or

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = (1.152)(0.325)(116.67 + 83.33 - 200) + 100 = 100$$

At $\bar{z} = 0.75$,

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = \frac{\Delta\bar{t}_{(2)}}{(\Delta\bar{z})^2}(\bar{u}_{1,\bar{t}} + \bar{u}_{3,\bar{t}} - 2\bar{u}_{0,\bar{t}}) + \bar{u}_{0,\bar{t}}$$

$$= 0.475[100 + 0 - 2(100)] + 100 = 52.5$$

At $\bar{z} = 1.0$,

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = 0$$

For $t = 10$ days,
At $\bar{z} = 0$,

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = 0$$

At $\bar{z} = 0.25$,

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = 0.325[0 + 100 - 2(67.5)] + 67.5 = 56.13$$

At $\bar{z} = 0.5$,

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = (1.152)(0.325)\left[\frac{2 \times 2.8}{2 + 2.8}(67.5) + \frac{2 \times 2}{2 + 2.8}(52.5) - 2(100)\right] + 100$$

$$= (1.152)(0.325)(78.75 + 43.75 - 200) + 100 = 70.98$$

At $\bar{z} = 0.75$,

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = 0.475[100 + 0 - 2(52.5)] + 52.5 = 50.12$$

At $\bar{z} = 1.0$,

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = 0$$

The variation of the nondimensional excess pore water pressure is shown in Fig. 6.10*b*. Knowing $\bar{u} = (\bar{u})(u_R) = \bar{u}(1.5)$ kN/m², we can plot the variation of $u$ with depth.

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**EXAMPLE 6.7**

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For Example 6.6, assume that the surcharge $q$ is applied gradually. The relation between time and $q$ is shown in Fig. 6.11*a*. Using the numerical method, determine the distribution of excess pore water pressure after 15 days from the start of loading.

SOLUTION As before, $z_R = 8$ m, $u_R = 1.5$ kN/m². For $\Delta t = 5$ days,

$$\frac{\Delta\bar{t}_{(1)}}{(\Delta\bar{z})^2} = 0.325 \qquad \frac{\Delta\bar{t}_{(2)}}{(\Delta\bar{z})^2} = 0.475$$

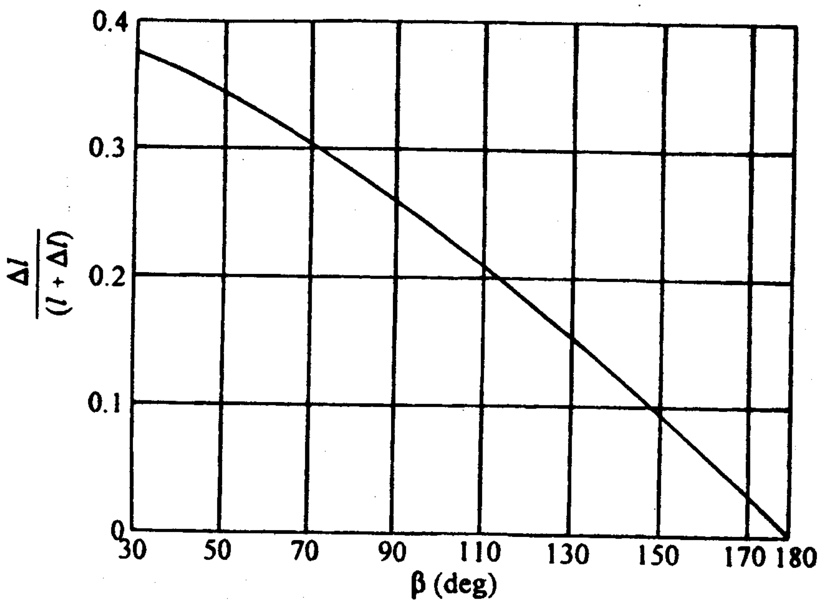


**Fig. 5.63** Casagrande's (1937) plot of $\Delta l/(l + \Delta l)$ against downstream slope angle.

SOLUTION

$$\beta = \tan^{-1}(1/1.5) = 33.69°$$

$$\Delta = 70 \cot 45° = 70 \text{ ft}$$

$$aa' = 0.3\Delta = 0.3(70) = 21 \text{ ft}$$

and

$$d = 80 \cot 33.69° + 15 + 10 \cot 45° + 21 = 120 + 15 + 10 + 21 = 166 \text{ ft}$$

From Eq. (5.201),

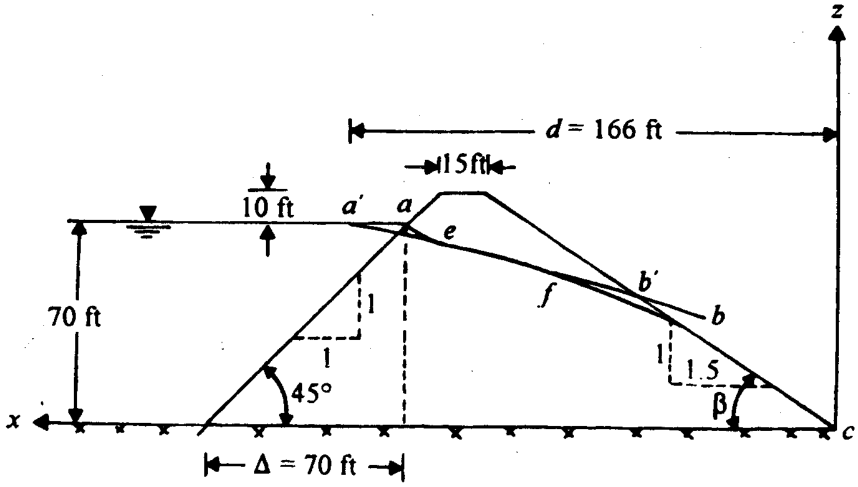


**Fig. 5.64** Plot of phreatic line in an earth dam.

$$p = \tfrac{1}{2}(\sqrt{d^2 + H^2} - d) = \tfrac{1}{2}(\sqrt{166^2 + 70^2} - 166)$$
$$= \tfrac{1}{2}(180.16 - 166) = 7.08 \text{ ft}$$

Using Eq. (5.202), we can now determine the coordinates of several points of the parabola $a'efb'c'$:

| $z$, ft | $x$ from Eq. (5.202), ft |
|---|---|
| 70 | 166 |
| 65 | 142.1 |
| 60 | 120.04 |
| 55 | 99.73 |
| 50 | 81.2 |
| 45 | 64.42 |

Using the values of $x$ and corresponding $z$ calculated in the above table, the basic parabola has been plotted in Fig. 5.64.

We calculate $l$ as follows. The equation of the line $cb'$ can be given by $z = x \tan \beta$, and the equation of the parabola [Eq. (5.202)] is $x = (z^2 - 4p^2)/4p$. The coordinates of point $b'$ can be determined by solving the above two equations:

$$x = \frac{z^2 - 4p^2}{4p} = \frac{(x \tan \beta)^2 - 4p^2}{4p}$$

$$\text{or} \qquad x^2 \tan^2 \beta - 4px - 4p^2 = 0$$

Hence

$$x^2 \tan^2 33.69° - 4(7.08)x - 4(7.08)^2 = 0$$

$$0.444x^2 - 28.32x - 200.5 = 0$$

The solution of the above equation gives $x = 70.22$ ft. So,

$$cb' = \sqrt{70.22^2 + (70.22 \tan 33.69°)^2} = 84.39 \text{ ft} = l + \Delta l$$

From Fig. 5.63, for $\beta = 33.69°$,

$$\frac{\Delta l}{l + \Delta l} = 0.366 \qquad \Delta l = (0.366)(84.39) = 30.9 \text{ ft}$$

$$l = (l + \Delta l) - (\Delta l)$$
$$= 84.39 - 30.9 = 53.49 \text{ ft} \approx 54 \text{ ft}$$

So, $l = cb = 54$ ft.

The curve portions $ae$ and $fb$ can now be approximately drawn by hand, which completes the phreatic line $aefb$ (Fig. 5.64).

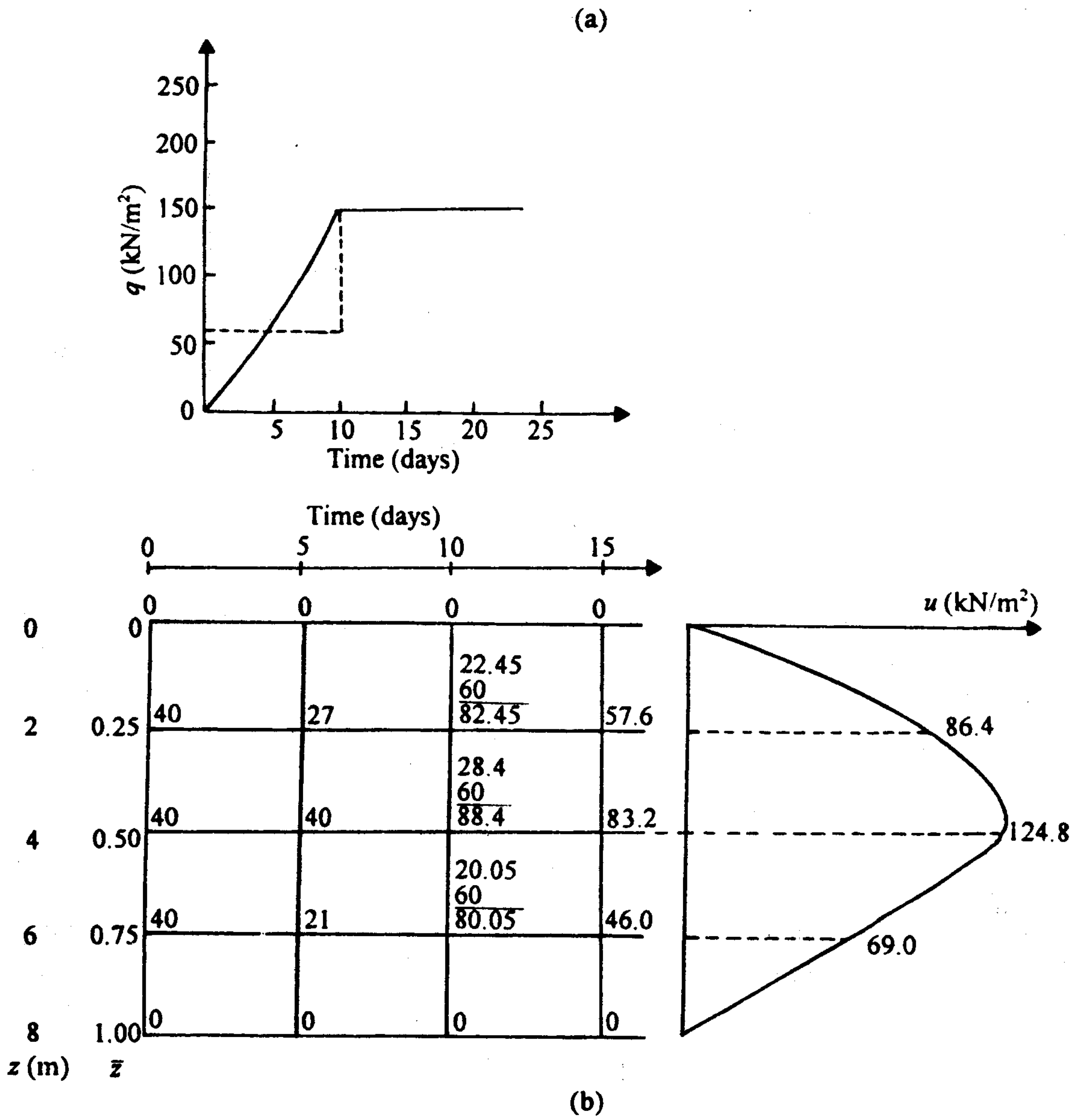


**Fig. 6.11** Numerical solution for ramp loading.

The continuous loading can be divided into step loads such as 60 kN/m$^2$ from 0 to 10 days and an added 90 kN/m$^2$ from the tenth day on. This is shown by dashed lines in Fig. 6.11*a*.

At $t$ = 0 days,

$$\bar{z} = 0 \qquad \bar{u} = 0$$

$$\bar{z} = 0.25 \qquad \bar{u} = 60/1.5 = 40$$

$$\bar{z} = 0.5 \qquad \bar{u} = 40$$

$$\bar{z} = 0.75 \qquad \bar{u} = 40$$

$$\bar{z} = 1 \qquad \bar{u} = 0$$

At $t$ = 5 days,

At $\bar{z} = 0$,

$$\bar{u} = 0$$

At $\bar{z} = 0.25$, from. Eq. (6.61),

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = 0.325[0 + 40 - 2(40)] + 40 = 27$$

At $\bar{z} = 0.5$, from Eq. (6.66),

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = (1.532)(0.325)\left[\frac{2 \times 2.8}{2 + 2.8}(40) + \frac{2 \times 2}{2 + 2.8}(40) - 2(40)\right] + 40 = 40$$

At $\bar{z} = 0.75$, from Eq. (6.61),

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = 0.475[40 + 0 - 2(40)] + 40 = 21$$

At $\bar{z} = 1$,

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = 0$$

At $t = 10$ days,
At $\bar{z} = 0$,

$$\bar{u} = 0$$

At $\bar{z} = 0.25$, from Eq. (6.61),

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = 0.325[0 + 40 - 2(27)] + 27 = 22.45$$

At this point, a new load of 90 kN/m$^2$ is added, so $\bar{u}$ will increase by an amount 90/1.5 = 60. The new $\bar{u}_{0,\bar{t}+\Delta\bar{t}}$ is 60 + 22.45 = 82.45. At $\bar{z} = 0.5$, from Eq. (6.66),

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = (1.152)(0.325)\left[\frac{2 \times 2.8}{2 + 2.8}(27) + \frac{2 \times 2}{2 + 2.8}(21) - 2(40)\right] + 40 = 28.4$$

$$\text{New } \bar{u}_{0,\bar{t}+\Delta\bar{t}} = 28.4 + 60 = 88.4$$

At $\bar{z} = 0.75$, from Eq. (6.61),

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = 0.475[40 + 0 - 2(21)] + 21 = 20.05$$

$$\text{New } \bar{u}_{0,\bar{t}+\Delta\bar{t}} = 60 + 20.05 = 80.05$$

At $\bar{z} = 1$,

$$\bar{u} = 0$$

At $t = 15$ days,
At $\bar{z} = 0$,

$$\bar{u} = 0$$

At $\bar{z} = 0.25$,

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = 0.325[0 + 88.4 - 2(82.45)] + 82.45 = 57.6$$

At $\bar{z} = 0.5$,

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = (1.152)(0.325)$$

$$\times\left[\frac{2 \times 2.8}{2 + 2.8}(82.45) + \frac{2 \times 2}{2 + 2.8}(80.05) - 2(88.4)\right] + 88.4 = 83.2$$

At $\bar{z} = 0.75$,

$$\bar{u}_{0,\bar{t}+\Delta\bar{t}} = 0.475[88.4 + 0 - 2(80.05)] + 80.05 = 46.0$$

At $\bar{z} = 1$,

$$\bar{u} = 0$$

The distribution of excess pore water pressure is shown in Fig. 6.11*b*.

## 6.5 STANDARD ONE-DIMENSIONAL CONSOLIDATION TEST AND INTERPRETATION

The standard one-dimensional consolidation test is usually carried out on saturated specimens about 1 in (25.4 mm) thick and 2.5 in (63.5 mm) in diameter (Fig. 6.12). The soil specimen is kept inside a metal ring, with a porous stone at the top and another at the bottom. The load $P$ on the specimen is applied through a lever arm, and the compression of the specimen is measured by a micrometer dial gauge. The load is usually doubled every 24 hours. The specimen is kept under water throughout the test.

For each load increment, the specimen deformation and the corresponding time $t$

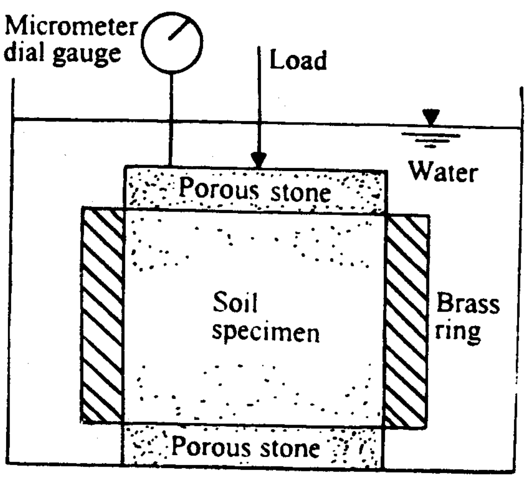


**Fig. 6.12** Consolidometer.