9 DETAILED DESIGN OF FOUNDATIONS

9.1 BEARING CAPACITY – PIER PILES

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9.3 STRUCTURAL DESIGN OF PIER PILE FOUNDATIONS

9.3.1 FLEXURAL DESIGN

9.3.2 SHEAR DESIGN

9.4 STRUCTURAL DESIGN OF ABUTMENT PILE FOUNDATIONS

9.4.1 FLEXURAL DESIGN

9.4.2 SHEAR DESIGN

Notes on Bearing Capacity (refer Design Criteria)

(1) General

The total ultimate bearing capacity Q_R of a pile shall be in accordance with the following:

$$Q_R := \eta \cdot (\phi p Q_p + \phi s Q_s)$$

where:

η	=	efficiency of pile group (see Section 3.3.1)
ϕ_p	=	resistance factor for base resistance
ϕ_s	=	resistance factor for shaft resistance
Q_p	=	ultimate base resistance $Q_p = q_p \cdot A_p$ q_p = unit base resistance
Q_s	=	ultimate shaft resistance $Q_s = \sum q_s \cdot C_P \cdot L_i$ q_s = unit shaft resistance
A_p	=	cross sectional area of pile
C_p	=	perimeter of pile
L_i	=	incremental length of pile included in summation

Where the methods to determine base or shaft resistance make reference to undrained shear strength, S_u, of cohesive soils, the following SPT correlations will be used, subject to confirmation through testing of undisturbed samples:

S_u = 5 x SPT "N" value — for bored piles

S_u = 10 x SPT "N" value — for driven piles

For pile groups founded in clay a check will also be made on resistance assuming that the pile group behaves as a block.

(2) Unit Base Resistance in Cohesive Soil - Bored Piles

The unit base resistance in cohesive soils shall be determined as follows:

$$q_p = N_c \cdot S_u \leq 4.0\text{MPa}$$

where:

N_c	=	bearing capacity factor $N_c = 6 \cdot \left(1 + 0.2 \cdot \left(\frac{Z}{D}\right)\right) \leq 9$
S_u	=	Un-drained shear strength of soil
Z	=	depth of soil at pile tip
D	=	diameter of pile

If the soil within 2.0 diameters of the pile tip has S_u < 0.024 MPa, the value of N_c shall be reduced by one-third.

For bored piles in clays with S_u > 0.096 MPa with D > 1900mm, and for which shaft settlements will not be evaluated, the value of q_p shall be reduced to q_{pr} as follows:

$$q_{pr} = q_p \cdot F_r$$

where:

$$F_r = \frac{760}{12.0aD_p + 760b} \leq 1.0$$

$$a = 0.0071 + 0.0021\frac{Z}{D_p} \leq 0.015$$

$$b = 1.45\sqrt{2.0S_u}$$

with $0.5 \leq b \leq 1.5$

where:

D_p = base diameter (mm)

(3) Unit Base Resistance in Cohesion-less Soil – Bored Piles

The unit base resistance in cohesion-less soils shall be determined using the Reese and O'Neill method as follows:

$$q_p = 0.057 \cdot N_{SPT} \leq 4.3MPa$$

where:

N_{SPT} = uncorrected SPT value at the pile base

For base diameters greater than 1270mm, q_p shall be reduced as follows:

$$q_{pr} = \frac{1270}{D_P} \cdot q_p$$

where:

D_p = diameter of bored pile (in mm)

(4) Unit Shaft Resistance in Cohesive Soil – Bored Piles

The unit shaft resistance in cohesive soils shall be determined as follows:

$$q_s = \alpha \cdot S_u$$

where:

α = adhesion factor correlated against S_u as follows:

α	S_u
0.55	< 0.2 MPa
0.49	0.2 MPa < S_u < 0.3 MPa

0.42	0.3 MPa < S_u < 0.4 MPa
0.38	0.4 MPa < S_u < 0.5 MPa
0.35	0.5 MPa < S_u < 0.6 MPa
0.33	0.6 MPa < S_u < 0.7 MPa
0.32	0.7 MPa < S_u < 0.8 MPa
0.31	0.8 MPa < S_u < 0.9 MPa

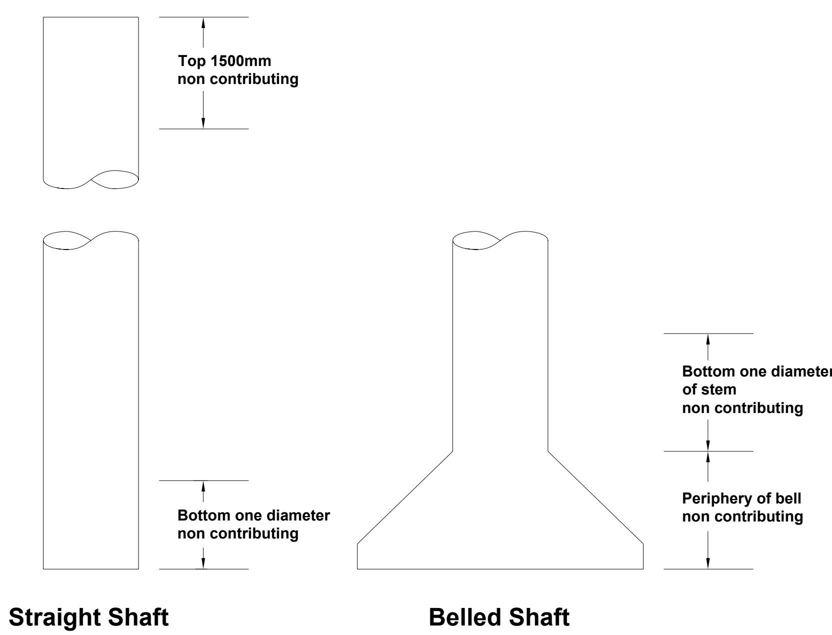
for un-drained shear strengths in excess of 0.9MPa, treat as rock

S_u = Un-drained shear strength of soil

The following portion of a bored pile, illustrated below, shall not be taken to contribute to the development of resistance through skin friction:

- At least the top 1500mm of any bored pile;
- For straight bored piles, a bottom length of the shaft taken as the shaft diameter;
- Periphery of belled ends, if used; and
- Distance above a belled end taken as equal to the shaft diameter.

In the case that un-drained shear strength has been determined from correlation the SPT, contributions from soil layers with SPT less than 2 will be ignored and the unit shaft resistance will be limited such that q_s < 100kN/m2.



PORTIONS OF BORED PILE NOT CONSIDERED

(5) Unit Shaft Resistance in Cohesion-less Soil – Bored Piles

The unit shaft resistance in cohesion-less soils shall be determined using the Reese and O'Neill method as follows:

$$q_s = \beta \cdot \sigma_v^{'} \leq 0.19MPa$$

where:

β	=	$1.5 - 7.7 \cdot 10^{-3} \cdot \sqrt{z}$
		$0.25 \leq \beta \leq 1.20$
$\sigma_v^{'}$	=	effective stress
z	=	depth below ground (in mm)

(6) Unit Shaft and Base Resistance in Rock or Intermediate Geomaterials

In determining the axial resistance of bored piles with rock sockets, the side resistance from overlying soil deposits shall be ignored.

The unit shaft and base resistance of piles in rock or intermediate geomaterials will be determined based on the methods given in FHWA-IF-99-025, including the methods established for rock by Carter and Kulhawy, Horvath and Kenny and the Canadian Geotechnical Society.

(7) Lateral Bearing Capacity

Lateral bearing capacity of the soils supporting the bored piles is taken into account in the analysis of the soil-structure interaction. The analysis makes use of non-linear ground springs distributed over the length of the pile with appropriate limiting horizontal reactions modeled at each level to represent the ultimate factored bearing capacity. Refer to Section 3.5 for details of the calculations of the ground spring values over the depth of the pile and to Section 10.2 for details of the soil-structure analysis.

(8) Resistance Factors – Bored Piles

Resistance factors for geotechnical strength limit state for axially loaded bored piles are given below.

RESISTANCE FACTORS FOR BORED PILES

Type of Loading	Component of Resistance/ Geo-material	Resistance Evaluation Method	Resistance Factor
Compression for Single Bored Pile	Side / Clay	a method	0.65
	Base / Clay	N_c S_u	0.55
	Side / Sand	Reese and O'Neill method (β method)	0.65
	Base / Sand	Reese and O'Neill method	0.50
	Side / Rock	Carter and Kulhawy method	0.55
		Horvath and Kenny method	0.65
	Base / Rock	Canadian Geotechnical Society Method	0.50
Compression on a Bored Pile Group	Clay	Block Failure	0.65
Uplift for Single Bored Pile	Clay	a method – for straight shafts	0.55
	Sand	Reese and O'Neill method (β method)	0.65
Uplift for Single Bored Pile	Rock	Carter and Kulhawy method	0.45
		Horvath and Kenny method	0.55
Uplift on Bored Pile Group	Sand or Clay	Sum of individual pile uplift resistance or uplift resistance of pile group considered as a block.	0.55

9.1 BEARING CAPACITY – PIER PILES

TABLE: Pile Reactions - SUMMARY AXIAL LOAD

Frame	**Max Reaction Comb 1 (Live Load)**	**Max Reaction Plastic Hinging**	**Min Reaction Comb 1 (Live Load)**	**Min Reaction Plastic Hinging**	**Pile Dia**	**Min Pile Length Required**	**Bearing Capacity**	**Uplift Capacity**
	kN	kN	kN	kN	m	m	kN	kN
P1	5347.5	**5586.8**	3004.3	-706.6	1.5	**20**	**6461**	**-4129**
P2	5647.0	**5846.4**	3305.9	-541.3	1.5	**20**	**6354**	**-4038**
P3	**9664.2**	4451.8	5745.3	4451.8	2.5	**21**	**10523**	**-7220**
P4	**13899.7**	6743.7	8389.0	6743.7	2.5	**29**	**14072**	**-10793**
P5	**13908.1**	6743.7	8394.2	6743.7	2.5	**29**	**14829**	**-11434**
P6	4908.6	**5399.2**	2669.0	-816.5	1.5	**18**	**5657**	**-3397**
P7	5734.9	**6203.4**	3285.1	-1243.0	1.5	**<u>23</u>**	**6472**	**-3645**
P8	**5229.8**	5153.0	2681.6	-516.1	1.5	**20**	**5421**	**-3249**
P9	**5612.5**	5653.5	2951.3	-659.3	1.5	**20**	**6107**	**-3829**

Average length 1.5m piles 20.2

Average length 2.5m piles 26.3

KATAHIRA & ENGINEERS INTERNATIONAL

Project: **Detailed Design Study of North Java Flyover Project**

Calculation: **Detailed Design**
Balaraja Flyover - Pier P1
1.5m Dia. BORED PILE AXIAL BEARING CAPACITY

Reference : **AASHTO LRFD Bridge Design Specification**
"Drilled Shafts: Construction Procedures and Design Methods"
FHWA-IF-99-025, August 1999

Definitions $kN := 1000 \cdot N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $kPa := 1000 \cdot Pa$

Pile Input Data

Pile Diameter	D (m)	1.50
Length of Pile	L (m)	20.00
Elevation at top of Pile	ElevTop (m)	-1.50
Effective Soil Density	γ (kN/m3)	10.00
Pile Cap 1. In firm contact with the ground 2. Not in firm contact with the ground		2
Pile center-to-center spacing	ctc (m)	6.000
Settlements evaluated?	(Y or N)	N

$D := D \cdot m$ $L := L \cdot m$ $ElevT := ElevT \cdot m$ $\gamma_{soil} := \gamma_{soil} \cdot \frac{kN}{m^3}$ $ctc := ctc \cdot m$

Subsoil Input Data - BOREHOLE BH 5

Ref.	Thickness	Level top of Layer	Level bottom of Layer	Soil Type	SPT N
	(cm)	(m)	(m)		
1.0	200	0.00	-2.00	Clay	0
2.0	200	-2.00	-4.00	Clay	13
3.0	200	-4.00	-6.00	Clay	15
4.0	200	-6.00	-8.00	Clay	14
5.0	200	-8.00	-10.00	Clay	41
6.0	200	-10.00	-12.00	Clay	50
7.0	300	-12.00	-15.00	Clay	50
8.0	400	-15.00	-19.00	Clay	50
9.0	500	-19.00	-24.00	Clay	50
10.0	800	-24.00	-32.00	Clay	50

$Lsoil_t := Lsoil_{top} \cdot m$ $Lsoil_b := Lsoil_{bottom} \cdot m$ $Depth := Depth \cdot cm$

COHESIVE SOILS - Shaft Resistance Using the α method (10.8.3.3.1)

$$q_{sc}(\alpha, S_u) := \begin{cases} 100\cdot kPa & \text{if } \alpha\cdot S_u > 100\cdot kPa \\ \alpha\cdot S_u & \text{otherwise} \end{cases}$$ (10.8.3.3.1-1)

(JRA Table C.10.4-4)

$$S_u(SPT) := 5\cdot SPT\cdot kPa$$

$$\alpha(S_u) := \begin{cases} 0.55 & \text{if } S_u < 0.2\cdot MPa \\ 0.49 & \text{if } (S_u \ge 0.2\cdot MPa)\cdot(S_u < 0.30\cdot MPa) \\ 0.42 & \text{if } (S_u \ge 0.3\cdot MPa)\cdot(S_u < 0.40\cdot MPa) \\ 0.38 & \text{if } (S_u \ge 0.4\cdot MPa)\cdot(S_u < 0.50\cdot MPa) \\ 0.35 & \text{if } (S_u \ge 0.5\cdot MPa)\cdot(S_u < 0.60\cdot MPa) \\ 0.33 & \text{if } (S_u \ge 0.6\cdot MPa)\cdot(S_u < 0.70\cdot MPa) \\ 0.32 & \text{if } (S_u \ge 0.7\cdot MPa)\cdot(S_u < 0.80\cdot MPa) \\ 0.31 & \text{if } (S_u \ge 0.8\cdot MPa)\cdot(S_u < 0.90\cdot MPa) \\ \text{"Treat as Rock"} & \text{otherwise} \end{cases}$$ (Table 10.8.3.3.1-1)

COHESIVE SOILS - Tip Resistance (10.8.3.3.2)

$$q_{pc}(N_c, S_u) := \begin{cases} N_c\cdot S_u & \text{if } N_c\cdot S_u \le 4.0\cdot MPa \\ 4.0\cdot MPa & \text{otherwise} \end{cases}$$ (10.8.3.3.2-1)

$$N_c(Z, SPT) := \begin{array}{|l} N_c \leftarrow 6\cdot\left[1 + 0.2\cdot\left(\frac{Z}{D}\right)\right] \\ N_c \leftarrow \frac{N_c}{3} \ \text{ if } 5\cdot SPT\cdot kPa < 0.024\cdot MPa \\ N_c \ \text{ if } N_c \le 9 \\ 9 \ \text{ otherwise} \end{array}$$ (10.8.3.3.2-2)

COHESIONLESS SOILS - Shaft Resistance Using Reese and O'Neill Method (10.8.3.4.2)

$$\beta(Z) := \begin{array}{|l} \beta \leftarrow 1.5 - 7.7\cdot 10^{-3}\cdot\sqrt{\frac{Z}{mm}} \\ \beta \leftarrow 0.25 \ \text{ if } \beta < 0.25 \\ \beta \leftarrow 1.2 \ \text{ if } \beta > 1.2 \\ \beta \ \text{ otherwise} \end{array}$$

$$q_{ss}(Z, \sigma_v) := \begin{cases} \beta(Z)\cdot\sigma_v & \text{if } \beta(Z)\cdot\sigma_v \le 0.19\cdot MPa \\ 0.19\cdot MPa & \text{otherwise} \end{cases}$$ (Table 10.8.3.4.2-1)

COHESIONLESS SOILS - Tip Resistance Using Reese and O'Neill Method (10.8.3.4.3)

$$q_{ps}(SPT, D) := \begin{cases} 0.057 \cdot SPT \cdot MPa & \text{if } (SPT \le 75) \cdot (D \le 1270 \cdot mm) \\ 0.057 \cdot SPT \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 75) \cdot (D > 1270 \cdot mm) \\ 4.3 \cdot MPa & \text{if } (SPT > 75) \cdot (D \le 1270 \cdot mm) \\ 4.3 \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

(Table 10.8.3.4.3-1)
&
(10.8.3.4.3-1)

JOINTED ROCK - Shaft Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{sr}(SPT, \sigma_v) := \begin{array}{|l} \phi \leftarrow \text{atan}\left[\left[\dfrac{SPT}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] \quad \text{if } SPT \le 100 \\ \phi \leftarrow \text{atan}\left[\left[\dfrac{100}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] \quad \text{if } SPT > 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot SPT}{\sigma_v}\right)^{\sin(\phi)} \quad \text{if } SPT \le 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot 100}{\sigma_v}\right)^{\sin(\phi)} \quad \text{if } SPT > 100 \\ \sigma_v \cdot K_o \cdot \tan(\phi) \end{array}$$

JOINTED ROCK - Tip Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{pr}(SPT, \sigma_v) := \begin{cases} 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT \le 100) \cdot (D \le 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT > 100) \cdot (D \le 1270 \cdot mm) \\ 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 100) \cdot (D > 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases} \quad (11.11)$$

RESISTANCE AT THE STRENGTH LIMIT STATE (10.8.3)

Factored bearing resistance $Q_R(\eta, \phi pQ_p, \phi sQ_s) := \eta \cdot (\phi pQ_p + \phi sQ_s)$ (10.7.3.2-1)

Side Resistance in Clay $\phi_{sc} := 0.65$ (Table 10.5.5-3)

Base resistance in Clay $\phi_{pc} := 0.55$ (Table 10.5.5-3)

Side Resistance in Sand $\phi_{ss} := 0.65$

Base resistance in Sand $\phi_{ps} := 0.5$

(Discussion in 10.8.3.4) & FHWA-IF-99-025 "Drilled Shafts: Construction Procedures and Design Methods"

Side Resistance in Rock $\phi_{sr} := 0.55$ (Table 10.5.5-3)

Base resistance in Rock $\phi_{pr} := 0.50$ (Table 10.5.5-3)

Calculate Shaft Resistance

$j := 1 .. 10$

Length of each soil layer down the pile

$$L_{Pile_j} := \begin{cases} Depth_j & \text{if } (ElevT \ge Lsoil_{t_j}) \cdot [(ElevT - L) \le Lsoil_{b_j}] \\ ElevT - Lsoil_{b_j} & \text{if } (ElevT < Lsoil_{t_j}) \cdot (ElevT \ge Lsoil_{b_j}) \cdot [(ElevT - L) \le Lsoil_{b_j}] \\ Lsoil_{t_j} - (ElevT - L) & \text{if } (ElevT \ge Lsoil_{t_j}) \cdot (ElevT - L > Lsoil_{b_j}) \cdot (ElevT - L < Lsoil_{t_j}) \\ 0 \cdot m & \text{otherwise} \end{cases}$$

Average depth of each soil layer

$$Z_j := \begin{cases} (Lsoil_{t_1} - Lsoil_{b_j}) - \dfrac{L_{Pile_j}}{2} & \text{if } (ElevT - L) \le Lsoil_{b_j} \\ [Lsoil_{t_1} - (ElevT - L)] - \dfrac{L_{Pile_j}}{2} & \text{otherwise} \end{cases}$$

Effective vertical soil stress at each soil layer

$$\sigma_{v_j} := Z_j \cdot \gamma_{soil}$$

Assign resistance factors

$$\phi_{s_j} := \begin{cases} \phi_{sc} & \text{if } SoilType_j = \text{"Clay"} \\ \phi_{ss} & \text{if } SoilType_j = \text{"Sand"} \\ \phi_{sr} & \text{otherwise} \end{cases}$$

Nominal unit shaft resistance

$$q_{s_j} := \begin{cases} q_{sc}(\alpha(S_u(SPT_j)), S_u(SPT_j)) & \text{if } SoilType_j = \text{"Clay"} \\ q_{ss}(Z_j, \sigma_{v_j}) & \text{if } SoilType_j = \text{"Sand"} \\ q_{sr}(SPT_j, \sigma_{v_j}) & \text{otherwise} \end{cases}$$

Calculate Tip Resistance

Locate pile tip soil layer "n"

$$n := \left| \begin{array}{l} s \leftarrow 0 \\ \text{for } j \in 1..10 \\ \quad s \leftarrow s+1 \text{ if } (ElevT - L) < Lsoil_{t_j} \\ s \end{array} \right.$$ $n = 9$

Effective stress at base

$$\sigma_{vbase} := \left(Z_n + \frac{L_{Pile_n}}{2} \right) \cdot \gamma_{soil}$$

Nominal unit tip resistance

$$q_p := \left| \begin{array}{l} q_{pc}\left(N_c\left(Z_n, SPT_n\right), S_u\left(SPT_n\right)\right) \text{ if } SoilType_n = \text{"Clay"} \\ q_{ps}\left(SPT_n, D\right) \text{ if } SoilType_n = \text{"Sand"} \\ q_{pr}\left(SPT_n, \sigma_{vbase}\right) \text{ otherwise} \end{array} \right.$$

Reduce Effective Pile Length at Pile Top (1.5m) and at Pile Base (One Pile Diameter)

Subtract 1.5m from pile top:

$value := L_{Pile_1} - 1.5m$ $value = -1\ m$

$value1 := L_{Pile_1} + L_{Pile_2} - 1.5m$ $value1 = 1\ m$

$value2 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} - 1.5m$ $value2 = 3\ m$

$value3 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} + L_{Pile_4} - 1.5m$ $value3 = 5\ m$

$$L_{Pile_1} := \left| \begin{array}{l} L_{Pile_1} - 1.5m \text{ if } value \ge 0 \cdot m \\ 0 \cdot m \text{ otherwise} \end{array} \right.$$ $L_{Pile_1} = 0.00\ m$

$$L_{Pile_2} := \left| \begin{array}{l} value1 \text{ if } (value < 0 \cdot m)(value1 \ge 0m) \\ 0 \cdot m \text{ if } value1 < 0 \cdot m \\ L_{Pile_2} \text{ otherwise} \end{array} \right.$$ $L_{Pile_2} = 1.00\ m$

$$L_{Pile_3} := \left| \begin{array}{l} value2 \text{ if } (value1 < 0 \cdot m)(value2 \ge 0m) \\ 0m \text{ if } value2 < 0 \cdot m \\ L_{Pile_3} \text{ otherwise} \end{array} \right.$$ $L_{Pile_3} = 2.00\ m$

$$L_{Pile_4} := \left| \begin{array}{l} value3 \text{ if } (value2 < 0 \cdot m)(value3 \ge 0m) \\ 0m \text{ if } value3 < 0 \cdot m \\ L_{Pile_4} \text{ otherwise} \end{array} \right.$$ $L_{Pile_4} = 2.00\ m$

Subtract length from pile length at base:

$value := L_{Pile_n} - D$ $\quad value = 1\ m$

$value1 := L_{Pile_n} + L_{Pile_{n-1}} - D$ $\quad value1 = 5\ m$

$value2 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} - D$ $\quad value2 = 8\ m$

$value3 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} + L_{Pile_{n-3}} - D$ $\quad value3 = 10\ m$

$$L_{Pile_n} := \begin{cases} L_{Pile_n} - D & \text{if } value \ge 0 \cdot m \\ 0 \cdot m & \text{otherwise} \end{cases} \qquad L_{Pile_n} = 1.00\ m$$

$$L_{Pile_{n-1}} := \begin{cases} value1 & \text{if } (value < 0 \cdot m)(value1 \ge 0m) \\ 0 \cdot m & \text{if } value1 < 0 \cdot m \\ L_{Pile_{n-1}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-1}} = 4.00\ m$$

$$L_{Pile_{n-2}} := \begin{cases} value2 & \text{if } (value1 < 0 \cdot m)(value2 \ge 0m) \\ 0m & \text{if } value2 < 0 \cdot m \\ L_{Pile_{n-2}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-2}} = 3.00\ m$$

$$L_{Pile_{n-3}} := \begin{cases} value3 & \text{if } (value2 < 0 \cdot m)(value3 \ge 0m) \\ 0m & \text{if } value3 < 0 \cdot m \\ L_{Pile_{n-3}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-3}} = 2.00\ m$$

Reduction factor for large diameter bored piles in clay

$$F_r := \left| \begin{array}{l} a \leftarrow 0.0071 + 0.0021 \cdot \dfrac{Z_n}{D} \\ a \leftarrow \min(0.015, a) \\ b \leftarrow 1.45 \cdot \sqrt{2.0 \cdot \dfrac{S_u(SPT_n)}{MPa}} \\ b \leftarrow 0.5 \ \text{ if } b \le 0.5 \\ b \leftarrow 1.5 \ \text{ if } 1.5 \le b \\ F_r \leftarrow \dfrac{760}{12.0 \cdot a \cdot \dfrac{D}{mm} + 760 \cdot b} \\ F_r \leftarrow \min(1.0, F_r) \end{array} \right. \qquad F_r = 0.724$$

$$q_p := \begin{cases} q_p \cdot F_r & \text{if } (D > 1900 \cdot mm) \cdot (SoilType_n = \text{"Clay"}) \cdot (S_u(SPT_n) > 0.096 \cdot MPa) \cdot (Settlement = \text{"N"}) \\ q_p & \text{otherwise} \end{cases}$$

Calculate Total factored Resistance

Assign resistance factor

$$\phi_p := \begin{cases} \phi_{pc} & \text{if } SoilType_n = \text{"Clay"} \\ \phi_{ps} & \text{if } SoilType_n = \text{"Sand"} \\ \phi_{pr} & \text{otherwise} \end{cases}$$

Total Factored Shaft Resistance

$$\phi sQ_s := \sum_j \left(\phi_{s_j} \cdot q_{s_j} \cdot L_{Pile_j} \cdot \pi \cdot D\right)$$

$\phi sQ_s = 4274\,kN$

Total Factored Tip Resistance

$$\phi pQ_p := \phi_p \cdot q_p \cdot \pi \cdot \frac{D^2}{4}$$

$\phi pQ_p = 2187\,kN$

Uplift resistance (assuming submerged pile)

$$Q_{su} := \phi sQ_s \cdot \frac{0.55}{0.65} + \pi \cdot \frac{D^2}{4} \cdot L \cdot 14.5 \cdot \frac{kN}{m^3}$$

$Q_{su} = 4129\,kN$

Check center-to-center spacing of piles

$$ctc := \begin{cases} 2.5 \cdot D & \text{if } ctc < 2.5 \cdot D \\ 6.0 \cdot D & \text{if } ctc > 6.0 \cdot D \\ ctc & \text{otherwise} \end{cases}$$

$ctc = 6\ m$

Determine if pile is predominantly driven in sand or clay

$$L_{sand} := \left| \begin{array}{l} L_s \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \left| \begin{array}{ll} L_s \leftarrow L_s + L_{Pile_j} & \text{if } SoilType_j = \text{"Sand"} \\ L_s & \text{otherwise} \end{array} \right. \end{array} \right.$$

$L_{sand} = 0.00\ m$

$$L_{clay} := \left| \begin{array}{l} L_c \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \left| \begin{array}{ll} L_c \leftarrow L_c + L_{Pile_j} & \text{if } SoilType_j = \text{"Clay"} \\ L_c & \text{otherwise} \end{array} \right. \end{array} \right.$$

$L_{clay} = 17.00\ m$

Assign overall soil type to pile

$$SoilTypeOverall := \begin{cases} \text{"Sand"} & \text{if } L_{sand} > L_{clay} \\ \text{"Clay"} & \text{otherwise} \end{cases}$$

SoilTypeOverall = "Clay"

Efficiency of pile group (10.7.3.10.2)

$$\eta := \begin{cases} 1.00 & \text{if } SoilType_n = \text{"Rock"} \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Sand"}) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \ge 5) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \ge 5) \\ 0.65 + (1 - 0.65)\cdot\dfrac{ctc - 2.5\cdot D}{3.5\cdot D} & \text{otherwise} \end{cases}$$

$\eta = 1.00$

SUMMARY
BORED Pile
Shaft and Tip Factored Resistance kN

Diameter of Pile $D = 1.5\ m$

Length of Pile $L = 20\ m$

Ref.	Thick ness	Length down Pile	Level	SPT N	Soil Type	q_s	φ_s	$\varphi_s Q_s$	q_p	φ_p	$\varphi_p Q_p$
	(m)	(m)	(m)			kN/m2		kN	kN/m2		kN
1.0	2.0	0.0	-2.0	0	Clay	0.0	0.65	0	0.0	0.00	0
2.0	2.0	1.0	-4.0	13	Clay	35.8	0.65	110	0.0	0.00	0
3.0	2.0	2.0	-6.0	15	Clay	41.3	0.65	253	0.0	0.00	0
4.0	2.0	2.0	-8.0	14	Clay	38.5	0.65	236	0.0	0.00	0
5.0	2.0	2.0	-10.0	41	Clay	100.0	0.65	613	0.0	0.00	0
6.0	2.0	2.0	-12.0	50	Clay	100.0	0.65	613	0.0	0.00	0
7.0	3.0	3.0	-15.0	50	Clay	100.0	0.65	919	0.0	0.00	0
8.0	4.0	4.0	-19.0	50	Clay	100.0	0.65	1225	0.0	0.00	0
9.0	5.0	1.0	-21.5	50	Clay	100.0	0.65	306	2250.0	0.55	2187
10.0	8.0	0.0	0.0	50	Clay	100.0	0.65	0	0.0	0.00	0
Total Factored Shaft Resistance $\varphi_s Q_s$								4274	Factored Tip Resistance $\varphi_p Q_p$		2187

$$\eta = 1.00$$

TOTAL FACTORED RESISTANCE PER PILE

$$Q_R(\eta, \phi p Q_p, \phi s Q_s) = 6461\ kN$$

.

TOTAL FACTORED UPLIFT RESISTANCE PER PILE

$$Q_{su} = 4129\ kN$$

KATAHIRA & ENGINEERS INTERNATIONAL

Project: **Detailed Design Study of North Java Flyover Project**

Calculation: **Detailed Design**
Balaraja Flyover - Pier P2
1.5m Dia. BORED PILE AXIAL BEARING CAPACITY

Reference : **AASHTO LRFD Bridge Design Specification**
"Drilled Shafts: Construction Procedures and Design Methods"
FHWA-IF-99-025, August 1999

Definitions $kN := 1000 \cdot N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $kPa := 1000 \cdot Pa$

Pile Input Data

Pile Diameter	D (m)	1.50
Length of Pile	L (m)	20.00
Elevation at top of Pile	ElevTop (m)	-1.00
Effective Soil Density	γ (kN/m3)	10.00
Pile Cap 1. In firm contact with the ground 2. Not in firm contact with the ground		2
Pile center-to-center spacing	ctc (m)	6.000
Settlements evaluated?	(Y or N)	N

$D := D \cdot m$ $L := L \cdot m$ $ElevT := ElevT \cdot m$ $\gamma_{soil} := \gamma_{soil} \cdot \frac{kN}{m^3}$ $ctc := ctc \cdot m$

Subsoil Input Data - BOREHOLE BH 6

Ref.	Thickness	Level top of Layer	Level bottom of Layer	Soil Type	SPT N
	(cm)	(m)	(m)		
1.0	200	0.00	-2.00	Clay	0
2.0	200	-2.00	-4.00	Clay	11
3.0	200	-4.00	-6.00	Clay	14
4.0	200	-6.00	-8.00	Clay	16
5.0	200	-8.00	-10.00	Clay	38
6.0	200	-10.00	-12.00	Clay	50
7.0	200	-12.00	-14.00	Clay	50
8.0	200	-14.00	-16.00	Clay	50
9.0	400	-16.00	-20.00	Clay	50
10.0	800	-20.00	-28.00	Clay	50

$Lsoil_t := Lsoil_{top} \cdot m$ $Lsoil_b := Lsoil_{bottom} \cdot m$ $Depth := Depth \cdot cm$

COHESIVE SOILS - Shaft Resistance Using the α method (10.8.3.3.1)

$$q_{sc}(\alpha, S_u) := \begin{cases} 100 \cdot kPa & \text{if } \alpha \cdot S_u > 100 \cdot kPa \\ \alpha \cdot S_u & \text{otherwise} \end{cases}$$ (10.8.3.3.1-1)

(JRA Table C.10.4-4)

$$S_u(SPT) := 5 \cdot SPT \cdot kPa$$

(Table 10.8.3.3.1-1)

$$\alpha(S_u) := \begin{cases} 0.55 & \text{if } S_u < 0.2 \cdot MPa \\ 0.49 & \text{if } (S_u \geq 0.2 \cdot MPa) \cdot (S_u < 0.30 \cdot MPa) \\ 0.42 & \text{if } (S_u \geq 0.3 \cdot MPa) \cdot (S_u < 0.40 \cdot MPa) \\ 0.38 & \text{if } (S_u \geq 0.4 \cdot MPa) \cdot (S_u < 0.50 \cdot MPa) \\ 0.35 & \text{if } (S_u \geq 0.5 \cdot MPa) \cdot (S_u < 0.60 \cdot MPa) \\ 0.33 & \text{if } (S_u \geq 0.6 \cdot MPa) \cdot (S_u < 0.70 \cdot MPa) \\ 0.32 & \text{if } (S_u \geq 0.7 \cdot MPa) \cdot (S_u < 0.80 \cdot MPa) \\ 0.31 & \text{if } (S_u \geq 0.8 \cdot MPa) \cdot (S_u < 0.90 \cdot MPa) \\ \text{"Treat as Rock"} & \text{otherwise} \end{cases}$$

COHESIVE SOILS - Tip Resistance (10.8.3.3.2)

(10.8.3.3.2-1)

$$q_{pc}(N_c, S_u) := \begin{cases} N_c \cdot S_u & \text{if } N_c \cdot S_u \leq 4.0 \cdot MPa \\ 4.0 \cdot MPa & \text{otherwise} \end{cases}$$

(10.8.3.3.2-2)

$$N_c(Z, SPT) := \begin{array}{|l} N_c \leftarrow 6 \cdot \left[1 + 0.2 \cdot \left(\frac{Z}{D}\right)\right] \\ N_c \leftarrow \frac{N_c}{3} \quad \text{if } 5 \cdot SPT \cdot kPa < 0.024 \cdot MPa \\ N_c \quad \text{if } N_c \leq 9 \\ 9 \quad \text{otherwise} \end{array}$$

COHESIONLESS SOILS - Shaft Resistance Using Reese and O'Neill Method (10.8.3.4.2)

$$\beta(Z) := \begin{array}{|l} \beta \leftarrow 1.5 - 7.7 \cdot 10^{-3} \cdot \sqrt{\frac{Z}{mm}} \\ \beta \leftarrow 0.25 \quad \text{if } \beta < 0.25 \\ \beta \leftarrow 1.2 \quad \text{if } \beta > 1.2 \\ \beta \quad \text{otherwise} \end{array}$$

(Table 10.8.3.4.2-1)

$$q_{ss}(Z, \sigma_v) := \begin{cases} \beta(Z) \cdot \sigma_v & \text{if } \beta(Z) \cdot \sigma_v \leq 0.19 \cdot MPa \\ 0.19 \cdot MPa & \text{otherwise} \end{cases}$$

COHESIONLESS SOILS - Tip Resistance Using Reese and O'Neill Method (10.8.3.4.3)

$$q_{ps}(SPT, D) := \begin{cases} 0.057 \cdot SPT \cdot MPa & \text{if } (SPT \le 75)\cdot(D \le 1270\cdot mm) \\ 0.057 \cdot SPT \cdot MPa \cdot \dfrac{1270\cdot mm}{D} & \text{if } (SPT \le 75)\cdot(D > 1270\cdot mm) \\ 4.3\cdot MPa & \text{if } (SPT > 75)\cdot(D \le 1270\cdot mm) \\ 4.3\cdot MPa \cdot \dfrac{1270\cdot mm}{D} & \text{otherwise} \end{cases}$$

(Table 10.8.3.4.3-1)
&
(10.8.3.4.3-1)

JOINTED ROCK - Shaft Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{sr}(SPT, \sigma_v) := \begin{array}{|l} \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{SPT}{12.3 + 20.3\cdot\left(\dfrac{\sigma_v}{101\cdot kPa}\right)}\right]^{0.34}\right] \quad \text{if } SPT \le 100 \\ \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{100}{12.3 + 20.3\cdot\left(\dfrac{\sigma_v}{101\cdot kPa}\right)}\right]^{0.34}\right] \quad \text{if } SPT > 100 \\ K_o \leftarrow (1 - \sin(\phi))\cdot\left(\dfrac{0.2\cdot 101\cdot kPa\cdot SPT}{\sigma_v}\right)^{\sin(\phi)} \quad \text{if } SPT \le 100 \\ K_o \leftarrow (1 - \sin(\phi))\cdot\left(\dfrac{0.2\cdot 101\cdot kPa\cdot 100}{\sigma_v}\right)^{\sin(\phi)} \quad \text{if } SPT > 100 \\ \sigma_v\cdot K_o\cdot\tan(\phi) \end{array}$$

JOINTED ROCK - Tip Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{pr}(SPT, \sigma_v) := \begin{cases} 0.59\cdot\left(SPT\cdot\dfrac{101\cdot kPa}{\sigma_v}\right)^{0.8}\cdot\sigma_v & \text{if } (SPT \le 100)\cdot(D \le 1270\cdot mm) \\ 0.59\cdot\left(100\cdot\dfrac{101\cdot kPa}{\sigma_v}\right)^{0.8}\cdot\sigma_v & \text{if } (SPT > 100)\cdot(D \le 1270\cdot mm) \\ 0.59\cdot\left(SPT\cdot\dfrac{101\cdot kPa}{\sigma_v}\right)^{0.8}\cdot\sigma_v\cdot\dfrac{1270\cdot mm}{D} & \text{if } (SPT \le 100)\cdot(D > 1270\cdot mm) \\ 0.59\cdot\left(100\cdot\dfrac{101\cdot kPa}{\sigma_v}\right)^{0.8}\cdot\sigma_v\cdot\dfrac{1270\cdot mm}{D} & \text{otherwise} \end{cases}$$

(11.11)

RESISTANCE AT THE STRENGTH LIMIT STATE (10.8.3)

Factored bearing resistance $Q_R(\eta, \phi pQ_p, \phi sQ_s) := \eta \cdot (\phi pQ_p + \phi sQ_s)$ (10.7.3.2-1)

Side Resistance in Clay $\phi_{sc} := 0.65$ (Table 10.5.5-3)

Base resistance in Clay $\phi_{pc} := 0.55$ (Table 10.5.5-3)

Side Resistance in Sand $\phi_{ss} := 0.65$

Base resistance in Sand $\phi_{ps} := 0.5$

(Discussion in 10.8.3.4) & FHWA-IF-99-025 "Drilled Shafts: Construction Procedures and Design Methods"

Side Resistance in Rock $\phi_{sr} := 0.55$ (Table 10.5.5-3)

Base resistance in Rock $\phi_{pr} := 0.50$ (Table 10.5.5-3)

Calculate Shaft Resistance

$j := 1 .. 10$

Length of each soil layer down the pile

$$L_{Pile_j} := \begin{cases} Depth_j & \text{if } (ElevT \ge Lsoil_{t_j}) \cdot [(ElevT - L) \le Lsoil_{b_j}] \\ ElevT - Lsoil_{b_j} & \text{if } (ElevT < Lsoil_{t_j}) \cdot (ElevT \ge Lsoil_{b_j}) \cdot [(ElevT - L) \le Lsoil_{b_j}] \\ Lsoil_{t_j} - (ElevT - L) & \text{if } (ElevT \ge Lsoil_{t_j}) \cdot (ElevT - L > Lsoil_{b_j}) \cdot (ElevT - L < Lsoil_{t_j}) \\ 0 \cdot m & \text{otherwise} \end{cases}$$

Average depth of each soil layer

$$Z_j := \begin{cases} (Lsoil_{t_1} - Lsoil_{b_j}) - \dfrac{L_{Pile_j}}{2} & \text{if } (ElevT - L) \le Lsoil_{b_j} \\ [Lsoil_{t_1} - (ElevT - L)] - \dfrac{L_{Pile_j}}{2} & \text{otherwise} \end{cases}$$

Effective vertical soil stress at each soil layer $\sigma_{v_j} := Z_j \cdot \gamma_{soil}$

Assign resistance factors

$$\phi_{s_j} := \begin{cases} \phi_{sc} & \text{if } SoilType_j = \text{"Clay"} \\ \phi_{ss} & \text{if } SoilType_j = \text{"Sand"} \\ \phi_{sr} & \text{otherwise} \end{cases}$$

Nominal unit shaft resistance

$$q_{s_j} := \begin{cases} q_{sc}(\alpha(S_u(SPT_j)), S_u(SPT_j)) & \text{if } SoilType_j = \text{"Clay"} \\ q_{ss}(Z_j, \sigma_{v_j}) & \text{if } SoilType_j = \text{"Sand"} \\ q_{sr}(SPT_j, \sigma_{v_j}) & \text{otherwise} \end{cases}$$

Calculate Tip Resistance

Locate pile tip soil layer "n"

$$n := \begin{vmatrix} s \leftarrow 0 \\ \text{for } j \in 1..10 \\ \quad s \leftarrow s + 1 \text{ if } (ElevT - L) < Lsoil_{t_j} \\ s \end{vmatrix} \qquad n = 10$$

Effective stress at base

$$\sigma_{vbase} := \left(Z_n + \frac{L_{Pile_n}}{2}\right)\cdot\gamma_{soil}$$

Nominal unit tip resistance

$$q_p := \begin{vmatrix} q_{pc}\left(N_c\left(Z_n, SPT_n\right), S_u\left(SPT_n\right)\right) \text{ if } SoilType_n = \text{"Clay"} \\ q_{ps}\left(SPT_n, D\right) \text{ if } SoilType_n = \text{"Sand"} \\ q_{pr}\left(SPT_n, \sigma_{vbase}\right) \text{ otherwise} \end{vmatrix}$$

Reduce Effective Pile Length at Pile Top (1.5m) and at Pile Base (One Pile Diameter)

Subtract 1.5m from pile top:

$$value := L_{Pile_1} - 1.5m \qquad value = -0.5\ m$$

$$value1 := L_{Pile_1} + L_{Pile_2} - 1.5m \qquad value1 = 1.5\ m$$

$$value2 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} - 1.5m \qquad value2 = 3.5\ m$$

$$value3 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} + L_{Pile_4} - 1.5m \qquad value3 = 5.5\ m$$

$$L_{Pile_1} := \begin{vmatrix} L_{Pile_1} - 1.5m \text{ if } value \geq 0\cdot m \\ 0\cdot m \text{ otherwise} \end{vmatrix} \qquad L_{Pile_1} = 0.00\ m$$

$$L_{Pile_2} := \begin{vmatrix} value1 \text{ if } (value < 0\cdot m)(value1 \geq 0m) \\ 0\cdot m \text{ if } value1 < 0\cdot m \\ L_{Pile_2} \text{ otherwise} \end{vmatrix} \qquad L_{Pile_2} = 1.50\ m$$

$$L_{Pile_3} := \begin{vmatrix} value2 \text{ if } (value1 < 0\cdot m)(value2 \geq 0m) \\ 0m \text{ if } value2 < 0\cdot m \\ L_{Pile_3} \text{ otherwise} \end{vmatrix} \qquad L_{Pile_3} = 2.00\ m$$

$$L_{Pile_4} := \begin{vmatrix} value3 \text{ if } (value2 < 0\cdot m)(value3 \geq 0m) \\ 0m \text{ if } value3 < 0\cdot m \\ L_{Pile_4} \text{ otherwise} \end{vmatrix} \qquad L_{Pile_4} = 2.00\ m$$

Subtract length from pile length at base:

$value := L_{Pile_n} - D$ $\quad value = -0.5\ m$

$value1 := L_{Pile_n} + L_{Pile_{n-1}} - D$ $\quad value1 = 3.5\ m$

$value2 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} - D$ $\quad value2 = 5.5\ m$

$value3 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} + L_{Pile_{n-3}} - D$ $\quad value3 = 7.5\ m$

$$L_{Pile_n} := \begin{cases} L_{Pile_n} - D & \text{if } value \ge 0 \cdot m \\ 0 \cdot m & \text{otherwise} \end{cases} \qquad L_{Pile_n} = 0.00\ m$$

$$L_{Pile_{n-1}} := \begin{cases} value1 & \text{if } (value < 0 \cdot m)(value1 \ge 0m) \\ 0 \cdot m & \text{if } value1 < 0 \cdot m \\ L_{Pile_{n-1}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-1}} = 3.50\ m$$

$$L_{Pile_{n-2}} := \begin{cases} value2 & \text{if } (value1 < 0 \cdot m)(value2 \ge 0m) \\ 0m & \text{if } value2 < 0 \cdot m \\ L_{Pile_{n-2}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-2}} = 2.00\ m$$

$$L_{Pile_{n-3}} := \begin{cases} value3 & \text{if } (value2 < 0 \cdot m)(value3 \ge 0m) \\ 0m & \text{if } value3 < 0 \cdot m \\ L_{Pile_{n-3}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-3}} = 2.00\ m$$

Reduction factor for large diameter bored piles in clay

$$F_r := \left| \begin{array}{l} a \leftarrow 0.0071 + 0.0021 \cdot \dfrac{Z_n}{D} \\ a \leftarrow \min(0.015, a) \\ b \leftarrow 1.45 \cdot \sqrt{2.0 \cdot \dfrac{S_u(SPT_n)}{MPa}} \\ b \leftarrow 0.5 \text{ if } b \le 0.5 \\ b \leftarrow 1.5 \text{ if } 1.5 \le b \\ F_r \leftarrow \dfrac{760}{12.0 \cdot a \cdot \dfrac{D}{mm} + 760 \cdot b} \\ F_r \leftarrow \min(1.0, F_r) \end{array} \right. \qquad F_r = 0.724$$

$$q_p := \begin{cases} q_p \cdot F_r & \text{if } (D > 1900 \cdot mm) \cdot (SoilType_n = \text{"Clay"}) \cdot (S_u(SPT_n) > 0.096 \cdot MPa) \cdot (Settlement = \text{"N"}) \\ q_p & \text{otherwise} \end{cases}$$

Calculate Total factored Resistance

Assign resistance factor

$$\phi_p := \begin{cases} \phi_{pc} & \text{if } SoilType_n = \text{"Clay"} \\ \phi_{ps} & \text{if } SoilType_n = \text{"Sand"} \\ \phi_{pr} & \text{otherwise} \end{cases}$$

Total Factored Shaft Resistance

$$\phi sQ_s := \sum_j \left(\phi_{s_j} \cdot q_{s_j} \cdot L_{Pile_j} \cdot \pi \cdot D\right)$$

$\phi sQ_s = 4167\,kN$

Total Factored Tip Resistance

$$\phi pQ_p := \phi_p \cdot q_p \cdot \pi \cdot \frac{D^2}{4}$$

$\phi pQ_p = 2187\,kN$

Uplift resistance (assuming submerged pile)

$$Q_{su} := \phi sQ_s \cdot \frac{0.55}{0.65} + \pi \cdot \frac{D^2}{4} \cdot L \cdot 14.5 \cdot \frac{kN}{m^3}$$

$Q_{su} = 4038\,kN$

Check center-to-center spacing of piles

$$ctc := \begin{cases} 2.5 \cdot D & \text{if } ctc < 2.5 \cdot D \\ 6.0 \cdot D & \text{if } ctc > 6.0 \cdot D \\ ctc & \text{otherwise} \end{cases}$$

$ctc = 6\ m$

Determine if pile is predominantly driven in sand or clay

$$L_{sand} := \begin{array}{|l} L_s \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{array}{|l} L_s \leftarrow L_s + L_{Pile_j} \ \text{if } SoilType_j = \text{"Sand"} \\ L_s \ \text{otherwise} \end{array} \end{array}$$

$L_{sand} = 0.00\ m$

$$L_{clay} := \begin{array}{|l} L_c \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{array}{|l} L_c \leftarrow L_c + L_{Pile_j} \ \text{if } SoilType_j = \text{"Clay"} \\ L_c \ \text{otherwise} \end{array} \end{array}$$

$L_{clay} = 17.00\ m$

Assign overall soil type to pile

$$SoilTypeOverall := \begin{cases} \text{"Sand"} & \text{if } L_{sand} > L_{clay} \\ \text{"Clay"} & \text{otherwise} \end{cases}$$

SoilTypeOverall = "Clay"

Efficiency of pile group (10.7.3.10.2)

$$\eta := \begin{cases} 1.00 & \text{if } SoilType_n = \text{"Rock"} \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Sand"}) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \ge 5) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \ge 5) \\ 0.65 + (1 - 0.65)\cdot\dfrac{ctc - 2.5\cdot D}{3.5\cdot D} & \text{otherwise} \end{cases}$$

$\eta = 1.00$

SUMMARY
BORED Pile
Shaft and Tip Factored Resistance kN

Diameter of Pile $D = 1.5\ m$

Length of Pile $L = 20\ m$

Ref.	Thick ness	Length down Pile	Level	SPT N	Soil Type	q_s	φ_s	$\varphi_s Q_s$	q_p	φ_p	$\varphi_p Q_p$
	(m)	(m)	(m)			kN/m2		kN	kN/m2		kN
1.0	2.0	0.0	-2.0	0	Clay	0.0	0.65	0	0.0	0.00	0
2.0	2.0	1.5	-4.0	11	Clay	30.3	0.65	139	0.0	0.00	0
3.0	2.0	2.0	-6.0	14	Clay	38.5	0.65	236	0.0	0.00	0
4.0	2.0	2.0	-8.0	16	Clay	44.0	0.65	270	0.0	0.00	0
5.0	2.0	2.0	-10.0	38	Clay	100.0	0.65	613	0.0	0.00	0
6.0	2.0	2.0	-12.0	50	Clay	100.0	0.65	613	0.0	0.00	0
7.0	2.0	2.0	-14.0	50	Clay	100.0	0.65	613	0.0	0.00	0
8.0	2.0	2.0	-16.0	50	Clay	100.0	0.65	613	0.0	0.00	0
9.0	4.0	3.5	-20.0	50	Clay	100.0	0.65	1072	0.0	0.00	0
10.0	8.0	0.0	-21.0	50	Clay	100.0	0.65	0	2250.0	0.55	2187
Total Factored Shaft Resistance $\varphi_s Q_s$								4167	Factored Tip Resistance $\varphi_p Q_p$		2187

$\eta = 1.00$

TOTAL FACTORED RESISTANCE PER PILE

$$Q_R(\eta, \phi p Q_p, \phi s Q_s) = 6354\ kN$$

TOTAL FACTORED UPLIFT RESISTANCE PER PILE

$$Q_{su} = 4038\ kN$$

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Project: **Detailed Design Study of North Java Flyover Project**

Calculation: **Detailed Design**
Balaraja Flyover - Pier P3
2.5m Dia. BORED PILE AXIAL BEARING CAPACITY

Reference : **AASHTO LRFD Bridge Design Specification**
"Drilled Shafts: Construction Procedures and Design Methods"
FHWA-IF-99-025, August 1999

Definitions $kN := 1000 \cdot N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $kPa := 1000 \cdot Pa$

Pile Input Data

Pile Diameter	D (m)	2.50
Length of Pile	L (m)	21.00
Elevation at top of Pile	ElevTop (m)	-0.50
Effective Soil Density	γ (kN/m3)	10.00
Pile Cap		2
1. In firm contact with the ground		
2. Not in firm contact with the ground		
Pile center-to-center spacing	ctc (m)	0.000
Settlements evaluated?	(Y or N)	N

$D := D \cdot m$ $L := L \cdot m$ $ElevT := ElevT \cdot m$ $\gamma_{soil} := \gamma_{soil} \cdot \frac{kN}{m^3}$ $ctc := ctc \cdot m$

Subsoil Input Data - BOREHOLE BH 6

Ref.	Thickness	Level top of Layer	Level bottom of Layer	Soil Type	SPT N
	(cm)	(m)	(m)		
1.0	200	0.00	-2.00	Clay	0
2.0	200	-2.00	-4.00	Clay	11
3.0	200	-4.00	-6.00	Clay	14
4.0	200	-6.00	-8.00	Clay	16
5.0	200	-8.00	-10.00	Clay	38
6.0	200	-10.00	-12.00	Clay	50
7.0	200	-12.00	-14.00	Clay	50
8.0	200	-14.00	-16.00	Clay	50
9.0	400	-16.00	-20.00	Clay	50
10.0	400	-20.00	-24.00	Clay	50

$Lsoil_t := Lsoil_{top} \cdot m$ $Lsoil_b := Lsoil_{bottom} \cdot m$ $Depth := Depth \cdot cm$

COHESIVE SOILS - Shaft Resistance Using the α method (10.8.3.3.1)

$$q_{sc}(\alpha, S_u) := \begin{cases} 100 \cdot kPa & \text{if } \alpha \cdot S_u > 100 \cdot kPa \\ \alpha \cdot S_u & \text{otherwise} \end{cases}$$ (10.8.3.3.1-1)

(JRA Table C.10.4-4)

$$S_u(SPT) := 5 \cdot SPT \cdot kPa$$

$$\alpha(S_u) := \begin{cases} 0.55 & \text{if } S_u < 0.2 \cdot MPa \\ 0.49 & \text{if } (S_u \geq 0.2 \cdot MPa) \cdot (S_u < 0.30 \cdot MPa) \\ 0.42 & \text{if } (S_u \geq 0.3 \cdot MPa) \cdot (S_u < 0.40 \cdot MPa) \\ 0.38 & \text{if } (S_u \geq 0.4 \cdot MPa) \cdot (S_u < 0.50 \cdot MPa) \\ 0.35 & \text{if } (S_u \geq 0.5 \cdot MPa) \cdot (S_u < 0.60 \cdot MPa) \\ 0.33 & \text{if } (S_u \geq 0.6 \cdot MPa) \cdot (S_u < 0.70 \cdot MPa) \\ 0.32 & \text{if } (S_u \geq 0.7 \cdot MPa) \cdot (S_u < 0.80 \cdot MPa) \\ 0.31 & \text{if } (S_u \geq 0.8 \cdot MPa) \cdot (S_u < 0.90 \cdot MPa) \\ \text{"Treat as Rock"} & \text{otherwise} \end{cases}$$ (Table 10.8.3.3.1-1)

COHESIVE SOILS - Tip Resistance (10.8.3.3.2)

$$q_{pc}(N_c, S_u) := \begin{cases} N_c \cdot S_u & \text{if } N_c \cdot S_u \leq 4.0 \cdot MPa \\ 4.0 \cdot MPa & \text{otherwise} \end{cases}$$ (10.8.3.3.2-1)

$$N_c(Z, SPT) := \begin{vmatrix} N_c \leftarrow 6 \cdot \left[1 + 0.2 \cdot \left(\frac{Z}{D}\right)\right] \\ N_c \leftarrow \frac{N_c}{3} \text{ if } 5 \cdot SPT \cdot kPa < 0.024 \cdot MPa \\ N_c \text{ if } N_c \leq 9 \\ 9 \text{ otherwise} \end{vmatrix}$$ (10.8.3.3.2-2)

COHESIONLESS SOILS - Shaft Resistance Using Reese and O'Neill Method (10.8.3.4.2)

$$\beta(Z) := \begin{vmatrix} \beta \leftarrow 1.5 - 7.7 \cdot 10^{-3} \cdot \sqrt{\frac{Z}{mm}} \\ \beta \leftarrow 0.25 \text{ if } \beta < 0.25 \\ \beta \leftarrow 1.2 \text{ if } \beta > 1.2 \\ \beta \text{ otherwise} \end{vmatrix}$$

$$q_{ss}(Z, \sigma_v) := \begin{cases} \beta(Z) \cdot \sigma_v & \text{if } \beta(Z) \cdot \sigma_v \leq 0.19 \cdot MPa \\ 0.19 \cdot MPa & \text{otherwise} \end{cases}$$ (Table 10.8.3.4.2-1)

COHESIONLESS SOILS - Tip Resistance Using Reese and O'Neill Method (10.8.3.4.3)

$$q_{ps}(SPT, D) := \begin{cases} 0.057 \cdot SPT \cdot MPa & \text{if } (SPT \le 75) \cdot (D \le 1270 \cdot mm) \\ 0.057 \cdot SPT \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 75) \cdot (D > 1270 \cdot mm) \\ 4.3 \cdot MPa & \text{if } (SPT > 75) \cdot (D \le 1270 \cdot mm) \\ 4.3 \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

(Table 10.8.3.4.3-1)
&
(10.8.3.4.3-1)

JOINTED ROCK - Shaft Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{sr}(SPT, \sigma_v) := \begin{array}{|l} \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{SPT}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] \quad \text{if } SPT \le 100 \\ \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{100}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] \quad \text{if } SPT > 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot SPT}{\sigma_v}\right)^{\sin(\phi)} \quad \text{if } SPT \le 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot 100}{\sigma_v}\right)^{\sin(\phi)} \quad \text{if } SPT > 100 \\ \sigma_v \cdot K_o \cdot \tan(\phi) \end{array}$$

JOINTED ROCK - Tip Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{pr}(SPT, \sigma_v) := \begin{cases} 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT \le 100) \cdot (D \le 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT > 100) \cdot (D \le 1270 \cdot mm) \\ 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 100) \cdot (D > 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

(11.11)

RESISTANCE AT THE STRENGTH LIMIT STATE (10.8.3)

Factored bearing resistance $Q_R(\eta, \phi pQ_p, \phi sQ_s) := \eta \cdot (\phi pQ_p + \phi sQ_s)$ (10.7.3.2-1)

Side Resistance in Clay $\phi_{sc} := 0.65$ (Table 10.5.5-3)

Base resistance in Clay $\phi_{pc} := 0.55$ (Table 10.5.5-3)

Side Resistance in Sand $\phi_{ss} := 0.65$

Base resistance in Sand $\phi_{ps} := 0.5$

(Discussion in 10.8.3.4) & FHWA-IF-99-025 "Drilled Shafts: Construction Procedures and Design Methods"

Side Resistance in Rock $\phi_{sr} := 0.55$ (Table 10.5.5-3)

Base resistance in Rock $\phi_{pr} := 0.50$ (Table 10.5.5-3)

Calculate Shaft Resistance

$j := 1..10$

Length of each soil layer down the pile

$$L_{Pile_j} := \begin{cases} Depth_j & \text{if } (ElevT \ge Lsoil_{t_j}) \cdot [(ElevT - L) \le Lsoil_{b_j}] \\ ElevT - Lsoil_{b_j} & \text{if } (ElevT < Lsoil_{t_j}) \cdot (ElevT \ge Lsoil_{b_j}) \cdot [(ElevT - L) \le Lsoil_{b_j}] \\ Lsoil_{t_j} - (ElevT - L) & \text{if } (ElevT \ge Lsoil_{t_j}) \cdot (ElevT - L > Lsoil_{b_j}) \cdot (ElevT - L < Lsoil_{t_j}) \\ 0 \cdot m & \text{otherwise} \end{cases}$$

Average depth of each soil layer

$$Z_j := \begin{cases} (Lsoil_{t_1} - Lsoil_{b_j}) - \dfrac{L_{Pile_j}}{2} & \text{if } (ElevT - L) \le Lsoil_{b_j} \\ [Lsoil_{t_1} - (ElevT - L)] - \dfrac{L_{Pile_j}}{2} & \text{otherwise} \end{cases}$$

Effective vertical soil stress at each soil layer

$$\sigma_{v_j} := Z_j \cdot \gamma_{soil}$$

Assign resistance factors

$$\phi_{s_j} := \begin{cases} \phi_{sc} & \text{if } SoilType_j = \text{"Clay"} \\ \phi_{ss} & \text{if } SoilType_j = \text{"Sand"} \\ \phi_{sr} & \text{otherwise} \end{cases}$$

Nominal unit shaft resistance

$$q_{s_j} := \begin{cases} q_{sc}(\alpha(S_u(SPT_j)), S_u(SPT_j)) & \text{if } SoilType_j = \text{"Clay"} \\ q_{ss}(Z_j, \sigma_{v_j}) & \text{if } SoilType_j = \text{"Sand"} \\ q_{sr}(SPT_j, \sigma_{v_j}) & \text{otherwise} \end{cases}$$

Calculate Tip Resistance

Locate pile tip soil layer "n"

$$n := \begin{array}{|l} s \leftarrow 0 \\ \text{for } j \in 1..10 \\ \quad s \leftarrow s + 1 \text{ if } (ElevT - L) < Lsoil_{t_j} \\ s \end{array} \qquad n = 10$$

Effective stress at base

$$\sigma_{vbase} := \left(Z_n + \frac{L_{Pile_n}}{2} \right) \cdot \gamma_{soil}$$

Nominal unit tip resistance

$$q_p := \begin{array}{|l} q_{pc}\left(N_c\left(Z_n, SPT_n\right), S_u\left(SPT_n\right)\right) \text{ if } SoilType_n = \text{"Clay"} \\ q_{ps}\left(SPT_n, D\right) \text{ if } SoilType_n = \text{"Sand"} \\ q_{pr}\left(SPT_n, \sigma_{vbase}\right) \text{ otherwise} \end{array}$$

Reduce Effective Pile Length at Pile Top (1.5m) and at Pile Base (One Pile Diameter)

Subtract 1.5m from pile top:

$$value := L_{Pile_1} - 1.5m \qquad value = 0\ m$$

$$value1 := L_{Pile_1} + L_{Pile_2} - 1.5m \qquad value1 = 2\ m$$

$$value2 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} - 1.5m \qquad value2 = 4\ m$$

$$value3 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} + L_{Pile_4} - 1.5m \qquad value3 = 6\ m$$

$$L_{Pile_1} := \begin{array}{|l} L_{Pile_1} - 1.5m \text{ if } value \ge 0 \cdot m \\ 0 \cdot m \text{ otherwise} \end{array} \qquad L_{Pile_1} = 0.00\ m$$

$$L_{Pile_2} := \begin{array}{|l} value1 \text{ if } (value < 0 \cdot m)(value1 \ge 0m) \\ 0 \cdot m \text{ if } value1 < 0 \cdot m \\ L_{Pile_2} \text{ otherwise} \end{array} \qquad L_{Pile_2} = 2.00\ m$$

$$L_{Pile_3} := \begin{array}{|l} value2 \text{ if } (value1 < 0 \cdot m)(value2 \ge 0m) \\ 0m \text{ if } value2 < 0 \cdot m \\ L_{Pile_3} \text{ otherwise} \end{array} \qquad L_{Pile_3} = 2.00\ m$$

$$L_{Pile_4} := \begin{array}{|l} value3 \text{ if } (value2 < 0 \cdot m)(value3 \ge 0m) \\ 0m \text{ if } value3 < 0 \cdot m \\ L_{Pile_4} \text{ otherwise} \end{array} \qquad L_{Pile_4} = 2.00\ m$$

Subtract length from pile length at base:

$value := L_{Pile_n} - D$ $\quad value = -1\ m$

$value1 := L_{Pile_n} + L_{Pile_{n-1}} - D$ $\quad value1 = 3\ m$

$value2 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} - D$ $\quad value2 = 5\ m$

$value3 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} + L_{Pile_{n-3}} - D$ $\quad value3 = 7\ m$

$$L_{Pile_n} := \begin{cases} L_{Pile_n} - D & \text{if } value \ge 0\cdot m \\ 0\cdot m & \text{otherwise} \end{cases} \qquad L_{Pile_n} = 0.00\ m$$

$$L_{Pile_{n-1}} := \begin{cases} value1 & \text{if } (value < 0\cdot m)(value1 \ge 0m) \\ 0\cdot m & \text{if } value1 < 0\cdot m \\ L_{Pile_{n-1}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-1}} = 3.00\ m$$

$$L_{Pile_{n-2}} := \begin{cases} value2 & \text{if } (value1 < 0\cdot m)(value2 \ge 0m) \\ 0m & \text{if } value2 < 0\cdot m \\ L_{Pile_{n-2}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-2}} = 2.00\ m$$

$$L_{Pile_{n-3}} := \begin{cases} value3 & \text{if } (value2 < 0\cdot m)(value3 \ge 0m) \\ 0m & \text{if } value3 < 0\cdot m \\ L_{Pile_{n-3}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-3}} = 2.00\ m$$

Reduction factor for large diameter bored piles in clay

$$F_r := \begin{array}{|l} a \leftarrow 0.0071 + 0.0021\cdot\frac{Z_n}{D} \\ a \leftarrow \min(0.015, a) \\ b \leftarrow 1.45\cdot\sqrt{2.0\cdot\frac{S_u(SPT_n)}{MPa}} \\ b \leftarrow 0.5 \text{ if } b \le 0.5 \\ b \leftarrow 1.5 \text{ if } 1.5 \le b \\ F_r \leftarrow \frac{760}{12.0\cdot a\cdot\frac{D}{mm} + 760\cdot b} \\ F_r \leftarrow \min(1.0, F_r) \end{array} \qquad F_r = 0.618$$

$$q_p := \begin{cases} q_p\cdot F_r & \text{if } (D > 1900\cdot mm)\cdot(SoilType_n = \text{"Clay"})\cdot(S_u(SPT_n) > 0.096\cdot MPa)\cdot(Settlement = \text{"N"}) \\ q_p & \text{otherwise} \end{cases}$$

Calculate Total factored Resistance

Assign resistance factor

$$\phi_p := \begin{cases} \phi_{pc} & \text{if } SoilType_n = \text{"Clay"} \\ \phi_{ps} & \text{if } SoilType_n = \text{"Sand"} \\ \phi_{pr} & \text{otherwise} \end{cases}$$

Total Factored Shaft Resistance

$$\phi sQ_s := \sum_j \left(\phi_{s_j} \cdot q_{s_j} \cdot L_{Pile_j} \cdot \pi \cdot D\right) \qquad \phi sQ_s = 6767\,kN$$

Total Factored Tip Resistance

$$\phi pQ_p := \phi_p \cdot q_p \cdot \pi \cdot \frac{D^2}{4} \qquad \phi pQ_p = 3756\,kN$$

Uplift resistance (assuming submerged pile)

$$Q_{su} := \phi sQ_s \cdot \frac{0.55}{0.65} + \pi \cdot \frac{D^2}{4} \cdot L \cdot 14.5 \cdot \frac{kN}{m^3}$$

$$Q_{su} = 7220\,kN$$

Check center-to-center spacing of piles

$$ctc := \begin{cases} 2.5 \cdot D & \text{if } ctc < 2.5 \cdot D \\ 6.0 \cdot D & \text{if } ctc > 6.0 \cdot D \\ ctc & \text{otherwise} \end{cases} \qquad ctc = 6.25\ m$$

Determine if pile is predominantly driven in sand or clay

$$L_{sand} := \begin{array}{|l} L_s \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{array}{|l} L_s \leftarrow L_s + L_{Pile_j} \ \text{ if } SoilType_j = \text{"Sand"} \\ L_s \ \text{ otherwise} \end{array} \end{array} \qquad L_{sand} = 0.00\ m$$

$$L_{clay} := \begin{array}{|l} L_c \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{array}{|l} L_c \leftarrow L_c + L_{Pile_j} \ \text{ if } SoilType_j = \text{"Clay"} \\ L_c \ \text{ otherwise} \end{array} \end{array} \qquad L_{clay} = 17.00\ m$$

Assign overall soil type to pile

$$SoilTypeOverall := \begin{cases} \text{"Sand"} & \text{if } L_{sand} > L_{clay} \\ \text{"Clay"} & \text{otherwise} \end{cases}$$

$$SoilTypeOverall = \text{"Clay"}$$

Efficiency of pile group (10.7.3.10.2)

$$\eta := \begin{cases} 1.00 & \text{if } SoilType_n = \text{"Rock"} \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Sand"}) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \geq 5) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \geq 5) \\ 0.65 + (1 - 0.65)\cdot\dfrac{ctc - 2.5\cdot D}{3.5\cdot D} & \text{otherwise} \end{cases}$$

$\eta = 1.00$

SUMMARY
BORED Pile
Shaft and Tip Factored Resistance kN

Diameter of Pile $D = 2.5\ \text{m}$

Length of Pile $L = 21\ \text{m}$

Ref.	Thick ness	Length down Pile	Level	SPT N	Soil Type	q_s	φ_s	$\varphi_s Q_s$	q_p	φ_p	$\varphi_p Q_p$
	(m)	(m)	(m)			kN/m2		kN	kN/m2		kN
1.0	2.0	0.0	-2.0	0	Clay	0.0	0.65	0	0.0	0.00	0
2.0	2.0	2.0	-4.0	11	Clay	30.3	0.65	309	0.0	0.00	0
3.0	2.0	2.0	-6.0	14	Clay	38.5	0.65	393	0.0	0.00	0
4.0	2.0	2.0	-8.0	16	Clay	44.0	0.65	449	0.0	0.00	0
5.0	2.0	2.0	-10.0	38	Clay	100.0	0.65	1021	0.0	0.00	0
6.0	2.0	2.0	-12.0	50	Clay	100.0	0.65	1021	0.0	0.00	0
7.0	2.0	2.0	-14.0	50	Clay	100.0	0.65	1021	0.0	0.00	0
8.0	2.0	2.0	-16.0	50	Clay	100.0	0.65	1021	0.0	0.00	0
9.0	4.0	3.0	-20.0	50	Clay	100.0	0.65	1532	0.0	0.00	0
10.0	4.0	0.0	-21.5	50	Clay	100.0	0.65	0	1391.1	0.55	3756
Total Factored Shaft Resistance $\varphi_s Q_s$								6767	Factored Tip Resistance $\varphi_p Q_p$		3756

$$\eta = 1.00$$

TOTAL FACTORED RESISTANCE PER PILE

$$Q_R\left(\eta, \phi p Q_p, \phi s Q_s\right) = 10523\ \text{kN}$$

TOTAL FACTORED UPLIFT RESISTANCE PER PILE

$$Q_{su} = 7220\ \text{kN}$$

KATAHIRA & ENGINEERS INTERNATIONAL

Project: **Detailed Design Study of North Java Flyover Project**

Calculation: **Detailed Design**
Balaraja Flyover - Pier P4
2.5m Dia. BORED PILE AXIAL BEARING CAPACITY

Reference : **AASHTO LRFD Bridge Design Specification**
"Drilled Shafts: Construction Procedures and Design Methods"
FHWA-IF-99-025, August 1999

Definitions $kN := 1000 \cdot N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $kPa := 1000 \cdot Pa$

Pile Input Data

Pile Diameter	D (m)	2.50
Length of Pile	L (m)	29.00
Elevation at top of Pile	ElevTop (m)	-2.00
Effective Soil Density	γ (kN/m3)	10.00
Pile Cap 1. In firm contact with the ground 2. Not in firm contact with the ground		2
Pile center-to-center spacing	ctc (m)	0.000
Settlements evaluated?	(Y or N)	N

$D := D \cdot m$ $L := L \cdot m$ $ElevT := ElevT \cdot m$ $\gamma_{soil} := \gamma_{soil} \cdot \frac{kN}{m^3}$ $ctc := ctc \cdot m$

Subsoil Input Data - BOREHOLE BH 7

Ref.	Thickness	Level top of Layer	Level bottom of Layer	Soil Type	SPT N
	(cm)	(m)	(m)		
1.0	250	0.00	-2.50	Clay	0
2.0	200	-2.50	-4.50	Clay	25
3.0	200	-4.50	-6.50	Clay	11
4.0	200	-6.50	-8.50	Clay	13
5.0	200	-8.50	-10.50	Clay	50
6.0	300	-10.50	-13.50	Clay	50
7.0	400	-13.50	-17.50	Clay	20
8.0	500	-17.50	-22.50	Clay	50
9.0	600	-22.50	-28.50	Clay	50
10.0	700	-28.50	-35.50	Clay	50

$Lsoil_t := Lsoil_{top} \cdot m$ $Lsoil_b := Lsoil_{bottom} \cdot m$ $Depth := Depth \cdot cm$

COHESIVE SOILS - Shaft Resistance Using the α method (10.8.3.3.1)

$$q_{sc}(\alpha, S_u) := \begin{cases} 100 \cdot kPa & \text{if } \alpha \cdot S_u > 100 \cdot kPa \\ \alpha \cdot S_u & \text{otherwise} \end{cases}$$ (10.8.3.3.1-1)

(JRA Table C.10.4-4)

$$S_u(SPT) := 5 \cdot SPT \cdot kPa$$

$$\alpha(S_u) := \begin{cases} 0.55 & \text{if } S_u < 0.2 \cdot MPa \\ 0.49 & \text{if } (S_u \ge 0.2 \cdot MPa) \cdot (S_u < 0.30 \cdot MPa) \\ 0.42 & \text{if } (S_u \ge 0.3 \cdot MPa) \cdot (S_u < 0.40 \cdot MPa) \\ 0.38 & \text{if } (S_u \ge 0.4 \cdot MPa) \cdot (S_u < 0.50 \cdot MPa) \\ 0.35 & \text{if } (S_u \ge 0.5 \cdot MPa) \cdot (S_u < 0.60 \cdot MPa) \\ 0.33 & \text{if } (S_u \ge 0.6 \cdot MPa) \cdot (S_u < 0.70 \cdot MPa) \\ 0.32 & \text{if } (S_u \ge 0.7 \cdot MPa) \cdot (S_u < 0.80 \cdot MPa) \\ 0.31 & \text{if } (S_u \ge 0.8 \cdot MPa) \cdot (S_u < 0.90 \cdot MPa) \\ \text{"Treat as Rock"} & \text{otherwise} \end{cases}$$ (Table 10.8.3.3.1-1)

COHESIVE SOILS - Tip Resistance (10.8.3.3.2)

$$q_{pc}(N_c, S_u) := \begin{cases} N_c \cdot S_u & \text{if } N_c \cdot S_u \le 4.0 \cdot MPa \\ 4.0 \cdot MPa & \text{otherwise} \end{cases}$$ (10.8.3.3.2-1)

$$N_c(Z, SPT) := \begin{array}{|l} N_c \leftarrow 6 \cdot \left[1 + 0.2 \cdot \left(\frac{Z}{D}\right)\right] \\ N_c \leftarrow \frac{N_c}{3} \;\; \text{if } 5 \cdot SPT \cdot kPa < 0.024 \cdot MPa \\ N_c \;\; \text{if } N_c \le 9 \\ 9 \;\; \text{otherwise} \end{array}$$ (10.8.3.3.2-2)

COHESIONLESS SOILS - Shaft Resistance Using Reese and O'Neill Method (10.8.3.4.2)

$$\beta(Z) := \begin{array}{|l} \beta \leftarrow 1.5 - 7.7 \cdot 10^{-3} \cdot \sqrt{\frac{Z}{mm}} \\ \beta \leftarrow 0.25 \;\; \text{if } \beta < 0.25 \\ \beta \leftarrow 1.2 \;\; \text{if } \beta > 1.2 \\ \beta \;\; \text{otherwise} \end{array}$$

$$q_{ss}(Z, \sigma_v) := \begin{cases} \beta(Z) \cdot \sigma_v & \text{if } \beta(Z) \cdot \sigma_v \le 0.19 \cdot MPa \\ 0.19 \cdot MPa & \text{otherwise} \end{cases}$$ (Table 10.8.3.4.2-1)

COHESIONLESS SOILS - Tip Resistance Using Reese and O'Neill Method (10.8.3.4.3)

(Table 10.8.3.4.3-1) & (10.8.3.4.3-1)

$$q_{ps}(SPT, D) := \begin{cases} 0.057 \cdot SPT \cdot MPa & \text{if } (SPT \le 75) \cdot (D \le 1270 \cdot mm) \\ 0.057 \cdot SPT \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 75) \cdot (D > 1270 \cdot mm) \\ 4.3 \cdot MPa & \text{if } (SPT > 75) \cdot (D \le 1270 \cdot mm) \\ 4.3 \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

JOINTED ROCK - Shaft Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{sr}(SPT, \sigma_v) := \begin{array}{|l} \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{SPT}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] \quad \text{if } SPT \le 100 \\ \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{100}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] \quad \text{if } SPT > 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot SPT}{\sigma_v}\right)^{\sin(\phi)} \quad \text{if } SPT \le 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot 100}{\sigma_v}\right)^{\sin(\phi)} \quad \text{if } SPT > 100 \\ \sigma_v \cdot K_o \cdot \tan(\phi) \end{array}$$

JOINTED ROCK - Tip Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{pr}(SPT, \sigma_v) := \begin{cases} 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT \le 100) \cdot (D \le 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT > 100) \cdot (D \le 1270 \cdot mm) \\ 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 100) \cdot (D > 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases} \quad (11.11)$$

RESISTANCE AT THE STRENGTH LIMIT STATE (10.8.3)

Factored bearing resistance $Q_R(\eta, \phi pQ_p, \phi sQ_s) := \eta \cdot (\phi pQ_p + \phi sQ_s)$ (10.7.3.2-1)

Side Resistance in Clay $\phi_{sc} := 0.65$ (Table 10.5.5-3)

Base resistance in Clay $\phi_{pc} := 0.55$ (Table 10.5.5-3)

Side Resistance in Sand $\phi_{ss} := 0.65$

Base resistance in Sand $\phi_{ps} := 0.5$

(Discussion in 10.8.3.4) & FHWA-IF-99-025 "Drilled Shafts: Construction Procedures and Design Methods"

Side Resistance in Rock $\phi_{sr} := 0.55$ (Table 10.5.5-3)

Base resistance in Rock $\phi_{pr} := 0.50$ (Table 10.5.5-3)

Calculate Shaft Resistance

$j := 1 .. 10$

Length of each soil layer down the pile

$$L_{Pile_j} := \begin{cases} Depth_j & \text{if } (ElevT \ge Lsoil_{t_j}) \cdot [(ElevT - L) \le Lsoil_{b_j}] \\ ElevT - Lsoil_{b_j} & \text{if } (ElevT < Lsoil_{t_j}) \cdot (ElevT \ge Lsoil_{b_j}) \cdot [(ElevT - L) \le Lsoil_{b_j}] \\ Lsoil_{t_j} - (ElevT - L) & \text{if } (ElevT \ge Lsoil_{t_j}) \cdot (ElevT - L > Lsoil_{b_j}) \cdot (ElevT - L < Lsoil_{t_j}) \\ 0 \cdot m & \text{otherwise} \end{cases}$$

Average depth of each soil layer

$$Z_j := \begin{cases} (Lsoil_{t_1} - Lsoil_{b_j}) - \dfrac{L_{Pile_j}}{2} & \text{if } (ElevT - L) \le Lsoil_{b_j} \\ [Lsoil_{t_1} - (ElevT - L)] - \dfrac{L_{Pile_j}}{2} & \text{otherwise} \end{cases}$$

Effective vertical soil stress at each soil layer

$$\sigma_{v_j} := Z_j \cdot \gamma_{soil}$$

Assign resistance factors

$$\phi_{s_j} := \begin{cases} \phi_{sc} & \text{if } SoilType_j = \text{"Clay"} \\ \phi_{ss} & \text{if } SoilType_j = \text{"Sand"} \\ \phi_{sr} & \text{otherwise} \end{cases}$$

Nominal unit shaft resistance

$$q_{s_j} := \begin{cases} q_{sc}(\alpha(S_u(SPT_j)), S_u(SPT_j)) & \text{if } SoilType_j = \text{"Clay"} \\ q_{ss}(Z_j, \sigma_{v_j}) & \text{if } SoilType_j = \text{"Sand"} \\ q_{sr}(SPT_j, \sigma_{v_j}) & \text{otherwise} \end{cases}$$

Calculate Tip Resistance

Locate pile tip soil layer "n"

$$n := \begin{array}{|l} s \leftarrow 0 \\ \text{for } j \in 1..10 \\ \quad s \leftarrow s+1 \text{ if } (ElevT - L) < Lsoil_{t_j} \\ s \end{array}$$

$n = 10$

Effective stress at base

$$\sigma_{vbase} := \left(Z_n + \frac{L_{Pile_n}}{2}\right)\cdot\gamma_{soil}$$

Nominal unit tip resistance

$$q_p := \begin{array}{|l} q_{pc}\left(N_c\left(Z_n, SPT_n\right), S_u\left(SPT_n\right)\right) \text{ if } SoilType_n = \text{"Clay"} \\ q_{ps}\left(SPT_n, D\right) \text{ if } SoilType_n = \text{"Sand"} \\ q_{pr}\left(SPT_n, \sigma_{vbase}\right) \text{ otherwise} \end{array}$$

Reduce Effective Pile Length at Pile Top (1.5m) and at Pile Base (One Pile Diameter)

Subtract 1.5m from pile top:

$value := L_{Pile_1} - 1.5m$ $\qquad value = -1\ m$

$value1 := L_{Pile_1} + L_{Pile_2} - 1.5m$ $\qquad value1 = 1\ m$

$value2 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} - 1.5m$ $\qquad value2 = 3\ m$

$value3 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} + L_{Pile_4} - 1.5m$ $\qquad value3 = 5\ m$

$$L_{Pile_1} := \begin{array}{|l} L_{Pile_1} - 1.5m \text{ if } value \ge 0\cdot m \\ 0\cdot m \text{ otherwise} \end{array}$$

$L_{Pile_1} = 0.00\ m$

$$L_{Pile_2} := \begin{array}{|l} value1 \text{ if } (value < 0\cdot m)(value1 \ge 0m) \\ 0\cdot m \text{ if } value1 < 0\cdot m \\ L_{Pile_2} \text{ otherwise} \end{array}$$

$L_{Pile_2} = 1.00\ m$

$$L_{Pile_3} := \begin{array}{|l} value2 \text{ if } (value1 < 0\cdot m)(value2 \ge 0m) \\ 0m \text{ if } value2 < 0\cdot m \\ L_{Pile_3} \text{ otherwise} \end{array}$$

$L_{Pile_3} = 2.00\ m$

$$L_{Pile_4} := \begin{array}{|l} value3 \text{ if } (value2 < 0\cdot m)(value3 \ge 0m) \\ 0m \text{ if } value3 < 0\cdot m \\ L_{Pile_4} \text{ otherwise} \end{array}$$

$L_{Pile_4} = 2.00\ m$

Subtract length from pile length at base:

$value := L_{Pile_n} - D$ $\quad value = 0\ m$

$value1 := L_{Pile_n} + L_{Pile_{n-1}} - D$ $\quad value1 = 6\ m$

$value2 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} - D$ $\quad value2 = 11\ m$

$value3 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} + L_{Pile_{n-3}} - D$ $\quad value3 = 15\ m$

$$L_{Pile_n} := \begin{cases} L_{Pile_n} - D & \text{if } value \geq 0 \cdot m \\ 0 \cdot m & \text{otherwise} \end{cases} \qquad L_{Pile_n} = 0.00\ m$$

$$L_{Pile_{n-1}} := \begin{cases} value1 & \text{if } (value < 0 \cdot m)(value1 \geq 0m) \\ 0 \cdot m & \text{if } value1 < 0 \cdot m \\ L_{Pile_{n-1}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-1}} = 6.00\ m$$

$$L_{Pile_{n-2}} := \begin{cases} value2 & \text{if } (value1 < 0 \cdot m)(value2 \geq 0m) \\ 0m & \text{if } value2 < 0 \cdot m \\ L_{Pile_{n-2}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-2}} = 5.00\ m$$

$$L_{Pile_{n-3}} := \begin{cases} value3 & \text{if } (value2 < 0 \cdot m)(value3 \geq 0m) \\ 0m & \text{if } value3 < 0 \cdot m \\ L_{Pile_{n-3}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-3}} = 4.00\ m$$

Reduction factor for large diameter bored piles in clay

$$F_r := \left| \begin{array}{l} a \leftarrow 0.0071 + 0.0021 \cdot \dfrac{Z_n}{D} \\ a \leftarrow \min(0.015, a) \\ b \leftarrow 1.45 \cdot \sqrt{2.0 \cdot \dfrac{S_u(SPT_n)}{MPa}} \\ b \leftarrow 0.5 \ \text{ if } \ b \leq 0.5 \\ b \leftarrow 1.5 \ \text{ if } \ 1.5 \leq b \\ F_r \leftarrow \dfrac{760}{12.0 \cdot a \cdot \dfrac{D}{mm} + 760 \cdot b} \\ F_r \leftarrow \min(1.0, F_r) \end{array} \right. \qquad F_r = 0.618$$

$$q_p := \begin{cases} q_p \cdot F_r & \text{if } (D > 1900 \cdot mm) \cdot (SoilType_n = \text{"Clay"}) \cdot (S_u(SPT_n) > 0.096 \cdot MPa) \cdot (Settlement = \text{"N"}) \\ q_p & \text{otherwise} \end{cases}$$

Calculate Total factored Resistance

Assign resistance factor

$$\phi_p := \begin{cases} \phi_{pc} & \text{if } SoilType_n = \text{"Clay"} \\ \phi_{ps} & \text{if } SoilType_n = \text{"Sand"} \\ \phi_{pr} & \text{otherwise} \end{cases}$$

Total Factored Shaft Resistance

$$\phi sQ_s := \sum_j \left(\phi_{s_j} \cdot q_{s_j} \cdot L_{Pile_j} \cdot \pi \cdot D \right) \qquad \phi sQ_s = 10316\,kN$$

Total Factored Tip Resistance

$$\phi pQ_p := \phi_p \cdot q_p \cdot \pi \cdot \frac{D^2}{4} \qquad \phi pQ_p = 3756\,kN$$

Uplift resistance (assuming submerged pile)

$$Q_{su} := \phi sQ_s \cdot \frac{0.55}{0.65} + \pi \cdot \frac{D^2}{4} \cdot L \cdot 14.5 \cdot \frac{kN}{m^3}$$

$$Q_{su} = 10793\,kN$$

Check center-to-center spacing of piles

$$ctc := \begin{cases} 2.5 \cdot D & \text{if } ctc < 2.5 \cdot D \\ 6.0 \cdot D & \text{if } ctc > 6.0 \cdot D \\ ctc & \text{otherwise} \end{cases} \qquad ctc = 6.25\ m$$

Determine if pile is predominantly driven in sand or clay

$$L_{sand} := \begin{array}{|l} L_s \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{array}{|l} L_s \leftarrow L_s + L_{Pile_j} \ \text{if } SoilType_j = \text{"Sand"} \\ L_s \ \text{otherwise} \end{array} \end{array}$$

$$L_{sand} = 0.00\ m$$

$$L_{clay} := \begin{array}{|l} L_c \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{array}{|l} L_c \leftarrow L_c + L_{Pile_j} \ \text{if } SoilType_j = \text{"Clay"} \\ L_c \ \text{otherwise} \end{array} \end{array}$$

$$L_{clay} = 25.00\ m$$

Assign overall soil type to pile

$$SoilTypeOverall := \begin{cases} \text{"Sand"} & \text{if } L_{sand} > L_{clay} \\ \text{"Clay"} & \text{otherwise} \end{cases}$$

$$SoilTypeOverall = \text{"Clay"}$$

Efficiency of pile group (10.7.3.10.2)

$$\eta := \begin{cases} 1.00 & \text{if } SoilType_n = \text{"Rock"} \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"}) \cdot (SoilType_n = \text{"Sand"}) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"}) \cdot (SoilType_n = \text{"Clay"}) \cdot (PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"}) \cdot (SoilType_n = \text{"Clay"}) \cdot (PileCapType = 2) \cdot (SPT_2 \geq 5) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"}) \cdot (PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"}) \cdot (PileCapType = 2) \cdot (SPT_2 \geq 5) \\ 0.65 + (1 - 0.65) \cdot \dfrac{ctc - 2.5 \cdot D}{3.5 \cdot D} & \text{otherwise} \end{cases}$$

$\eta = 1.00$

SUMMARY
BORED Pile
Shaft and Tip Factored Resistance kN

Diameter of Pile $D = 2.5\ m$

Length of Pile $L = 29\ m$

Ref.	Thick ness	Length down Pile	Level	SPT N	Soil Type	q_s	φ_s	$\varphi_s Q_s$	q_p	φ_p	$\varphi_p Q_p$
	(m)	(m)	(m)			kN/m2		kN	kN/m2		kN
1.0	2.5	0.0	-2.5	0	Clay	0.0	0.65	0	0.0	0.00	0
2.0	2.0	1.0	-4.5	25	Clay	68.8	0.65	351	0.0	0.00	0
3.0	2.0	2.0	-6.5	11	Clay	30.3	0.65	309	0.0	0.00	0
4.0	2.0	2.0	-8.5	13	Clay	35.8	0.65	365	0.0	0.00	0
5.0	2.0	2.0	-10.5	50	Clay	100.0	0.65	1021	0.0	0.00	0
6.0	3.0	3.0	-13.5	50	Clay	100.0	0.65	1532	0.0	0.00	0
7.0	4.0	4.0	-17.5	20	Clay	55.0	0.65	1123	0.0	0.00	0
8.0	5.0	5.0	-22.5	50	Clay	100.0	0.65	2553	0.0	0.00	0
9.0	6.0	6.0	-28.5	50	Clay	100.0	0.65	3063	0.0	0.00	0
10.0	7.0	0.0	-31.0	50	Clay	100.0	0.65	0	1391.1	0.55	3756
Total Factored Shaft Resistance $\varphi_s Q_s$								10316	Factored Tip Resistance $\varphi_p Q_p$		3756

$$\eta = 1.00$$

TOTAL FACTORED RESISTANCE PER PILE

$$Q_R(\eta, \phi p Q_p, \phi s Q_s) = 14072\ kN$$

TOTAL FACTORED UPLIFT RESISTANCE PER PILE

$$Q_{su} = 10793\ kN$$

KATAHIRA & ENGINEERS INTERNATIONAL

Project: **Detailed Design Study of North Java Flyover Project**

Calculation: **Detailed Design**
Balaraja Flyover - Pier P5
2.5m Dia. BORED PILE AXIAL BEARING CAPACITY

Reference : **AASHTO LRFD Bridge Design Specification**
"Drilled Shafts: Construction Procedures and Design Methods"
FHWA-IF-99-025, August 1999

Definitions $kN := 1000 \cdot N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $kPa := 1000 \cdot Pa$

Pile Input Data

Pile Diameter	D (m)	2.50
Length of Pile	L (m)	29.00
Elevation at top of Pile	ElevTop (m)	-2.00
Effective Soil Density	γ (kN/m3)	10.00
Pile Cap 1. In firm contact with the ground 2. Not in firm contact with the ground		2
Pile center-to-center spacing	ctc (m)	0.000
Settlements evaluated?	(Y or N)	N

$D := D \cdot m$ $L := L \cdot m$ $ElevT := ElevT \cdot m$ $\gamma_{soil} := \gamma_{soil} \cdot \frac{kN}{m^3}$ $ctc := ctc \cdot m$

Subsoil Input Data - BOREHOLE BH 8

Ref.	Thickness (cm)	Level top of Layer (m)	Level bottom of Layer (m)	Soil Type	SPT N
1.0	400	0.00	-4.00	Clay	0
2.0	200	-4.00	-6.00	Clay	15
3.0	200	-6.00	-8.00	Clay	11
4.0	200	-8.00	-10.00	Clay	32
5.0	200	-10.00	-12.00	Clay	50
6.0	200	-12.00	-14.00	Clay	50
7.0	600	-14.00	-20.00	Clay	50
8.0	600	-20.00	-26.00	Clay	50
9.0	600	-26.00	-32.00	Clay	50
10.0	600	-32.00	-38.00	Clay	50

$Lsoil_t := Lsoil_{top} \cdot m$ $Lsoil_b := Lsoil_{bottom} \cdot m$ $Depth := Depth \cdot cm$

COHESIVE SOILS - Shaft Resistance Using the α method (10.8.3.3.1)

$$q_{sc}(\alpha, S_u) := \begin{cases} 100 \cdot kPa & \text{if } \alpha \cdot S_u > 100 \cdot kPa \\ \alpha \cdot S_u & \text{otherwise} \end{cases}$$ (10.8.3.3.1-1)

(JRA Table C.10.4-4)

$$S_u(SPT) := 5 \cdot SPT \cdot kPa$$

(Table 10.8.3.3.1-1)

$$\alpha(S_u) := \begin{cases} 0.55 & \text{if } S_u < 0.2 \cdot MPa \\ 0.49 & \text{if } (S_u \geq 0.2 \cdot MPa) \cdot (S_u < 0.30 \cdot MPa) \\ 0.42 & \text{if } (S_u \geq 0.3 \cdot MPa) \cdot (S_u < 0.40 \cdot MPa) \\ 0.38 & \text{if } (S_u \geq 0.4 \cdot MPa) \cdot (S_u < 0.50 \cdot MPa) \\ 0.35 & \text{if } (S_u \geq 0.5 \cdot MPa) \cdot (S_u < 0.60 \cdot MPa) \\ 0.33 & \text{if } (S_u \geq 0.6 \cdot MPa) \cdot (S_u < 0.70 \cdot MPa) \\ 0.32 & \text{if } (S_u \geq 0.7 \cdot MPa) \cdot (S_u < 0.80 \cdot MPa) \\ 0.31 & \text{if } (S_u \geq 0.8 \cdot MPa) \cdot (S_u < 0.90 \cdot MPa) \\ \text{"Treat as Rock"} & \text{otherwise} \end{cases}$$

COHESIVE SOILS - Tip Resistance (10.8.3.3.2)

(10.8.3.3.2-1)

$$q_{pc}(N_c, S_u) := \begin{cases} N_c \cdot S_u & \text{if } N_c \cdot S_u \leq 4.0 \cdot MPa \\ 4.0 \cdot MPa & \text{otherwise} \end{cases}$$

(10.8.3.3.2-2)

$$N_c(Z, SPT) := \begin{array}{|l} N_c \leftarrow 6 \cdot \left[1 + 0.2 \cdot \left(\frac{Z}{D}\right)\right] \\ N_c \leftarrow \frac{N_c}{3} \quad \text{if } 5 \cdot SPT \cdot kPa < 0.024 \cdot MPa \\ N_c \quad \text{if } N_c \leq 9 \\ 9 \quad \text{otherwise} \end{array}$$

COHESIONLESS SOILS - Shaft Resistance Using Reese and O'Neill Method (10.8.3.4.2)

$$\beta(Z) := \begin{array}{|l} \beta \leftarrow 1.5 - 7.7 \cdot 10^{-3} \cdot \sqrt{\frac{Z}{mm}} \\ \beta \leftarrow 0.25 \quad \text{if } \beta < 0.25 \\ \beta \leftarrow 1.2 \quad \text{if } \beta > 1.2 \\ \beta \quad \text{otherwise} \end{array}$$

(Table 10.8.3.4.2-1)

$$q_{ss}(Z, \sigma_v) := \begin{cases} \beta(Z) \cdot \sigma_v & \text{if } \beta(Z) \cdot \sigma_v \leq 0.19 \cdot MPa \\ 0.19 \cdot MPa & \text{otherwise} \end{cases}$$

COHESIONLESS SOILS - Tip Resistance Using Reese and O'Neill Method (10.8.3.4.3)

$$q_{ps}(SPT, D) := \begin{cases} 0.057 \cdot SPT \cdot MPa & \text{if } (SPT \le 75) \cdot (D \le 1270 \cdot mm) \\ 0.057 \cdot SPT \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 75) \cdot (D > 1270 \cdot mm) \\ 4.3 \cdot MPa & \text{if } (SPT > 75) \cdot (D \le 1270 \cdot mm) \\ 4.3 \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

(Table 10.8.3.4.3-1)
&
(10.8.3.4.3-1)

JOINTED ROCK - Shaft Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{sr}(SPT, \sigma_v) := \begin{cases} \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{SPT}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] & \text{if } SPT \le 100 \\ \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{100}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] & \text{if } SPT > 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot SPT}{\sigma_v}\right)^{\sin(\phi)} & \text{if } SPT \le 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot 100}{\sigma_v}\right)^{\sin(\phi)} & \text{if } SPT > 100 \\ \sigma_v \cdot K_o \cdot \tan(\phi) & \end{cases}$$

JOINTED ROCK - Tip Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{pr}(SPT, \sigma_v) := \begin{cases} 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT \le 100) \cdot (D \le 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT > 100) \cdot (D \le 1270 \cdot mm) \\ 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 100) \cdot (D > 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

(11.11)

RESISTANCE AT THE STRENGTH LIMIT STATE (10.8.3)

Factored bearing resistance $Q_R(\eta, \phi pQ_p, \phi sQ_s) := \eta\cdot(\phi pQ_p + \phi sQ_s)$ (10.7.3.2-1)

Side Resistance in Clay $\phi_{sc} := 0.65$ (Table 10.5.5-3)

Base resistance in Clay $\phi_{pc} := 0.55$ (Table 10.5.5-3)

Side Resistance in Sand $\phi_{ss} := 0.65$

Base resistance in Sand $\phi_{ps} := 0.5$

(Discussion in 10.8.3.4) & FHWA-IF-99-025 "Drilled Shafts: Construction Procedures and Design Methods"

Side Resistance in Rock $\phi_{sr} := 0.55$ (Table 10.5.5-3)

Base resistance in Rock $\phi_{pr} := 0.50$ (Table 10.5.5-3)

Calculate Shaft Resistance

$j := 1..10$

Length of each soil layer down the pile

$$L_{Pile_j} := \begin{cases} Depth_j & \text{if } (ElevT \ge Lsoil_{t_j})\cdot[(ElevT - L) \le Lsoil_{b_j}] \\ ElevT - Lsoil_{b_j} & \text{if } (ElevT < Lsoil_{t_j})\cdot(ElevT \ge Lsoil_{b_j})\cdot[(ElevT - L) \le Lsoil_{b_j}] \\ Lsoil_{t_j} - (ElevT - L) & \text{if } (ElevT \ge Lsoil_{t_j})\cdot(ElevT - L > Lsoil_{b_j})\cdot(ElevT - L < Lsoil_{t_j}) \\ 0\cdot m & \text{otherwise} \end{cases}$$

Average depth of each soil layer

$$Z_j := \begin{cases} (Lsoil_{t_1} - Lsoil_{b_j}) - \dfrac{L_{Pile_j}}{2} & \text{if } (ElevT - L) \le Lsoil_{b_j} \\ [Lsoil_{t_1} - (ElevT - L)] - \dfrac{L_{Pile_j}}{2} & \text{otherwise} \end{cases}$$

Effective vertical soil stress at each soil layer

$$\sigma_{v_j} := Z_j\cdot\gamma_{soil}$$

Assign resistance factors

$$\phi_{s_j} := \begin{cases} \phi_{sc} & \text{if } SoilType_j = \text{"Clay"} \\ \phi_{ss} & \text{if } SoilType_j = \text{"Sand"} \\ \phi_{sr} & \text{otherwise} \end{cases}$$

Nominal unit shaft resistance

$$q_{s_j} := \begin{cases} q_{sc}(\alpha(S_u(SPT_j)), S_u(SPT_j)) & \text{if } SoilType_j = \text{"Clay"} \\ q_{ss}(Z_j, \sigma_{v_j}) & \text{if } SoilType_j = \text{"Sand"} \\ q_{sr}(SPT_j, \sigma_{v_j}) & \text{otherwise} \end{cases}$$

Calculate Tip Resistance

Locate pile tip soil layer "n"

$$n := \left| \begin{array}{l} s \leftarrow 0 \\ \text{for } j \in 1..10 \\ \quad s \leftarrow s + 1 \text{ if } (ElevT - L) < Lsoil_{t_j} \\ s \end{array} \right. \qquad n = 9$$

Effective stress at base

$$\sigma_{vbase} := \left(Z_n + \frac{L_{Pile_n}}{2} \right) \cdot \gamma_{soil}$$

Nominal unit tip resistance

$$q_p := \left| \begin{array}{l} q_{pc}\left(N_c\left(Z_n, SPT_n\right), S_u\left(SPT_n\right)\right) \text{ if } SoilType_n = \text{"Clay"} \\ q_{ps}\left(SPT_n, D\right) \text{ if } SoilType_n = \text{"Sand"} \\ q_{pr}\left(SPT_n, \sigma_{vbase}\right) \text{ otherwise} \end{array} \right.$$

Reduce Effective Pile Length at Pile Top (1.5m) and at Pile Base (One Pile Diameter)

Subtract 1.5m from pile top:

$$value := L_{Pile_1} - 1.5m \qquad value = 0.5\ m$$

$$value1 := L_{Pile_1} + L_{Pile_2} - 1.5m \qquad value1 = 2.5\ m$$

$$value2 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} - 1.5m \qquad value2 = 4.5\ m$$

$$value3 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} + L_{Pile_4} - 1.5m \qquad value3 = 6.5\ m$$

$$L_{Pile_1} := \left| \begin{array}{l} L_{Pile_1} - 1.5m \text{ if } value \ge 0 \cdot m \\ 0 \cdot m \text{ otherwise} \end{array} \right. \qquad L_{Pile_1} = 0.50\ m$$

$$L_{Pile_2} := \left| \begin{array}{l} value1 \text{ if } (value < 0 \cdot m)(value1 \ge 0m) \\ 0 \cdot m \text{ if } value1 < 0 \cdot m \\ L_{Pile_2} \text{ otherwise} \end{array} \right. \qquad L_{Pile_2} = 2.00\ m$$

$$L_{Pile_3} := \left| \begin{array}{l} value2 \text{ if } (value1 < 0 \cdot m)(value2 \ge 0m) \\ 0m \text{ if } value2 < 0 \cdot m \\ L_{Pile_3} \text{ otherwise} \end{array} \right. \qquad L_{Pile_3} = 2.00\ m$$

$$L_{Pile_4} := \left| \begin{array}{l} value3 \text{ if } (value2 < 0 \cdot m)(value3 \ge 0m) \\ 0m \text{ if } value3 < 0 \cdot m \\ L_{Pile_4} \text{ otherwise} \end{array} \right. \qquad L_{Pile_4} = 2.00\ m$$

Subtract length from pile length at base:

$value := L_{Pile_n} - D$ $\quad$ $value = 2.5\ m$

$value1 := L_{Pile_n} + L_{Pile_{n-1}} - D$ $\quad$ $value1 = 8.5\ m$

$value2 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} - D$ $\quad$ $value2 = 14.5\ m$

$value3 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} + L_{Pile_{n-3}} - D$ $\quad$ $value3 = 16.5\ m$

$$L_{Pile_n} := \begin{cases} L_{Pile_n} - D & \text{if } value \geq 0 \cdot m \\ 0 \cdot m & \text{otherwise} \end{cases}$$ $L_{Pile_n} = 2.50\ m$

$$L_{Pile_{n-1}} := \begin{cases} value1 & \text{if } (value < 0 \cdot m)(value1 \geq 0m) \\ 0 \cdot m & \text{if } value1 < 0 \cdot m \\ L_{Pile_{n-1}} & \text{otherwise} \end{cases}$$ $L_{Pile_{n-1}} = 6.00\ m$

$$L_{Pile_{n-2}} := \begin{cases} value2 & \text{if } (value1 < 0 \cdot m)(value2 \geq 0m) \\ 0m & \text{if } value2 < 0 \cdot m \\ L_{Pile_{n-2}} & \text{otherwise} \end{cases}$$ $L_{Pile_{n-2}} = 6.00\ m$

$$L_{Pile_{n-3}} := \begin{cases} value3 & \text{if } (value2 < 0 \cdot m)(value3 \geq 0m) \\ 0m & \text{if } value3 < 0 \cdot m \\ L_{Pile_{n-3}} & \text{otherwise} \end{cases}$$ $L_{Pile_{n-3}} = 2.00\ m$

Reduction factor for large diameter bored piles in clay

$$F_r := \left| \begin{array}{l} a \leftarrow 0.0071 + 0.0021 \cdot \dfrac{Z_n}{D} \\ a \leftarrow \min(0.015, a) \\ b \leftarrow 1.45 \cdot \sqrt{2.0 \cdot \dfrac{S_u(SPT_n)}{MPa}} \\ b \leftarrow 0.5 \ \text{ if } b \leq 0.5 \\ b \leftarrow 1.5 \ \text{ if } 1.5 \leq b \\ F_r \leftarrow \dfrac{760}{12.0 \cdot a \cdot \dfrac{D}{mm} + 760 \cdot b} \\ F_r \leftarrow \min(1.0, F_r) \end{array} \right.$$ $F_r = 0.618$

$$q_p := \begin{cases} q_p \cdot F_r & \text{if } (D > 1900 \cdot mm) \cdot (SoilType_n = \text{"Clay"}) \cdot (S_u(SPT_n) > 0.096 \cdot MPa) \cdot (Settlement = \text{"N"}) \\ q_p & \text{otherwise} \end{cases}$$

Calculate Total factored Resistance

Assign resistance factor

$$\phi_p := \begin{cases} \phi_{pc} & \text{if } SoilType_n = \text{"Clay"} \\ \phi_{ps} & \text{if } SoilType_n = \text{"Sand"} \\ \phi_{pr} & \text{otherwise} \end{cases}$$

Total Factored Shaft Resistance

$$\phi sQ_s := \sum_j \left(\phi_{s_j} \cdot q_{s_j} \cdot L_{Pile_j} \cdot \pi \cdot D\right)$$

$\phi sQ_s = 11073\,kN$

Total Factored Tip Resistance

$$\phi pQ_p := \phi_p \cdot q_p \cdot \pi \cdot \frac{D^2}{4}$$

$\phi pQ_p = 3756\,kN$

Uplift resistance (assuming submerged pile)

$$Q_{su} := \phi sQ_s \cdot \frac{0.55}{0.65} + \pi \cdot \frac{D^2}{4} \cdot L \cdot 14.5 \cdot \frac{kN}{m^3}$$

$Q_{su} = 11434\,kN$

Check center-to-center spacing of piles

$$ctc := \begin{cases} 2.5 \cdot D & \text{if } ctc < 2.5 \cdot D \\ 6.0 \cdot D & \text{if } ctc > 6.0 \cdot D \\ ctc & \text{otherwise} \end{cases}$$

$ctc = 6.25\ m$

Determine if pile is predominantly driven in sand or clay

$$L_{sand} := \begin{array}{|l} L_s \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{array}{|l} L_s \leftarrow L_s + L_{Pile_j} \ \text{if } SoilType_j = \text{"Sand"} \\ L_s \ \text{otherwise} \end{array} \end{array}$$

$L_{sand} = 0.00\ m$

$$L_{clay} := \begin{array}{|l} L_c \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{array}{|l} L_c \leftarrow L_c + L_{Pile_j} \ \text{if } SoilType_j = \text{"Clay"} \\ L_c \ \text{otherwise} \end{array} \end{array}$$

$L_{clay} = 25.00\ m$

Assign overall soil type to pile

$$SoilTypeOverall := \begin{cases} \text{"Sand"} & \text{if } L_{sand} > L_{clay} \\ \text{"Clay"} & \text{otherwise} \end{cases}$$

SoilTypeOverall = "Clay"

Efficiency of pile group (10.7.3.10.2)

$$\eta := \begin{cases} 1.00 & \text{if } SoilType_n = \text{"Rock"} \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Sand"}) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \geq 5) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \geq 5) \\ 0.65 + (1 - 0.65)\cdot\frac{ctc - 2.5\cdot D}{3.5\cdot D} & \text{otherwise} \end{cases}$$

$\eta = 1.00$

SUMMARY
BORED Pile
Shaft and Tip Factored Resistance kN

Diameter of Pile $D = 2.5\ m$

Length of Pile $L = 29\ m$

Ref.	Thick ness	Length down Pile	Level	SPT N	Soil Type	q_s	φ_s	$\varphi_s Q_s$	q_p	φ_p	$\varphi_p Q_p$
	(m)	(m)	(m)			kN/m2		kN	kN/m2		kN
1.0	4.0	0.5	-4.0	0	Clay	0.0	0.65	0	0.0	0.00	0
2.0	2.0	2.0	-6.0	15	Clay	41.3	0.65	421	0.0	0.00	0
3.0	2.0	2.0	-8.0	11	Clay	30.3	0.65	309	0.0	0.00	0
4.0	2.0	2.0	-10.0	32	Clay	88.0	0.65	898	0.0	0.00	0
5.0	2.0	2.0	-12.0	50	Clay	100.0	0.65	1021	0.0	0.00	0
6.0	2.0	2.0	-14.0	50	Clay	100.0	0.65	1021	0.0	0.00	0
7.0	6.0	6.0	-20.0	50	Clay	100.0	0.65	3063	0.0	0.00	0
8.0	6.0	6.0	-26.0	50	Clay	100.0	0.65	3063	0.0	0.00	0
9.0	6.0	2.5	-31.0	50	Clay	100.0	0.65	1276	1391.1	0.55	3756
10.0	6.0	0.0	0.0	50	Clay	100.0	0.65	0	0.0	0.00	0
Total Factored Shaft Resistance $\varphi_s Q_s$								11073	Factored Tip Resistance $\varphi_p Q_p$		3756

$\eta = 1.00$

TOTAL FACTORED RESISTANCE PER PILE

$$Q_R(\eta, \phi p Q_p, \phi s Q_s) = 14829\ kN$$

TOTAL FACTORED UPLIFT RESISTANCE PER PILE

$$Q_{su} = 11434\ kN$$

KATAHIRA & ENGINEERS INTERNATIONAL

Project: **Detailed Design Study of North Java Flyover Project**

Calculation: **Detailed Design**
Balaraja Flyover - Pier P6
1.5m Dia. BORED PILE AXIAL BEARING CAPACITY

Reference : **AASHTO LRFD Bridge Design Specification**
"Drilled Shafts: Construction Procedures and Design Methods"
FHWA-IF-99-025, August 1999

Definitions $kN := 1000 \cdot N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $kPa := 1000 \cdot Pa$

Pile Input Data

Pile Diameter	D (m)	1.50
Length of Pile	L (m)	18.00
Elevation at top of Pile	ElevTop (m)	-2.00
Effective Soil Density	γ (kN/m3)	10.00
Pile Cap		2
1. In firm contact with the ground		
2. Not in firm contact with the ground		
Pile center-to-center spacing	ctc (m)	6.000
Settlements evaluated?	(Y or N)	N

$D := D \cdot m$ $L := L \cdot m$ $ElevT := ElevT \cdot m$ $\gamma_{soil} := \gamma_{soil} \cdot \frac{kN}{m^3}$ $ctc := ctc \cdot m$

Subsoil Input Data - BOREHOLE BH 9

Ref.	Thickness	Level top of Layer	Level bottom of Layer	Soil Type	SPT N
	(cm)	(m)	(m)		
1.0	200	0.00	-2.00	Clay	0
2.0	200	-2.00	-4.00	Clay	17
3.0	200	-4.00	-6.00	Clay	11
4.0	200	-6.00	-8.00	Clay	14
5.0	200	-8.00	-10.00	Clay	50
6.0	200	-10.00	-12.00	Clay	27
7.0	200	-12.00	-14.00	Clay	50
8.0	200	-14.00	-16.00	Clay	50
9.0	400	-16.00	-20.00	Clay	50
10.0	800	-20.00	-28.00	Clay	50

$Lsoil_t := Lsoil_{top} \cdot m$ $Lsoil_b := Lsoil_{bottom} \cdot m$ $Depth := Depth \cdot cm$

COHESIVE SOILS - Shaft Resistance Using the α method (10.8.3.3.1)

$$q_{sc}(\alpha, S_u) := \begin{cases} 100\cdot kPa & \text{if } \alpha\cdot S_u > 100\cdot kPa \\ \alpha\cdot S_u & \text{otherwise} \end{cases}$$ (10.8.3.3.1-1)

(JRA Table C.10.4-4)

$$S_u(SPT) := 5\cdot SPT\cdot kPa$$

$$\alpha(S_u) := \begin{cases} 0.55 & \text{if } S_u < 0.2\cdot MPa \\ 0.49 & \text{if } (S_u \ge 0.2\cdot MPa)\cdot(S_u < 0.30\cdot MPa) \\ 0.42 & \text{if } (S_u \ge 0.3\cdot MPa)\cdot(S_u < 0.40\cdot MPa) \\ 0.38 & \text{if } (S_u \ge 0.4\cdot MPa)\cdot(S_u < 0.50\cdot MPa) \\ 0.35 & \text{if } (S_u \ge 0.5\cdot MPa)\cdot(S_u < 0.60\cdot MPa) \\ 0.33 & \text{if } (S_u \ge 0.6\cdot MPa)\cdot(S_u < 0.70\cdot MPa) \\ 0.32 & \text{if } (S_u \ge 0.7\cdot MPa)\cdot(S_u < 0.80\cdot MPa) \\ 0.31 & \text{if } (S_u \ge 0.8\cdot MPa)\cdot(S_u < 0.90\cdot MPa) \\ \text{"Treat as Rock"} & \text{otherwise} \end{cases}$$ (Table 10.8.3.3.1-1)

COHESIVE SOILS - Tip Resistance (10.8.3.3.2)

$$q_{pc}(N_c, S_u) := \begin{cases} N_c\cdot S_u & \text{if } N_c\cdot S_u \le 4.0\cdot MPa \\ 4.0\cdot MPa & \text{otherwise} \end{cases}$$ (10.8.3.3.2-1)

$$N_c(Z, SPT) := \left| \begin{array}{l} N_c \leftarrow 6\cdot\left[1 + 0.2\cdot\left(\frac{Z}{D}\right)\right] \\ N_c \leftarrow \frac{N_c}{3} \quad \text{if } 5\cdot SPT\cdot kPa < 0.024\cdot MPa \\ N_c \quad \text{if } N_c \le 9 \\ 9 \quad \text{otherwise} \end{array} \right.$$ (10.8.3.3.2-2)

COHESIONLESS SOILS - Shaft Resistance Using Reese and O'Neill Method (10.8.3.4.2)

$$\beta(Z) := \left| \begin{array}{l} \beta \leftarrow 1.5 - 7.7\cdot 10^{-3}\cdot\sqrt{\frac{Z}{mm}} \\ \beta \leftarrow 0.25 \quad \text{if } \beta < 0.25 \\ \beta \leftarrow 1.2 \quad \text{if } \beta > 1.2 \\ \beta \quad \text{otherwise} \end{array} \right.$$

$$q_{ss}(Z, \sigma_v) := \begin{cases} \beta(Z)\cdot\sigma_v & \text{if } \beta(Z)\cdot\sigma_v \le 0.19\cdot MPa \\ 0.19\cdot MPa & \text{otherwise} \end{cases}$$ (Table 10.8.3.4.2-1)

COHESIONLESS SOILS - Tip Resistance Using Reese and O'Neill Method (10.8.3.4.3)

$$q_{ps}(SPT, D) := \begin{cases} 0.057 \cdot SPT \cdot MPa & \text{if } (SPT \le 75)\cdot(D \le 1270 \cdot mm) \\ 0.057 \cdot SPT \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 75)\cdot(D > 1270 \cdot mm) \\ 4.3 \cdot MPa & \text{if } (SPT > 75)\cdot(D \le 1270 \cdot mm) \\ 4.3 \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

(Table 10.8.3.4.3-1) & (10.8.3.4.3-1)

JOINTED ROCK - Shaft Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{sr}(SPT, \sigma_v) := \begin{cases} \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{SPT}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] & \text{if } SPT \le 100 \\ \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{100}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] & \text{if } SPT > 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot SPT}{\sigma_v}\right)^{\sin(\phi)} & \text{if } SPT \le 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot 100}{\sigma_v}\right)^{\sin(\phi)} & \text{if } SPT > 100 \\ \sigma_v \cdot K_o \cdot \tan(\phi) & \end{cases}$$

JOINTED ROCK - Tip Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{pr}(SPT, \sigma_v) := \begin{cases} 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT \le 100)\cdot(D \le 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT > 100)\cdot(D \le 1270 \cdot mm) \\ 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 100)\cdot(D > 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

(11.11)

RESISTANCE AT THE STRENGTH LIMIT STATE (10.8.3)

Factored bearing resistance $Q_R(\eta, \phi pQ_p, \phi sQ_s) := \eta \cdot (\phi pQ_p + \phi sQ_s)$ (10.7.3.2-1)

Side Resistance in Clay $\phi_{sc} := 0.65$ (Table 10.5.5-3)

Base resistance in Clay $\phi_{pc} := 0.55$ (Table 10.5.5-3)

Side Resistance in Sand $\phi_{ss} := 0.65$ (Discussion in 10.8.3.4) & FHWA-IF-99-025 "Drilled Shafts: Construction Procedures and Design Methods"

Base resistance in Sand $\phi_{ps} := 0.5$

Side Resistance in Rock $\phi_{sr} := 0.55$ (Table 10.5.5-3)

Base resistance in Rock $\phi_{pr} := 0.50$ (Table 10.5.5-3)

Calculate Shaft Resistance

$j := 1..10$

Length of each soil layer down the pile

$$L_{Pile_j} := \begin{cases} Depth_j & \text{if } (ElevT \ge Lsoil_{t_j}) \cdot [(ElevT - L) \le Lsoil_{b_j}] \\ ElevT - Lsoil_{b_j} & \text{if } (ElevT < Lsoil_{t_j}) \cdot (ElevT \ge Lsoil_{b_j}) \cdot [(ElevT - L) \le Lsoil_{b_j}] \\ Lsoil_{t_j} - (ElevT - L) & \text{if } (ElevT \ge Lsoil_{t_j}) \cdot (ElevT - L > Lsoil_{b_j}) \cdot (ElevT - L < Lsoil_{t_j}) \\ 0 \cdot m & \text{otherwise} \end{cases}$$

Average depth of each soil layer

$$Z_j := \begin{cases} (Lsoil_{t_1} - Lsoil_{b_j}) - \dfrac{L_{Pile_j}}{2} & \text{if } (ElevT - L) \le Lsoil_{b_j} \\ [Lsoil_{t_1} - (ElevT - L)] - \dfrac{L_{Pile_j}}{2} & \text{otherwise} \end{cases}$$

Effective vertical soil stress at each soil layer

$$\sigma_{v_j} := Z_j \cdot \gamma_{soil}$$

Assign resistance factors

$$\phi_{s_j} := \begin{cases} \phi_{sc} & \text{if } SoilType_j = \text{"Clay"} \\ \phi_{ss} & \text{if } SoilType_j = \text{"Sand"} \\ \phi_{sr} & \text{otherwise} \end{cases}$$

Nominal unit shaft resistance

$$q_{s_j} := \begin{cases} q_{sc}(\alpha(S_u(SPT_j)), S_u(SPT_j)) & \text{if } SoilType_j = \text{"Clay"} \\ q_{ss}(Z_j, \sigma_{v_j}) & \text{if } SoilType_j = \text{"Sand"} \\ q_{sr}(SPT_j, \sigma_{v_j}) & \text{otherwise} \end{cases}$$

Calculate Tip Resistance

Locate pile tip soil layer "n"

$$n := \begin{array}{|l} s \leftarrow 0 \\ \text{for } j \in 1..10 \\ \quad s \leftarrow s + 1 \text{ if } (ElevT - L) < Lsoil_{t_j} \\ s \end{array} \qquad n = 9$$

Effective stress at base

$$\sigma_{vbase} := \left(Z_n + \frac{L_{Pile_n}}{2} \right) \cdot \gamma_{soil}$$

Nominal unit tip resistance

$$q_p := \begin{array}{|l} q_{pc}\left(N_c\left(Z_n, SPT_n\right), S_u\left(SPT_n\right)\right) \text{ if } SoilType_n = \text{"Clay"} \\ q_{ps}\left(SPT_n, D\right) \text{ if } SoilType_n = \text{"Sand"} \\ q_{pr}\left(SPT_n, \sigma_{vbase}\right) \text{ otherwise} \end{array}$$

Reduce Effective Pile Length at Pile Top (1.5m) and at Pile Base (One Pile Diameter)

Subtract 1.5m from pile top:

$$value := L_{Pile_1} - 1.5m \qquad value = -1.5 \text{ m}$$

$$value1 := L_{Pile_1} + L_{Pile_2} - 1.5m \qquad value1 = 0.5 \text{ m}$$

$$value2 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} - 1.5m \qquad value2 = 2.5 \text{ m}$$

$$value3 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} + L_{Pile_4} - 1.5m \qquad value3 = 4.5 \text{ m}$$

$$L_{Pile_1} := \begin{array}{|l} L_{Pile_1} - 1.5m \text{ if } value \geq 0 \cdot m \\ 0 \cdot m \text{ otherwise} \end{array} \qquad L_{Pile_1} = 0.00 \text{ m}$$

$$L_{Pile_2} := \begin{array}{|l} value1 \text{ if } (value < 0 \cdot m)(value1 \geq 0m) \\ 0 \cdot m \text{ if } value1 < 0 \cdot m \\ L_{Pile_2} \text{ otherwise} \end{array} \qquad L_{Pile_2} = 0.50 \text{ m}$$

$$L_{Pile_3} := \begin{array}{|l} value2 \text{ if } (value1 < 0 \cdot m)(value2 \geq 0m) \\ 0m \text{ if } value2 < 0 \cdot m \\ L_{Pile_3} \text{ otherwise} \end{array} \qquad L_{Pile_3} = 2.00 \text{ m}$$

$$L_{Pile_4} := \begin{array}{|l} value3 \text{ if } (value2 < 0 \cdot m)(value3 \geq 0m) \\ 0m \text{ if } value3 < 0 \cdot m \\ L_{Pile_4} \text{ otherwise} \end{array} \qquad L_{Pile_4} = 2.00 \text{ m}$$

Subtract length from pile length at base:

$value := L_{Pile_n} - D$ $\quad$ $value = 2.5\ m$

$value1 := L_{Pile_n} + L_{Pile_{n-1}} - D$ $\quad$ $value1 = 4.5\ m$

$value2 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} - D$ $\quad$ $value2 = 6.5\ m$

$value3 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} + L_{Pile_{n-3}} - D$ $\quad$ $value3 = 8.5\ m$

$$L_{Pile_n} := \begin{cases} L_{Pile_n} - D & \text{if } value \geq 0 \cdot m \\ 0 \cdot m & \text{otherwise} \end{cases}$$ $L_{Pile_n} = 2.50\ m$

$$L_{Pile_{n-1}} := \begin{cases} value1 & \text{if } (value < 0 \cdot m)(value1 \geq 0m) \\ 0 \cdot m & \text{if } value1 < 0 \cdot m \\ L_{Pile_{n-1}} & \text{otherwise} \end{cases}$$ $L_{Pile_{n-1}} = 2.00\ m$

$$L_{Pile_{n-2}} := \begin{cases} value2 & \text{if } (value1 < 0 \cdot m)(value2 \geq 0m) \\ 0m & \text{if } value2 < 0 \cdot m \\ L_{Pile_{n-2}} & \text{otherwise} \end{cases}$$ $L_{Pile_{n-2}} = 2.00\ m$

$$L_{Pile_{n-3}} := \begin{cases} value3 & \text{if } (value2 < 0 \cdot m)(value3 \geq 0m) \\ 0m & \text{if } value3 < 0 \cdot m \\ L_{Pile_{n-3}} & \text{otherwise} \end{cases}$$ $L_{Pile_{n-3}} = 2.00\ m$

Reduction factor for large diameter bored piles in clay

$$F_r := \left| \begin{array}{l} a \leftarrow 0.0071 + 0.0021 \cdot \dfrac{Z_n}{D} \\ a \leftarrow \min(0.015, a) \\ b \leftarrow 1.45 \cdot \sqrt{2.0 \cdot \dfrac{S_u(SPT_n)}{MPa}} \\ b \leftarrow 0.5 \ \text{ if } \ b \leq 0.5 \\ b \leftarrow 1.5 \ \text{ if } \ 1.5 \leq b \\ F_r \leftarrow \dfrac{760}{12.0 \cdot a \cdot \dfrac{D}{mm} + 760 \cdot b} \\ F_r \leftarrow \min(1.0, F_r) \end{array} \right.$$ $F_r = 0.724$

$$q_p := \begin{cases} q_p \cdot F_r & \text{if } (D > 1900 \cdot mm) \cdot (SoilType_n = \text{"Clay"}) \cdot (S_u(SPT_n) > 0.096 \cdot MPa) \cdot (Settlement = \text{"N"}) \\ q_p & \text{otherwise} \end{cases}$$

Calculate Total factored Resistance

Assign resistance factor

$$\phi_p := \begin{cases} \phi_{pc} & \text{if } SoilType_n = \text{"Clay"} \\ \phi_{ps} & \text{if } SoilType_n = \text{"Sand"} \\ \phi_{pr} & \text{otherwise} \end{cases}$$

Total Factored Shaft Resistance

$$\phi sQ_s := \sum_j \left(\phi_{s_j} \cdot q_{s_j} \cdot L_{Pile_j} \cdot \pi \cdot D\right) \qquad \phi sQ_s = 3551\,kN$$

Total Factored Tip Resistance

$$\phi pQ_p := \phi_p \cdot q_p \cdot \pi \cdot \frac{D^2}{4} \qquad \phi pQ_p = 2187\,kN$$

Uplift resistance (assuming submerged pile)

$$Q_{su} := \phi sQ_s \cdot \frac{0.55}{0.65} + \pi \cdot \frac{D^2}{4} \cdot L \cdot 14.5 \cdot \frac{kN}{m^3}$$

$$Q_{su} = 3466\,kN$$

Check center-to-center spacing of piles

$$ctc := \begin{cases} 2.5 \cdot D & \text{if } ctc < 2.5 \cdot D \\ 6.0 \cdot D & \text{if } ctc > 6.0 \cdot D \\ ctc & \text{otherwise} \end{cases} \qquad ctc = 6\ m$$

Determine if pile is predominantly driven in sand or clay

$$L_{sand} := \begin{array}{|l} L_s \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{array}{|l} L_s \leftarrow L_s + L_{Pile_j} \ \text{if } SoilType_j = \text{"Sand"} \\ L_s \ \text{otherwise} \end{array} \end{array}$$

$$L_{sand} = 0.00\ m$$

$$L_{clay} := \begin{array}{|l} L_c \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{array}{|l} L_c \leftarrow L_c + L_{Pile_j} \ \text{if } SoilType_j = \text{"Clay"} \\ L_c \ \text{otherwise} \end{array} \end{array}$$

$$L_{clay} = 15.00\ m$$

Assign overall soil type to pile

$$SoilTypeOverall := \begin{cases} \text{"Sand"} & \text{if } L_{sand} > L_{clay} \\ \text{"Clay"} & \text{otherwise} \end{cases}$$

$$SoilTypeOverall = \text{"Clay"}$$

Efficiency of pile group (10.7.3.10.2)

$$\eta := \begin{cases} 1.00 & \text{if } SoilType_n = \text{"Rock"} \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Sand"}) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \geq 5) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \geq 5) \\ 0.65 + (1 - 0.65)\cdot\dfrac{ctc - 2.5\cdot D}{3.5\cdot D} & \text{otherwise} \end{cases}$$

$$\eta = 1.00$$

SUMMARY
BORED Pile
Shaft and Tip Factored Resistance kN

Diameter of Pile $D = 1.5\ m$

Length of Pile $L = 18\ m$

Ref.	Thick ness	Length down Pile	Level	SPT N	Soil Type	q_s	φ_s	$\varphi_s Q_s$	q_p	φ_p	$\varphi_p Q_p$
	(m)	(m)	(m)			kN/m2		kN	kN/m2		kN
1.0	2.0	0.0	-2.0	0	Clay	0.0	0.65	0	0.0	0.00	0
2.0	2.0	0.5	-4.0	17	Clay	46.8	0.65	72	0.0	0.00	0
3.0	2.0	2.0	-6.0	11	Clay	30.3	0.65	185	0.0	0.00	0
4.0	2.0	2.0	-8.0	14	Clay	38.5	0.65	236	0.0	0.00	0
5.0	2.0	2.0	-10.0	50	Clay	100.0	0.65	613	0.0	0.00	0
6.0	2.0	2.0	-12.0	27	Clay	74.3	0.65	455	0.0	0.00	0
7.0	2.0	2.0	-14.0	50	Clay	100.0	0.65	613	0.0	0.00	0
8.0	2.0	2.0	-16.0	50	Clay	100.0	0.65	613	0.0	0.00	0
9.0	4.0	2.5	-20.0	50	Clay	100.0	0.65	766	2250.0	0.55	2187
10.0	8.0	0.0	0.0	50	Clay	100.0	0.65	0	0.0	0.00	0
Total Factored Shaft Resistance $\varphi_s Q_s$								3551	Factored Tip Resistance $\varphi_p Q_p$		2187

$$\eta = 1.00$$

TOTAL FACTORED RESISTANCE PER PILE

$$Q_R(\eta, \phi p Q_p, \phi s Q_s) = 5738\,kN$$

TOTAL FACTORED UPLIFT RESISTANCE PER PILE

$$Q_{su} = 3466\,kN$$

KATAHIRA & ENGINEERS INTERNATIONAL

Project: **Detailed Design Study of North Java Flyover Project**

Calculation: **Detailed Design**
Balaraja Flyover - Pier P7
1.5m Dia. BORED PILE AXIAL BEARING CAPACITY

Reference : **AASHTO LRFD Bridge Design Specification**
"Drilled Shafts: Construction Procedures and Design Methods"
FHWA-IF-99-025, August 1999

Definitions $kN := 1000 \cdot N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $kPa := 1000 \cdot Pa$

Pile Input Data

Pile Diameter	D (m)	1.50
Length of Pile	L (m)	23.00
Elevation at top of Pile	ElevTop (m)	-2.00
Effective Soil Density	γ (kN/m3)	10.00
Pile Cap		2
1. In firm contact with the ground		
2. Not in firm contact with the ground		
Pile center-to-center spacing	ctc (m)	6.000
Settlements evaluated?	(Y or N)	N

$D := D \cdot m$ $L := L \cdot m$ $ElevT := ElevT \cdot m$ $\gamma_{soil} := \gamma_{soil} \cdot \frac{kN}{m^3}$ $ctc := ctc \cdot m$

Subsoil Input Data - BOREHOLE BH 10

Ref.	Thickness	Level top of Layer	Level bottom of Layer	Soil Type	SPT N
	(cm)	(m)	(m)		
1.0	200	0.00	-2.00	Clay	0
2.0	200	-2.00	-4.00	Clay	5
3.0	200	-4.00	-6.00	Clay	5
4.0	200	-6.00	-8.00	Clay	7
5.0	200	-8.00	-10.00	Clay	10
6.0	200	-10.00	-12.00	Clay	22
7.0	200	-12.00	-14.00	Clay	37
8.0	200	-14.00	-16.00	Clay	50
9.0	400	-16.00	-20.00	Clay	50
10.0	800	-20.00	-28.00	Clay	50

$Lsoil_t := Lsoil_{top} \cdot m$ $Lsoil_b := Lsoil_{bottom} \cdot m$ $Depth := Depth \cdot cm$

COHESIVE SOILS - Shaft Resistance Using the α method (10.8.3.3.1)

$$q_{sc}(\alpha, S_u) := \begin{cases} 100 \cdot kPa & \text{if } \alpha \cdot S_u > 100 \cdot kPa \\ \alpha \cdot S_u & \text{otherwise} \end{cases}$$ (10.8.3.3.1-1)

(JRA Table C.10.4-4)

$$S_u(SPT) := 5 \cdot SPT \cdot kPa$$

$$\alpha(S_u) := \begin{cases} 0.55 & \text{if } S_u < 0.2 \cdot MPa \\ 0.49 & \text{if } (S_u \ge 0.2 \cdot MPa) \cdot (S_u < 0.30 \cdot MPa) \\ 0.42 & \text{if } (S_u \ge 0.3 \cdot MPa) \cdot (S_u < 0.40 \cdot MPa) \\ 0.38 & \text{if } (S_u \ge 0.4 \cdot MPa) \cdot (S_u < 0.50 \cdot MPa) \\ 0.35 & \text{if } (S_u \ge 0.5 \cdot MPa) \cdot (S_u < 0.60 \cdot MPa) \\ 0.33 & \text{if } (S_u \ge 0.6 \cdot MPa) \cdot (S_u < 0.70 \cdot MPa) \\ 0.32 & \text{if } (S_u \ge 0.7 \cdot MPa) \cdot (S_u < 0.80 \cdot MPa) \\ 0.31 & \text{if } (S_u \ge 0.8 \cdot MPa) \cdot (S_u < 0.90 \cdot MPa) \\ \text{"Treat as Rock"} & \text{otherwise} \end{cases}$$ (Table 10.8.3.3.1-1)

COHESIVE SOILS - Tip Resistance (10.8.3.3.2)

$$q_{pc}(N_c, S_u) := \begin{cases} N_c \cdot S_u & \text{if } N_c \cdot S_u \le 4.0 \cdot MPa \\ 4.0 \cdot MPa & \text{otherwise} \end{cases}$$ (10.8.3.3.2-1)

$$N_c(Z, SPT) := \begin{array}{|l} N_c \leftarrow 6 \cdot \left[1 + 0.2 \cdot \left(\frac{Z}{D}\right)\right] \\ N_c \leftarrow \frac{N_c}{3} \ \text{ if } 5 \cdot SPT \cdot kPa < 0.024 \cdot MPa \\ N_c \ \text{ if } N_c \le 9 \\ 9 \ \text{ otherwise} \end{array}$$ (10.8.3.3.2-2)

COHESIONLESS SOILS - Shaft Resistance Using Reese and O'Neill Method (10.8.3.4.2)

$$\beta(Z) := \begin{array}{|l} \beta \leftarrow 1.5 - 7.7 \cdot 10^{-3} \cdot \sqrt{\frac{Z}{mm}} \\ \beta \leftarrow 0.25 \ \text{ if } \beta < 0.25 \\ \beta \leftarrow 1.2 \ \text{ if } \beta > 1.2 \\ \beta \ \text{ otherwise} \end{array}$$

$$q_{ss}(Z, \sigma_v) := \begin{cases} \beta(Z) \cdot \sigma_v & \text{if } \beta(Z) \cdot \sigma_v \le 0.19 \cdot MPa \\ 0.19 \cdot MPa & \text{otherwise} \end{cases}$$ (Table 10.8.3.4.2-1)

COHESIONLESS SOILS - Tip Resistance Using Reese and O'Neill Method (10.8.3.4.3)

$$q_{ps}(SPT, D) := \begin{cases} 0.057 \cdot SPT \cdot MPa & \text{if } (SPT \le 75)\cdot(D \le 1270 \cdot mm) \\ 0.057 \cdot SPT \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 75)\cdot(D > 1270 \cdot mm) \\ 4.3 \cdot MPa & \text{if } (SPT > 75)\cdot(D \le 1270 \cdot mm) \\ 4.3 \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

(Table 10.8.3.4.3-1)
&
(10.8.3.4.3-1)

JOINTED ROCK - Shaft Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{sr}(SPT, \sigma_v) := \begin{array}{|l} \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{SPT}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] \text{ if } SPT \le 100 \\ \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{100}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] \text{ if } SPT > 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot SPT}{\sigma_v}\right)^{\sin(\phi)} \text{ if } SPT \le 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot 100}{\sigma_v}\right)^{\sin(\phi)} \text{ if } SPT > 100 \\ \sigma_v \cdot K_o \cdot \tan(\phi) \end{array}$$

JOINTED ROCK - Tip Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{pr}(SPT, \sigma_v) := \begin{cases} 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT \le 100)\cdot(D \le 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT > 100)\cdot(D \le 1270 \cdot mm) \\ 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 100)\cdot(D > 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

(11.11)

RESISTANCE AT THE STRENGTH LIMIT STATE (10.8.3)

Factored bearing resistance $Q_R(\eta, \phi pQ_p, \phi sQ_s) := \eta \cdot (\phi pQ_p + \phi sQ_s)$ (10.7.3.2-1)

Side Resistance in Clay $\phi_{sc} := 0.65$ (Table 10.5.5-3)

Base resistance in Clay $\phi_{pc} := 0.55$ (Table 10.5.5-3)

Side Resistance in Sand $\phi_{ss} := 0.65$

Base resistance in Sand $\phi_{ps} := 0.5$

(Discussion in 10.8.3.4) & FHWA-IF-99-025 "Drilled Shafts: Construction Procedures and Design Methods"

Side Resistance in Rock $\phi_{sr} := 0.55$ (Table 10.5.5-3)

Base resistance in Rock $\phi_{pr} := 0.50$ (Table 10.5.5-3)

Calculate Shaft Resistance

$j := 1 .. 10$

Length of each soil layer down the pile

$$L_{Pile_j} := \begin{cases} Depth_j & \text{if } (ElevT \geq Lsoil_{t_j}) \cdot [(ElevT - L) \leq Lsoil_{b_j}] \\ ElevT - Lsoil_{b_j} & \text{if } (ElevT < Lsoil_{t_j}) \cdot (ElevT \geq Lsoil_{b_j}) \cdot [(ElevT - L) \leq Lsoil_{b_j}] \\ Lsoil_{t_j} - (ElevT - L) & \text{if } (ElevT \geq Lsoil_{t_j}) \cdot (ElevT - L > Lsoil_{b_j}) \cdot (ElevT - L < Lsoil_{t_j}) \\ 0 \cdot m & \text{otherwise} \end{cases}$$

Average depth of each soil layer

$$Z_j := \begin{cases} (Lsoil_{t_1} - Lsoil_{b_j}) - \dfrac{L_{Pile_j}}{2} & \text{if } (ElevT - L) \leq Lsoil_{b_j} \\ [Lsoil_{t_1} - (ElevT - L)] - \dfrac{L_{Pile_j}}{2} & \text{otherwise} \end{cases}$$

Effective vertical soil stress at each soil layer

$$\sigma_{v_j} := Z_j \cdot \gamma_{soil}$$

Assign resistance factors

$$\phi_{s_j} := \begin{cases} \phi_{sc} & \text{if } SoilType_j = \text{"Clay"} \\ \phi_{ss} & \text{if } SoilType_j = \text{"Sand"} \\ \phi_{sr} & \text{otherwise} \end{cases}$$

Nominal unit shaft resistance

$$q_{s_j} := \begin{cases} q_{sc}(\alpha(S_u(SPT_j)), S_u(SPT_j)) & \text{if } SoilType_j = \text{"Clay"} \\ q_{ss}(Z_j, \sigma_{v_j}) & \text{if } SoilType_j = \text{"Sand"} \\ q_{sr}(SPT_j, \sigma_{v_j}) & \text{otherwise} \end{cases}$$

Calculate Tip Resistance

Locate pile tip soil layer "n"

$$n := \left| \begin{array}{l} s \leftarrow 0 \\ \text{for } j \in 1..10 \\ \quad s \leftarrow s+1 \text{ if } (ElevT - L) < Lsoil_{t_j} \\ s \end{array} \right. \qquad n = 10$$

Effective stress at base

$$\sigma_{vbase} := \left(Z_n + \frac{L_{Pile_n}}{2} \right) \cdot \gamma_{soil}$$

Nominal unit tip resistance

$$q_p := \left| \begin{array}{l} q_{pc}\left(N_c\left(Z_n, SPT_n\right), S_u\left(SPT_n\right)\right) \text{ if } SoilType_n = \text{"Clay"} \\ q_{ps}\left(SPT_n, D\right) \text{ if } SoilType_n = \text{"Sand"} \\ q_{pr}\left(SPT_n, \sigma_{vbase}\right) \text{ otherwise} \end{array} \right.$$

Reduce Effective Pile Length at Pile Top (1.5m) and at Pile Base (One Pile Diameter)

Subtract 1.5m from pile top:

$$value := L_{Pile_1} - 1.5m \qquad value = -1.5\ m$$

$$value1 := L_{Pile_1} + L_{Pile_2} - 1.5m \qquad value1 = 0.5\ m$$

$$value2 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} - 1.5m \qquad value2 = 2.5\ m$$

$$value3 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} + L_{Pile_4} - 1.5m \qquad value3 = 4.5\ m$$

$$L_{Pile_1} := \left| \begin{array}{l} L_{Pile_1} - 1.5m \text{ if } value \geq 0 \cdot m \\ 0 \cdot m \text{ otherwise} \end{array} \right. \qquad L_{Pile_1} = 0.00\ m$$

$$L_{Pile_2} := \left| \begin{array}{l} value1 \text{ if } (value < 0 \cdot m)(value1 \geq 0m) \\ 0 \cdot m \text{ if } value1 < 0 \cdot m \\ L_{Pile_2} \text{ otherwise} \end{array} \right. \qquad L_{Pile_2} = 0.50\ m$$

$$L_{Pile_3} := \left| \begin{array}{l} value2 \text{ if } (value1 < 0 \cdot m)(value2 \geq 0m) \\ 0m \text{ if } value2 < 0 \cdot m \\ L_{Pile_3} \text{ otherwise} \end{array} \right. \qquad L_{Pile_3} = 2.00\ m$$

$$L_{Pile_4} := \left| \begin{array}{l} value3 \text{ if } (value2 < 0 \cdot m)(value3 \geq 0m) \\ 0m \text{ if } value3 < 0 \cdot m \\ L_{Pile_4} \text{ otherwise} \end{array} \right. \qquad L_{Pile_4} = 2.00\ m$$

Subtract length from pile length at base:

$value := L_{Pile_n} - D$ $\quad$ $value = 3.5\ m$

$value1 := L_{Pile_n} + L_{Pile_{n-1}} - D$ $\quad$ $value1 = 7.5\ m$

$value2 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} - D$ $\quad$ $value2 = 9.5\ m$

$value3 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} + L_{Pile_{n-3}} - D$ $\quad$ $value3 = 11.5\ m$

$$L_{Pile_n} := \begin{cases} L_{Pile_n} - D & \text{if } value \ge 0\cdot m \\ 0\cdot m & \text{otherwise} \end{cases}$$ $\quad$ $L_{Pile_n} = 3.50\ m$

$$L_{Pile_{n-1}} := \begin{cases} value1 & \text{if } (value < 0\cdot m)(value1 \ge 0m) \\ 0\cdot m & \text{if } value1 < 0\cdot m \\ L_{Pile_{n-1}} & \text{otherwise} \end{cases}$$ $\quad$ $L_{Pile_{n-1}} = 4.00\ m$

$$L_{Pile_{n-2}} := \begin{cases} value2 & \text{if } (value1 < 0\cdot m)(value2 \ge 0m) \\ 0m & \text{if } value2 < 0\cdot m \\ L_{Pile_{n-2}} & \text{otherwise} \end{cases}$$ $\quad$ $L_{Pile_{n-2}} = 2.00\ m$

$$L_{Pile_{n-3}} := \begin{cases} value3 & \text{if } (value2 < 0\cdot m)(value3 \ge 0m) \\ 0m & \text{if } value3 < 0\cdot m \\ L_{Pile_{n-3}} & \text{otherwise} \end{cases}$$ $\quad$ $L_{Pile_{n-3}} = 2.00\ m$

Reduction factor for large diameter bored piles in clay

$$F_r := \begin{array}{|l} a \leftarrow 0.0071 + 0.0021\cdot\frac{Z_n}{D} \\ a \leftarrow \min(0.015, a) \\ b \leftarrow 1.45\cdot\sqrt{2.0\cdot\frac{S_u(SPT_n)}{MPa}} \\ b \leftarrow 0.5 \text{ if } b \le 0.5 \\ b \leftarrow 1.5 \text{ if } 1.5 \le b \\ F_r \leftarrow \frac{760}{12.0\cdot a\cdot\frac{D}{mm} + 760\cdot b} \\ F_r \leftarrow \min(1.0, F_r) \end{array}$$ $\quad$ $F_r = 0.724$

$$q_p := \begin{cases} q_p\cdot F_r & \text{if } (D > 1900\cdot mm)\cdot(SoilType_n = \text{"Clay"})\cdot(S_u(SPT_n) > 0.096\cdot MPa)\cdot(Settlement = \text{"N"}) \\ q_p & \text{otherwise} \end{cases}$$

Calculate Total factored Resistance

Assign resistance factor

$$\phi_p := \begin{cases} \phi_{pc} & \text{if } SoilType_n = \text{"Clay"} \\ \phi_{ps} & \text{if } SoilType_n = \text{"Sand"} \\ \phi_{pr} & \text{otherwise} \end{cases}$$

Total Factored Shaft Resistance

$$\phi sQ_s := \sum_j \left(\phi_{s_j} \cdot q_{s_j} \cdot L_{Pile_j} \cdot \pi \cdot D\right)$$

$\phi sQ_s = 4285\,kN$

Total Factored Tip Resistance

$$\phi pQ_p := \phi_p \cdot q_p \cdot \pi \cdot \frac{D^2}{4}$$

$\phi pQ_p = 2187\,kN$

Uplift resistance (assuming submerged pile)

$$Q_{su} := \phi sQ_s \cdot \frac{0.55}{0.65} + \pi \cdot \frac{D^2}{4} \cdot L \cdot 14.5 \cdot \frac{kN}{m^3}$$

$Q_{su} = 4215\,kN$

Check center-to-center spacing of piles

$$ctc := \begin{cases} 2.5 \cdot D & \text{if } ctc < 2.5 \cdot D \\ 6.0 \cdot D & \text{if } ctc > 6.0 \cdot D \\ ctc & \text{otherwise} \end{cases}$$

$ctc = 6\ m$

Determine if pile is predominantly driven in sand or clay

$$L_{sand} := \left| \begin{array}{l} L_s \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \left| \begin{array}{ll} L_s \leftarrow L_s + L_{Pile_j} & \text{if } SoilType_j = \text{"Sand"} \\ L_s & \text{otherwise} \end{array} \right. \end{array} \right.$$

$L_{sand} = 0.00\ m$

$$L_{clay} := \left| \begin{array}{l} L_c \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \left| \begin{array}{ll} L_c \leftarrow L_c + L_{Pile_j} & \text{if } SoilType_j = \text{"Clay"} \\ L_c & \text{otherwise} \end{array} \right. \end{array} \right.$$

$L_{clay} = 20.00\ m$

Assign overall soil type to pile

$$SoilTypeOverall := \begin{cases} \text{"Sand"} & \text{if } L_{sand} > L_{clay} \\ \text{"Clay"} & \text{otherwise} \end{cases}$$

SoilTypeOverall = "Clay"

Efficiency of pile group (10.7.3.10.2)

$$\eta := \begin{cases} 1.00 & \text{if } SoilType_n = \text{"Rock"} \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Sand"}) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \geq 5) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \geq 5) \\ 0.65 + (1 - 0.65)\cdot\dfrac{ctc - 2.5\cdot D}{3.5\cdot D} & \text{otherwise} \end{cases}$$

$$\eta = 1.00$$

SUMMARY
BORED Pile
Shaft and Tip Factored Resistance kN

Diameter of Pile $D = 1.5 \text{ m}$

Length of Pile $L = 23 \text{ m}$

Ref.	Thick ness	Length down Pile	Level	SPT N	Soil Type	q_s	φ_s	$\varphi_s Q_s$	q_p	φ_p	$\varphi_p Q_p$
	(m)	(m)	(m)			kN/m2		kN	kN/m2		kN
1.0	2.0	0.0	-2.0	0	Clay	0.0	0.65	0	0.0	0.00	0
2.0	2.0	0.5	-4.0	5	Clay	13.8	0.65	21	0.0	0.00	0
3.0	2.0	2.0	-6.0	5	Clay	13.8	0.65	84	0.0	0.00	0
4.0	2.0	2.0	-8.0	7	Clay	19.3	0.65	118	0.0	0.00	0
5.0	2.0	2.0	-10.0	10	Clay	27.5	0.65	168	0.0	0.00	0
6.0	2.0	2.0	-12.0	22	Clay	60.5	0.65	371	0.0	0.00	0
7.0	2.0	2.0	-14.0	37	Clay	100.0	0.65	613	0.0	0.00	0
8.0	2.0	2.0	-16.0	50	Clay	100.0	0.65	613	0.0	0.00	0
9.0	4.0	4.0	-20.0	50	Clay	100.0	0.65	1225	0.0	0.00	0
10.0	8.0	3.5	-25.0	50	Clay	100.0	0.65	1072	2250.0	0.55	2187
Total Factored Shaft Resistance $\varphi_s Q_s$								4285	Factored Tip Resistance $\varphi_p Q_p$		2187

$\eta = 1.00$

TOTAL FACTORED RESISTANCE PER PILE

$$Q_R(\eta, \phi p Q_p, \phi s Q_s) = 6472 \text{ kN}$$

TOTAL FACTORED UPLIFT RESISTANCE PER PILE

$$Q_{su} = 4215 \text{ kN}$$

KATAHIRA & ENGINEERS INTERNATIONAL

Project: **Detailed Design Study of North Java Flyover Project**

Calculation: **Detailed Design**
Balaraja Flyover - Pier P8
1.5m Dia. BORED PILE AXIAL BEARING CAPACITY

Reference : **AASHTO LRFD Bridge Design Specification**
"Drilled Shafts: Construction Procedures and Design Methods"
FHWA-IF-99-025, August 1999

Definitions $kN := 1000 \cdot N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $kPa := 1000 \cdot Pa$

Pile Input Data

Pile Diameter	D (m)	1.50
Length of Pile	L (m)	20.00
Elevation at top of Pile	ElevTop (m)	-1.50
Effective Soil Density	γ (kN/m3)	10.00
Pile Cap 1. In firm contact with the ground 2. Not in firm contact with the ground		2
Pile center-to-center spacing	ctc (m)	6.000
Settlements evaluated?	(Y or N)	N

$D := D \cdot m$ $L := L \cdot m$ $ElevT := ElevT \cdot m$ $\gamma_{soil} := \gamma_{soil} \cdot \frac{kN}{m^3}$ $ctc := ctc \cdot m$

Subsoil Input Data - BOREHOLE BH 10

Ref.	Thickness	Level top of Layer	Level bottom of Layer	Soil Type	SPT N
	(cm)	(m)	(m)		
1.0	200	0.00	-2.00	Clay	0
2.0	200	-2.00	-4.00	Clay	5
3.0	200	-4.00	-6.00	Clay	5
4.0	200	-6.00	-8.00	Clay	7
5.0	200	-8.00	-10.00	Clay	10
6.0	200	-10.00	-12.00	Clay	22
7.0	200	-12.00	-14.00	Clay	37
8.0	400	-14.00	-18.00	Clay	50
9.0	600	-18.00	-24.00	Clay	50
10.0	800	-24.00	-32.00	Clay	50

$Lsoil_t := Lsoil_{top} \cdot m$ $Lsoil_b := Lsoil_{bottom} \cdot m$ $Depth := Depth \cdot cm$

COHESIVE SOILS - Shaft Resistance Using the α method (10.8.3.3.1)

$$q_{sc}(\alpha, S_u) := \begin{cases} 100 \cdot kPa & \text{if } \alpha \cdot S_u > 100 \cdot kPa \\ \alpha \cdot S_u & \text{otherwise} \end{cases}$$ (10.8.3.3.1-1)

(JRA Table C.10.4-4)

$$S_u(SPT) := 5 \cdot SPT \cdot kPa$$

$$\alpha(S_u) := \begin{cases} 0.55 & \text{if } S_u < 0.2 \cdot MPa \\ 0.49 & \text{if } (S_u \geq 0.2 \cdot MPa) \cdot (S_u < 0.30 \cdot MPa) \\ 0.42 & \text{if } (S_u \geq 0.3 \cdot MPa) \cdot (S_u < 0.40 \cdot MPa) \\ 0.38 & \text{if } (S_u \geq 0.4 \cdot MPa) \cdot (S_u < 0.50 \cdot MPa) \\ 0.35 & \text{if } (S_u \geq 0.5 \cdot MPa) \cdot (S_u < 0.60 \cdot MPa) \\ 0.33 & \text{if } (S_u \geq 0.6 \cdot MPa) \cdot (S_u < 0.70 \cdot MPa) \\ 0.32 & \text{if } (S_u \geq 0.7 \cdot MPa) \cdot (S_u < 0.80 \cdot MPa) \\ 0.31 & \text{if } (S_u \geq 0.8 \cdot MPa) \cdot (S_u < 0.90 \cdot MPa) \\ \text{"Treat as Rock"} & \text{otherwise} \end{cases}$$ (Table 10.8.3.3.1-1)

COHESIVE SOILS - Tip Resistance (10.8.3.3.2)

$$q_{pc}(N_c, S_u) := \begin{cases} N_c \cdot S_u & \text{if } N_c \cdot S_u \leq 4.0 \cdot MPa \\ 4.0 \cdot MPa & \text{otherwise} \end{cases}$$ (10.8.3.3.2-1)

$$N_c(Z, SPT) := \begin{array}{|l} N_c \leftarrow 6 \cdot \left[1 + 0.2 \cdot \left(\frac{Z}{D}\right)\right] \\ N_c \leftarrow \frac{N_c}{3} \quad \text{if } 5 \cdot SPT \cdot kPa < 0.024 \cdot MPa \\ N_c \quad \text{if } N_c \leq 9 \\ 9 \quad \text{otherwise} \end{array}$$ (10.8.3.3.2-2)

COHESIONLESS SOILS - Shaft Resistance Using Reese and O'Neill Method (10.8.3.4.2)

$$\beta(Z) := \begin{array}{|l} \beta \leftarrow 1.5 - 7.7 \cdot 10^{-3} \cdot \sqrt{\frac{Z}{mm}} \\ \beta \leftarrow 0.25 \quad \text{if } \beta < 0.25 \\ \beta \leftarrow 1.2 \quad \text{if } \beta > 1.2 \\ \beta \quad \text{otherwise} \end{array}$$

$$q_{ss}(Z, \sigma_v) := \begin{cases} \beta(Z) \cdot \sigma_v & \text{if } \beta(Z) \cdot \sigma_v \leq 0.19 \cdot MPa \\ 0.19 \cdot MPa & \text{otherwise} \end{cases}$$ (Table 10.8.3.4.2-1)

COHESIONLESS SOILS - Tip Resistance Using Reese and O'Neill Method (10.8.3.4.3)

$$q_{ps}(SPT,D) := \begin{cases} 0.057 \cdot SPT \cdot MPa & \text{if } (SPT \le 75) \cdot (D \le 1270 \cdot mm) \\ 0.057 \cdot SPT \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 75) \cdot (D > 1270 \cdot mm) \\ 4.3 \cdot MPa & \text{if } (SPT > 75) \cdot (D \le 1270 \cdot mm) \\ 4.3 \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

(Table 10.8.3.4.3-1)
&
(10.8.3.4.3-1)

JOINTED ROCK - Shaft Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{sr}(SPT,\sigma_v) := \begin{vmatrix} \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{SPT}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] & \text{if } SPT \le 100 \\ \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{100}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] & \text{if } SPT > 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot SPT}{\sigma_v}\right)^{\sin(\phi)} & \text{if } SPT \le 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot 100}{\sigma_v}\right)^{\sin(\phi)} & \text{if } SPT > 100 \\ \sigma_v \cdot K_o \cdot \tan(\phi) & \end{vmatrix}$$

JOINTED ROCK - Tip Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{pr}(SPT,\sigma_v) := \begin{cases} 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT \le 100) \cdot (D \le 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT > 100) \cdot (D \le 1270 \cdot mm) \\ 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 100) \cdot (D > 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

(11.11)

RESISTANCE AT THE STRENGTH LIMIT STATE (10.8.3)

Factored bearing resistance $Q_R(\eta, \phi pQ_p, \phi sQ_s) := \eta \cdot (\phi pQ_p + \phi sQ_s)$ (10.7.3.2-1)

Side Resistance in Clay $\phi_{sc} := 0.65$ (Table 10.5.5-3)

Base resistance in Clay $\phi_{pc} := 0.55$ (Table 10.5.5-3)

Side Resistance in Sand $\phi_{ss} := 0.65$

Base resistance in Sand $\phi_{ps} := 0.5$

(Discussion in 10.8.3.4) & FHWA-IF-99-025 "Drilled Shafts: Construction Procedures and Design Methods"

Side Resistance in Rock $\phi_{sr} := 0.55$ (Table 10.5.5-3)

Base resistance in Rock $\phi_{pr} := 0.50$ (Table 10.5.5-3)

Calculate Shaft Resistance

$j := 1 .. 10$

Length of each soil layer down the pile

$$L_{Pile_j} := \begin{cases} Depth_j & \text{if } (ElevT \geq Lsoil_{t_j}) \cdot [(ElevT - L) \leq Lsoil_{b_j}] \\ ElevT - Lsoil_{b_j} & \text{if } (ElevT < Lsoil_{t_j}) \cdot (ElevT \geq Lsoil_{b_j}) \cdot [(ElevT - L) \leq Lsoil_{b_j}] \\ Lsoil_{t_j} - (ElevT - L) & \text{if } (ElevT \geq Lsoil_{t_j}) \cdot (ElevT - L > Lsoil_{b_j}) \cdot (ElevT - L < Lsoil_{t_j}) \\ 0 \cdot m & \text{otherwise} \end{cases}$$

Average depth of each soil layer

$$Z_j := \begin{cases} (Lsoil_{t_1} - Lsoil_{b_j}) - \dfrac{L_{Pile_j}}{2} & \text{if } (ElevT - L) \leq Lsoil_{b_j} \\ [Lsoil_{t_1} - (ElevT - L)] - \dfrac{L_{Pile_j}}{2} & \text{otherwise} \end{cases}$$

Effective vertical soil stress at each soil layer

$$\sigma_{v_j} := Z_j \cdot \gamma_{soil}$$

Assign resistance factors

$$\phi_{s_j} := \begin{cases} \phi_{sc} & \text{if } SoilType_j = \text{"Clay"} \\ \phi_{ss} & \text{if } SoilType_j = \text{"Sand"} \\ \phi_{sr} & \text{otherwise} \end{cases}$$

Nominal unit shaft resistance

$$q_{s_j} := \begin{cases} q_{sc}(\alpha(S_u(SPT_j)), S_u(SPT_j)) & \text{if } SoilType_j = \text{"Clay"} \\ q_{ss}(Z_j, \sigma_{v_j}) & \text{if } SoilType_j = \text{"Sand"} \\ q_{sr}(SPT_j, \sigma_{v_j}) & \text{otherwise} \end{cases}$$

Calculate Tip Resistance

Locate pile tip soil layer "n"

$$n := \left| \begin{array}{l} s \leftarrow 0 \\ \text{for } j \in 1..10 \\ \quad s \leftarrow s + 1 \ \text{ if } (ElevT - L) < Lsoil_{t_j} \\ s \end{array} \right.$$

$n = 9$

Effective stress at base

$$\sigma_{vbase} := \left(Z_n + \frac{L_{Pile_n}}{2} \right) \cdot \gamma_{soil}$$

Nominal unit tip resistance

$$q_p := \left| \begin{array}{l} q_{pc}\left(N_c\left(Z_n, SPT_n\right), S_u\left(SPT_n\right)\right) \ \text{ if } SoilType_n = \text{"Clay"} \\ q_{ps}\left(SPT_n, D\right) \ \text{ if } SoilType_n = \text{"Sand"} \\ q_{pr}\left(SPT_n, \sigma_{vbase}\right) \ \text{ otherwise} \end{array} \right.$$

Reduce Effective Pile Length at Pile Top (1.5m) and at Pile Base (One Pile Diameter)

Subtract 1.5m from pile top:

$value := L_{Pile_1} - 1.5m$ $\qquad value = -1\ m$

$value1 := L_{Pile_1} + L_{Pile_2} - 1.5m$ $\qquad value1 = 1\ m$

$value2 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} - 1.5m$ $\qquad value2 = 3\ m$

$value3 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} + L_{Pile_4} - 1.5m$ $\qquad value3 = 5\ m$

$$L_{Pile_1} := \left| \begin{array}{l} L_{Pile_1} - 1.5m \ \text{ if } value \ge 0 \cdot m \\ 0 \cdot m \ \text{ otherwise} \end{array} \right.$$

$L_{Pile_1} = 0.00\ m$

$$L_{Pile_2} := \left| \begin{array}{l} value1 \ \text{ if } (value < 0 \cdot m)(value1 \ge 0m) \\ 0 \cdot m \ \text{ if } value1 < 0 \cdot m \\ L_{Pile_2} \ \text{ otherwise} \end{array} \right.$$

$L_{Pile_2} = 1.00\ m$

$$L_{Pile_3} := \left| \begin{array}{l} value2 \ \text{ if } (value1 < 0 \cdot m)(value2 \ge 0m) \\ 0m \ \text{ if } value2 < 0 \cdot m \\ L_{Pile_3} \ \text{ otherwise} \end{array} \right.$$

$L_{Pile_3} = 2.00\ m$

$$L_{Pile_4} := \left| \begin{array}{l} value3 \ \text{ if } (value2 < 0 \cdot m)(value3 \ge 0m) \\ 0m \ \text{ if } value3 < 0 \cdot m \\ L_{Pile_4} \ \text{ otherwise} \end{array} \right.$$

$L_{Pile_4} = 2.00\ m$

Subtract length from pile length at base:

$value := L_{Pile_n} - D$ $\quad value = 2\ m$

$value1 := L_{Pile_n} + L_{Pile_{n-1}} - D$ $\quad value1 = 6\ m$

$value2 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} - D$ $\quad value2 = 8\ m$

$value3 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} + L_{Pile_{n-3}} - D$ $\quad value3 = 10\ m$

$$L_{Pile_n} := \begin{cases} L_{Pile_n} - D & \text{if } value \ge 0 \cdot m \\ 0 \cdot m & \text{otherwise} \end{cases} \qquad L_{Pile_n} = 2.00\ m$$

$$L_{Pile_{n-1}} := \begin{cases} value1 & \text{if } (value < 0 \cdot m)(value1 \ge 0m) \\ 0 \cdot m & \text{if } value1 < 0 \cdot m \\ L_{Pile_{n-1}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-1}} = 4.00\ m$$

$$L_{Pile_{n-2}} := \begin{cases} value2 & \text{if } (value1 < 0 \cdot m)(value2 \ge 0m) \\ 0m & \text{if } value2 < 0 \cdot m \\ L_{Pile_{n-2}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-2}} = 2.00\ m$$

$$L_{Pile_{n-3}} := \begin{cases} value3 & \text{if } (value2 < 0 \cdot m)(value3 \ge 0m) \\ 0m & \text{if } value3 < 0 \cdot m \\ L_{Pile_{n-3}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-3}} = 2.00\ m$$

Reduction factor for large diameter bored piles in clay

$$F_r := \left| \begin{array}{l} a \leftarrow 0.0071 + 0.0021 \cdot \dfrac{Z_n}{D} \\ a \leftarrow \min(0.015, a) \\ b \leftarrow 1.45 \cdot \sqrt{2.0 \cdot \dfrac{S_u(SPT_n)}{MPa}} \\ b \leftarrow 0.5 \ \text{ if } \ b \le 0.5 \\ b \leftarrow 1.5 \ \text{ if } \ 1.5 \le b \\ F_r \leftarrow \dfrac{760}{12.0 \cdot a \cdot \dfrac{D}{mm} + 760 \cdot b} \\ F_r \leftarrow \min(1.0, F_r) \end{array} \right. \qquad F_r = 0.724$$

$$q_p := \begin{cases} q_p \cdot F_r & \text{if } (D > 1900 \cdot mm) \cdot (SoilType_n = \text{"Clay"}) \cdot (S_u(SPT_n) > 0.096 \cdot MPa) \cdot (Settlement = \text{"N"}) \\ q_p & \text{otherwise} \end{cases}$$

Calculate Total factored Resistance

Assign resistance factor

$$\phi_p := \begin{cases} \phi_{pc} & \text{if } SoilType_n = \text{"Clay"} \\ \phi_{ps} & \text{if } SoilType_n = \text{"Sand"} \\ \phi_{pr} & \text{otherwise} \end{cases}$$

Total Factored Shaft Resistance

$$\phi sQ_s := \sum_j \left(\phi_{s_j} \cdot q_{s_j} \cdot L_{Pile_j} \cdot \pi \cdot D \right)$$

$\phi sQ_s = 3234\,kN$

Total Factored Tip Resistance

$$\phi pQ_p := \phi_p \cdot q_p \cdot \pi \cdot \frac{D^2}{4}$$

$\phi pQ_p = 2187\,kN$

Uplift resistance (assuming submerged pile)

$$Q_{su} := \phi sQ_s \cdot \frac{0.55}{0.65} + \pi \cdot \frac{D^2}{4} \cdot L \cdot 14.5 \cdot \frac{kN}{m^3}$$

$Q_{su} = 3249\,kN$

Check center-to-center spacing of piles

$$ctc := \begin{cases} 2.5 \cdot D & \text{if } ctc < 2.5 \cdot D \\ 6.0 \cdot D & \text{if } ctc > 6.0 \cdot D \\ ctc & \text{otherwise} \end{cases}$$

$ctc = 6\ m$

Determine if pile is predominantly driven in sand or clay

$$L_{sand} := \begin{array}{|l} L_s \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{array}{|l} L_s \leftarrow L_s + L_{Pile_j} \text{ if } SoilType_j = \text{"Sand"} \\ L_s \text{ otherwise} \end{array} \end{array}$$

$L_{sand} = 0.00\ m$

$$L_{clay} := \begin{array}{|l} L_c \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{array}{|l} L_c \leftarrow L_c + L_{Pile_j} \text{ if } SoilType_j = \text{"Clay"} \\ L_c \text{ otherwise} \end{array} \end{array}$$

$L_{clay} = 17.00\ m$

Assign overall soil type to pile

$$SoilTypeOverall := \begin{cases} \text{"Sand"} & \text{if } L_{sand} > L_{clay} \\ \text{"Clay"} & \text{otherwise} \end{cases}$$

SoilTypeOverall = "Clay"

Efficiency of pile group (10.7.3.10.2)

$$\eta := \begin{cases} 1.00 & \text{if } SoilType_n = \text{"Rock"} \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Sand"}) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \ge 5) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \ge 5) \\ 0.65 + (1 - 0.65)\cdot\dfrac{ctc - 2.5\cdot D}{3.5\cdot D} & \text{otherwise} \end{cases}$$

$\eta = 1.00$

SUMMARY
BORED Pile
Shaft and Tip Factored Resistance kN

Diameter of Pile $D = 1.5\ m$

Length of Pile $L = 20\ m$

Ref.	Thick ness	Length down Pile	Level	SPT N	Soil Type	q_s	φ_s	$\varphi_s Q_s$	q_p	φ_p	$\varphi_p Q_p$
	(m)	(m)	(m)			kN/m2		kN	kN/m2		kN
1.0	2.0	0.0	-2.0	0	Clay	0.0	0.65	0	0.0	0.00	0
2.0	2.0	1.0	-4.0	5	Clay	13.8	0.65	42	0.0	0.00	0
3.0	2.0	2.0	-6.0	5	Clay	13.8	0.65	84	0.0	0.00	0
4.0	2.0	2.0	-8.0	7	Clay	19.3	0.65	118	0.0	0.00	0
5.0	2.0	2.0	-10.0	10	Clay	27.5	0.65	168	0.0	0.00	0
6.0	2.0	2.0	-12.0	22	Clay	60.5	0.65	371	0.0	0.00	0
7.0	2.0	2.0	-14.0	37	Clay	100.0	0.65	613	0.0	0.00	0
8.0	4.0	4.0	-18.0	50	Clay	100.0	0.65	1225	0.0	0.00	0
9.0	6.0	2.0	-21.5	50	Clay	100.0	0.65	613	2250.0	0.55	2187
10.0	8.0	0.0	0.0	50	Clay	100.0	0.65	0	0.0	0.00	0
Total Factored Shaft Resistance $\varphi_s Q_s$								3234	Factored Tip Resistance $\varphi_p Q_p$		2187

$$\eta = 1.00$$

TOTAL FACTORED RESISTANCE PER PILE

$$Q_R(\eta, \phi p Q_p, \phi s Q_s) = 5421\ kN$$

TOTAL FACTORED UPLIFT RESISTANCE PER PILE

$$Q_{su} = 3249\ kN$$

KATAHIRA & ENGINEERS INTERNATIONAL

Project: **Detailed Design Study of North Java Flyover Project**

Calculation: **Detailed Design**
Balaraja Flyover - Pier P9
1.5m Dia. BORED PILE AXIAL BEARING CAPACITY

Reference : **AASHTO LRFD Bridge Design Specification**
"Drilled Shafts: Construction Procedures and Design Methods"
FHWA-IF-99-025, August 1999

Definitions $kN := 1000 \cdot N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $kPa := 1000 \cdot Pa$

Pile Input Data

Pile Diameter	D (m)	1.50
Length of Pile	L (m)	20.00
Elevation at top of Pile	ElevTop (m)	-2.00
Effective Soil Density	γ (kN/m3)	10.00
Pile Cap 1. In firm contact with the ground 2. Not in firm contact with the ground		2
Pile center-to-center spacing	ctc (m)	6.000
Settlements evaluated?	(Y or N)	N

$D := D \cdot m$ $L := L \cdot m$ $ElevT := ElevT \cdot m$ $\gamma_{soil} := \gamma_{soil} \cdot \frac{kN}{m^3}$ $ctc := ctc \cdot m$

Subsoil Input Data - BOREHOLE BH 11

Ref.	Thickness (cm)	Level top of Layer (m)	Level bottom of Layer (m)	Soil Type	SPT N
1.0	200	0.00	-2.00	Clay	0
2.0	200	-2.00	-4.00	Clay	14
3.0	200	-4.00	-6.00	Clay	7
4.0	200	-6.00	-8.00	Clay	9
5.0	200	-8.00	-10.00	Clay	50
6.0	200	-10.00	-12.00	Clay	50
7.0	200	-12.00	-14.00	Clay	40
8.0	200	-14.00	-16.00	Clay	23
9.0	200	-16.00	-18.00	Clay	49
10.0	800	-18.00	-26.00	Clay	50

$Lsoil_t := Lsoil_{top} \cdot m$ $Lsoil_b := Lsoil_{bottom} \cdot m$ $Depth := Depth \cdot cm$

COHESIVE SOILS - Shaft Resistance Using the α method (10.8.3.3.1)

$$q_{sc}(\alpha, S_u) := \begin{cases} 100 \cdot kPa & \text{if } \alpha \cdot S_u > 100 \cdot kPa \\ \alpha \cdot S_u & \text{otherwise} \end{cases}$$ (10.8.3.3.1-1)

(JRA Table C.10.4-4)

$$S_u(SPT) := 5 \cdot SPT \cdot kPa$$

(Table 10.8.3.3.1-1)

$$\alpha(S_u) := \begin{cases} 0.55 & \text{if } S_u < 0.2 \cdot MPa \\ 0.49 & \text{if } (S_u \geq 0.2 \cdot MPa) \cdot (S_u < 0.30 \cdot MPa) \\ 0.42 & \text{if } (S_u \geq 0.3 \cdot MPa) \cdot (S_u < 0.40 \cdot MPa) \\ 0.38 & \text{if } (S_u \geq 0.4 \cdot MPa) \cdot (S_u < 0.50 \cdot MPa) \\ 0.35 & \text{if } (S_u \geq 0.5 \cdot MPa) \cdot (S_u < 0.60 \cdot MPa) \\ 0.33 & \text{if } (S_u \geq 0.6 \cdot MPa) \cdot (S_u < 0.70 \cdot MPa) \\ 0.32 & \text{if } (S_u \geq 0.7 \cdot MPa) \cdot (S_u < 0.80 \cdot MPa) \\ 0.31 & \text{if } (S_u \geq 0.8 \cdot MPa) \cdot (S_u < 0.90 \cdot MPa) \\ \text{"Treat as Rock"} & \text{otherwise} \end{cases}$$

COHESIVE SOILS - Tip Resistance (10.8.3.3.2)

$$q_{pc}(N_c, S_u) := \begin{cases} N_c \cdot S_u & \text{if } N_c \cdot S_u \leq 4.0 \cdot MPa \\ 4.0 \cdot MPa & \text{otherwise} \end{cases}$$ (10.8.3.3.2-1)

$$N_c(Z, SPT) := \begin{array}{|l} N_c \leftarrow 6 \cdot \left[1 + 0.2 \cdot \left(\frac{Z}{D}\right)\right] \\ N_c \leftarrow \frac{N_c}{3} \quad \text{if } 5 \cdot SPT \cdot kPa < 0.024 \cdot MPa \\ N_c \quad \text{if } N_c \leq 9 \\ 9 \quad \text{otherwise} \end{array}$$ (10.8.3.3.2-2)

COHESIONLESS SOILS - Shaft Resistance Using Reese and O'Neill Method (10.8.3.4.2)

$$\beta(Z) := \begin{array}{|l} \beta \leftarrow 1.5 - 7.7 \cdot 10^{-3} \cdot \sqrt{\frac{Z}{mm}} \\ \beta \leftarrow 0.25 \quad \text{if } \beta < 0.25 \\ \beta \leftarrow 1.2 \quad \text{if } \beta > 1.2 \\ \beta \quad \text{otherwise} \end{array}$$

(Table 10.8.3.4.2-1)

$$q_{ss}(Z, \sigma_v) := \begin{cases} \beta(Z) \cdot \sigma_v & \text{if } \beta(Z) \cdot \sigma_v \leq 0.19 \cdot MPa \\ 0.19 \cdot MPa & \text{otherwise} \end{cases}$$

COHESIONLESS SOILS - Tip Resistance Using Reese and O'Neill Method (10.8.3.4.3)

$$q_{ps}(SPT, D) := \begin{cases} 0.057 \cdot SPT \cdot MPa & \text{if } (SPT \le 75) \cdot (D \le 1270 \cdot mm) \\ 0.057 \cdot SPT \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 75) \cdot (D > 1270 \cdot mm) \\ 4.3 \cdot MPa & \text{if } (SPT > 75) \cdot (D \le 1270 \cdot mm) \\ 4.3 \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

(Table 10.8.3.4.3-1)
&
(10.8.3.4.3-1)

JOINTED ROCK - Shaft Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{sr}(SPT, \sigma_v) := \begin{cases} \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{SPT}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] & \text{if } SPT \le 100 \\ \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{100}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] & \text{if } SPT > 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot SPT}{\sigma_v}\right)^{\sin(\phi)} & \text{if } SPT \le 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot 100}{\sigma_v}\right)^{\sin(\phi)} & \text{if } SPT > 100 \\ \sigma_v \cdot K_o \cdot \tan(\phi) \end{cases}$$

JOINTED ROCK - Tip Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{pr}(SPT, \sigma_v) := \begin{cases} 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT \le 100) \cdot (D \le 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT > 100) \cdot (D \le 1270 \cdot mm) \\ 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 100) \cdot (D > 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases} \quad (11.11)$$

RESISTANCE AT THE STRENGTH LIMIT STATE (10.8.3)

Factored bearing resistance $Q_R(\eta, \phi pQ_p, \phi sQ_s) := \eta \cdot (\phi pQ_p + \phi sQ_s)$ (10.7.3.2-1)

Side Resistance in Clay $\phi_{sc} := 0.65$ (Table 10.5.5-3)

Base resistance in Clay $\phi_{pc} := 0.55$ (Table 10.5.5-3)

Side Resistance in Sand $\phi_{ss} := 0.65$

Base resistance in Sand $\phi_{ps} := 0.5$

(Discussion in 10.8.3.4) & FHWA-IF-99-025 "Drilled Shafts: Construction Procedures and Design Methods"

Side Resistance in Rock $\phi_{sr} := 0.55$ (Table 10.5.5-3)

Base resistance in Rock $\phi_{pr} := 0.50$ (Table 10.5.5-3)

Calculate Shaft Resistance

$j := 1 .. 10$

Length of each soil layer down the pile

$$L_{Pile_j} := \begin{cases} Depth_j & \text{if } (ElevT \geq Lsoil_{t_j}) \cdot [(ElevT - L) \leq Lsoil_{b_j}] \\ ElevT - Lsoil_{b_j} & \text{if } (ElevT < Lsoil_{t_j}) \cdot (ElevT \geq Lsoil_{b_j}) \cdot [(ElevT - L) \leq Lsoil_{b_j}] \\ Lsoil_{t_j} - (ElevT - L) & \text{if } (ElevT \geq Lsoil_{t_j}) \cdot (ElevT - L > Lsoil_{b_j}) \cdot (ElevT - L < Lsoil_{t_j}) \\ 0 \cdot m & \text{otherwise} \end{cases}$$

Average depth of each soil layer

$$Z_j := \begin{cases} (Lsoil_{t_1} - Lsoil_{b_j}) - \dfrac{L_{Pile_j}}{2} & \text{if } (ElevT - L) \leq Lsoil_{b_j} \\ [Lsoil_{t_1} - (ElevT - L)] - \dfrac{L_{Pile_j}}{2} & \text{otherwise} \end{cases}$$

Effective vertical soil stress at each soil layer

$$\sigma_{v_j} := Z_j \cdot \gamma_{soil}$$

Assign resistance factors

$$\phi_{s_j} := \begin{cases} \phi_{sc} & \text{if } SoilType_j = \text{"Clay"} \\ \phi_{ss} & \text{if } SoilType_j = \text{"Sand"} \\ \phi_{sr} & \text{otherwise} \end{cases}$$

Nominal unit shaft resistance

$$q_{s_j} := \begin{cases} q_{sc}(\alpha(S_u(SPT_j)), S_u(SPT_j)) & \text{if } SoilType_j = \text{"Clay"} \\ q_{ss}(Z_j, \sigma_{v_j}) & \text{if } SoilType_j = \text{"Sand"} \\ q_{sr}(SPT_j, \sigma_{v_j}) & \text{otherwise} \end{cases}$$

Calculate Tip Resistance

Locate pile tip soil layer "n"

$$n := \left| \begin{array}{l} s \leftarrow 0 \\ \text{for } j \in 1..10 \\ \quad s \leftarrow s+1 \text{ if } (ElevT - L) < Lsoil_{t_j} \\ s \end{array} \right. \qquad n = 10$$

Effective stress at base

$$\sigma_{vbase} := \left(Z_n + \frac{L_{Pile_n}}{2} \right) \cdot \gamma_{soil}$$

Nominal unit tip resistance

$$q_p := \left| \begin{array}{l} q_{pc}\left(N_c\left(Z_n, SPT_n\right), S_u\left(SPT_n\right)\right) \text{ if } SoilType_n = \text{"Clay"} \\ q_{ps}\left(SPT_n, D\right) \text{ if } SoilType_n = \text{"Sand"} \\ q_{pr}\left(SPT_n, \sigma_{vbase}\right) \text{ otherwise} \end{array} \right.$$

Reduce Effective Pile Length at Pile Top (1.5m) and at Pile Base (One Pile Diameter)

Subtract 1.5m from pile top:

$$value := L_{Pile_1} - 1.5m \qquad value = -1.5\text{ m}$$

$$value1 := L_{Pile_1} + L_{Pile_2} - 1.5m \qquad value1 = 0.5\text{ m}$$

$$value2 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} - 1.5m \qquad value2 = 2.5\text{ m}$$

$$value3 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} + L_{Pile_4} - 1.5m \qquad value3 = 4.5\text{ m}$$

$$L_{Pile_1} := \left| \begin{array}{l} L_{Pile_1} - 1.5m \text{ if } value \ge 0 \cdot m \\ 0 \cdot m \text{ otherwise} \end{array} \right. \qquad L_{Pile_1} = 0.00\text{ m}$$

$$L_{Pile_2} := \left| \begin{array}{l} value1 \text{ if } (value < 0 \cdot m)(value1 \ge 0m) \\ 0 \cdot m \text{ if } value1 < 0 \cdot m \\ L_{Pile_2} \text{ otherwise} \end{array} \right. \qquad L_{Pile_2} = 0.50\text{ m}$$

$$L_{Pile_3} := \left| \begin{array}{l} value2 \text{ if } (value1 < 0 \cdot m)(value2 \ge 0m) \\ 0m \text{ if } value2 < 0 \cdot m \\ L_{Pile_3} \text{ otherwise} \end{array} \right. \qquad L_{Pile_3} = 2.00\text{ m}$$

$$L_{Pile_4} := \left| \begin{array}{l} value3 \text{ if } (value2 < 0 \cdot m)(value3 \ge 0m) \\ 0m \text{ if } value3 < 0 \cdot m \\ L_{Pile_4} \text{ otherwise} \end{array} \right. \qquad L_{Pile_4} = 2.00\text{ m}$$

Subtract length from pile length at base:

$value := L_{Pile_n} - D$ $\qquad value = 2.5\ m$

$value1 := L_{Pile_n} + L_{Pile_{n-1}} - D$ $\qquad value1 = 4.5\ m$

$value2 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} - D$ $\qquad value2 = 6.5\ m$

$value3 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} + L_{Pile_{n-3}} - D$ $\qquad value3 = 8.5\ m$

$$L_{Pile_n} := \begin{cases} L_{Pile_n} - D & \text{if } value \ge 0 \cdot m \\ 0 \cdot m & \text{otherwise} \end{cases} \qquad L_{Pile_n} = 2.50\ m$$

$$L_{Pile_{n-1}} := \begin{cases} value1 & \text{if } (value < 0 \cdot m)(value1 \ge 0m) \\ 0 \cdot m & \text{if } value1 < 0 \cdot m \\ L_{Pile_{n-1}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-1}} = 2.00\ m$$

$$L_{Pile_{n-2}} := \begin{cases} value2 & \text{if } (value1 < 0 \cdot m)(value2 \ge 0m) \\ 0m & \text{if } value2 < 0 \cdot m \\ L_{Pile_{n-2}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-2}} = 2.00\ m$$

$$L_{Pile_{n-3}} := \begin{cases} value3 & \text{if } (value2 < 0 \cdot m)(value3 \ge 0m) \\ 0m & \text{if } value3 < 0 \cdot m \\ L_{Pile_{n-3}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-3}} = 2.00\ m$$

Reduction factor for large diameter bored piles in clay

$$F_r := \left| \begin{array}{l} a \leftarrow 0.0071 + 0.0021 \cdot \dfrac{Z_n}{D} \\ a \leftarrow \min(0.015, a) \\ b \leftarrow 1.45 \cdot \sqrt{2.0 \cdot \dfrac{S_u(SPT_n)}{MPa}} \\ b \leftarrow 0.5 \text{ if } b \le 0.5 \\ b \leftarrow 1.5 \text{ if } 1.5 \le b \\ F_r \leftarrow \dfrac{760}{12.0 \cdot a \cdot \dfrac{D}{mm} + 760 \cdot b} \\ F_r \leftarrow \min(1.0, F_r) \end{array} \right. \qquad F_r = 0.724$$

$$q_p := \begin{cases} q_p \cdot F_r & \text{if } (D > 1900 \cdot mm) \cdot (SoilType_n = \text{"Clay"}) \cdot (S_u(SPT_n) > 0.096 \cdot MPa) \cdot (Settlement = \text{"N"}) \\ q_p & \text{otherwise} \end{cases}$$

Calculate Total factored Resistance

Assign resistance factor

$$\phi_p := \begin{cases} \phi_{pc} & \text{if } SoilType_n = \text{"Clay"} \\ \phi_{ps} & \text{if } SoilType_n = \text{"Sand"} \\ \phi_{pr} & \text{otherwise} \end{cases}$$

Total Factored Shaft Resistance

$$\phi sQ_s := \sum_j \left(\phi_{s_j} \cdot q_{s_j} \cdot L_{Pile_j} \cdot \pi \cdot D\right) \qquad \phi sQ_s = 3920\,kN$$

Total Factored Tip Resistance

$$\phi pQ_p := \phi_p \cdot q_p \cdot \pi \cdot \frac{D^2}{4} \qquad \phi pQ_p = 2187\,kN$$

Uplift resistance (assuming submerged pile)

$$Q_{su} := \phi sQ_s \cdot \frac{0.55}{0.65} + \pi \cdot \frac{D^2}{4} \cdot L \cdot 14.5 \cdot \frac{kN}{m^3}$$

$$Q_{su} = 3829\,kN$$

Check center-to-center spacing of piles

$$ctc := \begin{cases} 2.5 \cdot D & \text{if } ctc < 2.5 \cdot D \\ 6.0 \cdot D & \text{if } ctc > 6.0 \cdot D \\ ctc & \text{otherwise} \end{cases} \qquad ctc = 6\ m$$

Determine if pile is predominantly driven in sand or clay

$$L_{sand} := \begin{array}{|l} L_s \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{cases} L_s \leftarrow L_s + L_{Pile_j} & \text{if } SoilType_j = \text{"Sand"} \\ L_s & \text{otherwise} \end{cases} \end{array} \qquad L_{sand} = 0.00\ m$$

$$L_{clay} := \begin{array}{|l} L_c \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{cases} L_c \leftarrow L_c + L_{Pile_j} & \text{if } SoilType_j = \text{"Clay"} \\ L_c & \text{otherwise} \end{cases} \end{array} \qquad L_{clay} = 17.00\ m$$

Assign overall soil type to pile

$$SoilTypeOverall := \begin{cases} \text{"Sand"} & \text{if } L_{sand} > L_{clay} \\ \text{"Clay"} & \text{otherwise} \end{cases}$$

$$SoilTypeOverall = \text{"Clay"}$$

Efficiency of pile group (10.7.3.10.2)

$$\eta := \begin{cases} 1.00 & \text{if } SoilType_n = \text{"Rock"} \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Sand"}) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \geq 5) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \geq 5) \\ 0.65 + (1 - 0.65)\cdot\frac{ctc - 2.5\cdot D}{3.5\cdot D} & \text{otherwise} \end{cases}$$

$$\eta = 1.00$$

SUMMARY
BORED Pile
Shaft and Tip Factored Resistance kN

Diameter of Pile $D = 1.5\ m$

Length of Pile $L = 20\ m$

Ref.	Thickness	Length down Pile	Level	SPT N	Soil Type	q_s	φ_s	$\varphi_s Q_s$	q_p	φ_p	$\varphi_p Q_p$
	(m)	(m)	(m)			kN/m2		kN	kN/m2		kN
1.0	2.0	0.0	-2.0	0	Clay	0.0	0.65	0	0.0	0.00	0
2.0	2.0	0.5	-4.0	14	Clay	38.5	0.65	59	0.0	0.00	0
3.0	2.0	2.0	-6.0	7	Clay	19.3	0.65	118	0.0	0.00	0
4.0	2.0	2.0	-8.0	9	Clay	24.8	0.65	152	0.0	0.00	0
5.0	2.0	2.0	-10.0	50	Clay	100.0	0.65	613	0.0	0.00	0
6.0	2.0	2.0	-12.0	50	Clay	100.0	0.65	613	0.0	0.00	0
7.0	2.0	2.0	-14.0	40	Clay	98.0	0.65	600	0.0	0.00	0
8.0	2.0	2.0	-16.0	23	Clay	63.3	0.65	387	0.0	0.00	0
9.0	2.0	2.0	-18.0	49	Clay	100.0	0.65	613	0.0	0.00	0
10.0	8.0	2.5	-22.0	50	Clay	100.0	0.65	766	2250.0	0.55	2187
Total Factored Shaft Resistance $\varphi_s Q_s$								3920	Factored Tip Resistance $\varphi_p Q_p$		2187

$\eta = 1.00$

TOTAL FACTORED RESISTANCE PER PILE

$$Q_R(\eta, \phi p Q_p, \phi s Q_s) = 6107\,kN$$

TOTAL FACTORED UPLIFT RESISTANCE PER PILE

$$Q_{su} = 3829\,kN$$

9.2. BEARING CAPACITY – ABUTMENT PILES

TABLE: Pile Reactions - SUMMARY AXIAL LOAD						
Frame	**Max Reaction Comb 5 (Earthquake Load)**	**Min Reaction Comb 5 (Earthquake Load)**	**Pile Dia**	**Min Pile Length Required**	**Bearing Capacity**	**Uplift Capacity**
	kN	kN	m	m	kN	kN
A1	5202.0	-2262.0	1.8	16	5561	-3902
A2	6560.0	-3675.0	1.8	18	7421	-4279

Note:

Refer to abutment design calculations for abutment pile loads

KATAHIRA & ENGINEERS INTERNATIONAL

Project: **Detailed Design Study of North Java Flyover Project**

Calculation: **Detailed Design**
Balaraja Flyover - Pier A1
1.8m Dia. BORED PILE AXIAL BEARING CAPACITY

Reference : **AASHTO LRFD Bridge Design Specification**
"Drilled Shafts: Construction Procedures and Design Methods"
FHWA-IF-99-025, August 1999

Definitions $kN := 1000 \cdot N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $kPa := 1000 \cdot Pa$

Pile Input Data

Pile Diameter	D (m)	1.80
Length of Pile	L (m)	16.00
Elevation at top of Pile	ElevTop (m)	-3.10
Effective Soil Density	γ (kN/m3)	10.00
Pile Cap		2
1. In firm contact with the ground		
2. Not in firm contact with the ground		
Pile center-to-center spacing	ctc (m)	6.000
Settlements evaluated?	(Y or N)	N

$D := D \cdot m$ $L := L \cdot m$ $ElevT := ElevT \cdot m$ $\gamma_{soil} := \gamma_{soil} \cdot \frac{kN}{m^3}$ $ctc := ctc \cdot m$

Subsoil Input Data - BOREHOLE BH 5

Ref.	Thickness	Level top of Layer	Level bottom of Layer	Soil Type	SPT N
	(cm)	(m)	(m)		
1.0	200	0.00	-2.00	Clay	0
2.0	200	-2.00	-4.00	Clay	13
3.0	200	-4.00	-6.00	Clay	15
4.0	200	-6.00	-8.00	Clay	14
5.0	200	-8.00	-10.00	Clay	41
6.0	200	-10.00	-12.00	Clay	50
7.0	300	-12.00	-15.00	Clay	50
8.0	400	-15.00	-19.00	Clay	50
9.0	500	-19.00	-24.00	Clay	50
10.0	800	-24.00	-32.00	Clay	50

$Lsoil_t := Lsoil_{top} \cdot m$ $Lsoil_b := Lsoil_{bottom} \cdot m$ $Depth := Depth \cdot cm$

COHESIVE SOILS - Shaft Resistance Using the α method (10.8.3.3.1)

$$q_{sc}(\alpha, S_u) := \begin{cases} 100 \cdot kPa & \text{if } \alpha \cdot S_u > 100 \cdot kPa \\ \alpha \cdot S_u & \text{otherwise} \end{cases}$$ (10.8.3.3.1-1)

(JRA Table C.10.4-4)

$$S_u(SPT) := 5 \cdot SPT \cdot kPa$$

(Table 10.8.3.3.1-1)

$$\alpha(S_u) := \begin{cases} 0.55 & \text{if } S_u < 0.2 \cdot MPa \\ 0.49 & \text{if } (S_u \ge 0.2 \cdot MPa) \cdot (S_u < 0.30 \cdot MPa) \\ 0.42 & \text{if } (S_u \ge 0.3 \cdot MPa) \cdot (S_u < 0.40 \cdot MPa) \\ 0.38 & \text{if } (S_u \ge 0.4 \cdot MPa) \cdot (S_u < 0.50 \cdot MPa) \\ 0.35 & \text{if } (S_u \ge 0.5 \cdot MPa) \cdot (S_u < 0.60 \cdot MPa) \\ 0.33 & \text{if } (S_u \ge 0.6 \cdot MPa) \cdot (S_u < 0.70 \cdot MPa) \\ 0.32 & \text{if } (S_u \ge 0.7 \cdot MPa) \cdot (S_u < 0.80 \cdot MPa) \\ 0.31 & \text{if } (S_u \ge 0.8 \cdot MPa) \cdot (S_u < 0.90 \cdot MPa) \\ \text{"Treat as Rock"} & \text{otherwise} \end{cases}$$

COHESIVE SOILS - Tip Resistance (10.8.3.3.2)

(10.8.3.3.2-1)

$$q_{pc}(N_c, S_u) := \begin{cases} N_c \cdot S_u & \text{if } N_c \cdot S_u \le 4.0 \cdot MPa \\ 4.0 \cdot MPa & \text{otherwise} \end{cases}$$

(10.8.3.3.2-2)

$$N_c(Z, SPT) := \begin{array}{|l} N_c \leftarrow 6 \cdot \left[1 + 0.2 \cdot \left(\frac{Z}{D}\right)\right] \\ N_c \leftarrow \frac{N_c}{3} \quad \text{if } 5 \cdot SPT \cdot kPa < 0.024 \cdot MPa \\ N_c \quad \text{if } N_c \le 9 \\ 9 \quad \text{otherwise} \end{array}$$

COHESIONLESS SOILS - Shaft Resistance Using Reese and O'Neill Method (10.8.3.4.2)

$$\beta(Z) := \begin{array}{|l} \beta \leftarrow 1.5 - 7.7 \cdot 10^{-3} \cdot \sqrt{\frac{Z}{mm}} \\ \beta \leftarrow 0.25 \quad \text{if } \beta < 0.25 \\ \beta \leftarrow 1.2 \quad \text{if } \beta > 1.2 \\ \beta \quad \text{otherwise} \end{array}$$

(Table 10.8.3.4.2-1)

$$q_{ss}(Z, \sigma_v) := \begin{cases} \beta(Z) \cdot \sigma_v & \text{if } \beta(Z) \cdot \sigma_v \le 0.19 \cdot MPa \\ 0.19 \cdot MPa & \text{otherwise} \end{cases}$$

COHESIONLESS SOILS - Tip Resistance Using Reese and O'Neill Method (10.8.3.4.3)

$$q_{ps}(SPT, D) := \begin{cases} 0.057 \cdot SPT \cdot MPa & \text{if } (SPT \le 75) \cdot (D \le 1270 \cdot mm) \\ 0.057 \cdot SPT \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 75) \cdot (D > 1270 \cdot mm) \\ 4.3 \cdot MPa & \text{if } (SPT > 75) \cdot (D \le 1270 \cdot mm) \\ 4.3 \cdot MPa \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

(Table 10.8.3.4.3-1)
&
(10.8.3.4.3-1)

JOINTED ROCK - Shaft Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{sr}(SPT, \sigma_v) := \begin{vmatrix} \phi \leftarrow \text{atan}\left[\left[\dfrac{SPT}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] & \text{if } SPT \le 100 \\ \phi \leftarrow \text{atan}\left[\left[\dfrac{100}{12.3 + 20.3 \cdot \left(\dfrac{\sigma_v}{101 \cdot kPa}\right)}\right]^{0.34}\right] & \text{if } SPT > 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot SPT}{\sigma_v}\right)^{\sin(\phi)} & \text{if } SPT \le 100 \\ K_o \leftarrow (1 - \sin(\phi)) \cdot \left(\dfrac{0.2 \cdot 101 \cdot kPa \cdot 100}{\sigma_v}\right)^{\sin(\phi)} & \text{if } SPT > 100 \\ \sigma_v \cdot K_o \cdot \tan(\phi) & \end{vmatrix}$$

JOINTED ROCK - Tip Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{pr}(SPT, \sigma_v) := \begin{cases} 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT \le 100) \cdot (D \le 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v & \text{if } (SPT > 100) \cdot (D \le 1270 \cdot mm) \\ 0.59 \cdot \left(SPT \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{if } (SPT \le 100) \cdot (D > 1270 \cdot mm) \\ 0.59 \cdot \left(100 \cdot \dfrac{101 \cdot kPa}{\sigma_v}\right)^{0.8} \cdot \sigma_v \cdot \dfrac{1270 \cdot mm}{D} & \text{otherwise} \end{cases}$$

(11.11)

RESISTANCE AT THE STRENGTH LIMIT STATE (10.8.3)

Factored bearing resistance $Q_R(\eta, \phi pQ_p, \phi sQ_s) := \eta \cdot (\phi pQ_p + \phi sQ_s)$ (10.7.3.2-1)

Side Resistance in Clay $\phi_{sc} := 0.65$ (Table 10.5.5-3)

Base resistance in Clay $\phi_{pc} := 0.55$ (Table 10.5.5-3)

Side Resistance in Sand $\phi_{ss} := 0.65$

Base resistance in Sand $\phi_{ps} := 0.5$

(Discussion in 10.8.3.4) & FHWA-IF-99-025 "Drilled Shafts: Construction Procedures and Design Methods"

Side Resistance in Rock $\phi_{sr} := 0.55$ (Table 10.5.5-3)

Base resistance in Rock $\phi_{pr} := 0.50$ (Table 10.5.5-3)

Calculate Shaft Resistance

$j := 1 .. 10$

Length of each soil layer down the pile

$$L_{Pile_j} := \begin{cases} Depth_j & \text{if } (ElevT \geq Lsoil_{t_j}) \cdot [(ElevT - L) \leq Lsoil_{b_j}] \\ ElevT - Lsoil_{b_j} & \text{if } (ElevT < Lsoil_{t_j}) \cdot (ElevT \geq Lsoil_{b_j}) \cdot [(ElevT - L) \leq Lsoil_{b_j}] \\ Lsoil_{t_j} - (ElevT - L) & \text{if } (ElevT \geq Lsoil_{t_j}) \cdot (ElevT - L > Lsoil_{b_j}) \cdot (ElevT - L < Lsoil_{t_j}) \\ 0 \cdot m & \text{otherwise} \end{cases}$$

Average depth of each soil layer

$$Z_j := \begin{cases} (Lsoil_{t_1} - Lsoil_{b_j}) - \dfrac{L_{Pile_j}}{2} & \text{if } (ElevT - L) \leq Lsoil_{b_j} \\ [Lsoil_{t_1} - (ElevT - L)] - \dfrac{L_{Pile_j}}{2} & \text{otherwise} \end{cases}$$

Effective vertical soil stress at each soil layer

$$\sigma_{v_j} := Z_j \cdot \gamma_{soil}$$

Assign resistance factors

$$\phi_{s_j} := \begin{cases} \phi_{sc} & \text{if } SoilType_j = \text{"Clay"} \\ \phi_{ss} & \text{if } SoilType_j = \text{"Sand"} \\ \phi_{sr} & \text{otherwise} \end{cases}$$

Nominal unit shaft resistance

$$q_{s_j} := \begin{cases} q_{sc}(\alpha(S_u(SPT_j)), S_u(SPT_j)) & \text{if } SoilType_j = \text{"Clay"} \\ q_{ss}(Z_j, \sigma_{v_j}) & \text{if } SoilType_j = \text{"Sand"} \\ q_{sr}(SPT_j, \sigma_{v_j}) & \text{otherwise} \end{cases}$$

Calculate Tip Resistance

Locate pile tip soil layer "n"

$$n := \left| \begin{array}{l} s \leftarrow 0 \\ \text{for } j \in 1..10 \\ \quad s \leftarrow s+1 \text{ if } (ElevT - L) < Lsoil_{t_j} \\ s \end{array} \right. \qquad n = 9$$

Effective stress at base

$$\sigma_{vbase} := \left(Z_n + \frac{L_{Pile_n}}{2} \right) \cdot \gamma_{soil}$$

Nominal unit tip resistance

$$q_p := \left| \begin{array}{l} q_{pc}\left(N_c\left(Z_n, SPT_n\right), S_u\left(SPT_n\right)\right) \text{ if } SoilType_n = \text{"Clay"} \\ q_{ps}\left(SPT_n, D\right) \text{ if } SoilType_n = \text{"Sand"} \\ q_{pr}\left(SPT_n, \sigma_{vbase}\right) \text{ otherwise} \end{array} \right.$$

Reduce Effective Pile Length at Pile Top (1.5m) and at Pile Base (One Pile Diameter)

Subtract 1.5m from pile top:

$$value := L_{Pile_1} - 1.5m \qquad value = -1.5\ m$$

$$value1 := L_{Pile_1} + L_{Pile_2} - 1.5m \qquad value1 = -0.6\ m$$

$$value2 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} - 1.5m \qquad value2 = 1.4\ m$$

$$value3 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} + L_{Pile_4} - 1.5m \qquad value3 = 3.4\ m$$

$$L_{Pile_1} := \left| \begin{array}{l} L_{Pile_1} - 1.5m \text{ if } value \ge 0 \cdot m \\ 0 \cdot m \text{ otherwise} \end{array} \right. \qquad L_{Pile_1} = 0.00\ m$$

$$L_{Pile_2} := \left| \begin{array}{l} value1 \text{ if } (value < 0 \cdot m)(value1 \ge 0m) \\ 0 \cdot m \text{ if } value1 < 0 \cdot m \\ L_{Pile_2} \text{ otherwise} \end{array} \right. \qquad L_{Pile_2} = 0.00\ m$$

$$L_{Pile_3} := \left| \begin{array}{l} value2 \text{ if } (value1 < 0 \cdot m)(value2 \ge 0m) \\ 0m \text{ if } value2 < 0 \cdot m \\ L_{Pile_3} \text{ otherwise} \end{array} \right. \qquad L_{Pile_3} = 1.40\ m$$

$$L_{Pile_4} := \left| \begin{array}{l} value3 \text{ if } (value2 < 0 \cdot m)(value3 \ge 0m) \\ 0m \text{ if } value3 < 0 \cdot m \\ L_{Pile_4} \text{ otherwise} \end{array} \right. \qquad L_{Pile_4} = 2.00\ m$$

Subtract length from pile length at base:

$value := L_{Pile_n} - D$ $\quad value = -1.7\ m$

$value1 := L_{Pile_n} + L_{Pile_{n-1}} - D$ $\quad value1 = 2.3\ m$

$value2 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} - D$ $\quad value2 = 5.3\ m$

$value3 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} + L_{Pile_{n-3}} - D$ $\quad value3 = 7.3\ m$

$$L_{Pile_n} := \begin{cases} L_{Pile_n} - D & \text{if } value \ge 0 \cdot m \\ 0 \cdot m & \text{otherwise} \end{cases} \qquad L_{Pile_n} = 0.00\ m$$

$$L_{Pile_{n-1}} := \begin{cases} value1 & \text{if } (value < 0 \cdot m)(value1 \ge 0m) \\ 0 \cdot m & \text{if } value1 < 0 \cdot m \\ L_{Pile_{n-1}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-1}} = 2.30\ m$$

$$L_{Pile_{n-2}} := \begin{cases} value2 & \text{if } (value1 < 0 \cdot m)(value2 \ge 0m) \\ 0m & \text{if } value2 < 0 \cdot m \\ L_{Pile_{n-2}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-2}} = 3.00\ m$$

$$L_{Pile_{n-3}} := \begin{cases} value3 & \text{if } (value2 < 0 \cdot m)(value3 \ge 0m) \\ 0m & \text{if } value3 < 0 \cdot m \\ L_{Pile_{n-3}} & \text{otherwise} \end{cases} \qquad L_{Pile_{n-3}} = 2.00\ m$$

Reduction factor for large diameter bored piles in clay

$$F_r := \left| \begin{array}{l} a \leftarrow 0.0071 + 0.0021 \cdot \frac{Z_n}{D} \\ a \leftarrow \min(0.015, a) \\ b \leftarrow 1.45 \cdot \sqrt{2.0 \cdot \frac{S_u(SPT_n)}{MPa}} \\ b \leftarrow 0.5 \text{ if } b \le 0.5 \\ b \leftarrow 1.5 \text{ if } 1.5 \le b \\ F_r \leftarrow \frac{760}{12.0 \cdot a \cdot \frac{D}{mm} + 760 \cdot b} \\ F_r \leftarrow \min(1.0, F_r) \end{array} \right. \qquad F_r = 0.689$$

$$q_p := \begin{cases} q_p \cdot F_r & \text{if } (D > 1900 \cdot mm) \cdot (SoilType_n = \text{"Clay"}) \cdot (S_u(SPT_n) > 0.096 \cdot MPa) \cdot (Settlement = \text{"N"}) \\ q_p & \text{otherwise} \end{cases}$$

Calculate Total factored Resistance

Assign resistance factor

$$\phi_p := \begin{cases} \phi_{pc} & \text{if } SoilType_n = \text{"Clay"} \\ \phi_{ps} & \text{if } SoilType_n = \text{"Sand"} \\ \phi_{pr} & \text{otherwise} \end{cases}$$

Total Factored Shaft Resistance

$$\phi sQ_s := \sum_j \left(\phi_{s_j} \cdot q_{s_j} \cdot L_{Pile_j} \cdot \pi \cdot D \right)$$

$\phi sQ_s = 3914\,kN$

Total Factored Tip Resistance

$$\phi pQ_p := \phi_p \cdot q_p \cdot \pi \cdot \frac{D^2}{4}$$

$\phi pQ_p = 3149\,kN$

Uplift resistance (assuming submerged pile)

$$Q_{su} := \phi sQ_s \cdot \frac{0.55}{0.65} + \pi \cdot \frac{D^2}{4} \cdot L \cdot 14.5 \cdot \frac{kN}{m^3}$$

$Q_{su} = 3902\,kN$

Check center-to-center spacing of piles

$$ctc := \begin{cases} 2.5 \cdot D & \text{if } ctc < 2.5 \cdot D \\ 6.0 \cdot D & \text{if } ctc > 6.0 \cdot D \\ ctc & \text{otherwise} \end{cases}$$

$ctc = 6\ m$

Determine if pile is predominantly driven in sand or clay

$$L_{sand} := \begin{array}{|l} L_s \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{array}{|l} L_s \leftarrow L_s + L_{Pile_j} \ \text{if } SoilType_j = \text{"Sand"} \\ L_s \ \text{otherwise} \end{array} \end{array}$$

$L_{sand} = 0.00\ m$

$$L_{clay} := \begin{array}{|l} L_c \leftarrow 0 \cdot m \\ \text{for } j \in 1..10 \\ \quad \begin{array}{|l} L_c \leftarrow L_c + L_{Pile_j} \ \text{if } SoilType_j = \text{"Clay"} \\ L_c \ \text{otherwise} \end{array} \end{array}$$

$L_{clay} = 12.70\ m$

Assign overall soil type to pile

$$SoilTypeOverall := \begin{cases} \text{"Sand"} & \text{if } L_{sand} > L_{clay} \\ \text{"Clay"} & \text{otherwise} \end{cases}$$

$SoilTypeOverall = \text{"Clay"}$

Efficiency of pile group (10.7.3.10.2)

$$\eta := \begin{cases} 1.00 & \text{if } SoilType_n = \text{"Rock"} \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Sand"}) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \ge 5) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \ge 5) \\ 0.65 + (1 - 0.65)\cdot\dfrac{ctc - 2.5\cdot D}{3.5\cdot D} & \text{otherwise} \end{cases}$$

$$\eta = 1.00$$

SUMMARY
BORED Pile
Shaft and Tip Factored Resistance kN

Diameter of Pile $D = 1.8\ m$

Length of Pile $L = 16\ m$

Ref.	Thickness	Length down Pile	Level	SPT N	Soil Type	q_s	φ_s	$\varphi_s Q_s$	q_p	φ_p	$\varphi_p Q_p$
	(m)	(m)	(m)			kN/m2		kN	kN/m2		kN
1.0	2.0	0.0	-2.0	0	Clay	0.0	0.65	0	0.0	0.00	0
2.0	2.0	0.0	-4.0	13	Clay	35.8	0.65	0	0.0	0.00	0
3.0	2.0	1.4	-6.0	15	Clay	41.3	0.65	212	0.0	0.00	0
4.0	2.0	2.0	-8.0	14	Clay	38.5	0.65	283	0.0	0.00	0
5.0	2.0	2.0	-10.0	41	Clay	100.0	0.65	735	0.0	0.00	0
6.0	2.0	2.0	-12.0	50	Clay	100.0	0.65	735	0.0	0.00	0
7.0	3.0	3.0	-15.0	50	Clay	100.0	0.65	1103	0.0	0.00	0
8.0	4.0	2.3	-19.0	50	Clay	100.0	0.65	845	0.0	0.00	0
9.0	5.0	0.0	-19.1	50	Clay	100.0	0.65	0	2250.0	0.55	3149
10.0	8.0	0.0	0.0	50	Clay	100.0	0.65	0	0.0	0.00	0
Total Factored Shaft Resistance $\varphi_s Q_s$								3914	Factored Tip Resistance $\varphi_p Q_p$		3149

$$\eta = 1.00$$

TOTAL FACTORED RESISTANCE PER PILE

$$Q_R(\eta, \phi p Q_p, \phi s Q_s) = 7063\,kN$$

.

TOTAL FACTORED UPLIFT RESISTANCE PER PILE

$$Q_{su} = 3902\,kN$$

KATAHIRA & ENGINEERS INTERNATIONAL

Project: **Detailed Design Study of North Java Flyover Project**

Calculation: **Detailed Design**
Balaraja Flyover - Abutment A2
1.8m Dia. BORED PILE AXIAL BEARING CAPACITY

Reference : **AASHTO LRFD Bridge Design Specification**
"Drilled Shafts: Construction Procedures and Design Methods"
FHWA-IF-99-025, August 1999

Definitions $kN := 1000 \cdot N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $kPa := 1000 \cdot Pa$

Pile Input Data

Pile Diameter	D (m)	1.80
Length of Pile	L (m)	18.00
Elevation at top of Pile	ElevTop (m)	-3.00
Effective Soil Density	γ (kN/m3)	10.00
Pile Cap 1. In firm contact with the ground 2. Not in firm contact with the ground		2
Pile center-to-center spacing	ctc (m)	6.000
Settlements evaluated?	(Y or N)	N

$D := D \cdot m$ $L := L \cdot m$ $ElevT := ElevT \cdot m$ $\gamma_{soil} := \gamma_{soil} \cdot \frac{kN}{m^3}$ $ctc := ctc \cdot m$

Subsoil Input Data - BOREHOLE BH 13

Ref.	Thickness	Level top of Layer	Level bottom of Layer	Soil Type	SPT N
	(cm)	(m)	(m)		
1.0	200	0.00	-2.00	Clay	6
2.0	200	-2.00	-4.00	Sand	5
3.0	200	-4.00	-6.00	Sand	4
4.0	200	-6.00	-8.00	Clay	13
5.0	200	-8.00	-10.00	Clay	18
6.0	200	-10.00	-12.00	Clay	50
7.0	300	-12.00	-15.00	Clay	50
8.0	400	-15.00	-19.00	Clay	50
9.0	500	-19.00	-24.00	Clay	50
10.0	600	-24.00	-30.00	Clay	50

$Lsoil_t := Lsoil_{top} \cdot m$ $Lsoil_b := Lsoil_{bottom} \cdot m$ $Depth := Depth \cdot cm$

COHESIVE SOILS - Shaft Resistance Using the α method (10.8.3.3.1)

$$q_{sc}(\alpha, S_u) := \begin{cases} 100 \cdot kPa & \text{if } \alpha \cdot S_u > 100 \cdot kPa \\ \alpha \cdot S_u & \text{otherwise} \end{cases}$$ (10.8.3.3.1-1)

(JRA Table C.10.4-4)

$$S_u(SPT) := 5 \cdot SPT \cdot kPa$$

$$\alpha(S_u) := \begin{cases} 0.55 & \text{if } S_u < 0.2 \cdot MPa \\ 0.49 & \text{if } (S_u \geq 0.2 \cdot MPa) \cdot (S_u < 0.30 \cdot MPa) \\ 0.42 & \text{if } (S_u \geq 0.3 \cdot MPa) \cdot (S_u < 0.40 \cdot MPa) \\ 0.38 & \text{if } (S_u \geq 0.4 \cdot MPa) \cdot (S_u < 0.50 \cdot MPa) \\ 0.35 & \text{if } (S_u \geq 0.5 \cdot MPa) \cdot (S_u < 0.60 \cdot MPa) \\ 0.33 & \text{if } (S_u \geq 0.6 \cdot MPa) \cdot (S_u < 0.70 \cdot MPa) \\ 0.32 & \text{if } (S_u \geq 0.7 \cdot MPa) \cdot (S_u < 0.80 \cdot MPa) \\ 0.31 & \text{if } (S_u \geq 0.8 \cdot MPa) \cdot (S_u < 0.90 \cdot MPa) \\ \text{"Treat as Rock"} & \text{otherwise} \end{cases}$$ (Table 10.8.3.3.1-1)

COHESIVE SOILS - Tip Resistance (10.8.3.3.2)

$$q_{pc}(N_c, S_u) := \begin{cases} N_c \cdot S_u & \text{if } N_c \cdot S_u \leq 4.0 \cdot MPa \\ 4.0 \cdot MPa & \text{otherwise} \end{cases}$$ (10.8.3.3.2-1)

$$N_c(Z, SPT) := \begin{array}{|l} N_c \leftarrow 6 \cdot \left[1 + 0.2 \cdot \left(\frac{Z}{D}\right)\right] \\ N_c \leftarrow \frac{N_c}{3} \quad \text{if } 5 \cdot SPT \cdot kPa < 0.024 \cdot MPa \\ N_c \quad \text{if } N_c \leq 9 \\ 9 \quad \text{otherwise} \end{array}$$ (10.8.3.3.2-2)

COHESIONLESS SOILS - Shaft Resistance Using Reese and O'Neill Method (10.8.3.4.2)

$$\beta(Z) := \begin{array}{|l} \beta \leftarrow 1.5 - 7.7 \cdot 10^{-3} \cdot \sqrt{\frac{Z}{mm}} \\ \beta \leftarrow 0.25 \quad \text{if } \beta < 0.25 \\ \beta \leftarrow 1.2 \quad \text{if } \beta > 1.2 \\ \beta \quad \text{otherwise} \end{array}$$

$$q_{ss}(Z, \sigma_v) := \begin{cases} \beta(Z) \cdot \sigma_v & \text{if } \beta(Z) \cdot \sigma_v \leq 0.19 \cdot MPa \\ 0.19 \cdot MPa & \text{otherwise} \end{cases}$$ (Table 10.8.3.4.2-1)

COHESIONLESS SOILS - Tip Resistance Using Reese and O'Neill Method (10.8.3.4.3)

$$q_{ps}(SPT,D) := \begin{cases} 0.057\cdot SPT\cdot MPa & \text{if } (SPT \le 75)\cdot(D \le 1270\cdot mm) \\ 0.057\cdot SPT\cdot MPa\cdot\dfrac{1270\cdot mm}{D} & \text{if } (SPT \le 75)\cdot(D > 1270\cdot mm) \\ 4.3\cdot MPa & \text{if } (SPT > 75)\cdot(D \le 1270\cdot mm) \\ 4.3\cdot MPa\cdot\dfrac{1270\cdot mm}{D} & \text{otherwise} \end{cases}$$

(Table 10.8.3.4.3-1)
&
(10.8.3.4.3-1)

JOINTED ROCK - Shaft Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{sr}(SPT,\sigma_v) := \begin{array}{|l} \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{SPT}{12.3 + 20.3\cdot\left(\dfrac{\sigma_v}{101\cdot kPa}\right)}\right]^{0.34}\right] \quad \text{if } SPT \le 100 \\ \phi \leftarrow \operatorname{atan}\left[\left[\dfrac{100}{12.3 + 20.3\cdot\left(\dfrac{\sigma_v}{101\cdot kPa}\right)}\right]^{0.34}\right] \quad \text{if } SPT > 100 \\ K_o \leftarrow (1 - \sin(\phi))\cdot\left(\dfrac{0.2\cdot 101\cdot kPa\cdot SPT}{\sigma_v}\right)^{\sin(\phi)} \quad \text{if } SPT \le 100 \\ K_o \leftarrow (1 - \sin(\phi))\cdot\left(\dfrac{0.2\cdot 101\cdot kPa\cdot 100}{\sigma_v}\right)^{\sin(\phi)} \quad \text{if } SPT > 100 \\ \sigma_v\cdot K_o\cdot\tan(\phi) \end{array}$$

JOINTED ROCK - Tip Resistance (FHWA Report)

Note: calculation based on assumption that the rock is highly weathered to a cohesionless intermediate geomaterial (IGM)

$$q_{pr}(SPT,\sigma_v) := \begin{cases} 0.59\cdot\left(SPT\cdot\dfrac{101\cdot kPa}{\sigma_v}\right)^{0.8}\cdot\sigma_v & \text{if } (SPT \le 100)\cdot(D \le 1270\cdot mm) \\ 0.59\cdot\left(100\cdot\dfrac{101\cdot kPa}{\sigma_v}\right)^{0.8}\cdot\sigma_v & \text{if } (SPT > 100)\cdot(D \le 1270\cdot mm) \\ 0.59\cdot\left(SPT\cdot\dfrac{101\cdot kPa}{\sigma_v}\right)^{0.8}\cdot\sigma_v\cdot\dfrac{1270\cdot mm}{D} & \text{if } (SPT \le 100)\cdot(D > 1270\cdot mm) \\ 0.59\cdot\left(100\cdot\dfrac{101\cdot kPa}{\sigma_v}\right)^{0.8}\cdot\sigma_v\cdot\dfrac{1270\cdot mm}{D} & \text{otherwise} \end{cases} \qquad (11.11)$$

RESISTANCE AT THE STRENGTH LIMIT STATE (10.8.3)

Factored bearing resistance $Q_R(\eta, \phi pQ_p, \phi sQ_s) := \eta \cdot (\phi pQ_p + \phi sQ_s)$ (10.7.3.2-1)

Side Resistance in Clay $\phi_{sc} := 0.65$ (Table 10.5.5-3)

Base resistance in Clay $\phi_{pc} := 0.55$ (Table 10.5.5-3)

Side Resistance in Sand $\phi_{ss} := 0.65$

Base resistance in Sand $\phi_{ps} := 0.5$

(Discussion in 10.8.3.4) & FHWA-IF-99-025 "Drilled Shafts: Construction Procedures and Design Methods"

Side Resistance in Rock $\phi_{sr} := 0.55$ (Table 10.5.5-3)

Base resistance in Rock $\phi_{pr} := 0.50$ (Table 10.5.5-3)

Calculate Shaft Resistance

$j := 1 .. 10$

Length of each soil layer down the pile

$$L_{Pile_j} := \begin{cases} Depth_j & \text{if } (ElevT \ge Lsoil_{t_j}) \cdot [(ElevT - L) \le Lsoil_{b_j}] \\ ElevT - Lsoil_{b_j} & \text{if } (ElevT < Lsoil_{t_j}) \cdot (ElevT \ge Lsoil_{b_j}) \cdot [(ElevT - L) \le Lsoil_{b_j}] \\ Lsoil_{t_j} - (ElevT - L) & \text{if } (ElevT \ge Lsoil_{t_j}) \cdot (ElevT - L > Lsoil_{b_j}) \cdot (ElevT - L < Lsoil_{t_j}) \\ 0 \cdot m & \text{otherwise} \end{cases}$$

Average depth of each soil layer

$$Z_j := \begin{cases} (Lsoil_{t_1} - Lsoil_{b_j}) - \dfrac{L_{Pile_j}}{2} & \text{if } (ElevT - L) \le Lsoil_{b_j} \\ [Lsoil_{t_1} - (ElevT - L)] - \dfrac{L_{Pile_j}}{2} & \text{otherwise} \end{cases}$$

Effective vertical soil stress at each soil layer

$$\sigma_{v_j} := Z_j \cdot \gamma_{soil}$$

Assign resistance factors

$$\phi_{s_j} := \begin{cases} \phi_{sc} & \text{if } SoilType_j = \text{"Clay"} \\ \phi_{ss} & \text{if } SoilType_j = \text{"Sand"} \\ \phi_{sr} & \text{otherwise} \end{cases}$$

Nominal unit shaft resistance

$$q_{s_j} := \begin{cases} q_{sc}(\alpha(S_u(SPT_j)), S_u(SPT_j)) & \text{if } SoilType_j = \text{"Clay"} \\ q_{ss}(Z_j, \sigma_{v_j}) & \text{if } SoilType_j = \text{"Sand"} \\ q_{sr}(SPT_j, \sigma_{v_j}) & \text{otherwise} \end{cases}$$

Calculate Tip Resistance

Locate pile tip soil layer "n"

$$n := \begin{array}{|l} s \leftarrow 0 \\ \text{for } j \in 1..10 \\ \quad s \leftarrow s + 1 \ \text{ if } (ElevT - L) < Lsoil_{t_j} \\ s \end{array} \qquad n = 9$$

Effective stress at base

$$\sigma_{vbase} := \left(Z_n + \frac{L_{Pile_n}}{2}\right) \cdot \gamma_{soil}$$

Nominal unit tip resistance

$$q_p := \begin{array}{|l} q_{pc}\left(N_c\left(Z_n, SPT_n\right), S_u\left(SPT_n\right)\right) \ \text{ if } SoilType_n = \text{"Clay"} \\ q_{ps}\left(SPT_n, D\right) \ \text{ if } SoilType_n = \text{"Sand"} \\ q_{pr}\left(SPT_n, \sigma_{vbase}\right) \ \text{ otherwise} \end{array}$$

Reduce Effective Pile Length at Pile Top (1.5m) and at Pile Base (One Pile Diameter)

Subtract 1.5m from pile top:

$$value := L_{Pile_1} - 1.5m \qquad value = -1.5\ m$$

$$value1 := L_{Pile_1} + L_{Pile_2} - 1.5m \qquad value1 = -0.5\ m$$

$$value2 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} - 1.5m \qquad value2 = 1.5\ m$$

$$value3 := L_{Pile_1} + L_{Pile_2} + L_{Pile_3} + L_{Pile_4} - 1.5m \qquad value3 = 3.5\ m$$

$$L_{Pile_1} := \begin{array}{|l} L_{Pile_1} - 1.5m \ \text{ if } value \geq 0 \cdot m \\ 0 \cdot m \ \text{ otherwise} \end{array} \qquad L_{Pile_1} = 0.00\ m$$

$$L_{Pile_2} := \begin{array}{|l} value1 \ \text{ if } (value < 0 \cdot m)(value1 \geq 0m) \\ 0 \cdot m \ \text{ if } value1 < 0 \cdot m \\ L_{Pile_2} \ \text{ otherwise} \end{array} \qquad L_{Pile_2} = 0.00\ m$$

$$L_{Pile_3} := \begin{array}{|l} value2 \ \text{ if } (value1 < 0 \cdot m)(value2 \geq 0m) \\ 0m \ \text{ if } value2 < 0 \cdot m \\ L_{Pile_3} \ \text{ otherwise} \end{array} \qquad L_{Pile_3} = 1.50\ m$$

$$L_{Pile_4} := \begin{array}{|l} value3 \ \text{ if } (value2 < 0 \cdot m)(value3 \geq 0m) \\ 0m \ \text{ if } value3 < 0 \cdot m \\ L_{Pile_4} \ \text{ otherwise} \end{array} \qquad L_{Pile_4} = 2.00\ m$$

Subtract length from pile length at base:

$value := L_{Pile_n} - D$ $\qquad$ $value = 0.2\ m$

$value1 := L_{Pile_n} + L_{Pile_{n-1}} - D$ $\qquad$ $value1 = 4.2\ m$

$value2 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} - D$ $\qquad$ $value2 = 7.2\ m$

$value3 := L_{Pile_n} + L_{Pile_{n-1}} + L_{Pile_{n-2}} + L_{Pile_{n-3}} - D$ $\qquad$ $value3 = 9.2\ m$

$$L_{Pile_n} := \begin{cases} L_{Pile_n} - D & \text{if } value \ge 0 \cdot m \\ 0 \cdot m & \text{otherwise} \end{cases}$$ $\qquad$ $L_{Pile_n} = 0.20\ m$

$$L_{Pile_{n-1}} := \begin{cases} value1 & \text{if } (value < 0 \cdot m)(value1 \ge 0m) \\ 0 \cdot m & \text{if } value1 < 0 \cdot m \\ L_{Pile_{n-1}} & \text{otherwise} \end{cases}$$ $\qquad$ $L_{Pile_{n-1}} = 4.00\ m$

$$L_{Pile_{n-2}} := \begin{cases} value2 & \text{if } (value1 < 0 \cdot m)(value2 \ge 0m) \\ 0m & \text{if } value2 < 0 \cdot m \\ L_{Pile_{n-2}} & \text{otherwise} \end{cases}$$ $\qquad$ $L_{Pile_{n-2}} = 3.00\ m$

$$L_{Pile_{n-3}} := \begin{cases} value3 & \text{if } (value2 < 0 \cdot m)(value3 \ge 0m) \\ 0m & \text{if } value3 < 0 \cdot m \\ L_{Pile_{n-3}} & \text{otherwise} \end{cases}$$ $\qquad$ $L_{Pile_{n-3}} = 2.00\ m$

Reduction factor for large diameter bored piles in clay

$$F_r := \left| \begin{array}{l} a \leftarrow 0.0071 + 0.0021 \cdot \dfrac{Z_n}{D} \\ a \leftarrow \min(0.015, a) \\ b \leftarrow 1.45 \cdot \sqrt{2.0 \cdot \dfrac{S_u(SPT_n)}{MPa}} \\ b \leftarrow 0.5 \ \text{ if } b \le 0.5 \\ b \leftarrow 1.5 \ \text{ if } 1.5 \le b \\ F_r \leftarrow \dfrac{760}{12.0 \cdot a \cdot \dfrac{D}{mm} + 760 \cdot b} \\ F_r \leftarrow \min(1.0, F_r) \end{array} \right.$$ $\qquad$ $F_r = 0.689$

$$q_p := \begin{cases} q_p \cdot F_r & \text{if } (D > 1900 \cdot mm) \cdot (SoilType_n = \text{"Clay"}) \cdot (S_u(SPT_n) > 0.096 \cdot MPa) \cdot (Settlement = \text{"N"}) \\ q_p & \text{otherwise} \end{cases}$$

Calculate Total factored Resistance

Assign resistance factor

$$\phi_p := \begin{cases} \phi_{pc} & \text{if } SoilType_n = \text{"Clay"} \\ \phi_{ps} & \text{if } SoilType_n = \text{"Sand"} \\ \phi_{pr} & \text{otherwise} \end{cases}$$

Total Factored Shaft Resistance

$$\phi sQ_s := \sum_j \left(\phi_{s_j} \cdot q_{s_j} \cdot L_{Pile_j} \cdot \pi \cdot D\right)$$

$\phi sQ_s = 4272\,kN$

Total Factored Tip Resistance

$$\phi pQ_p := \phi_p \cdot q_p \cdot \pi \cdot \frac{D^2}{4}$$

$\phi pQ_p = 3149\,kN$

Uplift resistance (assuming submerged pile)

$$Q_{su} := \phi sQ_s \cdot \frac{0.55}{0.65} + \pi \cdot \frac{D^2}{4} \cdot L \cdot 14.5 \cdot \frac{kN}{m^3}$$

$Q_{su} = 4279\,kN$

Check center-to-center spacing of piles

$$ctc := \begin{cases} 2.5 \cdot D & \text{if } ctc < 2.5 \cdot D \\ 6.0 \cdot D & \text{if } ctc > 6.0 \cdot D \\ ctc & \text{otherwise} \end{cases}$$

$ctc = 6\ m$

Determine if pile is predominantly driven in sand or clay

$$L_{sand} := \left| \begin{array}{l} L_s \leftarrow 0 \cdot m \\ \text{for } j \in 1 .. 10 \\ \quad \left| \begin{array}{ll} L_s \leftarrow L_s + L_{Pile_j} & \text{if } SoilType_j = \text{"Sand"} \\ L_s & \text{otherwise} \end{array} \right. \end{array} \right.$$

$L_{sand} = 1.50\ m$

$$L_{clay} := \left| \begin{array}{l} L_c \leftarrow 0 \cdot m \\ \text{for } j \in 1 .. 10 \\ \quad \left| \begin{array}{ll} L_c \leftarrow L_c + L_{Pile_j} & \text{if } SoilType_j = \text{"Clay"} \\ L_c & \text{otherwise} \end{array} \right. \end{array} \right.$$

$L_{clay} = 13.20\ m$

Assign overall soil type to pile

$$SoilTypeOverall := \begin{cases} \text{"Sand"} & \text{if } L_{sand} > L_{clay} \\ \text{"Clay"} & \text{otherwise} \end{cases}$$

$SoilTypeOverall = \text{"Clay"}$

Efficiency of pile group (10.7.3.10.2)

$$\eta := \begin{cases} 1.00 & \text{if } SoilType_n = \text{"Rock"} \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Sand"}) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Sand"})\cdot(SoilType_n = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \geq 5) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 1) \\ 1.00 & \text{if } (SoilTypeOverall = \text{"Clay"})\cdot(PileCapType = 2)\cdot(SPT_2 \geq 5) \\ 0.65 + (1 - 0.65)\cdot\dfrac{ctc - 2.5\cdot D}{3.5\cdot D} & \text{otherwise} \end{cases}$$

$$\eta = 1.00$$

SUMMARY
BORED Pile
Shaft and Tip Factored Resistance kN

Diameter of Pile $D = 1.8\ m$

Length of Pile $L = 18\ m$

Ref.	Thick ness	Length down Pile	Level	SPT N	Soil Type	q_s	φ_s	$\varphi_s Q_s$	q_p	φ_p	$\varphi_p Q_p$
	(m)	(m)	(m)			kN/m2		kN	kN/m2		kN
1.0	2.0	0.0	-2.0	6	Clay	16.5	0.65	0	0.0	0.00	0
2.0	2.0	0.0	-4.0	5	Sand	36.6	0.65	0	0.0	0.00	0
3.0	2.0	1.5	-6.0	4	Sand	47.8	0.65	263	0.0	0.00	0
4.0	2.0	2.0	-8.0	13	Clay	35.8	0.65	263	0.0	0.00	0
5.0	2.0	2.0	-10.0	18	Clay	49.5	0.65	364	0.0	0.00	0
6.0	2.0	2.0	-12.0	50	Clay	100.0	0.65	735	0.0	0.00	0
7.0	3.0	3.0	-15.0	50	Clay	100.0	0.65	1103	0.0	0.00	0
8.0	4.0	4.0	-19.0	50	Clay	100.0	0.65	1470	0.0	0.00	0
9.0	5.0	0.2	-21.0	50	Clay	100.0	0.65	74	2250.0	0.55	3149
10.0	6.0	0.0	0.0	50	Clay	100.0	0.65	0	0.0	0.00	0
Total Factored Shaft Resistance $\varphi_s Q_s$								4272	Factored Tip Resistance $\varphi_p Q_p$		3149

$\eta = 1.00$

TOTAL FACTORED RESISTANCE PER PILE

$$Q_R(\eta, \phi p Q_p, \phi s Q_s) = 7421\ kN$$

.

TOTAL FACTORED UPLIFT RESISTANCE PER PILE

$$Q_{su} = 4279\ kN$$

9.3. STRUCTURAL DESIGN OF PILE FOUNDATIONS

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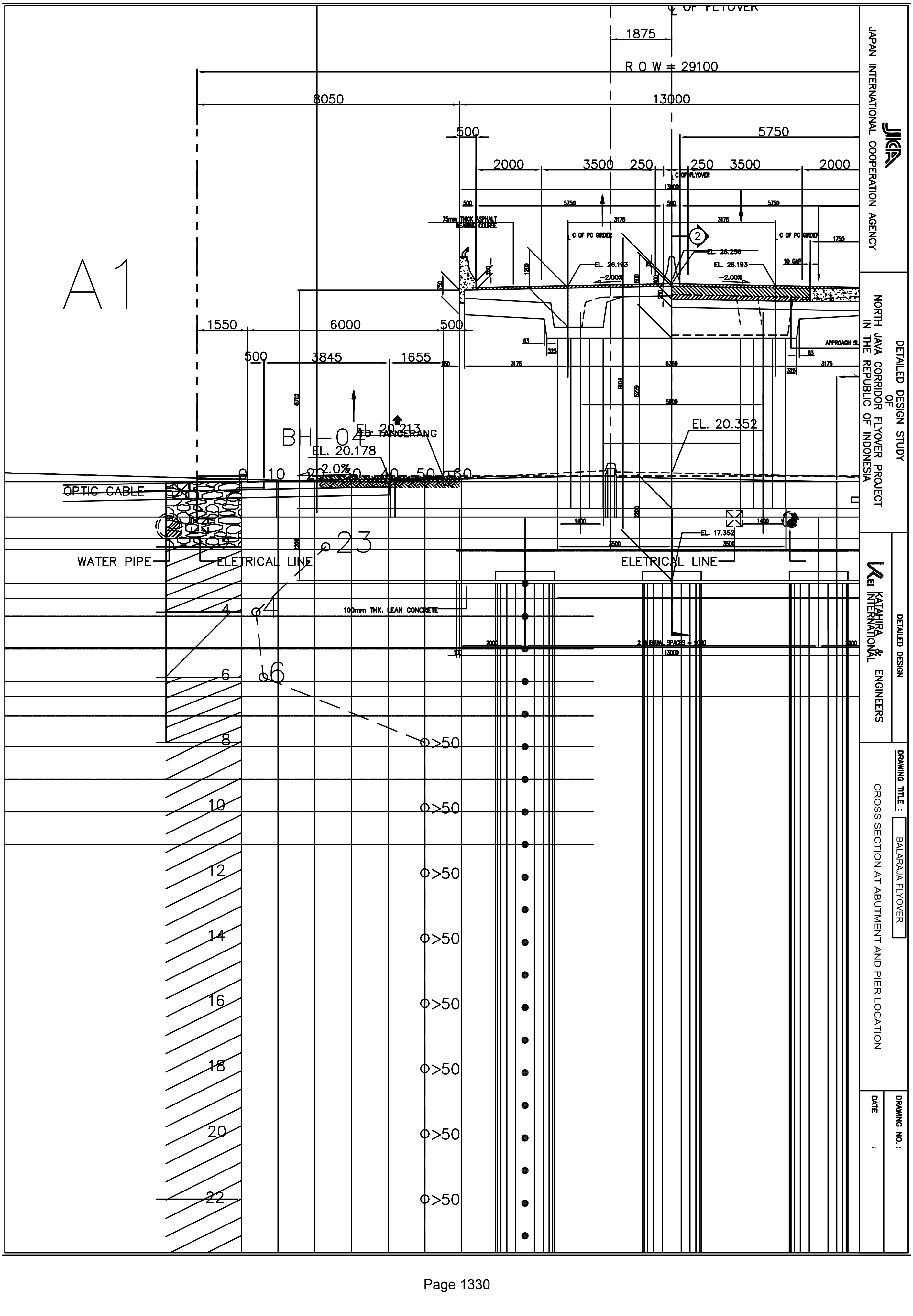

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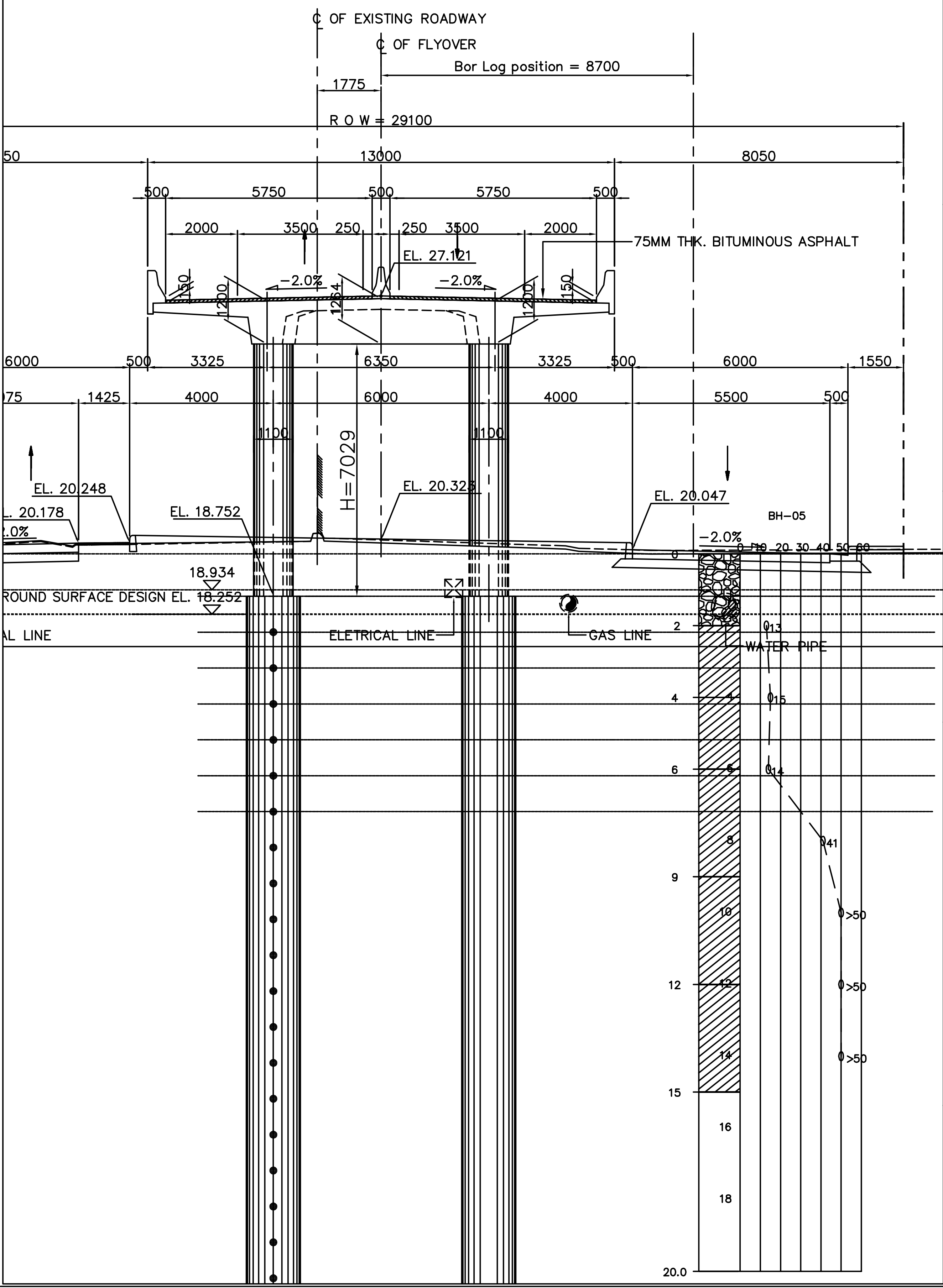

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DETAILED DESIGN STUDY
OF
NORTH JAVA CORRIDOR FLYOVER PROJECT
IN THE REPUBLIC OF INDONESIA

DETAILED DESIGN

KATAHIRA & ENGINEERS INTERNATIONAL

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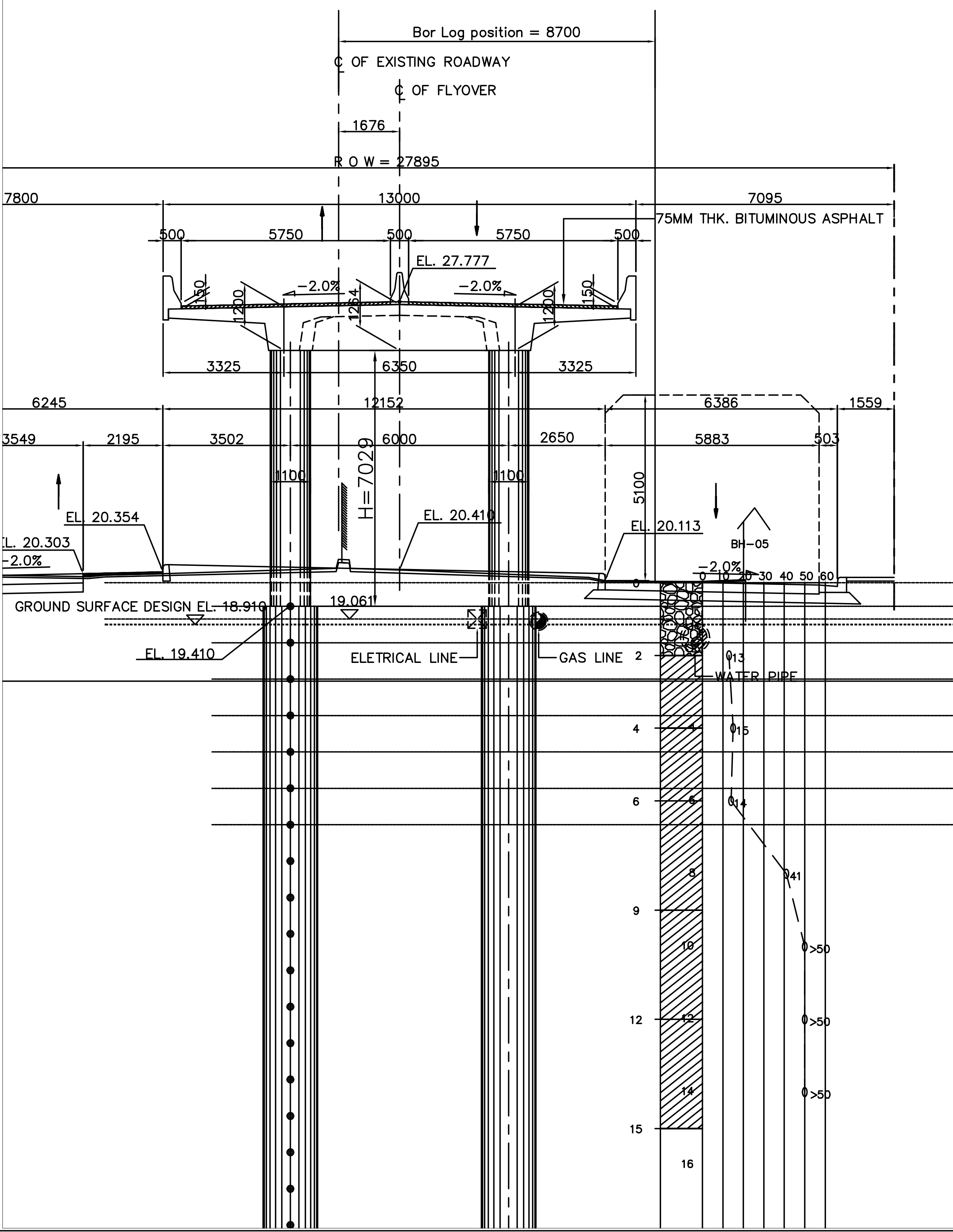
BALARAJA – P2



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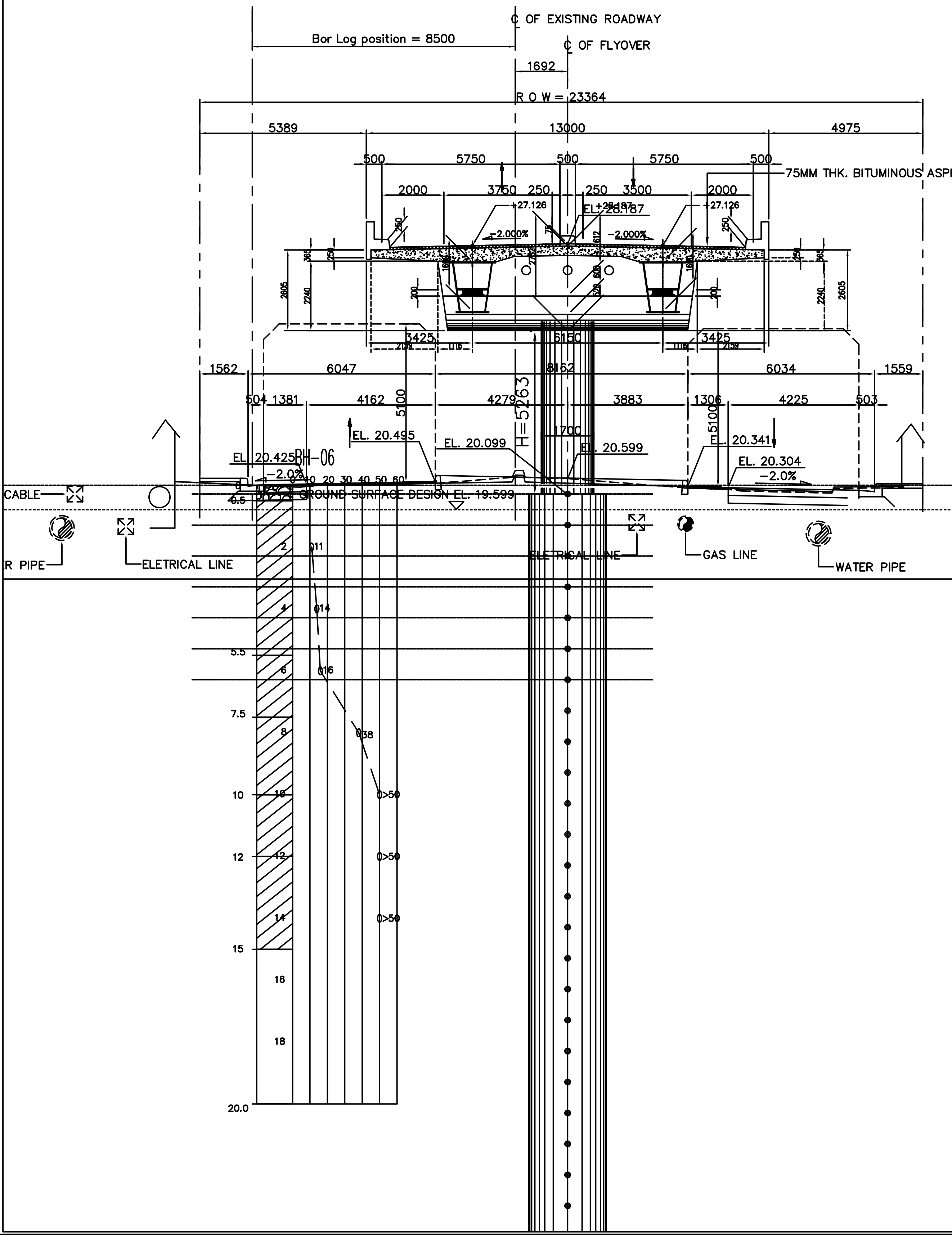
BALARAJA – P3



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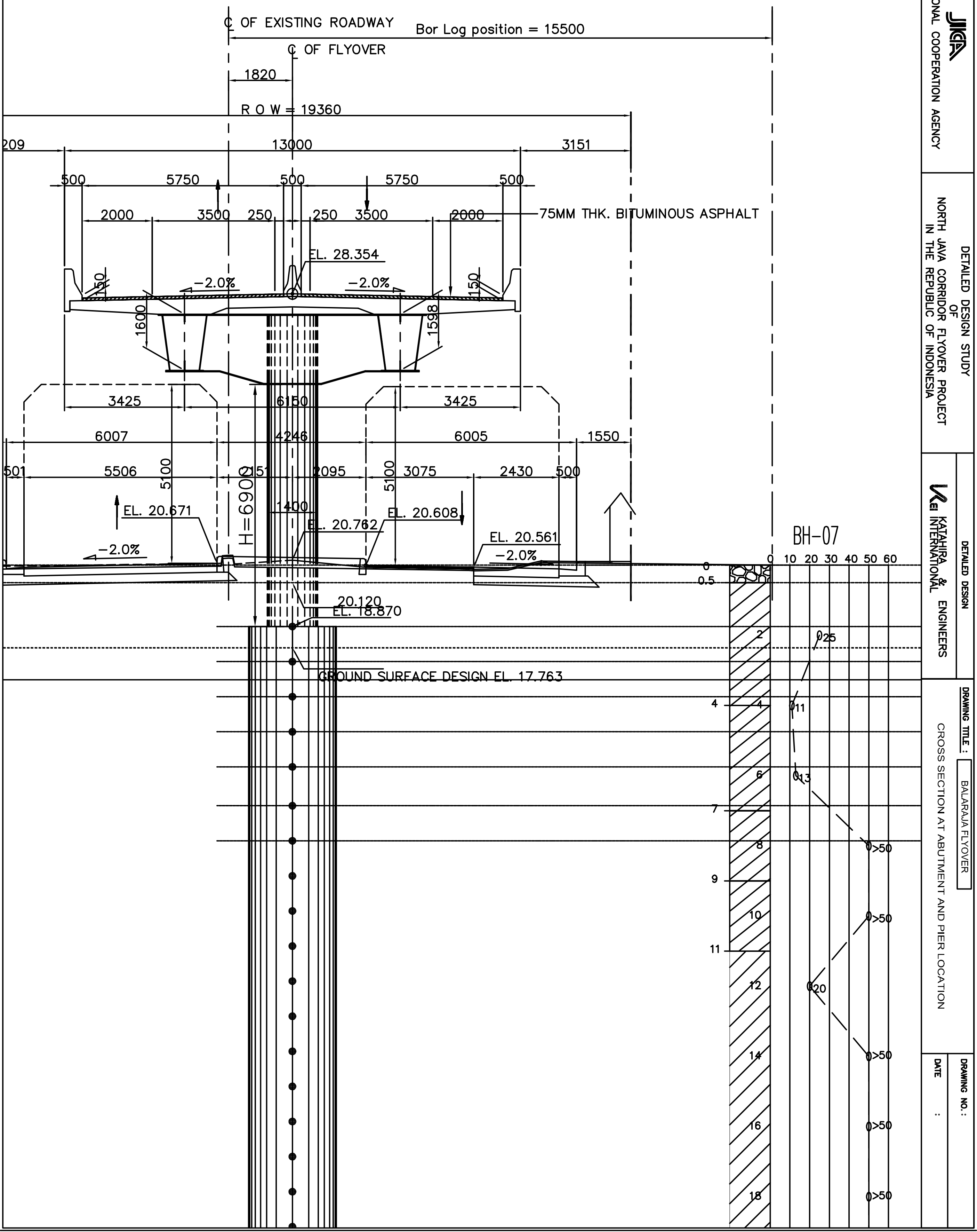
BALARAJA – P4



C OF EXISTING ROADWAY
Bor Log position = 15500
C OF FLYOVER
1820
R O W = 19360
209
13000
3151
500
5750
500
5750
500
2000
3500
250
250
3500
2000
75MM THK. BITUMINOUS ASPHALT
EL. 28.354
-2.0%
-2.0%
150
150
1600
1598
3425
6150
3425
6007
4246
6005
1550
501
5506
2151
2095
3075
2430
500
5100
5100
H=6900
1400
EL. 20.671
EL. 20.762
EL. 20.608
EL. 20.561
-2.0%
-2.0%
20.120
EL. 18.870
GROUND SURFACE DESIGN EL. 17.763
BH-07
0 10 20 30 40 50 60
0
0.5
2
4
6
7
8
9
10
11
12
14
16
18
25
11
13
>50
>50
20
>50
>50
>50
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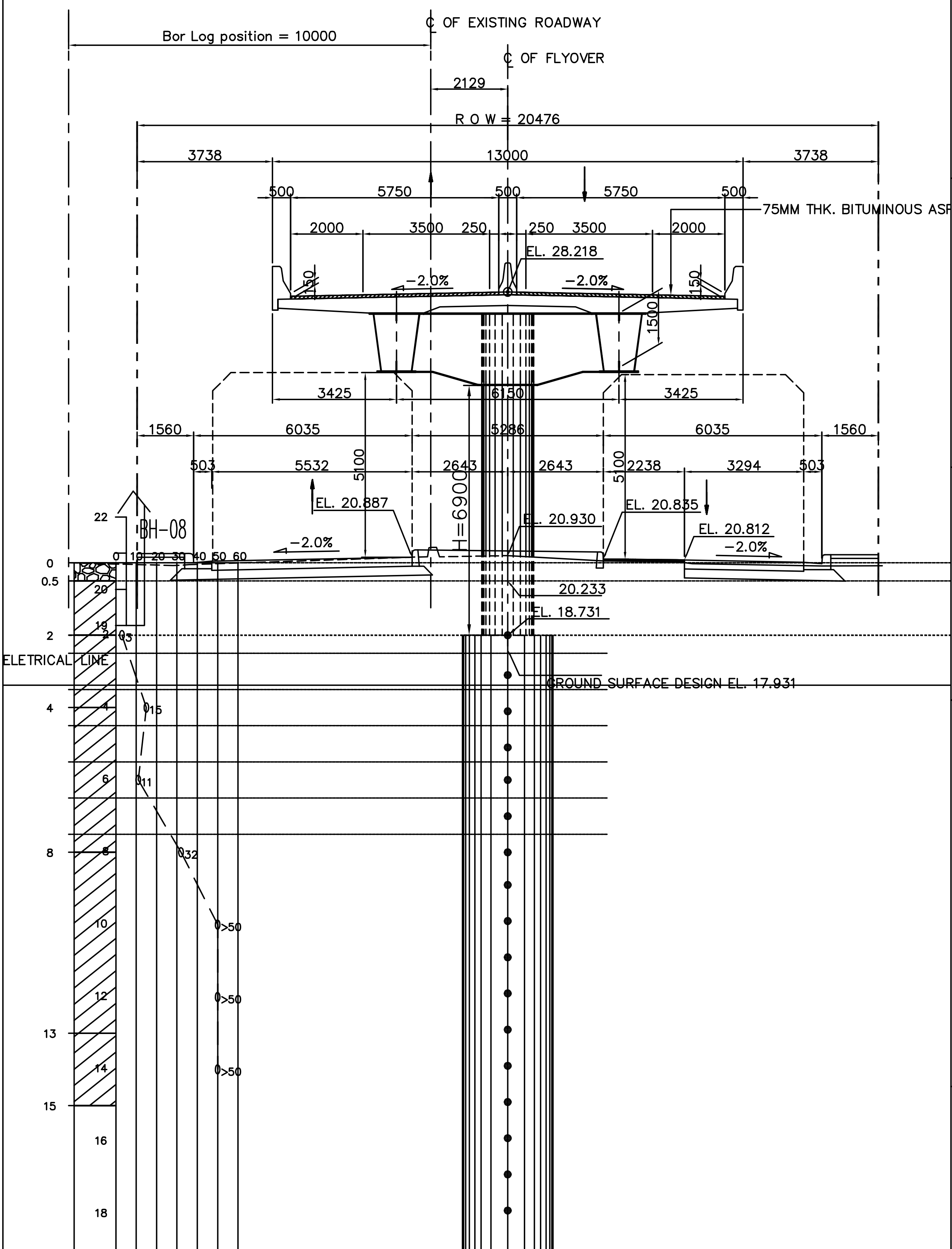
BALARAJA – P5



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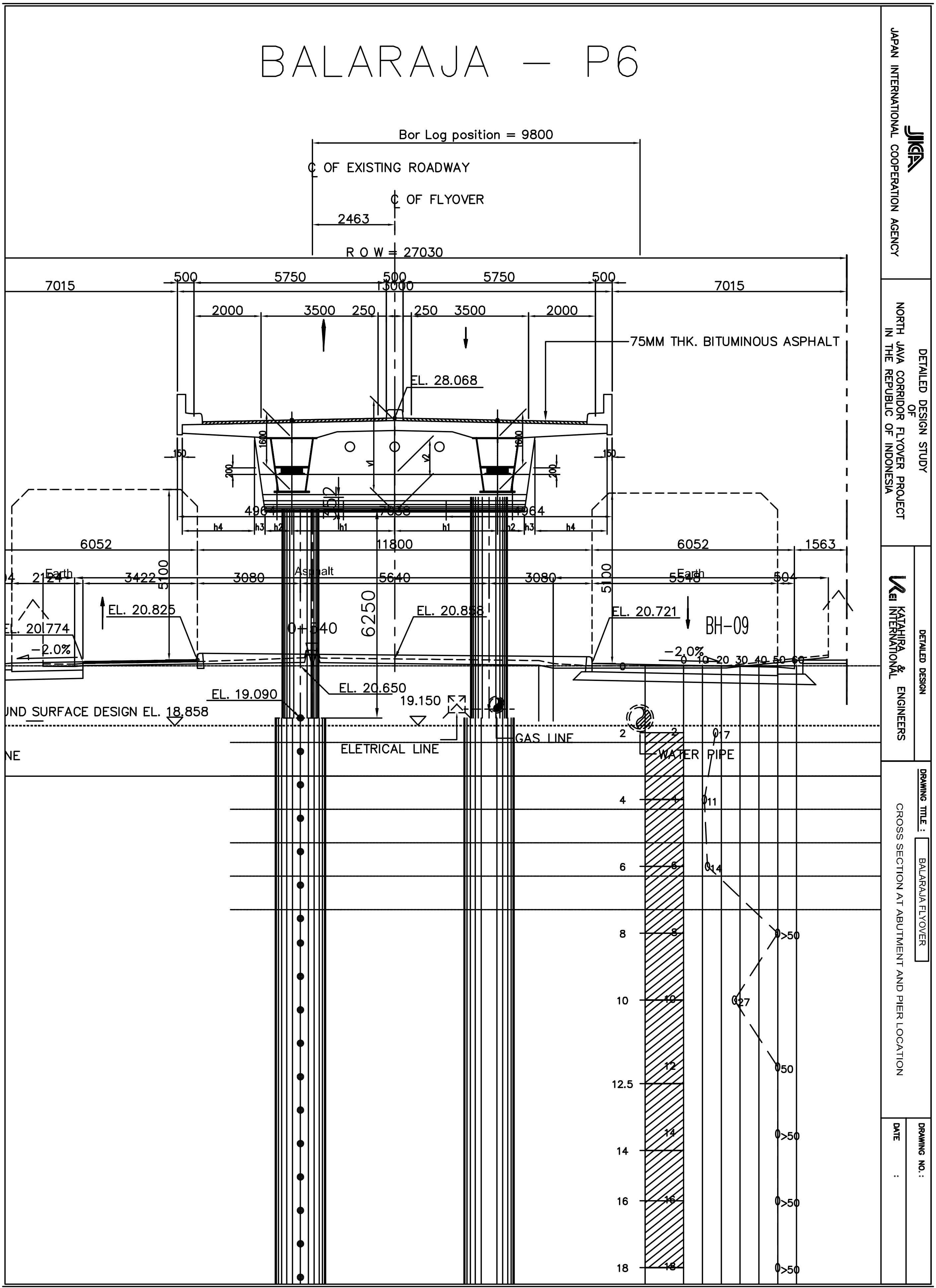

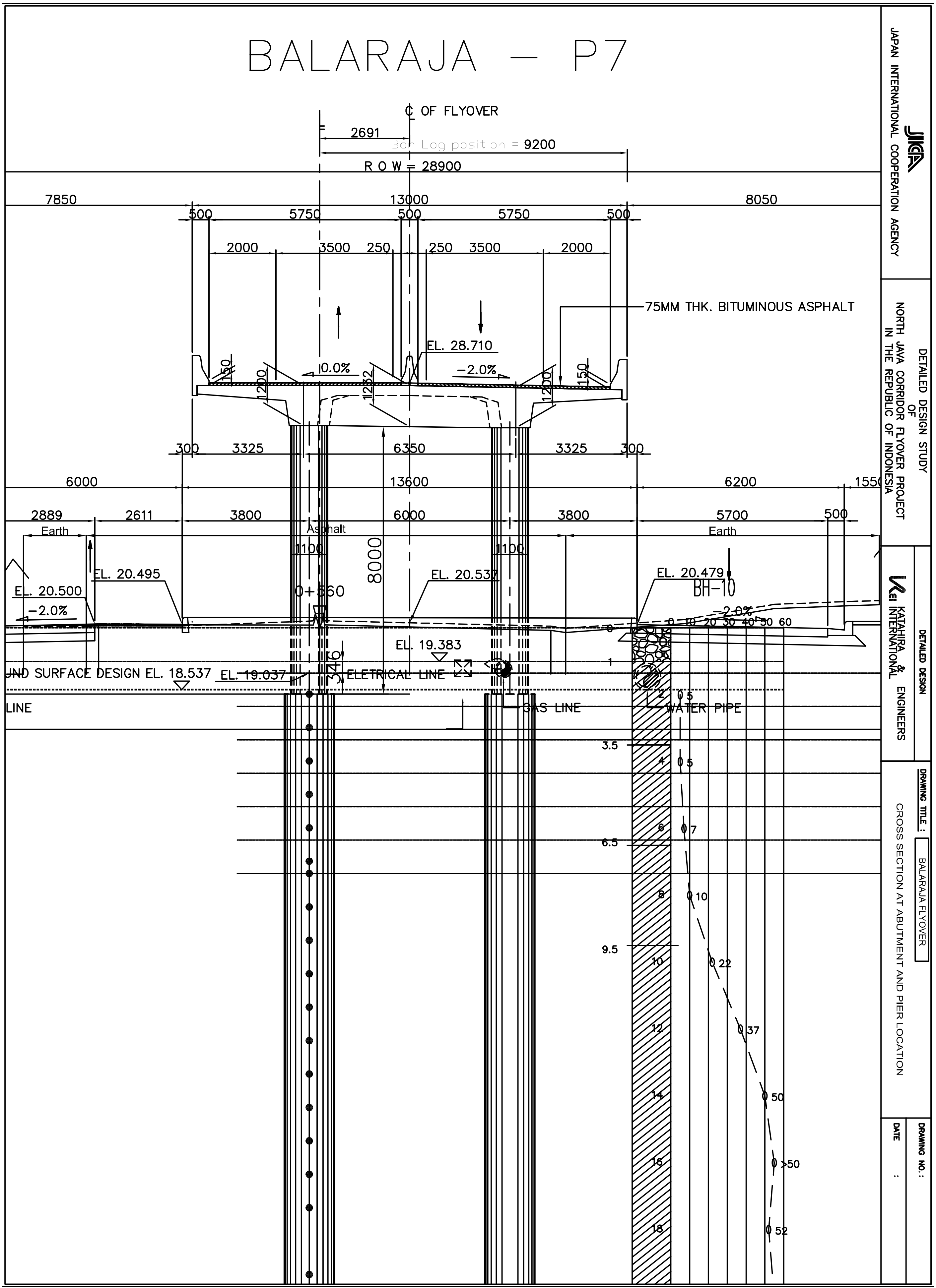

BALARAJA – P7
℄ OF FLYOVER
2691
Bor Log position = 9200
R O W = 28900
7850
13000
8050
500
5750
500
5750
500
2000
3500
250
250
3500
2000
75MM THK. BITUMINOUS ASPHALT
EL. 28.710
0.0%
-2.0%
150
1200
1232
1200
150
300
3325
6350
3325
300
6000
13600
6200
1550
2889
2611
3800
6000
3800
5700
500
Earth
Asphalt
Earth
1100
8000
1100
EL. 20.495
EL. 20.537
EL. 20.479
EL. 20.500
0+560
BH-10
-2.0%
-2.0%
0 10 20 30 40 50 60
EL. 19.383
GROUND SURFACE DESIGN EL. 18.537
EL. 19.037
3416
ELETRICAL LINE
GAS LINE
WATER PIPE
LINE
3.5
6.5
9.5
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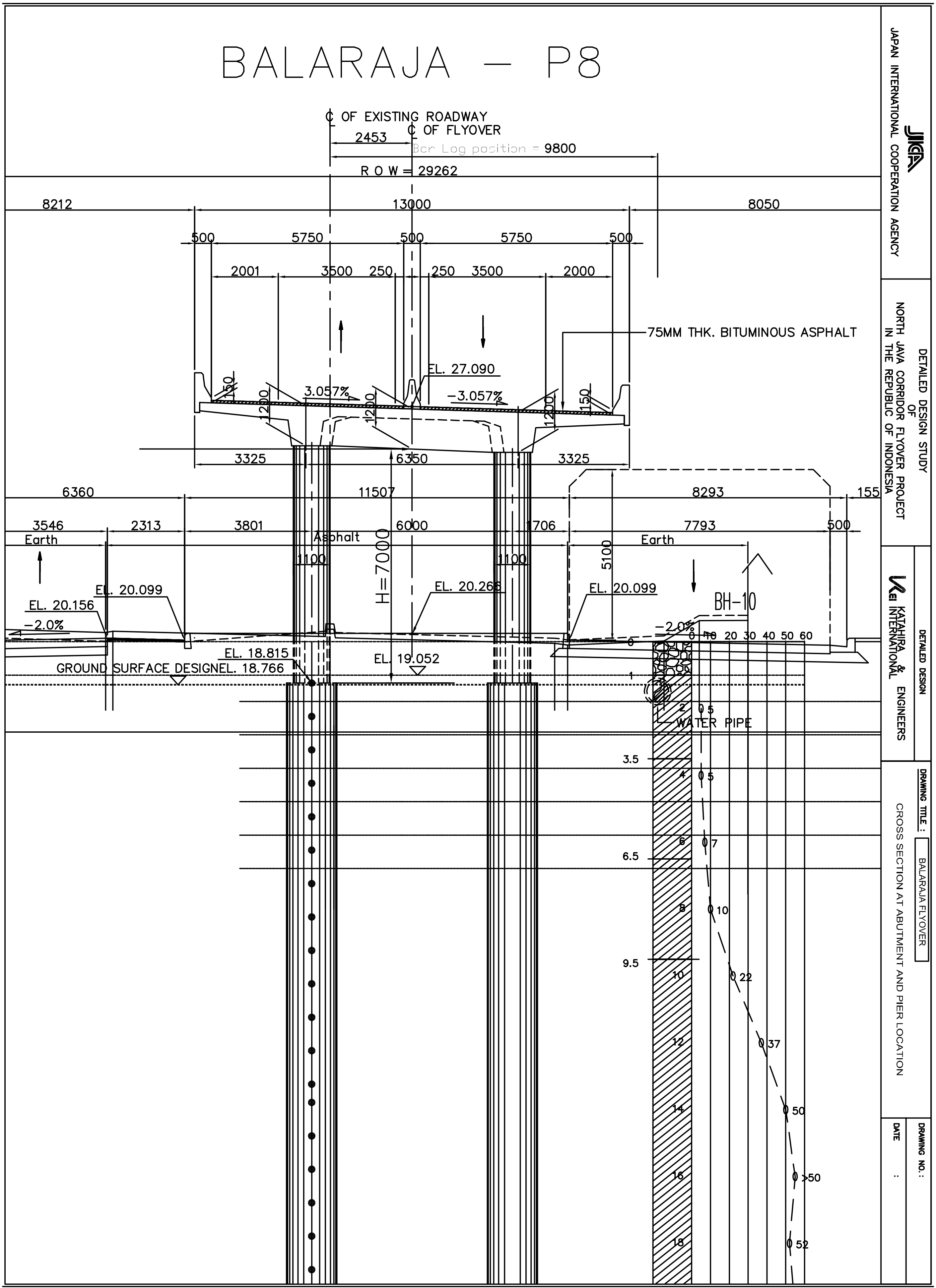

BALARAJA – P8
℄ OF EXISTING ROADWAY
℄ OF FLYOVER
2453
Bor Log position = 9800
R O W = 29262
8212
13000
8050
500
5750
500
5750
500
2001
3500
250
250
3500
2000
75MM THK. BITUMINOUS ASPHALT
EL. 27.090
3.057%
-3.057%
150
1200
1200
1200
150
3325
6350
3325
6360
11507
8293
155
3546
2313
3801
6000
1706
7793
500
Earth
Asphalt
Earth
1100
1100
H=7000
5100
EL. 20.099
EL. 20.156
-2.0%
EL. 20.266
EL. 20.099
BH-10
-2.0%
0 10 20 30 40 50 60
EL. 18.815
EL. 19.052
GROUND SURFACE DESIGNEL. 18.766
WATER PIPE
3.5
6.5
9.5
5
5
7
10
22
37
50
>50
52
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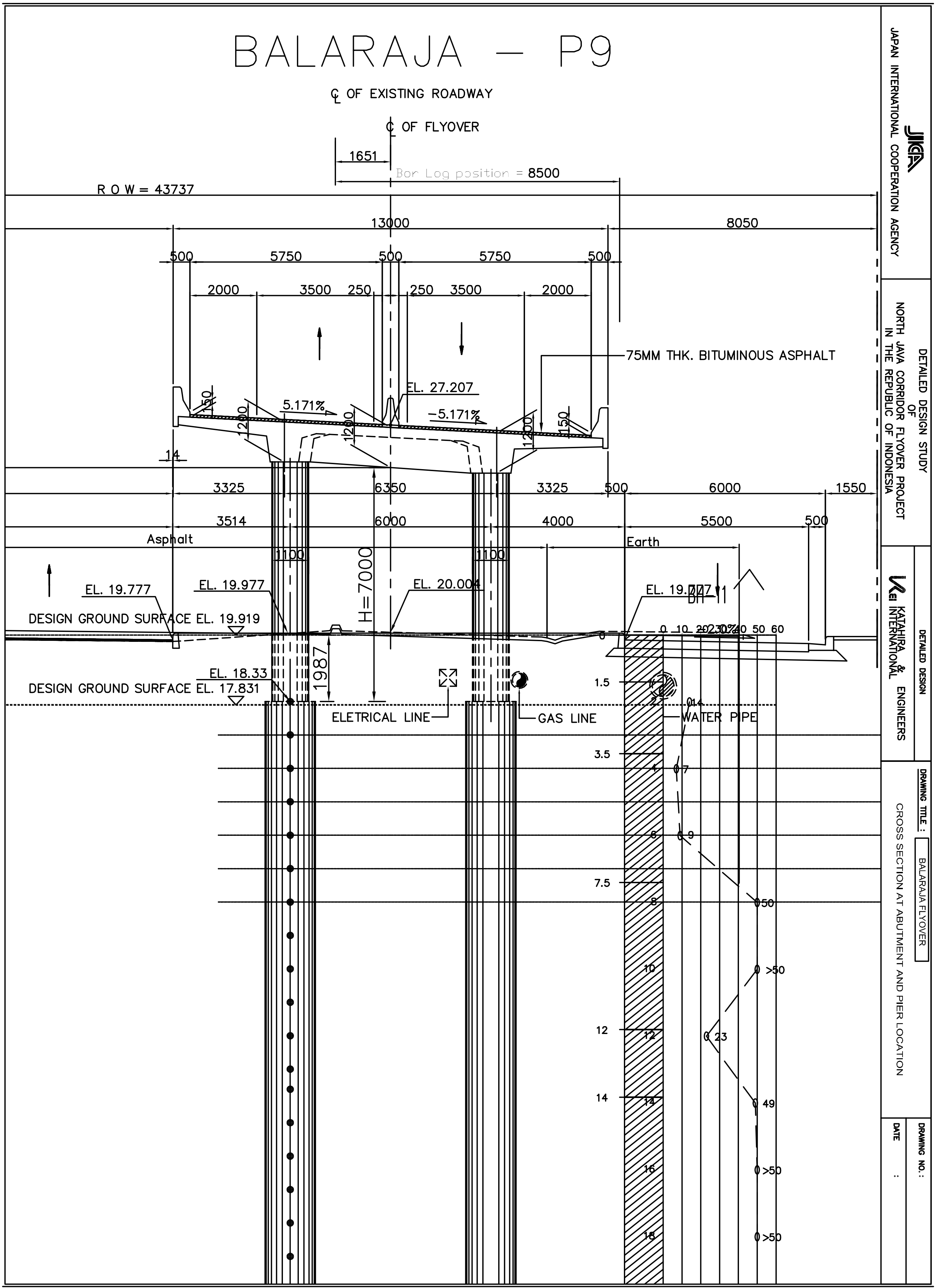

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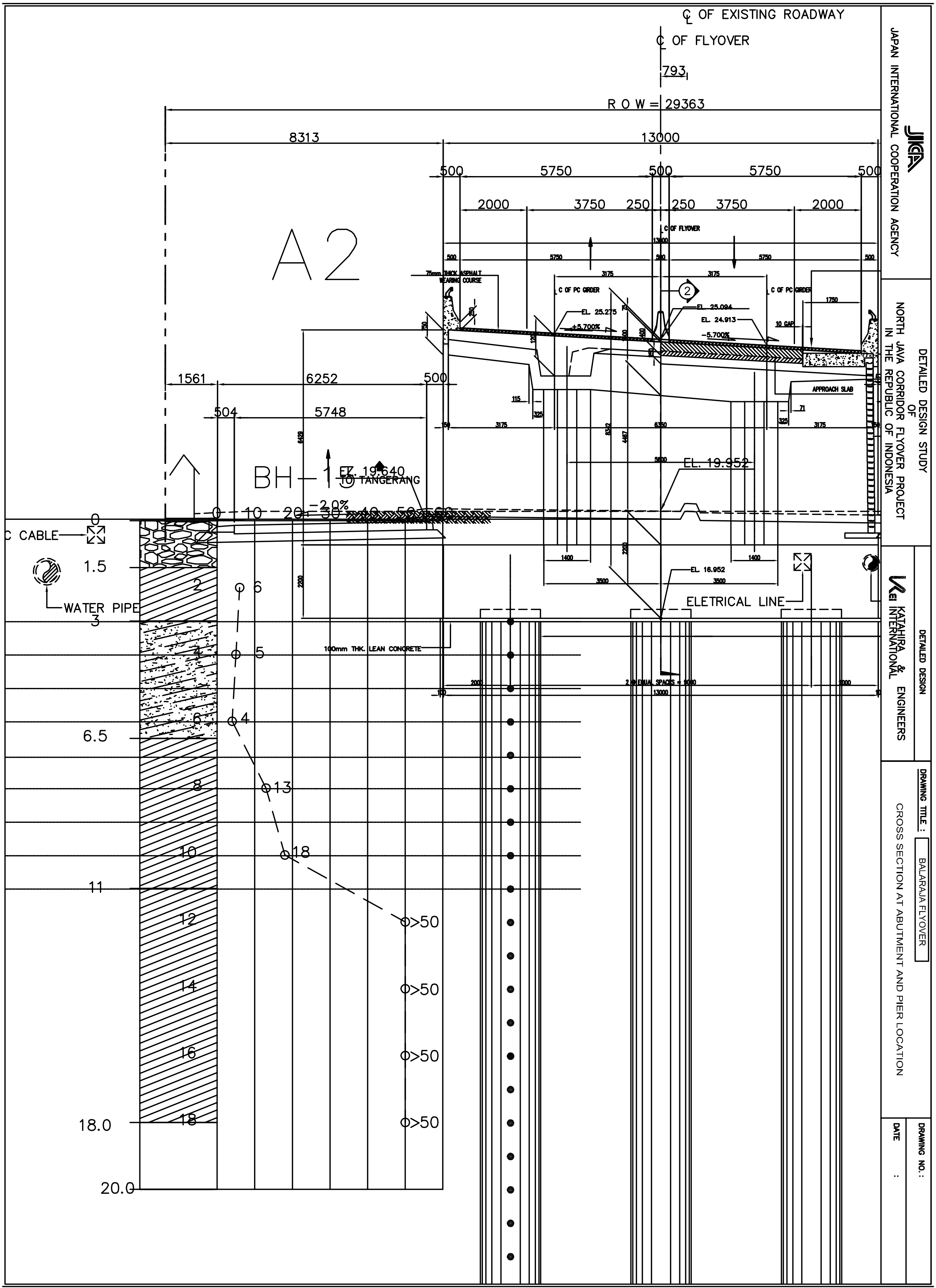

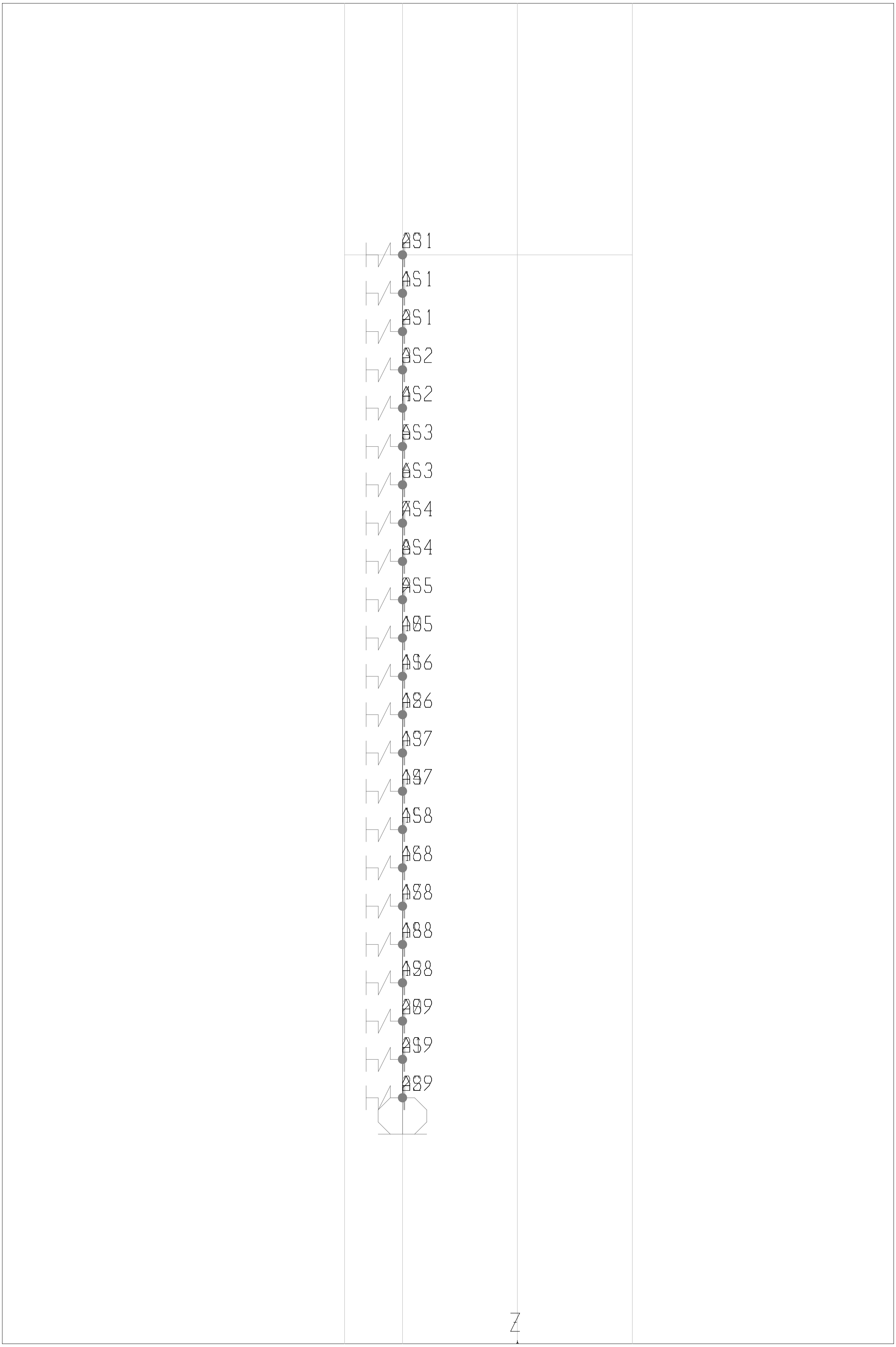

TABLE: Link Property Definitions 03 - MultiLinear A1					
Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
AS1	U2	Yes	1	-251	-0.1
AS1	U2		2	-250	-0.018
AS1	U2		3	0	0
AS1	U2		4	250	0.018
AS1	U2		5	251	0.1
AS1	U3	Yes	1	-251	-0.1
AS1	U3		2	-250	-0.018
AS1	U3		3	0	0
AS1	U3		4	250	0.018
AS1	U3		5	251	0.1
AS10	U2	Yes	1	-1801	-0.1
AS10	U2		2	-1800	-0.012
AS10	U2		3	0	0
AS10	U2		4	1800	0.012
AS10	U2		5	1801	0.1
AS10	U3	Yes	1	-1801	-0.1
AS10	U3		2	-1800	-0.012
AS10	U3		3	0	0
AS10	U3		4	1800	0.012
AS10	U3		5	1801	0.1
AS11	U2	Yes	1	-126	-0.1
AS11	U2		2	-125	-0.018
AS11	U2		3	0	0
AS11	U2		4	125	0.018
AS11	U2		5	126	0.1
AS11	U3	Yes	1	-126	-0.1
AS11	U3		2	-125	-0.018
AS11	U3		3	0	0
AS11	U3		4	125	0.018
AS11	U3		5	126	0.1
AS2	U2	Yes	1	-351	-0.1
AS2	U2		2	-350	-0.018
AS2	U2		3	0	0
AS2	U2		4	350	0.018
AS2	U2		5	351	0.1
AS2	U3	Yes	1	-351	-0.1
AS2	U3		2	-350	-0.018
AS2	U3		3	0	0
AS2	U3		4	350	0.018
AS2	U3		5	351	0.1
AS3	U2	Yes	1	-426	-0.1
AS3	U2		2	-425	-0.018
AS3	U2		3	0	0
AS3	U2		4	425	0.018
AS3	U2		5	426	0.1
AS3	U3	Yes	1	-426	-0.1
AS3	U3		2	-425	-0.018
AS3	U3		3	0	0
AS3	U3		4	425	0.018
AS3	U3		5	426	0.1
AS4	U2	Yes	1	-751	-0.1
AS4	U2		2	-750	-0.012
AS4	U2		3	0	0
AS4	U2		4	750	0.012
AS4	U2		5	751	0.1
AS4	U3	Yes	1	-751	-0.1
AS4	U3		2	-750	-0.012

Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
AS1	U2	Yes	1	-251	-0.1
AS4	U3		3	0	0
AS4	U3		4	750	0.012
AS4	U3		5	751	0.1
AS5	U2	Yes	1	-926	-0.1
AS5	U2		2	-925	-0.012
AS5	U2		3	0	0
AS5	U2		4	925	0.012
AS5	U2		5	926	0.1
AS5	U3	Yes	1	-926	-0.1
AS5	U3		2	-925	-0.012
AS5	U3		3	0	0
AS5	U3		4	925	0.012
AS5	U3		5	926	0.1
AS6	U2	Yes	1	-1451	-0.1
AS6	U2		2	-1450	-0.012
AS6	U2		3	0	0
AS6	U2		4	1450	0.012
AS6	U2		5	1451	0.1
AS6	U3	Yes	1	-1451	-0.1
AS6	U3		2	-1450	-0.012
AS6	U3		3	0	0
AS6	U3		4	1450	0.012
AS6	U3		5	1451	0.1
AS7	U2	Yes	1	-1501	-0.1
AS7	U2		2	-1500	-0.012
AS7	U2		3	0	0
AS7	U2		4	1500	0.012
AS7	U2		5	1501	0.1
AS7	U3	Yes	1	-1501	-0.1
AS7	U3		2	-1500	-0.012
AS7	U3		3	0	0
AS7	U3		4	1500	0.012
AS7	U3		5	1501	0.1
AS8	U2	Yes	1	-1601	-0.1
AS8	U2		2	-1600	-0.012
AS8	U2		3	0	0
AS8	U2		4	1600	0.012
AS8	U2		5	1601	0.1
AS8	U3	Yes	1	-1601	-0.1
AS8	U3		2	-1600	-0.012
AS8	U3		3	0	0
AS8	U3		4	1600	0.012
AS8	U3		5	1601	0.1
AS9	U2	Yes	1	-1701	-0.1
AS9	U2		2	-1700	-0.012
AS9	U2		3	0	0
AS9	U2		4	1700	0.012
AS9	U2		5	1701	0.1
AS9	U3	Yes	1	-1701	-0.1
AS9	U3		2	-1700	-0.012
AS9	U3		3	0	0
AS9	U3		4	1700	0.012
AS9	U3		5	1701	0.1

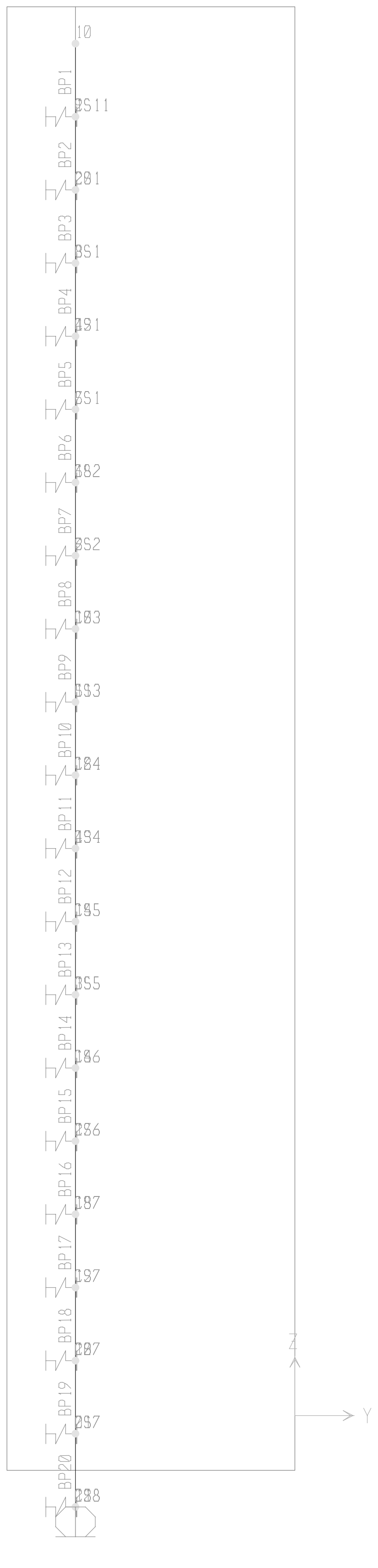

TABLE: Link Property Definitions 03 - MultiLinear P1					
Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
CS1	U2	Yes	1	-221	-0.1
CS1	U2		2	-220	-0.015
CS1	U2		3	0	0
CS1	U2		4	220	0.015
CS1	U2		5	221	0.1
CS1	U3	Yes	1	-221	-0.1
CS1	U3		2	-220	-0.015
CS1	U3		3	0	0
CS1	U3		4	220	0.015
CS1	U3		5	221	0.1
CS10	U2	Yes	1	-3001	-0.1
CS10	U2		2	-3000	-0.01
CS10	U2		3	0	0
CS10	U2		4	3000	0.01
CS10	U2		5	3001	0.1
CS10	U3	Yes	1	-3001	-0.1
CS10	U3		2	-3000	-0.01
CS10	U3		3	0	0
CS10	U3		4	3000	0.01
CS10	U3		5	3001	0.1
CS11	U2	Yes	1	-111	-0.1
CS11	U2		2	-110	-0.015
CS11	U2		3	0	0
CS11	U2		4	110	0.015
CS11	U2		5	111	0.1
CS11	U3	Yes	1	-111	-0.1
CS11	U3		2	-110	-0.015
CS11	U3		3	0	0
CS11	U3		4	110	0.015
CS11	U3		5	111	0.1
CS2	U2	Yes	1	-301	-0.1
CS2	U2		2	-300	-0.015
CS2	U2		3	0	0
CS2	U2		4	300	0.015
CS2	U2		5	301	0.1
CS2	U3	Yes	1	-301	-0.1
CS2	U3		2	-300	-0.015
CS2	U3		3	0	0
CS2	U3		4	300	0.015
CS2	U3		5	301	0.1
CS3	U2	Yes	1	-351	-0.1
CS3	U2		2	-350	-0.015
CS3	U2		3	0	0
CS3	U2		4	350	0.015
CS3	U2		5	351	0.1
CS3	U3	Yes	1	-351	-0.1
CS3	U3		2	-350	-0.015
CS3	U3		3	0	0
CS3	U3		4	350	0.015
CS3	U3		5	351	0.1
CS4	U2	Yes	1	-526	-0.1
CS4	U2		2	-525	-0.015
CS4	U2		3	0	0
CS4	U2		4	525	0.015
CS4	U2		5	526	0.1
CS4	U3	Yes	1	-526	-0.1
CS4	U3		2	-525	-0.015

Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
CS1	U2	Yes	1	-221	-0.1
CS4	U3		3	0	0
CS4	U3		4	525	0.015
CS4	U3		5	526	0.1
CS5	U2	Yes	1	-876	-0.1
CS5	U2		2	-875	-0.01
CS5	U2		3	0	0
CS5	U2		4	875	0.01
CS5	U2		5	876	0.1
CS5	U3	Yes	1	-876	-0.1
CS5	U3		2	-875	-0.01
CS5	U3		3	0	0
CS5	U3		4	875	0.01
CS5	U3		5	876	0.1
CS6	U2	Yes	1	-1001	-0.1
CS6	U2		2	-1000	-0.01
CS6	U2		3	0	0
CS6	U2		4	1000	0.01
CS6	U2		5	1001	0.1
CS6	U3	Yes	1	-1001	-0.1
CS6	U3		2	-1000	-0.01
CS6	U3		3	0	0
CS6	U3		4	1000	0.01
CS6	U3		5	1001	0.1
CS7	U2	Yes	1	-1276	-0.1
CS7	U2		2	-1275	-0.01
CS7	U2		3	0	0
CS7	U2		4	1275	0.01
CS7	U2		5	1276	0.1
CS7	U3	Yes	1	-1276	-0.1
CS7	U3		2	-1275	-0.01
CS7	U3		3	0	0
CS7	U3		4	1275	0.01
CS7	U3		5	1276	0.1
CS8	U2	Yes	1	-1351	-0.1
CS8	U2		2	-1350	-0.01
CS8	U2		3	0	0
CS8	U2		4	1350	0.01
CS8	U2		5	1351	0.1
CS8	U3	Yes	1	-1351	-0.1
CS8	U3		2	-1350	-0.01
CS8	U3		3	0	0
CS8	U3		4	1350	0.01
CS8	U3		5	1351	0.1
CS9	U2	Yes	1	-1451	-0.1
CS9	U2		2	-1450	-0.01
CS9	U2		3	0	0
CS9	U2		4	1450	0.01
CS9	U2		5	1451	0.1
CS9	U3	Yes	1	-1451	-0.1
CS9	U3		2	-1450	-0.01
CS9	U3		3	0	0
CS9	U3		4	1450	0.01
CS9	U3		5	1451	0.1

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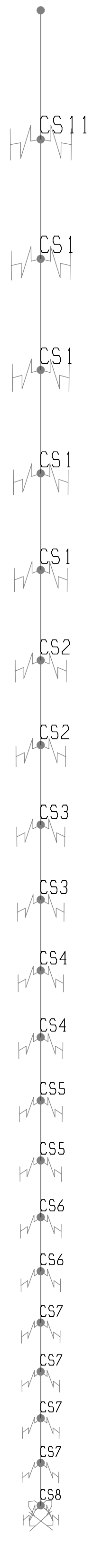

SAP2000 v10.0.1 - File:P2-BP1500MM - 3-D View - KN, m, C Units

TABLE: Link Property Definitions 03 - MultiLinear P2					
Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
CS1	U2	Yes	1	-221	-0.1
CS1	U2		2	-220	-0.015
CS1	U2		3	0	0
CS1	U2		4	220	0.015
CS1	U2		5	221	0.1
CS1	U3	Yes	1	-221	-0.1
CS1	U3		2	-220	-0.015
CS1	U3		3	0	0
CS1	U3		4	220	0.015
CS1	U3		5	221	0.1
CS10	U2	Yes	1	-3001	-0.1
CS10	U2		2	-3000	-0.01
CS10	U2		3	0	0
CS10	U2		4	3000	0.01
CS10	U2		5	3001	0.1
CS10	U3	Yes	1	-3001	-0.1
CS10	U3		2	-3000	-0.01
CS10	U3		3	0	0
CS10	U3		4	3000	0.01
CS10	U3		5	3001	0.1
CS11	U2	Yes	1	-111	-0.1
CS11	U2		2	-110	-0.015
CS11	U2		3	0	0
CS11	U2		4	110	0.015
CS11	U2		5	111	0.1
CS11	U3	Yes	1	-111	-0.1
CS11	U3		2	-110	-0.015
CS11	U3		3	0	0
CS11	U3		4	110	0.015
CS11	U3		5	111	0.1
CS2	U2	Yes	1	-301	-0.1
CS2	U2		2	-300	-0.015
CS2	U2		3	0	0
CS2	U2		4	300	0.015
CS2	U2		5	301	0.1
CS2	U3	Yes	1	-301	-0.1
CS2	U3		2	-300	-0.015
CS2	U3		3	0	0
CS2	U3		4	300	0.015
CS2	U3		5	301	0.1
CS3	U2	Yes	1	-351	-0.1
CS3	U2		2	-350	-0.015
CS3	U2		3	0	0
CS3	U2		4	350	0.015
CS3	U2		5	351	0.1
CS3	U3	Yes	1	-351	-0.1
CS3	U3		2	-350	-0.015
CS3	U3		3	0	0
CS3	U3		4	350	0.015
CS3	U3		5	351	0.1
CS4	U2	Yes	1	-526	-0.1
CS4	U2		2	-525	-0.015
CS4	U2		3	0	0
CS4	U2		4	525	0.015
CS4	U2		5	526	0.1
CS4	U3	Yes	1	-526	-0.1
CS4	U3		2	-525	-0.015

Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
CS1	U2	Yes	1	-221	-0.1
CS4	U3		3	0	0
CS4	U3		4	525	0.015
CS4	U3		5	526	0.1
CS5	U2	Yes	1	-876	-0.1
CS5	U2		2	-875	-0.01
CS5	U2		3	0	0
CS5	U2		4	875	0.01
CS5	U2		5	876	0.1
CS5	U3	Yes	1	-876	-0.1
CS5	U3		2	-875	-0.01
CS5	U3		3	0	0
CS5	U3		4	875	0.01
CS5	U3		5	876	0.1
CS6	U2	Yes	1	-1001	-0.1
CS6	U2		2	-1000	-0.01
CS6	U2		3	0	0
CS6	U2		4	1000	0.01
CS6	U2		5	1001	0.1
CS6	U3	Yes	1	-1001	-0.1
CS6	U3		2	-1000	-0.01
CS6	U3		3	0	0
CS6	U3		4	1000	0.01
CS6	U3		5	1001	0.1
CS7	U2	Yes	1	-1276	-0.1
CS7	U2		2	-1275	-0.01
CS7	U2		3	0	0
CS7	U2		4	1275	0.01
CS7	U2		5	1276	0.1
CS7	U3	Yes	1	-1276	-0.1
CS7	U3		2	-1275	-0.01
CS7	U3		3	0	0
CS7	U3		4	1275	0.01
CS7	U3		5	1276	0.1
CS8	U2	Yes	1	-1351	-0.1
CS8	U2		2	-1350	-0.01
CS8	U2		3	0	0
CS8	U2		4	1350	0.01
CS8	U2		5	1351	0.1
CS8	U3	Yes	1	-1351	-0.1
CS8	U3		2	-1350	-0.01
CS8	U3		3	0	0
CS8	U3		4	1350	0.01
CS8	U3		5	1351	0.1
CS9	U2	Yes	1	-1451	-0.1
CS9	U2		2	-1450	-0.01
CS9	U2		3	0	0
CS9	U2		4	1450	0.01
CS9	U2		5	1451	0.1
CS9	U3	Yes	1	-1451	-0.1
CS9	U3		2	-1450	-0.01
CS9	U3		3	0	0
CS9	U3		4	1450	0.01
CS9	U3		5	1451	0.1

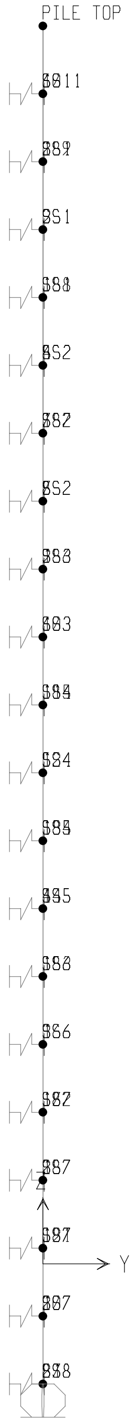
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TABLE: Link Property Definitions 03 - MultiLinear P3					
Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
SS1	U2	Yes	1	-351	-0.1
SS1	U2		2	-350	-0.018
SS1	U2		3	0	0
SS1	U2		4	350	0.018
SS1	U2		5	351	0.1
SS1	U3	Yes	1	-351	-0.1
SS1	U3		2	-350	-0.018
SS1	U3		3	0	0
SS1	U3		4	350	0.018
SS1	U3		5	351	0.1
SS10	U2	Yes	1	-2501	-0.1
SS10	U2		2	-2500	-0.015
SS10	U2		3	0	0
SS10	U2		4	2500	0.015
SS10	U2		5	2501	0.1
SS10	U3	Yes	1	-2501	-0.1
SS10	U3		2	-2500	-0.015
SS10	U3		3	0	0
SS10	U3		4	2500	0.015
SS10	U3		5	2501	0.1
SS11	U2	Yes	1	-176	-0.1
SS11	U2		2	-175	-0.018
SS11	U2		3	0	0
SS11	U2		4	175	0.018
SS11	U2		5	176	0.1
SS11	U3	Yes	1	-176	-0.1
SS11	U3		2	-175	-0.018
SS11	U3		3	0	0
SS11	U3		4	175	0.018
SS11	U3		5	176	0.1
SS2	U2	Yes	1	-676	-0.1
SS2	U2		2	-675	-0.018
SS2	U2		3	0	0
SS2	U2		4	675	0.018
SS2	U2		5	676	0.1
SS2	U3	Yes	1	-676	-0.1
SS2	U3		2	-675	-0.018
SS2	U3		3	0	0
SS2	U3		4	675	0.018
SS2	U3		5	676	0.1
SS3	U2	Yes	1	-751	-0.1
SS3	U2		2	-750	-0.018
SS3	U2		3	0	0
SS3	U2		4	750	0.018
SS3	U2		5	751	0.1
SS3	U3	Yes	1	-751	-0.1
SS3	U3		2	-750	-0.018
SS3	U3		3	0	0
SS3	U3		4	750	0.018
SS3	U3		5	751	0.1
SS4	U2	Yes	1	-1551	-0.1
SS4	U2		2	-1550	-0.015
SS4	U2		3	0	0
SS4	U2		4	1550	0.015
SS4	U2		5	1551	0.1
SS4	U3	Yes	1	-1551	-0.1
SS4	U3		2	-1550	-0.015

Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
SS1	U2	Yes	1	-351	-0.1
SS4	U3		3	0	0
SS4	U3		4	1550	0.015
SS4	U3		5	1551	0.1
SS5	U2	Yes	1	-1601	-0.1
SS5	U2		2	-1600	-0.015
SS5	U2		3	0	0
SS5	U2		4	1600	0.015
SS5	U2		5	1601	0.1
SS5	U3	Yes	1	-1601	-0.1
SS5	U3		2	-1600	-0.015
SS5	U3		3	0	0
SS5	U3		4	1600	0.015
SS5	U3		5	1601	0.1
SS6	U2	Yes	1	-1351	-0.1
SS6	U2		2	-1350	-0.015
SS6	U2		3	0	0
SS6	U2		4	1350	0.015
SS6	U2		5	1351	0.1
SS6	U3	Yes	1	-1351	-0.1
SS6	U3		2	-1350	-0.015
SS6	U3		3	0	0
SS6	U3		4	1350	0.015
SS6	U3		5	1351	0.1
SS7	U2	Yes	1	-2076	-0.1
SS7	U2		2	-2075	-0.015
SS7	U2		3	0	0
SS7	U2		4	2075	0.015
SS7	U2		5	2076	0.1
SS7	U3	Yes	1	-2076	-0.1
SS7	U3		2	-2075	-0.015
SS7	U3		3	0	0
SS7	U3		4	2075	0.015
SS7	U3		5	2076	0.1
SS8	U2	Yes	1	-2201	-0.1
SS8	U2		2	-2200	-0.015
SS8	U2		3	0	0
SS8	U2		4	2200	0.015
SS8	U2		5	2201	0.1
SS8	U3	Yes	1	-2201	-0.1
SS8	U3		2	-2200	-0.015
SS8	U3		3	0	0
SS8	U3		4	2200	0.015
SS8	U3		5	2201	0.1
SS9	U2	Yes	1	-2351	-0.1
SS9	U2		2	-2350	-0.015
SS9	U2		3	0	0
SS9	U2		4	2350	0.015
SS9	U2		5	2351	0.1
SS9	U3	Yes	1	-2351	-0.1
SS9	U3		2	-2350	-0.015
SS9	U3		3	0	0
SS9	U3		4	2350	0.015
SS9	U3		5	2351	0.1

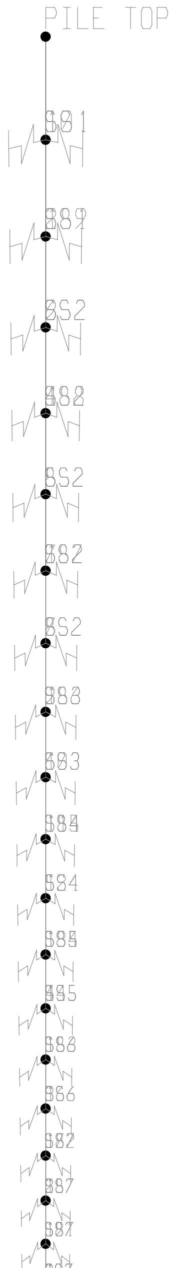
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TABLE: Link Property Definitions 03 - MultiLinear P4					
Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
SS1	U2	Yes	1	-351	-0.1
SS1	U2		2	-350	-0.018
SS1	U2		3	0	0
SS1	U2		4	350	0.018
SS1	U2		5	351	0.1
SS1	U3	Yes	1	-351	-0.1
SS1	U3		2	-350	-0.018
SS1	U3		3	0	0
SS1	U3		4	350	0.018
SS1	U3		5	351	0.1
SS10	U2	Yes	1	-2501	-0.1
SS10	U2		2	-2500	-0.015
SS10	U2		3	0	0
SS10	U2		4	2500	0.015
SS10	U2		5	2501	0.1
SS10	U3	Yes	1	-2501	-0.1
SS10	U3		2	-2500	-0.015
SS10	U3		3	0	0
SS10	U3		4	2500	0.015
SS10	U3		5	2501	0.1
SS11	U2	Yes	1	-176	-0.1
SS11	U2		2	-175	-0.018
SS11	U2		3	0	0
SS11	U2		4	175	0.018
SS11	U2		5	176	0.1
SS11	U3	Yes	1	-176	-0.1
SS11	U3		2	-175	-0.018
SS11	U3		3	0	0
SS11	U3		4	175	0.018
SS11	U3		5	176	0.1
SS2	U2	Yes	1	-676	-0.1
SS2	U2		2	-675	-0.018
SS2	U2		3	0	0
SS2	U2		4	675	0.018
SS2	U2		5	676	0.1
SS2	U3	Yes	1	-676	-0.1
SS2	U3		2	-675	-0.018
SS2	U3		3	0	0
SS2	U3		4	675	0.018
SS2	U3		5	676	0.1
SS3	U2	Yes	1	-751	-0.1
SS3	U2		2	-750	-0.018
SS3	U2		3	0	0
SS3	U2		4	750	0.018
SS3	U2		5	751	0.1
SS3	U3	Yes	1	-751	-0.1
SS3	U3		2	-750	-0.018
SS3	U3		3	0	0
SS3	U3		4	750	0.018
SS3	U3		5	751	0.1
SS4	U2	Yes	1	-1551	-0.1
SS4	U2		2	-1550	-0.015
SS4	U2		3	0	0
SS4	U2		4	1550	0.015
SS4	U2		5	1551	0.1
SS4	U3	Yes	1	-1551	-0.1
SS4	U3		2	-1550	-0.015

Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
SS1	U2	Yes	1	-351	-0.1
SS4	U3		3	0	0
SS4	U3		4	1550	0.015
SS4	U3		5	1551	0.1
SS5	U2	Yes	1	-1601	-0.1
SS5	U2		2	-1600	-0.015
SS5	U2		3	0	0
SS5	U2		4	1600	0.015
SS5	U2		5	1601	0.1
SS5	U3	Yes	1	-1601	-0.1
SS5	U3		2	-1600	-0.015
SS5	U3		3	0	0
SS5	U3		4	1600	0.015
SS5	U3		5	1601	0.1
SS6	U2	Yes	1	-1351	-0.1
SS6	U2		2	-1350	-0.015
SS6	U2		3	0	0
SS6	U2		4	1350	0.015
SS6	U2		5	1351	0.1
SS6	U3	Yes	1	-1351	-0.1
SS6	U3		2	-1350	-0.015
SS6	U3		3	0	0
SS6	U3		4	1350	0.015
SS6	U3		5	1351	0.1
SS7	U2	Yes	1	-2076	-0.1
SS7	U2		2	-2075	-0.015
SS7	U2		3	0	0
SS7	U2		4	2075	0.015
SS7	U2		5	2076	0.1
SS7	U3	Yes	1	-2076	-0.1
SS7	U3		2	-2075	-0.015
SS7	U3		3	0	0
SS7	U3		4	2075	0.015
SS7	U3		5	2076	0.1
SS8	U2	Yes	1	-2201	-0.1
SS8	U2		2	-2200	-0.015
SS8	U2		3	0	0
SS8	U2		4	2200	0.015
SS8	U2		5	2201	0.1
SS8	U3	Yes	1	-2201	-0.1
SS8	U3		2	-2200	-0.015
SS8	U3		3	0	0
SS8	U3		4	2200	0.015
SS8	U3		5	2201	0.1
SS9	U2	Yes	1	-2351	-0.1
SS9	U2		2	-2350	-0.015
SS9	U2		3	0	0
SS9	U2		4	2350	0.015
SS9	U2		5	2351	0.1
SS9	U3	Yes	1	-2351	-0.1
SS9	U3		2	-2350	-0.015
SS9	U3		3	0	0
SS9	U3		4	2350	0.015
SS9	U3		5	2351	0.1

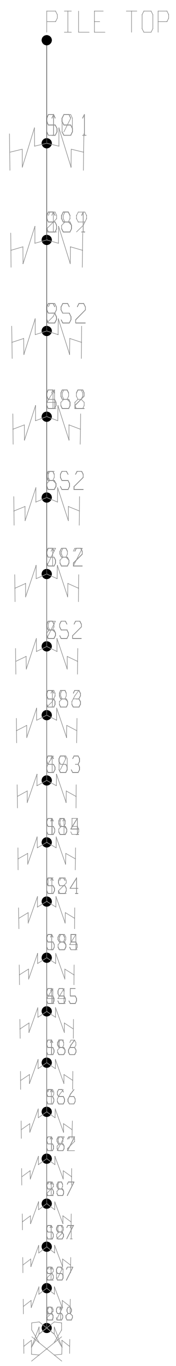
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TABLE: Link Property Definitions 03 - MultiLinear P5					
Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
SS1	U2	Yes	1	-351	-0.1
SS1	U2		2	-350	-0.018
SS1	U2		3	0	0
SS1	U2		4	350	0.018
SS1	U2		5	351	0.1
SS1	U3	Yes	1	-351	-0.1
SS1	U3		2	-350	-0.018
SS1	U3		3	0	0
SS1	U3		4	350	0.018
SS1	U3		5	351	0.1
SS10	U2	Yes	1	-2501	-0.1
SS10	U2		2	-2500	-0.015
SS10	U2		3	0	0
SS10	U2		4	2500	0.015
SS10	U2		5	2501	0.1
SS10	U3	Yes	1	-2501	-0.1
SS10	U3		2	-2500	-0.015
SS10	U3		3	0	0
SS10	U3		4	2500	0.015
SS10	U3		5	2501	0.1
SS11	U2	Yes	1	-176	-0.1
SS11	U2		2	-175	-0.018
SS11	U2		3	0	0
SS11	U2		4	175	0.018
SS11	U2		5	176	0.1
SS11	U3	Yes	1	-176	-0.1
SS11	U3		2	-175	-0.018
SS11	U3		3	0	0
SS11	U3		4	175	0.018
SS11	U3		5	176	0.1
SS2	U2	Yes	1	-676	-0.1
SS2	U2		2	-675	-0.018
SS2	U2		3	0	0
SS2	U2		4	675	0.018
SS2	U2		5	676	0.1
SS2	U3	Yes	1	-676	-0.1
SS2	U3		2	-675	-0.018
SS2	U3		3	0	0
SS2	U3		4	675	0.018
SS2	U3		5	676	0.1
SS3	U2	Yes	1	-751	-0.1
SS3	U2		2	-750	-0.018
SS3	U2		3	0	0
SS3	U2		4	750	0.018
SS3	U2		5	751	0.1
SS3	U3	Yes	1	-751	-0.1
SS3	U3		2	-750	-0.018
SS3	U3		3	0	0
SS3	U3		4	750	0.018
SS3	U3		5	751	0.1
SS4	U2	Yes	1	-1551	-0.1
SS4	U2		2	-1550	-0.015
SS4	U2		3	0	0
SS4	U2		4	1550	0.015
SS4	U2		5	1551	0.1
SS4	U3	Yes	1	-1551	-0.1
SS4	U3		2	-1550	-0.015

Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
SS1	U2	Yes	1	-351	-0.1
SS4	U3		3	0	0
SS4	U3		4	1550	0.015
SS4	U3		5	1551	0.1
SS5	U2	Yes	1	-1601	-0.1
SS5	U2		2	-1600	-0.015
SS5	U2		3	0	0
SS5	U2		4	1600	0.015
SS5	U2		5	1601	0.1
SS5	U3	Yes	1	-1601	-0.1
SS5	U3		2	-1600	-0.015
SS5	U3		3	0	0
SS5	U3		4	1600	0.015
SS5	U3		5	1601	0.1
SS6	U2	Yes	1	-1351	-0.1
SS6	U2		2	-1350	-0.015
SS6	U2		3	0	0
SS6	U2		4	1350	0.015
SS6	U2		5	1351	0.1
SS6	U3	Yes	1	-1351	-0.1
SS6	U3		2	-1350	-0.015
SS6	U3		3	0	0
SS6	U3		4	1350	0.015
SS6	U3		5	1351	0.1
SS7	U2	Yes	1	-2076	-0.1
SS7	U2		2	-2075	-0.015
SS7	U2		3	0	0
SS7	U2		4	2075	0.015
SS7	U2		5	2076	0.1
SS7	U3	Yes	1	-2076	-0.1
SS7	U3		2	-2075	-0.015
SS7	U3		3	0	0
SS7	U3		4	2075	0.015
SS7	U3		5	2076	0.1
SS8	U2	Yes	1	-2201	-0.1
SS8	U2		2	-2200	-0.015
SS8	U2		3	0	0
SS8	U2		4	2200	0.015
SS8	U2		5	2201	0.1
SS8	U3	Yes	1	-2201	-0.1
SS8	U3		2	-2200	-0.015
SS8	U3		3	0	0
SS8	U3		4	2200	0.015
SS8	U3		5	2201	0.1
SS9	U2	Yes	1	-2351	-0.1
SS9	U2		2	-2350	-0.015
SS9	U2		3	0	0
SS9	U2		4	2350	0.015
SS9	U2		5	2351	0.1
SS9	U3	Yes	1	-2351	-0.1
SS9	U3		2	-2350	-0.015
SS9	U3		3	0	0
SS9	U3		4	2350	0.015
SS9	U3		5	2351	0.1

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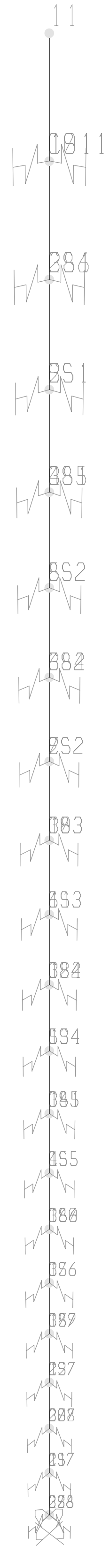
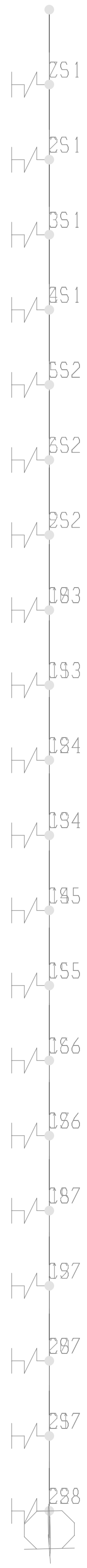


SAP2000 v10.0.1 - File:P6-BP1500MM - 3-D View - KN, m, C Units

TABLE: Link Property Definitions 03 - MultiLinear P6					
Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
CS1	U2	Yes	1	-221	-0.1
CS1	U2		2	-220	-0.015
CS1	U2		3	0	0
CS1	U2		4	220	0.015
CS1	U2		5	221	0.1
CS1	U3	Yes	1	-221	-0.1
CS1	U3		2	-220	-0.015
CS1	U3		3	0	0
CS1	U3		4	220	0.015
CS1	U3		5	221	0.1
CS10	U2	Yes	1	-3001	-0.1
CS10	U2		2	-3000	-0.01
CS10	U2		3	0	0
CS10	U2		4	3000	0.01
CS10	U2		5	3001	0.1
CS10	U3	Yes	1	-3001	-0.1
CS10	U3		2	-3000	-0.01
CS10	U3		3	0	0
CS10	U3		4	3000	0.01
CS10	U3		5	3001	0.1
CS11	U2	Yes	1	-111	-0.1
CS11	U2		2	-110	-0.015
CS11	U2		3	0	0
CS11	U2		4	110	0.015
CS11	U2		5	111	0.1
CS11	U3	Yes	1	-111	-0.1
CS11	U3		2	-110	-0.015
CS11	U3		3	0	0
CS11	U3		4	110	0.015
CS11	U3		5	111	0.1
CS2	U2	Yes	1	-301	-0.1
CS2	U2		2	-300	-0.015
CS2	U2		3	0	0
CS2	U2		4	300	0.015
CS2	U2		5	301	0.1
CS2	U3	Yes	1	-301	-0.1
CS2	U3		2	-300	-0.015
CS2	U3		3	0	0
CS2	U3		4	300	0.015
CS2	U3		5	301	0.1
CS3	U2	Yes	1	-351	-0.1
CS3	U2		2	-350	-0.015
CS3	U2		3	0	0
CS3	U2		4	350	0.015
CS3	U2		5	351	0.1
CS3	U3	Yes	1	-351	-0.1
CS3	U3		2	-350	-0.015
CS3	U3		3	0	0
CS3	U3		4	350	0.015
CS3	U3		5	351	0.1
CS4	U2	Yes	1	-526	-0.1
CS4	U2		2	-525	-0.015
CS4	U2		3	0	0
CS4	U2		4	525	0.015
CS4	U2		5	526	0.1
CS4	U3	Yes	1	-526	-0.1
CS4	U3		2	-525	-0.015

Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
CS1	U2	Yes	1	-221	-0.1
CS4	U3		3	0	0
CS4	U3		4	525	0.015
CS4	U3		5	526	0.1
CS5	U2	Yes	1	-876	-0.1
CS5	U2		2	-875	-0.01
CS5	U2		3	0	0
CS5	U2		4	875	0.01
CS5	U2		5	876	0.1
CS5	U3	Yes	1	-876	-0.1
CS5	U3		2	-875	-0.01
CS5	U3		3	0	0
CS5	U3		4	875	0.01
CS5	U3		5	876	0.1
CS6	U2	Yes	1	-1001	-0.1
CS6	U2		2	-1000	-0.01
CS6	U2		3	0	0
CS6	U2		4	1000	0.01
CS6	U2		5	1001	0.1
CS6	U3	Yes	1	-1001	-0.1
CS6	U3		2	-1000	-0.01
CS6	U3		3	0	0
CS6	U3		4	1000	0.01
CS6	U3		5	1001	0.1
CS7	U2	Yes	1	-1276	-0.1
CS7	U2		2	-1275	-0.01
CS7	U2		3	0	0
CS7	U2		4	1275	0.01
CS7	U2		5	1276	0.1
CS7	U3	Yes	1	-1276	-0.1
CS7	U3		2	-1275	-0.01
CS7	U3		3	0	0
CS7	U3		4	1275	0.01
CS7	U3		5	1276	0.1
CS8	U2	Yes	1	-1351	-0.1
CS8	U2		2	-1350	-0.01
CS8	U2		3	0	0
CS8	U2		4	1350	0.01
CS8	U2		5	1351	0.1
CS8	U3	Yes	1	-1351	-0.1
CS8	U3		2	-1350	-0.01
CS8	U3		3	0	0
CS8	U3		4	1350	0.01
CS8	U3		5	1351	0.1
CS9	U2	Yes	1	-1451	-0.1
CS9	U2		2	-1450	-0.01
CS9	U2		3	0	0
CS9	U2		4	1450	0.01
CS9	U2		5	1451	0.1
CS9	U3	Yes	1	-1451	-0.1
CS9	U3		2	-1450	-0.01
CS9	U3		3	0	0
CS9	U3		4	1450	0.01
CS9	U3		5	1451	0.1



SAP2000 v10.0.1 - File:P7-BP1500MM - 3-D View - KN, m, C Units

TABLE: Link Property Definitions 03 - MultiLinear P7					
Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
CS1	U2	Yes	1	-221	-0.1
CS1	U2		2	-220	-0.015
CS1	U2		3	0	0
CS1	U2		4	220	0.015
CS1	U2		5	221	0.1
CS1	U3	Yes	1	-221	-0.1
CS1	U3		2	-220	-0.015
CS1	U3		3	0	0
CS1	U3		4	220	0.015
CS1	U3		5	221	0.1
CS10	U2	Yes	1	-3001	-0.1
CS10	U2		2	-3000	-0.01
CS10	U2		3	0	0
CS10	U2		4	3000	0.01
CS10	U2		5	3001	0.1
CS10	U3	Yes	1	-3001	-0.1
CS10	U3		2	-3000	-0.01
CS10	U3		3	0	0
CS10	U3		4	3000	0.01
CS10	U3		5	3001	0.1
CS11	U2	Yes	1	-111	-0.1
CS11	U2		2	-110	-0.015
CS11	U2		3	0	0
CS11	U2		4	110	0.015
CS11	U2		5	111	0.1
CS11	U3	Yes	1	-111	-0.1
CS11	U3		2	-110	-0.015
CS11	U3		3	0	0
CS11	U3		4	110	0.015
CS11	U3		5	111	0.1
CS2	U2	Yes	1	-301	-0.1
CS2	U2		2	-300	-0.015
CS2	U2		3	0	0
CS2	U2		4	300	0.015
CS2	U2		5	301	0.1
CS2	U3	Yes	1	-301	-0.1
CS2	U3		2	-300	-0.015
CS2	U3		3	0	0
CS2	U3		4	300	0.015
CS2	U3		5	301	0.1
CS3	U2	Yes	1	-351	-0.1
CS3	U2		2	-350	-0.015
CS3	U2		3	0	0
CS3	U2		4	350	0.015
CS3	U2		5	351	0.1
CS3	U3	Yes	1	-351	-0.1
CS3	U3		2	-350	-0.015
CS3	U3		3	0	0
CS3	U3		4	350	0.015
CS3	U3		5	351	0.1
CS4	U2	Yes	1	-526	-0.1
CS4	U2		2	-525	-0.015
CS4	U2		3	0	0
CS4	U2		4	525	0.015
CS4	U2		5	526	0.1
CS4	U3	Yes	1	-526	-0.1
CS4	U3		2	-525	-0.015

Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
CS1	U2	Yes	1	-221	-0.1
CS4	U3		3	0	0
CS4	U3		4	525	0.015
CS4	U3		5	526	0.1
CS5	U2	Yes	1	-876	-0.1
CS5	U2		2	-875	-0.01
CS5	U2		3	0	0
CS5	U2		4	875	0.01
CS5	U2		5	876	0.1
CS5	U3	Yes	1	-876	-0.1
CS5	U3		2	-875	-0.01
CS5	U3		3	0	0
CS5	U3		4	875	0.01
CS5	U3		5	876	0.1
CS6	U2	Yes	1	-1001	-0.1
CS6	U2		2	-1000	-0.01
CS6	U2		3	0	0
CS6	U2		4	1000	0.01
CS6	U2		5	1001	0.1
CS6	U3	Yes	1	-1001	-0.1
CS6	U3		2	-1000	-0.01
CS6	U3		3	0	0
CS6	U3		4	1000	0.01
CS6	U3		5	1001	0.1
CS7	U2	Yes	1	-1276	-0.1
CS7	U2		2	-1275	-0.01
CS7	U2		3	0	0
CS7	U2		4	1275	0.01
CS7	U2		5	1276	0.1
CS7	U3	Yes	1	-1276	-0.1
CS7	U3		2	-1275	-0.01
CS7	U3		3	0	0
CS7	U3		4	1275	0.01
CS7	U3		5	1276	0.1
CS8	U2	Yes	1	-1351	-0.1
CS8	U2		2	-1350	-0.01
CS8	U2		3	0	0
CS8	U2		4	1350	0.01
CS8	U2		5	1351	0.1
CS8	U3	Yes	1	-1351	-0.1
CS8	U3		2	-1350	-0.01
CS8	U3		3	0	0
CS8	U3		4	1350	0.01
CS8	U3		5	1351	0.1
CS9	U2	Yes	1	-1451	-0.1
CS9	U2		2	-1450	-0.01
CS9	U2		3	0	0
CS9	U2		4	1450	0.01
CS9	U2		5	1451	0.1
CS9	U3	Yes	1	-1451	-0.1
CS9	U3		2	-1450	-0.01
CS9	U3		3	0	0
CS9	U3		4	1450	0.01
CS9	U3		5	1451	0.1

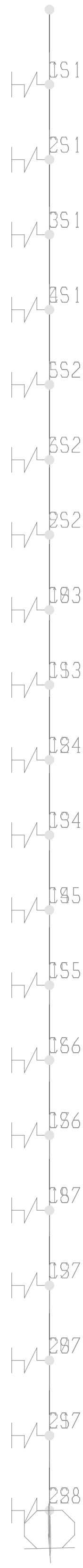


TABLE: Link Property Definitions 03 - MultiLinear P8					
Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
CS1	U2	Yes	1	-221	-0.1
CS1	U2		2	-220	-0.015
CS1	U2		3	0	0
CS1	U2		4	220	0.015
CS1	U2		5	221	0.1
CS1	U3	Yes	1	-221	-0.1
CS1	U3		2	-220	-0.015
CS1	U3		3	0	0
CS1	U3		4	220	0.015
CS1	U3		5	221	0.1
CS10	U2	Yes	1	-3001	-0.1
CS10	U2		2	-3000	-0.01
CS10	U2		3	0	0
CS10	U2		4	3000	0.01
CS10	U2		5	3001	0.1
CS10	U3	Yes	1	-3001	-0.1
CS10	U3		2	-3000	-0.01
CS10	U3		3	0	0
CS10	U3		4	3000	0.01
CS10	U3		5	3001	0.1
CS11	U2	Yes	1	-111	-0.1
CS11	U2		2	-110	-0.015
CS11	U2		3	0	0
CS11	U2		4	110	0.015
CS11	U2		5	111	0.1
CS11	U3	Yes	1	-111	-0.1
CS11	U3		2	-110	-0.015
CS11	U3		3	0	0
CS11	U3		4	110	0.015
CS11	U3		5	111	0.1
CS2	U2	Yes	1	-301	-0.1
CS2	U2		2	-300	-0.015
CS2	U2		3	0	0
CS2	U2		4	300	0.015
CS2	U2		5	301	0.1
CS2	U3	Yes	1	-301	-0.1
CS2	U3		2	-300	-0.015
CS2	U3		3	0	0
CS2	U3		4	300	0.015
CS2	U3		5	301	0.1
CS3	U2	Yes	1	-351	-0.1
CS3	U2		2	-350	-0.015
CS3	U2		3	0	0
CS3	U2		4	350	0.015
CS3	U2		5	351	0.1
CS3	U3	Yes	1	-351	-0.1
CS3	U3		2	-350	-0.015
CS3	U3		3	0	0
CS3	U3		4	350	0.015
CS3	U3		5	351	0.1
CS4	U2	Yes	1	-526	-0.1
CS4	U2		2	-525	-0.015
CS4	U2		3	0	0
CS4	U2		4	525	0.015
CS4	U2		5	526	0.1
CS4	U3	Yes	1	-526	-0.1
CS4	U3		2	-525	-0.015

Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
CS1	U2	Yes	1	-221	-0.1
CS4	U3		3	0	0
CS4	U3		4	525	0.015
CS4	U3		5	526	0.1
CS5	U2	Yes	1	-876	-0.1
CS5	U2		2	-875	-0.01
CS5	U2		3	0	0
CS5	U2		4	875	0.01
CS5	U2		5	876	0.1
CS5	U3	Yes	1	-876	-0.1
CS5	U3		2	-875	-0.01
CS5	U3		3	0	0
CS5	U3		4	875	0.01
CS5	U3		5	876	0.1
CS6	U2	Yes	1	-1001	-0.1
CS6	U2		2	-1000	-0.01
CS6	U2		3	0	0
CS6	U2		4	1000	0.01
CS6	U2		5	1001	0.1
CS6	U3	Yes	1	-1001	-0.1
CS6	U3		2	-1000	-0.01
CS6	U3		3	0	0
CS6	U3		4	1000	0.01
CS6	U3		5	1001	0.1
CS7	U2	Yes	1	-1276	-0.1
CS7	U2		2	-1275	-0.01
CS7	U2		3	0	0
CS7	U2		4	1275	0.01
CS7	U2		5	1276	0.1
CS7	U3	Yes	1	-1276	-0.1
CS7	U3		2	-1275	-0.01
CS7	U3		3	0	0
CS7	U3		4	1275	0.01
CS7	U3		5	1276	0.1
CS8	U2	Yes	1	-1351	-0.1
CS8	U2		2	-1350	-0.01
CS8	U2		3	0	0
CS8	U2		4	1350	0.01
CS8	U2		5	1351	0.1
CS8	U3	Yes	1	-1351	-0.1
CS8	U3		2	-1350	-0.01
CS8	U3		3	0	0
CS8	U3		4	1350	0.01
CS8	U3		5	1351	0.1
CS9	U2	Yes	1	-1451	-0.1
CS9	U2		2	-1450	-0.01
CS9	U2		3	0	0
CS9	U2		4	1450	0.01
CS9	U2		5	1451	0.1
CS9	U3	Yes	1	-1451	-0.1
CS9	U3		2	-1450	-0.01
CS9	U3		3	0	0
CS9	U3		4	1450	0.01
CS9	U3		5	1451	0.1

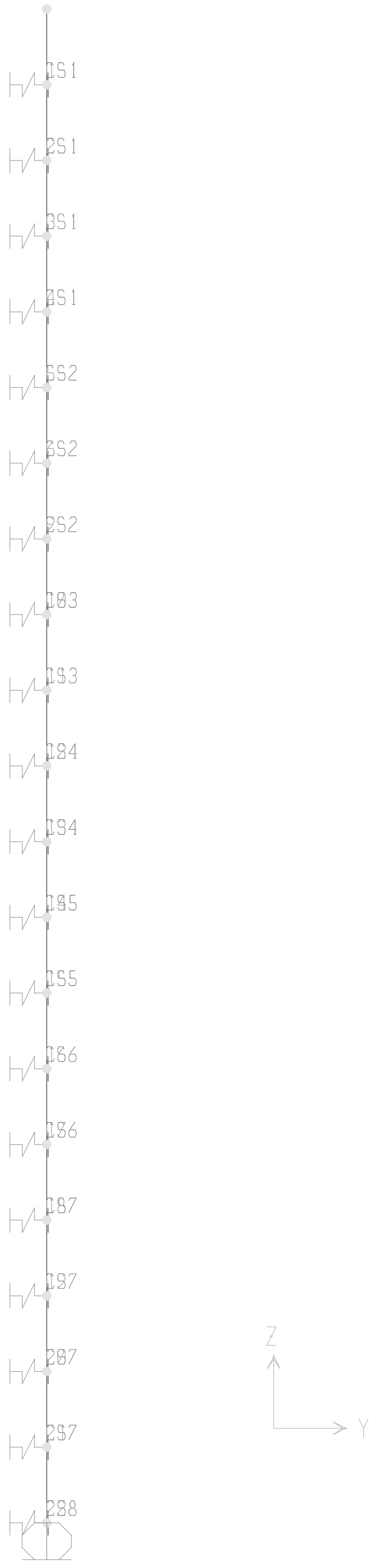

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TABLE: Link Property Definitions 03 - MultiLinear P9					
Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
CS1	U2	Yes	1	-221	-0.1
CS1	U2		2	-220	-0.015
CS1	U2		3	0	0
CS1	U2		4	220	0.015
CS1	U2		5	221	0.1
CS1	U3	Yes	1	-221	-0.1
CS1	U3		2	-220	-0.015
CS1	U3		3	0	0
CS1	U3		4	220	0.015
CS1	U3		5	221	0.1
CS10	U2	Yes	1	-3001	-0.1
CS10	U2		2	-3000	-0.01
CS10	U2		3	0	0
CS10	U2		4	3000	0.01
CS10	U2		5	3001	0.1
CS10	U3	Yes	1	-3001	-0.1
CS10	U3		2	-3000	-0.01
CS10	U3		3	0	0
CS10	U3		4	3000	0.01
CS10	U3		5	3001	0.1
CS11	U2	Yes	1	-111	-0.1
CS11	U2		2	-110	-0.015
CS11	U2		3	0	0
CS11	U2		4	110	0.015
CS11	U2		5	111	0.1
CS11	U3	Yes	1	-111	-0.1
CS11	U3		2	-110	-0.015
CS11	U3		3	0	0
CS11	U3		4	110	0.015
CS11	U3		5	111	0.1
CS2	U2	Yes	1	-301	-0.1
CS2	U2		2	-300	-0.015
CS2	U2		3	0	0
CS2	U2		4	300	0.015
CS2	U2		5	301	0.1
CS2	U3	Yes	1	-301	-0.1
CS2	U3		2	-300	-0.015
CS2	U3		3	0	0
CS2	U3		4	300	0.015
CS2	U3		5	301	0.1
CS3	U2	Yes	1	-351	-0.1
CS3	U2		2	-350	-0.015
CS3	U2		3	0	0
CS3	U2		4	350	0.015
CS3	U2		5	351	0.1
CS3	U3	Yes	1	-351	-0.1
CS3	U3		2	-350	-0.015
CS3	U3		3	0	0
CS3	U3		4	350	0.015
CS3	U3		5	351	0.1
CS4	U2	Yes	1	-526	-0.1
CS4	U2		2	-525	-0.015
CS4	U2		3	0	0
CS4	U2		4	525	0.015
CS4	U2		5	526	0.1
CS4	U3	Yes	1	-526	-0.1
CS4	U3		2	-525	-0.015

Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
CS1	U2	Yes	1	-221	-0.1
CS4	U3		3	0	0
CS4	U3		4	525	0.015
CS4	U3		5	526	0.1
CS5	U2	Yes	1	-876	-0.1
CS5	U2		2	-875	-0.01
CS5	U2		3	0	0
CS5	U2		4	875	0.01
CS5	U2		5	876	0.1
CS5	U3	Yes	1	-876	-0.1
CS5	U3		2	-875	-0.01
CS5	U3		3	0	0
CS5	U3		4	875	0.01
CS5	U3		5	876	0.1
CS6	U2	Yes	1	-1001	-0.1
CS6	U2		2	-1000	-0.01
CS6	U2		3	0	0
CS6	U2		4	1000	0.01
CS6	U2		5	1001	0.1
CS6	U3	Yes	1	-1001	-0.1
CS6	U3		2	-1000	-0.01
CS6	U3		3	0	0
CS6	U3		4	1000	0.01
CS6	U3		5	1001	0.1
CS7	U2	Yes	1	-1276	-0.1
CS7	U2		2	-1275	-0.01
CS7	U2		3	0	0
CS7	U2		4	1275	0.01
CS7	U2		5	1276	0.1
CS7	U3	Yes	1	-1276	-0.1
CS7	U3		2	-1275	-0.01
CS7	U3		3	0	0
CS7	U3		4	1275	0.01
CS7	U3		5	1276	0.1
CS8	U2	Yes	1	-1351	-0.1
CS8	U2		2	-1350	-0.01
CS8	U2		3	0	0
CS8	U2		4	1350	0.01
CS8	U2		5	1351	0.1
CS8	U3	Yes	1	-1351	-0.1
CS8	U3		2	-1350	-0.01
CS8	U3		3	0	0
CS8	U3		4	1350	0.01
CS8	U3		5	1351	0.1
CS9	U2	Yes	1	-1451	-0.1
CS9	U2		2	-1450	-0.01
CS9	U2		3	0	0
CS9	U2		4	1450	0.01
CS9	U2		5	1451	0.1
CS9	U3	Yes	1	-1451	-0.1
CS9	U3		2	-1450	-0.01
CS9	U3		3	0	0
CS9	U3		4	1450	0.01
CS9	U3		5	1451	0.1

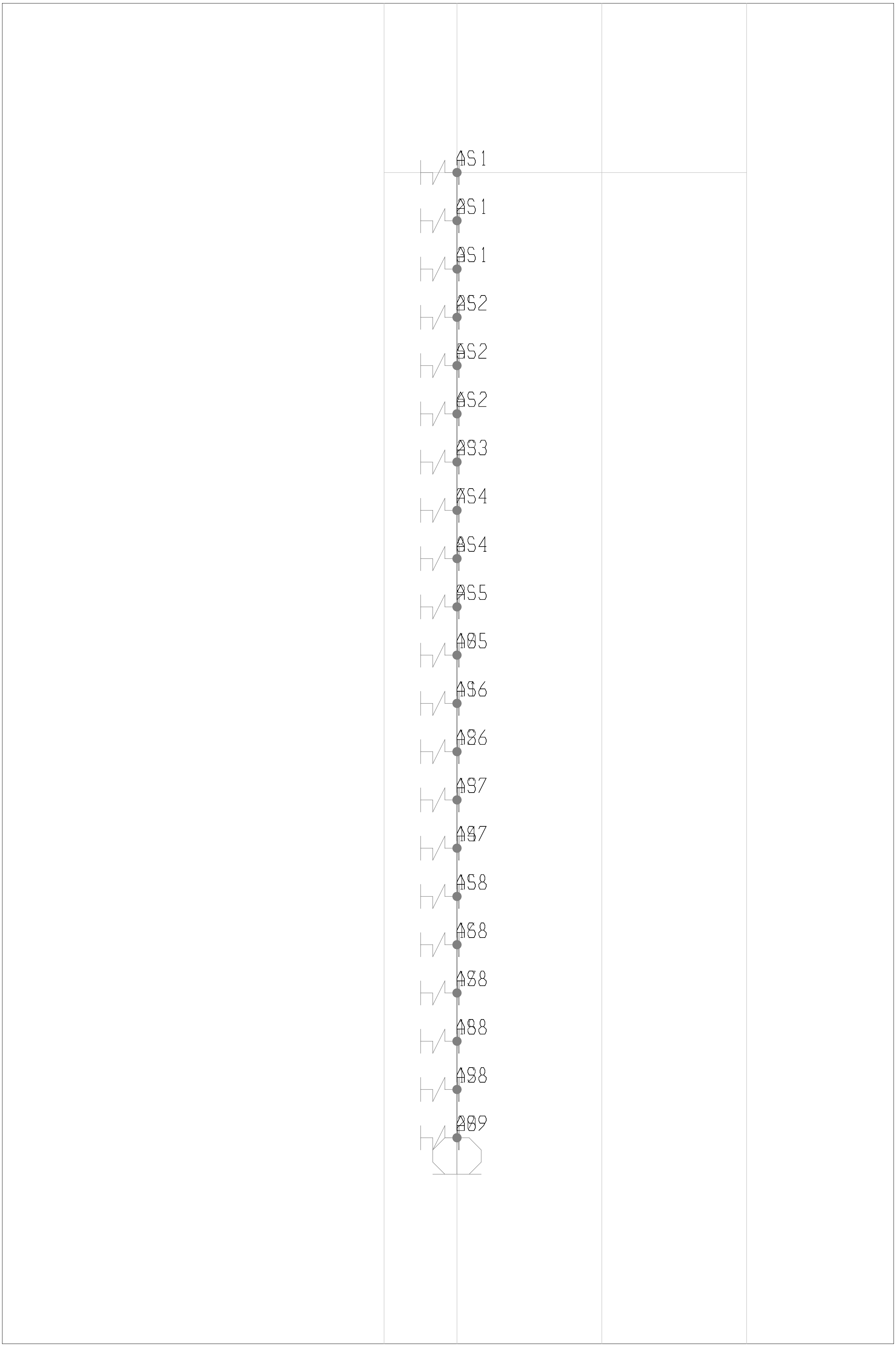


TABLE: Link Property Definitions 03 - MultiLinear A2					
Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
AS1	U2	Yes	1	-251	-0.1
AS1	U2		2	-250	-0.018
AS1	U2		3	0	0
AS1	U2		4	250	0.018
AS1	U2		5	251	0.1
AS1	U3	Yes	1	-251	-0.1
AS1	U3		2	-250	-0.018
AS1	U3		3	0	0
AS1	U3		4	250	0.018
AS1	U3		5	251	0.1
AS10	U2	Yes	1	-1801	-0.1
AS10	U2		2	-1800	-0.012
AS10	U2		3	0	0
AS10	U2		4	1800	0.012
AS10	U2		5	1801	0.1
AS10	U3	Yes	1	-1801	-0.1
AS10	U3		2	-1800	-0.012
AS10	U3		3	0	0
AS10	U3		4	1800	0.012
AS10	U3		5	1801	0.1
AS11	U2	Yes	1	-126	-0.1
AS11	U2		2	-125	-0.018
AS11	U2		3	0	0
AS11	U2		4	125	0.018
AS11	U2		5	126	0.1
AS11	U3	Yes	1	-126	-0.1
AS11	U3		2	-125	-0.018
AS11	U3		3	0	0
AS11	U3		4	125	0.018
AS11	U3		5	126	0.1
AS2	U2	Yes	1	-351	-0.1
AS2	U2		2	-350	-0.018
AS2	U2		3	0	0
AS2	U2		4	350	0.018
AS2	U2		5	351	0.1
AS2	U3	Yes	1	-351	-0.1
AS2	U3		2	-350	-0.018
AS2	U3		3	0	0
AS2	U3		4	350	0.018
AS2	U3		5	351	0.1
AS3	U2	Yes	1	-426	-0.1
AS3	U2		2	-425	-0.018
AS3	U2		3	0	0
AS3	U2		4	425	0.018
AS3	U2		5	426	0.1
AS3	U3	Yes	1	-426	-0.1
AS3	U3		2	-425	-0.018
AS3	U3		3	0	0
AS3	U3		4	425	0.018
AS3	U3		5	426	0.1
AS4	U2	Yes	1	-751	-0.1
AS4	U2		2	-750	-0.012
AS4	U2		3	0	0
AS4	U2		4	750	0.012
AS4	U2		5	751	0.1
AS4	U3	Yes	1	-751	-0.1
AS4	U3		2	-750	-0.012

Link	DOF	NonLinear	Point	Force	Displ
Text	Text	Yes/No	Text	KN	m
AS1	U2	Yes	1	-251	-0.1
AS4	U3		3	0	0
AS4	U3		4	750	0.012
AS4	U3		5	751	0.1
AS5	U2	Yes	1	-926	-0.1
AS5	U2		2	-925	-0.012
AS5	U2		3	0	0
AS5	U2		4	925	0.012
AS5	U2		5	926	0.1
AS5	U3	Yes	1	-926	-0.1
AS5	U3		2	-925	-0.012
AS5	U3		3	0	0
AS5	U3		4	925	0.012
AS5	U3		5	926	0.1
AS6	U2	Yes	1	-1451	-0.1
AS6	U2		2	-1450	-0.012
AS6	U2		3	0	0
AS6	U2		4	1450	0.012
AS6	U2		5	1451	0.1
AS6	U3	Yes	1	-1451	-0.1
AS6	U3		2	-1450	-0.012
AS6	U3		3	0	0
AS6	U3		4	1450	0.012
AS6	U3		5	1451	0.1
AS7	U2	Yes	1	-1501	-0.1
AS7	U2		2	-1500	-0.012
AS7	U2		3	0	0
AS7	U2		4	1500	0.012
AS7	U2		5	1501	0.1
AS7	U3	Yes	1	-1501	-0.1
AS7	U3		2	-1500	-0.012
AS7	U3		3	0	0
AS7	U3		4	1500	0.012
AS7	U3		5	1501	0.1
AS8	U2	Yes	1	-1601	-0.1
AS8	U2		2	-1600	-0.012
AS8	U2		3	0	0
AS8	U2		4	1600	0.012
AS8	U2		5	1601	0.1
AS8	U3	Yes	1	-1601	-0.1
AS8	U3		2	-1600	-0.012
AS8	U3		3	0	0
AS8	U3		4	1600	0.012
AS8	U3		5	1601	0.1
AS9	U2	Yes	1	-1701	-0.1
AS9	U2		2	-1700	-0.012
AS9	U2		3	0	0
AS9	U2		4	1700	0.012
AS9	U2		5	1701	0.1
AS9	U3	Yes	1	-1701	-0.1
AS9	U3		2	-1700	-0.012
AS9	U3		3	0	0
AS9	U3		4	1700	0.012
AS9	U3		5	1701	0.1

9.3.1. FLEXURAL DESIGN

Notes on Flexural Design

(1) Demand on Piles

The design forces for foundations may be either the forces determined from the load combinations or the forces at the bottom of the columns corresponding to column plastic hinging. For the load combinations of seismic design forces the Response Modification Factor R is equal to 1.0 for foundations (refer Design Criteria Clause 2.32).

The demand on the foundations from the load combinations is presented on the following pages together with a comparison of the demand with plastic hinging effects. As can be seen for single column piers, in all cases the demand from plastic hinging is less than the demand from the load combinations. For the twin column piers the bending moments on the column bases from the load combinations are typically less than plastic hinging effects. However the shear forces from the load combinations are substantially larger than the plastic hinging case. Given the limited capacity of the soil to resist the shear forces from the foundations at shallow depth it is envisaged the load combination effects will create at least equivalent demand on the piles as the plastic hinging effects.

The plastic hinging effects are therefore selected for design and are investigated at the ultimate limit state.

(2) Ultimate Moment Capacity

The Ultimate Moment Capacity of the reinforced concrete piles is determined using the computer program PCACOL. This is based on ACI-95 and is consistent with the requirements of AASHTO LRFD.

(3) Reinforcement Detailing of 2.5m Diameter Bored Piles

The 2.5m diameter bored piles require 2.5% reinforcement at Pier P3, P4 and P5 (refer to Summary Plastic Hinging Effects).

Several options have been investigated regarding reinforcement provision at these piles as follows:

1. Use 32mm diameter bars throughout (largest size available without special order in Indonesia)
2. Use 51mm diameter bars throughout (largest bar available from Japan without special order – yield strength 345MPa)
3. Use 32mm diameter bars in combination with an extended steel jacket acting compositely with the pile.

The evaluation of these alternatives is presented on the following pages.

As a result of the evaluation, alternative (2) – use of 51mm diameter bars – is selected for the detailed design.

(4) Steel Socket for Composite Columns

AASHTO LRFD requires that the upper end of every pile shall be reinforced and confined as a potential plastic hinge region. The potential plastic hinge region shall extend from the underside of the pile cap over a length not less than 2.0 diameters or 600mm.

In the case of the 2.5m diameter piles supporting the composite columns, the confinement will be provided by the steel jacket required to ensure the socket connection of the composite column. The steel jacket will be extended over a length at least equal to 2.0 pile diameters and will be checked to ensure adequate confinement of the pile concrete. The tie steel requirements at the top of the pile can therefore be waived in this case.

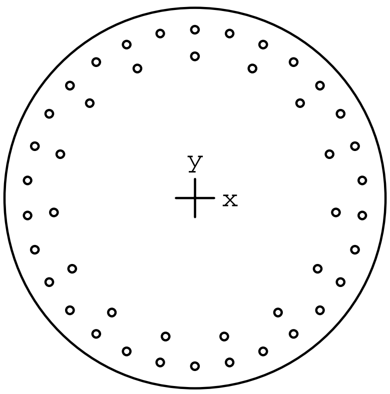
SUMMARY OF LOAD EFFECTS

PILE SECTIONS

LOAD EFFECTS 2.5 M PILES

TABLE: Element Forces - 2.5m PILE at PIER P3, BP1 0.5 m bellow NGL						
Frame	**Station**	**OutputCase**	**StepType**	**P AXIAL**	**V2 SHEAR**	**M3 MOMENT**
Text	m	Text	Text	KN	KN	KN-m
BP1	0	P3-LOAD	Max	-4649.7	2612	17401
BP1	1	P3-LOAD	Max	-4513	2612	14789
BP1	0	P3-LOAD	Min	-4649.7	2612	17401
BP1	1	P3-LOAD	Min	-4513	2612	14789
BP2	0	P3-LOAD	Max	-4786.4	2435.4	19836.4
BP2	1	P3-LOAD	Max	-4649.7	2435.4	17401
BP2	0	P3-LOAD	Min	-4786.4	2435.4	19836.4
BP2	1	P3-LOAD	Min	-4649.7	2435.4	17401
BP3	0	P3-LOAD	Max	-4923.1	2083.5	21919.9
BP3	1	P3-LOAD	Max	-4786.4	2083.5	19836.4
BP3	0	P3-LOAD	Min	-4923.1	2083.5	21919.9
BP3	1	P3-LOAD	Min	-4786.4	2083.5	19836.4
BP4	0	P3-LOAD	Max	-5059.9	1732	23651.9
BP4	1	P3-LOAD	Max	-4923.1	1732	21919.9
BP4	0	P3-LOAD	Min	-5059.9	1732	23651.9
BP4	1	P3-LOAD	Min	-4923.1	1732	21919.9
BP5	0	P3-LOAD	Max	-5196.6	1380.9	25032.8
BP5	1	P3-LOAD	Max	-5059.9	1380.9	23651.9
BP5	0	P3-LOAD	Min	-5196.6	1380.9	25032.8
BP5	1	P3-LOAD	Min	-5059.9	1380.9	23651.9
BP6	0	P3-LOAD	Max	-5333.3	704.7	25737.5
BP6	1	P3-LOAD	Max	-5196.6	704.7	25032.8
BP6	0	P3-LOAD	Min	-5333.3	704.7	25737.5
BP6	1	P3-LOAD	Min	-5196.6	704.7	25032.8
BP7	0	P3-LOAD	Max	-5449	28.5	25766.1
BP7	1	P3-LOAD	Max	-5333.3	28.5	25737.5
BP7	0	P3-LOAD	Min	-5449	28.5	25766.1
BP7	1	P3-LOAD	Min	-5333.3	28.5	25737.5
BP8	0	P3-LOAD	Max	-5564.6	-647.1	25118.9
BP8	1	P3-LOAD	Max	-5449	-647.1	25766.1
BP8	0	P3-LOAD	Min	-5564.6	-647.1	25118.9
BP8	1	P3-LOAD	Min	-5449	-647.1	25766.1
BP9	0	P3-LOAD	Max	-5680.3	-1336.5	23782.4
BP9	1	P3-LOAD	Max	-5564.6	-1336.5	25118.9
BP9	0	P3-LOAD	Min	-5680.3	-1336.5	23782.4
BP9	1	P3-LOAD	Min	-5564.6	-1336.5	25118.9
BP10	0	P3-LOAD	Max	-5795.9	-1804.9	21977.5
BP10	1	P3-LOAD	Max	-5680.3	-1804.9	23782.4
BP10	0	P3-LOAD	Min	-5795.9	-1804.9	21977.5
BP10	1	P3-LOAD	Min	-5680.3	-1804.9	23782.4

TABLE: Element Forces - 2.5m PILE at PIER P3, BP1 0.5 m bellow NGL						
Frame	**Station**	**OutputCase**	**StepType**	**P AXIAL**	**V2 SHEAR**	**M3 MOMENT**
Text	m	Text	Text	KN	KN	KN-m
BP11	0	P3-LOAD	Max	-5911.6	-2523.4	19454.1
BP11	1	P3-LOAD	Max	-5795.9	-2523.4	21977.5
BP11	0	P3-LOAD	Min	-5911.6	-2523.4	19454.1
BP11	1	P3-LOAD	Min	-5795.9	-2523.4	21977.5
BP12	0	P3-LOAD	Max	-6027.3	-2897	16557.1
BP12	1	P3-LOAD	Max	-5911.6	-2897	19454.1
BP12	0	P3-LOAD	Min	-6027.3	-2897	16557.1
BP12	1	P3-LOAD	Min	-5911.6	-2897	19454.1
BP13	0	P3-LOAD	Max	-6142.9	-3015.2	13541.9
BP13	1	P3-LOAD	Max	-6027.3	-3015.2	16557.1
BP13	0	P3-LOAD	Min	-6142.9	-3015.2	13541.9
BP13	1	P3-LOAD	Min	-6027.3	-3015.2	16557.1
BP14	0	P3-LOAD	Max	-6258.6	-2940.7	10601.2
BP14	1	P3-LOAD	Max	-6142.9	-2940.7	13541.9
BP14	0	P3-LOAD	Min	-6258.6	-2940.7	10601.2
BP14	1	P3-LOAD	Min	-6142.9	-2940.7	13541.9
BP15	0	P3-LOAD	Max	-6374.3	-2766.2	7834.9
BP15	1	P3-LOAD	Max	-6258.6	-2766.2	10601.2
BP15	0	P3-LOAD	Min	-6374.3	-2766.2	7834.9
BP15	1	P3-LOAD	Min	-6258.6	-2766.2	10601.2
BP16	0	P3-LOAD	Max	-6489.9	-2519.6	5315.3
BP16	1	P3-LOAD	Max	-6374.3	-2519.6	7834.9
BP16	0	P3-LOAD	Min	-6489.9	-2519.6	5315.3
BP16	1	P3-LOAD	Min	-6374.3	-2519.6	7834.9
BP17	0	P3-LOAD	Max	-6605.6	-2074	3241.4
BP17	1	P3-LOAD	Max	-6489.9	-2074	5315.3
BP17	0	P3-LOAD	Min	-6605.6	-2074	3241.4
BP17	1	P3-LOAD	Min	-6489.9	-2074	5315.3
BP18	0	P3-LOAD	Max	-6721.3	-1590.4	1651
BP18	1	P3-LOAD	Max	-6605.6	-1590.4	3241.4
BP18	0	P3-LOAD	Min	-6721.3	-1590.4	1651
BP18	1	P3-LOAD	Min	-6605.6	-1590.4	3241.4
BP19	0	P3-LOAD	Max	-6836.9	-1085.3	565.7
BP19	1	P3-LOAD	Max	-6721.3	-1085.3	1651
BP19	0	P3-LOAD	Min	-6836.9	-1085.3	565.7
BP19	1	P3-LOAD	Min	-6721.3	-1085.3	1651
BP20	0	P3-LOAD	Max	-6952.6	-565.7	0
BP20	1	P3-LOAD	Max	-6836.9	-565.7	565.7
BP20	0	P3-LOAD	Min	-6952.6	-565.7	0
BP20	1	P3-LOAD	Min	-6836.9	-565.7	565.7



2500 mm diam.

Code: ACI 318-95

Units: Metric

Run axis: About X-axis

Run option: Investigation

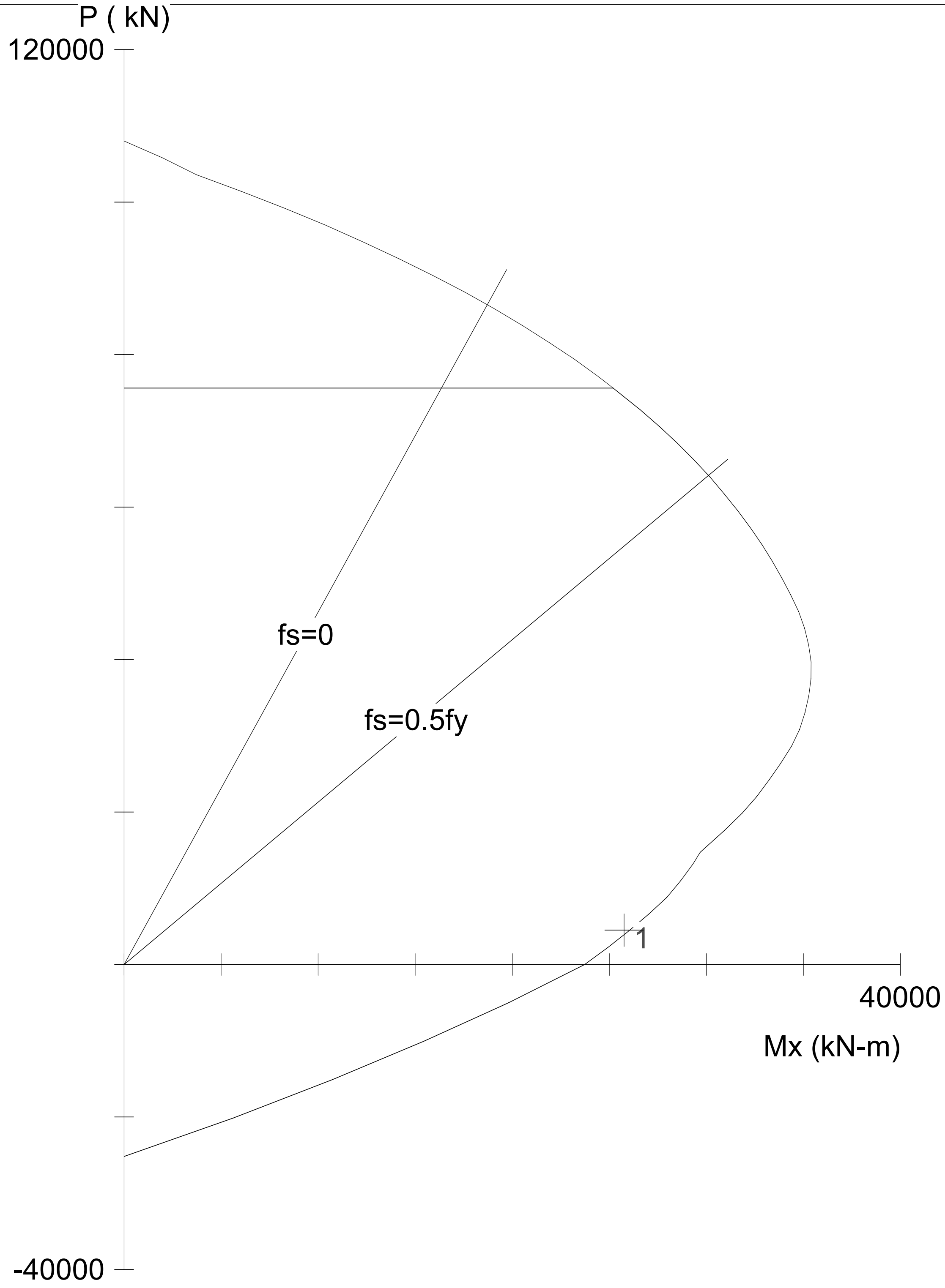
Slenderness: Not considered

Column type: Structural

Bars: User-defined

Date: 08/19/06

Time: 11:13:26



PCACOL V3.00 (PCA 1999) - Licensed to: KEI, MANILA, ST

File: C:\0-BALA~1\RC-DES~1\BOREPI~1\2.5M\P3\P3XSEC1.COL

Project: BALARAJA FLYOVER

Column: BP-P3 Engineer:

f'c = 30 MPa	fy = 345 MPa	Ag = 4.90874e+006 mm^2	45 #51 bars
Ec = 25743 MPa	Es = 200000 MPa	As = 91215 mm^2	Rho = 1.86%
fc = 25.5 MPa	e_rup = Infinity	Xo = 0 mm	Iy = 1.92e+012 mm^4
e_u = 0.003 mm/mm		Yo = 0 mm	Iy = 1.92e+012 mm^4
Beta1 = 0.83245		Clear spacing = 124 mm	Clear cover = 119 mm

Confinement: Other phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

```
OOOOOOO    OOOOO    OOOOO    OOOOO    OOOOO   OO
OO    OO  OO   OO  OO   OO  OO   OO  OO   OO  OO
OO    OO  OO   OO  OO   OO  OO   OO  OO   OO  OO
OO    OO  OO       OO   OO  OO       OO   OO  OO
OO    OO  OO       OOOOOOO  OO       OO   OO  OO
OOOOOOO   OO   OO  OO   OO  OO   OO  OO   OO  OO
OO        OO   OO  OO   OO  OO   OO  OO   OO  OO
OO         OOOOO   OO   OO   OOOOO    OOOOO   OOOOO  (TM)
```

==
Computer program for the Strength Design of Reinforced Concrete Sections
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General Information:
====================
File Name: I:\1-BALA~1\RC-DES~1\BOREPI~1\2.5M\P3\P3XSEC1.COL
Project: BALARAJA FLYOVER
Column: BP-P3 Engineer:
Code: ACI 318-95 Units: Metric

Run Option: Investigation Slenderness: Not considered
Run Axis: X-axis Column Type: Structural

Material Properties:
====================
f'c = 30 MPa fy = 345 MPa
Ec = 25743 MPa Es = 200000 MPa
fc = 25.5 MPa Rupture strain = Infinity
Ultimate strain = 0.003 mm/mm
Beta1 = 0.83245

Section:
========
Circular: Diameter = 2500 mm

Gross section area, Ag = 4.90874e+006 mm^2
Ix = 1.91748e+012 mm^4 Iy = 1.91748e+012 mm^4
Xo = 0 mm Yo = 0 mm

Reinforcement:
==============
Rebar Database: User-defined

Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)
# 6	6	28	# 8	8	50	# 10	10	79
# 12	12	113	# 14	14	154	# 16	16	201
# 20	20	314	# 25	25	491	# 28	28	616
# 32	32	801	# 40	40	1256	# 51	51	2027

Confinement: User-defined; #6 ties with #25 bars, #6 with larger bars.
phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

Pattern: Irregular

Total steel area, As = 91215 mm^2 at 1.86%

Area mm^2	X (mm)	Y (mm)	Area mm^2	X (mm)	Y (mm)	Area mm^2	X (mm)	Y (mm)
2027	0	1106	2027	230	1081	2027	450	1010
2027	650	894	2027	822	740	2027	957	553
2027	1051	342	2027	1099	116	2027	1099	-116
2027	1051	-342	2027	957	-553	2027	822	-740
2027	650	-894	2027	450	-1010	2027	230	-1081
2027	-0	-1106	2027	-230	-1081	2027	-450	-1010
2027	-650	-894	2027	-822	-740	2027	-957	-553
2027	-1051	-342	2027	-1099	-116	2027	-1099	116
2027	-1051	342	2027	-957	553	2027	-822	740
2027	-650	894	2027	-450	1010	2027	-230	1081
2027	0	931	2027	378	850	2027	-378	850
2027	691	623	2027	-691	623	2027	885	288
2027	-885	288	2027	925	-97	2027	-925	-97
2027	806	-465	2027	-806	-465	2027	547	-753
2027	-547	-753	2027	193	-910	2027	-193	-910

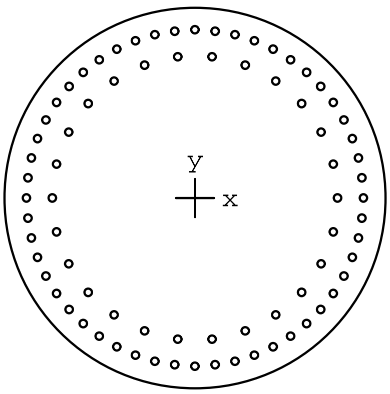
Factored Loads and Moments with Corresponding Capacities: (see user's manual for notation)

No.	Pu kN	Mux kN-m	fMnx kN-m	fMn/Mu
1	4513.2	25766.1	26052.0	1.011

*** Program completed as requested! ***

TABLE: Element Forces - 2.5m PILE at PIER P4, BP1 2.0 m below NGL						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP1	0	P4-LOAD	Max	-6879.7	4749	21136
BP1	1	P4-LOAD	Max	-6743	4749	16387
BP1	0	P4-LOAD	Min	-6879.7	4749	21136
BP1	1	P4-LOAD	Min	-6743	4749	16387
BP2	0	P4-LOAD	Max	-7016.4	4395.1	25531.1
BP2	1	P4-LOAD	Max	-6879.7	4395.1	21136
BP2	0	P4-LOAD	Min	-7016.4	4395.1	25531.1
BP2	1	P4-LOAD	Min	-6879.7	4395.1	21136
BP3	0	P4-LOAD	Max	-7153.1	4042	29573.1
BP3	1	P4-LOAD	Max	-7016.4	4042	25531.1
BP3	0	P4-LOAD	Min	-7153.1	4042	29573.1
BP3	1	P4-LOAD	Min	-7016.4	4042	25531.1
BP4	0	P4-LOAD	Max	-7289.9	3363.2	32936.3
BP4	1	P4-LOAD	Max	-7153.1	3363.2	29573.1
BP4	0	P4-LOAD	Min	-7289.9	3363.2	32936.3
BP4	1	P4-LOAD	Min	-7153.1	3363.2	29573.1
BP5	0	P4-LOAD	Max	-7426.6	2685.3	35621.6
BP5	1	P4-LOAD	Max	-7289.9	2685.3	32936.3
BP5	0	P4-LOAD	Min	-7426.6	2685.3	35621.6
BP5	1	P4-LOAD	Min	-7289.9	2685.3	32936.3
BP6	0	P4-LOAD	Max	-7563.3	2008.3	37629.8
BP6	1	P4-LOAD	Max	-7426.6	2008.3	35621.6
BP6	0	P4-LOAD	Min	-7563.3	2008.3	37629.8
BP6	1	P4-LOAD	Min	-7426.6	2008.3	35621.6
BP7	0	P4-LOAD	Max	-7679	1331.9	38961.8
BP7	1	P4-LOAD	Max	-7563.3	1331.9	37629.8
BP7	0	P4-LOAD	Min	-7679	1331.9	38961.8
BP7	1	P4-LOAD	Min	-7563.3	1331.9	37629.8
BP8	0	P4-LOAD	Max	-7794.6	656.2	39617.9
BP8	1	P4-LOAD	Max	-7679	656.2	38961.8
BP8	0	P4-LOAD	Min	-7794.6	656.2	39617.9
BP8	1	P4-LOAD	Min	-7679	656.2	38961.8
BP9	0	P4-LOAD	Max	-7910.3	-94	39523.9
BP9	1	P4-LOAD	Max	-7794.6	-94	39617.9
BP9	0	P4-LOAD	Min	-7910.3	-94	39523.9
BP9	1	P4-LOAD	Min	-7794.6	-94	39617.9
BP10	0	P4-LOAD	Max	-8025.9	-843.8	38680.1
BP10	1	P4-LOAD	Max	-7910.3	-843.8	39523.9
BP10	0	P4-LOAD	Min	-8025.9	-843.8	38680.1
BP10	1	P4-LOAD	Min	-7910.3	-843.8	39523.9

TABLE: Element Forces - 2.5m PILE at PIER P4, BP1 2.0 m below NGL						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP11	0	P4-LOAD	Max	-8141.6	-2393.4	36286.7
BP11	1	P4-LOAD	Max	-8025.9	-2393.4	38680.1
BP11	0	P4-LOAD	Min	-8141.6	-2393.4	36286.7
BP11	1	P4-LOAD	Min	-8025.9	-2393.4	38680.1
BP12	0	P4-LOAD	Max	-8257.3	-3927.3	32359.4
BP12	1	P4-LOAD	Max	-8141.6	-3927.3	36286.7
BP12	0	P4-LOAD	Min	-8257.3	-3927.3	32359.4
BP12	1	P4-LOAD	Min	-8141.6	-3927.3	36286.7
BP13	0	P4-LOAD	Max	-8372.9	-4848.2	27511.3
BP13	1	P4-LOAD	Max	-8257.3	-4848.2	32359.4
BP13	0	P4-LOAD	Min	-8372.9	-4848.2	27511.3
BP13	1	P4-LOAD	Min	-8257.3	-4848.2	32359.4
BP14	0	P4-LOAD	Max	-8488.6	-5255.2	22256.1
BP14	1	P4-LOAD	Max	-8372.9	-5255.2	27511.3
BP14	0	P4-LOAD	Min	-8488.6	-5255.2	22256.1
BP14	1	P4-LOAD	Min	-8372.9	-5255.2	27511.3
BP15	0	P4-LOAD	Max	-8604.3	-5270.5	16985.6
BP15	1	P4-LOAD	Max	-8488.6	-5270.5	22256.1
BP15	0	P4-LOAD	Min	-8604.3	-5270.5	16985.6
BP15	1	P4-LOAD	Min	-8488.6	-5270.5	22256.1
BP16	0	P4-LOAD	Max	-8719.9	-5041.8	11943.8
BP16	1	P4-LOAD	Max	-8604.3	-5041.8	16985.6
BP16	0	P4-LOAD	Min	-8719.9	-5041.8	11943.8
BP16	1	P4-LOAD	Min	-8604.3	-5041.8	16985.6
BP17	0	P4-LOAD	Max	-8835.6	-4413	7530.8
BP17	1	P4-LOAD	Max	-8719.9	-4413	11943.8
BP17	0	P4-LOAD	Min	-8835.6	-4413	7530.8
BP17	1	P4-LOAD	Min	-8719.9	-4413	11943.8
BP18	0	P4-LOAD	Max	-8951.3	-3573.1	3957.7
BP18	1	P4-LOAD	Max	-8835.6	-3573.1	7530.8
BP18	0	P4-LOAD	Min	-8951.3	-3573.1	3957.7
BP18	1	P4-LOAD	Min	-8835.6	-3573.1	7530.8
BP19	0	P4-LOAD	Max	-9066.9	-2561.5	1396.2
BP19	1	P4-LOAD	Max	-8951.3	-2561.5	3957.7
BP19	0	P4-LOAD	Min	-9066.9	-2561.5	1396.2
BP19	1	P4-LOAD	Min	-8951.3	-2561.5	3957.7
BP20	0	P4-LOAD	Max	-9182.6	-1396.2	0
BP20	1	P4-LOAD	Max	-9066.9	-1396.2	1396.2
BP20	0	P4-LOAD	Min	-9182.6	-1396.2	0
BP20	1	P4-LOAD	Min	-9066.9	-1396.2	1396.2



2500 mm diam.

Code: ACI 318-95

Units: Metric

Run axis: About X-axis

Run option: Investigation

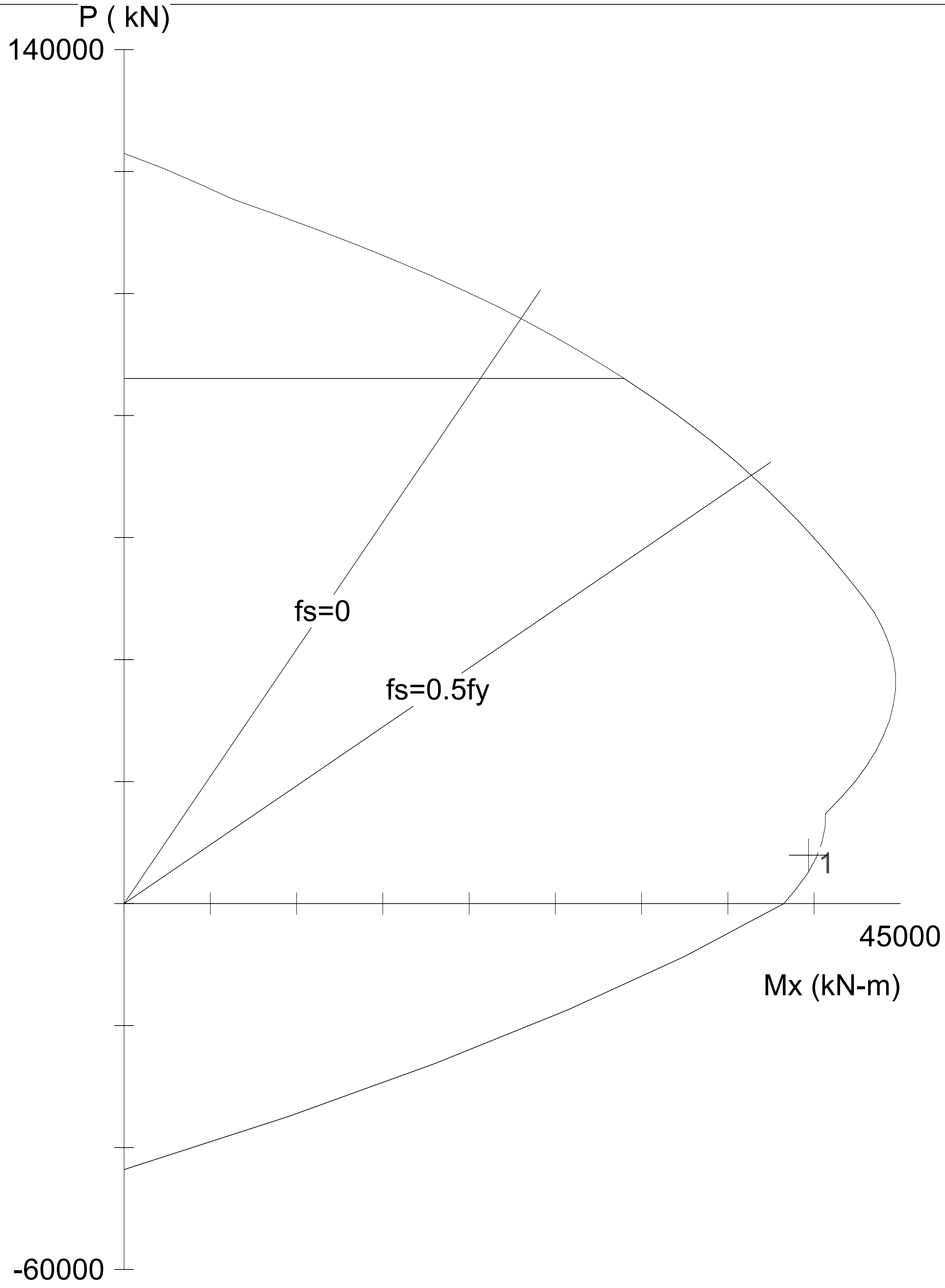
Slenderness: Not considered

Column type: Structural

Bars: User-defined

Date: 08/19/06

Time: 11:31:11



PCACOL V3.00 (PCA 1999) - Licensed to: KEI, MANILA, ST

File: C:\0-BALA~1\RC-DES~1\BOREPI~1\2.5M\P4\P4XSEC-1.COL

Project: BALARAJA FLYOVER

Column: BP-P4

Engineer:

f'c = 30 MPa	fy = 345 MPa	Ag = 4.90874e+006 mm^2	78 #51 bars
Ec = 25743 MPa	Es = 200000 MPa	As = 158106 mm^2	Rho = 3.22%
fc = 25.5 MPa	e_rup = Infinity	Xo = 0 mm	Iy = 1.92e+012 mm^4
e_u = 0.003 mm/mm		Yo = 0 mm	Iy = 1.92e+012 mm^4
Beta1 = 0.83245		Clear spacing = 83 mm	Clear cover = 119 mm

Confinement: Other

phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

```
0000000    00000    00000    00000    00000   00
00    00  00   00  00   00  00   00  00   00  00
00    00  00   00  00   00  00   00  00   00  00
00    00  00       00   00  00       00   00  00
00    00  00       0000000  00       00   00  00
0000000   00   00  00   00  00   00  00   00  00
00        00   00  00   00  00   00  00   00  00
00         00000   00   00   00000    00000   00000  (TM)
```

===
Computer program for the Strength Design of Reinforced Concrete Sections
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General Information:
====================

File Name: I:\1-BALA~1\RC-DES~1\BOREPI~1\2.5M\P4\BP78D51.COL
Project: BALARAJA FLYOVER
Column: BP-P4 Engineer:
Code: ACI 318-95 Units: Metric

Run Option: Investigation Slenderness: Not considered
Run Axis: X-axis Column Type: Structural

Material Properties:
====================

f'c = 30 MPa fy = 345 MPa
Ec = 25743 MPa Es = 200000 MPa
fc = 25.5 MPa Rupture strain = Infinity
Ultimate strain = 0.003 mm/mm
Beta1 = 0.83245

Section:
========

Circular: Diameter = 2500 mm

Gross section area, Ag = 4.90874e+006 mm^2
Ix = 1.91748e+012 mm^4 Iy = 1.91748e+012 mm^4
Xo = 0 mm Yo = 0 mm

Reinforcement:
==============

Rebar Database: User-defined

Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)
# 6	6	28	# 8	8	50	# 10	10	79
# 12	12	113	# 14	14	154	# 16	16	201
# 20	20	314	# 25	25	491	# 28	28	616
# 32	32	801	# 40	40	1256	# 51	51	2027

Confinement: User-defined; #6 ties with #25 bars, #6 with larger bars.
phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

Pattern: Irregular

Total steel area, As = 158106 mm^2 at 3.22%

Area mm^2	X (mm)	Y (mm)	Area mm^2	X (mm)	Y (mm)	Area mm^2	X (mm)	Y (mm)
2027	0	1106	2027	133	1097	2027	265	1073
2027	392	1034	2027	514	979	2027	628	910
2027	733	827	2027	827	733	2027	910	628
2027	979	514	2027	1034	392	2027	1073	265
2027	1097	133	2027	1106	-0	2027	1097	-133
2027	1073	-265	2027	1034	-392	2027	979	-514
2027	910	-628	2027	827	-733	2027	733	-827
2027	628	-910	2027	514	-979	2027	392	-1034
2027	265	-1073	2027	133	-1097	2027	-0	-1106
2027	-133	-1097	2027	-265	-1073	2027	-392	-1034
2027	-514	-979	2027	-628	-910	2027	-733	-827
2027	-827	-733	2027	-910	-628	2027	-979	-514
2027	-1034	-392	2027	-1073	-265	2027	-1097	-133
2027	-1106	0	2027	-1097	133	2027	-1073	265
2027	-1034	392	2027	-979	514	2027	-910	628
2027	-827	733	2027	-733	827	2027	-628	910
2027	-514	979	2027	-392	1034	2027	-265	1073
2027	-133	1097	2027	113	929	2027	-113	929
2027	113	-929	2027	-113	-929	2027	332	875
2027	-332	875	2027	332	-875	2027	-332	-875
2027	531	770	2027	-531	770	2027	531	-770
2027	-531	-770	2027	700	620	2027	-700	620

2027	700	-620	2027	-700	-620	2027	828	435
2027	-828	435	2027	828	-435	2027	-828	-435
2027	908	224	2027	-908	224	2027	-908	-224
2027	908	-224	2027	936	0	2027	-936	0

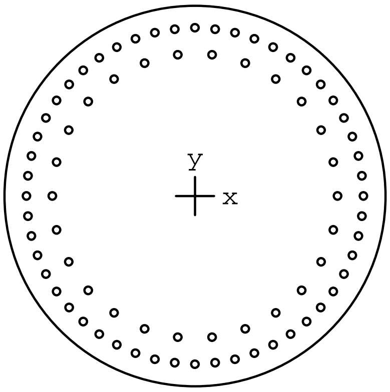
Factored Loads and Moments with Corresponding Capacities: (see user's manual for notation)

No.	Pu kN	Mux kN-m	fMnx kN-m	fMn/Mu
1	7950.0	39674.8	40187.3	1.013

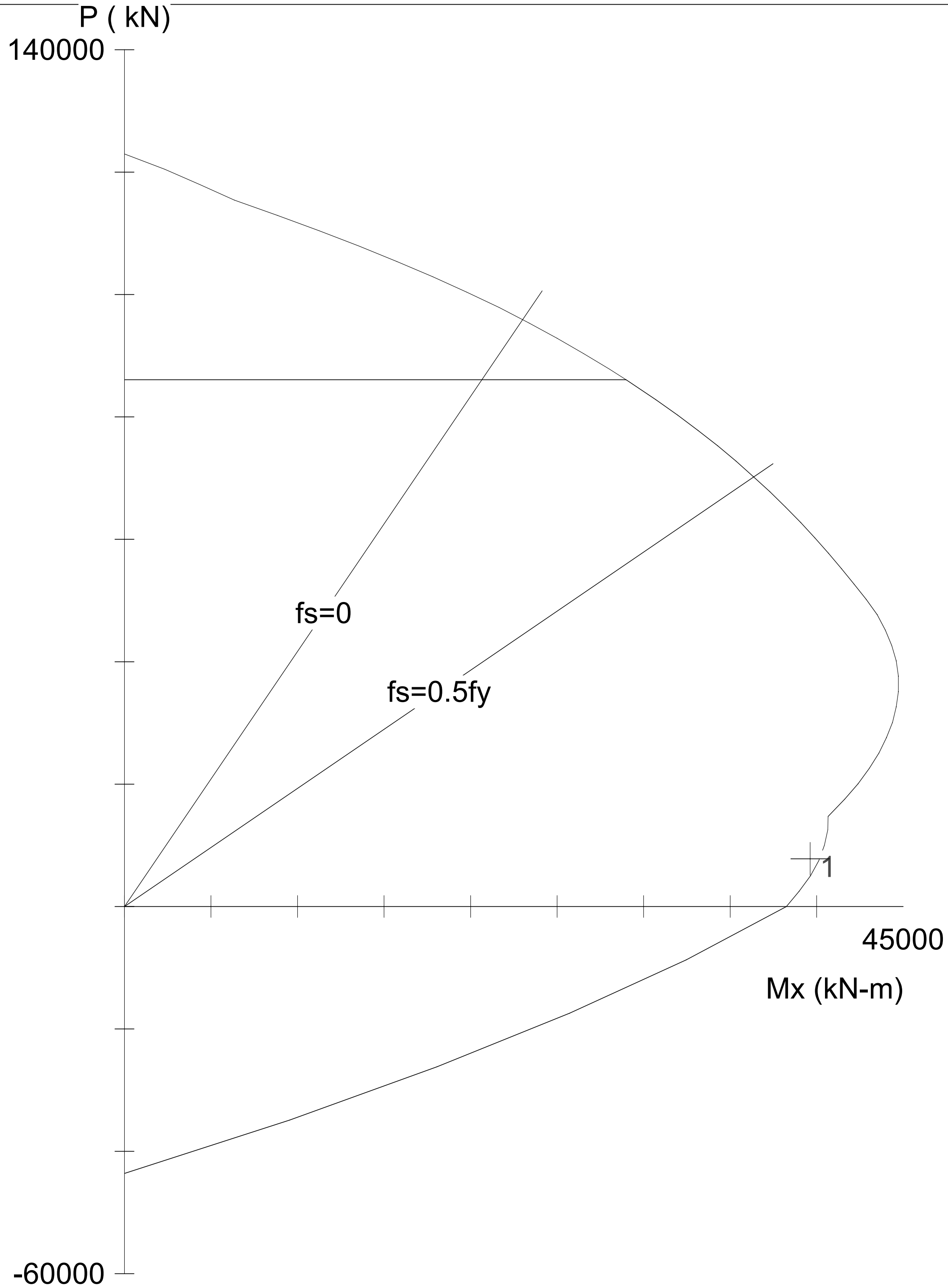
*** Program completed as requested! ***

TABLE: Element Forces - 2.5m PILE at PIER P5, BP1 2.0 m below NGL						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP1	0	P5-LOAD	Max	-6886.7	4750	21139
BP1	1	P5-LOAD	Max	-6750	4750	16389
BP1	0	P5-LOAD	Min	-6886.7	4750	21139
BP1	1	P5-LOAD	Min	-6750	4750	16389
BP2	0	P5-LOAD	Max	-7023.4	4396.1	25535.1
BP2	1	P5-LOAD	Max	-6886.7	4396.1	21139
BP2	0	P5-LOAD	Min	-7023.4	4396.1	25535.1
BP2	1	P5-LOAD	Min	-6886.7	4396.1	21139
BP3	0	P5-LOAD	Max	-7160.1	4042.9	29578.1
BP3	1	P5-LOAD	Max	-7023.4	4042.9	25535.1
BP3	0	P5-LOAD	Min	-7160.1	4042.9	29578.1
BP3	1	P5-LOAD	Min	-7023.4	4042.9	25535.1
BP4	0	P5-LOAD	Max	-7296.9	3364.2	32942.3
BP4	1	P5-LOAD	Max	-7160.1	3364.2	29578.1
BP4	0	P5-LOAD	Min	-7296.9	3364.2	32942.3
BP4	1	P5-LOAD	Min	-7160.1	3364.2	29578.1
BP5	0	P5-LOAD	Max	-7433.6	2686.3	35628.6
BP5	1	P5-LOAD	Max	-7296.9	2686.3	32942.3
BP5	0	P5-LOAD	Min	-7433.6	2686.3	35628.6
BP5	1	P5-LOAD	Min	-7296.9	2686.3	32942.3
BP6	0	P5-LOAD	Max	-7570.3	2009.2	37637.8
BP6	1	P5-LOAD	Max	-7433.6	2009.2	35628.6
BP6	0	P5-LOAD	Min	-7570.3	2009.2	37637.8
BP6	1	P5-LOAD	Min	-7433.6	2009.2	35628.6
BP7	0	P5-LOAD	Max	-7686	1332.9	38970.7
BP7	1	P5-LOAD	Max	-7570.3	1332.9	37637.8
BP7	0	P5-LOAD	Min	-7686	1332.9	38970.7
BP7	1	P5-LOAD	Min	-7570.3	1332.9	37637.8
BP8	0	P5-LOAD	Max	-7801.6	657.2	39627.9
BP8	1	P5-LOAD	Max	-7686	657.2	38970.7
BP8	0	P5-LOAD	Min	-7801.6	657.2	39627.9
BP8	1	P5-LOAD	Min	-7686	657.2	38970.7
BP9	0	P5-LOAD	Max	-7917.3	-93	39534.9
BP9	1	P5-LOAD	Max	-7801.6	-93	39627.9
BP9	0	P5-LOAD	Min	-7917.3	-93	39534.9
BP9	1	P5-LOAD	Min	-7801.6	-93	39627.9
BP10	0	P5-LOAD	Max	-8032.9	-842.8	38692.1
BP10	1	P5-LOAD	Max	-7917.3	-842.8	39534.9
BP10	0	P5-LOAD	Min	-8032.9	-842.8	38692.1
BP10	1	P5-LOAD	Min	-7917.3	-842.8	39534.9

TABLE: Element Forces - 2.5m PILE at PIER P5, BP1 2.0 m below NGL						
Frame	**Station**	**OutputCase**	**StepType**	**P AXIAL**	**V2 SHEAR**	**M3 MOMENT**
Text	m	Text	Text	KN	KN	KN-m
BP11	0	P5-LOAD	Max	-8148.6	-2392.4	36299.7
BP11	1	P5-LOAD	Max	-8032.9	-2392.4	38692.1
BP11	0	P5-LOAD	Min	-8148.6	-2392.4	36299.7
BP11	1	P5-LOAD	Min	-8032.9	-2392.4	38692.1
BP12	0	P5-LOAD	Max	-8264.3	-3927.5	32372.1
BP12	1	P5-LOAD	Max	-8148.6	-3927.5	36299.7
BP12	0	P5-LOAD	Min	-8264.3	-3927.5	32372.1
BP12	1	P5-LOAD	Min	-8148.6	-3927.5	36299.7
BP13	0	P5-LOAD	Max	-8379.9	-4849.3	27522.9
BP13	1	P5-LOAD	Max	-8264.3	-4849.3	32372.1
BP13	0	P5-LOAD	Min	-8379.9	-4849.3	27522.9
BP13	1	P5-LOAD	Min	-8264.3	-4849.3	32372.1
BP14	0	P5-LOAD	Max	-8495.6	-5256.9	22266
BP14	1	P5-LOAD	Max	-8379.9	-5256.9	27522.9
BP14	0	P5-LOAD	Min	-8495.6	-5256.9	22266
BP14	1	P5-LOAD	Min	-8379.9	-5256.9	27522.9
BP15	0	P5-LOAD	Max	-8611.3	-5272.4	16993.5
BP15	1	P5-LOAD	Max	-8495.6	-5272.4	22266
BP15	0	P5-LOAD	Min	-8611.3	-5272.4	16993.5
BP15	1	P5-LOAD	Min	-8495.6	-5272.4	22266
BP16	0	P5-LOAD	Max	-8726.9	-5043.9	11949.7
BP16	1	P5-LOAD	Max	-8611.3	-5043.9	16993.5
BP16	0	P5-LOAD	Min	-8726.9	-5043.9	11949.7
BP16	1	P5-LOAD	Min	-8611.3	-5043.9	16993.5
BP17	0	P5-LOAD	Max	-8842.6	-4415	7534.7
BP17	1	P5-LOAD	Max	-8726.9	-4415	11949.7
BP17	0	P5-LOAD	Min	-8842.6	-4415	7534.7
BP17	1	P5-LOAD	Min	-8726.9	-4415	11949.7
BP18	0	P5-LOAD	Max	-8958.3	-3574.8	3959.8
BP18	1	P5-LOAD	Max	-8842.6	-3574.8	7534.7
BP18	0	P5-LOAD	Min	-8958.3	-3574.8	3959.8
BP18	1	P5-LOAD	Min	-8842.6	-3574.8	7534.7
BP19	0	P5-LOAD	Max	-9073.9	-2562.9	1397
BP19	1	P5-LOAD	Max	-8958.3	-2562.9	3959.8
BP19	0	P5-LOAD	Min	-9073.9	-2562.9	1397
BP19	1	P5-LOAD	Min	-8958.3	-2562.9	3959.8
BP20	0	P5-LOAD	Max	-9189.6	-1397	0
BP20	1	P5-LOAD	Max	-9073.9	-1397	1397
BP20	0	P5-LOAD	Min	-9189.6	-1397	0
BP20	1	P5-LOAD	Min	-9073.9	-1397	1397



2500 mm diam.



Code: ACI 318-95

Units: Metric

Run axis: About X-axis

Run option: Investigation

Slenderness: Not considered

Column type: Structural

Bars: User-defined

Date: 08/19/06

Time: 11:33:42

PCACOL V3.00 (PCA 1999) - Licensed to: KEI, MANILA, ST

File: C:\0-BALA~1\RC-DES~1\BOREPI~1\2.5M\P5\P5XSEC1.COL

Project: BALARAJA FLYOVER

Column: BP-P5

Engineer:

f'c = 30 MPa	fy = 345 MPa	Ag = 4.90874e+006 mm^2	78 #51 bars
Ec = 25743 MPa	Es = 200000 MPa	As = 158106 mm^2	Rho = 3.22%
fc = 25.5 MPa	e_rup = Infinity	Xo = 0 mm	Iy = 1.92e+012 mm^4
e_u = 0.003 mm/mm		Yo = 0 mm	Iy = 1.92e+012 mm^4
Beta1 = 0.83245		Clear spacing = 83 mm	Clear cover = 119 mm

Confinement: Other phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

```
OOOOOOO    OOOOO    OOOOO    OOOOO    OOOOO   OO
OO    OO  OO   OO  OO   OO  OO   OO  OO   OO  OO
OO    OO  OO   OO  OO   OO  OO   OO  OO   OO  OO
OO    OO  OO       OO   OO  OO       OO   OO  OO
OO    OO  OO       OOOOOOO  OO       OO   OO  OO
OOOOOOO   OO   OO  OO   OO  OO   OO  OO   OO  OO
OO        OO   OO  OO   OO  OO   OO  OO   OO  OO
OO         OOOOO   OO   OO   OOOOO    OOOOO   OOOOO  (TM)
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Computer program for the Strength Design of Reinforced Concrete Sections

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General Information:
====================
File Name: I:\1-BALA~1\RC-DES~1\BOREPI~1\2.5M\P5\BP78D51.COL
Project: BALARAJA FLYOVER
Column: BP-P4 Engineer:
Code: ACI 318-95 Units: Metric

Run Option: Investigation Slenderness: Not considered
Run Axis: X-axis Column Type: Structural

Material Properties:
====================
f'c = 30 MPa fy = 345 MPa
Ec = 25743 MPa Es = 200000 MPa
fc = 25.5 MPa Rupture strain = Infinity
Ultimate strain = 0.003 mm/mm
Beta1 = 0.83245

Section:
========
Circular: Diameter = 2500 mm

Gross section area, Ag = 4.90874e+006 mm^2
Ix = 1.91748e+012 mm^4 Iy = 1.91748e+012 mm^4
Xo = 0 mm Yo = 0 mm

Reinforcement:
==============
Rebar Database: User-defined

Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)
# 6	6	28	# 8	8	50	# 10	10	79
# 12	12	113	# 14	14	154	# 16	16	201
# 20	20	314	# 25	25	491	# 28	28	616
# 32	32	801	# 40	40	1256	# 51	51	2027

Confinement: User-defined; #6 ties with #25 bars, #6 with larger bars.
phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

Pattern: Irregular

Total steel area, As = 158106 mm^2 at 3.22%

Area mm^2	X (mm)	Y (mm)	Area mm^2	X (mm)	Y (mm)	Area mm^2	X (mm)	Y (mm)
2027	0	1106	2027	133	1097	2027	265	1073
2027	392	1034	2027	514	979	2027	628	910
2027	733	827	2027	827	733	2027	910	628
2027	979	514	2027	1034	392	2027	1073	265
2027	1097	133	2027	1106	-0	2027	1097	-133
2027	1073	-265	2027	1034	-392	2027	979	-514
2027	910	-628	2027	827	-733	2027	733	-827
2027	628	-910	2027	514	-979	2027	392	-1034
2027	265	-1073	2027	133	-1097	2027	-0	-1106
2027	-133	-1097	2027	-265	-1073	2027	-392	-1034
2027	-514	-979	2027	-628	-910	2027	-733	-827
2027	-827	-733	2027	-910	-628	2027	-979	-514
2027	-1034	-392	2027	-1073	-265	2027	-1097	-133
2027	-1106	0	2027	-1097	133	2027	-1073	265
2027	-1034	392	2027	-979	514	2027	-910	628
2027	-827	733	2027	-733	827	2027	-628	910
2027	-514	979	2027	-392	1034	2027	-265	1073
2027	-133	1097	2027	113	929	2027	-113	929
2027	113	-929	2027	-113	-929	2027	332	875
2027	-332	875	2027	332	-875	2027	-332	-875
2027	531	770	2027	-531	770	2027	531	-770
2027	-531	-770	2027	700	620	2027	-700	620

2027	700	-620	2027	-700	-620	2027	828	435
2027	-828	435	2027	828	-435	2027	-828	-435
2027	908	224	2027	-908	224	2027	-908	-224
2027	908	-224	2027	936	0	2027	-936	0

Factored Loads and Moments with Corresponding Capacities: (see user's manual for notation)

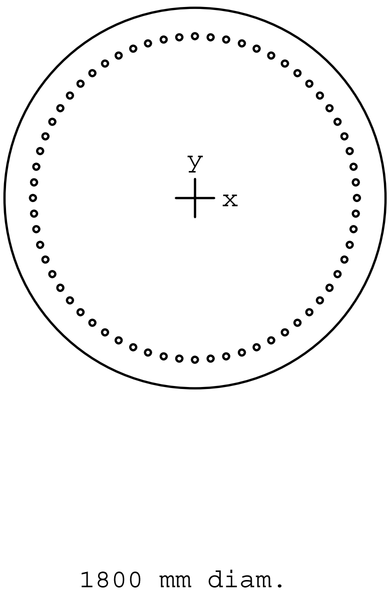
No.	Pu kN	Mux kN-m	fMnx kN-m	fMn/Mu
1	7950.0	39674.8	40187.3	1.013

*** Program completed as requested! ***

LOAD EFFECTS 1.8 M PILES

TABLE: Element Forces - 2.5m PILE at ABUTMENT A1						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP-1	0	A1	Max	-2529.3	1477.4	8105.1
BP-1	1	A1	Max	-2467.0	1477.4	6627.7
BP-1	0	A1	Min	-2529.3	1477.4	8105.1
BP-1	1	A1	Min	-2467.0	1477.4	6627.7
BP-2	0	A1	Max	-2591.7	1218.6	9323.7
BP-2	1	A1	Max	-2529.3	1218.6	8105.1
BP-2	0	A1	Min	-2591.7	1218.6	9323.7
BP-2	1	A1	Min	-2529.3	1218.6	8105.1
BP-3	0	A1	Max	-2654.0	961.2	10284.9
BP-3	1	A1	Max	-2591.7	961.2	9323.7
BP-3	0	A1	Min	-2654.0	961.2	10284.9
BP-3	1	A1	Min	-2591.7	961.2	9323.7
BP-4	0	A1	Max	-2716.4	602.8	10887.8
BP-4	1	A1	Max	-2654.0	602.8	10284.9
BP-4	0	A1	Min	-2716.4	602.8	10887.8
BP-4	1	A1	Min	-2654.0	602.8	10284.9
BP-5	0	A1	Max	-2778.7	246.2	11134.0
BP-5	1	A1	Max	-2716.4	246.2	10887.8
BP-5	0	A1	Min	-2778.7	246.2	11134.0
BP-5	1	A1	Min	-2716.4	246.2	10887.8
BP-6	0	A1	Max	-2841.1	-108.8	11025.1
BP-6	1	A1	Max	-2778.7	-108.8	11134.0
BP-6	0	A1	Min	-2841.1	-108.8	11025.1
BP-6	1	A1	Min	-2778.7	-108.8	11134.0
BP-7	0	A1	Max	-2903.4	-477.8	10547.3
BP-7	1	A1	Max	-2841.1	-477.8	11025.1
BP-7	0	A1	Min	-2903.4	-477.8	10547.3
BP-7	1	A1	Min	-2841.1	-477.8	11025.1
BP-8	0	A1	Max	-2965.8	-1086.8	9460.5
BP-8	1	A1	Max	-2903.4	-1086.8	10547.3
BP-8	0	A1	Min	-2965.8	-1086.8	9460.5
BP-8	1	A1	Min	-2903.4	-1086.8	10547.3
BP-9	0	A1	Max	-3028.1	-1416.8	8043.7
BP-9	1	A1	Max	-2965.8	-1416.8	9460.5
BP-9	0	A1	Min	-3028.1	-1416.8	8043.7
BP-9	1	A1	Min	-2965.8	-1416.8	9460.5
BP-10	0	A1	Max	-3090.4	-1577.4	6466.4
BP-10	1	A1	Max	-3028.1	-1577.4	8043.7
BP-10	0	A1	Min	-3090.4	-1577.4	6466.4
BP-10	1	A1	Min	-3028.1	-1577.4	8043.7

TABLE: Element Forces - 2.5m PILE at ABUTMENT A1						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP-11	0	A1	Max	-3152.8	-1573.9	4892.4
BP-11	1	A1	Max	-3090.4	-1573.9	6466.4
BP-11	0	A1	Min	-3152.8	-1573.9	4892.4
BP-11	1	A1	Min	-3090.4	-1573.9	6466.4
BP-12	0	A1	Max	-3215.1	-1414.5	3477.9
BP-12	1	A1	Max	-3152.8	-1414.5	4892.4
BP-12	0	A1	Min	-3215.1	-1414.5	3477.9
BP-12	1	A1	Min	-3152.8	-1414.5	4892.4
BP-13	0	A1	Max	-3277.5	-1178.3	2299.7
BP-13	1	A1	Max	-3215.1	-1178.3	3477.9
BP-13	0	A1	Min	-3277.5	-1178.3	2299.7
BP-13	1	A1	Min	-3215.1	-1178.3	3477.9
BP-14	0	A1	Max	-3339.8	-910.3	1389.4
BP-14	1	A1	Max	-3277.5	-910.3	2299.7
BP-14	0	A1	Min	-3339.8	-910.3	1389.4
BP-14	1	A1	Min	-3277.5	-910.3	2299.7
BP-15	0	A1	Max	-3402.2	-655.0	734.4
BP-15	1	A1	Max	-3339.8	-655.0	1389.4
BP-15	0	A1	Min	-3402.2	-655.0	734.4
BP-15	1	A1	Min	-3339.8	-655.0	1389.4
BP-16	0	A1	Max	-3464.5	-419.0	315.4
BP-16	1	A1	Max	-3402.2	-419.0	734.4
BP-16	0	A1	Min	-3464.5	-419.0	315.4
BP-16	1	A1	Min	-3402.2	-419.0	734.4
BP-17	0	A1	Max	-3526.9	-230.8	84.6
BP-17	1	A1	Max	-3464.5	-230.8	315.4
BP-17	0	A1	Min	-3526.9	-230.8	84.6
BP-17	1	A1	Min	-3464.5	-230.8	315.4
BP-18	0	A1	Max	-3589.2	-94.5	-9.9
BP-18	1	A1	Max	-3526.9	-94.5	84.6
BP-18	0	A1	Min	-3589.2	-94.5	-9.9
BP-18	1	A1	Min	-3526.9	-94.5	84.6
BP-19	0	A1	Max	-3651.6	-10.9	-20.8
BP-19	1	A1	Max	-3589.2	-10.9	-9.9
BP-19	0	A1	Min	-3651.6	-10.9	-20.8
BP-19	1	A1	Min	-3589.2	-10.9	-9.9
BP-20	0	A1	Max	-3713.9	20.8	0.0
BP-20	1	A1	Max	-3651.6	20.8	-20.8
BP-20	0	A1	Min	-3713.9	20.8	0.0
BP-20	1	A1	Min	-3651.6	20.8	-20.8



Code: ACI 318-95

Units: Metric

Run axis: About X-axis

Run option: Investigation

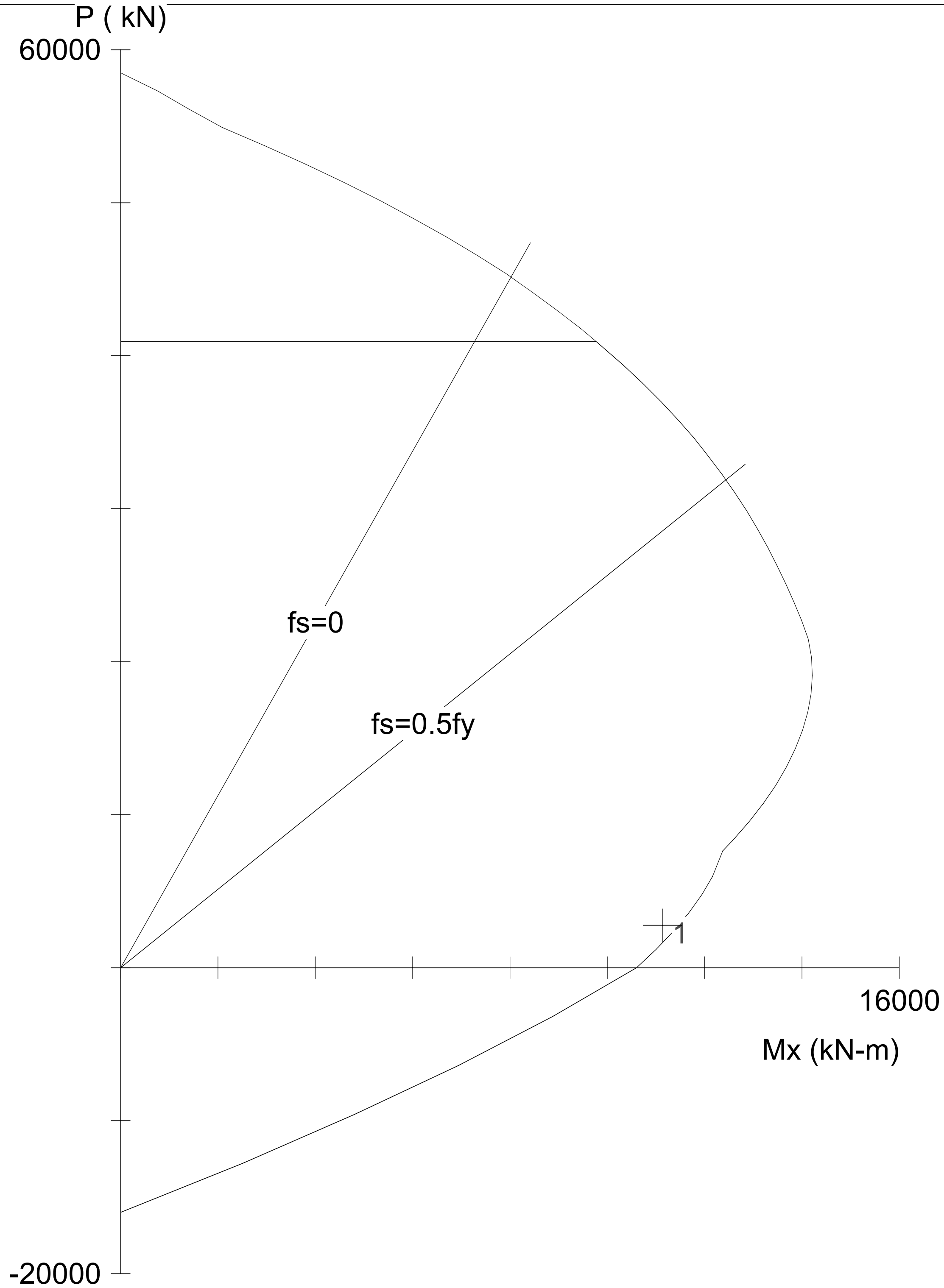
Slenderness: Not considered

Column type: Structural

Bars: prEN 10080

Date: 08/19/06

Time: 11:34:49



PCACOL V3.00 (PCA 1999) - Licensed to: KEI, MANILA, ST

File: C:\0-BALA~1\RC-DES~1\BOREPI~1\1.8M\BP-A1-T.COL

Project: BALARAJA FLYOVER

Column: A1-BP-TOP		Engineer:	
f'c = 30 MPa	fy = 390 MPa	Ag = 2.54469e+006 mm^2	64 #32 bars
Ec = 25743 MPa	Es = 200000 MPa	As = 51264 mm^2	Rho = 2.01%
fc = 25.5 MPa	e_rup = Infinity	Xo = 0 mm	Iy = 5.15e+011 mm^4
e_u = 0.003 mm/mm		Yo = 0 mm	Iy = 5.15e+011 mm^4
Beta1 = 0.83245		Clear spacing = 43 mm	Clear cover = 119 mm

Confinement: Other phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

```
OOOOOOO    OOOOO    OOOOO    OOOOO    OOOOO   OO
OO    OO  OO   OO  OO   OO  OO   OO  OO   OO  OO
OO    OO  OO   OO  OO   OO  OO   OO  OO   OO  OO
OO    OO  OO       OO   OO  OO       OO   OO  OO
OO    OO  OO       OOOOOOO  OO       OO   OO  OO
OOOOOOO   OO   OO  OO   OO  OO   OO  OO   OO  OO
OO        OO   OO  OO   OO  OO   OO  OO   OO  OO
OO         OOOOO   OO   OO   OOOOO    OOOOO   OOOOO  (TM)
```

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Computer program for the Strength Design of Reinforced Concrete Sections
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General Information:
====================

File Name: I:\1-BALA~1\RC-DES~1\BOREPI~1\1.8M\BP-A1-T.COL
Project: BALARAJA FLYOVER
Column: A1-BP-TOP Engineer:
Code: ACI 318-95 Units: Metric

Run Option: Investigation Slenderness: Not considered
Run Axis: X-axis Column Type: Structural

Material Properties:
====================

f'c = 30 MPa fy = 390 MPa
Ec = 25743 MPa Es = 200000 MPa
fc = 25.5 MPa Rupture strain = Infinity
Ultimate strain = 0.003 mm/mm
Beta1 = 0.83245

Section:
========

Circular: Diameter = 1800 mm

Gross section area, Ag = 2.54469e+006 mm^2
Ix = 5.153e+011 mm^4 Iy = 5.153e+011 mm^4
Xo = 0 mm Yo = 0 mm

Reinforcement:
==============

Rebar Database: prEN 10080

Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)
# 6	6	28	# 8	8	50	# 10	10	79
# 12	12	113	# 14	14	154	# 16	16	201
# 20	20	314	# 25	25	491	# 28	28	616
# 32	32	801	# 40	40	1256			

Confinement: User-defined; #6 ties with #25 bars, #6 with larger bars.
phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

Layout: Circular
Pattern: All Sides Equal (Cover to longitudinal reinforcement)
Total steel area, As = 51264 mm^2 at 2.01%
64 #32 Cover = 119 mm

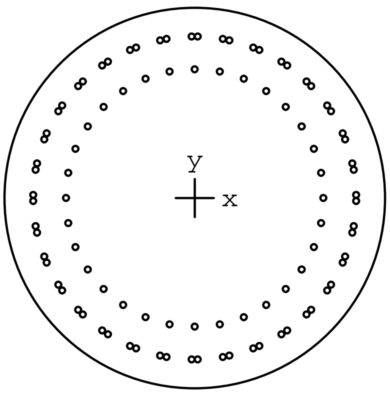
Factored Loads and Moments with Corresponding Capacities: (see user's manual for notation)
===

No.	Pu kN	Mux kN-m	fMnx kN-m	fMn/Mu
1	2779.0	11134.0	11470.0	1.030

*** Program completed as requested! ***

TABLE: Element Forces - ABUTMENT A2						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
A1	0	ABUT2	Max	-1350.0	-1771.6	7790.5
A1	1	ABUT2	Max	-1412.3	-1771.6	9592.7
A1	0	ABUT2	Min	-1350.0	-1771.6	7790.5
A1	1	ABUT2	Min	-1412.3	-1771.6	9592.7
A2	0	ABUT2	Max	-1412.3	-1467.0	9592.7
A2	1	ABUT2	Max	-1474.7	-1467.0	11089.5
A2	0	ABUT2	Min	-1412.3	-1467.0	9592.7
A2	1	ABUT2	Min	-1474.7	-1467.0	11089.5
A3	0	ABUT2	Max	-1474.7	-1166.0	11089.5
A3	1	ABUT2	Max	-1537.0	-1166.0	12284.2
A3	0	ABUT2	Min	-1474.7	-1166.0	11089.5
A3	1	ABUT2	Min	-1537.0	-1166.0	12284.2
A4	0	ABUT2	Max	-1537.0	-863.6	12284.2
A4	1	ABUT2	Max	-1599.4	-863.6	13174.7
A4	0	ABUT2	Min	-1537.0	-863.6	12284.2
A4	1	ABUT2	Min	-1599.4	-863.6	13174.7
A5	0	ABUT2	Max	-1599.4	-503.0	13174.7
A5	1	ABUT2	Max	-1661.7	-503.0	13702.4
A5	0	ABUT2	Min	-1599.4	-503.0	13174.7
A5	1	ABUT2	Min	-1661.7	-503.0	13702.4
A6	0	ABUT2	Max	-1661.7	-141.5	13702.4
A6	1	ABUT2	Max	-1724.1	-141.5	13866.1
A6	0	ABUT2	Min	-1661.7	-141.5	13702.4
A6	1	ABUT2	Min	-1724.1	-141.5	13866.1
A7	0	ABUT2	Max	-1724.1	288.7	13866.1
A7	1	ABUT2	Max	-1786.4	288.7	13596.5
A7	0	ABUT2	Min	-1724.1	288.7	13866.1
A7	1	ABUT2	Min	-1786.4	288.7	13596.5
A8	0	ABUT2	Max	-1786.4	718.6	13596.5
A8	1	ABUT2	Max	-1848.8	718.6	12894.0
A8	0	ABUT2	Min	-1786.4	718.6	13596.5
A8	1	ABUT2	Min	-1848.8	718.6	12894.0
A9	0	ABUT2	Max	-1848.8	1291.2	12894.0
A9	1	ABUT2	Max	-1911.1	1291.2	11615.7
A9	0	ABUT2	Min	-1848.8	1291.2	12894.0
A9	1	ABUT2	Min	-1911.1	1291.2	11615.7
A10	0	ABUT2	Max	-1911.1	1607.7	11615.7
A10	1	ABUT2	Max	-1973.5	1607.7	10017.8
A10	0	ABUT2	Min	-1911.1	1607.7	11615.7
A10	1	ABUT2	Min	-1973.5	1607.7	10017.8

TABLE: Element Forces - ABUTMENT A2						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
A11	0	ABUT2	Max	-1973.5	1748.1	10017.8
A11	1	ABUT2	Max	-2035.8	1748.1	8276.7
A11	0	ABUT2	Min	-1973.5	1748.1	10017.8
A11	1	ABUT2	Min	-2035.8	1748.1	8276.7
A12	0	ABUT2	Max	-2035.8	1743.9	8276.7
A12	1	ABUT2	Max	-2098.1	1743.9	6537.5
A12	0	ABUT2	Min	-2035.8	1743.9	8276.7
A12	1	ABUT2	Min	-2098.1	1743.9	6537.5
A13	0	ABUT2	Max	-2098.1	1649.8	6537.5
A13	1	ABUT2	Max	-2160.5	1649.8	4890.3
A13	0	ABUT2	Min	-2098.1	1649.8	6537.5
A13	1	ABUT2	Min	-2160.5	1649.8	4890.3
A14	0	ABUT2	Max	-2160.5	1506.1	4890.3
A14	1	ABUT2	Max	-2222.8	1506.1	3385.3
A14	0	ABUT2	Min	-2160.5	1506.1	4890.3
A14	1	ABUT2	Min	-2222.8	1506.1	3385.3
A15	0	ABUT2	Max	-2222.8	1231.3	3385.3
A15	1	ABUT2	Max	-2285.2	1231.3	2153.9
A15	0	ABUT2	Min	-2222.8	1231.3	3385.3
A15	1	ABUT2	Min	-2285.2	1231.3	2153.9
A16	0	ABUT2	Max	-2285.2	958.5	2153.9
A16	1	ABUT2	Max	-2347.5	958.5	1194.6
A16	0	ABUT2	Min	-2285.2	958.5	2153.9
A16	1	ABUT2	Min	-2347.5	958.5	1194.6
A17	0	ABUT2	Max	-2347.5	709.7	1194.6
A17	1	ABUT2	Max	-2409.9	709.7	483.7
A17	0	ABUT2	Min	-2347.5	709.7	1194.6
A17	1	ABUT2	Min	-2409.9	709.7	483.7
A18	0	ABUT2	Max	-2409.9	497.0	483.7
A18	1	ABUT2	Max	-2472.2	497.0	-14.8
A18	0	ABUT2	Min	-2409.9	497.0	483.7
A18	1	ABUT2	Min	-2472.2	497.0	-14.8
A19	0	ABUT2	Max	-2472.2	325.4	-14.8
A19	1	ABUT2	Max	-2534.6	325.4	-341.7
A19	0	ABUT2	Min	-2472.2	325.4	-14.8
A19	1	ABUT2	Min	-2534.6	325.4	-341.7
A20	0	ABUT2	Max	-2534.6	194.3	-341.7
A20	1	ABUT2	Max	-2596.9	194.3	-537.4
A20	0	ABUT2	Min	-2534.6	194.3	-341.7
A20	1	ABUT2	Min	-2596.9	194.3	-537.4



1800 mm diam.

Code: ACI 318-95

Units: Metric

Run axis: About X-axis

Run option: Investigation

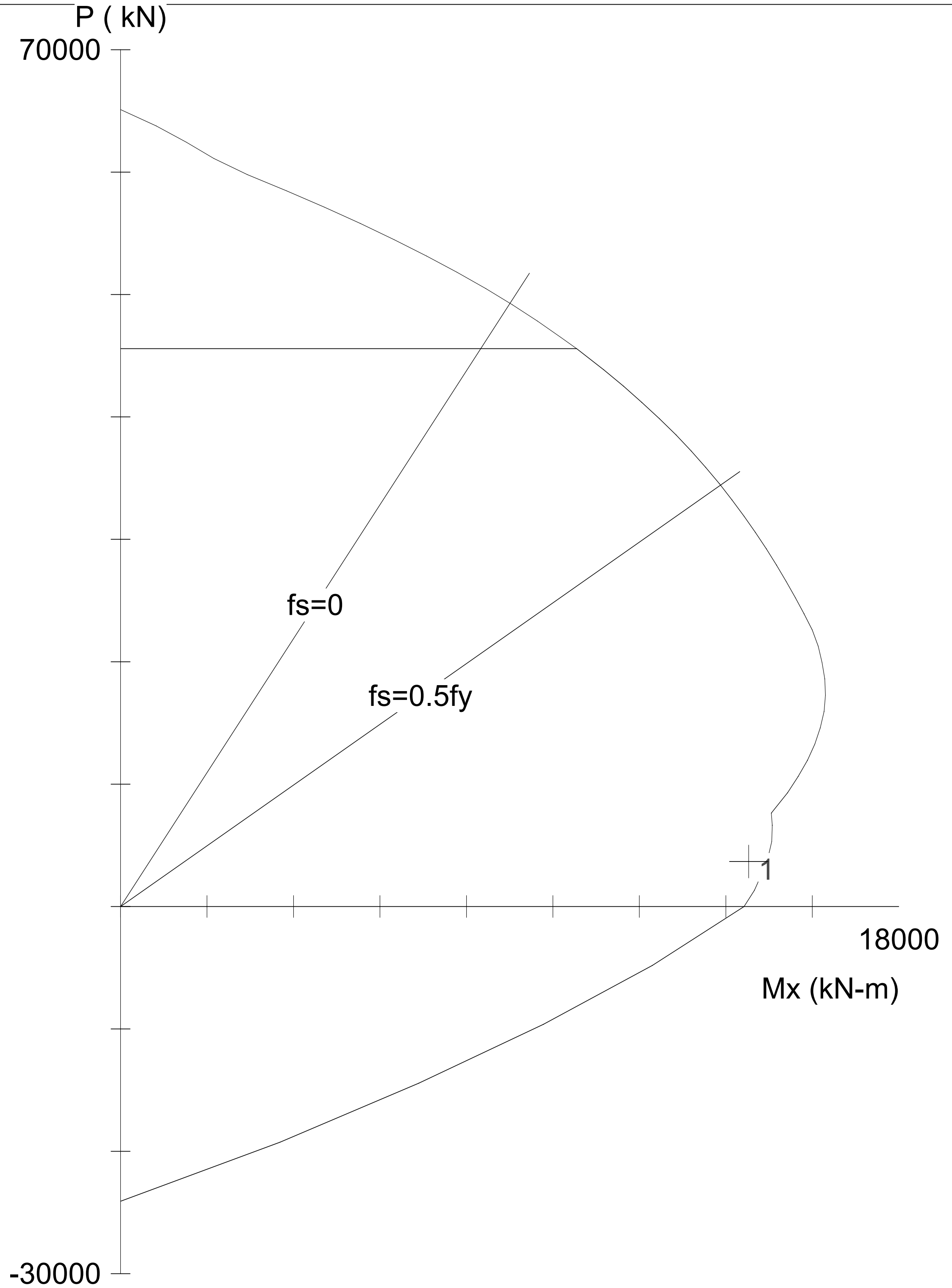
Slenderness: Not considered

Column type: Structural

Bars: prEN 10080

Date: 08/19/06

Time: 16:43:45



PCACOL V3.00 (PCA 1999) - Licensed to: KEI, MANILA, ST

File: C:\0-BALA~1\RC-DES~1\BOREPI~1\1.8M\BP-A2-T.COL

Project: BALARAJA FLYOVER

Column: A2-BP-TOP		Engineer:	
f'c = 30 MPa	fy = 390 MPa	Ag = 2.54469e+006 mm^2	96 bars
Ec = 25743 MPa	Es = 200000 MPa	As = 77184 mm^2	Rho = 3.03%
fc = 25.5 MPa	e_rup = Infinity	Xo = 0 mm	Iy = 5.15e+011 mm^4
e_u = 0.003 mm/mm		Yo = 0 mm	Iy = 5.15e+011 mm^4
Beta1 = 0.83245		Clear spacing = 0 mm	Clear cover = 119 mm
Confinement: Other	phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7		

```
OOOOOOO    OOOOO    OOOOO    OOOOO    OOOOO   OO
OO    OO  OO   OO  OO   OO  OO   OO  OO   OO  OO
OO    OO  OO   OO  OO   OO  OO   OO  OO   OO  OO
OO    OO  OO       OO   OO  OO       OO   OO  OO
OO    OO  OO       OOOOOOO  OO       OO   OO  OO
OOOOOOO   OO   OO  OO   OO  OO   OO  OO   OO  OO
OO        OO   OO  OO   OO  OO   OO  OO   OO  OO
OO         OOOOO   OO   OO   OOOOO    OOOOO   OOOOO  (TM)
```

===
Computer program for the Strength Design of Reinforced Concrete Sections
===

General Information:
====================
File Name: I:\1-BALA~1\RC-DES~1\BOREPI~1\1.8M\BP-A1-T.COL
Project: BALARAJA FLYOVER
Column: A1-BP-TOP   Engineer:
Code: ACI 318-95   Units: Metric

Run Option: Investigation   Slenderness: Not considered
Run Axis: X-axis   Column Type: Structural

Material Properties:
====================
f'c = 30 MPa   fy = 390 MPa
Ec = 25743 MPa   Es = 200000 MPa
fc = 25.5 MPa   Rupture strain = Infinity
Ultimate strain = 0.003 mm/mm
Beta1 = 0.83245

Section:
========
Circular: Diameter = 1800 mm

Gross section area, Ag = 2.54469e+006 mm^2
Ix = 5.153e+011 mm^4   Iy = 5.153e+011 mm^4
Xo = 0 mm   Yo = 0 mm

Reinforcement:
==============
Rebar Database: prEN 10080

Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)
# 6	6	28	# 8	8	50	# 10	10	79
# 12	12	113	# 14	14	154	# 16	16	201
# 20	20	314	# 25	25	491	# 28	28	616
# 32	32	801	# 40	40	1256			

Confinement: User-defined; #6 ties with #25 bars, #6 with larger bars.
phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

Layout: Circular
Pattern: All Sides Equal (Cover to longitudinal reinforcement)
Total steel area, As = 51264 mm^2 at 2.01%
64 #32 Cover = 119 mm

Factored Loads and Moments with Corresponding Capacities: (see user's manual for notation)
===

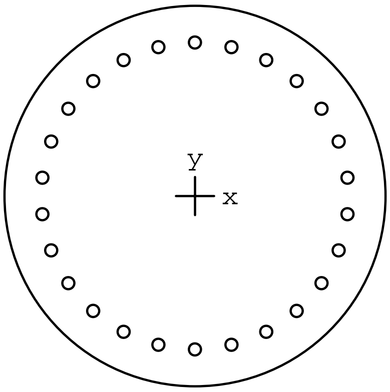
No.	Pu kN	Mux kN-m	fMnx kN-m	fMn/Mu
1	2779.0	11134.0	11470.0	1.030

*** Program completed as requested! ***

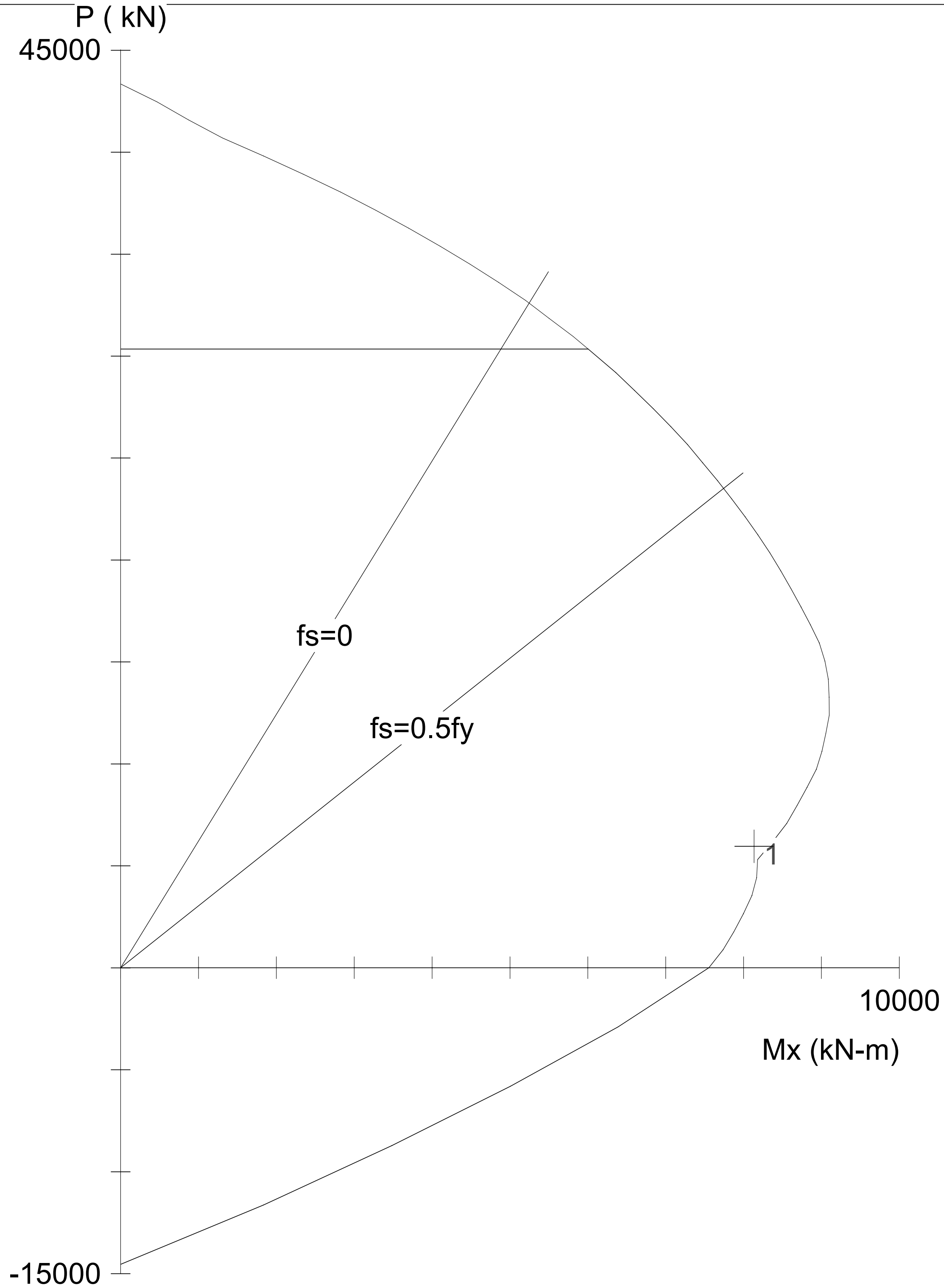
LOAD EFFECTS 1.5 M PILES

TABLE: Element Forces - 1.5m PILE at PIER P1 BP1 1.5 m below NGL						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP1	0	P1-LOAD	Max	-5632.3	1199	5381
BP1	1	P1-LOAD	Max	-5589	1199	4182
BP1	0	P1-LOAD	Min	-5632.3	1199	5381
BP1	1	P1-LOAD	Min	-5589	1199	4182
BP2	0	P1-LOAD	Max	-5675.6	1086.7	6467.7
BP2	1	P1-LOAD	Max	-5632.3	1086.7	5381
BP2	0	P1-LOAD	Min	-5675.6	1086.7	6467.7
BP2	1	P1-LOAD	Min	-5632.3	1086.7	5381
BP3	0	P1-LOAD	Max	-5718.9	864.4	7332.1
BP3	1	P1-LOAD	Max	-5675.6	864.4	6467.7
BP3	0	P1-LOAD	Min	-5718.9	864.4	7332.1
BP3	1	P1-LOAD	Min	-5675.6	864.4	6467.7
BP4	0	P1-LOAD	Max	-5762.2	642.7	7974.8
BP4	1	P1-LOAD	Max	-5718.9	642.7	7332.1
BP4	0	P1-LOAD	Min	-5762.2	642.7	7974.8
BP4	1	P1-LOAD	Min	-5718.9	642.7	7332.1
BP5	0	P1-LOAD	Max	-5805.5	421.6	8396.4
BP5	1	P1-LOAD	Max	-5762.2	421.6	7974.8
BP5	0	P1-LOAD	Min	-5805.5	421.6	8396.4
BP5	1	P1-LOAD	Min	-5762.2	421.6	7974.8
BP6	0	P1-LOAD	Max	-5848.8	200.9	8597.3
BP6	1	P1-LOAD	Max	-5805.5	200.9	8396.4
BP6	0	P1-LOAD	Min	-5848.8	200.9	8597.3
BP6	1	P1-LOAD	Min	-5805.5	200.9	8396.4
BP7	0	P1-LOAD	Max	-5892.1	-99.4	8498
BP7	1	P1-LOAD	Max	-5848.8	-99.4	8597.3
BP7	0	P1-LOAD	Min	-5892.1	-99.4	8498
BP7	1	P1-LOAD	Min	-5848.8	-99.4	8597.3
BP8	0	P1-LOAD	Max	-5935.4	-399.3	8098.6
BP8	1	P1-LOAD	Max	-5892.1	-399.3	8498
BP8	0	P1-LOAD	Min	-5935.4	-399.3	8098.6
BP8	1	P1-LOAD	Min	-5892.1	-399.3	8498
BP9	0	P1-LOAD	Max	-5978.7	-749	7349.6
BP9	1	P1-LOAD	Max	-5935.4	-749	8098.6
BP9	0	P1-LOAD	Min	-5978.7	-749	7349.6
BP9	1	P1-LOAD	Min	-5935.4	-749	8098.6
BP10	0	P1-LOAD	Max	-6022	-1018.9	6330.7
BP10	1	P1-LOAD	Max	-5978.7	-1018.9	7349.6
BP10	0	P1-LOAD	Min	-6022	-1018.9	6330.7
BP10	1	P1-LOAD	Min	-5978.7	-1018.9	7349.6
BP11	0	P1-LOAD	Max	-6065.2	-1212.4	5118.3
BP11	1	P1-LOAD	Max	-6022	-1212.4	6330.7
BP11	0	P1-LOAD	Min	-6065.2	-1212.4	5118.3
BP11	1	P1-LOAD	Min	-6022	-1212.4	6330.7
BP12	0	P1-LOAD	Max	-6108.5	-1265	3853.3
BP12	1	P1-LOAD	Max	-6065.2	-1265	5118.3
BP12	0	P1-LOAD	Min	-6108.5	-1265	3853.3
BP12	1	P1-LOAD	Min	-6065.2	-1265	5118.3

TABLE: Element Forces - 1.5m PILE at PIER P1 BP1 1.5 m below NGL						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP13	0	P1-LOAD	Max	-6151.8	-1186.3	2667
BP13	1	P1-LOAD	Max	-6108.5	-1186.3	3853.3
BP13	0	P1-LOAD	Min	-6151.8	-1186.3	2667
BP13	1	P1-LOAD	Min	-6108.5	-1186.3	3853.3
BP14	0	P1-LOAD	Max	-6195.1	-1003.2	1663.7
BP14	1	P1-LOAD	Max	-6151.8	-1003.2	2667
BP14	0	P1-LOAD	Min	-6195.1	-1003.2	1663.7
BP14	1	P1-LOAD	Min	-6151.8	-1003.2	2667
BP15	0	P1-LOAD	Max	-6238.4	-757.9	905.9
BP15	1	P1-LOAD	Max	-6195.1	-757.9	1663.7
BP15	0	P1-LOAD	Min	-6238.4	-757.9	905.9
BP15	1	P1-LOAD	Min	-6195.1	-757.9	1663.7
BP16	0	P1-LOAD	Max	-6281.7	-527.3	378.5
BP16	1	P1-LOAD	Max	-6238.4	-527.3	905.9
BP16	0	P1-LOAD	Min	-6281.7	-527.3	378.5
BP16	1	P1-LOAD	Min	-6238.4	-527.3	905.9
BP17	0	P1-LOAD	Max	-6325	-286.9	91.7
BP17	1	P1-LOAD	Max	-6281.7	-286.9	378.5
BP17	0	P1-LOAD	Min	-6325	-286.9	91.7
BP17	1	P1-LOAD	Min	-6281.7	-286.9	378.5
BP18	0	P1-LOAD	Max	-6368.3	-113.1	-21.4
BP18	1	P1-LOAD	Max	-6325	-113.1	91.7
BP18	0	P1-LOAD	Min	-6368.3	-113.1	-21.4
BP18	1	P1-LOAD	Min	-6325	-113.1	91.7
BP19	0	P1-LOAD	Max	-6411.6	-8.2	-29.6
BP19	1	P1-LOAD	Max	-6368.3	-8.2	-21.4
BP19	0	P1-LOAD	Min	-6411.6	-8.2	-29.6
BP19	1	P1-LOAD	Min	-6368.3	-8.2	-21.4
BP20	0	P1-LOAD	Max	-6454.9	29.6	0
BP20	1	P1-LOAD	Max	-6411.6	29.6	-29.6
BP20	0	P1-LOAD	Min	-6454.9	29.6	0
BP20	1	P1-LOAD	Min	-6411.6	29.6	-29.6



1500 mm diam.



Code: ACI 318-95

Units: Metric

Run axis: About X-axis

Run option: Investigation

Slenderness: Not considered

Column type: Structural

Bars: User-defined

Date: 08/19/06

Time: 11:10:34

PCACOL V3.00 (PCA 1999) - Licensed to: KEI, MANILA, ST

File: C:\0-BALA~1\RC-DES~1\BOREPI~1\1.5M\P1\P1XSEC1.COL

Project: BALARAJA FLYOVER

Column: BP-P1

Engineer:

f'c = 30 MPa	fy = 345 MPa	Ag = 1.76715e+006 mm^2	26 #51 bars
Ec = 25743 MPa	Es = 200000 MPa	As = 52702 mm^2	Rho = 2.98%
fc = 25.5 MPa	e_rup = Infinity	Xo = 0 mm	Iy = 2.49e+011 mm^4
e_u = 0.003 mm/mm		Yo = 0 mm	Iy = 2.49e+011 mm^4
Beta1 = 0.83245		Clear spacing = 95 mm	Clear cover = 119 mm

Confinement: Other phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

```
OOOOOOO    OOOOO    OOOOO    OOOOO    OOOOO   OO
OO    OO  OO   OO  OO   OO  OO   OO  OO   OO  OO
OO    OO  OO   OO  OO   OO  OO   OO  OO   OO  OO
OO    OO  OO       OO   OO  OO       OO   OO  OO
OO    OO  OO       OOOOOOO  OO       OO   OO  OO
OOOOOOO   OO   OO  OO   OO  OO   OO  OO   OO  OO
OO        OO   OO  OO   OO  OO   OO  OO   OO  OO
OO         OOOOO   OO   OO   OOOOO    OOOOO   OOOOO  (TM)
```

===
Computer program for the Strength Design of Reinforced Concrete Sections
===

```
General Information:
====================
   File Name: I:\1-BALA~1\RC-DES~1\BOREPI~1\1.5M\P1\P1XSEC1.COL
   Project:  BALARAJA FLYOVER
   Column:   BP-P1                           Engineer:
   Code:     ACI 318-95                      Units: Metric

   Run Option: Investigation                 Slenderness: Not considered
   Run Axis:   X-axis                        Column Type: Structural

Material Properties:
====================
   f'c   = 30 MPa                            fy   = 345 MPa
   Ec    = 25743 MPa                         Es   = 200000 MPa
   fc    = 25.5 MPa                          Rupture strain = Infinity
   Ultimate strain = 0.003 mm/mm
   Beta1 = 0.83245

Section:
========
   Circular:    Diameter = 1500 mm

   Gross section area, Ag =  1.76715e+006 mm^2
   Ix =  2.48505e+011 mm^4                   Iy =  2.48505e+011 mm^4
   Xo =  0 mm                                Yo =  0 mm

Reinforcement:
==============
   Rebar Database: User-defined
   Size Diam (mm) Area (mm^2)   Size Diam (mm) Area (mm^2)   Size Diam (mm) Area (mm^2)
   ---- --------- -----------   ---- --------- -----------   ---- --------- -----------
   #  6         6          28   #  8         8          50   # 10        10          79
   # 12        12         113   # 14        14         154   # 16        16         201
   # 20        20         314   # 25        25         491   # 28        28         616
   # 32        32         801   # 40        40        1256   # 51        51        2027

   Confinement: User-defined; #6 ties with #25 bars,  #6 with larger bars.
   phi(a) = 0.7,  phi(b) = 0.8,  phi(c) = 0.7

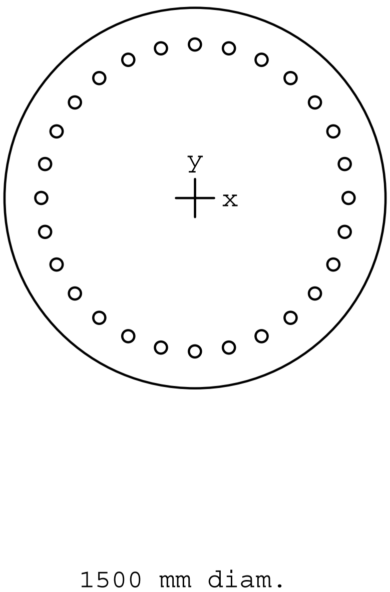
   Layout: Circular
   Pattern: All Sides Equal  (Cover to longitudinal reinforcement)
   Total steel area, As = 52702 mm^2 at 2.98%
   26 #51   Cover = 119 mm

Factored Loads and Moments with Corresponding Capacities: (see user's manual for notation)
=========================================================
                 Pu          Mux         fMnx
   No.           kN         kN-m         kN-m   fMn/Mu
   --- ------------ ------------ ------------ --------
     1       5952.0       8134.2       8324.1    1.023

   *** Program completed as requested! ***
```

TABLE: Element Forces - 1.5m PILE at PIER P2 BP1 1.0 m below NGL						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP1	0	P2-LOAD	Max	-5889.3	1217	5460
BP1	1	P2-LOAD	Max	-5846	1217	4243
BP1	0	P2-LOAD	Min	-5889.3	1217	5460
BP1	1	P2-LOAD	Min	-5846	1217	4243
BP2	0	P2-LOAD	Max	-5932.6	1104.6	6564.6
BP2	1	P2-LOAD	Max	-5889.3	1104.6	5460
BP2	0	P2-LOAD	Min	-5932.6	1104.6	6564.6
BP2	1	P2-LOAD	Min	-5889.3	1104.6	5460
BP3	0	P2-LOAD	Max	-5975.9	882.2	7446.9
BP3	1	P2-LOAD	Max	-5932.6	882.2	6564.6
BP3	0	P2-LOAD	Min	-5975.9	882.2	7446.9
BP3	1	P2-LOAD	Min	-5932.6	882.2	6564.6
BP4	0	P2-LOAD	Max	-6019.2	660.5	8107.4
BP4	1	P2-LOAD	Max	-5975.9	660.5	7446.9
BP4	0	P2-LOAD	Min	-6019.2	660.5	8107.4
BP4	1	P2-LOAD	Min	-5975.9	660.5	7446.9
BP5	0	P2-LOAD	Max	-6062.5	439.4	8546.7
BP5	1	P2-LOAD	Max	-6019.2	439.4	8107.4
BP5	0	P2-LOAD	Min	-6062.5	439.4	8546.7
BP5	1	P2-LOAD	Min	-6019.2	439.4	8107.4
BP6	0	P2-LOAD	Max	-6105.8	218.6	8765.4
BP6	1	P2-LOAD	Max	-6062.5	218.6	8546.7
BP6	0	P2-LOAD	Min	-6105.8	218.6	8765.4
BP6	1	P2-LOAD	Min	-6062.5	218.6	8546.7
BP7	0	P2-LOAD	Max	-6149.1	-81.7	8683.7
BP7	1	P2-LOAD	Max	-6105.8	-81.7	8765.4
BP7	0	P2-LOAD	Min	-6149.1	-81.7	8683.7
BP7	1	P2-LOAD	Min	-6105.8	-81.7	8765.4
BP8	0	P2-LOAD	Max	-6192.4	-381.7	8302
BP8	1	P2-LOAD	Max	-6149.1	-381.7	8683.7
BP8	0	P2-LOAD	Min	-6192.4	-381.7	8302
BP8	1	P2-LOAD	Min	-6149.1	-381.7	8683.7
BP9	0	P2-LOAD	Max	-6235.7	-731.4	7570.7
BP9	1	P2-LOAD	Max	-6192.4	-731.4	8302
BP9	0	P2-LOAD	Min	-6235.7	-731.4	7570.7
BP9	1	P2-LOAD	Min	-6192.4	-731.4	8302
BP10	0	P2-LOAD	Max	-6279	-1019.4	6551.2
BP10	1	P2-LOAD	Max	-6235.7	-1019.4	7570.7
BP10	0	P2-LOAD	Min	-6279	-1019.4	6551.2
BP10	1	P2-LOAD	Min	-6235.7	-1019.4	7570.7
BP11	0	P2-LOAD	Max	-6322.2	-1230.1	5321.1
BP11	1	P2-LOAD	Max	-6279	-1230.1	6551.2
BP11	0	P2-LOAD	Min	-6322.2	-1230.1	5321.1
BP11	1	P2-LOAD	Min	-6279	-1230.1	6551.2
BP12	0	P2-LOAD	Max	-6365.5	-1292.1	4029
BP12	1	P2-LOAD	Max	-6322.2	-1292.1	5321.1
BP12	0	P2-LOAD	Min	-6365.5	-1292.1	4029
BP12	1	P2-LOAD	Min	-6322.2	-1292.1	5321.1

TABLE: Element Forces - 1.5m PILE at PIER P2 BP1 1.0 m below NGL						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP13	0	P2-LOAD	Max	-6408.8	-1223.3	2805.7
BP13	1	P2-LOAD	Max	-6365.5	-1223.3	4029
BP13	0	P2-LOAD	Min	-6408.8	-1223.3	2805.7
BP13	1	P2-LOAD	Min	-6365.5	-1223.3	4029
BP14	0	P2-LOAD	Max	-6452.1	-1041.5	1764.1
BP14	1	P2-LOAD	Max	-6408.8	-1041.5	2805.7
BP14	0	P2-LOAD	Min	-6452.1	-1041.5	1764.1
BP14	1	P2-LOAD	Min	-6408.8	-1041.5	2805.7
BP15	0	P2-LOAD	Max	-6495.4	-792.1	972
BP15	1	P2-LOAD	Max	-6452.1	-792.1	1764.1
BP15	0	P2-LOAD	Min	-6495.4	-792.1	972
BP15	1	P2-LOAD	Min	-6452.1	-792.1	1764.1
BP16	0	P2-LOAD	Max	-6538.7	-555.2	416.8
BP16	1	P2-LOAD	Max	-6495.4	-555.2	972
BP16	0	P2-LOAD	Min	-6538.7	-555.2	416.8
BP16	1	P2-LOAD	Min	-6495.4	-555.2	972
BP17	0	P2-LOAD	Max	-6582	-306	110.8
BP17	1	P2-LOAD	Max	-6538.7	-306	416.8
BP17	0	P2-LOAD	Min	-6582	-306	110.8
BP17	1	P2-LOAD	Min	-6538.7	-306	416.8
BP18	0	P2-LOAD	Max	-6625.3	-124.6	-13.8
BP18	1	P2-LOAD	Max	-6582	-124.6	110.8
BP18	0	P2-LOAD	Min	-6625.3	-124.6	-13.8
BP18	1	P2-LOAD	Min	-6582	-124.6	110.8
BP19	0	P2-LOAD	Max	-6668.6	-13.9	-27.7
BP19	1	P2-LOAD	Max	-6625.3	-13.9	-13.8
BP19	0	P2-LOAD	Min	-6668.6	-13.9	-27.7
BP19	1	P2-LOAD	Min	-6625.3	-13.9	-13.8
BP20	0	P2-LOAD	Max	-6711.9	27.7	0
BP20	1	P2-LOAD	Max	-6668.6	27.7	-27.7
BP20	0	P2-LOAD	Min	-6711.9	27.7	0
BP20	1	P2-LOAD	Min	-6668.6	27.7	-27.7



Code: ACI 318-95

Units: Metric

Run axis: About X-axis

Run option: Investigation

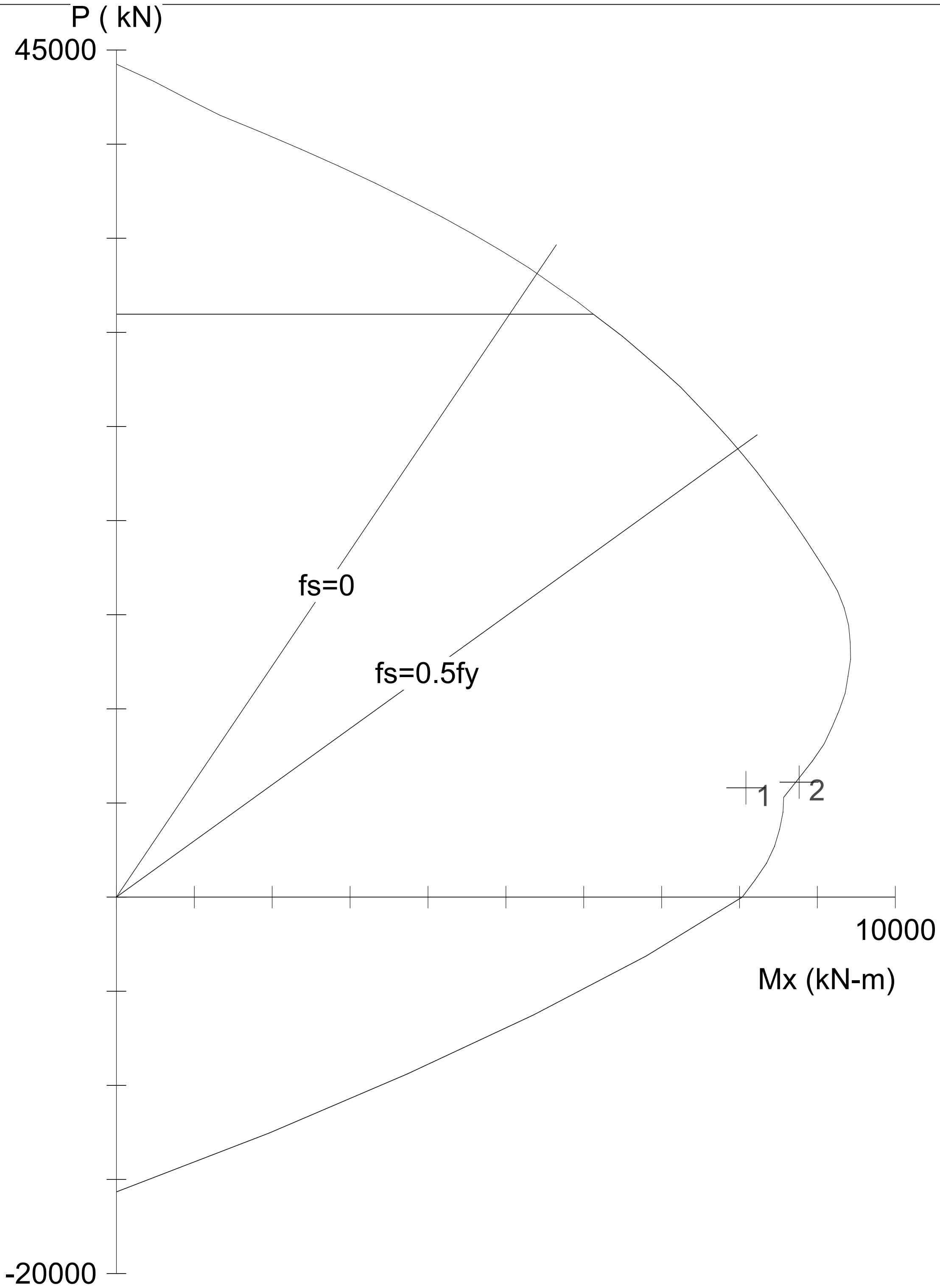
Slenderness: Not considered

Column type: Structural

Bars: User-defined

Date: 08/19/06

Time: 11:11:39



PCACOL V3.00 (PCA 1999) - Licensed to: KEI, MANILA, ST

File: C:\0-BALA~1\RC-DES~1\BOREPI~1\1.5M\P2\P2XSEC1.COL

Project: BALARAJA FLYOVER

Column: BP-P1		Engineer:	
f'c = 30 MPa	fy = 345 MPa	Ag = 1.76715e+006 mm^2	28 #51 bars
Ec = 25743 MPa	Es = 200000 MPa	As = 56756 mm^2	Rho = 3.21%
fc = 25.5 MPa	e_rup = Infinity	Xo = 0 mm	Iy = 2.49e+011 mm^4
e_u = 0.003 mm/mm		Yo = 0 mm	Iy = 2.49e+011 mm^4
Beta1 = 0.83245		Clear spacing = 85 mm	Clear cover = 119 mm
Confinement: Other	phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7		

```
OOOOOOO    OOOOO    OOOOO    OOOOO    OOOOO   OO
OO     OO  OO   OO  OO   OO  OO   OO  OO   OO OO
OO     OO  OO   OO  OO   OO  OO   OO  OO   OO OO
OO     OO  OO       OO   OO  OO       OO   OO OO
OO     OO  OO       OOOOOOO  OO       OO   OO OO
OOOOOOO    OO   OO  OO   OO  OO   OO  OO   OO OO
OO         OO   OO  OO   OO  OO   OO  OO   OO OO
OO          OOOOO   OO   OO   OOOOO    OOOOO  OOOOO  (TM)
```

==
Computer program for the Strength Design of Reinforced Concrete Sections
==

General Information:
====================

File Name: I:\1-BALA~1\RC-DES~1\BOREPI~1\1.5M\P2\P2XSEC1.COL
Project: BALARAJA FLYOVER
Column: BP-P1 Engineer:
Code: ACI 318-95 Units: Metric

Run Option: Investigation Slenderness: Not considered
Run Axis: X-axis Column Type: Structural

Material Properties:
====================

f'c = 30 MPa fy = 345 MPa
Ec = 25743 MPa Es = 200000 MPa
fc = 25.5 MPa Rupture strain = Infinity
Ultimate strain = 0.003 mm/mm
Beta1 = 0.83245

Section:
========

Circular: Diameter = 1500 mm

Gross section area, Ag = 1.76715e+006 mm^2
Ix = 2.48505e+011 mm^4 Iy = 2.48505e+011 mm^4
Xo = 0 mm Yo = 0 mm

Reinforcement:
==============

Rebar Database: User-defined

Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)
# 6	6	28	# 8	8	50	# 10	10	79
# 12	12	113	# 14	14	154	# 16	16	201
# 20	20	314	# 25	25	491	# 28	28	616
# 32	32	801	# 40	40	1256	# 51	51	2027

Confinement: User-defined; #6 ties with #25 bars, #6 with larger bars.
phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

Layout: Circular
Pattern: All Sides Equal (Cover to longitudinal reinforcement)
Total steel area, As = 56756 mm^2 at 3.21%
28 #51 Cover = 119 mm

Factored Loads and Moments with Corresponding Capacities: (see user's manual for notation)
===

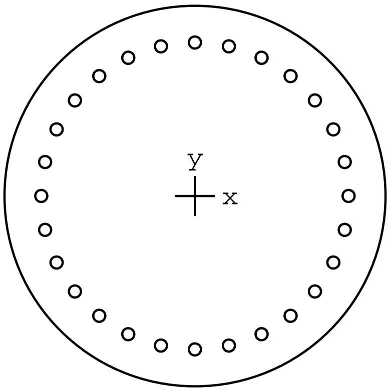
No.	Pu kN	Mux kN-m	fMnx kN-m	fMn/Mu
1	5807.0	8082.0	8666.4	1.072
2	6106.0	8765.4	8724.1	0.995

*** Program completed as requested! ***

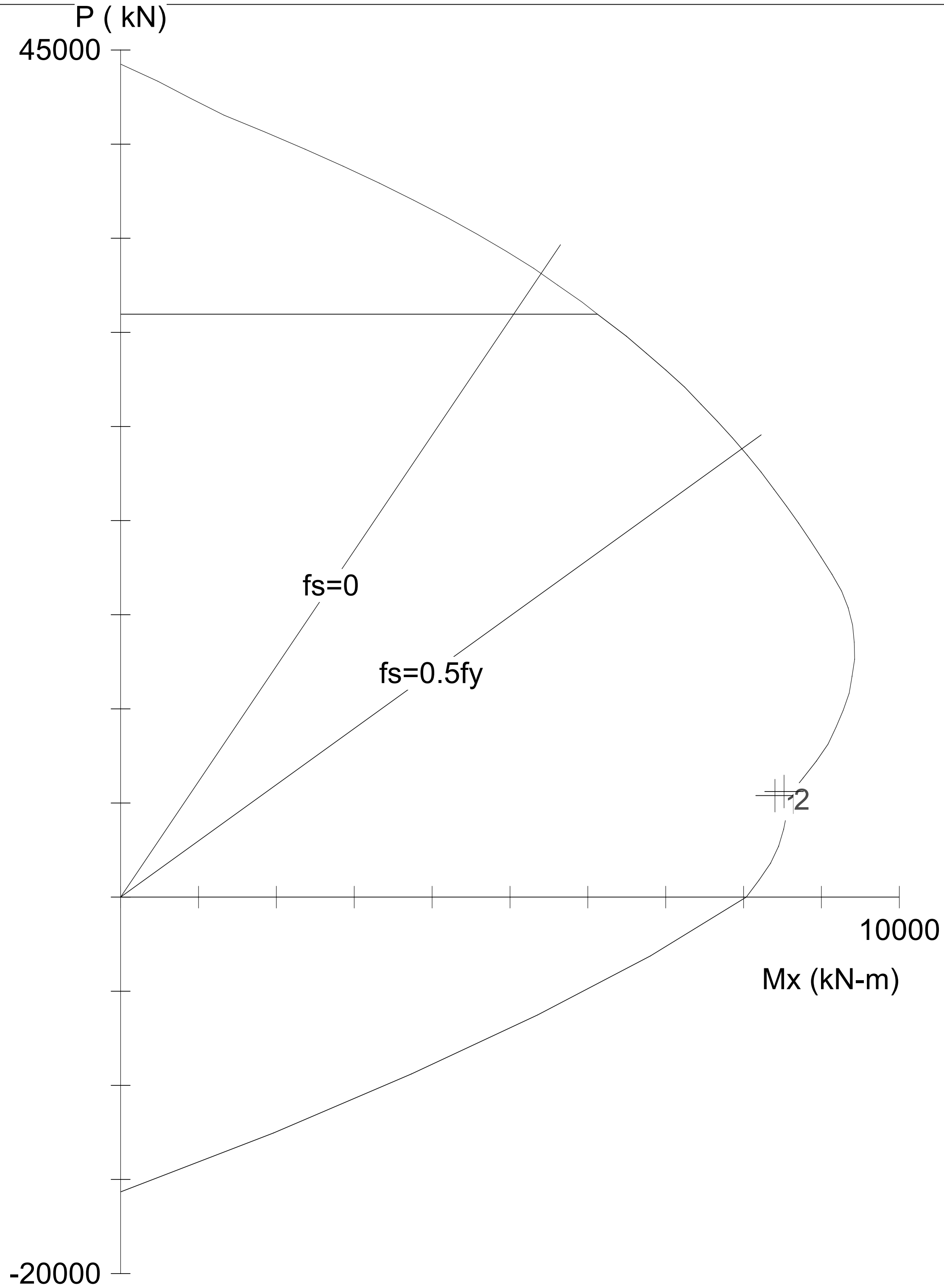
TABLE: Element Forces - 1.5m PILE at PIER P6, BP1 1.5 m below NGL

Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP1	0	P6-LOAD	Max	-5442.3	1207	5342
BP1	1	P6-LOAD	Max	-5399	1207	4135
BP1	0	P6-LOAD	Min	-5442.3	1207	5342
BP1	1	P6-LOAD	Min	-5399	1207	4135
BP2	0	P6-LOAD	Max	-5485.6	1094.8	6436.8
BP2	1	P6-LOAD	Max	-5442.3	1094.8	5342
BP2	0	P6-LOAD	Min	-5485.6	1094.8	6436.8
BP2	1	P6-LOAD	Min	-5442.3	1094.8	5342
BP3	0	P6-LOAD	Max	-5528.9	872.6	7309.4
BP3	1	P6-LOAD	Max	-5485.6	872.6	6436.8
BP3	0	P6-LOAD	Min	-5528.9	872.6	7309.4
BP3	1	P6-LOAD	Min	-5485.6	872.6	6436.8
BP4	0	P6-LOAD	Max	-5572.2	651	7960.4
BP4	1	P6-LOAD	Max	-5528.9	651	7309.4
BP4	0	P6-LOAD	Min	-5572.2	651	7960.4
BP4	1	P6-LOAD	Min	-5528.9	651	7309.4
BP5	0	P6-LOAD	Max	-5615.5	429.9	8390.3
BP5	1	P6-LOAD	Max	-5572.2	429.9	7960.4
BP5	0	P6-LOAD	Min	-5615.5	429.9	8390.3
BP5	1	P6-LOAD	Min	-5572.2	429.9	7960.4
BP6	0	P6-LOAD	Max	-5658.8	129.3	8519.6
BP6	1	P6-LOAD	Max	-5615.5	129.3	8390.3
BP6	0	P6-LOAD	Min	-5658.8	129.3	8519.6
BP6	1	P6-LOAD	Min	-5615.5	129.3	8390.3
BP7	0	P6-LOAD	Max	-5702.1	-171	8348.6
BP7	1	P6-LOAD	Max	-5658.8	-171	8519.6
BP7	0	P6-LOAD	Min	-5702.1	-171	8348.6
BP7	1	P6-LOAD	Min	-5658.8	-171	8519.6
BP8	0	P6-LOAD	Max	-5745.4	-470.9	7877.7
BP8	1	P6-LOAD	Max	-5702.1	-470.9	8348.6
BP8	0	P6-LOAD	Min	-5745.4	-470.9	7877.7
BP8	1	P6-LOAD	Min	-5702.1	-470.9	8348.6
BP9	0	P6-LOAD	Max	-5788.7	-820.5	7057.2
BP9	1	P6-LOAD	Max	-5745.4	-820.5	7877.7
BP9	0	P6-LOAD	Min	-5788.7	-820.5	7057.2
BP9	1	P6-LOAD	Min	-5745.4	-820.5	7877.7
BP10	0	P6-LOAD	Max	-5832	-1054.3	6003
BP10	1	P6-LOAD	Max	-5788.7	-1054.3	7057.2
BP10	0	P6-LOAD	Min	-5832	-1054.3	6003
BP10	1	P6-LOAD	Min	-5788.7	-1054.3	7057.2
BP11	0	P6-LOAD	Max	-5875.2	-1211.6	4791.4
BP11	1	P6-LOAD	Max	-5832	-1211.6	6003
BP11	0	P6-LOAD	Min	-5875.2	-1211.6	4791.4
BP11	1	P6-LOAD	Min	-5832	-1211.6	6003
BP12	0	P6-LOAD	Max	-5918.5	-1242.4	3549
BP12	1	P6-LOAD	Max	-5875.2	-1242.4	4791.4
BP12	0	P6-LOAD	Min	-5918.5	-1242.4	3549
BP12	1	P6-LOAD	Min	-5875.2	-1242.4	4791.4

TABLE: Element Forces - 1.5m PILE at PIER P6, BP1 1.5 m below NGL						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP13	0	P6-LOAD	Max	-5961.8	-1135.7	2413.4
BP13	1	P6-LOAD	Max	-5918.5	-1135.7	3549
BP13	0	P6-LOAD	Min	-5961.8	-1135.7	2413.4
BP13	1	P6-LOAD	Min	-5918.5	-1135.7	3549
BP14	0	P6-LOAD	Max	-6005.1	-942.8	1470.6
BP14	1	P6-LOAD	Max	-5961.8	-942.8	2413.4
BP14	0	P6-LOAD	Min	-6005.1	-942.8	1470.6
BP14	1	P6-LOAD	Min	-5961.8	-942.8	2413.4
BP15	0	P6-LOAD	Max	-6048.4	-698.8	771.8
BP15	1	P6-LOAD	Max	-6005.1	-698.8	1470.6
BP15	0	P6-LOAD	Min	-6048.4	-698.8	771.8
BP15	1	P6-LOAD	Min	-6005.1	-698.8	1470.6
BP16	0	P6-LOAD	Max	-6091.7	-476.2	295.5
BP16	1	P6-LOAD	Max	-6048.4	-476.2	771.8
BP16	0	P6-LOAD	Min	-6091.7	-476.2	295.5
BP16	1	P6-LOAD	Min	-6048.4	-476.2	771.8
BP17	0	P6-LOAD	Max	-6135	-248.9	46.6
BP17	1	P6-LOAD	Max	-6091.7	-248.9	295.5
BP17	0	P6-LOAD	Min	-6135	-248.9	46.6
BP17	1	P6-LOAD	Min	-6091.7	-248.9	295.5
BP18	0	P6-LOAD	Max	-6178.3	-88	-41.3
BP18	1	P6-LOAD	Max	-6135	-88	46.6
BP18	0	P6-LOAD	Min	-6178.3	-88	-41.3
BP18	1	P6-LOAD	Min	-6135	-88	46.6
BP19	0	P6-LOAD	Max	-6221.6	6	-35.4
BP19	1	P6-LOAD	Max	-6178.3	6	-41.3
BP19	0	P6-LOAD	Min	-6221.6	6	-35.4
BP19	1	P6-LOAD	Min	-6178.3	6	-41.3
BP20	0	P6-LOAD	Max	-6264.9	35.4	0
BP20	1	P6-LOAD	Max	-6221.6	35.4	-35.4
BP20	0	P6-LOAD	Min	-6264.9	35.4	0
BP20	1	P6-LOAD	Min	-6221.6	35.4	-35.4



1500 mm diam.



Code: ACI 318-95

Units: Metric

Run axis: About X-axis

Run option: Investigation

Slenderness: Not considered

Column type: Structural

Bars: User-defined

Date: 08/19/06

Time: 11:11:57

PCACOL V3.00 (PCA 1999) - Licensed to: KEI, MANILA, ST

File: C:\0-BALA~1\RC-DES~1\BOREPI~1\1.5M\P6\P6XSEC1.COL

Project: BALARAJA FLYOVER

Column: BP-P1		Engineer:	
f'c = 30 MPa	fy = 345 MPa	Ag = 1.76715e+006 mm^2	28 #51 bars
Ec = 25743 MPa	Es = 200000 MPa	As = 56756 mm^2	Rho = 3.21%
fc = 25.5 MPa	e_rup = Infinity	Xo = 0 mm	Iy = 2.49e+011 mm^4
e_u = 0.003 mm/mm		Yo = 0 mm	Iy = 2.49e+011 mm^4
Beta1 = 0.83245		Clear spacing = 85 mm	Clear cover = 119 mm
Confinement: Other	phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7		

```
0000000    00000    00000    00000    00000   00
00    00  00   00  00   00  00   00  00   00  00
00    00  00   00  00   00  00   00  00   00  00
00    00  00       00   00  00       00   00  00
00    00  00       0000000  00       00   00  00
0000000   00   00  00   00  00   00  00   00  00
00        00   00  00   00  00   00  00   00  00
00         00000   00   00   00000    00000   00000  (TM)
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===
Computer program for the Strength Design of Reinforced Concrete Sections
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General Information:
====================

File Name: I:\1-BALA~1\RC-DES~1\BOREPI~1\1.5M\P6\P6XSEC1.COL
Project: BALARAJA FLYOVER
Column: BP-P1 Engineer:
Code: ACI 318-95 Units: Metric

Run Option: Investigation Slenderness: Not considered
Run Axis: X-axis Column Type: Structural

Material Properties:
====================

f'c = 30 MPa fy = 345 MPa
Ec = 25743 MPa Es = 200000 MPa
fc = 25.5 MPa Rupture strain = Infinity
Ultimate strain = 0.003 mm/mm
Beta1 = 0.83245

Section:
========

Circular: Diameter = 1500 mm

Gross section area, Ag = 1.76715e+006 mm^2
Ix = 2.48505e+011 mm^4 Iy = 2.48505e+011 mm^4
Xo = 0 mm Yo = 0 mm

Reinforcement:
==============

Rebar Database: User-defined

Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)
# 6	6	28	# 8	8	50	# 10	10	79
# 12	12	113	# 14	14	154	# 16	16	201
# 20	20	314	# 25	25	491	# 28	28	616
# 32	32	801	# 40	40	1256	# 51	51	2027

Confinement: User-defined; #6 ties with #25 bars, #6 with larger bars.
phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

Layout: Circular
Pattern: All Sides Equal (Cover to longitudinal reinforcement)
Total steel area, As = 56756 mm^2 at 3.21%
28 #51 Cover = 119 mm

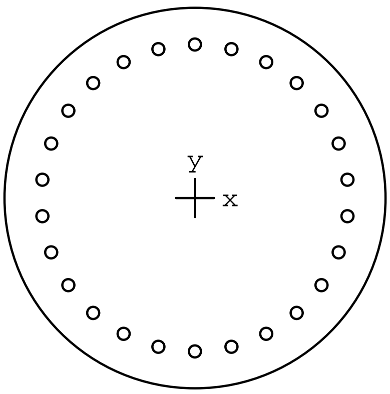
Factored Loads and Moments with Corresponding Capacities: (see user's manual for notation)
===

No.	Pu kN	Mux kN-m	fMnx kN-m	fMn/Mu
1	5392.0	8404.2	8585.1	1.022
2	5615.0	8520.0	8628.9	1.013

*** Program completed as requested! ***

TABLE: Element Forces - 1.5m PILE at PIER P7, BP1 2.0 m below NGL						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP1	0	P7-LOAD	Max	-6246.3	1198	5632
BP1	1	P7-LOAD	Max	-6203	1198	4434
BP1	0	P7-LOAD	Min	-6246.3	1198	5632
BP1	1	P7-LOAD	Min	-6203	1198	4434
BP2	0	P7-LOAD	Max	-6289.6	975.5	6607.5
BP2	1	P7-LOAD	Max	-6246.3	975.5	5632
BP2	0	P7-LOAD	Min	-6289.6	975.5	6607.5
BP2	1	P7-LOAD	Min	-6246.3	975.5	5632
BP3	0	P7-LOAD	Max	-6332.9	753.6	7361.1
BP3	1	P7-LOAD	Max	-6289.6	753.6	6607.5
BP3	0	P7-LOAD	Min	-6332.9	753.6	7361.1
BP3	1	P7-LOAD	Min	-6289.6	753.6	6607.5
BP4	0	P7-LOAD	Max	-6376.2	532.3	7893.4
BP4	1	P7-LOAD	Max	-6332.9	532.3	7361.1
BP4	0	P7-LOAD	Min	-6376.2	532.3	7893.4
BP4	1	P7-LOAD	Min	-6332.9	532.3	7361.1
BP5	0	P7-LOAD	Max	-6419.5	311.5	8204.8
BP5	1	P7-LOAD	Max	-6376.2	311.5	7893.4
BP5	0	P7-LOAD	Min	-6419.5	311.5	8204.8
BP5	1	P7-LOAD	Min	-6376.2	311.5	7893.4
BP6	0	P7-LOAD	Max	-6462.8	11	8215.9
BP6	1	P7-LOAD	Max	-6419.5	11	8204.8
BP6	0	P7-LOAD	Min	-6462.8	11	8215.9
BP6	1	P7-LOAD	Min	-6419.5	11	8204.8
BP7	0	P7-LOAD	Max	-6506.1	-289.1	7926.8
BP7	1	P7-LOAD	Max	-6462.8	-289.1	8215.9
BP7	0	P7-LOAD	Min	-6506.1	-289.1	7926.8
BP7	1	P7-LOAD	Min	-6462.8	-289.1	8215.9
BP8	0	P7-LOAD	Max	-6549.4	-588.9	7338
BP8	1	P7-LOAD	Max	-6506.1	-588.9	7926.8
BP8	0	P7-LOAD	Min	-6549.4	-588.9	7338
BP8	1	P7-LOAD	Min	-6506.1	-588.9	7926.8
BP9	0	P7-LOAD	Max	-6592.7	-914	6424
BP9	1	P7-LOAD	Max	-6549.4	-914	7338
BP9	0	P7-LOAD	Min	-6592.7	-914	6424
BP9	1	P7-LOAD	Min	-6549.4	-914	7338
BP10	0	P7-LOAD	Max	-6636	-1084.8	5339.2
BP10	1	P7-LOAD	Max	-6592.7	-1084.8	6424
BP10	0	P7-LOAD	Min	-6636	-1084.8	5339.2
BP10	1	P7-LOAD	Min	-6592.7	-1084.8	6424
BP11	0	P7-LOAD	Max	-6679.2	-1181	4158.1
BP11	1	P7-LOAD	Max	-6636	-1181	5339.2
BP11	0	P7-LOAD	Min	-6679.2	-1181	4158.1
BP11	1	P7-LOAD	Min	-6636	-1181	5339.2
BP12	0	P7-LOAD	Max	-6722.5	-1176.5	2981.7
BP12	1	P7-LOAD	Max	-6679.2	-1176.5	4158.1
BP12	0	P7-LOAD	Min	-6722.5	-1176.5	2981.7
BP12	1	P7-LOAD	Min	-6679.2	-1176.5	4158.1

TABLE: Element Forces - 1.5m PILE at PIER P7, BP1 2.0 m below NGL						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP13	0	P7-LOAD	Max	-6765.8	-1028.1	1953.6
BP13	1	P7-LOAD	Max	-6722.5	-1028.1	2981.7
BP13	0	P7-LOAD	Min	-6765.8	-1028.1	1953.6
BP13	1	P7-LOAD	Min	-6722.5	-1028.1	2981.7
BP14	0	P7-LOAD	Max	-6809.1	-824.3	1129.3
BP14	1	P7-LOAD	Max	-6765.8	-824.3	1953.6
BP14	0	P7-LOAD	Min	-6809.1	-824.3	1129.3
BP14	1	P7-LOAD	Min	-6765.8	-824.3	1953.6
BP15	0	P7-LOAD	Max	-6852.4	-588.5	540.8
BP15	1	P7-LOAD	Max	-6809.1	-588.5	1129.3
BP15	0	P7-LOAD	Min	-6852.4	-588.5	540.8
BP15	1	P7-LOAD	Min	-6809.1	-588.5	1129.3
BP16	0	P7-LOAD	Max	-6895.7	-383.8	157
BP16	1	P7-LOAD	Max	-6852.4	-383.8	540.8
BP16	0	P7-LOAD	Min	-6895.7	-383.8	157
BP16	1	P7-LOAD	Min	-6852.4	-383.8	540.8
BP17	0	P7-LOAD	Max	-6939	-182.8	-25.8
BP17	1	P7-LOAD	Max	-6895.7	-182.8	157
BP17	0	P7-LOAD	Min	-6939	-182.8	-25.8
BP17	1	P7-LOAD	Min	-6895.7	-182.8	157
BP18	0	P7-LOAD	Max	-6982.3	-46.1	-71.9
BP18	1	P7-LOAD	Max	-6939	-46.1	-25.8
BP18	0	P7-LOAD	Min	-6982.3	-46.1	-71.9
BP18	1	P7-LOAD	Min	-6939	-46.1	-25.8
BP19	0	P7-LOAD	Max	-7025.6	28.2	-43.7
BP19	1	P7-LOAD	Max	-6982.3	28.2	-71.9
BP19	0	P7-LOAD	Min	-7025.6	28.2	-43.7
BP19	1	P7-LOAD	Min	-6982.3	28.2	-71.9
BP20	0	P7-LOAD	Max	-7068.9	43.7	0
BP20	1	P7-LOAD	Max	-7025.6	43.7	-43.7
BP20	0	P7-LOAD	Min	-7068.9	43.7	0
BP20	1	P7-LOAD	Min	-7025.6	43.7	-43.7



1500 mm diam.

Code: ACI 318-95

Units: Metric

Run axis: About X-axis

Run option: Investigation

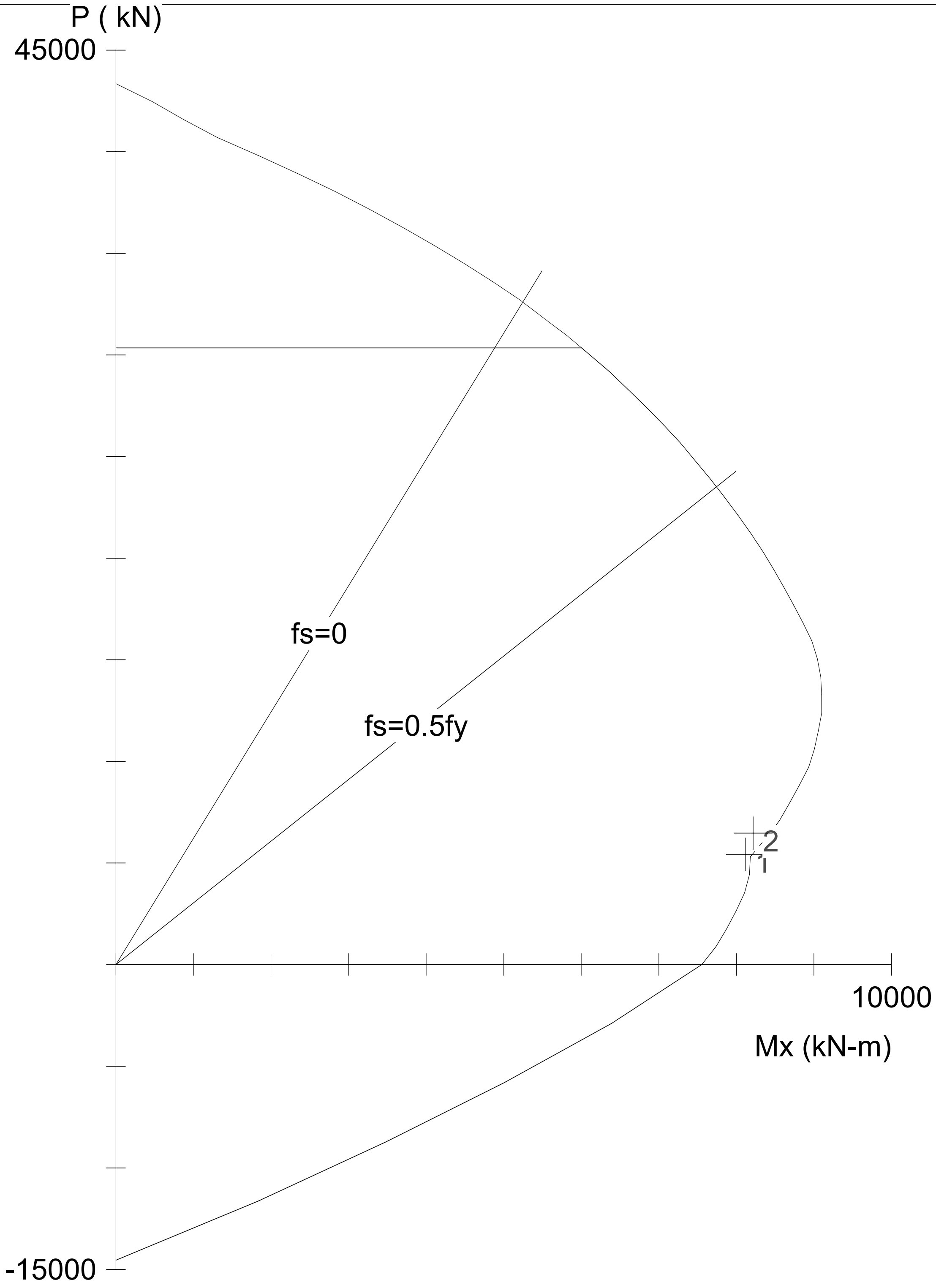
Slenderness: Not considered

Column type: Structural

Bars: User-defined

Date: 08/19/06

Time: 11:12:19



PCACOL V3.00 (PCA 1999) - Licensed to: KEI, MANILA, ST

File: C:\0-BALA~1\RC-DES~1\BOREPI~1\1.5M\P7\P7XSEC1.COL

Project: BALARAJA FLYOVER

Column: BP-P7		Engineer:	
f'c = 30 MPa	fy = 345 MPa	Ag = 1.76715e+006 mm^2	26 #51 bars
Ec = 25743 MPa	Es = 200000 MPa	As = 52702 mm^2	Rho = 2.98%
fc = 25.5 MPa	e_rup = Infinity	Xo = 0 mm	Iy = 2.49e+011 mm^4
e_u = 0.003 mm/mm		Yo = 0 mm	Iy = 2.49e+011 mm^4
Beta1 = 0.83245		Clear spacing = 95 mm	Clear cover = 119 mm

Confinement: Other phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

```
OOOOOOO    OOOOO    OOOOO    OOOOO    OOOOO   OO
OO    OO  OO   OO  OO   OO  OO   OO  OO   OO  OO
OO    OO  OO   OO  OO   OO  OO   OO  OO   OO  OO
OO    OO  OO       OO   OO  OO       OO   OO  OO
OO    OO  OO       OOOOOOO  OO       OO   OO  OO
OOOOOOO   OO   OO  OO   OO  OO   OO  OO   OO  OO
OO        OO   OO  OO   OO  OO   OO  OO   OO  OO
OO         OOOOO   OO   OO   OOOOO    OOOOO   OOOOO  (TM)
```

===
Computer program for the Strength Design of Reinforced Concrete Sections
===

General Information:
====================
File Name: I:\1-BALA~1\RC-DES~1\BOREPI~1\1.5M\P7\P7XSEC1.COL
Project: BALARAJA FLYOVER
Column: BP-P7 Engineer:
Code: ACI 318-95 Units: Metric

Run Option: Investigation Slenderness: Not considered
Run Axis: X-axis Column Type: Structural

Material Properties:
====================
f'c = 30 MPa fy = 345 MPa
Ec = 25743 MPa Es = 200000 MPa
fc = 25.5 MPa Rupture strain = Infinity
Ultimate strain = 0.003 mm/mm
Beta1 = 0.83245

Section:
========
Circular: Diameter = 1500 mm

Gross section area, Ag = 1.76715e+006 mm^2
Ix = 2.48505e+011 mm^4 Iy = 2.48505e+011 mm^4
Xo = 0 mm Yo = 0 mm

Reinforcement:
==============
Rebar Database: User-defined

Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)
# 6	6	28	# 8	8	50	# 10	10	79
# 12	12	113	# 14	14	154	# 16	16	201
# 20	20	314	# 25	25	491	# 28	28	616
# 32	32	801	# 40	40	1256	# 51	51	2027

Confinement: User-defined; #6 ties with #25 bars, #6 with larger bars.
phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

Layout: Circular
Pattern: All Sides Equal (Cover to longitudinal reinforcement)
Total steel area, As = 52702 mm^2 at 2.98%
26 #51 Cover = 119 mm

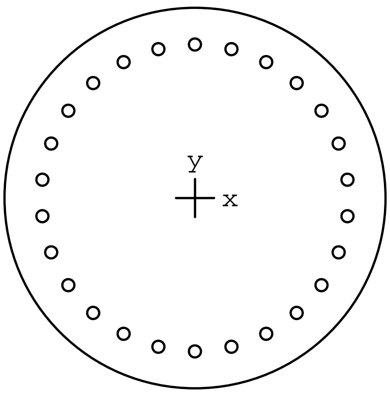
Factored Loads and Moments with Corresponding Capacities: (see user's manual for notation)
===

No.	Pu kN	Mux kN-m	fMnx kN-m	fMn/Mu
1	5419.0	8118.6	8207.9	1.011
2	6463.0	8216.0	8432.6	1.026

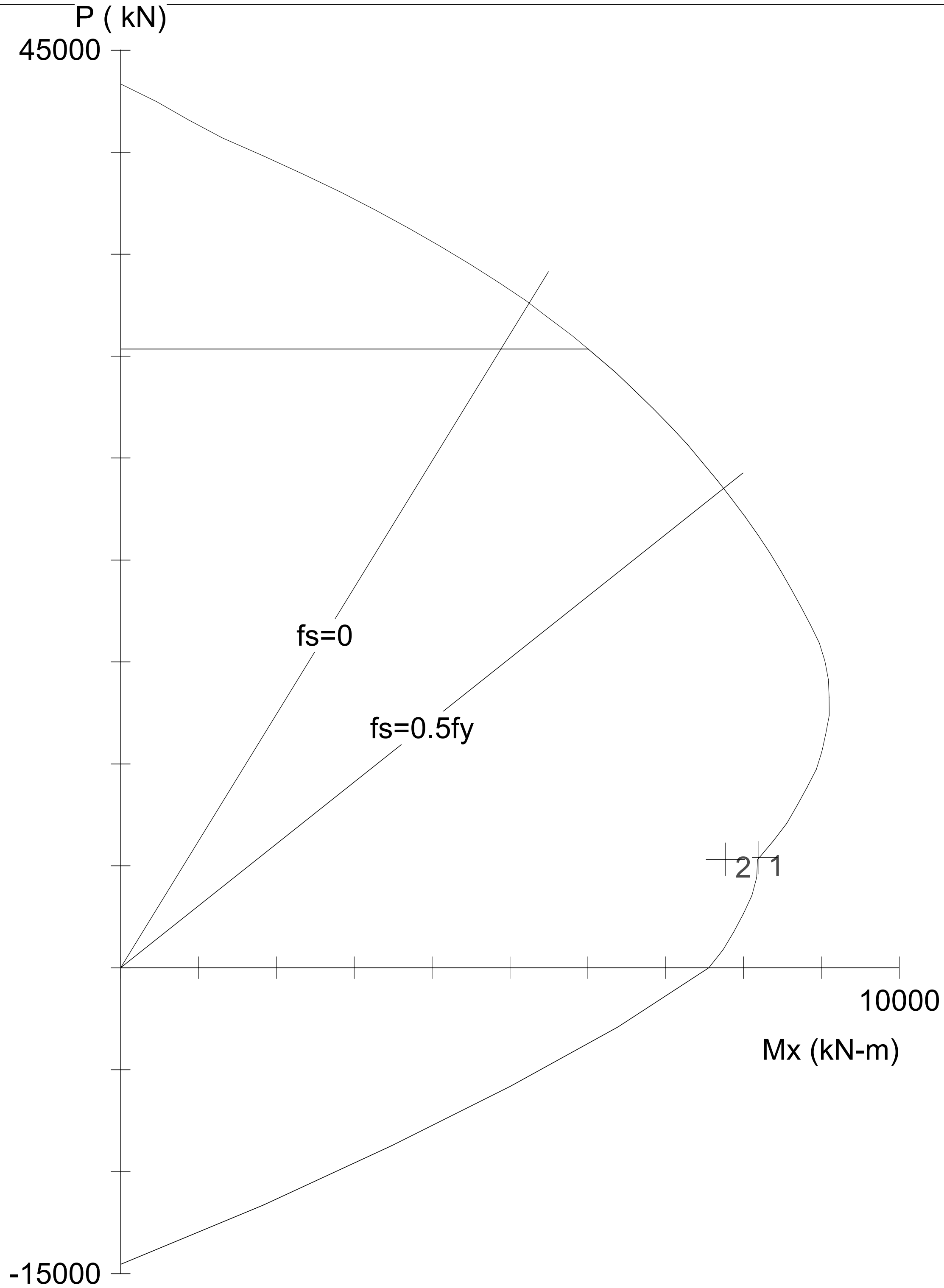
*** Program completed as requested! ***

TABLE: Element Forces - 1.5m PILE at PIER P8, BP1 1.5 m below NGL						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP1	0	P8-LOAD	Max	-5196.3	1091	5164
BP1	1	P8-LOAD	Max	-5153	1091	4073
BP1	0	P8-LOAD	Min	-5196.3	1091	5164
BP1	1	P8-LOAD	Min	-5153	1091	4073
BP2	0	P8-LOAD	Max	-5239.6	979.1	6143.1
BP2	1	P8-LOAD	Max	-5196.3	979.1	5164
BP2	0	P8-LOAD	Min	-5239.6	979.1	6143.1
BP2	1	P8-LOAD	Min	-5196.3	979.1	5164
BP3	0	P8-LOAD	Max	-5282.9	757.2	6900.3
BP3	1	P8-LOAD	Max	-5239.6	757.2	6143.1
BP3	0	P8-LOAD	Min	-5282.9	757.2	6900.3
BP3	1	P8-LOAD	Min	-5239.6	757.2	6143.1
BP4	0	P8-LOAD	Max	-5326.2	535.9	7436.3
BP4	1	P8-LOAD	Max	-5282.9	535.9	6900.3
BP4	0	P8-LOAD	Min	-5326.2	535.9	7436.3
BP4	1	P8-LOAD	Min	-5282.9	535.9	6900.3
BP5	0	P8-LOAD	Max	-5369.5	315.1	7751.3
BP5	1	P8-LOAD	Max	-5326.2	315.1	7436.3
BP5	0	P8-LOAD	Min	-5369.5	315.1	7751.3
BP5	1	P8-LOAD	Min	-5326.2	315.1	7436.3
BP6	0	P8-LOAD	Max	-5412.8	14.6	7765.9
BP6	1	P8-LOAD	Max	-5369.5	14.6	7751.3
BP6	0	P8-LOAD	Min	-5412.8	14.6	7765.9
BP6	1	P8-LOAD	Min	-5369.5	14.6	7751.3
BP7	0	P8-LOAD	Max	-5456.1	-285.5	7480.4
BP7	1	P8-LOAD	Max	-5412.8	-285.5	7765.9
BP7	0	P8-LOAD	Min	-5456.1	-285.5	7480.4
BP7	1	P8-LOAD	Min	-5412.8	-285.5	7765.9
BP8	0	P8-LOAD	Max	-5499.4	-585.3	6895.1
BP8	1	P8-LOAD	Max	-5456.1	-585.3	7480.4
BP8	0	P8-LOAD	Min	-5499.4	-585.3	6895.1
BP8	1	P8-LOAD	Min	-5456.1	-585.3	7480.4
BP9	0	P8-LOAD	Max	-5542.7	-881.5	6013.6
BP9	1	P8-LOAD	Max	-5499.4	-881.5	6895.1
BP9	0	P8-LOAD	Min	-5542.7	-881.5	6013.6
BP9	1	P8-LOAD	Min	-5499.4	-881.5	6895.1
BP10	0	P8-LOAD	Max	-5586	-1034.9	4978.6
BP10	1	P8-LOAD	Max	-5542.7	-1034.9	6013.6
BP10	0	P8-LOAD	Min	-5586	-1034.9	4978.6
BP10	1	P8-LOAD	Min	-5542.7	-1034.9	6013.6
BP11	0	P8-LOAD	Max	-5629.2	-1117.7	3860.9
BP11	1	P8-LOAD	Max	-5586	-1117.7	4978.6
BP11	0	P8-LOAD	Min	-5629.2	-1117.7	3860.9
BP11	1	P8-LOAD	Min	-5586	-1117.7	4978.6
BP12	0	P8-LOAD	Max	-5672.5	-1108.4	2752.6
BP12	1	P8-LOAD	Max	-5629.2	-1108.4	3860.9
BP12	0	P8-LOAD	Min	-5672.5	-1108.4	2752.6
BP12	1	P8-LOAD	Min	-5629.2	-1108.4	3860.9

TABLE: Element Forces - 1.5m PILE at PIER P8, BP1 1.5 m below NGL						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP13	0	P8-LOAD	Max	-5715.8	-961.5	1791
BP13	1	P8-LOAD	Max	-5672.5	-961.5	2752.6
BP13	0	P8-LOAD	Min	-5715.8	-961.5	1791
BP13	1	P8-LOAD	Min	-5672.5	-961.5	2752.6
BP14	0	P8-LOAD	Max	-5759.1	-766.4	1024.7
BP14	1	P8-LOAD	Max	-5715.8	-766.4	1791
BP14	0	P8-LOAD	Min	-5759.1	-766.4	1024.7
BP14	1	P8-LOAD	Min	-5715.8	-766.4	1791
BP15	0	P8-LOAD	Max	-5802.4	-543.5	481.2
BP15	1	P8-LOAD	Max	-5759.1	-543.5	1024.7
BP15	0	P8-LOAD	Min	-5802.4	-543.5	481.2
BP15	1	P8-LOAD	Min	-5759.1	-543.5	1024.7
BP16	0	P8-LOAD	Max	-5845.7	-351.6	129.6
BP16	1	P8-LOAD	Max	-5802.4	-351.6	481.2
BP16	0	P8-LOAD	Min	-5845.7	-351.6	129.6
BP16	1	P8-LOAD	Min	-5802.4	-351.6	481.2
BP17	0	P8-LOAD	Max	-5889	-164.3	-34.7
BP17	1	P8-LOAD	Max	-5845.7	-164.3	129.6
BP17	0	P8-LOAD	Min	-5889	-164.3	-34.7
BP17	1	P8-LOAD	Min	-5845.7	-164.3	129.6
BP18	0	P8-LOAD	Max	-5932.3	-37.9	-72.6
BP18	1	P8-LOAD	Max	-5889	-37.9	-34.7
BP18	0	P8-LOAD	Min	-5932.3	-37.9	-72.6
BP18	1	P8-LOAD	Min	-5889	-37.9	-34.7
BP19	0	P8-LOAD	Max	-5975.6	29.9	-42.7
BP19	1	P8-LOAD	Max	-5932.3	29.9	-72.6
BP19	0	P8-LOAD	Min	-5975.6	29.9	-42.7
BP19	1	P8-LOAD	Min	-5932.3	29.9	-72.6
BP20	0	P8-LOAD	Max	-6018.9	42.7	0
BP20	1	P8-LOAD	Max	-5975.6	42.7	-42.7
BP20	0	P8-LOAD	Min	-6018.9	42.7	0
BP20	1	P8-LOAD	Min	-5975.6	42.7	-42.7



1500 mm diam.



Code: ACI 318-95

Units: Metric

Run axis: About X-axis

Run option: Investigation

Slenderness: Not considered

Column type: Structural

Bars: User-defined

Date: 08/19/06

Time: 11:12:37

PCACOL V3.00 (PCA 1999) - Licensed to: KEI, MANILA, ST

File: C:\0-BALA~1\RC-DES~1\BOREPI~1\1.5M\P8\P8XSEC1.COL

Project: BALARAJA FLYOVER

Column: BP-P8		Engineer:	
f'c = 30 MPa	fy = 345 MPa	Ag = 1.76715e+006 mm^2	26 #51 bars
Ec = 25743 MPa	Es = 200000 MPa	As = 52702 mm^2	Rho = 2.98%
fc = 25.5 MPa	e_rup = Infinity	Xo = 0 mm	Iy = 2.49e+011 mm^4
e_u = 0.003 mm/mm		Yo = 0 mm	Iy = 2.49e+011 mm^4
Beta1 = 0.83245		Clear spacing = 95 mm	Clear cover = 119 mm
Confinement: Other	phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7		

```
OOOOOOO    OOOOO    OOOOO    OOOOO    OOOOO   OO
OO   OO   OO   OO  OO   OO  OO   OO  OO   OO  OO
OO   OO   OO   OO  OO   OO  OO   OO  OO   OO  OO
OO   OO   OO       OO   OO  OO       OO   OO  OO
OO   OO   OO       OOOOOOO  OO       OO   OO  OO
OOOOOOO   OO   OO  OO   OO  OO   OO  OO   OO  OO
OO        OO   OO  OO   OO  OO   OO  OO   OO  OO
OO         OOOOO   OO   OO   OOOOO    OOOOO   OOOOO  (TM)
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==
Computer program for the Strength Design of Reinforced Concrete Sections
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General Information:
====================

File Name: I:\1-BALA~1\RC-DES~1\BOREPI~1\1.5M\P8\P8XSEC1.COL
Project: BALARAJA FLYOVER
Column: BP-P8 Engineer:
Code: ACI 318-95 Units: Metric

Run Option: Investigation Slenderness: Not considered
Run Axis: X-axis Column Type: Structural

Material Properties:
====================

f'c = 30 MPa fy = 345 MPa
Ec = 25743 MPa Es = 200000 MPa
fc = 25.5 MPa Rupture strain = Infinity
Ultimate strain = 0.003 mm/mm
Beta1 = 0.83245

Section:
========

Circular: Diameter = 1500 mm

Gross section area, Ag = 1.76715e+006 mm^2
Ix = 2.48505e+011 mm^4 Iy = 2.48505e+011 mm^4
Xo = 0 mm Yo = 0 mm

Reinforcement:
==============

Rebar Database: User-defined

Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)
# 6	6	28	# 8	8	50	# 10	10	79
# 12	12	113	# 14	14	154	# 16	16	201
# 20	20	314	# 25	25	491	# 28	28	616
# 32	32	801	# 40	40	1256	# 51	51	2027

Confinement: User-defined; #6 ties with #25 bars, #6 with larger bars.
phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

Layout: Circular
Pattern: All Sides Equal (Cover to longitudinal reinforcement)
Total steel area, As = 52702 mm^2 at 2.98%
26 #51 Cover = 119 mm

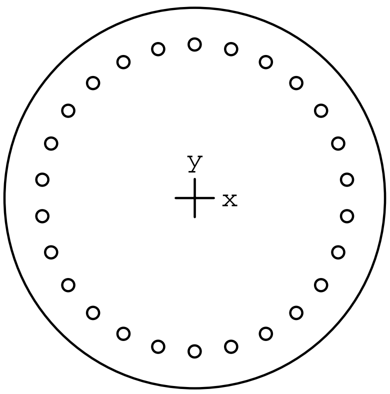
Factored Loads and Moments with Corresponding Capacities: (see user's manual for notation)
===

No.	Pu kN	Mux kN-m	fMnx kN-m	fMn/Mu
1	5398.7	8188.0	8203.4	1.002
2	5320.0	7766.0	8186.0	1.054

*** Program completed as requested! ***

TABLE: Element Forces - 1.5m PILE at PIER P9, BP1 2 m below NGL						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP1	0	P9-LOAD	Max	-5699.3	1209	5406
BP1	1	P9-LOAD	Max	-5656	1209	4197
BP1	0	P9-LOAD	Min	-5699.3	1209	5406
BP1	1	P9-LOAD	Min	-5656	1209	4197
BP2	0	P9-LOAD	Max	-5742.6	986.5	6392.5
BP2	1	P9-LOAD	Max	-5699.3	986.5	5406
BP2	0	P9-LOAD	Min	-5742.6	986.5	6392.5
BP2	1	P9-LOAD	Min	-5699.3	986.5	5406
BP3	0	P9-LOAD	Max	-5785.9	764.7	7157.2
BP3	1	P9-LOAD	Max	-5742.6	764.7	6392.5
BP3	0	P9-LOAD	Min	-5785.9	764.7	7157.2
BP3	1	P9-LOAD	Min	-5742.6	764.7	6392.5
BP4	0	P9-LOAD	Max	-5829.2	543.4	7700.6
BP4	1	P9-LOAD	Max	-5785.9	543.4	7157.2
BP4	0	P9-LOAD	Min	-5829.2	543.4	7700.6
BP4	1	P9-LOAD	Min	-5785.9	543.4	7157.2
BP5	0	P9-LOAD	Max	-5872.5	322.6	8023.2
BP5	1	P9-LOAD	Max	-5829.2	322.6	7700.6
BP5	0	P9-LOAD	Min	-5872.5	322.6	8023.2
BP5	1	P9-LOAD	Min	-5829.2	322.6	7700.6
BP6	0	P9-LOAD	Max	-5915.8	22.2	8045.4
BP6	1	P9-LOAD	Max	-5872.5	22.2	8023.2
BP6	0	P9-LOAD	Min	-5915.8	22.2	8045.4
BP6	1	P9-LOAD	Min	-5872.5	22.2	8023.2
BP7	0	P9-LOAD	Max	-5959.1	-277.9	7767.5
BP7	1	P9-LOAD	Max	-5915.8	-277.9	8045.4
BP7	0	P9-LOAD	Min	-5959.1	-277.9	7767.5
BP7	1	P9-LOAD	Min	-5915.8	-277.9	8045.4
BP8	0	P9-LOAD	Max	-6002.4	-577.7	7189.8
BP8	1	P9-LOAD	Max	-5959.1	-577.7	7767.5
BP8	0	P9-LOAD	Min	-6002.4	-577.7	7189.8
BP8	1	P9-LOAD	Min	-5959.1	-577.7	7767.5
BP9	0	P9-LOAD	Max	-6045.7	-896.1	6293.7
BP9	1	P9-LOAD	Max	-6002.4	-896.1	7189.8
BP9	0	P9-LOAD	Min	-6045.7	-896.1	6293.7
BP9	1	P9-LOAD	Min	-6002.4	-896.1	7189.8
BP10	0	P9-LOAD	Max	-6089	-1063.3	5230.4
BP10	1	P9-LOAD	Max	-6045.7	-1063.3	6293.7
BP10	0	P9-LOAD	Min	-6089	-1063.3	5230.4
BP10	1	P9-LOAD	Min	-6045.7	-1063.3	6293.7
BP11	0	P9-LOAD	Max	-6132.2	-1157.4	4073.1
BP11	1	P9-LOAD	Max	-6089	-1157.4	5230.4
BP11	0	P9-LOAD	Min	-6132.2	-1157.4	4073.1
BP11	1	P9-LOAD	Min	-6089	-1157.4	5230.4
BP12	0	P9-LOAD	Max	-6175.5	-1152.8	2920.3
BP12	1	P9-LOAD	Max	-6132.2	-1152.8	4073.1
BP12	0	P9-LOAD	Min	-6175.5	-1152.8	2920.3
BP12	1	P9-LOAD	Min	-6132.2	-1152.8	4073.1

TABLE: Element Forces - 1.5m PILE at PIER P9, BP1 2 m below NGL						
Frame	Station	OutputCase	StepType	P AXIAL	V2 SHEAR	M3 MOMENT
Text	m	Text	Text	KN	KN	KN-m
BP13	0	P9-LOAD	Max	-6218.8	-1007.2	1913.1
BP13	1	P9-LOAD	Max	-6175.5	-1007.2	2920.3
BP13	0	P9-LOAD	Min	-6218.8	-1007.2	1913.1
BP13	1	P9-LOAD	Min	-6175.5	-1007.2	2920.3
BP14	0	P9-LOAD	Max	-6262.1	-807.5	1105.6
BP14	1	P9-LOAD	Max	-6218.8	-807.5	1913.1
BP14	0	P9-LOAD	Min	-6262.1	-807.5	1105.6
BP14	1	P9-LOAD	Min	-6218.8	-807.5	1913.1
BP15	0	P9-LOAD	Max	-6305.4	-576.4	529.3
BP15	1	P9-LOAD	Max	-6262.1	-576.4	1105.6
BP15	0	P9-LOAD	Min	-6305.4	-576.4	529.3
BP15	1	P9-LOAD	Min	-6262.1	-576.4	1105.6
BP16	0	P9-LOAD	Max	-6348.7	-375.9	153.4
BP16	1	P9-LOAD	Max	-6305.4	-375.9	529.3
BP16	0	P9-LOAD	Min	-6348.7	-375.9	153.4
BP16	1	P9-LOAD	Min	-6305.4	-375.9	529.3
BP17	0	P9-LOAD	Max	-6392	-178.9	-25.5
BP17	1	P9-LOAD	Max	-6348.7	-178.9	153.4
BP17	0	P9-LOAD	Min	-6392	-178.9	-25.5
BP17	1	P9-LOAD	Min	-6348.7	-178.9	153.4
BP18	0	P9-LOAD	Max	-6435.3	-45.1	-70.6
BP18	1	P9-LOAD	Max	-6392	-45.1	-25.5
BP18	0	P9-LOAD	Min	-6435.3	-45.1	-70.6
BP18	1	P9-LOAD	Min	-6392	-45.1	-25.5
BP19	0	P9-LOAD	Max	-6478.6	27.7	-42.9
BP19	1	P9-LOAD	Max	-6435.3	27.7	-70.6
BP19	0	P9-LOAD	Min	-6478.6	27.7	-42.9
BP19	1	P9-LOAD	Min	-6435.3	27.7	-70.6
BP20	0	P9-LOAD	Max	-6521.9	42.9	0
BP20	1	P9-LOAD	Max	-6478.6	42.9	-42.9
BP20	0	P9-LOAD	Min	-6521.9	42.9	0
BP20	1	P9-LOAD	Min	-6478.6	42.9	-42.9



1500 mm diam.

Code: ACI 318-95

Units: Metric

Run axis: About X-axis

Run option: Investigation

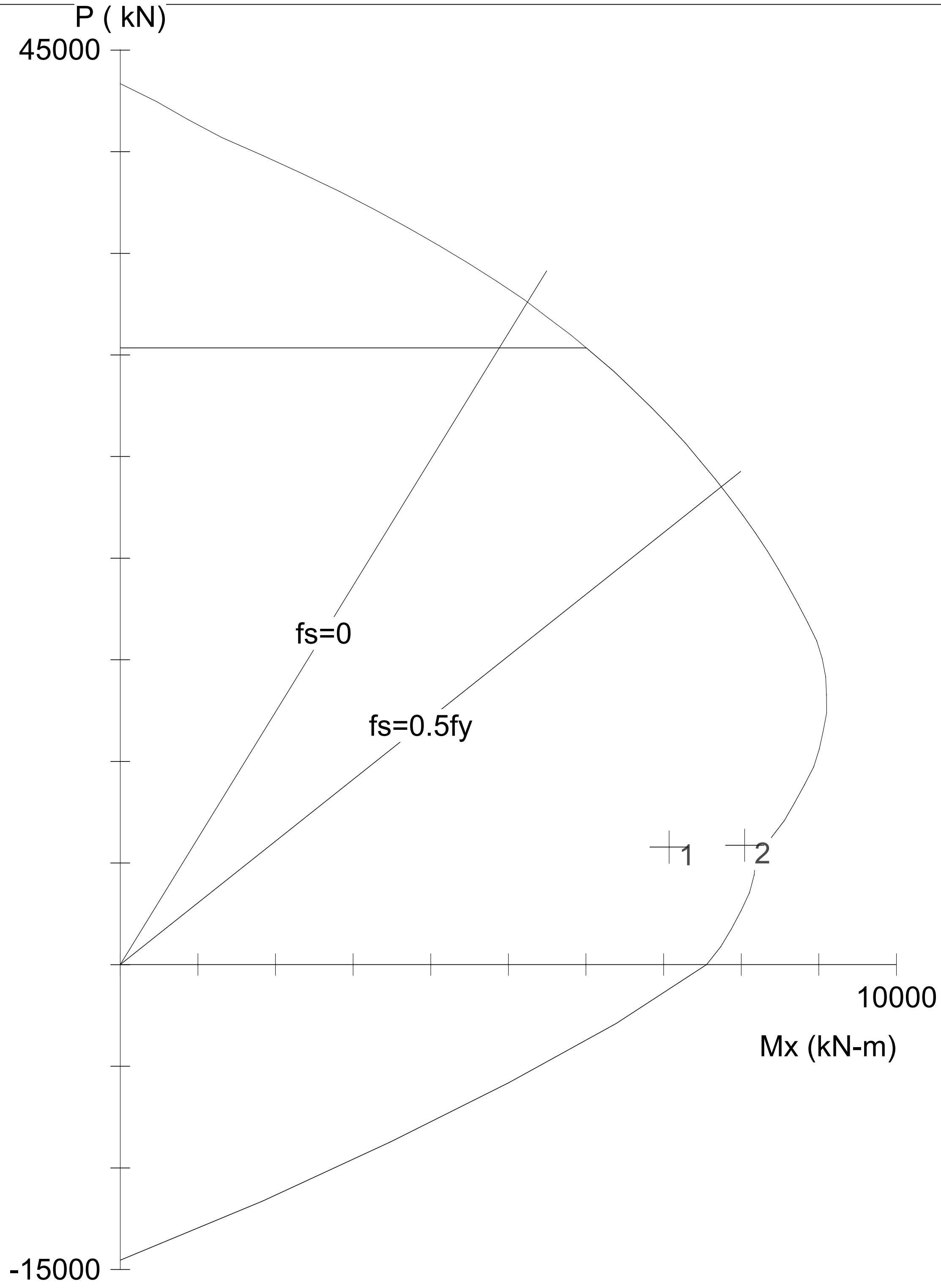
Slenderness: Not considered

Column type: Structural

Bars: User-defined

Date: 08/19/06

Time: 11:12:56



PCACOL V3.00 (PCA 1999) - Licensed to: KEI, MANILA, ST

File: C:\0-BALA~1\RC-DES~1\BOREPI~1\1.5M\P9\P9XSEC1.COL

Project: BALARAJA FLYOVER

Column: BP-P9		Engineer:	
f'c = 30 MPa	fy = 345 MPa	Ag = 1.76715e+006 mm^2	26 #51 bars
Ec = 25743 MPa	Es = 200000 MPa	As = 52702 mm^2	Rho = 2.98%
fc = 25.5 MPa	e_rup = Infinity	Xo = 0 mm	Iy = 2.49e+011 mm^4
e_u = 0.003 mm/mm		Yo = 0 mm	Iy = 2.49e+011 mm^4
Beta1 = 0.83245		Clear spacing = 95 mm	Clear cover = 119 mm
Confinement: Other	phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7		

```
OOOOOOO    OOOOO    OOOOO    OOOOO    OOOOO   OO
OO    OO  OO   OO  OO   OO  OO   OO  OO   OO  OO
OO    OO  OO   OO  OO   OO  OO   OO  OO   OO  OO
OO    OO  OO       OO   OO  OO       OO   OO  OO
OO    OO  OO       OOOOOOO  OO       OO   OO  OO
OOOOOOO   OO   OO  OO   OO  OO   OO  OO   OO  OO
OO        OO   OO  OO   OO  OO   OO  OO   OO  OO
OO         OOOOO   OO   OO   OOOOO    OOOOO   OOOOO  (TM)
```

==
Computer program for the Strength Design of Reinforced Concrete Sections
==

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General Information:
====================

File Name: I:\1-BALA~1\RC-DES~1\BOREPI~1\1.5M\P9\P9XSEC1.COL
Project: BALARAJA FLYOVER
Column: BP-P9 Engineer:
Code: ACI 318-95 Units: Metric

Run Option: Investigation Slenderness: Not considered
Run Axis: X-axis Column Type: Structural

Material Properties:
====================

f'c = 30 MPa fy = 345 MPa
Ec = 25743 MPa Es = 200000 MPa
fc = 25.5 MPa Rupture strain = Infinity
Ultimate strain = 0.003 mm/mm
Beta1 = 0.83245

Section:
========

Circular: Diameter = 1500 mm

Gross section area, Ag = 1.76715e+006 mm^2
Ix = 2.48505e+011 mm^4 Iy = 2.48505e+011 mm^4
Xo = 0 mm Yo = 0 mm

Reinforcement:
==============

Rebar Database: User-defined

Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)	Size	Diam (mm)	Area (mm^2)
# 6	6	28	# 8	8	50	# 10	10	79
# 12	12	113	# 14	14	154	# 16	16	201
# 20	20	314	# 25	25	491	# 28	28	616
# 32	32	801	# 40	40	1256	# 51	51	2027

Confinement: User-defined; #6 ties with #25 bars, #6 with larger bars.
phi(a) = 0.7, phi(b) = 0.8, phi(c) = 0.7

Layout: Circular
Pattern: All Sides Equal (Cover to longitudinal reinforcement)
Total steel area, As = 52702 mm^2 at 2.98%
26 #51 Cover = 119 mm

Factored Loads and Moments with Corresponding Capacities: (see user's manual for notation)
==

No.	Pu kN	Mux kN-m	fMnx kN-m	fMn/Mu
1	5780.0	7071.0	8286.9	1.172
2	5872.0	8045.0	8306.8	1.033

*** Program completed as requested! ***

TABLE: Joint Displacements						
Joint	**OutputCase**	**CaseType**	**StepType**	**U1**	**U3**	**R2**
Text	Text	Text	Text	m	m	Radians
PILE TOP	P3-LOAD	NonStatic	Max	0.100035	-0.001827	0.0127
PILE TOP	P3-LOAD	NonStatic	Min	0.100035	-0.001827	0.0127
PILE TOP	P4-LOAD	NonStatic	Max	0.159324	-0.002572	0.0187
PILE TOP	P4-LOAD	NonStatic	Min	0.159324	-0.002572	0.0187
PILE TOP	P5-LOAD	NonStatic	Max	0.188349	-0.002577	0.0212
PILE TOP	P5-LOAD	NonStatic	Min	0.188349	-0.002577	0.0212

Notes:

P3-LOAD Load case for the 2.5m piles at Pier 3
P4-LOAD Load case for the 2.5m piles at Pier 4
P5-LOAD Load case for the 2.5m piles at Pier 5

JRA Specifications for Highway Bridges, Part IV Substructurres, 1996 includes the following guidelines for limiting values of displacement of foudations designed using the ductility design method (plastic hinge method):

For the limit value of foundation dislacement, a horizontal displacement of about 40cm and an angular displacement of about 0.025 rad may be taken as a guideline. (Clause 10.10.5)

On the basis of the above guideline, the pile displacements for 2.5m diameter piles under plastic hinging effects are acceptable.

TABLE: Joint Displacements						
Joint	**OutputCase**	**CaseType**	**StepType**	**U1**	**U3**	**R2**
Text	Text	Text	Text	m	m	Radians
PILE TOP	A1	NonStatic	Max	0.054865	-0.00232	0.010529
PILE TOP	A1	NonStatic	Min	0.054865	-0.00232	0.010529
PILE TOP	A2	NonStatic	Max	0.11594	-0.0021	0.01972
PILE TOP	A2	NonStatic	Min	0.11594	-0.0021	0.01972

Notes:

A1 Load case for the 1.8m piles at Abutment A1
A2 Load case for the 1.8m piles at Abutment A2

JRA Specifications for Highway Bridges, Part IV Substructurres, 1996 includes the following guidelines for limiting values of displacement of foudations designed using the ductility design method (plastic hinge method):

For the limit value of foundation dislacement, a horizontal displacement of about 40cm and an angular displacement of about 0.025 rad may be taken as a guideline. (Clause 10.10.5)

On the basis of the above guideline, the pile displacements for 1.8m diameter piles under plastic hinging effects are acceptable.

TABLE: Joint Displacements						
Joint	**OutputCase**	**CaseType**	**StepType**	**U1**	**U3**	**R2**
Text	Text	Text	Text	m	m	Radians
PILETOP	P1-LOAD	NonStatic	Max	0.179258	-0.005351	0.02828
PILETOP	P1-LOAD	NonStatic	Min	0.179258	-0.005351	0.02828
PILETOP	P2-LOAD	NonStatic	Max	0.185139	-0.005579	0.029008
PILETOP	P2-LOAD	NonStatic	Min	0.185139	-0.005579	0.029008
PILETOP	P6-LOAD	NonStatic	Max	0.171124	-0.005182	0.02749
PILETOP	P6-LOAD	NonStatic	Min	0.171124	-0.005182	0.02749
PILETOP	P7-LOAD	NonStatic	Max	0.155033	-0.005897	0.026071
PILETOP	P7-LOAD	NonStatic	Min	0.155033	-0.005897	0.026071
PILETOP	P8-LOAD	NonStatic	Max	0.144692	-0.004964	0.024368
PILETOP	P8-LOAD	NonStatic	Min	0.144692	-0.004964	0.024368
PILETOP	P9-LOAD	NonStatic	Max	0.151672	-0.005411	0.025424
PILETOP	P9-LOAD	NonStatic	Min	0.151672	-0.005411	0.025424

Notes:

P1-LOAD Load case for the 1.5m piles at Pier 1
P2-LOAD Load case for the 1.5m piles at Pier 2
P6-LOAD Load case for the 1.5m piles at Pier 6
P7-LOAD Load case for the 1.5m piles at Pier 7
P8-LOAD Load case for the 1.5m piles at Pier 8
P9-LOAD Load case for the 1.5m piles at Pier 9

JRA Specifications for Highway Bridges, Part IV Substructurres, 1996 includes the following guidelines for limiting values of displacement of foudations designed using the ductility design method (plastic hinge method):

For the limit value of foundation dislacement, a horizontal displacement of about 40cm and an angular displacement of about 0.025 rad may be taken as a guideline. (Clause 10.10.5)

On the basis of the above guideline, the pile displacements for 1.5m diameter piles under plastic hinging effects are acceptable.

9.3.2. SHEAR DESIGN

Notes on Shear Design – Reinforced Concrete Piles

(1) General

Refer to Notes on Shear Design – Reinforced Concrete for the design approach.

(2) Provisions for Seismic Design

Refer to Notes on Cast-In-Place Concrete Piles for the seismic requirements.

Note that the full strength of the concrete is assumed in resisting shear forces due to plastic hinging of the column, given that the plastic hinge will form in the column above the pile column connection rather than in the pile.

TABLE: Ultimate Shear Capacity - Bored Piles							
Pile	**Vp PLASTIC HINGE SHEAR**	**dv**	**Vc**	**Vs Required**	**Link diameter**	**Required link spacing s**	**Design link spacing sd**
Text	KN	mm	KN	KN	mm	mm	mm
P3	2648	1727	3925	0	19	225	**200**
P4	4560	1727	3925	2590	19	147	**150**
P5	4561	1727	3925	2591	19	147	**125**

f_c = 30 MPa
f_{yh} = 390 MPa
ϕ = 0.70 Strength Reduction Factor
D = 2500 mm
D_r = 2100 mm

Note:

1. Within the confinement length of the pile the confinement is provide by socket pipe.
2. The confinement length of the pile is 2.0 diameters from the underside of pile cap.
3. The maximum allowable spiral link spacing is 225mm.
4. For a definition of d_v and D_r refer to Notes on Shear Design - Reinforced Concrete
5. Plastic Hinge Shear Force Based on 18mm CHS thickness

TABLE: Ultimate Shear Capacity - Bored Piles

Pile	Vp PLASTIC HINGE SHEAR	dv	Vc	Vs Required	Link diameter	Required link spacing s	Design link spacing sd
Text	KN	mm	KN	KN	mm	mm	mm
A1	1918	1248	2042	698	19	395	**225**
A2	1935	1248	2042	722	19	382	**225**

f_c = 30 MPa
f_{yh} = 390 MPa
ϕ = 0.70 Strength Reduction Factor
D = 1800 mm
D_r = 1528 mm

Note:
1. Refer to Abutment Design Calculations for plastic hinge shear forces.
2. Within the confinement length of the pile the maximum spiral spacing shall be 70mm.
   Number of additional 16mm cross-ties required at 300mm c/c is 4 (see attached sheet)
3. The confinement length of the pile is 2.0 diameters from the underside of pile cap.
4. The maximum allowable spiral link spacing is 225mm.
5. For a definition of d_v and D_r refer to Notes on Shear Design - Reinforced Concrete

TABLE: Ultimate Shear Capacity - Bored Piles							
Pile	**Vp PLASTIC HINGE SHEAR**	**dv**	**Vc**	**Vs Required**	**Link diameter**	**Required link spacing s**	**Design link spacing sd**
Text	KN	mm	KN	KN	mm	mm	mm
P1	1199	1033	1409	304	19	751	**225**
P2	1218	1033	1409	330	19	692	**225**
P6	1208	1033	1409	317	19	722	**225**
P7	1198	1033	1409	303	19	754	**225**
P8	1092	1033	1409	150	19	1518	**225**
P9	1209	1033	1409	318	19	717	**225**

f_c = 30 MPa
f_{yh} = 390 MPa
ϕ = 0.70 Strength Reduction Factor
D = 1500 mm
D_r = 1250 mm

Note:

1. Within the confinement length of the pile the maximum spiral spacing shall be 75mm. No additional cross-ties required if spiral spacing is 70mm (see attached sheet)
2. The confinement length of the pile is 2.0 diameters from the underside of pile cap.
3. The maximum allowable spiral link spacing is 225mm.
4. For a definition of d_v and D_r refer to Notes on Shear Design - Reinforced Concrete

Reinforcement Detailing
Plastic Hing Zone - PILES

		Pile Diameter (mm)		
		1500	1800	2500
		Single Spiral	Single Spiral	Single Spiral
A_g	mm^2	1767146	2544690	4908739
A_c	mm^2	1327323	2010619	4154756
ρ(1)		0.0115	0.0092	0.0063
ρ(2)		0.0092	0.0092	0.0092
ρ_s		**0.0115**	**0.0092**	**0.0092**
		Required Steel Volume (mm^3)		
s (mm) =		50	60	75
V (mm^3) =		1013475	1409367	3398357
		Spiral Steel Volume (mm^3)		
d_b(mm) =	19	1141027	1408247	2031759
		Required ∅16mm Tie Steel Volume (mm^3)		
st (mm) =	150	0	2800	2733196
st (mm) =	300	0	5599	5466393
		Required Number of ∅16mmTies		
st (mm) =	150	0.0	0.0	7.3
st (mm) =	300	0.0	0.0	14.5

Note:

ρ(1) $$\rho_s = 0.45\left(\frac{A_g}{A_c} - 1\right)\frac{f_c^{'}}{f_{yh}}$$

ρ(2) $$\rho_s = 0.12\frac{f_c^{'}}{f_{yh}}$$

cover = 100 mm

f_c = 30 Mpa

f_y = 390 Mpa

s = spiral link spacing

st = tie link spacing

Take tie bar length to be 75% of pile diameter