

SOFTWARE FOR THE STRUCTURAL DESIGN OF CONCRETE MASONRY

TEK 14-17A
Structural (2010)

INTRODUCTION

Structural design of masonry can be tedious and complex. Software allows the design professional to quickly determine designs that work and therefore optimize solutions. This TEK describes the capabilities of Version 5.0 of *Structural Masonry Design System* software (ref. 1). The software includes the design of walls loaded out-of-plane, walls loaded in-plane (shear-walls), masonry and precast concrete lintels, and columns. Both concrete and clay masonry elements can be designed using either allowable stress design (ASD) or strength design (SD) using various editions of *Building Code Requirements for Masonry Structures* (MSJC) (1995, 1999, 2002, 2005 or 2008) and the *International Building Code* (IBC) (2000, 2003, 2006 or 2009) (refs. 2, 3). The software also includes Alternative Basic Load Combinations that permit the use of the one-third stress increase in allowable stress design per the IBC. See *Strength Design Provisions for Concrete Masonry*, [TEK 14-4B](#), and *Allowable Stress Design of Concrete Masonry*, [TEK 14-7B](#), (refs. 6, 7) for information on these design methods.

The engineer may specify the critical design forces or may choose to have them calculated from specified design loads, boundary conditions and dimensions. In the latter case, load combinations are calculated at very small intervals along the wall, and the critical design forces are determined and reported. Note that although dual units are shown in the text of this TEK, the software itself uses inch-pound units only. Finally, printable documentation is provided for inclusion in design calculations that may be submitted to building officials or to archive designs.

The software is limited to hollow unit masonry in single wythe construction, but the masonry can be fully or partially grouted (including ungrouted), and reinforcement may be included within grouted cells. The reinforcement

location is specified by the user and may be off-center when an increase in effective depth is desired, such as for retaining wall construction.

THE DESIGN BASIS

The "Design Basis" icon located on the toolbar allows the designer to select material properties and design codes for all elements in a structure at one time without having to redefine them for each element (such as lintels, shear walls and columns). Figure 1 shows the "Design Codes" tab in the "Design Basis" window. The building code, design criteria (strength design or allowable stress design), type of masonry (concrete or clay), concrete building code (for precast concrete lintels) and design criteria are selected on this tab.

Figure 2 illustrates the options available for selecting

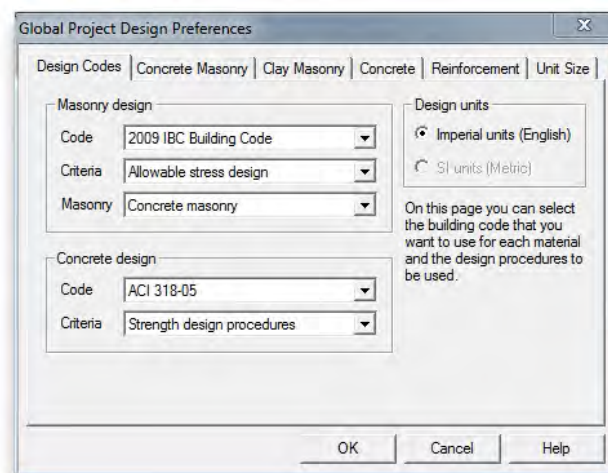


Figure 1—Design Basis—Building Code

Related TEK:

[14-4B](#), [14-7B](#), [17-1C](#),
[17-2A](#), [17-3A](#), [18-1A](#)

Keywords: allowable stress design, columns, interaction diagram, in-plane loads, lintels, out-of-plane walls, plain concrete masonry, reinforced concrete masonry, shear walls, single wythe walls, software, strength design, structural design, walls

hollow concrete masonry unit properties as well as the mortar used with concrete masonry. The unit length and height are specified by the engineer because the spacing of reinforcement depends on unit length, and the height of masonry courses in lintels depends upon the unit height. Density of the material used in making the units is needed to calculate the masonry weight. Specified masonry compressive strength, f'_m , is entered by using either the unit strength method or the prism test method (see Reference 5 for information on masonry compressive strength). In the unit strength method, it is not necessary to test prisms to determine compliance with f'_m , so that is the option most often used. In Figure 2, a unit strength of 1,900 psi (13.1 MPa) with Type S mortar results in an f'_m of 1,500 psi (10.3 MPa) based on the unit strength method.

Unit size is specified on the "Unit Size" tab shown in Figure 3. The default values correspond to the minimum face shell and web thicknesses required by the applicable ASTM Standard. Sometimes units with thicker face shells

and webs are desired, such as for fire ratings or sound attenuation. Engineers can now take advantage of the additional material in these cases by increasing the default values. Section properties and wall weights are adjusted in accordance with the selected web and face shell dimensions.

After specifying the design basis, the engineer is ready to select the type of component to be designed – lintel, wall with out-of-plane loads, wall with in-plane loads (shear wall) or column. The type of component is chosen using the "Design" drop-down menu just over the left tool bar or by using the appropriate icon on the tool bar.

WALL DESIGN

Walls can be designed as either reinforced or unreinforced. Strength design of walls loaded out-of-plane includes the P-Delta effect if the wall is reinforced, including walls with boundary conditions other than simply supported. Graphical information makes it easy to quickly converge on an economical design.

The software takes full advantage of code provisions that optimize the design by using the beneficial effects of axial load on the moment capacity. Partially grouted construction is included as an option in the software to minimize the amount of grout required in reinforced masonry construction. Shear walls can be designed with special end-zone reinforcement that greatly increases the bending capacity of the wall with minimal increase in reinforcing steel area. Earth retaining structures can be designed with reinforcement placed off-center to optimize the capacity of retaining walls and basement walls.

WALLS WITH OUT-OF-PLANE LOADS

If "Wall Design for Out-of-Plane Load" is selected, Figure 4 will appear. The three tabs at the top of the window are "Design Data," "Construction Data" and "Load Data." "Design Data" includes the forces at the design section. The engineer can calculate these forces at the section assumed to control the design and specify them, or if the "Compute using load data" box is checked, the software will calculate the design forces based on information the engineer specifies on this and other tabs in the "Design" window. In this mode, the software divides the wall into one hundred increments along its height and designs for all required load combinations at each increment. This ensures that the critical design section and load combination is used in the final design. The engineer can select reinforced or unreinforced masonry and boundary conditions with the dropdown menu.

Use of the one-third stress increase button is limited to allowable stress design (ASD) when "Compute Using Load Data" is not selected. When "Compute Using Load Data" is selected, the software automatically uses the one-third stress increase for load combinations for which it is permitted (MSJC ASD and IBC ASD with alternative

Figure 2—Concrete Masonry Properties

Concrete Masonry				Clay Masonry			
Nominal Width	Width	Face Shell	Web	Width	Face Shell	End Web	Middle Web
4" Units	5.625	1	1	3.625	0.75	0.75	0.375
6" Units	7.625	1.25	1	5.625	1	1	0.375
8" Units	9.625	1.25	1.125	7.625	1.25	1	0.375
10" Units	11.625	1.25	1.125	9.625	1.375	1.125	0.375
12" Units	13.625	1.25	1.125	11.625	1.5	1.125	0.375
14" Units	15.625	1.25	1.125				
16" Units							

Figure 3—Design Basis—Unit Size

basic load combinations only). Display options include "Design Calculations," "Interaction Diagram" or "Calculated Loads."

The "Construction Data" tab (Figure 5) allows the engineer to specify the wall thickness, wall height, location of reinforcement (centered or off-center), grouting (full or partial), bond pattern (running or stack), and horizontal spacing of reinforcement. Default values are recommended until an initial trial design is performed. Then these values

Wall Design for Out-of-Plane Loads

Design Data | Construction Data | Load Data

Forces at design section

V 6.47499620914459 lb/ft

M -7652.35202183532 lb-in / ft

P 485.12736 lb / ft

e -0.65549797067 in

☒ Compute using load data

Design criteria

2009 IBC ASD Code

Reinforced Masonry Wall

Simply Supported Wall

Reinforcement

Use #5 Bars (A=0.31, D=0.625)

Display results

Interaction Diagram

Family None

Design notes

OK Cancel Help

Figure 4—Design Data Tab for Out-of-Plane Walls

Wall Design for Out-of-Plane Loads

Design Data | Construction Data | Load Data

Wall masonry units

8 in. CMU (t=7.625 in.)

Wall construction dimensions

t 7.625 in.

x 3.8125 in.

H 16 ft. 0.00 in.

L Length is not required

Wall construction and spacing

Construction

Partial grout, running bond

Reinforcement and grout spacing

48 in. on center

Wall design dimensions

H 192 in.

OK Cancel Help

Figure 5—Construction Data Tab for Walls Loaded Out-of-Plane

can be quickly changed to arrive at an optimum design.

Partially grouted construction requires that only the cells receiving reinforcement are grouted. In the example shown in Figure 5, with a grout spacing of 48 in. (1,219 mm), every sixth cell is grouted and the five cells in between are not. This can save significantly on grouting costs. Mortaring of the cross-webs is required adjacent to the grouted cells, however, and is included in the section properties for analysis. The internal calculations for partially grouted construction are rigorous. Performing such calculations by hand would be tedious and time-consuming, but the software does them almost instantaneously.

The value of x enables the engineer to position the reinforcing steel within the wall. The default location is the center of the wall, which is most common since most lateral loads such as wind and earthquake are reversible. However, in cases of lateral loads from soil, placing the steel farther from the soil (or, in the case of cantilever construction, closer to the soil) increases the effective depth of the reinforcement and can result in significant savings.

If unreinforced masonry is selected in the "Design Data" tab, then another option in the "Construction" drop-down menu is "ungROUTED."

When a bar spacing is selected that exceeds six times the wall thickness or 72 in. (1,829 mm), the software uses only that width in conjunction with a single bar to calculate the wall resistance. A message will appear to notify the engineer in this case.

The "Load Data" tab (Figure 6) permits the engineer to specify various loads (dead, live, wind, etc.). As shown in the inset drawing in Figure 6, loads can be axial (with or without eccentricity), lateral distributed loads (such as wind or earthquake) that can vary with height (as with earth

Wall Design for Out-of-Plane Loads

Design Data | Construction Data | Load Data

Dead | Live | Soil | Fluid

Wind | Seismic | Roof | Rain | Snow

Lateral loads

W1 -20 psf

W2 -20 psf

h2 192 in

L 0 lbs / ft

h1 0 in

Axial load

P 0 lbs / ft

e 0 in

Wall design dimensions

H 192 in.

OK Cancel Help

All loads specified are unfactored service loads. The individual load components will be combined to form load combinations according to the design code selected.

Figure 6—Load Data Tab for Walls Loaded Out-of-Plane

retaining walls), and concentrated lateral loads. Loads can be positive or negative. The directions of the loads shown in the inset in Figure 6 are positive in the directions shown. Depending on the code selected and whether ASD or SD was selected, the software uses the appropriate set of load factors and load combinations to conduct the design if the "Compute using load data" box is checked on the "Design Data" tab (Figure 4).

If "Interaction Diagram" was selected on the "Design Data" tab, it will be displayed. When "Family" is selected, the interaction diagram (Figure 7) allows the designer to quickly select the optimum bar spacing for the wall thickness selected. For example, in Figure 7, the different contours represent the interaction diagram for an 8 in. (203 mm) partially grouted wall with No. 6 (M#19) bars. Each contour corresponds to a different reinforcing bar spacing. The dots are the calculated or specified forces at the critical sections. By selecting any contour that encompasses all of the loading dots, an acceptable design for combined flexure and axial load results. The closer the dots are to the contour, the more optimum the design. Under "Family," if "none" is selected, only the single bar spacing selected is shown in the interaction diagram. Figure 8 shows the interaction diagram for a spacing of 48 in. (1,219 mm) only from the graph above where all of the loading dots clearly fall within the contour. The center of the loading dot must fall inside the contour, not its outer periphery.

If no satisfactory contour is displayed, the engineer can either select different bar sizes or different wall thicknesses. When a satisfactory wall design is determined from the interaction diagram, the "Design Calculation" display can be selected. The information on the design calculation page is intended to

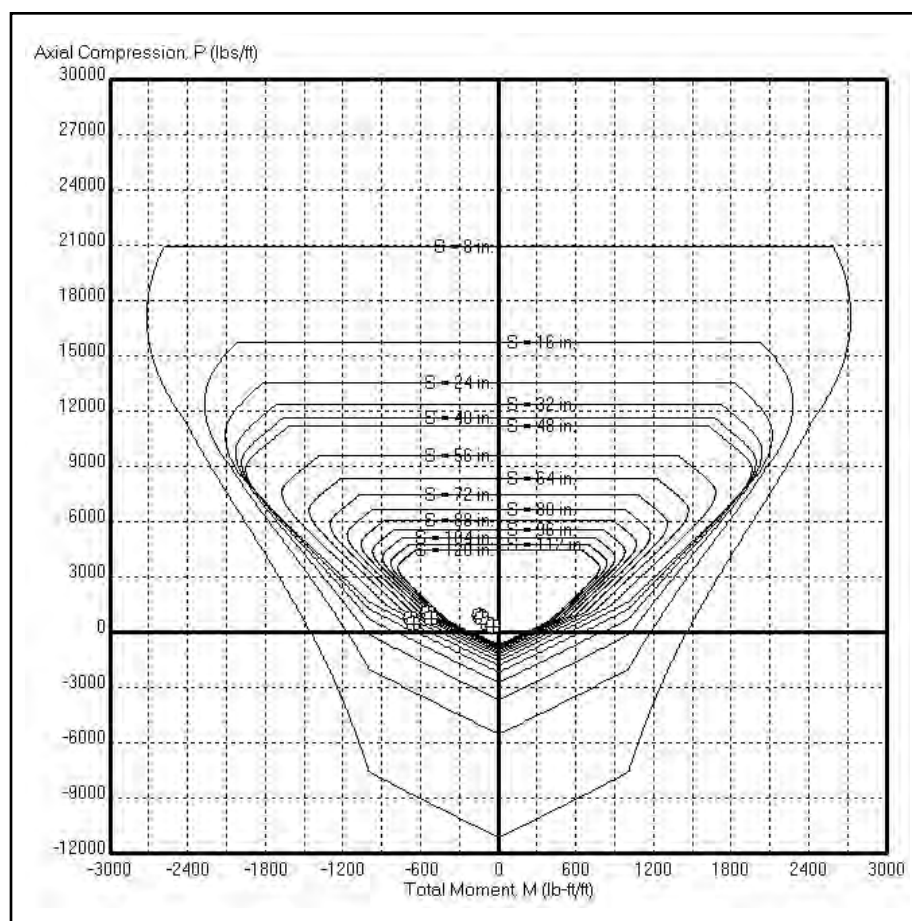


Figure 7—Interaction Diagram, Family of Curves

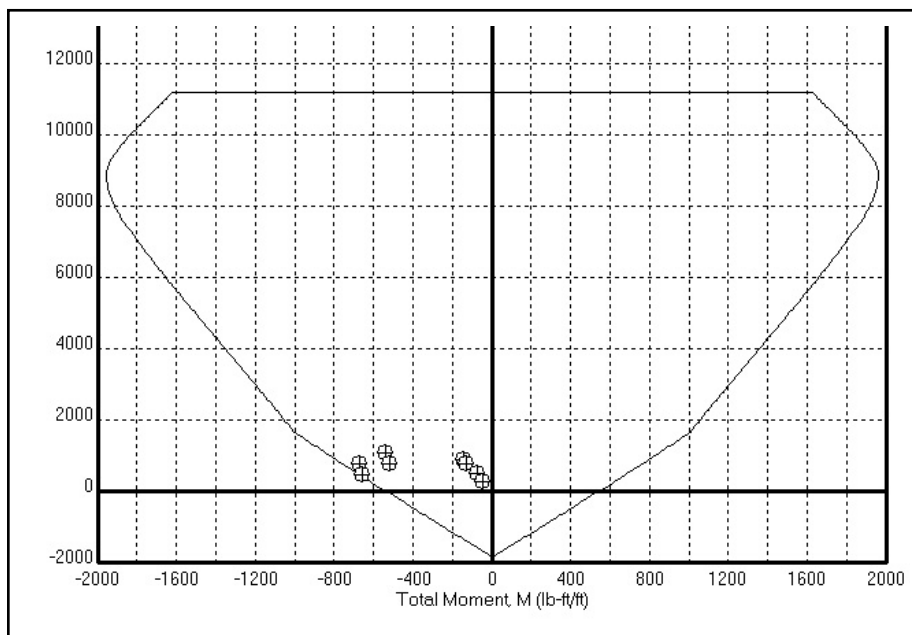


Figure 8—Interaction Diagram for Reinforcement Spacing of 48 in. (1,219 mm) Only

provide the engineer with more detailed information including shear design and reinforcing bar development and splice lengths. Specified design data is presented in a format intended to be suitable for submitting to building officials. Files can be easily saved electronically as well.

SHEAR WALL DESIGN

If “Wall Design for In-Plane Load” from the “Design” drop-down menu or icon at the top and the “Reinforce-

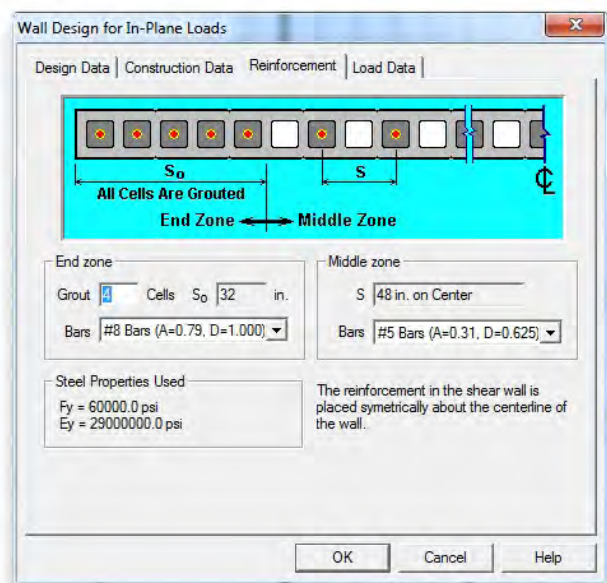


Figure 9—Reinforcement Tab for Shear Wall Design

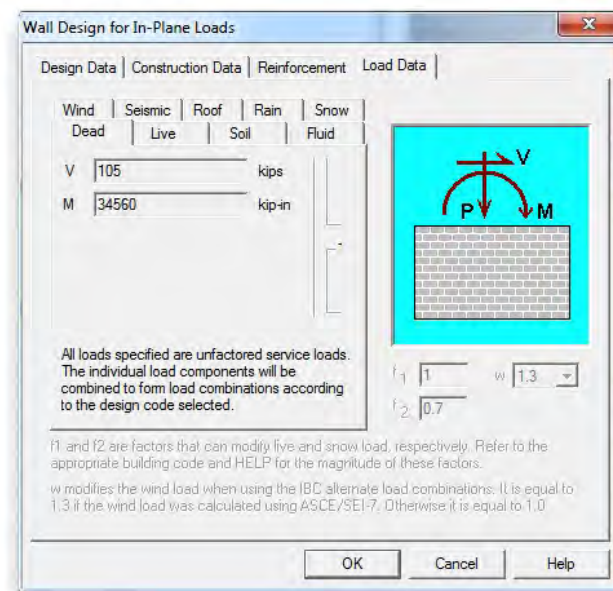


Figure 10—Load Data Tab for Shear Wall Design

ment” tab are selected, Figure 9 will appear. An end zone can be included in a shear wall to increase its moment carrying capacity with little increase in reinforcing steel. Reinforcement placed in such an end zone is subjected to higher stress than interior bars, and these steel forces have a larger lever arm than those for interior bars. End zone steel significantly increases moment capacity with little impact on the maximum area of reinforcement limitations in strength design and allowable stress design. All of the cells in the end zone are reinforced and grouted, whereas cells in the middle zone can be partially grouted and reinforced with different sized bars.

Loading for shear walls is specified in the window displayed when the “Load Data” tab is selected (Figure 10). The engineer specifies the shearing force, the bending moment, and the axial load at the top of the shear wall and the software internally calculates the forces at other locations. Walls with openings are not included in the design. However, a pier between two openings can be designed as a shear wall if the forces are determined using some other method, such as a finite element program.

After all information is entered, the interaction diagram can be displayed to determine if the wall has adequate capacity (see Figure 11). Since all of the loading “dots” fall inside the interaction diagram, the wall is satisfactory for flexure and axial loads.

Once a design is found that satisfies the interaction diagram, select “Design Calculations” on the “Design Data” tab, and Figure 12 is displayed. Only a portion of the design calculation output is shown in this figure. The critical loading combination and location for flexure and

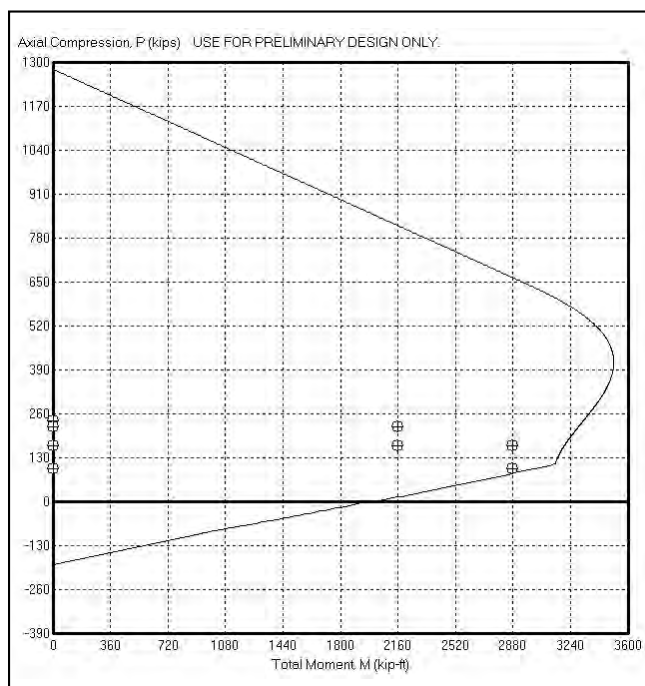


Figure 11—Interaction Diagram for Shear Wall

Controlling load case for bending moment: $0.6D + H + W$
 Controlling x/H ratio for bending moment: 0
 $M = 34560 \text{ kip-in (2880 kip-ft)}$
 $V = 105 \text{ kips}$
 $P = 100.199 \text{ kips}$
 Controlling bending moment capacity: $36300.71 \text{ kip-in (3025.06 kip-ft)}$

Controlling load case for shearing force: $D + W$
 Controlling x/H ratio for shearing force: 0
 $M = 34560 \text{ kip-in (2880 kip-ft)}$
 $V = 105 \text{ kips}$
 $P = 166.998 \text{ kips}$

The following design calculations are for the section with controlling bending moment.

Section Design Forces Used
 $V = 105 \text{ kips (Computed from Loads)}$
 $M = 34560 \text{ kip-in (Computed from Loads)}$
 $P = 100.2 \text{ kips (Computed from Loads)}$

Computed Design Values

Wall Flexural Design Data
 Maximum $P = 751 \text{ kips (MSJC 2.3.3.2)}$
 $M = 3.63e+004 \text{ kip-in (3025 kip-ft) for Design P}$

Wall Shear Design Data
 Design as a normal shear wall.
 $f_v = 0.04148 \text{ ksi (MSJC 2.3.5.2.1)}$
 $M/Vd = 3.456e+004 / (105 * 332) = 0.9914$
 $F_v = 0.03539 \text{ ksi without reinforcement (MSJC 2.3.5.2.2)}$
 $F_v = 0.05826 \text{ ksi with reinforcement (MSJC 2.3.5.2.3)}$
 $A_v/s = 105 / (2.4e+004 * 332) = 0.01318 \text{ (MSJC 2.3.5.3)}$

Figure 12—Design Calculations Output for Shear Wall

axial load are shown along with the applied loads and capacities. The same information is also shown for the critical shear case. When shear reinforcement is needed, suggested horizontal bar sizes and spacings are also displayed.

LINTEL DESIGN

Lintels also can be designed according to the MSJC, the IBC or, in the case of reinforced concrete lintels, the ACI 318 (2002, 2005 or 2008) Code (References 8 and 9 provide an overview of concrete masonry and reinforced concrete lintel design, respectively). As with walls, the critical shearing force and bending moment can be entered directly or the software can compute them from specified load data and dimensions. Stirrups can be used to resist shear forces if the masonry or concrete alone is not sufficient. Lintel deflections are also displayed for service dead and live loads. Service level loads are used for deflection calculation even if strength design is used to proportion the lintel.

The “Lintel” icon or the “Design” drop-down menu is used to activate lintel design. The “Design Data” tab (Figure 13) will first appear. The design shear and moment can be input by the designer, or, if “Compute using load data”

Figure 13—Lintel Design Data Tab

Figure 14—Lintel Construction Design Data Tab

is selected, the software will calculate the critical values of shear and moment based on input loads and geometry. Dimensions (b , d and h) are calculated by the software, not input by the user. Cover and distance from the bottom of the reinforcing steel to the bottom of the lintel (X) must also be input. The variable X is included to accommodate masonry bond beam units (units with recessed webs) used as a bottom course of the lintel. When these units are used, the reinforcement must be significantly farther from the bottom of the lintel or, if the architectural features of the unit permit, it can be placed upside down in the wall with the longitudinal reinforcement tied to hold it up in place.

Under “Type and Exposure,” the type of lintel (masonry or precast concrete) and exposure to weather are selected. Finally, the bar size designation for longitudinal reinforcement and stirrup size and configuration are selected.

Under “Construction Data” (Figure 14), the user inputs the thickness of the wall in which the lintel is embedded along with bond pattern, extent of grouting in the masonry above the lintel, and whether or not arching is to be used. If the ratio H/L is too small or if the masonry is not constructed in running bond, arching will not be used regardless of whether the box is checked. Wall weight is displayed based on material densities selected in “Design Basis” and on extent of grouting.

Using “Lintel construction preferences,” the user can affect the dimensions calculated by the software. A minimum and maximum number of courses and maximum number of longitudinal reinforcing bars can be chosen from drop-down menus. Also, the user can select whether or not shear reinforcement is to be used. If it is, the required width of the lintel to accommodate the stirrup and longitudinal reinforcement will be significantly increased. Finally the values of H , L and B are entered under “Construction Dimensions.”

The “Load Data” tab is needed only if “Compute using load data” is selected on the “Design Data” tab. Three types of loads are permitted: uniform, joist and point loads. The location of each type of load must also be input. For example, a uniform load does not have to span the entire opening. In this case, the value of S_w and S_o are used to define where the load starts and stops. The self weight of the lintel and the wall above it are calculated by the software and are not to be included in the user input value of dead load.

When all data is entered, selecting OK prompts the design calculation sheet to appear (Figure 16). In addition

Lintel Design

Design Data | Construction Data | Load Data

Uniform Load | Joist Load | Point A | Point B | Point C

Uniform load data

Dead	400	plf
Live	300	plf
Roof	0	plf
Snow	0	plf
Rain	0	plf

Position

S_o	0	in.
S_w	152	in.

This data sheet is used to specify the uniform loads acting on the lintel and the position of the loads relative to the lintel.

f_1 1 f_2 0.7 f_1 and f_2 are factors that can modify live and snow load, respectively. Refer to the appropriate building code and HELP for the magnitude of these factors.

OK Cancel Help

Figure 15—Lintel Design Load Data Tab

tion to displaying the input, the lintel sizes (b , d and h) are displayed along with the required area of steel and number of reinforcing bars. Moment capacity, deflection and lap splice and development lengths are also provided.

COLUMN DESIGN

Column provisions are very similar to those for shear wall design (Reference 10 provides an overview of masonry column design), with the main difference in the “Reinforcement” tab (Figure 17). The user can specify up to eight layers of reinforcing steel in a concrete masonry or clay masonry column. Columns are assumed to be symmetric, so only four of the eight layers need be identified. In the example shown in Figure 17, the column has four layers of reinforcement. Note that the figure displayed is generic and is not indicative of the number of units or reinforcing bars used in the design. All cells including the central core are solidly grouted in the design. Layers d_1 are symmetric about the column's axis of bending and include three No. 7 (M#22) bars located at 5.4 in. (137 mm) on each side of the axis. Layers d_2 include two No. 7 (M#22) bars located

Required Cross-Sectional Dimensions

$b = 7.625$ in. (Specified)
 $x = 1.75$ in. (Specified)
 $h = 31.63$ in. (4 courses used)
 $d = 29.56$ in. (Computed for bars and dimensions specified)

Check Shear Capacity

Maximum Permitted $V = 8730$ lbs without stirrups
 OK – Shear capacity is acceptable

Compute Required Steel Area

Computing balanced conditions
 $K_b = 1 / [1 + 24000 / (21.4815(500))] = 0.3092$
 $J_b = 1 - 0.3092/3 = 0.8969$
 $d_b = \text{sqrt}[(2(291843)) / (500(0.3092)(0.8969)(7.625))] = 23.5$ in

Section is under-reinforced – F_s controls

Conditions for this section

$K = 0.2529$
 $J = 1 - 0.2529/3 = 0.9157$
 $A_s = 0.449$ sq.in (Required)

Use 2 #5 Bars (A_s Provided = 0.62 sq.in)

Final $K = 0.2897$
 $M_{max} = 397409$ lb-in
 $I_{cr} = 7469.05$ in⁴
 $M_{cr} = 152521$ lb-in
 $I_{eff} = 9271.69$ in⁴
 Maximum deflection = -0.06215 in.

Maximum allowable deflection at $L_e/240 = 0.6667$ in.
 Maximum allowable deflection at $L_e/360 = 0.4444$ in.
 Maximum allowable deflection at $L_e/600 = 0.2667$ in.

Figure 16—Lintel Design Calculations Output

Layer	Number of bars	Distance From the Center
d ₁	8	5.4 in
d ₂	2	2 in
d ₃	0	0 in
d ₄	0	0 in

Reinforcement used and cover:

Longitudinal bars: #7 bars (d=0.875", A=0.600")

Horizontal ties: #3 bars (d=0.375", A=0.110")

Cover: 1.75 in.

There must be at least two bars in a layer, if bars are placed in a layer. A distance d of zero places the bar on the centerline of the column. The reinforcement is assumed to be symmetric about the centerline of the column parallel to the axis of bending.

Figure 17—Column Reinforcement Data

at 2 in. (51 mm) on each side of the axis.

Allowable stress design and strength design procedures are supported, and code provisions such as maximum axial load or maximum steel area are calculated. Interaction diagrams can be displayed and compared to calculated axial loads and bending moments. The shearing force capacity is also calculated and compared to calculated design shearing forces. If needed, shear reinforcement (in the form of column ties) can be used to resist shear forces.

SUMMARY

Software to structurally design masonry has the capability to design masonry elements constructed with either hollow concrete masonry units or hollow clay masonry units. Masonry elements include lintels, walls loaded out-of-plane, shear walls and masonry columns using the newest building codes (IBC 2009 and MSJC 2008). Elements can be designed using allowable stress design or strength design and, with the exception of columns and lintels, can be either reinforced or unreinforced.

A free trial version of the software is available for download at <http://www.ncma.org/Pages/StructuralMasonryDesignSoftware.aspx>.

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