# DESIGN CALCULATIONS – FOUNDATION WALL STRAPS

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Projection Name: Foundation Wall Strap Design Calculations

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## REPORT DESCRIPTION

This report documents the structural design of steel foundation wall straps and certifies their ability to permanently strengthen concrete block foundation walls against inward lateral movement. Concrete block foundation walls were often constructed without installing steel reinforcement and without filling the cores solid with concrete. As a result, the lateral pressure of the earth acting on the exterior of the wall displaces/bulges the wall inward creating horizontal cracks in the mortar joints. The steel strapping is akin to installing steel reinforcement on the interior side of the foundation wall. The steel is mechanically fastened to the face of the wall and resists stretching. As the steel resists stretching, the wall is unable to displace inward laterally and the stability and load carry ability of the wall is maintained.

## USE LIMITATIONS

Per most codes, a structure is unsafe when "the exterior walls or other vertical structural members lists, lean or buckle to such an extent that a plumb line passing through the center of gravity does not fall inside the middle one third of the base." A nominally 8" thick concrete block wall actually has a wall thickness of 7-5/8", 1/3rd would equate to 2.54". Testing revealed that a strapped wall deflects 5/8". Therefore, these straps are not recommended for installation on a wall that has deflected inward more than 2".

## STEEL STRAP DESCRIPTION

The steel straps galvanized carbon steel treated as such to conform to ASTM D3953 Finish B (galvanized), Grade 1, steel specifications and are 1.25" wide by 0.031" thick. The straps have a breaking strength of 5,500#.

## DESIGN ALLOWANCE

The Building Codes permits design of building elements as long as they are in accordance with accepted engineering practices:

As an alternative to the requirements in Section R301.1, the following standards are permitted subject to the limitations of this code and the limitations therein. Where engineered design is used in conjunction with these standards, the design shall comply with the *International Building Code*.

**R301.1.3 Engineered design.** Where a building of otherwise conventional construction contains structural elements exceeding the limits of Section R301 or otherwise not conforming to this code, these elements shall be designed in accordance with accepted engineering practice. The extent of such design need only demonstrate compliance of nonconventional elements with other applicable provisions and shall be compatible with the performance of the conventional framed system. Engineered design in accordance with the *International Building Code* is permitted for buildings and structures, and parts thereof, included in the scope of this code.

## DESIGN METHODOLOGY

ASD- Allowable Stress Design

## DESIGN CODE REFERENCES

American Institute of Steel Construction (AISC) – Thirteenth Edition, Part 14, page 14-4, reference (a)

2018 International Residential Code (IRC)

2018 International Existing Residential Code (IERC)

ASCE 7, Minimum Design Loads for Buildings and Other Structures

Building Code Requirements for Structural Concrete (ACI-318) and Commentary, Fourth Printing January 2011

## DESIGN ASSUMPTIONS

- Maximum soil lateral design pressure 60 PSF
- The weight of the foundation wall and the supporting structure above is ignored, this is conservative as the wall weight and structure weight would help stabilize the wall.
- There is no strength provided by the mortar joints.

## DESIGN PROCEDURE

The maximum bending moment in the foundation wall created by the exterior lateral earth pressure is calculated. The tension required in the strap to resist the bending moment is then calculated along with the stress in the fasteners and the bearing stress in the face of the concrete block walls. The calculation is performed with a maximum wall height of 8', full backfill height of 8' and 60 PSF soil pressure. Strap spacing for other wall specifications are determined based on this design case and provided below in Figure 1.

*Soil classes and design lateral soil (psf per foot depth).*

There are three soils classes used in the International Residential Building Code, Group 1 soils consist of GW, GP, SW & SP and have a lateral pressure of 30 PSF, Group 2 soils consisted of GM, GC, SM,-SC & ML and have a lateral pressure of 45 PSF and Group 3 soils consists of SC, ML-CL and inorganic CL and have a lateral pressure of 60 PSF.

The ASCE-7, Minimum Design Loads for Buildings and Other Structures, Chapter 3 list several lateral loads based on soil types ranging from 35 PSF to 100 PSF. With most of the soils types at 45 PSF or below. Therefore, a lateral soil design pressure of 60 PSF is used throughout this analysis. The straps were also tested at the maximum design pressure of 60 PSF for a fully back-filled wall. Subsequent spacing requirements for soils with less lateral load, various foundation wall heights and various wall back-fill heights are also provided in Figure 1.

The lateral load acting on the foundation wall is triangular in shape. This load acts perpendicular to the wall and pushes the wall inward. The load at the base of the wall is equal to the soil depth (back-fill height) times that soil lateral pressure. This maximum load linearly tapers to zero at the ground surface which may or not be at the top of the wall. The bending moment in the wall is a function of the tapered lateral load, the wall thickness, the wall height and the back-fill height. The maximum bending moment in the wall would therefore be for a soil pressure of 60 PSF, 8' tall wall, 8" thick wall and 8' back-fill height.

*Bending Moment in Foundation Wall*

The maximum bending moment for a uniformly increasing load (triangular load) is:

$$M = \frac{2Wl}{9\sqrt{3}} = 0.1283Wl$$

Where "l" is the height of the completely back-filled wall, 8' and where W is the total lateral load acting on the wall and is equal to:

$W = Q \times H^2 / 2$

Where Q is taken as 60PSF and H is the height of the wall, 8'.

$W = 60 \times 8^2 / 2 = 1920$ #

The Moment is:

M = 0.1283 x 1920# x 8' = 1971 ft #

The maximum moment occurs at: $\frac{l}{\sqrt{3}} = 0.5774l$

L = 0.05774 x 8' = 4.62'

*Tension in strap*

In order for the wall to resist this bending moment, the straps must provide a tension force on the inside of the wall. This tensions force (T) is a function of the wall thickness and is calculated below. An 8" thick concrete block wall is actually 7- 5/8" thick.

T = 1971 ft # / (7.625 in) * (12 in / 1ft) = 3,102#. This would be the tension in the strap if they were spaced at 1' on center along the foundation wall. The minimum proposed spacing is 8" or 0.67' on center. Therefore if the straps are spaced at 8" on center the tension would be:

$T_{16"OC}$ = 3,102# x 0.67' = 2,078# which less than the 5,500# strength of the strap with a safety factor or 5,500# / 2,078# = 2.65.

*Fastening Hardware*

The straps are mechanically fastened to the wall using either 3/8" diameter x 1.5" long, galvanized steel bolts or 3/8" diameter Simpson Titen HD screw. It should be noted that the bolts or screws securing the strap to the wall experience shear only when under load and there is no significant tension in the fasteners.

The shear stress of 3/8" diameter is calculated below.

The maximum tension developed in the strap is 2,078#. This tension is actually shared amongst several bolts. Per the hole locations in the strap, at the location in the wall where the maximum tension force occurs, there are 8 fasteners to one side and 7 fasteners to the other side. Therefore, 7 fasteners share the tension load.

Fastener Shear Area = $\pi/4 \times (0.375\text{in})^2 = 0.11\ \text{in}^2$

The shear stress in the fastener is:

$\sigma^{bolt} = (2{,}078\# / 0.11\text{in}^2)/ 7 = 2{,}699$ psi

This shear stress in much lower than the fastener allowable which would be equal to or greater than 36,000 psi x 0.6 = 21,600 psi.

Since all concrete block should conform to ASTM C90, the minimum compressive strength should be 1,900 psi. The thickness of the wall face is 1.25". The bearing area is equal to the fastener diameter times the wall thickness:

$B_{area} = 0.375\ \text{in} \times 1.25\ \text{in} = 0.469\ \text{in}^2$

The bearing stress on the concrete block wall is:

$\sigma_{conc} = (2{,}078\# / 7) / 0.469$ in2 = 633 psi which is less than the 1,900 psi minimum bearing strength of the concrete.

*Deflection in Wall*

Measurements taken during the full load test, showed that the concrete wall deflected 5/8" when fully loaded. The deflection occurred when the wall was loaded to about ¼ of the maximum design load and the deflection stopped increasing. Most likely, the early deflection occurred as the any slack was taken out of the steel strapping and/or as the fasteners made tight contact with the holes in the straps.

## STRAP SPACING

The table below provides the strap spacing requirement based on soil type, wall height and backfill height. The spacing in the table ensure that the tension in the strap, shear load in the fasteners and bearing stress in the concrete block wall will be at or below what was design and tested.

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**Table 1 - Maximum Strap Spacing per Soil Backfill Height & Soil Type**

| | | **Strap Spacing [in]** | | |
|---|---|---|---|---|
| Wall Height [ft] | Maximum Backfill Height [ft] | Class I – GW, GP, SW and SP | Class II – GM, GC, SM, SM-SC and ML | Class III – SC, MH, ML-CL and inorganic CL |
| 4 | 2 | 48 | 48 | 48 |
| | 3 | 48 | 48 | 48 |
| | 4 | 48 | 48 | 48 |
| 5 | 3 | 48 | 48 | 48 |
| | 4 | 48 | 48 | 48 |
| | 5 | 48 | 48 | 48 |
| 6 | 4 | 48 | 48 | 48 |
| | 5 | 48 | 48 | 40 |
| | 6 | 48 | 40 | 24 |
| 7 | 4 | 48 | 48 | 48 |
| | 5 | 48 | 48 | 40 |
| | 6 | 48 | 32 | 24 |
| | 7 | 40 | 24 | 16 |
| 8 | 4 | 48 | 48 | 48 |
| | 5 | 48 | 40 | 32 |
| | 6 | 48 | 24 | 16 |
| | 7 | 32 | 16 | 16 |
| | 8 | 24 | 16 | 8 |
| 9 | 5 | 48 | 32 | 32 |
| | 6 | 40 | 24 | 16 |
| | 7 | 24 | 16 | 8 |
| | 8 | 16 | 8 | 8 |
| | 9 | 16 | 8 | 8 |

**Figure 1 – Strap Spacing**

## TESTING

The product was testing on an 8” thick concrete block wall, that was 11-courses or 7’-4” tall. Note that even though the tested wall was not 8’ high, the strap spacing was 16” on center resulting in more strap tension and bolt loading than an 8’ tall wall with the straps spaced at 8” on center.

Instead of mortar joints, 3/8” plywood sheathing was installed between the concrete block. This plywood sheathing provided the same spacing as a mortar joint but provided zero strength to resist the bending moment in the wall so that the straps would be 100% responsible for resisting the moment in the wall.

To simulate the lateral earth pressure the wall was built vertically but laid on its side horizontally and loaded up with 50 pound sand bags. The ends of the wall were supported on 6”x6” beams resting on the floor. The wall was methodically and accurately loaded with sand bags to simulate the triangular load shape of 60 PSF from the base to the top of the wall. It will be noted in the photographs that the sand bags do not reach the top of the test wall. This was on purpose as the weight of the concrete blocks themselves at the top of the wall provided the correct lateral load at that location.

The wall deflected 5/8” near the center when the wall was loaded to about ¼ of its total design maximum load and did not deflect significantly further when 100% of the load was applied. The wall remained the loaded position for several weeks. No adverse or anomalous conditions were observed during the test.

**Figure 1 – Fully Loaded Wall ~ 5000# total**

**INTALLATION EXAMPLE**

**Figure 2 – Sample of installed strap**

**Figure 3 – Sample of installed straps**

**Figure 4 – Top of strap secured to sill**