5.20 Tolerable Settlement of Buildings

In most instances of construction, the subsoil is not homogeneous and the load carried by various shallow foundations of a given structure can vary widely. As a result, it is reasonable to expect varying degrees of settlement in different parts of a given building. The *differential settlement* of the parts of a building can lead to damage of the superstructure. Hence, it is important to define certain parameters that quantify differential settlement and to develop limiting values for those parameters in order that the resulting structures be safe. Burland and Worth (1970) summarized the important parameters relating to differential settlement.

Figure 5.40 shows a structure in which various foundations, at A, B, C, D, and E, have gone through some settlement. The settlement at A is AA', at B is BB', etc. Based on this figure, the definitions of the various parameters are as follows:

S_T = total settlement of a given point

ΔS_T = difference in total settlement between any two points

α = gradient between two successive points

$$\beta = \text{angular distortion} = \frac{\Delta S_{T(ij)}}{l_{ij}}$$

(*Note*: l_{ij} = distance between points i and j)

ω = tilt

Δ = relative deflection (i.e. movement from a straight line joining two reference points)

$\frac{\Delta}{L}$ = deflection ratio

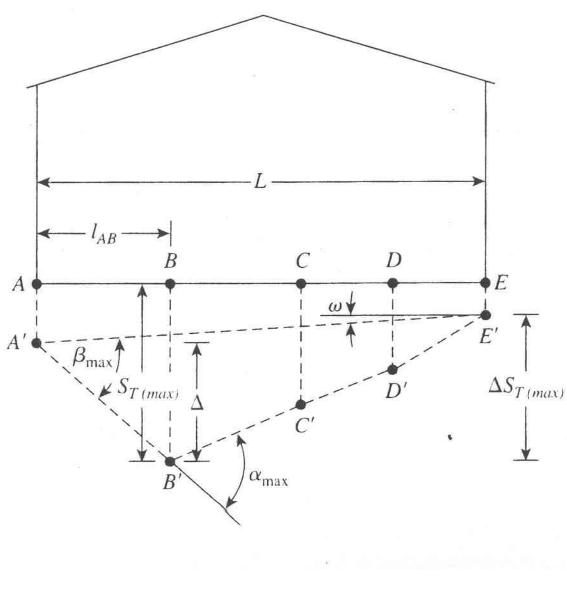

Figure 5.40 Definition of parameters for differential settlement

Since the 1950s, various researchers and building codes have recommended allowable values for the preceding parameters. A summary of several of these recommendations is presented next.

In 1956, Skempton and McDonald proposed the following limiting values for maximum settlement and maximum angular distortion, to be used for building purposes:

Maximum settlement, $S_{T(\max)}$	
In sand	32 mm
In clay	45 mm
Maximum differential settlement, $\Delta S_{T(\max)}$	
Isolated foundations in sand	51 mm
Isolated foundations in clay	76 mm
Raft in sand	51–76 mm
Raft in clay	76–127 mm
Maximum angular distortion, $\beta_{\max}$	1/300

On the basis of experience, Polshin and Tokar (1957) suggested the following allowable deflection ratios for buildings as a function of L/H, the ratio of the length to the height of a building:

$$\Delta/L = 0.0003 \text{ for } L/H \leqslant 2$$

$$\Delta/L = 0.001 \text{ for } L/H = 8$$

The 1955 Soviet Code of Practice gives the following allowable values:

Type of building	L/H	Δ/L
Multistory buildings and civil dwellings	$\leqslant 3$	0.0003 (for sand) 0.0004 (for clay)
	$\geqslant 5$	0.0005 (for sand) 0.0007 (for clay)
One-story mills		0.001 (for sand and clay)

Bjerrum (1963) recommended the following limiting angular distortion, $\beta_{\max}$ for various structures:

Category of potential damage	$\beta_{\max}$
Safe limit for flexible brick wall ($L/H > 4$)	1/150
Danger of structural damage to most buildings	1/150
Cracking of panel and brick walls	1/150
Visible tilting of high rigid buildings	1/250
First cracking of panel walls	1/300
Safe limit for no cracking of building	1/500
Danger to frames with diagonals	1/600

If the maximum allowable values of $\beta_{\max}$ are known, the magnitude of the allowable $S_{T(\max)}$ can be calculated with the use of the foregoing correlations.

The European Committee for Standardization has also provided limiting values for serviceability and the maximum accepted foundation movements. (See Table 5.13.)

Table 5.13 Recommendations of European Committee for Standardization on Differential Settlement Parameters

Item	Parameter	Magnitude	Comments
Limiting values for serviceability (European Committee for Standardization, 1994a)	S_T	25 mm	Isolated shallow foundation
		50 mm	Raft foundation
	ΔS_T	5 mm	Frames with rigid cladding
		10 mm	Frames with flexible cladding
		20 mm	Open frames
	β	1/500	—
Maximum acceptable foundation movement (European Committee for Standardization, 1994b)	S_T	50	Isolated shallow foundation
	ΔS_T	20	Isolated shallow foundation
	β	≈1/500	—

Problems

5.1 A flexible circular area is subjected to a uniformly distributed load of 3000 lb/ft². The diameter of the loaded area is 9.5 ft. Determine the stress increase in a soil mass at a point located 7.5 ft below the center of the loaded area.

5.2 Refer to Figure 5.4, which shows a flexible rectangular area. Given: $B_1 = 1.2$ m, $B_2 = 3$ m, $L_1 = 3$ m, and $L_2 = 6$ m. If the area is subjected to a uniform load of 110 kN/m², determine the stress increase at a depth of 8 m located immediately below point O.

5.3 Repeat Problem 5.2 with the following: $B_1 = 5$ ft, $B_2 = 10$ ft, $L_1 = 7$ ft, $L_2 = 12$ ft, and the uniform load on the flexible area = 2500 lb/ft². Determine the stress increase below point O at a depth of 20 ft.

5.4 Using Eq. (5.10), determine the stress increase ($\Delta\sigma$) from $z = 0$ to $z = 5$ m below the center of the area described in Problem 5.2.

5.5 Using Eq. (5.10), determine the stress increase ($\Delta\sigma$) from $z = 0$ to $z = 20$ ft below the center of the area described in Problem 5.3.

5.6 Refer to Figure P5.6. Using the procedure outlined in Section 5.5, determine the average stress increase in the clay layer below the center of the foundation due to the net foundation load of 50 ton.

5.7 Solve Problem 5.6 using the 2:1 method [Eqs. (5.14) and (5.70)].

5.8 Figure P5.8 shows an embankment load on a silty clay soil layer. Determine the stress increase at points A, B, and C, which are located at a depth of 15 ft below the ground surface.

5.9 A planned flexible load area (see Figure P5.9) is to be 3 m × 4.6 m and carries a uniformly distributed load of 180 kN/m². Estimate the elastic settlement below the center of the loaded area. Assume that $D_f = 2$ m and $H = \infty$. Use Eq. (5.25).

5.10 Redo Problem 5.9 assuming that $D_f = 5$ m and $H = 3$ m.

5.11 Figure 5.14 shows a foundation of 10 ft × 6.25 ft resting on a sand deposit. The net load per unit area at the level of the foundation, q_o, is 3000 lb/ft². For the sand, $\mu_s = 0.3$, $E_s = 3200$ lb/in.², $D_f = 2.5$ ft and $H = 32$ ft. Assume that the foundation is rigid, and determine the elastic settlement the foundation would undergo. Use Eqs. (5.25) and (5.33).