APPENDIX

C

Properties of Soils

This appendix presents some information and tables containing properties of soils which will be of interest to the structural designer.

C.1 Soil Tests

For low-rise buildings, depth of borings may be specified to be about 6 m below the anticipated foundation level, with at least one boring continuing deeper, to a lesser of 30 m, the least building dimension, or refusal. At least one soil boring should be specified for every 230 square metres of the building area for buildings over 12 m height, or having more than three storeys. For large buildings founded on poor soils, borings should be spaced at less than 15 m intervals. A minimum of five borings, one at the centre and the rest at the corners of the building, is recommended.

C.2 Order of Soil Suitability for Foundation Support

Best	:	Bed rock
Very good	:	Sand and gravel
Good	:	Medium to hard clay (that is kept dry)
Poor	:	Silts and soft clay
Undesirable	:	Organic silts and organic clay
Unsuitable	:	Peat

C.3 The Plasticity Index (PI)

The plasticity index (PI) of the soil provides an indication of how much clay will shrink or swell. The higher the PI, the greater is the shrink-swell potential.

PI of 0–15%	:	Low expansion potential
PI of 15–25%	:	Medium expansion potential
PI of 25% and above	:	High expansion potential

Table C.1 Typical mass densities of basic soil types

Type of Soil	*Mass density ρ (Mg/m³)**			
	Poorly graded soil		*Well-graded soil*	
	Range	*Typical value*	*Range*	*Typical value*
Loose sand	1.70–1.90	1.75	1.75–2.00	1.85
Dense sand	1.90–2.10	2.07	2.00–2.20	2.10
Soft clay	1.60–1.90	1.75	1.60–1.90	1.75
Stiff clay	1.90–2.25	2.00	1.90–2.25	2.07
Silty soils	1.60–2.00	1.75	1.60–2.00	1.75
Gravelly soils	1.90–2.25	2.07	2.00–2.30	2.15

*Values are representative of moist sand, gravel, saturated silt, and clay.

Table C.2 Typical values of modulus of elasticity (E_S) for different types of soils

Type of Soil	E_s (N/mm²)
Clay	
Very soft	2–15
Soft	5–25
Medium	15–50
Hard	50–100
Sandy	25–250
Glacial till	
Loose	10–153
Dense	144–720
Very dense	478–1,440
Loess	14–57
Sand	
Silty	7–21
Loose	10–24
Dense	48–81
Sand and gravel	
Loose	48–148
Dense	96–192
Shale	144–14,400
Silt	2–20

Table C.3 Typical values of modulus of subgrade reaction (k_s) for different types of soils

Type of Soil	**k_s (kN/m³)**
Loose sand	4,800–16,000
Medium dense sand	9,600–80,000
Dense sand	64,000–1,28,000
Clayey medium dense sand	32,000–80,000
Silty medium dense sand	24,000–48,000

(contd)

(contd)

Clayey soil:	
$q_u \leq 200$ N/mm^2	12,000–24,000
$200 < q_u \leq 400$ N/mm^2	24,000–48,000
$q_u > 800$ N/mm^2	> 48,000
q_u – Safe bearing capacity	

Table C.4 Typical values of Poisson's ratio (μ) for soils

Type of soil	μ
Clay (saturated)	0.4 – 0.5
Clay (unsaturated)	0.1 – 0.3
Sandy clay	0.2 – 0.3
Silt	0.3 – 0.35
Sand (dense)	0.2 – 0.4
Course (void ratio = 0.4 – 0.7)	0.15
Fine grained (void ratio = 0.4 – 0.7)	0.25
Rock	0.1–0.4 (depends on type of rock)
Loess	0.1 – 0.3
Ice	0.36
Concrete	0.15

Table C.5 Allowable bearing pressures on soils (for preliminary design)

Type of rock/soil		Allowable bearing pressure (kN/m^2)	Standard penetration blow count (N)	Apparent cohesion c_u (kPa)
Hard rock without lamination and defects (e.g., granite, trap, and diorite)		3,200	>30	—
Laminated rocks (e.g., sand-stone and lime-stone in sound condition)		1,600	>30	—
Soft or broken rock, hard shale, cemented material		900	30	—
Soft rock		450		
Gravel	Dense	450	>30	—
	Medium	96–285	>30	—
		Compact and dry	Loose and dry	
Sand*	Coarse	450	250	30–50
	Medium	250	48–120	15–30
	Fine or silt	150	100	<15
	Very stiff	190–450	15–30	100–200
Clay+	Medium stiff	200–250	4–15	25–100
	Soft	50–100	0–4	0–25
Peat, silts, made-up ground	To be determined after investigation			

Notes: * Reduce bearing pressures by half below the water table.

+ Alternatively, allow 1.2 times c_u for round and square footings, and 1.0 times c_u for length/width ratios of more than 4.0. Interpolate for intermediate values.

Table C.6 Typical interface friction angles (NAVFAC 1982)

	Interface materials	Interface friction angle δ
Mass concrete against	Clean sound rock	25
	Clean gravel, gravel-sand mixtures, coarse sand	29 – 31
	Clean fine to medium sand, silty medium to coarse sand, silty or clayey gravel	24 – 29
	Clean fine sand, silty or clayey fine to medium sand	19 – 24
	Fine sandy silt, nonplastic silt	17 – 19
	Medium-stiff, stiff and silty clay	17 – 19
Formed concrete against	Clean gravel, gravel-sand mixture, well-graded rock fill with spalls	22 – 26
	Clean gravel, silty sand-gravel mixture, single-size hard rock fill	17 – 22
	Silty sand, gravel, or sand mixed with silt, or clay	17
	Fine sandy silt, non-plastic silt	14
Steel sheet piles against	Clean gravel, gravel-sand mixture, well-graded rock fill with spalls	22
	Clean sand, silty sand-gravel mixture, single-size hard rock fill	17
	Silty sand, gravel, or sand mixed with silt or clay	14
	Fine sandy silt, nonplastic silt	11

Table C.7 Typical values of fundamental period for soil deposits (for rock motions with a_{max} = 0.4g) (SEAOC 1980)

Soil depth (m)	Dense sand (s)	5 m of fill over normally consolidated clay* (s)
10	0.3–0.5	0.5–1.0
30	0.6–1.2	1.5–2.3
60	1.0–1.8	1.8–2.8
90	1.5–2.3	2.0–3.0
150	2.0–3.5	—

*Representative of San Francisco bay area.

Table C.8 Mean shear wave velocities (m/s) for the top 30 m of ground (Borcherdt 1994)

General description	*Mean shear–wave velocity*		
	Minimum	*Average*	*Maximum*
Firm and hard rocks			
Hard rocks (e.g., metamorphic rocks with very widely spaced fractures)	1400	1620	—

(contd)

(contd)

Firm to hard rocks (e.g., granites, igneous rocks, conglomerates, sandstones, and shales with close to widely spaced fractures)	700	1050	1400
Gravelly soils and soft to firm rocks (e.g., soft igneous sedimentary rocks, sandstones, shales, gravels, and soils with > 20% gravel)	375	540	700
Stiff clays and sandy soils (e.g., loose to very dense sands, silt loams, sandy clays, and medium stiff to hard clays and silty clays (N > 5 blows/ 300mm)	200	290	375
Soft soils (e.g., loose submerged fills and very soft (N < 5 blows/300 mm) clays and silty clays < 37 m thick)	100	150	200
Very soft soils (e.g., loose saturated sand, marshland, recent reclamation)	50?	75?	100

Note: The fundamental time period T of soil layer of thickness H, having average shear wave velocity V_s is approximately

$$T = 4H/V_s$$

If we assume the weighted average shear wave velocity for 30 – 50 m soil layer as 290 m/s, then the fundamental period of soil layer will range from 0.41 to 0.69 second. The fundamental time period of 4 – 6 storey buildings, including the soil-structure interaction, should fall in the above range of time period of soil layers, i.e., 0.41 – 0.69 sec. That is, the seismic waves in this range of time period will be allowed only to pass and filter-out the other frequencies. Therefore, there will be quasi resonance of building and the soil layer. At this point the damaging energy from the seismic waves get into the buildings having similar time period of vibration as the soil layer. If the seismic damaging energy getting into the building is more than the capacity of the structure, then the building will show distress and may collapse.

Similarly, if we assume that the weighted average shear wave velocity for 150 – 300 m soil layer is around 500 m/s, then the fundamental time period will range from 1.2 – 2.4 s. The fundamental time period of 10 – 15 storey building, including soil structure interaction, will fall in the above range of time period of vibrations. Therefore, there will be quasi resonance of the buildings and the soil layer and the seismic waves will affect this group of buildings which will result in damage/ collapse of buildings. Hence, it is important to know the depth of soil layers above the bedrock and its properties such as the shear wave velocities, which are related in the microzonation of a region.