US Army Corps
of Engineers®
New England District

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

APPENDIX D2:
STRUCTURAL DESIGN

October 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.

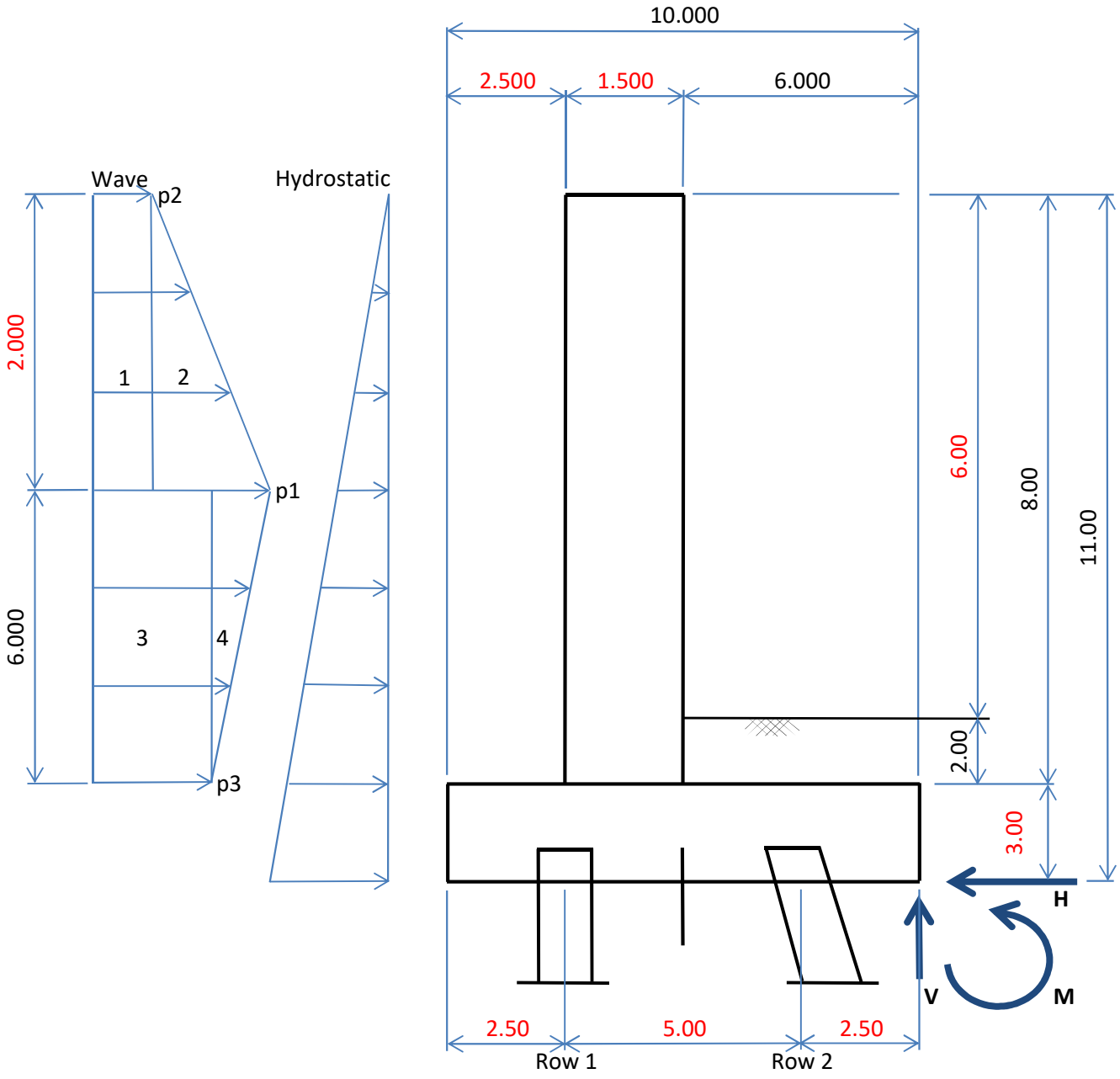
New Haven Coastal Study
Flood Wall - Type 1

Prepared by: TPN
Checked by: JHK

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

4FT - 6FT 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) =	0.150	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 $\Sigma A_i d_i^2$ - 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	

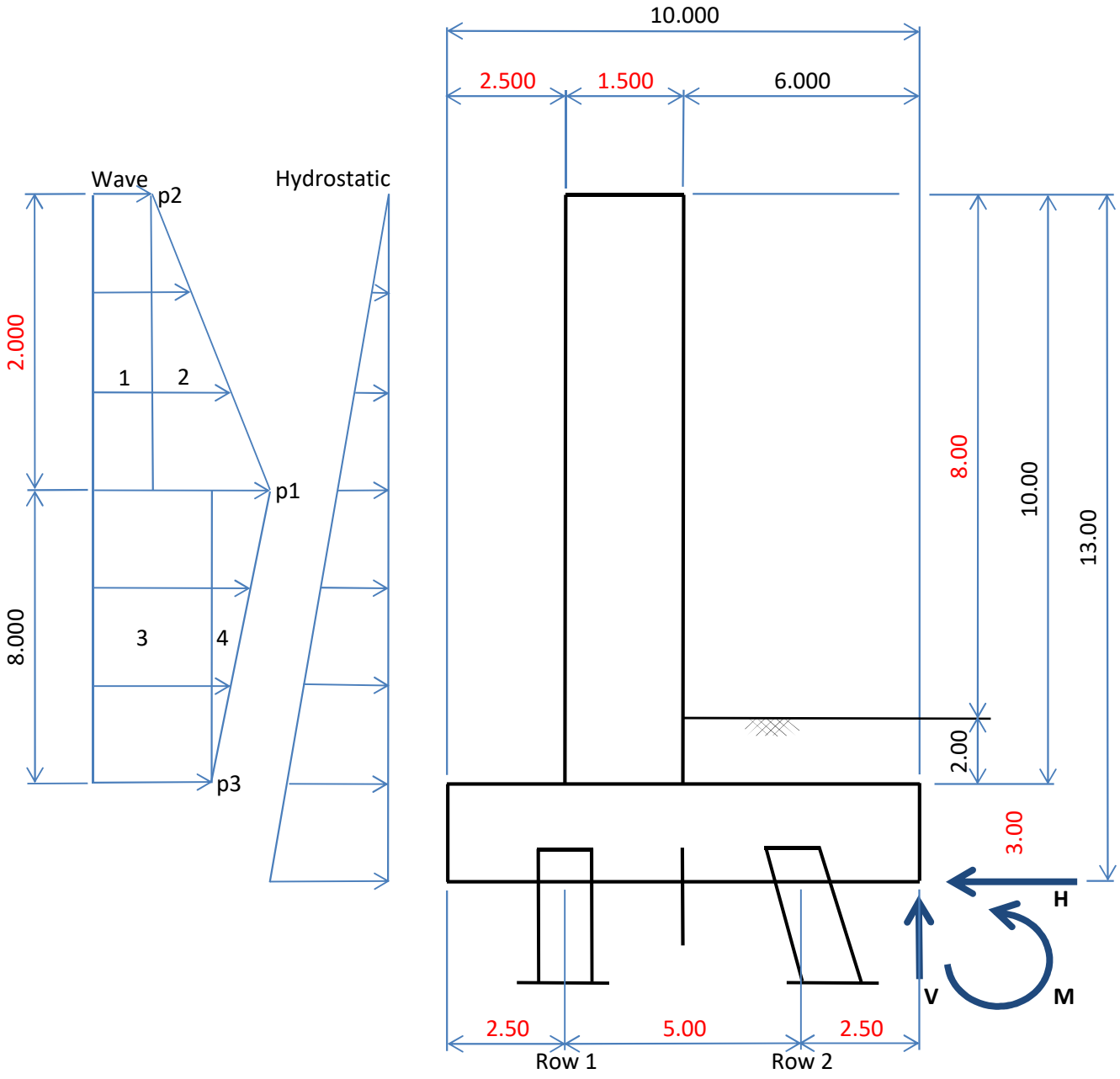
New Haven Coastal Study
Flood Wall - Type 2

Prepared by: TPN
Checked by: JHK

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

6FT - 8FT 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) =	0.250	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 $\Sigma A_i d_i^2$ - 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	

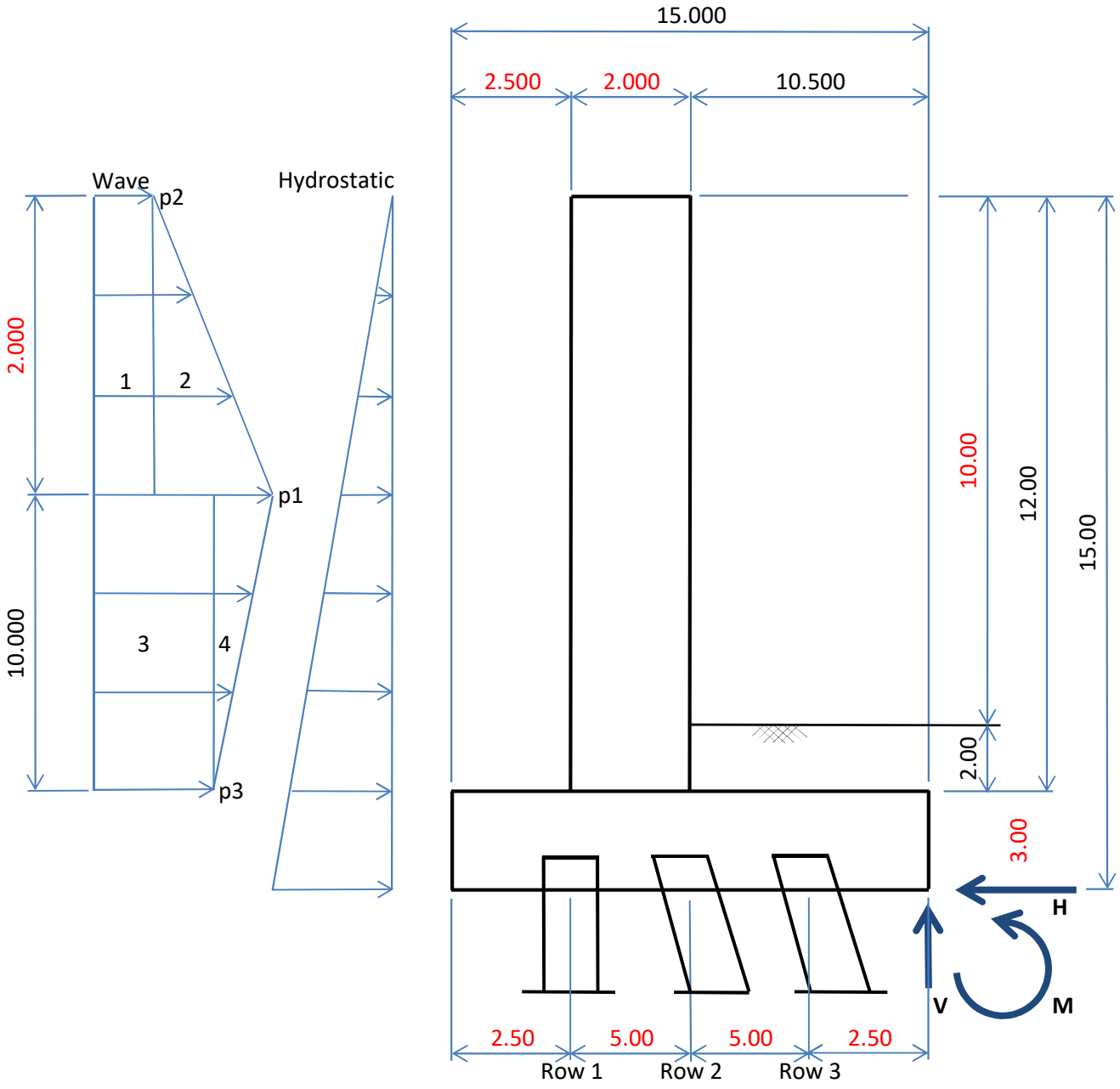
New Haven Coastal Study
Flood Wall - Type 3

Prepared by: TPN
Checked by: JHK

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

8FT - 10FT 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) =	0.350	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:

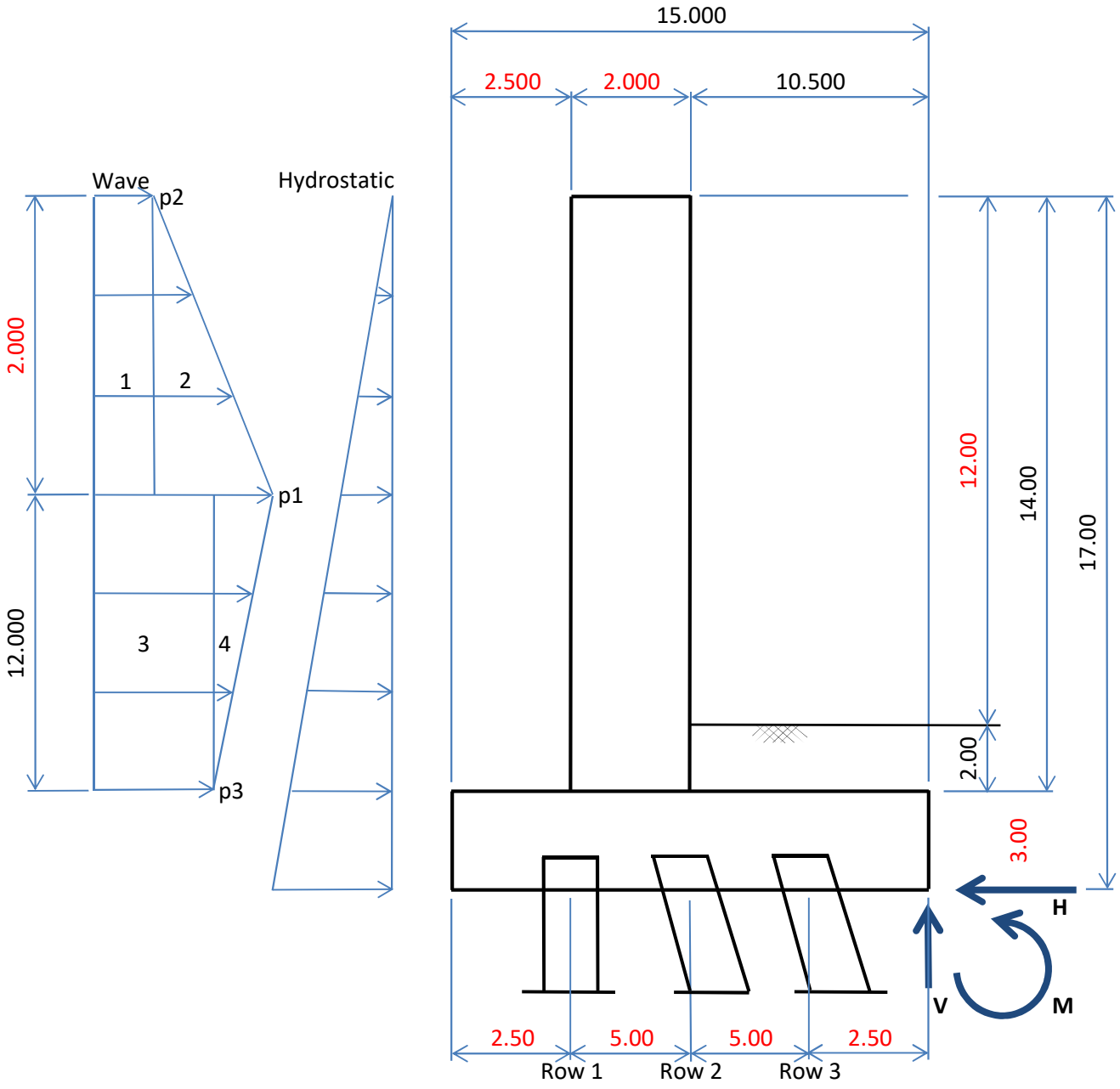
V =	10.350	kips
H =	12.261	kips
M =	44.697	kips

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 $\Sigma A_i d_i^2$ - 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 $\Sigma A_i d_i^2$ - 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	

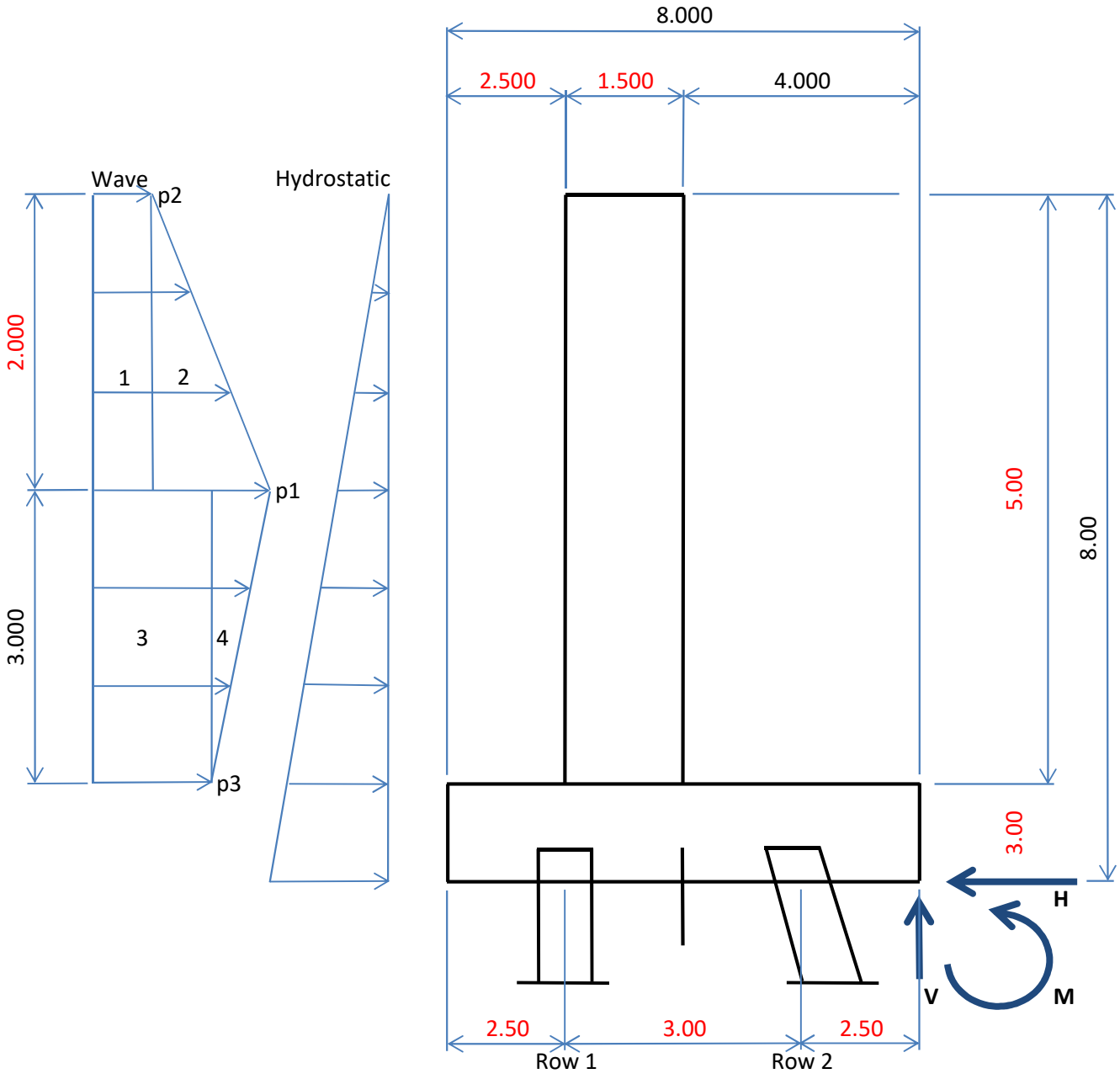
New Haven Coastal Study
Flood Gate - Type 1

Prepared by: TPN
Checked by: JHK

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

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 $\Sigma A_i d_i^2$ - 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	

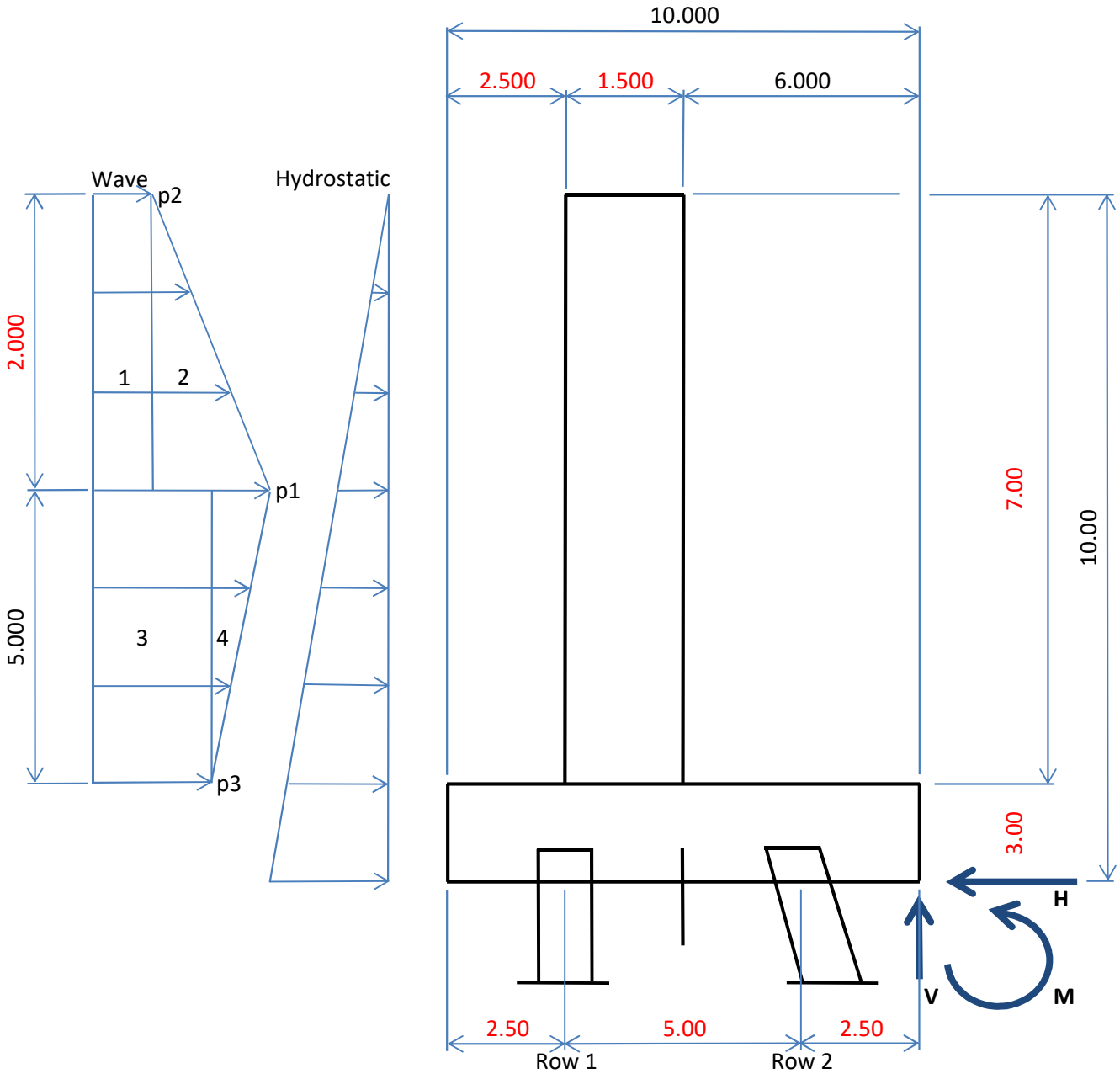
New Haven Coastal Study
Flood Gate - Type 2

Prepared by: TPN
Checked by: JHK

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

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 $\Sigma A_i d_i^2$ - 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	

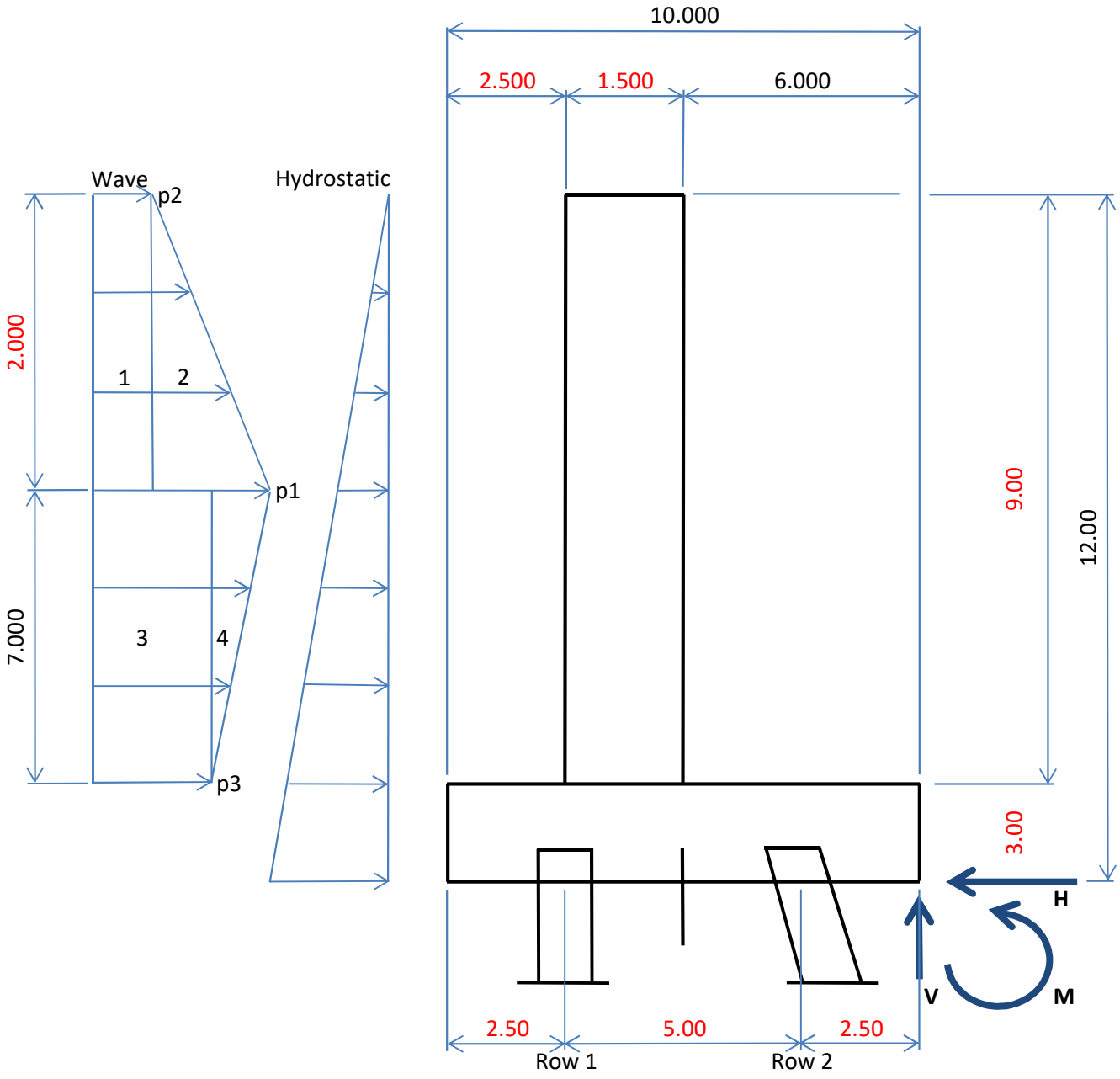
New Haven Coastal Study
Flood Gate - Type 3

Prepared by: TPN
Checked by: JHK

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

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

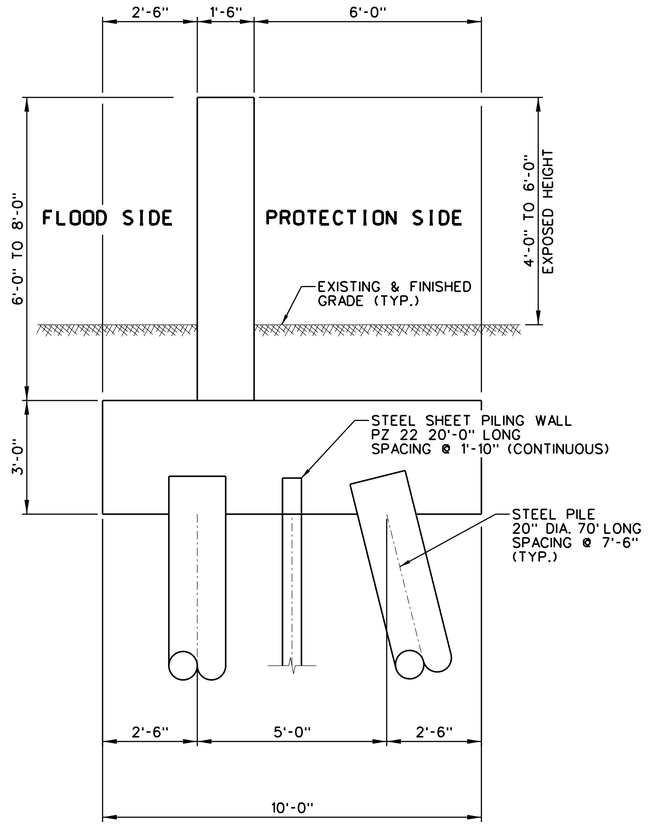
		LF	L_V	V	M_V	L_H	H	M_H
LC	Load Description	---	ft	Kip	Kip.ft	ft	Kip	Kip.ft
	Stem Weight	1.000	6.750	2.025	13.669			
V	Footing Weight	1.000	5.000	4.500	22.500			
	Subtotal	---	---	6.525	36.169			
H	Hydrostatic Pressure	1.000				4.000	4.615	18.461
H	Wave Pressure (1)	1.000				8.000	0.500	4.000
H	Wave Pressure (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

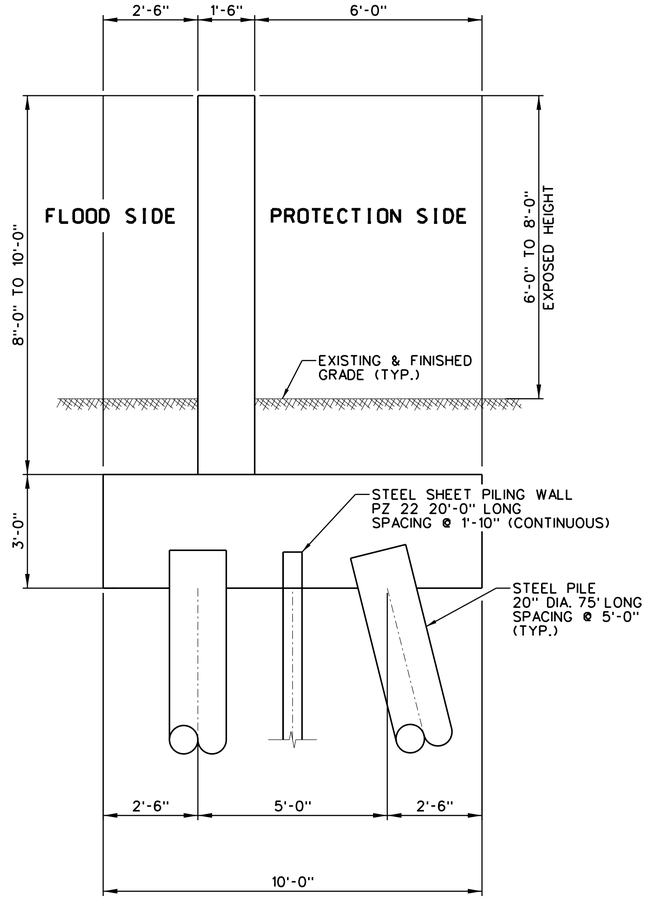
Row 1 Pile Spacing =	**5.000**	ft			
Row 1 Pile Area pet LF - A_1 =	0.200	Piles	d_1 =	2.500	ft
Row 2 Pile Spacing =	**5.000**	ft			
Row 2 Pile Area pet LF - A_2 =	0.200	Piles	d_2 =	-2.500	ft
Dist. From NA to Toe -D =	5.000	ft			
Total Pile Area pet LF - A =	0.400	Piles			
Moment of Inertia $\Sigma A_i d_i^2$ - 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	



TYPE 1 T-WALL
4'-0" TO 6'-0" EXPOSED HEIGHT

SCALE: 1½" = 1'-0"



TYPE 2 T-WALL
6'-0" TO 8'-0 EXPOSED HEIGHT

SCALE: 1½" = 1'-0"

PRELIMINARY - NOT FOR CONSTRUCTION

US Army Corps of Engineers®
New England District

MARK	DESCRIPTION	DATE	APPR.
MARK	DESCRIPTION	DATE	APPR.

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS

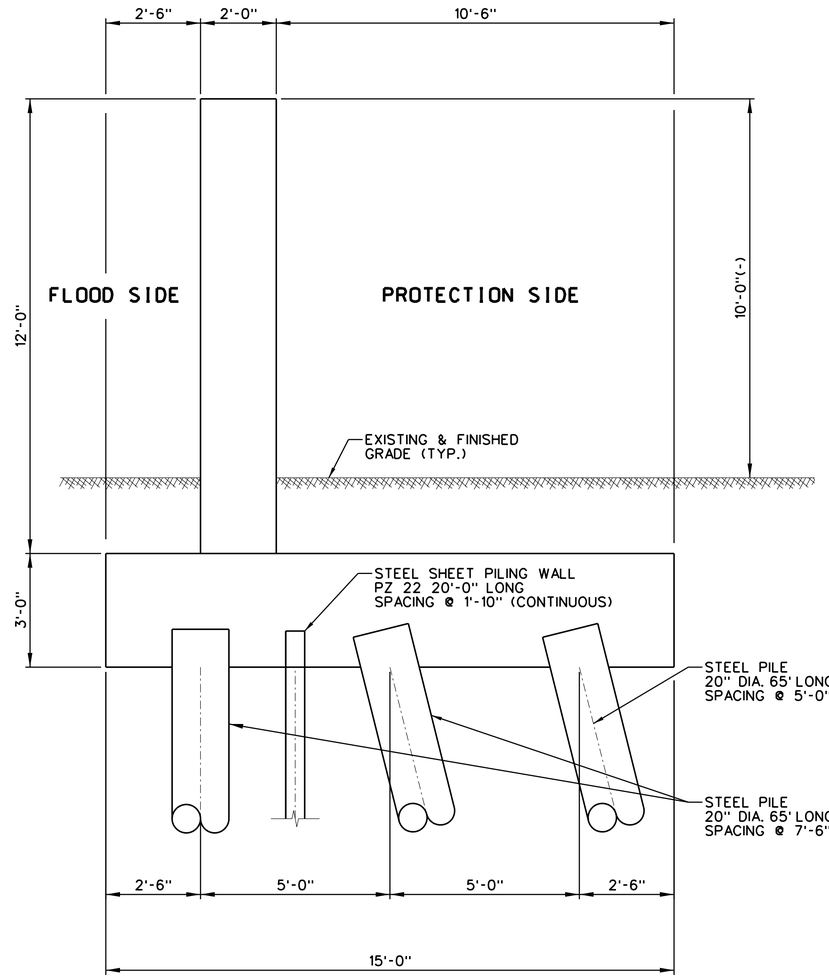
DESIGNED BY: THUYEN NGUYEN
DWN BY: TN
CKD BY:
SUBMITTED BY:
DATE:
SOLICITATION NO.:
CONTRACT NO.:
DRAWING CODE:
PLOT SCALE: 1:1
PLOT DATE: 2015
SIZE: ANSI D
FILE NAME: Fig 2 T-Wall.dgn

FLOOD PROTECTION
CONNECTICUT COASTAL STUDY

NEW HAVEN & FAIRFIELD, CONNECTICUT
T-WALLS, TYPES 1&2

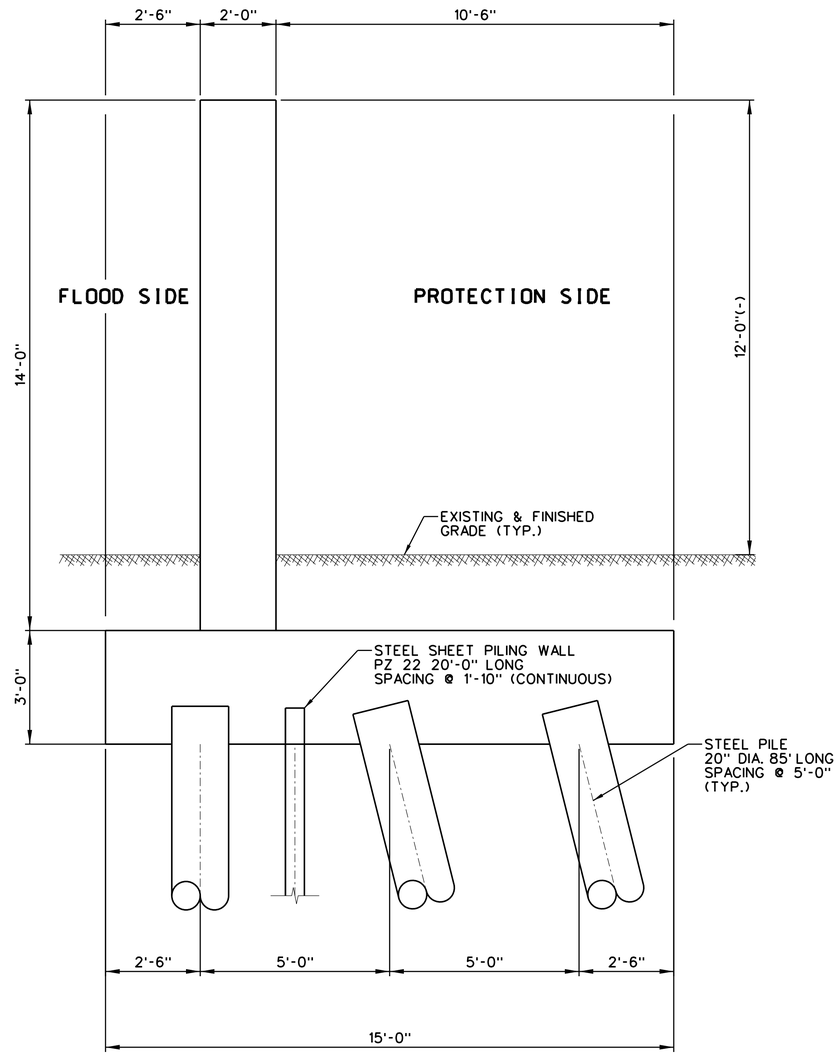
SECTIONS

SHEET IDENTIFICATION
S-01



TYPE 3 T-WALL
8'-0" TO 10'-0 EXPOSED HEIGHT

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



TYPE 4 T-WALL
10'-0" TO 12'-0 EXPOSED HEIGHT

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

NOTE:

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

US Army Corps of Engineers
New England District

MARK	DESCRIPTION	DATE	APPR.
MARK	DESCRIPTION	DATE	APPR.

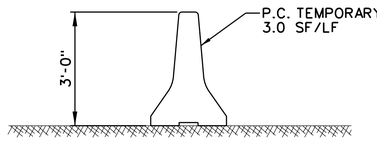
U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS

DESIGNED BY: THUYEN NGUYEN
DWN BY: TN
CKD BY:
SUBMITTED BY:
DATE:
SOLICITATION NO.:
CONTRACT NO.:
DRAWING CODE:
PLOT SCALE: 1:1
PLOT DATE: 2015
SIZE: ANSI D
FILE NAME: PZ-S-02.dgn

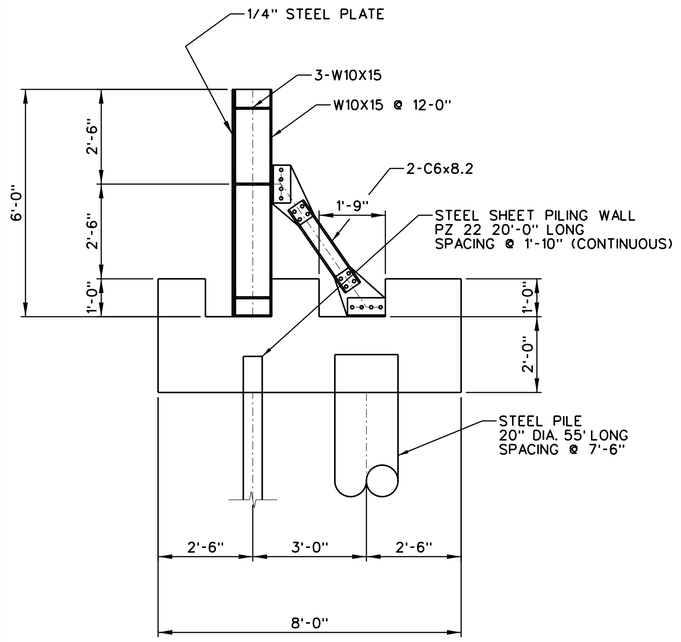
FLOOD PROTECTION
CONNECTICUT COASTAL STUDY
NEW HAVEN & FAIRFIELD, CONNECTICUT
T-WALLS - TYPES 3&4
SECTIONS

SHEET IDENTIFICATION
S-02

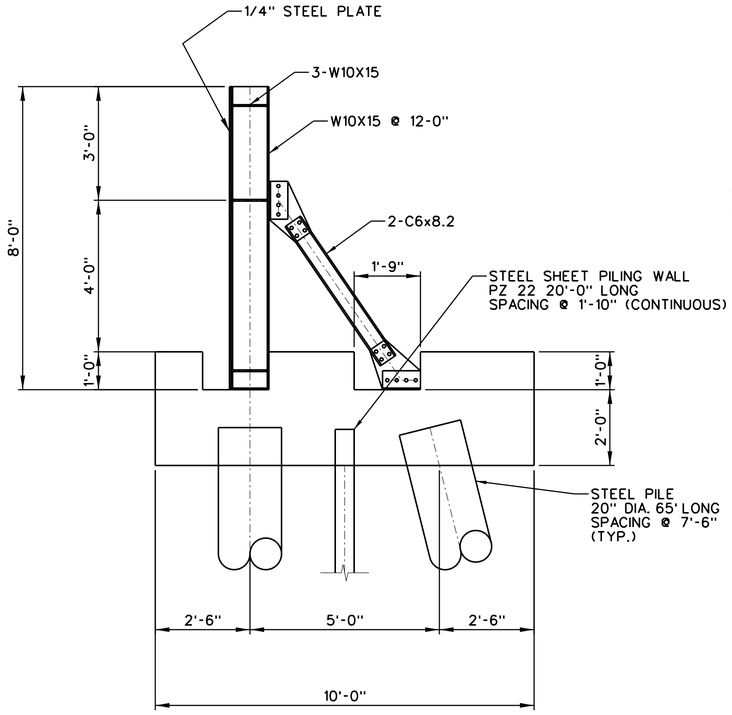
PRELIMINARY - NOT FOR CONSTRUCTION



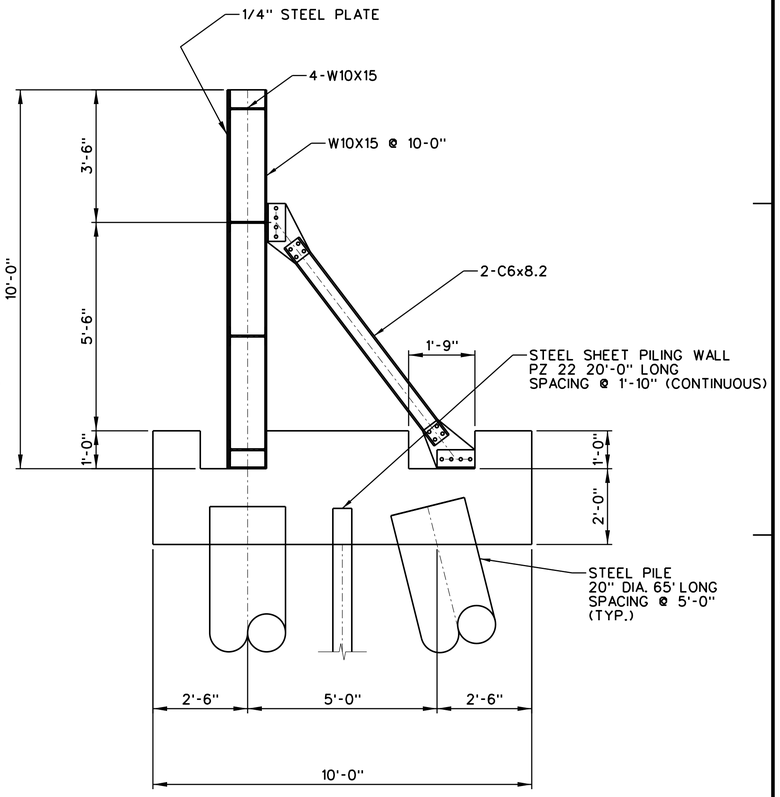
P.C. TEMPORARY BARRIER
3'-0"
SCALE: 1/2" = 1'-0"



TYPE 1 FLOOD GATE
5'-0"
SCALE: 1/2" = 1'-0"



TYPE 2 FLOOD GATE
7'-0"
SCALE: 1/2" = 1'-0"



TYPE 3 FLOOD GATE
9'-0"
SCALE: 1/2" = 1'-0"

US Army Corps of Engineers
New England District

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS

DESIGNED BY: THUYEN NGUYEN
DWN BY: TN
CKD BY:
SUBMITTED BY:
DATE:
SOLICITATION NO.:
CONTRACT NO.:
DRAWING CODE:
PLOT SCALE: 1:1
PLOT DATE: 2015
SIZE: ANSI D
FILE NAME: PZ-22-Sht.dgn

FLOOD PROTECTION
CONNECTICUT COASTAL STUDY
NEW HAVEN & FAIRFIELD, CONNECTICUT
FLOOD GATES- TYPES 1-3
SECTIONS

SHEET IDENTIFICATION
S-03

PRELIMINARY - NOT FOR CONSTRUCTION