Cantilever Solider Pile Wall Steel Design: AASHTO LRFD vs. AASHTO 17th Ed.

For:

Western Bridge Engineers' Seminar

By:

Jim Schettler, P.E., S.E.

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Agenda

ITEM	TOPIC
1.	Meeting Goals
2.	Soldier Pile Wall Locations and Configurations
3.	Geotechnical Considerations
4.	AASHTO LRFD Three Part Design Process
	• Design Process Overview
	• Part 1: Establish LRFD Design Parameters
	• Part 2: Wall Analysis
	• Part 3: Wall Design
5.	AASHTO LRFD vs. AASHTO 17^{th} Edition Comparison
6.	Closing Comments & Questions

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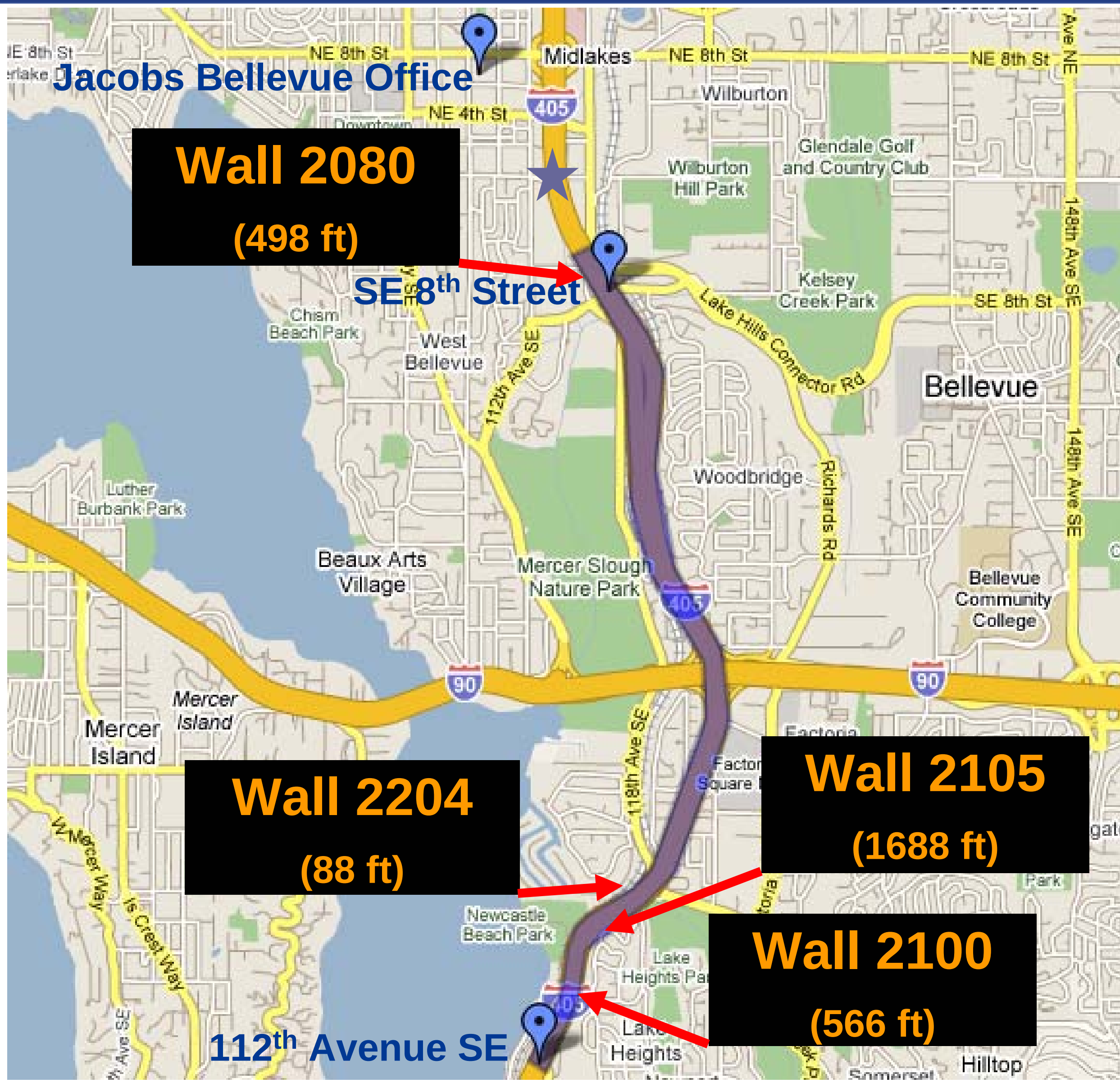
1. Meeting Goals

- **Understand of a soldier pile wall design process with AASHTO LRFD**
- **Gain an appreciation of how AASHTO LRFD compares with AASHTO 17th Edition**

2. Soldier Pile Wall Locations and Configurations



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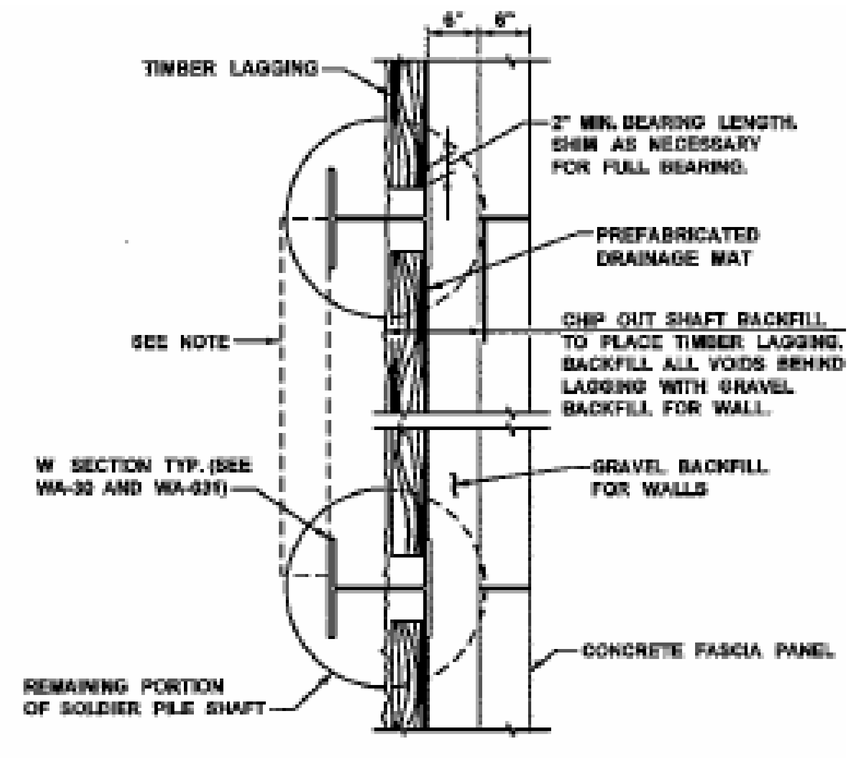
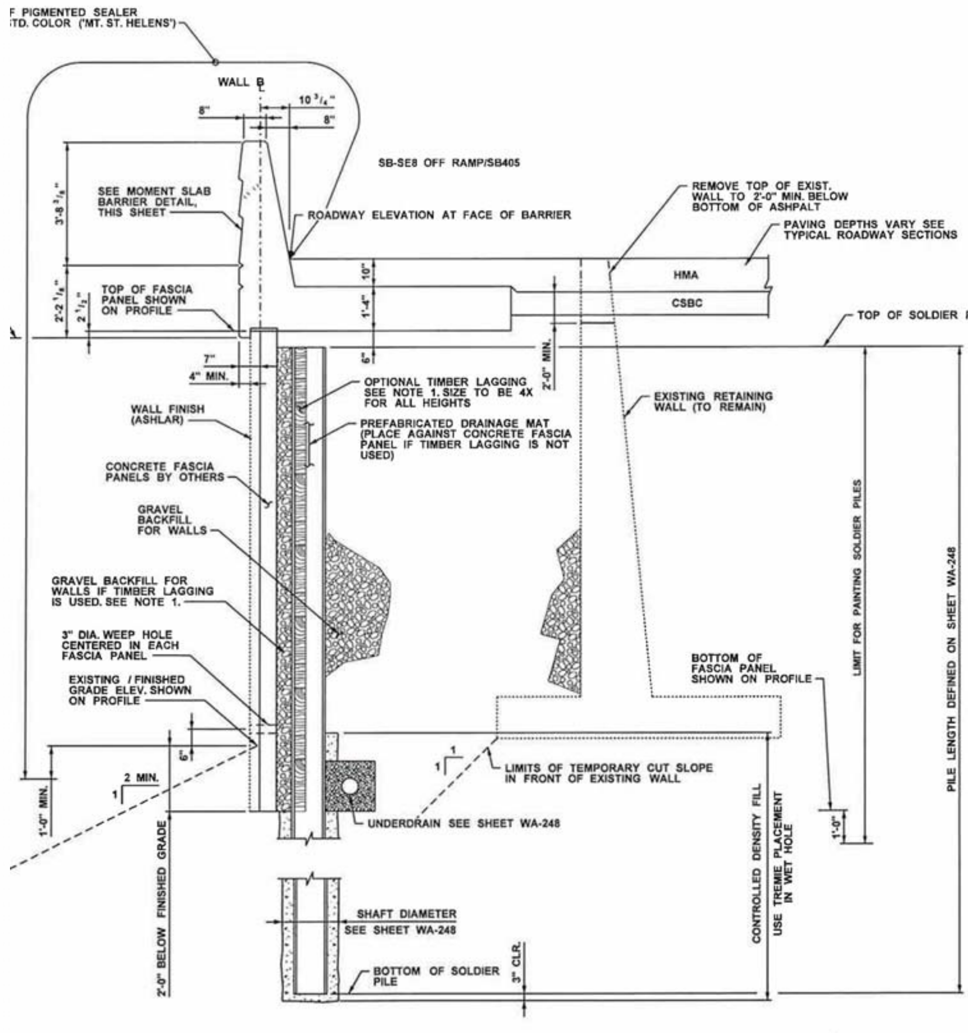
2. Soldier Pile Wall Locations and Configurations

- **Typical Soldier Pile**



TYPICAL PLAN - SOLDIER PILE

NOTE: FOR LOCATIONS WITH VERTICLE DRAIN PIPE BEHIND FASCIA PANEL, LAGGING SHALL BE PLACED ON BACKSIDE OF SOLDIER PILE.



WALL 2080 - SOLDIER PILE SECTION

W2080 16+14.20 TO 19+95.20

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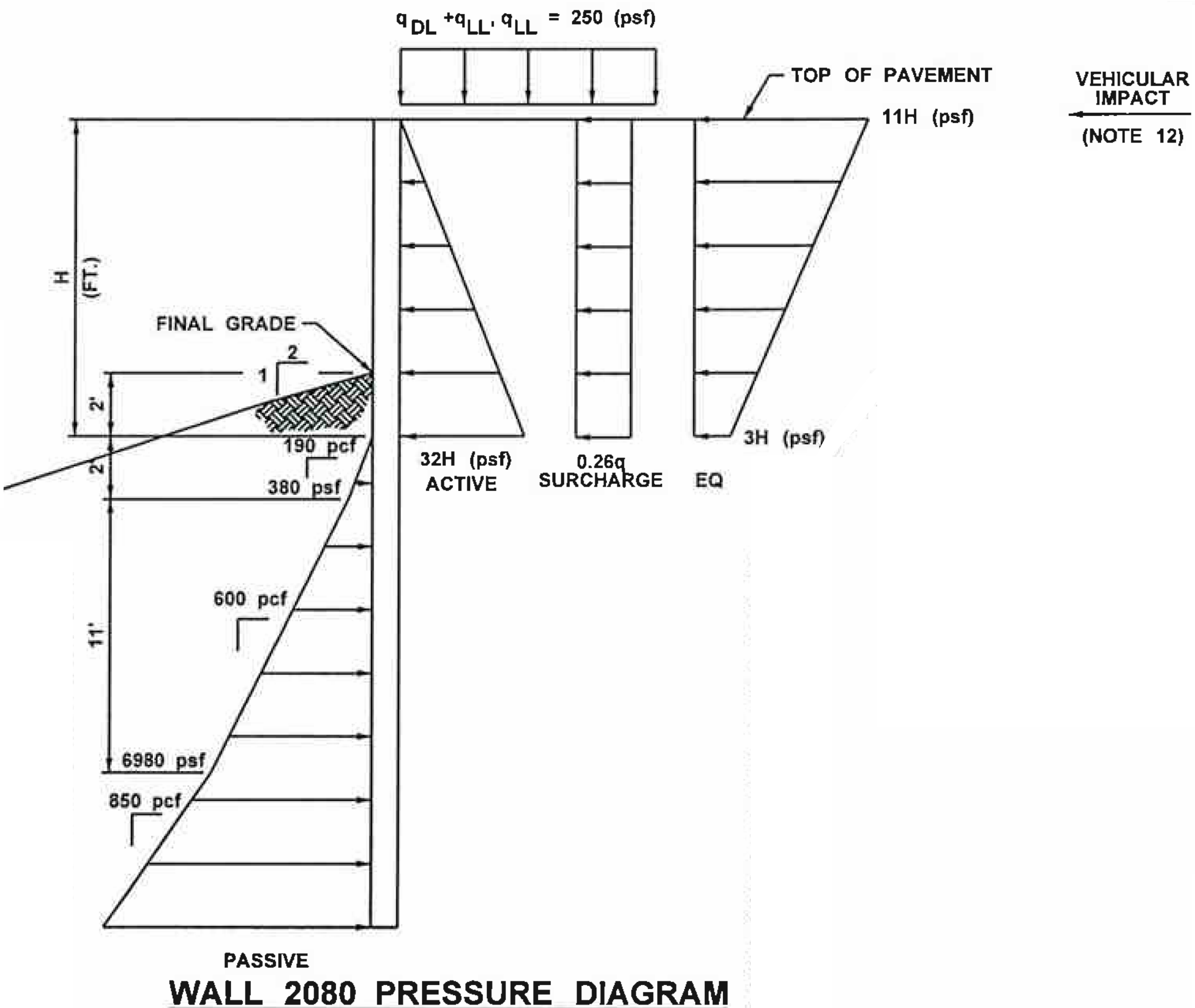
3. Geotechnical Considerations

- **Soldier Pile Pressure Diagrams**



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4. AASHTO LRFD Three Part Design Process
Design Process Overview

- **Wall Design Parameters:**
  - **AASHTO LRFD**
  - **Seismic Earth Press: PGA = 0.38g**
  - **Steel: ASTM A572, Grade 50**
  - **2 foot max. excavation below finished grade**
  - **Passive resistance: 2 ½ times the soldier pile dia.**
  - **Vehicular impact load at wall 2080 from moment slab**
- **CT Shoring Software & Spreadsheets**
  - **Example - 12 foot wall**

4. AASHTO LRFD Three Part Design Process
Part 1: Establish LRFD Design Parameters

- **Establish Loading & Load Factors**

CT SHORING INPUT DATA FOR CANTILEVER SOLDIER PILE WALL DESIGN

Project:	I-405 South Bellevue Design Build	
Wall #:	**2100**	
Finished Wall Height:	**12**	**ft**
Design Wall Height:	**12**	**ft = height of active earth pressure @ final**
Input by:	cjc	
Date Prepared:	4/20/2007	
Input Checked by:		

Note: [shaded] = input (shaded cell)

LL Surcharge Loading (input as lateral pressures)

Final Pressure: 0 psf

Construction Pressure: 0 psf

(input 0 for no surcharge loading)

Vehicle Collision on Barrier Loading

Traffic Barrier Impact: 0 kips/pile

(input 0 for no impact)

Backslope Conditions

Max Backslope = 2H: 1V

(from rdwy X-Sections)

Pile Spacing

Pile Spa = 8.00 ft

Seismic Loading

Top Pressure: 259.2 psf

Bot Pressure: 64.8 psf

SOIL LAYERS

Note: input 0 for soil layers not used

Active Soil Layers		
Soil Layer	Layer Thickn. (ft)	Equiv Fluid Density, α (pcf)
Active 1	12	49
Active 2	0	0
total =	12	
Check wall ht:	OK	

Passive Soil Layers		
Soil Layer	Layer Thickn. (ft)	Equiv Fluid Density (pcf)
Passive 1	5	650
Passive 2	25	330
Passive 3	0	0
total =	30	

LOAD AND RESISTANCE FACTORS

Case	γ_p Perm Lds	γ_{LS} LL Surch	γ_{EQ} EQ	γ_{CT} Barrier Imp	ϕ_{ep} Passive Res.
Strength I	1.5	1.75	--	--	0.75
Extreme Event I- EQ	1.5	0.5	1	--	1
Extreme Event II- Vehicle Collision	1.5	0.5	--	1	1
Service I	1	1	--	--	1

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4. AASHTO LRFD Three Part Design Process Part 1: Establish LRFD Design Parameters

- **Calculate Limit-State Loading**

UNFACTORED LOADS

Loading	Z1 top (ft)	P1 top (ksf)	Z2 bot. (ft)	P2 bot. (ksf)	Slope (ksf/ft)
Active 1	0	0.000	12	0.588	0.0490
Active 2	n/a	n/a	n/a	n/a	n/a
LL Surch Final	n/a	n/a	n/a	n/a	n/a
LL Surch Const.	n/a	n/a	n/a	n/a	n/a
Seismic	0	0.259	12	0.065	-0.0162
Passive 1	12	0.000	17	3.250	0.6500
Passive 2	17	3.250	42	11.500	0.3300
Passive 3	n/a	n/a	n/a	n/a	n/a

Loading	Depth (ft)	Force/ Pile (kips)	Angle (deg)	Spacing (ft)
Barrier Impact	n/a	n/a	0	8.00

Notes: Angle assumed 0 (horiz load), spacing = pile spacing

1. STRENGTH I LIMIT STATE LOADING- FINAL CONDITION

Loading	Z1 top (ft)	P1 top (ksf)	Z2 bot. (ft)	P2 bot. (ksf)	Slope (ksf/ft)
Active 1	0	0.000	12	0.882	0.0735
Active 2	n/a	n/a	n/a	n/a	n/a
LL Surch- Final	n/a	n/a	n/a	n/a	n/a
Passive 1	12	0.000	17	2.438	0.4875
Passive 2	17	2.438	42	8.625	0.2475
Passive 3	n/a	n/a	n/a	n/a	n/a

2. STRENGTH I LIMIT STATE LOADING- TEMPORARY LOADING

- Check temporary loading as required by GeoEngineers
- For Active & Passive pressures, use slopes from Strength I Limit State- Final Condition above
- LL Surch Const Pressure = n/a
- Use wall height and soil layer geometry as recommended by GeoEngineers

4. AASHTO LRFD Three Part Design Process Part 1: Establish LRFD Design Parameters

- **Calculate Limit-State Loading**

  (cont.)

3. EXTREME EVENT I LIMIT STATE LOADING- EARTHQUAKE

Loading	Z1 top (ft)	P1 top (ksf)	Z2 bot. (ft)	P2 bot. (ksf)	Slope (ksf/ft)
Active 1	0	0.000	12	0.882	0.0735
Active 2	n/a	n/a	n/a	n/a	n/a
LL Surch Final	n/a	n/a	n/a	n/a	n/a
Seismic	0	0.259	12	0.065	-0.0162
Passive 1	12	0.000	17	3.250	0.6500
Passive 2	17	3.250	42	11.500	0.3300
Passive 3	n/a	n/a	n/a	n/a	n/a

4. EXTREME EVENT II LIMIT STATE LOADING- VEHICLE COLLISION

Loading	Z1 top (ft)	P1 top (ksf)	Z2 bot. (ft)	P2 bot. (ksf)	Slope (ksf/ft)
Active 1	0	0.000	12	0.882	0.0735
Active 2	n/a	n/a	n/a	n/a	n/a
LL Surch	n/a	n/a	n/a	n/a	n/a
Passive 1	12	0.000	17	3.250	0.6500
Passive 2	17	3.250	42	11.500	0.3300
Passive 3	n/a	n/a	n/a	n/a	n/a

Loading	Depth (ft)	Force/ Pile (kips)	Angle (deg)	Spacing (ft)
Barrier Impact	n/a	n/a	0	8.00

Notes: Angle assumed 0 (horiz load), spacing = pile spacing

5. SERVICE I LIMIT STATE LOADING- FINAL CONDITION

Loading	Z1 top (ft)	P1 top (ksf)	Z2 bot. (ft)	P2 bot. (ksf)	Slope (ksf/ft)
Active 1	0	0.000	12	0.588	0.0490
Active 2	n/a	n/a	n/a	n/a	n/a
Final LL Surch	n/a	n/a	n/a	n/a	n/a
Passive 1	12	0.000	17	3.250	0.6500
Passive 2	17	3.250	42	11.500	0.3300
Passive 3	n/a	n/a	n/a	n/a	n/a

6. SERVICE I LIMIT STATE LOADING- TEMPORARY LOADING

Loading Input

CT Shoring Input- Wall 2100, H=12'

4. AASHTO LRFD Three Part Design Process
Part 2: Wall Analysis

- **CT Shoring Software**

report.out

No	DEPTH ft	PRESS. ksf	LOAD kip/ft	SHEAR kip	MOMENT kip-ft	DEFLECTION in
1	0.00	0.22	1.73	0.00	0.00	0.830
2	0.03	0.22	1.74	0.05	0.00	0.828
3	0.06	0.22	1.74	0.10	0.00	0.826
4	0.09	0.22	1.75	0.15	0.01	0.825
5	0.12	0.22	1.76	0.20	0.01	0.823
6	0.15	0.22	1.77	0.26	0.02	0.821
7	0.18	0.22	1.77	0.31	0.03	0.820
8	0.20	0.22	1.78	0.36	0.04	0.818
9	0.23	0.22	1.79	0.41	0.05	0.816
10	0.26	0.22	1.80	0.46	0.06	0.815
11	0.29	0.23	1.80	0.52	0.07	0.813
12	0.32	0.23	1.81	0.57	0.09	0.811
13	0.35	0.23	1.82	0.62	0.11	0.810
14	0.38	0.23	1.83	0.67	0.13	0.808
15	0.41	0.23	1.84	0.73	0.15	0.806
16	0.44	0.23	1.84	0.78	0.17	0.805
17	0.47	0.23	1.85	0.84	0.19	0.803
18	0.50	0.23	1.86	0.89	0.22	0.801
19	0.53	0.23	1.87	0.94	0.24	0.800
20	0.55	0.23	1.87	1.00	0.27	0.798
21	0.58	0.24	1.88	1.05	0.30	0.796
22	0.61	0.24	1.89	1.11	0.33	0.795
23	0.64	0.24	1.90	1.16	0.37	0.793
24	0.67	0.24	1.90	1.22	0.40	0.791
25	0.70	0.24	1.91	1.28	0.44	0.790
26	0.73	0.24	1.92	1.33	0.48	0.788
27	0.76	0.24	1.93	1.39	0.52	0.786
28	0.79	0.24	1.93	1.44	0.56	0.785
29	0.82	0.24	1.94	1.50	0.60	0.783
30	0.85	0.24	1.95	1.56	0.65	0.781
31	0.88	0.24	1.96	1.61	0.69	0.780
32	0.90	0.25	1.97	1.67	0.74	0.778
33	0.93	0.25	1.97	1.73	0.79	0.776
34	0.96	0.25	1.98	1.79	0.84	0.775
35	0.99	0.25	1.99	1.84	0.89	0.773
36	1.02	0.25	2.00	1.90	0.95	0.771
37	1.05	0.25	2.00	1.96	1.00	0.770
38	1.08	0.25	2.01	2.02	1.06	0.768
39	1.11	0.25	2.02	2.08	1.12	0.766

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4. AASHTO LRFD Three Part Design Process Part 3: Wall Design

- **Spreadsheet Input**

I - 405 South Bellevue Design Build

CT SHORING ANALYSIS OUTPUT FOR CANTILEVER SOLDIER PILE DESIGN

Project:	I-405 South Bellevue Design Build
Wall #:	**2100**
Wall Height:	**12** **ft = Exposed height @ final**
Input by:	CJC
Date Prepared:	4/20/2007
Input Checked by:	

Note: = input (shaded cell)

A. INPUT

Factored Loads (From Ct Shoring Output)		Resistance Factors		Section Properties	
				Section type	W24X76
$P_{u\ str}$ (kips)	0.00	$\phi_{c\ str}$ (6.5.4.2)	0.70	A (in^2)	22.40
$M_{u\ str}$ (kips-ft)	506.00	ϕ_f (6.5.4.2)	1.00	Z (in^3)	200.00
V_u (kips)	169.00	ϕ_v (6.5.4.2)	1.00	S (in^3)	176.00
F_y (ksi)	50.00			L_b (ft)	12.00
$M_{u\ ext.}$ (kips-ft)	487.00			t_w (in)	0.44
$M_{u\ unbraced.str}$ (kips-ft)	270.00			t_f (in)	0.68
$M_{u\ unbraced.ext}$ (kips-ft)	281.00			b_f (in)	8.99
				r_x (in)	9.69
				D_w (in)	23.92
				E (ksi)	29000.00
				K	2.00

Note: Resistance factor ϕ_c is 0.7 for Strength and 1.0 for Extreme Event Limit State, conservatively use 0.70 for both cases

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4. AASHTO LRFD Three Part Design Process
Part 3: Wall Design

- **Comp Check**

AASHTO

6.9.2 – 6.9.4

(Compression Members)

B. ANALYSIS

1. Compression Check

$P_{u\ str}$ =	0.00	Max axial load.		AASHTO
P_n =		Nominal compression resistance.		LRFD Ref.

For members that satisfy the width/thickness requirements specified in Article 6.9.4.2, the nominal compressive resistance, Pn, shall be taken as:

Limiting Slenderness Ratio (6.9.3)

For main members: $Kl/r_x \le 120$ 29.72 OK

Where K, effective length factor, specified in Article 4.6.2.5.

If $\lambda \le 2.25$, then:	$P_n = (0.66^{\lambda})*Fy*As$	(6.9.4.1-1)
If $\lambda > 2.25$, then:	$P_n = 0.88*Fy*As/\lambda$	(6.9.4.1-2)
λ =	$(k*L/r_x/3.14)^2*(Fy/E)$	(6.9.4.1-3)
	0.15	

The slenderness of plates shall satisfy:

$(b/t) \le 0.56\ (E/Fy)^{0.5}$			(6.9.4.2-1)
$(b/t)\ /\ 0.56\ (E/Fy)^{0.5}$ =	0.49	**Satisfied.**	

P_n (kips) =	1120.00		
$P_r = (\phi_c)*Pn$			(6.9.2.1-1)
$P_{r\ str}$ (kips) =	784.00		
$(P_u/P_r)_{str}$ =	0.00	OK	

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4. AASHTO LRFD Three Part Design Process Part 3: Wall Design

- **Comb Axial & Bending Cap Check**

AASHTO

6.10

(I-Section Flexural Members)

2. Combined Axial and Bending Capacity Check

6.10.2 Cross-Section Proportion Limits

6.10.2.1 Web Proportions

6.10.2.1.1 Webs without Longitudinal Stiffeners

Webs shall be proportioned such that:

$D/tw \le 150$			(6.10.2.1.1-1)
D/tw	54.36	OK	

6.10.2.2 Flange Proportions

$(b_f/2t_f) \le 12$			(6.10.2.2-1)
$b_f/2t_f$	6.61	OK	
$b_f \ge D/6,$			(6.10.2.2-2)
b_f	8.99	OK	
$t_f \ge 1.1\ t_w$			(6.10.2.2-3)
t_f	0.68	OK	
$0.1 \le (I_{yc}/I_{yt}) \le 10$	for rolled section	OK	(6.10.2.2-4)

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4. AASHTO LRFD Three Part Design Process Part 3: Wall Design

- Comb Axial & Bending Cap Check
- Below Fin Grade

AASHTO A6.1-Bracing

6.9.2.2- Combined Axial Comp & Flexure

A. For the Soldier Pile section below finished ground line.

$M_{u\ str}$ =(kips-ft)	506.00	
$M_{u\ ext}$=(kips-ft)	487.00	
$M_{r\ str}$ = (ϕf)*(Fy * S)(kips-ft)	733.33	Per WDDOT policy - Bennion e-mail to Schetler 4/16/07
$M_{r\ ext}$ = (ϕf)*(Fy * Z)(kips-ft)	833.33	(A6.1.3/A6.1.4)

Since the pile is supported all around it can be considered that unbraced length is zero and has a compact web section
The buckling considerations of section 6.10.4 generally result in no reduction of ultimate
bending stresses and Mn= the plastic moment or Mn= Fy*Z.

Mu str / Mr str	0.69
Mu Ext / Mr Ext	0.58

Combined Loads must satisfy the following:

(Pu/2Pr)+(Mu/Mr) <= 1.0.....if Pu/Pr < 0.2 (6.9.2.2-1)

(Pu/Pr)+(8/9)(Mu/Mr)<= 1.0.....if Pu/Pr >= 0.2 (6.9.2.2-2)

Therefore,

For Strength Limit State	0.69	OK
For Extreme Event Limit State	0.58	OK

4. AASHTO LRFD Three Part Design Process Part 3: Wall Design

- **Comb Axial & Bending Cap Check**
- **Above Lower Fin Grade**

AASHTO

6.10

(I Section Flexural Members)

B. For the Soldier Pile section above finished ground line.

L_b	(ft)	12.00				
			M_{yc}	(k-ft)	733.33	
			C_b		1.75	(A6.3.3)
			R_b		1.00	(6.10.1.10.2)
Note:			L_p	(ft)	4.59	(6.10.8.2.3)
1. M_1 is moment at the lowest brace point and M2 is at the upper end of unbraced len(			R_h		1.00	(6.10.1.10.1)
2. L_b is the unbraced length of the pile under consideration.						(6.10.1.6)
3. L_p is limiting unbraced length						(6.10.1.6)
4. F_{bu} is compressive stress in the flange under consideration						(6.10.1.6)

For Strength and Extreme Event conditions

$f_{bu} + (1/3)f_l \leq \phi f F_{nc}$			(6.10.8.1.1-1)
f_l	(ksi) (No lateral bending stresses)	0.00	(6.10.1.6)
f_{bu}	(ksi) (Strength Limit State)	18.41	(6.10.1.6)
f_{bu}	(ksi) (Extreme Event Limit State)	19.16	(6.10.1.6)

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4. AASHTO LRFD Three Part Design Process
Part 3: Wall Design

- **Comp Flange Flex Resist-**

  Local Buckling / Lateral Torsional Buckling

  Check

AASHTO

6.10.8

(comp flange flexural resistance

6.10.8.2 Compression-Flange Flexural Resistance

The nominal flexural resistance of the compression flange shall be taken as the smaller of the local buckling resistance and the lateral torsional buckling resistance.

6.10.8.2.2 Local Buckling Resistance

If $\lambda_f \leq \lambda_{pf}$ then:	$F_{nc} = R_b R_h F_{yc}$	(6.10.8.2.2-1)
Otherwise:	$F_{nc} = (1-(1-(F_{yr}/R_h F_{yc}))(\lambda_f - \lambda_{pf} / \lambda_{rf} - \lambda_{pf}))R_b R_h F_{yc}$	(6.10.8.2.2-2)
$\lambda_f = b_{fc}/2t_{fc}$	6.61	(6.10.8.2.2-3)
$\lambda_{pf} = 0.38(E/F_{yr})^{0.5}$	10.94	(6.10.8.2.2-4)
$\lambda_{rf} = 0.56 \cdot (E/F_{yr})^{0.5}$	16.12	(6.10.8.2.2-5)
F_{yr} (ksi)	35.00	
F_{nc} (ksi)	50.00	

6.10.8.2.3 Lateral Torsional Buckling Resistance

If $L_b \leq L_p$, then:	$F_{nc} = R_b R_h F_{yc}$	(6.10.8.2.3-1)
If $L_b \leq L_p \leq L_r$, then:	$F_{nc} = C_b(1-(1-(F_{yr}/R_h F_{yc}))(L_b - L_p / L_r - L_p))R_b R_h F_{yc} \leq R_b R_h F_{yc}$	(6.10.8.2.3-2)
If $L_b > L_r$, then:	$F_{nc} = F_{cr} \leq R_b R_h F_{yc}$	(6.10.8.2.3-3)
$r_t = b_{fc}/(12(1+(D_c t_w/3b_{fc} t_{fc})))^{0.5}$		(6.10.8.2.3-9)
(in)	2.29	
$L_r = 3.14\, r_t\, (E/F_{yr})^{0.5}$ (in)	172.99	(6.10.8.2.3-5)
$F_{cr} = C_b R_b 3.14^2 E/(L_b/r_t)^2$	126.28	
$L_b - L_p$ (ft)	7.41	
$L_r - L_p$ (ft)	9.83	
$R_b R_h F_{yc}$	50.00	
F_{nc} (ksi)	67.71	

The Smallest F_{nc} of the two case

F_{nc} (ksi)	50.00	
$f_{bu} + (1/3)f_l \leq \phi f F_{nc}$		(6.10.8.1.1-1)
$f_{bu} + (1/3)f_l$ (Strength)	18.41	
$f_{bu} + (1/3)f_l$ (Ex Event)	19.16	
$\phi f F_{nc}$	50.00	
$f_{bu} + (1/3)f_l \leq \phi f F_{nc}$ (Strength)	OK	
$f_{bu} + (1/3)f_l \leq \phi f F_{nc}$ (Ex Event)	OK	

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4. AASHTO LRFD Three Part Design Process Part 3: Wall Design

- **Shear Cap Check**

AASHTO 6.10.9

3.Check Structural Shear Capacity				
$V_n = C.\ V_p$				(6.10.9.2-1)
$V_p = 0.58Fyw{*}D.t_w$	305.22			(6.10.9.2-2)
$D/t_w =$	54.36			
k (Shear Buckling Coefficient)	5.00			
$1.12{*}(E{*}k/F_{yw})^{0.5}$	60.31			
$1.4{*}(E{*}k/F_{yw})^{0.5}$	75.39			
If $(D/tw) \leq (1.12{*}(E{*}k/F_{yw})^{0.5})$			$C = 1$	(6.10.9.3.2-4)
$(1.12{*}(E{*}k/F_{yw})^{0.5}) < (D/T_w) \leq (1.4{*}(E{*}k/F_{yw})^{0.5})$			$C = (1.12{*}(E{*}k/Fyw)^{0.5})/(D/Tw)$	(6.10.9.3.2-5)
$(D/t_w) > (1.4{*}(E{*}k/F_{yw})^{0.5})$			$C = (1.57{*}(Ek/Fyw))/(D/Tw)^2$	(6.10.9.3.2-6)
C =	1.00			
$V_n =$ (kips)	305.22			
$V_r = (\phi_v){*}Vn$ (kips)	305.22	OK		

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5. AASHTO LRFD vs. AASHTO 17th Edition Comparison

PILE SIZE COMPARISON TABLE			
Wall Height (ft)	AASHTO 17th Ed.	AASHTO LRFD	RATIO Mu Strength I / Mu Extreme Event I
8	W16 X 36	W16 X 31	127%
10	W16 X 57	W16 X 50	114%
12	W24 X 68	W24 X 62	104%
14	W24 X 84	W24 X 84	98%
16	W24 X 146	W24 X 117	93%

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Closing Comments

Questions?