3.2 SUMMARY OF SPT'S

											1.8m Dia Pile		1.5m Dia Pile		2.5m Dia Pile	
BH Ref.	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**13**	**Ave**	**Design**	**Ave**	**Design**	**Ave**	**Design**
	SPT value										**3,4,13**	**3,4,13**	**4-6, 9-11**	**4-6, 9-11**	**6-9**	**6-9**
Depth m																
2	16	23	13	11	25	3	17	5	14	6	15	5	14	5	14	5
4	27	4	15	14	11	15	11	5	7	**5**	12	5	9	5	13	10
6	38	6	14	16	13	11	14	7	9	**4**	16	5	11	5	14	10
8	43	50	41	38	50	32	50	10	50	13	35	15	40	10	43	30
10	50	50	50	50	50	50	27	22	50	18	39	20	42	25	44	30
12	50	50	50	50	20	50	50	37	23	50	50	40	43	30	43	20
14	50	50	50	50	50	50	50	50	49	50	50	40	50	40	50	40
16	50	50			50		50	50	50	50	50	40	50	40	50	40
18	50	50			50		50	50	50	50	50	40	50	40	50	40
20		50			50			50	50		50	40	50	40	50	40
22		50			50						50	40	50	40	50	40
24		50			50						50	40	50	40	50	40
26		***50***			***50***						50	40	50	40	50	40
28		***50***			50						50	40	50	40	50	40
30		***50***			50						50	40	50	40	50	40
32																
34																
36																
38																
40																

NOTE: SPT value underlined is sand.

3.3 SUMMARY OF UNDISTURBED TESTS

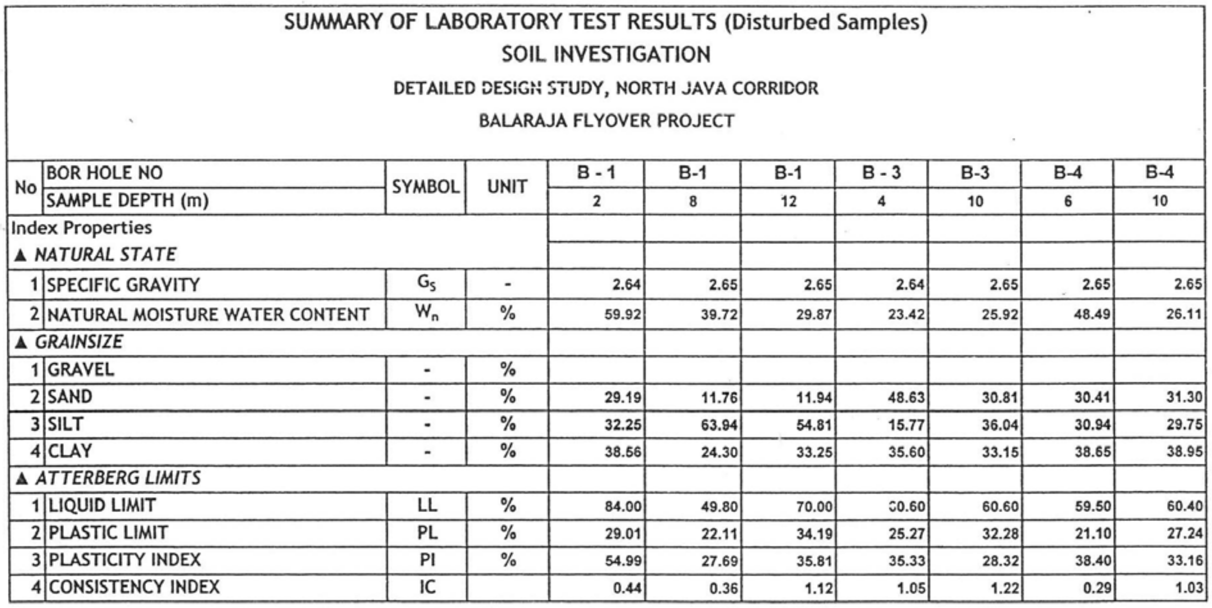
SUMMARY OF LABORATORY TEST RESULTS
SOIL INVESTIGATION
DETAILED DESIGN STUDY, NORTH JAVA CORRIDOR
BALARAJA FLYOVER PROJECT

No	BOR HOLE NO	SYMBOL	UNIT	B - 2			B - 7		
	SAMPLE DEPTH (m)			4,5			5		
				top	middle	bottom	top	middle	bottom
	Index Properties								
	▲ *NATURAL STATE*								
1	SPECIFIC GRAVITY	G_s	-	2.65			2.51		
2	NATURAL MOISTURE WATER CONTENT	W_n	%	77.19			35.92		
4	UNIT WEIGHT	γ_m	t/m^3	1.44			1.77		
5	DRY UNIT WEIGHT	γ_d	t/m^3	0.81			1.30		
7	VOID RATIO	e	-	2.26			0.93		
8	POROSITY	n	%	0.31			0.52		
9	DEGREE OF SATURATION	Sr	%	90.48			97.21		
	▲ *GRAINSIZE*								
1	GRAVEL	-	%						
2	SAND	-	%	14.27			18.20		
3	SILT	-	%	42.61			51.39		
4	CLAY	-	%	43.12			30.41		
5	ACTIVITY	A	-						
	▲ *ATTERBERG LIMITS*								
1	LIQUID LIMIT	LL	%	117.60			91.60		
2	PLASTIC LIMIT	PL	%	20.95			28.04		
3	PLASTICITY INDEX	PI	%	96.65			63.56		
4	LIQUIDITY INDEX	IL		0.58			0.12		
5	CONSISTENCY INDEX	IC		0.42			0.88		
	Engineering Properties								
	▲ *UNCONFINED COMPRESSION TEST (UCT)*								
1	UNCONFINED COMPRESSIVE STRENGTH (Undisturbed)	q_u	kg/cm^2	1.415	1.624	0.961	0.757	0.651	0.632
2	UNCONFINED COMPRESSIVE STRENGTH (Remolded)	q_r	kg/cm^2	0.710	0.800	0.450	0.380	0.334	0.331
3	SENSITIVITY	S_t	-	1.993	2.030	2.136	1.992	1.949	1.909
4	SHEAR STRENGTH	c_u	kg/cm^2	0.708	0.812	0.481	0.379	0.326	0.316
5	MODULUS OF ELASTICITY	E_s	kg/cm^2	42.105	45.000	55.556	17.021	14.000	14.000
	▲ *DIRECT SHEAR TEST*								
1	Angle of internal friction	ϕ	deg	14.300	17.060	15.770	15.320	16.750	16.170
2	Cohesion	c	kg/cm^2	0.010	0.010	0.030	0.030	0.015	0.015
	▲ *CONSOLIDATION TEST*								
1	Compression Index	Cc	-	0.269	0.236	0.306	0.398	0.332	0.390
2	Coefficient of Consolidation	cv	cm^2/min	5.200E-03	7.600E-03	7.600E-03	5.500E-03	3.300E-03	2.600E-03

SUMMARY OF LABORATORY TEST RESULTS
SOIL INVESTIGATION
DETAILED DESIGN STUDY, NORTH JAVA CORRIDOR
BALARAJA FLYOVER PROJECT

No	BOR HOLE NO SAMPLE DEPTH (m)	SYMBOL	UNIT	B - 7 12,5			B - 7 22,5		
				top	middle	bottom	top	middle	bottom
	Index Properties								
	▲ *NATURAL STATE*								
1	SPECIFIC GRAVITY	G_s	-	2.65			2.51		
2	NATURAL MOISTURE WATER CONTENT	W_n	%	77.19			35.92		
4	UNIT WEIGHT	γ_m	t/m^3	1.44			1.77		
5	DRY UNIT WEIGHT	γ_d	t/m^3	0.81			1.30		
7	VOID RATIO	e	-	2.26			0.93		
8	POROSITY	n	%	0.31			0.52		
9	DEGREE OF SATURATION	Sr	%	90.48			97.21		
	▲ *GRAINSIZE*								
1	GRAVEL	-	%						
2	SAND	-	%	14.27			18.20		
3	SILT	-	%	42.61			51.39		
4	CLAY	-	%	43.12			30.41		
5	ACTIVITY	A	-						
	▲ *ATTERBERG LIMITS*								
1	LIQUID LIMIT	LL	%	117.60			91.60		
2	PLASTIC LIMIT	PL	%	20.95			28.04		
3	PLASTICITY INDEX	PI	%	96.65			63.56		
4	LIQUIDITY INDEX	IL		0.58			0 12		
5	CONSISTENCY INDEX	IC		0.42			0.88		
	Engineering Properties								
	▲ *UNCONFINED COMPRESSION TEST (UCT)*								
1	UNCONFINED COMPRESSIVE STRENGTH (Undisturbed)	q_u	kg/cm^2	1.790	1.883	2.149	1.939	1.860	2.152
2	UNCONFINED COMPRESSIVE STRENGTH (Remolded)	q_r	kg/cm^2	0.914	0.968	1.041	1.262	0.983	1.293
3	SENSITIVITY	S_t	-	1.958	1.945	2.064	1.536	1.892	1.664
4	SHEAR STRENGTH	c_u	kg/cm^2	0.895	0.942	1.075	0.970	0.930	1.076
5	MODULUS OF ELASTICITY	E_s	kg/cm^2	68.968	90.909	104.167	96.154	105.263	96.154
	▲ *DIRECT SHEAR TEST*								
1	Angle of internal friction	ϕ	deg	21.800	21.000	20.600	27.560	27.780	28.720
2	Cohesion	c	kg/cm^2	0.050	0.110	0.070	0.300	0.300	0.250
	▲ *CONSOLIDATION TEST*								
1	Compression Index	Cc	-	0.168	0.190	0.157	0.095	0.088	0.088
2	Coefficient of Consolidation	cv	cm^2/min	1.900E-03	1.700E-03	2.600E-03	6.700E-03	1.120E-02	1.600E-02

3.4 SUMMARY OF DISTURBED TESTS



SUMMARY OF LABORATORY TEST RESULTS (Disturbed Samples)

SOIL INVESTIGATION

DETAILED DESIGN STUDY, NORTH JAVA CORRIDOR
BALARAJA FLYOVER PROJECT

No	BOR HOLE NO	SYMBOL	UNIT	B - 1	B-1	B-1	B - 3	B-3	B-4	B-4
	SAMPLE DEPTH (m)			2	8	12	4	10	6	10
Index Properties										
▲ *NATURAL STATE*										
1	SPECIFIC GRAVITY	G_S	-	2.64	2.65	2.65	2.64	2.65	2.65	2.65
2	NATURAL MOISTURE WATER CONTENT	W_n	%	59.92	39.72	29.87	23.42	25.92	48.49	26.11
▲ *GRAINSIZE*										
1	GRAVEL	-	%							
2	SAND	-	%	29.19	11.76	11.94	48.63	30.81	30.41	31.30
3	SILT	-	%	32.25	63.94	54.81	15.77	36.04	30.94	29.75
4	CLAY	-	%	38.56	24.30	33.25	35.60	33.15	38.65	38.95
▲ *ATTERBERG LIMITS*										
1	LIQUID LIMIT	LL	%	84.00	49.80	70.00	60.60	60.60	59.50	60.40
2	PLASTIC LIMIT	PL	%	29.01	22.11	34.19	25.27	32.28	21.10	27.24
3	PLASTICITY INDEX	PI	%	54.99	27.69	35.81	35.33	28.32	38.40	33.16
4	CONSISTENCY INDEX	IC		0.44	0.36	1.12	1.05	1.22	0.29	1.03

SUMMARY OF LABORATORY TEST RESULTS (Disturbed Samples)

SOIL INVESTIGATION

DETAILED DESIGN STUDY, NORTH JAVA CORRIDOR

BALARAJA FLYOVER PROJECT

No	BOR HOLE NO	SYMBOL	UNIT	B-4	B-5	B-5	B-6	B-6	B-7	B-8
	SAMPLE DEPTH (m)			28	4	8	6	12	18	6
Index Properties										
▲ *NATURAL STATE*										
1	SPECIFIC GRAVITY	G_s	-	2.63	2.64	2.63	2.64	2.64	2.63	2.66
2	NATURAL MOISTURE WATER CONTENT	W_n	%	30.91	32.52	25.01	32.13	32.15	25.49	36.14
▲ *GRAINSIZE*										
1	GRAVEL	-	%							
2	SAND	-	%	43.03	23.46	26.37	34.20	11.17	32.90	31.93
3	SILT	-	%	31.37	47.04	43.57	38.00	48.83	28.69	39.65
4	CLAY	-	%	25.60	29.50	30.06	27.80	40.00	38.41	28.42
▲ *ATTERBERG LIMITS*										
1	LIQUID LIMIT	LL	%	78.00	64.20	79.00	64.90	63.00	64.80	61.00
2	PLASTIC LIMIT	PL	%	32.91	27.30	27.16	29.57	34.98	28.30	34.71
3	PLASTICITY INDEX	PI	%	45.09	36.90	51.84	35.33	28.02	36.50	26.29
4	CONSISTENCY INDEX	IC		1.04	0.86	1.04	0.93	1.10	1.08	0.95

SUMMARY OF LABORATORY TEST RESULTS (Disturbed Samples)
SOIL INVESTIGATION

DETAILED DESIGN STUDY, NORTH JAVA CORRIDOR
BALARAJA FLYOVER PROJECT

No	BOR HOLE NO	SYMBOL	UNIT	B-8	B-9	B-9	B-9	B-10	B-10	B-10
	SAMPLE DEPTH (m)			12	4	10	16	2	6	12
Index Properties										
▲ *NATURAL STATE*										
1	SPECIFIC GRAVITY	G_s	-	2.64	2.64	2.64	2.64	2.65	2.66	2.63
2	NATURAL MOISTURE WATER CONTENT	W_n	%	30.16	25.64	53.83	40.34	57.82	44.15	18.22
▲ *GRAINSIZE*										
1	GRAVEL	-	%							
2	SAND	-	%	32.72	29.37	25.96	34.75	22.57	40.34	39.13
3	SILT	-	%	39.78	27.20	41.54	36.65	33.63	40.66	19.02
4	CLAY	-	%	27.50	43.43	32.50	28.60	43.80	19.00	41.85
▲ *ATTERBERG LIMITS*										
1	LIQUID LIMIT	LL	%	67.00	53.50	87.50	73.50	76.00	55.50	39.13
2	PLASTIC LIMIT	PL	%	31.39	19.43	56.01	46.12	29.54	36.26	19.02
3	PLASTICITY INDEX	PI	%	35.61	34.07	31.49	27.38	46.46	19.24	19.24
4	CONSISTENCY INDEX	IC		1.03	0.82	1.07	1.21	0.39	0.59	1.09

SUMMARY OF LABORATORY TEST RESULTS (Disturbed Samples)

SOIL INVESTIGATION

DETAILED DESIGN STUDY, NORTH JAVA CORRIDOR

BALARAJA FLYOVER PROJECT

No	BOR HOLE NO	SYMBOL	UNIT	B-11	B-11	B-11	B-13	B-13	B-13	B-13
	SAMPLE DEPTH (m)			6	12	16	2	4	6	10
Index Properties										
▲ *NATURAL STATE*										
1	SPECIFIC GRAVITY	G_S	-	2.66	2.66	2.64	2.66	2.66	2.64	2.64
2	NATURAL MOISTURE WATER CONTENT	W_n	%	65.02	26.19	26.86	34.48	35.25	37.18	40.56
▲ *GRAINSIZE*										
1	GRAVEL	-	%							
2	SAND	-	%	37.47	34.06	9.97	21.97	67.18	65.00	9.65
3	SILT	-	%	38.73	26.44	49.03	29.73	13.62	15.50	42.75
4	CLAY	-	%	23.80	39.50	41.00	48.30	19.20	19.50	47.60
▲ *ATTERBERG LIMITS*										
1	LIQUID LIMIT	LL	%	88.30	83.50	52.80	62.00			83.00
2	PLASTIC LIMIT	PL	%	55.54	27.13	30.88	19.41			28.09
3	PLASTICITY INDEX	PI	%	32.85	56.37	21.92	42.59			54.91
4	CONSISTENCY INDEX	IC		0.71	1.02	1.18	0.65			0.77

SUMMARY OF LABORATORY TEST RESULTS (Disturbed Samples)

SOIL INVESTIGATION

DETAILED DESIGN STUDY, NORTH JAVA CORRIDOR

BALARAJA FLYOVER PROJECT

No	BOR HOLE NO	SYMBOL	UNIT	B15	B-15	B15				
	SAMPLE DEPTH (m)			4	8	12				
Index Properties										
▲ *NATURAL STATE*										
1	SPECIFIC GRAVITY	G_s	-	2.65	2.65	2.64				
2	NATURAL MOISTURE WATER CONTENT	W_n	%	70.46	24.84	26.97				
▲ *GRAINSIZE*										
1	GRAVEL	-	%							
2	SAND	-	%	13.25	41.74	11.37				
3	SILT	-	%	35.75	15.06	35.23				
4	CLAY	-	%	51.00	43.20	53.40				
▲ *ATTERBERG LIMITS*										
1	LIQUID LIMIT	LL	%	95.30	31.60	80.50				
2	PLASTIC LIMIT	PL	%	33.53	18.92	27.75				
3	PLASTICITY INDEX	PI	%	61.77	12.68	52.75				
4	CONSISTENCY INDEX	IC		0.40	0.53	1.01				

3.5 SOIL SPRINGS AND LATERAL BEARING CAPACITY OBTAINED FROM SPT CORRELATIONS

Notes on Soil Springs and Lateral Bearing Capacity

(1) Soil Characteristics – SPT Correlations

- **SPT Corrected for Overburden (refer AASHTO LRFD Article 10.8.34.3)**

  SPT shall be corrected for overburden as follows:

  $$N_{corr} = \left[0.77 \log_{10}\left(1.92/\sigma_v'\right)\right] \cdot N$$

  where:

  N = uncorrected SPT blow count (blows 300mm)

  σ_v' = vertical effective stress (MPa)

- **Internal Friction Angle of Soils (refer LA DOT Pile Capacity Guide, 2001)**

  Refer to the following chart for the correlation of SPT (corrected) against soil internal friction angle/

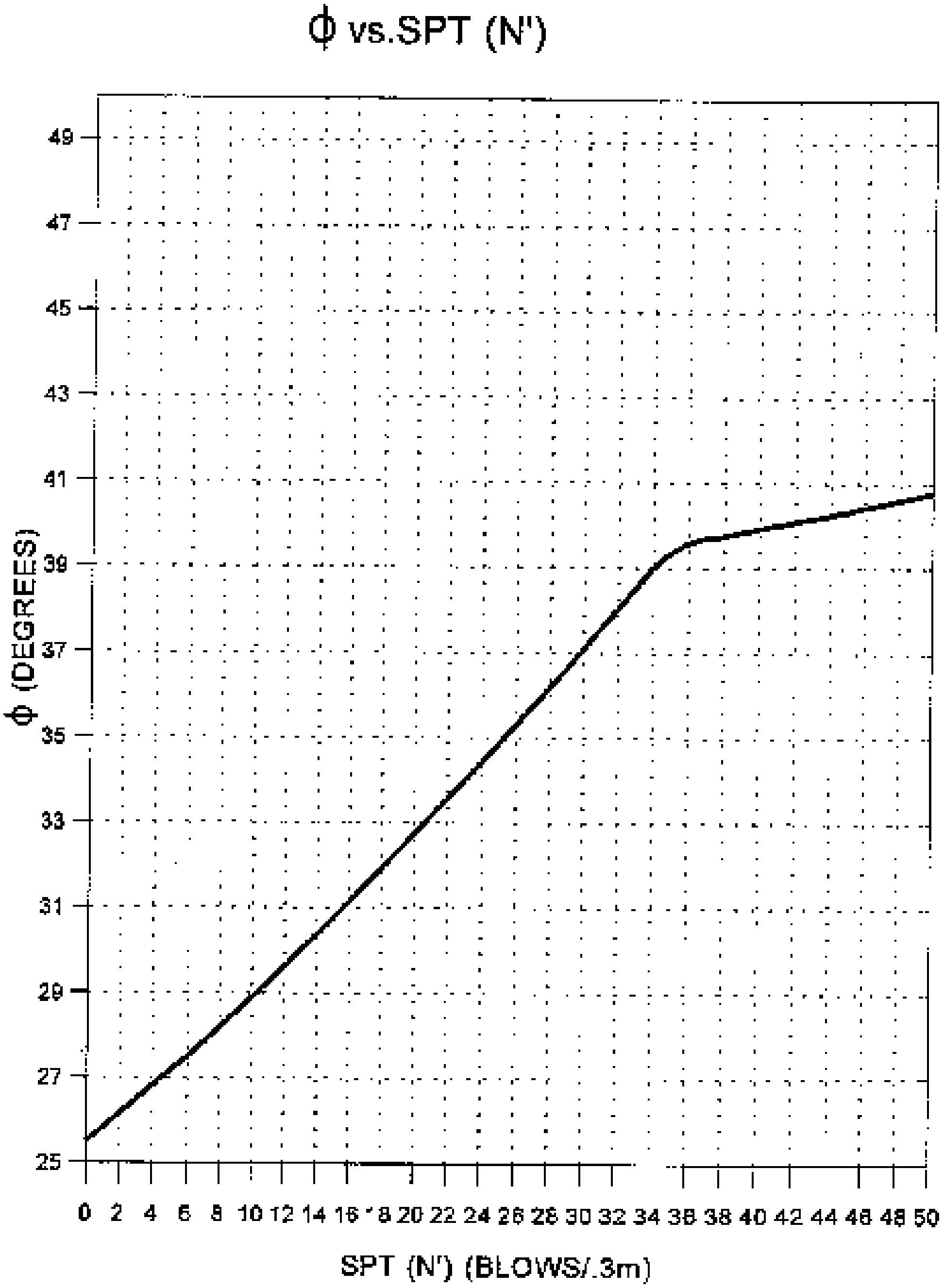
- **Undrained Shear Strength (refer JRA)**

  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:

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

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

  Note that the above correlation has been confirmed through testing of undisturbed samples.



Correlation of SPT (corrected) against Soil Internal Friction Angle, ϕ (degrees)

(Louisiana Department of Transportation, Pile Capacity Guide, 2001)

(2) Coefficient of Lateral Sub-Grade Reaction (Soil Spring)

The coefficient of lateral sub-grade reaction of the pile shall be computed as given below (refer to JRA Specifications for Highway Bridges, Part IV):

$$k_H = k_{H0} \cdot \left(\frac{B_H}{30} \right)^{-\frac{3}{4}}$$

where:

k_H : coefficient of horizontal sub-grade reaction (kgf/cm^3)

k_{H0} : coefficient of horizontal sub-grade reaction (kgf/cm^3) equivalent to a value of plate bearing test using a rigid disk of 30cm in diameter, obtained by the following formula:

$$k_{HO} = \frac{1}{30} \cdot \alpha \cdot E_0$$

E_0 : modulus of deformation (kgf/cm^2) of a particular soil layer given by the following relation:

$$E_0 = 28 \cdot N$$

where N is SPT value for that soil layer

(Note: The above correlation has been found, following testing of undisturbed samples obtained for the project, to overestimate the modulus of deformation. The result obtained from the above correlation has therefore been reduced to 40% of its value for the detailed design)

α : coefficient as given below:

normal time	during earthquake
$\alpha = 1$	$\alpha = 2$

B_H : equivalent loading width of a foundation (cm) which intersects orthogonally a load-working direction and for a pile foundation is given by the following formula:

$$B_H = \sqrt{\frac{D}{\beta}}$$

D : loading width (cm) of a foundation intersecting orthogonally a load working direction

β : characteristic value (cm-1) of the foundation as given by the following formula:

$$\beta = \sqrt[4]{\frac{k_H \cdot D}{4 \cdot EI}}$$

EI : bending rigidity (kgf·cm2) of the pile

(3) Lateral Bearing Capacity (refer JRA Part IV, 1996 and Design Criteria)

The critical design condition for the bored piles under lateral loading will be the effects of plastic hinging of the columns, during an earthquake. The horizontal bearing capacity will therefore be calculated considering conditions during an earthquake.

The horizontal bearing capacity of soil layers in front of the pile shall be determined as follows:

$$P_u = \left(K_{ep} \cdot \sigma_v^{'} \cdot K_\phi^R + 2 \cdot c \cdot \sqrt{K_{ep}} \cdot K_c^R\right) \cdot \eta_p$$

where:

K_{ep} = coefficient of passive earth pressure during an earthquake

$$K_{ep} = \frac{\cos(\phi)^2}{\cos(\delta_e) \cdot \left(1 - \sqrt{\frac{\sin(\phi - \delta_e) \cdot \sin(\phi)}{\cos(\delta_e)}}\right)^2} \leq 6$$

ϕ = effective internal friction angle

δ_e = friction angle between bored pile and soil, during an earthquake

$\delta_e = -\phi / 6$

c = effective soil cohesion

η_p = correction factor for horizontal ground reaction around a single pile

$\eta_p = 1.5$

K_ϕ^R, K_c^R = **s**trength reduction factors for soil properties

$K_\phi^R = 0.80$

$K_c^R = 0.70$

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **North Java Corridor Flyover Project**

Calculation: **Balaraja Flyover**
Soil Characteristics from SPT Correlations
Average Borehole Data
1.5m Dia Abutment Bored Pile

Reference: **JRA Specifications for Highway Bridges, Part IV, 1996**

Define Units: $kN := 1000N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $MN := 1000 \cdot kN$

Strength Reduction Factors for Soil Properties - Refer Design Criteria

$K_{\phi} := 0.8$ $K_c := 0.70$

Correction factor for horizontal groud reaction around a single pile - Refer JRA

$\eta_p := 1.5$

Pile Input Data

Type of Pile		
Rect.Reinforced Concrete (RC) **Rect. Prestressed Concrete (PC)** **Bored Pile (BP)** **Steel Pipe (SP)**	Ptype	BP
Width (or Dia.) of Pile (mm)	D	1500
Thickness of Pile (mm - for pipe piles)	t	0
Length of Pile (m)	L	30.0
Unsupported height of pile (m)	h	0.0
Modulus of Elasticity of Pile - kN/mm2	E	26.5
Sugrade reaction coefficient α **(α =1 normal case, α = 2 for seismic case)**	α	2
Elevation at Top of Pile	ElevTop (m)	-0.50
Soil Density	γ (kN/m3)	18.00
Depth to water table from ground surface (m)	z_w	1.00

$D := D \cdot mm$ $L := L \cdot m$ $ElevT := ElevT \cdot m$ $\gamma_{soil} := \gamma_{soil} \cdot \frac{kN}{m^3}$ $t := t \cdot mm$ $E := E \cdot \frac{kN}{mm^2}$

Subsoil Input Data

Ref.	Thickness	Level top of Layer	Level bottom of Layer	Soil Type	SPT N
	(cm)	(m)	(m)		
1.0	400	0.00	-4.00	Clay	5
2.0	200	-4.00	-6.00	Clay	5
3.0	200	-6.00	-8.00	Clay	5
4.0	200	-8.00	-10.00	Clay	10
5.0	200	-10.00	-12.00	Clay	25
6.0	200	-12.00	-14.00	Clay	30
7.0	200	-14.00	-16.00	Clay	40
8.0	200	-16.00	-18.00	Clay	40
9.0	200	-18.00	-20.00	Clay	40
10.0	200	-20.00	-22.00	Clay	40
11.0	200	-22.00	-24.00	Clay	40
12.0	200	-24.00	-26.00	Clay	40
13.0	200	-26.00	-28.00	Clay	40
14.0	200	-28.00	-30.00	Clay	40
15.0	200	-30.00	-32.00	Clay	40
16.0	200	-32.00	-34.00	Clay	40
17.0	200	-34.00	-36.00	Clay	40
18.0	200	-36.00	-38.00	Clay	40
19.0	200	-38.00	-40.00	Clay	40
20.0	200	-40.00	-42.00	Clay	40

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

$j := 1..20$

Length of each soil layer down the pile

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

Average depth of each soil layer

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

Effective vertical soil stress
at each soil layer

$$\gamma_{soil_j} := \begin{cases} \gamma_{soil} & \text{if } Z_j < z_w \cdot m \\ \gamma_{soil} - 10 \cdot \dfrac{kN}{m^3} & \text{otherwise} \end{cases}$$

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

Calculate corrected SPT values - Refer AASHTO LRFD 10.8.3.4.3 and LA DOT

$$SPTcorr_j := \left| \begin{array}{l} SPTcorr_j \leftarrow \left(0.77 \cdot \log\left(\dfrac{1.92 \cdot MPa}{\sigma_{v_j}}\right)\right) \cdot SPT_j \\ SPT_j \cdot 2 \quad \text{if } \dfrac{SPTcorr_j}{SPT_j} > 2 \\ 40 \quad \text{if } \left(SPT_j \geq 50\right) \cdot \left(SPTcorr_j < 40\right) \\ 40 \quad \text{if } SPTcorr_j \geq 40 \\ SPTcorr_j \quad \text{otherwise} \end{array} \right.$$

Calculate Internal Friction Angle of Soils - Correlated Against SPT - Refer LA DOT

$$\phi_j := \begin{cases} \left(\dfrac{39.2 - 25}{35} \cdot SPTcorr_j + 25\right) \cdot deg & \text{if } SPTcorr_j \leq 35 \\ \left(\dfrac{40.8 - 39.2}{50 - 35} \cdot SPTcorr_j + 35.47\right) \cdot deg & \text{otherwise} \end{cases}$$

$$\phi_j := \begin{cases} \phi_j & \text{if } SoilType_j = \text{"Sand"} \\ 0 \cdot deg & \text{otherwise} \end{cases}$$

Calculate Undrained Shear Strength of Soils - Correlated Against SPT

$$c_j := \begin{cases} SPT_j \cdot 5 \cdot \dfrac{kN}{m^2} & \text{if } \left(P_{type} = \text{"BP"}\right) \cdot \left(SoilType_j = \text{"Clay"}\right) \\ SPT_j \cdot 10 \cdot \dfrac{kN}{m^2} & \text{if } \left(P_{type} \neq \text{"BP"}\right) \cdot \left(SoilType_j = \text{"Clay"}\right) \\ 0 \cdot MPa & \text{otherwise} \end{cases}$$

$$c_j := \min\left(c_j, 200 \cdot \frac{kN}{m^2}\right)$$

Calculate Ultimate Bearing Capacities

Effective soil density: $\gamma := \gamma_{soil}$

Length of embedded pile $L = 30.0\ \text{m}$

Width of pile foundation $D = 1.5\ \text{m}$

Calculate horizontal passive earth resistance of soil layers in front of the bored pile

Friction angle between bored pile and rock during earthquake $\delta_e := -\frac{\phi}{6}$

Passive earth resistance during an earthquake

$$K_{ep_j} := \frac{\cos(\phi_j)^2}{\cos\left(\delta_{e_j}\right)\cdot\left(1 - \sqrt{\frac{\sin\left(\phi_j - \delta_{e_j}\right)\cdot\sin(\phi_j)}{\cos\left(\delta_{e_j}\right)}}\right)^2}$$

$$K_{ep_j} := \left|\begin{array}{l} 6 \ \text{ if } \ K_{ep_j} \geq 6 \\ K_{ep_j} \ \text{ otherwise} \end{array}\right.$$

Calculate ultimate horizontal bearing capacity of soil layers in front of the bored pile, Pu

Taking : $k_j := \sqrt{K_{ep_j}}$

Gives horizontal bearing capacity: $P_{u_j} := \left(K_{ep_j}\cdot\sigma_{v_j}K_\phi + 2\cdot c_j\cdot k_j\cdot K_c\right)\cdot\eta_p$

Total capacity
Pu

ϕ
component of capacity

c
component of capacity

$P_u =$

	1
1	74.1
2	100.5
3	119.7
4	191.4
5	368.1
6	439.8
7	564.0
8	583.2
9	602.4
10	621.6
11	640.8
12	660.0
13	679.2
14	698.4
15	710.4
16	712.8
17	712.8
18	712.8
19	712.8
20	712.8

$\frac{kN}{m^2}$

$\overrightarrow{\left(K_{ep}\cdot\sigma_v\cdot K_\phi\cdot\eta_p\right)} =$

	1
1	21.6
2	48.0
3	67.2
4	86.4
5	105.6
6	124.8
7	144.0
8	163.2
9	182.4
10	201.6
11	220.8
12	240.0
13	259.2
14	278.4
15	290.4
16	292.8
17	292.8
18	292.8
19	292.8
20	292.8

$\frac{kN}{m^2}$

$\overrightarrow{\left(2\cdot c\cdot k\cdot K_c\cdot\eta_p\right)} =$

	1
1	52.5
2	52.5
3	52.5
4	105.0
5	262.5
6	315.0
7	420.0
8	420.0
9	420.0
10	420.0
11	420.0
12	420.0
13	420.0
14	420.0
15	420.0
16	420.0
17	420.0
18	420.0
19	420.0
20	420.0

$\frac{kN}{m^2}$

Calculate Pile Section Properties:

Moment of Inertia of Pile

$$I := \left| \begin{array}{ll} \frac{D^4}{12}\cdot\frac{1}{2} & \text{if } P_{type} = \text{"RC"} \\ \frac{D^4}{12} & \text{if } P_{type} = \text{"PC"} \\ \pi\,\frac{D^4}{64}\cdot\frac{1}{2} & \text{if } P_{type} = \text{"BP"} \\ \pi\left[\frac{D^4}{64} - \frac{(D-2\cdot t)^4}{64}\right] & \text{otherwise} \end{array} \right.$$

Reduce by 1/2 to account for cracking of concrete for RC piles and Bored Piles

$I = 124.25 \times 10^9\,mm^4$

Area of pile

$$A_{pile} := \begin{cases} D^2 \text{ if } (P_{type} = \text{"RC"}) + (P_{type} = \text{"PC"}) \\ \pi\frac{D^2}{4} \text{ if } P_{type} = \text{"BP"} \\ \pi\left[\frac{D^2}{4} - \frac{(D-2\cdot t)^2}{4}\right] \text{ otherwise} \end{cases}$$

$A_{pile} = 1767146\,mm^2$

Bending rigidity of Pile

$E\cdot I = 3292690\,kN\cdot m^2$

Calculate subgrade reaction on pile , k_H :

Modulus of deformation assumed for each layer: $E_0 := SPT\cdot 28\cdot 0.4\cdot\frac{kgf}{cm^2}$

Apply 0.4 reduction factor to account for soil testing results - See Separate Calculation

Subgrade reaction coefficient $\alpha = 2.0$

$k_{H0} := \frac{1.0}{30\cdot cm}\cdot\alpha\cdot E_0$

$j := 1$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5\cdot\frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho}\cdot\left(\frac{\sqrt[4]{\frac{D}{\sqrt[4]{\frac{k_h\cdot D}{4\cdot E\cdot I}}}}}{30\cdot cm}\right)^{\frac{-3}{4}}$$

$k_{H_1} := Find(k_h)$ $k_{H_1} = 6483.8\frac{kN}{m^3}$

$j := 2$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5\cdot\frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho}\cdot\left(\frac{\sqrt[4]{\frac{D}{\sqrt[4]{\frac{k_h\cdot D}{4\cdot E\cdot I}}}}}{30\cdot cm}\right)^{\frac{-3}{4}}$$

$k_{H_2} := Find(k_h)$ $k_{H_2} = 6483.8\frac{kN}{m^3}$

$j := 3$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5\cdot\frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho}\cdot\left(\frac{\sqrt{\dfrac{D}{\sqrt[4]{\dfrac{k_h\cdot D}{4\cdot E\cdot I}}}}}{30\cdot cm}\right)^{\frac{-3}{4}} \qquad k_{H_3} := \mathrm{Find}\left(k_h\right) \qquad k_{H_3} = 6483.8\,\frac{kN}{m^3}$$

$j := 4$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5\cdot\frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho}\cdot\left(\frac{\sqrt{\dfrac{D}{\sqrt[4]{\dfrac{k_h\cdot D}{4\cdot E\cdot I}}}}}{30\cdot cm}\right)^{\frac{-3}{4}} \qquad k_{H_4} := \mathrm{Find}\left(k_h\right) \qquad k_{H_4} = 13931.5\,\frac{kN}{m^3}$$

$j := 5$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5\cdot\frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho}\cdot\left(\frac{\sqrt{\dfrac{D}{\sqrt[4]{\dfrac{k_h\cdot D}{4\cdot E\cdot I}}}}}{30\cdot cm}\right)^{\frac{-3}{4}} \qquad k_{H_5} := \mathrm{Find}\left(k_h\right) \qquad k_{H_5} = 38291.8\,\frac{kN}{m^3}$$

$j := 6$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5\cdot\frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho}\cdot\left(\frac{\sqrt{\dfrac{D}{\sqrt[4]{\dfrac{k_h\cdot D}{4\cdot E\cdot I}}}}}{30\cdot cm}\right)^{\frac{-3}{4}} \qquad k_{H_6} := \mathrm{Find}\left(k_h\right) \qquad k_{H_6} = 46825.0\,\frac{kN}{m^3}$$

$j := 7$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}}$$

$k_{H_7} := \text{Find}(k_h)$ $k_{H_7} = 64319.3 \frac{kN}{m^3}$

$j := 8$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}}$$

$k_{H_8} := \text{Find}(k_h)$ $k_{H_8} = 64319.3 \frac{kN}{m^3}$

$j := 9$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}}$$

$k_{H_9} := \text{Find}(k_h)$ $k_{H_9} = 64319.3 \frac{kN}{m^3}$

$j := 10$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}}$$

$k_{H_{10}} := \text{Find}(k_h)$ $k_{H_{10}} = 64319.3 \frac{kN}{m^3}$

$j := 11$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{11}} := \mathrm{Find}(k_h) \qquad k_{H_{11}} = 64319.3 \frac{kN}{m^3}$$

$j := 12$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{12}} := \mathrm{Find}(k_h) \qquad k_{H_{12}} = 64319.3 \frac{kN}{m^3}$$

$j := 13$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{13}} := \mathrm{Find}(k_h) \qquad k_{H_{13}} = 64319.3 \frac{kN}{m^3}$$

$j := 14$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{14}} := \text{Find}(k_h) \qquad k_{H_{14}} = 64319.3 \frac{kN}{m^3}$$

$j := 15$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{15}} := \text{Find}(k_h) \qquad k_{H_{15}} = 64319.3 \frac{kN}{m^3}$$

$j := 16$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{16}} := \text{Find}(k_h) \qquad k_{H_{16}} = 64319.3 \frac{kN}{m^3}$$

$j := 17$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{17}} := \text{Find}(k_h) \qquad k_{H_{17}} = 64319.3 \frac{kN}{m^3}$$

$j := 18$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{18}} := \text{Find}(k_h) \qquad k_{H_{18}} = 64319.3 \frac{kN}{m^3}$$

$j := 19$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{19}} := \text{Find}(k_h) \qquad k_{H_{19}} = 64319.3 \frac{kN}{m^3}$$

$j := 20$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{20}} := \text{Find}(k_h) \qquad k_{H_{20}} = 64319.3 \frac{kN}{m^3}$$

$j := 1..20$

Determine equivalent loading width of pile, B_H:

$$\beta := \sqrt[4]{\frac{k_H \cdot D}{4 \cdot E \cdot I}}$$

$\beta =$ (m^{-1})

	1
1	0.165
2	0.165
3	0.165
4	0.200
5	0.257
6	0.270
7	0.293
8	0.293
9	0.293
10	0.293
11	0.293
12	0.293
13	0.293
14	0.293
15	0.293
16	0.293
17	0.293
18	0.293
19	0.293
20	0.293

$\frac{1}{\beta} =$ (m)

	1
1	6.07
2	6.07
3	6.07
4	5.01
5	3.89
6	3.70
7	3.42
8	3.42
9	3.42
10	3.42
11	3.42
12	3.42
13	3.42
14	3.42
15	3.42
16	3.42
17	3.42
18	3.42
19	3.42
20	3.42

$$B_H := \sqrt{\frac{D}{\beta}}$$

$B_H =$ (cm)

	1
1	302
2	302
3	302
4	274
5	242
6	236
7	226
8	226
9	226
10	226
11	226
12	226
13	226
14	226
15	226
16	226
17	226
18	226
19	226
20	226

Calculate Spring Stiffness of Each Soil Layer along the Pile

$$k_{HE_j} := k_{H_j} \cdot B_{H_j} \cdot L_{Pile_j}$$

$k_{HE} =$ ($\frac{kN}{mm}$)

	1
1	68.5
2	39.1
3	39.1
4	76.4
5	185
6	220.6
7	291.3
8	291.3
9	291.3
10	291.3
11	291.3
12	291.3
13	291.3
14	291.3
15	72.8
16	0
17	0
18	0
19	0
20	0

$k_H =$ ($\frac{kN}{m^3}$)

	1
1	6484
2	6484
3	6484
4	13932
5	38292
6	46825
7	64319
8	64319
9	64319
10	64319
11	64319
12	64319
13	64319
14	64319
15	64319
16	64319
17	64319
18	64319
19	64319
20	64319

Calculate Limiting Horizontal Displacement and Force at each Soil Layer at Ultimate Capacity

Diameter of pile $D = 1.5\ \mathrm{m}$

$$\delta_{U_j} := \frac{P_{u_j} \cdot B_{H_j} \cdot L_{Pile_j}}{k_{HE_j}}$$

$$REAC_{U_j} := P_{u_j} \cdot B_{H_j} \cdot L_{Pile_j}$$

$$REAC_{LINM_j} := \left| \begin{array}{ll} \dfrac{REAC_{U_j}}{L_{Pile_j}} & \text{if } L_{Pile_j} > 0 \cdot m \\ 0 \cdot \dfrac{kN}{m} & \text{otherwise} \end{array} \right.$$

$\delta_{U_j} =$

11.43
15.50
18.46
13.74
9.61
9.39
8.77
9.07
9.37
9.66
9.96
10.26
10.56
10.86
11.04
0.00
0.00
0.00
0.00
0.00

mm

$REAC_{U_j} =$

	1
1	782
2	606
3	722
4	1049
5	1779
6	2072
7	2554
8	2641
9	2728
10	2815
11	2902
12	2989
13	3076
14	3163
15	804
16	0
17	0
18	0
19	0
20	0

kN

$REAC_{LINM_j} =$

	1
1	224
2	303
3	361
4	525
5	889
6	1036
7	1277
8	1321
9	1364
10	1408
11	1451
12	1494
13	1538
14	1581
15	1609
16	0
17	0
18	0
19	0
20	0

$\frac{kN}{m}$

SOIL CHARACTERISTICS FOR BORED PILE

Diameter of pile $D = 1.5$ m

	Borehole Data			Soil Strength Parameters			Sub-grade Reaction	Factored Ultimate Horizontal Bearing Capacity	Soil Spring	Equiv. Width	Limiting Reaction down Pile
Ref.	Depth	Soil Type	SPT	SPT corr	φ	c	k_H				
	m				deg	kN/m^2	kN/m^3	kN/m^2	kN/mm	cm	kN/m
1	-4	Clay	5	7.8	0	25.0	6484	74.1	68.5	302	223.5
2	-6	Clay	5	6.5	0	25.0	6484	100.5	39.1	302	303.2
3	-8	Clay	5	5.9	0	25.0	6484	119.7	39.1	302	361.1
4	-10	Clay	10	11.0	0	50.0	13932	191.4	76.4	274	524.7
5	-12	Clay	25	25.8	0	125.0	38292	368.1	185.0	242	889.3
6	-14	Clay	30	29.3	0	150.0	46825	439.8	220.6	236	1036.2
7	-16	Clay	40	37.1	0	200.0	64319	564.0	291.3	226	1277.1
8	-18	Clay	40	35.4	0	200.0	64319	583.2	291.3	226	1320.6
9	-20	Clay	40	33.9	0	200.0	64319	602.4	291.3	226	1364.0
10	-22	Clay	40	32.6	0	200.0	64319	621.6	291.3	226	1407.5
11	-24	Clay	40	31.4	0	200.0	64319	640.8	291.3	226	1451.0
12	-26	Clay	40	30.3	0	200.0	64319	660.0	291.3	226	1494.5
13	-28	Clay	40	29.2	0	200.0	64319	679.2	291.3	226	1537.9
14	-30	Clay	40	28.3	0	200.0	64319	698.4	291.3	226	1581.4
15	-32	Clay	40	27.7	0	200.0	64319	710.4	72.8	226	1608.6
16	-34	Clay	40	27.6	0	200.0	64319	712.8	0.0	226	0.0
17	-36	Clay	40	27.6	0	200.0	64319	712.8	0.0	226	0.0
18	-38	Clay	40	27.6	0	200.0	64319	712.8	0.0	226	0.0
19	-40	Clay	40	27.6	0	200.0	64319	712.8	0.0	226	0.0
20	-42	Clay	40	27.6	0	200.0	64319	712.8	0.0	226	0.0

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **North Java Corridor Flyover Project**

Calculation: **Balaraja Flyover**
Soil Characteristics from SPT Correlations
Average Borehole Data
1.8m Dia Abutment Bored Pile

Reference: **JRA Specifications for Highway Bridges, Part IV, 1996**

Define Units: $kN := 1000N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $MN := 1000 \cdot kN$

Strength Reduction Factors for Soil Properties - Refer Design Criteria

$K_{\phi} := 0.8$ $K_c := 0.70$

Correction factor for horizontal groud reaction around a single pile - Refer JRA

$\eta_p := 1.5$

Pile Input Data

Type of Pile		
Rect.Reinforced Concrete (RC)	Ptype	BP
Rect. Prestressed Concrete (PC)		
Bored Pile (BP)		
Steel Pipe (SP)		
Width (or Dia.) of Pile (mm)	D	1800
Thickness of Pile (mm - for pipe piles)	t	0
Length of Pile (m)	L	30.0
Unsupported height of pile (m)	h	0.0
Modulus of Elasticity of Pile - kN/mm2	E	26.5
Sugrade reaction coefficient α	α	2
(α =1 normal case, α = 2 for seismic case)		
Elevation at Top of Pile	ElevTop (m)	-0.50
Soil Density	γ (kN/m3)	18.00
Depth to water table from ground surface (m)	z_w	1.00

$D := D \cdot mm$ $L := L \cdot m$ $ElevT := ElevT \cdot m$ $\gamma_{soil} := \gamma_{soil} \cdot \frac{kN}{m^3}$ $t := t \cdot mm$ $E := E \cdot \frac{kN}{mm^2}$

Subsoil Input Data

Ref.	Thickness	Level top of Layer	Level bottom of Layer	Soil Type	SPT N
	(cm)	(m)	(m)		
1.0	400	0.00	-4.00	Clay	5
2.0	200	-4.00	-6.00	Clay	5
3.0	200	-6.00	-8.00	Clay	5
4.0	200	-8.00	-10.00	Clay	15
5.0	200	-10.00	-12.00	Clay	20
6.0	200	-12.00	-14.00	Clay	40
7.0	200	-14.00	-16.00	Clay	40
8.0	200	-16.00	-18.00	Clay	40
9.0	200	-18.00	-20.00	Clay	40
10.0	200	-20.00	-22.00	Clay	40
11.0	200	-22.00	-24.00	Clay	40
12.0	200	-24.00	-26.00	Clay	40
13.0	200	-26.00	-28.00	Clay	40
14.0	200	-28.00	-30.00	Clay	40
15.0	200	-30.00	-32.00	Clay	40
16.0	200	-32.00	-34.00	Clay	40
17.0	200	-34.00	-36.00	Clay	40
18.0	200	-36.00	-38.00	Clay	40
19.0	200	-38.00	-40.00	Clay	40
20.0	200	-40.00	-42.00	Clay	40

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

$j := 1 .. 20$

Length of each soil layer down the pile

$$L_{Pile_j} := \left| \begin{array}{l} Depth_j \quad \text{if } \left(ElevT \ge Lsoil_{t_j}\right)\cdot\left[(ElevT - L) \le Lsoil_{b_j}\right] \\ ElevT - Lsoil_{b_j} \quad \text{if } \left(ElevT < Lsoil_{t_j}\right)\cdot\left(ElevT \ge Lsoil_{b_j}\right)\cdot\left[(ElevT - L) \le Lsoil_{b_j}\right] \\ Lsoil_{t_j} - (ElevT - L) \quad \text{if } \left(ElevT \ge Lsoil_{t_j}\right)\cdot\left[(ElevT - L) > Lsoil_{b_j}\right]\cdot\left[(ElevT - L) < Lsoil_{t_j}\right] \\ 0 \cdot m \quad \text{otherwise} \end{array} \right.$$

Average depth of each soil layer

$$Z_j := \left| \begin{array}{l} \left(Lsoil_{t_1} - Lsoil_{b_j}\right) - \dfrac{L_{Pile_j}}{2} \quad \text{if } (ElevT - L) \le Lsoil_{b_j} \\ \left[Lsoil_{t_1} - (ElevT - L)\right] - \dfrac{L_{Pile_j}}{2} \quad \text{otherwise} \end{array} \right.$$

Effective vertical soil stress
at each soil layer

$$\gamma_{soil_j} := \left| \begin{array}{l} \gamma_{soil} \ \text{ if } Z_j < z_w \cdot m \\ \gamma_{soil} - 10 \cdot \dfrac{kN}{m^3} \ \text{ otherwise} \end{array} \right.$$

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

Calculate corrected SPT values - Refer AASHTO LRFD 10.8.3.4.3 and LA DOT

$$SPTcorr_j := \left| \begin{array}{l} SPTcorr_j \leftarrow \left(0.77 \cdot \log\left(\dfrac{1.92 \cdot MPa}{\sigma_{v_j}}\right)\right) \cdot SPT_j \\ SPT_j \cdot 2 \ \text{ if } \dfrac{SPTcorr_j}{SPT_j} > 2 \\ 40 \ \text{ if } \left(SPT_j \geq 50\right) \cdot \left(SPTcorr_j < 40\right) \\ 40 \ \text{ if } SPTcorr_j \geq 40 \\ SPTcorr_j \ \text{ otherwise} \end{array} \right.$$

Calculate Internal Friction Angle of Soils - Correlated Against SPT - Refer LA DOT

$$\phi_j := \left| \begin{array}{l} \left(\dfrac{39.2 - 25}{35} \cdot SPTcorr_j + 25\right) \cdot deg \ \text{ if } SPTcorr_j \leq 35 \\ \left(\dfrac{40.8 - 39.2}{50 - 35} \cdot SPTcorr_j + 35.47\right) \cdot deg \ \text{ otherwise} \end{array} \right.$$

$$\phi_j := \left| \begin{array}{l} \phi_j \ \text{ if } SoilType_j = \text{"Sand"} \\ 0 \cdot deg \ \text{ otherwise} \end{array} \right.$$

Calculate Undrained Shear Strength of Soils - Correlated Against SPT

$$c_j := \left| \begin{array}{l} SPT_j \cdot 5 \cdot \dfrac{kN}{m^2} \ \text{ if } \left(P_{type} = \text{"BP"}\right) \cdot \left(SoilType_j = \text{"Clay"}\right) \\ SPT_j \cdot 10 \cdot \dfrac{kN}{m^2} \ \text{ if } \left(P_{type} \neq \text{"BP"}\right) \cdot \left(SoilType_j = \text{"Clay"}\right) \\ 0 \cdot MPa \ \text{ otherwise} \end{array} \right.$$

$$c_j := \min\left(c_j, 200 \cdot \dfrac{kN}{m^2}\right)$$

Calculate Ultimate Bearing Capacities

Effective soil density: $\gamma := \gamma_{soil}$

Length of embedded pile $L = 30.0 \text{ m}$

Width of pile foundation $D = 1.8 \text{ m}$

Calculate horizontal passive earth resistance of soil layers in front of the bored pile

Friction angle between bored pile and rock during earthquake $\delta_e := -\frac{\phi}{6}$

Passive earth resistance during an earthquake

$$K_{ep_j} := \frac{\cos(\phi_j)^2}{\cos\left(\delta_{e_j}\right)\cdot\left(1-\sqrt{\frac{\sin\left(\phi_j-\delta_{e_j}\right)\cdot\sin\left(\phi_j\right)}{\cos\left(\delta_{e_j}\right)}}\right)^2}$$

$$K_{ep_j} := \left| \begin{array}{l} 6 \ \text{ if } \ K_{ep_j} \geq 6 \\ K_{ep_j} \ \text{ otherwise} \end{array} \right.$$

Calculate ultimate horizontal bearing capacity of soil layers in front of the bored pile, Pu

Taking : $k_j := \sqrt{K_{ep_j}}$

Gives horizontal bearing capacity: $P_{u_j} := \left(K_{ep_j}\cdot\sigma_{v_j}K_\phi + 2\cdot c_j\cdot k_j\cdot K_c\right)\cdot\eta_p$

Total capacity
Pu

ϕ
component of capacity

c
component of capacity

$P_u =$

	1
1	74.1
2	100.5
3	119.7
4	243.9
5	315.6
6	544.8
7	564.0
8	583.2
9	602.4
10	621.6
11	640.8
12	660.0
13	679.2
14	698.4
15	710.4
16	712.8
17	712.8
18	712.8
19	712.8
20	712.8

$\frac{kN}{m^2}$

$\overrightarrow{\left(K_{ep} \cdot \sigma_v \cdot K_\phi \cdot \eta_p\right)} =$

	1
1	21.6
2	48.0
3	67.2
4	86.4
5	105.6
6	124.8
7	144.0
8	163.2
9	182.4
10	201.6
11	220.8
12	240.0
13	259.2
14	278.4
15	290.4
16	292.8
17	292.8
18	292.8
19	292.8
20	292.8

$\frac{kN}{m^2}$

$\overrightarrow{\left(2 \cdot c \cdot k \cdot K_c \cdot \eta_p\right)} =$

	1
1	52.5
2	52.5
3	52.5
4	157.5
5	210.0
6	420.0
7	420.0
8	420.0
9	420.0
10	420.0
11	420.0
12	420.0
13	420.0
14	420.0
15	420.0
16	420.0
17	420.0
18	420.0
19	420.0
20	420.0

$\frac{kN}{m^2}$

Calculate Pile Section Properties:

Moment of Inertia of Pile

$$I := \left| \begin{array}{l} \frac{D^4}{12} \cdot \frac{1}{2} \quad \text{if } P_{type} = \text{"RC"} \\ \frac{D^4}{12} \quad \text{if } P_{type} = \text{"PC"} \\ \pi \frac{D^4}{64} \cdot \frac{1}{2} \quad \text{if } P_{type} = \text{"BP"} \\ \pi \left[\frac{D^4}{64} - \frac{(D - 2 \cdot t)^4}{64} \right] \quad \text{otherwise} \end{array} \right.$$

Reduce by 1/2 to account for cracking of concrete for RC piles and Bored Piles

$I = 257.65 \times 10^9 mm^4$

Area of pile

$$A_{pile} := \left| \begin{array}{l} D^2 \ \text{if } (P_{type} = \text{"RC"}) + (P_{type} = \text{"PC"}) \\ \pi \dfrac{D^2}{4} \ \text{if } P_{type} = \text{"BP"} \\ \pi \left[\dfrac{D^2}{4} - \dfrac{(D - 2 \cdot t)^2}{4} \right] \ \text{otherwise} \end{array} \right.$$

$$A_{pile} = 2544690\,\text{mm}^2$$

Bending rigidity of Pile

$$E \cdot I = 6827721\,\text{kN} \cdot \text{m}^2$$

Calculate subgrade reaction on pile , k_H :

Modulus of deformation assumed for each layer: $E_0 := SPT \cdot 28 \cdot 0.4 \cdot \dfrac{\text{kgf}}{\text{cm}^2}$

Apply 0.4 reduction factor to account for soil testing results - See Separate Calculation

Subgrade reaction coefficient $\alpha = 2.0$

$$k_{H0} := \frac{1.0}{30 \cdot \text{cm}} \cdot \alpha \cdot E_0$$

$j := 1$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \dfrac{\text{kgf}}{\text{cm}^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\dfrac{D}{\sqrt[4]{\dfrac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot \text{cm}} \right)^{\frac{-3}{4}} \qquad k_{H_1} := \text{Find}(k_h) \qquad k_{H_1} = 5681.9 \frac{\text{kN}}{\text{m}^3}$$

$j := 2$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \dfrac{\text{kgf}}{\text{cm}^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\dfrac{D}{\sqrt[4]{\dfrac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot \text{cm}} \right)^{\frac{-3}{4}} \qquad k_{H_2} := \text{Find}(k_h) \qquad k_{H_2} = 5681.9 \frac{\text{kN}}{\text{m}^3}$$

$j := 3$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_3} := \text{Find}(k_h) \qquad k_{H_3} = 5681.9 \frac{kN}{m^3}$$

$j := 4$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_4} := \text{Find}(k_h) \qquad k_{H_4} = 19097.2 \frac{kN}{m^3}$$

$j := 5$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_5} := \text{Find}(k_h) \qquad k_{H_5} = 26232.0 \frac{kN}{m^3}$$

$j := 6$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_6} := \text{Find}(k_h) \qquad k_{H_6} = 56364.2 \frac{kN}{m^3}$$

$j := 7$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_7} := \mathrm{Find}(k_h) \qquad k_{H_7} = 56364.2 \frac{kN}{m^3}$$

$j := 8$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_8} := \mathrm{Find}(k_h) \qquad k_{H_8} = 56364.2 \frac{kN}{m^3}$$

$j := 9$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_9} := \mathrm{Find}(k_h) \qquad k_{H_9} = 56364.2 \frac{kN}{m^3}$$

$j := 10$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{10}} := \mathrm{Find}(k_h) \qquad k_{H_{10}} = 56364.2 \frac{kN}{m^3}$$

$j := 11$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{11}} := \mathrm{Find}(k_h) \qquad k_{H_{11}} = 56364.2 \frac{kN}{m^3}$$

$j := 12$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{12}} := \mathrm{Find}(k_h) \qquad k_{H_{12}} = 56364.2 \frac{kN}{m^3}$$

$j := 13$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{13}} := \mathrm{Find}(k_h) \qquad k_{H_{13}} = 56364.2 \frac{kN}{m^3}$$

$j := 14$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{14}} := \mathrm{Find}(k_h) \qquad k_{H_{14}} = 56364.2 \frac{kN}{m^3}$$

$j := 15$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{15}} := \mathrm{Find}(k_h) \qquad k_{H_{15}} = 56364.2 \frac{kN}{m^3}$$

$j := 16$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{16}} := \mathrm{Find}(k_h) \qquad k_{H_{16}} = 56364.2 \frac{kN}{m^3}$$

$j := 17$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{17}} := \mathrm{Find}(k_h) \qquad k_{H_{17}} = 56364.2 \frac{kN}{m^3}$$

$j := 18$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{18}} := \text{Find}(k_h) \qquad k_{H_{18}} = 56364.2 \frac{kN}{m^3}$$

$j := 19$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{19}} := \text{Find}(k_h) \qquad k_{H_{19}} = 56364.2 \frac{kN}{m^3}$$

$j := 20$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{20}} := \text{Find}(k_h) \qquad k_{H_{20}} = 56364.2 \frac{kN}{m^3}$$

$j := 1..20$

Determine equivalent loading width of pile, B_H:

$$\beta := \sqrt[4]{\frac{k_H \cdot D}{4 \cdot E \cdot I}}$$

$\beta =$

	1
1	0.139
2	0.139
3	0.139
4	0.188
5	0.204
6	0.247
7	0.247
8	0.247
9	0.247
10	0.247
11	0.247
12	0.247
13	0.247
14	0.247
15	0.247
16	0.247
17	0.247
18	0.247
19	0.247
20	0.247

m^{-1}

$\frac{1}{\beta} =$

	1
1	7.19
2	7.19
3	7.19
4	5.31
5	4.90
6	4.05
7	4.05
8	4.05
9	4.05
10	4.05
11	4.05
12	4.05
13	4.05
14	4.05
15	4.05
16	4.05
17	4.05
18	4.05
19	4.05
20	4.05

m

$$B_H := \sqrt{\frac{D}{\beta}}$$

$B_H =$

	1
1	360
2	360
3	360
4	309
5	297
6	270
7	270
8	270
9	270
10	270
11	270
12	270
13	270
14	270
15	270
16	270
17	270
18	270
19	270
20	270

cm

Calculate Spring Stiffness of Each Soil Layer along the Pile

$$k_{HE_j} := k_{H_j} \cdot B_{H_j} \cdot L_{Pile_j}$$

$k_{HE} =$

	1
1	71.5
2	40.9
3	40.9
4	118.1
5	155.9
6	304.4
7	304.4
8	304.4
9	304.4
10	304.4
11	304.4
12	304.4
13	304.4
14	304.4
15	76.1
16	0
17	0
18	0
19	0
20	0

$\frac{kN}{mm}$

$k_H =$

	1
1	5682
2	5682
3	5682
4	19097
5	26232
6	56364
7	56364
8	56364
9	56364
10	56364
11	56364
12	56364
13	56364
14	56364
15	56364
16	56364
17	56364
18	56364
19	56364
20	56364

$\frac{kN}{m^3}$

Calculate Limiting Horizontal Displacement and Force at each Soil Layer at Ultimate Capacity

Diameter of pile $D = 1.8\ \mathrm{m}$

$$\delta_{U_j} := \frac{P_{u_j} \cdot B_{H_j} \cdot L_{Pile_j}}{k_{HE_j}}$$

$$REAC_{U_j} := P_{u_j} \cdot B_{H_j} \cdot L_{Pile_j}$$

$$REAC_{LINM_j} := \begin{vmatrix} \dfrac{REAC_{U_j}}{L_{Pile_j}} & \text{if } L_{Pile_j} > 0 \cdot \mathrm{m} \\ 0 \cdot \dfrac{\mathrm{kN}}{\mathrm{m}} & \text{otherwise} \end{vmatrix}$$

$\delta_{U_j} =$ mm

13.04
17.69
21.07
12.77
12.03
9.67
10.01
10.35
10.69
11.03
11.37
11.71
12.05
12.39
12.60
0.00
0.00
0.00
0.00
0.00

$REAC_{U_j} =$ kN

	1
1	933
2	723
3	861
4	1508
5	1875
6	2942
7	3046
8	3149
9	3253
10	3357
11	3461
12	3564
13	3668
14	3772
15	959
16	0
17	0
18	0
19	0
20	0

$REAC_{LINM_j} =$ $\frac{\mathrm{kN}}{\mathrm{m}}$

	1
1	267
2	362
3	431
4	754
5	938
6	1471
7	1523
8	1575
9	1627
10	1678
11	1730
12	1782
13	1834
14	1886
15	1918
16	0
17	0
18	0
19	0
20	0

SOIL CHARACTERISTICS FOR BORED PILE

Diameter of pile $D = 1.8$ m

	Borehole Data			Soil Strength Parameters			Sub-grade Reaction	Factored Ultimate Horizontal Bearing Capacity	Soil Spring	Equiv. Width	Limiting Reaction down Pile
Ref.	Depth	Soil Type	SPT	SPT corr	φ	c	k_H				
	m				deg	kN/m^2	kN/m^3	kN/m^2	kN/mm	cm	kN/m
1	-4	Clay	5	7.8	0	25.0	5682	74.1	71.5	360	266.5
2	-6	Clay	5	6.5	0	25.0	5682	100.5	40.9	360	361.5
3	-8	Clay	5	5.9	0	25.0	5682	119.7	40.9	360	430.6
4	-10	Clay	15	16.5	0	75.0	19097	243.9	118.1	309	754.0
5	-12	Clay	20	20.6	0	100.0	26232	315.6	155.9	297	937.7
6	-14	Clay	40	39.0	0	200.0	56364	544.8	304.4	270	1471.1
7	-16	Clay	40	37.1	0	200.0	56364	564.0	304.4	270	1522.9
8	-18	Clay	40	35.4	0	200.0	56364	583.2	304.4	270	1574.7
9	-20	Clay	40	33.9	0	200.0	56364	602.4	304.4	270	1626.6
10	-22	Clay	40	32.6	0	200.0	56364	621.6	304.4	270	1678.4
11	-24	Clay	40	31.4	0	200.0	56364	640.8	304.4	270	1730.3
12	-26	Clay	40	30.3	0	200.0	56364	660.0	304.4	270	1782.1
13	-28	Clay	40	29.2	0	200.0	56364	679.2	304.4	270	1834.0
14	-30	Clay	40	28.3	0	200.0	56364	698.4	304.4	270	1885.8
15	-32	Clay	40	27.7	0	200.0	56364	710.4	76.1	270	1918.2
16	-34	Clay	40	27.6	0	200.0	56364	712.8	0.0	270	0.0
17	-36	Clay	40	27.6	0	200.0	56364	712.8	0.0	270	0.0
18	-38	Clay	40	27.6	0	200.0	56364	712.8	0.0	270	0.0
19	-40	Clay	40	27.6	0	200.0	56364	712.8	0.0	270	0.0
20	-42	Clay	40	27.6	0	200.0	56364	712.8	0.0	270	0.0

KATAHIRA & ENGINEERS
INTERNATIONAL

Project: **North Java Corridor Flyover Project**

Calculation: **Balaraja Flyover**
Soil Characteristics from SPT Correlations
Average Borehole Data
2.5m Dia Bored Pile

Reference: **JRA Specifications for Highway Bridges, Part IV, 1996**

Define Units: $kN := 1000N$ $kNm := kN \cdot m$ $MPa := 1000000 \cdot Pa$ $MN := 1000 \cdot kN$

Strength Reduction Factors for Soil Properties - Refer Design Criteria

$K_{\phi} := 0.8$ $K_c := 0.70$

Correction factor for horizontal groud reaction around a single pile - Refer JRA

$\eta_p := 1.5$

Pile Input Data

Type of Pile		
Rect.Reinforced Concrete (RC)	Ptype	BP
Rect. Prestressed Concrete (PC)		
Bored Pile (BP)		
Steel Pipe (SP)		
Width (or Dia.) of Pile (mm)	D	2500
Thickness of Pile (mm - for pipe piles)	t	0
Length of Pile (m)	L	30.0
Unsupported height of pile (m)	h	0.0
Modulus of Elasticity of Pile - kN/mm2	E	26.5
Sugrade reaction coefficient α	α	2
(α =1 normal case, α = 2 for seismic case)		
Elevation at Top of Pile	ElevTop (m)	-0.50
Soil Density	γ (kN/m3)	18.00
Depth to water table from ground surface (m)	z_w	1.00

$D := D \cdot mm$ $L := L \cdot m$ $ElevT := ElevT \cdot m$ $\gamma_{soil} := \gamma_{soil} \cdot \frac{kN}{m^3}$ $t := t \cdot mm$ $E := E \cdot \frac{kN}{mm^2}$

Subsoil Input Data

Ref.	Thickness	Level top of Layer	Level bottom of Layer	Soil Type	SPT N
	(cm)	(m)	(m)		
1.0	400	0.00	-4.00	Clay	5
2.0	200	-4.00	-6.00	Clay	10
3.0	200	-6.00	-8.00	Clay	10
4.0	200	-8.00	-10.00	Clay	30
5.0	200	-10.00	-12.00	Clay	30
6.0	200	-12.00	-14.00	Clay	20
7.0	200	-14.00	-16.00	Clay	40
8.0	200	-16.00	-18.00	Clay	40
9.0	200	-18.00	-20.00	Clay	40
10.0	200	-20.00	-22.00	Clay	40
11.0	200	-22.00	-24.00	Clay	40
12.0	200	-24.00	-26.00	Clay	40
13.0	200	-26.00	-28.00	Clay	40
14.0	200	-28.00	-30.00	Clay	40
15.0	200	-30.00	-32.00	Clay	40
16.0	200	-32.00	-34.00	Clay	40
17.0	200	-34.00	-36.00	Clay	40
18.0	200	-36.00	-38.00	Clay	40
19.0	200	-38.00	-40.00	Clay	40
20.0	200	-40.00	-42.00	Clay	40

$\mathrm{Lsoil}_t := \mathrm{Lsoil}_{top} \cdot m \qquad \mathrm{Lsoil}_b := \mathrm{Lsoil}_{bottom} \cdot m \qquad \mathrm{Depth} := \mathrm{Depth} \cdot cm$

$j := 1 .. 20$

Length of each soil layer down the pile

$$L_{Pile_j} := \left| \begin{array}{l} \mathrm{Depth}_j \ \text{ if } \left(\mathrm{ElevT} \ge \mathrm{Lsoil}_{t_j}\right) \cdot \left[(\mathrm{ElevT} - L) \le \mathrm{Lsoil}_{b_j}\right] \\ \mathrm{ElevT} - \mathrm{Lsoil}_{b_j} \ \text{ if } \left(\mathrm{ElevT} < \mathrm{Lsoil}_{t_j}\right) \cdot \left(\mathrm{ElevT} \ge \mathrm{Lsoil}_{b_j}\right) \cdot \left[(\mathrm{ElevT} - L) \le \mathrm{Lsoil}_{b_j}\right] \\ \mathrm{Lsoil}_{t_j} - (\mathrm{ElevT} - L) \ \text{ if } \left(\mathrm{ElevT} \ge \mathrm{Lsoil}_{t_j}\right) \cdot \left[(\mathrm{ElevT} - L) > \mathrm{Lsoil}_{b_j}\right] \cdot \left[(\mathrm{ElevT} - L) < \mathrm{Lsoil}_{t_j}\right] \\ 0 \cdot m \ \text{ otherwise} \end{array} \right.$$

Average depth of each soil layer

$$Z_j := \left| \begin{array}{l} \left(\mathrm{Lsoil}_{t_1} - \mathrm{Lsoil}_{b_j}\right) - \dfrac{L_{Pile_j}}{2} \ \text{ if } \ (\mathrm{ElevT} - L) \le \mathrm{Lsoil}_{b_j} \\ \left[\mathrm{Lsoil}_{t_1} - (\mathrm{ElevT} - L)\right] - \dfrac{L_{Pile_j}}{2} \ \text{ otherwise} \end{array} \right.$$

Effective vertical soil stress
at each soil layer

$$\gamma_{soil_j} := \begin{cases} \gamma_{soil} & \text{if } Z_j < z_w \cdot m \\ \gamma_{soil} - 10 \cdot \dfrac{kN}{m^3} & \text{otherwise} \end{cases}$$

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

Calculate corrected SPT values - Refer AASHTO LRFD 10.8.3.4.3 and LA DOT

$$SPTcorr_j := \left| \begin{array}{l} SPTcorr_j \leftarrow \left(0.77 \cdot \log\left(\dfrac{1.92 \cdot MPa}{\sigma_{v_j}}\right)\right) \cdot SPT_j \\ SPT_j \cdot 2 \ \text{ if } \ \dfrac{SPTcorr_j}{SPT_j} > 2 \\ 40 \ \text{ if } \ (SPT_j \geq 50) \cdot (SPTcorr_j < 40) \\ 40 \ \text{ if } \ SPTcorr_j \geq 40 \\ SPTcorr_j \ \text{ otherwise} \end{array} \right.$$

Calculate Internal Friction Angle of Soils - Correlated Against SPT - Refer LA DOT

$$\phi_j := \begin{cases} \left(\dfrac{39.2 - 25}{35} \cdot SPTcorr_j + 25\right) \cdot deg & \text{if } SPTcorr_j \leq 35 \\ \left(\dfrac{40.8 - 39.2}{50 - 35} \cdot SPTcorr_j + 35.47\right) \cdot deg & \text{otherwise} \end{cases}$$

$$\phi_j := \begin{cases} \phi_j & \text{if } SoilType_j = \text{"Sand"} \\ 0 \cdot deg & \text{otherwise} \end{cases}$$

Calculate Undrained Shear Strength of Soils - Correlated Against SPT

$$c_j := \begin{cases} SPT_j \cdot 5 \cdot \dfrac{kN}{m^2} & \text{if } (P_{type} = \text{"BP"}) \cdot (SoilType_j = \text{"Clay"}) \\ SPT_j \cdot 10 \cdot \dfrac{kN}{m^2} & \text{if } (P_{type} \neq \text{"BP"}) \cdot (SoilType_j = \text{"Clay"}) \\ 0 \cdot MPa & \text{otherwise} \end{cases}$$

$$c_j := \min\left(c_j, 200 \cdot \frac{kN}{m^2}\right)$$

Calculate Ultimate Bearing Capacities

Effective soil density: $\gamma := \gamma_{soil}$

Length of embedded pile $L = 30.0\ \text{m}$

Width of pile foundation $D = 2.5\ \text{m}$

Calculate horizontal passive earth resistance of soil layers in front of the bored pile

Friction angle between bored pile and rock during earthquake $\delta_e := -\frac{\phi}{6}$

Passive earth resistance during an earthquake

$$K_{ep_j} := \frac{\cos(\phi_j)^2}{\cos(\delta_{e_j})\cdot\left(1-\sqrt{\frac{\sin(\phi_j-\delta_{e_j})\cdot\sin(\phi_j)}{\cos(\delta_{e_j})}}\right)^2}$$

$$K_{ep_j} := \begin{array}{|l} 6 \quad \text{if } K_{ep_j} \geq 6 \\ K_{ep_j} \quad \text{otherwise} \end{array}$$

Calculate ultimate horizontal bearing capacity of soil layers in front of the bored pile, Pu

Taking : $k_j := \sqrt{K_{ep_j}}$

Gives horizontal bearing capacity: $P_{u_j} := \left(K_{ep_j}\cdot\sigma_{v_j}K_\phi + 2\cdot c_j\cdot k_j\cdot K_c\right)\cdot\eta_p$

Total capacity
Pu

$P_u =$

	1
1	74.1
2	153.0
3	172.2
4	401.4
5	420.6
6	334.8
7	564.0
8	583.2
9	602.4
10	621.6
11	640.8
12	660.0
13	679.2
14	698.4
15	710.4
16	712.8
17	712.8
18	712.8
19	712.8
20	712.8

$\frac{kN}{m^2}$

ϕ
component of capacity

$\overrightarrow{\left(K_{ep}\cdot\sigma_v\cdot K_\phi\cdot\eta_p\right)} =$

	1
1	21.6
2	48.0
3	67.2
4	86.4
5	105.6
6	124.8
7	144.0
8	163.2
9	182.4
10	201.6
11	220.8
12	240.0
13	259.2
14	278.4
15	290.4
16	292.8
17	292.8
18	292.8
19	292.8
20	292.8

$\frac{kN}{m^2}$

c
component of capacity

$\overrightarrow{\left(2\cdot c\cdot k\cdot K_c\cdot\eta_p\right)} =$

	1
1	52.5
2	105.0
3	105.0
4	315.0
5	315.0
6	210.0
7	420.0
8	420.0
9	420.0
10	420.0
11	420.0
12	420.0
13	420.0
14	420.0
15	420.0
16	420.0
17	420.0
18	420.0
19	420.0
20	420.0

$\frac{kN}{m^2}$

Calculate Pile Section Properties:

Moment of Inertia of Pile

$$I := \left| \begin{array}{l} \frac{D^4}{12}\cdot\frac{1}{2} \;\text{ if }\; P_{type} = \text{"RC"} \\ \frac{D^4}{12} \;\text{ if }\; P_{type} = \text{"PC"} \\ \pi\frac{D^4}{64}\cdot\frac{1}{2} \;\text{ if }\; P_{type} = \text{"BP"} \\ \pi\left[\frac{D^4}{64} - \frac{(D-2\cdot t)^4}{64}\right] \;\text{ otherwise} \end{array} \right.$$

Reduce by 1/2 to account for cracking of concrete for RC piles and Bored Piles

$I = 958.74 \times 10^9 mm^4$

Area of pile

$$A_{pile} := \begin{array}{|l} D^2 \ \text{if } \left(P_{type} = \text{"RC"}\right) + \left(P_{type} = \text{"PC"}\right) \\ \pi \dfrac{D^2}{4} \ \text{if } P_{type} = \text{"BP"} \\ \pi \left[\dfrac{D^2}{4} - \dfrac{(D - 2 \cdot t)^2}{4}\right] \ \text{otherwise} \end{array}$$

$$A_{pile} = 4908739\,\text{mm}^2$$

Bending rigidity of Pile

$$E \cdot I = 25406557\,\text{kN} \cdot \text{m}^2$$

<u>Calculate subgrade reaction on pile , k_H :</u>

Modulus of deformation assumed for each layer: $E_0 := SPT \cdot 28 \cdot 0.4 \cdot \dfrac{\text{kgf}}{\text{cm}^2}$

Apply 0.4 reduction factor to account for soil testing results - See Separate Calculation

Subgrade reaction coefficient

$\alpha = 2.0$

$$k_{H0} := \frac{1.0}{30 \cdot \text{cm}} \cdot \alpha \cdot E_0$$

$j := 1$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \dfrac{\text{kgf}}{\text{cm}^3}$ $\qquad k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\dfrac{D}{\sqrt[4]{\dfrac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot \text{cm}} \right)^{\frac{-3}{4}} \qquad k_{H_1} := \text{Find}\left(k_h\right) \qquad k_{H_1} = 4479.0 \frac{\text{kN}}{\text{m}^3}$$

$j := 2$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \dfrac{\text{kgf}}{\text{cm}^3}$ $\qquad k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\dfrac{D}{\sqrt[4]{\dfrac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot \text{cm}} \right)^{\frac{-3}{4}} \qquad k_{H_2} := \text{Find}\left(k_h\right) \qquad k_{H_2} = 9623.9 \frac{\text{kN}}{\text{m}^3}$$

$j := 3$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_3} := \text{Find}(k_h) \qquad k_{H_3} = 9623.9 \frac{kN}{m^3}$$

$j := 4$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_4} := \text{Find}(k_h) \qquad k_{H_4} = 32346.6 \frac{kN}{m^3}$$

$j := 5$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_5} := \text{Find}(k_h) \qquad k_{H_5} = 32346.6 \frac{kN}{m^3}$$

$j := 6$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_6} := \text{Find}(k_h) \qquad k_{H_6} = 20678.6 \frac{kN}{m^3}$$

$j := 7$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5\cdot\frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho}\cdot\left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h\cdot D}{4\cdot E\cdot I}}}}}{30\cdot cm}\right)^{\frac{-3}{4}} \qquad k_{H_7} := \mathrm{Find}(k_h) \qquad k_{H_7} = 44431.6\frac{kN}{m^3}$$

$j := 8$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5\cdot\frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho}\cdot\left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h\cdot D}{4\cdot E\cdot I}}}}}{30\cdot cm}\right)^{\frac{-3}{4}} \qquad k_{H_8} := \mathrm{Find}(k_h) \qquad k_{H_8} = 44431.6\frac{kN}{m^3}$$

$j := 9$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5\cdot\frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho}\cdot\left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h\cdot D}{4\cdot E\cdot I}}}}}{30\cdot cm}\right)^{\frac{-3}{4}} \qquad k_{H_9} := \mathrm{Find}(k_h) \qquad k_{H_9} = 44431.6\frac{kN}{m^3}$$

$j := 10$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5\cdot\frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho}\cdot\left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h\cdot D}{4\cdot E\cdot I}}}}}{30\cdot cm}\right)^{\frac{-3}{4}} \qquad k_{H_{10}} := \mathrm{Find}(k_h) \qquad k_{H_{10}} = 44431.6\frac{kN}{m^3}$$

$j := 11$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{11}} := \mathrm{Find}(k_h) \qquad k_{H_{11}} = 44431.6 \frac{kN}{m^3}$$

$j := 12$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{12}} := \mathrm{Find}(k_h) \qquad k_{H_{12}} = 44431.6 \frac{kN}{m^3}$$

$j := 13$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{13}} := \mathrm{Find}(k_h) \qquad k_{H_{13}} = 44431.6 \frac{kN}{m^3}$$

$j := 14$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{14}} := \mathrm{Find}(k_h) \qquad k_{H_{14}} = 44431.6 \frac{kN}{m^3}$$

$j := 15$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{15}} := \mathrm{Find}(k_h) \qquad k_{H_{15}} = 44431.6 \frac{kN}{m^3}$$

$j := 16$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{16}} := \mathrm{Find}(k_h) \qquad k_{H_{16}} = 44431.6 \frac{kN}{m^3}$$

$j := 17$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{17}} := \mathrm{Find}(k_h) \qquad k_{H_{17}} = 44431.6 \frac{kN}{m^3}$$

$j := 18$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{18}} := \mathrm{Find}(k_h) \qquad k_{H_{18}} = 44431.6 \frac{kN}{m^3}$$

$j := 19$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{19}} := \mathrm{Find}(k_h) \qquad k_{H_{19}} = 44431.6 \frac{kN}{m^3}$$

$j := 20$

Determine subgrade reaction k_H:

Trial value of subgrade reaction of each layer: $k_h := 5 \cdot \frac{kgf}{cm^3}$ $k_{ho} := k_{H0_j}$

Given

$$k_h = k_{ho} \cdot \left(\frac{\sqrt{\frac{D}{\sqrt[4]{\frac{k_h \cdot D}{4 \cdot E \cdot I}}}}}{30 \cdot cm} \right)^{\frac{-3}{4}} \qquad k_{H_{20}} := \mathrm{Find}(k_h) \qquad k_{H_{20}} = 44431.6 \frac{kN}{m^3}$$

$j := 1..20$

Determine equivalent loading width of pile, B_H:

$$\beta := \sqrt[4]{\frac{k_H \cdot D}{4 \cdot E \cdot I}}$$

$\beta =$ (m^{-1})

	1
1	0.102
2	0.124
3	0.124
4	0.168
5	0.168
6	0.150
7	0.182
8	0.182
9	0.182
10	0.182
11	0.182
12	0.182
13	0.182
14	0.182
15	0.182
16	0.182
17	0.182
18	0.182
19	0.182
20	0.182

$\frac{1}{\beta} =$ (m)

	1
1	9.76
2	8.06
3	8.06
4	5.95
5	5.95
6	6.66
7	5.50
8	5.50
9	5.50
10	5.50
11	5.50
12	5.50
13	5.50
14	5.50
15	5.50
16	5.50
17	5.50
18	5.50
19	5.50
20	5.50

$$B_H := \sqrt{\frac{D}{\beta}}$$

$B_H =$ (cm)

	1
1	494
2	449
3	449
4	386
5	386
6	408
7	371
8	371
9	371
10	371
11	371
12	371
13	371
14	371
15	371
16	371
17	371
18	371
19	371
20	371

Calculate Spring Stiffness of Each Soil Layer along the Pile

$$k_{HE_j} := k_{H_j} \cdot B_{H_j} \cdot L_{Pile_j}$$

$k_{HE} =$ ($\frac{kN}{mm}$)

	1
1	77.4
2	86.4
3	86.4
4	249.6
5	249.6
6	168.7
7	329.5
8	329.5
9	329.5
10	329.5
11	329.5
12	329.5
13	329.5
14	329.5
15	82.4
16	0
17	0
18	0
19	0
20	0

$k_H =$ ($\frac{kN}{m^3}$)

	1
1	4479
2	9624
3	9624
4	32347
5	32347
6	20679
7	44432
8	44432
9	44432
10	44432
11	44432
12	44432
13	44432
14	44432
15	44432
16	44432
17	44432
18	44432
19	44432
20	44432

Calculate Limiting Horizontal Displacement and Force at each Soil Layer at Ultimate Capacity

Diameter of pile $D = 2.5\ \mathrm{m}$

$$\delta_{U_j} := \frac{P_{u_j} \cdot B_{H_j} \cdot L_{Pile_j}}{k_{HE_j}}$$

$$REAC_{U_j} := P_{u_j} \cdot B_{H_j} \cdot L_{Pile_j}$$

$$REAC_{LINM_j} := \begin{cases} \dfrac{REAC_{U_j}}{L_{Pile_j}} & \text{if } L_{Pile_j} > 0 \cdot m \\ 0 \cdot \dfrac{kN}{m} & \text{otherwise} \end{cases}$$

$\delta_{U_j} =$

16.54
15.90
17.89
12.41
13.00
16.19
12.69
13.13
13.56
13.99
14.42
14.85
15.29
15.72
15.99
0.00
0.00
0.00
0.00
0.00

mm

$REAC_{U_j} =$

	1
1	1281
2	1374
3	1546
4	3097
5	3245
6	2732
7	4183
8	4325
9	4467
10	4610
11	4752
12	4895
13	5037
14	5179
15	1317
16	0
17	0
18	0
19	0
20	0

kN

$REAC_{LINM_j} =$

	1
1	366
2	687
3	773
4	1549
5	1623
6	1366
7	2091
8	2163
9	2234
10	2305
11	2376
12	2447
13	2518
14	2590
15	2634
16	0
17	0
18	0
19	0
20	0

$\frac{kN}{m}$

SOIL CHARACTERISTICS FOR BORED PILE

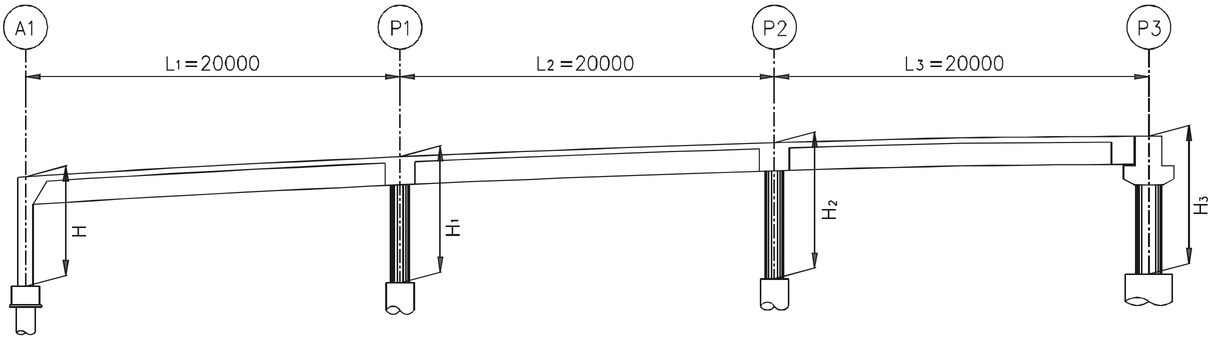
Diameter of pile $D = 2.5$ m

	Borehole Data			**Soil Strength Parameters**			**Sub-grade Reaction**	**Factored Ultimate Horizontal Bearing Capacity**	**Soil Spring**	**Equiv. Width**	**Limiting Reaction down Pile**
Ref.	**Depth**	**Soil Type**	**SPT**	**SPT corr**	φ	**c**	k_H				
	m				**deg**	**kN/m^2**	**kN/m^3**	**kN/m^2**	**kN/mm**	**cm**	**kN/m**
1	-4	Clay	5	7.8	0	25.0	4479	74.1	77.4	494	366.0
2	-6	Clay	10	12.9	0	50.0	9624	153.0	86.4	449	686.9
3	-8	Clay	10	11.8	0	50.0	9624	172.2	86.4	449	773.1
4	-10	Clay	30	32.9	0	150.0	32347	401.4	249.6	386	1548.6
5	-12	Clay	30	30.9	0	150.0	32347	420.6	249.6	386	1622.7
6	-14	Clay	20	19.5	0	100.0	20679	334.8	168.7	408	1366.0
7	-16	Clay	40	37.1	0	200.0	44432	564.0	329.5	371	2091.3
8	-18	Clay	40	35.4	0	200.0	44432	583.2	329.5	371	2162.5
9	-20	Clay	40	33.9	0	200.0	44432	602.4	329.5	371	2233.7
10	-22	Clay	40	32.6	0	200.0	44432	621.6	329.5	371	2304.9
11	-24	Clay	40	31.4	0	200.0	44432	640.8	329.5	371	2376.1
12	-26	Clay	40	30.3	0	200.0	44432	660.0	329.5	371	2447.3
13	-28	Clay	40	29.2	0	200.0	44432	679.2	329.5	371	2518.5
14	-30	Clay	40	28.3	0	200.0	44432	698.4	329.5	371	2589.7
15	-32	Clay	40	27.7	0	200.0	44432	710.4	82.4	371	2634.2
16	-34	Clay	40	27.6	0	200.0	44432	712.8	0.0	371	0.0
17	-36	Clay	40	27.6	0	200.0	44432	712.8	0.0	371	0.0
18	-38	Clay	40	27.6	0	200.0	44432	712.8	0.0	371	0.0
19	-40	Clay	40	27.6	0	200.0	44432	712.8	0.0	371	0.0
20	-42	Clay	40	27.6	0	200.0	44432	712.8	0.0	371	0.0

4. NOMINAL LOADS

1. ARRANGEMENT

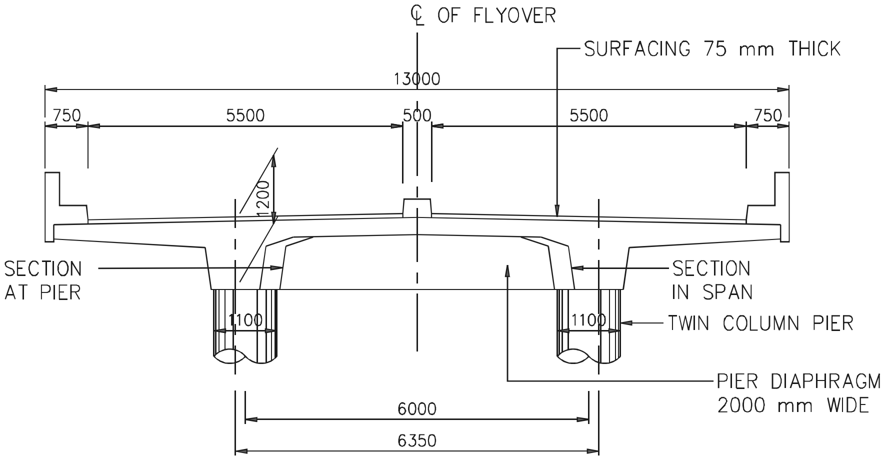
a. Span Length



L_1 = 20 m
L_2 = 20 m
L_3 = 20 m

H = 5.23 m
H_1 = 8.29 m
H_2 = 8.29 m
H_3 = 8.39 m

2. DECK SECTION



3. UNIT WEIGHT OF MATERIALS

a. Unit Weight of Concrete = 24.5 kN/ m^3
b. Unit Weight of Asphalt Surfacing = 22.5 kN/ m^3

4. SECTION AREAS

a. X – Sectional Area of Deck in Span = 5.898 m^2
b. X – Sectional Area of Deck at Pier = 10.861 m^2
c. X – Sectional Area of Deck at Diaphragm = 10.861 m^2
d. X – Sectional Area of Median & Railing = 1.029 m^2
e. X – Sectional Area of Surfacing = 1.313 m^2

(Including 50 mm allowance for future Resurfacing)

5. PERMANENT LOADS

a. U-D-L of Deck in Span = 144.501 kN/m
b. U-D-L of Deck at Pier = 266.094 kN/m
c. U-D-L of Deck at Diaphragm = 266.094 kN/m
d. U-D-L of Median & Railing = 25.210 kN/m
e. U-D-L of Surfacing = 28.886 kN/m

6. IMPOSED DEFORMATIONS

a. Shrinkage and Creep Effects.

Shrinkage and creep effects will normally not be calculated for bridge substructures unless the effects of applied loads other than earthquake effects are governing.

b. Pre-stressing Effects

Refer to separate calculation for the secondary effects of prestress in the elastomeric bearing design.

Secondary effects of prestress will normally not be calculated for bridge substructures unless the effects of applied loads other than earthquake effect are governing.

c. Settlements

A differential settlement of 25 mm shall be taken into account in the design of the substructure.

d. Earth Pressure

Abutment will be not take earth pressure, due to the applied load will be taking by MSE wall.

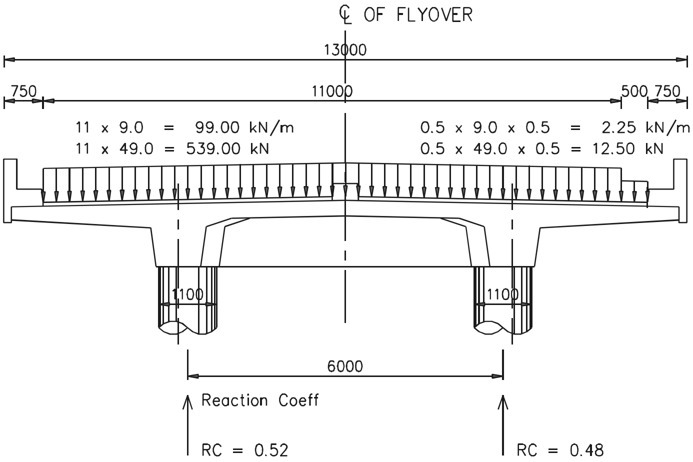
7. TRAFFIC LOADING – DESIGN TRAFFIC LANES

a. Design Lane Width = 2.75 m
b. Number of Design Traffic Lanes = 4

8. TRAFFIC LOADING – "D" LANE LOADING

a. U – D – L: (L ≤ 30m) q = 9.000 kN/m^2
(L = 40m) q = 7.875 kN/m^2
(L = 45m) q = 7.500 kN/m^2
b. K – E – L p = 49.000 kN/m

c. Layout of “D” Lane Loading



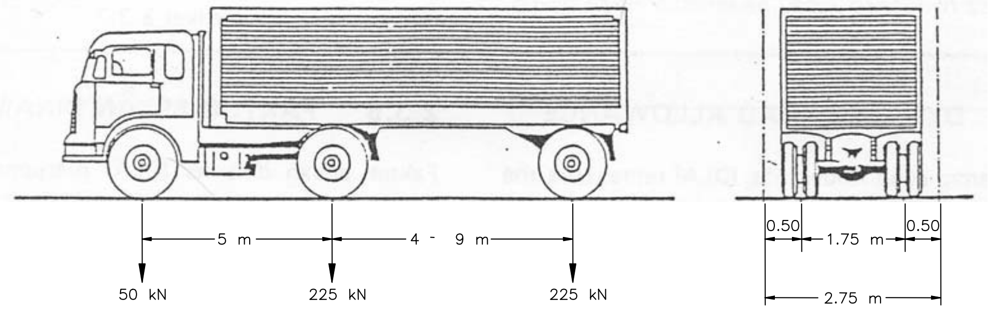
Total U – D – L: (L $\leq$ 30 m) = 11.00 x 9.0 + 0.50 x 9.0 x 0.5 =101.25 kN/m
(L = 40m) = 11.00 x 7.875 + 0.50 x 0.5 x 7.875 = 88.594 kN/m
(L = 45m) = 11.00 x 7.5 + 0.50 x 0.5 x 7. 5 = 84.375 kN/m

Total K – E – L = 11.00 x 49.0 + 0.50 x 49.0 x 0.5 = 551.25 kN

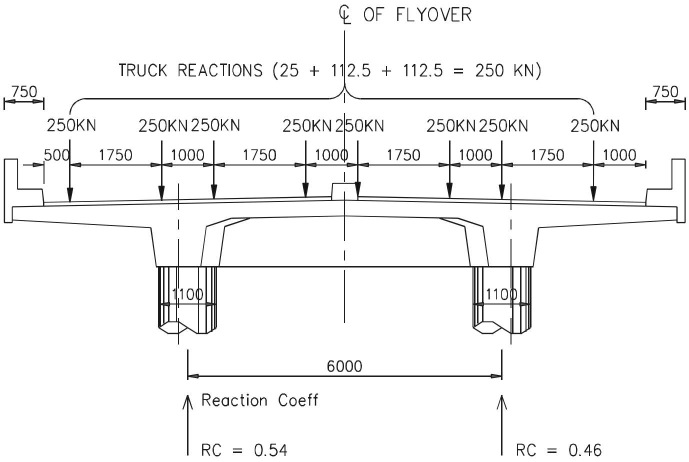
d. Dynamic Load Allowance
Lav = 20 m
Lmax = 20 m
$L_E = \sqrt{L_{av} \times L_{\max}}$ = 20 m
For K – E – L Load I = 0.4 – (L_E-50)/400
$0.3 \leq I \leq 0.4$
I = 0.4

9. TRAFFIC LOAD – “T” TRUCK LOADING

a. Truck Load



b. Layout of “T” Truck Loading



c. Dynamic Load Allowance

I = 0.30

10. TRAFFIC LOAD – BRAKING FORCE

Braking Force = 5 % of “D” Loading
a. U – D – L = 0.05 x 101.25
= 5.06 kN/m
b. K – E – L = 0.05 x 551.25
= 27.56 kN

Applied 1.8 m above road surface.

11. TRAFFIC LOAD – CENTRIFUGAL FORCE

TTR = $0.0079 \text{ x } \frac{V^2}{r} T_T$

V = 40 km/h
Span A1 – P3 = R = ~ ⟶ TTR = 0 kN

Applied 1.8 m above road surface.

12. PEDESTRIAN LOADING

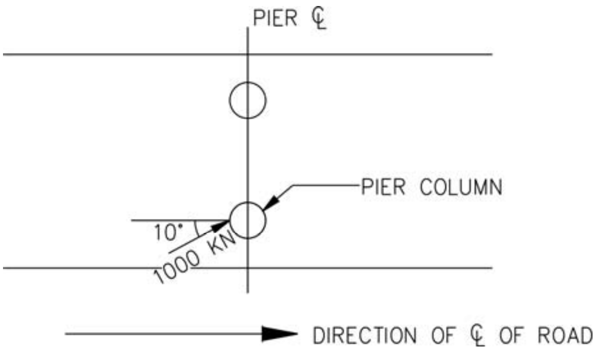
For side walk attached to the road bridge

W = $\frac{1}{30}(160 - A)$ kN/m^2 $[2 \leq W \leq 5]$
Width = 2 x 0.5 = 1.0 m
A = L x 3 $(2x0.5)$= 60 m^2
W = $\frac{1}{30}(160 - 60) = 3.33$ kN/m^2
W = 3.33 x 1.0 = 3.33 kN/m

13. COLLISION LOADS ON BRIDGE SUPPORTS – VEHICLE

a. An Equivalent Static load of 1000 kN shall be applied at an angle of 10 degrees from the direction of the center line of the road passing under the bridge. The load shall be applied at 1.6 m above the road surface.

b. Arrangement of Collision Load



14. COLLISION LOADS ON BRIDGE SUPPORTS - TRAIN

Not applicable

15. TEMPERATURE EFFECTS

a. Nominal Average Bridge Temperature

Minimum = 15° C
Maximum = 40° C
Design Temperature Range ± 25^{o} C

b. Average Material Properties For Temperature Effects

- Concrete Compressive Strength = 30 MPa
  Coefficient of thermal expansion = 10 x 10^{-6} per ° C
  Modulus of elasticity = 25,000 MPa

16. HYDROSTASTIC PRESSURE AND BUOYANCY

Not applicable

17. WIND LOADS

a. Design Wind Velocity (>5km from coast)

V_W = 25 m/s SLS
Vw = 30 m/s ULS

b. Drag Coefficient C_W

Width of bridge deck b = 13.00 m
Depth of solid area d = (1.2 + 0.9) m = 2.10 m

b/d = 6.19

$C_W = \left(1.5-1.25\right)\left(1-\frac{\left(b/d-2\right)}{4}\right)+1.25$

C_W = 1.24

c. Equivalent Side Area of Bridge (per m)

A_b = d x 1 m = 2.10 m^2/m

d. Wind Load on Bridge Structure (per m)

T_{EW} = 0.0006 . C_W $(V_W)^2$ A_b
= 0.98 kN/m @ SLS
= 1.41 kN/m @ ULS

e. Wind Load on Vehicle Traffic

Drag Coefficient $C_W = 1.2$
T_{EW} = 0.0012 C_W $(V_W)^2$
= 0.90 kN/m @ SLS
= 1.30 kN/m @ ULS

T_{EW} is additional horizontal line load due to wind on traffic applied at deck level

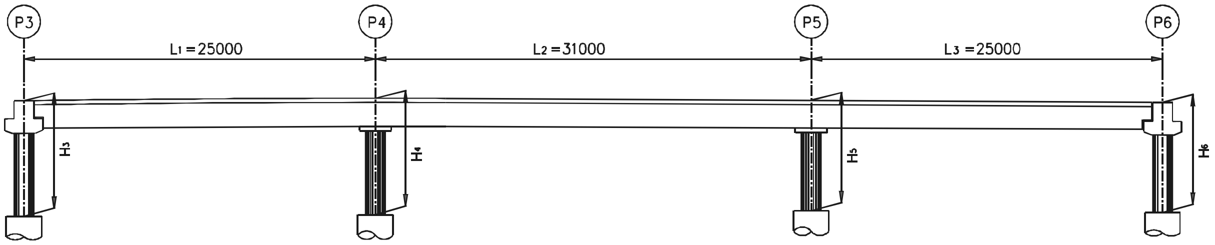
18. EARTHQUAKE EFFECTS

Seismic Zone = 3
Peak Ground Acceleration (See separate sheet for tabulation of C elastic) = 0.40 g
Soil Coefficient S = 1.2 (Medium Soil)
The elastic base shear coefficient

C elastic = $\frac{1{,}2.A.S}{T^{2/3}} \leq 2{,}5.A$

1. ARRANGEMENT

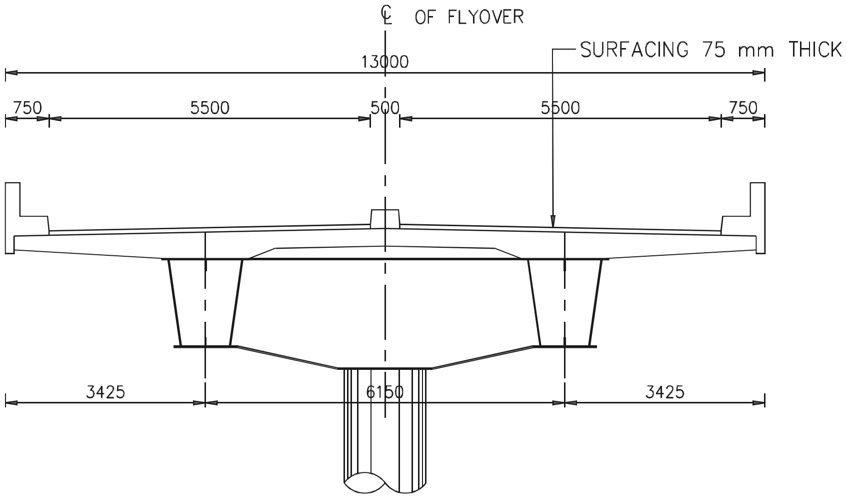
a. Span Length



$_1$ = 25 m
L_2 = 31 m
L_3 = 25 m

H_3 = 8.39 m
H_4 = 8.5 m
H_5 = 8.5 m
H_6 = 8.9 m

2. DECK SECTION



3. UNIT WEIGHT OF MATERIALS

a. Unit Weight of Concrete = 24.5 kN/ m^3
b. Unit Weight of Asphalt Surfacing = 22.5 kN/ m^3

4. SECTION AREAS

a. X – Sectional Area of Deck Slab = 4.489 m^2
b. X – Sectional Area of Structural Steel = 0.206 m^2
c. X – Sectional Area of Median & Railing = 1.029 m^2
d. X – Sectional Area of Surfacing = 1.313 m^2

(Including 50 mm allowance for future Resurfacing)

5. PERMANENT LOADS

a.	U-D-L	of Deck Slab	=	107.738	kN/m
b.	U-D-L	of Structural Steel Girder	=	24.000	kN/m
c.	U-D-L	of Median & Railing	=	25.210	kN/m
d.	U-D-L	of Surfacing	=	28.886	kN/m

6. IMPOSED DEFORMATIONS

a. Shrinkage and Creep Effects.

Shrinkage and creep effects will normally not be calculated for bridge substructures unless the effects of applied loads other than earthquake effects are governing.

b. Pre-stressing Effects

Refer to separate calculation for the secondary effects of prestress in the elastomeric bearing design.

Secondary effects of prestress will normally not be calculated for bridge substructures unless the effects of applied loads other than earthquake effect are governing.

c. Settlements

A differential settlement of 25 mm shall be taken into account in the design of the substructure.

d. Earth Pressure

Abutment will be not take earth pressure, due to the applied load will be taking by MSE wall.

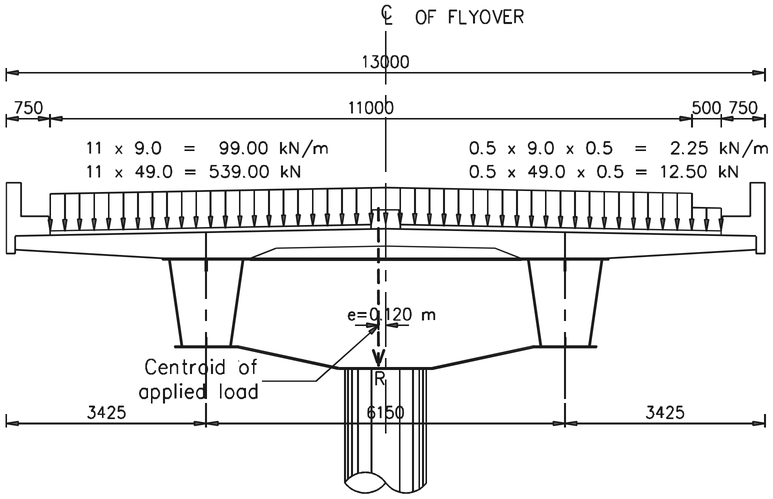
7. TRAFFIC LOADING – DESIGN TRAFFIC LANES

a. Design Lane Width = 2.75 m
b. Number of Design Traffic Lanes = 4

8. TRAFFIC LOADING – “D” LANE LOADING

a. U – D – L	(L $\leq$ 30m)	q =	9.000	kN/m²
	(L = 31m)	q =	8.855	kN/m²
	(L = 45m)	q =	7.500	kN/m²
	(L = 56m)	q =	6.911	kN/m²
K – E – L		p =	49.000	kN/m

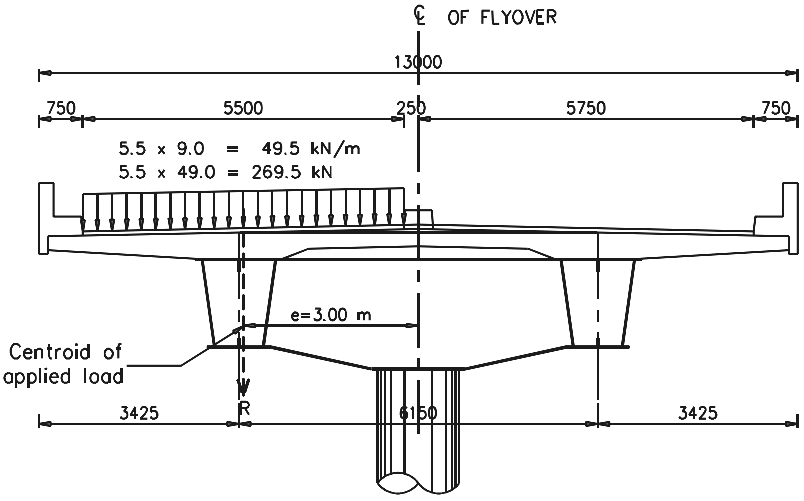
b. Layout of “D” Lane Loading (1)



Total U – D – L: (L ≤ 30m) = 11.00 x 9.0 + 0.50 x 9.0 x 0.5 = 101.250 kN/m
(L ≤ 31m) = 11.00 x 8.855 + 0.50 x 8.855 x 0.5 = 99.619 kN/m
(L = 45m) = 11.00 x 7.5 + 0.50 x 7.5 x 0.5 = 84.375 kN/m
(L = 56m) = 11.00 x 6.911 + 0.50 x 6.911 x 0.5 = 77.749 kN/m

Total K – E – L = 11.00 x 49.0 + 0.50 x 49.0 x 0.5 = 551.25 kN

c. Layout of “D” Lane Loading (2)



Total U – D – L: (L ≤ 30m) = 5.5 x 9.0 = 49.500 kN/m
(L ≤ 31m) = 5.5 x 8.855 = 48.702 kN/m
(L = 45m) = 5.5 x 7.5 = 41.250 kN/m
(L = 56m) = 5.5 x 6.911 = 38.010 kN/m

Total K – E – L = 5.5 x 49.0 = 269.5 kN

d. Dynamic Load Allowance

Lav = 27 m

Lmax = 31 m

$L_E = \sqrt{L_{av} \times L_{\max}} = 28.931$ m

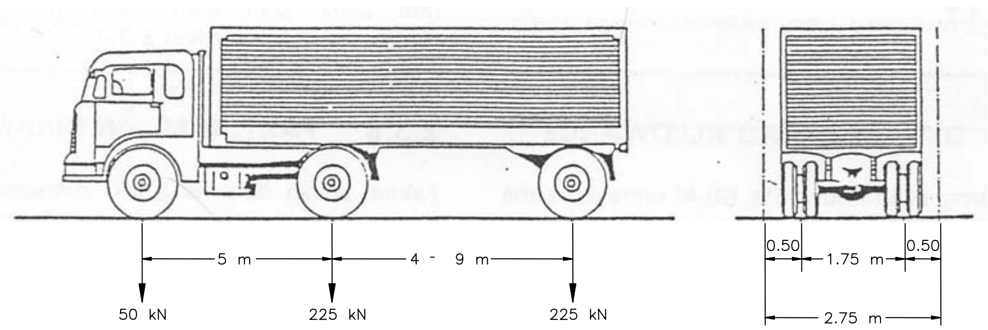
For K – E – L Load $I = 0.4 - (L_E-50)/400$

$0.3 \leq I \leq 0.4$

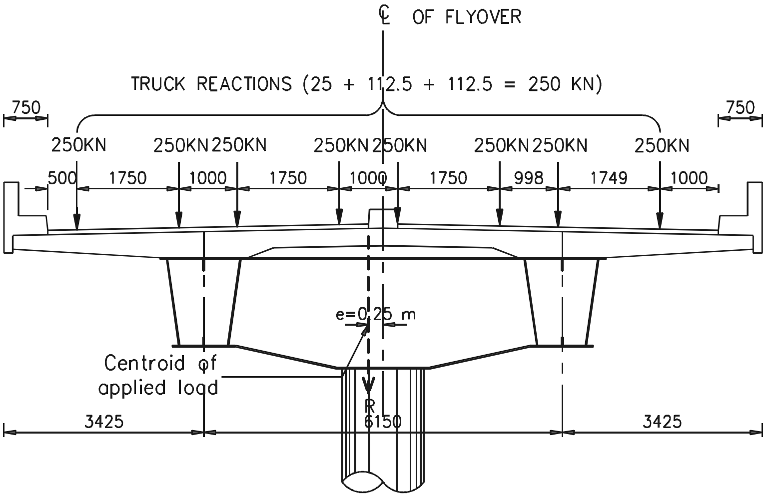
I = 0.4

9. TRAFFIC LOAD – "T" TRUCK LOADING

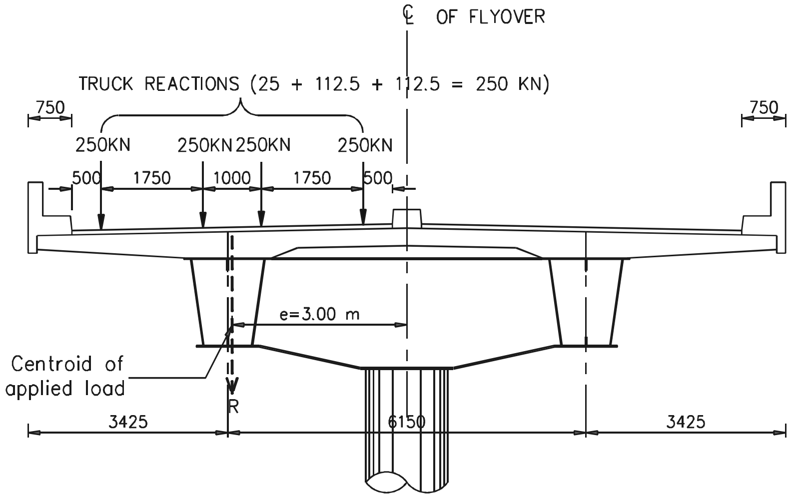
a. Truck Load



b. Layout of "T" Truck Loading (1)



c. Layout of “T” Truck Loading (2)



d. Dynamic Load Allowance

I = 0.30

10. TRAFFIC LOAD – BRAKING FORCE

Braking Force = 5 % of “D” Loading
a. U-D-L = 0.05 x 101.25
= 5.06 kN/m
b. K-E-L = 0.05 x 551.25
= 27.56 kN

Applied 1.8 m above road surface

11. TRAFFIC LOAD – CENTRIFUGAL FORCE

$T_{TR} = 0.0079 \times \frac{V^2}{r} . T_T$

V = 40 km/h

Span P3 – P6 = R = ~ → T_{TR} = 0 kN

Applied 1.8 m above road surface

12. PEDESTRIAN LOADING

For side walk attached to the road bridge

$W = \frac{1}{30}(160 - A)$ kN/m^2 $[2 \le W \le 5]$

Width = 2 x 0.5 = 1.0 m

A = 81 x $(2x0.5)$ = 81 m^2

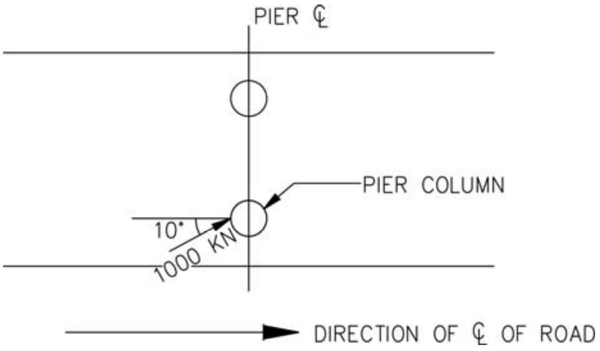
W = $\frac{1}{30}(160-81)$ = 2.63 kN/m^2

W = 2.63 x 1.0 = 2.63 kN/m

13. COLLISION LOADS ON BRIDGE SUPPORTS – VEHICLE

a. An Equivalent Static load of 1000 kN shall be applied at an angle of 10 degrees from the direction of the center line of the road passing under the bridge. The load shall be applied at 1.6 m above the road surface.

b. Arrangement of Collision Load



14. COLLISION LOADS ON BRIDGE SUPPORTS - TRAIN

Not applicable

15. TEMPERATURE EFFECTS

a. Nominal Average Bridge Temperature

Minimum = 15° C
Maximum = 40° C
Design Temperature Range ± 25° C

b. Average Material Properties For Temperature Effects

- Concrete Compressive Strength = 30 MPa
  Coefficient of thermal expansion = 10 x 10^{-6} per ° C
  Modulus of elasticity = 25,000 MPa

16. HYDROSTASTIC PRESSURE AND BUOYANCY

Not applicable

17. WIND LOADS

a. Design Wind Velocity (>5km from coast)

V_W = 25 m/s SLS
V_W = 30 m/s ULS

b. Drag Coefficient C_W

Width of bridge deck b = 13.00 m

Depth of solid area d = (1.95 + 0.90)m = 2.85 m

b/d = 4.56

$C_W = (1.5 - 1.25)\left(1 - \frac{(b/d - 2)}{4}\right) + 1.25$

C_W = 1.34

c. Equivalent Side Area of Bridge (per m)

A_b = d x 1 m = 2.85 m^2/m

d. Wind Load on Bridge Structure (per m)

T_{EW} = 0.0006 . C_W $(V_W)^2$ A_b

= 1.43 kN/m @ SLS

= 2.06 kN/m @ ULS

e. Wind Load on Vehicle Traffic

Drag Coefficient C_W = 1.2

T_{EW} = 0.0012 $C_W (V_W)^2$

= 0.90 kN/m @ SLS

= 1.30 kN/m @ ULS

T_{EW} is additional horizontal line load due to wind on traffic applied at deck level

18. EARTHQUAKE EFFECTS

Seismic Zone = 3

Peak Ground Acceleration (See separate sheet for tabulation of C elastic) = 0.40 g

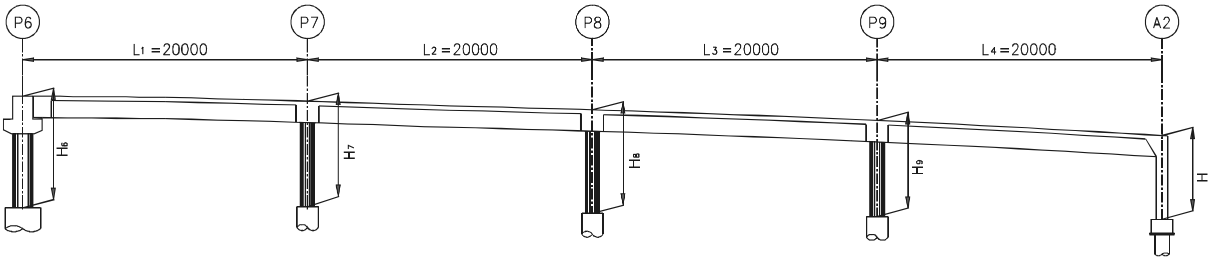
Soil Coefficient S = 1.2 (Medium Soil)

The elastic base shear coefficient

C elastic $= \frac{1,2.A.S}{T^{2/3}} \le 2,5.A$

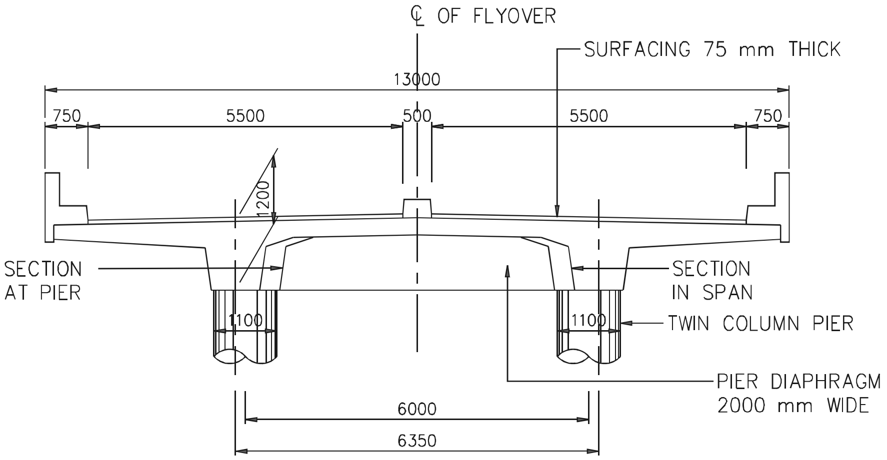
1. ARRANGEMENT

a. Span Length



L_1 = 20 m H_6 = 8.9 m
L_2 = 20 m H_7 = 8.2 m
L_3 = 20 m H_8 = 8.2 m
L_4 = 20 m H_9 = 8.2 m
H = 4.47 m

2. DECK SECTION



3. UNIT WEIGHT OF MATERIALS

a. Unit Weight of Concrete = 24.5 kN/ m^3
b. Unit Weight of Asphalt Surfacing = 22.5 kN/ m^3

4. SECTION AREAS

a. X – Sectional Area of Deck in Span = 5.898 m^2
b. X – Sectional Area of Deck at Pier = 10.861 m^2
c. X – Sectional Area of Deck at Diaphragm = 10.861 m^2
d. X – Sectional Area of Median & Railing = 1.029 m^2
e. X – Sectional Area of Surfacing = 1.313 m^2

(Including 50 mm allowance for future Resurfacing)

5. PERMANENT LOADS

a. U-D-L of Deck in Span = 144.501 kN/m
b. U-D-L of Deck at Pier = 266.094 kN/m
c. U-D-L of Deck at Diaphragm = 266.094 kN/m
d. U-D-L of Median & Railing = 25.210 kN/m
e. U-D-L of Surfacing = 28.886 kN/m

6. IMPOSED DEFORMATIONS

a. Shrinkage and Creep Effects.

Shrinkage and creep effects will normally not be calculated for bridge substructures unless the effects of applied loads other than earthquake effects are governing.

b. Pre-stressing Effects

Refer to separate calculation for the secondary effects of prestress in the elastomeric bearing design.

Secondary effects of prestress will normally not be calculated for bridge substructures unless the effects of applied loads other than earthquake effect are governing.

c. Settlements

A differential settlement of 25 mm shall be taken into account in the design of the substructure.

d. Earth Pressure

Abutment will be not take earth pressure, due to the applied load will be taking by MSE wall.

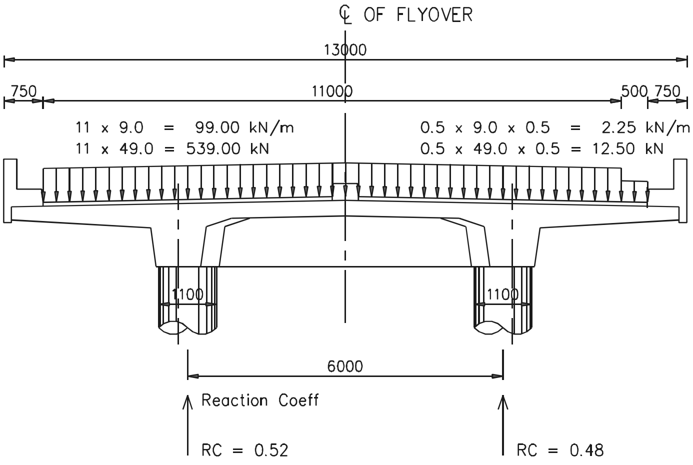
7. TRAFFIC LOADING – DESIGN TRAFFIC LANES

a. Design Lane Width = 2.75 m
b. Number of Design Traffic Lanes = 4

8. TRAFFIC LOADING – “D” LANE LOADING

a. U – D – L: ($L \leq 30$m) $q = 9.000$ kN/m^2
($L = 40$m) $q = 7.875$ kN/m^2
($L = 45$m) $q = 7.500$ kN/m^2
b. K – E – L $p = 49.000$ kN/m

c. Layout of “D” Lane Loading

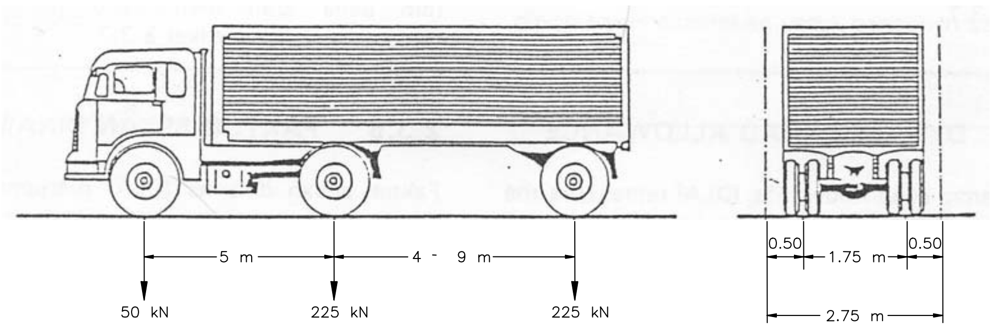


Total U – D – L: ($L \leq 30$m) = 11.00 x 9.0 + 0.50x 9.0 x 0.5 = 101.25 kN/m
(L = 40m) = 11.00 x 7.875 + 0.50 x 0.5 x 7.875 = 88.594 kN/m
(L = 45m) = 11.00 x 7.5 + 0.50 x 0.5 x 7. 5 = 84.375 kN/m
Total K – E – L = 11.00 x 49.0+ 0.50 x 49.0 x 0.5 = 551.25 kN

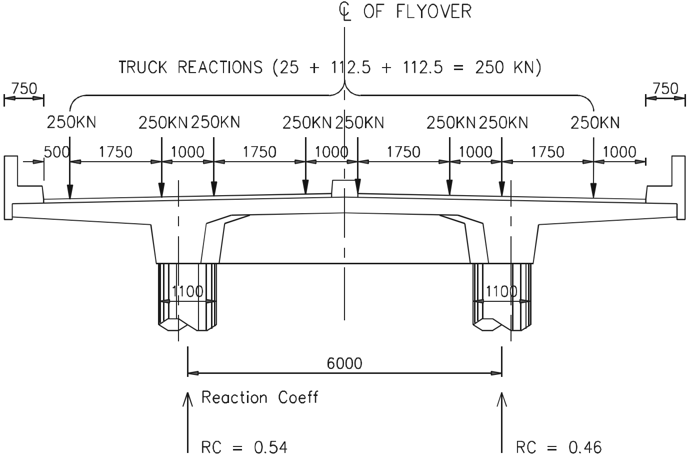
d. Dynamic Load Allowance
Lav = 20 m
Lmax = 20 m
L_E = $\sqrt{L_{av} \times L_{\max}}$ = 20 m
For K – E – L Load I = 0.4 – (L_E-50)/400
$0.3 \leq I \leq 0.4$
I = 0.4

9. TRAFFIC LOAD – “T” TRUCK LOADING

a. Truck Load



b. Layout of “T” Truck Loading



c. Dynamic Load Allowance
I = 0.30

10. TRAFFIC LOAD – BRAKING FORCE

Braking Force = 5 % of “D” Loading
a. U – D – L = 0.05 x 101.25
= 5.06 kN/m
b. K – E – L = 0.05 x 551.25
= 27.56 kN

Applied 1.8 m above road surface.

11. TRAFFIC LOAD – CENTRIFUGAL FORCE

$$T_{TR} = 0.0079 \text{ x } \frac{V^2}{r} T_T$$

V = 40 km/h
Span P6 – P8 = R = ~ ⟶ T_{TR} = 0 kN

Span P8 – P9 = R = 167 m

$$T_{TR} = 0.0079 \text{ x } \frac{40^2}{167} \times (101.25 \times 20 + 551.25)$$

= 194.99 kN ≈ 9.75 kN/m
M=9.75*(1.8+0.305)*0.07= 20.52 kN m

Span P9 – A2 = R = 88 m

$$T_{TR} = 0.0079 \text{ x } \frac{40^2}{88} \times (101.25 \times 20 + 551.25)$$

= 370.04 kN ≈ 18.50 kN/m

M=9.75*(1.8+0.305)*0.07= 20.52 kN m
Applied 1.8 m above road surface.

12. PEDESTRIAN LOADING

For side walk attached to the road bridge

W = $\frac{1}{30}(160 - A)$ kN/m^2 $[2 \leq W \leq 5]$

Width = 2 x 0.5 = 1.0 m

A = L x 4 $(2x0.5)$ = 80 m^2

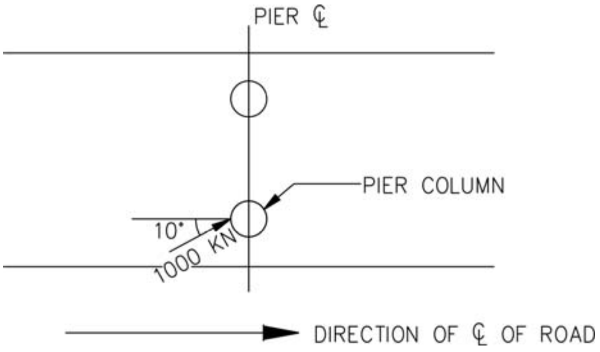
W = $\frac{1}{30}(160 - 80)$ = 2.67 kN/m^2

W = 2.67 x 1.0 = 2.67 kN/m

13. COLLISION LOADS ON BRIDGE SUPPORTS – VEHICLE

a. An Equivalent Static load of 1000 kN shall be applied at an angle of 10 degrees from the direction of the center line of the road passing under the bridge. The load shall be applied at 1.6 m above the road surface.

b. Arrangement of Collision Load



14. COLLISION LOADS ON BRIDGE SUPPORTS - TRAIN

Not applicable

15. TEMPERATURE EFFECTS

a. Nominal Average Bridge Temperature

Minimum = 15° C
Maximum = 40° C
Design Temperature Range ± 25^o C

b. Average Material Properties For Temperature Effects

- Concrete Compressive Strength = 30 MPa
  Coefficient of thermal expansion = 10 x 10^{-6} per ° C
  Modulus of elasticity = 25,000 Mpa

16. HYDROSTASTIC PRESSURE AND BUOYANCY

Not applicable

17. WIND LOADS

a. Design Wind Velocity (>5km from coast)

V_W = 25 m/s SLS
V_W = 30 m/s ULS

b. Drag Coefficient C_W

Width of bridge deck b = 13.00 m
Depth of solid area d = (1.2 + 0.9) m = 2.10 m

b/d = 6.19

$$C_W = (1.5 - 1.25)\left(1 - \frac{(b/d - 2)}{4}\right) + 1.25$$

C_W = 1.24

c. Equivalent Side Area of Bridge (per m)

A_b = d x 1 m = 2.10 m^2/m

d. Wind Load on Bridge Structure (per m)

T_{EW} = 0.0006 . C_W $(V_W)^2$ A_b
= 0.98 kN/m @ SLS
= 1.41 kN/m @ ULS

e. Wind Load on Vehicle Traffic

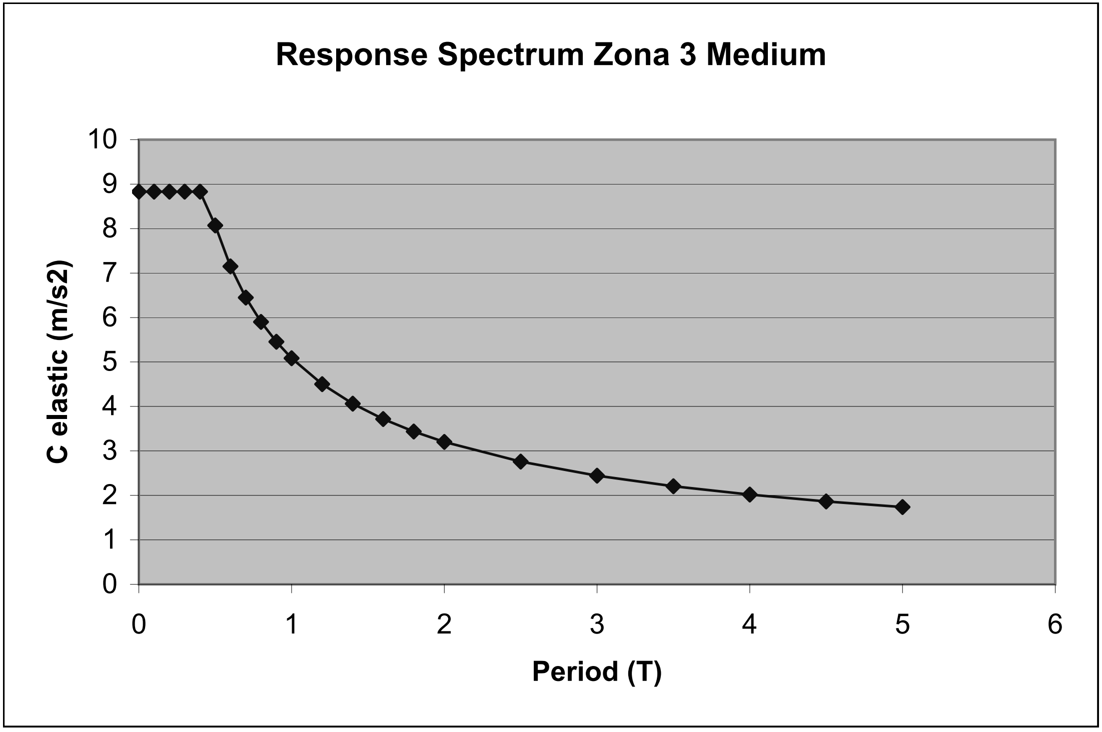
Drag Coefficient C_W = 1.2
T_{EW} = 0.0012 C_W $(V_W)^2$
= 0.90 kN/m @ SLS
= 1.30 kN/m @ ULS

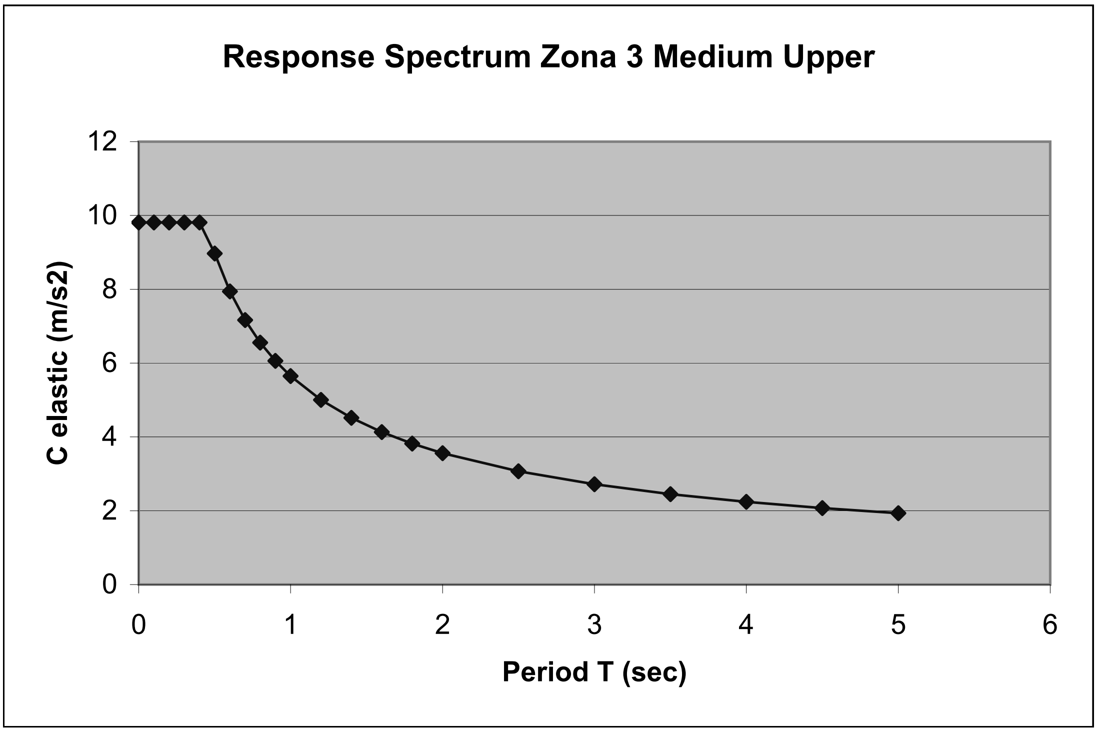
T_{EW} is additional horizontal line load due to wind on traffic applied at deck level

18. EARTHQUAKE EFFECTS

Seismic Zone = 3
Peak Ground Acceleration (See separate sheet for tabulation of C elastic) = 0.40 g
Soil Coefficient S = 1.2 (Medium Soil)
The elastic base shear coefficient

$$C\ elastic = \frac{1{,}2.A.S}{T^{2/3}} \leq 2{,}5.A$$


Response Spectrum Zona 3 Medium
C elastic (m/s2)
0
1
2
3
4
5
6
7
8
9
10
Period (T)
0
1
2
3
4
5
6


Response Spectrum Zona 3 Medium Upper
C elastic (m/s2)
0
2
4
6
8
10
12
Period T (sec)
0
1
2
3
4
5
6

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

Calculation: **Detailed DEsign Substructure**
Balaraja Flyover
Deck Dead Load

PC DOUBLE TRAPEZOIDAL GIRDER DECK - 20m Span

Initial Data

Area of Structural Concrete - In Span $A_{SC1} := 5.8984 \cdot m^2$

Area of Structural Concrete - At Pier $A_{SC2} := 5.8984 \cdot m^2$

Area of Structural Concrete - At Diaphragm $A_{SC3} := 5.8984 \cdot m^2$

Area of levelling concrete $A_{level} := 0.11 \cdot m \cdot (0m + 0m)$

$A_{level} = 0$

Edge barrier $A_{barrier} := 2 \cdot (0.434) \cdot m^2$

$A_{barrier} = 0.868\ m^2$

Center median $A_{median} := 0.5 \cdot m \cdot 0.325 \cdot m$

$A_{median} = 0.163\ m^2$

Area of surfacing $A_{surface} := 0.125 \cdot m \cdot 2 \cdot 5.5 \cdot m$

$A_{surface} = 1.375\ m^2$

Unit weight of RC concrete $\gamma_c := 24.5 \cdot \frac{kN}{m^3}$

Unit weight of surfacing $\gamma_s := 22.5 \cdot \frac{kN}{m^3}$

Total nominal unit weight of deck

In span section

$$W_1 := \left(A_{SC1} + A_{level} + A_{barrier} + A_{median}\right)\cdot\gamma_c$$

$$W_1 = 169.8\,\frac{kN}{m}$$

At pier section

$$W_2 := \left[\left(\frac{A_{SC1} + A_{SC2}}{2}\right) + A_{level} + A_{barrier} + A_{median}\right]\cdot\gamma_c$$

$$W_2 = 169.8\,\frac{kN}{m}$$

At diaphragm section

$$W_3 := \left(A_{SC3} + A_{level} + A_{barrier} + A_{median}\right)\cdot\gamma_c$$

$$W_3 = 169.8\,\frac{kN}{m}$$

Total nominal unit weight of surfacing

$W_{super} := A_{surface}\cdot\gamma_s$ $W_{super} = 30.938\,\frac{kN}{m}$

Multipliers for dead load weight (based on structural concrete area)

In span section $Fac1 := \frac{W_1}{\gamma_c}\cdot\frac{1}{A_{SC1}}$ $Fac1 = 1.17$

Near pier section $Fac2 := \frac{W_2}{\gamma_c}\cdot\frac{2}{A_{SC1} + A_{SC2}}$ $Fac2 = 1.17$

At pier section $Fac3 := \frac{W_3}{\gamma_c}\cdot\frac{1}{A_{SC3}}$ $Fac3 = 1.17$

Multipliers for dead and superdead load mass (based on structural concrete area)

In span section $Fac1 := \frac{W_1 + W_{super}}{\gamma_c}\cdot\frac{1}{A_{SC1}}$ $Fac1 = 1.39$

Near pier section $Fac2 := \frac{W_2 + W_{super}}{\gamma_c}\cdot\frac{2}{A_{SC1} + A_{SC2}}$ $Fac2 = 1.39$

At pier section $Fac3 := \frac{W_3 + W_{super}}{\gamma_c}\cdot\frac{1}{A_{SC3}}$ $Fac3 = 1.39$

Centroid of Dead Load

Centroid - in span deck section
- wrt to deck surface

$Centroid_{Deck1} := -0.398m$

Centroid - at pier deck section
- wrt to deck surface

$Centroid_{Deck2} := -0.398 \cdot m$

Centroid - at diaphragm deck section
- wrt to deck surface

$Centroid_{Deck3} := -0.398 \cdot m$

Combined centroid - in span section

$$Centroid_{11} := \left(Centroid_{Deck1} \cdot A_{SC1} + 0.06 \cdot m\, A_{level} + 0.283 \cdot m\, A_{barrier} + 0.15 \cdot m\, A_{median}\right) \cdot \gamma_c$$

$$Centroid_{12} := \left(\frac{0.125}{2} \cdot m\, A_{surface}\right) \cdot \gamma_s$$

$$Centroid_1 := \frac{Centroid_{11} + Centroid_{12}}{W_1 + W_{super}} \qquad Centroid_1 = -0.244\ m$$

Combined centroid - near pier section

$$Centroid_{21} := \left(Centroid_{Deck2} \cdot A_{SC2} + 0.06 \cdot m\, A_{level} + 0.283 \cdot m\, A_{barrier} + 0.15 \cdot m\, A_{median}\right) \cdot \gamma_c$$

$$Centroid_{22} := \left(\frac{0.125}{2} \cdot m\, A_{surface}\right) \cdot \gamma_s$$

$$Centroid_2 := \frac{Centroid_{21} + Centroid_{22}}{W_2 + W_{super}} \qquad Centroid_2 = -0.244\ m$$

Combined centroid - at diapragm section

$$Centroid_{31} := \left(Centroid_{Deck3} \cdot A_{SC3} + 0.06 \cdot m\, A_{level} + 0.283 \cdot m\, A_{barrier} + 0.15 \cdot m\, A_{median}\right) \cdot \gamma_c$$

$$Centroid_{32} := \left(\frac{0.125}{2} \cdot m\, A_{surface}\right) \cdot \gamma_s$$

$$Centroid_3 := \frac{Centroid_{31} + Centroid_{32}}{W_3 + W_{super}} \qquad Centroid_3 = -0.244\ m$$

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

Calculation: **Detailed Design Substructure**
Balaraja Flyover
Deck Dead Load

STEEL BOX GIRDER DECK

Initial Data

Area of Structural Concrete - In Span $A_{SC1} := 4.549 \cdot m^2$

Area of Structural Concrete - At Pier $A_{SC2} := 4.549 \cdot m^2$

Area of Structural Concrete - At Diaphragm $A_{SC3} := 4.549 \cdot m^2$

Area of Structural Steel - In Span $A_{SS1} := 0.2161 \cdot 1.3 \cdot m^2$

Area of Structural Steel - At Pier $A_{SS2} := 0.2161 \cdot 1.3 \cdot m^2$

Area of Structural Steel - At Diaphragm $A_{SS3} := 0.2161 \cdot 1.3 \cdot m^2$

Area of levelling concrete $A_{level} := 0.11 \cdot m \cdot (0m + 0m)$

$A_{level} = 0$

Edge barrier $A_{barrier} := 2 \cdot (0.434) \cdot m^2$

$A_{barrier} = 0.868\ m^2$

Center median $A_{median} := 0.5 \cdot m \cdot 0.325 \cdot m$

$A_{median} = 0.163\ m^2$

Area of surfacing $A_{surface} := 0.125 \cdot m \cdot (2 \cdot 5.5) \cdot m$

$A_{surface} = 1.375\ m^2$

Unit weight of RC concrete $\gamma_c := 24.5 \cdot \frac{kN}{m^3}$

Unit weight of Structrual Steel $\gamma_S := 77.0 \cdot \frac{kN}{m^3}$

Unit weight of surfacing $\gamma_s := 22.5 \cdot \frac{kN}{m^3}$

Total nominal unit weight of deck

In span section $W_1 := \left(A_{SC1} + A_{level} + A_{barrier} + A_{median}\right)\cdot\gamma_c + A_{SS1}\cdot\gamma_S$

$W_1 = 158.3\,\frac{kN}{m}$ $A_{SS1}\cdot\gamma_S = 21.632\,\frac{kN}{m}$

At pier section $W_2 := \left[\left(\frac{A_{SC1} + A_{SC2}}{2}\right) + A_{level} + A_{barrier} + A_{median}\right]\cdot\gamma_c + A_{SS2}\cdot\gamma_S$

$W_2 = 158.3\,\frac{kN}{m}$ $A_{SS2}\cdot\gamma_S = 21.632\,\frac{kN}{m}$

At diaphragm section $W_3 := \left(A_{SC3} + A_{level} + A_{barrier} + A_{median}\right)\cdot\gamma_c + A_{SS3}\cdot\gamma_S$

$W_3 = 158.3\,\frac{kN}{m}$ $A_{SS3}\cdot\gamma_S = 21.632\,\frac{kN}{m}$

Total nominal unit weight of surfacing

$W_{super} := A_{surface}\cdot\gamma_s$ $W_{super} = 30.938\,\frac{kN}{m}$

Multipliers for dead load weight (based on equivalent concrete section area)

In span section $A_{EQC1} := A_{SC1} + A_{SS1}\cdot\frac{\gamma_S}{\gamma_c}$ $A_{EQC1} = 5.432\ m^2$

$Fac1 := \frac{W_1}{\gamma_c}\cdot\frac{1}{A_{EQC1}}$ $Fac1 = 1.19$

Near pier section $A_{EQC2} := A_{SC2} + A_{SS2}\cdot\frac{\gamma_S}{\gamma_c}$ $A_{EQC2} = 5.432\ m^2$

$Fac2 := \frac{W_2}{\gamma_c}\cdot\frac{2}{A_{EQC1} + A_{EQC2}}$ $Fac2 = 1.19$

At pier section $A_{EQC3} := A_{SC3} + A_{SS3}\cdot\frac{\gamma_S}{\gamma_c}$ $A_{EQC3} = 5.432\ m^2$

$Fac3 := \frac{W_3}{\gamma_c}\cdot\frac{1}{A_{EQC3}}$ $Fac3 = 1.19$

Multipliers for dead and superdead load weight (based on equivalent concrete area)

In span section $Fac1 := \frac{W_1 + W_{super}}{\gamma_c} \cdot \frac{1}{A_{EQC1}}$ $Fac1 = 1.42$

Near pier section $Fac2 := \frac{W_2 + W_{super}}{\gamma_c} \cdot \frac{2}{A_{EQC1} + A_{EQC2}}$ $Fac2 = 1.42$

At diaphragm section $Fac3 := \frac{W_3 + W_{super}}{\gamma_c} \cdot \frac{1}{A_{EQC3}}$ $Fac3 = 1.42$

Centroid of Dead Load

Centroid - in span deck section
- wrt to deck surface $Centroid_{Deck1} := -0.2492 \cdot m$

Centroid - at pier deck section
- wrt to deck surface $Centroid_{Deck2} := -0.2492 \cdot m$

Centroid - at diaphragm deck section
- wrt to deck surface $Centroid_{Deck3} := -0.2492 \cdot m$

Centroid - in span steel section
- wrt to deck surface $Centroid_{Steel1} := -1.2063 \cdot m$

Centroid - at pier steel section
- wrt to deck surface $Centroid_{Steel2} := -1.2063 \cdot m$

Centroid - at diaphragm steel section
- wrt to deck surface $Centroid_{Steel3} := -1.2063 \cdot m$

Combined centroid - in span section

$$\mathrm{Centroid}_{11} := \left(\mathrm{Centroid}_{Deck1} \cdot A_{SC1} + 0.06 \cdot m\, A_{level} + 0.283 \cdot m\, A_{barrier} + 0.15 \cdot m\, A_{median}\right) \cdot \gamma_c$$

$$\mathrm{Centroid}_{12} := \mathrm{Centroid}_{Steel1} \cdot A_{SS1} \cdot \gamma_S$$

$$\mathrm{Centroid}_{13} := \left(\frac{0.125}{2} \cdot m\, A_{surface}\right) \cdot \gamma_s$$

$$\mathrm{Centroid}_1 := \frac{\mathrm{Centroid}_{11} + \mathrm{Centroid}_{12} + \mathrm{Centroid}_{13}}{W_1 + W_{super}} \qquad \mathrm{Centroid}_1 = -0.239 \text{ m}$$

Combined centroid - near pier section

$$\mathrm{Centroid}_{21} := \left(\mathrm{Centroid}_{Deck2} \cdot A_{SC2} + 0.06 \cdot m\, A_{level} + 0.283 \cdot m\, A_{barrier} + 0.15 \cdot m\, A_{median}\right) \cdot \gamma_c$$

$$\mathrm{Centroid}_{22} := \mathrm{Centroid}_{Steel2} \cdot A_{SS2} \cdot \gamma_S$$

$$\mathrm{Centroid}_{23} := \left(\frac{0.125}{2} \cdot m\, A_{surface}\right) \cdot \gamma_s$$

$$\mathrm{Centroid}_2 := \frac{\mathrm{Centroid}_{21} + \mathrm{Centroid}_{22} + \mathrm{Centroid}_{23}}{W_2 + W_{super}} \qquad \mathrm{Centroid}_2 = -0.239 \text{ m}$$

Combined centroid - at diapragm section

$$\mathrm{Centroid}_{31} := \left(\mathrm{Centroid}_{Deck3} \cdot A_{SC3} + 0.06 \cdot m\, A_{level} + 0.283 \cdot m\, A_{barrier} + 0.15 \cdot m\, A_{median}\right) \cdot \gamma_c$$

$$\mathrm{Centroid}_{32} := \mathrm{Centroid}_{Steel3} \cdot A_{SS3} \cdot \gamma_S$$

$$\mathrm{Centroid}_{33} := \left(\frac{0.125}{2} \cdot m\, A_{surface}\right) \cdot \gamma_s$$

$$\mathrm{Centroid}_3 := \frac{\mathrm{Centroid}_{31} + \mathrm{Centroid}_{32} + \mathrm{Centroid}_{33}}{W_3 + W_{super}} \qquad \mathrm{Centroid}_3 = -0.239 \text{ m}$$