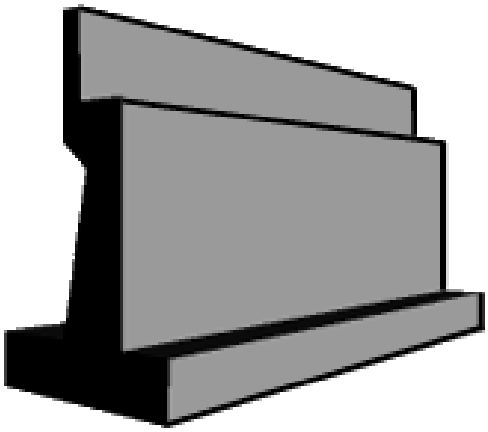
STRUCTWARE®

Program Documentation

for

BRGABUT®

Bridge Abutment Design Program



CONTENTS

INTRODUCTION

BRGABUT may be used to perform analysis of cantilevered concrete seat type bridge abutments. The program supports both english and metric units. Options are available for spread or pile footings and haunched or non-haunched abutments. The bridge abutments may be analyzed using any American or Canadian bridge design criteria.

The online help file and graphical interface is shown in Section B. Verification problems are included in Section C. Additional information is contained in the following files installed in the program directory.

License.txt - The license agreement contains the terms and conditions for use of this program and documentation.

Readme.txt – The installation instructions, copyright and trademark notices and version history is contained in this file.

The following steps are recommended for users new to the program or specific features.

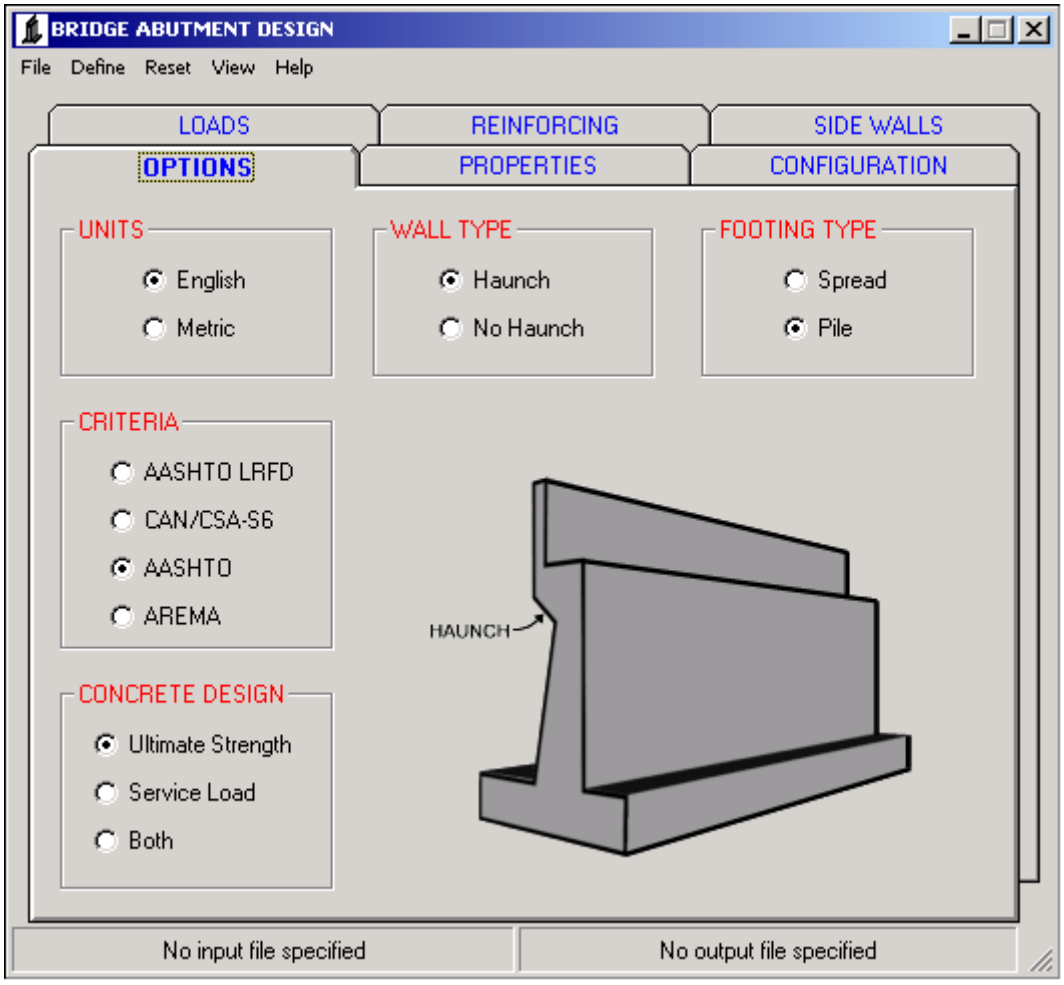
1. To learn how to use the program, view the Flash Demonstration Movie that is installed along with the program and read the "Instructions" section of the help file.

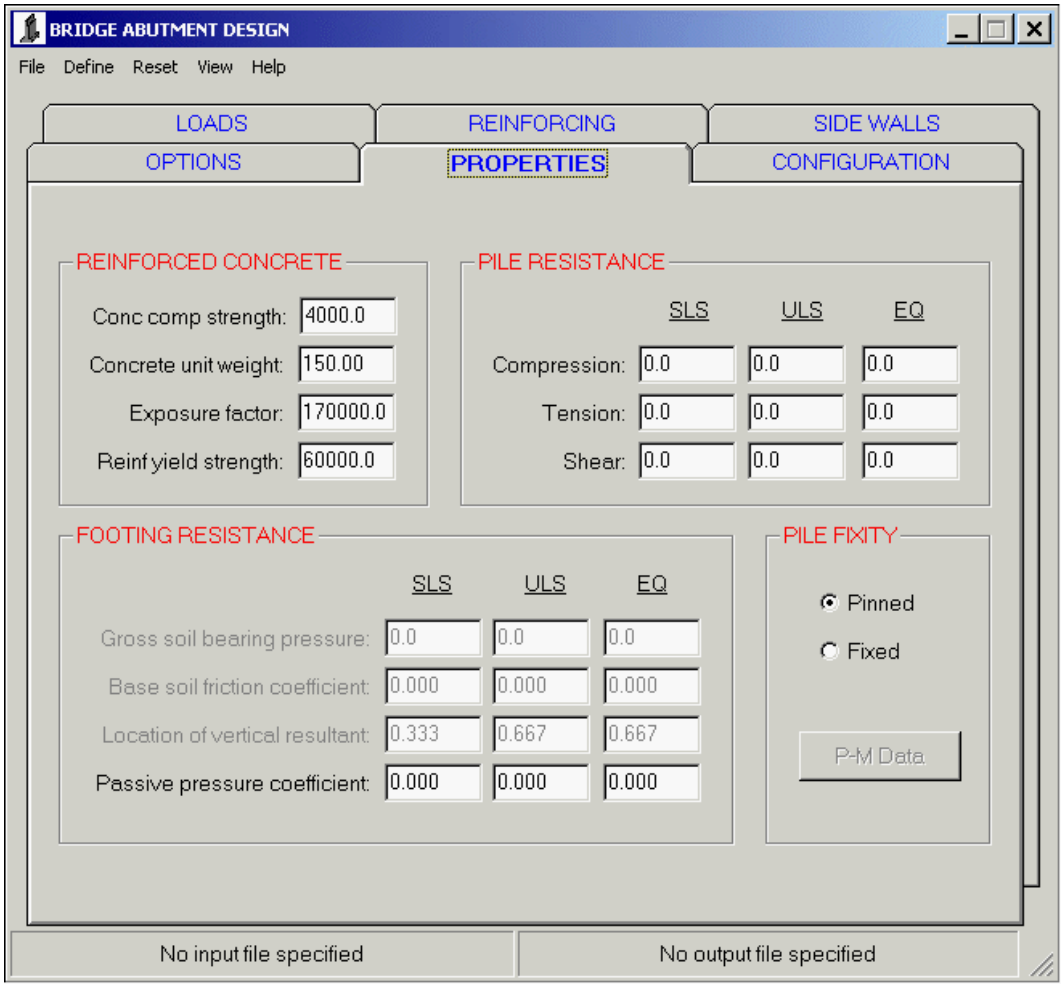
2. To apply this program to a specific problem, find a similar case in the Verification Problems section of this document. Run the program to see if you can reproduce the results. If your problem varies significantly from the Verification Problem, you should perform manual calculations for verification.

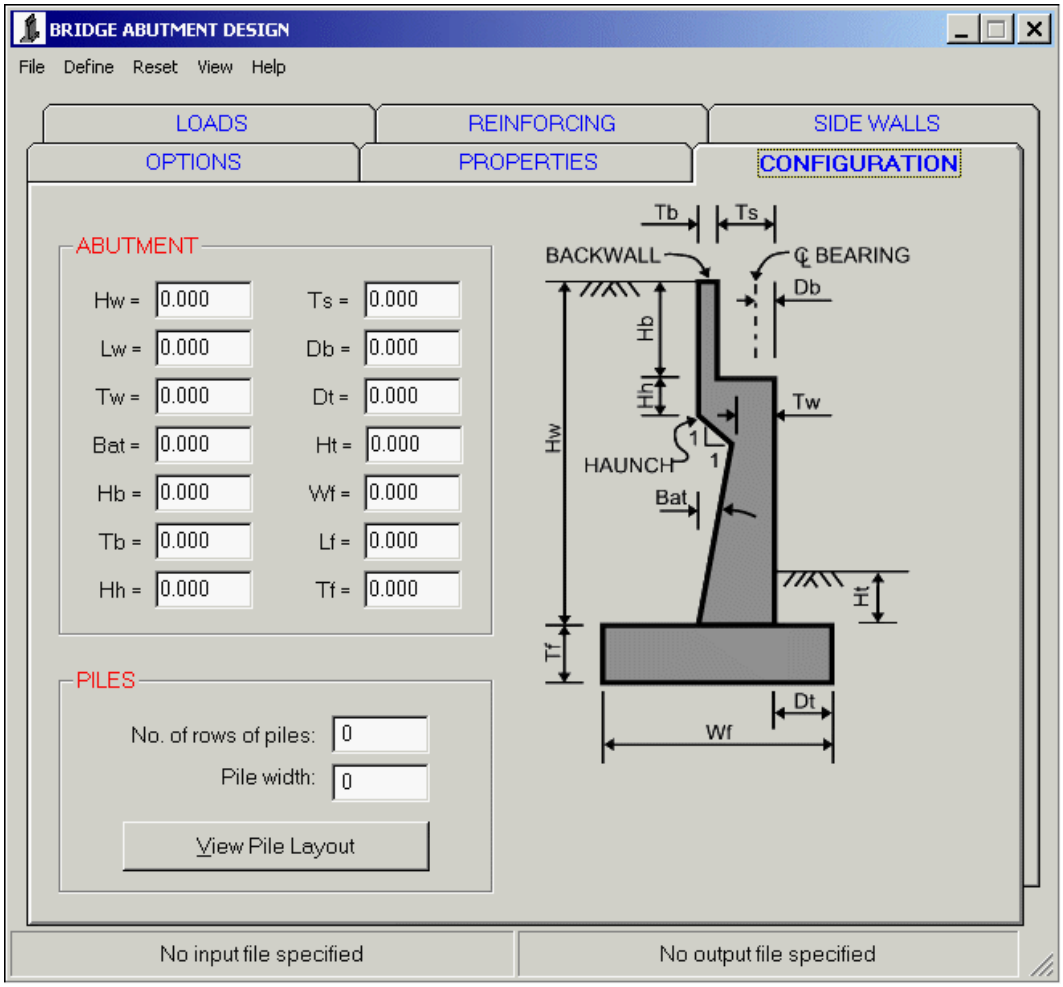
ONLINE HELP FILE

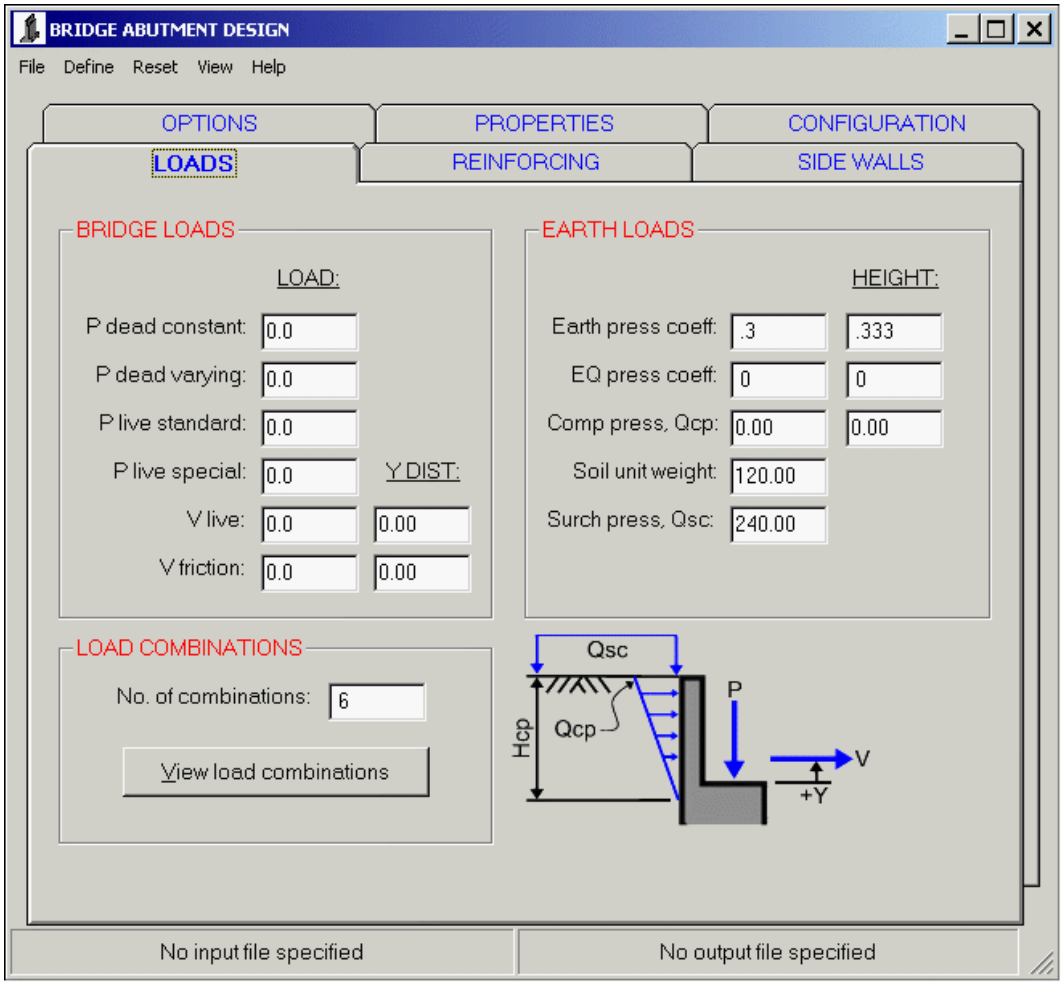
Brgabut Help

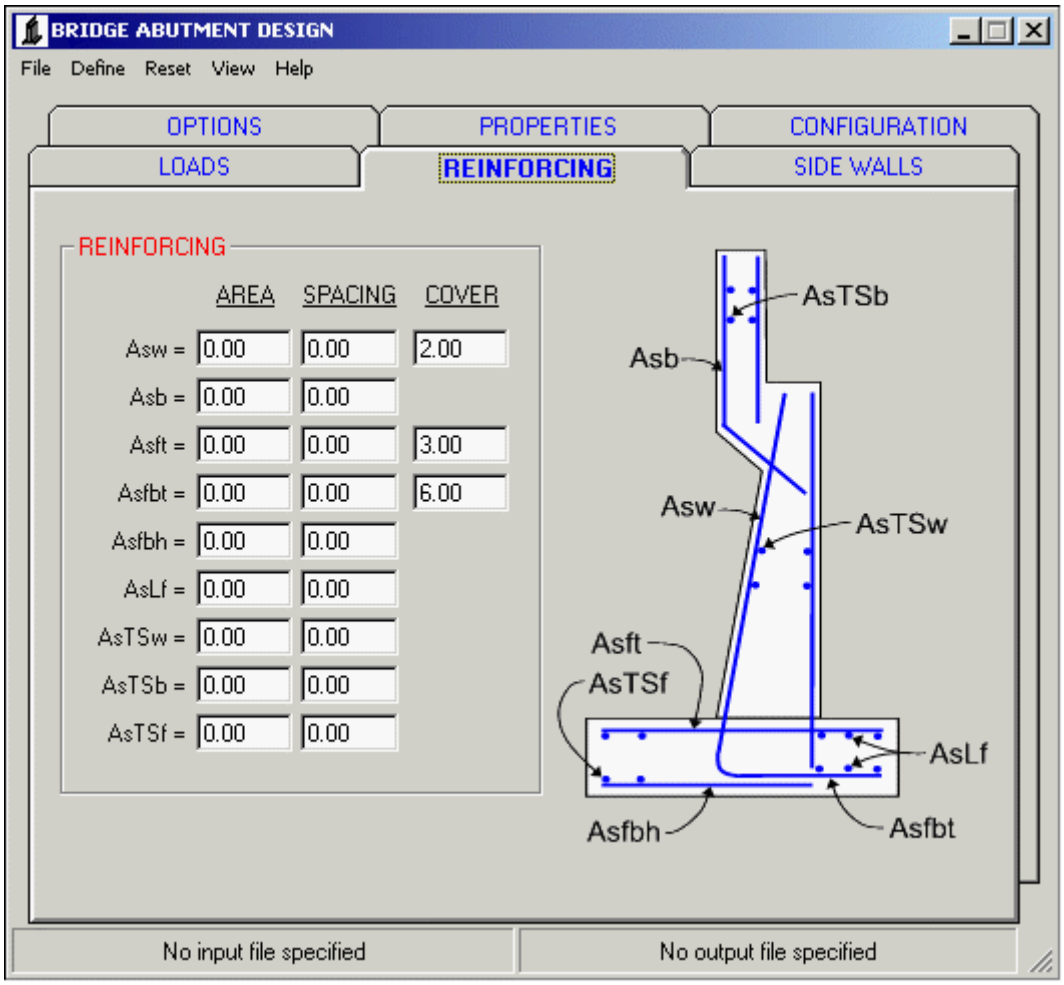
GRAPHICAL INTERFACE

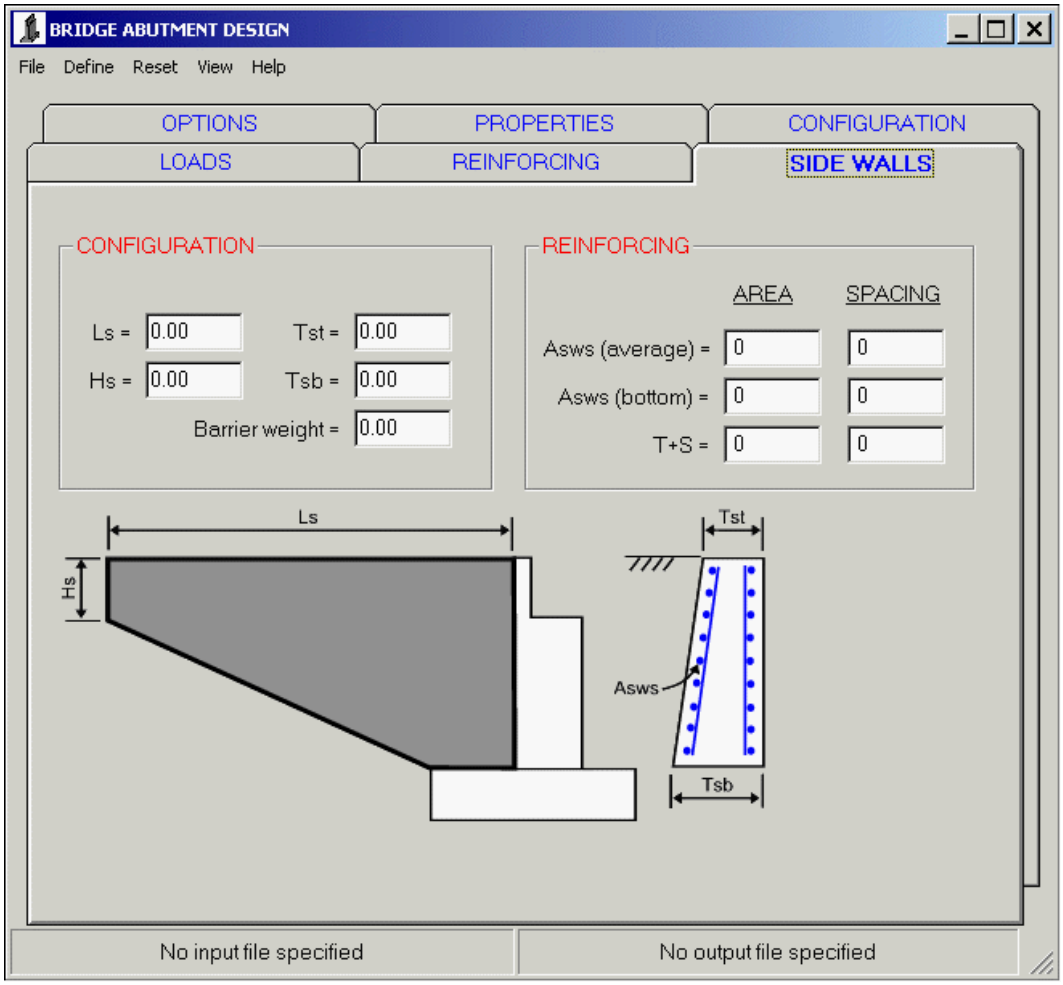


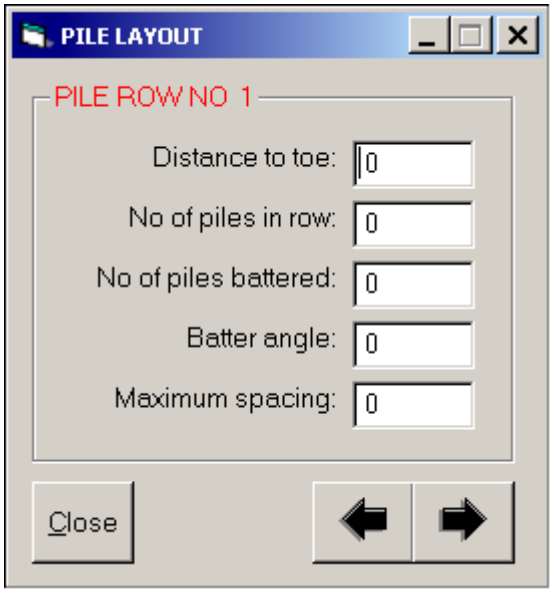

BRIDGE ABUTMENT DESIGN
File Define Reset View Help
LOADS
REINFORCING
SIDE WALLS
OPTIONS
PROPERTIES
CONFIGURATION
REINFORCED CONCRETE
Conc comp strength: 4000.0
Concrete unit weight: 150.00
Exposure factor: 170000.0
Reinf yield strength: 60000.0
PILE RESISTANCE
SLS ULS EQ
Compression: 0.0 0.0 0.0
Tension: 0.0 0.0 0.0
Shear: 0.0 0.0 0.0
FOOTING RESISTANCE
SLS ULS EQ
Gross soil bearing pressure: 0.0 0.0 0.0
Base soil friction coefficient: 0.000 0.000 0.000
Location of vertical resultant: 0.333 0.667 0.667
Passive pressure coefficient: 0.000 0.000 0.000
PILE FIXITY
Pinned
Fixed
P-M Data
No input file specified
No output file specified

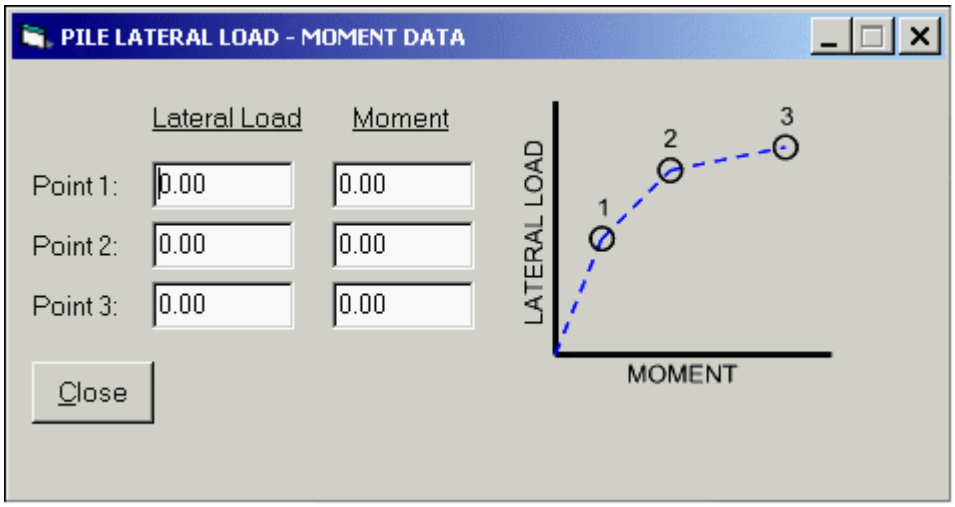

BRIDGE ABUTMENT DESIGN
File Define Reset View Help
LOADS
REINFORCING
SIDE WALLS
OPTIONS
PROPERTIES
CONFIGURATION
ABUTMENT
Hw = 0.000
Ts = 0.000
Lw = 0.000
Db = 0.000
Tw = 0.000
Dt = 0.000
Bat = 0.000
Ht = 0.000
Hb = 0.000
Wf = 0.000
Tb = 0.000
Lf = 0.000
Hh = 0.000
Tf = 0.000
PILES
No. of rows of piles: 0
Pile width: 0
View Pile Layout
Tb
Ts
BACKWALL
℄ BEARING
Db
Hb
Hh
Tw
Hw
HAUNCH
1
1
Bat
Ht
Tf
Dt
Wf
No input file specified
No output file specified

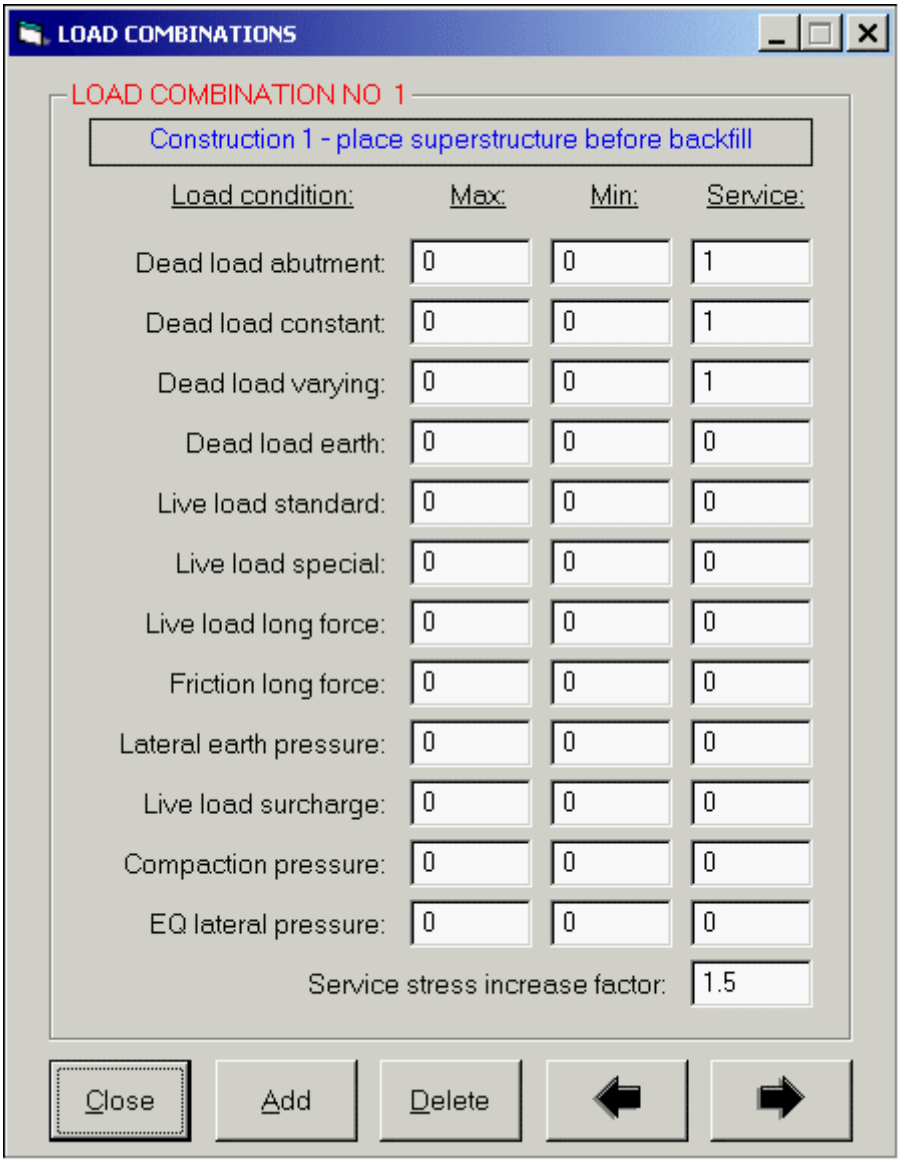

BRIDGE ABUTMENT DESIGN
File Define Reset View Help
OPTIONS
PROPERTIES
CONFIGURATION
LOADS
REINFORCING
SIDE WALLS
BRIDGE LOADS
LOAD:
P dead constant: 0.0
P dead varying: 0.0
P live standard: 0.0
P live special: 0.0
V live: 0.0
V friction: 0.0
Y DIST:
0.00
0.00
EARTH LOADS
HEIGHT:
Earth press coeff: .3 .333
EQ press coeff: 0 0
Comp press, Qcp: 0.00 0.00
Soil unit weight: 120.00
Surch press, Qsc: 240.00
LOAD COMBINATIONS
No. of combinations: 6
View load combinations
Qsc
Qcp
Hcp
P
V
+Y
No input file specified
No output file specified


BRIDGE ABUTMENT DESIGN
File Define Reset View Help
OPTIONS
PROPERTIES
CONFIGURATION
LOADS
REINFORCING
SIDE WALLS
REINFORCING
AREA SPACING COVER
Asw = 0.00 0.00 2.00
Asb = 0.00 0.00
Asft = 0.00 0.00 3.00
Asfbt = 0.00 0.00 6.00
Asfbh = 0.00 0.00
AsLf = 0.00 0.00
AsTSw = 0.00 0.00
AsTSb = 0.00 0.00
AsTSf = 0.00 0.00
AsTSb
Asb
Asw
AsTSw
Asft
AsTSf
AsLf
Asfbh
Asfbt
No input file specified
No output file specified


BRIDGE ABUTMENT DESIGN
File Define Reset View Help
OPTIONS
PROPERTIES
CONFIGURATION
LOADS
REINFORCING
SIDE WALLS
CONFIGURATION
Ls = 0.00
Tst = 0.00
Hs = 0.00
Tsb = 0.00
Barrier weight = 0.00
REINFORCING
AREA
SPACING
Asws (average) = 0 0
Asws (bottom) = 0 0
T+S = 0 0
Ls
Hs
Tst
Asws
Tsb
No input file specified
No output file specified


PILE LAYOUT
PILE ROW NO 1
Distance to toe: 0
No of piles in row: 0
No of piles battered: 0
Batter angle: 0
Maximum spacing: 0
Close


PILE LATERAL LOAD - MOMENT DATA
Lateral Load
Moment
Point 1: 0.00 0.00
Point 2: 0.00 0.00
Point 3: 0.00 0.00
Close
LATERAL LOAD
MOMENT
1
2
3


LOAD COMBINATIONS
LOAD COMBINATION NO 1
Construction 1 - place superstructure before backfill
Load condition:
Max:
Min:
Service:
Dead load abutment: 0 0 1
Dead load constant: 0 0 1
Dead load varying: 0 0 1
Dead load earth: 0 0 0
Live load standard: 0 0 0
Live load special: 0 0 0
Live load long force: 0 0 0
Friction long force: 0 0 0
Lateral earth pressure: 0 0 0
Live load surcharge: 0 0 0
Compaction pressure: 0 0 0
EQ lateral pressure: 0 0 0
Service stress increase factor: 1.5
Close
Add
Delete

VERIFICATION PROBLEMS

1. Roadway bridge abutment

   A. Haunched abutment configuration
   B. No side walls
   C. Vertical piles pinned at top
   D. AASHTO design criteria
   E. English units
   F. Ultimate strength design and service load design

2. Roadway bridge abutment

   A. Haunched abutment configuration
   B. Stub walls included
   C. Vertical piles fixed at top
   D. AASHTO LRFD design criteria
   E. Metric units

3. Railroad bridge abutment

   A. No haunch abutment configuration
   B. No side walls
   C. Vertical and battered piles, pinned at top
   D. AREMA design criteria
   E. English units
   F. Service load design

4. Roadway bridge abutment

   A. No haunch abutment configuration
   B. Wingwalls included
   C. Spread footing
   D. CAN/CSA-S6 design criteria
   E. Metric units

STRUCTWARE

SHEET C1-1 OF

JOB TITLE BRGABUT Verification Problem 1 ORIGINATOR RM DATE 9/18/2005

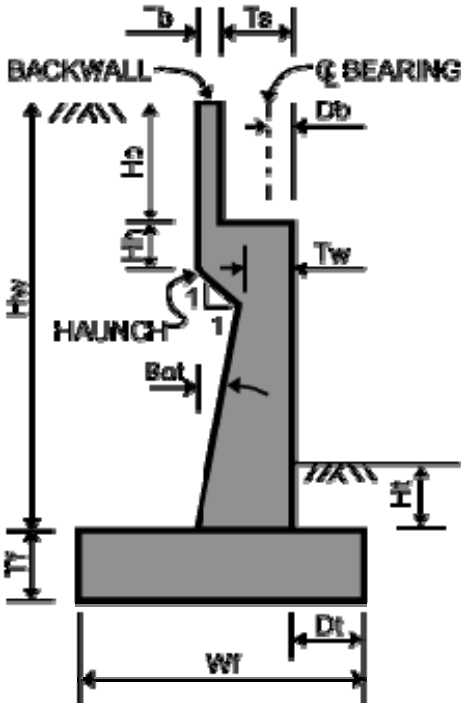
JOB No. CALCULATION No. REVIEWER DATE

VERIFICATION PROBLEM NO 1

- Roadway bridge abutment with haunch
- Vertical, pinned-head piles
- AASHTO design criteria
- English units

CONFIGURATION

VARIABLE	VALUE
Hw	27.23 ft
Ht	2 ft
Lw	30.77 ft
Tw	2 ft
Bat	3.43 degrees
Hb	6.64 ft
Tb	1 ft
Hh	2 ft
Ts	2.5 ft
Db	1.25 ft
Dt	5.64 ft
Wf	19.69
Lf	30.77
Tf	3.77



The pile configuration is described below.

DESCRIPTION	VALUE
Number of pile rows	3
Pile diameter	30"
Distance(s) from pile to toe	2.46', 9.84', 17.22'
Pile batter from vertical	0
Number of piles in row(s)	4, 4, 4
Number of batter piles in row (s)	0, 0, 0
Maximum pile spacing	8.5', 8.5', 8.5'

PROPERTIES

REINFORCED CONCRETE:

Concrete compressive strength	= 4000.0 psi
Concrete unit weight	= 150.00 pcf
Exposure factor	= 170000.0 lb/in
Reinforcing yield strength	= 60000.0 psi

PILE RESISTANCE:

LOAD	RESISTANCE (kip) SLS	ULS	EQ
Compression:	400.0	800.0	800.0
Tension:	200.0	400.0	400.0
Shear:	100.0	200.0	200.0

FOOTING RESISTANCE:

PARAMETER	SLS	ULS	EQ
Passive coefficient:	1.000	1.500	3.000

LOADS

BRIDGE LOADS:

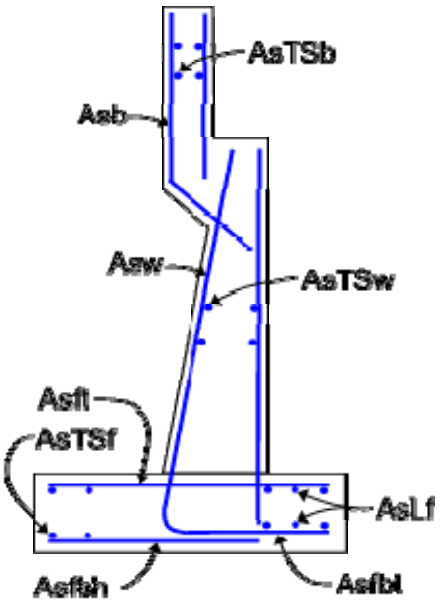
Dead load	= 372.0 kip
Live load	= 124.0 kip
Bearing pad shear	= 74.0 kip at top of seat

EARTH LOADS:

Lateral pressure coeff	= 0.300 at height ratio = 0.333
Soil unit weight	= 120.00 pcf
Surcharge pressure	= 240.00 psf

REINFORCING

VARIABLE	DESCRIPTION
REINFORCING AREA:	
Asw	1.27 in^2 @ 7 in
Asb	0.44 in^2 @ 14 in
Asft	0.79 in^2 @ 7 in
Asfbt	1.27 in^2 @ 7 in
Asfbh	0.79 in^2 @ 7 in
AsLf	0.79 in^2 @ 12 in
AsTSw	0.44 in^2 @ 12 in
AsTSb	0.20 in^2 @ 12 in
AsTSf	0.20 in^2 @ 12 in
REINFORCING COVER:	
Cover Asw	2"
Cover Asft	3"
Cover Asfb	6"



BACKWALL CALCULATIONS

Effective depth, d = 12 - 2 - $(0.44 / 3.1416)^{1/2}$ = 9.63 in
Backwall height for shear = 6.64 - 9.63 / 12 = 5.84 ft

Lateral earth pressure: V = 0.036 $(5.84)^2$ / 2 = 0.614 kip/ft
M = 0.036 $(6.64)^3$ / 6 = 1.757 k-ft/ft

Surcharge pressure: V = 0.072 (5.84) = 0.420 kip/ft
M = 0.072 $(6.64)^2$ / 2 = 1.587 k-ft/ft

Service loads: V = 0.614 + 0.420 = 1.034 kip/ft
M = 1.757 + 1.587 = 3.344 k-ft/ft

Factored loads: V = 1.69 x 1.034 = 1.747 kip/ft
M = 1.69 x 3.344 = 5.651 k-ft/ft

Run REBEAM program to verify flexural calculations (see REBEAM output below):

Area of reinforcing per foot = 0.44 x 12 / 14 = 0.377 in^2

Service stresses: f_c = 380 psi < 1600 psi
f_s = 11859 psi < 24000 psi

Crack control: f_{crack} = 31547 psi > 11859 psi

Ultimate flexure: A_s > 0.176 x 14 / 12 = 0.205 in^2
A_{smax} = 2.471 x 14 / 12 = 2.88 in^2

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* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
8/30/02, 6:58 pm

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO (1996)
Units = English (pounds, inches - moments in kip-ft)
```

```
MATERIAL PROPERTIES:

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6050E+06
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

S E C T I O N   P R O P E R T I E S:
==================================================

RECTANGULAR SECTION:

     Width  = 12
     Height = 12

PROPERTIES:

     Gross moment of inertia     = 1.7280E+03
     Gross section modulus       = 2.8800E+02
     Distance to neutral axis    = 6.0000E+00
     Cracked moment of inertia   = 2.0755E+02
     Effective moment of inertia = 1.7280E+03

R E V I E W   C A L C U L A T I O N S:
==================================================

REINFORCING STEEL:

     Tensile steel area         = 0.377
     Compressive steel area     = 0
     Depth to tensile steel     = 9.63
     Depth to Compressive steel = 0

     Maximum tensile steel area = 2.4707E+00
```

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DESIGN MOMENTS:

     Factored ultimate moment    = 5.651
     Maximum service load moment = 3.344
     Minimum service load moment = 0

MOMENT CAPABILITY:

     Ultimate moment capability  = 1.5867E+01
     1.2 * Cracking moment       = 1.3661E+01
     Design moment               = 7.5347E+00
     Stress block depth          = 5.5441E-01

SERVICE LOAD STRESS:

     Maximum steel stress    = 1.1859E+04
     Minimum steel stress    = 0.0000E+00
     Maximum concrete stress = 3.7956E+02
     Minimum concrete stress = 0.0000E+00

CRACK CONTROL:

     Concrete cover            = 2.37
     Effective tension area    = 66.36
     Exposure factor           = 170000
     Maximum steel stress      = 1.1859E+04
     Allowable cracking stress = 3.1547E+04

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```

Perform hand calculations to verify shear calculations:

Ultimate shear: $d > 1.747 \times 1000 / (0.85 \times 2 \times (4000)^{1/2} \times 12) = 1.35$ in

Service shear: $d > 1.034 \times 1000 / (0.95 \times (4000)^{1/2} \times 12) = 1.43$ in

Temperature and shrinkage reinforcement:

$A_s > 0.125$ in^2/ft $\times$ 12 / 12 = 0.125 in^2

STEM WALL CALCULATIONS

Height to bottom of haunch = 27.23 - 6.64 - 2 - (1 + 2.5 - 2) = 17.09 ft
Concrete thickness at top of footing = 2 + 17.09 x tan(3.43) = 3.024 ft (36.3 in)
Effective depth, d = 36.3 - 2 - $(1.27 / 3.1416)^{1/2}$ = 33.66 in
Stem wall height for shear = 27.23 - 33.66 / 12 = 24.425 ft

Lateral earth pressure: V = 0.036 $(24.425)^2$ / 2 = 10.74 kip/ft
M = 0.036 $(27.23)^3$ / 6 = 121.1 k-ft/ft

Surcharge pressure: V = 0.072 (24.425) = 1.759 kip/ft
M = 0.072 $(27.23)^2$ / 2 = 26.69 k-ft/ft

Bridge dead load: M = 372 x (3.024 / 2 - 1.25) / 30.77= 3.167 k-ft/ft

Bridge live load: M = 124 x (3.024 / 2 - 1.25) / 30.77= 1.056 k-ft/ft

Bearing pad shear: V = 74 / 30.77 = 2.405 kip/ft
M = 74 x (27.23 - 6.64 + 0) / 30.77 = 49.52 k-ft/ft

Service loads: V = 10.74 + 1.759 = 12.50 kip/ft (comb 4)
M = 121.1 + 26.69 + 3.167 + 1.056 + 49.52 = 201.5 k-ft/ft (comb 6)

Factored loads: V = 1.3 x 2.405 + 1.69 x (10.74 + 1.759) = 24.25 kip/ft (comb 6)
M = 1.3 x (3.167 + 1.056 + 49.52) + 1.69 x (121.1 + 26.69)
M = 319.6 k-ft/ft (comb 6)

Run REBEAM program to verify flexural calculations (see REBEAM output below):

Area of reinforcing per foot = 1.27 x 12 / 7 = 2.177 in^2

Service stresses: f_c = 1532 psi < 1600 x 1.25 psi
f_s = 36046 psi > 24000 x 1.25 psi

k = 2000 / (30000 / 8 + 2000) = 0.3478
j = 1 - 0.3478 / 3 = 0.8840
A_s required > 7 * 201.5 x 1000 / (30000 x 0.884 x 33.66) = 1.58 in^2

Crack control: f_{crack} = 36000 psi < 36046 psi

Ultimate flexure: A_s > 2.217 x 7 / 12 = 1.29 in^2
A_{smax} = 8.636 x 7 / 12 = 5.04 in^2

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                         *
*           P R O G R A M   R E B E A M                   *
*                                                         *
*                    OUTPUT DATA                          *
*                                                         *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
8/31/02, 1:33 pm

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO (1996)
Units = English (pounds, inches - moments in kip-ft)

MATERIAL PROPERTIES:

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6050E+06
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

S E C T I O N   P R O P E R T I E S:
=====================================================

RECTANGULAR SECTION:

     Width  = 12
     Height = 36.3

PROPERTIES:

     Gross moment of inertia     = 4.7832E+04
     Gross section modulus       = 2.6354E+03
     Distance to neutral axis    = 1.8150E+01
     Cracked moment of inertia   = 1.3481E+04
     Effective moment of inertia = 1.8228E+04
```

```
R E V I E W   C A L C U L A T I O N S:
=====================================================

REINFORCING STEEL:

     Tensile steel area         = 2.177
     Compressive steel area     = 0
     Depth to tensile steel     = 33.66
     Depth to Compressive steel = 0

     Maximum tensile steel area = 8.6359E+00

DESIGN MOMENTS:

     Factored ultimate moment    = 319.6
     Maximum service load moment = 201.5
     Minimum service load moment = 0

MOMENT CAPABILITY:

     Ultimate moment capability  = 3.1407E+02
     1.2 * Cracking moment       = 1.2501E+02
     Design moment               = 3.1960E+02
     Stress block depth          = 3.2015E+00

SERVICE LOAD STRESS:

     Maximum steel stress    = 3.6046E+04
     Minimum steel stress    = 0.0000E+00
     Maximum concrete stress = 1.5316E+03
     Minimum concrete stress = 0.0000E+00

CRACK CONTROL:

     Concrete cover            = 2.64
     Effective tension area    = 36.96
     Exposure factor           = 170000
     Maximum steel stress      = 3.6046E+04
     Allowable cracking stress = 3.6000E+04
```

Required depth for shear:

Ultimate shear: $d > 24.25 \times 1000 / (0.85 \times 2 \times (4000)^{1/2} \times 12) = 18.80$ in

Service shear: $d > 12.50 \times 1000 / (0.95 \times (4000)^{1/2} \times 12) = 17.34$ in

Temperature and shrinkage reinforcement:

$A_s > 0.125 \text{ in}^2/\text{ft} \times 12 / 12 = 0.125 \text{ in}^2$

Verify required flexural reinforcement area for the ultimate limit state at 10 sections using REBEAM program. The height, thickness and effective depth are verified directly. The moment is verified with a separate spreadsheet (not shown). The REBEAM output is summarized in the last column below.

HEIGHT (ft)	THICK (in)	Deff (in)	MOMENT (k-ft/ft)	AREA (in^2)
25.52	35.06	32.43	267.21	1.117
23.81	33.83	31.20	225.09	0.977
22.10	32.60	29.97	187.56	0.841
20.39	31.38	28.74	154.31	0.719
18.69	30.15	27.51	125.05	0.606
16.98	28.92	26.28	99.45	0.503
15.27	27.69	25.05	77.25	0.408
13.56	26.46	23.82	58.08	0.369
11.85	25.23	22.59	41.70	0.325
10.14	24.00	21.36	27.77	0.228

STABILITY CALCULATIONS

Calculate weight and righting moment:

1. Dead load abutment

   w1 = 1 x 6.64 x 30.77 x 0.15 = 30.65 kips
   x1 = 8.64 ft

   w2 = 2 x 3.5 x 30.77 x 0.15 = 32.31 kips
   x2 = 7.39 ft

   w3 = 1.5 x 1.5 x 30.77 x 0.15 / 2 = 5.19 kips
   x3 = 8.14 ft

   w4 = 1.5 x 2 x 30.77 x 0.15 = 13.85 kips
   x4 = 6.64 ft

   w5 = 2 x 17.09 x 30.77 x 0.15 = 157.76 kips
   x5 = 6.64 ft

   w6 = 17.09 x 1.024 x 30.77 x 0.15 / 2 = 40.40 kips
   x6 = 7.98 ft

   w7 = 19.69 x 3.77 x 30.77 x 0.15 = 342.61 kips
   x7 = 9.84 ft

   Weight = 622.8 kips
   Righting moment = 5379.0 k-ft

2. Dead load constant

   Weight = 372 kips
   Righting moment = 372 x 6.89 = 2563.1 k-ft

3. Dead load earth

   w1 = 10.14 x 10.55 x 30.77 x 0.12 = 395.00 kips
   x1 = 14.41 ft

   w2 = 1.5 x 1.5 x 30.77 x 0.12 / 2 = 4.15 kips
   x2 = 8.64 ft

   w3 = 11.03 x 17.09 x 30.77 x 0.12 = 695.77 kips
   x3 = 14.18 ft

   w4 = 17.09 x 1.024 x 30.77 x 0.12 / 2 = 32.31 kips
   x4 = 8.32 ft

   w5 = 2 x 5.64 x 30.77 x 0.12 = 41.65 kips
   x5 = 2.82 ft

Weight = 1168.9 kips
Righting moment = 15980.1 k-ft

4. Live load standard

   Weight = 124 kips
   Righting moment = 124 x 6.89 = 854.4 k-ft

5. Live load surcharge

   Weight = .24 x 10.55 x 30.77 = 77.9 kips
   Righting moment = 77.9 x 14.41 = 1123.1 k-ft

Calculate lateral load and overturning moment:

1. Friction longitudinal force

   Force = 74 kips
   Overturning moment = 74 x 24.36 = 1802.6 k-ft

2. Lateral earth pressure

   Force = $0.3 \times 0.12 \times 30.77 \times (31)^2 / 2 = 532.3$ kips
   Overturning moment = 532.3 x 31 / 3 = 5500 k-ft

3. Surcharge pressure

   Force = 0.3 x 0.24 x 31 x 30.77 = 68.7 kips
   Overturning moment = 68.7 x 31 / 2 = 1064.5 k-ft

Check resultant load combinations (use spreadsheet):

Combination 1:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN
da	622.8	5379	0	0	1	0	0
dc	372	2563.1	0	0	1	0	0
dv	0	0	0	0	1	0	0
de	1168.9	15980.1	0	0	0	0	0
l1	124	854.4	0	0	0	0	0
fr	0	0	74	1802.6	0	0	0
ep	0	0	532.3	5500	0	0	0
sc	77.9	1123.1	68.7	1064.5	0	0	0
cp	0	0	0	0	0	0	0
SLS	995	7942	0	0			
ULS MAX	0	0	0	0			
ULS MIN	0	0	0	0			

Combination 2:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN
da	622.8	5379	0	0	1	0	0
dc	372	2563.1	0	0	0	0	0
dv	0	0	0	0	0	0	0
de	1168.9	15980.1	0	0	1	0	0
l1	124	854.4	0	0	0	0	0
fr	0	0	74	1802.6	0	0	0
ep	0	0	532.3	5500	1	0	0
sc	77.9	1123.1	68.7	1064.5	0	0	0
cp	0	0	0	0	0	0	0
SLS	1792	21359	532	5500			
ULS MAX	0	0	0	0			
ULS MIN	0	0	0	0			

Combination 3:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN
da	622.8	5379	0	0	1	1.3	0.975
dc	372	2563.1	0	0	1	1.3	0.975
dv	0	0	0	0	1	1.3	0.975
de	1168.9	15980.1	0	0	1	1.3	0.975
l1	124	854.4	0	0	0	0	0
fr	0	0	74	1802.6	0	0	0
ep	0	0	532.3	5500	1	1.69	1.69
sc	77.9	1123.1	68.7	1064.5	1	1.69	0
cp	0	0	0	0	0	0	0
SLS	2242	25045	601	6565			
ULS MAX	2944	32997	1016	11094			
ULS MIN	2110	23324	900	9295			

Combination 4:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN
da	622.8	5379	0	0	1	1.3	0.975
dc	372	2563.1	0	0	1	1.3	0.975
dv	0	0	0	0	1	1.3	0.975
de	1168.9	15980.1	0	0	1	1.3	0.975
l1	124	854.4	0	0	1	2.171	2.171
fr	0	0	74	1802.6	0	0	0
ep	0	0	532.3	5500	1	1.69	1.69
sc	77.9	1123.1	68.7	1064.5	1	1.69	0
cp	0	0	0	0	0	0	0
SLS	2366	25900	601	6565			
ULS MAX	3214	34852	1016	11094			
ULS MIN	2379	25179	900	9295			

Combination 5:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN
da	622.8	5379	0	0	1	1.25	0.937
dc	372	2563.1	0	0	1	1.25	0.937
dv	0	0	0	0	1	1.25	0.937
de	1168.9	15980.1	0	0	1	1.25	0.937
l1	124	854.4	0	0	0	0	0
fr	0	0	74	1802.6	1	1.25	1.25
ep	0	0	532.3	5500	1	1.25	1.25
sc	77.9	1123.1	68.7	1064.5	1	1.25	0
cp	0	0	0	0	0	0	0
SLS	2242	25045	675	8367			
ULS MAX	2802	31307	844	10459			
ULS MIN	2027	22415	758	9128			

Combination 6:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN
da	622.8	5379	0	0	1	1.3	0.975
dc	372	2563.1	0	0	1	1.3	0.975
dv	0	0	0	0	1	1.3	0.975
de	1168.9	15980.1	0	0	1	1.3	0.975
l1	124	854.4	0	0	1	1.3	1.3
fr	0	0	74	1802.6	1	1.3	1.3
ep	0	0	532.3	5500	1	1.69	1.69
sc	77.9	1123.1	68.7	1064.5	1	1.69	0
cp	0	0	0	0	0	0	0
SLS	2366	25900	675	8367			
ULS MAX	3106	34108	1112	13437			
ULS MIN	2271	24435	996	11638			

Check vertical resultant (use spreadsheet):

X = (Mrt - Mot) / Pv
Locate = Fractional portion of footing = (Wf - 2X) / Wf

Combination 1:

CASE	X	LOCATE
SLS	7.984	0.189

Combination 2:

CASE	X	LOCATE
SLS	8.851	0.101

Combination 3:

CASE	X	LOCATE
SLS	8.244	0.163
ULS 1	7.439	0.244
ULS 2	5.797	0.411
ULS 3	8.050	0.182
ULS 4	6.650	0.325

Combination 4:

CASE	X	LOCATE
SLS	8.173	0.170
ULS 1	7.393	0.249
ULS 2	5.921	0.399
ULS 3	7.953	0.192
ULS 4	6.677	0.322

Combination 5:

CASE	X	LOCATE
SLS	7.440	0.244
ULS 1	7.440	0.244
ULS 2	5.897	0.401
ULS 3	7.915	0.196
ULS 4	6.554	0.334

Combination 6:

CASE	X	LOCATE
SLS	7.411	0.247
ULS 1	6.656	0.324
ULS 2	4.843	0.508
ULS 3	7.235	0.265
ULS 4	5.635	0.428

PILE FOOTING CALCULATIONS

Calculate pile group properties:

n = 12
Xcg = 9.84 feet
Ipiles = $4(9.84 - 2.46)^2 + 4(9.84 - 9.84)^2 + 4(9.84 - 17.22)^2 = 435.7\ ft^2$

Calculate pile loads and shear resistance (use spreadsheet):

Vertical load = Pv
Horizontal load = Ph
Resultant distance = X
Distance to pile from toe = x

Lateral pile capacity, Vpile = 100 x Fsls kips (SLS) and 200 kips (ULS)
Passive resistance, Vpas = 0.12 x 30.77 (2 + 3.77)2 / 2 = 61.5 x Fsls (SLS) and 92.2 (ULS)

Axial load, P = Pv / n + Pv x (Xcg - X) x (Xcg - x) / Ipiles
Shear load, V = (Ph - Passive) / n > 0
Shear resistance, Vr = Vpas + Vpile x n

Load combination 1:

n = 12
Xcg = 9.84
Ipile = 435.7
Fsls = 1.5

	SLS
Vpas =	92.20
Vpile =	150
Pv =	995
Ph =	0
X =	7.984

Row	x	n	Psls
1	2.46	4	114.2
2	9.84	4	82.9
3	17.22	4	51.6

V =	0.0
Vr =	1892.2

Load combination 2:

n = 12
Xcg = 9.84
Ipile = 435.7
Fsls = 1.5

	SLS
Vpas =	92.20
Vpile =	150
Pv =	1792
Ph =	532
X =	8.851

Row	x	n	Psls
1	2.46	4	179.3
2	9.84	4	149.3
3	17.22	4	119.3

V =	36.7
Vr =	1892.2

Load combination 3:

n = 12
Xcg = 9.84
Ipile = 435.7
Fsls = 1.25

	SLS	ULS 1	ULS 2	ULS 3	ULS 4
Vpas =	76.83	92.20	92.20	92.20	92.20
Vpile =	125	200	200	200	200
Pv =	2242	2944	2110	2944	2110
Ph =	601	1016	1016	900	900
X =	8.244	7.439	5.797	8.050	6.650

Row	x	n	Psls	Pu1	Pu2	Pu3	Pu4
1	2.46	4	247.4	365.1	320.3	334.7	289.8
2	9.84	4	186.8	245.4	175.8	245.4	175.8
3	17.22	4	126.2	125.6	31.3	156.1	61.8

V =	43.7	77.0	77.0	67.3	67.3
Vr =	1576.8	2492.2	2492.2	2492.2	2492.2

Load combination 4:

n = 12
Xcg = 9.84
Ipile = 435.7
Fsls = 1.0

	SLS	ULS 1	ULS 2	ULS 3	ULS 4
Vpas =	61.47	92.20	92.20	92.20	92.20
Vpile =	100	200	200	200	200
Pv =	2366	3214	2379	3214	2379
Ph =	601	1016	1016	900	900
X =	8.173	7.393	5.921	7.953	6.677

Row	x	n	Psls	Pu1	Pu2	Pu3	Pu4
1	2.46	4	263.9	401.0	356.1	370.5	325.7
2	9.84	4	197.1	267.8	198.2	267.8	198.2
3	17.22	4	130.4	134.6	40.3	165.1	70.8

V =	45.0	77.0	77.0	67.3	67.3
Vr =	1261.5	2492.2	2492.2	2492.2	2492.2

Load combination 5:

n = 12
Xcg = 9.84
Ipile = 435.7
Fsls = 1.4

	SLS	ULS 1	ULS 2	ULS 3	ULS 4
Vpas =	86.05	92.20	92.20	92.20	92.20
Vpile =	140	200	200	200	200
Pv =	2242	2802	2027	2802	2027
Ph =	675	844	844	758	758
X =	7.440	7.440	5.897	7.915	6.554

Row	x	n	Psls	Pu1	Pu2	Pu3	Pu4
1	2.46	4	277.9	347.4	304.3	324.9	281.8
2	9.84	4	186.8	233.5	168.9	233.5	168.9
3	17.22	4	95.7	119.6	33.6	142.1	56.1

V =	49.1	62.6	62.6	55.5	55.5
Vr =	1766.1	2492.2	2492.2	2492.2	2492.2

Load combination 6:

n = 12
Xcg = 9.84
Ipile = 435.7
Fsls = 1.25

	SLS	ULS 1	ULS 2	ULS 3	ULS 4
Vpas =	76.83	92.20	92.20	92.20	92.20
Vpile =	125	200	200	200	200
Pv =	2366	3106	2271	3106	2271
Ph =	675	1112	1112	996	996
X =	7.411	6.656	4.843	7.235	5.635

Row	x	n	Psls	Pu1	Pu2	Pu3	Pu4
1	2.46	4	294.4	426.3	381.4	395.8	351.0
2	9.84	4	197.1	258.8	189.2	258.8	189.2
3	17.22	4	99.8	91.3	-3.0	121.8	27.5

V =	49.8	85.0	85.0	75.3	75.3
Vr =	1576.8	2492.2	2492.2	2492.2	2492.2

Footing loads:

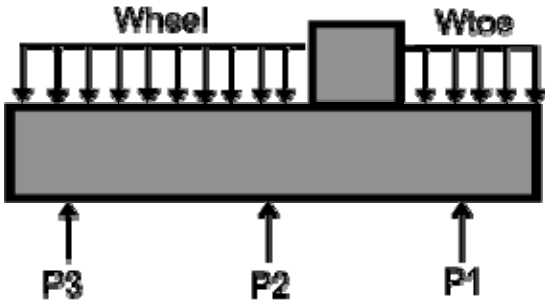
The footing load calculations for the toe and heel will be verified by checking a couple critical load combinations.

Dt = 5.64 ft
Lheel = 19.69 - 5.64 - 2 - 17.09 x tan(3.43) = 11.03 ft
dtop = 45.24 - 3 - $(0.79 / 3.1416)^{1/2}$ = 41.74 in
dbot (toe) = 45.24 - 6 - $(1.27 / 3.1416)^{1/2}$ = 38.60 in
dbot (heel) = 45.24 - 6 - $(0.79 / 3.1416)^{1/2}$ = 38.74 in

W(conc) = 3.77 x 0.150 = 0.565 ksf
Wtoe(soil) = 2 x 0.120 =0.240 ksf
Wheel (soil) = 27.23 x 0.120 = 3.268 ksf
Wheel (surch) = 0.240 ksf

SLS combination 4:

P1v = 263.9 kips
P2v = 197.1 kips
P3v = 130.4 kips
Wtoe = 0.805 ksf
Wheel = 4.073 ksf



Toe moment and shear:

M = (4 x 263.9 x 3.18) / 30.77 - 0.805 x $(5.64)^2$ / 2 = 96.3 k-ft/ft

Lv = 5.64 - 38.6 / 12 = 2.423 ft

V = 4 x 263.9 x (2.5 - 1.287) / (2.5 x 30.77) - 0.805 x 2.423 = 14.7 k/ft

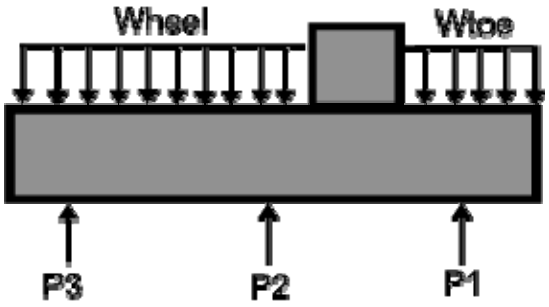
Heel moment and shear:

M = 4(197.1 x 1.18 + 130.4 x 8.56) / 30.77 - 4.073 $(11.03)^2$ / 2 = -72.4 k-ft/ft

V = 4(197.1 x 2.43 / 2.5 + 130.4) / 30.77 - 4.073 x 11.03 = -3.1 k/ft

ULS combination 6, Case 1:

P1v = 426.3 kips
P2v = 258.8 kips
P3v = 91.3 kips
Wtoe = 1.047 ksf
Wheel = 5.388 ksf



Toe moment and shear:

$M = (4 \times 426.3 \times 3.18) / 30.77 - 1.047 \times (5.64)^2 / 2 = 159.6$ k-ft/ft

$Lv = 5.64 - 38.6 / 12 = 2.423$ ft

$V = 4 \times 426.3 \times (2.5 - 1.287) / (2.5 \times 30.77) - 1.047 \times 2.423 = 24.3$ k/ft

Heel moment and shear:

$M = 4(258.8 \times 1.18 + 91.3 \times 8.56) / 30.77 - 5.388 (11.03)^2 / 2 = -186.5$ k-ft/ft

$V = 4(258.8 \times 2.43 / 2.5 + 91.3) / 30.77 - 5.388 \times 11.03 = -14.9$ k/ft

Reinforcement calculations for footing:

The footing reinforcement calculations use the same subroutines which were previously validated for the backwall and stemwall calculations. Therefore, only the critical calculations at the footing toe will be validated.

Perform hand calculations to verify shear calculations:

Ultimate shear Vf = 24.3 k/ft
d > 24.3 x 1000 / (12 x 0.85 x 2 x $(4000)^{1/2}$) = 18.8 in

Run REBEAM program to verify flexural calculations (see REBEAM output below):

Area of reinforcing 1.27 in^2 @ 7 in
Mu @ 7 in = 159.6 x 7 / 12 = 93.1 k-ft
Ms @ 7 in = 96.3 x 7 / 12 = 56.2 k-ft

Service stresses: f_s = 14949 psi

Crack control: fcr = 36000 psi > 14949 psi

Ultimate flexure: $A_s > 0.67\ in^2$
$As_{max} = 5.78\ in^2$

```
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11/28/02, 1:15 pm

D E S I G N   C R I T E R I A
=================================================

Code  = AASHTO (1996)
Units = English (pounds, inches - moments in kip-ft)

MATERIAL PROPERTIES:

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6050E+06
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8
```

```
STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

S E C T I O N   P R O P E R T I E S:
==================================================

RECTANGULAR SECTION:

     Width  = 7
     Height = 45.24

PROPERTIES:

     Gross moment of inertia     = 5.4011E+04
     Gross section modulus       = 2.3878E+03
     Distance to neutral axis    = 2.2620E+01
     Cracked moment of inertia   = 1.0599E+04
     Effective moment of inertia = 5.4011E+04

R E V I E W   C A L C U L A T I O N S:
==================================================

REINFORCING STEEL:

     Tensile steel area         = 1.27
     Compressive steel area     = 0
     Depth to tensile steel     = 38.6
     Depth to Compressive steel = 0

     Maximum tensile steel area = 5.7769E+00

DESIGN MOMENTS:

     Factored ultimate moment    = 93.1
     Maximum service load moment = 56.2
     Minimum service load moment = 0

MOMENT CAPABILITY:

     Ultimate moment capability  = 2.1145E+02
     1.2 * Cracking moment       = 1.1326E+02
     Design moment               = 1.1326E+02
     Stress block depth          = 3.2017E+00
```

```
SERVICE LOAD STRESS:

     Maximum steel stress    = 1.4949E+04
     Minimum steel stress    = 0.0000E+00
     Maximum concrete stress = 5.8750E+02
     Minimum concrete stress = 0.0000E+00

CRACK CONTROL:

     Concrete cover           = 2.64
     Effective tension area   = 36.96
     Exposure factor          = 170000
     Maximum steel stress     = 1.4949E+04
     Allowable cracking stress = 3.6000E+04
```

Footing longitudinal reinforcement:

The longitudinal reinforcement calculations will be verified for the footing toe and heel.

AsLf = 0.79 in^2 @ 12 in
d = 45.24 - 6 - 2(1.27 / 3.1416)$^{1/2}$ - (0.79 / 3.1416)$^{1/2}$ = 37.47 in

Footing toe

Combination 6, ULS 1 pile load = 426.1 kips at row 1

Tributory area = 30.77 x (2.46 + 7.38 / 2) = 189.24 ft^2
Uniform load W = 4 x 426.1 / 189.24 = 9.00 ksf
Pile spacing S = 8.5 ft

M = 9 $(8.5)^2$ / 10 = 65.1 k-ft/ft
As > 0.52 in^2 (REBEAM calculations not shown)
Asmax = 9.61 in^2 (REBEAM calculations not shown)

Footing heel

Combination 4, ULS 1 pile load = 267.8 kips at row 2

Tributory area = 30.77 x 7.38 = 227.08 ft^2
Uniform load W = 4 x 267.8 / 227.08 = 4.72 ksf

Combination 3, ULS 1 pressure on footing:

Uniform load W = 1.3 x (3.77 x .15 + 27.23 x .12) + 1.69 x .24 = 5.39 ksf <= critical
Pile spacing S = 8.5 ft

M = 5.39 $(8.5)^2$ / 10 = 38.9 k-ft/ft
As > 0.31 in^2 (REBEAM calculations not shown)
Asmax = 9.61 in^2 (REBEAM calculations not shown)

BRGABUT OUTPUT FILE = VER1BOTH.OUT

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12/14/02, 12:37 pm

O P T I O N S
=====================================================================

Units           = English
Design Criteria = AASHTO (1996)
Concrete Design = Both SLD and USD
Wall Type       = Haunch
Footing Type    = Pile

P R O P E R T I E S
=====================================================================

REINFORCED CONCRETE:

     MATERIAL PROPERTIES:

     Concrete compressive strength  = 4000.0 psi
     Concrete modulus of elasticity = 3604997.0 psi
     Concrete modulus of rupture    = 474.34 psi
     Concrete modular ratio         = 8
     Concrete unit weight           = 150.00 pcf
     Reinforcing yield strength     = 60000.0 psi
     Crack control exposure factor  = 170000.0 lb/in

     STRENGTH REDUCTION FACTORS:

     Flexure                        = 0.900
     Shear                          = 0.850

     STRESS BLOCK:

     Compression block stress ratio = 0.8500
     Compression block depth ratio  = 0.8500
     Maximum concrete strain        = 0.0030
```

PILE RESISTANCE:

LOAD	RESISTANCE (kip) SLS	ULS	EQ
Compression:	400.0	800.0	800.0
Tension:	200.0	400.0	400.0
Shear:	100.0	200.0	200.0

FOOTING RESISTANCE:

PARAMETER	SLS	ULS	EQ
Passive coefficient:	1.000	1.500	3.000

C O N F I G U R A T I O N

WALL:

Stem wall height	= 27.230 ft
Stem wall length	= 30.770 ft
Stem wall thickness	= 2.000 ft
Stem wall batter	= 3.430 deg
Haunch depth	= 2.000 ft
Back wall height	= 6.640 ft
Back wall thickness	= 1.000 ft
Seat width	= 2.500 ft
Distance to CL bearing	= 1.250 ft

FOOTING:

Width of toe	= 5.640 ft
Soil cover over toe	= 2.000 ft
Footing width	= 19.690 ft
Footing length	= 30.770 ft
Footing thickness	= 3.770 ft

PILES:

Pile width = 30.0 in

ROW	TOE DIST (ft)	NO OF PILES	NO OF BATTER	BATTER (deg)	SPACING (ft)
1	2.460	4	0	0	8.500
2	9.840	4	0	0	8.500
3	17.220	4	0	0	8.500

L O A D S

BRIDGE LOADS:

Dead load constant = 372.0 kip
Dead load varying = 0.0 kip
Live load standard = 124.0 kip
Live load special = 0.0 kip
Live load long force = 0.0 kip at height = 0.000 ft
Friction long force = 74.0 kip at height = 0.000 ft

EARTH LOADS:

Lateral pressure coeff = 0.300 at height = 0.333 H
Earthquake pressure coeff = 0.000 at height = 0.000 H
Compaction pressure = 0.00 psf at height = 0.000 ft
Soil unit weight = 120.00 pcf
Surcharge pressure = 240.00 psf

LOAD COMBINATIONS:

NO	LOAD CONDITION	MAXIMUM	MINIMUM	SERVICE
1	Construction 1 - place superstructure before backfill			
	Dead load abutment	0	0	1
	Dead load constant	0	0	1
	Dead load varying	0	0	1
	Service stress increase factor =	1.5		

2 Construction 2 - place backfill before superstructure

Dead load abutment	0	0	1
Dead load earth	0	0	1
Lateral earth pressure	0	0	1

Service stress increase factor = 1.5

---

3 Group II - no live load on bridge

Dead load abutment	1.3	0.975	1
Dead load constant	1.3	0.975	1
Dead load varying	1.3	0.975	1
Dead load earth	1.3	0.975	1
Lateral earth pressure	1.69	1.69	1
Live load surcharge	1.69	0	1

Service stress increase factor = 1.25

---

4 Group I - live load on bridge

Dead load abutment	1.3	0.975	1
Dead load constant	1.3	0.975	1
Dead load varying	1.3	0.975	1
Dead load earth	1.3	0.975	1
Live load standard	2.171	2.171	1
Lateral earth pressure	1.69	1.69	1
Live load surcharge	1.69	0	1

Service stress increase factor = 1

---

5 Group V - no live load with bearing friction

Dead load abutment	1.25	0.937	1
Dead load constant	1.25	0.937	1
Dead load varying	1.25	0.937	1
Dead load earth	1.25	0.937	1
Friction longitudinal force	1.25	1.25	1
Lateral earth pressure	1.25	1.25	1
Live load surcharge	1.25	0	1

Service stress increase factor = 1.4

```
     6   Group IV - live load with bearing friction

         Dead load abutment             1.3      0.975    1
         Dead load constant             1.3      0.975    1
         Dead load varying              1.3      0.975    1
         Dead load earth                1.3      0.975    1
         Live load standard             1.3      1.3      1
         Friction longitudinal force    1.3      1.3      1
         Lateral earth pressure         1.69     1.69     1
         Live load surcharge            1.69     0        1

                      Service stress increase factor =  1.25
    ------------------------------------------------------------

R E I N F O R C I N G
====================================================================

--------------------------------------------------------------------
LOCATION                AREA      SPACING   COVER
                        (in^2)    (in)      (in)
--------------------------------------------------------------------
Wall stem               1.27      7.00      2.00
Backwall                0.44      14.00
Footing top             0.79      7.00      3.00
Footing bottom at toe   1.27      7.00      6.00
Footing bottom at heel  0.79      7.00
Footing long w/piles    0.79      12.00
T&S in wall stem        0.44      12.00
T&S in backwall         0.20      12.00
T&S in footing          0.44      12.00
--------------------------------------------------------------------

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                   *
*                 P R O G R A M   B R G A B U T                     *
*                                                                   *
*                          OUTPUT DATA                              *
*                                                                   *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

B A C K W A L L
====================================================================

UNFACTORED LOADS:

    ------------------------------------------------------------
    LOAD CONDITION              SHEAR          MOMENT
                                (kip/ft)       (k-ft/ft)
    ------------------------------------------------------------
    Lateral earth pressure      0.613          1.757
    Surcharge pressure          0.420          1.587
    ------------------------------------------------------------
```

ULTIMATE LIMIT STATE CALCULATIONS:

SHEAR (Comb 3):

Effective depth = 9.63 in
Factored shear = 1.747 kip/ft
d required = 1.35 < d provided = 9.63 OKAY

MOMENT (Comb 3):

Factored moment = 5.651 k-ft/ft
As required = 0.21 < As provided = 0.44 OKAY
As maximum = 2.88 > As provided = 0.44 OKAY

SERVICEABILITY LIMIT STATE CALCULATIONS:

SHEAR (Comb 4):

Effective depth = 9.63 in
Service shear = 1.034 kip/ft
d required = 1.43 < d provided = 9.63 OKAY

MOMENT (Comb 4):

Service moment = 3.344 k-ft/ft
Steel stress = 11859.07 < Allowable stress = 24000.00 OKAY
Concrete stress = 379.74 psi

CRACK CONTROL (Comb 4):

Allowable stress = 31509.81 > Service stress = 11859.07 OKAY

TEMPERATURE AND SHRINKAGE:

T&S reinforcement = 0.20 > Area required = 0.13 OKAY

S T E M W A L L

UNFACTORED LOADS:

LOAD CONDITION	SHEAR (kip/ft)	MOMENT (k-ft/ft)
Dead load constant		3.169
Live load standard		1.056
FR longitudinal force	2.405	49.518
Lateral earth pressure	10.739	121.141
Surcharge pressure	1.759	26.694

```
ULTIMATE LIMIT STATE CALCULATIONS:

     SHEAR (Comb 6):

     Effective depth = 33.66 in
     Factored shear  = 24.247 kip/ft
     d required      = 18.79 < d provided = 33.66 OKAY

     MOMENT (Comb 6):

     Factored moment = 319.707 k-ft/ft
     As required     = 1.29 > As provided = 1.27 NO GOOD ***
     As maximum      = 5.04 > As provided = 1.27 OKAY

SERVICEABILITY LIMIT STATE CALCULATIONS:

     SHEAR (Comb 4):

     Effective depth = 33.66 in
     Service shear   = 12.497 kip/ft
     d required      = 17.33 < d provided = 33.66 OKAY

     MOMENT (Comb 6):

     Service moment  = 201.578 k-ft/ft
     Steel stress    = 36062.05 > Allowable stress = 30000.00 NO GOOD ***
     As required     = 1.58 in^2

     CRACK CONTROL (Comb 6):

     Allowable stress = 37022.00 > Service stress = 36062.05 OKAY

     TEMPERATURE AND SHRINKAGE:

     T&S reinforcement = 0.44 > Area required = 0.13 OKAY
```

REQUIRED REINFORCEMENT AREA IN STEM WALL SECTIONS:
(Ultimate Strength Design)

HEIGHT (ft)	THICK (in)	deff (in)	MOMENT (k-ft/ft)	AREA (in^2)	LOAD COMB
25.52	35.06	32.43	271.63	1.14	6
23.81	33.83	31.20	228.44	0.99	6
22.10	32.60	29.97	189.83	0.85	6
20.39	31.38	28.74	155.51	0.72	6
18.69	30.15	27.51	125.17	0.61	6
16.98	28.92	26.28	99.46	0.50	6
15.27	27.69	25.05	77.24	0.41	6
13.56	26.46	23.82	58.08	0.37	6
11.85	25.23	22.59	41.70	0.32	6
10.14	24.00	21.36	27.77	0.23	6

S T A B I L I T Y

UNFACTORED WEIGHT AND RIGHTING MOMENT:

LOAD CONDITION	WEIGHT (kip)	MOMENT AT TOE (k-ft)
Dead load abutment	622.8	5380.7
Dead load constant	372.0	2563.1
Dead load earth	1168.9	15980.0
Live load standard	124.0	854.4
Live load surcharge	77.9	1123.1

UNFACTORED LATERAL FORCE AND OVERTURNING MOMENT:

LOAD CONDITION	FORCE (kip)	MOMENT AT TOE (k-ft)
FR longitudinal force	74.0	1802.6
Lateral earth pressure	532.3	5494.5
Surcharge pressure	68.7	1064.5

RESULTANT LOAD COMBINATIONS:

COMB NO	LIMIT STATE	VERTICAL LOAD (kip)	RIGHTING MOMENT (k-ft)	LATERAL LOAD (kip)	OVERTURNING MOMENT (k-ft)
1	SLS	994.8	7943.8	0.0	0.0
2	SLS	1791.6	21360.7	532.3	5494.5
3	SLS	2241.5	25046.9	600.9	6559.0
	ULS MAX	2944.4	32999.0	1015.6	11084.8
	ULS MIN	2109.5	23325.7	899.5	9285.7
4	SLS	2365.5	25901.3	600.9	6559.0
	ULS MAX	3213.6	34853.8	1015.6	11084.8
	ULS MIN	2378.7	25180.5	899.5	9285.7
5	SLS	2241.5	25046.9	674.9	8361.7
	ULS MAX	2801.9	31308.6	843.7	10452.1
	ULS MIN	2027.3	22416.6	757.8	9121.4
6	SLS	2365.5	25901.3	674.9	8361.7
	ULS MAX	3105.6	34109.6	1111.8	13428.2
	ULS MIN	2270.7	24436.4	995.7	11629.1

VERTICAL RESULTANT:

COMB NO	LIMIT STATE	CASE NO	VERTICAL LOAD (kip)	TOE DISTANCE (ft)	RESULTANT LOCATION
1	SLS		994.8	7.986	0.189
2	SLS		1791.6	8.856	0.100
3	SLS		2241.5	8.248	0.162
	ULS	1	2944.4	7.443	0.244
	ULS	2	2109.5	5.803	0.411
	ULS	3	2944.4	8.054	0.182
	ULS	4	2109.5	6.655	0.324
4	SLS		2365.5	8.177	0.169
	ULS	1	3213.6	7.396	0.249
	ULS	2	2378.7	5.926	0.398
	ULS	3	3213.6	7.956	0.192
	ULS	4	2378.7	6.682	0.321

```
      5     SLS          2241.5    7.444     0.244
            ULS    1     2801.9    7.444     0.244
            ULS    2     2027.3    5.902     0.401
            ULS    3     2801.9    7.919     0.196
            ULS    4     2027.3    6.558     0.334

      6     SLS          2365.5    7.415     0.247
            ULS    1     3105.6    6.659     0.324
            ULS    2     2270.7    4.848     0.508
            ULS    3     3105.6    7.239     0.265
            ULS    4     2270.7    5.640     0.427

    ------------------------------------------------------------

    ULS CASES:

         Case 1  = Max vertical + max overturning
         Case 2  = Min vertical + max overturning
         Case 3  = Max vertical + min overturning
         Case 4  = Min vertical + min overturning

P I L E   F O O T I N G
==========================================================================

PILE GROUP PROPERTIES:

    Number of piles    = 12
    Pile CG distance   = 9.840 ft
    Pile group inertia = 4.357E+02 ft^2

PILE LOADS:

    ------------------------------------------------------------
    COMB      LIMIT     PILE      VERTICAL  SHEAR     BENDING
     NO       STATE     ROW         LOAD    LOAD      MOMENT
                                   (kip)     (kip)     (k-ft)
    ------------------------------------------------------------

     1        SLS        1        114.1     0.0       0.0
                         2        82.9      0.0       0.0
                         3        51.7      0.0       0.0

     2        SLS        1        179.2     36.7      0.0
                         2        149.3     36.7      0.0
                         3        119.4     36.7      0.0
```

3	SLS	1	247.2	43.7	0.0
		2	186.8	43.7	0.0
		3	126.3	43.7	0.0
	ULS 1	1	364.9	76.9	0.0
		2	245.4	76.9	0.0
		3	125.8	76.9	0.0
	ULS 2	1	320.1	76.9	0.0
		2	175.8	76.9	0.0
		3	31.5	76.9	0.0
	ULS 3	1	334.5	67.3	0.0
		2	245.4	67.3	0.0
		3	156.3	67.3	0.0
	ULS 4	1	289.6	67.3	0.0
		2	175.8	67.3	0.0
		3	62.0	67.3	0.0
4	SLS	1	263.8	45.0	0.0
		2	197.1	45.0	0.0
		3	130.5	45.0	0.0
	ULS 1	1	400.8	76.9	0.0
		2	267.8	76.9	0.0
		3	134.8	76.9	0.0
	ULS 2	1	355.9	76.9	0.0
		2	198.2	76.9	0.0
		3	40.5	76.9	0.0
	ULS 3	1	370.3	67.3	0.0
		2	267.8	67.3	0.0
		3	165.3	67.3	0.0
	ULS 4	1	325.5	67.3	0.0
		2	198.2	67.3	0.0
		3	71.0	67.3	0.0

5	SLS	1	277.8	49.1	0.0
		2	186.8	49.1	0.0
		3	95.8	49.1	0.0
	ULS 1	1	347.2	62.6	0.0
		2	233.5	62.6	0.0
		3	119.8	62.6	0.0
	ULS 2	1	304.2	62.6	0.0
		2	168.9	62.6	0.0
		3	33.7	62.6	0.0
	ULS 3	1	324.7	55.5	0.0
		2	233.5	55.5	0.0
		3	142.3	55.5	0.0
	ULS 4	1	281.6	55.5	0.0
		2	168.9	55.5	0.0
		3	56.2	55.5	0.0
6	SLS	1	294.3	49.8	0.0
		2	197.1	49.8	0.0
		3	100.0	49.8	0.0
	ULS 1	1	426.1	85.0	0.0
		2	258.8	85.0	0.0
		3	91.5	85.0	0.0
	ULS 2	1	381.2	85.0	0.0
		2	189.2	85.0	0.0
		3	-2.8	85.0	0.0
	ULS 3	1	395.6	75.3	0.0
		2	258.8	75.3	0.0
		3	122.0	75.3	0.0
	ULS 4	1	350.8	75.3	0.0
		2	189.2	75.3	0.0
		3	27.7	75.3	0.0

MAXIMUM PILE LOADS:

SLS Compression (Comb 4) = 263.8 < 400.0 OKAY
SLS Shear (Comb 4) = 45.0 < 100.0 OKAY

LATERAL STABILITY:

COMB NO	LIMIT STATE	FORCE (kip)	RESISTANCE (kip)	
1	SLS	0.0	1892.2	OKAY
2	SLS	532.3	1892.2	OKAY
3	SLS	600.9	1576.8	OKAY
4	SLS	600.9	1261.5	OKAY
5	SLS	674.9	1766.1	OKAY
6	SLS	674.9	1576.8	OKAY

FOOTING LOADS:

COMB NO	LIMIT STATE	CASE NO	TOE SHEAR (kip/ft)	TOE MOMENT (k-ft/ft)	HEEL SHEAR (kip/ft)	HEEL MOMENT (k-ft/ft)
1	SLS		5.829	38.191	2.305	35.746
2	SLS		9.349	61.256	-7.904	-77.330
3	SLS		13.643	89.397	-4.923	-78.501
	ULS	1	20.480	134.201	-12.110	-150.107
	ULS	2	18.284	119.815	-14.932	-165.216
	ULS	3	18.558	121.604	-8.148	-116.216
	ULS	4	16.362	107.219	-10.971	-131.325
4	SLS		14.685	96.230	-3.082	-72.320
	ULS	1	22.743	149.035	-8.112	-136.688
	ULS	2	20.547	134.650	-10.935	-151.797
	ULS	3	20.821	136.438	-4.151	-102.797
	ULS	4	18.625	122.053	-6.974	-117.905
5	SLS		15.569	102.019	-8.892	-112.460
	ULS	1	19.461	127.524	-11.115	-140.575
	ULS	2	17.357	113.741	-13.909	-154.997
	ULS	3	18.039	118.207	-8.185	-115.507
	ULS	4	15.935	104.424	-10.979	-129.929

```
        6     SLS          16.611    108.852   -7.051    -106.279
              ULS     1    24.339    159.492   -14.876   -186.218
              ULS     2    22.143    145.107   -17.699   -201.327
              ULS     3    22.417    146.895   -10.915   -152.327
              ULS     4    20.221    132.510   -13.737   -167.435
      ------------------------------------------------------------

      ULS CASES:

           Case 1 = Max vertical + max overturning
           Case 2 = Min vertical + max overturning
           Case 3 = Max vertical + min overturning
           Case 4 = Min vertical + min overturning

      SIGN CONVENTION:

           Positive moment => tension on bottom of footing
           Positive shear  => upward direction

  ------------------------------------------------------------
  F O O T I N G   T O E
  ------------------------------------------------------------

  ULTIMATE LIMIT STATE CALCULATIONS:

       SHEAR (Comb 6):

       Effective depth = 38.60 in
       Factored shear  = 24.339 kip/ft
       d required      = 18.86 < d provided = 38.60 OKAY

       TENSION AT FOOTING BOTTOM:
       ----------------------------

       MOMENT (Comb 6):

       Factored moment = 159.492 k-ft/ft
       As required     = 0.67 < As provided = 1.27 OKAY
       As maximum      = 5.78 > As provided = 1.27 OKAY

       NO TENSION AT FOOTING TOP:
       ----------------------------

  SERVICEABILITY LIMIT STATE CALCULATIONS:

       SHEAR (Comb 4):

       Effective depth = 38.60 in
       Service shear   = 14.685 kip/ft
       d required      = 20.37 < d provided = 38.60 OKAY
```

```
        TENSION AT FOOTING BOTTOM:
        --------------------------

        MOMENT (Comb 4):

        Service moment  = 96.230 k-ft/ft
        Steel stress    = 14929.84 < Allowable stress = 24000.00 OKAY
        Concrete stress = 586.71 psi

        CRACK CONTROL (Comb 4):

        Allowable stress = 36000.00 > Service stress = 14929.84 OKAY

        NO TENSION AT FOOTING TOP:
        --------------------------

   ------------------------------------------------------------
   F O O T I N G   H E E L
   ------------------------------------------------------------

   ULTIMATE LIMIT STATE CALCULATIONS:

        SHEAR (Comb 6):

        Effective depth = 41.74 in
        Factored shear  = 17.699 kip/ft
        d required      = 13.72 < d provided = 41.74 OKAY

        NO TENSION AT FOOTING BOTTOM:
        -----------------------------

        TENSION AT FOOTING TOP:
        -----------------------------

        MOMENT (Comb 6):

        Factored moment = 201.327 k-ft/ft
        As required     = 0.64 < As provided = 0.79 OKAY
        As maximum      = 6.25 > As provided = 0.79 OKAY

   SERVICEABILITY LIMIT STATE CALCULATIONS:

        SHEAR (Comb 5):

        Effective depth = 41.74 in
        Service shear   = 8.892 kip/ft
        d required      = 8.81 < d provided = 41.74 OKAY
```

```
      TENSION AT FOOTING BOTTOM:
      ---------------------------

      MOMENT (Comb 1):

      Service moment  = 35.746 k-ft/ft
      Steel stress    = 8740.99 < Allowable stress = 36000.00 OKAY
      Concrete stress = 262.73 psi

      CRACK CONTROL (Comb 1):

      Allowable stress = 38334.62 > Service stress = 8740.99 OKAY

      TENSION AT FOOTING TOP:
      ---------------------------

      MOMENT (Comb 6):

      Service moment  = 106.279 k-ft/ft
      Steel stress    = 24066.13 < Allowable stress = 30000.00 OKAY
      Concrete stress = 694.16 psi

      CRACK CONTROL (Comb 6):

      Allowable stress = 38334.62 > Service stress = 24066.13 OKAY

      TEMPERATURE AND SHRINKAGE:

      T&S reinforcement = 0.44 > Area required = 0.13 OKAY

-------------------------------------------------------------
L O N G I T U D I N A L   R E I N F O R C E M E N T
-------------------------------------------------------------

ULS CALCULATIONS FOR FOOTING TOE:

      Pressure = 9006.8 psf
      Spacing  = 8.500 ft

      MOMENT (Comb 6):

      Factored moment = 65.074 k-ft/ft
      As required     = 0.52 < As provided = 0.79 OKAY
      As maximum      = 9.61 > As provided = 0.79 OKAY
```

ULS CALCULATIONS FOR FOOTING HEEL:

Pressure = 5388.6 psf
Spacing = 8.500 ft

MOMENT (Comb 3):

Factored moment = 38.933 k-ft/ft
As required = 0.31 < As provided = 0.79 OKAY
As maximum = 9.61 > As provided = 0.79 OKAY

Q U A N T I T I E S

CONCRETE:

ITEM	VOLUME (yd^3)
Abutment	69.2
Footing	84.6

REINFORCING:

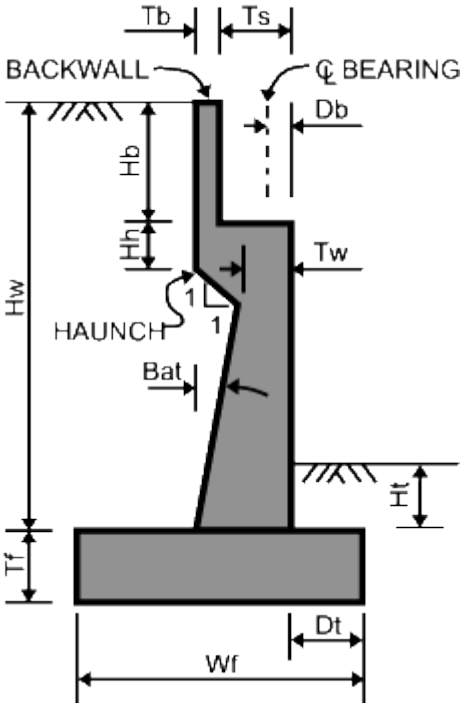
BAR	AREA (in^2)	LENGTH (in)	NO	WEIGHT (lb)	DESCRIPTION
Asb	0.44	152.7	27	513.5	
AsTSb	0.20	97.9	32	177.3	Vertical
AsTSb	0.20	365.2	16	330.8	Longitudinal
Asw	1.27	384.8	54	7469.1	
AsTSw	0.44	284.3	32	1132.9	Vertical
AsTSw	0.44	365.2	44	2001.1	Longitudinal
Asft	0.79	230.3	54	2780.1	
Asfbt	1.27	0.0	0	0.0	
Asfbh	0.79	165.6	54	1999.3	
AsLf	0.79	363.2	42	3410.8	
Total =			355	19814.8	

VERIFICATION PROBLEM NO 2

- Roadway bridge abutment with haunch and sidewalls
- Vertical, fixed-head piles
- AASHTO LRFD design criteria
- Metric units

CONFIGURATION

VARIABLE	VALUE
Hw	8.3 m
Ht	0.61 m
Lw	9.38 m
Tw	0.61 m
Bat	3.43 degrees
Hb	2.025 m
Tb	0.305 m
Hh	0.61 m
Ts	0.76 m
Db	0.38 m
Dt	1.72 m
Wf	6.0 m
Lf	9.38 m
Tf	1.15 m



The pile configuration is described below.

DESCRIPTION	VALUE
Number of pile rows	3
Pile diameter	750 mm
Distance(s) from pile to toe	0.75, 3.0, 5.25 m
Pile batter from vertical	0
Number of piles in row(s)	4, 4, 4
Number of batter piles in row (s)	0, 0, 0
Longitudinal pile spacing	2.625 m

PROPERTIES

REINFORCED CONCRETE:

Concrete compressive strength	= 28 MPa
Concrete unit weight	= 23.56 kN/m^3
Exposure factor	= 1
Reinforcing yield strength	= 420 MPa

PILE RESISTANCE:

LOAD	RESISTANCE (kN) SLS	ULS
Compression:	1800.0	3600.0
Tension:	900.0	1800.0
Shear:	450.0	900.0

PILE LATERAL LOAD - MOMENT DATA:

POINT	LATERAL LOAD (kN)	MOMENT (kN-m)
1	500.00	497.00
2	1000.00	1195.00
3	2000.00	3225.00

FOOTING RESISTANCE:

PARAMETER	SLS	ULS	EQ
Passive coefficient:	0.000	0.000	0.000

LOADS

BRIDGE LOADS:

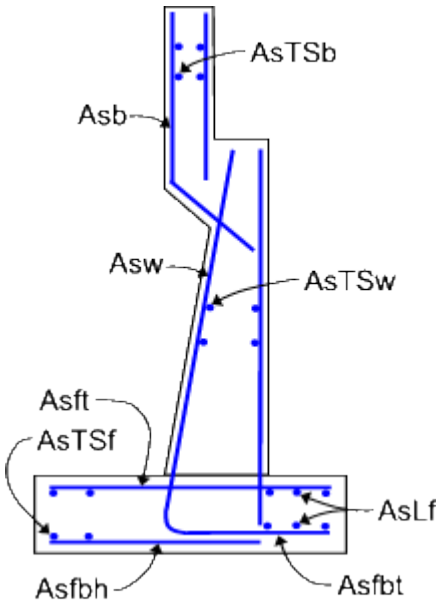
Dead load	= 1655.0 kN
Live load	= 550.0 kN
Bearing pad shear	= 330.0 kN at top of seat

EARTH LOADS:

Lateral pressure coeff = 0.300 at height ratio = 0.4
Soil unit weight = 18.85 kN/m^3
Surcharge pressure = 14.4 kPa

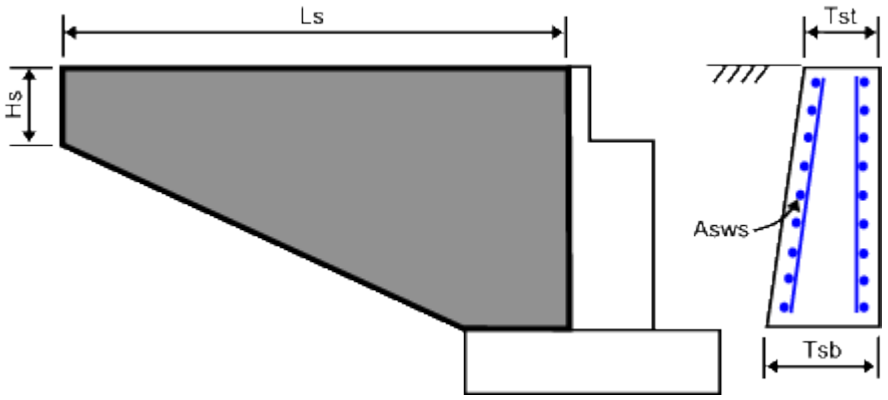
REINFORCING

VARIABLE	DESCRIPTION
REINFORCING AREA:	
Asw	819 mm^2 @ 180 mm
Asb	284 mm ^2 @ 360 mm
Asft	510 mm ^2 @ 180 mm
Asfbt	819 mm ^2 @ 180 mm
Asfbh	510 mm ^2 @ 180 mm
AsLf	510 mm ^2 @ 300 mm
AsTSw	284 mm ^2 @ 300 mm
AsTSb	129 mm ^2 @ 300 mm
AsTSf	284 mm ^2 @ 300 mm
REINFORCING COVER:	
Cover Asw	50 mm
Cover Asft	75 mm
Cover Asfb	150 mm



SIDE WALLS

VARIABLE	VALUE
CONFIGURATION:	
Ls Hs Tst Tsb Wbarrier	3.215 m 8.3 m 0.59 m 0.59 m 5.0 kN/m
REINFORCING:	
Asws Aswsb AsTSws	284 mm^2 @ 150 mm 510 mm^2 @ 150 mm 199 mm^2 @ 300 mm



BACKWALL CALCULATIONS

Effective depth, d = 305 - 50 - $(284 / 3.1416)^{1/2}$ = 245.5 mm
Backwall height for shear = 2.025 - 0.2455 = 1.780 m

Lateral earth pressure: V = 0.3 x 18.85 $(1.78)^2$ / 2 = 8.96 kN/m
M = 0.4 x 2.025 [0.3 x 18.85 $(2.025)^2$ / 2] = 9.39 kN-m/m

Surcharge pressure: V = 0.3 x 14.4 (1.78) = 7.69 kN/m
M = 0.3 x 14.4 $(2.025)^2$ / 2 = 8.86 kN-m/m

Service loads: M = 9.39 + 8.86 = 18.25 kN-m/m

Factored loads: V = 1.5 x 8.96 + 1.75 x 7.69 = 26.90 kN/m
M = 1.5 x 9.39 + 1.75 x 8.86 = 29.59 kN-m/m

Run REBEAM program to verify flexural calculations (see REBEAM output below):

Area of reinforcing per meter = 284 x 1000 / 360 = 789 mm^2

Service stresses: f_s = 101 MPa

Crack control: dc = 59.5 mm (2.34 in)
fs = 101 MPa (14649 psi)
B = 1 + 2.34/(0.7 x (12 – 2.34)) = 1.346
s < 700 x 1 / (1.346 x 14.649) – 2 x 2.34 = 30.8 in (782 mm)

Ultimate flexure: A_s > 432 x 360 / 1000 = 156 mm^2 (432 from REBEAM design run)
e = 0.003 x (245.5 – (13.9/0.85))/(13.9/0.85) = 0.042 > 0.005
Note: “a” obtained from REBEAM run

Perform hand calculations to verify shear calculations:

Ultimate shear:

V = 26.9 kN/m (154 lb/in)
fc = 28 MPa (4 ksi)

d > 154 / (0.9 x 0.9 x 2 x $(4000)^{1/2}$) = 1.50 in (38 mm)

Temperature and shrinkage reinforcement:

b = 1000 mm (39.37 in)
h = 305 mm (12 in)
fy = 420 MPa (60.9 ksi)

A_s > 1.3 x 39.37 x 12 / (2 x 60.9 x 51.4) = 0.098 in^2 (63 mm^2) < 0.11 in^2 (71 mm^2)

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                         *
*           P R O G R A M   R E B E A M                   *
*                                                         *
*                    OUTPUT DATA                          *
*                                                         *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.2)                    6/21/17, 7:29 pm

Output file = rebeam_backwall.out

Shear and moment review problem


D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO LRFD
Units = Metric (Newtons, millimeters - shear and moments in kN-m)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.90
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 28
     Concrete modulus of elasticity      = 2.4000E+04
     Concrete modulus of rupture         = 3.334
     Reinforcing yield strength          = 420
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 8
     Maximum aggregate size              = 25.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 789
     Depth to tensile reinf     = 245.5
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
     Shear reinf area           = 0
     Shear reinf spacing        = 0
```

```
D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 29.588
     Maximum service load moment = 18.249
     Minimum service load moment = 0
     Factored (ultimate) shear   = 26.844

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 1000
     Height = 305

PROPERTIES:

     Gross moment of inertia     = 2.3644E+09
     Gross section modulus       = 1.5504E+07
     Distance to neutral axis    = 1.5250E+02
     Cracked moment of inertia   = 2.8291E+08
     Effective moment of inertia = 2.3644E+09

M O M E N T   R E V I E W   C A L C U L A T I O N S
==================================================

MINIMUM REINFORCING:

     1.2 * Cracking moment      = 6.2029E+01
     Design moment              = 3.9451E+01

MAXIMUM REINFORCING:

     Strain in tensile reinf    = 4.1962E-02
     Minimum strain             = 5.0000E-03

MOMENT CAPABILITY:

     Ultimate moment capability  = 7.1142E+01
     Stress block depth          = 1.3924E+01

SERVICE LOAD STRESS:

     Maximum steel stress    = 1.0103E+02
     Minimum steel stress    = 0.0000E+00
     Maximum concrete stress = 3.2069E+00
     Minimum concrete stress = 0.0000E+00

CRACK CONTROL:

     Concrete cover            = 59.5
     Exposure factor           = 1
     Maximum rebar spacing     = 7.8185E+02
```

STEM WALL CALCULATIONS

Height to bottom of haunch = 8.3 - 2.025 - 0.61 - (0.305 + 0.76 - 0.61) = 5.21 m
Concrete thickness at top of footing = 0.61 + 5.21 x tan(3.43) = 0.922 m
Effective depth, d = 922 - 50 - $(819 / 3.1416)^{1/2}$ = 856.1 mm
Stem wall height for shear = 8.3 - 0.8561 = 7.444 m

Lateral earth pressure: $P_r = 0.3 \times 18.85 (8.3)^2 / 2 = 194.786$ kN
$D_t = 1/3$
$P_t = 194.786 \times (0.4 - 0.5) / (1/3 - 0.5) = 116.872$ kN
$P_u = 194.786 - 116.872 = 77.914$ kN
$Q_u = 77.914 / 8.3 = 9.387$ kN/m
$Q_t = 2 \times 116.872 \times 7.444 / (8.3)^2 = 25.258$ kN/m

V = 9.387 x 7.444 + 25.258 x 7.444 / 2 = 163.9 kN/m
M = 194.786 x 0.4 x 8.3 = 646.7 kN-m/m

Surcharge pressure: V = 0.3 x 14.4 (7.444) = 32.16 kN/m
M = 0.3 x 14.4 $(8.3)^2$ / 2 = 148.8 kN-m/m

Bridge dead load: M = 1655 x (0.922 / 2 - 0.38) / 9.38 = 14.29 kN-m/m

Bridge live load: M = 550 x (0.922 / 2 - 0.38) / 9.38 = 4.75 kN-m/m

Bearing pad shear: V = 330 / 9.38 = 35.18 kN/m
M = 330 x (8.3 - 2.025 + 0) / 9.38 = 220.76 kN-m/m

Service loads: M = 646.7 + 148.8 + 14.29 + 4.75 + 220.76 = 1035.3 kN-m/m (comb 4)

Factored loads: V = 1.2 x 35.18 + 1.5 x 163.9 +1.75 X 32.16 = 344.3 kN/m (comb 4)
M = 1.25 x 14.29 + 1.75 x 4.75 + 1.2 x 220.76 + 1.5 x 646.7 +1.75 X 148.8
M = 1521.5 kN-m/m (comb 4)

Run REBEAM program to verify flexural calculations (see REBEAM output below):

Area of reinforcing per meter = 819 x 1000 / 180 = 4550 mm^2

Service stresses: $f_s = 290.2$ MPa

Ultimate flexure: $A_s > 4955 \times 180 / 1000 = 892$ mm^2
e = 0.003 x (856 – (80.3/0.85))/(80.3/0.85) = 0.024 > 0.005
Note: “a” obtained from REBEAM run

Crack control: dc = 66 mm (2.60 in)
fs = 290 MPa (42061 psi)
B = 1 + 2.60/(0.7 x (33.7 – 2.60)) = 1.119
s < 700 x 1 / (1.119 x 42.061) – 2 x 2.60 = 9.7 in (245 mm)

Ultimate flexure: $A_s > 432 \times 360 / 1000 = 156$ mm^2 (432 from REBEAM design run)
e = 0.003 x (245.5 – (13.9/0.85))/(13.9/0.85) = 0.042 > 0.005
Note: “a” obtained from REBEAM run

Perform hand calculations to verify shear calculations:

Ultimate shear:

V = 26.9 kN/m (154 lb/in)
fc = 28 MPa (4 ksi)

$d > 154 / (0.9 \times 0.9 \times 2 \times (4000)^{1/2}) = 1.50$ in (38 mm)

Temperature and shrinkage reinforcement:

b = 1000 mm (39.37 in)
h = 922 mm (36.3 in)
fy = 420 MPa (60.9 ksi)

$A_s > 1.3 \times 39.37 \times 36.3 / (2 \times 60.9 \times 75.7) = 0.20$ in^2 (130 mm^2)

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                           *
*           P R O G R A M   R E B E A M                     *
*                                                           *
*                    OUTPUT DATA                            *
*                                                           *
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(Version  5.2)                    6/21/17, 9:24 pm

Output file = rebeam_stemwall.out

Moment review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO LRFD
Units = Metric (Newtons, millimeters - shear and moments in kN-m)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.90
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030
```

```
M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 28
     Concrete modulus of elasticity      = 2.4000E+04
     Concrete modulus of rupture         = 3.334
     Reinforcing yield strength          = 420
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 8
     Maximum aggregate size              = 25.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 4550
     Depth to tensile reinf     = 856
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
     Shear reinf area           = 0
     Shear reinf spacing        = 0

D E S I G N   L O A D S
=====================================================

     Factored (ultimate) moment  = 1521.5
     Maximum service load moment = 1035.3
     Minimum service load moment = 0
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
=====================================================

RECTANGULAR SECTION:

     Width  = 1000
     Height = 922

PROPERTIES:

     Gross moment of inertia     = 6.5315E+10
     Gross section modulus       = 1.4168E+08
     Distance to neutral axis    = 4.6100E+02
     Cracked moment of inertia   = 1.8269E+10
     Effective moment of inertia = 2.2737E+10

M O M E N T   R E V I E W   C A L C U L A T I O N S
=====================================================

MINIMUM REINFORCING:

     1.2 * Cracking moment      = 5.6684E+02
     Design moment              = 1.5215E+03
```

```
MAXIMUM REINFORCING:

     Strain in tensile reinf    = 2.4185E-02
     Minimum strain             = 5.0000E-03

MOMENT CAPABILITY:

     Ultimate moment capability  = 1.4032E+03
     Stress block depth          = 8.0294E+01

     *** Design moment exceeds capacity ***

SERVICE LOAD STRESS:

     Maximum steel stress    = 2.9021E+02
     Minimum steel stress    = 0.0000E+00
     Maximum concrete stress = 1.2234E+01
     Minimum concrete stress = 0.0000E+00

CRACK CONTROL:

     Concrete cover            = 66
     Exposure factor           = 1
     Maximum rebar spacing     = 2.4831E+02
```

Verify required flexural reinforcement area for the ultimate limit state at 10 sections using REBEAM program. The height, thickness and effective depth are verified directly. The moment is verified with a separate spreadsheet (not shown). The REBEAM output is summarized in the last column below.

HEIGHT (m)	THICK (m)	Deff (m)	MOMENT (kN-m/m)	AREA (mm^2)
7.779	0.891	0.825	1318.1	799
7.258	0.860	0.794	1131.3	709
6.737	0.828	0.762	960.5	625
6.216	0.797	0.731	804.8	544
5.695	0.766	0.700	663.5	466
5.174	0.735	0.669	540.1	396
4.653	0.704	0.638	430.7	330
4.132	0.672	0.606	333.5	268
3.611	0.641	0.575	248.0	231
3.090	0.610	0.544	173.3	206

STABILITY CALCULATIONS

Calculate weight and righting moment:

1. Dead load abutment

w1 = 0.305 x 2.025 x 9.38 x 23.56 = 136.49 kN
x1 = 2.63 m

w2 = 0.61 x 1.065 x 9.38 x 23.56 = 143.57 kN
x2 = 2.25 m

w3 = 0.455 x 0.455 x 9.38 x 23.56 / 2 = 22.88 kN
x3 = 2.48 m

w4 = 0.455 x 0.61 x 9.38 x 23.56 = 61.34 kN
x4 = 2.025 m

w5 = 0.61 x 5.21 x 9.38 x 23.56 = 702.34 kN
x5 = 2.205 m

w6 = 5.21 x 0.312 x 9.38 x 23.56 / 2 = 179.61 kN
x6 = 2.43 m

w7 = 6 x 1.15 x 9.38 x 23.56 = 1524.85 kN
x7 = 3.0 m

w8 = 3.09 x 3.215 x 0.59 x 2 x 23.56 = 276.18 kN
x8 = 4.39 m

w9 = 0.455 x 0.455 x 0.59 x 2 x 23.56 / 2 = 2.88 kN
x9 = 2.63 m

w10 = 3.358 x 5.21 x 0.59 x 2 x 23.56 = 486.38 kN
x10 = 4.32 m

w11 = 0.312 x 5.21 x 0.59 x 2 x 23.56 / 2 = 22.60 kN
x11 = 2.54 m

w12 = 5.0 x 3.215 x 2 = 32.15 kN
x12 = 4.39 m

Weight = 3591.27 kN
Righting moment = 10815.9 kN-m

2. Dead load constant

   Weight = 1655 kN
   Righting moment = 1655 x 2.1 = 3475.5 kN-m

3. Dead load earth

   w1 = 3.09 x 3.215 x 8.2 x 18.85 = 1535.55 kN
   x1 = 4.39 m

   w2 = 0.455 x 0.455 x 8.2 x 18.85 / 2 = 16.0 kN
   x2 = 2.63 m

   w3 = 3.358 x 5.21 x 8.2 x 18.85 = 2704.23 kN
   x3 = 4.32 m

   w4 = 0.312 x 5.21 x 8.2 x 18.85 / 2 = 125.63 kN
   x4 = 2.54 m

   w5 = 0.61 x 1.72 x 9.38 x 18.85 = 185.51
   x5 = 0.86 m

   Weight = 4566.92 kN
   Righting moment = 18944.0 kN-m

4. Live load standard

   Weight = 550 kN
   Righting moment = 550 x 2.1 = 1155 kN-m

5. Live load surcharge

   Weight = 14.4 x 3.215 x 9.38 = 434.26 kN
   Righting moment = 434.26 x 4.39 = 1907.5 kN-m

Calculate lateral load and overturning moment:

1. Friction longitudinal force

   Force = 330 kN
   Overturning moment = 330 x 7.425 = 2450.2 kN-m

2. Lateral earth pressure

   Force = $0.3 \times 18.85 \times 8.2 \times (9.45)^2 / 2 = 2070.52$ kN
   Overturning moment = 2070.52 x 0.4 x 9.45 = 7826.6 kN-m

3. Surcharge pressure

Force = 0.3 x 14.4 x 9.45 x 8.2 = 334.76 kN
Overturning moment = 334.76 x 9.45 / 2 = 1581.7 kN-m

Check resultant load combinations (use spreadsheet):

Combination 1:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN
da	3591.3	10815.9	0	0	1	0	0
dc	1655	3475.5	0	0	1	0	0
dv	0	0	0	0	1	0	0
de	4566.9	18944	0	0	0	0	0
l1	550	1155	0	0	0	0	0
fr	0	0	330	2450.2	0	0	0
ep	0	0	2070.5	7826.6	0	0	0
sc	434.3	1907.5	334.8	1581.7	0	0	0
cp	0	0	0	0	0	0	0
SLS	5246	14291	0	0			
ULS MAX	0	0	0	0			
ULS MIN	0	0	0	0			

Combination 2:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN
da	3591.3	10815.9	0	0	1	0	0
dc	1655	3475.5	0	0	0	0	0
dv	0	0	0	0	0	0	0
de	4566.9	18944	0	0	1	0	0
l1	550	1155	0	0	0	0	0
fr	0	0	330	2450.2	0	0	0
ep	0	0	2070.5	7826.6	1	0	0
sc	434.3	1907.5	334.8	1581.7	0	0	0
cp	0	0	0	0	0	0	0
SLS	8158	29760	2071	7827			
ULS MAX	0	0	0	0			
ULS MIN	0	0	0	0			

Combination 3:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN
da	3591.3	10815.9	0	0	0	1.25	0.9
dc	1655	3475.5	0	0	0	1.25	0.9
dv	0	0	0	0	0	1.5	0.65
de	4566.9	18944	0	0	0	1.35	1
l1	550	1155	0	0	0	0	0
fr	0	0	330	2450.2	0	1.2	0.5
ep	0	0	2070.5	7826.6	0	1.5	0.9
sc	434.3	1907.5	334.8	1581.7	0	1.35	0
cp	0	0	0	0	0	0	0
SLS	0	0	0	0			
ULS MAX	13309	46014	3954	16815			
ULS MIN	9289	31806	2028	8269			

Combination 4:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN
da	3591.3	10815.9	0	0	1	1.25	0.9
dc	1655	3475.5	0	0	1	1.25	0.9
dv	0	0	0	0	1	1.5	0.65
de	4566.9	18944	0	0	1	1.35	1
l1	550	1155	0	0	1	1.75	1.75
fr	0	0	330	2450.2	1	1.2	0.5
ep	0	0	2070.5	7826.6	1	1.5	0.9
sc	434.3	1907.5	334.8	1581.7	1	1.75	0
cp	0	0	0	0	0	0	0
SLS	10798	36298	2735	11859			
ULS MAX	14446	48798	4088	17448			
ULS MIN	10251	33828	2028	8269			

Check vertical resultant (use spreadsheet):

X = (Mrt - Mot) / Pv
Locate = Fractional portion of footing = (Wf - 2X) / Wf

Combination 1:

CASE	X	LOCATE
SLS	2.724	0.092

Combination 2:

CASE	X	LOCATE
SLS	2.688	0.104

Combination 3:

CASE	X	LOCATE
ULS 1	2.194	0.269
ULS 2	1.614	0.462
ULS 3	2.836	0.055
ULS 4	2.534	0.155

Combination 4:

CASE	X	LOCATE
SLS	2.263	0.246
ULS 1	2.170	0.277
ULS 2	1.598	0.467
ULS 3	2.806	0.065
ULS 4	2.493	0.169

PILE FOOTING CALCULATIONS

Calculate pile group properties:

n = 12
Xcg = 3 m
Ipiles = $4(3 - 0.75)^2 + 4(3 - 3)^2 + 4(3 - 5.25)^2 = 40.5$ m^2

Calculate pile loads and shear resistance (use spreadsheet):

Vertical load = Pv
Horizontal load = Ph
Resultant distance = X
Distance to pile from toe = x

Lateral pile capacity, Vpile = 450 x Fsls kips (SLS) and 900 kips (ULS)
Passive resistance, Vpas = 0.

Shear load, V = (Ph - Passive) / n > 0
Pile moment, Mpile = function of Vpile (interpolate from data on page 2)
Axial load, P = Pv / n + [Mpile x n + Pv x (Xcg - X)] x (Xcg - x) / Ipiles
Shear resistance, Vr = Vpas + Vpile x n

Load combination 1:

n = 12
Xcg = 3
Ipile = 40.5
Fsls = 1.5

	SLS
Vpas =	0.00
Vpile =	675
Pv =	5246
Ph =	0
X =	2.724

Row	x	n	Psls
1	0.75	4	517.6
2	3	4	437.2
3	5.25	4	356.8
		M =	0.000
		V =	0.0
		Vr =	8100.0

Load combination 2:

n = 12
Xcg = 3
Ipile = 40.5
Fsls = 1.5

	SLS
Vpas =	0.00
Vpile =	675
Pv =	8158
Ph =	2071
X =	2.688

Row	x	n	Psls
1	0.75	4	935.4
2	3	4	679.9
3	5.25	4	424.3
		M =	171.5
		V =	172.5
		Vr =	8100.0

Load combination 3:

n = 12
Xcg = 3
Ipile = 40.5
Fsls = 1.0

	SLS	ULS 1	ULS 2	ULS 3	ULS 4
Vpas =	0.00	0.00	0.00	0.00	0.00
Vpile =	450	900	900	900	900
Pv =	0	13309	9289	13309	9289
Ph =	0	3954	3954	2028	2028
X =	0.000	2.194	1.614	2.836	2.534

Row	x	n	Psls	Pu1	Pu2	Pu3	Pu4
1	0.75	4	0.0	1923.6	1707.7	1342.4	1126.5
2	3	4	0.0	1109.1	774.0	1109.1	774.0
3	5.25	4	0.0	294.7	-159.6	875.8	421.6
		M =	0.0	327.5	327.5	168.0	168.0
		V =	0.0	329.5	329.5	169.0	169.0
		Vr =	5400.0	10800.0	10800.0	10800.0	10800.0

Load combination 4:

n = 12
Xcg = 3
Ipile = 40.5
Fsls = 1.0

	SLS	ULS 1	ULS 2	ULS 3	ULS 4
Vpas =	0.00	0.00	0.00	0.00	0.00
Vpile =	450	900	900	900	900
Pv =	10798	14446	10251	14446	10251
Ph =	2735	4088	4088	2028	2028
X =	2.263	2.170	1.598	2.806	2.493

Row	x	n	Psls	Pu1	Pu2	Pu3	Pu4
1	0.75	4	1492.6	2095.5	1878.5	1471.8	1254.9
2	3	4	899.8	1203.8	854.3	1203.8	854.3
3	5.25	4	307.0	312.1	-170.0	935.8	453.7
		M =	226.5	338.6	338.6	168.0	168.0
		V =	227.9	340.6	340.6	169.0	169.0
		Vr =	5400.0	10800.0	10800.0	10800.0	10800.0

Footing loads:

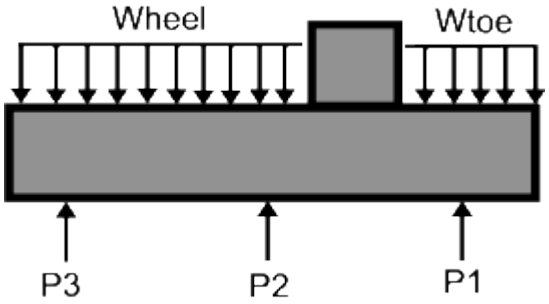
The footing load calculations for the toe and heel will be verified by checking a couple critical load combinations.

Dt = 1.72 m
Lheel = 6 - 1.72 - 0.61 - 5.21 x tan(3.43) = 3.358 ft
dtop = 1150 - 75 - (510 / 3.1416)$^{1/2}$ = 1062 mm
dbot (toe) = 1150 - 150 - (819 / 3.1416)$^{1/2}$ = 984 mm
dbot (heel) = 1150 - 150 - (510 / 3.1416)$^{1/2}$ = 987 mm

W(conc) = 1.15 x 23.56 = 27.09 kPa
Wtoe(soil) = 0.61 x 18.85 = 11.50 kPa
Wheel (soil) = 8.3 x 18.85 = 156.45 kPa
Wheel (surch) = 14.4 kPa

SLS combination 4:

P1v = 1492.6 kN
P2v = 899.8 kN
P3v = 307.0 kN
Mpile = 226.5 kN-m
Wtoe = 38.59 kPa
Wheel = 197.94 kPa



Toe moment and shear:

M = (4 x 1492.2 x 0.97 - 4 x 226.5) / 9.38 - 38.59 x (1.72)^2 / 2 = 463.6 kN-m

Lv = 1.72 - 0.984 = 0.736 m

V = 4 x 1492.2 x 0.361 / (0.75 x 9.38) - 38.59 x 0.736 = 277.9 kN

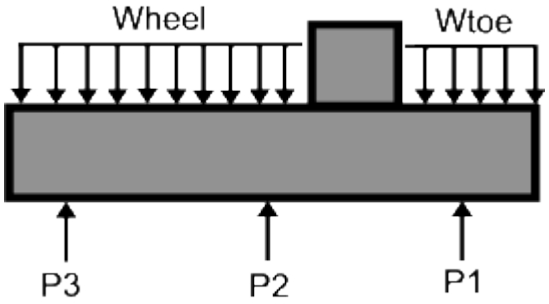
Heel moment and shear:

M = 4(899.8 x 0.358 + 307 x 2.608 + 2 x 226.5) / 9.38 - 197.94 (3.358)^2 / 2
= -444.0 kN-m

V = 4(899.8 x 0.733 / 0.75 + 307) / 9.38 - 197.94 x 3.358 = -158.8 kN

ULS combination 4, Case 1:

P1v = 2095.5 kN
P2v = 1203.8 kN
P3v = 312.1 kN
Mpile = 338.6 kN-m
Wtoe = 49.39 kPa
Wheel = 270.27 kPa



Toe moment and shear:

$M = (4 \times 2095.5 \times 0.97 - 4 \times 338.6) / 9.38 - 49.39 \times (1.72)^2 / 2 = 649.3$ kN-m

$Lv = 1.72 - 0.984 = 0.736$ m

$V = 4 \times 2095.5 \times 0.361 / (0.75 \times 9.38) - 49.39 \times 0.736 = 393.8$ kN

Heel moment and shear:

$M = 4(1203.8 \times 0.358 + 312.1 \times 2.608 + 2 \times 338.6) / 9.38$
$- 270.27 (3.358)^2 / 2 = -704.1$ kN-m

$V = 4(1203.8 \times 0.733 / 0.75 + 312.1) / 9.38 - 270.27 \times 3.358 = -272.8$ kN

Reinforcement calculations for footing:

The footing reinforcement calculations use the same subroutines which were previously validated for the backwall and stemwall calculations. Therefore, only the critical calculations at the footing toe will be validated.

Perform hand calculations to verify shear calculations:

Ultimate shear Vf = 393.8 kN/m
$d > 393.8 / (0.9 \times 0.9 \times (28)^{1/2} / 6) = 551$ mm

Run REBEAM program to verify flexural calculations (see REBEAM output below):

Area of reinforcing 819 mm^2 @ 180 mm
Mu @ 180 mm = 649.3 x 180 / 1000 = 116.9 kN-m
Ms @ 180 mm = 463.6 x 180 / 1000 = 83.4 kN-m

Service stresses: f_s = 112 MPa

Crack control: fcr = 252 MPa > 112 MPa

Ultimate flexure: $A_s > 428$ mm^2
c/d = 0.096

```
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11/28/02, 7:26 pm

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO LRFD (1998)
Units = Metric (Newtons, millimeters - moments in kN-m)

MATERIAL PROPERTIES:

     Concrete compressive strength       = 28
     Concrete modulus of elasticity      = 2.4000E+04
     Reinforcing yield strength          = 420
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 8

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00
```

```
STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

S E C T I O N   P R O P E R T I E S:
===================================================

RECTANGULAR SECTION:

     Width  = 180
     Height = 1150

PROPERTIES:

     Gross moment of inertia     = 2.2813E+10
     Gross section modulus       = 3.9675E+07
     Distance to neutral axis    = 5.7500E+02
     Cracked moment of inertia   = 4.4543E+09
     Effective moment of inertia = 2.2813E+10

R E V I E W   C A L C U L A T I O N S:
===================================================

REINFORCING STEEL:

     Tensile steel area         = 819
     Compressive steel area     = 0
     Depth to tensile steel     = 984
     Depth to Compressive steel = 0

     c/d                        = 9.6000E-02
     Maximum c/d                = 4.2000E-01

DESIGN MOMENTS:

     Factored ultimate moment    = 116.9
     Maximum service load moment = 83.4
     Minimum service load moment = 0

MOMENT CAPABILITY:

     Ultimate moment capability  = 2.9220E+02
     1.2 * Cracking moment       = 1.5871E+02
     Design moment               = 1.5587E+02
     Stress block depth          = 8.0294E+01
```

```
SERVICE LOAD STRESS:

     Maximum steel stress    = 1.1238E+02
     Minimum steel stress    = 0.0000E+00
     Maximum concrete stress = 4.3759E+00
     Minimum concrete stress = 0.0000E+00

CRACK CONTROL:

     Concrete cover            = 66
     Effective tension area    = 23760
     Exposure factor           = 30000
     Maximum steel stress      = 1.1238E+02
     Allowable cracking stress = 2.5200E+02
```

Footing longitudinal reinforcement:

The longitudinal reinforcement calculations will be verified for the footing toe and heel.

AsLf = 510 mm^2 @ 300 mm
d = 1150 - 150 - 2(819 / 3.1416)$^{1/2}$ - (510 / 3.1416)$^{1/2}$ = 955 mm

Footing toe

Combination 4, ULS 1 pile load = 2094.8 kN at row 1

Tributory area = 9.380 x (.750 + 2.250 / 2) = 17.59 m^2
Uniform load W = 4 x 2094.8 / 17.59 = 476.4 kPa
Pile spacing S = 2.625 m

M = 476.4 (2.625)^2 / 10 = 328.3 kN-m/m (98.5 kN-m / 300 mm)
As > 368 mm^2 (REBEAM calculations not shown)
c/d = 0.04 (REBEAM calculations not shown)

Footing heel

Combination 4, ULS 1 pile load = 1203.8 kN at row 2

Tributory area = 9.38 x 2.25 = 21.11 m^2
Uniform load W = 4 x 1203.8 / 21.11 = 228.1 kPa

Combination 4, ULS 1 pressure on footing:

Uniform load W = 1.25 x 1.15 x 23.56 + 1.35 x 8.3 x 18.85 + 1.75 x 14.4 = 270.3 kPa
Pile spacing S = 2.625 m

M = 270.3 (2.625)^2 / 10 = 186.3 kN-m/m (55.9 kN-m / 300 mm)
As > 208 mm^2 (REBEAM calculations not shown)
c/d = 0.04 (REBEAM calculations not shown)

SIDE WALL CALCULATIONS

Wall length = 6 - 1.72 - 0.76 - 0.305 = 3.215 m

Loads at wall mid-height:

H = 8.3 / 2 = 4.15 m

Lateral earth pressure: $P_r = 0.3 \times 18.85 (8.3)^2 / 2 = 194.786$ kN
$D_t = 1/3$
$P_t = 194.786 \times (0.4 - 0.5) / (1/3 - 0.5) = 116.872$ kN
$P_u = 194.786 - 116.872 = 77.914$ kN
$Q_u = 77.914 / 8.3 = 9.387$ kN/m
$Q_t = 2 \times 116.872 / (8.3) = 28.162$ kN/m
Quni = 9.387 + 28.162 x 4.15 / 8.3 = 23.438 kN/m

Shear = 23.438 x 3.215 = 75.4 kN/m
Moment = $23.438 \times (3.215)^2 / 2 = 121.1$ kN-m/m

Surcharge pressure: Quni = 0.3 x 14.4 = 4.32 kN/m
Shear = 4.32 x 3.215 = 13.9 kN/m
Moment = $4.32 \times (3.215)^2 / 2 = 22.3$ kN-m/m

Load combination 4: Shear = 1.5 x 75.4 + 1.75 x 13.9 = 137.4 kN/m
Moment = 1.5 x 121.1 + 1.75 x 22.3 = 220.7 kN-m/m

The reinforced concrete design calculations use identical subroutines that were used for the backwall, therefore they have already been verified.

Loads at wall bottom:

H = 8.3 m

Lateral earth pressure: $P_r = 0.3 \times 18.85 (8.3)^2 / 2 = 194.786$ kN
$D_t = 1/3$
$P_t = 194.786 \times (0.4 - 0.5) / (1/3 - 0.5) = 116.872$ kN
$P_u = 194.786 - 116.872 = 77.914$ kN
$Q_u = 77.914 / 8.3 = 9.387$ kN/m
$Q_t = 2 \times 116.872 / (8.3) = 28.162$ kN/m
Quni = 9.387 + 28.162 = 37.549 kN/m

Shear = 37.549 x 3.215 = 120.7 kN/m
Moment = $37.549 \times (3.215)^2 / 2 = 194.1$ kN-m/m

Surcharge pressure: Quni = 0.3 x 14.4 = 4.32 kN/m
Shear = 4.32 x 3.215 = 13.9 kN/m
Moment = $4.32 \times (3.215)^2 / 2 = 22.3$ kN-m/m

Load combination 4: Shear = 1.5 x 120.7 + 1.75 x 13.9 = 205.4 kN/m
Moment = 1.5 x 194.1 + 1.75 x 22.3 = 330.2 kN-m/m

BRGABUT OUTPUT FILE = VER2.OUT

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Input file  = ver2.in
Output file = ver2.out

O P T I O N S
=====================================================================

Units           = Metric
Design Criteria = AASHTO LRFD
Wall Type       = Haunch
Footing Type    = Pile

P R O P E R T I E S
=====================================================================

REINFORCED CONCRETE:

     MATERIAL PROPERTIES:

     Concrete compressive strength  = 28.0 MPa
     Concrete modulus of elasticity = 25399.0 MPa
     Concrete modulus of rupture    = 3.33 MPa
     Concrete modular ratio         = 8
     Concrete unit weight           = 23.56 kN/m^3
     Reinforcing yield strength     = 420.0 MPa
     Crack control exposure factor  = 1.00

     STRENGTH REDUCTION FACTORS:

     Flexure                        = 0.900
     Shear                          = 0.900

     STRESS BLOCK:

     Compression block stress ratio = 0.8500
     Compression block depth ratio  = 0.8500
     Maximum concrete strain        = 0.0030
```

PILE RESISTANCE:

LOAD	RESISTANCE (kN) SLS	ULS	EQ
Compression:	1800.0	3600.0	3600.0
Tension:	900.0	1800.0	1800.0
Shear:	450.0	900.0	900.0

PILE LATERAL LOAD - MOMENT DATA:

POINT	LATERAL LOAD (kN)	MOMENT (kN-m)
1	500.00	497.00
2	1000.00	1195.00
3	2000.00	3225.00

FOOTING RESISTANCE:

PARAMETER	SLS	ULS	EQ
Passive coefficient:	0.000	0.000	0.000

C O N F I G U R A T I O N

WALL:

Stem wall height = 8.300 m
Stem wall length = 9.380 m
Stem wall thickness = 0.610 m
Stem wall batter = 3.430 deg
Haunch depth = 0.610 m
Back wall height = 2.025 m
Back wall thickness = 0.305 m
Seat width = 0.760 m
Distance to CL bearing = 0.380 m

FOOTING:

Width of toe = 1.720 m
Soil cover over toe = 0.610 m
Footing width = 6.000 m
Footing length = 9.380 m
Footing thickness = 1.150 m

PILES:

Pile width = 750.0 mm

ROW	TOE DIST (m)	NO OF PILES	NO OF BATTER	BATTER (deg)	SPACING (m)
1	0.750	4	0	0	2.625
2	3.000	4	0	0	2.625
3	5.250	4	0	0	2.625

L O A D S

BRIDGE LOADS:

Dead load constant = 1655.0 kN
Dead load varying = 0.0 kN
Live load standard = 550.0 kN
Live load special = 0.0 kN
Live load long force = 0.0 kN at height = 0.000 m
Friction long force = 330.0 kN at height = 0.000 m

EARTH LOADS:

Lateral pressure coeff = 0.300 at height = 0.400 H
Earthquake pressure coeff = 0.000 at height = 0.000 H
Compaction pressure = 0.00 kPa at height = 0.000 m
Soil unit weight = 18.85 kN/m^3
Surcharge pressure = 14.40 kPa

LOAD COMBINATIONS:

NO	LOAD CONDITION	MAXIMUM	MINIMUM	SERVICE
1	Construction 1 - place superstructure before backfill			
	Dead load abutment	0	0	1
	Dead load constant	0	0	1
	Dead load varying	0	0	1
	Service stress increase factor =	1.5		
2	Construction 2 - place backfill before superstructure			
	Dead load abutment	0	0	1
	Dead load earth	0	0	1
	Lateral earth pressure	0	0	1

Service stress increase factor = 1.5

---

3 Strength III - no live load with bearing friction

Dead load abutment	1.25	0.9	0
Dead load constant	1.25	0.9	0
Dead load varying	1.5	0.65	0
Dead load earth	1.35	1	0
Friction longitudinal force	1.2	0.5	0
Lateral earth pressure	1.5	0.9	0
Live load surcharge	1.35	0	0

Service stress increase factor = 1

---

4 Strength I and Service I - live load with bearing friction

Dead load abutment	1.25	0.9	1
Dead load constant	1.25	0.9	1
Dead load varying	1.5	0.65	1
Dead load earth	1.35	1	1
Live load standard	1.75	1.75	1
Friction longitudinal force	1.2	0.5	1
Lateral earth pressure	1.5	0.9	1
Live load surcharge	1.75	0	1

Service stress increase factor = 1

R E I N F O R C I N G

LOCATION	AREA (mm^2)	SPACING (mm)	COVER (mm)
Wall stem	819.00	180.00	50.00
Backwall	284.00	360.00	
Footing top	510.00	180.00	75.00
Footing bottom at toe	819.00	180.00	150.00
Footing bottom at heel	510.00	180.00	
Footing long w/piles	510.00	300.00	
T&S in wall stem	284.00	300.00	
T&S in backwall	129.00	300.00	
T&S in footing	284.00	300.00	

S I D E W A L L S

CONFIGURATION:

Length beyond backwall = 3.215 m
Height at end = 8.300 m
Thickness at top = 0.590 m
Thickness at bottom = 0.590 m
Uniform barrier weight = 5.000 kN/m

REINFORCING:

LOCATION	AREA (mm^2)	SPACING (mm)
Average main horizontal	284.00	150.00
Bottom main horizontal	510.00	150.00
T&S reinforcing	199.00	300.00

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B A C K W A L L
===============================================================

UNFACTORED LOADS:

    ---------------------------------------------------------------
    LOAD CONDITION                SHEAR          MOMENT
                                  (kN/m)         (kN-m/m)
    ---------------------------------------------------------------
    Lateral earth pressure        8.954          9.392
    Surcharge pressure            7.687          8.857
    ---------------------------------------------------------------

ULTIMATE LIMIT STATE CALCULATIONS:

     SHEAR (Comb 4):

     Effective depth = 245.49 mm
     Factored shear  = 26.884 kN/m
     d required      = 37.63 < d provided = 245.49 OKAY

     MOMENT (Comb 4):

     Factored moment = 29.588 kN-m/m
     As required     = 155.46 < As provided = 284.00 OKAY
     Strain          = 0.0420 > 0.005 OKAY

SERVICEABILITY LIMIT STATE CALCULATIONS:

     CRACK CONTROL (Comb 4):

     Service moment   = 18.249 kN-m/m
     Steel stress     = 101.05 MPa
     Maximum spacing  = 782.10 mm > Reinf spacing = 360.00 OKAY

     TEMPERATURE AND SHRINKAGE:

     T&S reinforcement = 129.00 > Area required = 71.84 OKAY
```

S T E M W A L L

UNFACTORED LOADS:

LOAD CONDITION	SHEAR (kN/m)	MOMENT (kN-m/m)
Dead load constant		14.315
Live load standard		4.757
FR longitudinal force	35.181	220.762
Lateral earth pressure	163.883	646.691
Surcharge pressure	32.158	148.802

ULTIMATE LIMIT STATE CALCULATIONS:

SHEAR (Comb 4):

Effective depth = 856.12 mm
Factored shear = 344.318 kN/m
d required = 482.00 < d provided = 856.12 OKAY

MOMENT (Comb 4):

Factored moment = 1521.575 kN-m/m
As required = 891.87 > As provided = 819.00 NO GOOD ***
Strain = 0.0242 > 0.005 OKAY

SERVICEABILITY LIMIT STATE CALCULATIONS:

CRACK CONTROL (Comb 4):

Service moment = 1035.328 kN-m/m
Steel stress = 290.18 MPa
Maximum spacing = 248.18 mm > Reinf spacing = 180.00 OKAY

TEMPERATURE AND SHRINKAGE:

T&S reinforcement = 284.00 > Area required = 185.05 OKAY

REQUIRED REINFORCEMENT AREA IN STEM WALL SECTIONS:

HEIGHT (m)	THICK (mm)	deff (mm)	MOMENT (kN-m/m)	AREA (mm^2)	LOAD COMB
7.78	891.04	824.90	1318.17	798.87	4
7.26	859.82	793.67	1131.38	709.94	4
6.74	828.59	762.44	960.49	625.00	4
6.22	797.36	731.22	804.79	543.94	4
5.70	766.13	699.99	663.55	466.65	4
5.17	734.91	668.76	540.10	396.08	4

4.65	703.68	637.53	430.67	330.05	4
4.13	672.45	606.31	333.54	267.75	4
3.61	641.23	575.08	247.99	231.57	4
3.09	610.00	543.85	173.30	206.15	4

S T A B I L I T Y

UNFACTORED WEIGHT AND RIGHTING MOMENT:

LOAD CONDITION	WEIGHT (kN)	MOMENT AT TOE (kN-m)
Dead load abutment	3591.4	10818.9
Dead load constant	1655.0	3475.5
Dead load earth	4566.8	18950.1
Live load standard	550.0	1155.0
Live load surcharge	434.3	1907.5

UNFACTORED LATERAL FORCE AND OVERTURNING MOMENT:

LOAD CONDITION	FORCE (kN)	MOMENT AT TOE (kN-m)
FR longitudinal force	330.0	2450.3
Lateral earth pressure	2070.5	7826.6
Surcharge pressure	334.8	1581.7

RESULTANT LOAD COMBINATIONS:

COMB NO	LIMIT STATE	VERTICAL LOAD (kN)	RIGHTING MOMENT (kN-m)	LATERAL LOAD (kN)	OVERTURNING MOMENT (kN-m)
1	SLS	5246.4	14294.4	0.0	0.0
2	SLS	8158.2	29769.0	2070.5	7826.6
3	ULS MAX	13309.4	46025.8	3953.7	16815.5
	ULS MIN	9288.6	31815.1	2028.5	8269.0
4	SLS	10797.5	36307.0	2735.3	11858.6
	ULS MAX	14445.6	48810.0	4087.6	17448.2
	ULS MIN	10251.1	33836.4	2028.5	8269.0

VERTICAL RESULTANT:

COMB NO	LIMIT STATE	CASE NO	VERTICAL LOAD (kN)	TOE DISTANCE (m)	RESULTANT LOCATION
1	SLS		5246.4	2.725	0.092
2	SLS		8158.2	2.690	0.103
3	ULS	1	13309.4	2.195	0.268
	ULS	2	9288.6	1.615	0.462
	ULS	3	13309.4	2.837	0.054
	ULS	4	9288.6	2.535	0.155
4	SLS		10797.5	2.264	0.245
	ULS	1	14445.6	2.171	0.276
	ULS	2	10251.1	1.599	0.467
	ULS	3	14445.6	2.806	0.065
	ULS	4	10251.1	2.494	0.169

ULS CASES:

Case 1 = Max vertical + max overturning
Case 2 = Min vertical + max overturning
Case 3 = Max vertical + min overturning
Case 4 = Min vertical + min overturning

P I L E F O O T I N G

PILE GROUP PROPERTIES:

Number of piles = 12
Pile CG distance = 3.000 m
Pile group inertia = 4.050E+01 m^2

PILE LOADS:

COMB NO	LIMIT STATE	PILE ROW	VERTICAL LOAD (kN)	SHEAR LOAD (kN)	BENDING MOMENT (kN-m)
1	SLS	1	517.5	0.0	0.0
		2	437.2	0.0	0.0
		3	356.9	0.0	0.0
2	SLS	1	934.9	172.5	171.5

		2	679.9	172.5	171.5
		3	424.8	172.5	171.5
3	ULS 1	1	1922.9	329.5	327.5
		2	1109.1	329.5	327.5
		3	295.3	329.5	327.5
	ULS 2	1	1707.2	329.5	327.5
		2	774.0	329.5	327.5
		3	-159.1	329.5	327.5
	ULS 3	1	1341.8	169.0	168.0
		2	1109.1	169.0	168.0
		3	876.5	169.0	168.0
	ULS 4	1	1126.0	169.0	168.0
		2	774.0	169.0	168.0
		3	422.1	169.0	168.0
4	SLS	1	1492.2	227.9	226.6
		2	899.8	227.9	226.6
		3	307.4	227.9	226.6
	ULS 1	1	2094.8	340.6	338.6
		2	1203.8	340.6	338.6
		3	312.8	340.6	338.6
	ULS 2	1	1878.0	340.6	338.6
		2	854.3	340.6	338.6
		3	-169.5	340.6	338.6
	ULS 3	1	1471.2	169.0	168.0
		2	1203.8	169.0	168.0
		3	936.5	169.0	168.0
	ULS 4	1	1254.4	169.0	168.0
		2	854.3	169.0	168.0
		3	454.1	169.0	168.0

MAXIMUM PILE LOADS:

SLS Compression (Comb 4) = 1492.2 < 1800.0 OKAY
SLS Shear (Comb 4) = 227.9 < 450.0 OKAY
SLS Moment (Comb 4) = 226.6
ULS Compression (Comb 4) = 2094.8 < 3600.0 OKAY
ULS Tension (Comb 4) = -169.5 < 1800.0 OKAY
ULS Shear (Comb 4) = 340.6 < 900.0 OKAY
ULS Moment (Comb 4) = 338.6

LATERAL STABILITY:

COMB NO	LIMIT STATE		FORCE (kN)	RESISTANCE (kN)	
1	SLS		0.0	8100.0	OKAY
2	SLS		2070.5	8100.0	OKAY
3	ULS	1	3953.7	10800.0	OKAY
	ULS	2	3953.7	10800.0	OKAY
	ULS	3	2028.5	10800.0	OKAY
	ULS	4	2028.5	10800.0	OKAY
4	SLS		2735.3	5400.0	OKAY
	ULS	1	4087.6	10800.0	OKAY
	ULS	2	4087.6	10800.0	OKAY
	ULS	3	2028.5	10800.0	OKAY
	ULS	4	2028.5	10800.0	OKAY

FOOTING LOADS:

COMB NO	LIMIT STATE	CASE NO	TOE SHEAR (kN/m)	TOE MOMENT (kN-m/m)	HEEL SHEAR (kN/m)	HEEL MOMENT (kN-m/m)
1	SLS		86.312	173.970	87.985	310.886
2	SLS		163.558	256.479	-151.902	-312.277
3	ULS	1	358.494	582.683	-300.166	-714.212
	ULS	2	324.138	513.425	-352.560	-798.917
	ULS	3	239.166	410.311	-52.354	-203.997
	ULS	4	204.810	341.053	-104.748	-288.703
4	SLS		277.995	463.523	-158.697	-443.519
	ULS	1	393.796	649.065	-272.617	-703.371
	ULS	2	359.226	579.378	-323.604	-788.854
	ULS	3	265.731	463.825	-6.663	-155.305
	ULS	4	231.162	394.138	-57.650	-240.789

ULS CASES:

Case 1 = Max vertical + max overturning
Case 2 = Min vertical + max overturning
Case 3 = Max vertical + min overturning
Case 4 = Min vertical + min overturning

```
            SIGN CONVENTION:

                 Positive moment => tension on bottom of footing
                 Positive shear  => upward direction

          ---------------------------------------------------------------
          F O O T I N G   T O E
          ---------------------------------------------------------------

          ULTIMATE LIMIT STATE CALCULATIONS:

               SHEAR (Comb 4):

               Effective depth = 983.85 mm
               Factored shear  = 393.796 kN/m
               d required      = 551.26 < d provided = 983.85 OKAY

               TENSION AT FOOTING BOTTOM:
               ----------------------------

               MOMENT (Comb 4):

               Factored moment = 649.065 kN-m/m
               As required     = 427.99 < As provided = 819.00 OKAY
               Strain          = 0.0282 > 0.005 OKAY

               NO TENSION AT FOOTING TOP:
               ----------------------------

          SERVICEABILITY LIMIT STATE CALCULATIONS:

               TENSION AT FOOTING BOTTOM:
               ----------------------------

               CRACK CONTROL (Comb 4):

               Service moment   = 463.523 kN-m/m
               Steel stress     = 112.45 MPa
               Maximum spacing  = 870.46 mm > Reinf spacing = 180.00 OKAY

               NO TENSION AT FOOTING TOP:
               ----------------------------

          ---------------------------------------------------------------
          F O O T I N G   H E E L
          ---------------------------------------------------------------

          ULTIMATE LIMIT STATE CALCULATIONS:

               SHEAR (Comb 3):

               Effective depth = 1062.26 mm
               Factored shear  = 352.560 kN/m
               d required      = 493.54 < d provided = 1062.26 OKAY
```

```
              NO TENSION AT FOOTING BOTTOM:
              -----------------------------

              TENSION AT FOOTING TOP:
              -----------------------------

              MOMENT (Comb 3):

              Factored moment = 798.917 kN-m/m
              As required     = 402.76 < As provided = 510.00 OKAY
              Strain          = 0.0512 > 0.005 OKAY

         SERVICEABILITY LIMIT STATE CALCULATIONS:

              TENSION AT FOOTING BOTTOM:
              -----------------------------

              CRACK CONTROL (Comb 1):

              Service moment   = 310.886 kN-m/m
              Steel stress     = 118.76 MPa
              Maximum spacing  = 828.12 mm > Reinf spacing = 180.00 OKAY

              TENSION AT FOOTING TOP:
              -----------------------------

              CRACK CONTROL (Comb 4):

              Service moment   = 443.519 kN-m/m
              Steel stress     = 157.12 MPa
              Maximum spacing  = 595.32 mm > Reinf spacing = 180.00 OKAY

              TEMPERATURE AND SHRINKAGE:

              T&S reinforcement = 284.00 > Area required = 261.55 OKAY

         ------------------------------------------------------------
         L O N G I T U D I N A L   R E I N F O R C E M E N T
         ------------------------------------------------------------

         ULS CALCULATIONS FOR FOOTING TOE:

              Pressure = 476.4 kPa
              Spacing  = 2.625 m

              MOMENT (Comb 4):

              Factored moment = 328.292 kN-m/m
              As required     = 367.95 < As provided = 510.00 OKAY
              Strain          = 0.0782 > 0.005 OKAY
```

ULS CALCULATIONS FOR FOOTING HEEL:

Pressure = 270.3 kPa
Spacing = 2.625 m

MOMENT (Comb 4):

Factored moment = 186.241 kN-m/m
As required = 207.70 < As provided = 510.00 OKAY
Strain = 0.0782 > 0.005 OKAY

S I D E W A L L S
==========

W A L L M I D - H E I G H T

UNFACTORED LOADS:

LOAD CONDITION	SHEAR (kN/m)	MOMENT (kN-m/m)
Lateral earth pressure	75.450	121.287
Surcharge pressure	13.889	22.326

ULTIMATE LIMIT STATE CALCULATIONS:

SHEAR (Comb 4):

Effective depth = 530.49 mm
Factored shear = 137.481 kN/m
d required = 192.46 < d provided = 530.49 OKAY

MOMENT (Comb 4):

Factored moment = 221.001 kN-m/m
As required = 177.09 < As provided = 284.00 OKAY
Strain = 0.0375 > 0.005 OKAY

SERVICEABILITY LIMIT STATE CALCULATIONS:

CRACK CONTROL (Comb 4):

Service moment = 143.613 kN-m/m
Steel stress = 153.86 MPa
Maximum spacing = 567.68 mm > Reinf spacing = 150.00 OKAY

TEMPERATURE AND SHRINKAGE:

T&S reinforcement = 199.00 > Area required = 149.29 OKAY

W A L L B O T T O M

UNFACTORED LOADS:

LOAD CONDITION	SHEAR (kN/m)	MOMENT (kN-m/m)
Lateral earth pressure	120.721	194.059
Surcharge pressure	13.889	22.326

ULTIMATE LIMIT STATE CALCULATIONS:

SHEAR (Comb 4):

Effective depth = 527.26 mm
Factored shear = 205.386 kN/m
d required = 287.51 < d provided = 527.26 OKAY

MOMENT (Comb 4):

Factored moment = 330.159 kN-m/m
As required = 255.78 < As provided = 510.00 OKAY
Strain = 0.0194 > 0.005 OKAY

SERVICEABILITY LIMIT STATE CALCULATIONS:

CRACK CONTROL (Comb 4):

Service moment = 216.385 kN-m/m
Steel stress = 132.82 MPa
Maximum spacing = 663.36 mm > Reinf spacing = 150.00 OKAY

STRUCTWARE

SHEET C3-1 OF

JOB TITLE BRGABUT Verification Problem 3 ORIGINATOR RM DATE 9/18/2005

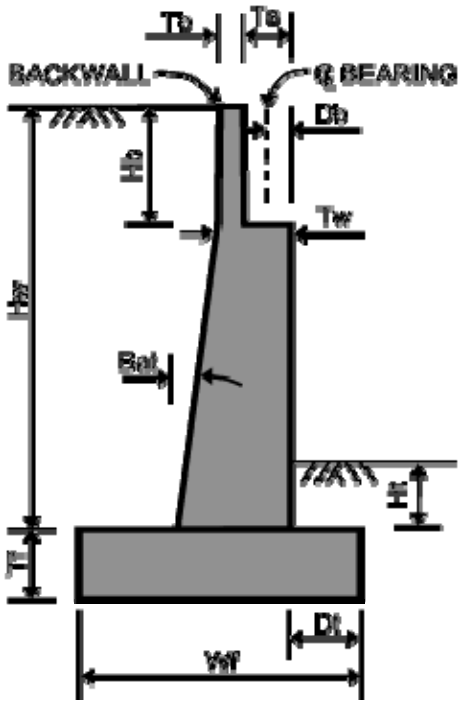
JOB No. CALCULATION No. REVIEWER DATE

VERIFICATION PROBLEM NO 3

- Railroad bridge abutment with no haunch
- Vertical and battered, pinned-head piles
- AREMA design criteria
- English units

CONFIGURATION

VARIABLE	VALUE
Hw	27.82 ft
Ht	2 ft
Lw	48.5 ft
Tw	5.076 ft
Bat	2.386 degrees
Hb	7.83 ft
Tb	1.5 ft
Ts	3.25 ft
Db	1.5 ft
Dt	5.0 ft
Wf	19.5 ft
Lf	48.5 ft
Tf	5.0 ft



The pile configuration is described below.

DESCRIPTION	VALUE
Number of pile rows	4
Pile diameter	14"
Distance(s) from pile to toe	1.5, 5.0', 8.5', 18.0'
Pile batter from vertical	18.435
Number of piles in row(s)	13, 14, 14, 8
Number of batter piles in row (s)	11, 11, 11, 0
Longitudinal pile spacing	3.5,3.5,3.5,6.5

PROPERTIES

REINFORCED CONCRETE:

Concrete compressive strength	= 4000.0 psi
Concrete unit weight	= 150.00 pcf
Reinforcing yield strength	= 60000.0 psi
Allowable stress factor	= 0.4

PILE RESISTANCE:

LOAD	RESISTANCE (kip) SLS
Compression:	200.0
Tension:	100.0
Shear:	16.0

FOOTING RESISTANCE:

Passive resistance = 0.

LOADS

BRIDGE LOADS:

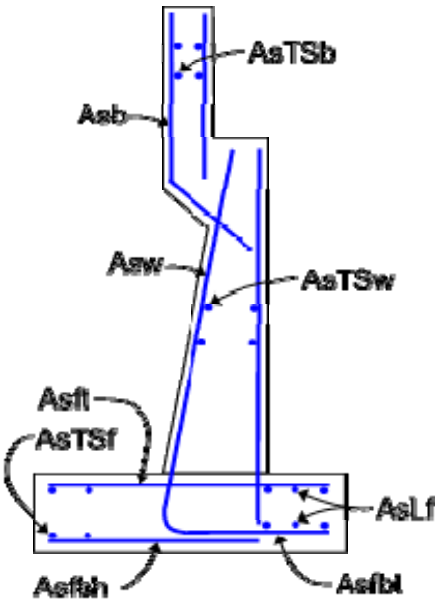
Dead load	= 969.0 kip
Live load	= 819.0 kip
Bearing pad shear	= 252.0 kip at top of seat

EARTH LOADS:

Lateral pressure coeff	= 0.300 at height ratio = 0.333
Soil unit weight	= 120.00 pcf
Surcharge pressure	= 1882.00 psf
Surcharge width	= 8.500 ft
No of surcharges	= 2
Surcharge spacing	= 15.00 ft

REINFORCING

VARIABLE	DESCRIPTION
REINFORCING AREA:	
Asw	1.27 in^2 @ 6 in
Asb	0.31 in^2 @ 6 in
Asft	1.27 in^2 @ 6 in
Asfbt	1.27 in^2 @ 6 in
Asfbh	0.79 in^2 @ 12 in
AsLf	0.79 in^2 @ 12 in
AsTSw	0.79 in^2 @ 12 in
AsTSb	0.44 in^2 @ 12 in
AsTSf	0.79 in^2 @ 12 in
REINFORCING COVER:	
Cover Asw	2"
Cover Asft	3"
Cover Asfb	6"



BACKWALL CALCULATIONS

Backwall thickness at seat = 5.076 - 3.25 = 1.826 (21.91")
Effective depth, d = 21.91 - 2 - $(0.31 / 3.1416)^{1/2}$ = 19.60 in
Backwall height for shear = 7.83 - 19.6 / 12 = 6.20 ft

Lateral earth pressure: V = 0.036 $(6.2)^2$ / 2 = 0.692 kip/ft
M = 0.036 $(7.83)^3$ / 6 = 2.88 k-ft/ft

Surcharge pressure: Effective width for shear = 8.5 + 6.2 - 0.5 = 14.2 ft
Q = 2 x 1.882 x 0.3 x 8.5 / 14.2 = 0.676 ksf
V = 0.676 (6.20) = 4.19 kip/ft

Effective width for moment = 8.5 + 7.83 - 0.5 = 15.83 use 15.0 ft
Q = 2 x 1.882 x 0.3 x 8.5 / 15 = 0.640 ksf
M = 0.64$(7.83)^2$ / 2 = 19.62 k-ft/ft

Service loads: V = 0.692 + 4.19 = 4.88 kip/ft
M = 2.88 + 19.62 = 22.5 k-ft/ft

Verify flexural calculations:

Service stresses: ρ = 0.31 / (6 x 19.6) = 0.002636
n = 8
ρn = 0.02109
k = $(2 \times 0.02109 + (0.02109)^2)^{1/2}$ - 0.02109 = 0.185
j = 1 - 0.185 / 3 = 0.938
f_c = 2 x 22500 / ($(19.6)^2$ x 0.185 x 0.938) = 675 psi < 1600 psi
f_s = 22500 x 6 / (0.31 x 0.938 x 19.6) = 23687 psi < 24000 psi

Verify shear calculations:

Service shear: d > 4880 / (0.95 x $(4000)^{1/2}$ x 12) = 6.77 in

Temperature and shrinkage reinforcement:

A_s > 0.25 in^2/ft x 12 / 12 = 0.25 in^2

STEM WALL CALCULATIONS

Height to seat level = 27.82 - 7.83 = 19.99 ft
Concrete thickness at top of footing = 5.076 + 19.99 x tan(2.386) = 5.909 ft (70.91 in)
Effective depth, d = 70.91 - 2 - $(1.27 / 3.1416)^{1/2}$ = 68.27 in
Stem wall height for shear = 27.82 - 68.27 / 12 = 22.13 ft

Lateral earth pressure: V = 0.036 $(22.13)^2$ / 2 = 8.82 kip/ft
M = 0.036 $(27.82)^3$ / 6 = 129.19 k-ft/ft

Surcharge pressure: V = 0.32 (22.13) = 7.08 kip/ft
M = 0.32 $(27.82)^2$ / 2 = 123.83 k-ft/ft

Bridge dead load: M = 969 x (5.909 / 2 - 1.5) / 48.5= 29.06 k-ft/ft

Bridge live load: M = 819 x (5.909 / 2 - 1.5) / 48.5= 24.56 k-ft/ft

Bearing pad shear: V = 252 / 48.5 = 5.196 kip/ft
M = 252 x (27.82 - 7.83 + 0) / 48.5 = 103.87 k-ft/ft

Service loads: V = 8.82 + 7.08 + 5.196 = 21.10 kip/ft (comb 6)
M = 129.19 + 123.83 + 29.06 + 24.56 + 103.87 = 410.51 k-ft/ft (comb 4)

Verify flexural calculations:

ρ = 1.27 / (6 x 68.27) = 0.0031
n = 8
ρn = 0.0248
k = (2 x 0.0248+ $(0.0248)^2)^{1/2}$ - 0.0248 = 0.199
j = 1 - 0.199 / 3 = 0.934
f_c = 2 x 410510 / ($(68.27)^2$ x 0.199 x 0.934) = 948 psi < 1600 psi x 1.25
f_s = 410510 x 6 / (1.27 x 0.934 x 68.27) = 30415 psi > 24000 psi x 1.25

k = 2000 / (30000 / 8 + 2000) = 0.3478
j = 1 - 0.3478 / 3 = 0.8840
A_s required > 6 x 410510 / (30000 x 0.884 x 68.27) = 1.36 in^2

Verify shear calculations:

Required depth for shear:

Service shear: d > 21100 / (1.25 x 0.95 x $(4000)^{1/2}$ x 12) = 23.41 in

Temperature and shrinkage reinforcement:

A_s > 0.25 in^2/ft x 12 / 12 = 0.25 in^2

Verify required flexural reinforcement area for the servicability limit state at 10 sections using a spreadsheet (not shown).

HEIGHT (ft)	THICK (ft)	Deff (ft)	MOMENT (k-ft/ft)	AREA (in^2)	LOAD COMB
25.821	5.826	5.606	355.5	1.20	6
23.822	5.742	5.522	305.6	1.04	6
21.823	5.659	5.439	260.3	0.90	6
19.824	5.576	5.356	219.4	0.77	6
17.825	5.493	5.273	182.7	0.65	6
15.826	5.409	5.189	149.8	0.54	6
13.827	5.326	5.106	120.5	0.44	6
11.828	5.243	5.023	94.4	0.35	6
9.829	5.159	4.939	61.0	0.29	4
7.830	5.076	4.856	51.0	0.25	4

STABILITY CALCULATIONS

Calculate weight and righting moment:

1. Dead load abutment

   w1 = 1.5 x 7.83 x 48.5 x 0.15 = 85.44 kips
   x1 = 9.0 ft

   w2 = 0.326 x 7.83 x 48.5 x 0.15 / 2 = 9.29 kips
   x2 = 9.86 ft

   w3 = 5.076 x 19.99 x 48.5 x 0.15 = 738.19 kips
   x3 = 7.54 ft

   w4 = 0.833 x 19.99 x 48.5 x 0.15 / 2 = 60.57 kips
   x4 = 10.35 ft

   w5 = 19.5 x 5.0 x 48.5 x 0.15 = 709.31 kips
   x5 = 9.75 ft

   Weight = 1602.8 kips
   Righting moment = 13969.2 k-ft

2. Dead load constant

   Weight = 969 kips
   Righting moment = 969 x 6.5 = 6298.5 k-ft

3. Dead load earth

   w1 = 8.591 x 27.82 x 48.5 x 0.12 = 1391.0 kips
   x1 = 15.20 ft

   w2 = 1.159 x 27.82 x 48.5 x 0.12 / 2 = 93.8 kips
   x2 = 10.52 ft

   w3 = 2 x 5 x 48.5 x 0.12 = 58.2 kips
   x3 = 2.5 ft

   Weight = 1543 kips
   Righting moment = 22275 k-ft

4. Live load standard

   Weight = 819 kips
   Righting moment = 819 x 6.5 = 5323.5 k-ft

5. Live load surcharge

   Weight = 1.882 x 8.5 x 2 x 9.75 = 311.9 kips
   Righting moment = 311.9 x 14.62 = 4562 k-ft

Calculate lateral load and overturning moment:

1. Friction longitudinal force

   Force = 252 kips
   Overturning moment = 252 x 24.99 = 6297.5 k-ft

2. Lateral earth pressure

   Force = 0.3 x 0.12 x 48.5 x $(32.82)^2$ / 2 = 940.4 kips
   Overturning moment = 940.4 x 32.82 / 3 = 10287 k-ft

3. Surcharge pressure

   Force = 0.3 x 1.882 x 8.5 x 2 x 32.82 = 315.0 kips
   Overturning moment = 315.0 x 32.82 / 2 = 5169.4 k-ft

Check resultant load combinations (use spreadsheet):

Combination 1:

CASE	Pv	Mrt	Ph	Mot	SLS
da	1602.8	13969.2	0	0	1
dc	969	6298.5	0	0	1
dv	0	0	0	0	1
de	1543	22275	0	0	0
l1	819	5323.5	0	0	0
fr	0	0	252	6297.5	0
ep	0	0	940.4	10287	0
sc	311.9	4562	315	5169.4	0
cp	0	0	0	0	0
SLS	2572	20268	0	0	

Combination 2:

CASE	Pv	Mrt	Ph	Mot	SLS
da	1602.8	13969.2	0	0	1
dc	969	6298.5	0	0	0
dv	0	0	0	0	0
de	1543	22275	0	0	1
l1	819	5323.5	0	0	0
fr	0	0	252	6297.5	0
ep	0	0	940.4	10287	1
sc	311.9	4562	315	5169.4	0
cp	0	0	0	0	0
SLS	3146	36244	940	10287	

Combination 3:

CASE	Pv	Mrt	Ph	Mot	SLS
da	1602.8	13969.2	0	0	1
dc	969	6298.5	0	0	1
dv	0	0	0	0	1
de	1543	22275	0	0	1
l1	819	5323.5	0	0	0
fr	0	0	252	6297.5	0
ep	0	0	940.4	10287	1
sc	311.9	4562	315	5169.4	1
cp	0	0	0	0	0
SLS	4427	47105	1255	15456	

Combination 4:

CASE	Pv	Mrt	Ph	Mot	SLS
da	1602.8	13969.2	0	0	1
dc	969	6298.5	0	0	1
dv	0	0	0	0	1
de	1543	22275	0	0	1
l1	819	5323.5	0	0	1
fr	0	0	252	6297.5	0
ep	0	0	940.4	10287	1
sc	311.9	4562	315	5169.4	1
cp	0	0	0	0	0
SLS	5246	52428	1255	15456	

Combination 5:

CASE	Pv	Mrt	Ph	Mot	SLS
da	1602.8	13969.2	0	0	1
dc	969	6298.5	0	0	1
dv	0	0	0	0	1
de	1543	22275	0	0	1
l1	819	5323.5	0	0	0
fr	0	0	252	6297.5	1
ep	0	0	940.4	10287	1
sc	311.9	4562	315	5169.4	1
cp	0	0	0	0	0
SLS	4427	47105	1507	21754	

Combination 6:

CASE	Pv	Mrt	Ph	Mot	SLS
da	1602.8	13969.2	0	0	1
dc	969	6298.5	0	0	1
dv	0	0	0	0	1
de	1543	22275	0	0	1
l1	819	5323.5	0	0	1
fr	0	0	252	6297.5	1
ep	0	0	940.4	10287	1
sc	311.9	4562	315	5169.4	1
cp	0	0	0	0	0
SLS	5246	52428	1507	21754	

Check vertical resultant (use spreadsheet):

X = (Mrt - Mot) / Pv
Locate = Fractional portion of footing = (Wf - 2X) / Wf

Combination 1:

CASE	X	LOCATE
SLS	7.881	0.192

Combination 2:

CASE	X	LOCATE
SLS	8.251	0.154

Combination 3:

CASE	X	LOCATE
SLS	7.149	0.267

Combination 4:

CASE	X	LOCATE
SLS	7.048	0.277

Combination 5:

CASE	X	LOCATE
SLS	5.727	0.413

Combination 6:

CASE	X	LOCATE
SLS	5.848	0.400

PILE FOOTING CALCULATIONS

Calculate pile group properties:

n = 49
Xcg = (13 x 1.5 + 14 x 5 + 14 x 8.5 + 8 x 18) / 49 = 7.19 feet
Ipiles = $13(7.19 - 1.5)^2 + 14(7.19 - 5)^2 + 14(8.5 - 7.19)^2 + 8(18 - 7.19)^2 = 1446.9$ ft^2

Calculate pile loads and shear resistance (use spreadsheet):

Vertical load = Pv
Horizontal load = Ph
Resultant distance = X
Distance from pile to CG = c
SLS increase factor = Fsls
Number of batter piles = nbat
Distance to pile from toe = x

Pile batter, bat = 18.435 degrees
Lateral pile capacity, Vpile = 16 kips
Passive resistance, Vpas = 0.

Axial load, P = Pv / n + Pv x (Xcg - X) x c / Ipiles
Lateral batter load, Vb = nbat x P x tan(bat)
Shear load, V = (Ph - Passive - ΣVb) / n > 0
Shear resistance, Vr = Vpas + ΣVb + Vpile x n x Fsls

Load combination 1:

Vpile = 16 Pv = 2572
Vpas = 0 Ph = 0
Fsls = 1.5 X = 7.881

Row	x	n	nbat	P	Vb
1	1.5	13	11	45.5	166.8
2	5	14	11	49.8	182.6
3	8.5	14	11	54.1	198.3
4	18	8	0	65.8	0.0

V = 0.0
Vr = 1723.7

Load combination 2:

Vpile = 16 Pv = 3146
Vpas = 0 Ph = 940
Fsls = 1.5 X = 8.251

Row	x	n	nbat	P	Vb
1	1.5	13	11	51.1	187.3
2	5	14	11	59.2	216.9
3	8.5	14	11	67.2	246.5
4	18	8	0	89.1	0.0

V = 5.9
Vr = 1826.6

Load combination 3:

Vpile = 16 Pv = 4427
Vpas = 0 Ph = 1255
Fsls = 1.25 X = 7.149

Row	x	n	nbat	P	Vb
1	1.5	13	11	91.1	333.9
2	5	14	11	90.6	332.2
3	8.5	14	11	90.2	330.6
4	18	8	0	89.0	0.0

V = 5.3
Vr = 1976.7

Load combination 4:

Vpile = 16 Pv = 5246
Vpas = 0 Ph = 1255
Fsls = 1 X = 7.048

Row	x	n	nbat	P	Vb
1	1.5	13	11	110.0	403.3
2	5	14	11	108.2	396.7
3	8.5	14	11	106.4	390.0
4	18	8	0	101.5	0.0

V = 1.3
Vr = 1974.0

Load combination 5:

Vpile = 16 Pv = 4427
Vpas = 0 Ph = 1507
Fsls = 1.4 X = 5.727

Row	x	n	nbat	P	Vb
1	1.5	13	11	115.8	424.6
2	5	14	11	100.1	367.2
3	8.5	14	11	84.5	309.7
4	18	8	0	42.0	0.0

V = 8.3
Vr = 2199.1

Load combination 6:

Vpile = 16 Pv = 5246
Vpas = 0 Ph = 1507
Fsls = 1.25 X = 5.848

Row	x	n	nbat	P	Vb
1	1.5	13	11	134.7	494.0
2	5	14	11	117.7	431.6
3	8.5	14	11	100.7	369.1
4	18	8	0	54.5	0.0

V = 4.3
Vr = 2274.8

Footing loads:

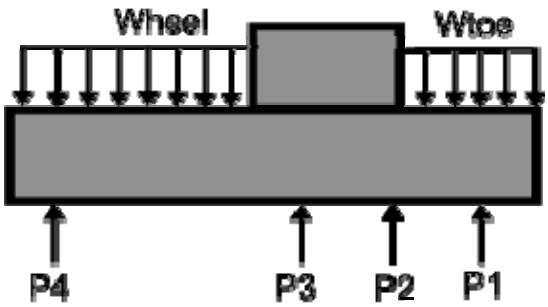
The footing load calculations for the toe and heel will be verified by checking one critical load combination.

Dt = 5.0 ft
Lheel = 19.5 - 5 - 5.076 - 19.99 x tan(2.386) = 8.591 ft
dtop = 60 - 3 - $(1.27 / 3.1416)^{1/2}$ = 56.36 in
dbot (toe) = 60 - 6 - $(1.27 / 3.1416)^{1/2}$ = 53.36 in
dbot (heel) = 60 - 6 - $(0.79 / 3.1416)^{1/2}$ = 53.50 in

W(conc) = 5 x 0.150 = 0.75 ksf
Wtoe(soil) = 2 x 0.120 =0.240 ksf
Wheel (soil) = 27.82 x 0.120 = 3.338 ksf
Wheel (surch) = 1.882 x 2 x 8.5 / 48.5 =0.660 ksf

SLS combination 6:

P1v = 134.7 kips
P2v = 117.7 kips
P3v = 100.7 kips
P4v = 54.5 kips
Wtoe = 0.99 ksf
Wheel = 4.748 ksf
Fsls = 1.25



Toe moment and shear:

M = (13 x 134.7 x 3.5) / 48.5 - 0.99 x $(5)^2$ / 2 = 114.0 k-ft/ft

Lv = 5 - 53.36 / 12 = 0.553 ft

V = -0.99 x 0.553 = -0.55 k/ft

Heel moment and shear:

M = 8 x 54.5 x 7.091 / 48.5 - 4.748 $(8.591)^2$ / 2 = -111.5 k-ft/ft

V = 8 x 54.5 / 48.5 - 4.748 x 8.591 = -31.8 k/ft

Reinforcement calculations for footing:

The footing reinforcement calculations use the same subroutines which were previously validated for the backwall and stemwall calculations. Therefore, only the critical calculations at the footing will be validated.

Perform hand calculations to verify shear and flexural calculations:

Shear V = 31.8 k/ft (heel)
$d > 31.8 \times 1000 / (12 \times 1.25 \times 0.95 \times (4000)^{1/2}) = 35.3$ in

Moment M = 114.0 k-ft/ft (toe)
d = 53.36 in
$\rho = 1.27 / (6 \times 53.36) = 0.00397$
n = 8
$\rho n = 0.0317$
$k = (2 \times 0.0317 + (0.0317)^2)^{1/2} - 0.0317 = 0.222$
$j = 1 - 0.222 / 3 = 0.926$
$f_c = 2 \times 114000 / ((53.36)^2 \times 0.222 \times 0.926) = 390$ psi < 1600 psi x 1.25
$f_s = 114000 \times 6 / (1.27 \times 0.926 \times 53.36) = 10900$ psi > 24000 psi x 1.25

Footing longitudinal reinforcement:

The longitudinal reinforcement calculations will be verified for the footing toe and heel.

AsLf = 0.79 in^2 @ 12 in
$d = 60 - 6 - 2(1.27 / 3.1416)^{1/2} - (0.79 / 3.1416)^{1/2} = 52.23$ in

Footing toe

Combination 4, SLS pile load = 110.0 kips at row 1

Tributory area = $48.5 \times (1.5 + 3.5 / 2) = 157.62$ ft^2
Uniform load W = 13 x 110 / 157.62 = 9.07 ksf
Pile spacing S = 3.5 ft

$M = 9.07 (3.5)^2 / 10 = 11.1$ k-ft/ft
fs = 3377 psi (REBEAM calculations not shown)
fc = 64.4 psi (REBEAM calculations not shown)

Footing heel

Combination 4, SLS pressure on footing:

Uniform load W = 5 x .15 + 27.82 x .12 + 1.882 x 2 x 8.5 / 48.5 = 4.75 ksf
Pile spacing S = 6.5 ft

$M = 4.75 (6.5)^2 / 10 = 20.1$ k-ft/ft
fs = 6115 psi (REBEAM calculations not shown)
fc = 116.5 psi (REBEAM calculations not shown)

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O P T I O N S
=====================================================================

Units           = English
Design Criteria = AREMA (2002)
Concrete Design = Service Load Design (SLD)
Wall Type       = No Haunch
Footing Type    = Pile

P R O P E R T I E S
=====================================================================

REINFORCED CONCRETE:

     MATERIAL PROPERTIES:

     Concrete compressive strength  = 4000.0 psi
     Concrete modulus of elasticity = 3604997.0 psi
     Concrete modulus of rupture    = 474.34 psi
     Concrete modular ratio         = 8
     Concrete unit weight           = 150.00 pcf
     Reinforcing yield strength     = 60000.0 psi
     Allowable stress factor        = 0.4

PILE RESISTANCE:

    ------------------------------------------------------------
    LOAD                RESISTANCE (kip)
                        SLS       ULS       EQ
    ------------------------------------------------------------
    Compression:        200.0     0.0       0.0
    Tension:            100.0     0.0       0.0
    Shear:              16.0      0.0       0.0
    ------------------------------------------------------------

FOOTING RESISTANCE:

    ------------------------------------------------------------
    PARAMETER                SLS       ULS       EQ
    ------------------------------------------------------------
    Passive coefficient:     0.000     0.000     0.000
    ------------------------------------------------------------
```

C O N F I G U R A T I O N

WALL:

Stem wall height	= 27.820 ft
Stem wall length	= 48.500 ft
Stem wall thickness	= 5.076 ft
Stem wall batter	= 2.386 deg
Back wall height	= 7.830 ft
Back wall thickness	= 1.500 ft
Seat width	= 3.250 ft
Distance to CL bearing	= 1.500 ft

FOOTING:

Width of toe	= 5.000 ft
Soil cover over toe	= 2.000 ft
Footing width	= 19.500 ft
Footing length	= 48.500 ft
Footing thickness	= 5.000 ft

PILES:

Pile width	= 14.0 in

ROW	TOE DIST (ft)	NO OF PILES	NO OF BATTER	BATTER (deg)	SPACING (ft)
1	1.500	13	11	18.435	3.500
2	5.000	14	11	18.435	3.500
3	8.500	14	11	18.435	3.500
4	18.000	8	0	0	6.500

L O A D S

BRIDGE LOADS:

Dead load constant	= 969.0 kip	
Dead load varying	= 0.0 kip	
Live load standard	= 819.0 kip	
Live load special	= 0.0 kip	
Live load long force	= 0.0 kip	at height = 0.000 ft
Friction long force	= 252.0 kip	at height = 0.000 ft

EARTH LOADS:

```
 Lateral pressure coeff    = 0.300        at height = 0.333 H
 Earthquake pressure coeff = 0.000        at height = 0.000 H
 Compaction pressure       = 0.00 psf     at height = 0.000 ft
 Soil unit weight          = 120.00 pcf
 Surcharge pressure        = 1882.00 psf
 Surcharge width at grade  = 8.500 ft
 Number of surcharges      = 2
 Min spacing of surcharges = 15.000 ft
```

LOAD COMBINATIONS:

NO	LOAD CONDITION	MAXIMUM	MINIMUM	SERVICE
1	Construction 1 - place superstructure before backfill			
	Dead load abutment	0	0	1
	Dead load constant	0	0	1
	Dead load varying	0	0	1
	Service stress increase factor = 1.5			
2	Construction 2 - place backfill before superstructure			
	Dead load abutment	0	0	1
	Dead load earth	0	0	1
	Lateral earth pressure	0	0	1
	Service stress increase factor = 1.5			
3	Group II - no live load on bridge			
	Dead load abutment	0	0	1
	Dead load constant	0	0	1
	Dead load varying	0	0	1
	Dead load earth	0	0	1
	Lateral earth pressure	0	0	1
	Live load surcharge	0	0	1
	Service stress increase factor = 1.25			

4 Group I - live load on bridge

Dead load abutment	0	0	1
Dead load constant	0	0	1
Dead load varying	0	0	1
Dead load earth	0	0	1
Live load standard	0	0	1
Lateral earth pressure	0	0	1
Live load surcharge	0	0	1

Service stress increase factor = 1

---

5 Group V - no live load with bearing friction

Dead load abutment	0	0	1
Dead load constant	0	0	1
Dead load varying	0	0	1
Dead load earth	0	0	1
Friction longitudinal force	0	0	1
Lateral earth pressure	0	0	1
Live load surcharge	0	0	1

Service stress increase factor = 1.4

---

6 Group III - live load with bearing friction

Dead load abutment	0	0	1
Dead load constant	0	0	1
Dead load varying	0	0	1
Dead load earth	0	0	1
Live load standard	0	0	1
Friction longitudinal force	0	0	1
Lateral earth pressure	0	0	1
Live load surcharge	0	0	1

Service stress increase factor = 1.25

```
R E I N F O R C I N G
=====================================================================

---------------------------------------------------------------------
LOCATION                AREA      SPACING   COVER
                        (in^2)    (in)      (in)
---------------------------------------------------------------------
Wall stem               1.27      6.00      2.00
Backwall                0.31      6.00
Footing top             1.27      6.00      3.00
Footing bottom at toe   1.27      6.00      6.00
Footing bottom at heel  0.79      12.00
Footing long w/piles    0.79      12.00
T&S in wall stem        0.79      12.00
T&S in backwall         0.44      12.00
T&S in footing          0.79      12.00
---------------------------------------------------------------------

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B A C K W A L L
=====================================================================

UNFACTORED LOADS:

    ---------------------------------------------------------------
    LOAD CONDITION              SHEAR          MOMENT
                                (kip/ft)       (k-ft/ft)
    ---------------------------------------------------------------
    Lateral earth pressure      0.691          2.880
    Surcharge pressure          4.190          19.615
    ---------------------------------------------------------------

SERVICEABILITY LIMIT STATE CALCULATIONS:

     SHEAR (Comb 4):

     Effective depth = 19.60 in
     Service shear   = 4.881 kip/ft
     d required      = 6.77 < d provided = 19.60 OKAY

     MOMENT (Comb 4):

     Service moment  = 22.495 k-ft/ft
     Steel stress    = 23679.64 < Allowable stress = 24000.00 OKAY
     Concrete stress = 673.54 psi
```

TEMPERATURE AND SHRINKAGE:

T&S reinforcement = 0.44 > Area required = 0.25 OKAY

S T E M W A L L

UNFACTORED LOADS:

LOAD CONDITION	SHEAR (kip/ft)	MOMENT (k-ft/ft)
Dead load constant		29.059
Live load standard		24.561
FR longitudinal force	5.196	103.866
Lateral earth pressure	8.816	129.187
Surcharge pressure	7.080	123.809

SERVICEABILITY LIMIT STATE CALCULATIONS:

SHEAR (Comb 6):

Effective depth = 68.27 in
Service shear = 21.092 kip/ft
d required = 23.40 < d provided = 68.27 OKAY

MOMENT (Comb 6):

Service moment = 410.483 k-ft/ft
Steel stress = 30426.87 > Allowable stress = 30000.00 NO GOOD ***
As required = 1.36 in^2

TEMPERATURE AND SHRINKAGE:

T&S reinforcement = 0.79 > Area required = 0.25 OKAY

REQUIRED REINFORCEMENT AREA IN STEM WALL SECTIONS:
(Service Load Design)

HEIGHT (ft)	THICK (in)	deff (in)	MOMENT (k-ft/ft)	AREA (in^2)	LOAD COMB
25.82	69.91	67.27	355.51	1.20	6
23.82	68.91	66.27	305.53	1.04	6
21.82	67.91	65.27	260.26	0.90	6
19.82	66.91	64.27	219.41	0.77	6
17.83	65.91	63.27	182.68	0.65	6
15.83	64.91	62.27	149.80	0.54	6
13.83	63.91	61.27	120.48	0.44	6
11.83	62.91	60.28	94.42	0.35	6
9.83	61.91	59.28	60.95	0.29	4
7.83	60.91	58.28	50.95	0.25	4

S T A B I L I T Y

UNFACTORED WEIGHT AND RIGHTING MOMENT:

LOAD CONDITION	WEIGHT (kip)	MOMENT AT TOE (k-ft)
Dead load abutment	1602.8	13967.8
Dead load constant	969.0	6298.5
Dead load earth	1543.0	22282.2
Live load standard	819.0	5323.5
Live load surcharge	311.9	4562.1

UNFACTORED LATERAL FORCE AND OVERTURNING MOMENT:

LOAD CONDITION	FORCE (kip)	MOMENT AT TOE (k-ft)
FR longitudinal force	252.0	6297.5
Lateral earth pressure	940.3	10277.1
Surcharge pressure	315.0	5169.4

RESULTANT LOAD COMBINATIONS:

COMB NO	LIMIT STATE	VERTICAL LOAD (kip)	RIGHTING MOMENT (k-ft)	LATERAL LOAD (kip)	OVERTURNING MOMENT (k-ft)
1	SLS	2571.8	20266.3	0.0	0.0
2	SLS	3145.8	36250.0	940.3	10277.1
3	SLS	4426.8	47110.6	1255.4	15446.5
4	SLS	5245.8	52434.1	1255.4	15446.5
5	SLS	4426.8	47110.6	1507.4	21744.0
6	SLS	5245.8	52434.1	1507.4	21744.0

VERTICAL RESULTANT:

COMB NO	LIMIT STATE	CASE NO	VERTICAL LOAD (kip)	TOE DISTANCE (ft)	RESULTANT LOCATION
1	SLS	-	2571.8	7.880	0.192
2	SLS	-	3145.8	8.256	0.153
3	SLS	-	4426.8	7.153	0.266
4	SLS	-	5245.8	7.051	0.277
5	SLS	-	4426.8	5.730	0.412
6	SLS	-	5245.8	5.850	0.400

P I L E F O O T I N G

PILE GROUP PROPERTIES:

Number of piles = 49
Pile CG distance = 7.194 ft
Pile group inertia = 1.447E+03 ft^2

PILE LOADS:

COMB NO	LIMIT STATE	PILE ROW	VERTICAL LOAD (kip)	SHEAR LOAD (kip)	BENDING MOMENT (k-ft)
1	SLS	1	45.5	0.0	0.0
		2	49.8	0.0	0.0
		3	54.1	0.0	0.0
		4	65.7	0.0	0.0
2	SLS	1	51.0	5.9	0.0
		2	59.1	5.9	0.0
		3	67.2	5.9	0.0
		4	89.2	5.9	0.0
3	SLS	1	91.1	5.3	0.0
		2	90.6	5.3	0.0
		3	90.2	5.3	0.0
		4	89.0	5.3	0.0
4	SLS	1	110.0	1.3	0.0
		2	108.2	1.3	0.0
		3	106.4	1.3	0.0
		4	101.5	1.3	0.0
5	SLS	1	115.8	8.3	0.0
		2	100.2	8.3	0.0
		3	84.5	8.3	0.0
		4	42.0	8.3	0.0
6	SLS	1	134.8	4.3	0.0
		2	117.7	4.3	0.0
		3	100.7	4.3	0.0
		4	54.4	4.3	0.0

MAXIMUM PILE LOADS:

SLS Compression (Comb 4) = 116.0 < 200.0 OKAY
SLS Shear (Comb 5) = 8.3 < 22.4 OKAY

NOTE: Maximum pile axial loads include effect of batter.

LATERAL STABILITY:

COMB NO	LIMIT STATE	FORCE (kip)	RESISTANCE (kip)	
1	SLS	0.0	1723.9	OKAY
2	SLS	940.3	1826.5	OKAY
3	SLS	1255.4	1976.8	OKAY
4	SLS	1255.4	1974.1	OKAY
5	SLS	1507.4	2199.4	OKAY
6	SLS	1507.4	2275.2	OKAY

FOOTING LOADS:

COMB NO	LIMIT STATE	CASE NO	TOE SHEAR (kip/ft)	TOE MOMENT (k-ft/ft)	HEEL SHEAR (kip/ft)	HEEL MOMENT (k-ft/ft)
1	SLS	-	-0.415	33.347	7.732	49.133
2	SLS	-	-0.547	35.515	-20.416	-46.585
3	SLS	-	-0.547	73.049	-26.112	-71.133
4	SLS	-	-0.547	90.827	-24.056	-56.547
5	SLS	-	-0.547	96.298	-33.870	-126.145
6	SLS	-	-0.547	114.076	-31.813	-111.559

```
      SIGN CONVENTION:

           Positive moment => tension on bottom of footing
           Positive shear  => upward direction

  ---------------------------------------------------------------
  F O O T I N G   T O E
  ---------------------------------------------------------------

  SERVICEABILITY LIMIT STATE CALCULATIONS:

       SHEAR (Comb 4):

       Effective depth = 56.36 in
       Service shear   = 0.547 kip/ft
       d required      = 0.76 < d provided = 56.36 OKAY

       TENSION AT FOOTING BOTTOM:
       ----------------------------

       MOMENT (Comb 6):

       Service moment  = 114.076 k-ft/ft
       Steel stress    = 10907.08 < Allowable stress = 30000.00 OKAY
       Concrete stress = 389.44 psi

       NO TENSION AT FOOTING TOP:
       ----------------------------

  ---------------------------------------------------------------
  F O O T I N G   H E E L
  ---------------------------------------------------------------

  SERVICEABILITY LIMIT STATE CALCULATIONS:

       SHEAR (Comb 6):

       Effective depth = 56.36 in
       Service shear   = 31.813 kip/ft
       d required      = 35.30 < d provided = 56.36 OKAY

       TENSION AT FOOTING BOTTOM:
       ----------------------------

       MOMENT (Comb 1):

       Service moment  = 49.133 k-ft/ft
       Steel stress    = 14586.30 < Allowable stress = 36000.00 OKAY
       Concrete stress = 274.42 psi
```

```
     TENSION AT FOOTING TOP:
     -----------------------------

     MOMENT (Comb 5):

     Service moment  = 126.145 k-ft/ft
     Steel stress    = 11397.47 < Allowable stress = 33600.00 OKAY
     Concrete stress = 394.64 psi

     TEMPERATURE AND SHRINKAGE:

     T&S reinforcement = 0.79 > Area required = 0.25 OKAY

-------------------------------------------------------------
L O N G I T U D I N A L   R E I N F O R C E M E N T
-------------------------------------------------------------

SLS CALCULATIONS FOR FOOTING TOE:

     Pressure = 9072.7 psf
     Spacing  = 3.500 ft

     MOMENT (Comb 4):

     Service moment  = 11.114 k-ft/ft
     Steel stress    = 3381.57 < Allowable stress = 24000.00 OKAY
     Concrete stress = 64.44 psi

SLS CALCULATIONS FOR FOOTING HEEL:

     Pressure = 4748.0 psf
     Spacing  = 6.500 ft

     MOMENT (Comb 4):

     Service moment  = 20.060 k-ft/ft
     Steel stress    = 6103.61 < Allowable stress = 24000.00 OKAY
     Concrete stress = 116.32 psi

Q U A N T I T I E S
=============================================================

CONCRETE:

    ------------------------------------------------------------
    ITEM           VOLUME
                   (yd^3)
    ------------------------------------------------------------
    Abutment       220.6
    Footing        175.1
    ------------------------------------------------------------
```

REINFORCING:

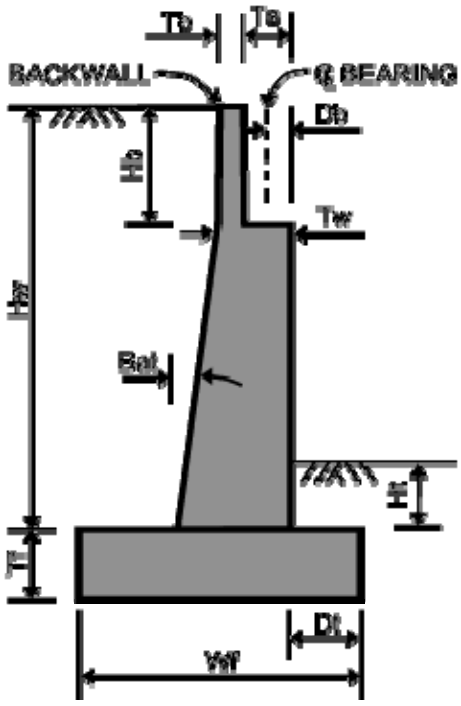
BAR	AREA (in^2)	LENGTH (in)	NO	WEIGHT (lb)	DESCRIPTION
Asb	0.31	124.6	98	1071.5	
AsTSb	0.44	121.9	49	743.8	Vertical
AsTSb	0.44	578.0	18	1295.5	Longitudinal
Asw	1.27	419.0	98	14757.8	
AsTSw	0.79	291.9	49	3197.5	Vertical
AsTSw	0.79	578.0	42	5427.4	Longitudinal
Asft	1.27	228.0	98	8030.7	
Asfbt	1.27	0.0	0	0.0	
Asfbh	0.79	171.0	49	1873.3	
AsTSf	0.79	576.0	42	5408.6	
Total =			543	41806.1	

VERIFICATION PROBLEM NO 4

- Roadway bridge short seat abutment with wingwalls
- Spread footing
- CAN/CSA-S6 design criteria
- Metric units

CONFIGURATION

VARIABLE	VALUE
Hw	3.8 m
Ht	0.61 m
Lw	9.0 m
Tw	1.065 m
Bat	0 degrees
Hb	2.025 m
Tb	0.305 m
Ts	0.76 m
Db	0.38 m
Dt	1.62 m
Wf	4.0 m
Lf	9.0 m
Tf	1.0 m



PROPERTIES

REINFORCED CONCRETE:

Concrete compressive strength	= 30 MPa
Concrete unit weight	= 24.0 kN/m^3
Exposure factor	= 30000.0 N/mm
Reinforcing yield strength	= 400 MPa

LOADS

BRIDGE LOADS:

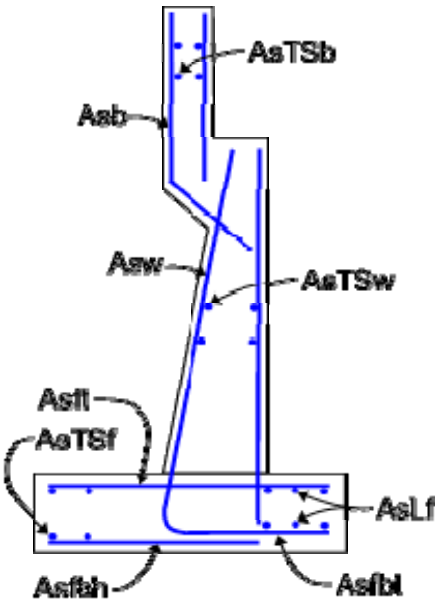
Dead load constant	= 1300.0 kN	
Dead load varying	= 355.0 kN	
Live load	= 550.0 kN	
Bearing pad shear	= 330.0 kN at top of seat	

EARTH LOADS:

Lateral pressure coeff	= 0.35	at height = 0.333 H
Soil unit weight	= 20.0 kN/m^3	
Surcharge pressure	= 16.0 kPa	
Compaction pressure	= 12.00 kPa	at height = 2.000 m

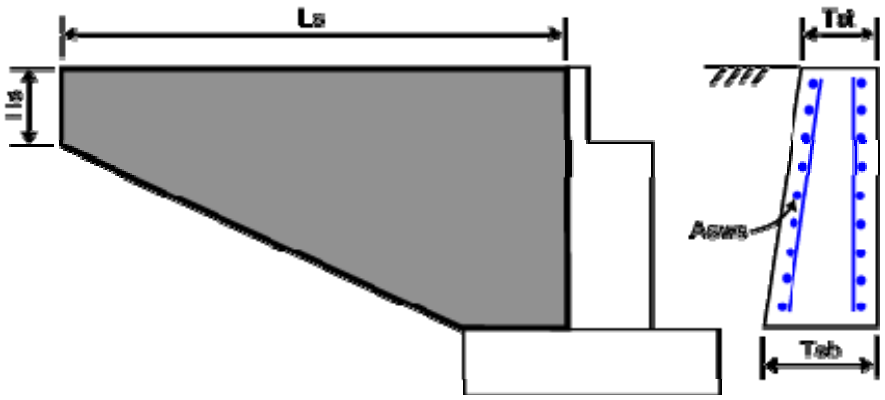
REINFORCING

VARIABLE	DESCRIPTION
REINFORCING AREA:	
Asw	510 mm^2 @ 150 mm
Asb	284 mm ^2 @ 300 mm
Asft	510 mm ^2 @ 300 mm
Asfbt	510 mm ^2 @ 150 mm
Asfbh	510 mm ^2 @ 300 mm
AsLf	N/A
AsTSw	284 mm ^2 @ 300 mm
AsTSb	129 mm ^2 @ 300 mm
AsTSf	284 mm ^2 @ 300 mm
REINFORCING COVER:	
Cover Asw	50 mm
Cover Asft	75 mm
Cover Asfb	75 mm



SIDE WALLS

VARIABLE	VALUE
CONFIGURATION:	
Ls Hs Tst Tsb Wbarrier	8.0 m 1.0 m 0.45 m 0.45 m 5.0 kN/m
REINFORCING:	
Asws Aswsb AsTSws	510 mm^2 @ 150 mm 510 mm^2 @ 150 mm 199 mm^2 @ 300 mm



BACKWALL CALCULATIONS

Effective depth, d = 305 - 50 - $(284 / 3.1416)^{1/2}$ = 245.5 mm
Backwall height for shear = 2.025 - 0.2455 = 1.780 m

Lateral earth pressure: V = 0.35 x 20.0 $(1.78)^2$ / 2 = 11.09 kN/m
M = 0.35 x 20.0 $(2.025)^3$ / 6 = 9.69 kN-m/m

Surcharge pressure: V = 0.35 x 16.0 (1.78) = 9.97 kN/m
M = 0.35 x 16.0 $(2.025)^2$ / 2 = 11.48 kN-m/m

Compaction pressure: Qu = 1.32 kPa
Qt = 10.68 kPa
V = 1.32 x 1.78 + 10.68 (1.78) / 2 = 11.85 kN/m
P = 12 x 2 / 2 = 12 kN/m
M = 12 x (2.025 - 2/3) = 16.3 kN-m/m

Service loads: M = 9.69 + 11.48 = 21.17 kN-m/m (comb 5)

Factored loads: V = 1.5 x 11.09 + 1.5 x 11.85 = 34.41 kN/m (comb 2)
M = 1.5 x 9.69 + 1.5 x 16.3 = 38.98 kN-m/m (comb 2)

Run REBEAM program to verify flexural calculations (see REBEAM output below):

Area of reinforcing per meter = 284 x 1000 / 300 = 947 mm^2

Service stresses: f_s = 98.2 MPa

Crack control: β = 20389 < 30000

Ultimate flexure: A_s > 470 x 300 / 1000 = 141 mm^2
c/d = 0.086 < 0.5

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D E S I G N   C R I T E R I A
=================================================

Code  = CAN/CSA-S6 (2000)
Units = Metric (Newtons, millimeters - moments in kN-m)
```

```
MATERIAL PROPERTIES:

     Concrete compressive strength       = 30
     Concrete modulus of elasticity      = 2.5650E+04
     Reinforcing yield strength          = 400
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 8

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 1.00
     Concrete resistance factor          = 0.75
     Reinforcing resistance factor       = 0.90

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8050
     Ratio of depth of compression block = 0.8950
     Maximum concrete strain             = 0.0035

S E C T I O N   P R O P E R T I E S:
==================================================

RECTANGULAR SECTION:

     Width  = 1000
     Height = 305

PROPERTIES:

     Gross moment of inertia     = 2.3644E+09
     Gross section modulus       = 1.5504E+07
     Distance to neutral axis    = 1.5250E+02
     Cracked moment of inertia   = 3.3032E+08
     Effective moment of inertia = 2.3644E+09

R E V I E W   C A L C U L A T I O N S:
==================================================

REINFORCING STEEL:

     Tensile steel area         = 947
     Compressive steel area     = 0
     Depth to tensile steel     = 245.5
     Depth to Compressive steel = 0

     c/d                        = 8.5664E-02
     Maximum c/d                = 5.0000E-01
```

```
DESIGN MOMENTS:

     Factored ultimate moment    = 38.98
     Maximum service load moment = 21.17
     Minimum service load moment = 0

MOMENT CAPABILITY:

     Ultimate moment capability  = 8.0487E+01
     1.2 * Cracking moment       = 4.0762E+01
     Design moment               = 4.0762E+01
     Stress block depth          = 1.8822E+01

SERVICE LOAD STRESS:

     Maximum steel stress    = 9.8246E+01
     Minimum steel stress    = 0.0000E+00
     Maximum concrete stress = 3.4534E+00
     Minimum concrete stress = 0.0000E+00

CRACK CONTROL:

     Clear concrete cover      = 50
     Clear rebar spacing       = 281
     Moment at 40% fcrack      = 1.3587E+01
     Computed exposure factor  = 2.0389E+04
     Allowable exposure factor = 3.0000E+04
```

Perform hand calculations to verify shear calculations:

Ultimate shear: d > 34.41 x 1000 / (0.9 x (600 x 0.75 x 2.19 - 34.41)) = 40.2 mm

Temperature and shrinkage reinforcement:

A_s > 500 x 300 / 1000 = 150 mm^2

STEM WALL CALCULATIONS

Height to bottom of seat = 3.8 - 2.025 = 1.775 m
Concrete thickness at top of footing = 1.065 m
Effective depth, d = 1065 - 50 - $(510 / 3.1416)^{1/2}$ = 1002 mm
Backwall height for shear = 3.8 - 1.002 = 2.798 m

Lateral earth pressure: V = 0.35 x 20.0 $(2.798)^2$ / 2 = 27.4 kN/m
M = 0.35 x 20.0 $(3.8)^3$ / 6 = 64.02 kN-m/m

Surcharge pressure: V = 0.35 x 16 (2.798) = 15.67 kN/m
M = 0.35 x 16 $(3.8)^2$ / 2 = 40.43 kN-m/m

Compaction pressure: V = 12 x 2 / 2 = 12 kN/m
M = 12 x (3.8 - 2/3) = 37.6 kN-m/m

Dead load constant: M = 1300 x (1.065 / 2 - 0.38) / 9.0 = 22.03 kN-m/m

Dead load varying: M = 355 x (1.065 / 2 - 0.38) / 9.0 = 6.02 kN-m/m

Bridge live load: M = 550 x (1.065 / 2 - 0.38) / 9.0 = 9.32 kN-m/m

Bearing pad shear: V = 330 / 9.0 = 36.67 kN/m
M = 330 x (3.8 - 2.025 + 0) / 9.0 = 65.08 kN-m/m

Service loads: M = 64.02 + 40.43 + 22.03 + 6.02 + 0.9 x 9.32 + 0.8 x 65.08
M = 192.95 kN-m/m (comb 5)

Factored loads: V = 1.25 (36.67 + 27.4 + 15.67) = 99.67 kN/m (comb 3)
M = 1.2 x 22.03 + 1.5 x 6.02 + 1.6 x 9.32 + 1.15 x 65.08
+ 1.25(64.02 + 40.43) = 255.78 kN-m/m (comb 5)

Run REBEAM program to verify flexural calculations (see REBEAM output below):

Area of reinforcing per meter = 510 x 1000 / 150 = 3400 mm^2

Service stresses: f_s = 60.8 MPa

Crack control: β = 3388 < 30000

Ultimate flexure: A_s > 954 x 150 / 1000 = 143 mm^2
c/d = 0.075 < 0.5

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                         *
*           P R O G R A M   R E B E A M                   *
*                                                         *
*                    OUTPUT DATA                          *
*                                                         *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
9/20/02, 6:18 pm

D E S I G N   C R I T E R I A
=====================================================

Code  = CAN/CSA-S6 (2000)
Units = Metric (Newtons, millimeters - moments in kN-m)

MATERIAL PROPERTIES:

     Concrete compressive strength       = 30
     Concrete modulus of elasticity      = 2.5650E+04
     Reinforcing yield strength          = 400
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 8

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 1.00
     Concrete resistance factor          = 0.75
     Reinforcing resistance factor       = 0.90

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8050
     Ratio of depth of compression block = 0.8950
     Maximum concrete strain             = 0.0035

S E C T I O N   P R O P E R T I E S:
=====================================================

RECTANGULAR SECTION:

     Width  = 1000
     Height = 1065

PROPERTIES:

     Gross moment of inertia     = 1.0066E+11
     Gross section modulus       = 1.8904E+08
     Distance to neutral axis    = 5.3250E+02
     Cracked moment of inertia   = 2.0191E+10
     Effective moment of inertia = 1.0066E+11
```

```
R E V I E W   C A L C U L A T I O N S:
=====================================================

REINFORCING STEEL:

     Tensile steel area         = 3400
     Compressive steel area     = 0
     Depth to tensile steel     = 1003
     Depth to Compressive steel = 0

     c/d                        = 7.5280E-02
     Maximum c/d                = 5.0000E-01

DESIGN MOMENTS:

     Factored ultimate moment    = 255.78
     Maximum service load moment = 192.95
     Minimum service load moment = 0

MOMENT CAPABILITY:

     Ultimate moment capability  = 1.1863E+03
     1.2 * Cracking moment       = 4.9699E+02
     Design moment               = 3.4104E+02
     Stress block depth          = 6.7578E+01

SERVICE LOAD STRESS:

     Maximum steel stress    = 6.0781E+01
     Minimum steel stress    = 0.0000E+00
     Maximum concrete stress = 1.9874E+00
     Minimum concrete stress = 0.0000E+00

CRACK CONTROL:

     Clear concrete cover      = 50
     Clear rebar spacing       = 124.5
     Moment at 40% fcrack      = 1.6566E+02
     Computed exposure factor  = 3.3875E+03
     Allowable exposure factor = 3.0000E+04
```

Perform hand calculations to verify shear calculations:

Ultimate shear: d > 99.67 x 1000 / (0.9 x (600 x 0.75 x 2.19 - 99.67)) = 125.0 mm

Temperature and shrinkage reinforcement:

A_s > 500 x 300 / 1000 = 150 mm^2

Verify required flexural reinforcement area for the ultimate limit state at 10 sections using REBEAM program. The height, thickness and effective depth are verified directly. The moment is verified with a separate spreadsheet (not shown). The REBEAM output is summarized in the last column below.

HEIGHT (m)	THICK (m)	Deff (m)	MOMENT (kN-m/m)	AREA (mm^2)
3.623	1.065	1.002	233.0	130.35
3.445	1.065	1.002	211.4	118.20
3.268	1.065	1.002	191.0	106.65
3.090	1.065	1.002	171.7	95.85
2.913	1.065	1.002	153.5	85.65
2.735	1.065	1.002	136.3	75.90
2.558	1.065	1.002	120.1	66.90
2.380	1.065	1.002	104.8	58.35
2.203	1.065	1.002	90.4	50.25
2.025	1.065	1.002	77.8	43.20

STABILITY CALCULATIONS

Calculate weight and righting moment:

1. Dead load abutment

   w1 = 0.305 x 2.025 x 9.0 x 24.0 = 133.41 kN
   x1 = 2.53 m

   w2 = 1.065 x 1.775 x 9.0 x 24.0 = 408.32 kN
   x2 = 2.15 m

   w3 = 1.0 x 4.0 x 9.0 x 24.0 = 864.00 kN
   x3 = 2.00 m

   w4 = 1.315 x 3.8 x 0.90 x 24.0 = 107.94 kN
   x4 = 3.34 m

   w5 = 2.8 x 6.685 x 0.90 x 24 / 2 = 202.15 kN
   x5 = 6.23 m

   w6 = 1.0 x 6.685 x 0.90 x 24 = 144.40 kN
   x6 = 7.34 m

   w7 = 5.0 x 8 x 2 = 80 kN
   x7 = 6.68 m

   Weight = 1940.2 kN
   Righting moment = 6157.6 kN-m

2. Dead load constant

   Weight = 1300 kN
   Righting moment = 1300 x 2.0 = 2600.0 kN-m

3. Dead load varying

   Weight = 355 kN
   Righting moment = 355 x 2.0 = 710.0 kN-m

4. Dead load earth

   w1 = 1.315 x 3.8 x 8.1 x 20.0 = 809.51 kN
   x1 = 3.34 m

   w2 = 0.61 x 1.62 x 9.0 x 20.0 = 177.88 kN
   x2 = 0.81 m

   Weight = 987.4 kN
   Righting moment = 2847.8 kN-m

5. Live load standard

   Weight = 550 kN
   Righting moment = 550 x 2.0 = 1100.0 kN-m

6. Live load surcharge

   Weight = 16.0 x 1.315 x 9.0 = 189.36 kN
   Righting moment = 189.36 x 3.34 = 632.46 kN-m

Calculate lateral load and overturning moment:

1. Friction longitudinal force

   Force = 330 kN
   Overturning moment = 330 x 2.775 = 915.8 kN-m

2. Lateral earth pressure

   Force = $0.35 \times 20.0 \times 9.0 \times (4.8)^2 / 2 = 725.8$ kN
   Overturning moment = 725.8 x 0.333 x 4.8 = 1160.1 kN-m

3. Surcharge pressure

   Force = 0.35 x 16.0 x 9.0 x 4.8 = 241.9 kN
   Overturning moment = 241.9 x 4.8 / 2 = 580.6 kN-m

4. Compaction pressure

   Force = 12 x 2 x 9 / 2 = 108 kN
   Overturning moment = 108 x (4.8 - 2/3) = 446.4 kN-m

Check resultant load combinations (use spreadsheet):

Combination 1:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN	ULS MIN*
da	1940.2	6157.6	0	0	1	1.2	1	1
dc	1300	2600	0	0	1	1.2	1	1
dv	355	710	0	0	1	1.2	1	1
de	987.4	2847.8	0	0	0	0	0	0
l1	550	1100	0	0	0	0	0	0
fr	0	0	330	915.8	0	0	0	0
ep	0	0	725.8	1160.1	0	0	0	0
sc	189.4	632.5	241.9	580.6	0	0	0	0
cp	0	0	108	446.4	0	0	0	0

SLS	3595	9468	0	0
ULS MAX	4314	11361	0	0
ULS MIN	3595	9468	0	0
ULS MIN*	3595	9468	0	0

* Minimum dead load to combine with maximum lateral loads for stability

Combination 2:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN	ULS MIN*
da	1940.2	6157.6	0	0	1	1.2	1	1
dc	1300	2600	0	0	0	0	0	0
dv	355	710	0	0	0	0	0	0
de	987.4	2847.8	0	0	1	1.2	1	1
l1	550	1100	0	0	0	0	0	0
fr	0	0	330	915.8	0	0	0	0
ep	0	0	725.8	1160.1	1	1.2	1	1
sc	189.4	632.5	241.9	580.6	0	0	0	0
cp	0	0	108	446.4	1	1.2	0	0

SLS	2928	9005	834	1607
ULS MAX	3513	10806	1001	1928
ULS MIN	2928	9005	726	1160
ULS MIN*	2928	9005	726	1160

* Minimum dead load to combine with maximum lateral loads for stability

Combination 3:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN	ULS MIN*
da	1940.2	6157.6	0	0	0	1.2	0.9	1
dc	1300	2600	0	0	0	1.2	0.9	1
dv	355	710	0	0	0	1.5	0.65	1
de	987.4	2847.8	0	0	0	1.25	0.8	1
l1	550	1100	0	0	0	0	0	0
fr	0	0	330	915.8	0	1.25	1.25	1.25
ep	0	0	725.8	1160.1	0	1.25	0.8	0.8
sc	189.4	632.5	241.9	580.6	0	1.25	0.8	0.8
cp	0	0	108	446.4	0	0	0	0

SLS	0	0	0	0
ULS MAX	5892	15924	1622	3321
ULS MIN	4088	11128	1187	2537
ULS MIN*	4734	12821	1187	2537

* Minimum dead load to combine with maximum lateral loads for stability

Combination 4:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN	ULS MIN*
da	1940.2	6157.6	0	0	0	1.2	0.9	1
dc	1300	2600	0	0	0	1.2	0.9	1
dv	355	710	0	0	0	1.5	0.65	1
de	987.4	2847.8	0	0	0	1.25	0.8	1
l1	550	1100	0	0	0	1.7	1.7	1.7
fr	0	0	330	915.8	0	0	0	0
ep	0	0	725.8	1160.1	0	1.25	0.8	0.8
sc	189.4	632.5	241.9	580.6	0	1.25	0.8	0.8
cp	0	0	108	446.4	0	0	0	0

SLS	0	0	0	0
ULS MAX	6827	17794	1210	2176
ULS MIN	5023	12998	774	1393
ULS MIN*	5669	14691	774	1393

* Minimum dead load to combine with maximum lateral loads for stability

Combination 5:

CASE	Pv	Mrt	Ph	Mot	SLS	ULS MAX	ULS MIN	ULS MIN*
da	1940.2	6157.6	0	0	1	1.2	0.9	1
dc	1300	2600	0	0	1	1.2	0.9	1
dv	355	710	0	0	1	1.5	0.65	1
de	987.4	2847.8	0	0	1	1.25	0.8	1
l1	550	1100	0	0	0.9	1.6	1.6	1.6
fr	0	0	330	915.8	0.8	1.15	1.15	1.15
ep	0	0	725.8	1160.1	1	1.25	0.8	0.8
sc	189.4	632.5	241.9	580.6	1	1.25	0.8	0.8
cp	0	0	108	446.4	0	0	0	0

SLS	5267	13938	1232	2473
ULS MAX	6772	17684	1589	3229
ULS MIN	4968	12888	1154	2446
ULS MIN*	5614	14581	1154	2446

* Minimum dead load to combine with maximum lateral loads for stability

Check vertical resultant (use spreadsheet):

X = (Mrt - Mot) / Pv
Locate = Fractional portion of footing = (Wf - 2 X) / Wf

Combination 1 -

CASE	X	LOCATE
SLS	2.633	-0.317
ULS 1	2.633	-0.317
ULS 2	2.633	-0.317
ULS 2*	2.633	-0.317
ULS 3	2.633	-0.317
ULS 4	2.633	-0.317

Combination 2 -

CASE	X	LOCATE
SLS	2.527	-0.264
ULS 1	2.527	-0.264
ULS 2	2.418	-0.209
ULS 2*	2.418	-0.209
ULS 3	2.746	-0.373
ULS 4	2.680	-0.340

Combination 3 -

CASE	X	LOCATE
SLS	0.000	0.000
ULS 1	2.139	-0.070
ULS 2	1.910	0.045
ULS 2*	2.007	-0.003
ULS 3	2.272	-0.136
ULS 4	2.101	-0.051

Combination 4 -

CASE	X	LOCATE
SLS	0.000	0.000
ULS 1	2.288	-0.144
ULS 2	2.154	-0.077
ULS 2*	2.208	-0.104
ULS 3	2.403	-0.201
ULS 4	2.310	-0.155

Combination 5 -

CASE	X	LOCATE
SLS	2.177	-0.088
ULS 1	2.135	-0.067
ULS 2	1.944	0.028
ULS 2*	2.022	-0.011
ULS 3	2.250	-0.125
ULS 4	2.102	-0.051

SPREAD FOOTING CALCULATIONS

Soil bearing pressures (use spreadsheet):

For SLS pressures: All vertical resultants are within the middle 1/3, and are negative, which indicates that the footing is in full compression with maximum pressure at the heel.

Toe pressure = $Pv / (4 \times 9) + 6 \times Pv \times (2 - X) / (9 \times (4)^2) = Pv [1/ 36 + (2 - X)/24]$
Heel pressure = $Pv / (4 \times 9) - 6 \times Pv \times (2 - X) / (9 \times (4)^2) = Pv [1/ 36 - (2 - X)/24]$

For ULS pressures: If vertical resultants are closer to the heel, the footing is in partial compression with maximum pressure at the heel.

Uniform pressure = $Pv / (2 \times (4 - X) \times 9)$

If vertical resultants are closer to the toe, the footing is in partial compression with maximum pressure at the toe.

Uniform pressure = $Pv / (2 \times X \times 9)$

Combination 1 -

CASE	Pv	Qtoe	Qheel
SLS	3595	5.0	194.8
ULS 1	4314	0.0	175.4
ULS 2	3595	0.0	146.2
ULS 2*	3595	0.0	146.2
ULS 3	4314	0.0	175.4
ULS 4	3595	0.0	146.2

Combination 2 -

CASE	Pv	Qtoe	Qheel
SLS	2928	17.0	145.6
ULS 1	3513	0.0	132.5
ULS 2	2928	0.0	102.8
ULS 2*	2928	0.0	102.8
ULS 3	3513	0.0	155.6
ULS 4	2928	0.0	123.2

Combination 3 -

CASE	Pv	Qtoe	Qheel
SLS	0	0.0	0.0
ULS 1	5892	0.0	175.9
ULS 2	4088	118.9	0.0
ULS 2*	4734	0.0	132.0
ULS 3	5892	0.0	189.4
ULS 4	4088	0.0	119.6

Combination 4 -

CASE	Pv	Qtoe	Qheel
SLS	0	0.0	0.0
ULS 1	6827	0.0	221.5
ULS 2	5023	0.0	151.2
ULS 2*	5669	0.0	175.7
ULS 3	6827	0.0	237.4
ULS 4	5023	0.0	165.2

Combination 5 -

CASE	Pv	Qtoe	Qheel
SLS	5267	107.5	185.1
ULS 1	6772	0.0	201.7
ULS 2	4968	142.0	0.0
ULS 2*	5614	0.0	157.7
ULS 3	6772	0.0	215.0
ULS 4	4968	0.0	145.4

Maximum SLS pressure (Comb 1) = 194.8 kPa
Maximum ULS pressure (Comb 4) = 237.4 kPa

Sliding stability:

Comb 1: Ph = 0.
Pr = 3595 x 0.6 + 3 x 20 x 9 x $(1.61)^2$ / 2 = 2857 kN

Comb 2: Ph = 1001.
Pr = 2928 x 0.6 + 3 x 20 x 9 x $(1.61)^2$ / 2 = 2457 kN

Comb 3: Ph = 1622
Pr = 4734 x 0.6 + 3 x 20 x 9 x $(1.61)^2$ / 2 = 3540 kN

Comb 4: Ph = 1210
Pr = 5669 x 0.6 + 3 x 20 x 9 x $(1.61)^2$ / 2 = 4101 kN

Comb 5: Ph = 1589
Pr = 5614 x 0.6 + 3 x 20 x 9 x $(1.61)^2$ / 2 = 4068 kN

Footing loads:

The footing load calculations are a function of the pressure distribution, therefore, it is only necessary to check a couple SLS and ULS load combinations to validate this function.

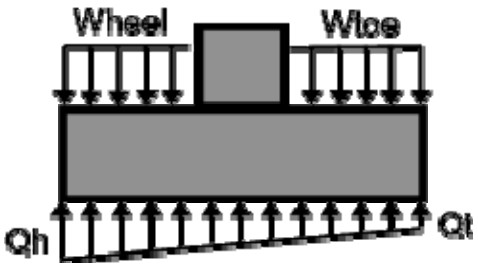
Dt = 1.62 m
Lheel = 4 - 1.62 - 1.065 = 1.315 m
dtop = 1000 - 50 - $(510 / 3.1416)^{1/2}$ = 937 mm
dbot = 1000 - 75 - $(510 / 3.1416)^{1/2}$ = 912 mm

W(conc) = 1.0 x 24 = 24 kPa
Wtoe(soil) = 0.61 x 20 =12.2 kPa
Wheel (soil) = 3.8 x 20 = 76 kPa
Wheel (surch) = 16 kPa

SLS combination 5:

Qt = 107.3 kPa
Qh = 185.3 kPa

Wtoe = 36.2 kPa
Wheel = 116 kPa



Toe moment and shear:

Quni = 107.3 kPa
Qtri = 1.62 (185.3 - 107.3) / 4 = 31.59 kPa

$M = (107.3 - 36.2)(1.62)^2 / 2 + 31.59(1.62)^2 / 6 = 107.1$ kN-m/m

Lv = 1.62 - 0.912 = 0.708 m
Qtri = 31.59 x 0.708 / 1.62 = 13.8 kPa

V = (107.3 - 36.2)(0.708) + 13.8(0.708) / 2 = 55.2 kN/m

Heel moment and shear:

Qtri = 1.315 (185.3 - 107.3) / 4 = 25.64 kPa
Quni = 185.3 - 25.64 = 159.7 kPa

$M = (159.7 - 116)(1.315)^2 / 2 + 25.64(1.315)^2 / 3 = 52.6$ kN-m/m

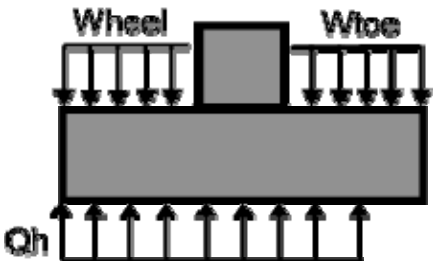
Lv = 1.315 - 0.912 = 0.403 m
Qtri = 25.64 x 0.403 / 1.315 = 7.86 kPa
Quni = 185.3 - 7.86 = 177.4 kPa

V = (177.4 - 116)(0.403) + 7.86(0.403) / 2 = 26.3 kN/m

ULS combination 4 - Case 3 (Max vertical and min overturning):

Qh = 237.5 kPa
Lp = 3.193 m

Wtoe = 1.2 x 24 + 1.25 x 12.2 = 44.0 kPa
Wheel = 1.2 x 24 + 1.25 x 76 + 1.25 x 16 = 143.8 kPa



Toe moment and shear:

$M = (237.5)(1.62 - 0.807)^2 / 2 - 44(1.62)^2 / 2 = 20.8$ kN-m/m

Lv = 1.62 - 0.912 = 0.708 m

V = -44(0.708) = -31.1 kN/m

Heel moment and shear:

$M = (237.5 - 143.8)(1.315)^2 / 2 = 81.0$ kN-m/m

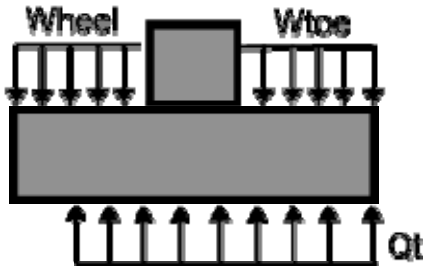
$Lv = 1.315 - 0.912 = 0.403$ m

$V = (237.5 - 143.8)(0.403) = 37.8$ kN/m

ULS combination 5 - Case 2 (Min vertical and max overturning):

Qt = 141.9 kPa
Lp = 3.89 m

Wtoe = 0.9 x 24 + 0.8 x 12.2 = 31.4 kPa
Wheel = 0.9 x 24 + 0.8 x 76 + 0.8 x 16 = 95.2 kPa



Toe moment and shear:

$M = (141.9 - 31.4)(1.62)^2 / 2 = 145.0$ kN-m/m

$Lv = 1.62 - 0.912 = 0.708$ m

$V = (141.9 - 31.4)(0.708) = 78.2$ kN/m

Heel moment and shear:

$M = (141.9)(1.315 - 0.11)^2 / 2 - 95.2(1.315)^2 / 2 = 20.7$ kN-m/m

$Lv = 1.315 - 0.912 = 0.403$ m

$V = (141.9)(0.403 - 0.11) - 95.2(0.403) = 3.2$ kN/m

Reinforcement calculations for footing:

The footing reinforcement calculations use the same subroutines which were previously validated for the backwall and stemwall calculations. Therefore, only the critical calculations at the footing toe will be validated.

Perform hand calculations to verify shear calculations:

Ultimate shear Vf = 78.2 kN
d > 78.2 x 1000 / (0.9 x (600 x 0.75 x 2.19 - 78.2)) = 96 mm

Run REBEAM program to verify flexural calculations (see REBEAM output below):

Area of reinforcing 510 mm^2 @ 150 mm
Mf @ 150 mm = 145 x 150 / 1000 = 21.75 kN-m
Ms @ 150 mm = 107.15 x 150 / 1000 = 16.07 kN-m

Service stresses: f_s = 37.2 MPa

Crack control: 40% Cracking moment, Mw = 21.9 x 1000 / 150 = 146 kN-m

Ultimate flexure: $A_s > 89\ mm^2$
c/d = 0.083 < 0.5

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D E S I G N   C R I T E R I A
=================================================

Code  = CAN/CSA-S6 (2000)
Units = Metric (Newtons, millimeters - moments in kN-m)

MATERIAL PROPERTIES:

     Concrete compressive strength       = 30
     Concrete modulus of elasticity      = 2.5650E+04
     Reinforcing yield strength          = 400
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 8

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 1.00
     Concrete resistance factor          = 0.75
     Reinforcing resistance factor       = 0.90
```

```
STRESS BLOCK:

     Ratio of average concrete strength  = 0.8050
     Ratio of depth of compression block = 0.8950
     Maximum concrete strain             = 0.0035

S E C T I O N   P R O P E R T I E S:
===================================================

RECTANGULAR SECTION:

     Width  = 150
     Height = 1000

PROPERTIES:

     Gross moment of inertia     = 1.2500E+10
     Gross section modulus       = 2.5000E+07
     Distance to neutral axis    = 5.0000E+02
     Cracked moment of inertia   = 2.4681E+09
     Effective moment of inertia = 1.2500E+10

R E V I E W   C A L C U L A T I O N S:
===================================================

REINFORCING STEEL:

     Tensile steel area         = 510
     Compressive steel area     = 0
     Depth to tensile steel     = 912
     Depth to Compressive steel = 0

     c/d                        = 8.2791E-02
     Maximum c/d                = 5.0000E-01

DESIGN MOMENTS:

     Factored ultimate moment    = 21.75
     Maximum service load moment = 16.07
     Minimum service load moment = 0

MOMENT CAPABILITY:

     Ultimate moment capability  = 1.6124E+02
     1.2 * Cracking moment       = 6.5727E+01
     Design moment               = 2.9000E+01
     Stress block depth          = 6.7578E+01
```

```
SERVICE LOAD STRESS:

     Maximum steel stress    = 3.7234E+01
     Minimum steel stress    = 0.0000E+00
     Maximum concrete stress = 1.2840E+00
     Minimum concrete stress = 0.0000E+00

CRACK CONTROL:

     Clear concrete cover      = 50
     Clear rebar spacing       = 125
     Moment at 40% fcrack      = 2.1909E+01
     Computed exposure factor  = -6.7942E+03
     Allowable exposure factor = 3.0000E+04
```

SIDE WALL CALCULATIONS

Wall length = 8.0 m
Length over footing = 4 - 1.62 - 0.76 - 0.305 = 1.315 m

Average loads: (integrate over 10 segments)

Xinc = 8 / 10 = 0.8 m
X1 = 8 - 0.4 = 7.6 m
H1 = 3.8 - (7.6 - 1.315) x 2.8 / 6.685 = 1.168 m

Lateral earth pressure: $V1 = 0.8 \times 0.35 \times 20 (1.168)^2 / 2 = 3.8$ kN
$M1 = 3.8 \times 7.6 = 29.0$ kN-m

Continue calculations with spreadsheet

X	H	**Vep**	**Mep**	**Vsc**	**Msc**	Quni	Qtri	**Vcp**	**Mcp**
7.6	1.2	3.8	29.0	5.2	39.8	5.0	7.0	7.9	60.3
6.8	1.5	6.3	43.0	6.7	45.8	3.0	9.0	9.0	61.2
6.0	1.8	9.5	56.7	8.2	49.4	1.0	11.0	9.5	57.2
5.2	2.2	13.2	68.7	9.7	50.6			9.6	49.9
4.4	2.5	17.6	77.5	11.2	49.4			9.6	42.2
3.6	2.8	22.6	81.5	12.7	45.9			9.6	34.6
2.8	3.2	28.3	79.2	14.2	39.9			9.6	26.9
2.0	3.5	34.6	69.1	15.7	31.5			9.6	19.2
1.2	3.8	40.4	48.5	17.0	20.4			9.6	11.5
0.4	3.8	40.4	16.2	17.0	6.8			9.6	3.8
TOTALS		216.8	569.4	117.9	379.4			93.7	366.9
AVERAGE		**57.0**	**149.8**	**31.0**	**99.8**			**24.7**	**96.6**

The remaining load combinations and reinforced concrete design calculations use identical subroutines that are used for the backwall calculations, therefore they have already been verified.

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O P T I O N S
=====================================================================

Units           = Metric
Design Criteria = CAN/CSA-S6 (2000)
Wall Type       = No Haunch
Footing Type    = Spread

P R O P E R T I E S
=====================================================================

REINFORCED CONCRETE:

     MATERIAL PROPERTIES:

     Concrete compressive strength  = 30.0 MPa
     Concrete modulus of elasticity = 25651.0 MPa
     Concrete modulus of rupture    = 2.19 MPa
     Concrete modular ratio         = 8
     Concrete unit weight           = 24.00 kN/m^3
     Reinforcing yield strength     = 400.0 MPa
     Crack control exposure factor  = 30000.0 N/mm

     RESISTANCE FACTORS:

     Concrete                       = 0.750
     Reinforcing                    = 0.900

     STRESS BLOCK:

     Compression block stress ratio = 0.8050
     Compression block depth ratio  = 0.8950
     Maximum concrete strain        = 0.0035
```

FOOTING RESISTANCE:

PARAMETER	SLS	ULS	EQ
Bearing pressure (kPa):	250.0	500.0	500.0
Friction coefficient:	0.400	0.600	0.600
Resultant location:	0.333	0.600	0.600
Passive coefficient:	1.500	3.000	3.000

C O N F I G U R A T I O N

WALL:

Stem wall height	= 3.800 m	
Stem wall length	= 9.000 m	
Stem wall thickness	= 1.065 m	
Stem wall batter	= 0.000 deg	
Back wall height	= 2.025 m	
Back wall thickness	= 0.305 m	
Seat width	= 0.760 m	
Distance to CL bearing	= 0.380 m	

FOOTING:

Width of toe	= 1.620 m	
Soil cover over toe	= 0.610 m	
Footing width	= 4.000 m	
Footing length	= 9.000 m	
Footing thickness	= 1.000 m	

L O A D S

BRIDGE LOADS:

Dead load constant	= 1300.0 kN	
Dead load varying	= 355.0 kN	
Live load standard	= 550.0 kN	
Live load special	= 0.0 kN	
Live load long force	= 0.0 kN	at height = 0.000 m
Friction long force	= 330.0 kN	at height = 0.000 m

EARTH LOADS:

Lateral pressure coeff	= 0.350	at height = 0.333 H
Earthquake pressure coeff	= 0.000	at height = 0.000 H
Compaction pressure	= 12.00 kPa	at height = 2.000 m
Soil unit weight	= 20.00 kN/m^3	
Surcharge pressure	= 16.00 kPa	

LOAD COMBINATIONS:

NO	LOAD CONDITION	MAXIMUM	MINIMUM	SERVICE
1	Construction 1 - place superstructure before backfill			
	Dead load abutment	1.2	1	1
	Dead load constant	1.2	1	1
	Dead load varying	1.2	1	1
	Service stress increase factor = 1.5			
2	Construction 2 - place backfill before superstructure			
	Dead load abutment	1.2	1	1
	Dead load earth	1.2	1	1
	Lateral earth pressure	1.2	1	1
	Compaction pressure	1.2	0	1
	Service stress increase factor = 1.5			
3	ULS 4 - no live load with bearing friction			
	Dead load abutment	1.2	0.9	0
	Dead load constant	1.2	0.9	0
	Dead load varying	1.5	0.65	0
	Dead load earth	1.25	0.8	0
	Friction longitudinal force	1.25	1.25	0
	Lateral earth pressure	1.25	0.8	0
	Live load surcharge	1.25	0.8	0
	Service stress increase factor = 1			
4	ULS 1 - live load on bridge			
	Dead load abutment	1.2	0.9	0
	Dead load constant	1.2	0.9	0
	Dead load varying	1.5	0.65	0
	Dead load earth	1.25	0.8	0
	Live load standard	1.7	1.7	0
	Lateral earth pressure	1.25	0.8	0
	Live load surcharge	1.25	0.8	0
	Service stress increase factor = 1			

5 ULS 2 and SLS 1 - live load with bearing friction

Dead load abutment	1.2	0.9	1
Dead load constant	1.2	0.9	1
Dead load varying	1.5	0.65	1
Dead load earth	1.25	0.8	1
Live load standard	1.6	1.6	0.9
Friction longitudinal force	1.15	1.15	0.8
Lateral earth pressure	1.25	0.8	1
Live load surcharge	1.25	0.8	1

Service stress increase factor = 1

R E I N F O R C I N G

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LOCATION	AREA (mm^2)	SPACING (mm)	COVER (mm)
Wall stem	510.00	150.00	50.00
Backwall	284.00	300.00	
Footing top	510.00	300.00	75.00
Footing bottom at toe	510.00	150.00	75.00
Footing bottom at heel	510.00	300.00	
Footing long w/piles	0.00	0.00	
T&S in wall stem	284.00	300.00	
T&S in backwall	129.00	300.00	
T&S in footing	284.00	300.00	

S I D E W A L L S

==========

CONFIGURATION:

Length beyond backwall = 8.000 m
Height at end = 1.000 m
Thickness at top = 0.450 m
Thickness at bottom = 0.450 m
Uniform barrier weight = 5.000 kN/m

REINFORCING:

LOCATION	AREA (mm^2)	SPACING (mm)
Average main horizontal	510.00	150.00
Bottom main horizontal	510.00	150.00
T&S reinforcing	199.00	300.00

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B A C K W A L L
================================================================

UNFACTORED LOADS:

    ---------------------------------------------------------------
    LOAD CONDITION                SHEAR          MOMENT
                                  (kN/m)         (kN-m/m)
    ---------------------------------------------------------------
    Compaction pressure           11.854         16.300
    Lateral earth pressure        11.083         9.688
    Surcharge pressure            9.965          11.482
    ---------------------------------------------------------------

ULTIMATE LIMIT STATE CALCULATIONS:

     SHEAR (Comb 2):

     Effective depth = 245.49 mm
     Factored shear  = 27.525 kN/m
     d required      = 31.91 < d provided = 245.49 OKAY

     MOMENT (Comb 2):

     Factored moment = 31.185 kN-m/m
     As required     = 141.05 < As provided = 284.00 OKAY
     c/d limit       = 0.50 > c/d ratio = 0.09 OKAY

SERVICEABILITY LIMIT STATE CALCULATIONS:

     CRACK CONTROL (Comb 5):

     Service moment       = 21.169 kN-m/m
     Steel stress         = 98.28 MPa
     Crack control factor = 20394.8 < 30000.0 OKAY

     TEMPERATURE AND SHRINKAGE:

     T&S reinforcement = 129.00 < Area required = 150.00 NO GOOD ***
```

S T E M W A L L

UNFACTORED LOADS:

LOAD CONDITION	SHEAR (kN/m)	MOMENT (kN-m/m)
Dead load constant		22.028
Dead load varying		6.015
Live load standard		9.319
FR longitudinal force	36.667	65.083
Compaction pressure	12.000	37.600
Lateral earth pressure	27.396	64.017
Surcharge pressure	15.667	40.432

ULTIMATE LIMIT STATE CALCULATIONS:

SHEAR (Comb 3):

Effective depth = 1002.26 mm
Factored shear = 99.662 kN/m
d required = 124.95 < d provided = 1002.26 OKAY

MOMENT (Comb 5):

Factored moment = 255.775 kN-m/m
As required = 143.13 < As provided = 510.00 OKAY
c/d limit = 0.50 > c/d ratio = 0.08 OKAY

SERVICEABILITY LIMIT STATE CALCULATIONS:

CRACK CONTROL (Comb 5):

Service moment = 192.947 kN-m/m
Steel stress = 60.83 MPa
Crack control factor = 3390.0 < 30000.0 OKAY

TEMPERATURE AND SHRINKAGE:

T&S reinforcement = 284.00 > Area required = 150.00 OKAY

REQUIRED REINFORCEMENT AREA IN STEM WALL SECTIONS:

HEIGHT (m)	THICK (mm)	deff (mm)	MOMENT (kN-m/m)	AREA (mm^2)	LOAD COMB
3.62	1065.00	1002.26	232.98	130.26	5
3.45	1065.00	1002.26	211.41	118.11	5
3.27	1065.00	1002.26	191.00	106.62	5
3.09	1065.00	1002.26	171.72	95.79	5
2.91	1065.00	1002.26	153.51	85.57	5
2.74	1065.00	1002.26	136.32	75.94	5
2.56	1065.00	1002.26	120.11	66.87	5
2.38	1065.00	1002.26	104.82	58.33	5
2.20	1065.00	1002.26	90.41	50.28	5
2.03	1065.00	1002.26	77.76	43.23	4

S T A B I L I T Y

UNFACTORED WEIGHT AND RIGHTING MOMENT:

LOAD CONDITION	WEIGHT (kN)	MOMENT AT TOE (kN-m)
Dead load abutment	1940.2	6159.7
Dead load constant	1300.0	2600.0
Dead load varying	355.0	710.0
Dead load earth	987.4	2849.9
Live load standard	550.0	1100.0
Live load surcharge	189.4	632.9

UNFACTORED LATERAL FORCE AND OVERTURNING MOMENT:

LOAD CONDITION	FORCE (kN)	MOMENT AT TOE (kN-m)
FR longitudinal force	330.0	915.8
Lateral earth pressure	725.8	1160.1
Compaction pressure	108.0	446.4
Surcharge pressure	241.9	580.6

RESULTANT LOAD COMBINATIONS:

COMB NO	LIMIT STATE	VERTICAL LOAD (kN)	RIGHTING MOMENT (kN-m)	LATERAL LOAD (kN)	OVERTURNING MOMENT (kN-m)
1	SLS	3595.2	9469.7	0.0	0.0
	ULS MAX	4314.3	11363.6	0.0	0.0
	ULS MIN	3595.2	9469.7	0.0	0.0
	ULS MIN*	3595.2	9469.7		
2	SLS	2927.6	9009.5	833.8	1606.5
	ULS MAX	3513.1	10811.4	1000.5	1927.7
	ULS MIN	2927.6	9009.5	725.8	1160.1
	ULS MIN*	2927.6	9009.5		
3	ULS MAX	5891.7	15930.1	1622.1	3320.5
	ULS MIN	4088.3	11131.4	1186.6	2537.2
	ULS MIN*	4734.1	12825.9		
4	ULS MAX	6826.7	17800.1	1209.6	2175.8
	ULS MIN	5023.3	13001.4	774.1	1392.5
	ULS MIN*	5669.1	14695.9		
5	SLS	5267.0	13942.5	1231.7	2473.3
	ULS MAX	6771.7	17690.1	1589.1	3228.9
	ULS MIN	4968.3	12891.4	1153.6	2445.6
	ULS MIN*	5614.1	14585.9		

LIMIT STATE COMBINATIONS:

SLS = Serviceability limit state (SLS) values
ULS MAX = Maximum ultimate limit state (ULS) values
ULS MIN = Minimum ULS values (except as noted below)
ULS MIN* = Minimum ULS values for stability calculations with maximum lateral loads

VERTICAL RESULTANT:

COMB NO	LIMIT STATE	CASE NO	VERTICAL LOAD (kN)	TOE DISTANCE (m)	RESULTANT LOCATION
1	SLS		3595.2	2.634	-0.317
	ULS	1	4314.3	2.634	-0.317
	ULS	2	3595.2	2.634	-0.317
	ULS	2*	3595.2	2.634	-0.317
	ULS	3	4314.3	2.634	-0.317
	ULS	4	3595.2	2.634	-0.317
2	SLS		2927.6	2.529	-0.264
	ULS	1	3513.1	2.529	-0.264
	ULS	2	2927.6	2.419	-0.209
	ULS	2*	2927.6	2.419	-0.209
	ULS	3	3513.1	2.747	-0.374
	ULS	4	2927.6	2.681	-0.341
3	ULS	1	5891.7	2.140	-0.070
	ULS	2	4088.3	1.911	0.045
	ULS	2*	4734.1	2.008	-0.004
	ULS	3	5891.7	2.273	-0.137
	ULS	4	4088.3	2.102	-0.051
4	ULS	1	6826.7	2.289	-0.144
	ULS	2	5023.3	2.155	-0.078
	ULS	2*	5669.1	2.208	-0.104
	ULS	3	6826.7	2.403	-0.202
	ULS	4	5023.3	2.311	-0.155
5	SLS		5267.0	2.178	-0.089
	ULS	1	6771.7	2.136	-0.068
	ULS	2	4968.3	1.945	0.028
	ULS	2*	5614.1	2.023	-0.011
	ULS	3	6771.7	2.251	-0.126
	ULS	4	4968.3	2.102	-0.051

ULS CASES:

Case 1 = Max vertical + max overturning
Case 2 = Min vertical + max overturning
Case 2* = Min vertical + max overturning (stability only)
Case 3 = Max vertical + min overturning
Case 4 = Min vertical + min overturning

MAXIMUM RESULTANT LOCATION(S):

ULS Resultant (Comb 2) = 0.374 < 0.600 OKAY

S P R E A D F O O T I N G

SOIL BEARING PRESSURE:

COMB NO	LIMIT STATE	PRESSURE CASE	CONTACT LENGTH (m)	TOE PRESSURE (kPa)	HEEL PRESSURE (kPa)
1	SLS	3	4.000	4.9	194.8
	ULS 1	12	2.732	0.0	175.5
	ULS 2	12	2.732	0.0	146.2
	ULS 2*	12	2.732	0.0	146.2
	ULS 3	12	2.732	0.0	175.5
	ULS 4	12	2.732	0.0	146.2
2	SLS	3	4.000	16.8	145.8
	ULS 1	12	2.943	0.0	132.7
	ULS 2	12	3.162	0.0	102.9
	ULS 2*	12	3.162	0.0	102.9
	ULS 3	12	2.506	0.0	155.8
	ULS 4	12	2.638	0.0	123.3
3	ULS 1	12	3.720	0.0	176.0
	ULS 2	11	3.821	118.9	0.0
	ULS 2*	12	3.984	0.0	132.0
	ULS 3	12	3.454	0.0	189.5
	ULS 4	12	3.796	0.0	119.7
4	ULS 1	12	3.423	0.0	221.6
	ULS 2	12	3.690	0.0	151.3
	ULS 2*	12	3.583	0.0	175.8
	ULS 3	12	3.193	0.0	237.5
	ULS 4	12	3.378	0.0	165.2
5	SLS	3	4.000	107.3	185.3
	ULS 1	12	3.729	0.0	201.8
	ULS 2	11	3.890	141.9	0.0
	ULS 2*	12	3.954	0.0	157.8
	ULS 3	12	3.498	0.0	215.1
	ULS 4	12	3.795	0.0	145.5

TRIANGULAR PRESSURE CASES:

Case 1 = Partial compression / max at toe
Case 2 = Full compression / max at toe
Case 3 = Full compression / max at heel
Case 4 = Partial compression / max at heel
Case 5 = Resultant outside footing width

UNIFORM PRESSURE CASES:

Case 11 = Partial compression / max at toe
Case 12 = Partial compression / max at heel
Case 13 = Resultant outside footing width

MAXIMUM PRESSURE(S):

SLS Pressure (Comb 5) = 185.3 < 250.0 OKAY
ULS Pressure (Comb 4) = 237.5 < 500.0 OKAY

SLIDING STABILITY:

COMB NO	LIMIT STATE	FORCE (kN)	RESISTANCE (kN)	
1	ULS	0.0	2857.0	OKAY
2	ULS	1000.5	2456.4	OKAY
3	ULS	1622.1	3540.3	OKAY
4	ULS	1209.6	4101.3	OKAY
5	ULS	1589.1	4068.3	OKAY

FOOTING LOADS:

COMB NO	LIMIT STATE	CASE NO	TOE SHEAR (kN/m)	TOE MOMENT (kN-m/m)	HEEL SHEAR (kN/m)	HEEL MOMENT (kN-m/m)
1	SLS		-1.626	8.583	64.951	129.710
	ULS	1	15.119	-26.917	59.065	126.801
	ULS	2	12.599	-22.430	49.221	105.668
	ULS	3	15.119	-26.917	59.065	126.801
	ULS	4	12.599	-22.430	49.221	105.668
2	SLS		10.932	-2.570	15.837	27.392
	ULS	1	4.255	-36.010	5.097	10.942
	ULS	2	21.809	-16.042	1.157	2.484
	ULS	3	-50.816	-55.775	14.416	30.948
	ULS	4	-26.874	-43.409	9.395	20.169

```
        3     ULS     1    3.840     100.100   12.968    27.839
              ULS     2    61.944    114.848   9.871     -5.593
              ULS     3    -40.772   51.444    18.425    39.555
              ULS     4    9.452     78.785    9.858     21.162

        4     ULS     1    -42.476   62.649    31.342    67.286
              ULS     2    9.343     88.618    22.580    48.474
              ULS     3    -31.176   20.726    37.757    81.057
              ULS     4    -36.634   41.137    28.204    60.549

        5     SLS          55.225    107.150   26.319    52.511
              ULS     1    16.750    125.777   23.349    50.127
              ULS     2    78.252    145.084   3.153     20.665
              ULS     3    -27.189   76.543    28.724    61.666
              ULS     4    22.335    104.486   20.243    43.457
     ------------------------------------------------------------

     ULS CASES:

          Case 1 = Max vertical + max overturning
          Case 2 = Min vertical + max overturning
          Case 3 = Max vertical + min overturning
          Case 4 = Min vertical + min overturning

     SIGN CONVENTION:

          Positive moment => tension on bottom of footing
          Positive shear  => upward direction

  ------------------------------------------------------------
  F O O T I N G   T O E
  ------------------------------------------------------------

  ULTIMATE LIMIT STATE CALCULATIONS:

       SHEAR (Comb 5):

       Effective depth = 912.26 mm
       Factored shear  = 78.252 kN/m
       d required      = 95.79 < d provided = 912.26 OKAY

       TENSION AT FOOTING BOTTOM:
       ----------------------------

       MOMENT (Comb 5):

       Factored moment = 145.084 kN-m/m
       As required     = 88.93 < As provided = 510.00 OKAY
       c/d limit       = 0.50 > c/d ratio = 0.08 OKAY
```

```
        TENSION AT FOOTING TOP:
        ---------------------------

        MOMENT (Comb 2):

        Factored moment = 55.775 kN-m/m
        As required     = 68.10 < As provided = 510.00 OKAY
        c/d limit       = 0.50 > c/d ratio = 0.04 OKAY

   SERVICEABILITY LIMIT STATE CALCULATIONS:

        TENSION AT FOOTING BOTTOM:
        ---------------------------

        CRACK CONTROL (Comb 5):

        Service moment       = 107.150 kN-m/m
        Steel stress         = 37.23 MPa
        40% Cracking moment  = 146.059 > 107.150 OKAY

        TENSION AT FOOTING TOP:
        ---------------------------

        CRACK CONTROL (Comb 2):

        Service moment       = 2.570 kN-m/m
        Steel stress         = 1.75 MPa
        40% Cracking moment  = 146.059 > 2.570 OKAY

   ------------------------------------------------------------
   F O O T I N G   H E E L
   ------------------------------------------------------------

   ULTIMATE LIMIT STATE CALCULATIONS:

        SHEAR (Comb 1):

        Effective depth = 912.26 mm
        Factored shear  = 59.065 kN/m
        d required      = 70.81 < d provided = 912.26 OKAY

        TENSION AT FOOTING BOTTOM:
        ---------------------------

        MOMENT (Comb 1):

        Factored moment = 126.801 kN-m/m
        As required     = 155.32 < As provided = 510.00 OKAY
        c/d limit       = 0.50 > c/d ratio = 0.04 OKAY
```

TENSION AT FOOTING TOP:

MOMENT (Comb 3):

Factored moment = 5.593 kN-m/m
As required = 6.81 < As provided = 510.00 OKAY
c/d limit = 0.50 > c/d ratio = 0.04 OKAY

SERVICEABILITY LIMIT STATE CALCULATIONS:

TENSION AT FOOTING BOTTOM:

CRACK CONTROL (Comb 1):

Service moment = 129.710 kN-m/m
Steel stress = 88.30 MPa
40% Cracking moment = 146.059 > 129.710 OKAY

NO TENSION AT FOOTING TOP:

TEMPERATURE AND SHRINKAGE:

T&S reinforcement = 284.00 > Area required = 150.00 OKAY

S I D E W A L L S
==========

UNFACTORED LOADS:

LOAD CONDITION	SHEAR (kN/m)	MOMENT (kN-m/m)
Compaction pressure	24.653	96.564
Lateral earth pressure	57.041	149.845
Surcharge pressure	31.033	99.844

ULTIMATE LIMIT STATE CALCULATIONS:

SHEAR (Comb 3):

Effective depth = 387.26 mm
Factored shear = 110.092 kN/m
d required = 139.67 < d provided = 387.26 OKAY

```
      MOMENT (Comb 3):

      Factored moment = 312.112 kN-m/m
      As required     = 357.70 < As provided = 510.00 OKAY
      c/d limit       = 0.50 > c/d ratio = 0.19 OKAY

SERVICEABILITY LIMIT STATE CALCULATIONS:

      CRACK CONTROL (Comb 5):

      Service moment       = 249.689 kN-m/m
      Steel stress         = 211.58 MPa
      Crack control factor = 44238.3 > 30000.0 NO GOOD ***
      As required          = 510.00 mm^2 at the same reinf spacing, or
      Maximum spacing      = 135.63 mm with the same reinf area/width

      TEMPERATURE AND SHRINKAGE:

      T&S reinforcement = 199.00 > Area required = 150.00 OKAY

Q U A N T I T I E S
=================================================================

CONCRETE:

    ---------------------------------------------------------------
    ITEM           VOLUME
                   (m^3)
    ---------------------------------------------------------------
    Abutment       41.5
    Footing        36.0
    ---------------------------------------------------------------

REINFORCING:

    ---------------------------------------------------------------
    BAR       AREA      LENGTH    NO   WEIGHT    DESCRIPTION
              (mm^2)    (mm)           (kg)
    ---------------------------------------------------------------
    Asb       284.00    2963.8    31   204.3
    AsTSb     129.00    2487.6    31   77.9      Vertical
    AsTSb     129.00    8900.0    16   143.8     Longitudinal
    Asw       510.00    5184.5    61   1262.9
    AsTSw     284.00    2650.0    31   182.7     Vertical
    AsTSw     284.00    8900.0    14   277.1     Longitudinal
    Asft      510.00    3850.0    31   476.6
    Asfbt     510.00    0.0       0    0.0
    Asfbh     510.00    2305.0    31   285.3
    AsTSf     284.00    8850.0    28   551.0
    Asws      510.00    8965.0    1    35.8      Bar @ y = 62.7
    Asws      510.00    8965.0    1    35.8      Bar @ y = 209.7
    Asws      510.00    8965.0    1    35.8      Bar @ y = 356.7
```

Asws	510.00	8965.0	1	35.8	Bar @ y = 503.7
Asws	510.00	8965.0	1	35.8	Bar @ y = 650.7
Asws	510.00	8965.0	1	35.8	Bar @ y = 797.6
Asws	510.00	8965.0	1	35.8	Bar @ y = 944.6
Asws	510.00	8666.9	1	34.6	Bar @ y = 1091.6
Asws	510.00	8316.0	1	33.2	Bar @ y = 1238.6
Asws	510.00	7965.0	1	31.8	Bar @ y = 1385.6
Asws	510.00	7614.1	1	30.4	Bar @ y = 1532.5
Asws	510.00	7263.2	1	29.0	Bar @ y = 1679.5
Asws	510.00	6912.3	1	27.6	Bar @ y = 1826.5
Asws	510.00	6561.4	1	26.2	Bar @ y = 1973.5
Asws	510.00	6210.5	1	24.8	Bar @ y = 2120.5
Asws	510.00	5859.5	1	23.4	Bar @ y = 2267.5
Asws	510.00	5508.6	1	22.0	Bar @ y = 2414.4
Asws	510.00	5157.7	1	20.6	Bar @ y = 2561.4
Asws	510.00	4806.8	1	19.2	Bar @ y = 2708.4
Asws	510.00	4455.9	1	17.8	Bar @ y = 2855.4
Asws	510.00	4105.0	1	16.4	Bar @ y = 3002.4
Asws	510.00	3754.0	1	15.0	Bar @ y = 3149.3
Asws	510.00	3403.1	1	13.6	Bar @ y = 3296.3
Asws	510.00	3052.2	1	12.2	Bar @ y = 3443.3
Asws	510.00	2701.3	1	10.8	Bar @ y = 3590.3
Asws	510.00	2350.4	1	9.4	Bar @ y = 3737.3
AsTSws	199.00	8965.0	1	14.0	Bar @ y = 58.0
AsTSws	199.00	8965.0	1	14.0	Bar @ y = 341.3
AsTSws	199.00	8965.0	1	14.0	Bar @ y = 624.7
AsTSws	199.00	8965.0	1	14.0	Bar @ y = 908.1
AsTSws	199.00	8428.3	1	13.1	Bar @ y = 1191.5
AsTSws	199.00	7751.7	1	12.1	Bar @ y = 1474.9
AsTSws	199.00	7075.1	1	11.0	Bar @ y = 1758.3
AsTSws	199.00	6398.5	1	10.0	Bar @ y = 2041.7
AsTSws	199.00	5721.9	1	8.9	Bar @ y = 2325.1
AsTSws	199.00	5045.3	1	7.9	Bar @ y = 2608.5
AsTSws	199.00	4368.7	1	6.8	Bar @ y = 2891.9
AsTSws	199.00	3692.1	1	5.8	Bar @ y = 3175.3
AsTSws	199.00	3015.6	1	4.7	Bar @ y = 3458.7
AsTSws	199.00	2339.0	1	3.6	Bar @ y = 3742.0
AsTSws	199.00	920.1	2	2.9	Bar @ x = 58.0
AsTSws	199.00	1042.4	2	3.2	Bar @ x = 350.0
AsTSws	199.00	1164.7	2	3.6	Bar @ x = 642.0
AsTSws	199.00	1287.0	2	4.0	Bar @ x = 934.0
AsTSws	199.00	1409.3	2	4.4	Bar @ x = 1226.0
AsTSws	199.00	1531.6	2	4.8	Bar @ x = 1518.0
AsTSws	199.00	1653.9	2	5.2	Bar @ x = 1810.0
AsTSws	199.00	1776.2	2	5.5	Bar @ x = 2102.0
AsTSws	199.00	1898.5	2	5.9	Bar @ x = 2394.0
AsTSws	199.00	2020.8	2	6.3	Bar @ x = 2686.0
AsTSws	199.00	2143.1	2	6.7	Bar @ x = 2978.0
AsTSws	199.00	2265.4	2	7.1	Bar @ x = 3270.0
AsTSws	199.00	2387.7	2	7.4	Bar @ x = 3562.0
AsTSws	199.00	2510.0	2	7.8	Bar @ x = 3854.0

AsTSws	199.00	2632.3	2	8.2	Bar @ x = 4146.0
AsTSws	199.00	2754.6	2	8.6	Bar @ x = 4438.0
AsTSws	199.00	2876.9	2	9.0	Bar @ x = 4730.0
AsTSws	199.00	2999.3	2	9.3	Bar @ x = 5022.0
AsTSws	199.00	3121.6	2	9.7	Bar @ x = 5314.0
AsTSws	199.00	3243.9	2	10.1	Bar @ x = 5606.0
AsTSws	199.00	3366.2	2	10.5	Bar @ x = 5898.0
AsTSws	199.00	3488.5	2	10.9	Bar @ x = 6190.0
AsTSws	199.00	3610.8	2	11.3	Bar @ x = 6482.0
AsTSws	199.00	4675.0	2	14.6	Bar @ x = 6774.0
AsTSws	199.00	4675.0	2	14.6	Bar @ x = 7066.0
AsTSws	199.00	4675.0	2	14.6	Bar @ x = 7358.0
AsTSws	199.00	4675.0	2	14.6	Bar @ x = 7650.0
AsTSws	199.00	4675.0	2	14.6	Bar @ x = 7942.0
Total =			370	4505.2	