FOUNDATION MODELING

Programs M-STRUDL and COM624P can be used in an iterative approach to model a structure-soil problem through the use of footing support springs. The approach is to determine the approximate force magnitudes for the controlling loading and then use these forces to develop a better representation of the structure-soil problem. This example shows a method to model the non-linearity of the substructure-soil interaction.

The following steps would be typical for foundation modeling design:

1. Run the M-STRUDL model using the fixed condition.

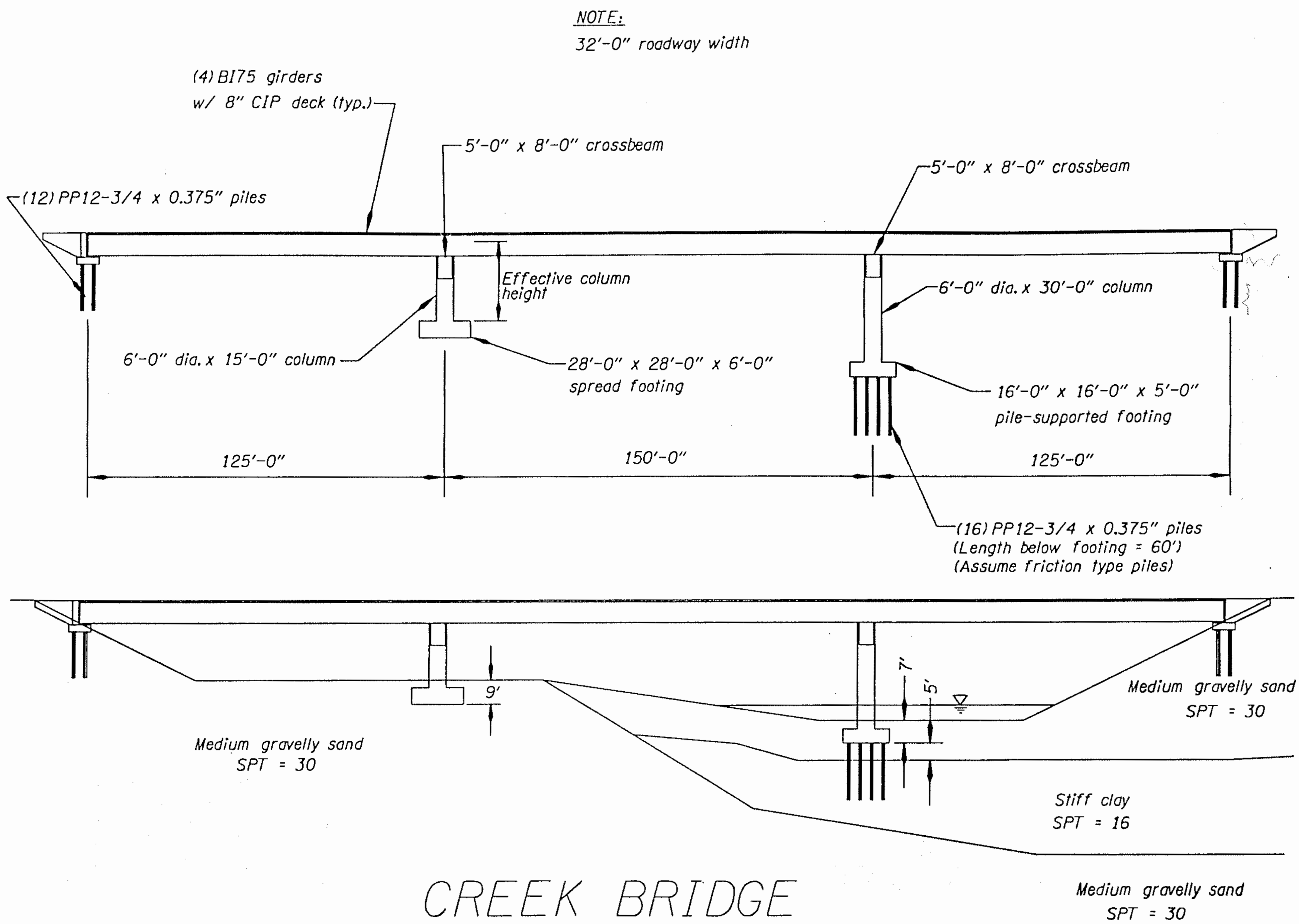
2. Develop the pile top load-deflection curve and initial translational spring constant for pile-supported footings using COM624P. Rotational spring constants for pile-supported footings are calculated using force-deformation relationships, and translational and rotational spring constants for spread footings are calculated using the procedure found in the Office Practice Manual.

3. Develop a full M-STRUDL model using the calculated spring constants. Using the model, run the controlling load case (typically seismic loading will be the controlling case).

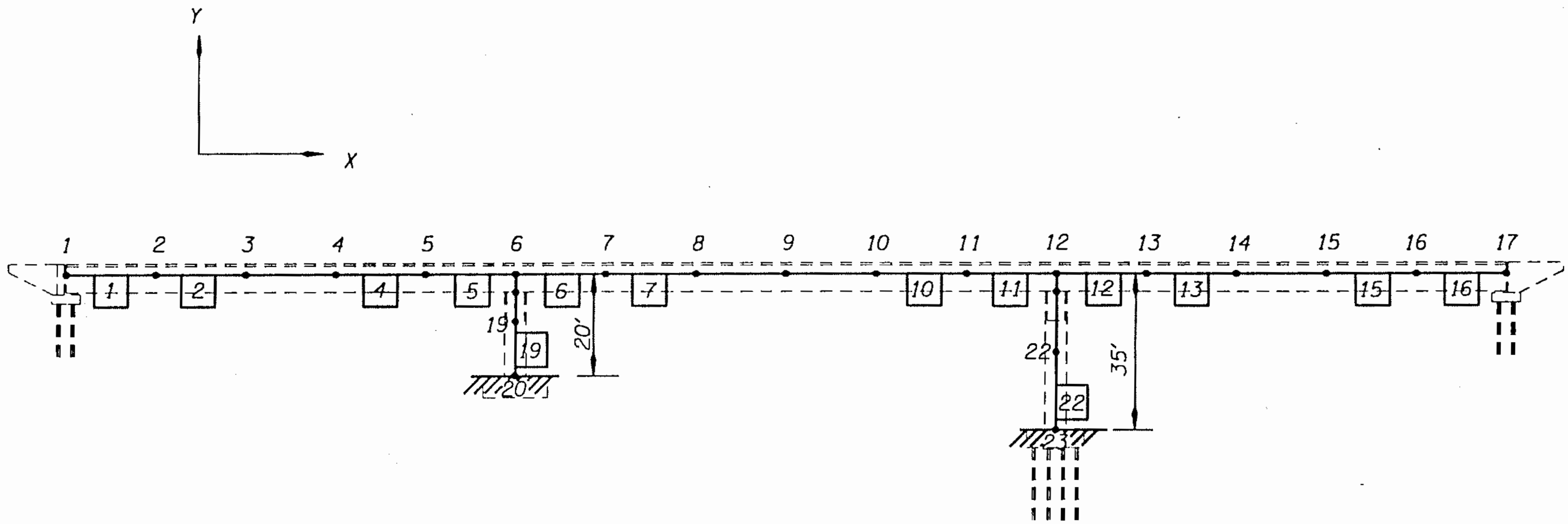
4. Calculate the ultimate translational and rotational capacities using the same COM624P run, statics, or the procedure found in the Office Practice Manual, as appropriate. The force-deflection relations for each spring are required to compare with the equivalent spring, and to determine that the system capacity has not been exceeded.

5. Compare the results from the M-STRUDL run with the ultimate capacities. Recalculate the spring constants (if necessary) based upon this comparison, and rerun M-STRUDL using these revised spring constants.

6. Repeat the above step as necessary to achieve better convergence. Results which change no more than 15% per cycle are normally sufficiently close and further cycling is usually not required.



CREEK BRIDGE



M-STRUDL MODEL

Bridge Name: Creek Bridge

Calculations by: Peter R. Pagter Date: June 1, 1995 Bridge No.: 1

Bent 2

Determine translational spring coefficient:

Nc = 30 G = 750 ksf μ = 0.35

$$R = \sqrt{\frac{4BL}{\pi}} = \sqrt{\frac{(2B)\ (2L)}{\pi}} = \sqrt{\frac{(28')\ (28')}{\pi}} = 15.8'$$

$$\frac{2L}{2B} = \frac{(28')}{(28')} = 1.0$$

$$\therefore \alpha = 1.02$$

D = embedment depth = 9'

$$\frac{D}{R} = \frac{(9')}{(15.8')} = 0.57$$

$$\therefore \beta = 1.7$$

$$Ktx = \frac{8GR\alpha\beta}{(2 - \mu)} = \frac{(8)\ (750)\ (15.8')\ (1.02)\ (1.7)}{(2 - 0.35)} = 99{,}600 \text{ k/ft}$$

Determine rotational spring coefficient:

$$\sqrt[4]{\frac{(2B)^3(2L)}{3\pi}} = \sqrt[4]{\frac{(28')^3(28')}{(3)\ (\pi)}} = 16.0'$$

$$\frac{2L}{2B} = \frac{(28')}{(28')} = 1.0$$

$$\therefore \alpha = 1.05$$

$$\frac{D}{R} = \frac{(9')}{(16.0')} = 0.56$$

$$\therefore \beta = 2.1$$

$$Krx = \frac{8GR^3\alpha\beta}{3(1 - \mu)} = \frac{(8)\ (750)\ (16.0')^3(1.05)\ (2.1)}{(3)\ (1 - 0.35)} = 27{,}800{,}000 \text{ ft-k/radian}$$

```
Creek Bridge Bent 3;Seismic Design Example
   1    1    0
 100    2     2     0
   5    5     0
  720.000   29000000   -84.000      0.000
   1    1
   4    1     1              0
 100      0.00010000    100.00000000
   0.0000    12.7500   279.0000    14.6000
 720.0000    12.7500   279.0000    14.6000
   1    4    -84.0000    60.0000    60.0000
   2    2     60.0000   840.0000   500.0000
 -84.0000    0.03000
  60.0000    0.03000
  60.0000    0.02500
 720.0000    0.02500
 804.0000    0.02500
 -84.0000     0.0000    34.0000    0.00000
  60.0000     0.0000    34.0000    0.00000
  60.0000    14.0000     0.0000    0.00700
 720.0000    14.0000     0.0000    0.00700
 804.0000    14.0000     0.0000    0.00700
   3
  12.0000
  48.0000
  72.0000
  10
   1     0.5000     0.0000 149000.000
   1     1.0000     0.0000 149000.000
   1     1.5000     0.0000 149000.000
   1     2.0000     0.0000 149000.000
   1     2.5000     0.0000 149000.000
   1     3.0000     0.0000 149000.000
   1     3.5000     0.0000 149000.000
   1     4.0000     0.0000 149000.000
   1     4.5000     0.0000 149000.000
   1     5.0000     0.0000 149000.000
```

BENT 3 SINGLE PILE TRANSLATION SPRING COEFFICIENT [COM624P]

Creek Bridge Bent 3;Seismic Design Example

****

PILE DEFLECTION, BENDING MOMENT, SHEAR & SOIL RESISTANCE

****

I N P U T   I N F O R M A T I O N

****

THE LOADING IS STATIC

PILE GEOMETRY AND PROPERTIES

PILE LENGTH = 720.00 IN
MODULUS OF ELASTICITY OF PILE = .290E+05 KIP/IN**2
2 SECTION(S)

X	DIAMETER	MOMENT OF INERTIA	AREA
IN	IN	IN**4	IN**2
.00			
	12.750	.279E+03	.146E+02
720.00			
	12.750	.279E+03	.146E+02
720.00			

SOILS INFORMATION

X-COORDINATE AT THE GROUND SURFACE = -84.00 IN

SLOPE ANGLE AT THE GROUND SURFACE = .00 DEG.

2 LAYER(S) OF SOIL

LAYER 1
THE LAYER IS A SAND
X AT THE TOP OF THE LAYER = -84.00 IN
X AT THE BOTTOM OF THE LAYER = 60.00 IN
VARIATION OF SOIL MODULUS, k = .600E+02 LBS/IN**3

LAYER 2
THE LAYER IS A STIFF CLAY BELOW THE WATER TABLE
X AT THE TOP OF THE LAYER = 60.00 IN
X AT THE BOTTOM OF THE LAYER = 840.00 IN
VARIATION OF SOIL MODULUS, k = .500E+03 LBS/IN**3

DISTRIBUTION OF EFFECTIVE UNIT WEIGHT WITH DEPTH
5 POINTS

X,IN	WEIGHT,LBS/IN**3
-84.00	.30E-01
60.00	.30E-01
60.00	.25E-01
720.00	.25E-01
804.00	.25E-01

DISTRIBUTION OF STRENGTH PARAMETERS WITH DEPTH
5 POINTS

X,IN	C,LBS/IN**2	PHI,DEGREES	E50
-84.00	.000E+00	34.000	-----
60.00	.000E+00	34.000	-----
60.00	.140E+02	.000	.700E-02
720.00	.140E+02	.000	.700E-02
804.00	.140E+02	.000	.700E-02

FINITE DIFFERENCE PARAMETERS

NUMBER OF PILE INCREMENTS = 100
TOLERANCE ON DETERMINATION OF DEFLECTIONS = .100E-03 IN
MAXIMUM NUMBER OF ITERATIONS ALLOWED FOR PILE ANALYSIS = 100
MAXIMUM ALLOWABLE DEFLECTION = .10E+03 IN

INPUT CODES

OUTPT = 1
KCYCL = 1
KBC = 4
KPYOP = 1
INC = 1

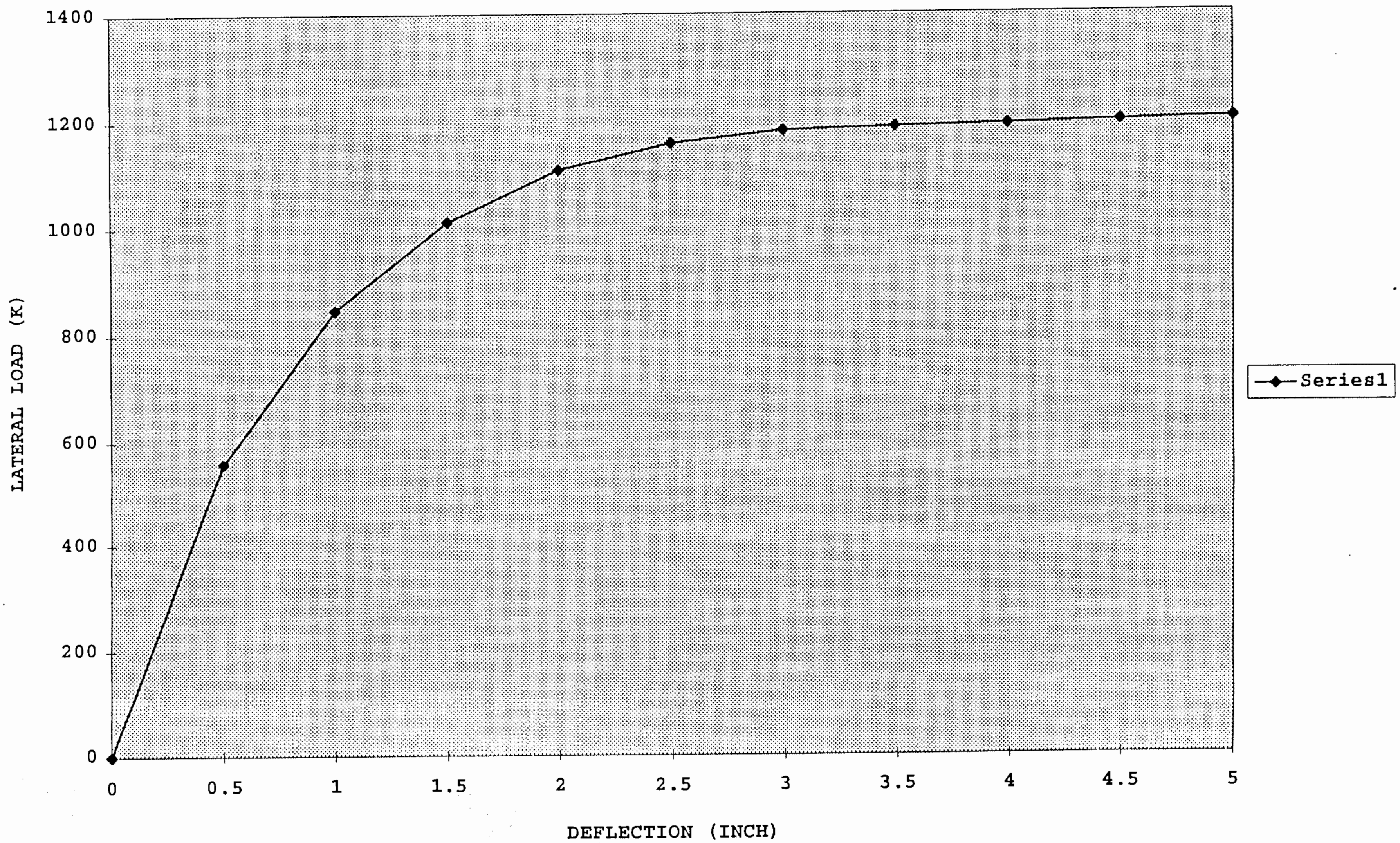
Creek Bridge Bent 3;Seismic Design Example

O U T P U T   I N F O R M A T I O N
****

S U M M A R Y   T A B L E
****

LATERAL LOAD (KIP)	BOUNDARY CONDITION BC2	AXIAL LOAD (KIP)	YT (IN)	ST (IN/IN)	MAX. MOMENT (IN-KIP)	MAX. STRESS (LBS/IN**2)
.348E+02	.000E+00	1.49E+02	.500E+00	-.894E-02	.940E+03	.229E+05
.528E+02	.000E+00	1.49E+02	.100E+01	-.167E-01	.165E+04	.390E+05
.632E+02	.000E+00	1.49E+02	.150E+01	-.234E-01	.220E+04	.516E+05
.693E+02	.000E+00	1.49E+02	.200E+01	-.293E-01	.257E+04	.601E+05
.724E+02	.000E+00	1.49E+02	.250E+01	-.343E-01	.279E+04	.651E+05
.738E+02	.000E+00	1.49E+02	.300E+01	-.387E-01	.292E+04	.681E+05
.742E+02	.000E+00	1.49E+02	.350E+01	-.426E-01	.300E+04	.699E+05
.745E+02	.000E+00	1.49E+02	.400E+01	-.462E-01	.306E+04	.713E+05
.748E+02	.000E+00	1.49E+02	.450E+01	-.497E-01	.312E+04	.726E+05
.751E+02	.000E+00	1.49E+02	.500E+01	-.531E-01	.317E+04	.738E+05

LATERAL LOAD-DEFLECTION CURVE
[BOTTOM OF FOOTING, 16 PILES, NO GROUP REDUCTION]



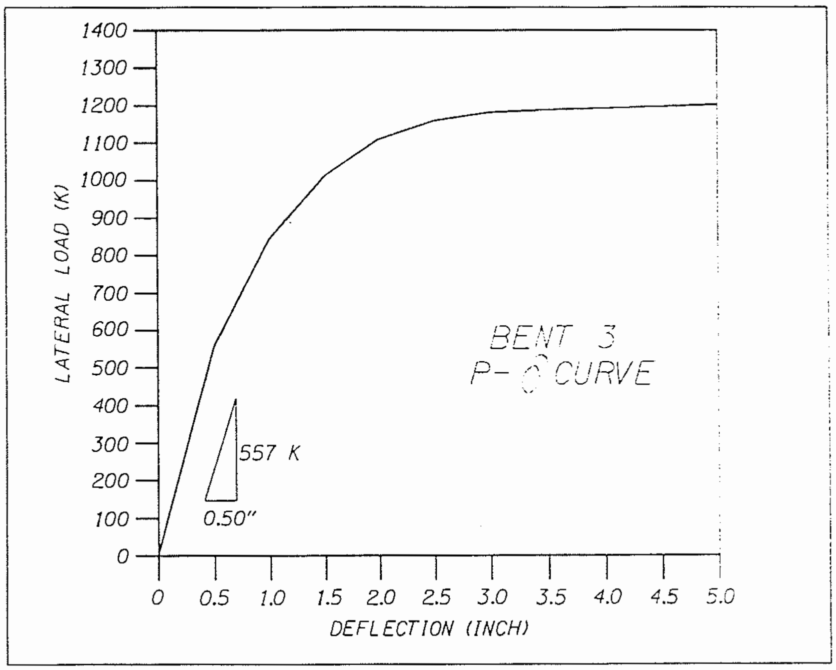
Bridge Name: Creek Bridge

Calculations by: Peter R. Pagter Date: June 1, 1995 Bridge No.: 1

Bent 3

Determine Translational Spring Constant:

Pile Contribution



c:\data\dgn\misc.dgn May 31, 1995 14:11:29

Lateral load = (34.8 k/pile)(16 piles) = 557 k

Soil Contribution

Effective pressure = [(0.115 kcf)(4.5')-(0.062 kcf)(4.5')]
= 0.237 ksf

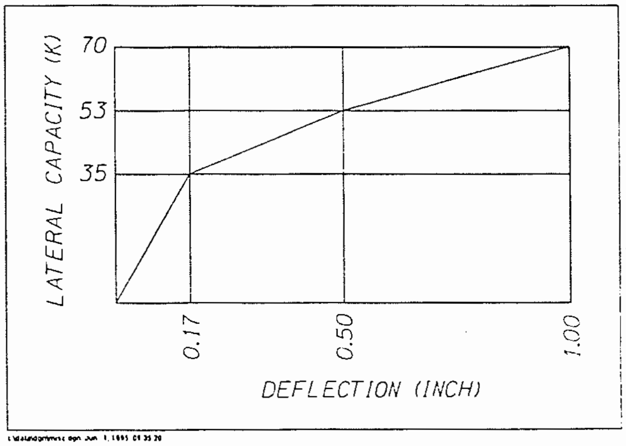
Force = [(Kp)(Eff. Unit Pressure)(Footing side area)

= [(3.7)(0.237 ksf)(16')(5')]
= 70 k

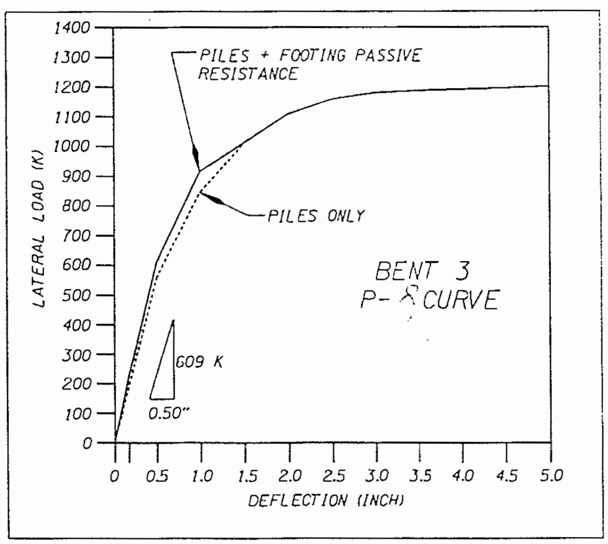
Assume that this fully effective at 1" deflection. Therefore, the P-δ curve for the footing passive resistance is as follows:

Bridge Name: Creek Bridge

Calculations by: Peter R. Pagter **Date:** June 1, 1995 **Bridge No.:** 1



Combining the pile and footing passive resistance P-δ curves is as follows:



Note that the contribution from the footing passive resistance is small for this example.

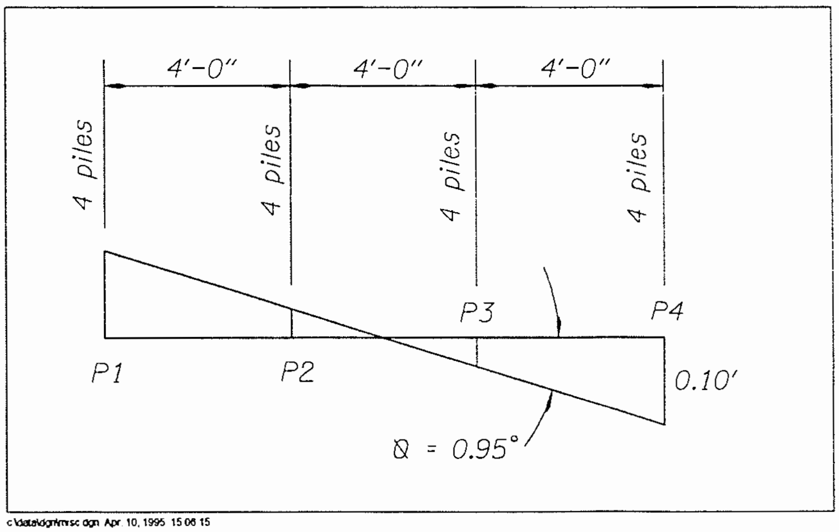
Total Translational Spring Constant:

$$K_{TX1} = \frac{(609k)\ (12in\ /\ ft)}{(0.5")} = 14,620\ k/ft$$

Bridge Name: Creek Bridge

Calculations by: Peter R. Pagter **Date:** June 1, 1995 **Bridge No.:** 1

Determine Rotational Spring Constant:



A_{PILE} = 14.6 in^2
E_{PILE} = 29,000 ksi
$L_{EFFECTIVE}$ = (0.50)(60') = 30'

$$P_1 = \frac{\Delta EA}{L} = \frac{(0.10')(29000ksi)(14.6in2)}{(30')} = 1410 \text{ k/pile}$$

$$P_2 = (1/3)(P_1) = 470 \text{ k/pile}$$

M = (470 k/pile)(2')(4 piles)(2 rows) + (1410 k/pile)(6')(4 piles)(2 rows)
= 75,200 ft-k

$$K_{RX} = \frac{(75{,}200ft - k)(57.3^\circ/radian)}{(0.95^\circ)}$$

= 4,536,000 ft-k/radian

```
TITLE  CREEK BRIDGE - BRIDGE 1
TITLE  PETER R. PAGTER   JUNE 1995
TYPE PLANE FRAME
REPORT DEVICE C:\DATA\SEISMIC\OUT
UNITS FEET KIPS RADIANS
$
$ SEISMIC ANALYSIS
$ ITERATION #1
$
JOINT COORDINATES
   1     0.00      35.00    SUPPORT
   2    25.00      35.00
   3    50.00      35.00
   4    75.00      35.00
   5   100.00      35.00
   6   125.00      35.00
   7   150.00      35.00
   8   175.00      35.00
   9   200.00      35.00
  10   225.00      35.00
  11   250.00      35.00
  12   275.00      35.00
  13   300.00      35.00
  14   325.00      35.00
  15   350.00      35.00
  16   375.00      35.00
  17   400.00      35.00  SUPPORT
  18   125.00      30.00
  19   125.00      25.00
  20   125.00      15.00  SUPPORT
  21   275.00      30.00
  22   275.00      15.00
  23   275.00       0.00  SUPPORT
$
JOINT RELEASE
  1  FORCE X MOMENT Z   $ROLLER SUPPORT @ BENT 1
 17  FORCE X MOMENT Z   $ROLLER SUPPORT @ BENT 4
 20  KFX  99600    KMZ  27800000
 23  KFX  14200    KMZ  4536000
$
MEMBER INCIDENCES
 1           1            2
 2           2            3
 3           3            4
 4           4            5
 5           5            6
 6           6            7
 7           7            8
 8           8            9
 9           9            10
```

```
  10          10            11
  11          11            12
  12          12            13
  13          13            14
  14          14            15
  15          15            16
  16          16            17
  17           6            18   $CROSSBEAM
  18          18            19   $COLUMN
  19          19            20   $COLUMN
  20          12            21   $CROSSBEAM
  21          21            22   $COLUMN
  22          22            23   $COLUMN
$
MATERIAL PROPERTY
 BEAM   E 550600   DEN 0.211     CT 0.000006      1  TO 16
 COL    E 519200   DEN 0.150     CT 0.000006     17  TO 22
$
MEMBER PROPERTIES
 A1       AX  40.83    IZ 229.1   1  TO 16
$SUPERSTRUCTURE
 A2       AX  28.27    IZ  63.6   17 20           $CROSSBEAM
 A3       AX  28.27    IZ  63.6   18 19 21 22     $COLUMN
$
DYNAMIC ANALYSIS REACTIONS MODES 10
$
$ A=0.24   S=1.2   G=32.2
LOAD EQL
  RSA X 9.27 RESSOIL2
$
UNITS INCH
OUTPUT DECIMAL 10
LIST JOINT DISPLACEMENTS ALL
$
UNITS FEET
OUTPUT DECIMAL 1
LIST MEMBER FORCES 19 22
$
FINISH
```

*** LOAD INDEX : 1 LOAD TAG : EQL ***

* X - RSA, FACTOR = 9.27 FREQ. VS. ACCEL. CURVE

RESULTANT JOINT DISPLACEMENTS -----

JOINT	/--- GLOBAL DISPLACEMENTS ---/		-- ROTATION --/
NO.	X DIRECTION	Y DIRECTION	Z DIRECTION
1	0.6235262750	0.0000000004	0.0024831517
2	0.6230702754	0.6944699778	0.0019795820
3	0.6217031809	1.1088846474	0.0007181373
4	0.6194277017	1.0871247748	0.0008808909
5	0.6162483445	0.6585935637	0.0019567845
6	0.6121713988	0.0046747348	0.0023402468
7	0.6195249526	0.6734315296	0.0021393360
8	0.6260033914	1.1881300658	0.0014137657
9	0.6315899693	1.3734220526	0.0006630122
10	0.6362699096	1.1561265602	0.0014576608
11	0.6400303946	0.6248045906	0.0021041875
12	0.6428605617	0.0082642747	0.0019584668
13	0.6472224497	0.6093660656	0.0019284083
14	0.6506242820	1.0533559732	0.0009263057
15	0.6530591333	1.0986647689	0.0006418695
16	0.6545220371	0.6951293228	0.0019665484
17	0.6550100043	0.0000000004	0.0024926233
18	0.4797910718	0.0035063630	0.0026122091
19	0.3276689570	0.0023377419	0.0025510238
20	0.1252716772	0.0000000005	0.0004274597
21	0.6213876807	0.0070848538	0.0014592232
22	0.4402199139	0.0035435641	0.0014330906
23	0.2355366178	0.0000000005	0.0007366430

```
=====================================================================
| M-STRUDL BY CAST / REV.  V2.90 SER :  722d TIME : 5/31/1995 16:16:45 |
| L I C E N S E E : Oregon DOT #11, OR                                  |
| TITLE:  PETER R. PAGTER                                    PAGE    2  |
=====================================================================
```

*** LOAD INDEX : 1 LOAD TAG : EQL ***

* X - RSA, FACTOR = 9.27 FREQ. VS. ACCEL. CURVE

0.3:4.4	0.3:4.8	0.3:5.4	0.4:6.0	0.5:7.0
0.5:7.2	0.6:7.5	0.6:7.8	0.6:8.2	0.7:8.5
0.7:8.9	0.8:9.4	0.8:9.8	0.9:10.5	1.0:11.1
1.1:12.0	1.3:12.9	1.4:14.1	1.7:15.7	2.0:17.6
2.3:19.3	100.0:19.3			

RESULTANT MEMBER FORCES -----

MEMBER NO.	SECTION TAG.	JOINT NO.	/--- AXIAL ---/ FORCE	--- LOCAL Y --/ SHEAR FORCE	-- LOCAL Z --/ MOMENT
19	A3	19	285.9	1038.0	3418.6
		20	285.9	1038.0	11883.4
22	A3	22	289.0	274.9	1635.7
		23	289.0	274.9	3341.4

Bridge Name: Creek Bridge

Calculations by: Peter R. Pagter **Date:** June 1, 1995 **Bridge No.:** 1

Bent 2

Determine Ultimate Translational Force Capacity:

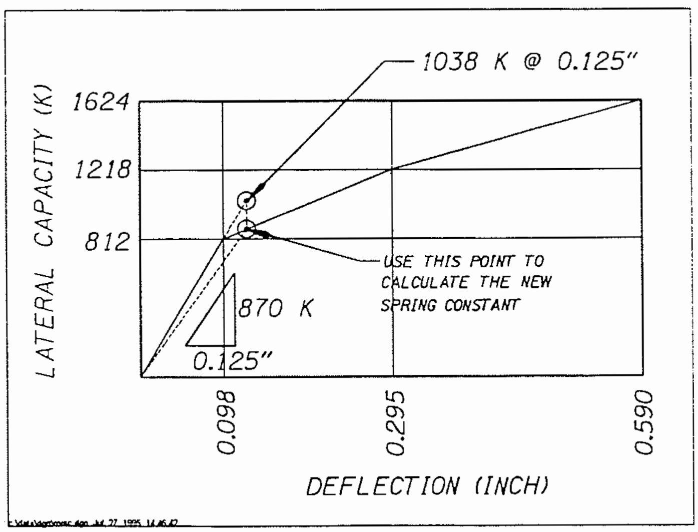
Nc = 30 G = 750 ksf μ = 0.35

Dead load support reaction = 2390 k

Force capacity = [(Kp)(Eff. unit pressure)(Ftg. side area) + (F)(Support Reaction)

= [(3.7)((0.115 kcf)(6'))(6')(28') + (0.5)(2390 k)]

= 1624 k



∴ The translation spring is too stiff. Recalculate the translational spring constant as follows:

$$K_{TX} = \frac{(870k)(12in / ft)}{(0.125")} = 83,500 \text{ k/ft}$$

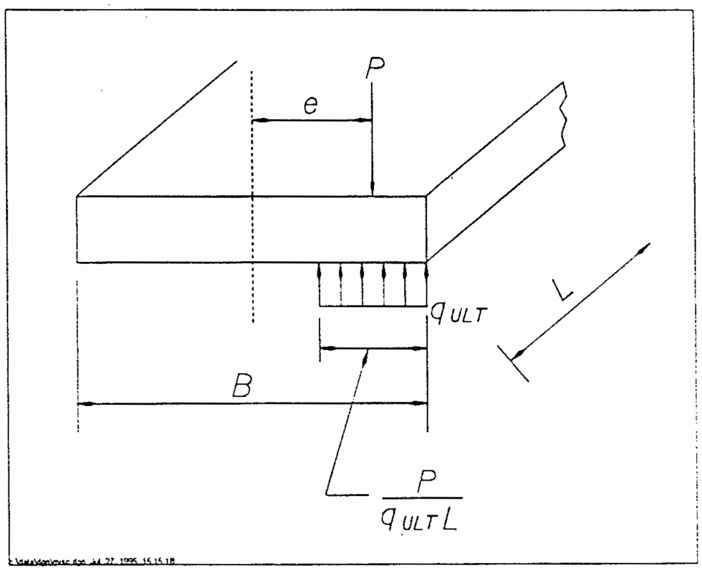
Determine Ultimate Moment Capacity:

q_{ULT} = 18 ksf (from the Foundations Unit)
P = 2390 k

BRIDGE ENGINEERING SECTION
OREGON DEPARTMENT OF TRANSPORTATION

Bridge Name: Creek Bridge

Calculations by: Peter R. Pagter **Date:** June 1, 1995 **Bridge No.:** 1



$$e = \frac{B}{2} - \frac{P}{2Lq_{ULT}}$$

$$= \frac{(28')}{(2)} - \frac{(2390k)^2}{(2)\ (28')\ (18ksf)}$$

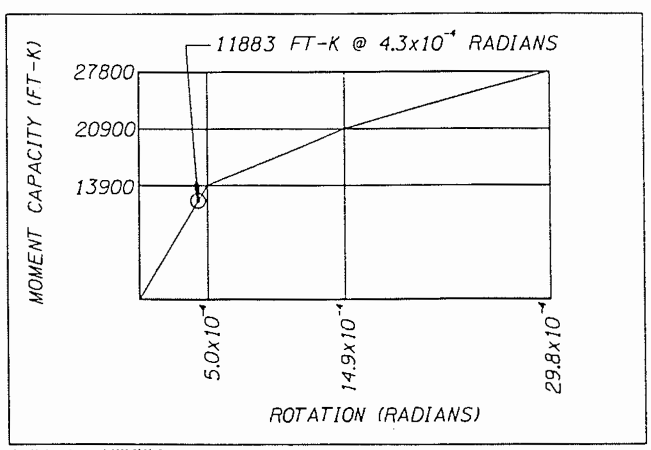
$$= 14' - 2.37'$$

$$= 11.63'$$

$$M = Pe$$

$$= (2390\ k)(11.63')$$

$$= 27{,}793\ \text{ft-k}$$



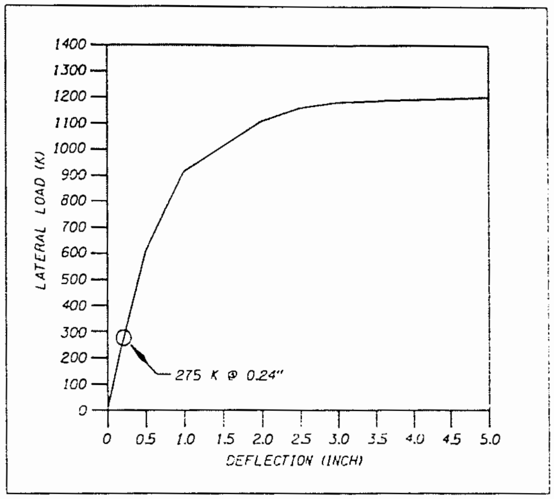
∴ The rotational spring is adequate.

Bridge Name: Creek Bridge

Calculations by: Peter R. Pagter **Date:** June 1, 1995 **Bridge No.:** 1

Bent 3

Determine Ultimate Translational Force Capacity:



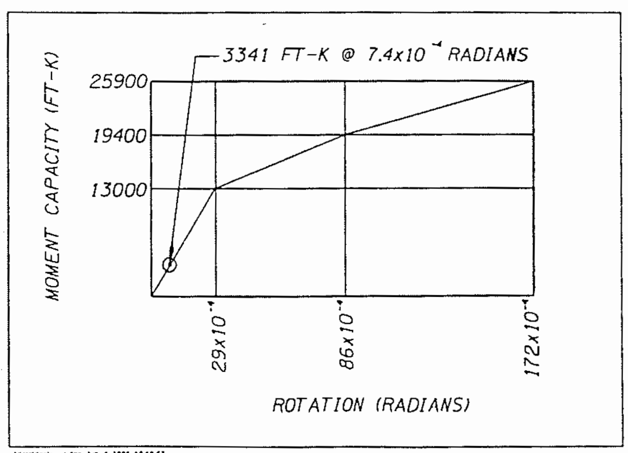
∴ The translation spring is adequate.

Determine Ultimate Moment Capacity:

Ultimate pile capacity = 405 k/pile (from Foundations Unit)

Ultimate moment capacity = (405 k/pile)(4 piles)(6')(2 rows)
+ (405 k/pile)(4 piles)(2')(2 rows)

= 25,900 ft-k



∴ The rotational spring is adequate.