14.485 Capstone Design
Civil and Environmental Engineering

Spring 2014 | Section 201 | Team #1

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BRIDGE DESIGN INTRODUCTION

2014 Capstone Project: Design Brimfield, MA, Kings Bridge Road Replacement Bridge.

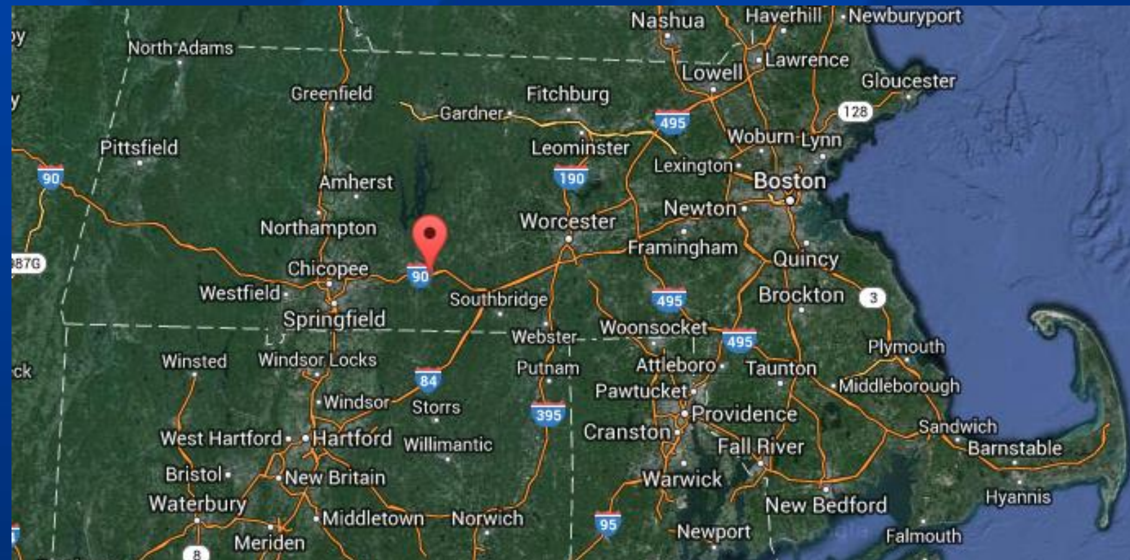
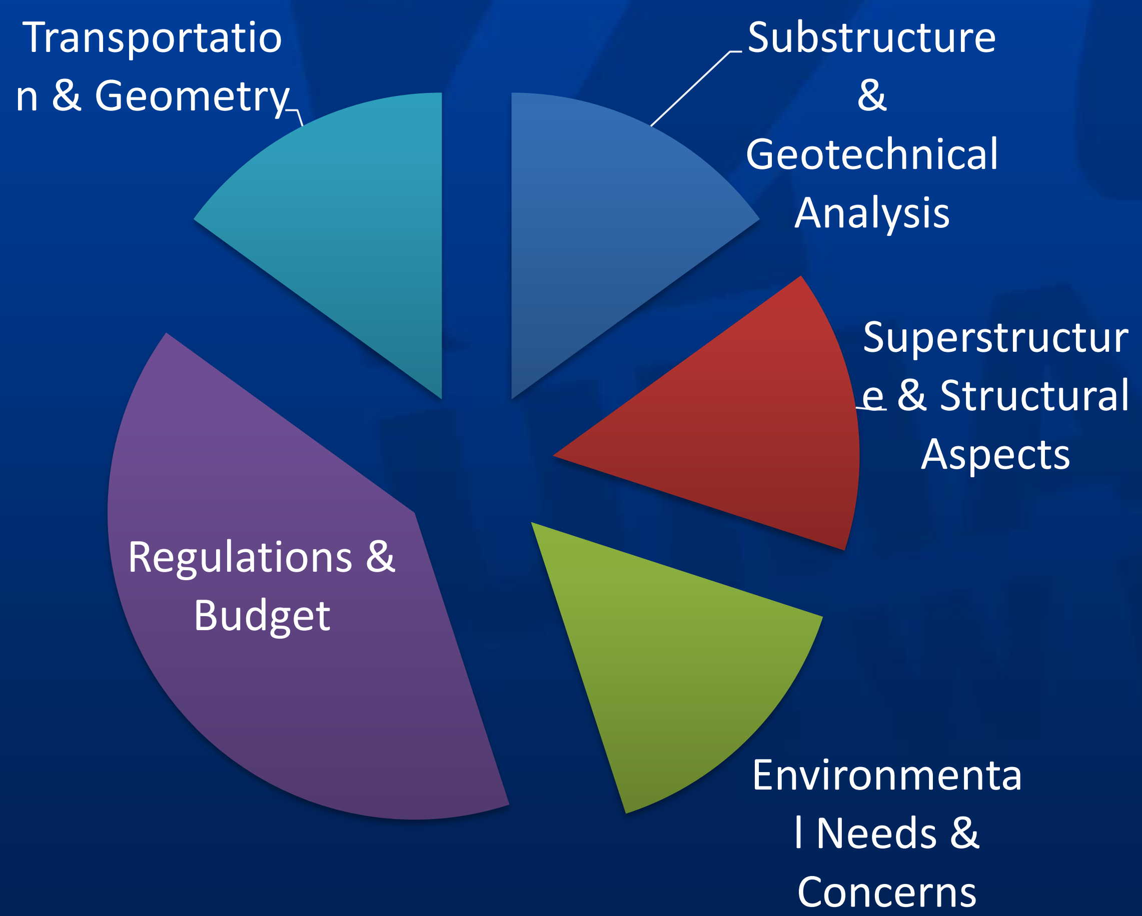


Figure 2. Overview of Massachusetts and Brimfield, MA.

Figure 1. Aerial View of Kings Bridge Rd.

BRIDGE DESIGN INTRODUCTION



Transportation

Presented by: Thomas Duval, E.I.T.

HIGHWAY & BRIDGE GEOMETRY

- **Bridge Span:** 170′
- **Bridge Cross Section:** 86′9″ composed of –
  - 4 Lanes @ 12′-0″
  - 2 Shoulder/ Bicycle Lanes @ 10′-0″
  - 2 Sidewalks @ 8′0″
  - S3-PL2 Bridge Rail @ 16.5″
- **Substructure:** Strip Abutment
- **Superstructure:** Single Span Composite Steel Plate Girders with Reinforced Concrete Deck
- **Environmental:** 100-year flood clearance and wetland area.

HIGHWAY & BRIDGE GEOMETRY

Thermal Movement

MassDOT LRFD 3.1.8.1 defines the max one-way thermal movement for design of structural components to be:

$$\delta T = L\alpha\Delta T$$

L = (170 ft / 2)(12 in) = 1,020 in

α = 6.5 x 10^6 (coefficient of thermal expansion for structural steel)

ΔT = 100° F (temp. fall from assumed ambient temp. of 70° F)

$$\delta T = 0.7 \text{ in}$$

HIGHWAY & BRIDGE GEOMETRY

Depth of Girder:

- **Minimum Depth = 0.033L**
- **Overall Depth of Comp. Beam = 0.040L**

0.033(170 ft)(12 in / ft) = 68 in
0.040(170 ft)(12 in /ft) = 84 in
84 in - 8 in (deck) = 76 in = 6.3 ft

HIGHWAY & BRIDGE GEOMETRY

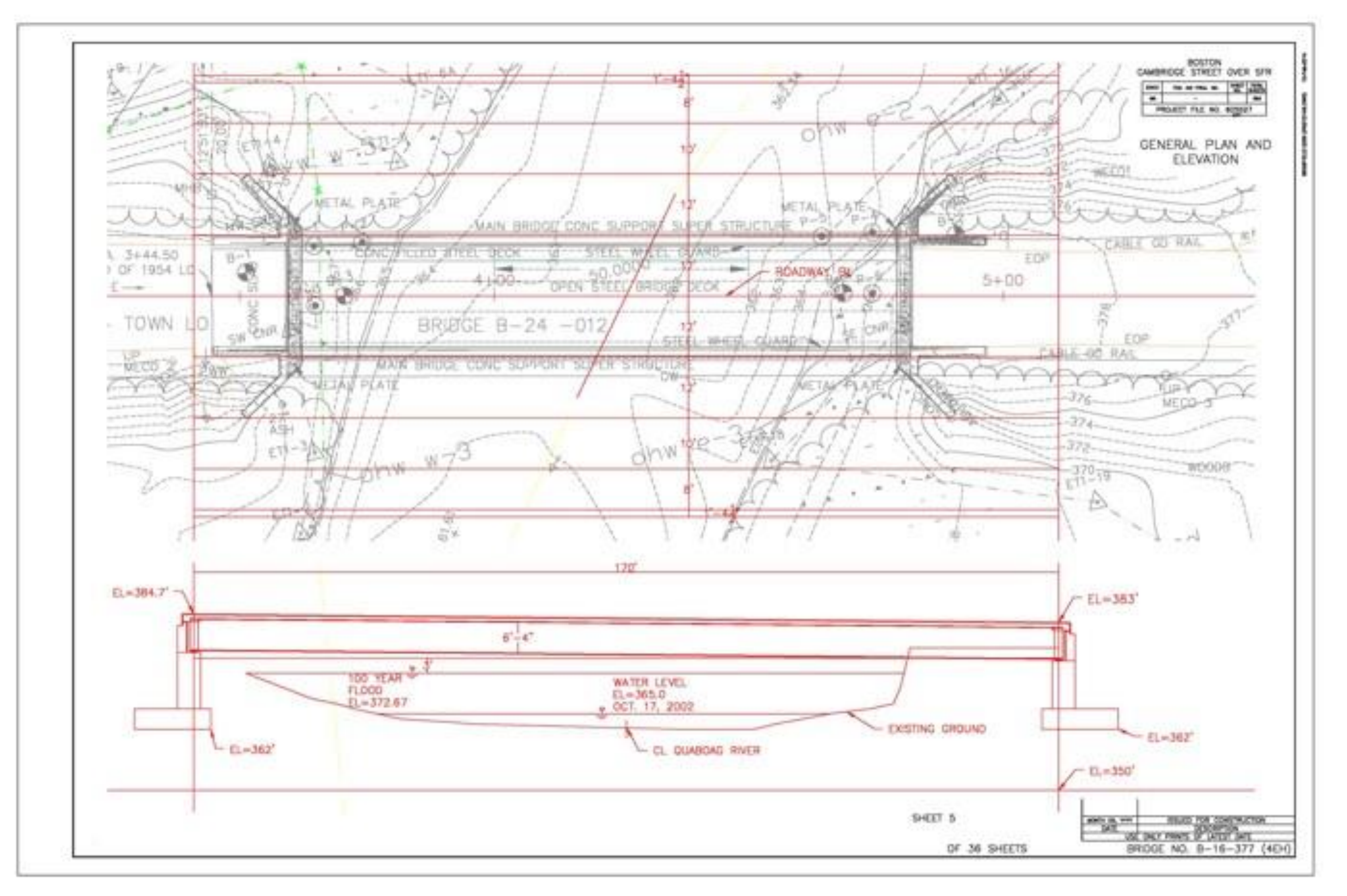


Figure 3. *General Plan and Elevation*

HIGHWAY & BRIDGE GEOMETRY

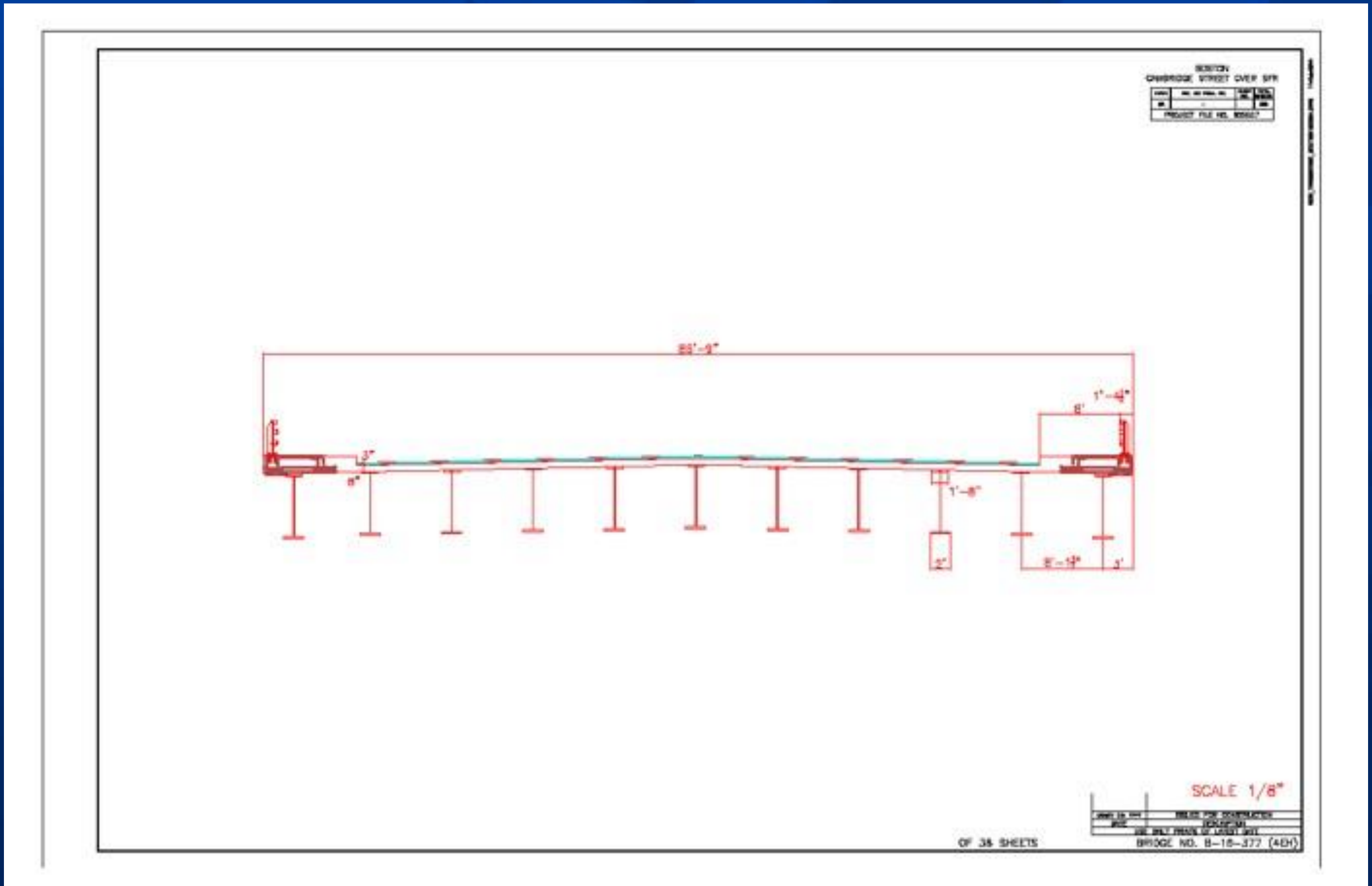


Figure 4. *Transverse Section of Bridge*

Geotechnical

Presented by: Thomas Duval, E.I.T.
Ana Gouveia, E.I.T.

GEOTECHNICAL ENGINEERING

Corrections to SPT N Values

$N_{measured}$ = Raw SPT Value from Field Test (ASTM D1586-11)

Energy correction:

N_{60} = Corrected N Values Corresponding to 60% Energy Efficiency

$$N_{60} = C_E C_B C_S C_R N_{measured}$$

- C_E = Energy Ratio
- C_B = Borehole Diameter
- C_S = Sampling Method
- C_R = Rod Length

Normalizing correction:

$(N_1)_{60}$ = N_{60} Values Normalized to 1 Atmosphere Overburden Stress

$$(N_1)_{60} = C_N N_{60}$$

- $C_N = (P_a/\sigma'_{VO})^n$
- P_a = Atmospheric Pressure (1 atm = 14.7 psi = 2116 psf)
- σ'_{VO} = Insitu Vertical Effective Stress (n = 0.5 to 0.6 for sands)

Effective Friction Angle

- Effective Friction Angle, ϕ' , Calculated with Meyerhoff (1996) Correlations:

$$\phi' = [15.4(N_1)_{60}]^{(1/2)} + 20^{\circ}$$

$$\phi' = 37^{\circ} \text{ (Averaged)}$$

GEOTECHNICAL ENGINEERING

General Bearing Capacity Equation

$$q_u = \underbrace{c'N_cF_{cs}F_{cd}F_{ci}}_{\text{Cohesion Component}} + \underbrace{qN_qF_{qs}F_{qd}F_{qi}}_{\text{Surcharge Component Soil Above Footing}} + \underbrace{0.5\gamma BN_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i}}_{\text{Soil Component Soil Below Footing}}$$

Where:

c' = Soil Cohesion N_c = Bearing Capacity Factor - Cohesion

q = Surcharge = $D_f\gamma$ N_q = Bearing Capacity Factor - Surcharge

γ = Soil Unit Weight N_γ = Bearing Capacity Factor – Soil B = Footing Width

F_{cs}, F_{qs}, $F_{\gamma s}$ = Shape Factors

F_{cd}, F_{qd}, $F_{\gamma d}$ = Depth Factors

F_{ci}, F_{qi}, $F_{\gamma i}$ = Inclination Factors

Figure 5. *Bearing Capacity Equation ((Meyerhof, 1963) Hajduk, 2014)*

Section	ϕ' (deg)	N_q	N_γ	F_{qs}	$F_{\gamma s}$	F_{qd}	$F_{\gamma d}$
1	37	42.9	66.2	1.05	0.97	1.08	1

F_{ci}	F_{qi}	$F_{\gamma i}$
1	1	1

Figure 6. *Shape, Depth, and Inclination Factors*

Bearing Resistance of Soil

- $\varphi_b = 0.45$
- $q_n = q_u = 52.6$ ksf
- $q_R = 23.67$ ksf

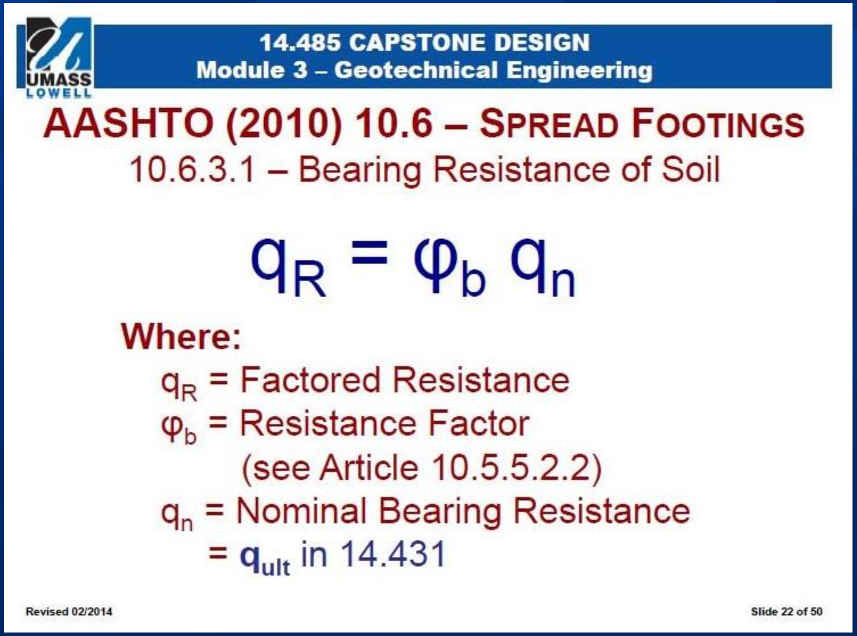


Figure 7. *Bearing Resistance of Soil Equation ((AASHTO 10.6, 2010) Hajduk, 2014)*

GEOTECHNICAL ENGINEERING

Calculation of Applied Vertical Stress

- Given Maximum Settlement, S_e, of 1 in, Elastic Half-Space Method Used to Calc. Applied Vertical Stress, q_0
- q_0 = 32.6 ksf

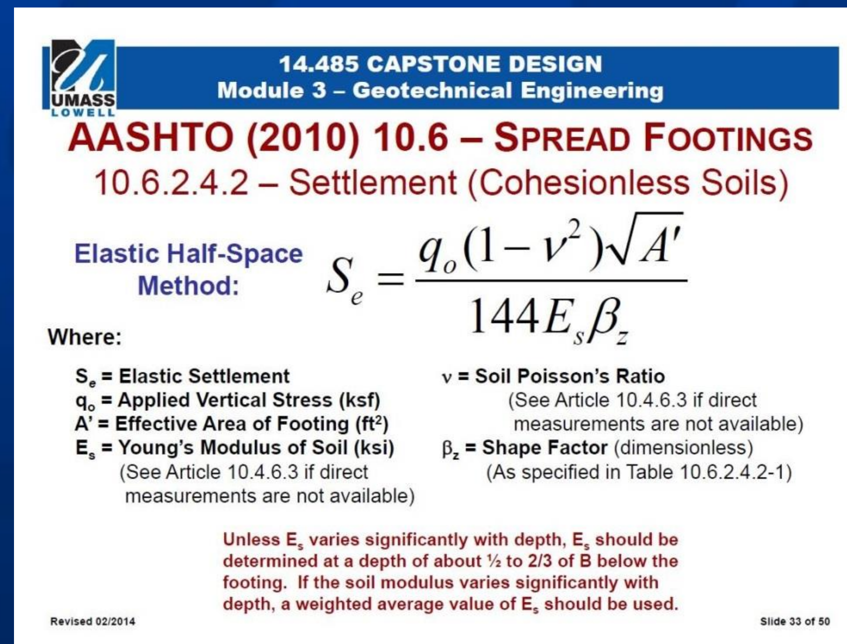


Figure 8. *Elastic Half-Space Settlement Equation ((AASHTO 10.6) Hajduk, 2014)*

ABUTMENT DESIGN

- **Loading Considerations:**
  - Dead Loads: See Figure 3.
  - Live Loads: HL-93 Truck & Lane Load of 640 plf
  - Seismic & Wind Loads: Given
  - Strength I Min. and Service I. Factors Used

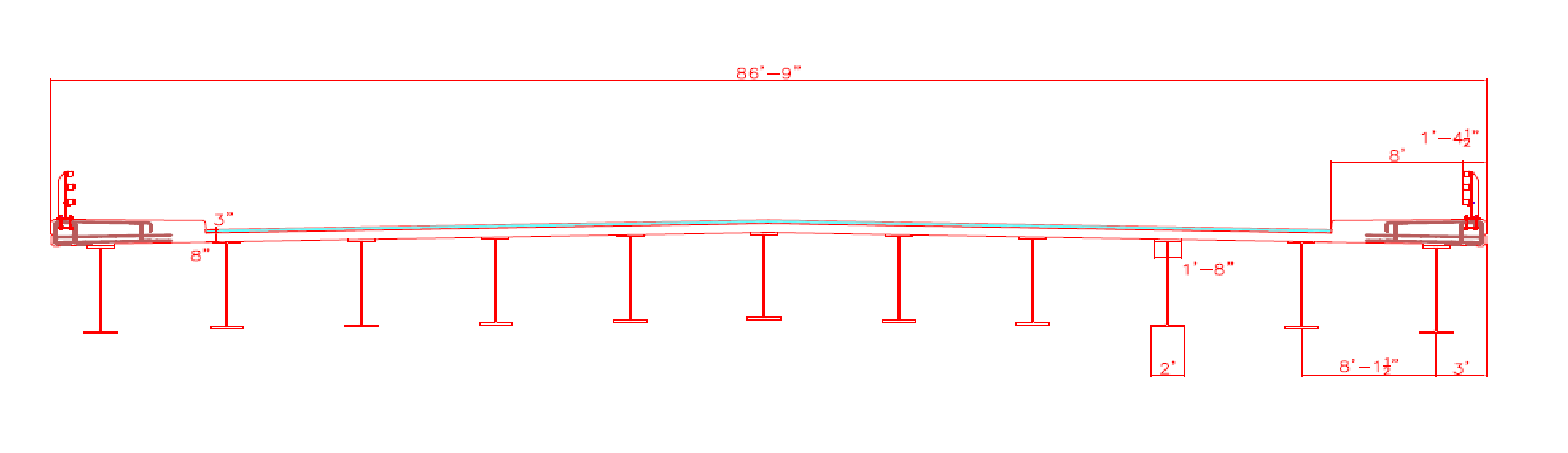


Figure 9. Transverse Section

ABUTMENT DESIGN

- **Abutment Dimensions & Design:**
  - Height: 22′0″
  - Stem Thickness: 4′6″
  - Footing Width: 15′0″
  - Toe Width: 2′0″
  - Footing Thickness: 2′6″

- **Safety Checks:**
  - Earth Pressures, Vertical & Horizontal forces and moments about Toe and Stem were obtained.
  - Results checked stability, eccentricity, bearing and sliding.

Structural

Presented by: Anas Al Sayed Ali

REINFORCED CONCRETE DESIGN

- Determine Reinforcement on Footing according to AASHTO and MassDOT specifications
- Assess 4 specific re-bars within the abutment design:
  - Footing (1)
  - Abutment Stem (1)
  - Abutment Backwall (1)
  - Abutment Bearing Seat (1)
- Check if these reinforcement bars will maintain force loads and bearing pressures of the settlement and concrete

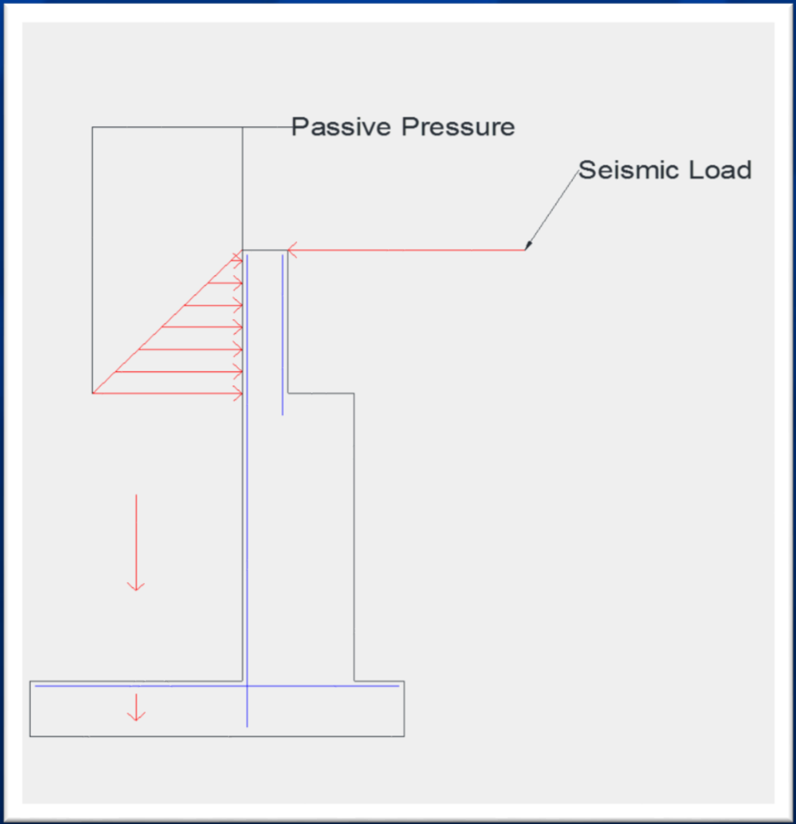


Figure 10. *Abutment Reinforcement Locations*

REINFORCED CONCRETE DESIGN

- Determine Ultimate Moment (M_u)
- Determine Moment of Inertia (I_g)
  - $I_g = (b \times h^3) / 12$
- Determine Section Modulus (S_c)
  - $S_c = I_g / (h/2)$
- Determine Modulus of Rupture (f_r)
  - $F_r = 0.24 \times (fcp)^{0.5}$
- Determine Cracking Moment (M_{cr})
  - $M_{cr} = S_c \times f_r$
  - Compare 1.2* Mcr & 1.33Mu (LRFD)

REINFORCED CONCRETE DESIGN

- Design Moments, Re-bar size and spacing used were determined as follow:

Table 1. Abutment Reinforcement Values

Location	1.33*Mu k-ft	1.2*Mcr k-ft	?Mn k-ft	Rebar	Spacing
Back of Stem wall @ bottom *As(req) = 0.79	90.69	279.94	137.86	#8	12"
Top of Heel *As(req) = 2.25	98.08	86.4	95.7	#12	12"
Inside face of backwall *As(req) = 1.27	58.26	22.3	26.88	#10	12"
Outside face of backwall *As(req) = 2.25	33.89	22.3	26.88	#10	12"

*Check Minimum Temp and Shrinkage Reinforcement Based on 2009 MassDOT BR. Man. 3.1.3

SUPERSTRUCTURE DESIGN

Girder Dimensions:

- **Top flange:** Thickness = 1.5 in
  Width = 20 in
- **Bottom Flange:** Thickness = 2 in
  Width = 24 in
- **Web:** Thickness = 0.75 in
  Depth = 72.50 in
- **Spacing:** 8.08 ft

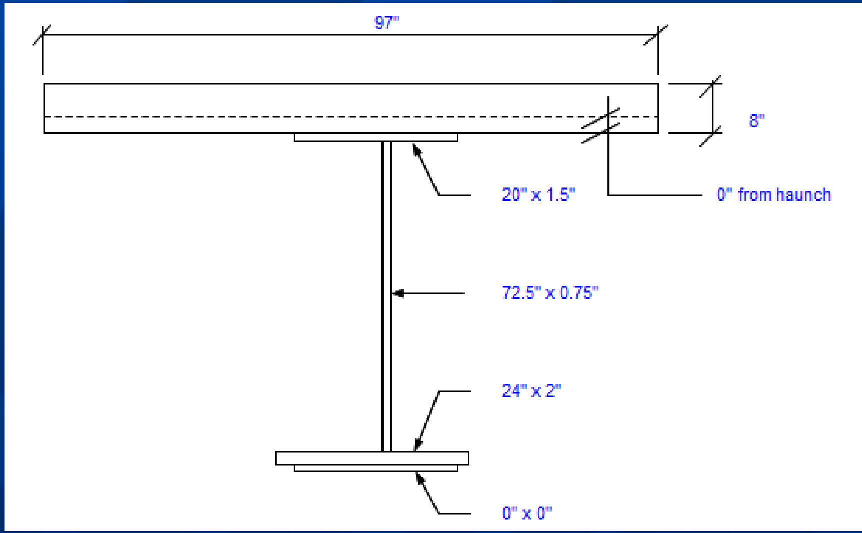


Figure 11. *Composite Steel Beam and Girder Cross-Section*

Concrete Slab Dimensions:

Thickness = 8 in
Effective Width = 97 in

Pavement Dimensions:

Base Pave Thickness = 1.5 in
Surface Pavement = 1.5 in

SUPERSTRUCTURE DESIGN

Material Properties:

- $F'c = 4$ ksi
- F_y (Girder) = 50 ksi
- F_y (rebar) = 60 ksi
- $E_c = 57*(4000)^{1/2}$
- $E_c = 3605$ ksi
- $E_s = 29000$ ksi
- n (E_s/E_c) = 8

SUPERSTRUCTURE DESIGN

Deflection Calculations:

- **Deflection by Dead Load:**

$$\delta = \frac{Wx}{24EI}\left[l^3 - 2lx^2 + x^3\right]$$

- **Deflection by Live Load:**

$$\delta = \frac{Px}{12EI}\left(\frac{3L^2}{4} - x^2\right)$$

Table 2. Total *Deflection results at each of the distances x, ft from the support.*

x(ft)	Deflection (in)
0	0.0000
17	2.4271
34	4.5999
51	6.3118
68	7.4085
85	7.7880
102	7.4006
119	6.2486
136	4.3867
153	2.1349
170	0

Environmental

Presented by: Sarah Shaw

DRAINAGE AND EROSION CONTROL

Objectives:

- **Prepare Roadway Drainage Design for Brimfield/Palmer Bridge End of Site**
  - Determine 10 year storm event peak discharge
  - Compute Hillside, Bridge, & Roadway Drainage Areas
  - Calculate Required Manhole Inlet & Outlet Elevations
  - Compute Required Drainpipe Sizes

DRAINAGE AND EROSION CONTROL

Module 7

Reference: MassDOT Highway Design Guide, 2006, Section 8-110

- **Rational Method:**

$$Q = C\,i\,A$$

where:

Q = peak discharge (cfs)

C = runoff coefficient

i = rainfall intensity (in/hr)

A = drainage area (acres)

DRAINAGE AND EROSION CONTROL

Module 7

- **Runoff Coefficient (C)**
  - MassDOT Exhibit 8-8: hillside coefficient of 0.25 (woodland surface)
  - MassDOT Exhibit 8-9: bridge & roadway surface coefficient of 0.95 (pavement)
- **Drainage Area (A)**
  - Bridge & Roadway Areas: 0.34 acres and 1.34 acres respectively
  - Hillside Area: 95 acres
    - Calculated from AutoCAD
    - Drainage Area Determined from Top of Hillside to Washington Road

DRAINAGE AND EROSION CONTROL

Module 7

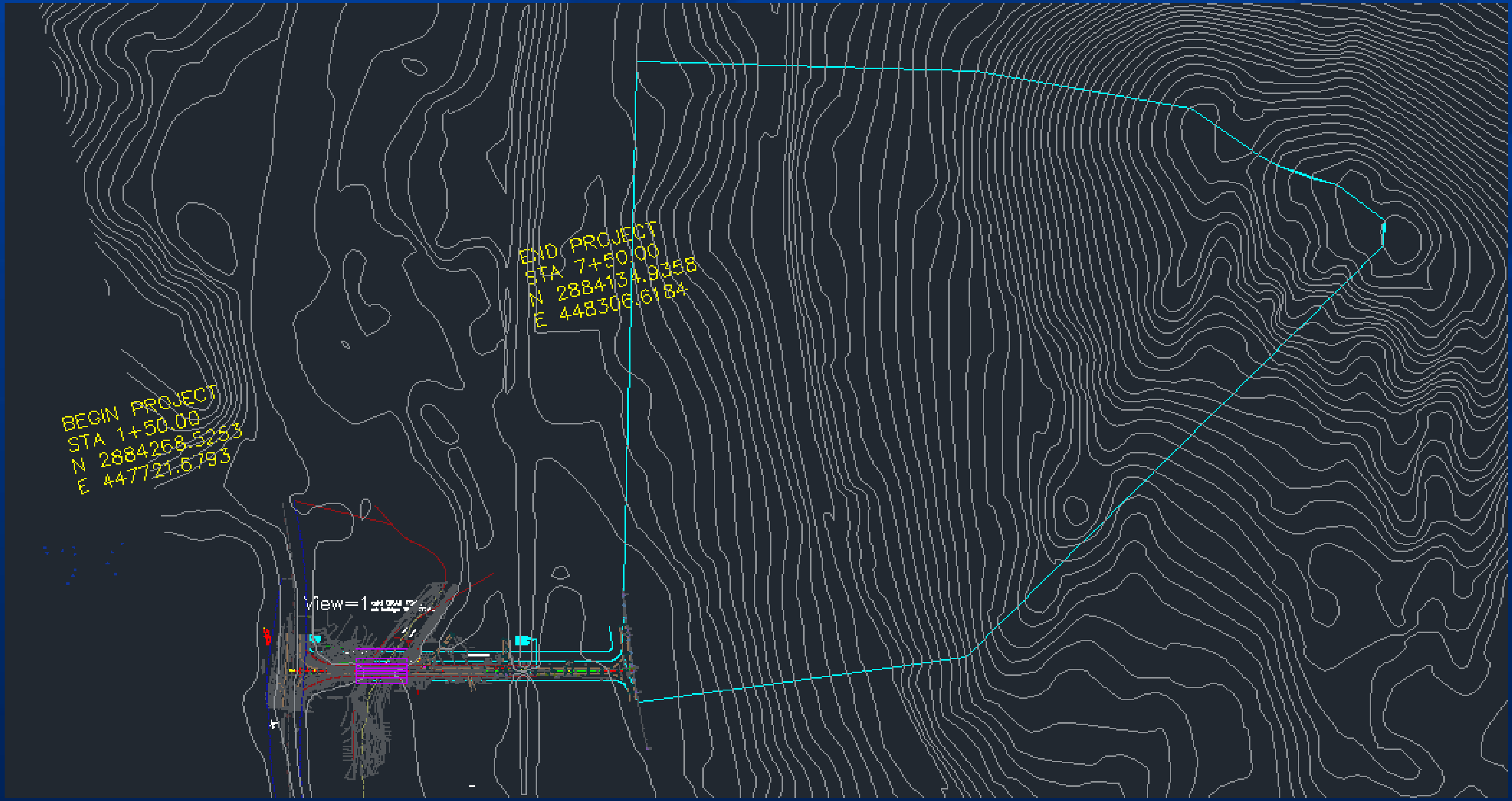


Figure 12. CAD drawing of the Area studied

UMASS LOWELL

DRAINAGE AND EROSION CONTROL

Module 7

Rainfall Intensity (i)

- Hill Drainage Area
  - Watercourse Slope = 21%
  - Exhibit 8-11 Yields Average Velocity of Overland Flow: 1.2 ft/s
  - Travel Time: 53 minutes
  - Exhibit 8-15 Yields: i = **1.9 in/hr**

- **Bridge & Roadway Area**
  - Travel Time: 5 minutes
  - Rainfall Intensity: **6.2 in/hr**

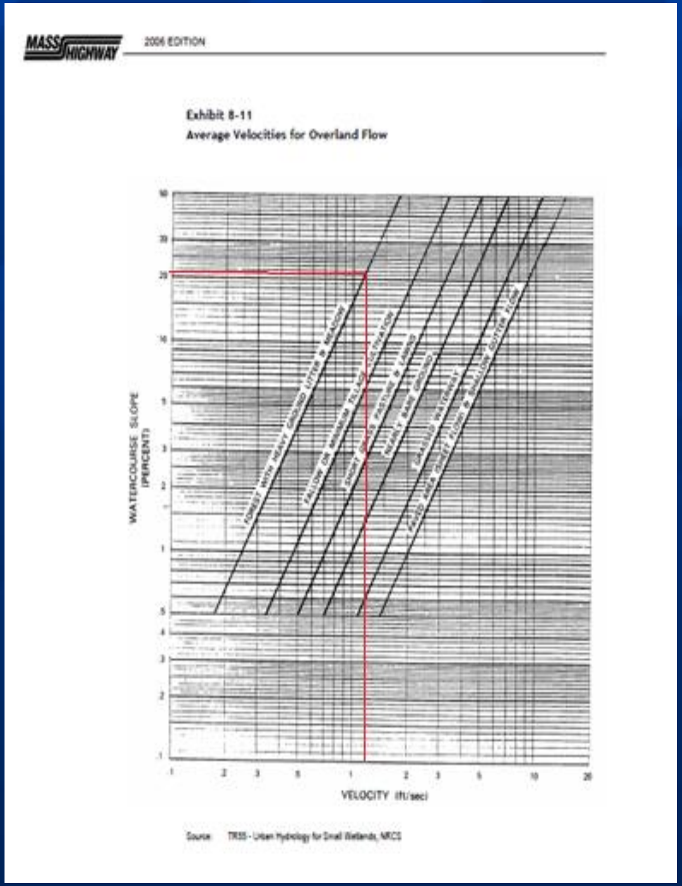


Figure 13. Mass Highway Design Chart

DRAINAGE AND EROSION CONTROL

Peak Discharge Results:

Table 3. Manhole Locations and Runoff values obtained

	MANHOLE LOCATION			RUNOFF					
INLET NO	ROAD	CENTERLINE STATION		SIZE	COEFF				DESIGN RUN OFF
		FROM	TO	A	C	Tc	TOTAL Tc	INTENSITY (i)	Q=CiA
		(ft)	(ft)	(acres)		(min)	(min)	(in/hr)	(cfs)
1	Washington		12+74.35	94.91	0.25	53.1	53.1	1.9	45.1
2	King's Bridge	12+74.35	10+63.93	0.42	0.95	5.0	58.1	6.2	2.5
3	King's Bridge	10+63.93	08+50.35	0.43	0.95	5.0	63.1	6.2	2.5
4	King's Bridge	08+50.35	07+11.91	0.28	0.95	5.0	68.1	6.2	1.6
5	King's Bridge	07+11.91	05+10.91	0.21	0.95	5.0	73.1	6.2	1.3

DRAINAGE AND EROSION CONTROL

Module 7

- Inlet/Outlet Elevations

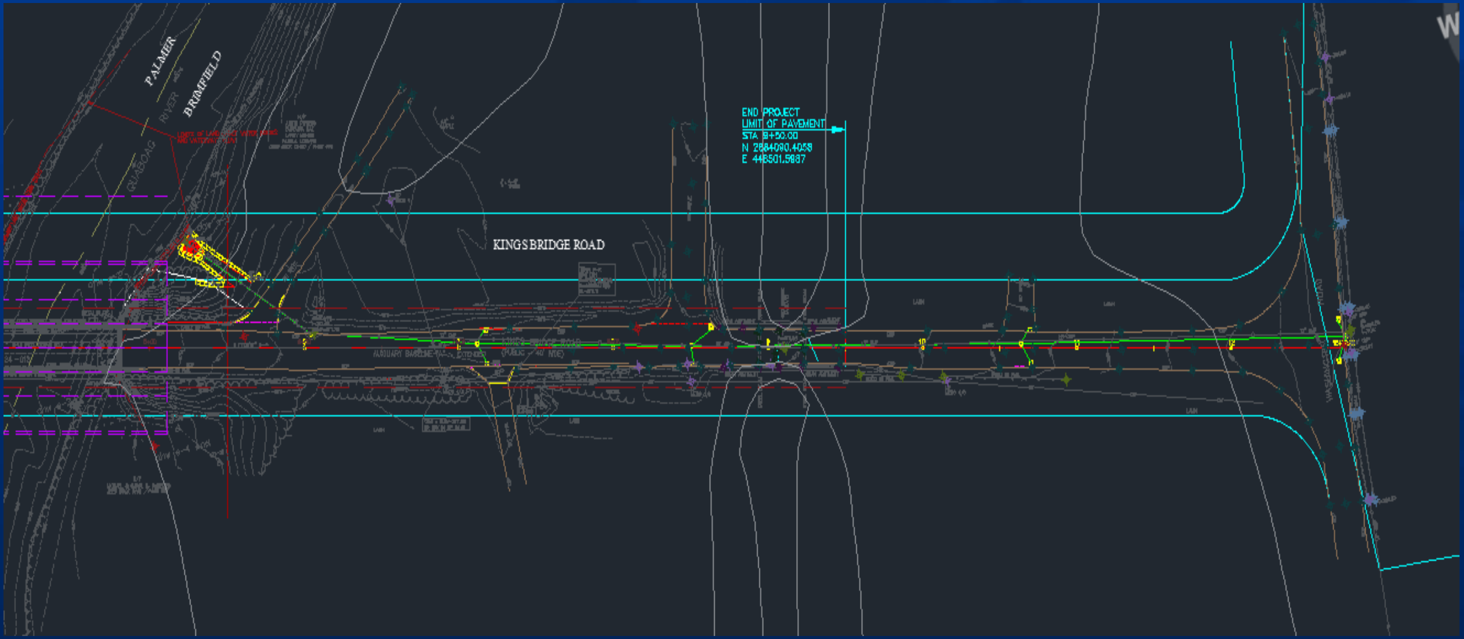


Figure 14. Mass Highway Design Chart

DRAINAGE AND EROSION CONTROL

Module 7

- Initial Ground Elevation, MH1: 383.4'
- 3' Ground Cover
- 1% Total Downward Drainage Slope Along Roadway
- Manhole 8' Depth
- Elevation of Final MH Lower Invert: 369.3'
- River Elevation Near MH5: 365'

Table 4. Manhole Locations and Vertical Controls

	MANHOLE LOCATION			VERTICAL CONTROL			
INLET NO	ROAD	CENTERLINE STATION		INVERT ELEVATION (ft)		TOP OF MH EL (ft)	
		FROM	TO	UPPER	LOWER	UPPER	LOWER
		(ft)	(ft)				
1	Washington		12+74.35		375.4	383.4	375.4
2	King's Bridge	12+74.35	10+63.93	374.9	374.0	382.0	374.0
3	King's Bridge	10+63.93	08+50.35	373.5	371.5	379.5	371.5
4	King's Bridge	08+50.35	07+11.91	371.2	370.0	378.0	370.0
5	King's Bridge	07+11.91	05+10.91	369.7	369.3	377.3	369.3

DRAINAGE AND EROSION CONTROL

Module 7

Drainage Pipe Diameter

- MassDOT Exhibit 8-50
- Manning's Formula for Full Flowing Concrete Pipe
- Pipe Size Dictated by Peak Discharge & Slope

Results:

- With Hillside Drainage:
  - Range: 30-36 in
- Without Hillside Drainage:
  - Range: 10-12 in

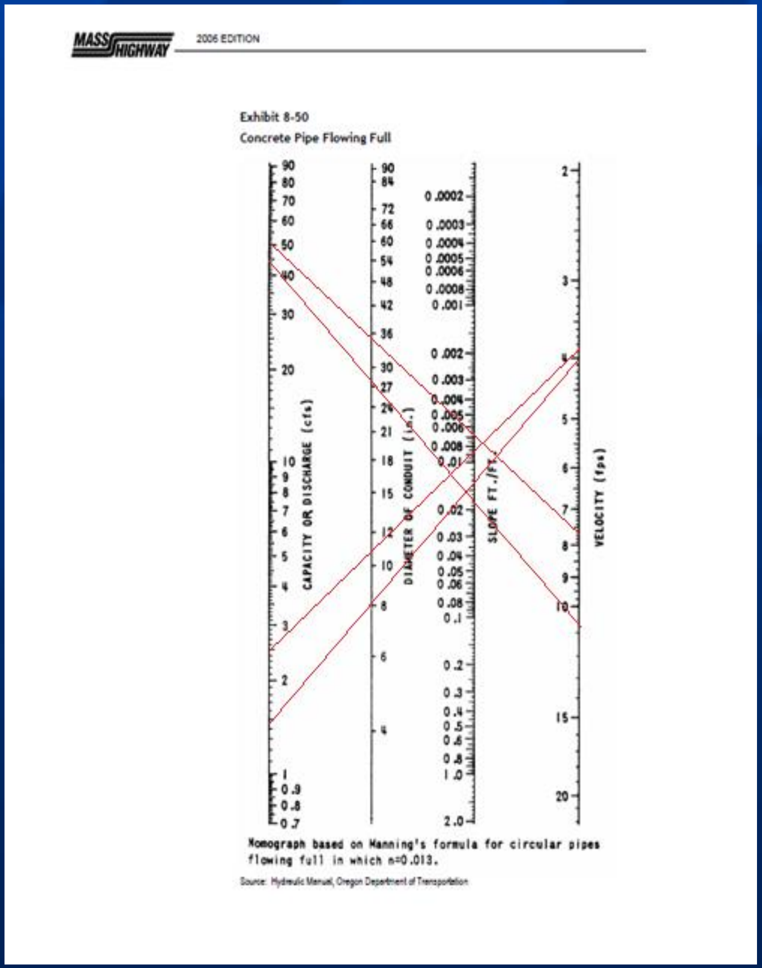


Figure 15. Mass Highway Design Chart

DRAINAGE AND EROSION CONTROL

Table 5. Pipe Diameters with Hillside Drainage:

	MANHOLE LOCATION			PIPE FLOW				
INLET NO	ROAD	CENTERLINE STATION						
		FROM	TO	LENGTH	SLOPE	DIA	CAP FLOW FULL	VEL FLOW FULL
		(ft)	(ft)	(ft)	(ft/ft)	(in)	(cfs)	(fps)
1	Washington		12+74.35				45.1	
2	King's Bridge	12+74.35	10+63.93	210.42	0.022	30	47.6	11.0
3	King's Bridge	10+63.93	08+50.35	213.58	0.008	36	50.1	8.3
4	King's Bridge	08+50.35	07+11.91	138.44	0.012	36	51.7	9.0
5	King's Bridge	07+11.91	05+10.91	107.59	0.015	36	53.0	9.5

Table 6. Pipe Diameters without Hillside Drainage:

	MANHOLE LOCATION			PIPE FLOW				
INLET NO	ROAD	CENTERLINE STATION						
		FROM	TO	LENGTH	SLOPE	DIA	CAP FLOW FULL	VEL FLOW FULL
		(ft)	(ft)	(ft)	(ft/ft)	(in)	(cfs)	(fps)
2	King's Bridge	12+74.35	10+63.93	210.42	0.022	10	2.5	5.2
3	King's Bridge	10+63.93	08+50.35	213.58	0.008	12	5.0	3.8
4	King's Bridge	08+50.35	07+11.91	138.44	0.012	10	6.6	4.0
5	King's Bridge	07+11.91	03+40.91	107.59	0.015	12	10.9	5.6

ENVIRONMENTAL PERMITTING

Module 8

- Determine Area of Required Wetland Fill
- Compute Toe of Slope with 2:1 Side Slope Design Specification
- Compose Informational Letter to MA DEP
- Prepare 401 Water Quality Data Form

ENVIRONMENTAL PERMITTING

- Survey Information Shows Area Bordering Vegetated Wetland (BVD): 3,432 ft^2
- Area of Disturbed BVD Must be Restored at Similar Elevation:

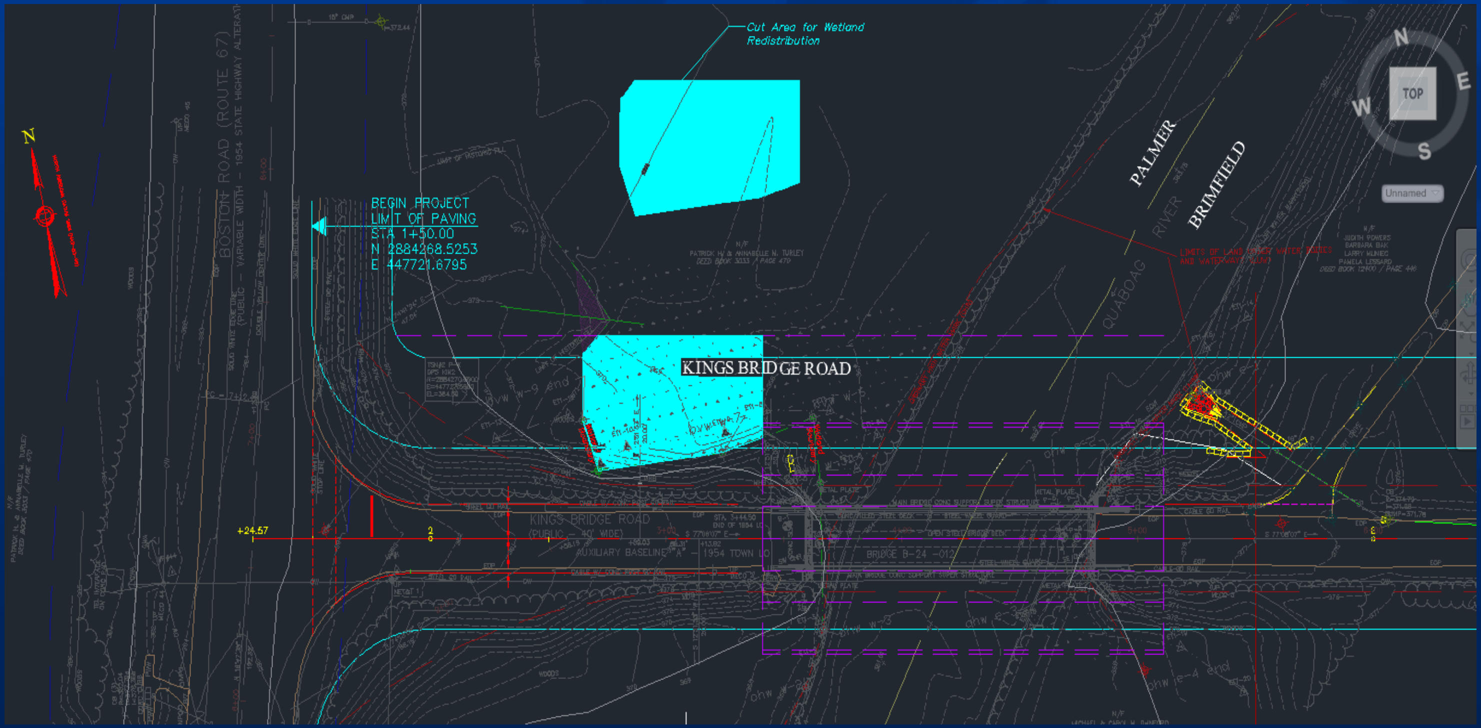


Figure 16. Area of Wetlands Displaced

ENVIRONMENTAL PERMITTING

- Required Side-Slope Specification of 2:1
- Elevation Drop from Roadway to Wetland:17 feet
- Resulting Horizontal Reach of Impacted BVD: <u>34 feet</u>

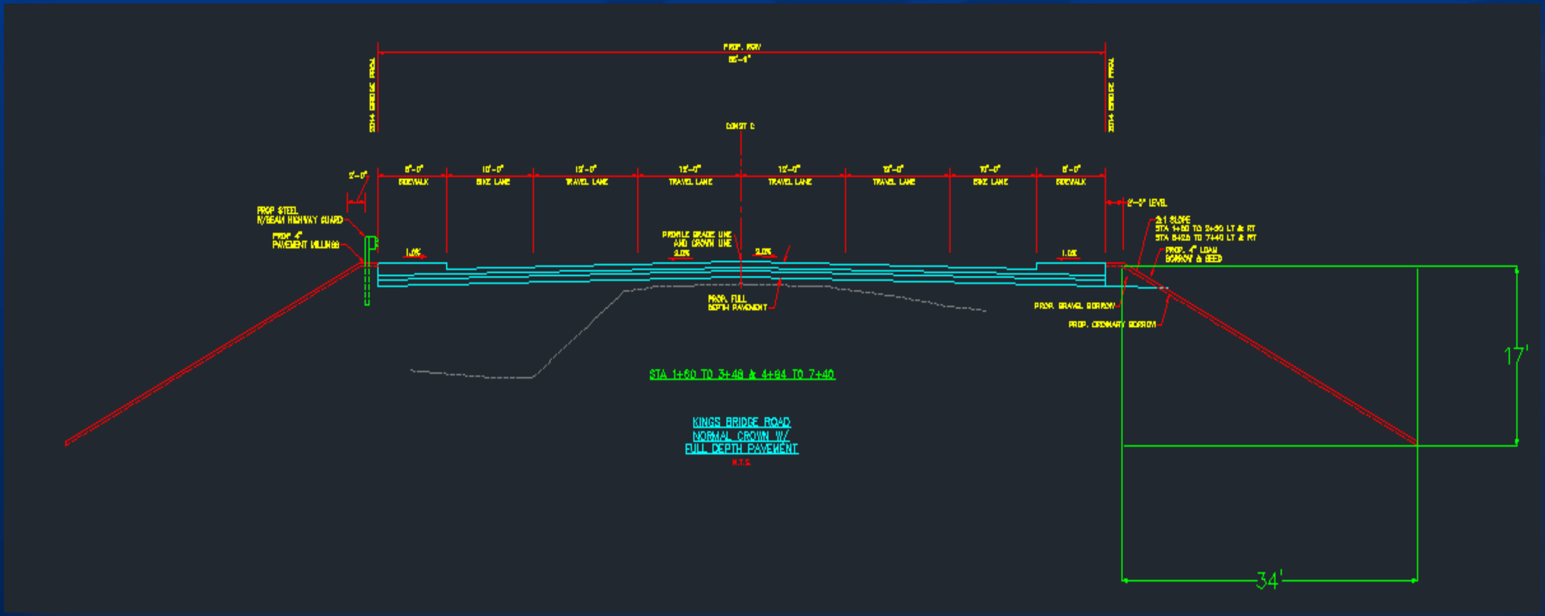


Figure 17. Transverse Section of Roadway

ENVIRONMENTAL PERMITTING

Module 8

- Letter to MA Department of Environmental Protection (MA DEP)
  - Project Detail Overview
  - 401 Water Quality Certificate (401 WQC) Requirement Inquiry

- 401 WQC (USACE/Clean Water Act)
  - BRP WW 10 Major Project Classification
  - Non-Water Dependent *DEP 310 CMR 10.04*
  - ORW *314 CMR 4.06(2)*
  - MEPA *301 CMR 11.01 (2)(a)*

Construction Management

Presented by: Anas Al Sayed Ali
Sarah Shaw

CONSTRUCTION ESTIMATE

Module 9 dealt with the computation of quantities and cost of materials for the bridge construction.

Table 7. Preliminary Estimate of Quantities and Cost of Bridge

			< PRELIMINARY ESTIMATE OF QUANTITIES AND COST OF BRIDGE >		
Item No.	Total Quantity	Unit	Description	Unit Price	Total Cost
140.	1826	CY	Bridge Excavation	$22.00	$40,172.00
151.2	1360	CY	Gravel Borrow for Bridge Foundations	$24.00	$32,640.00
455.61	114	TON	Superpave Bridge Surface Course	$90.00	$10,260.00
455.71	114	TON	Superpave Bridge Protective Course	$130.00	$14,820.00
904.	680	CY	4000 PSI, 3/4 IN., 610 CEMENT CONCRETE	$550.00	$374,000.00
904.3	175	CY	5000 PSI, 3/4 IN., 685 HP CEMENT CONCRETE	$1,650.00	$288,750.00
904.4	370	CY	4000 PSI, 3/4 IN., 585 HP CEMENT CONCRETE	$950.00	$351,500.00
960.502	64750	LB	Structural Steel M270 Grade 50W Uncoated Plate Girder Bridge	$1.50	$97,125.00
965.	1660	SY	Membrane Waterproofing for Bridge Decks	$22.00	$36,520.00
971.	176	FT	Asphaltic Bridge Joint	$220.00	$38,720.00
975.1	353	FT	Metal Bridge Rail (3 RAIL), STEEL (S3-TL4)	$315.00	$111,195.00

TOTAL	**$1,395,702.00**

NOTE: All unit prices have been obtain from the MassHighway Weighted Average Book-November 2008

MASSDOT SCOPE AND FEE

Module 10 dealt with the computation of quantities and cost of labor for the bridge construction.

Table 8. Design Costs summary

		DESIGN	CONSTRUCTION	TOTALS
(a) Salary Costs		$ 206,917.70	$ 16,716.24	$ 223,633.94
(b) Indirect Costs (%)	155.00%	$ 320,722.44	$ 25,910.17	$ 346,632.61
(c) Net Fee (%)	11.80%	$ 62,261.54	$ 5,029.92	$ 67,291.45
TOTAL LIMITING FEE		$ 589,901.67	$ 47,656.33	$ 637,558.00
(d) Direct Expenses		$ 25,000.00	$ 25,000.00	$ 50,000.00
MAXIMUM PAYMENT AMOUNT		$ 614,901.67	$ 72,656.33	$ 687,558.00
MAXIMUM OBLIGATION				$ 687,558.00
			SAY	$ 687,500.00

Total Material & Design Cost:

Materials:	$1,395,700
Design:	<u>$687,500</u>
	$2,083,200

QUESTIONS?