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PROJECT

Project Name: Downtown Excavation Support System
Soil Profile: SK1
Owner of Structure:
Code: TBDY APPENDIX 16B

LIQUEFACTION POTENTIAL

Potential of Liquefaction in TBDY:
16.6.2 – Liquefaction of soil shall be defined as a significant reduction in shear strength and rigidity, occurring in cohesionless or low-cohesion soils (PI < 12%) located below the groundwater table and up to 20 meters depth from the surface, due to an increase in pore water pressure under seismic shaking.
16.6.3 – Soil investigation studies aimed at assessing liquefaction potential shall include at a minimum the performance of a standard penetration test (SPT) and/or cone penetration test (CPT), as well as determining grain size distribution, water content, and Atterberg limit values of the relevant soil layers.
16.6.4 – Potentially liquefiable soils shall be defined as sands, gravelly sands, silty clayey sands, non-plastic silts, and silt-sand mixtures located below the groundwater table.
16.6.5 – An evaluation of liquefaction triggering shall be performed when the foundation soils consist of potentially liquefiable soils and the corrected SPT blow count, $N_{1,60}$, is less than 30 blows per 30 cm in these soil layers.
16.6.6 – Liquefaction triggering analysis may not be required when the Seismic Design Class is DTS = 4 and at least one of the following conditions is met: (a) In sandy soils with a clay content greater than 20% and a plasticity index higher than 10%; (b) In sandy soils with a fine-grain content exceeding 35% and a corrected SPT blow count, $N_{1,60}$, greater than 20 blows per 30 cm.
16.6.7 – In the evaluation of soil liquefaction, it is necessary to consider not only the risk of liquefaction triggering but also the post-liquefaction loss of soil strength and stiffness, as well as the displacements that may occur in the foundation soil.

SPT PROFILE AND SOIL PROPERTIES

SPTN: Number of blows for 30 cm of penetration depth (15 cm + 15 cm) after the first 15 cm in the SPT test.,
FC: Fine ratio,
I_p: Plasticity index,
wL: liquid limit,
w_p: Plastic limit,
IL: Liquidity index,
Em: Rod energy ratio,
Cb: Borehole diameter factor,
Cr: Rod length factor,
Cs: Sampling factor,
Ce: Energy Ratio Correction Factor,
$N_{1,60}$: Number of blows normalized to 60% of standard energy,

Table 1. SPT Profile and Soil Properties

Depth [m]	SPTN	$N_{1,60}$	Layer	FC [%]	I_p [%]	wL [%]	w_p [%]	IL	Liquefaction Potential
-6	10	13	Silty Sand (Alluvium)	5	48	0	0	0,38	Exists
-7,5	10	12	Silty Sand (Alluvium)	5	48	0	0	0,38	Exists
-9	13	15	Silty Sand (Alluvium)	5	48	0	0	0,38	Exists
-10,5	12	13	Silty Clay (Alluvium)	60	48	26	15	0,38	Exists
-12	14	15	Silty Clay (Alluvium)	60	48	26	15	0,38	Exists
-13,5	20	20	Silty Clay (Alluvium)	60	48	26	15	0,38	Exists
-15	22	21	ortaMedium Dense Sand (Alluvium)	80	0	0	0	∞	Exists
-16,5	32	30	ortaMedium Dense Sand (Alluvium)	80	0	0	0	∞	None
-18	34	31	Stiff Silty Clay	85	48	26	15	0,38	None
-19,5	38	33	Stiff Silty Clay	85	48	26	15	0,38	None
-21	40	34	Stiff Silty Clay	85	48	26	15	0,38	None

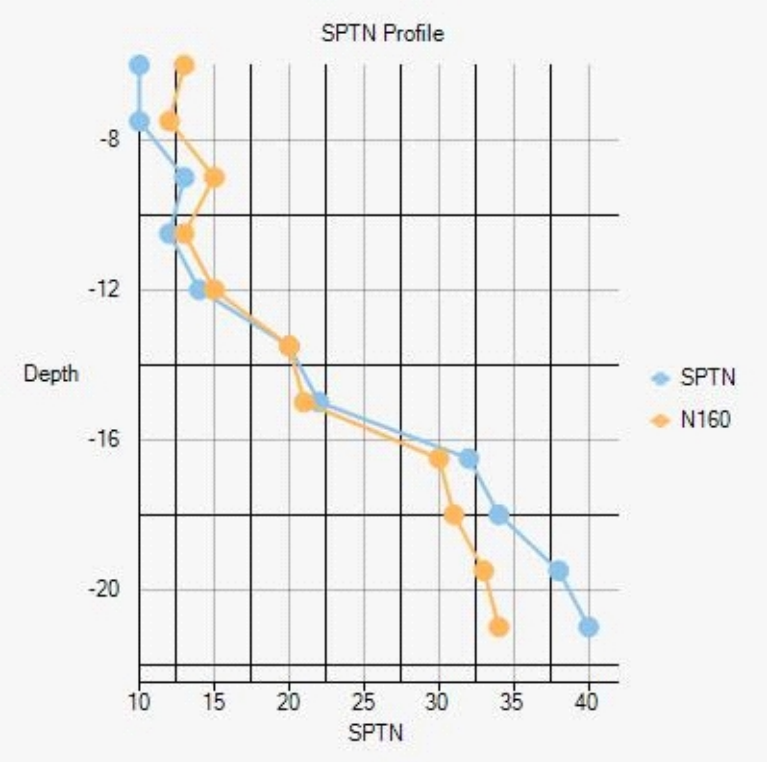

Figure 1. SPTN-Depth Plot

SOIL LIQUEFACTION ASSESSMENT

σ'_v: Vertical effective stress,
σ_v: Vertical total stress,
IDI: Fine ratio,
α, β: Coefficients depending on fine ratio,
$N_{1,60}^{f}$: Fine content-corrected blow count,
$CRR_{M_{7.5}}$: Cyclic resistance ratio corresponding to an earthquake with a moment magnitude of 7.5,
C_M: Earthquake Magnitude Correction Factor,
Mw: Moment magnitude of the design earthquake,
τR: Liquefaction resistance,
SDS: Short-period design spectral acceleration coefficient,
rd: Stress reduction coefficient,
τd_{eprem}: Average cyclic shear stress induced by earthquake in soil,
FS: Factor of Safety,
Δz: Effective soil height,
Si: Settlement,
ε_h: Unit volume change,

$$N_{1,60} = C_N \times C_R \times C_S \times C_B \times C_E$$

$$C_N = 9.78\sqrt{\frac{1}{\sigma'_{vo}}} \leq 1.70$$

$$N_1 = C_N \times SPTN$$

$$C_E = E_m / 0,60$$

$$N_{1,60f} = \alpha + \beta N_{1,60}$$

$\alpha=0,\ \beta=1 \quad (IDI \leq \%5)$

$\alpha=\exp\left[1,76-\left(190/IDI^2\right)\right],\ \beta=0,99+IDI^{1,5}/100 \quad (\%5<IDI<\%35)$

$\alpha=0,5 \quad \beta=1,2$

$$\tau_R = CRR_{M7,5} C_M \sigma'_{v0}$$

$$C_M = \frac{10^{2,24}}{M_w^{2,56}}$$

$$\tau_{earthquake} = 0,65 s_{v0} (0,4 S_{DS}) r_d$$

$r_d = 1,0-0,00765z \qquad z \leq 9,15$

$r_d = 1,174-0,0267z \qquad 9,15m < z < 30m$

$r_d = 0,744-0,008z \qquad 23m < z < 30m$

$r_d = 0,50 \qquad z > 30m$

$$\frac{\tau_R}{\tau_{earthquake}} \geq 1,10$$

Table 2. Liquefaction Calculations

Depth[m]	Layer	SPTN	σ'v [kN/m²]	σv [kN/m²]	N1,60	IDI [%]	α	β	N1,60f	CRRM7.5	CM	τR [kN/m²]	rd	τearthquake [kN/m²]	FS	Safety
-6	Silty Sand (Alluvium)	10	83,3	98	13	5	0	1	13	0,14	1	11,7	0,95	29,15	0,4	X
-7,5	Silty Sand (Alluvium)	10	97,4	126,8	12	5	0	1	12	0,13	1	12,77	0,94	37,26	0,3	X
-9	Silty Sand (Alluvium)	13	111,5	155,6	15	5	0	1	15	0,16	1	17,84	0,93	45,17	0,4	X
-10,5	Silty Clay (Alluvium)	12	125,25	184,05	13	60	5	1,2	20,6	0,22	1	27,92	0,89	51,27	0,5	X

-12	Silty Clay (Alluvium)	14	138,3	211,8	15	60	5	1,2	23	0,26	1	35,52	0,85	56,36	0,6	X
-13,5	Silty Clay (Alluvium)	20	151,35	239,55	20	60	5	1,2	29	0,41	1	62,07	0,81	60,75	1	X
-15	orta Medium Dense Sand (Alluvium)	22	164,4	267,3	21	80	5	1,2	30,2	0,48	1	79,26	0,77	64,45	1,2	√

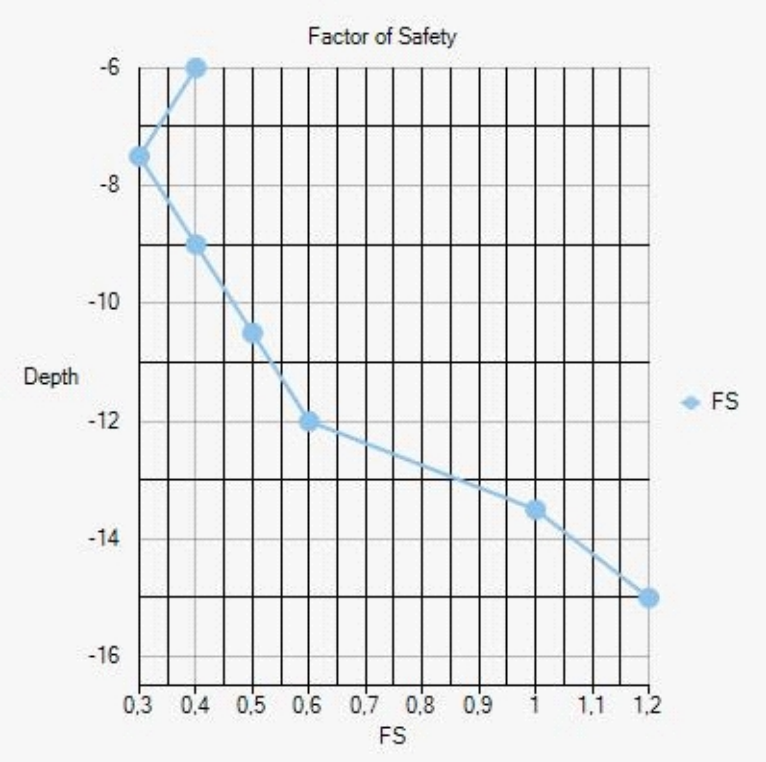

Figure 2. Factor of Safety-Depth Graph

Figure 3. Shear Stress and Liquefaction Resistance Plots

IMPROVED SOIL LIQUEFACTION ASSESSMENT

γ_s: Shear strain in the soil,
γc: Shear strain in column,
τ_s: Shear stress in soil,
τc: Shear stress in column,
Gs: Soil shear modulus,
Gc: Rigid column shear modulus,
τd: Shear stress induced by earthquake,
A: Total area,
As: Soil area,
Ac: Total cross-sectional area of columns,
ar: Area ratio,
Gr: Shear modulus ratio,
Kg: It is the reduction factor defined as the ratio of the reduced seismic shear stresses after improvement to the shear stresses in the original soil.

$$\gamma_s = \gamma_c$$

$$\frac{\tau_s}{G_s} = \frac{\tau_c}{G_c}$$

$$\tau_d A_t = \tau_s \times A_s$$

$$a_r = \frac{a_c}{A}$$

$$G_r = \frac{G_c}{G_s}$$

$$K_g = \frac{\tau_s}{\tau_d}$$

$$\gamma_r = 1.04 G_r^{-0.65} - 0.04 \leq 1$$

$$K_g = \frac{1}{G_r a_r + (1 - a_r)}$$

$$K_g = \frac{1}{\gamma_r G_r a_r + (1 - a_r)}$$

Number of rigid columns: 122
Diameter of rigid column: 650[mm]
Type of rigid column: Cast in place reinforced concrete pile
Length of rigid column: 15[m]
Improved area: A=443,61[m^2]
Ac= 40,48[m^2]
As= 403,13[m^2]
ar= 0,09

Table 3. Liquefaction Calculations of Improved Soil

Depth[m]	Layer	SPTN	σ'_v [kN/m^2]	σ_v [kN/m^2]	$N_{1,60}$	Gc	Gs	Gr	γr	Kg	τR [kN/m^2]	τ*earthquake [kN/m^2]	FS*	Safety*
-6	Silty Sand (Alluvium)	10	83,3	98	13	12500000	1923,1	6499,92	0,2	0,01	11,7	0,239	49	√
-7,5	Silty Sand (Alluvium)	10	97,4	126,8	12	12500000	1923,1	6499,92	0,2	0,01	12,77	0,305	41,8	√
-9	Silty Sand (Alluvium)	13	111,5	155,6	15	12500000	1923,1	6499,92	0,2	0,01	17,84	0,37	48,2	√

-10,5	Silty Clay (Alluvium)	12	125,25	184,05	13	12500000	3200	3906,25	0,23	0,01	27,92	0,63	44,3	√
-12	Silty Clay (Alluvium)	14	138,3	211,8	15	12500000	3200	3906,25	0,23	0,01	35,52	0,693	51,3	√
-13,5	Silty Clay (Alluvium)	20	151,35	239,55	20	12500000	3200	3906,25	0,23	0,01	62,07	0,747	83,1	√
-15	ortaMediu m Dense Sand (Alluvium)	22	164,4	267,3	21	12500000	4615,4	2708,32	0,24	0,02	79,26	1,06	74,7	√

Figure 4. Factor of Safety-Depth Graph

Figure 5. Shear Stress and Liquefaction Resistance Plots