Perforated Masonry Walls

Part 2: Wall Design Software

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In Part 1 of this series of articles (STRUCTURE magazine, May 2011), we discussed the load distribution for out-of-plane loads on perforated walls and performed the calculations for an example. In Part 2, we transition into the use of commercially available software and then solve the same example for comparison of the methods.

Wall Element Analysis

There are several software products that design masonry elements. One is the National Concrete Masonry Association (NCMA) *Structural Masonry Design System, Masonry 4.1*. It is possible to obtain a design for the solid wall and the pier. This program analyzes walls for out-of-plane and in-plane effects, columns, and lintels. The wall portion of the program does not allow for parapets for out-of-plane lateral loads; however, the weight of the parapet can be included as an added vertical load at the top of the wall. The same masonry properties were used for both methods, except that the program calculated the wall weight.

For the solid wall, the results are given in *Table 1* along with the results of the hand calculations (See *Perforated Masonry Walls, Part 1*).

The software was directed to evaluate the 48-inch grout spacing using #5 bars. It did not produce its own design. The software is primarily being used as an analysis tool.

Both methods require a trial and error procedure of assuming the grout and reinforcement spacing, and then analyzing the wall. The results are iterated until the allowable stresses are met. This is repetitious and tedious by hand, but faster using the program. For the software, the key is understanding the limitations of the program and staying within these limits. The size of the parapet in this example was not significant to affect the results.

The program does not directly design piers adjacent to openings. Piers have to be treated as an equivalent 1-foot width of a wall. The engineer must determine the loads on the pier and factor them to represent an average load per foot of width for the pier. Thus, it is not surprising that the hand calculations and this software provide similar results, because the software is simply using the hand-calculated loadings to analyze the strip of wall. The only significant difference is attributed to the effects of the parapet reducing the moment in the hand calculations.

Based upon the hand calculations, the design loads are P= 2986 pounds / 3.33-foot pier = 897 pounds per foot, and M = 10,406 foot-pounds / 3.33-foot pier = 3,124 foot-pounds per foot = 37,488 inch-pounds per foot. These loads must be input for the specific load combination to be checked. Using these values in the program, the

Table 1: Out-of-plane results for a solid strip of wall.

Method	Wall weight (psf)	Maximum moment (ft-lbs)	Design axial load at maximum moment (lbs) = 0.6D	Location of maximum moment from the foundation (ft)	Reinforcement
Hand	63	946	355	7.93	#5 @ 48 inches
NCMA	62.4	957	337	8.48	#5 @ 48 inches

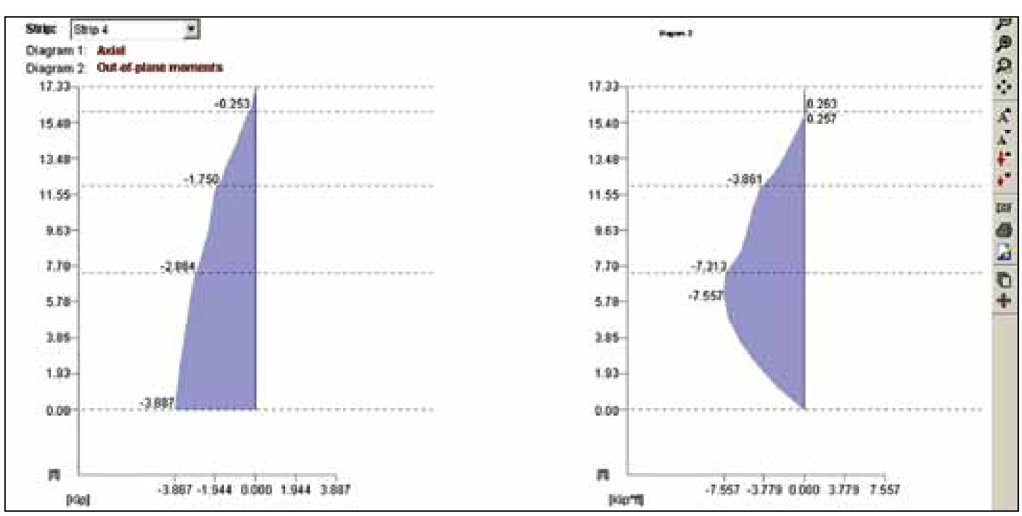

Figure 8: Strip of solid wall.

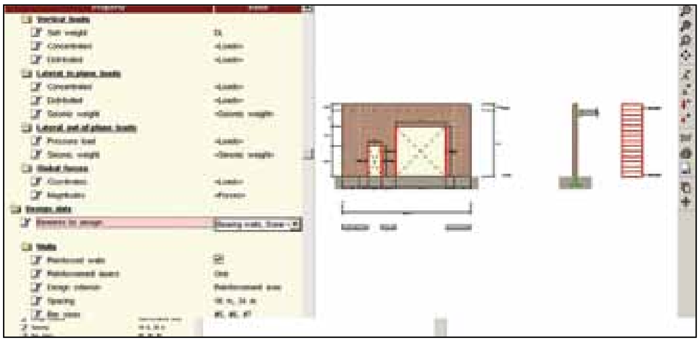

Figure 9: Wall model.

Figure 10: Loading combinations.

results come out to #4 @ 8 inches on center. The program can only accommodate 8-inch increments for reinforcement spacing. For a 3-foot, 4-inch pier, the total steel would be 5–#4 which is approximately equivalent to 3–#5 determined by hand.

The software removes the tedious repetitive calculations that are required by hand; however, for piers, every load combination must be generated by hand to use the software.

Finite Element-Based Design

There are several software products that analyze shells using finite element analysis. While there are drawbacks, the technology for masonry is improving. RAM Elements (formerly RAM Advanse) from Bentley is one program that has incorporated a masonry design module. It allows a wall segment to be designed with openings. The wall analysis is based upon linear elastic shells.

First assuming a solid wall (no openings), the design loads obtained from the software for 0.6D + W are axial load 320 pounds per foot (at mid height) and M= 938 foot-pounds per foot (*Figure 8*). The wall weight is equal to 58.5 psf. The reinforcement generated is #5@48. All values are comparable to the hand and element software.

Figure 9 shows the model of our wall using v9.5.1 of the software.

The input allows for selection of partial or full grouting, bar size selection, masonry strength, and more. Loading cases and combinations can be input or generated. *Figure 10* shows the 0.6D +W combination used throughout this article.

This software designs the entire wall, not just one element at a time. It does not distribute the wall loads at openings unless the engineer makes that choice in the configuration. When set, the distribution is as shown in *Figure 11*.

For the wall element being considered, *Figure 12 (page 28)* shows the segmentation created by the program. Extra strips were added on the left side of the personnel door and on the right side of the overhead door, in the event that we wanted to look specifically at the jambs. Segments 3, 9, and 15 between the doors represent the pier under discussion.

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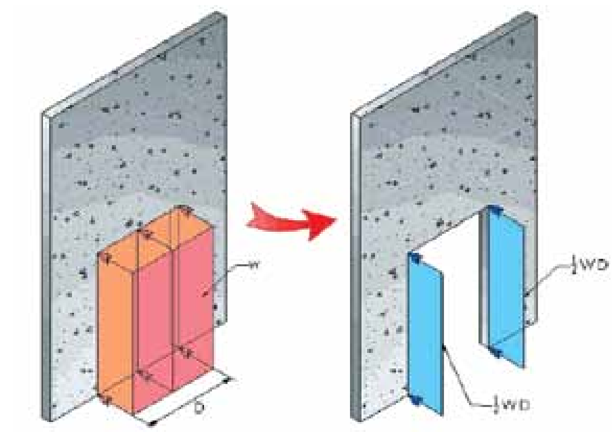

Figure 11: Lateral load distribution at openings.

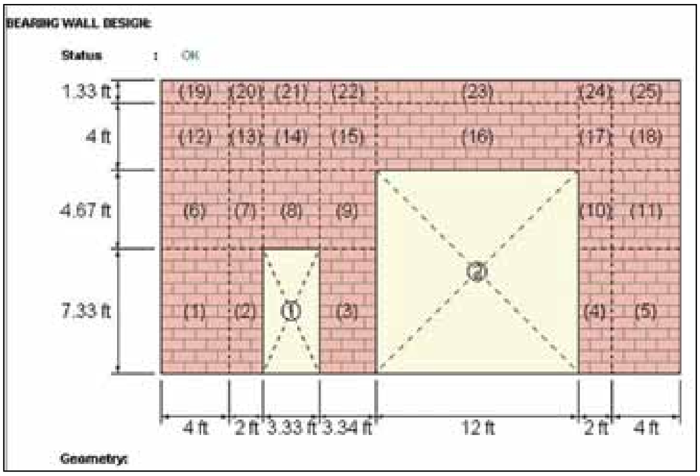

Figure 12: Wall segmentation.

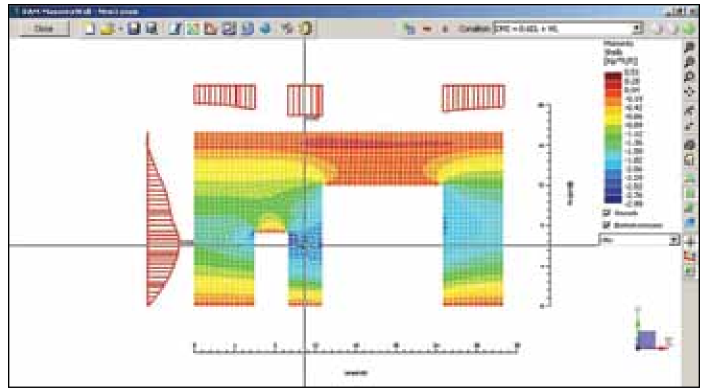

Figure 13: Finite element results.

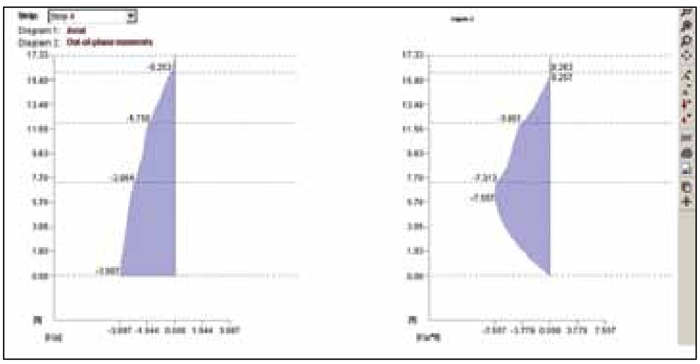

Figure 14: Pier loading.

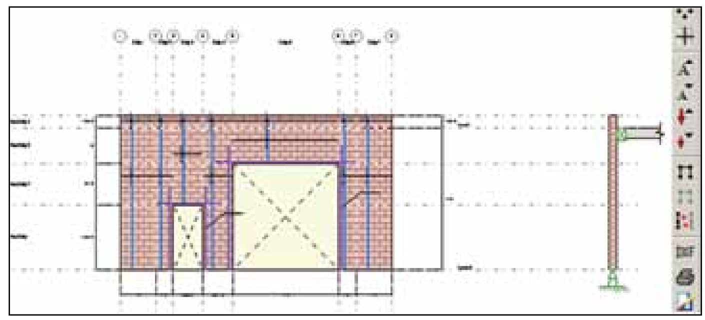

Figure 15: Wall detailing.

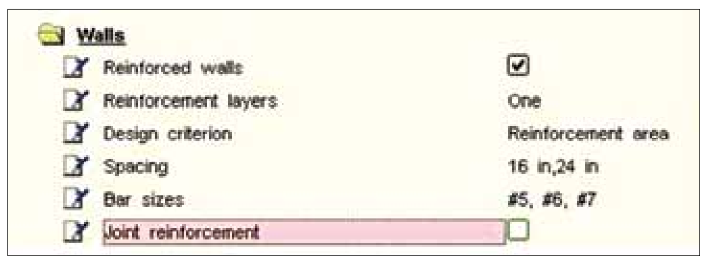

Figure 16: Design criteria.

Figure 13 shows the finite element results for the out-of-plane bending moment in the wall. The dark-blue area of the pier has the highest stress.

Figure 14 shows the axial load and moment diagrams for the pier for the 0.6D + W load combination.

The program produces a design axial load of 2.87 k, a moment of 7.6 ft-kips, and reinforcement of 3–#5. The wall is grouted at 16 to 32 inches on center. Note that the shell analysis produces a lower design moment than was determined by hand. Since this is a two-way analysis, some of the moment was distributed to the stiffer end segments. *Figure 15* shows the wall detailing with reinforcement for the entire wall including the pier.

The program uses an equivalent thickness method to determine an equivalent weight of 66.5 psf. It also gives several options for sizing the reinforcement. The engineer can control either the bar size or the bar spacing. This example was developed using the criteria shown in *Figure 16*.

Table 2: Out-of-plane results for a solid strip of wall.

Method	Wall weight (psf)	Maximum moment (ft-lbs)	Design axial load at maximum moment (lbs) = 0.6D	Location of maximum moment from the foundation (ft)	Reinforcement
Hand	63	946	355	7.93	#5 @ 48 inches
NCMA	62.4	957	337	8.48	#5 @ 48 inches
Finite element	58.5	938	320	8.0	#5 @ 48 inches

Summary

For the solid wall, the three methods described give comparable results (*Table 2*).

For the perforated wall, the load distribution varies between the methods but the reinforcement results are the same (*Table 3*).

Perforated walls are a challenge, but using some of the developing software, the design time can be shortened.▪

Table 3: Out-of-plane results for a wall pier for the perforated wall.

Method	Maximum moment (ft-lbs)	Design axial load at maximum moment (lbs) = 0.6D	Reinforcement	Grout
Hand	10,406	2,986	3 - #5	Solid pier
NCMA	10,406	2,986	3 - #5	Solid pier
Finite Element	7,557	2,870	3 - #5	Partial grouting