DURISOL
WALL FORM SYSTEM

STRUCTURAL DESIGN GUIDE

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WARRANTY

We warranty our products to be free of defects and manufactured to meet published physical properties when cured and tested according to ASTM, CSA and Durisol Standards.

Under this warranty, Durisol will replace any Durisol Wall Form proven to be defective when applied in accordance with written instructions and in applications recommended by Durisol for this product.

All claims must be made within 1 (one) year of shipment. Absence of such claim in writing during this period will constitute a waiver of all claims with respect of such products.

This warranty is in lieu of any and all other warranties expressed and implied.

DISCLAIMER

The recommendations, suggestions, statements and technical data in this technical guide are based on Durisol's best knowledge. ***They are given for informational purposes only and are not to be construed as overriding any requirements of any applicable building code.***

Durisol Inc. has no control over installation, workmanship, inspection, building conditions or applications. There is no responsibility, expressed or implied warranty, either as to merchantability or fitness for the parttheicular purpose, made as to the performance or results of an installation using Durisol Wall Forms.

Structures built with the Durisol Wall Forms should be designed and constructed in accordance with applicable building codes. ***Durisol material is not designed to carry any structural load other than temporary concrete pressures that occur during construction.*** The concrete core within the Wall Form is intended to be the primary load carrying material of the wall system. The design of the Durisol wall system should be conducted and reviewed by an engineer.

This document is not intended to override any applicable codes and practices that may be required in local jurisdictions. The user should refer to applicable building code requirements when exceeding the limitations of this document, when requirements conflict with the building code, or when an engineered design is specified. This specification is not intended to limit the appropriate use of concrete or construction not specifically prescribed. This document is also not intended to restrict the use of sound judgment or exact engineering analysis of specific applications that may result in designs with improved performance and economy.

GENERAL

This guide is intended to convey the standard methods of structural design using the Durisol Building Systems Inc. insulated concrete wall form system in conformance with the requirements of the acceptance criteria for concrete wall systems as mandated by ICC Evaluation Service Inc. (ICC-ES). Acceptance criteria guideline AC15 has been used for this report.

Design Assumptions

- The design method complies with current IBC, ASCE 7 and ACI 318 standards. No deviations from this standard are anticipated. All assumptions listed in the standard are applicable (e.g., assumptions about stress-strain relationships, acceptable material standards, etc.).
- Durisol insulated wall formed concrete behaves as conventional reinforced concrete.
- The Durisol material does not contribute to the design or strength of the wall system, thus, the strength of the wall under axial, flexural and shear loading is calculated based on net section properties (ratio of concrete filled wall to gross section properties). To account for this reduction in area of concrete to the gross concrete section, additional strength reduction factors are noted below, where applicable. There is a separate factor for shear resistance calculations to reflect the orthotropic nature of the reinforced concrete wall created by the Durisol system. This factor was determined based on empirical testing in accordance with AC15.

Structural Design

Below is the recommended structural design method for reinforced concrete walls using the Durisol Building Systems Inc. concrete wall form system, using the Load and Resistance Factor Design method described in the above referenced codes and standards

Load Factors:

Refer to the IBC Section 1605 for information on load combinations, including earthquake loading.

Strength Reduction Factors:

Refer to ACI 318 Section 9.3.2 for information on strength reduction factors. Below are the applicable factors typically used:

$\phi = 0.90$ for Tension-controlled sections
$\phi = 0.65$ for Compression controlled sections without spiral reinforcement
$\phi = 0.75$ for Shear and Torsion

Additional Resistance Factors:

Based on empirical testing and theoretical analysis, the following additional strength reduction factors have been established:

$\phi_{D1} = 0.75$ To be applied on top of all other concrete resistance factors for flexural, axial, out of plane shear and deflection calculations. This factor is based on accounting for the percentage of concrete area within the wall, when the Durisol web portions are removed along the length of a Durisol wall. The Durisol cores are spaced at 12" o/c and each core is nominally taken as 9.4". In other words, 9.4" of concrete resistance is present every 12" of wall length. This results in a calculated reduction of 9.4 / 12 = 0.78. Testing has proven that a factor of 0.75 is more accurate to reflect actual strength of the wall. The reduction from a theoretical value of 0.78 to 0.75 is due to the aggregrate response within wall as result of normal construction methods that result in vertical cores not being precisely aligned.

$\phi_{D2} = 0.85$ To be applied on top of all other resistance factors for concrete in-plane shear calculations. This is based on full scale racking tests and is higher than ϕ_{D1} above because ACI 318 equations already approximate the portion of wall resisting shear loads by taking 80% of the wall length. This is a conservative empirical assumption that results in a corresponding higher ϕ_{D2} multiplier when theoretical values are compared against empirical testing. Combining the ϕ_{D2} and the 0.8 from ACI equations result in a net lower resistance factor (0.8 x 0.85 = 0.68) for in-plane shear resistance. This net lower ϕ_{D2} reflects the interaction of orthotropic nature of the concrete grid within the Durisol wall system (i.e. the angle of crack formation is less than 45 degrees).

FLEXURAL DESIGN

Design to resist pure flexural loading shall be in conformance with conventional reinforced concrete design methods based on accepted practice and the stress-strain relationship of reinforced concrete. Refer to ACI 318 for more information.

The bending strength of a concrete section is defined as follows:

$\phi M_n = \phi_{D1} \bullet \phi \bullet \beta_1 \bullet f'_c \bullet b \bullet a \bullet (d - 0.5 \bullet a)$

Where:

M_n = the nominal bending resistance of the reinforced concrete wall.
ϕ_{D1} = 0.75 (see design assumptions above).
ϕ = strength reduction factor as per ACI 318 (see above).
β_1 = 0.85 for concrete with $f'_c \leq 4000$ psi (see ACI 318 for higher strength concrete)
f'_c = the compressive strength of concrete.
b = the width of the compression block (typically the length of wall).
d = effective depth of section (typically the distance from the outside face of wall on the compression side to the centroid of steel reinforcing).

a = the depth of the compression block to ensure ductile failure = $(A_s \bullet f_y) / (\phi_{D1} \bullet \beta_1 \bullet f'_c \bullet b)$

Where

A_s = the cross sectional area of tensile reinforcing steel.
f_y = the yield strength of reinforcing steel.

AXIAL DESIGN

Design to resist axial loading, with or without flexure, shall be in conformance with conventional reinforced concrete design based on accepted practice and the stress-strain relationship of reinforced concrete. Refer to IBC and ACI 318 for more information.

Axial Compression, Non-Slender, Without Flexure

The compressive resistance of a wall section is defined as follows. The use of this formula is allowed by ACI 318,

$\phi\ P_n = \phi_{D1}\ 0.8 \bullet \phi \bullet [\ 0.85 \bullet f'_c \bullet (A_g - A_s) + f_y \bullet\ A_s]$

Where:

$\phi\ P_n$ = the factored compressive resistance of the reinforced concrete wall.
ϕ = strength reduction factor (see above).
A_g = the gross cross section concrete area.
f'_c = the compressive strength of concrete.
A_s = the cross sectional area of tensile reinforcing steel.
f_y = the yield strength of reinforcing steel.
ϕ_{D1} = Durisol modification factor for axial-flexural strength = 0.7 (see design assumptions above).

Axial Compression With or Without Flexure, Slender

General assumption: it is anticipated that a wall built with the Durisol Building Systems Inc. concrete wall form system with be designed assuming structurally pinned ends at all intermediate supports (i.e., floor levels, foundation, roof level, etc.), and never in a sway frame condition. Therefore

$Kl_u/r \leq 34 - 12 \bullet (M_1/M_2)$

Reduces to:

$Kl_u/r \leq 34$

Since $M_1 = M_2 = 0$ (no end moments on wall). Therefore, slenderness will be considered for all wall sections where the effective length divided by the radius of gyration of the section (Kl_u/r) exceeds or equals 34.

Minimum Flexural Loading:

Regardless that there may be no anticipated applied flexural loading on the wall, a minimum bending moment due to eccentric loading shall be applied to the wall section for design purposes using the following formula:

$M_{min} = P_u \cdot (0.6 + 0.03 \cdot h)$

Where:

M_{min} = the minimum allowable factored bending moment.
P_u = the factored applied load on the wall section.
h = the height of the concrete section in the direction of bending (i.e., concrete thickness of wall).

Slender walls under axial loading will be designed for combined axial and flexural loading assuming flexural loading that is the greater of the bending moment resulting from the minimum eccentric loading defined above, and for second order effects using the Moment Magnifier Method as defined in ACI 318, summarized as follows:

$M_c = \delta_{ns} \cdot M_2$

Where:

M_c = the magnified bending moment, including second order effects.
M_2 = the greater of the minimum eccentric bending moment noted above, or the factored moment due to applied loads.
δ_{ns} = is the moment amplification factor, calculated as follows:

$$\delta_{ns} = \frac{C_m}{1 - \frac{P_u}{0.75 P_c}} \geq 1$$

Where:

C_m = 1 (typical for walls with transverse loads between supports)
P_u = factored axial load at eccentricity, must be $\leq \varphi P_n$

P_c = critical load, i.e., $P_c = \dfrac{\pi^2 EI}{(kl_u)^2}$

Where, EI = $\dfrac{0.15E_c I_g}{1+\beta_d}$

and,

E_c = Young's modulus for concrete
I_g = the moment of inertia of the gross concrete wall section
β_d = the ratio of factored dead load to the total factored axial load.

COMBINING FLEXURAL AND AXIAL LOADING

Flexural and axial compressive loads shall be combined by conventional analysis, with due consideration for interaction of bending moment and compressive forces in the wall section, considering pure bending, pure axial and balanced strain conditions. Interaction diagrams for any Wallform can be generated using the same equations and factors identified above for flexural and axial strength of a given section. Axial-flexural interaction is beyond the scope of this design guide, however, interaction diagrams for specific Durisol Wallform configurations (product type, concrete strength, rebar configuration) are available on request.

DEFLECTION CONTROL

Deflection of the Durisol Building Systems Inc. concrete wall form system under applied lateral load shall be limited to a maximum allowable deflection of wall span divided by 180, or L/180. This deflection limitation shall include both immediate and long term deflection (see below).

Immediate deflection shall be calculated using conventional structural analysis techniques, using the following stiffness formula:

Stiffness = $\phi_{D1} \bullet E_c \bullet I_e$

Where:

$E_c = 57{,}000\sqrt{f'_c}$ (in psi) for normal weight concrete.
I_e = The effective moment of inertia, or,
$I_e = \left(\dfrac{M_{cr}}{M_a}\right)^3 I_g + \left[1-\left(\dfrac{M_{cr}}{M_a}\right)^3\right] I_{cr}$

Where,

M_{cr} = the cracking moment of the concrete section, or $M_{cr} = \frac{f_r I_g}{y_t}$

$f_r = 7.5\sqrt{f'_c}$ (psi)

y_t = distance from the centroid of concrete to the extreme fiber in tension.
M_a = the applied moment at the stage deflection is computed
I_{cr} = the moment of inertia of a cracked section with reinforcing steel transformed to equivalent concrete.

Long term deflection shall be calculated, where applicable, by the following:

$$\lambda = \frac{\xi}{1 + 50\rho'}$$

Where:

ξ = 2.0 (assumes a sustained load period of 5 years or more).
ρ' = ratio of reinforcing steel to gross section area.

SHEAR DESIGN

Design to resist out of plane and in plane shear loading, shall be in conformance with conventional reinforced concrete design based on accepted practice and the stress-strain relationship of reinforced concrete. Refer to ACI 318 for more information.

Out of Plane Shear

Out of plane shear design shall be in accordance with IBC and ACI 318. Thus, for out of plane shear, the wall must be designed to satisfy the following:

$\phi V_n \geq V_u$

Where:

V_u = factored applied shear load.
ϕV_n = factored shear resistance of the concrete wall section.
$\phi V_n = \phi \cdot (V_c + V_s)$

It is not anticipated that shear reinforcement will be typical for out of plane loading for the Durisol Building Systems Inc. concrete wall form system, thus, the above equation reduces to:

$\phi V_n = \phi \cdot V_c$

This is only appropriate for out of plane loading, which uses excludes slabs (thus out of plane walls) from minimum shear reinforcing when V_u exceeds one half of $\varphi V_{n.}$ Thus, it is only necessary to ensure the factored shear capacity of plane concrete be greater than the factored applied out of plane shear loading.

V_c shall be computed for out of plane shear as follows:

$$V_c = 2\sqrt{f'_c}b\ d\ \phi_{D1}$$

In Plane Shear

In plane shear design shall be in accordance with ACI 318. As above, with the following modifications

$\phi V_n \geq V_u$

Where:

V_u = the factored applied shear load.
ϕV_n = factored shear resistance of the concrete wall section.

$\phi V_n = \phi\ (V_c + V_s)$ if $V_u \leq V_c$

or

$\phi V_n = \phi\ V_s$ if $V_u > V_c$

V_c shall be computed for in plane shear as follows:

$$V_c = 2\sqrt{f'_c}hd\ \phi_{D2}$$

Where d shall be taken as the 0.8 times the length of the wall or 0.8 times the depth of the wall section in shear (e.g., the wall acting as a lintel over an opening).

For in plane shear, minimum shear reinforcement is required where V_u exceeds one half of $\phi\, V_c$. ACI 318 allows that this minimum reinforcing be provided through the minimum wall reinforcing requirements, which will be defined in the next section. Thus, we are only concerned with calculating the required shear reinforcing where V_u exceeds ϕV_n. The strength of this added shear reinforcement is calculated as follows:

$$V_s = \frac{A_v f_y H}{s_2}$$

Where:

A_v = the area of shear reinforcement within distance s_2.
H = Height of the wall.
s_2 = spacing of shear reinforcement along the height of the wall

Note the substitution in this familiar ACI equation with the wall height H in place of d = 0.8 L. This is based on the theory that after initial cracking of the concrete, the smaller horizontal cores will fail creating a shear failure plane perpendicular to the shear reinforcing (crack angle initiates at angle less than 45 degrees and then transitions to close to 0 degrees and thus engages the shear reinforcing). Once the shear reinforcing is engaged and deforms, there is sufficient separation that concrete no longer contributes to the shear strength of the section. Shear forces are transferred across the cracks by the steel only. Hence the presence of the concrete shear strength only up to the point of cracking.

MINIMUM REINFORCEMENT

All walls built with the Durisol Building Systems Inc. concrete wall form system shall be reinforced in conformance with all applicable design requirements noted above, but will have minimum reinforcement as follows:

Minimum ratio of vertical reinforcing area to gross concrete area = 0.0012
Minimum ratio of horizontal reinforcing area to gross concrete area = 0.0020

COMPARISON OF DESIGN APPROACH AND TEST DATA

This section is intended to meet the requirements of section 3.3.2 of ICC Evaluation Service Inc. acceptance criteria guideline AC15.

Flexural:

Below is the summary table for flexural loading tests on a 3 core standard Durisol Building Systems Inc. 8” wall form (WF20). This table has been taken from test report “**Durisol Axial-Flexurial Test Report**” (report included elsewhere). Refer to this report for further information, including test setup, sample preparation, etc.

Reinforcing	Specimen	Maximum Load (kN)	Maximum Moment (kNm)
1-15M	1	10.78	4.38
	2	11.40	4.64
	3	10.79	4.39
3-15M	**Average**	**11.0**	**4.5**
	1	34.52	14.04
	2	31.37	12.76
	3	34.43	14.00
	Average	**33.4**	**13.6**

Table 2: Flexural Test Program Results

36” Reinforced Concrete Wall Form w/ 1 – 15M Vertical Bar

Sample Characteristics:

h = 4.72” (120mm)
A_s = 0.31 in^2
d = 2.36 in
b = 36 in
f'_c = 2908 psi (20 MPa)
f_y = 58000 psi (400 MPa)
ϕ_{D1} = 0.75

Therefore, using the approach shown for Flexural Design above:

$M_r = \phi_{D1} \cdot \beta_1 \cdot \varphi \cdot f'_c \cdot b \cdot a \cdot (d - 0.5 \cdot a)$

Since we are comparing actual test values to theoretical calculations, no strength reduction factor is used, i.e., $\varphi = 1$.

Thus $M_r = M_{ultimate} = \phi_{D1} \cdot \beta_1 \cdot f'_c \cdot b \cdot a \cdot (d - 0.5 \cdot a)$

Where:

$a = (A_s \cdot f_y) / (\beta_1 \cdot f'_c \cdot b \cdot \phi_{D1})$
$= (0.31 \cdot 58000)/(0.85 \cdot 2908 \cdot 36 \cdot 0.75)$
$= 17980 / 66738.6$
$= 0.269$ in.

Therefore,

$M_{ultimate} = \phi_{D1} \cdot \beta_1 \cdot f'_c \cdot b \cdot a \cdot (d - 0.5 \cdot a)$
$= 0.75 \cdot 0.85 \cdot 2908 \cdot 36 \cdot 0.289 \cdot (2.36 - 0.5 \cdot 0.269)$
$= 3.32$ ft•k

$M_{ultimate}$ = 4.52 kN•m

Average test value = 4.52 kN•m.

Therefore, theoretical value and test derived correspond exactly.

36” Reinforced Concrete Wall Form w/ 3 – 15M Vertical Bar

Sample Characteristics:

h = 4.72” (120mm)
A_s = 0.93 in^2
d = 2.36 in
b = 36 in
f'_c = 2908 psi (20 MPa)
f_y = 58000 psi (400 MPa)
ϕ_{D1} = 0.75

Thus $M_{ultimate} = \phi_{D1} \cdot \beta_1 \cdot f'_c \cdot b \cdot a \cdot (d - 0.5 \cdot a)$

Where:

$a = (0.93 \cdot 58000)/(0.85 \cdot 2908 \cdot 36 \cdot 0.75)$
$= 53940 / 66738.6$
$= 0.808$ in.

Therefore,

$M_{ultimate} = 0.75 \cdot 0.85 \cdot 2908 \cdot 36 \cdot 0.808 \cdot (2.36 - 0.5 \cdot 0.808)$
$= 8.79$ ft•k

$M_{ultimate}$ = 11.94 kN•m

Average test value = 13.6 kN•m.

Therefore, theoretical value is conservative when compared to test derived strength.

Axial - Flexural:

Below is the summary table for axial - flexural loading tests on a 3 core standard Durisol Building Systems Inc. 8” wall form (WF20). This table has been taken from test report “**Results of the Flexural and Axial Performance of the Durisol Insulated Concrete Form Test Program**” (report included elsewhere). Refer to this report for further information, including test setup, sample preparation, etc.

Reinforcing	Eccentricity (mm)	Specimen	Maximum Load (kN)
1-15M	60	1	148.6
	60	2	142.2
	60	3	133.3
	60	**Average**	**141.3**
3-15M	60	1	186.2
	60	2	167.5
	60	3	160.3
	60	**Average**	**171.4**

Part of Table 3: Axial-Flexural Test Program Results

36” Reinforced Concrete Wall Form w/ 1 – 15M Vertical Bar, Axially Loaded with 60mm Eccentricity

From the test data: average applied axial load at failure = 141.3 kN = 31.77 kips. The weight of the wall above the buckling point (mid height) = 150 pcf • 0.4 feet • 3 ft • 4 feet • ϕ_{D1} = 0.540 kips.

Therefore:

P = 31.77 + 0.420 = 32.30 kips

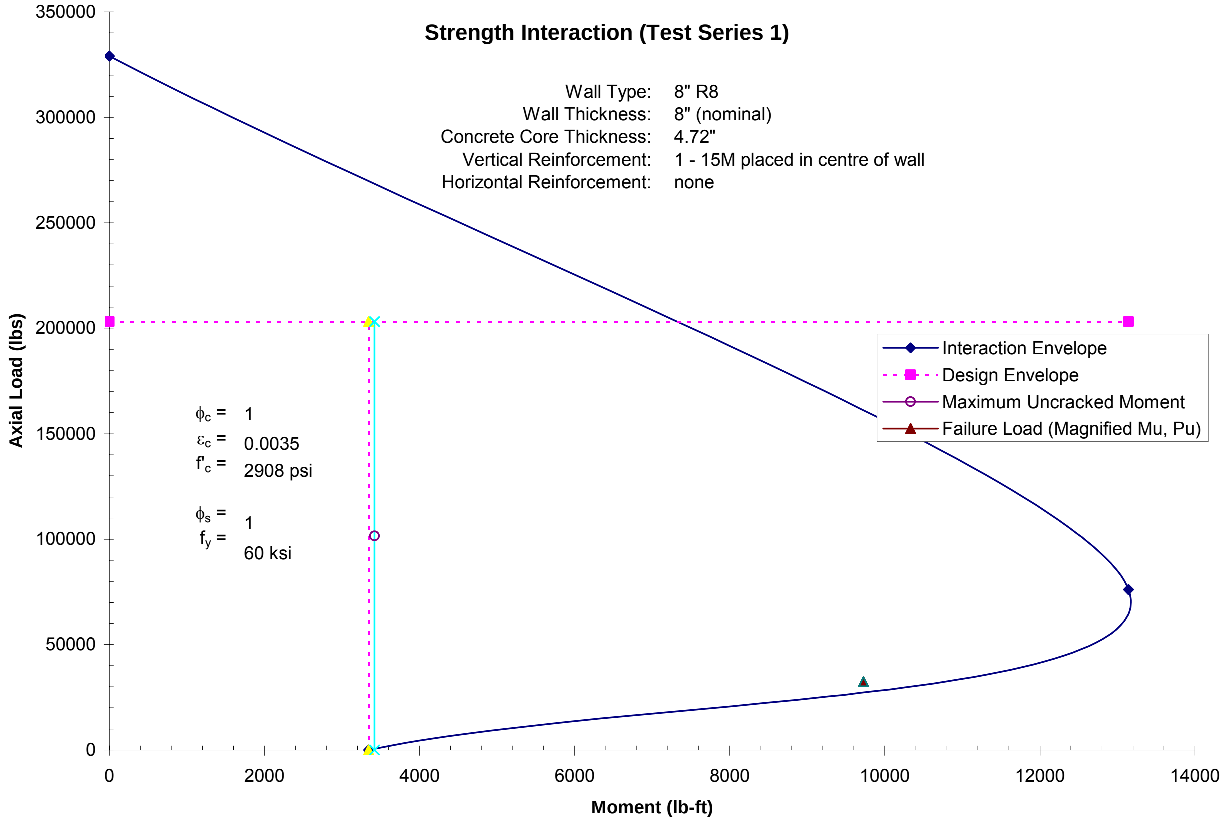
Eccentricity = 60mm, = 2.362 inches = 0.197 feet. Therefore, the applied bending moment =

M = 32.30 • 0.197 = 6.36 ft• k > M_n

$$\delta_{ns} = \frac{C_m}{1 - \frac{P_u}{0.75 P_c}} \geq 1$$

$$\delta_{ns} = \frac{1}{1-\frac{32.3}{0.75(122.8)}} = 1.54 \geq 1$$

$$\delta_{ns} M = 6.36 \times 1.54 = 9.7 \text{ ft} \bullet \text{k} > M_n$$



Note that resistance factors φ_c and φ_s have been set to unity to compare ultimate theoretical strength to ultimate test results. From the calculation (which is identical to the design approach described above), the resultant from combined axial and flexural loading at failure is just inside the interaction curve, which is a smoothed approximation of the true interaction design envelope

36” Reinforced Concrete Wall Form w/ 3 – 15M Vertical Bar, Axially Loaded with 60mm Eccentricity

From the test data: average applied axial load at failure = 171.4 kN = 38.53 kips. The weight of the wall above the buckling point (mid height) = 150 pcf • 0.4 feet • 3 ft • 4 feet • ϕ_{D1} = 0.540 kips.

Therefore:

P = 38.53 + 0..540 = 39.07 kips

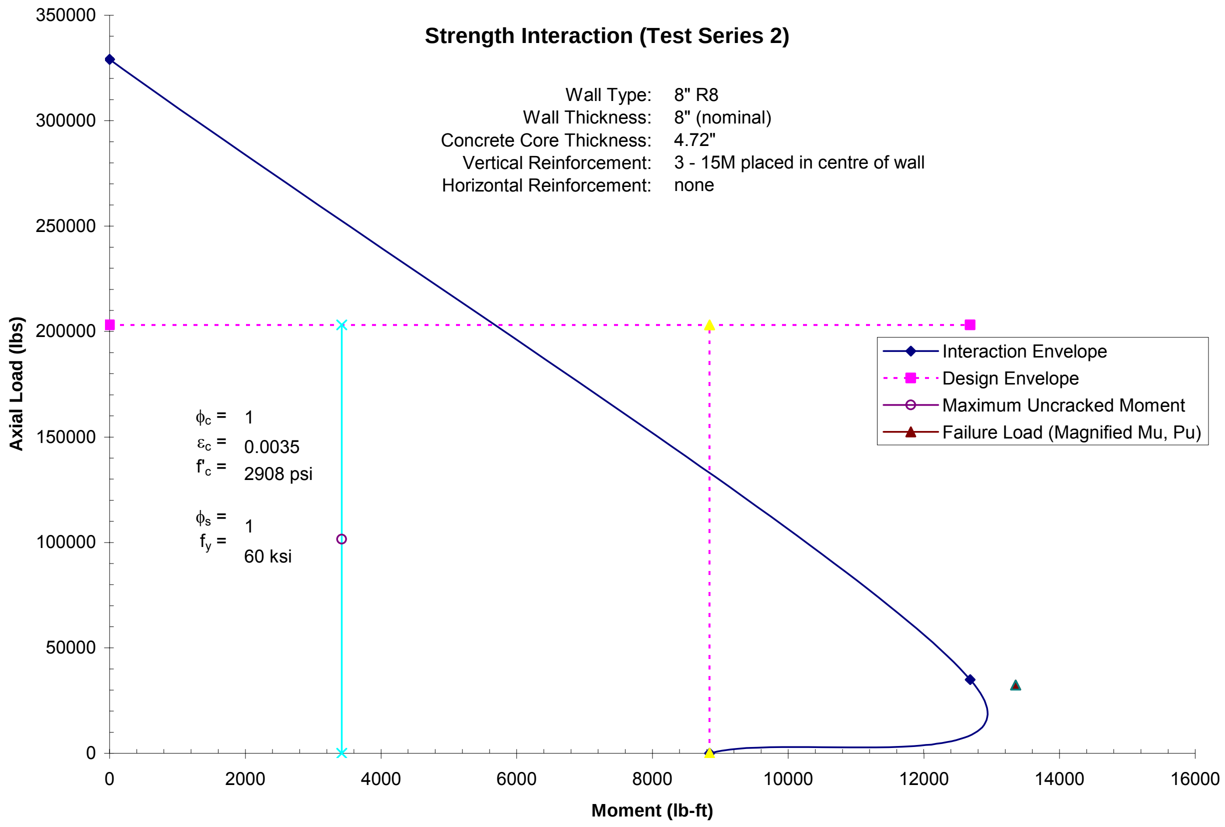
Eccentricity = 60mm, = 2.362 inches = 0.197 feet. Therefore, the applied bending moment =

M = 39.07 • 0.197 = 7.69 ft• k

$$\delta_{ns} = \frac{C_m}{1-\frac{P_u}{0.75P_c}} \geq 1$$

$$\delta_{ns} = \frac{1}{1-\frac{39.1}{0.75(122.8)}} = 1.74 \geq 1$$

δ_{ns} M = 7.69 x 1.74 = 13.4 ft• k > M_n



Note that resistance factors φ_c and φ_s have been set to unity to compare ultimate theoretical strength to ultimate test results. From the calculation (which is identical to the design approach described above), the resultant from combined axial and flexural loading at failure is just outside the interaction curve, which is a smoothed approximation of the true interaction design envelope.

Therefore, the ultimate test loading corresponds well with the theoretical calculated behavior, and the calculation approach is conservative.

Racking:

Below is the summary table for racking tests on a Durisol Building Systems Inc. 8” wall form (WF20) section, 7’-10.5” long x 8’-0” high. This table has been taken from test report “**Results of the Durisol Insulated Concrete Form Racking Strength Test Program**” (report included elsewhere). Refer to this report for further information, including test setup, sample preparation, etc.

Series	**Specimen**	**Maximum Load Pull (kN)**	**Maximum Load Push (kN)**
1	1	127.3	142.2
	2	151.2	161.0
	3	125.6	151.7
	Average	**134.7**	**151.7**
2	1	150.6	159.7
	2	166.1	130.0
	3	151.5	151.4
	Average	**156.1**	**147.0**

Table 2: Flexural Test Program Results

It should be noted that “Series 1” above was effectively an unreinforced wall section, whereas “Series 2” was reinforced with 10M horizontal bars @ 600mm c/c (approx. 24” c/c) shear reinforcing.

<u>Series 1: Wall Sample under Racking Load Without Shear Reinforcing</u>

Sample Characteristics:

h = 4.72” (120mm)
d = 0.8 • 7’-10.5” = 75.6 inches
f'_c = 3162 psi (21.8 MPa)

Using the design approach noted earlier for in plane shear:

$\varphi V_n = \phi V_c$ (no shear reinforcing)

In this case, φ will be taken as unity to compare ultimate calculated strength to witnessed test results. Furthermore, for this unreinforced sample, $V_s = 0$. Therefore,

$V_n = V_c$

Where,

$$V_c = 2\sqrt{f'_c}hd \ \phi_{D2}$$

Thus, the predicted calculated wall strength is:

V_n = $0.85 \cdot 2 \cdot (3162)^{1/2} \cdot 4.72 \cdot 75.6$
V_n = 34.11 kips
V_n = 151.7 kN

Average Failure load from testing = 151.7 kN.

Therefore, theoretical value is corresponds exactly when compared to test derived strength.

Note that by code (as described above), minimum reinforcing is required when applied factored load exceeds one half of the calculated factored shear strength based on concrete alone, however, this is not applicable when comparing theoretical strength to the tested strength.

Series 2: Wall Sample under Racking Load With 10M @ 610mm c/c Horizontal Shear Reinforcing

Sample Characteristics:

h = 4.72” (120mm)
d = 0.8 • 7’-10.5” = 75.6 inches
f'_c = 2908 psi (20 MPa)
A_v = 0.155in^2 ($100\text{mm}^{2)}$
s_2 = 24” (610mm)

Using the design approach noted earlier for in plane shear:

$\varphi V_n = \phi (V_c + V_s)$

In this case, φ will be taken as unity to compare ultimate calculated strength to witnessed test results. Therefore,

In this case, $V_u > V_c$, therefore in accordance with the procedure previously set,
$\phi V_n = \phi V_s$

$$V_s = \frac{A_v f_y H}{s_2}$$

Thus, the predicted calculated wall strength is:

V_n = (0.155 • 58000 • 96) / 24
V_n = 35.96 kips
V_n = 159.9 kN

Average Failure Load obtained from testing = 159.1 kN.

Therefore, theoretical value is compares within 0.5% when compared to test derived strength.