DIRECT DESIGN SOFTWARE:

Masonry Structural Design Simplified

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Direct Design Software enables design of an entire masonry structure in minutes

Direct Design Software (DDS) is a structural analysis program for designing single and multi-story, reinforced concrete masonry buildings. The software provides a streamlined procedure for determining loads, analyzing load paths, performing design checks, and creating drawings, resulting in an economical structural masonry design with little effort. The core goals for this application included:

- Automation of the full structural workflow, from loads to analysis to design checks to drawings
- Support for the majority of common masonry building configurations
- Transparency of calculations, design assumptions and methodology
- Ease of use with a low learning curve
- A masonry-specific application, rather than a general-purpose application adapted for masonry
Brains …

DDS v3 generates structural concrete masonry designs in compliance with the 2015 edition of the *International Building Code*, which references the 2013 TMS 402, *Building Code Requirements for Masonry Structures*. The basis for the design loading requirements is the 2010 ASCE 7, *Minimum Design Loads for Buildings and Other Structures*. Where applicable, specific references to these standards are included in the reports generated by DDS.

Platform …

A building is modeled in DDS by defining its plan dimensions, number of stories and story heights, diaphragm properties, roof configuration, and locations of openings within each elevation. Optional modeling inputs include the placement of control joints, defining interior column lines, identifying openings for which arching action is permitted, presence of parapets, length of roof overhangs, eccentricity of floor and roof connections, and adding the self-weight of nonstructural cladding systems.
Design Parameters …

Design parameters that are common throughout a structural system, such as unit thickness, specified masonry compressive strength ($f'_m$), reinforcement yield strength, mean roof height, spectral accelerations, and basic wind speed are defined by the user for each project. DDS uses this information to determine design loads and their distribution throughout the structural system. The software does not perform designs for unreinforced masonry; all components will include a minimum amount of reinforcement regardless of design load to meet the minimum requirements for reinforced masonry in accordance with TMS 402.
Design Preferences …

DDS allows the user to indicate reinforcement preferences to achieve different code-compliant design solutions that fit varying project needs and conditions. Users can select different input preferences for the size of the vertical and horizontal reinforcement used in each story. Alternatively, users can select ‘Maximum Spacing’ of the reinforcement, in which case DDS will make largest bar spacing (and hence fewest bars) the highest priority, using the smallest bar size that will meet code requirements while still maintaining the large spacing. Users are also given the option to specify the use of bed joint reinforcement (BJR) as horizontal reinforcement for resisting out-of-plane flexure or meeting the minimum prescriptive horizontal reinforcement requirements of TMS 402.

Loading Analysis …

Based on the given building geometry and loading criteria, DDS calculates the lateral loads resulting from the main wind force, components and cladding, and seismic loads. Gravity loads resulting from user-defined dead, live, and snow loads are also distributed using conventional engineering mechanics. One of the primary goals in the development of DDS was the complete transparency of all design calculations, thus allowing users the ability to verify design loads and material resistance at any stage of design by checking the design reports. In order to validate the assumptions made when applying the loading provisions of ASCE 7 and for general due diligence, the structure is checked for both vertical and horizontal structural irregularities in accordance with ASCE 7.
Masonry Design …

Each concrete masonry element in the structure is designed using the Strength Design provisions of TMS 402. Design checks include: in-plane wall design, out-of-plane wall design, design of lintels and deep beams, header and sill panels and diaphragm chords. The software considers an exhaustive set of load combinations, considering varying load sources (e.g. wind and seismic), methodologies (e.g. both MWFRS and C&C for wind), and directions (e.g. both windward & leeward pressures for wind). Design results are shown in varying levels of detail to allow for anything from a quick, at-a-glance overview of status to an in-depth calculation review.

Available results displays include:

- **Status Overview.** Overall pass/fail indicators for each component (e.g. walls & lintels).
- **Check Summary.** For each component type (e.g. lintels), a summary table showing which checks passed and which failed, along with the most critical load combination.
- **Design Loads.** A table of factored loads for all load combinations.
- **Calculation Details.** Highly detailed calculations for each component, including all checks and loads combinations.

Nominal shear capacity:

\[ V_n = \left( V_{nm} + V_{res} \right) f_y = \left( (940.57 \text{ k}) + (0.00 \text{ k}) \right)(0.75) = 705.43 \text{ k} \]

[TMS 402-13 Section 9.3.4.1.2, Equation 9-21]

\[ 6A_m A_f f_y = \left( 6 (6,144.02 \text{ in}^2) \sqrt[1.0]{(2,500.00 \text{ psi})} \right)(0.75) = 1,382.41 \text{ k} \]

[TMS 402-13 Section 9.3.4.1.2, Equation 9-22]

\[ 4A_m A_f f_y = \left( 4 (6,144.02 \text{ in}^2) \sqrt[1.0]{(2,500.00 \text{ psi})} \right)(0.75) = 921.60 \text{ k} \]

[TMS 402-13 Section 9.3.4.1.2, Equation 9-23]

\[ V_{n,\text{limit}} = 1,028.70 \text{ k} \]

[Linearly interpolating between the values above]

Limit does not control

\[ \phi V_n = \phi \left( 705.43 \text{ k} \right) = 564.34 \text{ k} \]

[TMS 402-13 Section 9.1.3, 9.1.4.5]

\[ V_u = 97.13 \text{ k} \]

\[ \phi V_n \geq V_u \]

Code Compliance Checks …

Based on user defined inputs, DDS verifies all applicable aspects of the structural analysis comply with the 2015 IBC and provides a condensed report.
Reports …

DDS generates a full set of design and analysis reports, allowing for designers to drill into specific design details or review the results from a global perspective. In addition to producing the design calculations for each masonry element in the structure, DDS also graphically displays the resulting design, including reinforcing bar size and location, for each elevation. In cases where DDS cannot arrive at a code-compliant design, the software will flag the failing element(s) in the summary output and identify those elements with red hatching in the design elevation outputs.
These forces are shown below, along with the story's center of mass (49.22 ft, 45.79 ft) and center of rigidity (71.82 ft, 71.82 ft), with the center of rigidity being calculated using only the full-height segments identified earlier.

In the X direction, the applied force at level 6 is offset -26.03 ft from the C.R., resulting in a torsional moment of -798.34 ft·k.

In the Z direction, the applied force of 30.67 k is offset -22.60 ft from the C.R., resulting in a torsional moment of -493.07 ft·k.

Forces are distributed to each line according to relative rigidities as follows, conservatively neglecting non-additive torsional shear per standard practice. Per ASCE 7-10 12.8.4.2, 5% accidental torsion is also applied.

### Roof Level

Note that this is not considering wind to act in both of these directions at the same time; they are just illustrated together for convenience and conciseness.

#### Scenario: +X, +Z Wind

The design pressures calculated above are applied to the various surfaces at this level as appropriate, over a tributary height of 15.00 ft.

This level is a flexible diaphragm. Forces are distributed according to the tributary area for each line.

<table>
<thead>
<tr>
<th>Force Distributed To Line (k)</th>
<th>Grid line A</th>
<th>Grid line B</th>
<th>Grid line C</th>
<th>Grid line D</th>
<th>Grid line 1</th>
<th>Grid line 2</th>
<th>Grid line 3</th>
<th>Grid line 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid line A</td>
<td>4.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid line B</td>
<td>32.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid line C</td>
<td>32.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid line D</td>
<td>4.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid line 1</td>
<td>22.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid line 2</td>
<td>51.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid line 3</td>
<td>51.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid line 4</td>
<td>22.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The story beneath this one is a rigid diaphragm. The forces from the walls at this level will be imparted to that diaphragm. To facilitate calculations at that level, the resultant of these forces is determined to be 73.08 k (X), 146.74 k (Z) applied at (50.00 ft, 25.00 ft).

### Floor Level 2

The design pressures calculated above are applied to the various surfaces at this level as appropriate, over a tributary height of 12.00 ft.
Floor Loads Distribution

This section will display calculation of the resultant forces on walls from floor and roof pressures. In this context positive loads are downward and negative loads are upward.

Out-Of-Plane Wall Checks

Check Summary

For each check, this shows whether it passed or failed, the index of the critical load combination, and the ratio of the two critical values for comparison (usually required/ provided, e.g. M/3M). A ratio greater than 1.0 is failing. Load combinations are listed beneath the table.

<table>
<thead>
<tr>
<th>Check</th>
<th>Stress</th>
<th>Axial Force</th>
<th>P-M In</th>
<th>TMS Wall</th>
<th>IBC Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.073 (1) Pass</td>
<td>0.061 (1) Pass</td>
<td>0.000 (1) Pass</td>
<td>0.688 (6) Pass</td>
<td>0.013 (6) Pass</td>
</tr>
<tr>
<td>B</td>
<td>0.131 (2) Pass</td>
<td>0.076 (2) Pass</td>
<td>0.000 (2) Pass</td>
<td>0.477 (16) Pass</td>
<td>0.012 (16) Pass</td>
</tr>
<tr>
<td>C</td>
<td>0.000 (1) Pass</td>
<td>0.000 (1) Pass</td>
<td>0.000 (1) Pass</td>
<td>0.500 (32) Pass</td>
<td>0.000 (32) Pass</td>
</tr>
<tr>
<td>D</td>
<td>0.057 (4) Pass</td>
<td>0.048 (4) Pass</td>
<td>0.000 (4) Pass</td>
<td>0.628 (16) Pass</td>
<td>0.019 (16) Pass</td>
</tr>
<tr>
<td>E</td>
<td>0.069 (1) Pass</td>
<td>0.094 (1) Pass</td>
<td>0.000 (1) Pass</td>
<td>0.325 (16) Pass</td>
<td>0.019 (16) Pass</td>
</tr>
<tr>
<td>F</td>
<td>0.000 (1) Pass</td>
<td>0.000 (1) Pass</td>
<td>0.000 (1) Pass</td>
<td>0.000 (32) Pass</td>
<td>0.000 (32) Pass</td>
</tr>
</tbody>
</table>
Reports: Elevations and Drawings

Wall along grid line 1 from grid lines A to B

Information to Include on Plans

Snow Loads
Ground Snow Load: 25.00 psf
Flat Roof Snow Load: 21.00 psf
Snow Exposure Factor: 1.00
Thermal Factor: 1.00
Drift Surcharge Load: 0.00 psf
Width of Snow Drift: 0.00 ft

Wind Loads
Ultimate Design Wind Speed: 120.00 mph
Nominal Design Wind Speed: 92.95 mph
Risk Category: II
Wind Exposure: B
Internal Pressure Coefficient (+/-): 0.18
C&C Wall Field Pressure (+): 23.26 psf
C&C Wall Field Pressure (-): -25.46 psf
C&C Wall Edge Pressure (+): 23.26 psf
C&C Wall Edge Pressure (-): -29.40 psf
C&C Roof Zone 1 (Field) Pressure (+): 8.34 psf
C&C Roof Zone 1 (Field) Pressure (-): -23.71 psf
C&C Roof Zone 2 (Field) Pressure (+): 8.34 psf
C&C Roof Zone 2 (Field) Pressure (-): -28.10 psf
C&C Roof Zone 3 (Corner) Pressure (+): 8.34 psf
C&C Roof Zone 3 (Corner) Pressure (-): -28.10 psf
C&C Overhang Edge Pressure (net): -24.15 psf
C&C Overhang Corner Pressure (net): -17.56 psf
C&C Parapet Field Pressure, Case A (net): 43.46 psf
C&C Parapet Field Pressure, Case B (net): -43.46 psf
C&C Parapet Edge Pressure, Case A (net): 43.46 psf
C&C Parapet Edge Pressure, Case B (net): -44.76 psf

Gravity Loads
Roof Live Load: 20.00 psf
Floor Live Load: 40.00 psf

Earthquake Loads
Risk Category: II
Site Class: D
Seismic Importance Factor: 1.00
Mapped 0.2 Second Spectral Response Acceleration: 0.200
Mapped 1.0 Second Spectral Response Acceleration: 0.050
Design 0.2 Second Spectral Response Acceleration: 0.213
Design 1.0 Second Spectral Response Acceleration: 0.053
Seismic Design Category: B
Lateral Force Resisting System: Ordinary Reinforced Masonry Shear Walls
Design Base Shear: 7.22 k
Seismic Response Coefficient: 0.11
Response Modification Factor: 2.00
Seismic Analysis Procedures: Equivalent Lateral Force Method

Flood Loads
This building has not been designed for flood loads.

Special Loads
This building has not been designed for any special loads.

Geotechnical Information
Soil bearing values and other geotechnical properties must be determined separately.

Masonry Design Criteria
Design Standard: TMS 402-13
Specified Compressive Strength of Masonry (f’m): 2,000.00 psi
Grade of Reinforcement (fy): 60,000.00 psi
Masonry Unit: 8 in CMU
CMU Density: Normal Weight

10 DDS
The Limitations and Constraints …

DDS was created with the goal of accommodating the majority of common masonry building configurations and the software supports a large number of the typical masonry structure layouts seen in so many projects. However, the current version will not handle every conceivable building geometry. There are limitations on the modeling capability that should be understood by the user. Some of the most prominent constraints imposed by DDS include:

- **Roof Types.** DDS currently only supports flat, hipped, gabled, and single-slope roof systems. These constraints on roof geometry are primarily driven by the software’s ability to model snow and wind loads.

- **Mean Roof Height.** While DDS does not place any restrictions on the number of stories in a building, it does limit the mean (average) height of the roof (or building for flat roof structures) to 60 feet above the adjacent grade.

- **Building Layout.** DDS currently only supports input of orthogonal dimensions for plan, elevation, and openings. Walls must be a part of the perimeter of rectangular plan building sections, and each story must maintain the same basic plan layout.

- **Reinforcing Bar Position.** The software assumes that vertical reinforcing bars are centered within cells, with one bar per cell. This accommodates the fact that there are negative (internal) and positive (external) pressures that act on the wall.

- **Concentrated Loads.** DDS does not currently allow for modeling discrete, user-defined concentrated loads applied to masonry walls. This precludes joist girders from being framed into the masonry walls without supplemental analysis.

- **Pilasters.** Walls are modeled as having uniform thickness so pilasters are not supported.

- **Diaphragm Design.** DDS assumes that diaphragms perform as indicated by the user (rigid or flexible) and does not provide comprehensive design of the diaphragm to resist the applied loads. It does however provide a check on the ability of diaphragm-level bond beam reinforcement to withstand chord forces, and also provides the loads required for the user to conduct a more thorough analysis.

When an input is not permitted by DDS, the software will let the user know.