DESIGN ANALYSIS

AKV291

LAUNCH RAMP

NONDALTON, ALASKA

DQC

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IFB NO. W911KB-12-B-00XX

Prepared by:
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A

GENERAL

A. Scope:

1. Base Bid: Construct a boat launch ramp to allow the community of Nondalton to more readily access Six Mile Lake. The ramp will be located off J Street where J Street connects Hill Street with the shore of Six Mile Lake. J Street is a 60' wide platted street with an unimproved gravel road currently in place. The lot to the south of J Street is held in Public Reserve and is available for use of this project. This location has historically been used as a barge landing for contractors working in the area. The gravel road along J Street and a parallel gravel road just to the south also currently serve as shoreline access to points further south along the shoreline. The drawings include a note requiring the contractor to clear and establish a trail around the new parking area to maintain this access.

2. Option 1: In addition to the base bid features an eight foot wide by two hundred foot long boarding float is included as an option. A timber abutment will be provided at the shoreward end of the floats. The floats will be positioned and moored via five 12 ¾" diameter steel piles driven twenty feet into the lake bottom. The floats will have pile hoops incorporated into the hinge area, which will allow the floats to be removed during the winter/ice season. Float removal during the winter/ice season is essential for float longevity. The steel guide piles and timber abutment will remain in place during all seasons. The necessity of armoring the perimeter and surface of the ramp construction, and the need to have a relatively smooth surface to support the floats during periods of low water requires the surface under the floats to be covered with concrete. Concrete float planks 8' wide by 4' long have been provided.

B

CIVIL

B. Civil

1. Excavation Side Slopes: The excavated side slopes have been set at 1V:7H for the in-water portions of the work where armor rock won't be placed. This is to provide a gradual transition from the existing lake bed to the full depth portions of the ramp access excavation; with the goal of minimizing future scour or infill of this excavated depression. Excavations that receive B-Rock and A-Rock are either 1V:1.5H or 1V:2H as shown on the drawings. Excavations above the water line are at a 1V:2H side slope and are all filled with Access Road/Parking Fill.

2. Constructed Side Slopes: Slopes of 1V:3H have been used for the armored portions of the in-water work where the new work will be above the existing grade. Steeper slopes are possible for armored slopes however a tradeoff must be made between armor rock size and side slope steepness. Using a 1V:3H side slope allows use of smaller armor rock (see Table 1 below) than would be required for steeper rock slopes. Fill placed above the high water line will have 1V:2H side slopes.

Table 1 – Side Slope – vs. – Armor Rock Size

Side Slope	A-Rock Design Wgt. (lbs)	B-Rock Design Wgt. (lbs)
1V : 1 1/2H	400	40
1V : 2H	300	30
1V : 3H	200	20

3. Road & Parking Excavation: The gravel access road and parking area require clearing and grubbing which has been assumed to require 0.5' of material to be removed. The fill for these features has been designed to be a minimum of 1.0' and additional excavation has been included where the clearing and grubbing alone would not provide sufficient fill thickness.

4. Water Levels & Ramp Elevation Information: Water levels have been estimated to vary from a high of 258' to a low of 250'. The high water elevation is based on the edge of vegetation along the shoreline, which occurs between elevations 256' and 258'. The low water elevation is based on a Google Earth image dated 23 May 2006 showing the water surface between elevation 250' and 251'. The top of the ramp has been set at an elevation of 259' with a vertical curve above this elevation tying into the edge of the parking area at an elevation of 260.28'. The existing lake bottom is too flat in this area for a ramp that matches the bottom slope, thus the 12% ramp will require in-water excavation. This excavation goes down to elevation 246', thus giving 4' water depth for the estimated lowest lake water levels. The bottom of the concrete ramp will be at an elevation of 247' with armor rock placed at the toe of the ramp.

5. Survey Information: Survey information shown is from the survey conducted by Dowl HKM from 27-30 July, 2010.

6. Wave Heights & Wind Speeds: Discussions with local residents indicate that waves in the range of four feet occur at the project site. This wave height has been used to size the armor stone for the project. No wind study has been performed however the maximum fetch distance of about 4.5 miles at about 50° east of north combined with a 1.1-hour wind of 44 mph gives a calculated significant wave height

of 4.0 feet with about a 3.5 second period. Since this is an unprotected sight, a criteria requiring the floats to be serviceable for 2.0 foot waves with a 2.5 second period. Waves larger than this will make the floats unsafe during the storm and maintenance should be expected to be required following the event.

C

STRUCTURAL

Structural

1. Design Loads: The design loads for boarding floats is in accordance with the principles of hydraulic and geotechnical engineering associated with waterside structures:

   a). Dead Loads:
   Weight of Materials.
   b). Live Loads:
   Float – Uniform 40 psf (buoyancy limited)
   c). Snow Load:
   Ground Snow Load: 70 psf

2. Materials: Materials used on this project and their strengths include:

   a). Structural Steel: f_y = 36 ksi
   b). Pipe Piles: f_y = 50 ksi

3. Codes and Standards: Elements within the structures are designed in accordance with the following codes and standards. The most stringent will govern where discrepancies occur:

   a). National Design Specification for Wood Construction, 2005 Edition.
   b). American Institute of Steel Construction (AISC) Manual of Steel Construction – Load and Resistance Factor Design, 13rd Edition.

4. Steel Pipe Piles: The basic callout for piles is 12 3/4" diameter, ASTM A572, Grade 50 material with ½" wall thickness. These 12 3/4" x ½" wall piles will require inside flanges (outside flush) driving shoes.

5. Additional Calculations: Repetitive calculations are, in general, not included in this DA. They are available upon request. Contact Robert Tedrick @ (907) 753-5745 or Robert.C.Tedrick@usace.army.mil.

6. Attachments: Please see the attached calculations for more information.

Ramp Plank Analysis: *Two supports with equal cantilevers beyond supports. Cantilevers length is beam length divided by a factor "n". Two equal point loads @ "a" from left end and spaced "b" apart. Beam has uniform weight.*

Sign Convention: Origin of Cartesian coordinates is at left end of beam. Positive directions are up and to the right.

Geometry of beam and loading:

$L := 16ft$ *Beam overall length*

$n := \frac{16}{3}$ *Factor that determines cantilever length, i.e. "L/n"*

$a := 10ft$ *Distance to first point load from beam's left end*

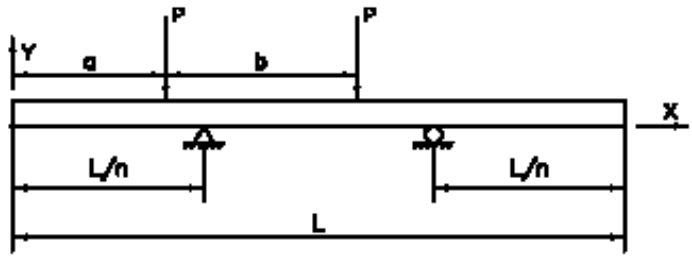
$b := 6ft$ *Distance to second point load from first point load*

Geometry checks:

$a_{check} := \begin{cases} \text{"OK"} & \text{if } 0ft \le a \le L - b \\ \text{"No Good"} & \text{otherwise} \end{cases}$ $a_{check} = \text{"OK"}$

$n_{check} := \begin{cases} \text{"OK"} & \text{if } n > 2 \\ \text{"No Good"} & \text{otherwise} \end{cases}$ $n_{check} = \text{"OK"}$

$b_{check} := \begin{cases} \text{"OK"} & \text{if } 0ft < b \le L \\ \text{"No Good"} & \text{otherwise} \end{cases}$ $b_{check} = \text{"OK"}$



$Check := \begin{cases} \text{"OK"} & \text{if } a_{check} = b_{check} = n_{check} = \text{"OK"} \\ \text{"No Good"} & \text{otherwise} \end{cases}$ $Check = \text{"OK"}$

Magnitude of loads:

$\omega := -0.21klf$ *Beam weight expressed as a uniform load, unfactored dead load*

$P := -10kip$ *Point load, unfactored live load*

Use_LRFD := Yes / No

User toggle for service or factored loads

$Impact_Factor := 1.1$ *Live load impact factor*

$LF_{D_with_L} := 1.2$ *Load factor for dead with live loads also*

$LF_L := 1.6$ *Load factor for live loads*

Revise magnitude of loads for impact & LRFD (if used):

$\omega := \text{if}\left(Use_LRFD = 1.0, \omega \cdot LF_{D_with_L}, \omega\right)$ $\omega = -0.25 \cdot klf$

$P := \text{if}\left(Use_LRFD = 1.0, P \cdot Impact_Factor \cdot LF_L, P \cdot Impact_Factor\right)$ $P = -17.6 \cdot kip$

Reactions:

$$R_1 := \begin{cases} \dfrac{-\omega \cdot L}{2} - \dfrac{\left(2 \cdot L - \dfrac{2 \cdot L}{n} - 2 \cdot a - b\right) \cdot P}{L - \dfrac{2 \cdot L}{n}} & \text{if } (\text{Check} = \text{"OK"}) \\ \text{"No Good"} & \text{otherwise} \end{cases} \qquad R_1 = 2.02 \cdot kip$$

$$R_2 := \begin{cases} \dfrac{-\omega \cdot L}{2} + \dfrac{\left(\dfrac{2 \cdot L}{n} - 2 \cdot a - b\right) \cdot P}{L - \dfrac{2 \cdot L}{n}} & \text{if } (\text{Check} = \text{"OK"}) \\ \text{"No Good"} & \text{otherwise} \end{cases} \qquad R_2 = 37.22 \cdot kip$$

Constants of integration

Shear equation:

$$V(x) := \begin{cases} \omega \cdot x + C_1(x) & \text{if } (\text{Check} = \text{"OK"}) \wedge \left(a + b \le \frac{L}{n}\right) \\ \left(\omega \cdot x + C_3(x)\right) & \text{if } (\text{Check} = \text{"OK"}) \wedge \left[\left(a \le \frac{L}{n}\right) \wedge \left(\frac{L}{n} < a + b \le L - \frac{L}{n}\right)\right] \\ \left(\omega \cdot x + C_5(x)\right) & \text{if } (\text{Check} = \text{"OK"}) \wedge \left[\left(a \le \frac{L}{n}\right) \wedge \left(a + b > L - \frac{L}{n}\right)\right] \\ \left(\omega \cdot x + C_7(x)\right) & \text{if } (\text{Check} = \text{"OK"}) \wedge \left[\left(a > \frac{L}{n}\right) \wedge \left(a + b \le L - \frac{L}{n}\right)\right] \\ \left(\omega \cdot x + C_9(x)\right) & \text{if } (\text{Check} = \text{"OK"}) \wedge \left[\left(\frac{L}{n} < a \le L - \frac{L}{n}\right) \wedge \left(a + b > L - \frac{L}{n}\right)\right] \\ \left(\omega \cdot x + C_{11}(x)\right) & \text{if } (\text{Check} = \text{"OK"}) \wedge \left[\left(a > L - \frac{L}{n}\right) \wedge (a + b \le L)\right] \\ \text{"No Good"} & \text{otherwise} \end{cases}$$

$V(0\,ft) = 0.0\,lbf$

$V(L) = 1.8 \times 10^4\,lbf$

$i := 0\,ft, 0.001\,ft .. L$

$y1 := 0.9 \cdot L$ $\quad y2 := \frac{3L}{4}$

Guess values to find Min. & Max. shear, User check to ensure values found are not just local Min. & Max. values - use graph below for comparision.

Solve Block to find location and magnitude of extreme shear values:

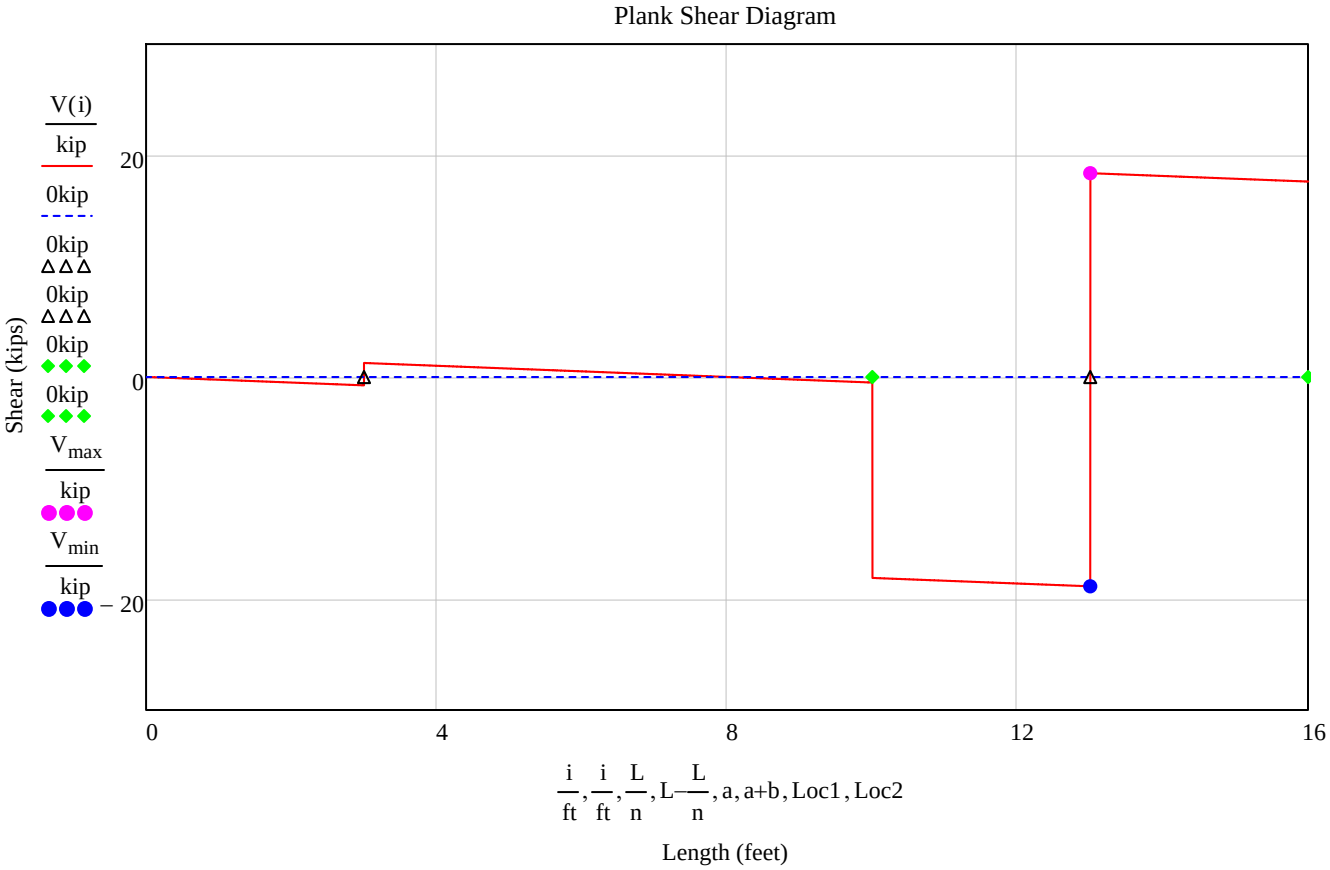
Given

$0\,ft \le y1 \le L$

$0\,ft \le y2 \le L$

$Loc1 := \text{Maximize}(V, y1)$ $\quad Loc1 = 13.00\,ft$ $\quad V_{max} := V(Loc1)$ $\quad V_{max} = 18.36 \cdot kip$

$Loc2 := \text{Minimize}(V, y2)$ $\quad Loc2 = 13.0\,ft$ $\quad V_{min} := V(Loc2)$ $\quad V_{min} = -18.86 \cdot kip$



$L = 16.0\,ft$

$n = 5.33$

$a = 10.0\,ft$

$b = 6.0\,ft$

Moment Equation:

$$M(x) := \begin{cases} \left(\frac{\omega \cdot x^2}{2} + C_1(x)\cdot x + C_2(x)\right) & \text{if } (\text{Check} = \text{"OK"}) \wedge \left(a + b \le \frac{L}{n}\right) \\ \left(\frac{\omega \cdot x^2}{2} + C_3(x)\cdot x + C_4(x)\right) & \text{if } (\text{Check} = \text{"OK"}) \wedge \left[\left(a \le \frac{L}{n}\right) \wedge \left(\frac{L}{n} < a + b \le L - \frac{L}{n}\right)\right] \\ \left(\frac{\omega \cdot x^2}{2} + C_5(x)\cdot x + C_6(x)\right) & \text{if } (\text{Check} = \text{"OK"}) \wedge \left[\left(a \le \frac{L}{n}\right) \wedge a + b > L - \frac{L}{n}\right] \\ \left(\frac{\omega \cdot x^2}{2} + C_7(x)\cdot x + C_8(x)\right) & \text{if } (\text{Check} = \text{"OK"}) \wedge \left[\left(a > \frac{L}{n}\right) \wedge \left(a + b \le L - \frac{L}{n}\right)\right] \\ \left(\frac{\omega \cdot x^2}{2} + C_9(x)\cdot x + C_{10}(x)\right) & \text{if } (\text{Check} = \text{"OK"}) \wedge \left[\left(\frac{L}{n} < a \le L - \frac{L}{n}\right) \wedge \left(a + b > L - \frac{L}{n}\right)\right] \\ \left(\frac{\omega \cdot x^2}{2} + C_{11}(x)\cdot x + C_{12}(x)\right) & \text{if } (\text{Check} = \text{"OK"}) \wedge \left[\left(a > L - \frac{L}{n}\right) \wedge (a + b \le L)\right] \\ \text{"No Good"} & \text{otherwise} \end{cases}$$

$M(0ft) = 0.0 \cdot kip \cdot ft$

$M(L) = 0.0 \cdot kip \cdot ft$

$y3 := \frac{1L}{4}$ $\quad$ $y4 := \frac{3L}{4}$

Guess values to find Min. & Max. moment, User check to ensure values found are not just local Min. & Max. values - use graph below for comparision.

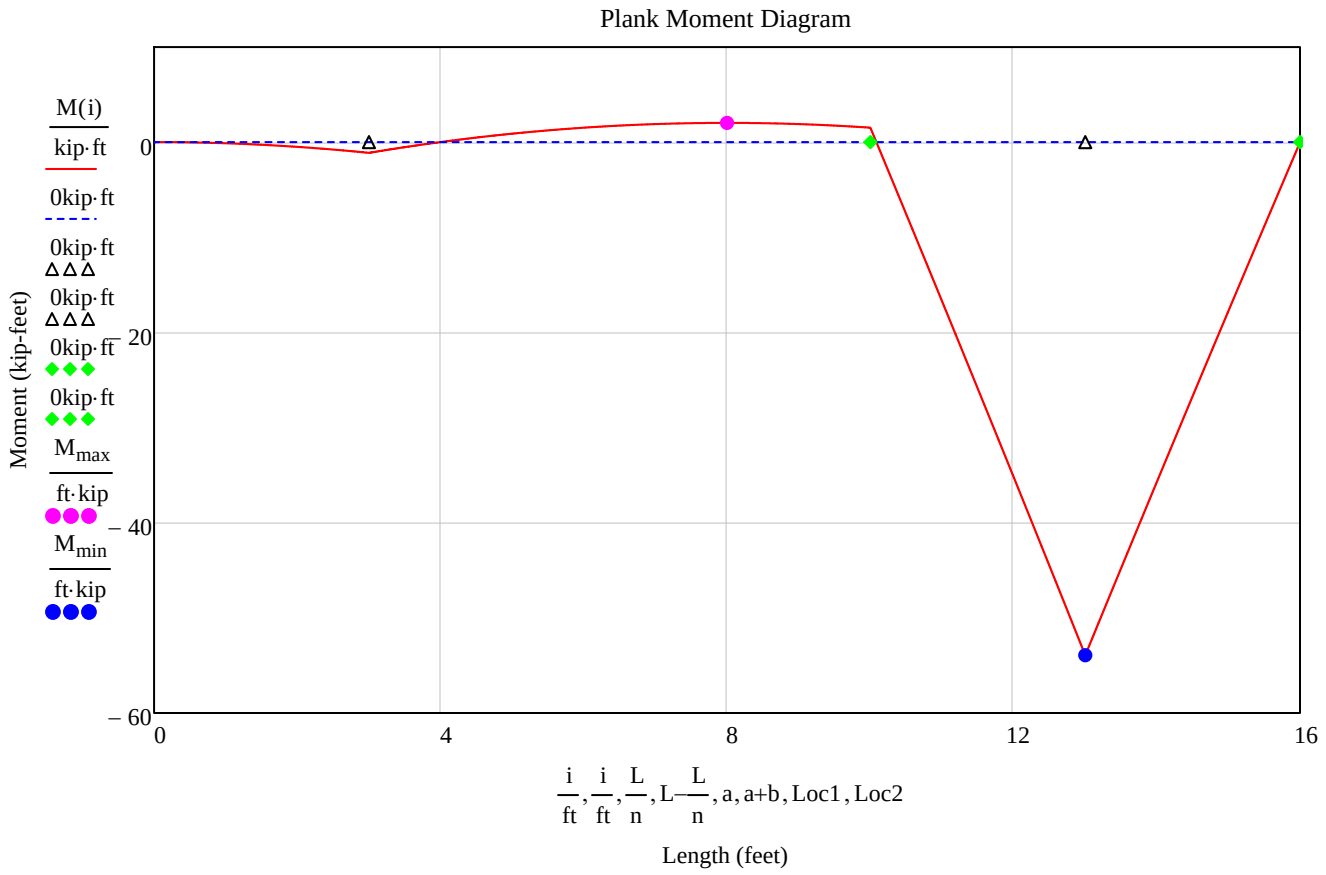
Solve Block to find location and magnitude of extreme moment values:

Given

$0ft \le y3 \le L \qquad 0ft \le y4 \le L$

$Loc1 := \text{Maximize}(M, y3) \qquad Loc1 = 8.00\,ft \qquad M_{max} := M(Loc1) \qquad M_{max} = 2.02\,ft \cdot kip$

$Loc2 := \text{Minimize}(M, y4) \qquad Loc2 = 13.0\,ft \qquad M_{min} := M(Loc2) \qquad M_{min} = -53.93\,ft \cdot kip$



Moment
Plank
Left Support
Right Support
Left Point Load
Right Point Load
Max Moment
Min Moment

$L = 16.0\,ft$

$n = 5.33$

$a = 10.0\,ft$

$b = 6.0\,ft$

Plank Loading - Summary of Moments and Shears

Plank Length: 16.00 ft

Service Loads

n	a	b	R_{left} (kip)	R_{right} (kip)	V_{max} (kip)	V_{min} (kip)	M_{max} (kip-ft)	M_{min} (kip-ft)
	0		26.43	-1.07	13.34	-10.84	0.00	-41.68
	1		23.68	1.68	10.84	-10.84	0.00	-31.68
	2		20.93	4.43	8.34	-10.84	10.00	-21.68
	3		18.18	7.18	5.84	-10.84	14.89	-11.68
	4		15.43	9.93	3.34	-8.34	14.58	-1.68
4	5	6	12.68	12.68	10.84	-10.84	10.00	-1.68
	6		9.93	15.43	8.34	-3.34	14.58	-1.68
	7		7.18	18.18	10.84	-5.84	14.89	-11.68
	8		4.43	20.93	10.84	-8.34	10.00	-21.68
	9		1.68	23.68	10.84	-10.84	0.00	-31.68
	10		-1.07	26.43	10.84	-13.34	0.00	-41.68
	Extreme Values =		26.43	26.43	13.34	-13.34	14.89	-41.68
	Minimum Value =		-1.07	-1.07				

Factored Loads

n	a	b	R_{left} (kip)	R_{right} (kip)	V_{max} (kip)	V_{min} (kip)	M_{max} (kip-ft)	M_{min} (kip-ft)
	0		41.62	-2.38	23.01	-18.61	0.00	-72.42
	1		37.22	2.02				
	2							
	3		28.42	10.82	9.81	-18.61	26.27	-19.62
	4							
4	5	6						
	6							
	7		10.82	28.42	18.61	-9.81	26.27	-19.62
	8							
	9							
	10		-2.38	41.62	18.61	-23.01	0.00	-72.42
	Extreme Values =		41.62	41.62	23.01	-23.01	26.27	-72.42
	Minimum Value =		-2.38	-2.38				

No Good - Max factored moment exceeds Phi * Mn = 62.5 kip-ft and minimum reaction is negative.

Factored Loads

n	a	b	R_{left} (kip)	R_{right} (kip)	V_{max} (kip)	V_{min} (kip)	M_{max} (kip-ft)	M_{min} (kip-ft)
	0		37.22	2.02	18.86	-18.36	2.02	-53.93
	1		33.7	5.54	15.34	-18.36	23.01	-36.33
	2		30.18	9.06	11.82	-18.36	37.22	-18.73
	3		26.66	12.58	8.30	-11.82	44.13	-1.13
	4		23.14	16.1	22.38	-15.34	43.75	-1.13
5.33	5	6	19.62	19.62	18.86	18.86	37.22	-1.13
	6		16.1	23.14	15.34	-22.38	43.75	-1.13
	7		12.58	26.66	11.82	-8.30	44.13	-1.13
	8		9.06	30.18	18.36	-11.82	37.22	-18.73
	9		5.54	33.7	18.36	-15.34	23.01	-36.33
	10		2.02	37.22	18.36	-18.86	2.02	-53.93
	Extreme Values =		37.22	37.22	22.38	-22.38	44.13	-53.93
	Minimum Value =		2.02	2.02				

OK - Max factored moment is less than Phi * Mn = 62.5 kip*ft and minimum reaction is positive.

Use this worksheet to estimate the required footprint area for a soil disposal area:

$Vol := 1200yd^3$	*Volume of soil to be disposed of*
$h := 5ft$	*Height of soil disposal pile*
$H := 3$	*Horizontal run of soil pile side slope for a rise of 1 unit*
$a := 45ft$	*Width of top of soil pile*
$b := 2$	*Length of top of soil pile is "b" x "a"*

Calculated volume based on dimensions entered above, iterate to closely match required & calculated volumes:

$$V_{calc} := h\cdot\left[\frac{b\cdot a^2 + (a + 2\cdot h\cdot H)\cdot(b\cdot a + 2\cdot h\cdot H)}{2}\right] \qquad V_{calc} = 1208.3\cdot yd^3$$

Base area of disposal pile:

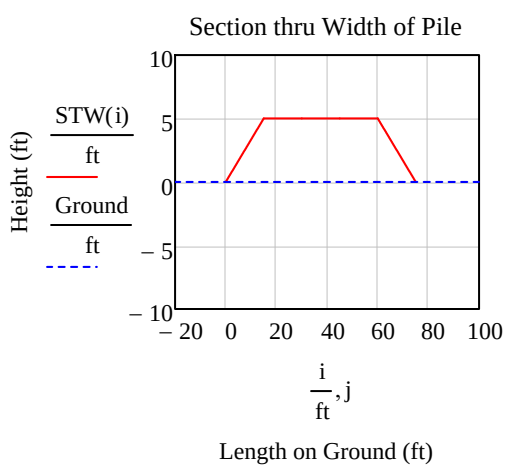
$$A_{base} := (a + 2\cdot h\cdot H)\cdot(b\cdot a + 2\cdot h\cdot H) \qquad A_{base} = 9000\cdot ft^2 \qquad A_{base} = 0.21\cdot acre$$

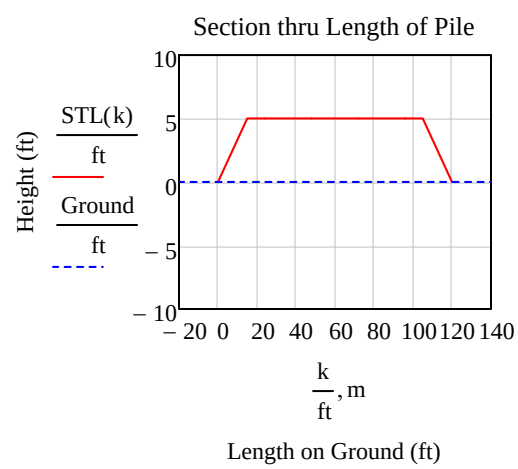
Base width and length of disposal pile:

$Base_Width := a + 2\cdot h\cdot H$ $\qquad Base_Width = 75.0\ ft$

$Base_Length := b\cdot a + 2\cdot h\cdot H$ $\qquad Base_Length = 120.0\ ft$

Graph Setup





ARMOR ROCK CALCULATION:

Direction:

$$W = \frac{w_r H^3}{K_D (S_r - 1)^3 \cot\theta}$$

Variables	
165	w_r = unit weight of armor unit in N/m^3 or **lb/ft^3**
4	**Hs** = design wave height at the structure site in meters or **feet**
5.1	**H_{10} = Average of highest 10% of all waves**
62.4	w_w = unit weight of water: fresh water = 9,800 N/m^3 (62.4 lb/ft^3) seawater = 10,047 N/m^3 **(64.0 lb/ft^3)**
3	**cotθ** = structure side slope (horizontal/vertical)
4	**K_D** = stability coeficient (see Table 7-8 in SPM)
2.644	**S_r** = specific gravity of armor unit, relative to the water at the structure ($S_r = w_r/w_w$)

Solution

198	**W** = weight in newtons or **pounds** of an individual armor unit in the primary cover layer
200	**USE**

1.32 **D** = diameter of stone in **feet**

1.32 **D** = diameter of stone in **feet**

4.1 H_b = Breaker height (ft.)

5.14 d_b = Depth of breaker (ft.)

CREST WIDTH:

$$B = nk_\Delta \left(\frac{W}{w_r}\right)^{\frac{1}{3}}$$

Solution

4.0	B = crest width, m **(or ft.)**

Variables	
3	n = number of stones (n = 3 is recommended minimum)
1.00	k_Δ = layer coefficient (Table 7-13)
200	W = mass of armor unit in primary cover layer, kg **(or weight in lb)**
165	w_r = mass density of armor unit, kg/m^3 **(or unit weight in lb/ft^3)**

ARMOR LAYER THICKNESS:

$$r = nk_\Delta \left(\frac{W}{w_r}\right)^{\frac{1}{3}}$$

Solution

2.6	r = average armor layer thickness, m **(or ft.)**

Variables	
2	n = number of stones in the thickness comprising the cover layer)
1.00	k_Δ = layer coefficient (Table 7-13)
200	W = mass of armor unit in primary cover layer, kg **(or weight in lb)**
165	w_r = mass density of armor unit, kg/m^3 **(or unit weight in lb/ft^3)**

WAVE RUN-UP:

-25	Depth at toe of structure (ft.)
7	Design high water level (ft.)
5	T = period (sec.)

MHHW = 19.8', toe at 21

32	ds = depth to toe from SWL (ft.)
0.0546	d/Lo = 2(pi)d / gT^2
4	Hs
0.9847	Coeff. From Table C-1 (H/H'$_o$)
4.1	H'$_0$ = unrefr. deep water wave height (ft.)

0.775	a coef.
0.361	b coef
50	cotϕ = beach slope

3	cotθ = structure side slope (horizontal/vertical)
0.0050	H'$_0$/gT^2
7.88	ds/H'$_0$
0.12	R/H'$_0$ (from Fig. 7-15 SPM)
0.98	R/H'$_0$ (from Fig. 7-20 SPM)
1.14	k = Runup correction for scale effects (Fig.7-13 S 0.243729 = R_{avg}.

Solution

0.49	R= run up from Fig. 7-15 SPM (ft.)
0.00	R= run up from Fig. 7-20 SPM (ft.)
0	R= run up from ACES program (ft.)

7	**Design high water level (HWL) (ft.)**
7	**Breakwater crest Elevation (ft.) = SWL + R_{avg}.**

BREAKING/NON-BREAKING WAVE CONDITIONS:

5	T = Period
0.02	m = Beach slope
4.1	H$_o$' = Wave height (ft.)

0.0050 = H'$_0$/gT^2

1.02 H_b/H'_0 = From Fig. 2-72 (SPM)

4.14 H_b = Breaker height (ft.) 0.0051 = H_b/gT^2

1.24 d_b/H_b = From Fig. 2-73 (SPM)

5.14 d_b = Depth of water to initiate breaker (ft.)

SECONDARY (B ROCK) DESIGN VALUES:

20 **W_{50} = W/10 (lbs.)**

$$r = nk_{\Delta}\left(\frac{W}{w_r}\right)^{\frac{1}{3}}$$

Solution

1.0 r = average Secondary layer thickness, m **(or ft.)**

Variables	
2	n = number of stones in the thickness comprising the secondary layer)
1.00	k_{Δ} = layer coefficient (Table 7-13)
20	W = mass of rock unit in secondary cover layer, kg **(or weight in lb)**
165	w_r = mass density of rock unit, kg/m^3 **(or unit weight in lb/ft^3)**

CORE ROCK DESIGN VALUES:

2 **W_{50} = W/10 (lbs.)**

Rock size gradations

Design weight (lbs.)	**Layer description**	Max size (lbs.)	Min size (lbs.)	Revised Gradations: to make use of quarry Max size (lbs.)	Min size (lbs.)
200	Armor Layer	250	150		
20	Secondary Layer	25	15		
2	Core Layer	3	2		

Boarding Float Weight & Draft Calculations

Project: AKV291, Nondalton Launch Ramp

	Item	Count	Area (Sq. In.) / Volume (Cubic In.)	Length (Ft.)	Lb/Ft	Lb/Each	PCF	Wgt.
Timber	2x8, Closure	2	10.875	20			30	90.6
	4x6, Bottom Sill	4	19.25	20			30	320.8
	6x6, Top Sill	2	30.25	20			30	252.1
	6x6, Chamfered Bullrail	2	29.75	20			30	247.9
	4X10" (net), Spacer	4	35	8			30	233.3
	4X6, Bullrail Blocking	6	19.25	2			30	48.1
	2x12, Decking	3	16.34	8			30	81.7
	2x10, Decking	22	14.56	8			30	533.9
	3X6, Skid	2	13.75	20			30	114.6
Billets	10" x 20"	8	198	8			1	88.0
UHMW-PE	2" x 12", Rub Strip	2	23.37	20			59	383.0
Economy Hd. Bolts	3/4" x 20"	12	9.61				490	32.7
	3/4" x 18"	12	8.73				490	29.7
	5/8" x 8"	4	2.97				490	3.4
Bolts	5/8" x 5"	1	1.92				490	0.5
	5/8" x 8"	12	2.85				490	9.7
	1" x 10"	1	9.43				490	2.7
Malleable Iron Washers	3/4"	24				0.42		10.1
Washers	1" SAE	2				0.083		0.2
	1/2" USS, Rub Strip	72				0.0385		2.8
	1/2" USS, Skid	52				0.0385		2.0
Nuts	3/4"	24				0.199		4.8
	5/8"	17				0.0733		1.2
	1"	1				0.283		0.3
Lag Screws	1/2" x 4", Rub Strip	72				0.2		14.4
	1/2" x 4", Skid	52				0.2		10.4
Screws	#14 x 4"	202				0.05		10.1
Plate Steel	3 1/2" x 6" x 5/16"	4	6.45				490	7.3
	3 1/2" x 11" x 5/16"	2	11.92				490	6.8
	3 1/2" x 20 1/4" x 1/2", Rnd. One End	8	33.78				490	76.6
	3" Dia. x 1/2" Thk.	8	3.09				490	7.0
HSS	3x2x1/4	4		4.083	7.08			115.6

Total Wgt. = 2742.3 Lbs.

Unit Wgt. Of Water = 62.4 pcf (62.4 for fresh water, 64.0 for sea water)

Draft Calculations:

(Note: Vertical measurements taken from bottom of skids, including draft)

Deck Length = 244.0"
Deck Clear Width = 85.0"
Deck Area = 144.03 Sq. Ft.

Applied Live Load = 0.0 psf
Live Load Wgt. = 0.0 Lbs.

Total Wgt. = 2742.3 Lbs.

Trial Value for Draft = 9.09"

Item	Bottom Elevation of Item	Top Elevation of Item	Effective Width	Length of Item	Displaced Volume	Max. Poss. Disp. Volume
Skids	0.00"	2.50"	11.00"	20.00 Ft.	3.82 Cu. Ft.	3.82 Cu. Ft.
Bottom Sills	2.50"	6.00"	16.50"	20.00 Ft.	8.02 Cu. Ft.	8.02 Cu. Ft.
Closures	3.75"	11.00"	3.00"	20.00 Ft.	2.23 Cu. Ft.	3.02 Cu. Ft.
Rub Strips	11.00"	23.00"	4.00"	20.00 Ft.	0.00 Cu. Ft.	6.67 Cu. Ft.
Spacers	6.00"	16.00"	14.00"	8.00 Ft.	2.40 Cu. Ft.	7.78 Cu. Ft.
Billets	6.00"	16.00"	160.00"	8.00 Ft.	27.48 Cu. Ft.	88.89 Cu. Ft.
Top Sills	16.00"	21.50"	14.50"	20.00 Ft.	0.00 Cu. Ft.	11.08 Cu. Ft.
Decking	21.50"	23.00"	237.25"	8.00 Ft.	0.00 Cu. Ft.	19.77 Cu. Ft.
				Total Disp. Vol. =	43.95 Cu. Ft.	149.04 Cu. Ft.
				Wgt. Of Disp. Water =	2742.3 Lbs.	9300.2 Lbs.
				Tot. Wgt. - Disp. Water =	0.0 Lbs.	
				Max. Live Load =		45.5 psf

STA	Grubbing Area (Ft^2)	Additional Cut Area (Ft^2)	Access Road Fill (Ft^2)	Ramp Cut Area (Ft^2)	A-Rock Area (Ft^2)	B-Rock Area (Ft^2)	Base Course Area (Ft^2)	Dist.	Grubbing Avg. End Area (Ft^2)	Additional Cut Area Avg. End Area (Ft^2)	Access Road Fill Avg. End Area (Ft^2)	Ramp Cut Avg. End Area (Ft^2)	A-Rock Avg. End Area (Ft^2)	B-Rock Avg. End Area (Ft^2)	Base Course Avg. End Area (Ft^2)	Grubbing Approx. Vol. (yd^3)	Additional Cut Area Approx Vol (yd^3)	Access Road Fill Approx. Vol. (yd^3)	Ramp Cut Approx. Vol. (yd^3)	A-Rock Approx. Vol. (yd^3)	B-Rock Approx. Vol. (yd^3)	Base Course Approx. Vol. (yd^3)
1130	0.0	0.0	0.0																			
								20.00	6.65	0	17.65	0	0	0	0	4.9	0.0	13.1	0.0	0.0	0.0	0.0
1150	13.3	0.0	35.3																			
								25.00	13.85	0	43	0	0	0	0	12.8	0.0	39.8	0.0	0.0	0.0	0.0
1175	14.4	0.0	50.7																			
								25.00	14	0	44.5	0	0	0	0	13.0	0.0	41.2	0.0	0.0	0.0	0.0
1200	13.6	0.0	38.3																			
								25.00	13.4	0.235	34.75	0	0	0	0	12.4	0.2	32.2	0.0	0.0	0.0	0.0
1225	13.2	0.5	31.2																			
								25.00	13.25	2.235	29.85	0	0	0	0	12.3	2.1	27.6	0.0	0.0	0.0	0.0
1250	13.3	4.0	28.5																			
								25.00	14	2	35.65	0	0	0	0	13.0	1.9	33.0	0.0	0.0	0.0	0.0
1275	14.7	0.0	42.8																			
								10.00	14.8	0	46.5	0	0	0	0	5.5	0.0	17.2	0.0	0.0	0.0	0.0
1285	14.9	0.0	50.2																			
								0.00	34.95	0	116.1	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1285	55.0	0.0	182.0																			
								15.00	55.65	0	191.5	0	0	0	0	30.9	0.0	106.4	0.0	0.0	0.0	0.0
1300	56.3	0.0	201.0																			
								25.00	56.5	0	202	0	0	0	0	52.3	0.0	187.0	0.0	0.0	0.0	0.0
1325	56.7	0.0	203.0																			
								25.00	55.55	0	175	0	0	0	0	51.4	0.0	162.0	0.0	0.0	0.0	0.0
1350	54.4	0.0	147.0																			
								25.00	54.2	0.33	147.5	0	0	0	0	50.2	0.3	136.6	0.0	0.0	0.0	0.0
1375	54.0	0.7	148.0																			
								10.00	53.65	2.25	139	0	0	0	0	19.9	0.8	51.5	0.0	0.0	0.0	0.0
1385	53.3	3.8	130.0	0.0	0.0	0.0	0.0															
								0.00	26.65	1.92	65	16.5	4.67	7.4	6.65	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1385	0.0	0.0	0.0	33.0	9.3	14.8	13.3															
								15.00	0	0	0	30.85	12.67	16.45	13.3	0.0	0.0	0.0	17.1	7.0	9.1	7.4
1400				28.7	16	18.1	13.3															
								25.00	0	0	0	14.35	8	9.05	6.65	0.0	0.0	0.0	13.3	7.4	8.4	6.2
1425				27.8	20.5	20.2	13.3															
								25.00	0	0	0	13.9	10.25	10.1	6.65	0.0	0.0	0.0	12.9	9.5	9.4	6.2
1450				41.9	8.68	14.7	13.3															
								25.00	0	0	0	20.95	4.34	7.35	6.65	0.0	0.0	0.0	19.4	4.0	6.8	6.2
1475				117	12.4	20.1	13.3															
								25.00	0	0	0	58.5	6.2	10.05	6.65	0.0	0.0	0.0	54.2	5.7	9.3	6.2
1500				285	11.5	18.4	13.3															
								25.00	0	0	0	142.5	5.75	9.2	6.65	0.0	0.0	0.0	131.9	5.3	8.5	6.2
1525				229			0															
								25.00	0	0	0	114.5	0	0	0	0.0	0.0	0.0	106.0	0.0	0.0	0.0
1550				167																		
								25.00	0	0	0	83.5	0	0	0	0.0	0.0	0.0	77.3	0.0	0.0	0.0
1575				113																		
								25.00	0	0	0	56.5	0	0	0	0.0	0.0	0.0	52.3	0.0	0.0	0.0
1600				71.5																		
								25.00	0	0	0	35.75	0	0	0	0.0	0.0	0.0	33.1	0.0	0.0	0.0
1625				18.4																		
								15.00	0	0	0	9.2	0	0	0	0.0	0.0	0.0	5.1	0.0	0.0	0.0
1640				0.0																		
								Total Volume =								279 Cu Yd	5 Cu Yd	848 Cu Yd	523 Cu Yd	39 Cu Yd	52 Cu Yd	38 Cu Yd

Total Cut = 807 Cu Yd
Total Fill = 976 Cu Yd

STA	Grubbing Area (Ft^2)	Additional Cut Area (Ft^2)	Access Road Fill (Ft^2)	Ramp Cut Area (Ft^2)	A-Rock Area (Ft^2)	B-Rock Area (Ft^2)	Base Course Area (Ft^2)
1130	0.0	0.0	0.0				
1150	13.3	0.0	35.3				
1175	14.4	0.0	50.7				
1200	13.6	0.0	38.3				
1225	13.2	0.5	31.2				
1250	13.3	4.0	28.5				
1275	14.7	0.0	42.8				
1285	14.9	0.0	50.2				
1285	55.0	0.0	182.0				
1300	56.3	0.0	201.0				
1325	56.7	0.0	203.0				
1350	54.4	0.0	147.0				
1375	54.0	0.7	148.0				
1385	53.3	3.8	130.0	0.0	0.0	0.0	0.0
1385	0.0	0.0	0.0	40.9	8.5	14.7	21.3
1400				31.7	14.7	17.2	21.3
1425				28.7	19.2	19.6	21.3
1450				51.4	8.74	15.1	21.3
1475				171	11.4	18.3	21.3
1500				421	10.9	17.5	21.3
1525				368			0
1550				279			
1575				211			
1600				148			
1625				63.8			
1640				0.0			

Dist.	Grubbing Avg. End Area (Ft^2)	Additional Cut Area Avg. End Area (Ft^2)	Access Road Fill Avg. End Area (Ft^2)	Ramp Cut Avg. End Area (Ft^2)	A-Rock Avg. End Area (Ft^2)	B-Rock Avg. End Area (Ft^2)	Base Course Avg. End Area (Ft^2)	Grubbing Approx. Vol. (yd^3)	Additional Cut Area Approx Vol (yd^3)	Access Road Fill Approx. Vol. (yd^3)	Ramp Cut Approx. Vol. (yd^3)	A-Rock Approx. Vol. (yd^3)	B-Rock Approx. Vol. (yd^3)	Base Course Approx. Vol. (yd^3)
20.00	6.65	0	17.65	0	0	0	0	4.9	0.0	13.1	0.0	0.0	0.0	0.0
25.00	13.85	0	43	0	0	0	0	12.8	0.0	39.8	0.0	0.0	0.0	0.0
25.00	14	0	44.5	0	0	0	0	13.0	0.0	41.2	0.0	0.0	0.0	0.0
25.00	13.4	0.235	34.75	0	0	0	0	12.4	0.2	32.2	0.0	0.0	0.0	0.0
25.00	13.25	2.235	29.85	0	0	0	0	12.3	2.1	27.6	0.0	0.0	0.0	0.0
25.00	14	2	35.65	0	0	0	0	13.0	1.9	33.0	0.0	0.0	0.0	0.0
10.00	14.8	0	46.5	0	0	0	0	5.5	0.0	17.2	0.0	0.0	0.0	0.0
0.00	34.95	0	116.1	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.00	55.65	0	191.5	0	0	0	0	30.9	0.0	106.4	0.0	0.0	0.0	0.0
25.00	56.5	0	202	0	0	0	0	52.3	0.0	187.0	0.0	0.0	0.0	0.0
25.00	55.55	0	175	0	0	0	0	51.4	0.0	162.0	0.0	0.0	0.0	0.0
25.00	54.2	0.33	147.5	0	0	0	0	50.2	0.3	136.6	0.0	0.0	0.0	0.0
10.00	53.65	2.25	139	0	0	0	0	19.9	0.8	51.5	0.0	0.0	0.0	0.0
0.00	26.65	1.92	65	20.45	4.26	7.35	10.65	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.00	0	0	0	36.3	11.61	15.95	21.3	0.0	0.0	0.0	20.2	6.5	8.9	11.8
25.00	0	0	0	15.85	7.35	8.6	10.65	0.0	0.0	0.0	14.7	6.8	8.0	9.9
25.00	0	0	0	14.35	9.6	9.8	10.65	0.0	0.0	0.0	13.3	8.9	9.1	9.9
25.00	0	0	0	25.7	4.37	7.55	10.65	0.0	0.0	0.0	23.8	4.0	7.0	9.9
25.00	0	0	0	85.5	5.7	9.15	10.65	0.0	0.0	0.0	79.2	5.3	8.5	9.9
25.00	0	0	0	210.5	5.45	8.75	10.65	0.0	0.0	0.0	194.9	5.0	8.1	9.9
25.00	0	0	0	184	0	0	0	0.0	0.0	0.0	170.4	0.0	0.0	0.0
25.00	0	0	0	139.5	0	0	0	0.0	0.0	0.0	129.2	0.0	0.0	0.0
25.00	0	0	0	105.5	0	0	0	0.0	0.0	0.0	97.7	0.0	0.0	0.0
25.00	0	0	0	74	0	0	0	0.0	0.0	0.0	68.5	0.0	0.0	0.0
15.00	0	0	0	31.9	0	0	0	0.0	0.0	0.0	17.7	0.0	0.0	0.0
Total Volume =								279 Cu Yd	5 Cu Yd	848 Cu Yd	829 Cu Yd	37 Cu Yd	49 Cu Yd	61 Cu Yd

Total Cut = 1,113 Cu Yd
Total Fill = 995 Cu Yd

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R. Tedrick

AKV291

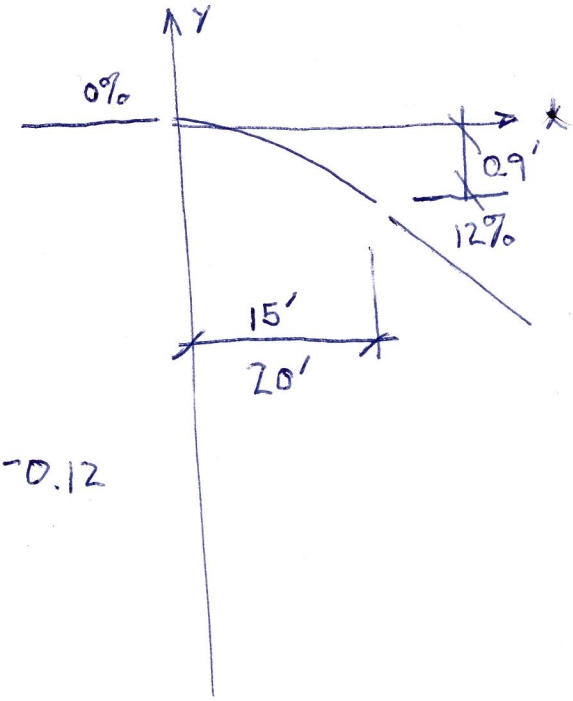
Nondalton

Low Water Elevation ≐ 250'

Bottom of Ramp Elev. ≐ +247' Max.

High Water Elev. ≐ 258'

Top of Ramp Elev. ≐ 259'



$y = -mx^2$

$y'(x) = -2mx$

$y'(x=0) = 0$ ✓

$y'(x=15) = -2m(15) = -0.12$

$m_{15} \doteq 0.004$

$y(x) = -0.004x^2$

$y(15) = -0.9'$

$m_{20} = 0.003$

$y_{20} = -1.2'$

x	y
0	0
1	-0.004
2	-0.016
3	-0.036
4	-0.064
5	-0.100
6	-0.144
7	-0.196
8	-0.256
9	-0.324
10	-0.400
11	-0.484
12	-0.576
13	-0.676
14	-0.784
15	-0.900

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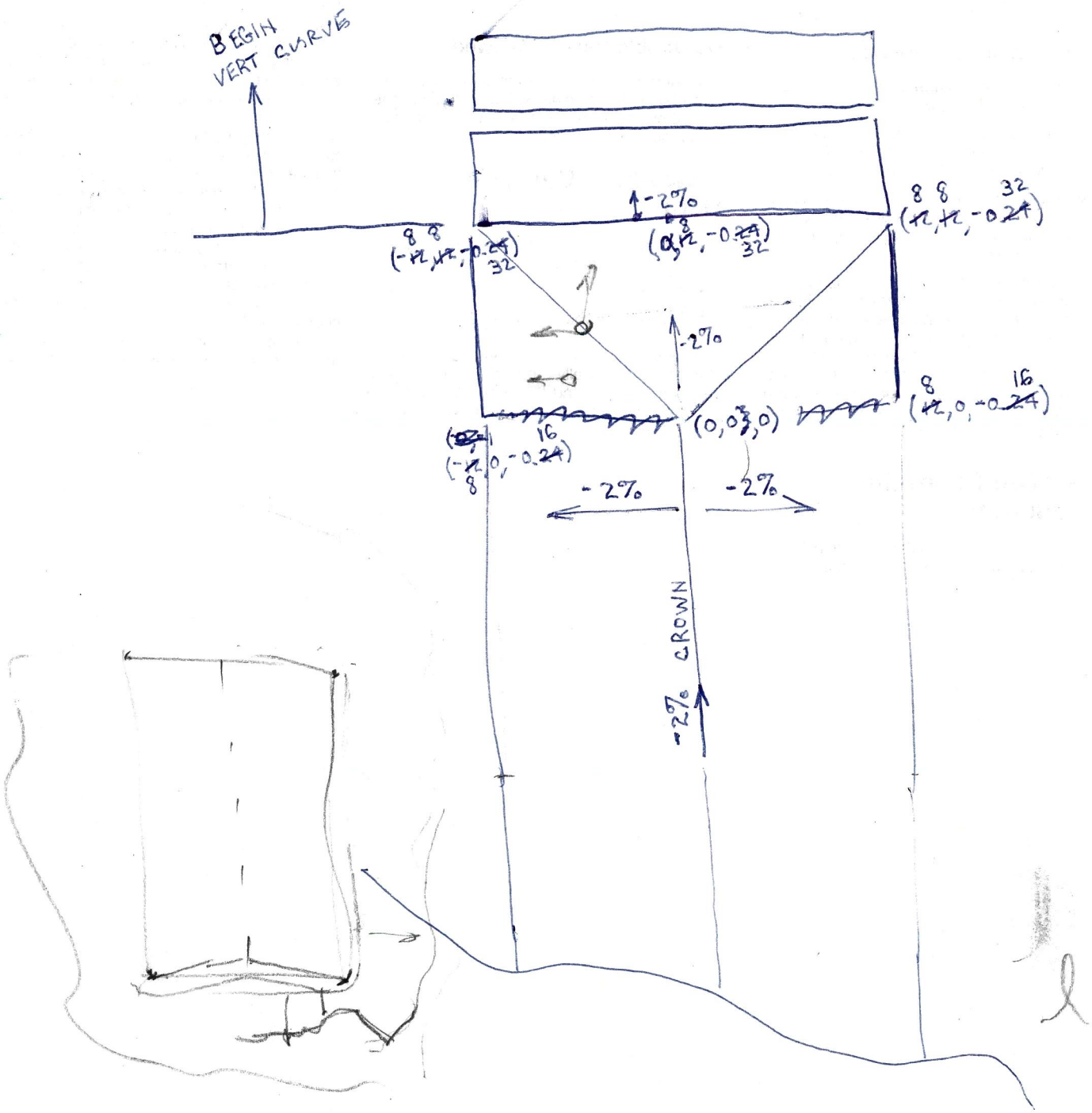

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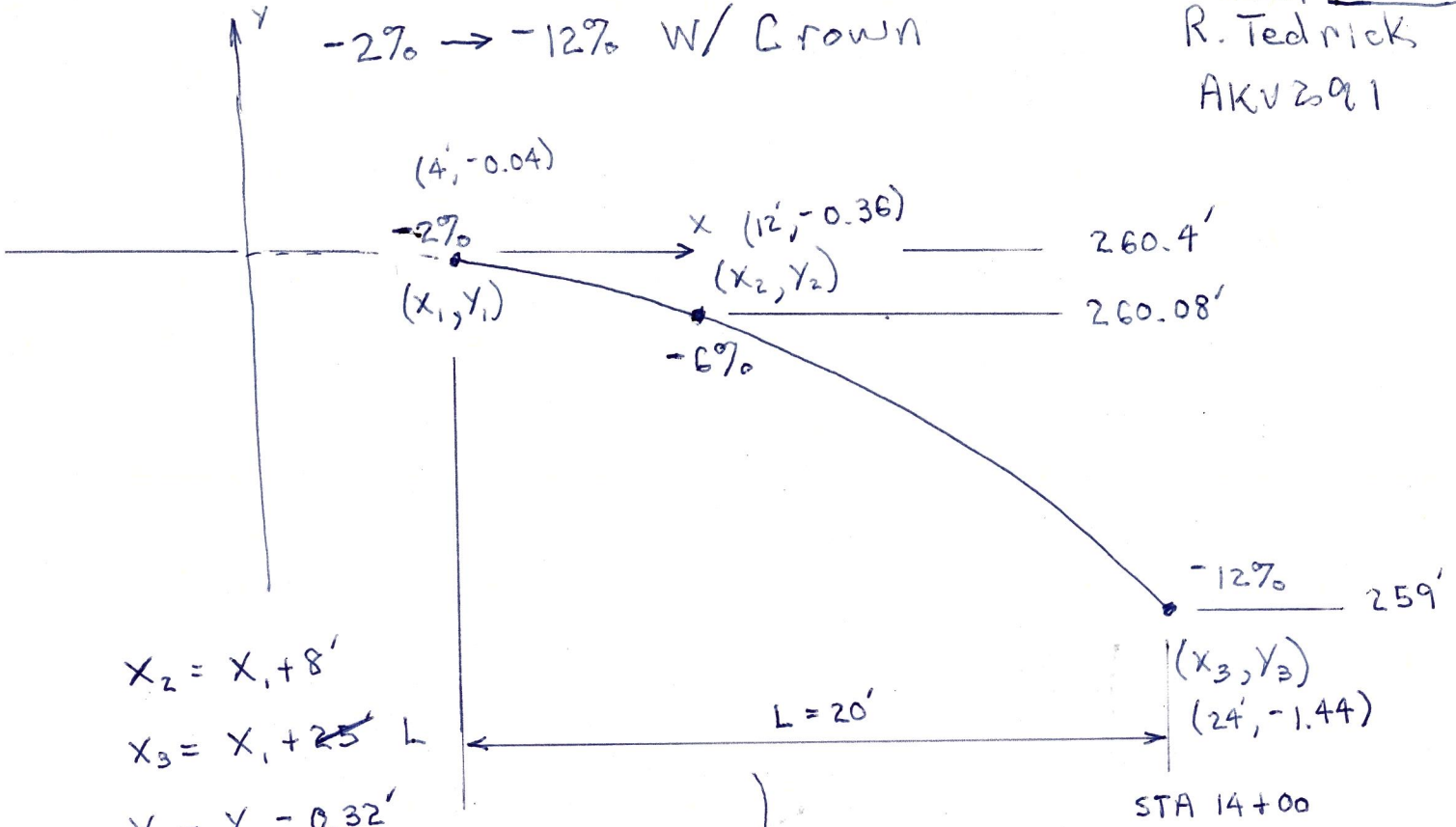
$-2\% \rightarrow -12\%$ W/ Crown



$x_2 = x_1 + 8'$

$x_3 = x_1 + \cancel{25}\ L$

$y_2 = y_1 - 0.32'$

$y'(x_1) = -0.02 \quad y'(x_3) = -0.12$

$y = ax^2 + bx + c$

$y(0) = 0 \Rightarrow c = 0$

$y' = 2ax + b$

$y'(0) = b = 0 \Rightarrow b = 0$

$y = ax^2$

$y' = 2ax$

$2ax_1 = -0.02$

$2a(x_1 + L) = -0.12$

$a(x_1 + 8')^2 = y_1 - 0.32'$

$ax_1^2 = y_1$

$a(x_1^2 + 16x_1 + 64) = y_1 - 0.32$

$y_1 + 16ax_1 + 64a = y_1 - 0.32$

$a = \frac{-0.32}{16x_1 + 64} = \frac{-0.02}{2x_1}$

$\frac{16x_1 + 64}{0.32} = \frac{2x_1}{0.02}$

$50x_1 + 200 = 100x_1$

$x_1 = \frac{200}{50} = 4' \quad y_1 = -0.04'$

$a = -0.0025$

$L = \frac{-0.12}{2a} - x_1 \doteq 20'$

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5/6/11

Vertical Curves

- No Crown

$m_{in} = -6\% = -0.06$

$m_{out} = -12\% = -0.12$

$L = 15'$

General Parabola

$y = ax^2 + bx + c$ see sketch

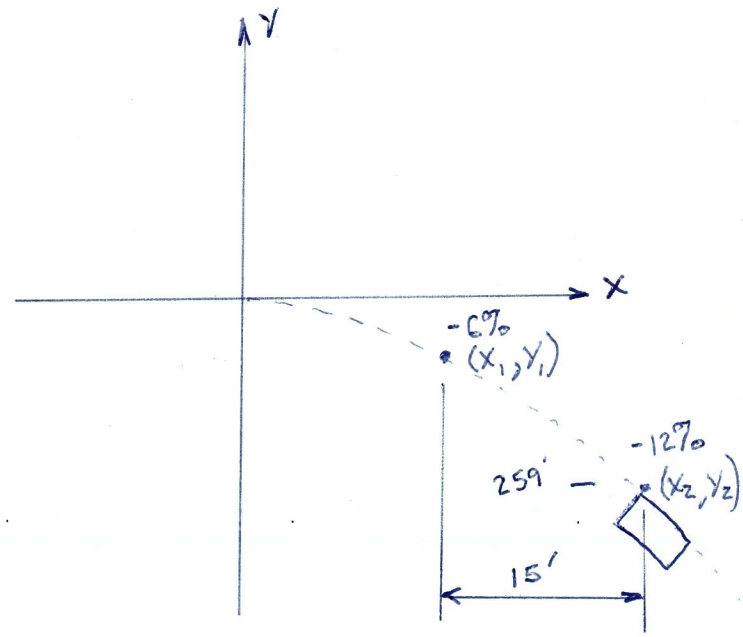
$y' = 2ax + b$

$y(0) = c = 0 \Rightarrow c = 0$

$y'(0) = b = 0 \Rightarrow b = 0$

$y = ax^2$

$y' = 2ax$



$y'(x_1) = 2ax_1 = -0.06$

$y'(x_2) = 2ax_2 = 2a(x_1 + 15') = -0.12$

$x_1 = \frac{-0.06}{2a}$

$2a\left(\frac{-0.06}{2a} + 15'\right) = -0.12$

$-0.06 + 2a \cdot 15' = -0.12$

$a = \frac{-0.06}{30'} = -0.002\ ft^{-1}$

$x_1 = 15'$ $y_1 = -0.45'$

$x_2 = 30'$ $y_2 = -1.8'$

X	Y
15	-0.45
16	-0.512
17	-0.578
18	-0.648
19	-0.722
20	-0.8
21	
22	
23	
24	
25	-1.25
26	
27	
28	
29	
30	-1.8

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$$a = \frac{m_2 - m_1}{2L} \qquad x_1 = \frac{m_1}{2a}$$

$$y_2 = y_1 - 2'$$

$$a x_2^2 = a x_1^2 - 2'$$

$$a(x_1 + L)^2 = a x_1^2 - 2'$$

$$a(x_1^2 + 2x_1 L + L^2) = a x_1^2 - 2$$

$$2a x_1 L + a L^2 = -2'$$

$$\frac{\cancel{2}(m_2 - m_1)}{\cancel{2}\,2}\left(\frac{m_1}{2a}\right) L + \left(\frac{m_2 - m_1}{2L}\right) L^2 = -2$$

$$\frac{m_1(m_2 - m_1)}{\cancel{2}} \cdot \left(\frac{\cancel{2}L}{\cancel{m_2 - m_1}}\right) + \left(\frac{m_2 - m_1}{2}\right) L = -2$$

$$m_1 L + \left(\frac{m_2 - m_1}{2}\right) L = -2$$

$$L\left(m_1 + \frac{m_2}{2} - \frac{m_1}{2}\right) = -2$$

$$L\left(\frac{m_1 + m_2}{2}\right) = -2'$$

$$L = \frac{-4'}{m_1 + m_2} = \frac{2(\Delta)}{m_1 + m_2} \qquad L = 22.\overline{22}'$$

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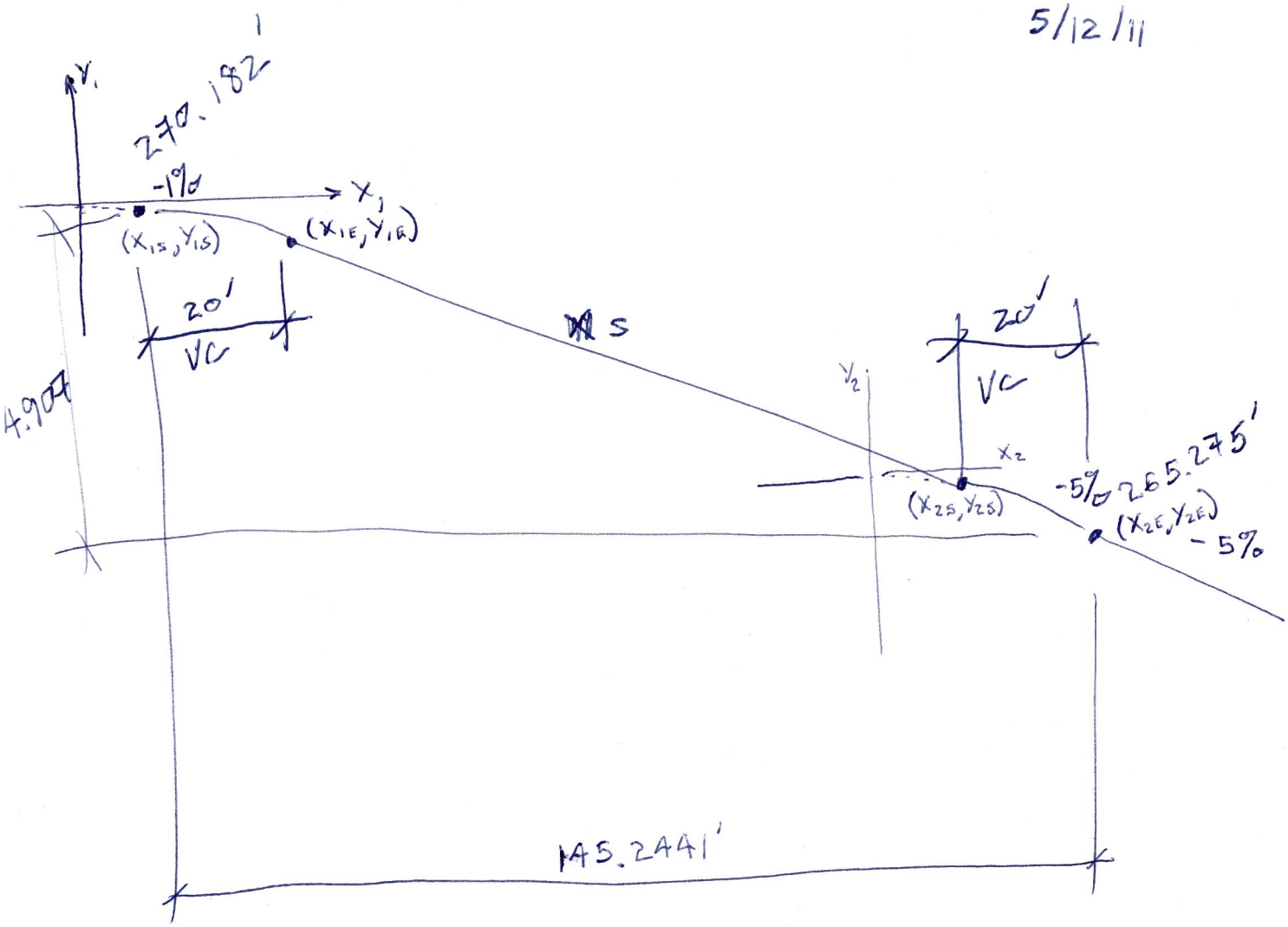

$$a_1 = \frac{m_{out} - m_{in}}{2 \cdot 20'} = \frac{5 - (-0.01)}{40'}$$

$$Y_1 = a_1 X_1^2$$

$$Y_2 = a_2 X_2^2$$

$$a_2 = \frac{m_{out} - m_{in}}{2 \cdot 20'} = \frac{-0.05 - 5}{40'}$$

$$X_{2E} = X_{2S} + 20'$$

$$X_2 = X_1 + X_{1S} + 145.2441' - X_{2E}$$

$$Y_2 = Y_{1S} - 4.907' - Y_{2E} + Y_1$$

$$Y_{1S} - Y_{1E} - S(105.2441') + (Y_{2S} - Y_{2E}) = 4.907'$$

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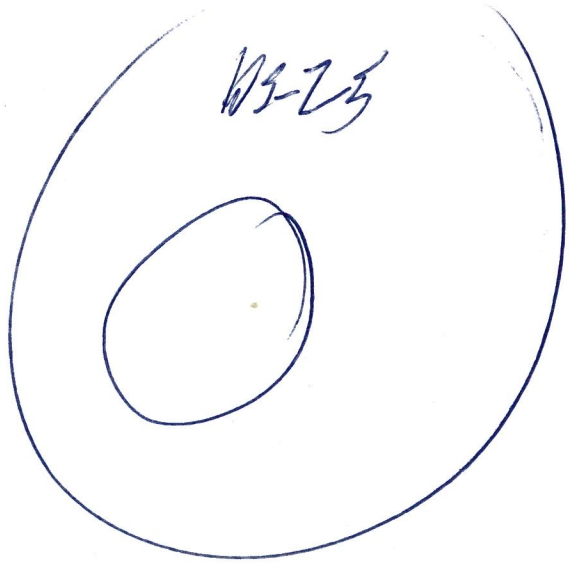
$$a_1 x_{1s}^2 - a_1 (x_{1s} + 20')^2 - s(105.2441')$$

Use Excel and iterate (solver) for solution



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Rubber Shims

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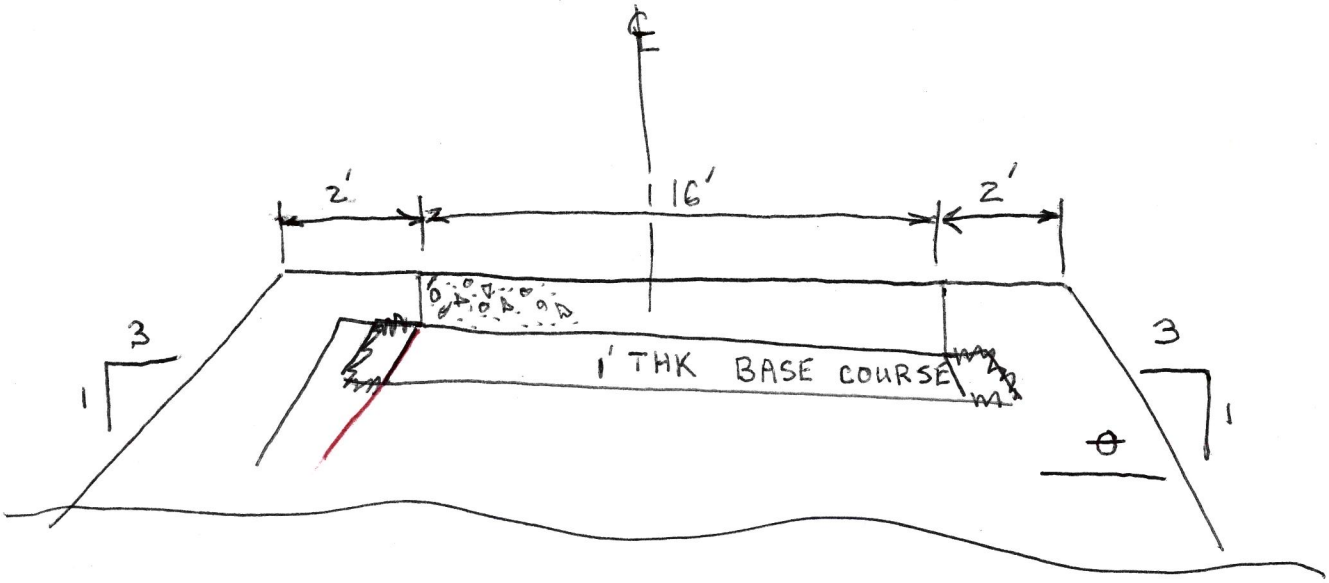
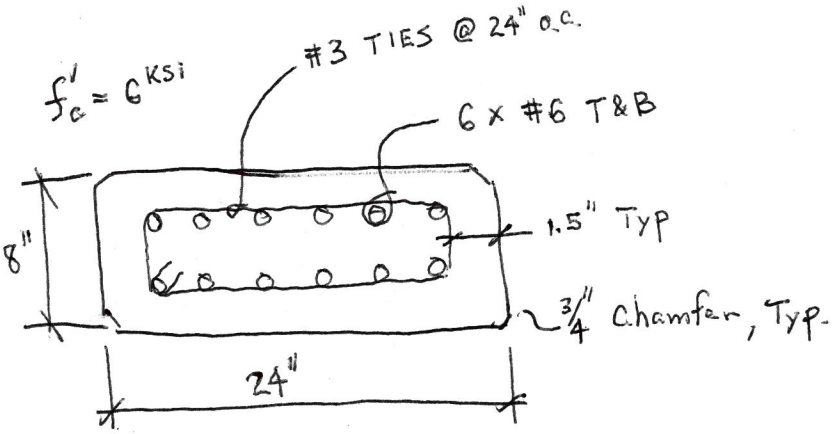
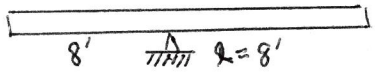




Severe Handling



$$\text{Serv.}M_{max} = \frac{w\ell^2}{2} \doteq \frac{(210\,plf)(8')^2}{2}$$

$$\doteq 6.72^{K\text{-}ft}$$

$$M_u = (1.4)M_{ser} \doteq 9.41^{K\text{-}ft}$$

$\phi M_n = 62.5$ K-ft. from MathCAD

$A_G \doteq 190.875^{\square''}$

$A_c \doteq 184.761^{\square''}$

$A_s \doteq 6.114^{\square''}$

$\gamma_{comb.} \doteq 150$ pcf (guess)

$\gamma_{conc} \doteq 145$ pcf

$\gamma_{STL} = 490$ pcf

$W_{comb} \doteq 198.828$ plf

$W_{conc.} \doteq 186.044$ plf

$W_{STL} \doteq 20.805$ plf

$+ W_{conc+STL} \doteq 206.849$ plf

$\gamma_{comb-calc} \doteq 156$ ~~plf~~ pcf

Use $W \doteq 210$ plf

Pick Points

Plain Conc.

$M_n = 5\sqrt{f'_c}\, S_m$

$S_m \doteq 256\ in^3$

$M_n \doteq 8.26^{K\text{-}ft}$

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Nondalton
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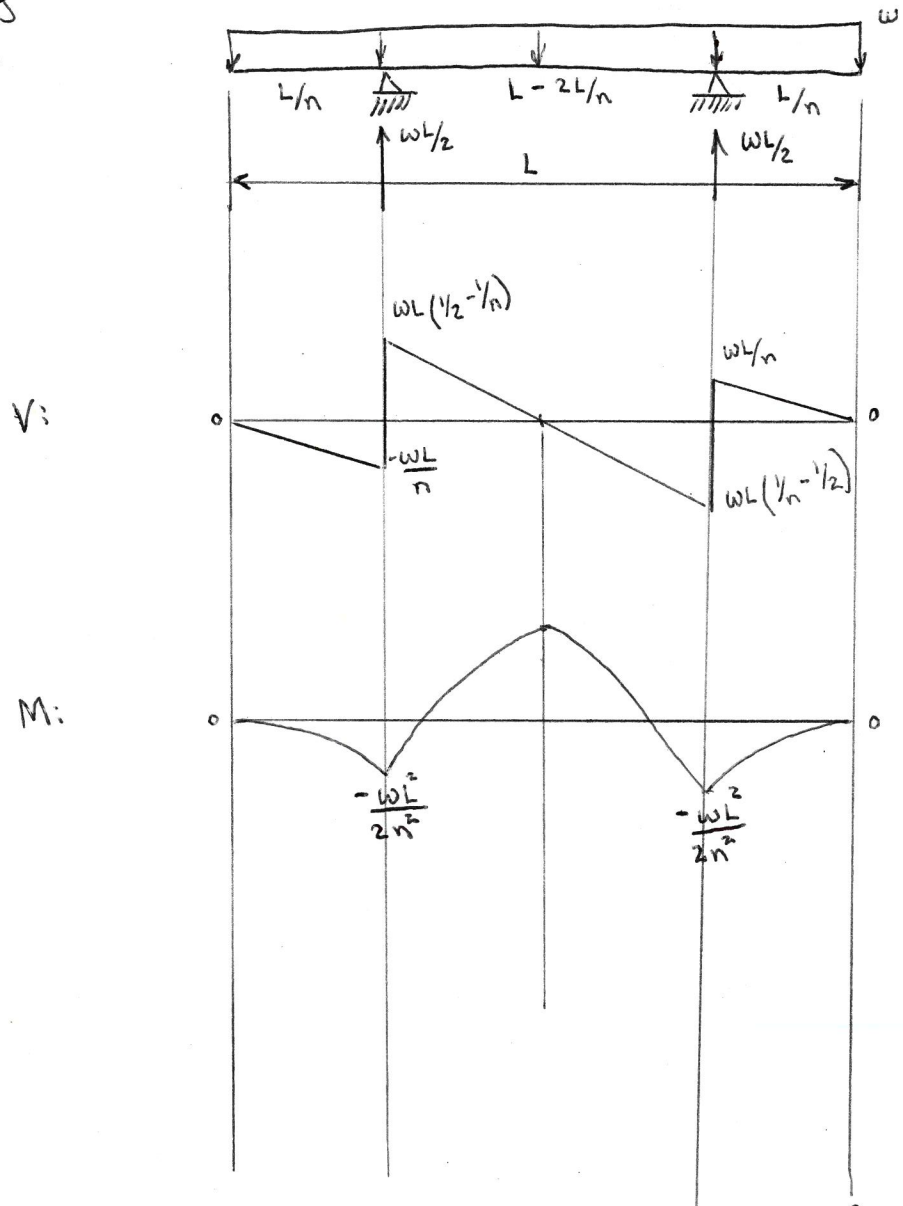
~~integer~~
$n \geq 3$



Use

$n = 5$

$M_{supp} \doteq -1.075^{K\text{-}ft}$

$M_{mid} \doteq 1.344^{K\text{-}ft}$

$n = 4.828$ Theoretical Balance

$M_{supp} \doteq -1.153^{K\text{-}ft}$

$M_{mid} \doteq 1.152^{K\text{-}ft}$

$n = 4$

$M_{supp} \doteq -1.68^{K\text{-}ft}$

$M_{mid} \doteq \emptyset$

$$M_{mid} = -\frac{wL^2}{2n^2} + \frac{wL(1/2 - 1/n)}{2}\left(\frac{L}{2} - \frac{L}{n}\right)$$

$$= -\frac{wL^2}{2n^2} + \frac{w}{2}\left(\frac{L}{2} - \frac{L}{n}\right)^2$$

$$= -\frac{wL^2}{2n^2} + \frac{wL^2}{2}\left(1/2 - 1/n\right)^2$$

$$= \frac{wL^2}{2}\left[(1/2 - 1/n)^2 - 1/n^2\right]$$

$$= \frac{wL^2}{2}\left(1/4 - 1/n + 1/n^2 - 1/n^2\right)$$

$$= \frac{wL^2}{2}\left(1/4 - 1/n\right)$$

$\frac{wL^2}{2n^2} \overset{\text{set}}{=} \frac{wL^2}{2}(1/4 - 1/n)$; divide by $wL^2/2$

$\therefore\ 1/n^2 = (1/4 - 1/n)$; multiply by $4n^2$

$4 = n^2 - 4n$

$n^2 - 4n - 4 = 0$

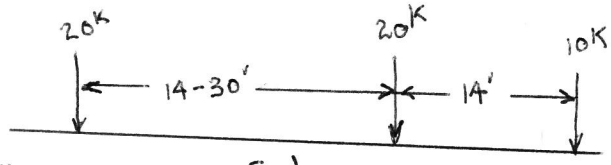
$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\frac{4 \pm \sqrt{16 + 16}}{2} = \frac{4 \pm 4\sqrt{2}}{2} = 2 \pm 2\sqrt{2}$$

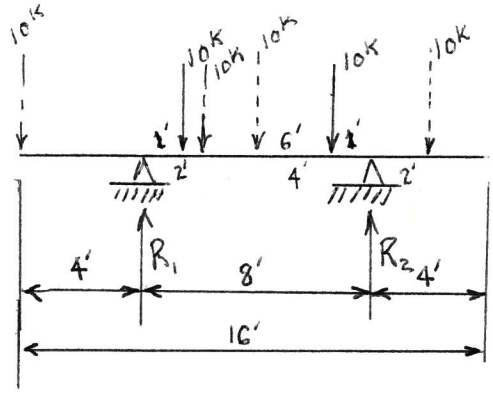
only positive solution is meaningful

$n = 4.828$

AASHTO
HS25-44 Truck



Side



$W_{DL} \doteq 210$ plf

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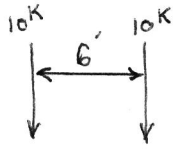
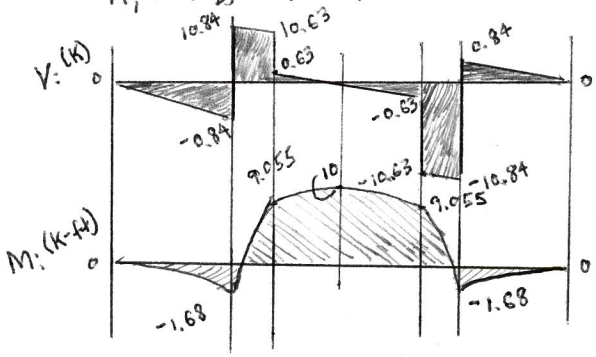


Load Case A: Truck Centered in between supports:

$$R_1 = R_2 = 10^K + DL = 10^K + 8'(0.21\,K/f) \doteq 11.68^K$$



$V_{max_A} \doteq \pm 10.84^K$

$M_{max_A} \doteq 10^{K\text{-}ft}$

$M_{min_A} \doteq -1.68^{K\text{-}ft}$

Load Case B: Truck ~~Cent~~ w/ One Wheel Centered between Supports

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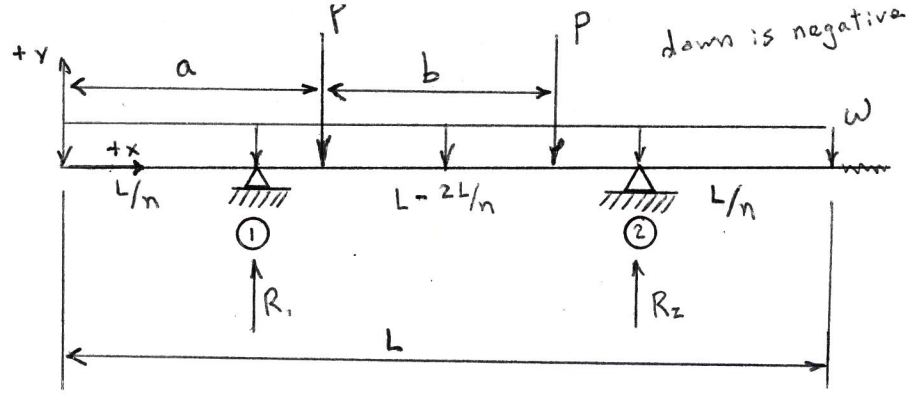


$$\text{Load} = \frac{d^4y}{dx}$$

$$\text{shear} = \frac{d^3y}{dx}$$

$$\text{Moment} = \frac{d^2y}{dx^2}$$

$0 \le a \le L - b$

$2 < n < \infty$

Case I:

$a + b \le L/n$

$$+\circlearrowleft \sum M_1 = 0 : \quad +\left(L/n - a\right)P + \left(L/n - a - b\right)P + {}^{-}\frac{wL}{2}\left(L - 2L/n\right) - R_2\left(L - 2L/n\right) = 0$$

$$R_2 = {}^{-}\frac{wL}{2} + \frac{P\left(2L/n - 2a - b\right)}{L - 2L/n}$$

$$+\circlearrowleft \sum M_2 = 0 : \quad +\left(L - L/n - a\right)P + \left(L - L/n - a - b\right)P + \frac{wL}{2}\left(L - 2L/n\right) + R_1\left(L - 2L/n\right) = 0$$

$$R_1 = {}^{-}\frac{wL}{2} + {}^{-}\frac{\left(2L - 2L/n - 2a - b\right)P}{L - 2L/n}$$

$$\frac{d^4y}{dx^4} = +w \; ; \quad \frac{d^3y}{dx^3} = wx + c_1 ; \quad 0 \le x \le a, \; c_1 = 0 \text{ K}$$

$a < x \le a + b, \; c_1 = P$

$a + b < x \le L/n, \; c_1 = 2P$

$L/n < x \le L - L/n, \; c_1 = 2P + R_1$

$L - L/n < x \le L, \; c_1 = 2P + R_1 + R_2$

$$\frac{d^2y}{dx^2} = M(x) = \frac{wx^2}{2} + c_1 x + c_2 ; \quad 0 \le x \le a, \; c_2 = 0 \text{ K-ft}$$

$a < x \le a + b, \; c_2 = -Pa$

$$\left\{ \begin{array}{l} \frac{w(a+b)^2}{2} + P(a+b) - Pa \\ = \frac{w(a+b)^2}{2} + 2P(a+b) - 2Pa - Pb \end{array} \right\} \quad a + b < x \le L/n, \; c_2 = -2Pa - Pb$$

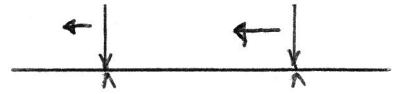
$L/n < x \le L - L/n, \; c_2 = -2Pa - Pb - R_1 L/n$

$$\left\{ \begin{array}{l} \frac{w(L/n)^2}{2} + 2PL/n - 2Pa - Pb \\ = \frac{w(L/n)^2}{2} + 2PL/n + R_1 L/n - 2Pa - Pb - R_1 L/n \end{array} \right. \quad L - L/n < x \le L, \; c_2 = -2Pa - Pb - R_1 L/n - R_2\left(L - L/n\right)$$

$$\left\{ \begin{array}{l} \frac{w(L - L/n)^2}{2} + (2P + R_1)(L - L/n) - 2Pa - Pb - R_1 L/n \\ = \frac{w(L - L/n)^2}{2} + (2P + R_1 + R_2)(L - L/n) - 2Pa - Pb - R_1 L/n - R_2\left(L - L/n\right) \end{array} \right.$$

Case II: $L/n <$

$a \le L/n$ & $a+b \le L - L/n$



$+\circlearrowleft M_1 = 0 \therefore$ $P(L/n - a) - P(a+b-L/n) - \frac{wL}{2}\left(L - \frac{2L}{n}\right) - R_2\left(L - \frac{2L}{n}\right) = 0$

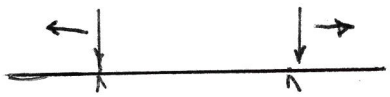
$$R_2 = -\frac{wL}{2} + \frac{P\left(\frac{2L}{n} - 2a - b\right)}{L - \frac{2L}{n}}$$

$V(x) = wx + C_3$;

$0 \le x \le a$,	$C_3 = 0$ K	$C_4 = 0$ K-ft
$a < x \le \frac{L}{n}$,	$C_3 = P$	$C_4 = -Pa$
$\frac{L}{n} < x \le a+b$,	$C_3 = P + R_1$	$C_4 = -Pa - R_1 L/n$
$a+b < x \le L - L/n$,	$C_3 = 2P + R_1$	$C_4 = -2Pa - R_1 L/n - Pb$
$L - L/n < x \le L$,	$C_3 = 2P + R_1 + R_2$	$C_4 = -2Pa - R_1 L/n - Pb - R_2(L - L/n)$

Case III:

$a \le L/n$ & $a+b > L - L/n$



$V(x) = wx + C_5$;

	C_5 (K)	C_6 (K-ft)
$0 \le x \le a$	$C_5 = 0^K$	$C_6 = 0$ K-ft
$a < x \le L/n$	$C_5 = P$	$-Pa$
$L/n < x \le L - L/n$	$P + R_1$	$-Pa - R_1 L/n$
$L - L/n < x < a+b$	$P + R_1 + R_2$	$-Pa - R_1 L/n - R_2(L - L/n)$
$a+b < x \le L$	$2P + R_1 + R_2$	$-2Pa - Pb - R_1 L/n - R_2(L - L/n)$

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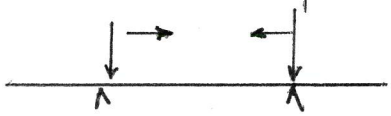
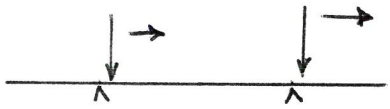
Case IV:

$a > L/n$ & $a+b \le L - L/n$



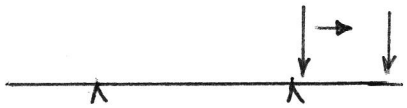
Case V:

$L/n < a \le L - L/n$ & $a+b > L - L/n$



Case VI:

$a > L - L/n$ & $a+b \le L$



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Bolt Size	A Outside Diameter	T Thickness Gauge	Weight In Pounds Per 100 Pieces
3/8	2-1/2	1/4	18
1/2	2-1/2	1/4	22
5/8	2-3/4	5/16	32
3/4	3	7/16	42
7/8	3-1/2	7/16	55
1	4	1/2	69
1-1/8	4-1/2	1/2	96
1-1/4	5	9/16	121
1-1/2	6	3/4	187

Reference ASTM A47 for general casting information

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