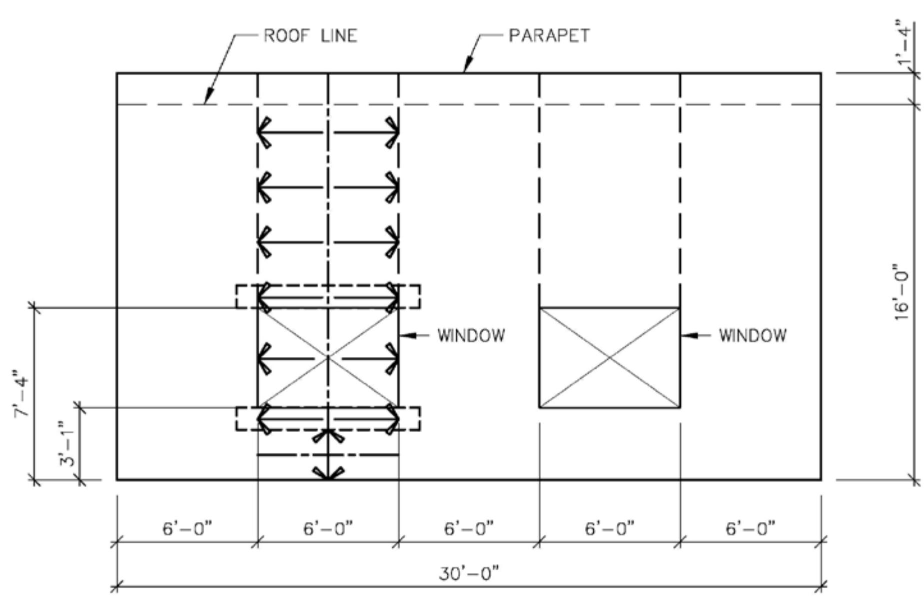

Figure 6: Lateral load distribution at windows.

7) Allowable Stress or Strength design methods can be used. For this example, we will use Allowable Stress.
8) Loading Combination: Check all combinations. For this example, we will only evaluate 0.6 D+W.
9) The wall is non-loadbearing. By MSJC definition, a bearing wall carries more than 200 lbs/ft in addition to its own weight.
10) The reinforcement is placed in the center of the wall, except two layers can be used for economy of grouting in 12-inch walls. Lintels and headers are masonry, not steel.

While we are interested in the pier, it is advisable to first design a section of solid wall (no openings) to form a basis for comparison. *Figure 7* shows the lateral load diagrams for a 1-foot section of wall. The axial load at maximum moment is P = 63psf x (17.33 – 7.93) = 592 lb/ft.

Based upon the loading combination 0.6D + W, the design loads become P = 355 pounds per foot and M = 946 foot-pounds per foot. This would result in reinforcing of #5 @ 40 inches on center if the axial load is ignored, and #5 @ 48 inches on center if the axial load is included. While it is not common to include axial loads in a non-loadbearing wall design, the effects of the dead weight can have a significant effect on the amount of reinforcing. The design calculations are not provided here. Refer to the *Masonry Designers Guide* (available at **www.masonrysociety.org**) or a masonry textbook for the techniques for designing load bearing and non-loadbearing walls for out-of-plane loading.

For our pier design, we first check the MSJC 1.6 Definitions to determine whether the pier is technically a wall element or a column. For our example, the pier exceeds 3 x t (wall thickness). Thus, the pier design that follows is for a wall (no stirrups are required and the vertical bars do not take compression). Had it been less than 3 x t, the pier would be designed as a column with tied stirrups using the vertical bars in compression. The lateral load diagram is similar to *Figure 7* except the loads are factored by 11 based upon contributory width (3.33 ft /2 for personnel door + 3.33 ft for the pier + 12 ft /2 for the overhead door). Therefore, the design M = 10,406 pounds for the entire pier. The axial load (wall weight) on the pier at maximum moment (7.93 feet above the foundation) is 4,977 pounds.

The engineer should consider a couple of items. The first is the affect of the lintels. If steel beams are used over openings, the bearing into the pier could narrow the effective width of the pier such that you should consider the pier as a column. For this example, masonry beams are used as headers so as to not reduce the effective pier size. A second concern is the distribution of the loads into the pier. For this example, 3 feet, 4 inches was used for the pier. What would have been the design if the pier was large, say 10 feet? In that case, the jambs adjacent to the openings would be designed for concentrated vertical and lateral loads. Usually, the distribution adjacent to the opening is half the typical bar spacing of a solid wall section but not to exceed 3t (3t being half the allowable bar spacing of 6t for a partially grouted, fully reinforced wall).

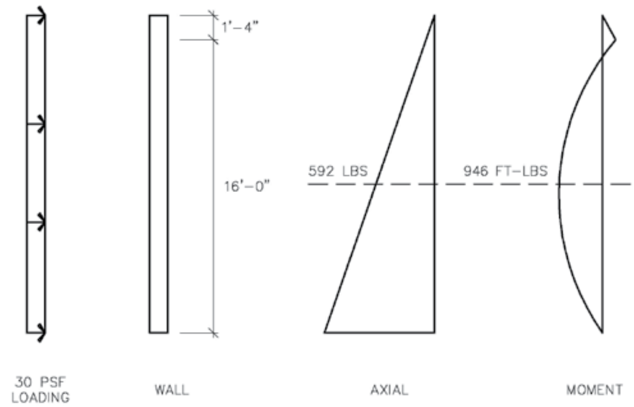

Figure 7: Loading diagrams for 1-foot section of wall.

Based upon the loading combination 0.6D + W, the design loads become P = 2,986 lb and M = 10,406 ft-lbs. These loads are for the entire pier width. These result in pier reinforcing of 3 – #5 in the center of the pier and a fully grouted pier. An alternative would be to use two layers of bars and less grouting. However, a solid grouted pier is advisable for a pier adjacent to an overhead door that receives truck traffic. The calculated results are not unreasonable given those for the solid wall.▪

In Part 2, we will use computer software to solve the same problem and compare the results.

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