Ground Support PLLC

15704 NE 157th St
Woodinville, WA 98072
Phone (425) 922-1501
www.groundsupport.com

November 12, 2025 Our ref: 25-17

Warren Company
2201 E Newton Street
Seattle, WA 98112

ATTENTION: Mr. Dana Warren

RE: TEMPORARY SHORING WALL DESIGN CALCULATIONS AND PLANS
BARNABIE POINT PROJECT
3700 EAST MERCER WAY, MERCER ISLAND, WA

Dear Dana:

Ground Support PLLC is pleased to present to Warren Company our engineering design submittal for a temporary cantilevered soldier pile and timber lagging shoring wall for the Barnabie Point Project located at 3700 East Mercer Way in Mercer Island, Washington. We have completed the temporary shoring wall design submittal in accordance with our contract proposal dated October 28, 2025. The project background and soil conditions, and the shoring design calculations and plans are described in the following sections.

1. PROJECT BACKGROUND AND SOIL CONDITIONS

In preparing the temporary shoring wall design, we have reviewed the following geotechnical report, site survey, and structural drawings for the development:

- "Subsurface Exploration, Geologic Hazard, and Geotechnical Engineering Report, Herzl-Ner Tamid Conservative Congregation K-8 Expansion, Mercer Island, Washington", prepared by Associated Earth Sciences Inc., dated December 12, 2024.

- The site survey titled: "Topographic Survey, 3700 East Mercer Way, Mercer Island, Washington", prepared by Chadwick & Winters, dated December 2, 2024.

- The structural plan sheets titled: "3700 E Mercer, Barnabie Point Project, Sheets S-100, S-101, S-201, S-304, and S-305", prepared by PCS Structural Solutions, dated June 4, 2025.

We understand that the proposed development includes a K-8 school expansion to the west of the existing Herzl-Ner Tamid Conservative Congregation Synagogue Campus. The new building is to be constructed a significant distance inside the site property for the most part except that a short portion of the basement wall must be located within a couple feet of the property line at the northwest corner. That portion of the basement excavation is about 10-ft deep and runs along the property line for about 30 feet. The proposed temporary shoring wall will be installed between the property line and the new basement in order to construct the basement without disturbing the area outside the property, which contains right-of-way and a number of significant utilities. The shoring wall will be 64-ft long to catch the adjacent slopes next to the foundation walls, and consist of nine soldier piles spaced 8-ft on center, ranging from W14x30 to W14x43 grade 50 beams placed in 24-inch shafts, with a 9-ft to 14-ft toe embedment.

Based on the referenced project geotechnical report, the subsurface conditions at the project site generally consist of a surficial layer of medium dense fill less than 5 feet thick, underlain by medium dense to dense non-glacial soils, which are typically comprised of silty sand and sandy silt. Groundwater was not encountered in the soil explorations which were performed in September, which is a very dry time of the year. Therefore, for the purposes of designing the shoring wall, the water table has been assumed to occur well below the bottom of the excavation. Nevertheless, during construction, localized wet zones and/or perched pockets and stringers of water-bearing soils may be encountered at any time in wetter seasons of the year. The wall face excavation must proceed cautiously to avoid excessive ground loss or disturbance in areas of water bearing soil. Gaps in the timber lagging will provide a free-draining face condition, and sump pumps and trenches may be required at the excavation base to control water during construction, certainly in wetter seasons.

2. SHORING DESIGN CALCULATIONS AND PLANS

2.1 General Design and Loading Considerations

We have performed the temporary shoring wall design in accordance with the 2018 International Building Code, generally accepted standards of practice for shoring wall design, and the following standard design publication:

- Publication No. FHWA-IF-99-015, Geotechnical Engineering Circular No. 4, Ground Anchors and Anchored Systems

A 250 psf vertical and 80 psf lateral standard traffic surcharge loading was considered in the design of the wall. Therefore, construction loads larger than this should be kept at least 6-ft from the wall.

2.2 Cantilevered Pile Design Calculations

The soldier piles provide cantilevered support for the adjacent lateral earth loads and surcharge pressures. Therefore, the cantilever conditions for five design cases with heights from 5-ft to 9.5-ft have been analyzed. The loading diagram for the cantilevered condition is based on recommendations sent to us via email from the geotechnical engineer and is illustrated on the shoring plans. Figure A-1 contains a summary of the cantilever analyses, including the required pile design moments and toe embedments. Toe embedment for the cantilever condition is determined by satisfying both force and moment equilibrium in the toe region. Example toe embedment calculations are attached in Figure A-2.

2.3 Timber Lagging Design Criteria

Based on the expected ground conditions, the typical pile spacing, and the excavation depths, the lagging thickness recommended by the referenced 1999 FHWA publication is interpolated to be 75 mm or about 3 inches. This is completely in line with experience and precedent in the area for similar projects. These guidelines are reproduced in Appendix B for reference.

3. SHORING DESIGN PLANS

Our design plans consist of four 24"x36" drawing sheets bound separately from this letter report:

SH1.0	Cover Sheet and Notes
SH2.0	Shoring Plan
SH3.0	Wall Elevation
SH4.0	Details

4. CLOSURE

We trust that the temporary shoring wall design submittal is in accordance with your needs at this time. If you have any questions, please call us anytime at 425-922-1501.

Sincerely,

GROUND SUPPORT PLLC

Chris J. Wolschlag, S.E., Ph.D.
Partner

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APPENDIX A

CANTILEVERED SOLDIER PILE DESIGN CALCULATIONS

CANTILEVER ANALYSIS SUMMARY

Pile(s)	Vertical Height H (ft)	Passive Diameter B (ft)	Pile Spacing S (ft)	Soil Self-Weight EFDA (pcf)	Below Base EFDA (pcf)	Live Lateral Surch (psf)	Seismic Lateral Surch (psf)	Top Shear (lb/ft)	Factored Upper EFDP (pcf)	Factored Lower EFDP (pcf)	Ignore Depth (ft)	Change Depth (ft)	Base Shear (lb)	Base Moment (ft-lb)	Limiting Moment Factor	Req'd D (ft)	Embed Moment (ft-lb)
9.5-FT	9.5	2.0	8.0	40	25	80	0	0	300	300	2	10	13,760	43,093	4.0	13.9	146,614
5-FT	5.0	2.0	8.0	40	25	80	0	0	300	300	2	10	7,200	14,667	4.0	9.0	39,784
6.5-FT	6.5	2.0	8.0	40	25	80	0	0	300	300	2	10	13,760	43,093	4.0	11.4	86,712
8-FT	8.0	2.0	8.0	40	25	80	0	0	300	300	2	10	13,760	43,093	4.0	12.6	112,248
8.5-FT	8.5	2.0	8.0	40	25	80	0	0	300	300	2	10	13,760	43,093	4.0	13.0	122,793
9.5-FT	9.5	2.0	8.0	40	25	80	0	0	300	300	2	10	13,760	43,093	4.0	13.9	146,614

Pile(s)	Computed Embed Moment Factor	Design Moment M (ft-k)	Steel Section	Steel Grade (ksi)	Pipe O.D. (in)	Wall Thick (in)	Pipe I.D. (in)	Section Modulus (in3)	fB (ksi)	Factored FB (ksi)	Design Ratio	Design Embed D (ft)
5-FT	2.7	39.8	W14x30	50				42.0	11.4	33.0	0.34	9.0
6.5-FT	2.0	86.7	W14x30	50				42.0	24.8	33.0	0.75	11.5
8-FT	2.6	112.2	W14x34	50				48.6	27.7	33.0	0.84	12.5
8.5-FT	2.8	122.8	W14x38	50				54.6	27.0	33.0	0.82	13.0
9.5-FT	3.4	146.6	W14x43	50				62.7	28.1	33.0	0.85	14.0

FIGURE A-1

Cantilever Analysis Summary

CANTILEVER -TOE EMBEDMENT CALCULATIONS

General Notes
Discrete model of embeded pile wall with shear and moment acting at top of embedment.
D = Depth of Embedment.
Z = Distance above pile tip that transition from passive to active, and vice versa, begins.
V = Pile shear force at top of embedment.
M = Pile moment at top of embedment.
Two analysis models available for passive zone: (1) variable pile width model; (2) fixed pile width model.
Variable width model applies active over full pile spacing, and passive over variable width.
Variable width varies linearly from 1 pile diameter at grade, to the pile spacing at a specified critical depth.
Fixed width model applies the active and passive components to a specified number of pile diameters on each side.
Analysis proceeds through iteration on assumed values of D & Z until force and moment equilibrium are satisfied.

General Input Data	
Pile Shear Force @ Top of Embedment, V (F)	20,520
Pile Moment @ Top of Embedment, M (F-L)	43,093
Pile Width or Diameter, B (L)	2.00
Horizontal Pile Spacing, S (L)	8.00

Pile Width Model Input Data		
Pile Model Type	(0 for variable pile width mode; 1 for fixed pile width model.)	1
Critical Depth (L)	(Only used for variable pile width model.)	8.0
Number of Resisting Pile Diameters	(Only used for fixed pile width model.)	2.0
Number of Driving Pile Diameters	(Only used for fixed pile width model.)	1.0

Embedment Zone Earth Pressure Input Data

Resisting Side			Driving Side		
Depth (L)	Allow Passive Press (F/L/L)	Active Press (F/L/L)	Depth (L)	Allow Passive Press (F/L/L)	Active Press (F/L/L)
0.0	0	0	0.0	2,850	238
2.0	0	0	10.0	5,850	488
2.0	600	50	10.0	5,850	488
10.0	3,000	250	100.0	32,850	2,738
10.0	3,000	250			
100.0	30,000	2,500			

Iteration Parameters	
Assumed Depth of Embedment, D (L)	13.88
Assumed Transition Point, Z (L)	4.16
Computed Toe Shear (F)	0
Computed Toe Moment (F-L)	0

FIGURE A-2 (Page 1 of 12)

Example Toe Embedment Calculations

Discrete Calculations Throughout the Depth of Embedment											
	Effect Driving Pile	Effect Resist Pile	Resist Pressure		Driving Pressure		Resist	Driving	Neg Driving	Shear	Bending
Depth	Width	Width	Passive	Active	Passive	Active	Force	Force	Force	Force	Moment
(L)	(L)	(L)	(F/L/L)	(F/L/L)	(F/L/L)	(F/L/L)	(F/L)	(F/L)	(F/L)	(F)	(F-L)
0.00	2.00	4.00	0	0	2,850	238	0	475	-475	20,520	43,093
0.03	2.00	4.00	0	0	2,858	238	0	476	-476	20,533	43,663
0.06	2.00	4.00	0	0	2,867	239	0	478	-478	20,546	44,233
0.08	2.00	4.00	0	0	2,875	240	0	479	-479	20,560	44,803
0.11	2.00	4.00	0	0	2,883	240	0	481	-481	20,573	45,374
0.14	2.00	4.00	0	0	2,892	241	0	482	-482	20,586	45,945
0.17	2.00	4.00	0	0	2,900	242	0	483	-483	20,600	46,517
0.19	2.00	4.00	0	0	2,908	242	0	485	-485	20,613	47,089
0.22	2.00	4.00	0	0	2,917	243	0	486	-486	20,627	47,661
0.25	2.00	4.00	0	0	2,925	244	0	487	-487	20,640	48,233
0.28	2.00	4.00	0	0	2,933	244	0	489	-489	20,654	48,806
0.31	2.00	4.00	0	0	2,942	245	0	490	-490	20,667	49,380
0.33	2.00	4.00	0	0	2,950	246	0	492	-492	20,681	49,953
0.36	2.00	4.00	0	0	2,958	247	0	493	-493	20,695	50,527
0.39	2.00	4.00	0	0	2,967	247	0	494	-494	20,708	51,102
0.42	2.00	4.00	0	0	2,975	248	0	496	-496	20,722	51,677
0.44	2.00	4.00	0	0	2,983	249	0	497	-497	20,736	52,252
0.47	2.00	4.00	0	0	2,992	249	0	499	-499	20,750	52,828
0.50	2.00	4.00	0	0	3,000	250	0	500	-500	20,764	53,404
0.53	2.00	4.00	0	0	3,008	251	0	501	-501	20,777	53,980
0.56	2.00	4.00	0	0	3,017	251	0	503	-503	20,791	54,557
0.58	2.00	4.00	0	0	3,025	252	0	504	-504	20,805	55,134
0.61	2.00	4.00	0	0	3,033	253	0	506	-506	20,819	55,712
0.64	2.00	4.00	0	0	3,041	253	0	507	-507	20,833	56,290
0.67	2.00	4.00	0	0	3,050	254	0	508	-508	20,847	56,868
0.69	2.00	4.00	0	0	3,058	255	0	510	-510	20,862	57,447
0.72	2.00	4.00	0	0	3,066	256	0	511	-511	20,876	58,026
0.75	2.00	4.00	0	0	3,075	256	0	512	-512	20,890	58,605
0.78	2.00	4.00	0	0	3,083	257	0	514	-514	20,904	59,185
0.80	2.00	4.00	0	0	3,091	258	0	515	-515	20,918	59,766
0.83	2.00	4.00	0	0	3,100	258	0	517	-517	20,933	60,346
0.86	2.00	4.00	0	0	3,108	259	0	518	-518	20,947	60,927
0.89	2.00	4.00	0	0	3,116	260	0	519	-519	20,962	61,509
0.92	2.00	4.00	0	0	3,125	260	0	521	-521	20,976	62,091
0.94	2.00	4.00	0	0	3,133	261	0	522	-522	20,990	62,673
0.97	2.00	4.00	0	0	3,141	262	0	524	-524	21,005	63,256
1.00	2.00	4.00	0	0	3,150	262	0	525	-525	21,019	63,839
1.03	2.00	4.00	0	0	3,158	263	0	526	-526	21,034	64,422
1.05	2.00	4.00	0	0	3,166	264	0	528	-528	21,049	65,006
1.08	2.00	4.00	0	0	3,175	265	0	529	-529	21,063	65,591
1.11	2.00	4.00	0	0	3,183	265	0	531	-531	21,078	66,175
1.14	2.00	4.00	0	0	3,191	266	0	532	-532	21,093	66,761
1.17	2.00	4.00	0	0	3,200	267	0	533	-533	21,108	67,346
1.19	2.00	4.00	0	0	3,208	267	0	535	-535	21,122	67,932
1.22	2.00	4.00	0	0	3,216	268	0	536	-536	21,137	68,518
1.25	2.00	4.00	0	0	3,225	269	0	537	-537	21,152	69,105
1.28	2.00	4.00	0	0	3,233	269	0	539	-539	21,167	69,692

Example Toe Embedment Calculations

Discrete Calculations Throughout the Depth of Embedment											
	Effect Driving Pile Width	Effect Resist Pile Width	Resist Pressure		Driving Pressure		Resist Force	Driving Force	Neg Driving Force	Shear Force	Bending Moment
Depth (L)	(L)	(L)	Passive (F/L/L)	Active (F/L/L)	Passive (F/L/L)	Active (F/L/L)	(F/L)	(F/L)	(F/L)	(F)	(F-L)
1.30	2.00	4.00	0	0	3,241	270	0	540	-540	21,182	70,280
1.33	2.00	4.00	0	0	3,250	271	0	542	-542	21,197	70,868
1.36	2.00	4.00	0	0	3,258	271	0	543	-543	21,212	71,456
1.39	2.00	4.00	0	0	3,266	272	0	544	-544	21,227	72,045
1.42	2.00	4.00	0	0	3,275	273	0	546	-546	21,242	72,635
1.44	2.00	4.00	0	0	3,283	274	0	547	-547	21,258	73,224
1.47	2.00	4.00	0	0	3,291	274	0	549	-549	21,273	73,814
1.50	2.00	4.00	0	0	3,300	275	0	550	-550	21,288	74,405
1.53	2.00	4.00	0	0	3,308	276	0	551	-551	21,303	74,996
1.55	2.00	4.00	0	0	3,316	276	0	553	-553	21,319	75,587
1.58	2.00	4.00	0	0	3,325	277	0	554	-554	21,334	76,179
1.61	2.00	4.00	0	0	3,333	278	0	555	-555	21,349	76,771
1.64	2.00	4.00	0	0	3,341	278	0	557	-557	21,365	77,364
1.67	2.00	4.00	0	0	3,350	279	0	558	-558	21,380	77,957
1.69	2.00	4.00	0	0	3,358	280	0	560	-560	21,396	78,551
1.72	2.00	4.00	0	0	3,366	281	0	561	-561	21,411	79,145
1.75	2.00	4.00	0	0	3,374	281	0	562	-562	21,427	79,739
1.78	2.00	4.00	0	0	3,383	282	0	564	-564	21,442	80,334
1.80	2.00	4.00	0	0	3,391	283	0	565	-565	21,458	80,929
1.83	2.00	4.00	0	0	3,399	283	0	567	-567	21,474	81,525
1.86	2.00	4.00	0	0	3,408	284	0	568	-568	21,490	82,121
1.89	2.00	4.00	0	0	3,416	285	0	569	-569	21,505	82,718
1.91	2.00	4.00	0	0	3,424	285	0	571	-571	21,521	83,315
1.94	2.00	4.00	0	0	3,433	286	0	572	-572	21,537	83,912
1.97	2.00	4.00	0	0	3,441	287	0	574	-574	21,553	84,510
2.00	2.00	4.00	0	0	3,449	287	0	575	-575	21,569	85,108
2.03	2.00	4.00	608	51	3,458	288	2,431	576	-576	21,551	85,707
2.05	2.00	4.00	616	51	3,466	289	2,464	578	-578	21,499	86,304
2.08	2.00	4.00	624	52	3,474	290	2,498	579	-579	21,446	86,900
2.11	2.00	4.00	633	53	3,483	290	2,531	580	-580	21,393	87,494
2.14	2.00	4.00	641	53	3,491	291	2,564	582	-582	21,338	88,087
2.16	2.00	4.00	649	54	3,499	292	2,597	583	-583	21,283	88,679
2.19	2.00	4.00	658	55	3,508	292	2,631	585	-585	21,226	89,269
2.22	2.00	4.00	666	56	3,516	293	2,664	586	-586	21,169	89,857
2.25	2.00	4.00	674	56	3,524	294	2,697	587	-587	21,111	90,444
2.28	2.00	4.00	683	57	3,533	294	2,731	589	-589	21,052	91,029
2.30	2.00	4.00	691	58	3,541	295	2,764	590	-590	20,992	91,612
2.33	2.00	4.00	699	58	3,549	296	2,797	592	-592	20,931	92,194
2.36	2.00	4.00	708	59	3,558	296	2,831	593	-593	20,870	92,774
2.39	2.00	4.00	716	60	3,566	297	2,864	594	-594	20,807	93,352
2.41	2.00	4.00	724	60	3,574	298	2,897	596	-596	20,744	93,929
2.44	2.00	4.00	733	61	3,583	299	2,931	597	-597	20,679	94,503
2.47	2.00	4.00	741	62	3,591	299	2,964	598	-598	20,614	95,076
2.50	2.00	4.00	749	62	3,599	300	2,997	600	-600	20,548	95,647
2.53	2.00	4.00	758	63	3,608	301	3,030	601	-601	20,481	96,217
2.55	2.00	4.00	766	64	3,616	301	3,064	603	-603	20,413	96,784
2.58	2.00	4.00	774	65	3,624	302	3,097	604	-604	20,345	97,350

Example Toe Embedment Calculations

Discrete Calculations Throughout the Depth of Embedment											
	Effect Driving Pile	Effect Resist Pile	Resist Pressure		Driving Pressure		Resist	Driving	Neg Driving	Shear	Bending
Depth	Width	Width	Passive	Active	Passive	Active	Force	Force	Force	Force	Moment
(L)	(L)	(L)	(F/L/L)	(F/L/L)	(F/L/L)	(F/L/L)	(F/L)	(F/L)	(F/L)	(F)	(F-L)
2.61	2.00	4.00	783	65	3,633	303	3,130	605	-605	20,275	97,913
2.64	2.00	4.00	791	66	3,641	303	3,164	607	-607	20,204	98,475
2.66	2.00	4.00	799	67	3,649	304	3,197	608	-608	20,133	99,035
2.69	2.00	4.00	808	67	3,658	305	3,230	610	-610	20,061	99,592
2.72	2.00	4.00	816	68	3,666	305	3,264	611	-611	19,988	100,148
2.75	2.00	4.00	824	69	3,674	306	3,297	612	-612	19,914	100,702
2.78	2.00	4.00	833	69	3,683	307	3,330	614	-614	19,839	101,253
2.80	2.00	4.00	841	70	3,691	308	3,363	615	-615	19,763	101,803
2.83	2.00	4.00	849	71	3,699	308	3,397	617	-617	19,686	102,350
2.86	2.00	4.00	858	71	3,708	309	3,430	618	-618	19,609	102,895
2.89	2.00	4.00	866	72	3,716	310	3,463	619	-619	19,530	103,439
2.91	2.00	4.00	874	73	3,724	310	3,497	621	-621	19,451	103,979
2.94	2.00	4.00	882	74	3,732	311	3,530	622	-622	19,370	104,518
2.97	2.00	4.00	891	74	3,741	312	3,563	623	-623	19,289	105,054
3.00	2.00	4.00	899	75	3,749	312	3,597	625	-625	19,207	105,589
3.02	2.00	4.00	907	76	3,757	313	3,630	626	-626	19,124	106,121
3.05	2.00	4.00	916	76	3,766	314	3,663	628	-628	19,041	106,650
3.08	2.00	4.00	924	77	3,774	315	3,696	629	-629	18,956	107,177
3.11	2.00	4.00	932	78	3,782	315	3,730	630	-630	18,870	107,702
3.14	2.00	4.00	941	78	3,791	316	3,763	632	-632	18,784	108,225
3.16	2.00	4.00	949	79	3,799	317	3,796	633	-633	18,697	108,745
3.19	2.00	4.00	957	80	3,807	317	3,830	635	-635	18,608	109,262
3.22	2.00	4.00	966	80	3,816	318	3,863	636	-636	18,519	109,777
3.25	2.00	4.00	974	81	3,824	319	3,896	637	-637	18,429	110,290
3.27	2.00	4.00	982	82	3,832	319	3,930	639	-639	18,338	110,800
3.30	2.00	4.00	991	83	3,841	320	3,963	640	-640	18,247	111,308
3.33	2.00	4.00	999	83	3,849	321	3,996	642	-642	18,154	111,813
3.36	2.00	4.00	1,007	84	3,857	321	4,029	643	-643	18,060	112,316
3.39	2.00	4.00	1,016	85	3,866	322	4,063	644	-644	17,966	112,815
3.41	2.00	4.00	1,024	85	3,874	323	4,096	646	-646	17,871	113,313
3.44	2.00	4.00	1,032	86	3,882	324	4,129	647	-647	17,774	113,807
3.47	2.00	4.00	1,041	87	3,891	324	4,163	648	-648	17,677	114,299
3.50	2.00	4.00	1,049	87	3,899	325	4,196	650	-650	17,579	114,788
3.52	2.00	4.00	1,057	88	3,907	326	4,229	651	-651	17,481	115,275
3.55	2.00	4.00	1,066	89	3,916	326	4,263	653	-653	17,381	115,759
3.58	2.00	4.00	1,074	89	3,924	327	4,296	654	-654	17,280	116,239
3.61	2.00	4.00	1,082	90	3,932	328	4,329	655	-655	17,179	116,718
3.64	2.00	4.00	1,091	91	3,941	328	4,362	657	-657	17,076	117,193
3.66	2.00	4.00	1,099	92	3,949	329	4,396	658	-658	16,973	117,665
3.69	2.00	4.00	1,107	92	3,957	330	4,429	660	-660	16,869	118,135
3.72	2.00	4.00	1,116	93	3,966	330	4,462	661	-661	16,764	118,602
3.75	2.00	4.00	1,124	94	3,974	331	4,496	662	-662	16,658	119,065
3.77	2.00	4.00	1,132	94	3,982	332	4,529	664	-664	16,551	119,526
3.80	2.00	4.00	1,141	95	3,991	333	4,562	665	-665	16,443	119,984
3.83	2.00	4.00	1,149	96	3,999	333	4,596	666	-666	16,335	120,439
3.86	2.00	4.00	1,157	96	4,007	334	4,629	668	-668	16,225	120,891
3.89	2.00	4.00	1,166	97	4,016	335	4,662	669	-669	16,115	121,339

Example Toe Embedment Calculations

Discrete Calculations Throughout the Depth of Embedment											
Depth (L)	Effect Driving Pile Width (L)	Effect Resist Pile Width (L)	Resist Pressure Passive (F/L/L)	Resist Pressure Active (F/L/L)	Driving Pressure Passive (F/L/L)	Driving Pressure Active (F/L/L)	Resist Force (F/L)	Driving Force (F/L)	Neg Driving Force (F/L)	Shear Force (F)	Bending Moment (F-L)
3.91	2.00	4.00	1,174	98	4,024	335	4,695	671	-671	16,004	121,785
3.94	2.00	4.00	1,182	99	4,032	336	4,729	672	-672	15,891	122,228
3.97	2.00	4.00	1,191	99	4,041	337	4,762	673	-673	15,778	122,667
4.00	2.00	4.00	1,199	100	4,049	337	4,795	675	-675	15,665	123,103
4.02	2.00	4.00	1,207	101	4,057	338	4,829	676	-676	15,550	123,536
4.05	2.00	4.00	1,215	101	4,065	339	4,862	678	-678	15,434	123,966
4.08	2.00	4.00	1,224	102	4,074	339	4,895	679	-679	15,318	124,393
4.11	2.00	4.00	1,232	103	4,082	340	4,929	680	-680	15,200	124,816
4.13	2.00	4.00	1,240	103	4,090	341	4,962	682	-682	15,082	125,237
4.16	2.00	4.00	1,249	104	4,099	342	4,995	683	-683	14,963	125,653
4.19	2.00	4.00	1,257	105	4,107	342	5,028	685	-685	14,842	126,067
4.22	2.00	4.00	1,265	105	4,115	343	5,062	686	-686	14,721	126,477
4.25	2.00	4.00	1,274	106	4,124	344	5,095	687	-687	14,600	126,884
4.27	2.00	4.00	1,282	107	4,132	344	5,128	689	-689	14,477	127,288
4.30	2.00	4.00	1,290	108	4,140	345	5,162	690	-690	14,353	127,688
4.33	2.00	4.00	1,299	108	4,149	346	5,195	691	-691	14,229	128,084
4.36	2.00	4.00	1,307	109	4,157	346	5,228	693	-693	14,103	128,477
4.38	2.00	4.00	1,315	110	4,165	347	5,262	694	-694	13,977	128,867
4.41	2.00	4.00	1,324	110	4,174	348	5,295	696	-696	13,850	129,253
4.44	2.00	4.00	1,332	111	4,182	349	5,328	697	-697	13,722	129,636
4.47	2.00	4.00	1,340	112	4,190	349	5,361	698	-698	13,593	130,015
4.50	2.00	4.00	1,349	112	4,199	350	5,395	700	-700	13,463	130,390
4.52	2.00	4.00	1,357	113	4,207	351	5,428	701	-701	13,332	130,762
4.55	2.00	4.00	1,365	114	4,215	351	5,461	703	-703	13,200	131,130
4.58	2.00	4.00	1,374	114	4,224	352	5,495	704	-704	13,068	131,494
4.61	2.00	4.00	1,382	115	4,232	353	5,528	705	-705	12,935	131,855
4.63	2.00	4.00	1,390	116	4,240	353	5,561	707	-707	12,800	132,212
4.66	2.00	4.00	1,399	117	4,249	354	5,595	708	-708	12,665	132,566
4.69	2.00	4.00	1,407	117	4,257	355	5,628	709	-709	12,529	132,915
4.72	2.00	4.00	1,415	118	4,265	355	5,661	711	-711	12,392	133,261
4.75	2.00	4.00	1,424	119	4,274	356	5,694	712	-712	12,254	133,603
4.77	2.00	4.00	1,432	119	4,282	357	5,728	714	-714	12,116	133,941
4.80	2.00	4.00	1,440	120	4,290	358	5,761	715	-715	11,976	134,275
4.83	2.00	4.00	1,449	121	4,299	358	5,794	716	-716	11,836	134,606
4.86	2.00	4.00	1,457	121	4,307	359	5,828	718	-718	11,694	134,932
4.88	2.00	4.00	1,465	122	4,315	360	5,861	719	-719	11,552	135,255
4.91	2.00	4.00	1,474	123	4,324	360	5,894	721	-721	11,409	135,574
4.94	2.00	4.00	1,482	123	4,332	361	5,928	722	-722	11,265	135,888
4.97	2.00	4.00	1,490	124	4,340	362	5,961	723	-723	11,120	136,199
5.00	2.00	4.00	1,499	125	4,349	362	5,994	725	-725	10,974	136,505
5.02	2.00	4.00	1,507	126	4,357	363	6,028	726	-726	10,827	136,808
5.05	2.00	4.00	1,515	126	4,365	364	6,061	728	-728	10,680	137,106
5.08	2.00	4.00	1,524	127	4,374	364	6,094	729	-729	10,531	137,401
5.11	2.00	4.00	1,532	128	4,382	365	6,127	730	-730	10,382	137,691
5.13	2.00	4.00	1,540	128	4,390	366	6,161	732	-732	10,232	137,977
5.16	2.00	4.00	1,549	129	4,399	367	6,194	733	-733	10,081	138,259
5.19	2.00	4.00	1,557	130	4,407	367	6,227	734	-734	9,929	138,536

Example Toe Embedment Calculations

Discrete Calculations Throughout the Depth of Embedment											
Depth (L)	Effect Driving Pile Width (L)	Effect Resist Pile Width (L)	Resist Pressure		Driving Pressure		Resist Force (F/L)	Driving Force (F/L)	Neg Driving Force (F/L)	Shear Force (F)	Bending Moment (F-L)
			Passive (F/L/L)	Active (F/L/L)	Passive (F/L/L)	Active (F/L/L)					
5.22	2.00	4.00	1,565	130	4,415	368	6,261	736	-736	9,776	138,810
5.24	2.00	4.00	1,573	131	4,423	369	6,294	737	-737	9,622	139,079
5.27	2.00	4.00	1,582	132	4,432	369	6,327	739	-739	9,467	139,344
5.30	2.00	4.00	1,590	133	4,440	370	6,361	740	-740	9,312	139,604
5.33	2.00	4.00	1,598	133	4,448	371	6,394	741	-741	9,156	139,861
5.36	2.00	4.00	1,607	134	4,457	371	6,427	743	-743	8,998	140,112
5.38	2.00	4.00	1,615	135	4,465	372	6,460	744	-744	8,840	140,360
5.41	2.00	4.00	1,623	135	4,473	373	6,494	746	-746	8,681	140,603
5.44	2.00	4.00	1,632	136	4,482	373	6,527	747	-747	8,521	140,842
5.47	2.00	4.00	1,640	137	4,490	374	6,560	748	-748	8,360	141,076
5.49	2.00	4.00	1,648	137	4,498	375	6,594	750	-750	8,198	141,306
5.52	2.00	4.00	1,657	138	4,507	376	6,627	751	-751	8,036	141,531
5.55	2.00	4.00	1,665	139	4,515	376	6,660	753	-753	7,872	141,752
5.58	2.00	4.00	1,673	139	4,523	377	6,694	754	-754	7,708	141,968
5.61	2.00	4.00	1,682	140	4,532	378	6,727	755	-755	7,543	142,180
5.63	2.00	4.00	1,690	141	4,540	378	6,760	757	-757	7,376	142,387
5.66	2.00	4.00	1,698	142	4,548	379	6,793	758	-758	7,209	142,589
5.69	2.00	4.00	1,707	142	4,557	380	6,827	759	-759	7,042	142,787
5.72	2.00	4.00	1,715	143	4,565	380	6,860	761	-761	6,873	142,980
5.74	2.00	4.00	1,723	144	4,573	381	6,893	762	-762	6,703	143,168
5.77	2.00	4.00	1,732	144	4,582	382	6,927	764	-764	6,532	143,352
5.80	2.00	4.00	1,740	145	4,590	382	6,960	765	-765	6,361	143,531
5.83	2.00	4.00	1,748	146	4,598	383	6,993	766	-766	6,189	143,705
5.86	2.00	4.00	1,757	146	4,607	384	7,027	768	-768	6,015	143,874
5.88	2.00	4.00	1,765	147	4,615	385	7,060	769	-769	5,841	144,039
5.91	2.00	4.00	1,773	148	4,623	385	7,093	771	-771	5,666	144,198
5.94	2.00	4.00	1,782	148	4,632	386	7,126	772	-772	5,490	144,353
5.97	2.00	4.00	1,790	149	4,640	387	7,160	773	-773	5,313	144,503
5.99	2.00	4.00	1,798	150	4,648	387	7,193	775	-775	5,136	144,648
6.02	2.00	4.00	1,807	151	4,657	388	7,226	776	-776	4,957	144,788
6.05	2.00	4.00	1,815	151	4,665	389	7,260	777	-777	4,778	144,923
6.08	2.00	4.00	1,823	152	4,673	389	7,293	779	-779	4,597	145,053
6.11	2.00	4.00	1,832	153	4,682	390	7,326	780	-780	4,416	145,178
6.13	2.00	4.00	1,840	153	4,690	391	7,360	782	-782	4,234	145,298
6.16	2.00	4.00	1,848	154	4,698	392	7,393	783	-783	4,051	145,413
6.19	2.00	4.00	1,857	155	4,707	392	7,426	784	-784	3,867	145,523
6.22	2.00	4.00	1,865	155	4,715	393	7,459	786	-786	3,683	145,628
6.24	2.00	4.00	1,873	156	4,723	394	7,493	787	-787	3,497	145,728
6.27	2.00	4.00	1,882	157	4,732	394	7,526	789	-789	3,310	145,822
6.30	2.00	4.00	1,890	157	4,740	395	7,559	790	-790	3,123	145,911
6.33	2.00	4.00	1,898	158	4,748	396	7,593	791	-791	2,935	145,995
6.35	2.00	4.00	1,906	159	4,756	396	7,626	793	-793	2,745	146,074
6.38	2.00	4.00	1,915	160	4,765	397	7,659	794	-794	2,555	146,148
6.41	2.00	4.00	1,923	160	4,773	398	7,693	796	-796	2,364	146,216
6.44	2.00	4.00	1,931	161	4,781	398	7,726	797	-797	2,173	146,279
6.47	2.00	4.00	1,940	162	4,790	399	7,759	798	-798	1,980	146,337
6.49	2.00	4.00	1,948	162	4,798	400	7,792	800	-800	1,786	146,389

FIGURE A-2 (Page 6 of 12)

Example Toe Embedment Calculations

Discrete Calculations Throughout the Depth of Embedment											
Depth (L)	Effect Driving Pile Width (L)	Effect Resist Pile Width (L)	Resist Pressure		Driving Pressure		Resist Force (F/L)	Driving Force (F/L)	Neg Driving Force (F/L)	Shear Force (F)	Bending Moment (F-L)
			Passive (F/L/L)	Active (F/L/L)	Passive (F/L/L)	Active (F/L/L)					
6.52	2.00	4.00	1,956	163	4,806	401	7,826	801	-801	1,592	146,436
6.55	2.00	4.00	1,965	164	4,815	401	7,859	802	-802	1,396	146,477
6.58	2.00	4.00	1,973	164	4,823	402	7,892	804	-804	1,200	146,513
6.60	2.00	4.00	1,981	165	4,831	403	7,926	805	-805	1,003	146,544
6.63	2.00	4.00	1,990	166	4,840	403	7,959	807	-807	805	146,569
6.66	2.00	4.00	1,998	167	4,848	404	7,992	808	-808	606	146,588
6.69	2.00	4.00	2,006	167	4,856	405	8,026	809	-809	406	146,602
6.72	2.00	4.00	2,015	168	4,865	405	8,059	811	-811	205	146,611
6.74	2.00	4.00	2,023	169	4,873	406	8,092	812	-812	4	146,614
6.77	2.00	4.00	2,031	169	4,881	407	8,125	814	-814	-199	146,611
6.80	2.00	4.00	2,040	170	4,890	407	8,159	815	-815	-402	146,603
6.83	2.00	4.00	2,048	171	4,898	408	8,192	816	-816	-606	146,589
6.85	2.00	4.00	2,056	171	4,906	409	8,225	818	-818	-811	146,569
6.88	2.00	4.00	2,065	172	4,915	410	8,259	819	-819	-1,017	146,544
6.91	2.00	4.00	2,073	173	4,923	410	8,292	820	-820	-1,224	146,513
6.94	2.00	4.00	2,081	173	4,931	411	8,325	822	-822	-1,432	146,476
6.97	2.00	4.00	2,090	174	4,940	412	8,359	823	-823	-1,641	146,433
6.99	2.00	4.00	2,098	175	4,948	412	8,392	825	-825	-1,850	146,385
7.02	2.00	4.00	2,106	176	4,956	413	8,425	826	-826	-2,061	146,331
7.05	2.00	4.00	2,115	176	4,965	414	8,458	827	-827	-2,272	146,270
7.08	2.00	4.00	2,123	177	4,973	414	8,492	829	-829	-2,484	146,204
7.10	2.00	4.00	2,131	178	4,981	415	8,525	830	-830	-2,697	146,133
7.13	2.00	4.00	2,140	178	4,990	416	8,558	832	-832	-2,911	146,055
7.16	2.00	4.00	2,148	179	4,998	416	8,592	833	-833	-3,126	145,971
7.19	2.00	4.00	2,156	180	5,006	417	8,625	834	-834	-3,342	145,881
7.22	2.00	4.00	2,165	180	5,015	418	8,658	836	-836	-3,559	145,785
7.24	2.00	4.00	2,173	181	5,023	419	8,692	837	-837	-3,776	145,684
7.27	2.00	4.00	2,181	182	5,031	419	8,725	839	-839	-3,994	145,576
7.30	2.00	4.00	2,190	182	5,040	420	8,758	840	-840	-4,214	145,462
7.33	2.00	4.00	2,198	183	5,048	421	8,792	841	-841	-4,434	145,342
7.35	2.00	4.00	2,206	184	5,056	421	8,825	843	-843	-4,655	145,216
7.38	2.00	4.00	2,215	185	5,065	422	8,858	844	-844	-4,877	145,084
7.41	2.00	4.00	2,223	185	5,073	423	8,891	845	-845	-5,100	144,945
7.44	2.00	4.00	2,231	186	5,081	423	8,925	847	-847	-5,324	144,801
7.47	2.00	4.00	2,240	187	5,090	424	8,958	848	-848	-5,548	144,650
7.49	2.00	4.00	2,248	187	5,098	425	8,991	850	-850	-5,774	144,493
7.52	2.00	4.00	2,256	188	5,106	426	9,025	851	-851	-6,000	144,329
7.55	2.00	4.00	2,264	189	5,114	426	9,058	852	-852	-6,227	144,160
7.58	2.00	4.00	2,273	189	5,123	427	9,091	854	-854	-6,455	143,984
7.60	2.00	4.00	2,281	190	5,131	428	9,125	855	-855	-6,684	143,801
7.63	2.00	4.00	2,289	191	5,139	428	9,158	857	-857	-6,914	143,613
7.66	2.00	4.00	2,298	191	5,148	429	9,191	858	-858	-7,145	143,418
7.69	2.00	4.00	2,306	192	5,156	430	9,224	859	-859	-7,377	143,216
7.71	2.00	4.00	2,314	193	5,164	430	9,258	861	-861	-7,610	143,008
7.74	2.00	4.00	2,323	194	5,173	431	9,291	862	-862	-7,843	142,794
7.77	2.00	4.00	2,331	194	5,181	432	9,324	864	-864	-8,077	142,573
7.80	2.00	4.00	2,339	195	5,189	432	9,358	865	-865	-8,313	142,345

Example Toe Embedment Calculations

Discrete Calculations Throughout the Depth of Embedment											
	Effect Driving Pile Width	Effect Resist Pile Width	Resist Pressure		Driving Pressure		Resist Force	Driving Force	Neg Driving Force	Shear Force	Bending Moment
Depth (L)	(L)	(L)	Passive (F/L/L)	Active (F/L/L)	Passive (F/L/L)	Active (F/L/L)	(F/L)	(F/L)	(F/L)	(F)	(F-L)
7.83	2.00	4.00	2,348	196	5,198	433	9,391	866	-866	-8,549	142,111
7.85	2.00	4.00	2,356	196	5,206	434	9,424	868	-868	-8,786	141,871
7.88	2.00	4.00	2,364	197	5,214	435	9,458	869	-869	-9,024	141,624
7.91	2.00	4.00	2,373	198	5,223	435	9,491	870	-870	-9,262	141,370
7.94	2.00	4.00	2,381	198	5,231	436	9,524	872	-872	-9,502	141,110
7.96	2.00	4.00	2,389	199	5,239	437	9,557	873	-873	-9,743	140,843
7.99	2.00	4.00	2,398	200	5,248	437	9,591	875	-875	-9,984	140,569
8.02	2.00	4.00	2,406	201	5,256	438	9,624	876	-876	-10,226	140,288
8.05	2.00	4.00	2,414	201	5,264	439	9,657	877	-877	-10,470	140,001
8.08	2.00	4.00	2,423	202	5,273	439	9,691	879	-879	-10,714	139,707
8.10	2.00	4.00	2,431	203	5,281	440	9,724	880	-880	-10,959	139,407
8.13	2.00	4.00	2,439	203	5,289	441	9,757	882	-882	-11,205	139,099
8.16	2.00	4.00	2,448	204	5,298	441	9,791	883	-883	-11,451	138,785
8.19	2.00	4.00	2,456	205	5,306	442	9,824	884	-884	-11,699	138,464
8.21	2.00	4.00	2,464	205	5,314	443	9,857	886	-886	-11,947	138,135
8.24	2.00	4.00	2,473	206	5,323	444	9,890	887	-887	-12,197	137,800
8.27	2.00	4.00	2,481	207	5,331	444	9,924	888	-888	-12,447	137,459
8.30	2.00	4.00	2,489	207	5,339	445	9,957	890	-890	-12,698	137,110
8.33	2.00	4.00	2,498	208	5,348	446	9,990	891	-891	-12,950	136,754
8.35	2.00	4.00	2,506	209	5,356	446	10,024	893	-893	-13,203	136,391
8.38	2.00	4.00	2,514	210	5,364	447	10,057	894	-894	-13,457	136,021
8.41	2.00	4.00	2,523	210	5,373	448	10,090	895	-895	-13,712	135,644
8.44	2.00	4.00	2,531	211	5,381	448	10,124	897	-897	-13,967	135,260
8.46	2.00	4.00	2,539	212	5,389	449	10,157	898	-898	-14,224	134,869
8.49	2.00	4.00	2,548	212	5,398	450	10,190	900	-900	-14,481	134,470
8.52	2.00	4.00	2,556	213	5,406	450	10,223	901	-901	-14,740	134,065
8.55	2.00	4.00	2,564	214	5,414	451	10,257	902	-902	-14,999	133,652
8.58	2.00	4.00	2,573	214	5,423	452	10,290	904	-904	-15,259	133,232
8.60	2.00	4.00	2,581	215	5,431	453	10,323	905	-905	-15,520	132,805
8.63	2.00	4.00	2,589	216	5,439	453	10,357	907	-907	-15,782	132,371
8.66	2.00	4.00	2,597	216	5,447	454	10,390	908	-908	-16,044	131,930
8.69	2.00	4.00	2,606	217	5,456	455	10,423	909	-909	-16,308	131,481
8.71	2.00	4.00	2,614	218	5,464	455	10,457	911	-911	-16,572	131,024
8.74	2.00	4.00	2,622	219	5,472	456	10,490	912	-912	-16,838	130,561
8.77	2.00	4.00	2,631	219	5,481	457	10,523	913	-913	-17,104	130,090
8.80	2.00	4.00	2,639	220	5,489	457	10,556	915	-915	-17,371	129,612
8.82	2.00	4.00	2,647	221	5,497	458	10,590	916	-916	-17,639	129,126
8.85	2.00	4.00	2,656	221	5,506	459	10,623	918	-918	-17,908	128,633
8.88	2.00	4.00	2,664	222	5,514	460	10,656	919	-919	-18,178	128,132
8.91	2.00	4.00	2,672	223	5,522	460	10,690	920	-920	-18,448	127,624
8.94	2.00	4.00	2,681	223	5,531	461	10,723	922	-922	-18,720	127,108
8.96	2.00	4.00	2,689	224	5,539	462	10,756	923	-923	-18,992	126,585
8.99	2.00	4.00	2,697	225	5,547	462	10,790	925	-925	-19,266	126,054
9.02	2.00	4.00	2,706	225	5,556	463	10,823	926	-926	-19,540	125,515
9.05	2.00	4.00	2,714	226	5,564	464	10,856	927	-927	-19,815	124,969
9.07	2.00	4.00	2,722	227	5,572	464	10,889	929	-929	-20,091	124,416
9.10	2.00	4.00	2,731	228	5,581	465	10,923	930	-930	-20,368	123,854

Example Toe Embedment Calculations

Discrete Calculations Throughout the Depth of Embedment												
	Effect Driving Pile Width	Effect Resist Pile Width	Resist Pressure		Driving Pressure		Resist Force	Driving Force	Neg Driving Force	Shear Force	Bending Moment
Depth (L)	(L)	(L)	Passive (F/L/L)	Active (F/L/L)	Passive (F/L/L)	Active (F/L/L)	(F/L)	(F/L)	(F/L)	(F)	(F-L)
9.13	2.00	4.00	2,739	228	5,589	466	10,956	932	-932	-20,646	123,285
9.16	2.00	4.00	2,747	229	5,597	466	10,989	933	-933	-20,924	122,708
9.19	2.00	4.00	2,756	230	5,606	467	11,023	934	-934	-21,204	122,124
9.21	2.00	4.00	2,764	230	5,614	468	11,056	936	-936	-21,484	121,531
9.24	2.00	4.00	2,772	231	5,622	469	11,089	937	-937	-21,765	120,931
9.27	2.00	4.00	2,781	232	5,631	469	11,123	938	-938	-22,048	120,323
9.30	2.00	4.00	2,789	232	5,639	470	11,156	940	-940	-22,331	119,708
9.32	2.00	4.00	2,797	233	5,647	471	11,189	941	-941	-22,615	119,084
9.35	2.00	4.00	2,806	234	5,656	471	11,222	943	-943	-22,899	118,452
9.38	2.00	4.00	2,814	234	5,664	472	11,256	944	-944	-23,185	117,813
9.41	2.00	4.00	2,822	235	5,672	473	11,289	945	-945	-23,472	117,166
9.44	2.00	4.00	2,831	236	5,681	473	11,322	947	-947	-23,759	116,510
9.46	2.00	4.00	2,839	237	5,689	474	11,356	948	-948	-24,048	115,847
9.49	2.00	4.00	2,847	237	5,697	475	11,389	950	-950	-24,337	115,176
9.52	2.00	4.00	2,856	238	5,706	475	11,422	951	-951	-24,627	114,496
9.55	2.00	4.00	2,864	239	5,714	476	11,456	952	-952	-24,918	113,809
9.57	2.00	4.00	2,872	239	5,722	477	11,489	954	-954	-25,210	113,113
9.60	2.00	4.00	2,881	240	5,731	478	11,522	955	-955	-25,503	112,410
9.63	2.00	4.00	2,889	241	5,739	478	11,556	956	-956	-25,796	111,698
9.66	2.00	4.00	2,897	241	5,747	479	11,589	958	-958	-26,091	110,978
9.69	2.00	4.00	2,906	242	5,756	480	11,622	959	-959	-26,386	110,250
9.71	2.00	4.00	2,914	243	5,764	480	11,655	961	-961	-26,683	109,513
9.74	2.00	4.00	2,922	244	5,772	481	11,625	1,093	-1,093	-26,977	108,769
9.77	2.00	4.00	2,931	244	5,781	482	11,587	1,243	-1,243	-27,267	108,016
9.80	2.00	4.00	2,939	245	5,789	482	11,548	1,393	-1,393	-27,551	107,255
9.82	2.00	4.00	2,947	246	5,797	483	11,508	1,543	-1,543	-27,831	106,487
9.85	2.00	4.00	2,955	246	5,805	484	11,468	1,694	-1,694	-28,105	105,711
9.88	2.00	4.00	2,964	247	5,814	484	11,428	1,845	-1,845	-28,373	104,927
9.91	2.00	4.00	2,972	248	5,822	485	11,388	1,996	-1,996	-28,636	104,136
9.93	2.00	4.00	2,980	248	5,830	486	11,347	2,148	-2,148	-28,894	103,338
9.96	2.00	4.00	2,989	249	5,839	487	11,305	2,301	-2,301	-29,147	102,532
9.99	2.00	4.00	2,997	250	5,847	487	11,263	2,453	-2,453	-29,394	101,720
10.02	2.00	4.00	3,005	250	5,855	488	11,221	2,607	-2,607	-29,636	100,901
10.05	2.00	4.00	3,014	251	5,864	489	11,178	2,760	-2,760	-29,872	100,075
10.07	2.00	4.00	3,022	252	5,872	489	11,135	2,914	-2,914	-30,103	99,243
10.10	2.00	4.00	3,030	253	5,880	490	11,092	3,069	-3,069	-30,329	98,405
10.13	2.00	4.00	3,039	253	5,889	491	11,048	3,224	-3,224	-30,548	97,560
10.16	2.00	4.00	3,047	254	5,897	491	11,004	3,379	-3,379	-30,763	96,709
10.18	2.00	4.00	3,055	255	5,905	492	10,959	3,535	-3,535	-30,972	95,853
10.21	2.00	4.00	3,064	255	5,914	493	10,914	3,691	-3,691	-31,175	94,990
10.24	2.00	4.00	3,072	256	5,922	494	10,869	3,848	-3,848	-31,372	94,122
10.27	2.00	4.00	3,080	257	5,930	494	10,823	4,005	-4,005	-31,564	93,249
10.30	2.00	4.00	3,089	257	5,939	495	10,776	4,162	-4,162	-31,751	92,370
10.32	2.00	4.00	3,097	258	5,947	496	10,730	4,320	-4,320	-31,932	91,487
10.35	2.00	4.00	3,105	259	5,955	496	10,683	4,479	-4,479	-32,107	90,598
10.38	2.00	4.00	3,114	259	5,964	497	10,635	4,638	-4,638	-32,276	89,705
10.41	2.00	4.00	3,122	260	5,972	498	10,587	4,797	-4,797	-32,439	88,807

FIGURE A-2 (Page 9 of 12)

Example Toe Embedment Calculations

Discrete Calculations Throughout the Depth of Embedment											
Depth (L)	Effect Driving Pile Width (L)	Effect Resist Pile Width (L)	Resist Pressure Passive (F/L/L)	Resist Pressure Active (F/L/L)	Driving Pressure Passive (F/L/L)	Driving Pressure Active (F/L/L)	Resist Force (F/L)	Driving Force (F/L)	Neg Driving Force (F/L)	Shear Force (F)	Bending Moment (F-L)
10.43	2.00	4.00	3,130	261	5,980	498	10,539	4,956	-4,956	-32,597	87,905
10.46	2.00	4.00	3,139	262	5,989	499	10,490	5,116	-5,116	-32,749	86,998
10.49	2.00	4.00	3,147	262	5,997	500	10,441	5,277	-5,277	-32,895	86,087
10.52	2.00	4.00	3,155	263	6,005	500	10,391	5,438	-5,438	-33,036	85,172
10.55	2.00	4.00	3,164	264	6,014	501	10,341	5,599	-5,599	-33,170	84,253
10.57	2.00	4.00	3,172	264	6,022	502	10,291	5,761	-5,761	-33,299	83,331
10.60	2.00	4.00	3,180	265	6,030	503	10,240	5,923	-5,923	-33,422	82,405
10.63	2.00	4.00	3,189	266	6,039	503	10,189	6,086	-6,086	-33,539	81,476
10.66	2.00	4.00	3,197	266	6,047	504	10,137	6,249	-6,249	-33,650	80,544
10.68	2.00	4.00	3,205	267	6,055	505	10,085	6,412	-6,412	-33,754	79,609
10.71	2.00	4.00	3,214	268	6,064	505	10,033	6,576	-6,576	-33,853	78,671
10.74	2.00	4.00	3,222	268	6,072	506	9,980	6,740	-6,740	-33,946	77,730
10.77	2.00	4.00	3,230	269	6,080	507	9,927	6,905	-6,905	-34,033	76,786
10.80	2.00	4.00	3,239	270	6,089	507	9,873	7,070	-7,070	-34,114	75,841
10.82	2.00	4.00	3,247	271	6,097	508	9,819	7,236	-7,236	-34,189	74,893
10.85	2.00	4.00	3,255	271	6,105	509	9,765	7,402	-7,402	-34,257	73,943
10.88	2.00	4.00	3,264	272	6,114	509	9,710	7,568	-7,568	-34,320	72,992
10.91	2.00	4.00	3,272	273	6,122	510	9,655	7,735	-7,735	-34,376	72,039
10.93	2.00	4.00	3,280	273	6,130	511	9,599	7,902	-7,902	-34,426	71,084
10.96	2.00	4.00	3,288	274	6,138	512	9,543	8,070	-8,070	-34,470	70,128
10.99	2.00	4.00	3,297	275	6,147	512	9,486	8,238	-8,238	-34,508	69,171
11.02	2.00	4.00	3,305	275	6,155	513	9,429	8,407	-8,407	-34,540	68,213
11.04	2.00	4.00	3,313	276	6,163	514	9,372	8,576	-8,576	-34,565	67,254
11.07	2.00	4.00	3,322	277	6,172	514	9,314	8,745	-8,745	-34,584	66,294
11.10	2.00	4.00	3,330	278	6,180	515	9,256	8,915	-8,915	-34,596	65,334
11.13	2.00	4.00	3,338	278	6,188	516	9,198	9,085	-9,085	-34,603	64,374
11.16	2.00	4.00	3,347	279	6,197	516	9,139	9,256	-9,256	-34,603	63,414
11.18	2.00	4.00	3,355	280	6,205	517	9,080	9,427	-9,427	-34,596	62,454
11.21	2.00	4.00	3,363	280	6,213	518	9,020	9,599	-9,599	-34,583	61,494
11.24	2.00	4.00	3,372	281	6,222	518	8,960	9,771	-9,771	-34,564	60,534
11.27	2.00	4.00	3,380	282	6,230	519	8,899	9,943	-9,943	-34,538	59,576
11.29	2.00	4.00	3,388	282	6,238	520	8,838	10,116	-10,116	-34,506	58,618
11.32	2.00	4.00	3,397	283	6,247	521	8,777	10,289	-10,289	-34,467	57,661
11.35	2.00	4.00	3,405	284	6,255	521	8,715	10,463	-10,463	-34,422	56,705
11.38	2.00	4.00	3,413	284	6,263	522	8,653	10,637	-10,637	-34,370	55,750
11.41	2.00	4.00	3,422	285	6,272	523	8,590	10,812	-10,812	-34,312	54,797
11.43	2.00	4.00	3,430	286	6,280	523	8,527	10,987	-10,987	-34,247	53,846
11.46	2.00	4.00	3,438	287	6,288	524	8,464	11,162	-11,162	-34,175	52,896
11.49	2.00	4.00	3,447	287	6,297	525	8,400	11,338	-11,338	-34,097	51,949
11.52	2.00	4.00	3,455	288	6,305	525	8,336	11,514	-11,514	-34,012	51,004
11.54	2.00	4.00	3,463	289	6,313	526	8,271	11,691	-11,691	-33,921	50,061
11.57	2.00	4.00	3,472	289	6,322	527	8,206	11,868	-11,868	-33,823	49,121
11.60	2.00	4.00	3,480	290	6,330	527	8,141	12,045	-12,045	-33,718	48,184
11.63	2.00	4.00	3,488	291	6,338	528	8,075	12,223	-12,223	-33,606	47,250
11.66	2.00	4.00	3,497	291	6,347	529	8,008	12,402	-12,402	-33,487	46,319
11.68	2.00	4.00	3,505	292	6,355	530	7,942	12,580	-12,580	-33,362	45,391
11.71	2.00	4.00	3,513	293	6,363	530	7,875	12,760	-12,760	-33,230	44,467

FIGURE A-2 (Page 10 of 12)

Example Toe Embedment Calculations

Discrete Calculations Throughout the Depth of Embedment											
Depth (L)	Effect Driving Pile Width (L)	Effect Resist Pile Width (L)	Resist Pressure		Driving Pressure		Resist Force (F/L)	Driving Force (F/L)	Neg Driving Force (F/L)	Shear Force (F)	Bending Moment (F-L)
			Passive (F/L/L)	Active (F/L/L)	Passive (F/L/L)	Active (F/L/L)					
11.74	2.00	4.00	3,522	293	6,372	531	7,807	12,939	-12,939	-33,091	43,547
11.77	2.00	4.00	3,530	294	6,380	532	7,739	13,119	-13,119	-32,945	42,631
11.79	2.00	4.00	3,538	295	6,388	532	7,671	13,300	-13,300	-32,792	41,719
11.82	2.00	4.00	3,547	296	6,397	533	7,602	13,481	-13,481	-32,633	40,811
11.85	2.00	4.00	3,555	296	6,405	534	7,533	13,662	-13,662	-32,466	39,908
11.88	2.00	4.00	3,563	297	6,413	534	7,464	13,844	-13,844	-32,292	39,009
11.91	2.00	4.00	3,572	298	6,422	535	7,394	14,026	-14,026	-32,112	38,115
11.93	2.00	4.00	3,580	298	6,430	536	7,323	14,209	-14,209	-31,924	37,227
11.96	2.00	4.00	3,588	299	6,438	537	7,253	14,392	-14,392	-31,730	36,344
11.99	2.00	4.00	3,597	300	6,447	537	7,181	14,575	-14,575	-31,528	35,466
12.02	2.00	4.00	3,605	300	6,455	538	7,110	14,759	-14,759	-31,319	34,594
12.04	2.00	4.00	3,613	301	6,463	539	7,038	14,943	-14,943	-31,103	33,728
12.07	2.00	4.00	3,622	302	6,472	539	6,966	15,128	-15,128	-30,881	32,868
12.10	2.00	4.00	3,630	302	6,480	540	6,893	15,313	-15,313	-30,650	32,014
12.13	2.00	4.00	3,638	303	6,488	541	6,820	15,499	-15,499	-30,413	31,167
12.15	2.00	4.00	3,646	304	6,496	541	6,746	15,685	-15,685	-30,169	30,326
12.18	2.00	4.00	3,655	305	6,505	542	6,672	15,871	-15,871	-29,917	29,492
12.21	2.00	4.00	3,663	305	6,513	543	6,598	16,058	-16,058	-29,658	28,666
12.24	2.00	4.00	3,671	306	6,521	543	6,523	16,246	-16,246	-29,392	27,846
12.27	2.00	4.00	3,680	307	6,530	544	6,448	16,433	-16,433	-29,118	27,034
12.29	2.00	4.00	3,688	307	6,538	545	6,372	16,622	-16,622	-28,838	26,230
12.32	2.00	4.00	3,696	308	6,546	546	6,296	16,810	-16,810	-28,550	25,434
12.35	2.00	4.00	3,705	309	6,555	546	6,219	16,999	-16,999	-28,254	24,646
12.38	2.00	4.00	3,713	309	6,563	547	6,143	17,189	-17,189	-27,951	23,866
12.40	2.00	4.00	3,721	310	6,571	548	6,065	17,378	-17,378	-27,641	23,094
12.43	2.00	4.00	3,730	311	6,580	548	5,988	17,569	-17,569	-27,323	22,332
12.46	2.00	4.00	3,738	312	6,588	549	5,910	17,759	-17,759	-26,998	21,578
12.49	2.00	4.00	3,746	312	6,596	550	5,831	17,951	-17,951	-26,666	20,833
12.52	2.00	4.00	3,755	313	6,605	550	5,752	18,142	-18,142	-26,326	20,098
12.54	2.00	4.00	3,763	314	6,613	551	5,673	18,334	-18,334	-25,978	19,372
12.57	2.00	4.00	3,771	314	6,621	552	5,593	18,527	-18,527	-25,623	18,656
12.60	2.00	4.00	3,780	315	6,630	552	5,513	18,719	-18,719	-25,260	17,950
12.63	2.00	4.00	3,788	316	6,638	553	5,433	18,913	-18,913	-24,890	17,254
12.65	2.00	4.00	3,796	316	6,646	554	5,352	19,106	-19,106	-24,512	16,569
12.68	2.00	4.00	3,805	317	6,655	555	5,270	19,301	-19,301	-24,126	15,894
12.71	2.00	4.00	3,813	318	6,663	555	5,189	19,495	-19,495	-23,733	15,230
12.74	2.00	4.00	3,821	318	6,671	556	5,106	19,690	-19,690	-23,332	14,577
12.77	2.00	4.00	3,830	319	6,680	557	5,024	19,885	-19,885	-22,924	13,935
12.79	2.00	4.00	3,838	320	6,688	557	4,941	20,081	-20,081	-22,507	13,305
12.82	2.00	4.00	3,846	321	6,696	558	4,857	20,278	-20,278	-22,083	12,686
12.85	2.00	4.00	3,855	321	6,705	559	4,774	20,474	-20,474	-21,652	12,079
12.88	2.00	4.00	3,863	322	6,713	559	4,690	20,671	-20,671	-21,212	11,484
12.90	2.00	4.00	3,871	323	6,721	560	4,605	20,869	-20,869	-20,765	10,902
12.93	2.00	4.00	3,880	323	6,730	561	4,520	21,067	-21,067	-20,309	10,332
12.96	2.00	4.00	3,888	324	6,738	561	4,435	21,265	-21,265	-19,846	9,775
12.99	2.00	4.00	3,896	325	6,746	562	4,349	21,464	-21,464	-19,375	9,230
13.02	2.00	4.00	3,905	325	6,755	563	4,262	21,663	-21,663	-18,896	8,699

FIGURE A-2 (Page 11 of 12)

Example Toe Embedment Calculations

Discrete Calculations Throughout the Depth of Embedment											
Depth (L)	Effect Driving Pile Width (L)	Effect Resist Pile Width (L)	Resist Pressure		Driving Pressure		Resist Force (F/L)	Driving Force (F/L)	Neg Driving Force (F/L)	Shear Force (F)	Bending Moment (F-L)
			Passive (F/L/L)	Active (F/L/L)	Passive (F/L/L)	Active (F/L/L)					
13.04	2.00	4.00	3,913	326	6,763	564	4,176	21,863	-21,863	-18,409	8,182
13.07	2.00	4.00	3,921	327	6,771	564	4,089	22,063	-22,063	-17,915	7,678
13.10	2.00	4.00	3,930	327	6,780	565	4,001	22,263	-22,263	-17,412	7,187
13.13	2.00	4.00	3,938	328	6,788	566	3,914	22,464	-22,464	-16,901	6,711
13.15	2.00	4.00	3,946	329	6,796	566	3,825	22,666	-22,666	-16,382	6,249
13.18	2.00	4.00	3,955	330	6,805	567	3,737	22,868	-22,868	-15,855	5,802
13.21	2.00	4.00	3,963	330	6,813	568	3,648	23,070	-23,070	-15,320	5,370
13.24	2.00	4.00	3,971	331	6,821	568	3,558	23,272	-23,272	-14,777	4,952
13.26	2.00	4.00	3,979	332	6,829	569	3,468	23,475	-23,475	-14,226	4,549
13.29	2.00	4.00	3,988	332	6,838	570	3,378	23,679	-23,679	-13,667	4,162
13.32	2.00	4.00	3,996	333	6,846	571	3,287	23,883	-23,883	-13,099	3,791
13.35	2.00	4.00	4,004	334	6,854	571	3,196	24,087	-24,087	-12,524	3,435
13.38	2.00	4.00	4,013	334	6,863	572	3,105	24,292	-24,292	-11,940	3,096
13.40	2.00	4.00	4,021	335	6,871	573	3,013	24,497	-24,497	-11,348	2,773
13.43	2.00	4.00	4,029	336	6,879	573	2,920	24,703	-24,703	-10,747	2,466
13.46	2.00	4.00	4,038	336	6,888	574	2,828	24,909	-24,909	-10,139	2,176
13.49	2.00	4.00	4,046	337	6,896	575	2,734	25,115	-25,115	-9,522	1,904
13.51	2.00	4.00	4,054	338	6,904	575	2,641	25,322	-25,322	-8,897	1,648
13.54	2.00	4.00	4,063	339	6,913	576	2,547	25,529	-25,529	-8,263	1,410
13.57	2.00	4.00	4,071	339	6,921	577	2,452	25,737	-25,737	-7,621	1,189
13.60	2.00	4.00	4,079	340	6,929	577	2,358	25,945	-25,945	-6,971	987
13.63	2.00	4.00	4,088	341	6,938	578	2,263	26,154	-26,154	-6,312	803
13.65	2.00	4.00	4,096	341	6,946	579	2,167	26,363	-26,363	-5,645	637
13.68	2.00	4.00	4,104	342	6,954	580	2,071	26,572	-26,572	-4,969	489
13.71	2.00	4.00	4,113	343	6,963	580	1,975	26,782	-26,782	-4,285	361
13.74	2.00	4.00	4,121	343	6,971	581	1,878	26,993	-26,993	-3,592	252
13.76	2.00	4.00	4,129	344	6,979	582	1,781	27,203	-27,203	-2,891	162
13.79	2.00	4.00	4,138	345	6,988	582	1,683	27,415	-27,415	-2,181	91
13.82	2.00	4.00	4,146	345	6,996	583	1,585	27,626	-27,626	-1,463	41
13.85	2.00	4.00	4,154	346	7,004	584	1,486	27,838	-27,838	-736	10
13.88	2.00	4.00	4,163	347	7,013	584	1,388	28,051	-28,051	0	0

FIGURE A-2 (Page 12 of 12)

Example Toe Embedment Calculations

APPENDIX B

TIMBER LAGGING REFERENCE DATA

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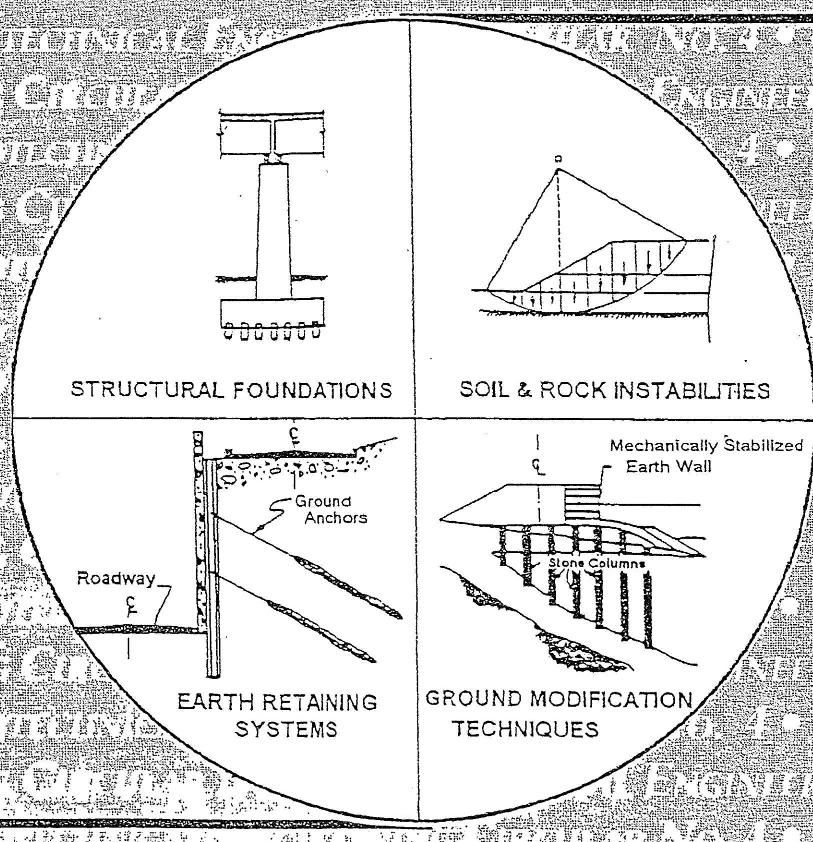
JUNE 1999

U.S. Department of Transportation
Federal Highway Administration

OFFICE OF BRIDGE TECHNOLOGY
400 SEVENTH STREET, SW
WASHINGTON, DC 20590

GEOTECHNICAL ENGINEERING CIRCULAR NO. 4

GROUND ANCHORS AND ANCHORED SYSTEMS



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16. Abstract:

This document presents state-of-the-practice information on the design and installation of cement-grouted ground anchors and anchored systems for highway applications. The anchored systems discussed include flexible anchored walls, slopes supported using ground anchors, landslide stabilization systems, and structures that incorporate tiedown anchors.

This document draws extensively from the FHWA-DP-68-IR (1988) design manual in describing issues such as subsurface investigation and laboratory testing, basic anchoring principles, ground anchor load testing, and inspection of construction materials and methods used for anchored systems. This document provides detailed information on design analyses for ground anchored systems. Topics discussed include selection of design earth pressures, ground anchor design, design of corrosion protection system for ground anchors, design of wall components to resist lateral and vertical loads, evaluation of overall anchored system stability, and seismic design of anchored systems. Also included in the document are two detailed design examples and technical specifications for ground anchors and for anchored walls.

17. Key Words Ground anchors, soldier beam and lagging walls, limit equilibrium, earth pressures, axial capacity, tiedowns, seismic design, contracting, specifications		18. Distribution Statement No Restrictions. This document is available to the public from the National Technical Information Service, Springfield, Virginia 22161	
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Form DOT F 1700.7 (8-72)

For permanent walls and temporary walls that are considered critical, an allowable bending stress in the soldier beam, F_b, of 0.55 F_y, where F_y is the yield stress of the steel, is recommended. Steel sheet-pile and soldier beams are commonly either Grade 36 (F_y = 248 MPa) or Grade 50 (F_y = 345 MPa). For temporary SOE walls, a 20 percent increase in the allowable stress may be allowed for positive wall bending moments between anchor locations; no allowable stress increase is recommended for negative wall bending movements at the anchor locations. The required section modulus S_{req}, is calculated as:

$$S_{req} = \frac{M_{max}}{F_b} \qquad \text{(Equation 22)}$$

Standard SI units are S(mm^3), M_{max} (kN-m), and F_b (MPa). In most cases, several available steel sections will typically meet this requirement. The actual wall section selected will be based on contractor/owner preference, cost, constructability, and details of the anchor/wall connection.

When designing permanent anchored walls in relatively uniform competent materials, it is usually only necessary to check the final stage of construction provided that: (1) the ground can develop adequate passive resistance below the excavation to support the wall; (2) apparent earth pressure diagrams are used to assess the loading on the wall; and (3) there is minimal over excavation below each anchor level (FHWA-RD-97-130, 1998). For cases where there are large concentrated surcharges or berms at the ground surface, it is prudent to check wall bending moments for the initial cantilever stage (i.e., stage just prior to installation and lock-off of uppermost anchor).

Where the final excavation height is not the most critical condition, designers commonly use a staged construction analysis where the maximum wall bending moment, wall deflections, and wall embedment depth are evaluated for several stages of construction. An analysis is required for this case since the maximum bending moment may occur at an intermediate stage of construction (i.e., before the final excavation depth is reached). Intermediate construction stages may be critical when: (1) triangular earth pressure diagrams are used to design the wall; (2) the excavation extends significantly below an anchor level prior to stressing that anchor; (3) a cutoff wall is used to maintain the water level behind the wall; (4) the soil below the bottom of the excavation is weak resulting in active earth pressures that are greater than available resistance provided by the toe of the wall; and (5) structures are located near the wall.

5.4.2 Design of Lagging for Temporary Support

The thickness of temporary timber lagging for soldier beam and lagging walls is based primarily on experience or semi-empirical rules. Table 12 presents recommended thicknesses of construction grade lumber for temporary timber lagging. For temporary SOE walls, contractors may use other lagging thicknesses provided they can demonstrate good performance of the lagging thickness for walls constructed in similar ground.

Permanent timber lagging has been used in lieu of a concrete face to carry permanent wall loads. For permanent applications, the timber grade and dimensions should be designed according to structural guidelines. Several problems may exist for permanent timber lagging including: (1) need to provide fire protection for the lagging; (2) limited service life for timber; and (3) difficulty in providing

Table 12. Recommended thickness of temporary timber lagging (after FHWA-RD-75-130, 1976)

	Soil Description	Unified Soil Classification	Depth (m)	Recommended thickness of lagging (roughcut) for clear spans of: 1.5 m	1.8 m	2.1 m	2.4 m	2.7 m	3.0 m
COMPETENT SOILS	Silt or fine sand and silt above water table	ML, SM-ML							
	Sands and gravels (medium dense to dense)	GW, GP, GM, GS, SW, SP, SM	0 - 8	50 mm	75 mm	75 mm	75 mm	100 mm	100 mm
	Clays (stiff to very stiff); non-fissured	CL, CH	8 - 18	75 mm	75 mm	75 mm	100 mm	100 mm	125 mm
	Clays, medium consistency and $\frac{\gamma H}{S_u} < 5$	CL, CH							
DIFFICULT SOILS	Sand and silty sand (loose)	SW, SP, SM							
	Clayey sands (medium dense to dense) below water table	SC	0 - 8	75 mm	75 mm	75 mm	100 mm	100 mm	125 mm
	Clay, heavily overconsolidated, fissured	CL, CH	8 - 18	75 mm	75 mm	100 mm	100 mm	125 mm	125 mm
	Cohesionless silt or fine sand and silt below water table	ML, SM-SL							
POTENTIALLY DANGEROUS SOILS	Soft clays $\frac{\gamma H}{S_u} > 5$	CL, CH	0 - 5	75 mm	75 mm	100 mm	125 mm	---------	--------
	Slightly plastic silts below water table	ML	5 - 8	75 mm	100 mm	125 mm	150 mm	---------	--------
	Clayey Sands (loose), below water table	SC	8-11	100 mm	125 mm	150 mm	---------	---------	---------

Notes:
1) In the category of "potentially dangerous soils", use of soldier beam and lagging wall systems is questionable.
2) The values shown are based on construction grade lumber.
3) Local experience may take precedence over recommended values in this table.

Table 10. Properties of 15-mm diameter prestressing steel strands (ASTM A416, Grade 270 (metric 1860)).

Number of 15-mm diameter strands	Cross section area		Ultimate strength		Prestressing force					
					0.8 $f_{pu}A_{ps}$		0.7 $f_{pu}A_{ps}$		0.6 $f_{pu}A_{ps}$	
	(in.^{2})	(mm^2)	(kips)	(kN)	(kips)	(kN)	(kips)	(kN)	(kips)	(kN)
1	0.217	140	58.6	260.7	46.9	209	41.0	182	35.2	156
3	0.651	420	175.8	782.1	140.6	626	123.1	547	105.5	469
4	0.868	560	234.4	1043	187.5	834	164.1	730	140.6	626
5	1.085	700	293.0	1304	234.4	1043	205.1	912	175.8	782
7	1.519	980	410.2	1825	328.2	1460	287.1	1277	246.1	1095
9	1.953	1260	527.4	2346	421.9	1877	369.2	1642	316.4	1408
12	2.604	1680	703.2	3128	562.6	2503	492.2	2190	421.9	1877
15	3.255	2100	879.0	3911	703.2	3128	615.3	2737	527.4	2346
19	4.123	2660	1113.4	4953	890.7	3963	779.4	3467	668.0	2972

The type and size of the anchors should be evaluated prior to design of the anchor bond zone because the required hole diameter varies as a function of the tendon size. Table 11 can be used to estimate the minimum trumpet opening for strand or bar tendons.

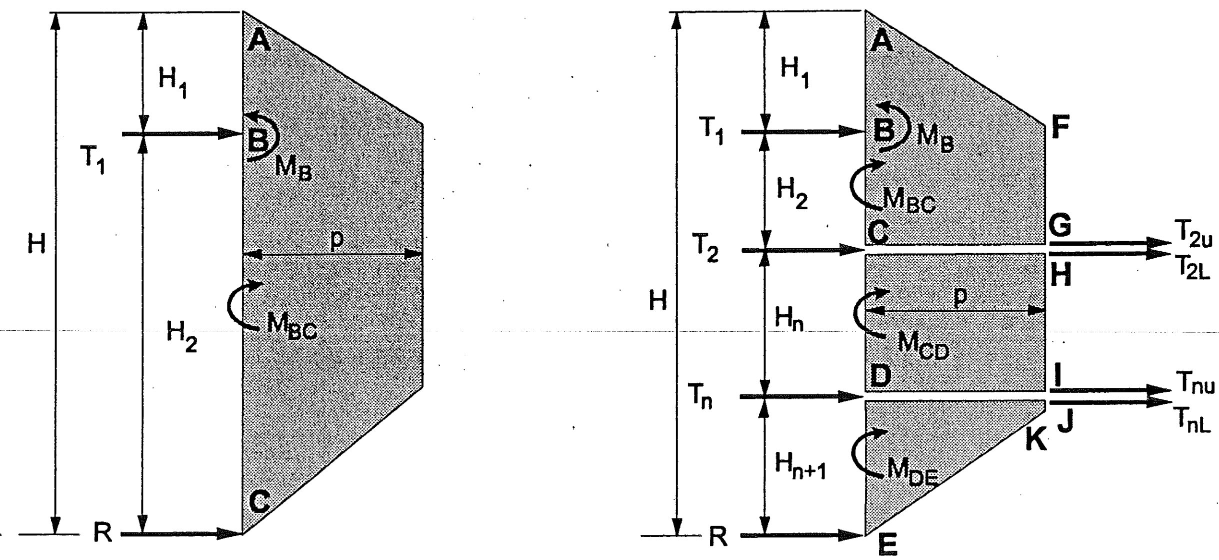
Table 11. Guidance relationship between tendon size and trumpet opening size.

Tendon type	Minimum suggested trumpet opening size (mm)	
	Class II corrosion protection	Class I corrosion protection
Number of 15-mm diameter strands		
4	102	150
7	115	165
9	127	178
11	140	191
13	153	203
17	165	216
Bar diameter (mm)		
26	64	89
32	70	95
36	76	102

5.4 WALL DESIGN BASED ON LATERAL PRESSURES

5.4.1 Design of Soldier Beams and Sheet-Piles

Anchored soldier beam and lagging walls and sheet-pile walls are designed to resist lateral loads resulting from apparent pressure envelopes including appropriate surcharges, water forces, and seismic forces. Figure 38 illustrates the method used to calculate wall bending moments for single-level and multi-level walls for the exposed portion of the wall using the hinge method. The exposed portion of the wall refers to the height of wall between the ground surface and the bottom of the excavation. Figure 39 shows the equations that may be used to calculate wall bending moments for single-level and multi-level walls using the tributary area method. For walls constructed in competent soils such as most sands and stiff clays, the maximum bending moment, M_{max}, occurs in the exposed portion of the wall. For walls that penetrate deep deposits of weak material, the maximum bending moment may occur in the embedded portion of the wall. The embedded portion of the wall refers to the length of wall that is below the base of the excavation. Bending moment calculation for the embedded portion of the wall is provided in section 5.5.



$M_B = \Sigma M_B$

M_{BC} = Maximum moment between B and C; located at point where shear = 0

(a) Walls with one level of ground anchors

$M_B = \Sigma M_B$

$M_C = M_D = M_E = 0$

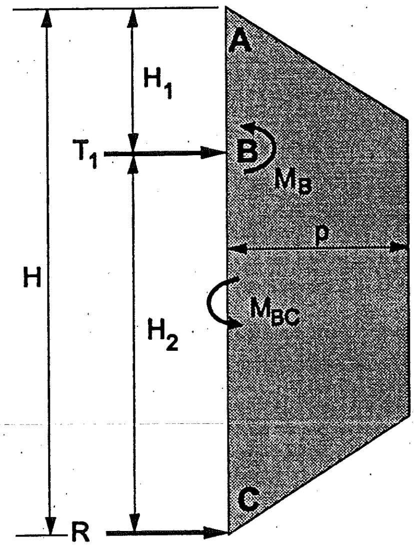
M_{BC} = Maximum moment between B and C; located at point where shear = 0

M_{CD} ; M_{DE} : Calculated as for M_{BC}

(b) Walls with multiple levels of ground anchors

Figure 38. Calculation of wall bending moments using hinge method.

Selection of an appropriate wall section is based on the calculated maximum bending moment in the vertical wall element. The negative bending moment calculated at the location of the first anchor is evaluated by summing moments about the first anchor location. The vertical wall elements are commonly assumed to be continuous between each support location. The maximum positive bending moment between each ground anchor is, for the tributary area method, assumed equal to $1/10\, p\ell^2$ where p is the maximum ordinate of the apparent pressure envelope and ℓ is the vertical spacing between adjacent anchors. For the hinge method, the maximum positive bending moment between each ground anchor corresponds to the point of zero shear. These methods provide conservative estimates of the calculated bending moments, but may not accurately predict the specific location. For continuous sheet-pile walls, the bending moment per unit of wall is used to select an appropriate sheet-pile section. To evaluate the maximum bending moment for design of a soldier beam, the maximum bending moment per unit of wall calculated from figure 38 and 39 is multiplied by the center-to-center spacing of the soldier beams.



$$M_B = \frac{13}{54} H_1^2 p$$

$$T_1 = \frac{(23H^2 - 10HH_1)}{54(H-H_1)} p$$

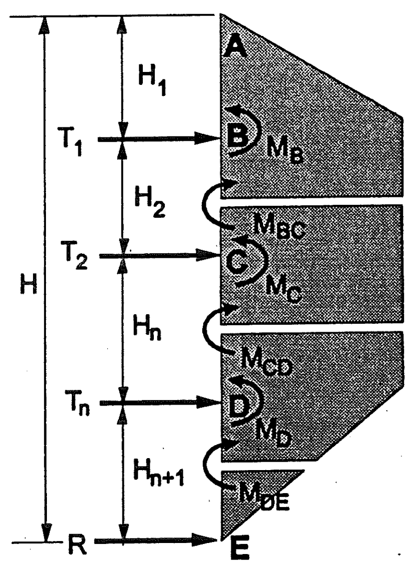
$$R = \frac{2}{3}Hp - T_1$$

Solve for point of zero shear

$$x = \frac{1}{9}\sqrt{(26H^2 - 52HH_1)}$$

$$M_{BC} = Rx - \frac{px^3}{4(H-H_1)}$$

(a) Walls with single level of ground anchors



$$M_B = \frac{13}{54} H_1^2 p$$

$$T_1 = \left(\frac{2}{3}H_1 + \frac{H_2}{2}\right) p$$

$$T_2 = \left(\frac{H_2}{2} + \frac{H_n}{2}\right) p$$

$$T_n = \left(\frac{H_n}{2} + \frac{23H_{n+1}}{48}\right) p$$

$$R = \left(\frac{3}{16} H_{n+1}\right) p$$

Maximum moment below B = $pL^2/10$
where L is the larger of H_2, H_n, H_{n+1}

(b) Walls with multiple level of ground anchors

Figure 39. Calculation of wall bending moments using tributary area method.