



**US Army Corps
of Engineers®**
New England District

**FAIRFIELD AND NEW HAVEN COUNTIES, CT
COASTAL STORM RISK
MANAGEMENT FEASIBILITY STUDY**

**APPENDIX D2:
STRUCTURAL DESIGN**

July 2020

PREPARED BY:

**DEPARTMENT OF ARMY
NEW ENGLAND DISTRICT, CORPS OF ENGINEERS
GEOTECHNICAL ENGINEERING SECTION
CONCORD, MASSACHUSETTS 01742**

INTRODUCTION

The New Haven County, CT study area is highly vulnerable to damages resulting from coastal storm events such as Hurricanes and Nor'easters. Hurricane Sandy (2012) is the most recent major event to cause wide spread damage to the region. The USACE North Atlantic Coast Comprehensive Study (completed in 2015) identified areas of high exposure and risk along the Connecticut coast study including New Haven County. Low lying coastal communities contain thousands of high-value residential structures, commercial properties and government facilities. Critical infrastructure throughout the region including the I-95 corridor and multiple railroad transportation systems, government facilities, and medical facilities become more at risk of damage from coastal storm events as climate changes.

This purpose of this general study was to determine the feasibility of a number of flood protection structures and alignments along the coast near Long Wharf adjacent to I-95.

DESIGN SUMMARY

According to Geotechnical Investigation and selected flood protection structures for this study, T-walls and closure structures will be utilized (see Geotechnical Design Appendix). This structural study contains only preliminary design calculations for T-walls and closure structures in 2 foot increments. Both T-Walls and closure structures includes sheet pile seepage cutoff walls and reinforced footing supporting by concrete filled friction pipe piles.

Some of the critical aspects of design include:

- Preliminary estimates of hydraulic data including wave forces at different wall height.
- Preliminary estimates of geotechnical data including pile type and capacity.

DESIGN CRITERIA

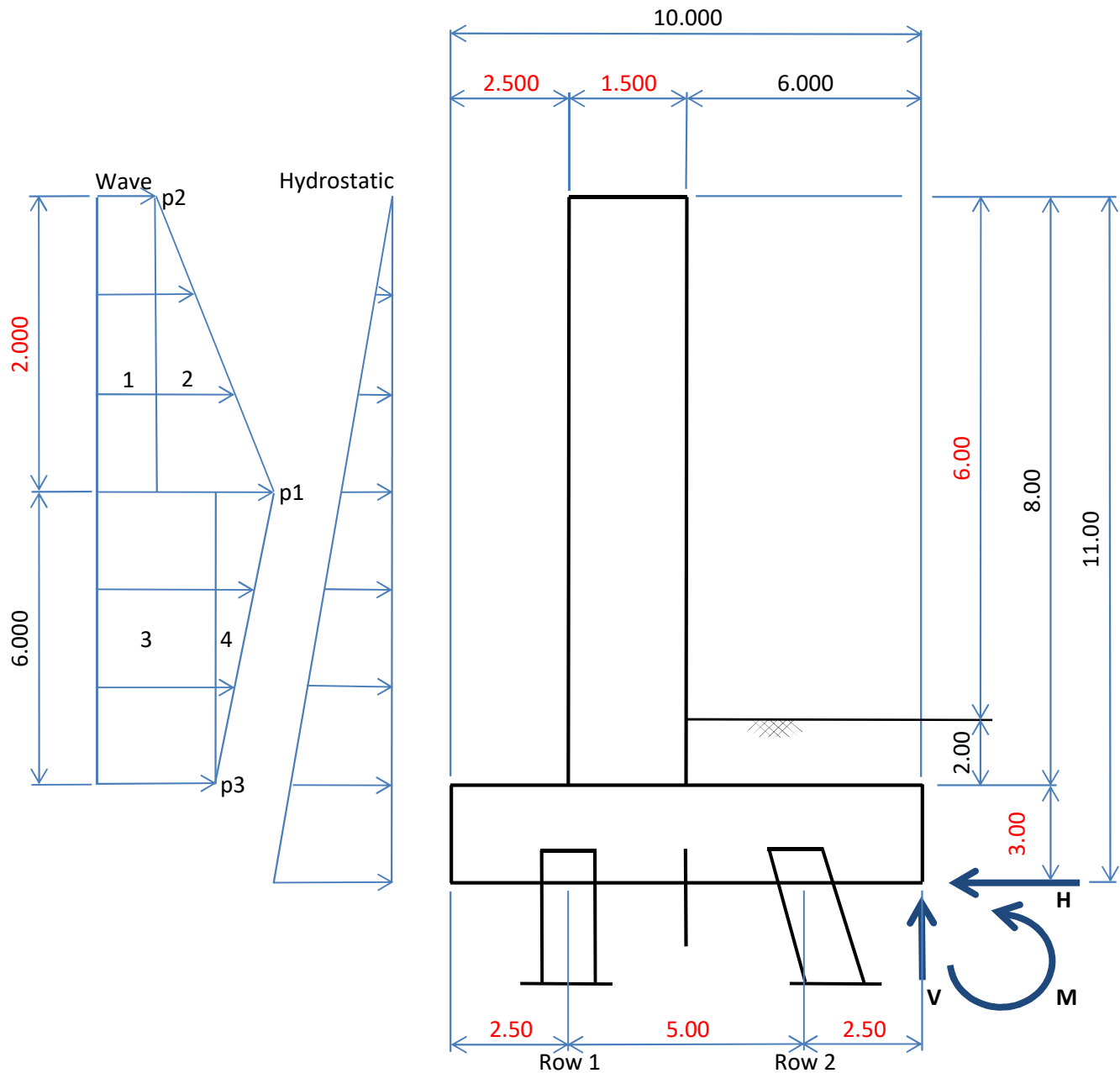
The various wall sections should meet the analysis and design requirements for stability outlines in Chapter 4 of EM 1110-2-2502 "Retaining and Flood Walls".

PRELIMINARY DESIGN

For both T-Walls and closure structures, only pile layouts were considered and designed in order to obtain the number of piles and their lengths. For the T-walls, the dimensions of the concrete stems and footings were reasonably assumed based upon common practice. And for the closure structures, the steel retaining configurations and components were assumed to be similar to ones from previous projects.

4FT - 6FT EXPOSED WALL HEIGHT

Consider 1 ft strip wall



**New Haven Coastal Study
Flood Wall - Type 1**

 Prepared by: TPN
 Checked by: JHK

 Date: 08/02/19
 Date: 10/29/19

PILE FORCES FOR SERVICE STAGES

Concrete Density =	0.150	Kcf
Salt Water Density =	0.064	Kcf
Wave Load on Wall - Top (p2) =	0.150	Ksf
Wave Load on Wall - Mid (p1) =	0.250	Ksf
Wave Load on Wall - Bot (p3) =	0.200	Kcf

	LF	L _v	V	M _v	L _H	H	M _H
LC Load Description	---	ft	Kip	Kip.ft	ft	Kip	Kip.ft
Stem Weight	1.000	6.750	1.800	12.150			
V Footing Weight	1.000	5.000	4.500	22.500			
Subtotal	---	---	6.300	34.650			
H Hydrostatic Pressure	1.000				3.667	3.878	14.220
H Wave Pressure (1)	1.000				7.000	0.300	2.100
H Wave Pressure (2)	1.000				6.667	0.100	0.667
H Wave Pressure (3)	1.000				3.000	1.200	3.600
H Wave Pressure (4)	1.000				4.000	0.150	0.600
Load Comb - SERVICE IV			6.300	34.650		5.628	21.186

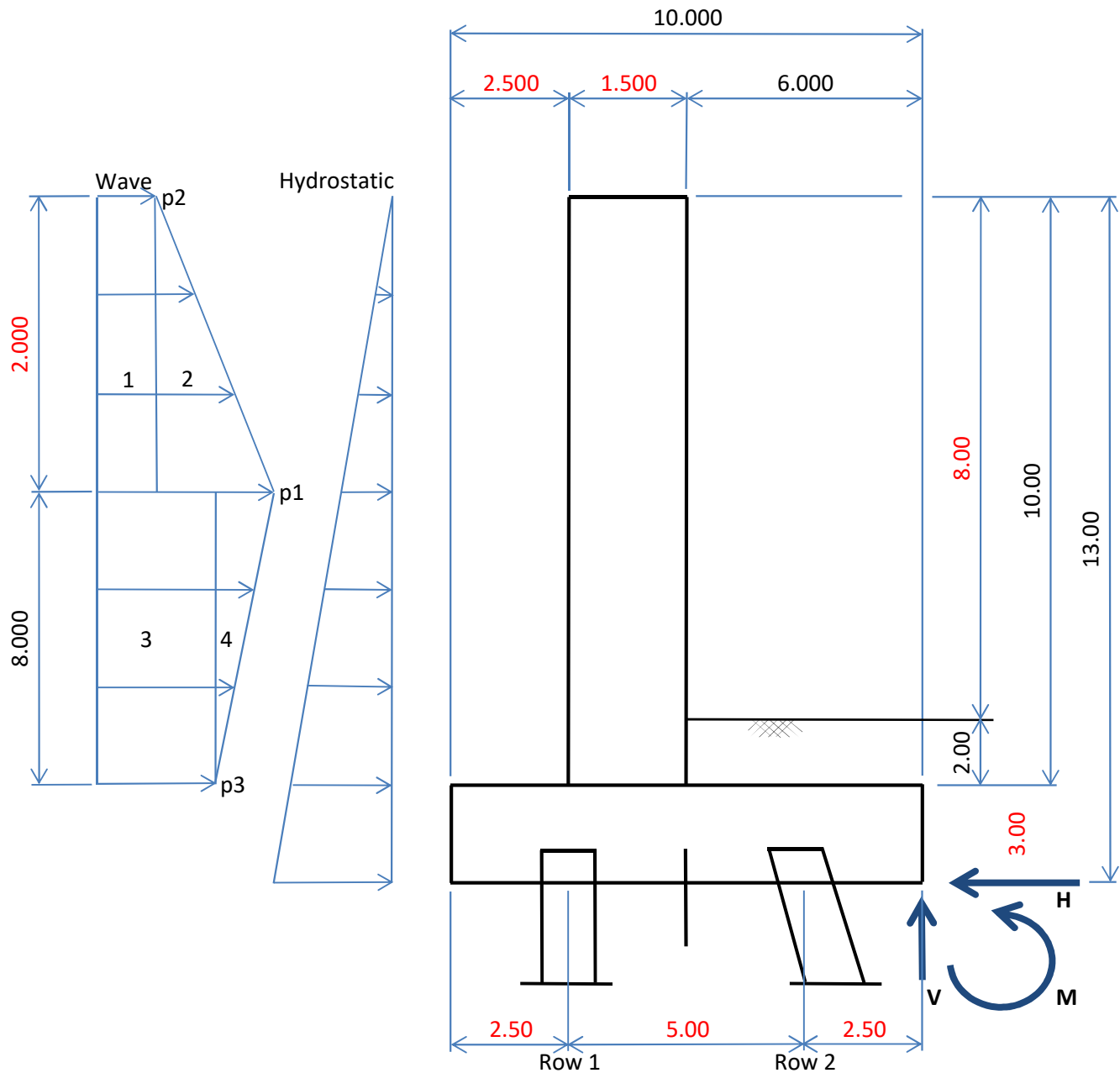
Resultant Forces at Neutral Axis:

V = 6.300 kips
 H = 5.628 kips
 M = 18.036 kips

Row 1 Pile Spacing =	7.500	ft		
Row 1 Pile Area pet LF - A ₁ =	0.133	Piles	d ₁ =	2.500 ft
Row 2 Pile Spacing =	7.500	ft		
Row 2 Pile Area pet LF - A ₂ =	0.133	Piles	d ₂ =	-2.500 ft
Dist. From NA to Toe -D =	5.000	ft		
Total Pile Area pet LF - A =	0.267	Piles		
Moment of Inertia $\sum A_i d_i^2$ - I =	1.667	Pile*ft ²		
Row 1 Axial Pile Load - P1 =	3.429	kips per Pile	(+ Tension)	
Row 1 Axial Pile Load - P2 =	-50.679	kips per Pile	(- Compression)	
Shear on Pile Head =	21.105	kips per Pile		

6FT - 8FT EXPOSED WALL HEIGHT

Consider 1 ft strip wall



**New Haven Coastal Study
Flood Wall - Type 2**

 Prepared by: TPN
 Checked by: JHK

 Date: 08/02/19
 Date: 10/29/19

PILE FORCES FOR SERVICE STAGES

Concrete Density =	0.150	Kcf
Salt Water Density =	0.064	Kcf
Wave Load on Wall - Top (p2) =	0.250	Ksf
Wave Load on Wall - Mid (p1) =	0.350	Ksf
Wave Load on Wall - Bot (p3) =	0.300	Kcf

	LF	L _v	V	M _v	L _H	H	M _H
LC Load Description	---	ft	Kip	Kip.ft	ft	Kip	Kip.ft
Stem Weight	1.000	6.750	2.250	15.188			
V Footing Weight	1.000	5.000	4.500	22.500			
Subtotal	---	---	6.750	37.688			
H Hydrostatic Pressure	1.000				4.333	5.416	23.471
H Wave Pressure (1)	1.000				9.000	0.500	4.500
H Wave Pressure (2)	1.000				8.667	0.100	0.867
H Wave Pressure (3)	1.000				4.000	2.400	9.600
H Wave Pressure (4)	1.000				5.333	0.200	1.067
Load Comb - SERVICE IV			6.750	37.688		8.616	39.505

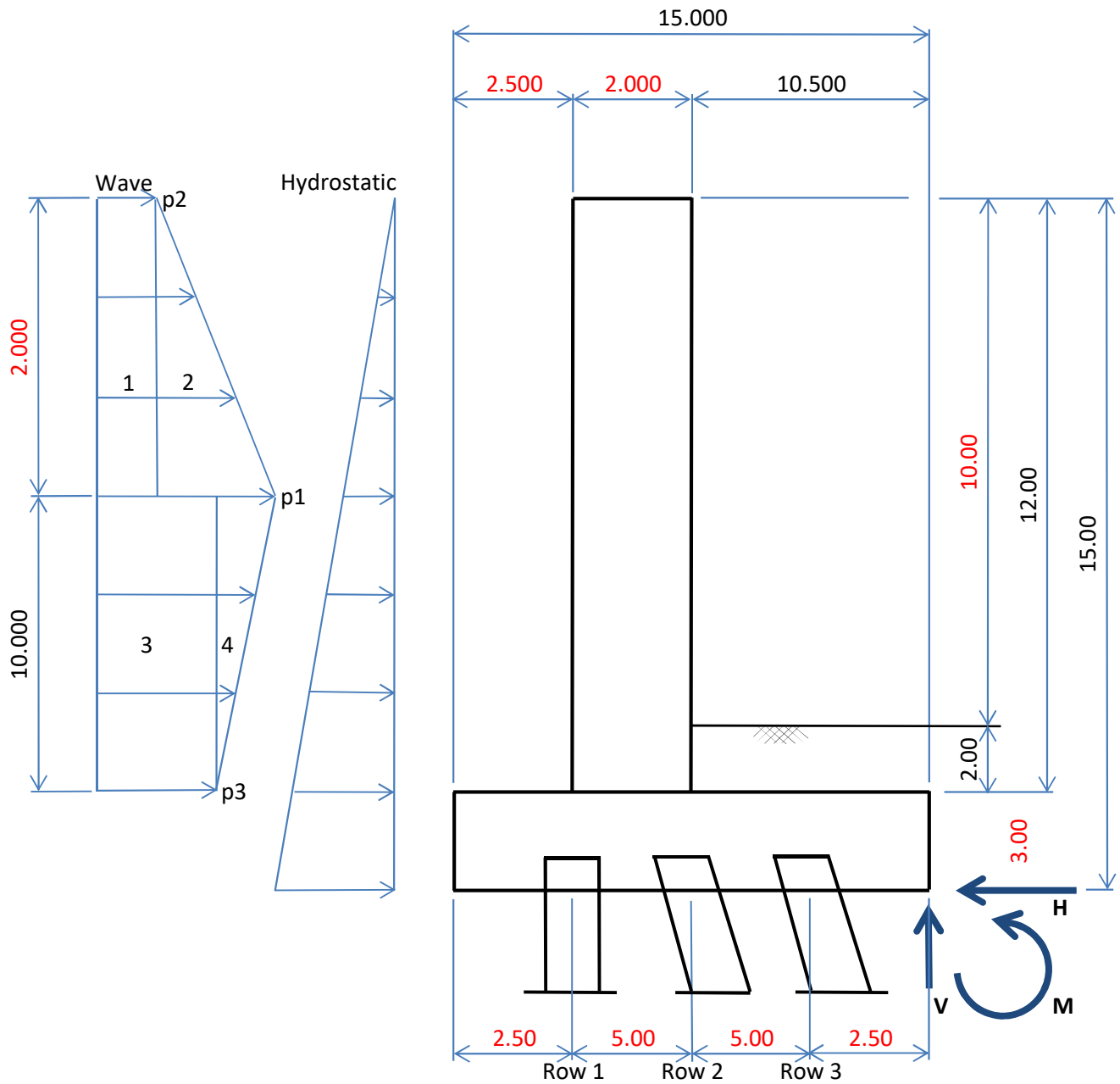
Resultant Forces at Neutral Axis:

V = 6.750 kips
 H = 8.616 kips
 M = 35.567 kips

Row 1 Pile Spacing =	5.000	ft		
Row 1 Pile Area pet LF - A ₁ =	0.200	Piles	d ₁ =	2.500 ft
Row 2 Pile Spacing =	5.000	ft		
Row 2 Pile Area pet LF - A ₂ =	0.200	Piles	d ₂ =	-2.500 ft
Dist. From NA to Toe -D =	5.000	ft		
Total Pile Area pet LF - A =	0.400	Piles		
Moment of Inertia $\sum A_i d_i^2$ - I =	2.500	Pile*ft ²		
Row 1 Axial Pile Load - P1 =	18.692	kips per Pile	(+ Tension)	
Row 1 Axial Pile Load - P2 =	-52.442	kips per Pile	(- Compression)	
Shear on Pile Head =	21.541	kips per Pile		

8FT - 10FT EXPOSED WALL HEIGHT

Consider 1 ft strip wall



**New Haven Coastal Study
Flood Wall - Type 3**

 Prepared by: TPN
 Checked by: JHK

 Date: 08/02/19
 Date: 10/29/19

PILE FORCES FOR SERVICE STAGES

Concrete Density =	0.150	Kcf
Salt Water Density =	0.064	Kcf
Wave Load on Wall - Top (p2) =	0.350	Ksf
Wave Load on Wall - Mid (p1) =	0.450	Ksf
Wave Load on Wall - Bot (p3) =	0.400	Kcf

	LF	L _V	V	M _V	L _H	H	M _H
LC Load Description	---	ft	Kip	Kip.ft	ft	Kip	Kip.ft
Stem Weight	1.000	11.500	3.600	41.400			
V Footing Weight	1.000	7.500	6.750	50.625			
Subtotal	---	---	10.350	92.025			
H Hydrostatic Pressure	1.000				5.000	7.211	36.056
H Wave Pressure (1)	1.000				11.000	0.700	7.700
H Wave Pressure (2)	1.000				10.667	0.100	1.067
H Wave Pressure (3)	1.000				5.000	4.000	20.000
H Wave Pressure (4)	1.000				6.667	0.250	1.667
Load Comb - SERVICE IV			10.350	92.025		12.261	66.490

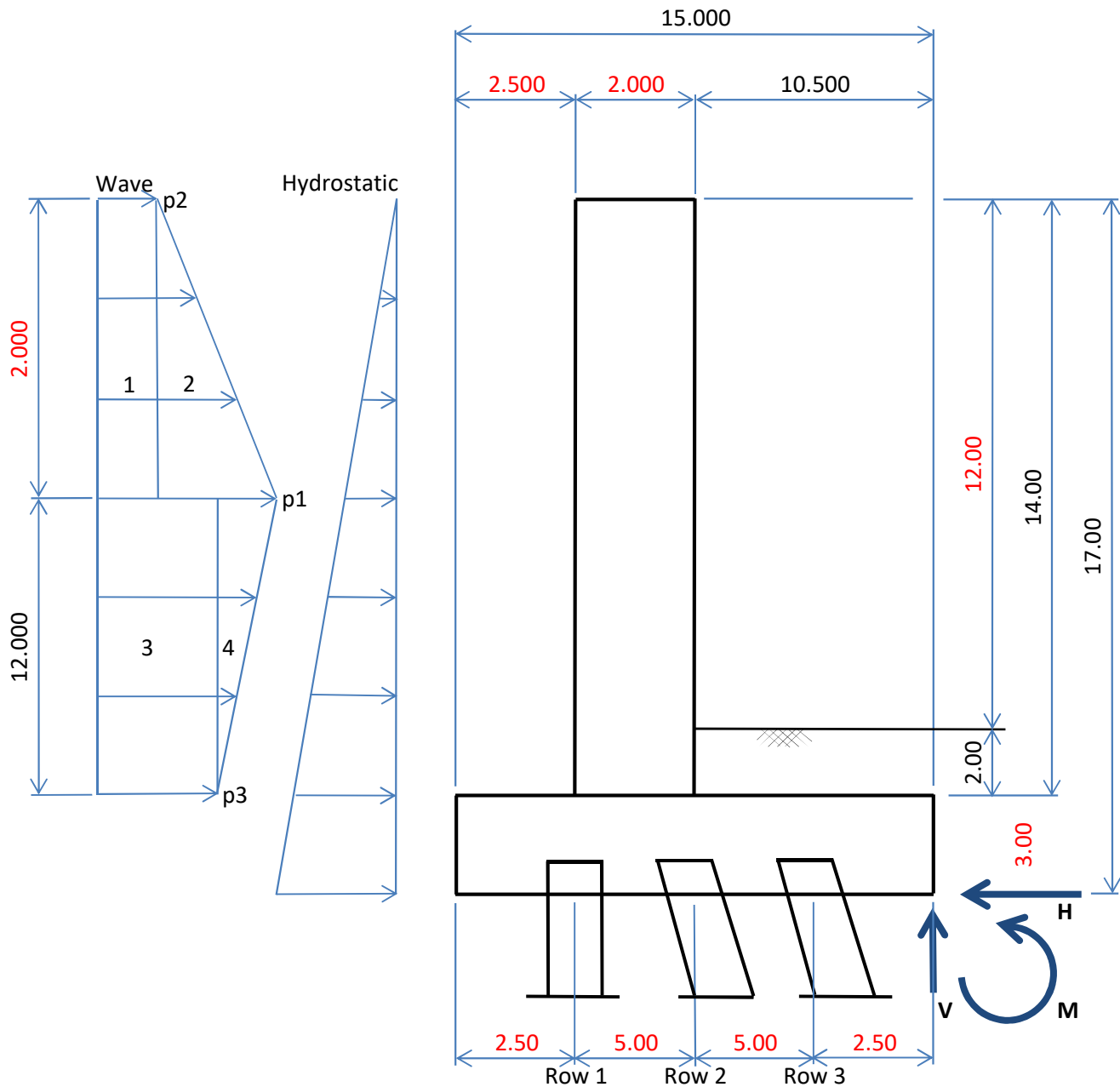
Resultant Forces at Neutral Axis:

V = 10.350 kips
 H = 12.261 kips
 M = 44.697 kips

Row 1 Pile Spacing =	7.500	ft		
Row 1 Pile Area pet LF - A ₁ =	0.133	Piles	d ₁ =	5.714 ft
Row 2 Pile Spacing =	7.500	ft		
Row 2 Pile Area pet LF - A ₂ =	0.133	Piles	d ₂ =	0.714 ft
Row 3 Pile Spacing =	5.000	ft		
Row 2 Pile Area pet LF - A ₃ =	0.200	Piles	d ₂ =	-4.286 ft
Dist. From NA to Toe -D =	6.786	ft		
Total Pile Area pet LF - A =	0.467	Piles		
Moment of Inertia $\sum A_i d_i^2$ - I =	8.095	Pile*ft ²		
Row 1 Axial Pile Load - P1 =	9.372	kips per Pile	(+ Tension)	
Row 1 Axial Pile Load - P2 =	-18.235	kips per Pile	(- Compression)	
Row 1 Axial Pile Load - P3 =	-45.842	kips per Pile	(- Compression)	
Shear on Pile Head =	26.274	kips per Pile		

10FT - 12FT EXPOSED WALL HEIGHT

Consider 1 ft strip wall



PILE FORCES FOR SERVICE STAGES

Concrete Density =	0.150	Kcf
Salt Water Density =	0.064	Kcf
Wave Load on Wall - Top (p2) =	0.450	Ksf
Wave Load on Wall - Mid (p1) =	0.550	Ksf
Wave Load on Wall - Bot (p3) =	0.500	Kcf

	LF	L _V	V	M _V	L _H	H	M _H
LC Load Description	---	ft	Kip	Kip.ft	ft	Kip	Kip.ft
Stem Weight	1.000	11.500	4.200	48.300			
V Footing Weight	1.000	7.500	6.750	50.625			
Subtotal	---	---	10.950	98.925			
H Hydrostatic Pressure	1.000				5.667	9.262	52.487
H Wave Pressure (1)	1.000				13.000	0.900	11.700
H Wave Pressure (2)	1.000				12.667	0.100	1.267
H Wave Pressure (3)	1.000				6.000	6.000	36.000
H Wave Pressure (4)	1.000				8.000	0.300	2.400
Load Comb - SERVICE IV			10.950	98.925		16.562	103.854

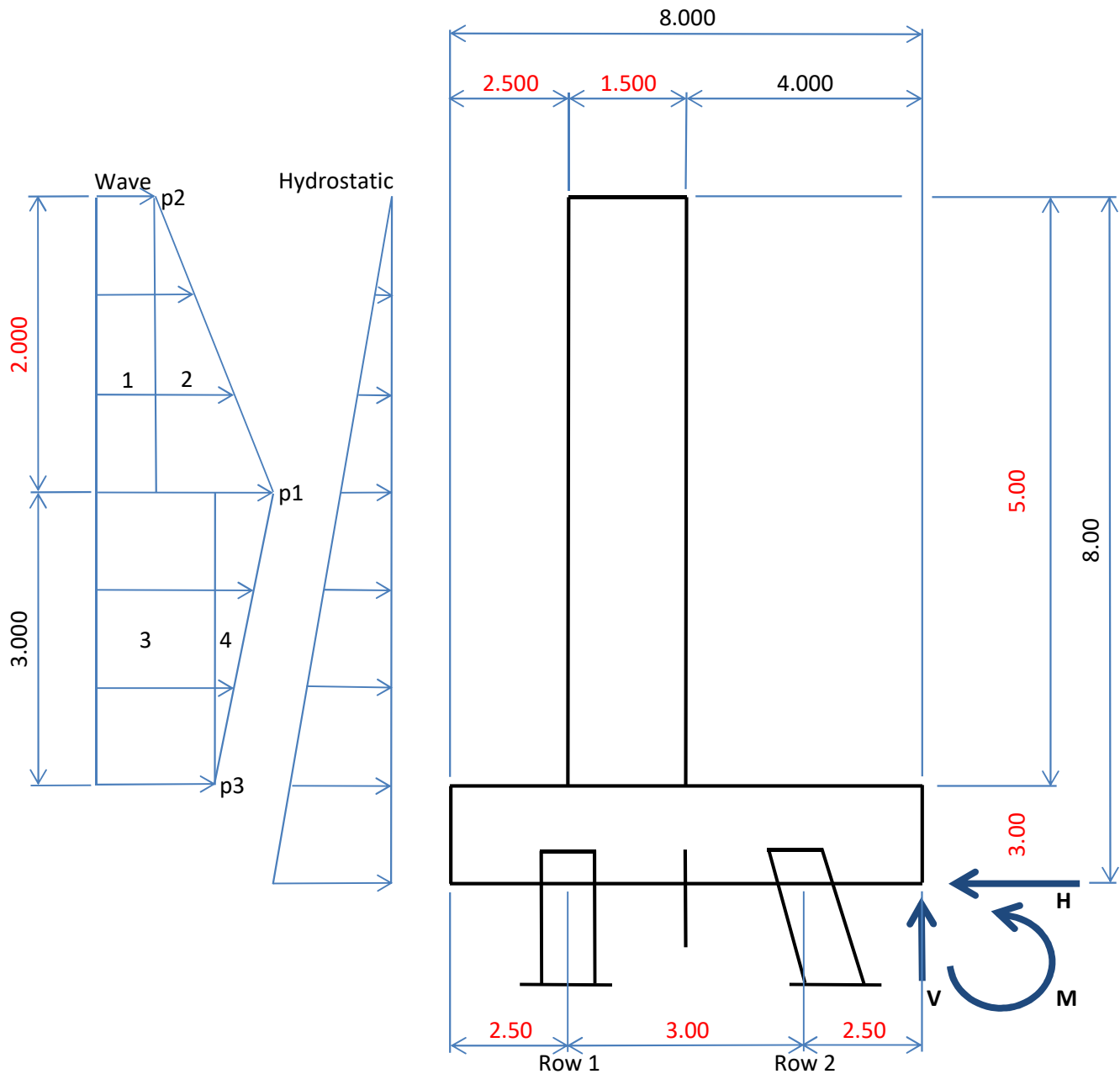
Resultant Forces at Neutral Axis:

V = 10.950 kips
H = 16.562 kips
M = 87.054 kips

Row 1 Pile Spacing =	5.000	ft		
Row 1 Pile Area pet LF - A ₁ =	0.200	Piles	d ₁ =	5.000 ft
Row 2 Pile Spacing =	5.000	ft		
Row 2 Pile Area pet LF - A ₂ =	0.200	Piles	d ₂ =	0.000 ft
Row 3 Pile Spacing =	5.000	ft		
Row 2 Pile Area pet LF - A ₃ =	0.200	Piles	d ₂ =	-5.000 ft
Dist. From NA to Toe -D =	7.500	ft		
Total Pile Area pet LF - A =	0.600	Piles		
Moment of Inertia $\sum A_i d_i^2$ - I =	10.000	Pile*ft ²		
Row 1 Axial Pile Load - P1 =	25.277	kips per Pile	(+ Tension)	
Row 1 Axial Pile Load - P2 =	-18.250	kips per Pile	(- Compression)	
Row 1 Axial Pile Load - P3 =	-61.777	kips per Pile	(- Compression)	
Shear on Pile Head =	27.604	kips per Pile		

5FT EXPOSED GATE HEIGHT

Consider 1 ft strip wall



PILE FORCES FOR SERVICE STAGES

Concrete Density =	0.150	Kcf
Salt Water Density =	0.064	Kcf
Wave Load on Wall - Top (p2) =	0.250	Ksf
Wave Load on Wall - Mid (p1) =	0.350	Ksf
Wave Load on Wall - Bot (p3) =	0.300	Kcf

	LF	L _v	V	M _v	L _H	H	M _H
LC Load Description	---	ft	Kip	Kip.ft	ft	Kip	Kip.ft
Stem Weight	1.000	4.750	1.125	5.344			
V Footing Weight	1.000	4.000	3.600	14.400			
Subtotal	---	---	4.725	19.744			
H Hydrostatic Pressure	1.000				2.667	2.051	5.470
H Wave Pressure (1)	1.000				4.000	0.500	2.000
H Wave Pressure (2)	1.000				3.667	0.100	0.367
H Wave Pressure (3)	1.000				1.500	0.900	1.350
H Wave Pressure (4)	1.000				2.000	0.075	0.150
Load Comb - SERVICE IV			4.725	19.744		3.626	9.337

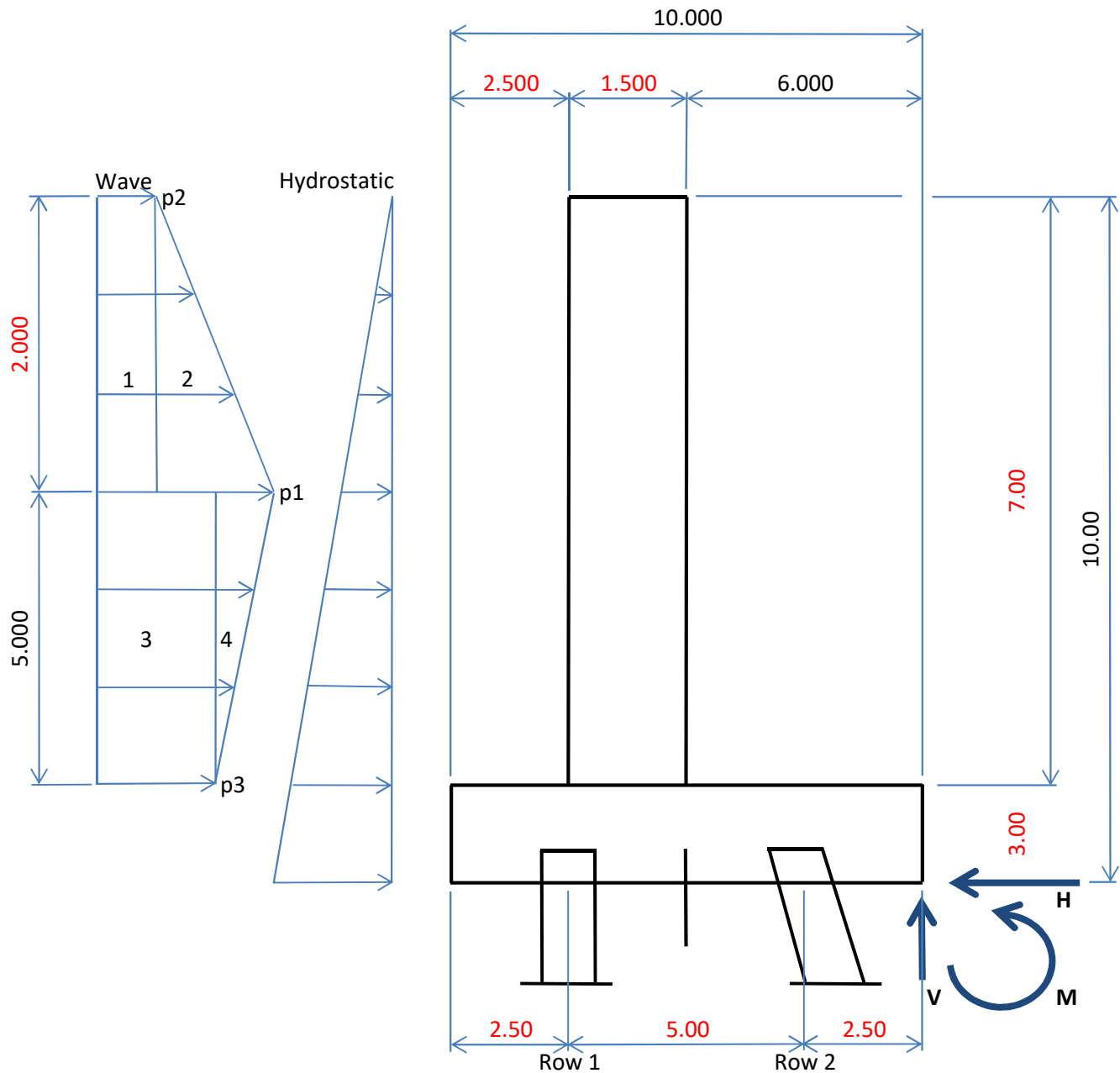
Resultant Forces at Neutral Axis:

V =	4.725	kips
H =	3.626	kips
M =	2.694	kips

Row 1 Pile Spacing =	75.000	ft		
Row 1 Pile Area pet LF - A ₁ =	0.013	Piles	d ₁ =	2.727 ft
Row 2 Pile Spacing =	7.500	ft		
Row 2 Pile Area pet LF - A ₂ =	0.133	Piles	d ₂ =	-0.273 ft
Dist. From NA to Toe -D =	2.773	ft		
Total Pile Area pet LF - A =	0.147	Piles		
Moment of Inertia $\sum A_i d_i^2$ - I =	0.109	Pile*ft ²		
Row 1 Axial Pile Load - P1 =	35.132	kips per Pile	(+ Tension)	
Row 1 Axial Pile Load - P2 =	-38.951	kips per Pile	(- Compression)	
Shear on Pile Head =	24.724	kips per Pile		

7FT EXPOSED GATE HEIGHT

Consider 1 ft strip wall



PILE FORCES FOR SERVICE STAGES

Concrete Density =	0.150	Kcf
Salt Water Density =	0.064	Kcf
Wave Load on Wall - Top (p2) =	0.250	Ksf
Wave Load on Wall - Mid (p1) =	0.350	Ksf
Wave Load on Wall - Bot (p3) =	0.300	Kcf

	LF	L _v	V	M _v	L _H	H	M _H
LC Load Description	---	ft	Kip	Kip.ft	ft	Kip	Kip.ft
Stem Weight	1.000	6.750	1.575	10.631			
V Footing Weight	1.000	5.000	4.500	22.500			
Subtotal	---	---	6.075	33.131			
H Hydrostatic Pressure	1.000				3.333	3.205	10.683
H Wave Pressure (1)	1.000				6.000	0.500	3.000
H Wave Pressure (2)	1.000				5.667	0.100	0.567
H Wave Pressure (3)	1.000				2.500	1.500	3.750
H Wave Pressure (4)	1.000				3.333	0.125	0.417
Load Comb - SERVICE IV			6.075	33.131		5.430	18.417

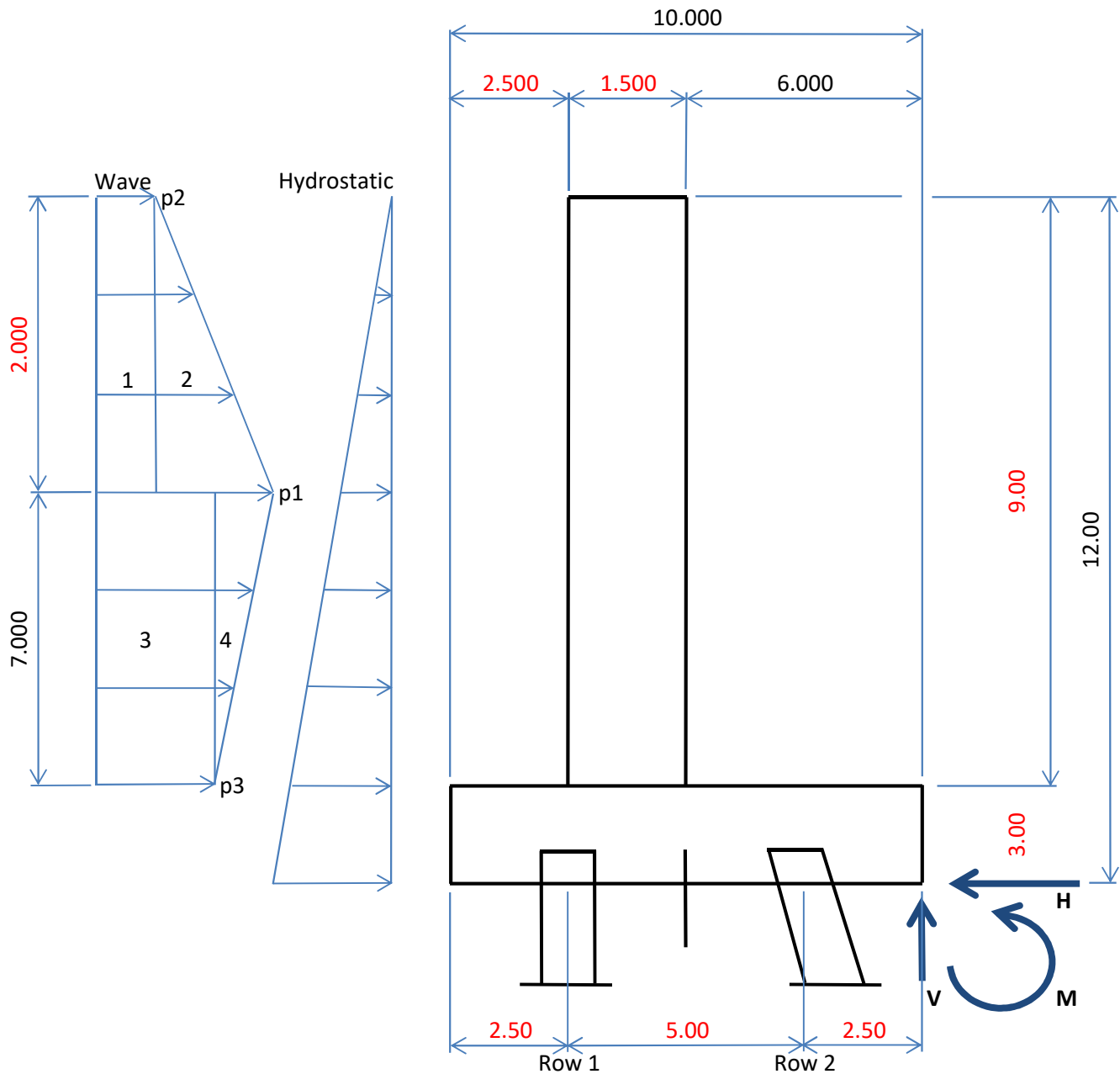
Resultant Forces at Neutral Axis:

V = 6.075 kips
H = 5.430 kips
M = 15.660 kips

Row 1 Pile Spacing =	7.500	ft		
Row 1 Pile Area pet LF - A ₁ =	0.133	Piles	d ₁ =	2.500 ft
Row 2 Pile Spacing =	7.500	ft		
Row 2 Pile Area pet LF - A ₂ =	0.133	Piles	d ₂ =	-2.500 ft
Dist. From NA to Toe -D =	5.000	ft		
Total Pile Area pet LF - A =	0.267	Piles		
Moment of Inertia $\sum A_i d_i^2$ - I =	1.667	Pile*ft ²		
Row 1 Axial Pile Load - P1 =	0.709	kips per Pile	(+ Tension)	
Row 1 Axial Pile Load - P2 =	-46.272	kips per Pile	(- Compression)	
Shear on Pile Head =	8.795	kips per Pile		

9FT EXPOSED GATE HEIGHT

Consider 1 ft strip wall



PILE FORCES FOR SERVICE STAGES

Concrete Density =	0.150	Kcf
Salt Water Density =	0.064	Kcf
Wave Load on Wall - Top (p2) =	0.250	Ksf
Wave Load on Wall - Mid (p1) =	0.350	Ksf
Wave Load on Wall - Bot (p3) =	0.300	Kcf

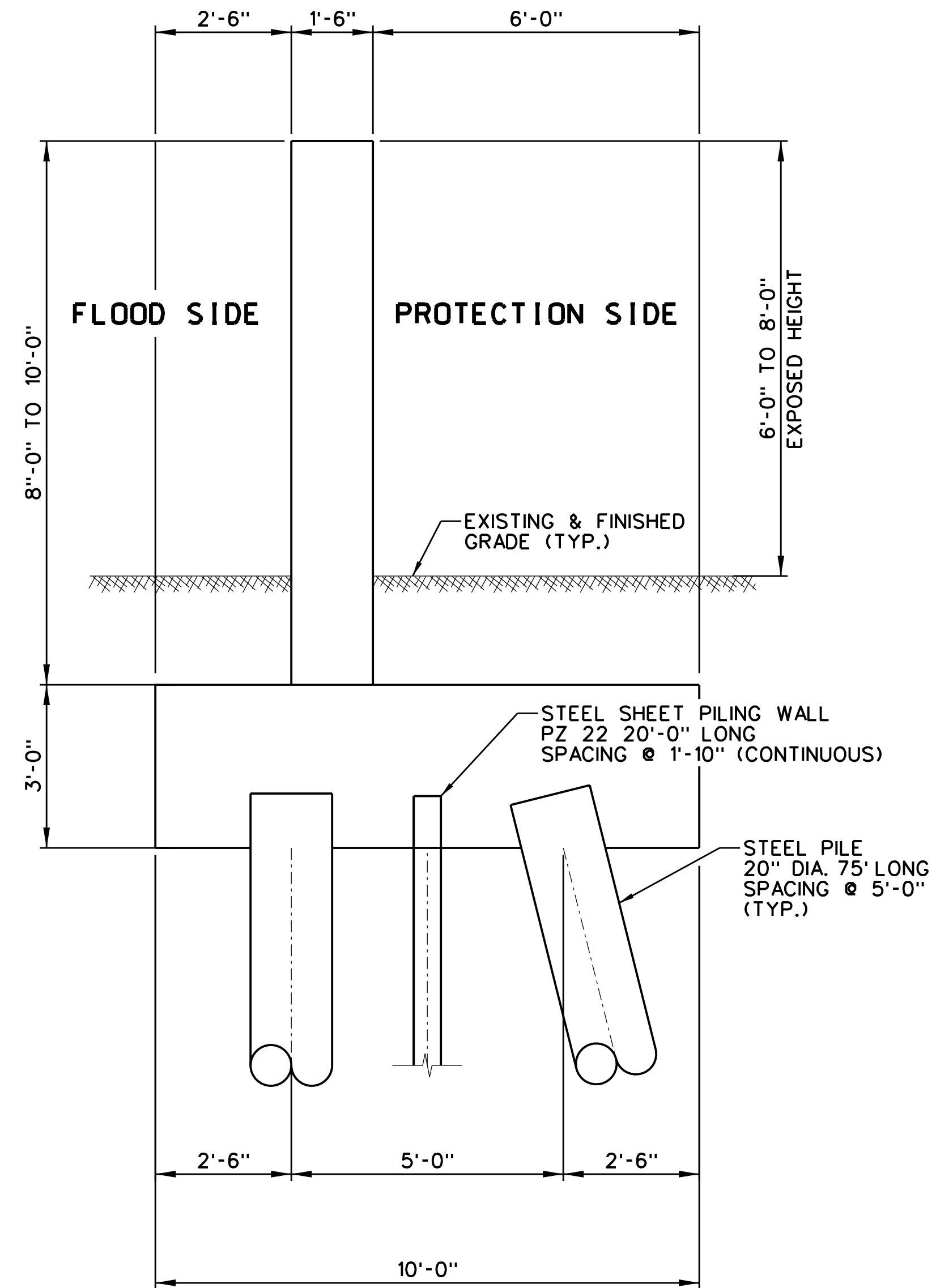
	LF	L _v	V	M _v	L _H	H	M _H
LC Load Description	---	ft	Kip	Kip.ft	ft	Kip	Kip.ft
Stem Weight	1.000	6.750	2.025	13.669			
V Footing Weight	1.000	5.000	4.500	22.500			
Subtotal	---	---	6.525	36.169			
H Hydrostatic Pressure	1.000				4.000	4.615	18.461
H Wave Pressure (1)	1.000				8.000	0.500	4.000
H Wave Pressure (2)	1.000				7.667	0.100	0.767
H Wave Pressure (3)	1.000				3.500	2.100	7.350
H Wave Pressure (4)	1.000				4.667	0.175	0.817
Load Comb - SERVICE IV			6.525	36.169		7.490	31.394

Resultant Forces at Neutral Axis:

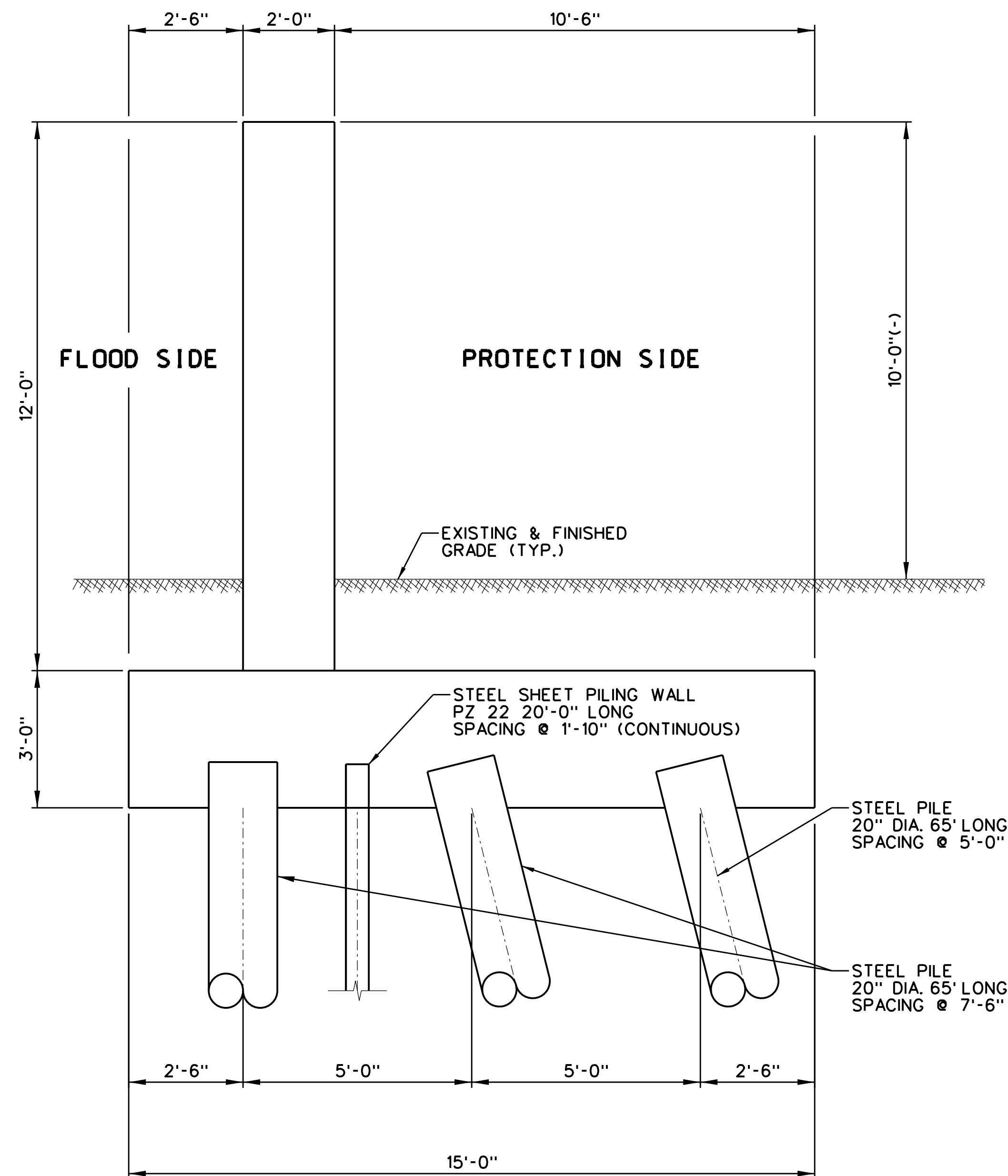
V = 6.525 kips
H = 7.490 kips
M = 27.850 kips

Row 1 Pile Spacing =	5.000	ft		
Row 1 Pile Area pet LF - A ₁ =	0.200	Piles	d ₁ =	2.500 ft
Row 2 Pile Spacing =	5.000	ft		
Row 2 Pile Area pet LF - A ₂ =	0.200	Piles	d ₂ =	-2.500 ft
Dist. From NA to Toe -D =	5.000	ft		
Total Pile Area pet LF - A =	0.400	Piles		
Moment of Inertia $\sum A_i d_i^2$ - I =	2.500	Pile*ft ²		
Row 1 Axial Pile Load - P1 =	11.538	kips per Pile	(+ Tension)	
Row 1 Axial Pile Load - P2 =	-44.163	kips per Pile	(- Compression)	
Shear on Pile Head =	7.685	kips per Pile		

5



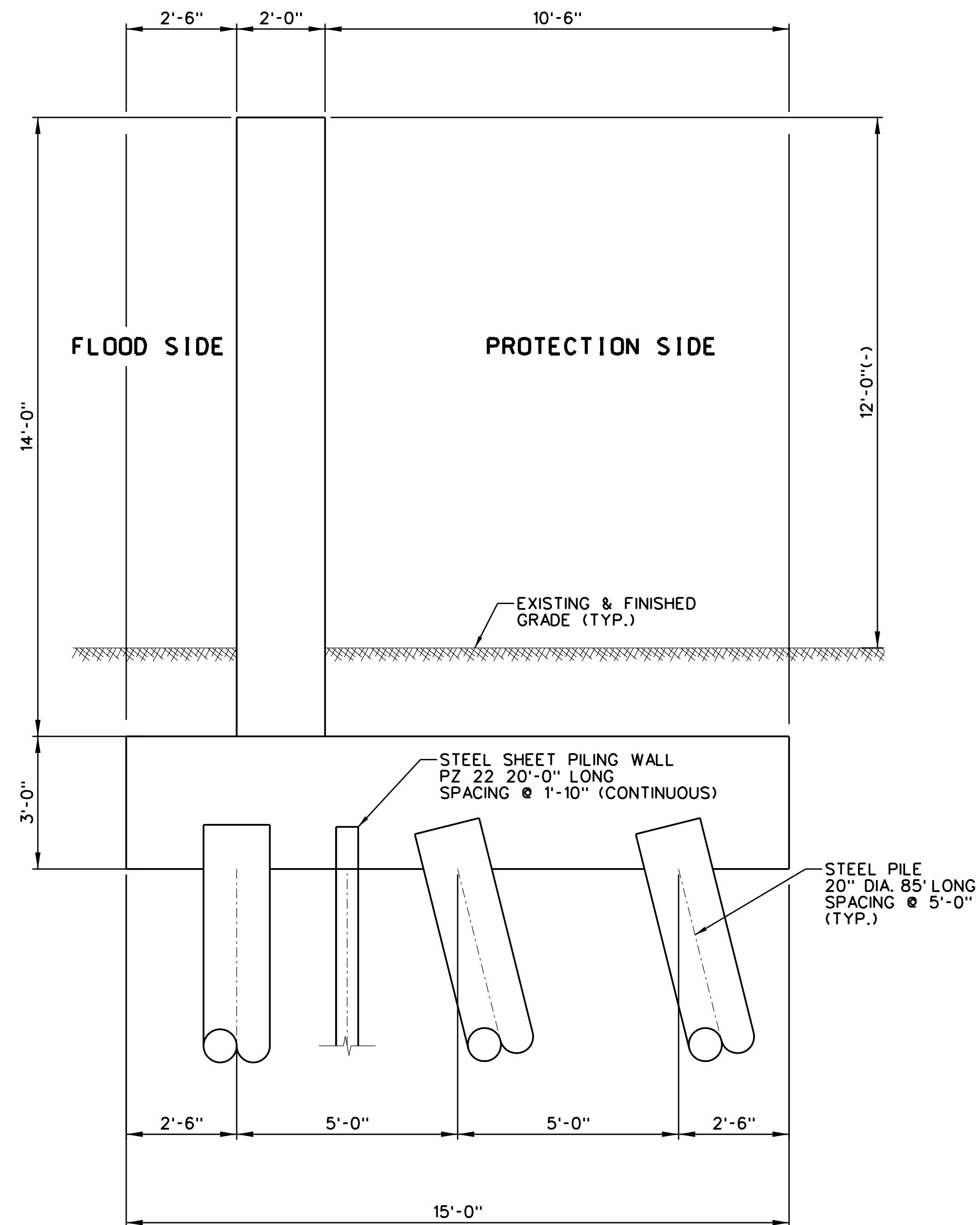
TYPE 2 T-WALL
6'-0" TO 8'-0 EXPOSED HEIGHT
SCALE: 1/2" = 1'-0"



TYPE 3 T-WALL
8'-0" TO 10'-0 EXPOSED HEIGHT
SCALE: $\frac{1}{2}" = 1'-0"$

NOTE:

SEE CIVIL DRAWINGS FOR LOCATION AND HORIZONTAL LIMIT FOR EACH TYPE OF WALLS.



TYPE 4 T-WALL
10'-0" TO 12'-0 EXPOSED HEIGHT
SCALE: 1/2" = 1'-0"



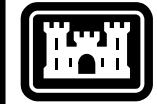
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District**

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	CKD BY:	CONTRACT NO.:
	SUBMITTED BY:	DRAWING CODE:
PLOT SCALE: 1:1		2015
FILED IN:		FILED IN:
ANSI Z39.18		ANSI Z39.18
LFD 5-101.dgn		LFD 5-101.dgn

FLOOD PROTECTION
CONNECTICUT COASTAL STUDY
NEW HAVEN & FAIRFIELD, CONNECTICUT
T-WALLS - TYPES 3&4
SECTIONS

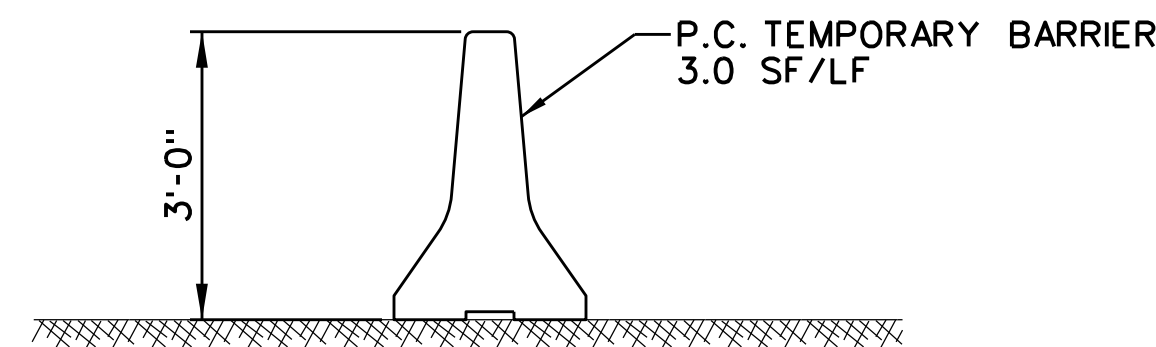
SHEET
IDENTIFICATION
S-02

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U.S. ARMY ENGINEER DISTRICT CORPS OF ENGINEERS CONCORD, MASSACHUSETTS	DESIGNED BY: HUTTEN NUTTEN	DATE:
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FLOOD PROTECTION
CONNECTICUT COASTAL STUDY
NEW HAVEN & FAIRFIELD, CONNECTICUT
FLOOD GATES- TYPES 1-3
SECTIONS

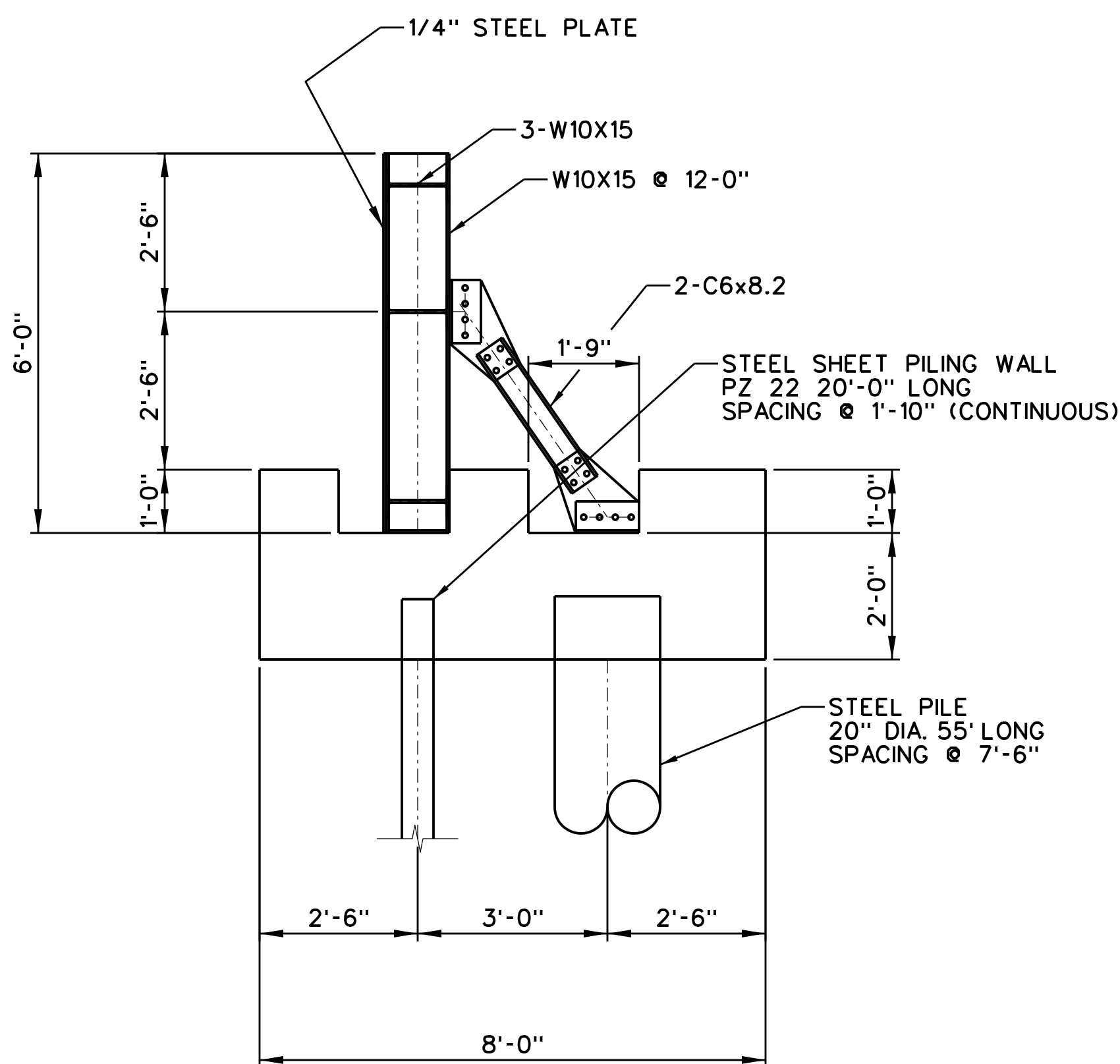
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IDENTIFICATION
S-03



P.C. TEMPORARY BARRIER

3' - 0''

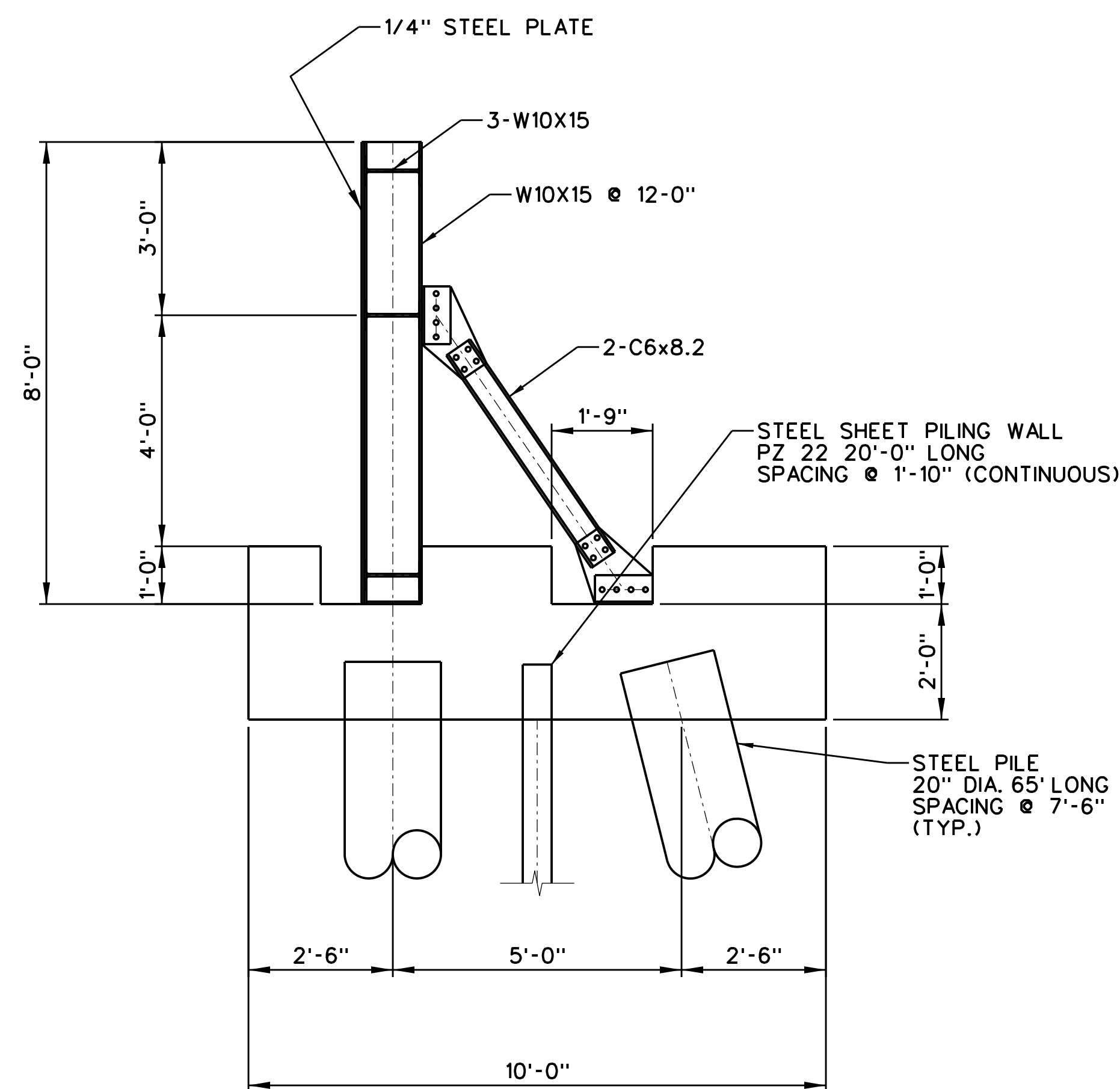
SCALE: $\frac{1}{2}'' = 1' - 0''$



TYPE 1 FLOOD GATE

5' - 0"

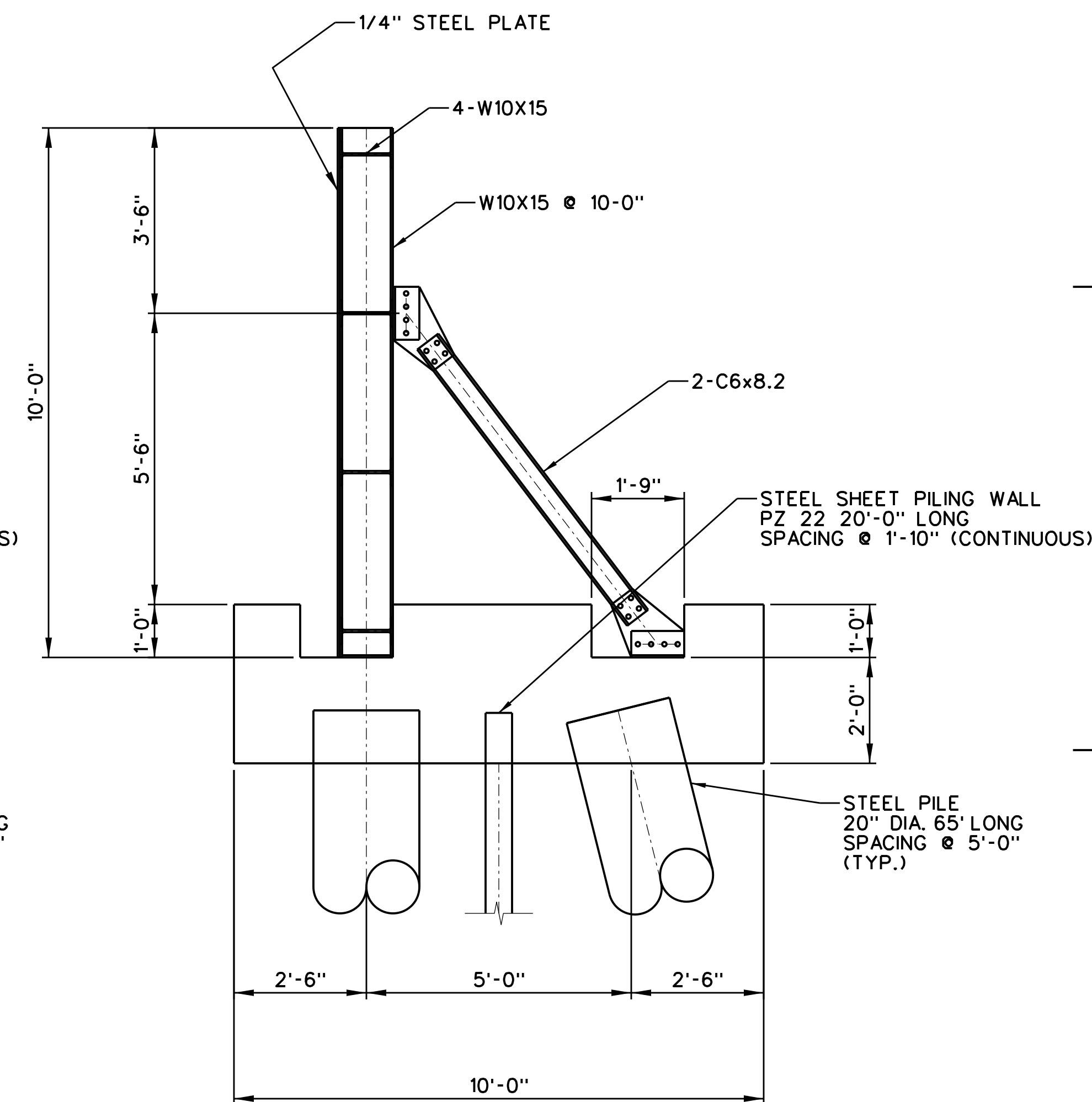
SCALE: $\frac{1}{2}'' = 1' - 0''$



TYPE 2 FLOOD GATE

7' - 0"

SCALE: $1/2'' = 1' - 0''$



TYPE 3 FLOOD GATE

 $9' - 0'$

SCALE: $\frac{1}{2}'' = 1' - 0$