Structural Design and Evaluation of Pile Shafts

(State of Caltrans' Practice)

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Division of Engineering Services

California Department of Transportation

Outline

- Applications and Types of Pile Shafts
- Overview of CT Seismic Design Procedure

  http://www.dot.ca.gov/hq/esc/techpubs/manual/othermanual/other-engin-manual/seismic-design-criteria/sdc.html

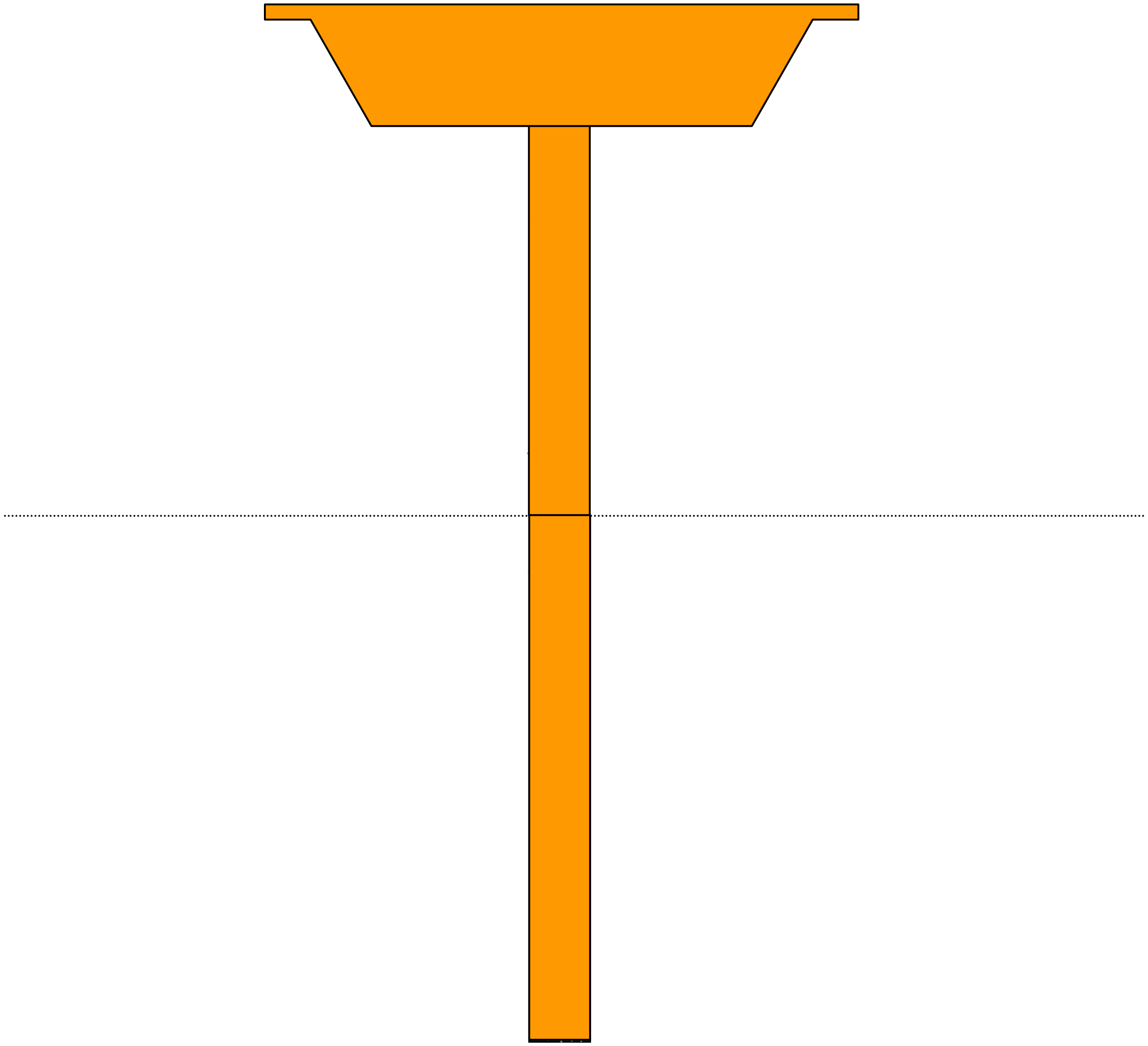
- Seismic Detailing of Pile Shafts
- General Design Requirements (LRFD)
- Inspection and Structural Evaluation of Defective Shafts

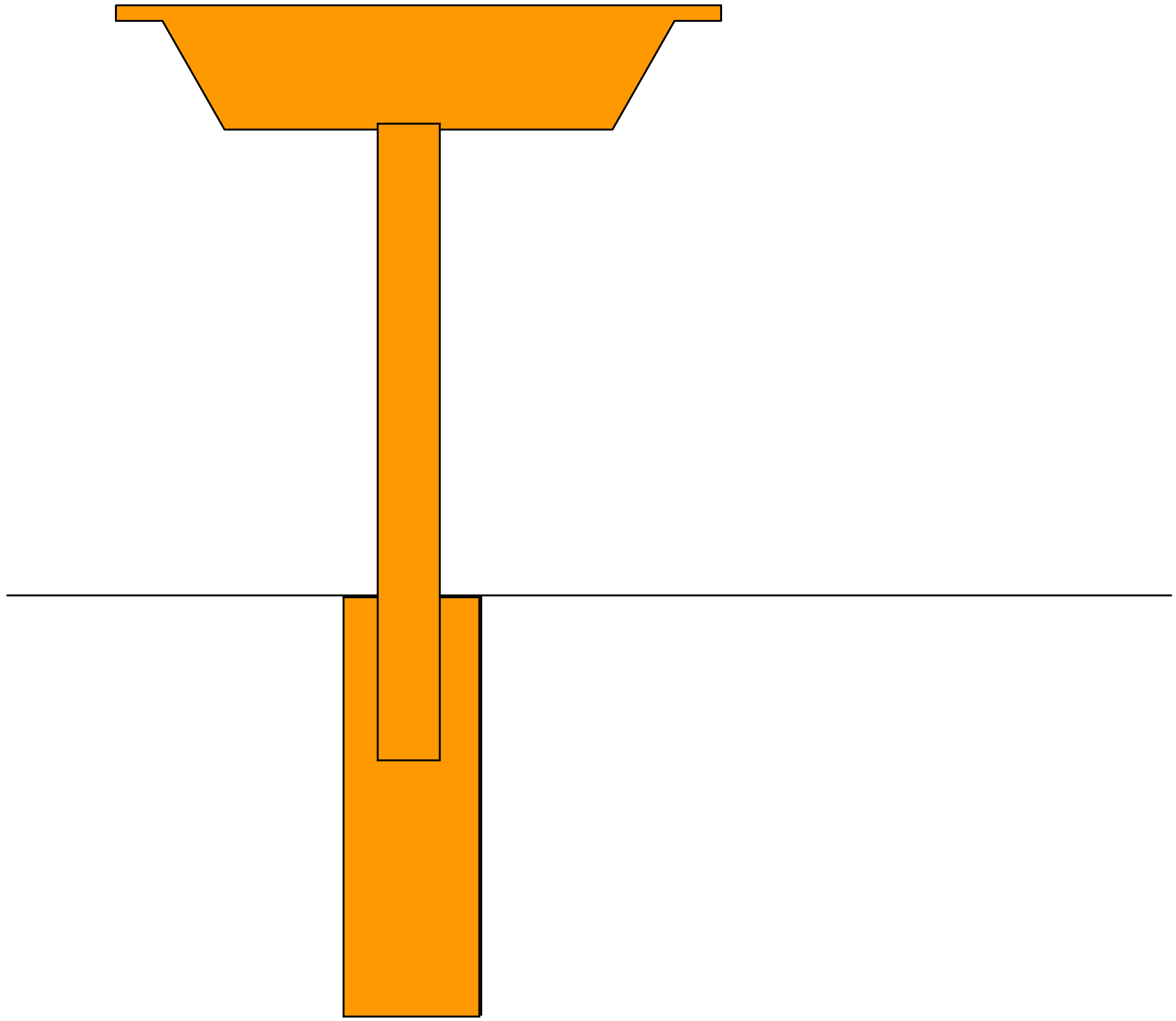
Applications and Types

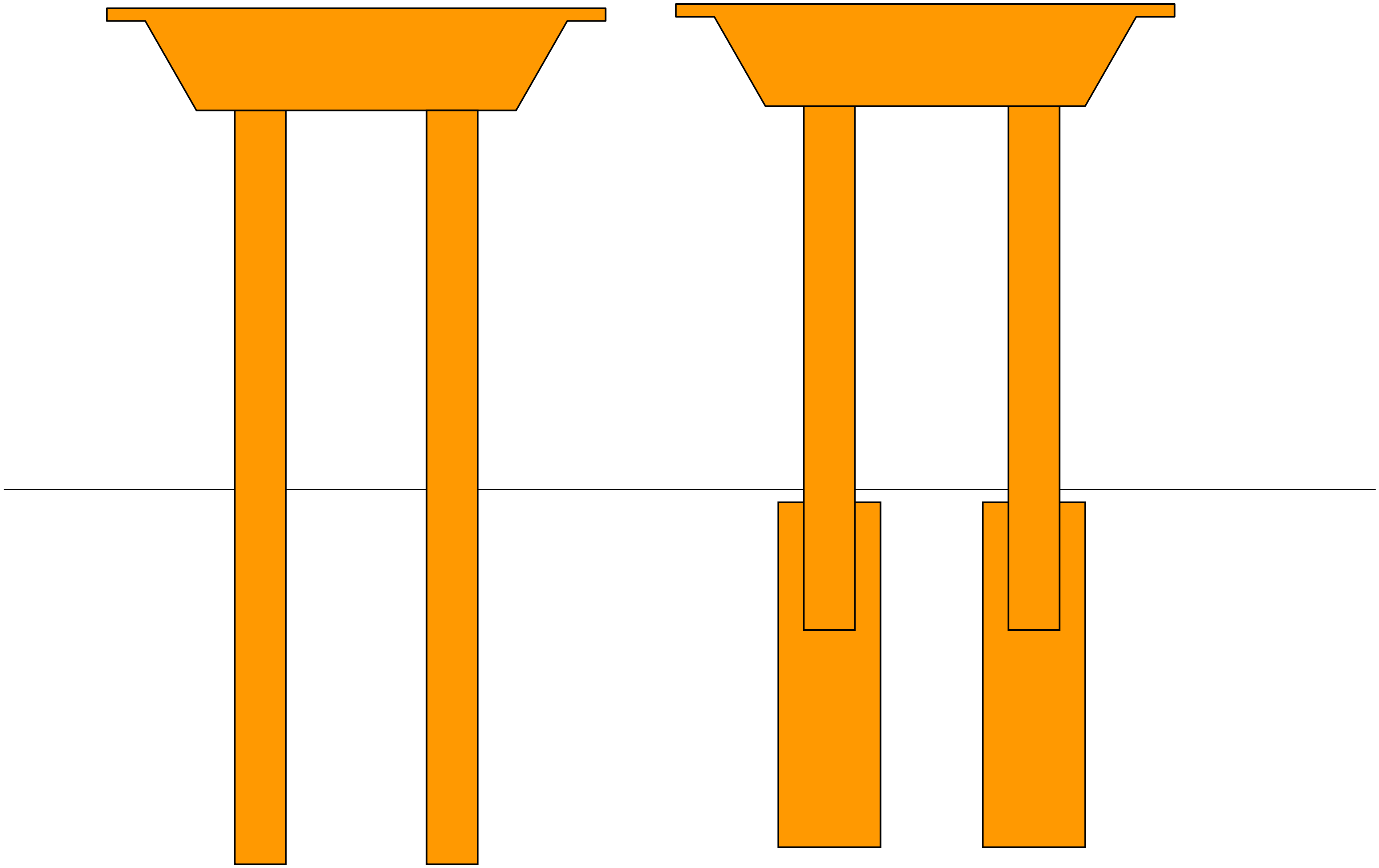
- Used for high seismic loads also where small footprint is desirable
- Most effective where hard layer (rock) is reachable
- Used with/without casing
- Types I & II per SDC classification

Type-I : More ductile performance, advantageous for Short columns

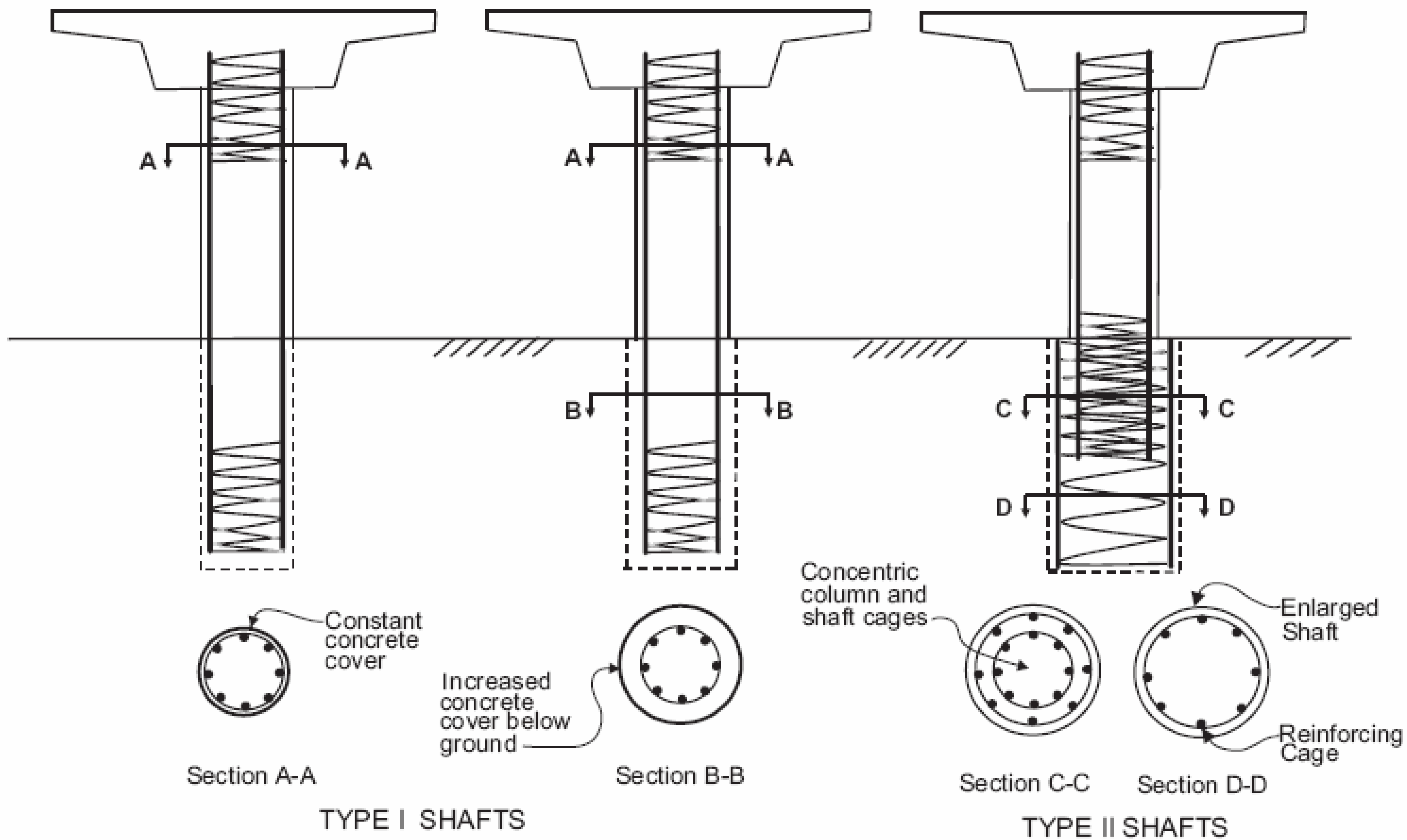
Type-II : Easier post-event repair, shaft enlargement of at least 24" to contain inelastic action to the column…………………..**(SDC 7.7.3.5)**





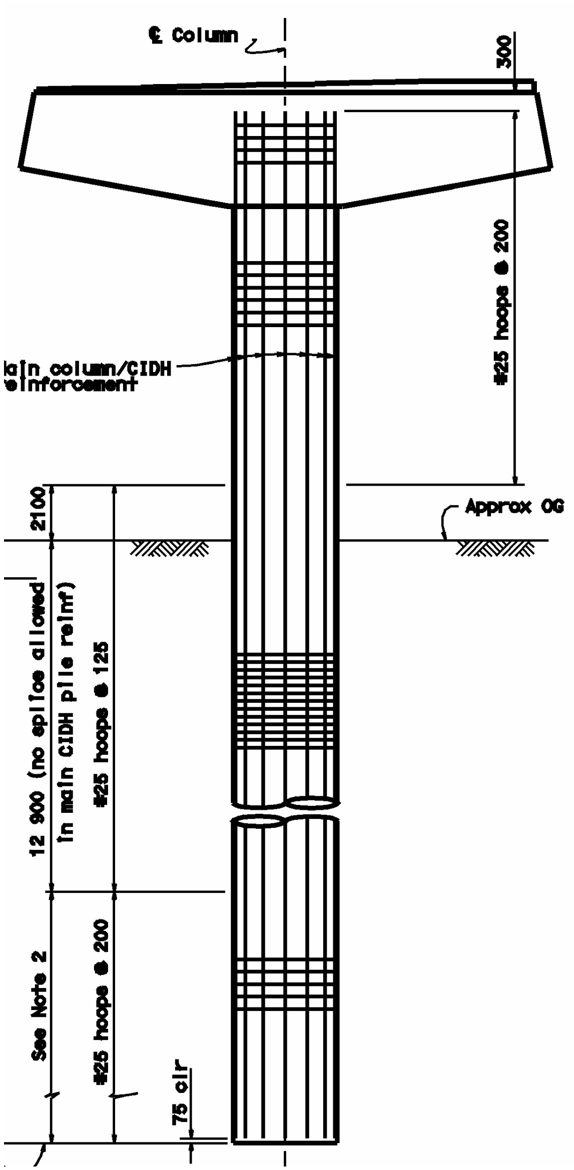


Types of Large Diameter Drilled Shafts (Caltrans SDC)

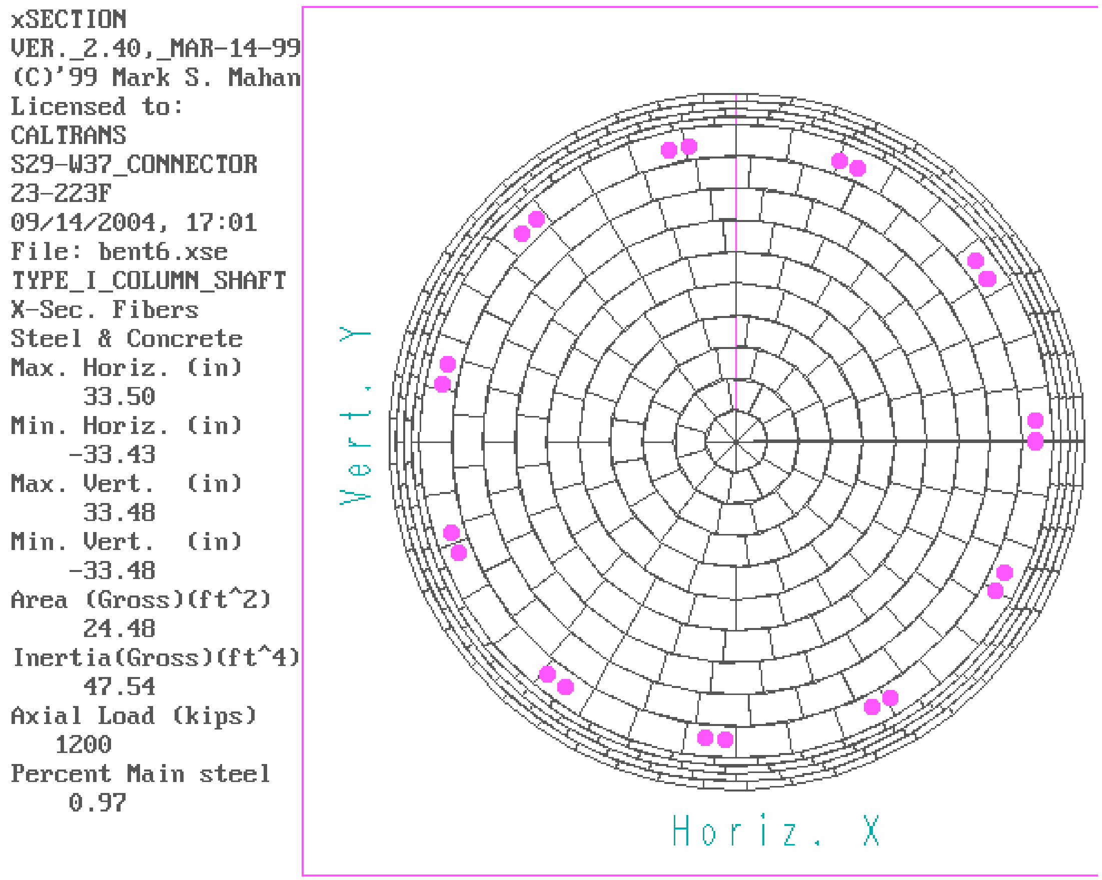


Test of 6' diameter Type-I Shaft at UCLA

Test of 6’ diameter Type-I Shaft at UCLA



℄ Column
300
#25 hoops @ 200
column/CIDH
Approx OG
2100
12 900 (no splice allowed
in main CIDH pile reinf)
#25 hoops @ 125
See Note 2
#25 hoops @ 200
75 clr



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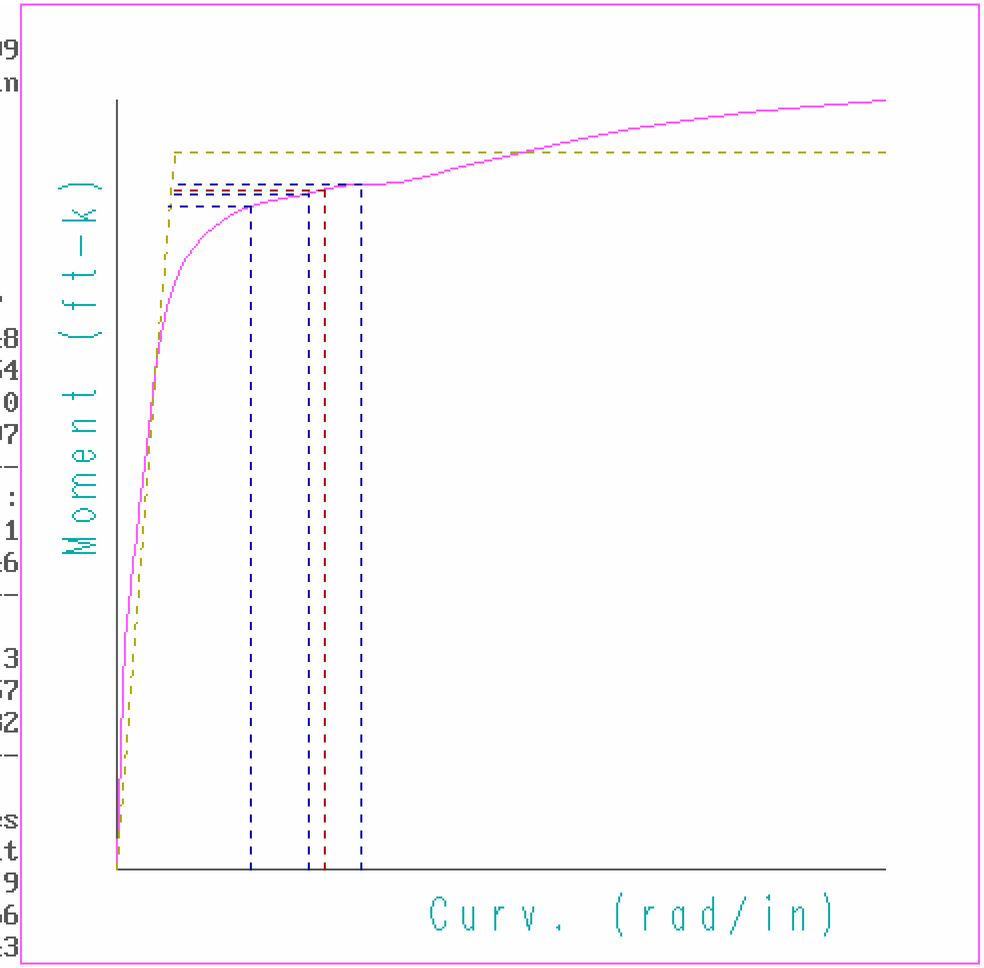
VER._2.40,_MAR-14-99
(C)'99 Mark S. Mahan
Licensed to:
CALTRANS
S29-W37_CONNECTOR
23-223F
09/14/2004, 17:01
File: bent6.xse
TYPE_I_COLUMN_SHAFT
X-Sec. Fibers
Steel & Concrete
Max. Horiz. (in)
33.50
Min. Horiz. (in)
-33.43
Max. Vert. (in)
33.48
Min. Vert. (in)
-33.48
Area (Gross)(ft^2)
24.48
Inertia(Gross)(ft^4)
47.54
Axial Load (kips)
1200
Percent Main steel
0.97
Vert. Y
Horiz. X

xSECTION
VER._2.40,_MAR-14-99
(C)'99 Mark S. Mahan
Licensed to:
CALTRANS
S29-W37_CONNECTOR
23-223F
09/14/2004, 16:53
File: bent6.xse
TYPE_I_COLUMN_SHAFT
Area_G(ft^2)= 24.48
I_G(ft^4)= 47.54
Axial (kips)= 1200.0
Percent steel= 0.97

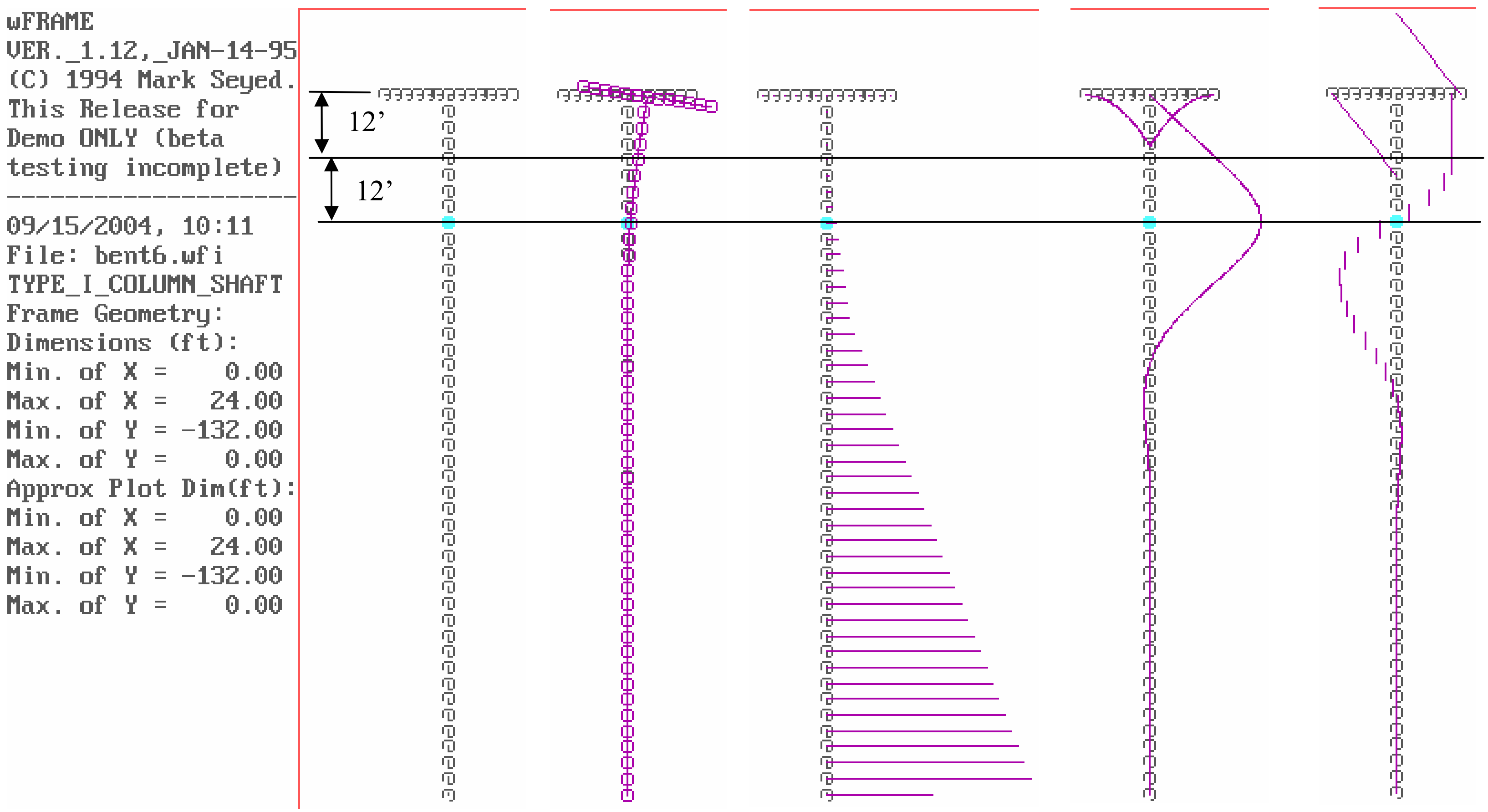
Moment-Curv. Curve :
Mmax ft-k= 8548.1
phi_max = 0.001046

Rebar Yield info:
My (k-ft)= 5705.3
phi_y = 0.000057
Ec (ksi)= 4032

Idealized values:
(CT) dark blue lines
others see print-out
Mp (k-ft)= 7947.9
phi_p = 0.000966
Icr(ft^4)= 14.43



Mp (k-ft)= 7947.9
phi_p = 0.000966
Icr(ft^4)= 14.43


wFRAME
VER._1.12,_JAN-14-95
(C) 1994 Mark Seyed.
This Release for
Demo ONLY (beta
testing incomplete)
09/15/2004, 10:11
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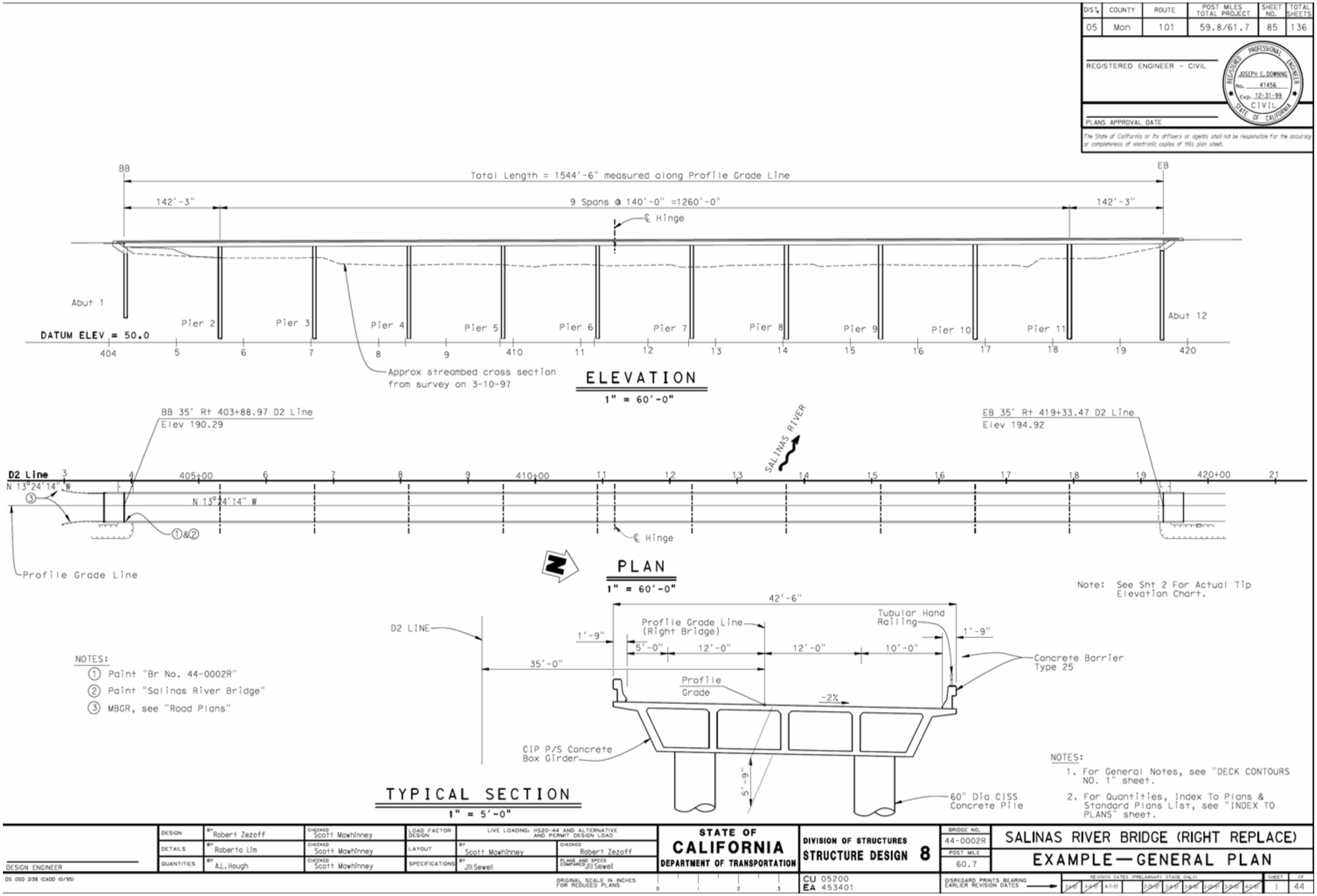
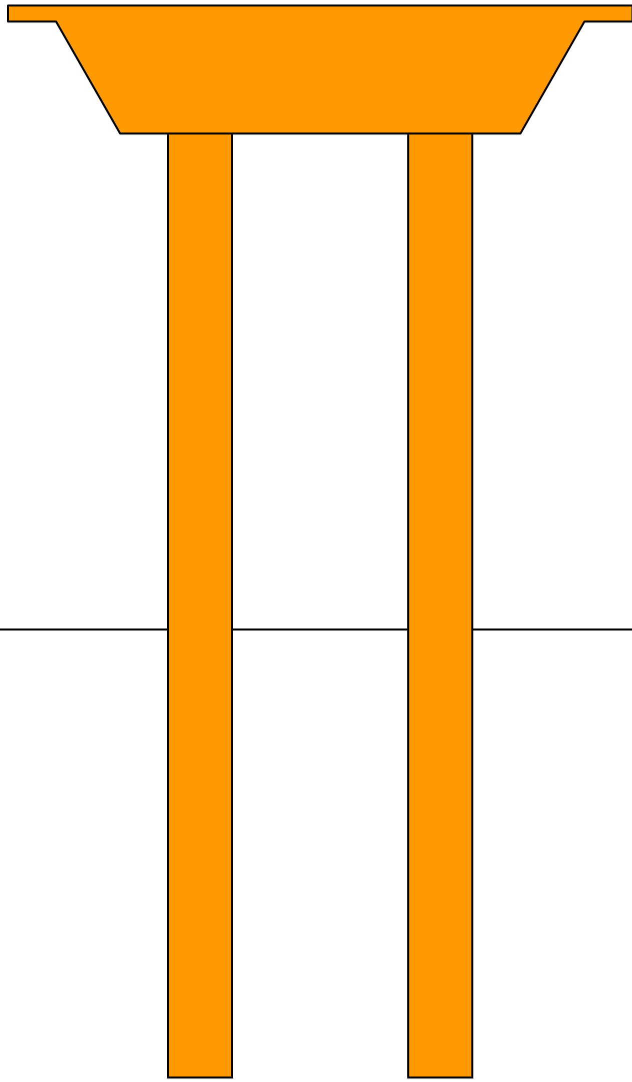
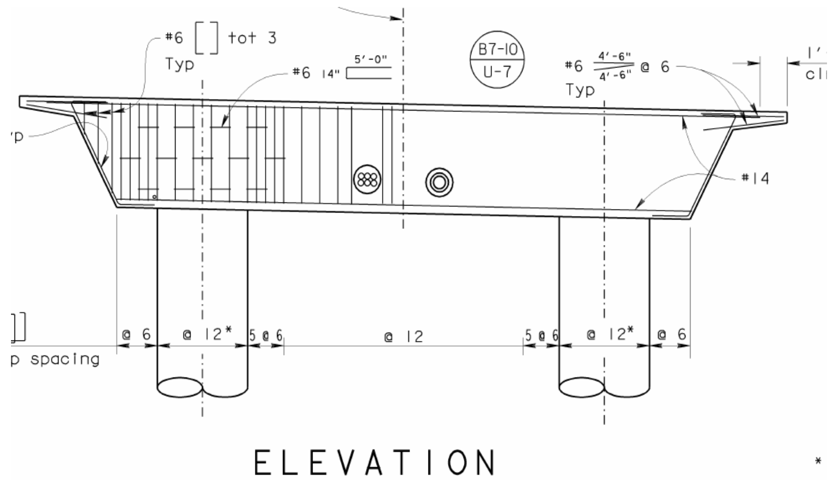
TYPE_I_COLUMN_SHAFT
Frame Geometry:
Dimensions (ft):
Min. of X = 0.00
Max. of X = 24.00
Min. of Y = -132.00
Max. of Y = 0.00
Approx Plot Dim(ft):
Min. of X = 0.00
Max. of X = 24.00
Min. of Y = -132.00
Max. of Y = 0.00
12’
12’

Salinas River Bridge

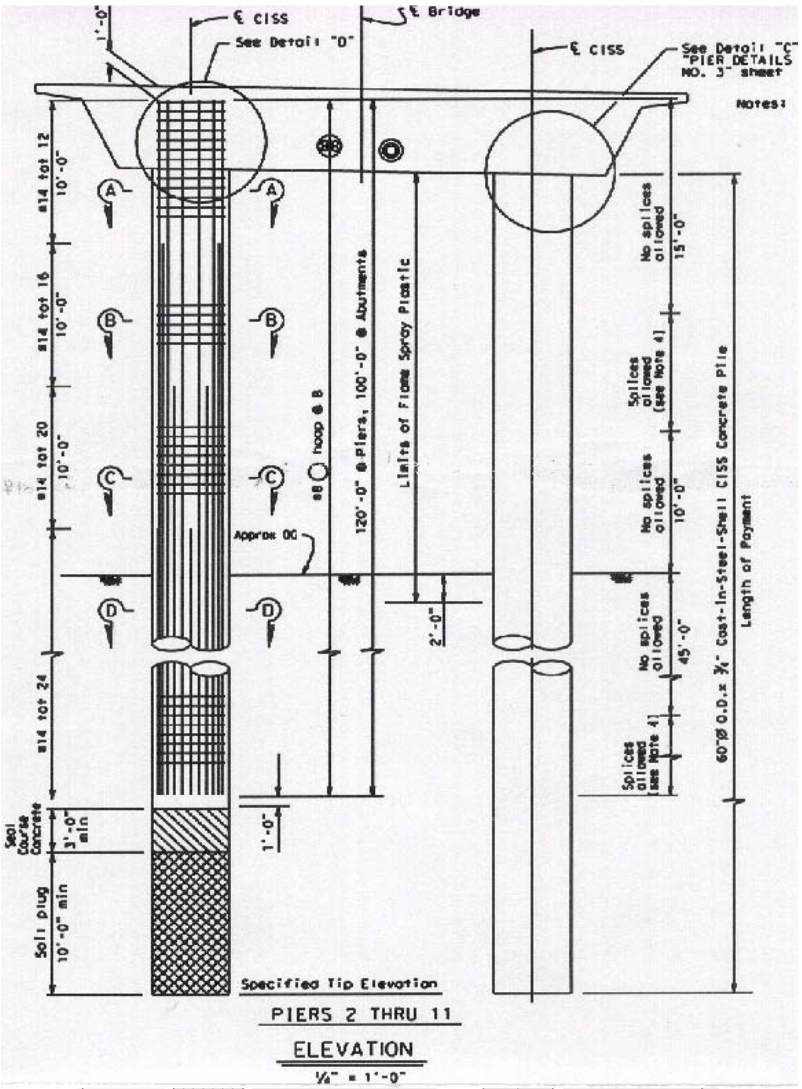


DIST. COUNTY ROUTE POST MILES TOTAL PROJECT SHEET NO. TOTAL SHEETS
05 Mon 101 59.8/61.7 85 136
REGISTERED ENGINEER - CIVIL
PLANS APPROVAL DATE
Total Length = 1544'-6" measured along Profile Grade Line
142'-3"
9 Spans @ 140'-0" =1260'-0"
142'-3"
℄ Hinge
Abut 1
Pier 2
Pier 3
Pier 4
Pier 5
Pier 6
Pier 7
Pier 8
Pier 9
Pier 10
Pier 11
Abut 12
DATUM ELEV = 50.0
Approx streambed cross section from survey on 3-10-97
ELEVATION
1" = 60'-0"
BB 35' Rt 403+88.97 D2 Line Elev 190.29
EB 35' Rt 419+33.47 D2 Line Elev 194.92
SALINAS RIVER
D2 Line
N 13°24'14" W
Profile Grade Line
PLAN
1" = 60'-0"
Note: See Sht 2 For Actual Tip Elevation Chart.
NOTES:
① Paint "Br No. 44-0002R"
② Paint "Salinas River Bridge"
③ MBGR, see "Road Plans"
D2 LINE
42'-6"
Profile Grade Line (Right Bridge)
Tubular Hand Railing
Concrete Barrier Type 25
Profile Grade
-2%
CIP P/S Concrete Box Girder
60" Dia CISS Concrete Pile
TYPICAL SECTION
1" = 5'-0"
NOTES:
1. For General Notes, see "DECK CONTOURS NO. 1" sheet.
2. For Quantities, Index To Plans & Standard Plans List, see "INDEX TO PLANS" sheet.
DESIGN Robert Zezoff CHECKED Scott Mawhinney
DETAILS Roberto Lim CHECKED Scott Mawhinney
QUANTITIES A.L. Hough CHECKED Scott Mawhinney
LIVE LOADING: HS20-44 AND ALTERNATIVE AND PERMIT DESIGN LOAD
STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES STRUCTURE DESIGN 8
BRIDGE NO. 44-0002R
POST MILE 60.7
SALINAS RIVER BRIDGE (RIGHT REPLACE)
EXAMPLE—GENERAL PLAN
CU 05200
EA 453401

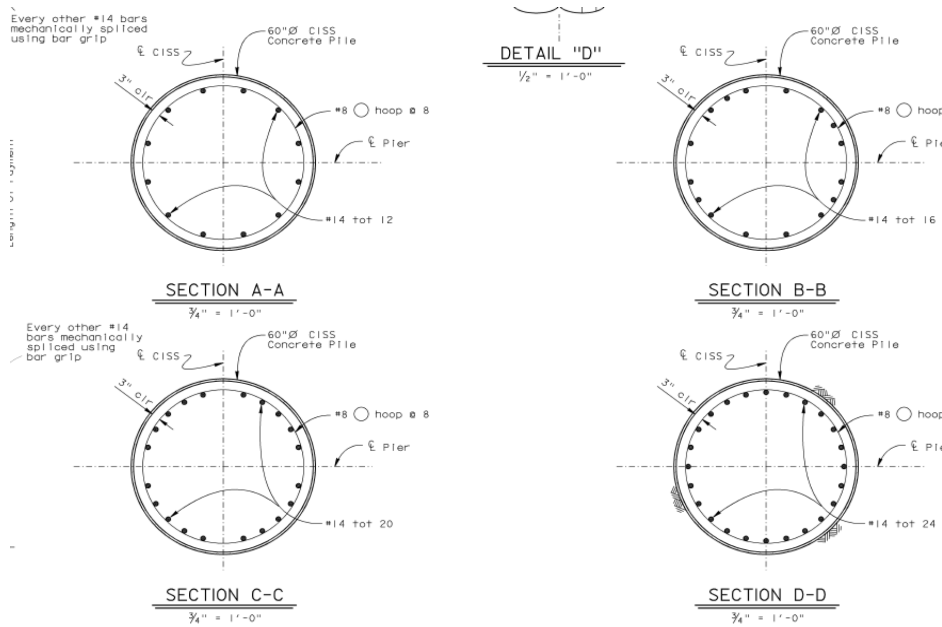




#6 tot 3
Typ
B7-10
U-7
#14
ELEVATION



℄ CISS
See Detail "D"
℄ Bridge
℄ CISS
See Detail "C" "PIER DETAILS NO. 3" sheet
Notes:
#14 tot 12 10'-0"
#14 tot 16 10'-0"
#14 tot 20 10'-0"
#14 tot 24
#8 hoop @ 8
120'-0" @ Piers, 100'-0" @ Abutments
Limits of Flame Spray Plastic
No splices allowed 15'-0"
Splices allowed (see Note 4)
No splices allowed 10'-0"
No splices allowed 45'-0"
Splices allowed (see Note 4)
60"Ø O.D. x ¾" Cast-In-Steel-Shell CISS Concrete Pile
Length of Payment
Approx OG
2'-0"
1'-0"
Seal Course Concrete 3'-0" min
Soil plug 10'-0" min
Specified Tip Elevation
PIERS 2 THRU 11
ELEVATION
¼" = 1'-0"



Every other #14 bars mechanically spliced using bar grip
60"Ø CISS Concrete Pile
℄ CISS
3" clr
#8 hoop @ 8
℄ Pier
#14 tot 12
SECTION A-A
¾" = 1'-0"
DETAIL "D"
½" = 1'-0"
#14 tot 16
SECTION B-B
¾" = 1'-0"
#14 tot 20
SECTION C-C
¾" = 1'-0"
#14 tot 24
SECTION D-D
¾" = 1'-0"

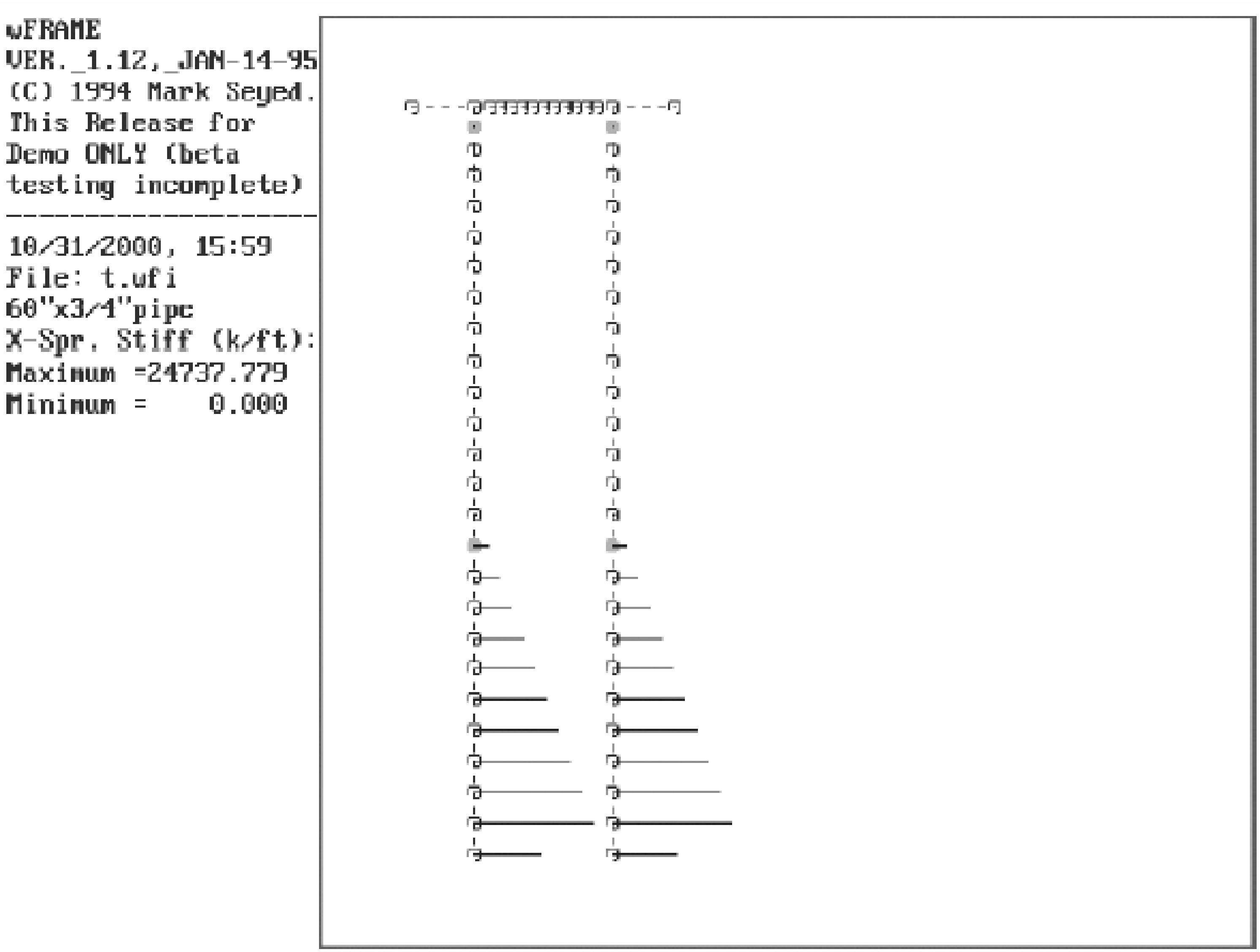


Figure II-C-16- Soil-Structure Interaction (p-y) Springs

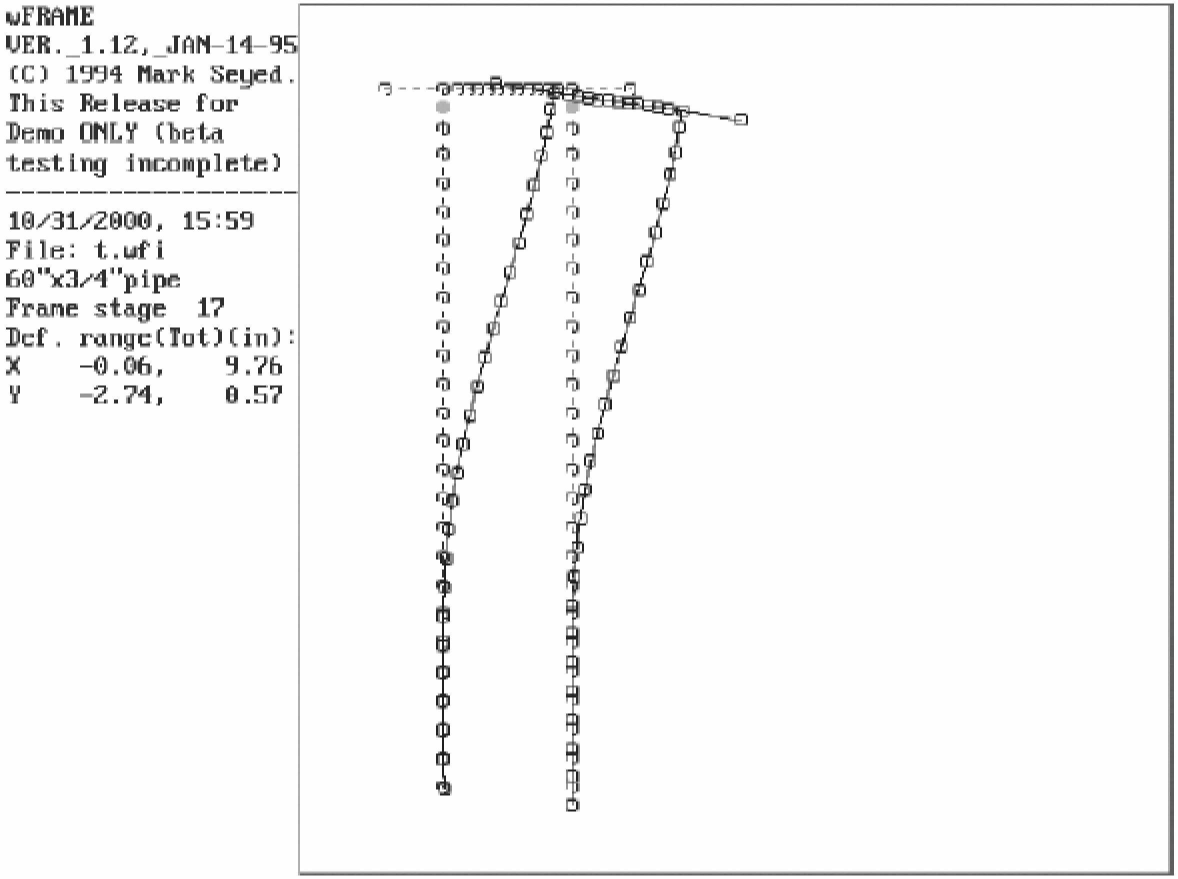


Figure II-C-13- Deflected Shape of Bent at Formation of Top Two Plastic Hinges

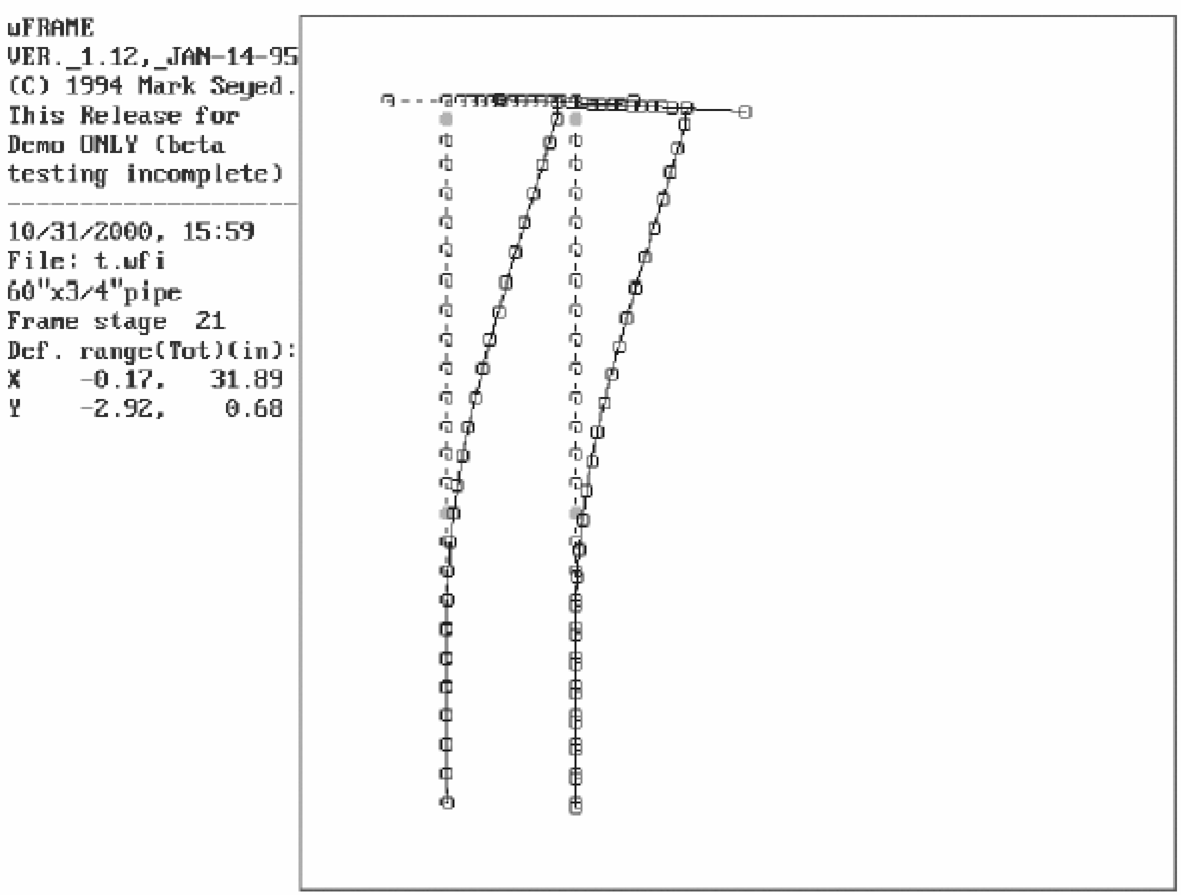


Figure II-C-14- Deflected Shape of Bent at Formation of Bottom Two Plastic Hinges

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(C) 1994 Mark Seyed.
This Release for
Demo ONLY (beta
testing incomplete)
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10/31/2000, 15:59
File: t.wfi
60"x3/4"pipe
Dead Load(k)= 1912.4
Frame Lat. Strength:
Loc/Stage/Force/Defl
       #     *g     in
P01X02 13 0.05  2.27
P02X02 14 0.05  2.32
P01X03 15 0.07  3.34
P02X03 16 0.08  3.37
C01-02 17 0.20  9.76
C02-02 17 0.20  9.76
P01X01 18 0.23 12.13
P02X01 18 0.23 12.13
P01X02 19 0.28 17.62
P02X02 19 0.28 17.62
P01X03 20 0.36 27.21
P02X03 20 0.36 27.21
P01-04 21 0.41 31.89
P01-05 21 0.41 31.89
P02-04 21 0.41 31.89
P02-05 21 0.41 31.89
```

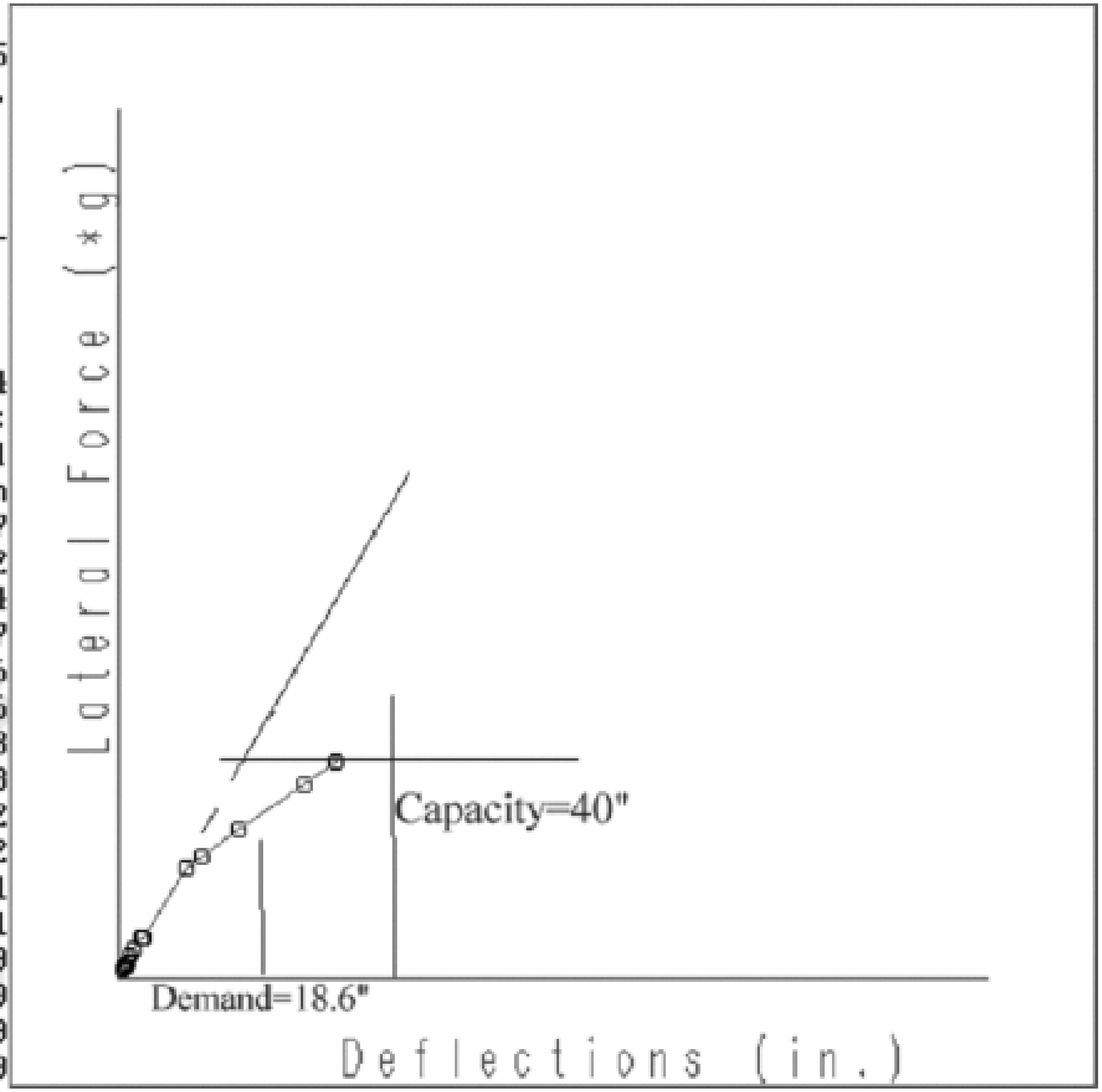
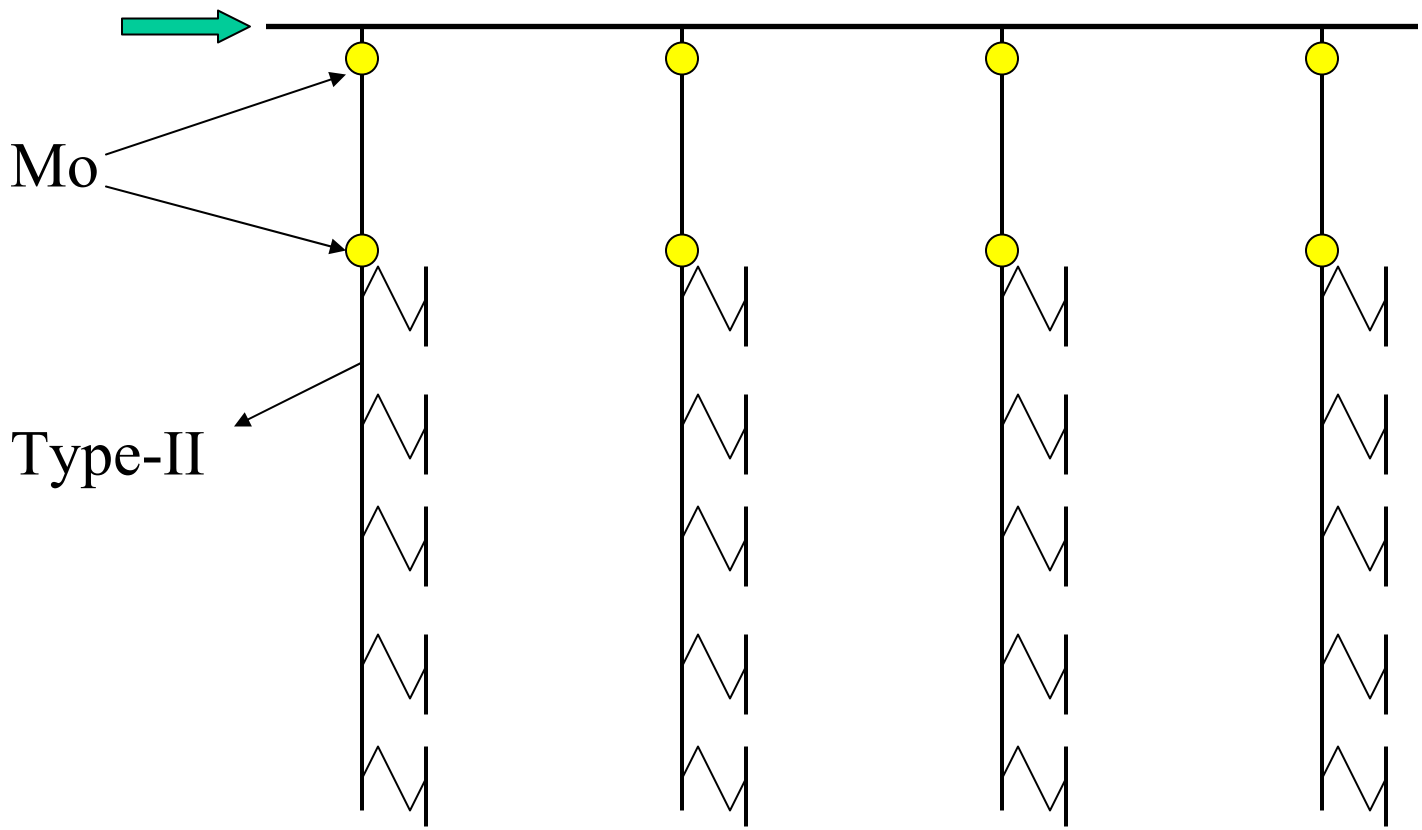


Figure II-C-15- Force-Deflection Curve for the Two-Column Bent

Seismic Demand Calculation
(Multi-Column Bent)



Note: For Type-I, the first hinge must form in the column, and the second hinge in the shaft

Design Procedure - Type-II

- Strength Check

$$1.25\ M_{max} \leq\ M_{ne}$$
$$V_{max} \leq \varphi\ V_n$$

- Maximum Ductility Demand Check

μ_D of column is checked against the Target values of SDC 2.2.4

- P-Δ Check

$$P_D\ .\ \Delta r \leq 0.2\ (M_p^{col})$$

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  http://www.dot.ca.gov/hq/esc/techpubs/manual/othermanual/other-engin-manual/seismic-design-criteria/sdc.html
- Seismic Detailing of Pile Shafts
- General Design Requirements (LRFD)
- Inspection and Structural Evaluation of Defective Shafts

Seismic Detailing Requirements

- No Splice Zones (SDC 8.1.1)

  Plastic hinge region and areas of $M_D > M_y$
- Ultimate Splices (SDC 8.1.2)

  Ductile members outside "No Splice Zone"
- Service Splice (MTD20-9)

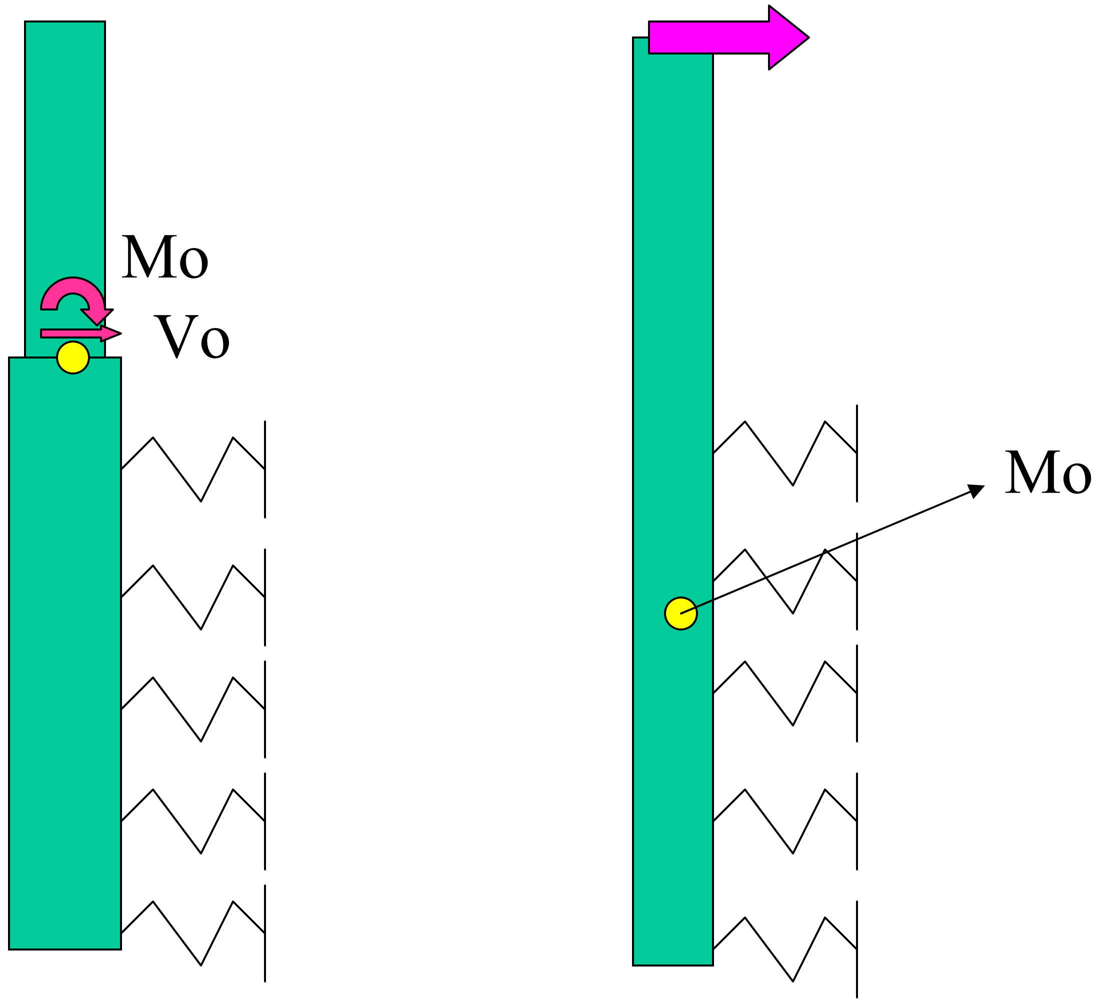
  Capacity Protected Members like Type-II Shaft
- For Hoops and Spirals in Ductile Members Use Ultimate Splices, Except:

  No splices in **spirals** used in "No Splice Zones" (end anchorage has been used to improve constructability)

General Design Requirements (LRFD)

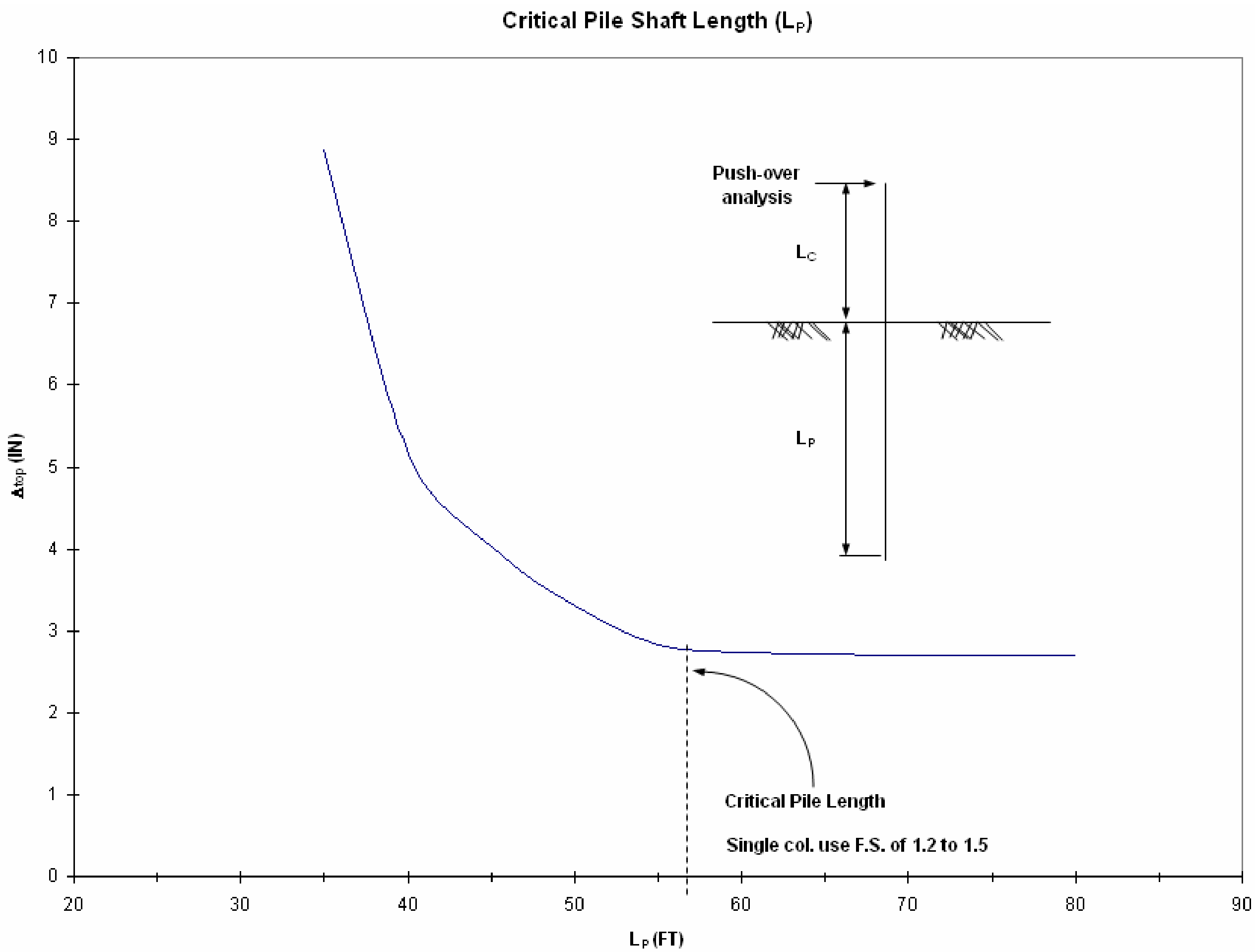
- Structural Designer provides Factored Loads for applicable Limit States
- Geotechnical Designer will provide tip elevations based on Compression, Tension, and Settlement
- Structural Designer performs **Stability Analysis** and provides tip elevation for Lateral Loads
- Scour, Liquefaction and Lateral Spreading are considered in design (if applicable)

Demand Calculation (Single Column Bent)



Lateral Stability

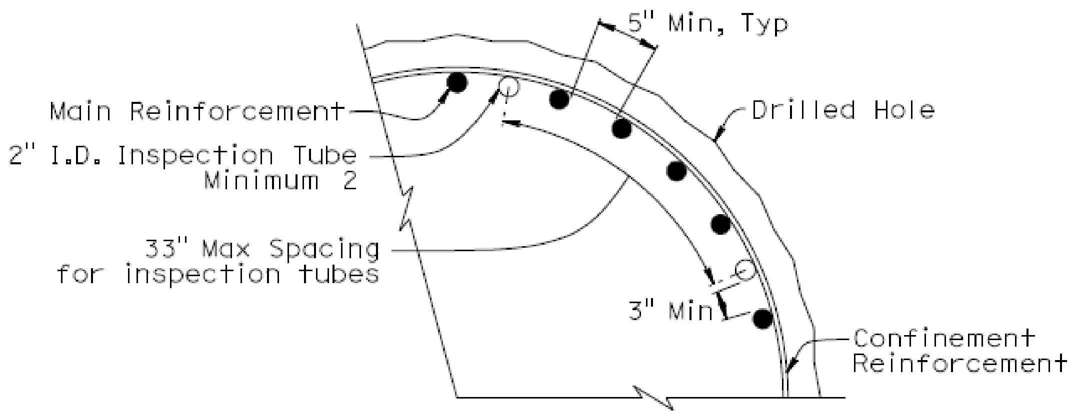
Available Software: LPILE, W-FRAME, or SAP



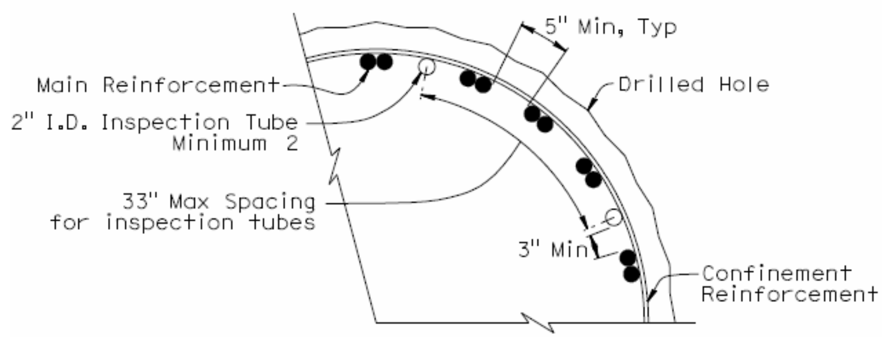
Inspection and Structural Evaluation of Defective Shafts

- Shafts 24 inches in diameter or larger must be inspected unless the holes are dry or dewatered without use of temporary casing
- Gamma-Gamma Logging is commonly used. Cross-hole Sonic Logging (CSL) may be used as complement.
- If anomaly is detected the pile is rejected and it will be subject to evaluation by Structural, Geotechnical and Corrosion units in Caltrans.
- Structural Designer has to accept or reject the pile (fast review)

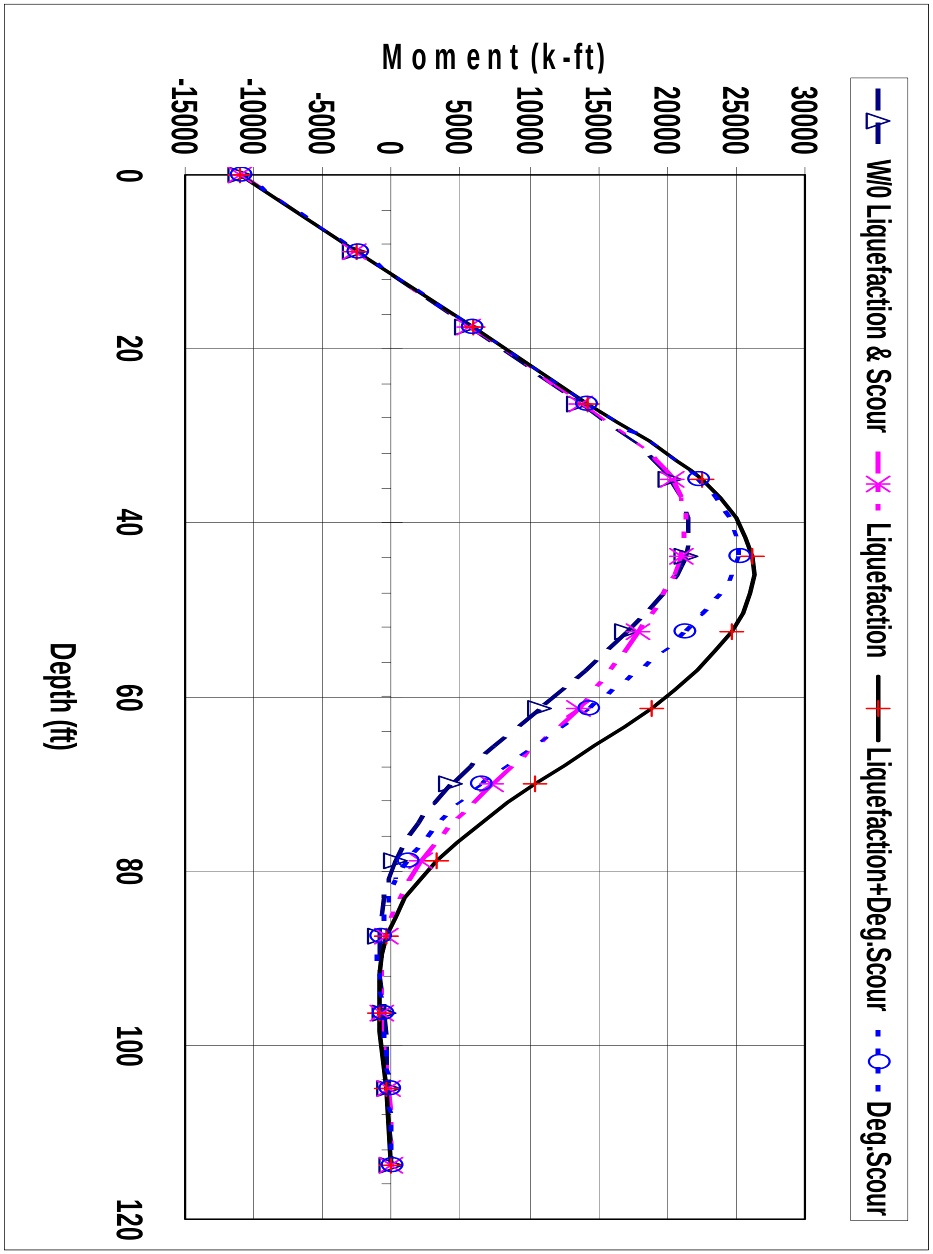
Inspection Tubes layout



PARTIAL PLAN VIEW

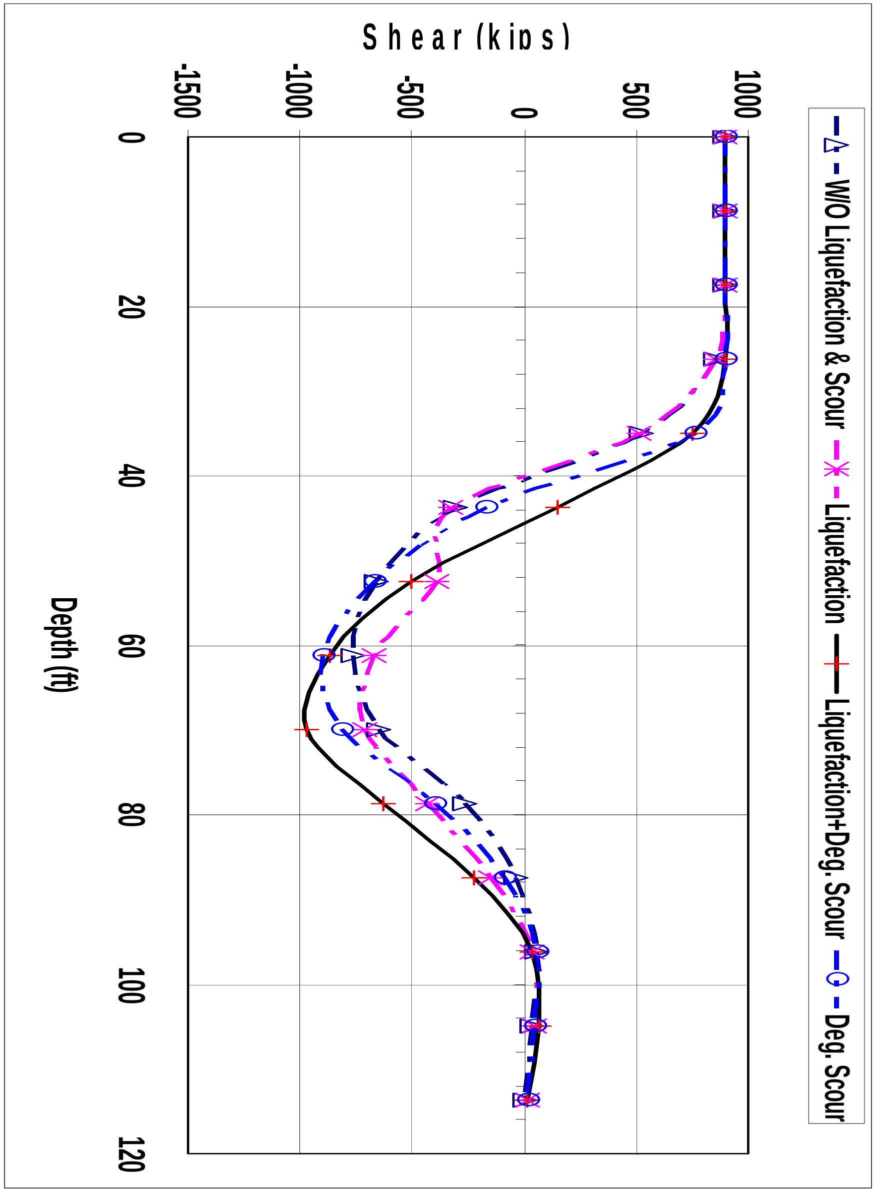


PARTIAL PLAN VIEW
BUNDLED BARS



Moment Diagram (Type-II Example)

Calculate M_D at location of the defect



Shear Diagram (Type-II Example)

Calculate V_D at location of the defect

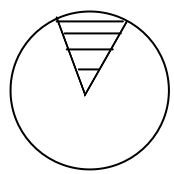
Evaluation of Type-II Shafts

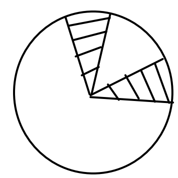
- The moment and shear checks are summarized as:

$$M_D \le M_{ne}$$

$$V_D \le \varphi V_n$$

One tube with low reading



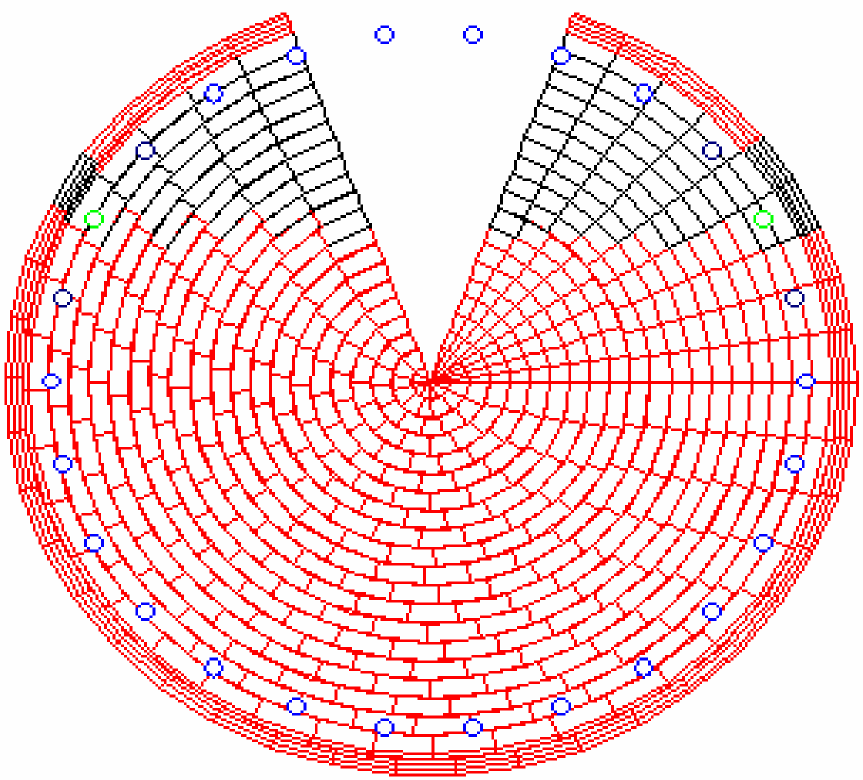


Two tubes with low readings

In general, moment should be applied in different directions to capture the minimum flexural capacity.

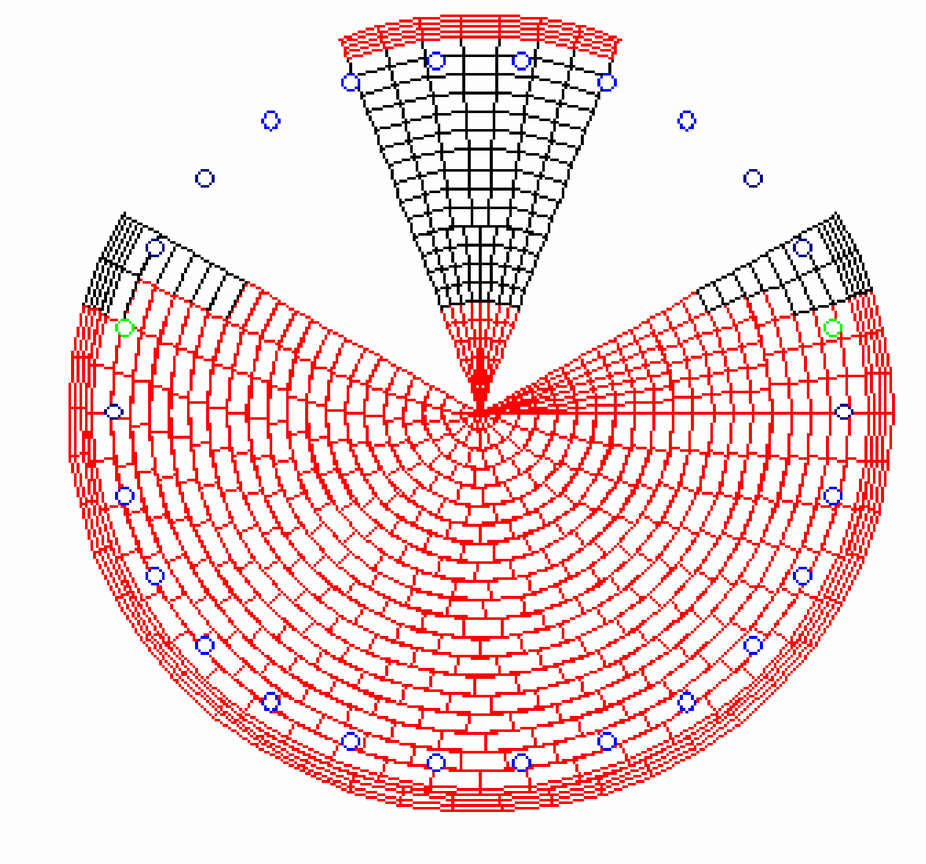
Evaluation of CIDH Shafts

One tubes with low reading



Evaluation of CIDH Shafts

Two tubes with low readings



Evaluation of Type-I Shafts

– Seismic moment demand (M_D) at the location of the anomaly should be less than:

1.25Mp for multicolumn bents

1.15Mp for single column bents

Where, *Mp* is the plastic moment of the reduced shaft cross section at the location of the anomaly.

– Seismic shear demand at the location of the anomaly shall be less than the factored nominal shear resistance of the pile (φV_n)

Compression Resistance Check (Types I & II)

- Factored nominal compression resistance of the pile at the anomaly location is calculated based on the reduced cross sectional area of the pile per LRFD.

$$P_u \leq \Phi P_n$$

Where $\Phi = 0.85$ and:

$$P_n = 0.85[0.85f'_c\,(A_g - A_{st}) + f_y A_{st}]$$

Pile Mitigation

- Shaft must be repaired, supplemented, or replaced if it is inadequate.
- Shaft can be stayed without repair if it is structurally adequate. However the contractor will pay administrative deduction (disincentive).

Thank You