AASHTO T-3 TRIAL DESIGN BRIDGE DESCRIPTION

State: *Illinois*

Trial Design Designation: *IL-4*

Bridge Name: ______________________________

Superstructure Type: *Simply supported PPC-I beam composite with concrete deck*

Span Length(s): *4@43.5 ft. (total 174.0 ft.)*

Substructure Type: *Pier wall supported on pile cap at bents*

Foundation: *Steel piles at abutments and bents*

Abutments: *Seat type supported on steel piles*

Seismic Design Category (SDC): *"C"*

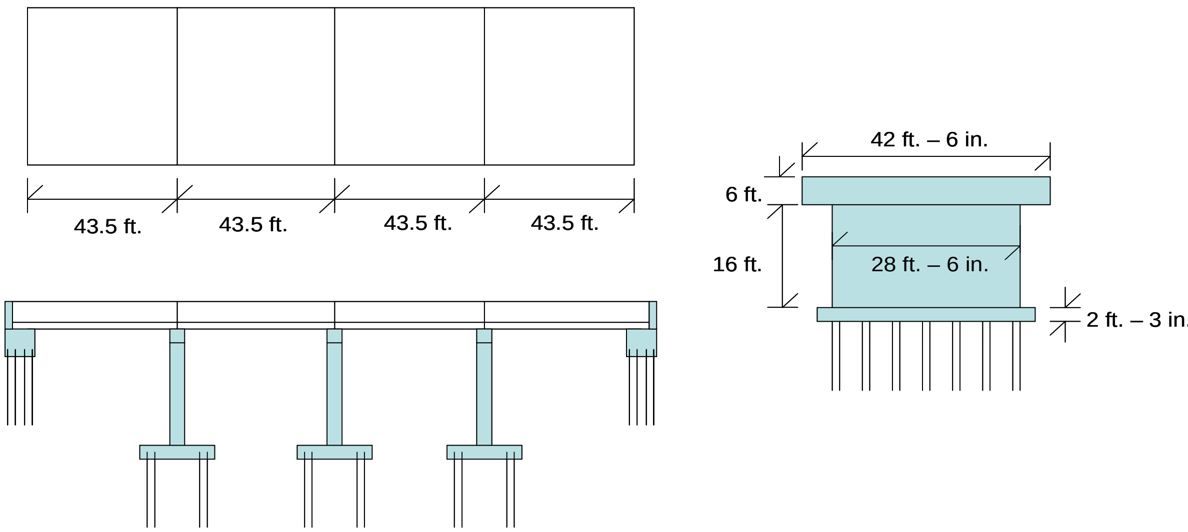
Seismic Design Strategy (Type 1, 2 or 3): *Type 1*

Design Spectral Acceleration at 1-second Period (S_{D1}): *0.487g*

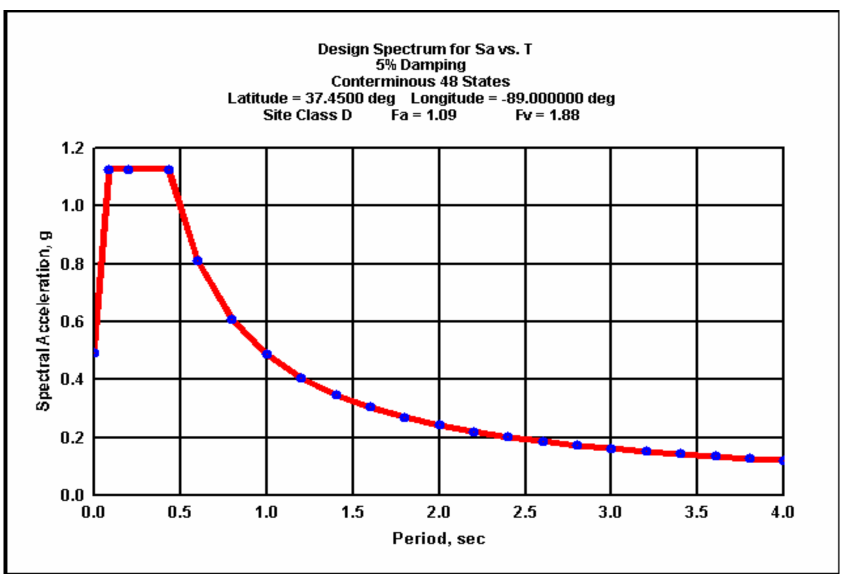
Additional Description (Optional): ______________________________

Bridge No.: 4 Transverse Seismic Calculations

Description: 4-Span PPC-I Beam with Wall Piers and Steel Piles at Piers and Abutments
(No Skew)
(Pile Design Method Similar for Imbsen and LRFD, therefore not shown - See Bridge No. 2)



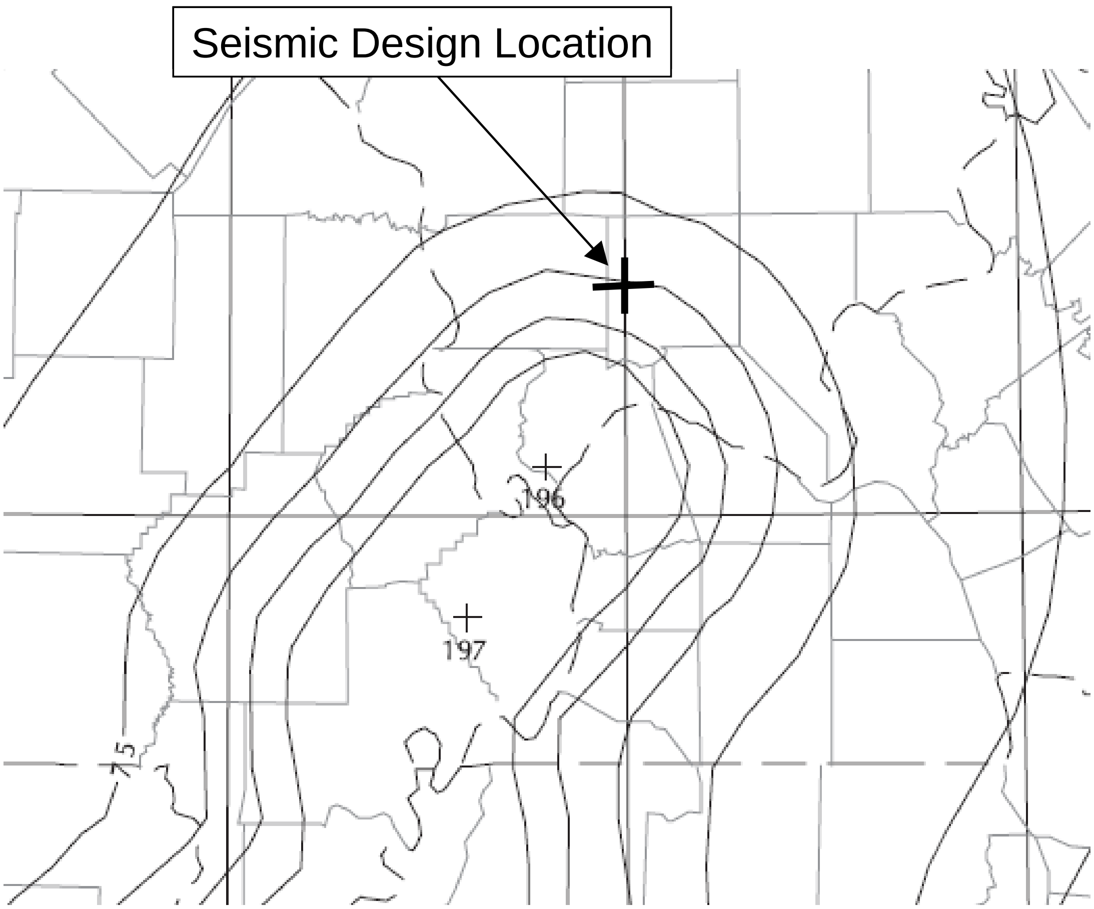
Design Response Specturm



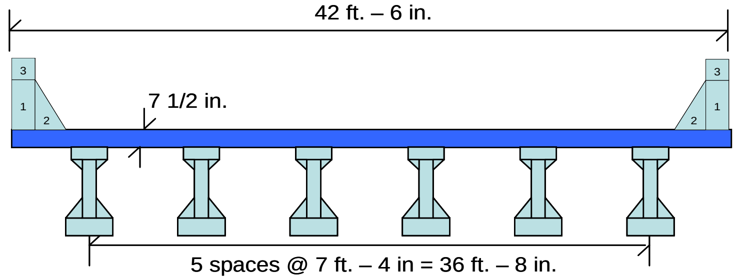
SDC and Other Pertinent Design Spectrum Information

S_{D1} =	0.487 g	Seismic Design Category C			
S_{DS} =	1.128 g	0.3g <=	0.487g	< 0.5 g	
End Plateau	0.432 Seconds	(Imbsen Table 3.5-1)			

Chosen Location for Bridge Study and 0.2 Second 1000 year Accleration Map (2006 Map)

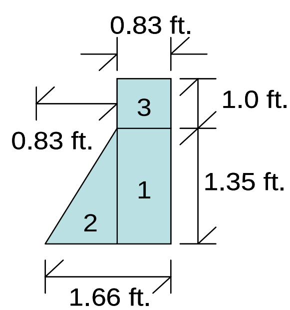


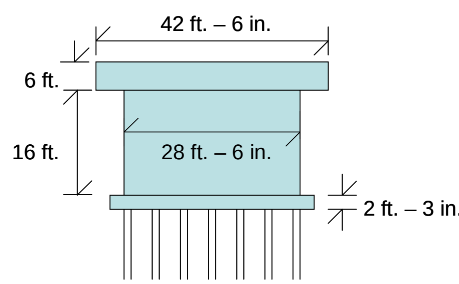
Simple Cross Section of Deck



Weight of Super and Sub Structure for Seismic Calculations

Beams	36 in PPC I				
No. Beams	6.00				
Beam Spacing	7.33	ft.			
Wt. of 1 Beam	0.37	k/ft.			
Wt. Tot. Beams	2.23	k/ft.			
Th. of Slab	7.50	in.			
Th. of Surface	0.00	in.			
Width	42.50	ft.			
Wt. of Slab	3.98	k/ft.			
Parapet					
Area 1	1.12	ft^2			
Area 2	0.56	ft^2			
Area 3	0.83	ft^2			
Total Area	2.51	ft^2			
Wt. of Parapet	0.38	k/ft.			
Pier Diaph.					
No. of Diaphr.	3.00				
Width	1.83	ft.	Height	3	ft.
Total Weight	105.19	kips	Length	42.5	ft.
Steel Parapet					
Rail					
(est. as	0.00	%			
0.02 k/ft)	0.02	k/ft			
Cap Beam					
Length	42.50	ft.			
Width	2.50	ft.			
Height	6.00	ft.			
Wt. of 1 Beam	95.63	kips			
Wt. of 3 Beams	286.88	kips			





Weight of Super and Sub Structure for Seismic Calculations (Cont.)

3 ft. of walls				
Width	28.50 ft.	Thickness	2.50 ft.	
Height	3.00 ft.			
Wt. of 1Wall	32.06 kips			
No. of Walls	3			
Wt. of 3 Walls	96.19 kips			
Total Wt. for Seismic Calculations				
Super Length	174 ft.			
Total Weight	1704 kips			

Transverse Period Calculation

Pier Piles Stiffness (Wall is Rigid)

$$k_p = \frac{12 \times E_s \times I_s}{h_c^3}$$

Pile Type	HP 8 x 36
E_s	29000 ksi
I_s	40 in^4
No. Piles	14
h_c	61.2 inches (depth of fixity)
k_p	61 k/in
k_{pier}	852 k/in

I of Superstructure Transverse

$$Area_{ConcBm} = \frac{n \times Area}{2}$$

Transf. Area with 50% Shear Lag

$Ec_{Prestressed}$	4031 ksi
f'_c	3500 psi
E_c	3372 ksi
n (mod. Ratio)	1.20
I_{slab}	82906875 in^4
$Area_{Parapet}$	361.4 in^2
Area 1 Beam	357 in^2
$Area_{Conc\ Bm}$	213.4 in^2 (Transformed)

Transverse Period Calculation (Cont.)

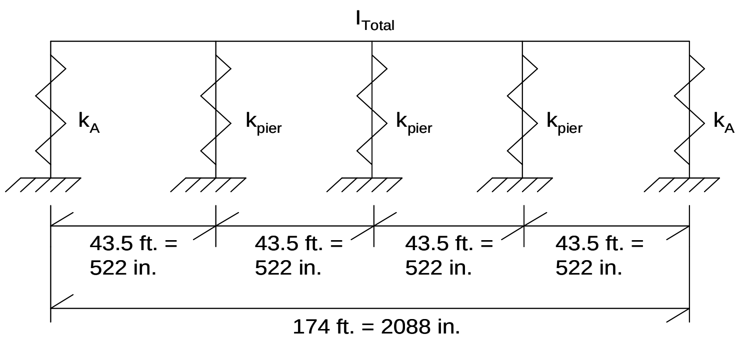
Momen of Inertia of Superstructure Table

	No.	I_0 (In^4)	A (in^2)	x bar (in)	A (x bar)^2 (in^4)	I (in^4)
Parapet	2	----	361.44	243	21342670.56	42685341.1
Slab	1	82906875	----	----	82906875	82906875
Steel 1	2	----	213.4	44	413092.6747	826185.349
Steel 2	2	----	213.4	132	3717834.072	7435668.14
Steel 3	2	----	213.4	220	10327316.87	20654633.7

I_{Total} 1.545E+08 in^4

A_{Total} 5828 in^2

Model the Bridge Transversely with I_{total} of the Superstr. and Springs for the Abutment Piles and Pier Cols.



Estimate the Abutment Pile Transverse Stiffness

k_A 450 k/in

Solve for the Displacement from Simple Model Above as Outlined Below for a 1 k/in Uniform Load

Find the Deflection at the Center of the Bridge Assuming No Piers and Infinitely Stiff Abutments

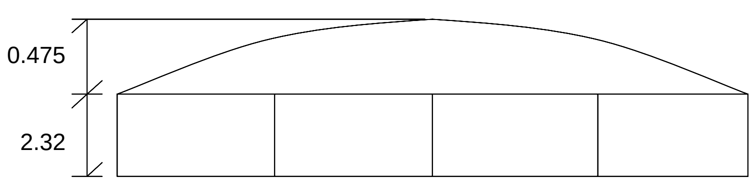
w	1	k/in
L	2088	in
E_c	3372	ksi
I_{Total}	1.545E+08	in^4
δ_c	0.475	in

$$\delta_C = \frac{5 \times w \times L^4}{384 \times E_c \times I_{Total}}$$

Find the Deflection Along the Bridge Assuming an Infinitely Stiff Superstr., No Piers, and Abut. Springs

w	1	k/in
L	2088	in
k_A	450	k/in
δ_e	2.32	in

$$\delta_e = \frac{\frac{w \times L}{2}}{k_A}$$

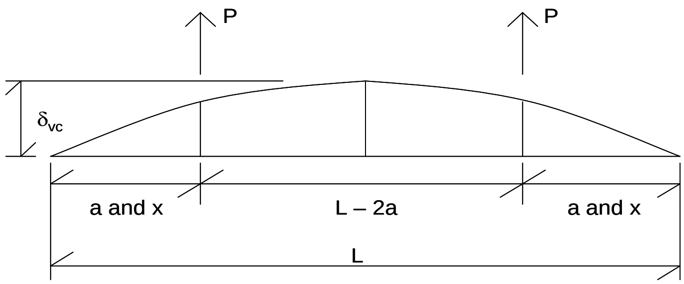


Transverse Period Calculation (Cont.)

Find the Total Estimated Displacement Without the Piers

$\delta_T = \delta_c + \delta_e$	2.795	in

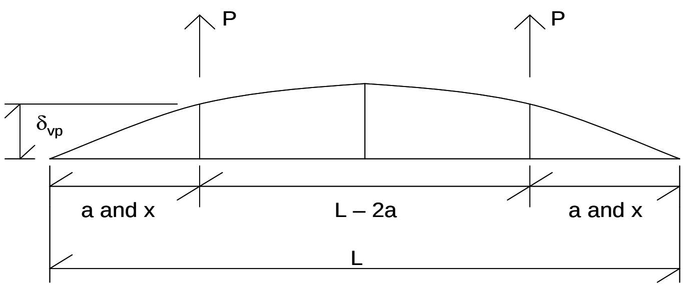
Find the Estimated Deflection at the Center of the Bridge for a Two Point Load at Piers with Infinitely Stiff Abuts.
In Terms of an Applied Load "P".



L	2088	in
x	522	in
a	522	in
E_c	3372	ksi
I_{Total}	1.545E+08	in^4
δ_{vc}	0.0005005	P

$$\delta_{vc} = \frac{P \times a}{24 \times E_c \times I_{Total}}\left(3 \times L^2 - 4 \times a^2\right)$$

Find the Estimated Deflection at the Pier of the Bridge for a Two Point Load at Piers with Infinitely Stiff Abuts.
In Terms of an Applied Load "P".

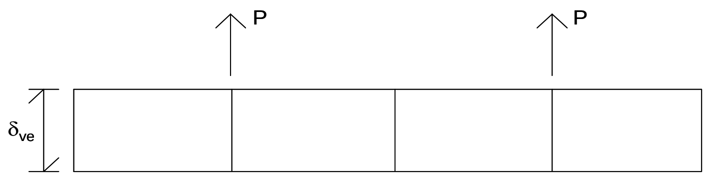


L	2088	in
x	522	in
a	522	in
E_c	3372	ksi
I_{Total}	1.545E+08	in^4
δ_{vp}	0.0003640	P

$$\delta_{vp} = \frac{P \times x}{6 \times E_c \times I_{Total}}\left(3 \times L \times a - 3 \times a^2 - x^2\right)$$

Transverse Period Calculation (Cont.)

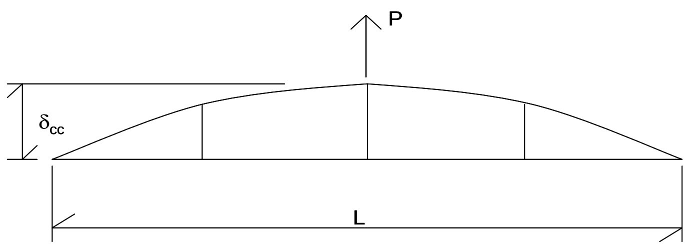
Find the Estimated Uniform Deflection for a 2 Point Load at Piers with Springs at Abuts.
In Terms of an Applied Load "P".



k_A	450	k/in
δ_{ve}	0.00222222	P

$$\delta_{ve} = P/k_A$$

Find the Estimated Deflection at the Center of the Bridge for a 1 Point Load at Piers with Infinitely Stiff Abuts.
In Terms of an Applied Load "P".

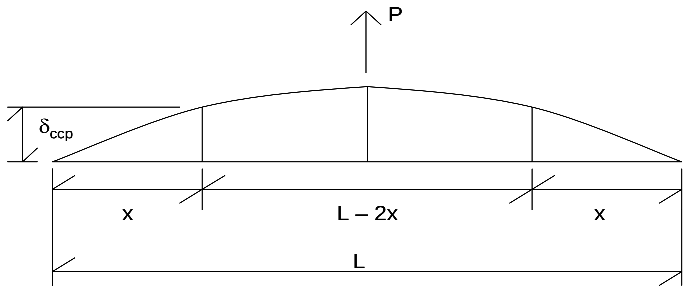


L	2088	in
E_c	3372	ksi
I_{Total}	1.545E+08	in^4
δ_{cc}	0.0003640	P

$$\delta_{cc} = \frac{P \times L^3}{48 \times E_c \times I_{Total}}$$

Transverse Period Calculation (Cont.)

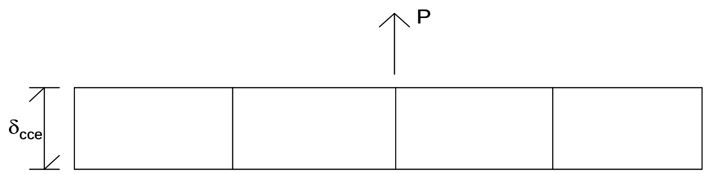
Find the Estimated Deflection at the Outer Piers of the Bridge for a 1 Point Load at Center Pier with Infinitely Stiff Abuts. In Terms of an Applied Load "P".



L	2088	in
x	522	in
E_c	3372	ksi
I_{Total}	1.545E+08	in^4
δ_{ccp}	0.0002502	P

$$\delta_{ccp} = \frac{P \times x}{48 \times E_c \times I_{Total}} \left(3 \times L^2 - 4 \times x^2\right)$$

Find the Estimated Uniform Deflection for a 1 Point Load at Piers with Springs at Abuts.
In Terms of an Applied Load "P".



k_A	450	k/in
δ_{cce}	0.00111111	P

$$\delta_{cce} = \frac{P}{2 \times k_A}$$

Find the Fraction of the Estimated Pier Deflection at the Outer Piers Versus that at Center Span

δ_{vc}	0.0005005	P
δ_{vp}	0.0003640	P
δ_{cc}	0.0003640	P
δ_{ccp}	0.0002502	P
δ_{ve}	0.00222222	P
δ_{cce}	0.00111111	P
fr	0.940	

$$fr = \frac{\delta_{ve} + \delta_{cce} + \delta_{vp} + \delta_{ccp}}{\delta_{ve} + \delta_{cce} + \delta_{vc} + \delta_{cc}}$$

<u>Transverse Period Calculation (Cont.)</u>

Find the Outer Pier Reactions (V_0) in Terms of δ_{max}, the Actual Estimated Deflection of the Bridge

fr	0.940	
k_{pier}	852.3 k/in	$V_{00p} = fr \times \delta_{max} \times k_{pier}$
V_{00p}	801.5 δ_{max}	

Find the Center Pier Reaction (V_0) in Terms of δ_{max}, the Actual Estimated Deflection of the Bridge

k_{pier}	852.3 k/in	$V_{00c} = \delta_{max} \times k_{pier}$
V_{00c}	852.3 δ_{max}	

Solve for δ_{max}:

$\delta_{vc} + \delta_{cc} + \delta_{ve} + \delta_{cce}$ = 0.004198 P

Or (splitting up deflection components)

$\delta_{vc} + \delta_{ve}$ = 0.002723 P

$\delta_{cc} + \delta_{cce}$ = 0.001475 P

Set:

$P = V_{00p}$ = 801.5 δ_{max}

$P = V_{00c}$ = 852.3 δ_{max}

Therefore:

$\delta_{vc} + \delta_{ve}$ = 0.002723 x 801.5 x δ_{max}

$\delta_{vc} + \delta_{ve}$ = 2.182253 δ_{max}

$\delta_{cc} + \delta_{cce}$ = 0.001475 x 852.3 x δ_{max}

$\delta_{cc} + \delta_{cce}$ = 1.257242 δ_{max}

And:

The Actual Estimated Delfection of the Bridge is the Deflection Without Piers Minus the Contribution with the Piers

δ_{max} = δ_T - 2.182253 δ_{max} - 1.257242 δ_{max}

δ_{max} = 2.795 / 4.439495

δ_{max} = 0.630 in

Transverse Period Calculation (Cont.)

Solve for the "Equivalent Stiffness" of the Bridge in the Transverse Direction

w	1	k/in
L	2088	in
δ_{max}	0.630	in
k_{Bridge}	3317	k/in

$$k_{Bridge} = \frac{w \times L}{\delta_{max}}$$

Solve for the Period T

Tot. Weight (W)	1704	kips
g	386.4	in/sec^2
k_{Bridge}	3316.510	k/in
T	0.23	seconds

$$T = 2\pi\sqrt{\frac{W}{g \times k_{Bridge}}}$$

Transverse Seismic Force On Superstructure (Base Shear)

0.23 < 0.432 seconds

Therefore: 112.8% of the Mass is "Effective" and the Total Seismic Load in the Transverse Direction is:

1.128 x 1704 = 1923 kips (Base Shear)

or:
1923 / 2088 = 0.92 k/in (Base Shear)

Transverse Seismic Force on Outer Piers (Base Shear)

$V_{Base\ Shear\ P}$ = 0.92 / 1 x 0.630 x 801.5

$V_{Base\ Shear\ P}$ = 465 kips

Transverse Seismic Force on Center Pier (Base Shear)

$V_{Base\ Shear\ P}$ = 0.92 / 1 x 0.630 x 852.3

$V_{Base\ Shear\ P}$ = 494 kips

Transverse Seismic Force on Abutments (Base Shear)

$V_{Base\ Shear\ A}$ = 1923 - 929.25248 - 494 / 2

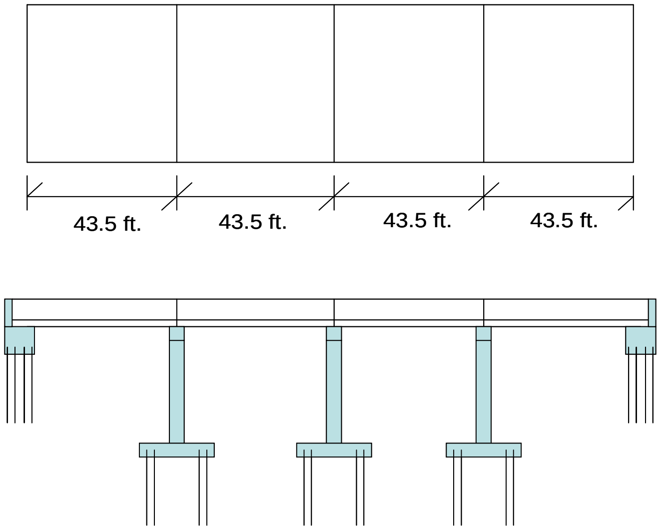
$V_{Base\ Shear\ A}$ = 250 kips

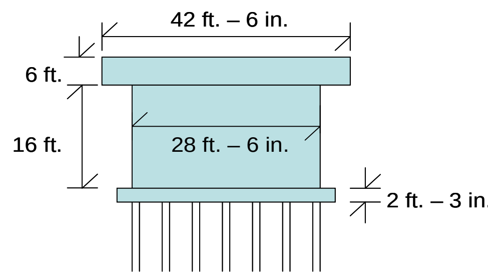
Transverse Seismic Displacement of Center Pier

δ_{PierT} = 494 / 852 = 0.58 in.

Bridge No.: 4 Longitudinal Seismic Calculations

Description: 4-Span PPC-I Beam with Wall Piers and Steel Piles at Piers and Abutments (No Skew)





Weight of Superstructure

Total Weight	1704 kips

Longitudinal Period Calculation

Pier Stiffness Longitudinal Direction

$$k_c = \frac{3 \times E_c \times I_c}{h_c^3} \qquad E_c = \frac{57000\sqrt{f_c'}}{1000} \qquad \theta_{TC} = \frac{P \times h_c^2}{2 \times E_c \times I_c}$$

Contribution from Column

f'_c	3500	psi		
E_c	3372	ksi		
Width	28.50	ft	Thickness	2.5 ft.
I_c	769500	in^4		
$I_c/2$	384750	in^4 Half Cracked Section		
No. Walls	1			
$1 \times I_c/2$	384750	in^4 Half Cracked Section		
h_c	192	inches (clear column height)		
k_c	550	k/in		
k_{pier}	550	k/in		

Contribution from Cap Beam (Stiffness is infinite but it deflects as a rigid body and contributes to pier stiffness)

Find the estimated deflection at the top of column for a load "P"

δ_{TC} = P / 550 in

Find the estimated rotation at the top of column for a load "P"

θ_{TC} = P / 70390.7 radians

Cap height 72 in

Find the added estimated deflection at the top of the pier

δ_A = Cap hght x θ_{TC} = P / 977.6 in

Find the total estimated delfection at the top of the pier

δ_{TD} = δ_A + δ_{TC} = P / 352.0 in

So, the stiffness of a pier is:

k_{pier} = 352 k/in

Find the Mass of the Superstructure

M = 1704 / 386.4 = 4.41 k-sec^2/in

Find the period T:

T = 0.41 sec. $T = 2\pi\sqrt{\dfrac{M}{3 \times k_{pier}}}$

Longitudinal Seismic Force On Superstructure (Base Shear)

0.41 < 0.432 Seconds

Therefore: 112.8% of the Mass is "Effective" and the Total Seismic Load in the Longitudinal Direction is:

1.128 x 1704 = 1923 kips (Base Shear)

Longitudinal Seismic Force On Each Pier assuming the abutments don't contribute (Base Shear)

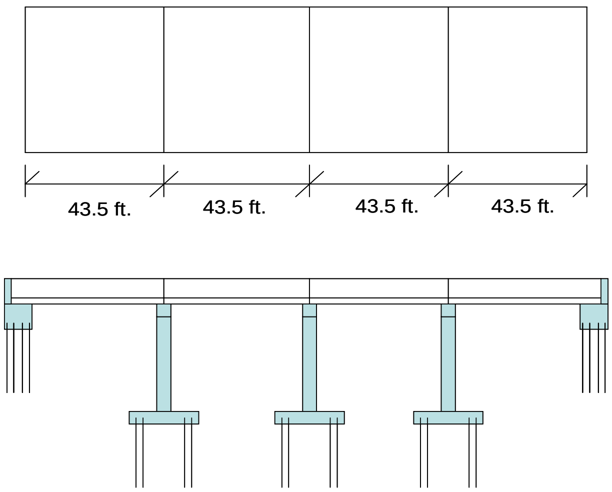
1923 / 3 = 641 kips (Base Shear)

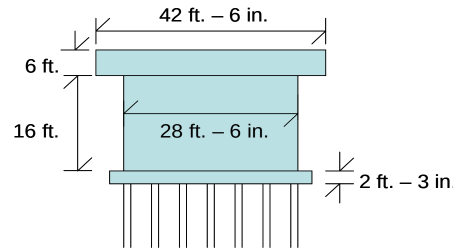
Longitudinal Seismic Displacement of Pier

δ_{PierL}	=	641	/	352.0	=	1.82 in.

Bridge No.: 4 **Force Based Wall Design and Displacement Check**

Description: 4-Span PPC-I Beam with Wall Piers and Steel Piles at Piers and Abutments (No Skew)





Center Wall Forces

Dead

Dead Load Total	1704	kips
Bridge Length	436.3	ft.
Dead Load per ft.	3.91	k/ft
Dead Load Ctr. pier	169.9	kips
No. of Walls	1	
Dead Ld. Ctr. Wall	169.9	kips
Plus Remaining Wall	138.9	kips
Design Dead	308.9	kips

Transverse Shear and Moment (Simple Cantilever/Shear Wall Statics)

S_P (Pier Base Shear)	494	kips
Col arm (h)	22.00	ft.
$M_{WallBot}$	10869.8	k-ft.

Longitudinal Shear and Moment (Simple Cantilever Statics)

S_L (Pier Base Shear)	641	kips
Col arm (h)	22.00	ft.
$M_{WallBot}$	14098.8	k-ft.

Orthogonally Combined Load Cases

Transverse Dominant - Load Case 1

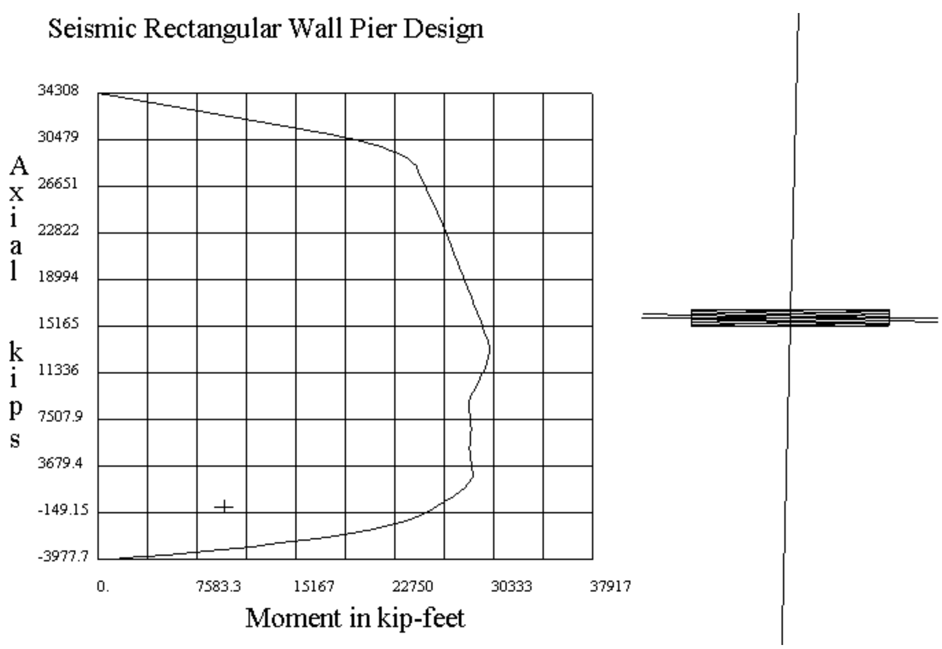
P =	308.9 kips						
M_T =	10869.8	/	1.5 (R-factor)			=	7247 k-ft
M_L =	14098.8	/	1.5 (R-facto	x	0.3	=	2820 k-ft
$M_{Combined}$ =							7776 k-ft
λ =	$\tan^{-1}$ (M_T/M_L)					=	68.7 degrees

Longitudinal Dominant - Load Case 2 - Governs the Design

P =	308.9 kips						
M_T =	10869.8	/	1.5 (R-facto	x	0.3	=	2174 k-ft
M_L =	14098.8	/	1.5 (R-factor)			=	9399 k-ft
$M_{Combined}$ =							9647 k-ft
λ =	$\tan^{-1}$ (M_T/M_L)						13.0 degrees
$\theta \cong$							0.5 - 1.5 degrees

Wall Vertical Reinforcement Design - "Nominal Provided"

Pier is Adequate with or without R-Factors Applied (i.e. "not as a ductile or seismic column")



Vertical Reinforcement

Bars:	#8
No.	84
No. Transverse Faces	39
No. Longitudial Faces	5
ρ_v	0.0072 > 0.0025 (LRFD 5.10.11.4.2 and Imbsen 8.17 - Provisions are Identical)

Displacement Check

We interpret this as a way to check deflections for walls.
Imbsen provsions are either somewhat incomplete or unclear on this.

Scratch Calculation Table

Imbsen Section 4.8					
Wall Height (ft)	Wall Width (ft)	H/100 (in)	x Fixed-Pinned	Delta Calc. Fixed - Pinned (in)	Delta Allow. Fixed - Pinned (in)
22	2.50	2.64	0.11	10.10	10.10

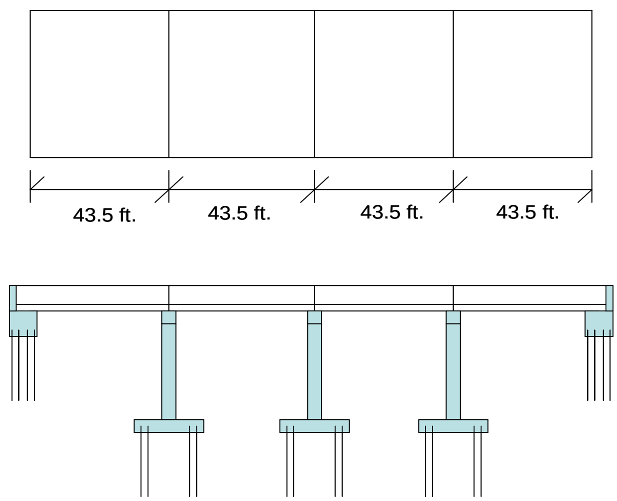
Longitudinal Direction

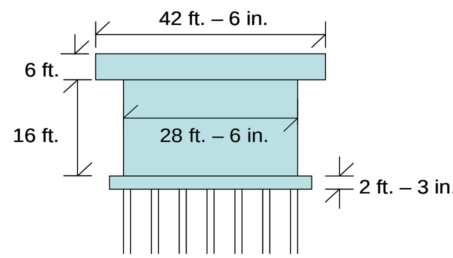
	Imbsen Fig. 5.4				
Wall Height (ft.)	Steel Ratio (Ast/Ag)	Fraction of Ig	Long. Period (Sec.)	Long. Deflection (in)	Long. Allowable Deflection (in)
22	0.0072	?	0.41	1.82*	10.10

*Even Amplified per Imbsen 4.3.3 will be OK

Bridge No. 4 Design for Shear

Descriptior 4-Span PPC-I Beam with Wall Piers and Steel Piles at Piers and Abutments
(No Skew)





<u>Transverse Shear</u>

S_P (Pier Base Shear) 494 kips

<u>Longitudinal Shear</u>

S_L (Pier Base Shear) 641 kips

<u>Orthogonally Combined Load Cases (Elastic)</u>

Transverse Dominant - Load Case 1

$S_{Combined}$ = 530 kips

Longitudinal Dominant - Load Case 2

$S_{Combined}$ = 658 kips

Shear Strength

LRFD 5.10.11.4.2 and Imbsen 8.8.3 are Identical
Check to see that Minimum Shear Reinforcement is Adequate

Take the Lesser of:

$V_r = 0.253\sqrt{f'_c}\,bd =$ 4771 kips

or

$V_r = 0.9\left[0.063\sqrt{f'_c} + \rho_h f_y\right]bd =$ 2430 kips

Minimum reinforcement is Adequate.

ρ_h set to:	minimun of 0.0025	
b set to	30	in
d set to	336	in
f'c	3.5	ksi
fy	60	ksi

A "short" spacing of bars may be used near the base of wall if confinement or plastic hinging is a potential concern in the longitudinal direction.

Bridge No.: 4 Seat Width Requirements
Descriptior 4-Span PPC-I Beam with Wall Piers and Steel Piles at Piers and Abutments
(No Skew)

Seat Width Requirements

Compare Imbsen with NCHRP 12-49 and the Current LRFD Code
LRFD calibrated for 500 years and 12-49 calibrated to 1.0 Sec. Accel. with improved Soil Coef.
so it is "return period independent".

NCHRP 12-49

$$N = \left[0.10 + 0.0017L + 0.007H + 0.05\sqrt{H}\sqrt{1+\left(2\frac{B}{L}\right)^2}\right]\left(1+1.25F_v S_1\right) \quad \text{(metric)}$$

L =	174 ft	or	53.04	meters
FvS1 =			0.487	g
H =	22 ft	or	6.71	meters
B =	42.5 ft	or	12.95	meters

Imbsen 4.12.2

$$N = \left(4 + \Delta_{ot} + 1.65\Delta_{eq}\right) \geq 12$$

Δot = 0.01L = 1.74 inches
Δeq = 3* inches
*Estimated Amplified

LRFD 4.7.4.4

$$N = 8 + 0.02L + 0.08H$$

L = 174 ft %N for Cat. C = 150
H = 22 ft

Summary of Seat Width Requirements (NCHRP 12-49, Imbsen and LRFD) for 16 Cases

Wall Height (ft.)	Imbsen Fig. 5.4 Steel Ratio (Ast/Ag)	Imbsen Fig. 5.4 Fraction of Ig	Long. Deflection (in)	Imbsen 4.12.2 Calc. Seat (in)	Imbsen 4.12.2 Req. Seat (in)	NCHRP 12-49 Req. Seat (in)	Current LRFD Req. Seat (in)
22	0.0072	?	3.00	11.0	12.0	24.1	19.9