SLAB RESPONSE

Analyze response of slab to design blast loads. Examine flexural response, shear capacity, and compliance with reinforcement limits

---

MATERIAL PROPERTIES

CLWS Drawings, S-001

Specified Properties

Concrete Compressive Strength	$f'_c := 5 \cdot ksi$	Concrete Unit Mass	$W_c := 145 \cdot \frac{lbm}{ft^3}$
Concrete Poisson Ratio	$\nu_c := .167$	Assumed Concrete Strain Rate	$SR_c := \frac{.33}{s}$
Reinforcing Steel Yield Strength	$f_{ry} := 60 \cdot ksi$	Reinforcing Steel Ultimate Strength	$f_{ru} := 90 \cdot ksi$
Reinforcing Steel Elastic Modulus	$E_s := 29000 \cdot ksi$	Assumed Reinforcement Strain Rate	$SR_r := \frac{.47}{s}$

Derived Concrete Properties

Dynamic Increase Factor (Bending)	$DIF_c = 1.26$	UFC 3-340-02, Figure 4-9
Dynamic Increase Factor (Direct Shear)	$DIF_{cds} := 1.1$	UFC 3-340-02, Table 4-1
Dynamic Compressive Strength	$f'_{cc} := f'_c \cdot DIF_c = 6.32\ ksi$	UFC 3-340-02, Equation 4-3
Dynamic Direct Shear Strength	$f'_{cds} := f'_c \cdot DIF_{cds} = 5.5\ ksi$	
Concrete Elastic Modulus	$E_c := \left(\frac{W_c}{\left(\frac{lbm}{ft^3}\right)}\right)^{1.5} \cdot 33 \cdot \sqrt[2]{f'_c \cdot psi} = 4074\ ksi$	UFC 3-340-02, Equation 4-4

Derived Steel Properties

Strength Increase Factor	$SIF_r := 1.1$	UFC 3-340-02, Section 4-12.2
Dynamic Increase Factor (Yield)	$DIF_{ry} = 1.27$	UFC 3-340-02, Figure 4-10

SEAN DONAHUE
NAVFAC EXWC

Dynamic Increase Factor (Ultimate)	$DIF_{ru} = 1.08$	
Dynamic Increase Factor (Diagonal Tension)	$DIF_{rdt} = 1.1$	UFC 3-340-02, Table 4-1
Dynamic Increase Factor (Direct Shear)	$DIF_{rds} := 1.1$	UFC 3-340-02, Table 4-1
Dynamic Yield Strength	$f_{ryb} := f_{ry} \cdot SIF_r \cdot DIF_{ry} = 84\ ksi$	UFC 3-340-02, Equation 4-3
Dynamic Ultimate Strength	$f_{rub} := DIF_{ru} \cdot f_{ru} = 97\ ksi$	
Dynamic Strength (Diagonal Tension)	$f_{rdt} := f_{ry} \cdot SIF_r \cdot DIF_{rdt} = 73\ ksi$	
Dynamic Strength (Direct Shear)	$f_{rds} := f_{ry} \cdot SIF_r \cdot DIF_{rds} = 73\ ksi$	
Modular Ratio	$n := \frac{E_s}{E_c} = 7.12$	UFC 3-340-02, Equation 4-6

BLAST LOADS

Pressure-Time History	$P_o := \begin{bmatrix} 301 \\ 0 \end{bmatrix} \cdot psi$	$t_d := \begin{bmatrix} 0 \\ 14.08 \end{bmatrix} \cdot ms$	Design Criteria: Containerized Long Weapons Storage Earth Covered Magazines
Does Load Induce Arching at Supports	$Arch :=$ "Yes"	"Yes" or "No"	
Does Load Induce Net Tension in Section	$Tens :=$ "No"	"Yes" or "No"	
Standoff Class.	$Range :=$ "Far"	"Close" or "Far"	
Protection Category	$PC := 1$		

SLAB GEOMETRIC PROPERTIES

CLWS Drawings - 20 March 2023, S-502 Detail B4, S-302, S-201

Assume "Height" is Span with Free Edge

Slab Span (In "Height" Direction) $H_s := 8 \cdot ft$

Slab Support Conditions (Height Direction) $Supp_h := 1$

=0 for Simply Supported
=1 for Fully Restrained

Slab Span (In "Length" Direction) $L_s := 32 \cdot ft$

Slab Support Conditions (Length Direction) $Supp_l := 1$

Slab Thickness $h_s := 24 \cdot in$

Slab Width (nominal) $w_s := 12 \cdot in$

Does Lateral Restraint Exist? $Restr := \text{"No"}$

"Yes" or "No"

Reinforcement Orientation $Reinf := 1$

"0" for Outer Reinf. Across Height,
"1" for Outer Reinf. Across Length

SLAB REINFORCEMENT LAYOUT AND PROPERTIES

Longitudinal Reinforcement (Height Direction)

CLWS Drawings, S-502 Detail B4

Size of Long. Bars $No_{bh} := 9$ Diameter of Long. Bars $d_{bh} := Dia_b(No_{bh}) = 1.13\ in$

Spacing of Long. Bars $s_{bh} := 6 \cdot in$ Area of Long. Bars $A_{bh} := \frac{w_s}{s_{bh}} \cdot A_{bar}(No_{bh}) = 2\ in^2$

Longitudinal Reinforcement (Length Direction)

Size of Long. Bars $No_{bl} := 9$ Diameter of Long. Bars $d_{bl} := Dia_b(No_{bl}) = 1.13\ in$

Spacing of Long. Bars $s_{bl} := 6 \cdot in$ Area of Bottom Bars $A_{bl} := \frac{w_s}{s_{bl}} \cdot A_{bar}(No_{bl}) = 2\ in^2$

Shear Reinforcement

Size of Shear Reinf. $No_v := 5$ Area of Shear Reinf. $A_v := A_{bar}(No_v) = 0.31\ in^2$

Lacing Reinf.? $Lac := \text{"No"}$ Diameter of Shear Reinf. $d_v := Dia_b(No_v) = 0.63\ in$

Reinf. Spacing (Along Outer Bars) $s_{vo} := \text{if}(Reinf = 0, s_{bh}, s_{bl}) = 6\ in$

Reinf. Spacing (Along Inner Bars) $s_{vi} := \text{if}(Reinf = 0, s_{bl}, s_{bh}) = 6\ in$

Diagonal Reinforcement

Size of Diag. Bars (Height Direction) $No_{dh} := 7$ Size of Diag. Bars (Length Direction) $No_{dl} := 0$

Area of Diag. Bars (Height Direction) $A_{dh} := A_{bar}(No_{dh}) = 0.6\ in^2$ Area of Diag. Bars (Length Direction) $A_{dl} := A_{bar}(No_{dl}) = 0\ in^2$

Spacing of Diag. Bars (Height Direction) $s_{dh} := 8 \cdot in$ Spacing of Diag. Bars (Length Direction) $s_{dl} := s_{bl} = 6\ in$

Reinforcement Locations (Top Represents Loaded Face of Slab)

Concrete Top Cover $c_t := 2 \cdot in$ Concrete Bottom Cover $c_b := 0.75 \cdot in$

Reinf. Depth (Positive Reinf, Height) $d_{ph} := h_s - c_b - d_v - \frac{d_{bh}}{2} - Reinf \cdot d_{bl} = 20.93\ in$

Reinf. Depth (Negative Reinf, Height) $d_{nh} := h_s - c_t - d_v - \frac{d_{th}}{2} - Reinf \cdot d_{tl} = 19.68\ in$

Reinf. Depth (Positive Reinf, Length) $d_{pl} := h_s - c_b - d_v - \frac{d_{bl}}{2} - (1 - Reinf) \cdot d_{bh} = 22.06\ in$

Reinf. Depth (Negative Reinf, Length) $d_{nl} := h_s - c_t - d_v - \frac{d_{tl}}{2} - (1 - Reinf) \cdot d_{th} = 20.81\ in$

SLAB FLEXURAL PROPERTIES

Maximum Support Rotation $\theta_{max} = 2\ deg$ UFC 3-340-02, Figure 4-17

Section Type $Sct := Type(\theta_{max}) = 1$

Gross Moment of Inertia $I_g := \frac{w_s \cdot h_s^3}{12} = (1.38 \cdot 10^4)\ in^4$ UFC 3-340-02, Equation 4-8a

$I_g = (1.38 \cdot 10^4)\ in^4$

Flexural Stiffness

Cracked Section Moment of Inertia

$$I_{cr}(A_p, A_n, d_p, d_n) := \begin{array}{l} c_n \leftarrow Quad\left(\frac{w_s}{2}, (n-1) \cdot A_n + n \cdot (A_p), (1-n) \cdot A_n \cdot (h_s - d_n) - n \cdot (A_p) \cdot d_p\right) \\ w_s \cdot \frac{c_n^3}{3} + (n-1) \cdot A_n \cdot (c_n - (h_s - d_n))^2 + (n) \cdot A_p \cdot (c_n - d_p)^2 \\ \text{if } c_n < (h_s - d_n) \\ \quad c_n \leftarrow Quad\left(\frac{w_s}{2}, n \cdot (A_p), -n \cdot (A_p) \cdot d_p\right) \\ \quad w_s \cdot \frac{c_n^3}{3} + (n) \cdot A_p \cdot (c_n - d_p)^2 \end{array}$$

Moment of Inertia (Pos. Height) $I_{ph} := I_{cr}(A_{bh}, A_{th}, d_{ph}, d_{nh}) = (4.07 \cdot 10^3)\ in^4$

Moment of Inertia (Neg. Height) $I_{nh} := I_{cr}(A_{th}, A_{bh}, d_{nh}, d_{ph}) = (3.6 \cdot 10^3)\ in^4$

Moment of Inertia (Pos. Length) $I_{pl} := I_{cr}(A_{bl}, A_{tl}, d_{pl}, d_{nl}) = (4.63 \cdot 10^3)\ in^4$

Moment of Inertia (Neg. Length) $I_{nl} := I_{cr}(A_{tl}, A_{bl}, d_{nl}, d_{pl}) = (4.16 \cdot 10^3)\ in^4$

Cracked Moment of Inertia for 2-way Element

$$I_{cr2} := \frac{L_s \cdot \text{if}(Supp_h = 0, I_{ph}, \text{mean}(I_{ph}, I_{nh})) + H_s \cdot \text{if}(Supp_l = 0, I_{pl}, \text{mean}(I_{pl}, I_{nl}))}{L_s + H_s}$$

$I_{cr2} = (3.95 \cdot 10^3)\ in^4$ UFC 3-340-02, Equation 4-10

Average Moment of Inertia $I_a := \frac{I_g + I_{cr2}}{2} = (8.88 \cdot 10^3)\ in^4$ UFC 3-340-02, Equation 4-7

Flexural Rigidity $D_a := \frac{E_c \cdot I_a}{\left(1 - {\nu_c}^2\right) \cdot w_s} = \left(3.1 \cdot 10^6\right)\ kip \cdot in$ UFC 3-340-02, Equation 3-33

Flexural Strength

Reinf. Dynamic Design Stress $f_{ds} := f_{ryb} + \left(Sct - 1\right) \cdot \frac{\left(f_{rub} - f_{ryb}\right)}{4} = \left(8.37 \cdot 10^4\right)\ psi$ UFC 3-340-02, Table 4-2

Compressive Force Centroid Depth $a_c\left(A_b, d_n\right) := \text{if}\left(Sct = 1, \frac{A_b \cdot f_{ryb}}{.85 \cdot w_s \cdot f'_{cc}} \cdot \frac{1}{2}, h_s - d_n\right)$ UFC 3-340-02, Equation 4-12

Reinforcement Centerline Spacing $d_{ch} := d_{ph} - \left(h_s - d_{nh}\right) = 16.62\ in$ $d_{cl} := d_{pl} - \left(h_s - d_{nl}\right) = 18.87\ in$

Ultimate Positive Moment Capacity $M_u\left(A_p, A_n, d_p, d_n\right) := \text{if}\left(Sct = 1, A_p, min\left(A_p, A_n\right)\right) \cdot f_{ds} \cdot \left(d_p - a_c\left(A_p, d_n\right)\right)$

Moment Capacity (Pos. Height) $M_{ph} := M_u\left(A_{bh}, A_{th}, d_{ph}, d_{nh}\right) = \left(3.29 \cdot 10^3\right)\ kip \cdot in$

Moment Capacity (Neg. Height) $M_{nh} := M_u\left(A_{th}, A_{bh}, d_{nh}, d_{ph}\right) = \left(3.08 \cdot 10^3\right)\ kip \cdot in$

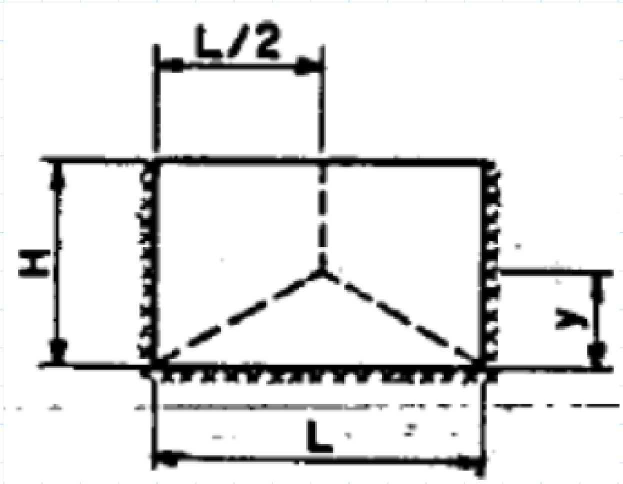
UFC 3-340-02, Equation 4-11 and 4-19

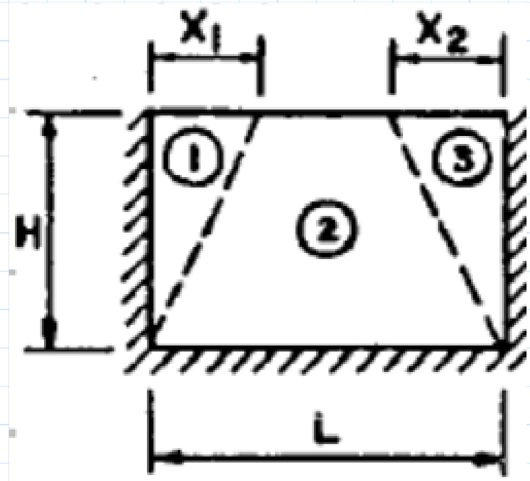
Moment Capacity (Pos. Length) $M_{pl} := M_u\left(A_{bl}, A_{tl}, d_{pl}, d_{nl}\right) = \left(3.48 \cdot 10^3\right)\ kip \cdot in$

Moment Capacity (Neg. Length) $M_{nl} := M_u\left(A_{tl}, A_{bl}, d_{nl}, d_{pl}\right) = \left(3.27 \cdot 10^3\right)\ kip \cdot in$

SLAB YIELD-LINE ANALYSIS

Location of Yield Lines taken from Figure 3-6,3-11 from UFC 3-340-02.





Length Ratio $R_l := \frac{H_s}{L_s} = 0.25$

Flexural Ratio $R_f := \frac{L_s}{H_s} \cdot \sqrt{\frac{M_{nh} \cdot Supp_h + M_{ph}}{M_{nl} \cdot Supp_l + M_{pl}}} = 3.8864$

Yield Line Location $y := \text{if}\left(R_f \geq 2, H_s, Fig3\_6\left(R_f\right) \cdot H_s\right) = 8\ ft$ UFC 3-340-02, Figure 3-6,11

$$x := \text{if}\left(R_f \geq 2, \text{if}\left(Supp_h = 1, Fig3\_11f\left(R_f \cdot \sqrt{\frac{1}{2}}\right), Fig3\_11s\left(R_f\right)\right), \frac{1}{2}\right) \cdot L_s$$

$x = 11.14\ ft$

First Yield UFC 3-340-02, Figure 3-27

Determine unit resistance corresponding to first point of yielding in slab. Check moment capacity at points of interest based on Figure 3-27.

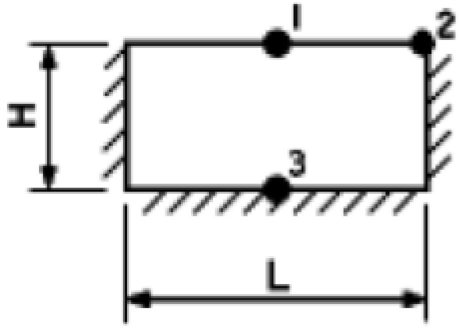


FIG. 3-27

Resistance Function $r\left(M_n, coeff, L_h\right) := M_n \cdot \left(coeff \cdot {L_h}^2 \cdot w_s\right)^{-1}$ UFC 3-340-02, Figure 3-27

Resistance (Height, Midspan) $r_{ph} := r\left(M_{ph}, Fig3\_27_{b1}\left(R_l\right), H_s\right) = 427.93\ psi$

Resistance (Length, Midspan) $r_{pl} := r\left(M_{pl}, Fig3\_27_{b1}\left(R_l\right), H_s\right) = 452.52\ psi$

Resistance (Height, Support) $r_{nh} := r\left(Supp_h \cdot M_{nh}, Fig3\_27_{b3}\left(R_l\right), H_s\right) = 61.83\ psi$

Resistance (Length, Support) $r_{nl} := r\left(Supp_l \cdot M_{nl}, Fig3\_27_{b2}\left(R_l\right), H_s\right) = 78.44\ psi$

Resistance at First Yield $r_e := min\left(r_{ph}, r_{pl}, r_{nh}, r_{nl}\right) = 61.83\ psi$ UFC 3-340-02, Equation 3-25

Deflection at First Yield $x_e := \dfrac{Fig3\_27_{\gamma}\left(R_l\right) \cdot r_e \cdot {H_s}^4}{D_a}$ UFC 3-340-02, Equation 3-32 and Figure 3-33

$x_e = 0.19\ in$

Stiffness to First Yield $K_e := \text{if}\left(r_e > 0, \dfrac{r_e}{x_e}, 0 \cdot \dfrac{psi}{in}\right) = 327.29\ \dfrac{psi}{in}$

Residual Moment Capacity at Each Potential Hinge

$$M_{re} := \begin{bmatrix} M_{ph} - Fig3\_27_{b1}\left(R_l\right) \cdot r_e \cdot {H_s}^2 \cdot w_s \\ M_{pl} - Fig3\_27_{b1}\left(R_l\right) \cdot r_e \cdot {H_s}^2 \cdot w_s \\ Supp_h \cdot M_{nh} - Fig3\_27_{b3}\left(R_l\right) \cdot r_e \cdot {H_s}^2 \cdot w_s \\ Supp_l \cdot M_{nl} - Fig3\_27_{b2}\left(R_l\right) \cdot r_e \cdot {H_s}^2 \cdot w_s \end{bmatrix} = \begin{bmatrix} 2811.69 \\ 3000.5 \\ 0 \\ 691.48 \end{bmatrix} kip \cdot in$$

Second Yield UFC 3-340-02, Figure 3-28,29

Determine unit resistance corresponding to second point of yielding in slab, based on Figure 3-28 and 3-29, depending on initial hinge location

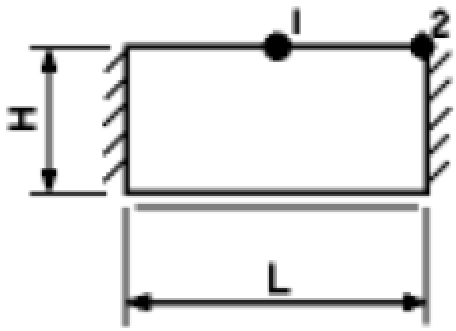


FIG. 3-28

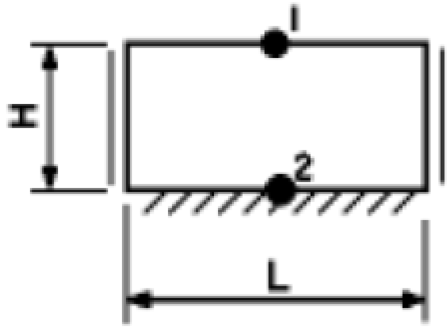


FIG. 3-29

Controlling Figure $Figure = \text{“Figure 3–28”}$

Resistance at Midspan (Height) $r_{ph2} := r\left(M_{re_1}, \text{if}\left(M_{re_3} = 0, Fig3\_28_{b1}\left(R_l\right), Fig3\_29_{b1}\left(R_l\right)\right), H_s\right) = 80.08\ psi$

Resistance at Midspan (Length) $r_{pl2} := r\left(M_{re_2}, \text{if}\left(M_{re_3} = 0, Fig3\_28_{b1}\left(R_l\right), Fig3\_29_{b1}\left(R_l\right)\right), H_s\right) = 85.46\ psi$

Resistance at Unyielded Support $r_{us} := r\left(\max\left(M_{re_3}, M_{re_4}\right), \text{if}\left(M_{re_3} = 0, Fig3\_28_{b2}\left(R_l\right), Fig3\_29_{b2}\left(R_l\right)\right), H_s\right)$

$r_{us} = 6.01\ psi$ UFC 3-340-02, Equation 3-32 and Figure 3-28,29

Resistance at Second Yield $r_{ep} := min\left(r_{ph2}, r_{pl2}, r_{us}\right) = 6.01\ psi$

Deflection at Second Yield $x_{ep} := \dfrac{\text{if}\left(M_{re_3} = 0, Fig3\_28_{\gamma}\left(R_l\right), Fig3\_29_{\gamma}\left(R_l\right)\right) \cdot r_{ep} \cdot H_s^{\ 4}}{D_a} = 0.05\ in$

Stiffness to Second Yield $K_{ep} := \text{if}\left(r_{ep} > 0, \dfrac{r_{ep}}{x_{ep}}, 0 \cdot \dfrac{psi}{in}\right) = 113.38\ \dfrac{psi}{in}$

Ultimate Resistance

Ultimate Resistance

$$r_u := \text{if}\left(R_f > 2, \frac{5 \cdot (M_{nl} \cdot Supp_l + M_{pl})}{x^2 \cdot w_s}, \frac{5 \cdot (M_{nh} \cdot Supp_h + M_{ph})}{y^2 \cdot w_s}\right)$$

$r_u = 157.25\ psi$ UFC 3-340-02, Table 3-2

Deflection at ultimate resistance based on residual resistance between point of second yield and ultimate resistance, and Figure 3-30

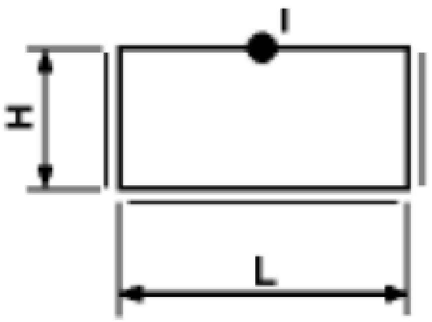


FIG. 3-30

Deflection at Ultimate Resistance

$$x_p := \frac{Fig3\_30_{\gamma}(R_l) \cdot (r_u - r_e - r_{ep}) \cdot H_s^4}{D_a} = 1.44\ in$$

UFC 3-340-02, Equation 3-32 and Figure 3-30

Stiffness to Final Yield

$$K_p := \frac{(r_u - r_e - r_{ep})}{x_p} = 62.1\ \frac{psi}{in}$$

SLAB LOAD-MASS FACTORS

Slab Mass $mass := \left(W_c + 5 \cdot \frac{lbm}{ft^3}\right) \cdot L_s \cdot H_s \cdot \left(h_s - (Sct = 3) \cdot \left(c_t + c_b + 2 \cdot d_v\right)\right) = \left(7.68 \cdot 10^4\right)\ lb$

Determine Load-Mass factor corresponding to each phase of slab response, and average load-mass factor for equivalent elastic response, based on UFC Table 3-13

Elastic Load-Mass Factor $K_{lme} := \max\left(.65, min\left(.65 - .16 \cdot \left(\frac{1}{2\ R_l} - 1\right), .77\right)\right) = 0.65$ UFC 3-340-02, Table 3-13

Elasto-Plastic Load-Mass Factor $K_{lmep} := \begin{cases} \max\left(.66, min\left(.66 - .144 \cdot \left(\frac{1}{2\ R_l} - 1\right), .77\right)\right) & \text{if } M_{re_4} < M_{re_3} \\ \max\left(.65, min\left(.65 - .186 \cdot \left(\frac{1}{2\ R_l} - 1\right), .79\right)\right) & \end{cases} = 0.66$

Ultimate Load-Mass Factor $K_{lmu} := \max\left(.66, min\left(.66 - .175 \cdot \left(\frac{1}{2\ R_l} - 1\right), .79\right)\right) = 0.66$

Plastic Load-Mass Factor $K_{lmp} := Fig3\_44\left(\text{if}\left(R_f > 2, \frac{2\ x}{L_s}, \frac{y}{H_s}\right)\right) = 0.57$ UFC 3-340-02, Figure 3-44

SDOF PARAMETERS

Applied Pressure $P_o = \begin{bmatrix} 301 \\ 0 \end{bmatrix} \, psi$

Pressure Duration $t_d = \begin{bmatrix} 0 \\ 14.08 \end{bmatrix} \, ms$

SBEDS Mass $mass_{sbeds} := \frac{mass}{H_s \cdot L_s} = \left(5.4 \cdot 10^3\right) \frac{psi \cdot ms^2}{in}$

Load-Mass Factors $K_{lm} = \begin{bmatrix} 0.65 \\ 0.66 \\ 0.66 \\ 0.57 \end{bmatrix}$

Resistances $r_s = \begin{bmatrix} 61.83 \\ 67.84 \\ 157.25 \\ 157.25 \end{bmatrix} \, psi$

Stiffness $K = \begin{bmatrix} 327.29 \\ 113.38 \\ 62.1 \\ 0 \end{bmatrix} \, \frac{psi}{in}$

Deflection $x_s = \begin{bmatrix} 0.19 \\ 0.24 \\ 1.68 \\ 1.68 \end{bmatrix} \, in$

Equivalent Elastic Deflection $x_{eq} := x_{s_1} \cdot \left(\frac{r_{s_2}}{r_{s_3}}\right) + \left(x_{s_2}\right) \cdot \left(1 - \frac{r_{s_1}}{r_{s_3}}\right) + \left(x_{s_3}\right) \cdot \left(1 - \frac{r_{s_2}}{r_{s_3}}\right) = 1.18 \, in$ UFC 3-340-02, Eqtn. 3-35

Yield Distance $Yield := min(x, y) = 96 \, in$

Output Summary See Attached SBEDS Sheet

Maximum Deflection $x_{max} := 3.16 \cdot in$

Time to Yield/Max Deflection $t_{yield} := 6.4 \cdot ms$

Maximum Ductility $\mu_{max} := \frac{x_{max}}{x_{eq}} = 2.67$

Support Rotation $\theta_{supp} := \text{atan}\left(\frac{x_{max}}{Yield}\right) = 1.89 \, deg$

Check Deflection Limits

$Defl_{chk} :=$ "Deflection Exceeds Limits"
if $\theta_{supp} \le \theta_{max}$
"Deflection Within Limits"

$Defl_{chk} =$ "Deflection Within Limits"

Check Type Assumption

$Type_{chk} :=$ "Assumed Section Type Correct"
if $\left(Sct = 2 \land \theta_{supp} < 2 \cdot deg\right) \lor \left(Sct = 3 \land \theta_{supp} < 6 \cdot deg\right) \lor \theta_{supp} > \theta_{max}$
"Section Type Assumption Incorrect"

$Type_{chk} =$ "Assumed Section Type Correct"

DYNAMIC INCREASE FACTOR CHECK

Confirm that strain rates seen in analysis are consistent with assumed strain rates for derivation of Dynamic Increase Factors

Strain Rate in Concrete

$$\varepsilon'_c := \frac{.002}{t_{yield}} \cdot min\left(1, \mu_{max}\right) = 0.31\ \frac{in}{in \cdot s}$$

Strain Rate in Steel

$$\varepsilon'_s := \frac{f_{ryb}}{E_s \cdot t_{yield}} \cdot min\left(1, \mu_{max}\right) = 0.45\ \frac{in}{in \cdot s}$$

Error in Assumed Strain Rate

$$Error_{src} := \left| \frac{\log\left(SR_c \cdot ms\right) - \log\left(\varepsilon'_c \cdot ms\right)}{\text{mean}\left(\log\left(SR_c \cdot ms\right), \log\left(\varepsilon'_c \cdot ms\right)\right)} \right| = 6.77 \cdot 10^{-3}$$

$$Error_{srs} := \left| \frac{\log\left(SR_r \cdot ms\right) - \log\left(\varepsilon'_s \cdot ms\right)}{\text{mean}\left(\log\left(SR_r \cdot ms\right), \log\left(\varepsilon'_s \cdot ms\right)\right)} \right| = 5.39 \cdot 10^{-3}$$

$$Check_{SR} := \begin{Vmatrix} \text{“Strain Rate Assumption Inaccurate”} \\ \text{if } \max\left(Error_{src}, Error_{srs}\right) < .05 \\ \quad \Vert\ \text{“Strain Rate Assumption Valid”} \end{Vmatrix}$$

$$Check_{SR} = \text{“Strain Rate Assumption Valid”}$$

FLEXURAL REINFORCEMENT CHECKS

Reinforcement Area/Ratios

Reinf. Areas

$$A_r := \begin{bmatrix} A_{bh} & A_{th} \\ A_{bl} & A_{tl} \end{bmatrix} = \begin{bmatrix} 2 & 2 \\ 2 & 2 \end{bmatrix} in^2$$

Tension Reinf. Ratios

$$\rho_r := \frac{1}{w_s} \cdot \begin{bmatrix} \frac{A_{bh}}{d_{ph}} & \frac{A_{th}}{d_{nh}} \\ \frac{A_{bl}}{d_{pl}} & \frac{A_{tl}}{d_{nl}} \end{bmatrix} = \begin{bmatrix} 7.96 \cdot 10^{-3} & 8.47 \cdot 10^{-3} \\ 7.55 \cdot 10^{-3} & 8.01 \cdot 10^{-3} \end{bmatrix}$$

UFC 3-340-02, Equation 4-13

Compression Reinf. Ratios

$$\rho'_r := \frac{1}{w_s} \cdot \begin{bmatrix} \frac{A_{th}}{d_{ph}} & \frac{A_{bh}}{d_{nh}} \\ \frac{A_{tl}}{d_{pl}} & \frac{A_{bl}}{d_{nl}} \end{bmatrix} = \begin{bmatrix} 7.96 \cdot 10^{-3} & 8.47 \cdot 10^{-3} \\ 7.55 \cdot 10^{-3} & 8.01 \cdot 10^{-3} \end{bmatrix}$$

UFC 3-340-02, Equation 4-17

Balanced Reinforcement Ratio

$$\rho_b := \frac{.85 \cdot \left(.85 - .05 \cdot \left(\frac{f'_{cc}}{ksi} - 4\right)\right) \cdot f'_{cc}}{f_{ds}} \cdot \left(\frac{87000}{87000 + \frac{f_{ds}}{psi}}\right) = 0.02$$

UFC 3-340-02, Equation 4-14

Reinforcement Limits

Minimum Tens Coeffs.

$t_h := \text{if}\left(Reinf = 0 \vee Sct \neq 1, 1.875, 1.25\right)$ $t_l := \text{if}\left(Reinf = 1 \vee Sct \neq 1, 1.875, 1.25\right)$

Minimum Comp Coeffs.

$c := \text{if}\left(Sct \neq 1, 1.875, 1.25\right)$ UFC 3-340-02, Table 4-3

Minimum Tens. Reinf. Areas

$$A_{min} := \left(\frac{w_s \cdot \sqrt{f'_c \cdot psi}}{f_{ry} \cdot SIF_r}\right) \cdot \begin{bmatrix} t_h \cdot \text{if}\left(Sct = 1, d_{ph}, d_{ch}\right) & Supp_h \cdot t_h \cdot \text{if}\left(Sct = 1, d_{nh}, d_{ch}\right) \\ t_l \cdot \text{if}\left(Sct = 1, d_{pl}, d_{cl}\right) & Supp_l \cdot t_l \cdot \text{if}\left(Sct = 1, d_{nl}, d_{cl}\right) \end{bmatrix}$$

$$A_{min} = \begin{bmatrix} 0.34 & 0.32 \\ 0.53 & 0.5 \end{bmatrix} in^2$$

Minimum Trans. Reinf. Areas

$$A_{tr} := \text{if}\left(Sct \neq 1, \frac{1}{4} \cdot \begin{bmatrix} A_{bl} & Supp_h \cdot Supp_l \cdot A_{tl} \\ A_{bh} & Supp_h \cdot Supp_l \cdot A_{th} \end{bmatrix}, \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \cdot in^2\right) = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} in^2$$

Minimum Comp. Reinf. Areas

$$A'_{min} := \left(\frac{w_s \cdot \sqrt{f'_c \cdot psi}}{f_{ry} \cdot SIF_r}\right) \cdot c \cdot \begin{bmatrix} Supp_h \cdot \text{if}\left(Sct = 1, d_{ph}, d_{ch}\right) & \text{if}\left(Sct = 1, d_{nh}, d_{ch}\right) \\ Supp_l \cdot \text{if}\left(Sct = 1, d_{pl}, d_{cl}\right) & \text{if}\left(Sct = 1, d_{nl}, d_{cl}\right) \end{bmatrix}$$

$$A'_{min} = \begin{bmatrix} 0.34 & 0.32 \\ 0.35 & 0.33 \end{bmatrix} in^2$$

$$A'_{min2} := \begin{bmatrix} Supp_h \cdot A_{th} & A_{bh} \\ Supp_l \cdot A_{tl} & A_{tl} \end{bmatrix} \cdot \frac{1}{2} = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} in^2$$

Reinforcement Check

```
Flex := || check ← "Longitudinal Reinforcement Adequate"
        || for n ∈ 1,2..2
        ||   for m ∈ 1,2..2
        ||     if A_r[n,m] < max(A_min[n,m], A_tr[n,m], A'_min[n,m], A'_min2[n,m])
        ||       check ← "Section Under−Reinforced"
        ||     if ρ_r[n,m] − ρ'_r[n,m] > 0.75 · ρ_b
        ||       check ← "Section Over−Reinforced"
        ||     else
        ||       result ← "OK"
        || return check
```

$Flex =$ "Longitudinal Reinforcement Adequate"

SHEAR (DIAGONAL TENSION) CHECKS

Maximum Resistance
$$r_{resp} := \text{if}\left(x_{max} > \max\left(x_s\right), \max\left(r_s\right), Interp\left(r_s, x_s, x_{max}\right)\right) = 157.25\ psi$$

Shear Loads

Support Shear along Height
$$V_{sh} := \text{if}\left(R_f < 2, \frac{3 \cdot r_{resp} \cdot y}{5}, \frac{3 \cdot r_{resp} \cdot H_s \cdot \left(1 - \frac{x}{L_s}\right)}{\left(3 - \frac{x}{L_s}\right)}\right) \cdot w_s = 133.6\ kip$$
UFC 3-340-02, Table 3-10

Support Shear along Length
$$V_{sl} := \text{if}\left(R_f > 2, \frac{3 \cdot r_{resp} \cdot x}{5}, \frac{3 \cdot r_{resp} \cdot L_s \cdot \left(2 - \frac{y}{H_s}\right)}{2 \cdot \left(6 - \frac{y}{H_s}\right)}\right) \cdot w_s = 151.32\ kip$$

Arching Shear (Height)
$$V_{uh} := V_{sh} \cdot \frac{\left(y - \text{if}\left(Sct = 1, d_{ph}, d_{ch}\right)\right)}{y} = 104.47\ kip$$
UFC 3-340-02, Section 4-18.1

Arching Shear (Length)
$$V_{ul} := V_{sl} \cdot \frac{\left(x - \text{if}\left(Sct = 1, d_{pl}, d_{cl}\right)\right)}{x} = 126.34\ kip$$

Shear Capacity

Shear Stress (Height)
$$v_{uh} := \frac{\text{if}\left(Arch = \text{“Yes”} \lor Lac = \text{“Yes”} \lor No_{dh} > 0, V_{uh}, V_{sh}\right)}{w_s \cdot \text{if}\left(Sct = 1, d_{ph}, d_{ch}\right)} = 415.89\ psi$$

Shear Stress (Length)
$$v_{ul} := \frac{\text{if}\left(Arch = \text{“Yes”} \lor Lac = \text{“Yes”} \lor No_{dl} > 0, V_{ul}, V_{sl}\right)}{w_s \cdot \text{if}\left(Sct = 1, d_{pl}, d_{cl}\right)} = 477.25\ psi$$
UFC 3-340-02, Eqtn. 4-21,22

Concrete Shear Capacity (Height)
$$v_{ch} := min\left(1.9 \cdot \sqrt[2]{\frac{f'_c}{psi}} + 2500\ \rho_{r_{1,1}}, 3.5 \cdot \sqrt[2]{\frac{f'_c}{psi}}\right) \cdot psi = 154.26\ psi$$
UFC 3-340-02, Equation 4-23

Concrete Shear Capacity (Length)
$$v_{cl} := min\left(1.9 \cdot \sqrt[2]{\frac{f'_c}{psi}} + 2500\ \rho_{r_{2,1}}, 3.5 \cdot \sqrt[2]{\frac{f'_c}{psi}}\right) \cdot psi = 153.24\ psi$$

Concrete Shear Capacity Check
$$Shear_{check} := \begin{array}{l} \text{“Shear Stress Acceptable”} \\ \text{if } Lac = \text{“No”} \land \max\left(v_{ch}, v_{cl}\right) > 10 \cdot \sqrt[2]{f'_c \cdot psi} \\ \quad \text{“Shear Stress Exceeds Sectional Capacity”} \end{array}$$

$$Shear_{check} = \text{“Shear Stress Acceptable”}$$

Shear Reinforcement

Shear Reinf. Design Stress (Height)

$$v_{sh} := \max\left(v_{uh} - v_{ch}, 0.85 \cdot v_{ch} \cdot \left(Sct \neq 1 \vee Range = \text{“Close”}\right)\right) = 261.63\ psi$$

UFC 3-340-02, Table 4-4

Shear Reinf. Design Stress (Length)

$$v_{sl} := \max\left(v_{ul} - v_{cl}, 0.85 \cdot v_{cl} \cdot \left(Sct \neq 1 \vee Range = \text{“Close”}\right)\right) = 324.02\ psi$$

Shear Reinf. Reduc Factor

$$\phi_s := .85$$

UFC 3-340-02, Section 4-18.3

Shear Reinf. Dynamic Stress

$$f_{dv} := f_{rdt} + \left(Lac = \text{“Yes”}\right) \cdot \left(Sct - 1\right) \cdot \frac{\left(f_{ru} - f_{rdt}\right)}{4} = \left(7.26 \cdot 10^{4}\right)\ psi$$

UFC 3-340-02, Table 4-1

Required Shear Reinf. (Height)

$$A_{vh\_r} := \frac{v_{sh} \cdot s_{vi} \cdot s_{vo}}{\phi_s \cdot f_{dv}} \cdot \text{if}\left(Lac = \text{“No”}, 1, \frac{1}{\sin\left(\alpha_{lac}\right) + \cos\left(\alpha_{lac}\right)}\right) = 0.15\ in^2$$

UFC 3-340-02, Eqtn. 4-141

Required Shear Reinf. (Length)

$$A_{vl\_r} := \frac{v_{sl} \cdot s_{vi} \cdot s_{vo}}{\phi_s \cdot f_{dv}} \cdot \text{if}\left(Lac = \text{“No”}, 1, \frac{1}{\sin\left(\alpha_{lac}\right) + \cos\left(\alpha_{lac}\right)}\right) = 0.19\ in^2$$

Max. Shear Reinf. Spacing

$$s_{vmax} := min\left(24 \cdot in, \max\left(\left(Sct = 1\right) \cdot \frac{\max\left(d_{ph}, d_{pl}\right)}{2}, \frac{\left(Lac = \text{“Yes”}\right) + 1}{2} \cdot \max\left(d_{ch}, d_{cl}\right)\right)\right)$$

$$s_{vmax} = 11.03\ in$$

UFC 3-340-02, Section 4-18.4

Shear Reinforcement Check

$$Reinf_{shear} := \begin{array}{l} \text{“Shear Reinforcement Sufficient”} \\ \text{if } A_v < \max\left(A_{vh\_r}, A_{vl\_r}\right) \vee \left(A_v < .0015 \cdot s_{bh} \cdot s_{bl} \wedge \max\left(A_{vh\_r}, A_{vl\_r}\right) > 0 \cdot in^2\right) \\ \quad \text{“Shear Reinf. Insufficient”} \\ \text{if } \left(s_{vo} > s_{vmax} \wedge \max\left(A_{vh\_r}, A_{vl\_r}\right) > 0 \cdot in^2\right) \\ \quad \text{“Shear Reinf. Spacing Exceeds Maximum”} \end{array}$$

$$Reinf_{shear} = \text{“Shear Reinforcement Sufficient”}$$

DIRECT SHEAR CHECKS

Concrete Direct Shear Cap. (Height)

$$V_{dh} := .16 \cdot f'_{cds} \cdot w_s \cdot d_{ph} \cdot \left(\left(Supp_h = 0 \vee Sct = 1\right)\right) = 221.05\ kip$$

UFC 3-340-02, Equation 4-30

Concrete Direct Shear Cap. (Length)

$$V_{dl} := .16 \cdot f'_{cds} \cdot w_s \cdot d_{pl} \cdot \left(\left(Supp_l = 0 \vee Sct = 1\right) \wedge Tens = \text{“No”}\right) = 232.96\ kip$$

Direct Shear Reinf. Dynamic Stress

$$f_{dds} := f_{rds} + (Sct - 1) \cdot \frac{\left(f_{ru} - f_{rds}\right)}{4} = \left(7.26 \cdot 10^4\right)\ psi$$

UFC 3-340-02, Table 4-1

Required Diagonal Bars (Height Side)

$$A_{dh\_r} := \frac{V_{sh} - V_{dh}}{f_{dds} \cdot \sin(45 \cdot deg)} \cdot \frac{s_{dh}}{w_s} = -1.14\ in^2$$

UFC 3-340-02, Equation 4-31

Required Diagonal Bars (Length Side)

$$A_{dl\_r} := \frac{V_{sl} - V_{dl}}{f_{dds} \cdot \sin(45 \cdot deg)} \cdot \frac{s_{dl}}{w_s} = -0.8\ in^2$$

Direct Shear Check

$D\_S_{check} :=$ “Direct Shear Capacity Sufficient”
if $A_{dh\_r} > A_{dh}$
  “Direct Shear Capacity Insufficient Along Height Span”
if $A_{dl\_r} > A_{dl}$
  “Direct Shear Capacity Insufficient Along Length Span”

$D\_S_{check} =$ “Direct Shear Capacity Sufficient”

SLAB RESPONSE SUMMARY

Slab deflections are within acceptable limits under design blast loads. Slab is adequately reinforced, and does not experience any brittle failure mechanisms. Performance of slab is adequate.

NAVFAC EXWC SDOF Dynamic Analysis Spreadsheet

Project/Location: CLWS ECM | Building: Single Bay Design | Component: Headwall - New Design

Command Prompt: | Analyzed By: SMD | Date: 2/15/2024

Blast Load	
User-Defined	
Time (ms)	Pressure (psi)
0	301
14.08	0
14.08	0
14.08	0
14.08	0
14.08	0

Constant Load (psi)	

Response Criteria	
Concr. Slab	
Shear Ties-No Tens Membr	
PC1	
Support Rotation (deg)	2
Max Ductility	
Max Displacement (in)	

2-Way Parameters	
Height	8
Length	32
Yield Line Dist (y)	8
Yield Line Dist (x)	11.14

Height must be Short Span (For 2 or 4-side supports) or Unsupported Span (for 3-side Supports)

SDOF Properties			
Property	Inbound	Rebound	Units
Mass	5400	5400	psi-ms^2/in
Load Mass Factors			
3-Side Supported	1st Yield Asym Span		
KLM1	0.65	0.65	
KLM2	0.66	0.66	
KLM3	0.66	0.66	
KLM4	0.57	0.57	
KLM5	0.57	0.57	
Stiffness			
K1	327.29	327.29	psi/in
K2	113.38	113.38	psi/in
K3	62.1	62.1	psi/in
K4	0	0	psi/in
Resistance			
R1	61.83	61.83	psi
R2	67.84	67.84	psi
R3	157.25	157.25	psi
R4	157.25	157.25	psi
Displacement			
Stiffness Controlled			
X1	0	0	
X2	0	0	
X3	0	0	
X4	0	0	
Equiv. Elastic Displ.	1.184	1.184	in
Yield Line Distance		96	in

Analysis Parameters		
Natural period	20.58	ms
Time step	0.10	ms
Duration	55.23	ms

Initial Conditions		
Initial Vel.	0	in/ms
Initial Displ.	0.000	in

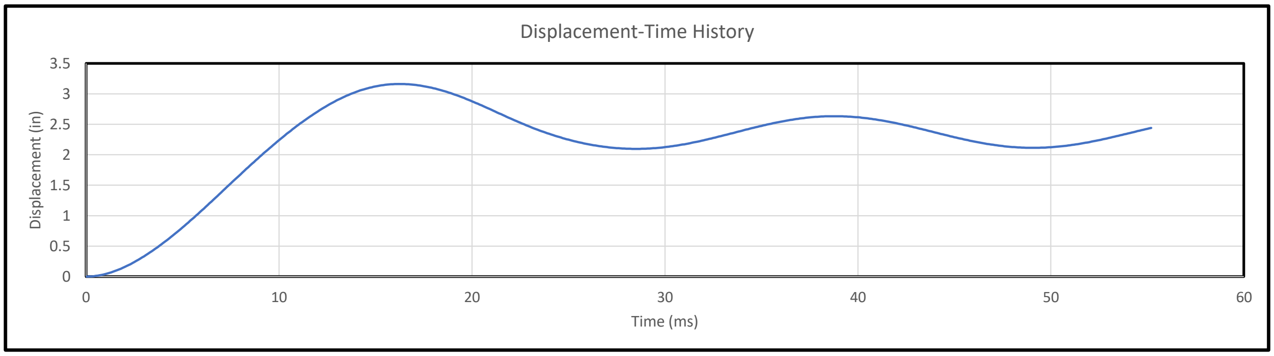
Damping Parameters		
% of Crit. Damp.	1	%
Elasto-plastic Damping	Yes	

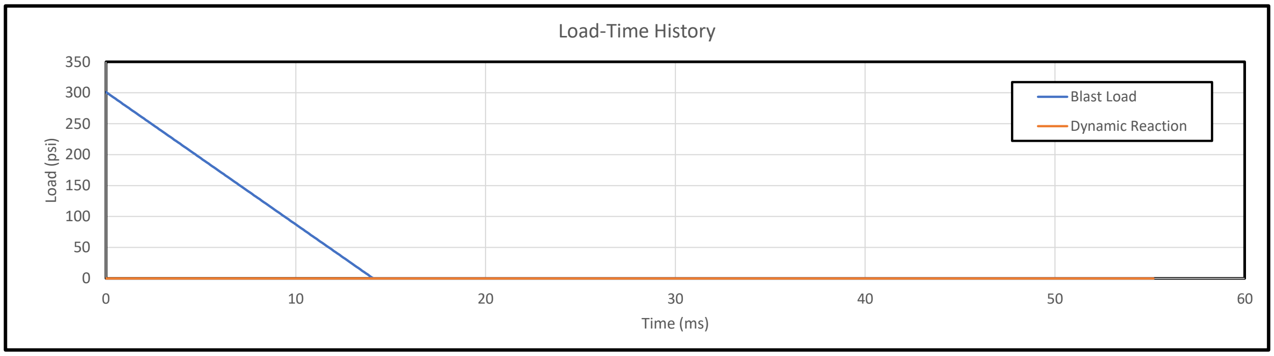
Dynamic Reaction Coefficients		
User-Defined		
Reaction 1	Force	Resistance
Elastic	0	0
Elasto-Plastic	0	0
Plastic	0	0
Reaction 2	Force	Resistance
Elastic	0	0
Elasto-Plastic	0	0
Plastic	0	0

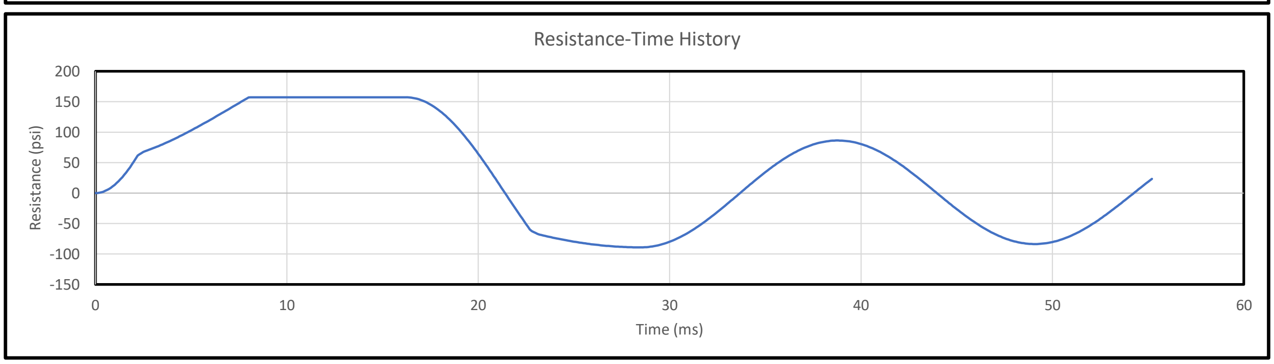
Results Summary					
Max. Defl. (in)	3.162	Max Supp. Rot.	1.89	deg	Response Meets Criteria
Time to Max. Resp. (ms)	16.200	Max Ductility	2.67		
Time to Yield Defl. (ms)	6.400				
		Max Inbound Resist	157.25	psi	
		Max Rebound Resist	-89.09	psi	

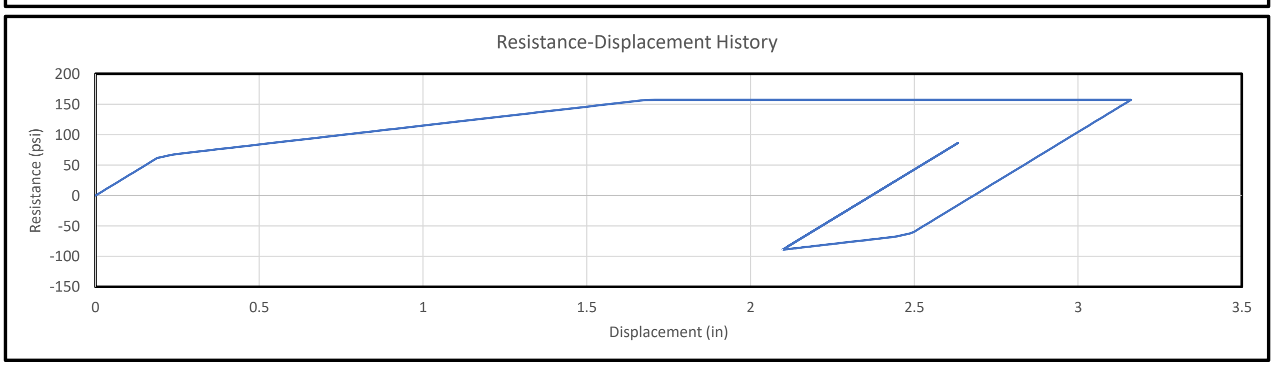
Project/Location	CLWS ECM	Building	Single Bay Design	Component	Headwall - New Design
		Analyzed By	SMD	Date	2/15/2024

Results Summary					
Max. Defl. (in)	3.162	Max Supp. Rot.	1.89	deg	Response Meets Criteria
Time to Max. Resp. (ms)	16.2	Max Ductility	2.67		
Time to Yield Defl. (ms)	6.4				
		Max Inbound Resist	157.25	psi	
		Max Rebound Resist	-89.09	psi	









SLAB RESPONSE

Analyze response of slab to design blast loads. Examine flexural response, shear capacity, and compliance with reinforcement limits

---

MATERIAL PROPERTIES

CLWS Drawings, S-001

Specified Properties

Concrete Compressive Strength	$f'_c := 5 \cdot ksi$	Concrete Unit Mass	$W_c := 145 \cdot \frac{lbm}{ft^3}$
Concrete Poisson Ratio	$\nu_c := .167$	Assumed Concrete Strain Rate	$SR_c := \frac{.33}{s}$
Reinforcing Steel Yield Strength	$f_{ry} := 60 \cdot ksi$	Reinforcing Steel Ultimate Strength	$f_{ru} := 90 \cdot ksi$
Reinforcing Steel Elastic Modulus	$E_s := 29000 \cdot ksi$	Assumed Reinforcement Strain Rate	$SR_r := \frac{.47}{s}$

Derived Concrete Properties

Dynamic Increase Factor (Bending) $DIF_c = 1.26$ UFC 3-340-02, Figure 4-9

Dynamic Increase Factor (Direct Shear) $DIF_{cds} := 1.1$ UFC 3-340-02, Table 4-1

Dynamic Compressive Strength $f'_{cc} := f'_c \cdot DIF_c = 6.32\ ksi$ UFC 3-340-02, Equation 4-3

Dynamic Direct Shear Strength $f'_{cds} := f'_c \cdot DIF_{cds} = 5.5\ ksi$

Concrete Elastic Modulus $E_c := \left(\frac{W_c}{\left(\frac{lbm}{ft^3}\right)}\right)^{1.5} \cdot 33 \cdot \sqrt[2]{f'_c \cdot psi} = 4074\ ksi$ UFC 3-340-02, Equation 4-4

Derived Steel Properties

Strength Increase Factor $SIF_r := 1.1$ UFC 3-340-02, Section 4-12.2

Dynamic Increase Factor (Yield) $DIF_{ry} = 1.27$ UFC 3-340-02, Figure 4-10

Dynamic Increase Factor (Ultimate)	$DIF_{ru}=1.08$	
Dynamic Increase Factor (Diagonal Tension)	$DIF_{rdt}=1.1$	UFC 3-340-02, Table 4-1
Dynamic Increase Factor (Direct Shear)	$DIF_{rds}:=1.1$	UFC 3-340-02, Table 4-1
Dynamic Yield Strength	$f_{ryb}:=f_{ry}\cdot SIF_r\cdot DIF_{ry}=84\ ksi$	UFC 3-340-02, Equation 4-3
Dynamic Ultimate Strength	$f_{rub}:=DIF_{ru}\cdot f_{ru}=97\ ksi$	
Dynamic Strength (Diagonal Tension)	$f_{rdt}:=f_{ry}\cdot SIF_r\cdot DIF_{rdt}=73\ ksi$	
Dynamic Strength (Direct Shear)	$f_{rds}:=f_{ry}\cdot SIF_r\cdot DIF_{rds}=73\ ksi$	
Modular Ratio	$n:=\frac{E_s}{E_c}=7.12$	UFC 3-340-02, Equation 4-6

BLAST LOADS

Pressure-Time History	$P_o:=\begin{bmatrix}301\\0\end{bmatrix}\cdot psi$ $t_d:=\begin{bmatrix}0\\14.08\end{bmatrix}\cdot ms$	Design Criteria: Containerized Long Weapons Storage Earth Covered Magazines
Does Load Induce Arching at Supports	$Arch:=\text{“Yes”}$	"Yes" or "No"
Does Load Induce Net Tension in Section	$Tens:=\text{“No”}$	"Yes" or "No"
Standoff Class.	$Range:=\text{“Far”}$	"Close" or "Far"
Protection Category	$PC:=1$	

SEAN DONAHUE
NAVFAC EXWC

SLAB GEOMETRIC PROPERTIES

CLWS Drawings - 20 March 2023, S-502 Detail B4, S-302, S-201

Assume "Height" is Span with Free Edge

Slab Span (In "Height" Direction) $H_s := 8 \cdot ft$

Slab Support Conditions (Height Direction) $Supp_h := 1$

=0 for Simply Supported
=1 for Fully Restrained

Slab Span (In "Length" Direction) $L_s := 32 \cdot ft$

Slab Support Conditions (Length Direction) $Supp_l := 1$

Slab Thickness $h_s := 24 \cdot in$

Slab Width (nominal) $w_s := 12 \cdot in$

Does Lateral Restraint Exist? $Restr := \text{"No"}$

"Yes" or "No"

Reinforcement Orientation $Reinf := 0$

"0" for Outer Reinf. Across Height,
"1" for Outer Reinf. Across Length

SLAB REINFORCEMENT LAYOUT AND PROPERTIES

Longitudinal Reinforcement (Height Direction)

CLWS Drawings, S-502 Detail B4

Size of Long. Bars $No_{bh} := 9$ Diameter of Long. Bars $d_{bh} := Dia_b\left(No_{bh}\right) = 1.13\ in$

Spacing of Long. Bars $s_{bh} := 6 \cdot in$ Area of Long. Bars $A_{bh} := \frac{w_s}{s_{bh}} \cdot A_{bar}\left(No_{bh}\right) = 2\ in^2$

Longitudinal Reinforcement (Length Direction)

Size of Long. Bars $No_{bl} := 9$ Diameter of Long. Bars $d_{bl} := Dia_b\left(No_{bl}\right) = 1.13\ in$

Spacing of Long. Bars $s_{bl} := 6 \cdot in$ Area of Bottom Bars $A_{bl} := \frac{w_s}{s_{bl}} \cdot A_{bar}\left(No_{bl}\right) = 2\ in^2$

Shear Reinforcement

Size of Shear Reinf. $No_v := 5$ Area of Shear Reinf. $A_v := A_{bar}\left(No_v\right) = 0.31\ in^2$

Lacing Reinf.? $Lac := \text{"No"}$ Diameter of Shear Reinf. $d_v := Dia_b\left(No_v\right) = 0.63\ in$

Reinf. Spacing (Along Outer Bars) $s_{vo} := \text{if}\left(Reinf = 0, s_{bh}, s_{bl}\right) = 6\ in$

Reinf. Spacing (Along Inner Bars) $s_{vi} := \text{if}\left(Reinf = 0, s_{bl}, s_{bh}\right) = 6\ in$

Diagonal Reinforcement

Size of Diag. Bars (Height Direction) $No_{dh} := 7$ Size of Diag. Bars (Length Direction) $No_{dl} := 0$

Area of Diag. Bars (Height Direction) $A_{dh} := A_{bar}\left(No_{dh}\right) = 0.6\ in^2$ Area of Diag. Bars (Length Direction) $A_{dl} := A_{bar}\left(No_{dl}\right) = 0\ in^2$

Spacing of Diag. Bars (Height Direction) $s_{dh} := 8 \cdot in$ Spacing of Diag. Bars (Length Direction) $s_{dl} := s_{bl} = 6\ in$

Reinforcement Locations (Top Represents Loaded Face of Slab)

Concrete Top Cover $c_t := 2 \cdot in$ Concrete Bottom Cover $c_b := 0.75 \cdot in$

Reinf. Depth (Positive Reinf, Height) $d_{ph} := h_s - c_b - d_v - \frac{d_{bh}}{2} - Reinf \cdot d_{bl} = 22.06\ in$

Reinf. Depth (Negative Reinf, Height) $d_{nh} := h_s - c_t - d_v - \frac{d_{th}}{2} - Reinf \cdot d_{tl} = 20.81\ in$

Reinf. Depth (Positive Reinf, Length) $d_{pl} := h_s - c_b - d_v - \frac{d_{bl}}{2} - \left(1 - Reinf\right) \cdot d_{bh} = 20.93\ in$

Reinf. Depth (Negative Reinf, Length) $d_{nl} := h_s - c_t - d_v - \frac{d_{tl}}{2} - \left(1 - Reinf\right) \cdot d_{th} = 19.68\ in$

SLAB FLEXURAL PROPERTIES

Maximum Support Rotation $\theta_{max} = 2\ deg$ UFC 3-340-02, Figure 4-17

Section Type $Sct := Type(\theta_{max}) = 1$

Gross Moment of Inertia $I_g := \frac{w_s \cdot h_s^3}{12} = (1.38 \cdot 10^4)\ in^4$ UFC 3-340-02, Equation 4-8a

$I_g = (1.38 \cdot 10^4)\ in^4$

Flexural Stiffness

Cracked Section Moment of Inertia

$$I_{cr}(A_p, A_n, d_p, d_n) := \begin{array}{l} c_n \leftarrow Quad\left(\frac{w_s}{2}, (n-1) \cdot A_n + n \cdot (A_p), (1-n) \cdot A_n \cdot (h_s - d_n) - n \cdot (A_p) \cdot d_p\right) \\ w_s \cdot \frac{c_n^3}{3} + (n-1) \cdot A_n \cdot (c_n - (h_s - d_n))^2 + (n) \cdot A_p \cdot (c_n - d_p)^2 \\ \text{if } c_n < (h_s - d_n) \\ \quad \begin{array}{l} c_n \leftarrow Quad\left(\frac{w_s}{2}, n \cdot (A_p), -n \cdot (A_p) \cdot d_p\right) \\ w_s \cdot \frac{c_n^3}{3} + (n) \cdot A_p \cdot (c_n - d_p)^2 \end{array} \end{array}$$

Moment of Inertia (Pos. Height) $I_{ph} := I_{cr}(A_{bh}, A_{th}, d_{ph}, d_{nh}) = (4.63 \cdot 10^3)\ in^4$

Moment of Inertia (Neg. Height) $I_{nh} := I_{cr}(A_{th}, A_{bh}, d_{nh}, d_{ph}) = (4.16 \cdot 10^3)\ in^4$

Moment of Inertia (Pos. Length) $I_{pl} := I_{cr}(A_{bl}, A_{tl}, d_{pl}, d_{nl}) = (4.07 \cdot 10^3)\ in^4$

Moment of Inertia (Neg. Length) $I_{nl} := I_{cr}(A_{tl}, A_{bl}, d_{nl}, d_{pl}) = (3.6 \cdot 10^3)\ in^4$

Cracked Moment of Inertia for 2-way Element

$$I_{cr2} := \frac{L_s \cdot \text{if}(Supp_h = 0, I_{ph}, \text{mean}(I_{ph}, I_{nh})) + H_s \cdot \text{if}(Supp_l = 0, I_{pl}, \text{mean}(I_{pl}, I_{nl}))}{L_s + H_s}$$

$I_{cr2} = (4.28 \cdot 10^3)\ in^4$ UFC 3-340-02, Equation 4-10

Average Moment of Inertia $I_a := \frac{I_g + I_{cr2}}{2} = (9.05 \cdot 10^3)\ in^4$ UFC 3-340-02, Equation 4-7

Flexural Rigidity $D_a := \frac{E_c \cdot I_a}{\left(1 - {\nu_c}^2\right) \cdot w_s} = \left(3.16 \cdot 10^6\right)\ kip \cdot in$ UFC 3-340-02, Equation 3-33

Flexural Strength

Reinf. Dynamic Design Stress $f_{ds} := f_{ryb} + (Sct - 1) \cdot \frac{\left(f_{rub} - f_{ryb}\right)}{4} = \left(8.37 \cdot 10^4\right)\ psi$ UFC 3-340-02, Table 4-2

Compressive Force Centroid Depth $a_c\left(A_b, d_n\right) := \text{if}\left(Sct = 1, \frac{A_b \cdot f_{ryb}}{.85 \cdot w_s \cdot f'_{cc}} \cdot \frac{1}{2}, h_s - d_n\right)$ UFC 3-340-02, Equation 4-12

Reinforcement Centerline Spacing $d_{ch} := d_{ph} - \left(h_s - d_{nh}\right) = 18.87\ in$ $d_{cl} := d_{pl} - \left(h_s - d_{nl}\right) = 16.62\ in$

Ultimate Positive Moment Capacity $M_u\left(A_p, A_n, d_p, d_n\right) := \text{if}\left(Sct = 1, A_p, min\left(A_p, A_n\right)\right) \cdot f_{ds} \cdot \left(d_p - a_c\left(A_p, d_n\right)\right)$

Moment Capacity (Pos. Height) $M_{ph} := M_u\left(A_{bh}, A_{th}, d_{ph}, d_{nh}\right) = \left(3.48 \cdot 10^3\right)\ kip \cdot in$ UFC 3-340-02, Equation 4-11 and 4-19

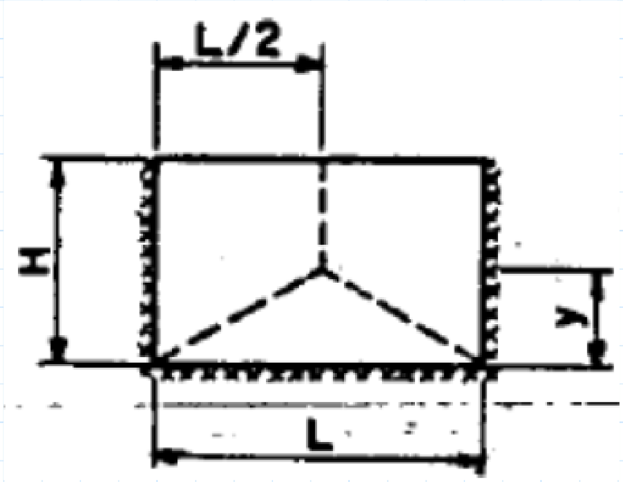
Moment Capacity (Neg. Height) $M_{nh} := M_u\left(A_{th}, A_{bh}, d_{nh}, d_{ph}\right) = \left(3.27 \cdot 10^3\right)\ kip \cdot in$

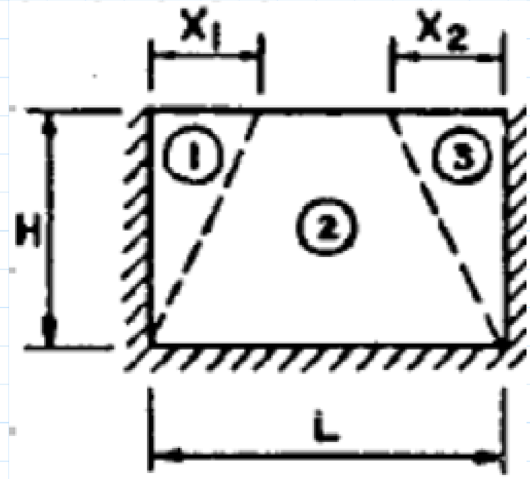
Moment Capacity (Pos. Length) $M_{pl} := M_u\left(A_{bl}, A_{tl}, d_{pl}, d_{nl}\right) = \left(3.29 \cdot 10^3\right)\ kip \cdot in$

Moment Capacity (Neg. Length) $M_{nl} := M_u\left(A_{tl}, A_{bl}, d_{nl}, d_{pl}\right) = \left(3.08 \cdot 10^3\right)\ kip \cdot in$

SLAB YIELD-LINE ANALYSIS

Location of Yield Lines taken from Figure 3-6,3-11 from UFC 3-340-02.





Length Ratio $R_l := \frac{H_s}{L_s} = 0.25$

Flexural Ratio $R_f := \frac{L_s}{H_s} \cdot \sqrt{\frac{M_{nh} \cdot Supp_h + M_{ph}}{M_{nl} \cdot Supp_l + M_{pl}}} = 4.117$

Yield Line Location $y := \text{if}\left(R_f \ge 2, H_s, Fig3\_6\left(R_f\right) \cdot H_s\right) = 8\ ft$

UFC 3-340-02, Figure 3-6,11

$$x := \text{if}\left(R_f \ge 2, \text{if}\left(Supp_h = 1, Fig3\_11f\left(R_f \cdot \sqrt{\frac{1}{2}}\right), Fig3\_11s\left(R_f\right)\right), \frac{1}{2}\right) \cdot L_s$$

$x = 10.74\ ft$

First Yield UFC 3-340-02, Figure 3-27

Determine unit resistance corresponding to first point of yielding in slab. Check moment capacity at points of interest based on Figure 3-27.

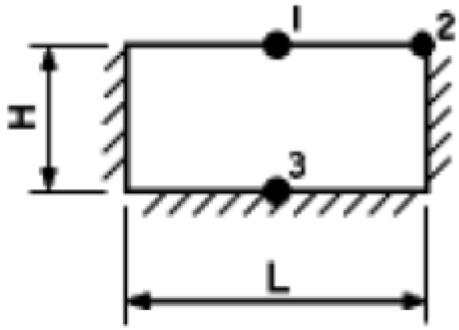


FIG. 3-27

Resistance Function $r\left(M_n, coeff, L_h\right) := M_n \cdot \left(coeff \cdot L_h^{\,2} \cdot w_s\right)^{-1}$ UFC 3-340-02, Figure 3-27

Resistance (Height, Midspan) $r_{ph} := r\left(M_{ph}, Fig3\_27_{b1}\left(R_l\right), H_s\right) = 452.52\ \boldsymbol{psi}$

Resistance (Length, Midspan) $r_{pl} := r\left(M_{pl}, Fig3\_27_{b1}\left(R_l\right), H_s\right) = 427.93\ \boldsymbol{psi}$

Resistance (Height, Support) $r_{nh} := r\left(Supp_h \cdot M_{nh}, Fig3\_27_{b3}\left(R_l\right), H_s\right) = 65.63\ \boldsymbol{psi}$

Resistance (Length, Support) $r_{nl} := r\left(Supp_l \cdot M_{nl}, Fig3\_27_{b2}\left(R_l\right), H_s\right) = 73.9\ \boldsymbol{psi}$

Resistance at First Yield $r_e := min\left(r_{ph}, r_{pl}, r_{nh}, r_{nl}\right) = 65.63\ \boldsymbol{psi}$ UFC 3-340-02, Equation 3-25

Deflection at First Yield $x_e := \dfrac{Fig3\_27_{\gamma}\left(R_l\right) \cdot r_e \cdot H_s^{\,4}}{D_a}$ UFC 3-340-02, Equation 3-32 and Figure 3-33

$x_e = 0.2\ \boldsymbol{in}$

Stiffness to First Yield $K_e := \text{if}\left(r_e > 0, \dfrac{r_e}{x_e}, 0 \cdot \dfrac{\boldsymbol{psi}}{\boldsymbol{in}}\right) = 333.46\ \dfrac{\boldsymbol{psi}}{\boldsymbol{in}}$

Residual Moment Capacity at Each Potential Hinge

$$M_{re} := \begin{bmatrix} M_{ph} - Fig3\_27_{b1}\left(R_l\right) \cdot r_e \cdot H_s^{\,2} \cdot w_s \\ M_{pl} - Fig3\_27_{b1}\left(R_l\right) \cdot r_e \cdot H_s^{\,2} \cdot w_s \\ Supp_h \cdot M_{nh} - Fig3\_27_{b3}\left(R_l\right) \cdot r_e \cdot H_s^{\,2} \cdot w_s \\ Supp_l \cdot M_{nl} - Fig3\_27_{b2}\left(R_l\right) \cdot r_e \cdot H_s^{\,2} \cdot w_s \end{bmatrix} = \begin{bmatrix} 2971.36 \\ 2782.55 \\ 0 \\ 344.7 \end{bmatrix} \boldsymbol{kip} \cdot \boldsymbol{in}$$

Second Yield UFC 3-340-02, Figure 3-28,29

Determine unit resistance corresponding to second point of yielding in slab, based on Figure 3-28 and 3-29, depending on initial hinge location

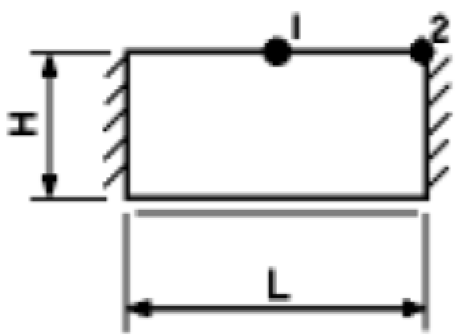


FIG. 3-28

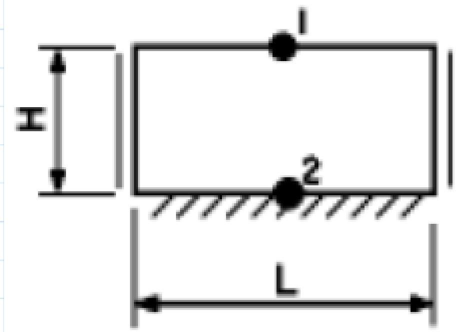


FIG. 3-29

Controlling Figure $Figure = \text{“Figure 3–28”}$

Resistance at Midspan (Height) $r_{ph2} := r\left(M_{re_1}, \text{if}\left(M_{re_3} = 0, Fig3\_28_{b1}\left(R_l\right), Fig3\_29_{b1}\left(R_l\right)\right), H_s\right) = 929.23\ psi$

Resistance at Midspan (Length) $r_{pl2} := r\left(M_{re_2}, \text{if}\left(M_{re_3} = 0, Fig3\_28_{b1}\left(R_l\right), Fig3\_29_{b1}\left(R_l\right)\right), H_s\right) = 870.18\ psi$

Resistance at Unyielded Support $r_{us} := r\left(\max\left(M_{re_3}, M_{re_4}\right), \text{if}\left(M_{re_3} = 0, Fig3\_28_{b2}\left(R_l\right), Fig3\_29_{b2}\left(R_l\right)\right), H_s\right)$

$r_{us} = 6.54\ psi$ UFC 3-340-02, Equation 3-32 and Figure 3-28,29

Resistance at Second Yield $r_{ep} := min\left(r_{ph2}, r_{pl2}, r_{us}\right) = 6.54\ psi$

Deflection at Second Yield $x_{ep} := \dfrac{\text{if}\left(M_{re_3} = 0, Fig3\_28_{\gamma}\left(R_l\right), Fig3\_29_{\gamma}\left(R_l\right)\right) \cdot r_{ep} \cdot H_s^{\,4}}{D_a} = 0.02\ in$

Stiffness to Second Yield $K_{ep} := \text{if}\left(r_{ep} > 0, \dfrac{r_{ep}}{x_{ep}}, 0 \cdot \dfrac{psi}{in}\right) = 329.89\ \dfrac{psi}{in}$

Ultimate Resistance

Ultimate Resistance $r_u := \text{if}\left(R_f > 2, \frac{5 \cdot (M_{nl} \cdot Supp_l + M_{pl})}{x^2 \cdot w_s}, \frac{5 \cdot (M_{nh} \cdot Supp_h + M_{ph})}{y^2 \cdot w_s}\right)$

$r_u = 159.62\ psi$ UFC 3-340-02, Table 3-2

Deflection at ultimate resistance based on residual resistance between point of second yield and ultimate resistance, and Figure 3-30

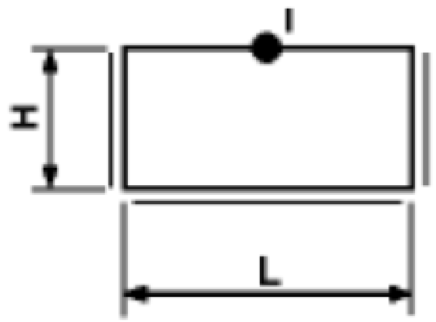


FIG. 3-30

Deflection at Ultimate Resistance $x_p := \frac{Fig3\_30_\gamma(R_l) \cdot (r_u - r_e - r_{ep}) \cdot {H_s}^4}{D_a} = 1.38\ in$ UFC 3-340-02, Equation 3-32 and Figure 3-30

Stiffness to Final Yield $K_p := \frac{(r_u - r_e - r_{ep})}{x_p} = 63.27\ \frac{psi}{in}$

SLAB LOAD-MASS FACTORS

Slab Mass $mass := \left(W_c + 5 \cdot \frac{lbm}{ft^3}\right) \cdot L_s \cdot H_s \cdot \left(h_s - (Sct = 3) \cdot \left(c_t + c_b + 2 \cdot d_v\right)\right) = \left(7.68 \cdot 10^4\right)\ lb$

Determine Load-Mass factor corresponding to each phase of slab response, and average load-mass factor for equivalent elastic response, based on UFC Table 3-13

Elastic Load-Mass Factor $K_{lme} := \max\left(.65, min\left(.65 - .16 \cdot \left(\frac{1}{2\ R_l} - 1\right), .77\right)\right) = 0.65$ UFC 3-340-02, Table 3-13

Elasto-Plastic Load-Mass Factor
$$K_{lmep} := \begin{array}{l} \max\left(.66, min\left(.66 - .144 \cdot \left(\frac{1}{2\ R_l} - 1\right), .77\right)\right) \\ \text{if } M_{re_4} < M_{re_3} \\ \quad \max\left(.65, min\left(.65 - .186 \cdot \left(\frac{1}{2\ R_l} - 1\right), .79\right)\right) \end{array} = 0.66$$

Ultimate Load-Mass Factor $K_{lmu} := \max\left(.66, min\left(.66 - .175 \cdot \left(\frac{1}{2\ R_l} - 1\right), .79\right)\right) = 0.66$

Plastic Load-Mass Factor $K_{lmp} := Fig3\_44\left(\text{if}\left(R_f > 2, \frac{2\ x}{L_s}, \frac{y}{H_s}\right)\right) = 0.57$ UFC 3-340-02, Figure 3-44

SDOF PARAMETERS

Applied Pressure $P_o = \begin{bmatrix} 301 \\ 0 \end{bmatrix}$ *psi*

Pressure Duration $t_d = \begin{bmatrix} 0 \\ 14.08 \end{bmatrix}$ *ms*

SBEDS Mass $mass_{sbeds} := \dfrac{mass}{H_s \cdot L_s} = (5.4 \cdot 10^3) \ \dfrac{psi \cdot ms^2}{in}$

Load-Mass Factors $K_{lm} = \begin{bmatrix} 0.65 \\ 0.66 \\ 0.66 \\ 0.57 \end{bmatrix}$

Resistances $r_s = \begin{bmatrix} 65.63 \\ 72.17 \\ 159.62 \\ 159.62 \end{bmatrix}$ *psi*

Stiffness $K = \begin{bmatrix} 333.46 \\ 329.89 \\ 63.27 \\ 0 \end{bmatrix} \dfrac{psi}{in}$

Deflection $x_s = \begin{bmatrix} 0.2 \\ 0.22 \\ 1.6 \\ 1.6 \end{bmatrix}$ *in*

Equivalent Elastic Deflection $x_{eq} := x_{s_1} \cdot \left(\dfrac{r_{s_2}}{r_{s_3}}\right) + \left(x_{s_2}\right) \cdot \left(1 - \dfrac{r_{s_1}}{r_{s_3}}\right) + \left(x_{s_3}\right) \cdot \left(1 - \dfrac{r_{s_2}}{r_{s_3}}\right) = 1.09 \ in$ UFC 3-340-02, Eqtn. 3-35

Yield Distance $Yield := min(x, y) = 96 \ in$

Output Summary See Attached SBEDS Sheet

Maximum Deflection $x_{max} := 3.03 \cdot in$

Time to Yield/Max Deflection $t_{yield} := 6.1 \cdot ms$

Maximum Ductility $\mu_{max} := \dfrac{x_{max}}{x_{eq}} = 2.77$

Support Rotation $\theta_{supp} := \operatorname{atan}\left(\dfrac{x_{max}}{Yield}\right) = 1.81 \ deg$

Check Deflection Limits

$Defl_{chk} :=$ "Deflection Exceeds Limits"
if $\theta_{supp} \le \theta_{max}$
"Deflection Within Limits"

$Defl_{chk} =$ "Deflection Within Limits"

Check Type Assumption

$Type_{chk} :=$ "Assumed Section Type Correct"
if $(Sct = 2 \wedge \theta_{supp} < 2 \cdot deg) \vee (Sct = 3 \wedge \theta_{supp} < 6 \cdot deg) \vee \theta_{supp} > \theta_{max}$
"Section Type Assumption Incorrect"

$Type_{chk} =$ "Assumed Section Type Correct"

DYNAMIC INCREASE FACTOR CHECK

Confirm that strain rates seen in analysis are consistent with assumed strain rates for derivation of Dynamic Increase Factors

Strain Rate in Concrete

$$\varepsilon'_c := \frac{.002}{t_{yield}} \cdot min(1, \mu_{max}) = 0.33 \ \frac{in}{in \cdot s}$$

Strain Rate in Steel

$$\varepsilon'_s := \frac{f_{ryb}}{E_s \cdot t_{yield}} \cdot min(1, \mu_{max}) = 0.47 \ \frac{in}{in \cdot s}$$

Error in Assumed Strain Rate

$$Error_{src} := \left| \frac{\log(SR_c \cdot ms) - \log(\varepsilon'_c \cdot ms)}{\text{mean}(\log(SR_c \cdot ms), \log(\varepsilon'_c \cdot ms))} \right| = 8.08 \cdot 10^{-4}$$

$$Error_{srs} := \left| \frac{\log(SR_r \cdot ms) - \log(\varepsilon'_s \cdot ms)}{\text{mean}(\log(SR_r \cdot ms), \log(\varepsilon'_s \cdot ms))} \right| = 8.6 \cdot 10^{-4}$$

$Check_{SR} :=$ "Strain Rate Assumption Inaccurate"
if $\max(Error_{src}, Error_{srs}) < .05$
"Strain Rate Assumption Valid"

$Check_{SR} =$ "Strain Rate Assumption Valid"

FLEXURAL REINFORCEMENT CHECKS

Reinforcement Area/Ratios

Reinf. Areas

$$A_r := \begin{bmatrix} A_{bh} & A_{th} \\ A_{bl} & A_{tl} \end{bmatrix} = \begin{bmatrix} 2 & 2 \\ 2 & 2 \end{bmatrix} in^2$$

Tension Reinf. Ratios — UFC 3-340-02, Equation 4-13

$$\rho_r := \frac{1}{w_s} \cdot \begin{bmatrix} \frac{A_{bh}}{d_{ph}} & \frac{A_{th}}{d_{nh}} \\ \frac{A_{bl}}{d_{pl}} & \frac{A_{tl}}{d_{nl}} \end{bmatrix} = \begin{bmatrix} 7.55 \cdot 10^{-3} & 8.01 \cdot 10^{-3} \\ 7.96 \cdot 10^{-3} & 8.47 \cdot 10^{-3} \end{bmatrix}$$

Compression Reinf. Ratios — UFC 3-340-02, Equation 4-17

$$\rho'_r := \frac{1}{w_s} \cdot \begin{bmatrix} \frac{A_{th}}{d_{ph}} & \frac{A_{bh}}{d_{nh}} \\ \frac{A_{tl}}{d_{pl}} & \frac{A_{bl}}{d_{nl}} \end{bmatrix} = \begin{bmatrix} 7.55 \cdot 10^{-3} & 8.01 \cdot 10^{-3} \\ 7.96 \cdot 10^{-3} & 8.47 \cdot 10^{-3} \end{bmatrix}$$

Balanced Reinforcement Ratio — UFC 3-340-02, Equation 4-14

$$\rho_b := \frac{.85 \cdot \left(.85 - .05 \cdot \left(\frac{f'_{cc}}{ksi} - 4\right)\right) \cdot f'_{cc}}{f_{ds}} \cdot \left(\frac{87000}{87000 + \frac{f_{ds}}{psi}}\right) = 0.02$$

Reinforcement Limits

Minimum Tens Coeffs.

$t_h := \text{if}(Reinf = 0 \vee Sct \neq 1, 1.875, 1.25)$ $\quad t_l := \text{if}(Reinf = 1 \vee Sct \neq 1, 1.875, 1.25)$

Minimum Comp Coeffs.

$c := \text{if}(Sct \neq 1, 1.875, 1.25)$ UFC 3-340-02, Table 4-3

Minimum Tens. Reinf. Areas

$$A_{min} := \left(\frac{w_s \cdot \sqrt{f'_c \cdot psi}}{f_{ry} \cdot SIF_r}\right) \cdot \begin{bmatrix} t_h \cdot \text{if}(Sct = 1, d_{ph}, d_{ch}) & Supp_h \cdot t_h \cdot \text{if}(Sct = 1, d_{nh}, d_{ch}) \\ t_l \cdot \text{if}(Sct = 1, d_{pl}, d_{cl}) & Supp_l \cdot t_l \cdot \text{if}(Sct = 1, d_{nl}, d_{cl}) \end{bmatrix}$$

$$A_{min} = \begin{bmatrix} 0.53 & 0.5 \\ 0.34 & 0.32 \end{bmatrix} in^2$$

Minimum Trans. Reinf. Areas

$$A_{tr} := \text{if}\left(Sct \neq 1, \frac{1}{4} \cdot \begin{bmatrix} A_{bl} & Supp_h \cdot Supp_l \cdot A_{tl} \\ A_{bh} & Supp_h \cdot Supp_l \cdot A_{th} \end{bmatrix}, \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \cdot in^2\right) = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} in^2$$

Minimum Comp. Reinf. Areas

$$A'_{min} := \left(\frac{w_s \cdot \sqrt{f'_c \cdot psi}}{f_{ry} \cdot SIF_r}\right) \cdot c \cdot \begin{bmatrix} Supp_h \cdot \text{if}(Sct = 1, d_{ph}, d_{ch}) & \text{if}(Sct = 1, d_{nh}, d_{ch}) \\ Supp_l \cdot \text{if}(Sct = 1, d_{pl}, d_{cl}) & \text{if}(Sct = 1, d_{nl}, d_{cl}) \end{bmatrix}$$

$$A'_{min} = \begin{bmatrix} 0.35 & 0.33 \\ 0.34 & 0.32 \end{bmatrix} in^2$$

$$A'_{min2} := \begin{bmatrix} Supp_h \cdot A_{th} & A_{bh} \\ Supp_l \cdot A_{tl} & A_{tl} \end{bmatrix} \cdot \frac{1}{2} = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} in^2$$

Reinforcement Check

```
Flex := | check ← "Longitudinal Reinforcement Adequate"
        | for n ∈ 1,2..2
        |   for m ∈ 1,2..2
        |     if A_r[n,m] < max(A_min[n,m], A_tr[n,m], A'_min[n,m], A'_min2[n,m])
        |       check ← "Section Under−Reinforced"
        |     if ρ_r[n,m] − ρ'_r[n,m] > 0.75 · ρ_b
        |       check ← "Section Over−Reinforced"
        |     else
        |       result ← "OK"
        | return check
```

$Flex =$ "Longitudinal Reinforcement Adequate"

SHEAR (DIAGONAL TENSION) CHECKS

Maximum Resistance $r_{resp} := \text{if}\left(x_{max} > \max\left(x_s\right), \max\left(r_s\right), Interp\left(r_s, x_s, x_{max}\right)\right) = 159.62\ psi$

Shear Loads

Support Shear along Height $V_{sh} := \text{if}\left(R_f < 2, \frac{3 \cdot r_{resp} \cdot y}{5}, \frac{3 \cdot r_{resp} \cdot H_s \cdot \left(1 - \frac{x}{L_s}\right)}{\left(3 - \frac{x}{L_s}\right)}\right) \cdot w_s = 137.56\ kip$ UFC 3-340-02, Table 3-10

Support Shear along Length $V_{sl} := \text{if}\left(R_f > 2, \frac{3 \cdot r_{resp} \cdot x}{5}, \frac{3 \cdot r_{resp} \cdot L_s \cdot \left(2 - \frac{y}{H_s}\right)}{2 \cdot \left(6 - \frac{y}{H_s}\right)}\right) \cdot w_s = 148.13\ kip$

Arching Shear (Height) $V_{uh} := V_{sh} \cdot \frac{\left(y - \text{if}\left(Sct = 1, d_{ph}, d_{ch}\right)\right)}{y} = 105.95\ kip$ UFC 3-340-02, Section 4-18.1

Arching Shear (Length) $V_{ul} := V_{sl} \cdot \frac{\left(x - \text{if}\left(Sct = 1, d_{pl}, d_{cl}\right)\right)}{x} = 124.07\ kip$

Shear Capacity

Shear Stress (Height) $v_{uh} := \frac{\text{if}\left(Arch = \text{“Yes”} \lor Lac = \text{“Yes”} \lor No_{dh} > 0, V_{uh}, V_{sh}\right)}{w_s \cdot \text{if}\left(Sct = 1, d_{ph}, d_{ch}\right)} = 400.2\ psi$ UFC 3-340-02, Eqtn. 4-21,22

Shear Stress (Length) $v_{ul} := \frac{\text{if}\left(Arch = \text{“Yes”} \lor Lac = \text{“Yes”} \lor No_{dl} > 0, V_{ul}, V_{sl}\right)}{w_s \cdot \text{if}\left(Sct = 1, d_{pl}, d_{cl}\right)} = 493.92\ psi$

Concrete Shear Capacity (Height) $v_{ch} := min\left(1.9 \cdot \sqrt[2]{\frac{f'_c}{psi}} + 2500\ \rho_{r_{1,1}}, 3.5 \cdot \sqrt[2]{\frac{f'_c}{psi}}\right) \cdot psi = 153.24\ psi$ UFC 3-340-02, Equation 4-23

Concrete Shear Capacity (Length) $v_{cl} := min\left(1.9 \cdot \sqrt[2]{\frac{f'_c}{psi}} + 2500\ \rho_{r_{2,1}}, 3.5 \cdot \sqrt[2]{\frac{f'_c}{psi}}\right) \cdot psi = 154.26\ psi$

Concrete Shear Capacity Check

$Shear_{check} :=$ “Shear Stress Acceptable”
if $Lac = \text{“No”} \land \max\left(v_{ch}, v_{cl}\right) > 10 \cdot \sqrt[2]{f'_c \cdot psi}$
“Shear Stress Exceeds Sectional Capacity”

$Shear_{check} =$ “Shear Stress Acceptable”

Shear Reinforcement

Shear Reinf. Design Stress (Height)

$$v_{sh} := \max\left(v_{uh} - v_{ch}, 0.85 \cdot v_{ch} \cdot \left(Sct \neq 1 \vee Range = \text{"Close"}\right)\right) = 246.96\ psi$$

UFC 3-340-02, Table 4-4

Shear Reinf. Design Stress (Length)

$$v_{sl} := \max\left(v_{ul} - v_{cl}, 0.85 \cdot v_{cl} \cdot \left(Sct \neq 1 \vee Range = \text{"Close"}\right)\right) = 339.66\ psi$$

Shear Reinf. Reduc Factor

$$\phi_s := .85$$

UFC 3-340-02, Section 4-18.3

Shear Reinf. Dynamic Stress

$$f_{dv} := f_{rdt} + (Lac = \text{"Yes"}) \cdot (Sct - 1) \cdot \frac{\left(f_{ru} - f_{rdt}\right)}{4} = \left(7.26 \cdot 10^{4}\right)\ psi$$

UFC 3-340-02, Table 4-1

Required Shear Reinf. (Height)

$$A_{vh\_r} := \frac{v_{sh} \cdot s_{vi} \cdot s_{vo}}{\phi_s \cdot f_{dv}} \cdot \text{if}\left(Lac = \text{"No"}, 1, \frac{1}{\sin\left(\alpha_{lac}\right) + \cos\left(\alpha_{lac}\right)}\right) = 0.14\ in^2$$

UFC 3-340-02, Eqtn. 4-141

Required Shear Reinf. (Length)

$$A_{vl\_r} := \frac{v_{sl} \cdot s_{vi} \cdot s_{vo}}{\phi_s \cdot f_{dv}} \cdot \text{if}\left(Lac = \text{"No"}, 1, \frac{1}{\sin\left(\alpha_{lac}\right) + \cos\left(\alpha_{lac}\right)}\right) = 0.2\ in^2$$

Max. Shear Reinf. Spacing

$$s_{vmax} := \min\left(24 \cdot in, \max\left((Sct = 1) \cdot \frac{\max\left(d_{ph}, d_{pl}\right)}{2}, \frac{(Lac = \text{"Yes"}) + 1}{2} \cdot \max\left(d_{ch}, d_{cl}\right)\right)\right)$$

$$s_{vmax} = 11.03\ in$$

UFC 3-340-02, Section 4-18.4

Shear Reinforcement Check

```
Reinf_shear := | "Shear Reinforcement Sufficient"
               | if A_v < max(A_vh_r, A_vl_r) ∨ (A_v < .0015·s_bh·s_bl ∧ max(A_vh_r, A_vl_r) > 0·in²)
               |   | "Shear Reinf. Insufficient"
               | if (s_vo > s_vmax ∧ max(A_vh_r, A_vl_r) > 0·in²)
               |   | "Shear Reinf. Spacing Exceeds Maximum"
```

$$Reinf_{shear} = \text{"Shear Reinforcement Sufficient"}$$

DIRECT SHEAR CHECKS

Concrete Direct Shear Cap. (Height) $V_{dh} := .16 \cdot f'_{cds} \cdot w_s \cdot d_{ph} \cdot ((Supp_h = 0 \lor Sct = 1)) = 232.96\ kip$ UFC 3-340-02, Equation 4-30

Concrete Direct Shear Cap. (Length) $V_{dl} := .16 \cdot f'_{cds} \cdot w_s \cdot d_{pl} \cdot ((Supp_l = 0 \lor Sct = 1) \land Tens = \text{"No"}) = 221.05\ kip$

Direct Shear Reinf. Dynamic Stress $f_{dds} := f_{rds} + (Sct - 1) \cdot \frac{(f_{ru} - f_{rds})}{4} = (7.26 \cdot 10^4)\ psi$ UFC 3-340-02, Table 4-1

Required Diagonal Bars (Height Side) $A_{dh\_r} := \frac{V_{sh} - V_{dh}}{f_{dds} \cdot \sin(45 \cdot deg)} \cdot \frac{s_{dh}}{w_s} = -1.24\ in^2$ UFC 3-340-02, Equation 4-31

Required Diagonal Bars (Length Side) $A_{dl\_r} := \frac{V_{sl} - V_{dl}}{f_{dds} \cdot \sin(45 \cdot deg)} \cdot \frac{s_{dl}}{w_s} = -0.71\ in^2$

Direct Shear Check $D\_S_{check} :=$
"Direct Shear Capacity Sufficient"
if $A_{dh\_r} > A_{dh}$
  "Direct Shear Capacity Insufficient Along Height Span"
if $A_{dl\_r} > A_{dl}$
  "Direct Shear Capacity Insufficient Along Length Span"

$D\_S_{check} =$ "Direct Shear Capacity Sufficient"

SLAB RESPONSE SUMMARY

Slab deflections are within acceptable limits under design blast loads. Slab is adequately reinforced, and does not experience any brittle failure mechanisms. Performance of slab is adequate.

NAVFAC EXWC SDOF Dynamic Analysis Spreadsheet

Project/Location: CLWS ECM | Building: Single Bay Design | Component: Headwall - Original Design

Command Prompt: | Analyzed By: SMD | Date: 2/15/2024

Blast Load	
User-Defined	
Time (ms)	Pressure (psi)
0	301
14.08	0
14.08	0
14.08	0
14.08	0
14.08	0

Constant Load (psi)	

Response Criteria	
Concr. Slab	
Shear Ties-No Tens Membr	
PC1	
Support Rotation (deg)	2
Max Ductility	
Max Displacement (in)	

2-Way Parameters	
Height	8
Length	32
Yield Line Dist (y)	8
Yield Line Dist (x)	10.74
Height must be Short Span (For 2 or 4-side supports) or Unsupported Span (for 3-side Supports)	

SDOF Properties			
Property	Inbound	Rebound	Units
Mass	5400	5400	psi-ms^2/in
Load Mass Factors			
3-Side Supported	1st Yield Asym Span		
KLM1	0.65	0.65	
KLM2	0.66	0.66	
KLM3	0.66	0.66	
KLM4	0.57	0.57	
KLM5	0.57	0.57	
Stiffness			
K1	333.46	333.46	psi/in
K2	329.89	329.89	psi/in
K3	63.27	63.27	psi/in
K4	0	0	psi/in
Resistance			
R1	65.63	65.63	psi
R2	72.17	72.17	psi
R3	159.62	159.62	psi
R4	159.62	159.62	psi
Displacement			
Stiffness Controlled			
X1	0	0	
X2	0	0	
X3	0	0	
X4	0	0	
Equiv. Elastic Displ.	1.092	1.092	in
Yield Line Distance		96	in

Analysis Parameters		
Natural period	20.39	ms
Time step	0.10	ms
Duration	54.85	ms

Initial Conditions		
Initial Vel.	0	in/ms
Initial Displ.	0.000	in

Damping Parameters		
% of Crit. Damp.	1	%
Elasto-plastic Damping	Yes	

Dynamic Reaction Coefficients		
User-Defined		
Reaction 1	Force	Resistance
Elastic	0	0
Elasto-Plastic	0	0
Plastic	0	0
Reaction 2	Force	Resistance
Elastic	0	0
Elasto-Plastic	0	0
Plastic	0	0

Results Summary

Max. Defl. (in)	3.033	Max Supp. Rot.	1.81	deg
Time to Max. Resp. (ms)	16.000	Max Ductility	2.78	
Time to Yield Defl. (ms)	6.100			
		Max Inbound Resist	159.62	psi
		Max Rebound Resist	-94.03	psi

Response Meets Criteria

Project/Location	CLWS ECM	Building	Single Bay Design	Component	Headwall - Original Design
		Analyzed By	SMD	Date	2/15/2024

Results Summary					
Max. Defl. (in)	3.033	Max Supp. Rot.	1.81	deg	Response Meets Criteria
Time to Max. Resp. (ms)	16	Max Ductility	2.78		
Time to Yield Defl. (ms)	6.1				
		Max Inbound Resist	159.62	psi	
		Max Rebound Resist	-94.03	psi