

Chapter 11: Compressibility of Soil

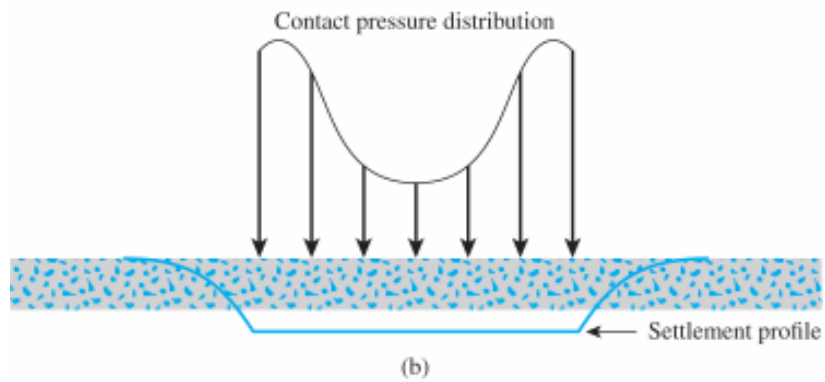
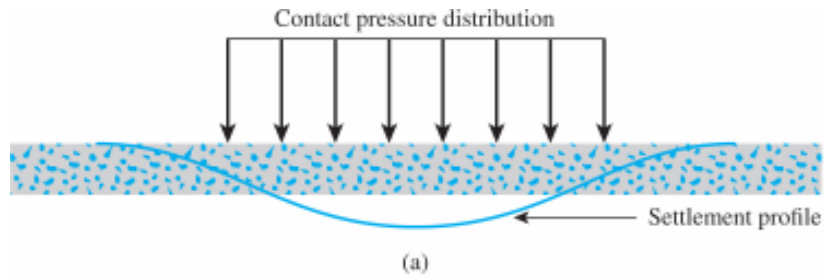


Figure 11.1
Elastic settlement profile and contact pressure in clay: (a) flexible foundation; (b) rigid foundation

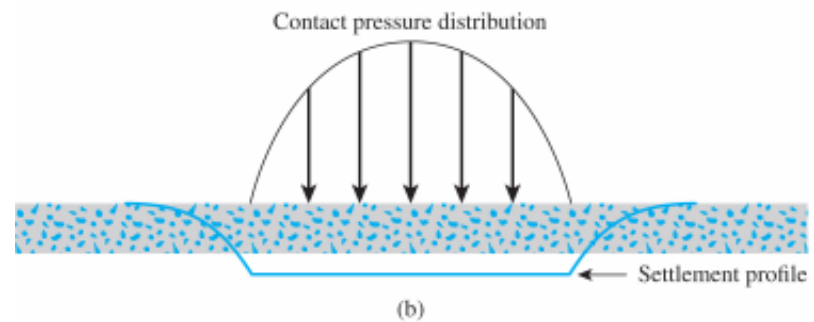
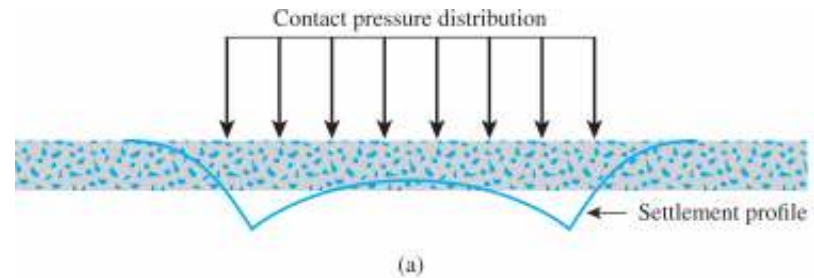


Figure 11.2
Elastic settlement profile and contact pressure in sand: (a) flexible foundation; (b) rigid foundation

Elastic Settlement Calculations

$$S_e = \Delta\sigma(\alpha B') \frac{1 - \mu_s^2}{E_s} I_s I_f$$

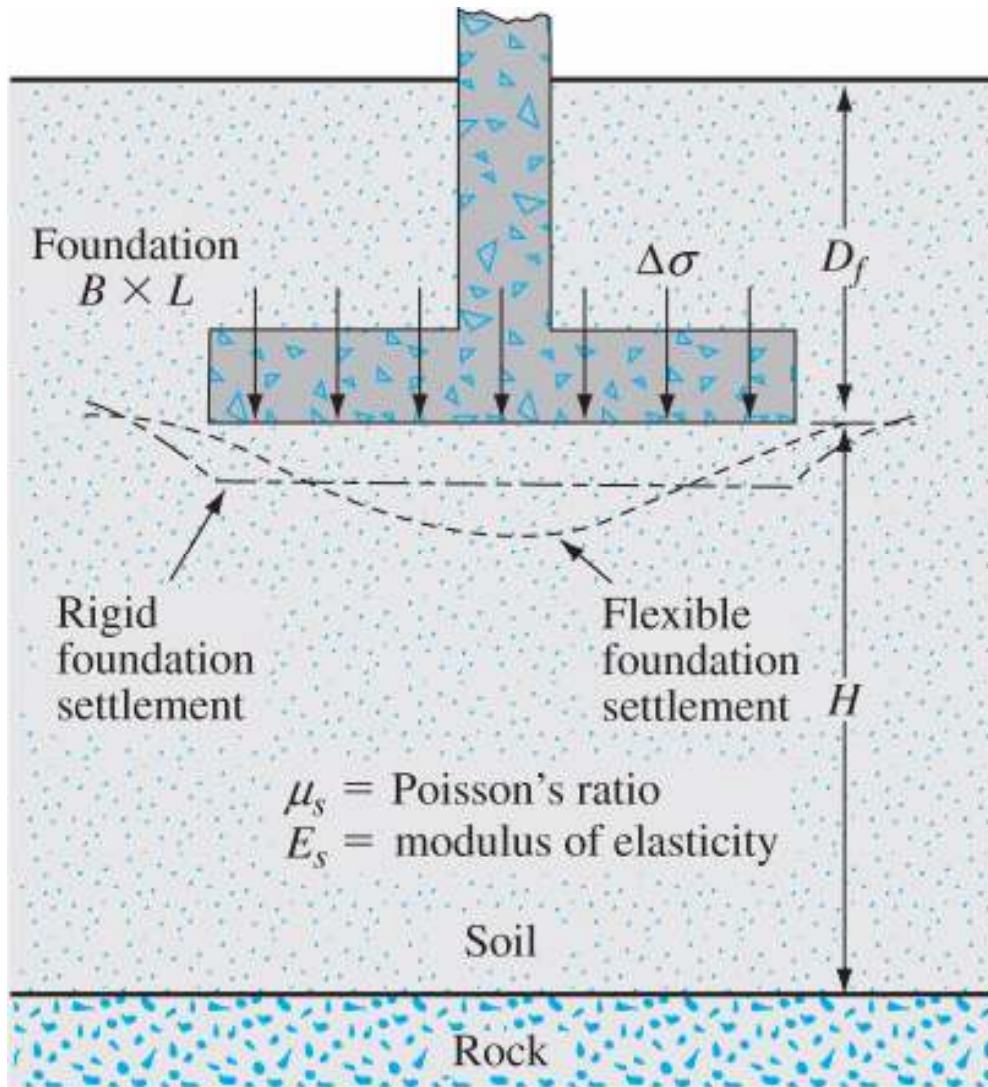


Figure 11.3 Elastic settlement of flexible and rigid foundations

Table 11.1 Variation of F_1 with m' and n'

| n' | m' | | | | | | | | | |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 |
| 0.25 | 0.014 | 0.013 | 0.012 | 0.011 | 0.011 | 0.011 | 0.010 | 0.010 | 0.010 | 0.010 |
| 0.50 | 0.049 | 0.046 | 0.044 | 0.042 | 0.041 | 0.040 | 0.038 | 0.038 | 0.037 | 0.037 |
| 0.75 | 0.095 | 0.090 | 0.087 | 0.084 | 0.082 | 0.080 | 0.077 | 0.076 | 0.074 | 0.074 |
| 1.00 | 0.142 | 0.138 | 0.134 | 0.130 | 0.127 | 0.125 | 0.121 | 0.118 | 0.116 | 0.115 |
| 1.25 | 0.186 | 0.183 | 0.179 | 0.176 | 0.173 | 0.170 | 0.165 | 0.161 | 0.158 | 0.157 |
| 1.50 | 0.224 | 0.224 | 0.222 | 0.219 | 0.216 | 0.213 | 0.207 | 0.203 | 0.199 | 0.197 |
| 1.75 | 0.257 | 0.259 | 0.259 | 0.258 | 0.255 | 0.253 | 0.247 | 0.242 | 0.238 | 0.235 |
| 2.00 | 0.285 | 0.290 | 0.292 | 0.292 | 0.291 | 0.289 | 0.284 | 0.279 | 0.275 | 0.271 |
| 2.25 | 0.309 | 0.317 | 0.321 | 0.323 | 0.323 | 0.322 | 0.317 | 0.313 | 0.308 | 0.305 |
| 2.50 | 0.330 | 0.341 | 0.347 | 0.350 | 0.351 | 0.351 | 0.348 | 0.344 | 0.340 | 0.336 |
| 2.75 | 0.348 | 0.361 | 0.369 | 0.374 | 0.377 | 0.378 | 0.377 | 0.373 | 0.369 | 0.365 |
| 3.00 | 0.363 | 0.379 | 0.389 | 0.396 | 0.400 | 0.402 | 0.402 | 0.400 | 0.396 | 0.392 |
| 3.25 | 0.376 | 0.394 | 0.406 | 0.415 | 0.420 | 0.423 | 0.426 | 0.424 | 0.421 | 0.418 |
| 3.50 | 0.388 | 0.408 | 0.422 | 0.431 | 0.438 | 0.442 | 0.447 | 0.447 | 0.444 | 0.441 |
| 3.75 | 0.399 | 0.420 | 0.436 | 0.447 | 0.454 | 0.460 | 0.467 | 0.458 | 0.466 | 0.464 |
| 4.00 | 0.408 | 0.431 | 0.448 | 0.460 | 0.469 | 0.476 | 0.484 | 0.487 | 0.486 | 0.484 |
| 4.25 | 0.417 | 0.440 | 0.458 | 0.472 | 0.481 | 0.484 | 0.495 | 0.514 | 0.515 | 0.515 |
| 4.50 | 0.424 | 0.450 | 0.469 | 0.484 | 0.495 | 0.503 | 0.516 | 0.521 | 0.522 | 0.522 |
| 4.75 | 0.431 | 0.458 | 0.478 | 0.494 | 0.506 | 0.515 | 0.530 | 0.536 | 0.539 | 0.539 |
| 5.00 | 0.437 | 0.465 | 0.487 | 0.503 | 0.516 | 0.526 | 0.543 | 0.551 | 0.554 | 0.554 |
| 5.25 | 0.443 | 0.472 | 0.494 | 0.512 | 0.526 | 0.537 | 0.555 | 0.564 | 0.568 | 0.569 |
| 5.50 | 0.448 | 0.478 | 0.501 | 0.520 | 0.534 | 0.546 | 0.566 | 0.576 | 0.581 | 0.584 |
| 5.75 | 0.453 | 0.483 | 0.508 | 0.527 | 0.542 | 0.555 | 0.576 | 0.588 | 0.594 | 0.597 |
| 6.00 | 0.457 | 0.489 | 0.514 | 0.534 | 0.550 | 0.563 | 0.585 | 0.598 | 0.606 | 0.609 |
| 6.25 | 0.461 | 0.493 | 0.519 | 0.540 | 0.557 | 0.570 | 0.594 | 0.609 | 0.617 | 0.621 |
| 6.50 | 0.465 | 0.498 | 0.524 | 0.546 | 0.563 | 0.577 | 0.603 | 0.618 | 0.627 | 0.632 |
| 6.75 | 0.468 | 0.502 | 0.529 | 0.551 | 0.569 | 0.584 | 0.610 | 0.627 | 0.637 | 0.643 |
| 7.00 | 0.471 | 0.506 | 0.533 | 0.556 | 0.575 | 0.590 | 0.618 | 0.635 | 0.646 | 0.653 |
| 7.25 | 0.474 | 0.509 | 0.538 | 0.561 | 0.580 | 0.596 | 0.625 | 0.643 | 0.655 | 0.662 |
| 7.50 | 0.477 | 0.513 | 0.541 | 0.565 | 0.585 | 0.601 | 0.631 | 0.650 | 0.663 | 0.671 |
| 7.75 | 0.480 | 0.516 | 0.545 | 0.569 | 0.589 | 0.606 | 0.637 | 0.658 | 0.671 | 0.680 |
| 8.00 | 0.482 | 0.519 | 0.549 | 0.573 | 0.594 | 0.611 | 0.643 | 0.664 | 0.678 | 0.688 |
| 8.25 | 0.485 | 0.522 | 0.552 | 0.577 | 0.598 | 0.615 | 0.648 | 0.670 | 0.685 | 0.695 |
| 8.50 | 0.487 | 0.524 | 0.555 | 0.580 | 0.601 | 0.619 | 0.653 | 0.676 | 0.692 | 0.703 |
| 8.75 | 0.489 | 0.527 | 0.558 | 0.583 | 0.605 | 0.623 | 0.658 | 0.682 | 0.698 | 0.710 |
| 9.00 | 0.491 | 0.529 | 0.560 | 0.587 | 0.609 | 0.627 | 0.663 | 0.687 | 0.705 | 0.716 |
| 9.25 | 0.493 | 0.531 | 0.563 | 0.589 | 0.612 | 0.631 | 0.667 | 0.693 | 0.710 | 0.723 |
| 9.50 | 0.495 | 0.533 | 0.565 | 0.592 | 0.615 | 0.634 | 0.671 | 0.697 | 0.716 | 0.719 |
| 9.75 | 0.496 | 0.536 | 0.568 | 0.595 | 0.618 | 0.638 | 0.675 | 0.702 | 0.721 | 0.735 |
| 10.00 | 0.498 | 0.537 | 0.570 | 0.597 | 0.621 | 0.641 | 0.679 | 0.707 | 0.726 | 0.740 |
| 20.00 | 0.529 | 0.575 | 0.614 | 0.647 | 0.677 | 0.702 | 0.756 | 0.797 | 0.830 | 0.858 |
| 50.00 | 0.548 | 0.598 | 0.640 | 0.678 | 0.711 | 0.740 | 0.803 | 0.853 | 0.895 | 0.931 |
| 100.00 | 0.555 | 0.605 | 0.649 | 0.688 | 0.722 | 0.753 | 0.819 | 0.872 | 0.918 | 0.956 |

Table 11.1 (continued)

| n' | m' | | | | | | | | | |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | 4.5 | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 | 10.0 | 25.0 | 50.0 | 100.0 |
| 0.25 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 |
| 0.50 | 0.036 | 0.036 | 0.036 | 0.036 | 0.036 | 0.036 | 0.036 | 0.036 | 0.036 | 0.036 |
| 0.75 | 0.073 | 0.073 | 0.072 | 0.072 | 0.072 | 0.072 | 0.071 | 0.071 | 0.071 | 0.071 |
| 1.00 | 0.114 | 0.113 | 0.112 | 0.112 | 0.112 | 0.111 | 0.111 | 0.110 | 0.110 | 0.110 |
| 1.25 | 0.155 | 0.154 | 0.153 | 0.152 | 0.152 | 0.151 | 0.151 | 0.150 | 0.150 | 0.150 |
| 1.50 | 0.195 | 0.194 | 0.192 | 0.191 | 0.190 | 0.190 | 0.189 | 0.188 | 0.188 | 0.188 |
| 1.75 | 0.233 | 0.232 | 0.229 | 0.228 | 0.227 | 0.226 | 0.225 | 0.223 | 0.223 | 0.223 |
| 2.00 | 0.269 | 0.267 | 0.264 | 0.262 | 0.261 | 0.260 | 0.259 | 0.257 | 0.256 | 0.256 |
| 2.25 | 0.302 | 0.300 | 0.296 | 0.294 | 0.293 | 0.291 | 0.291 | 0.287 | 0.287 | 0.287 |
| 2.50 | 0.333 | 0.331 | 0.327 | 0.324 | 0.322 | 0.321 | 0.320 | 0.316 | 0.315 | 0.315 |
| 2.75 | 0.362 | 0.359 | 0.355 | 0.352 | 0.350 | 0.348 | 0.347 | 0.343 | 0.342 | 0.342 |
| 3.00 | 0.389 | 0.386 | 0.382 | 0.378 | 0.376 | 0.374 | 0.373 | 0.368 | 0.367 | 0.367 |
| 3.25 | 0.415 | 0.412 | 0.407 | 0.403 | 0.401 | 0.399 | 0.397 | 0.391 | 0.390 | 0.390 |
| 3.50 | 0.438 | 0.435 | 0.430 | 0.427 | 0.424 | 0.421 | 0.420 | 0.413 | 0.412 | 0.411 |
| 3.75 | 0.461 | 0.458 | 0.453 | 0.449 | 0.446 | 0.443 | 0.441 | 0.433 | 0.432 | 0.432 |
| 4.00 | 0.482 | 0.479 | 0.474 | 0.470 | 0.466 | 0.464 | 0.462 | 0.453 | 0.451 | 0.451 |
| 4.25 | 0.516 | 0.496 | 0.484 | 0.473 | 0.471 | 0.471 | 0.470 | 0.468 | 0.462 | 0.460 |
| 4.50 | 0.520 | 0.517 | 0.513 | 0.508 | 0.505 | 0.502 | 0.499 | 0.489 | 0.487 | 0.487 |
| 4.75 | 0.537 | 0.535 | 0.530 | 0.526 | 0.523 | 0.519 | 0.517 | 0.506 | 0.504 | 0.503 |
| 5.00 | 0.554 | 0.552 | 0.548 | 0.543 | 0.540 | 0.536 | 0.534 | 0.522 | 0.519 | 0.519 |
| 5.25 | 0.569 | 0.568 | 0.564 | 0.560 | 0.556 | 0.553 | 0.550 | 0.537 | 0.534 | 0.534 |
| 5.50 | 0.584 | 0.583 | 0.579 | 0.575 | 0.571 | 0.568 | 0.585 | 0.551 | 0.549 | 0.548 |
| 5.75 | 0.597 | 0.597 | 0.594 | 0.590 | 0.586 | 0.583 | 0.580 | 0.565 | 0.583 | 0.562 |
| 6.00 | 0.611 | 0.610 | 0.608 | 0.604 | 0.601 | 0.598 | 0.595 | 0.579 | 0.576 | 0.575 |
| 6.25 | 0.623 | 0.623 | 0.621 | 0.618 | 0.615 | 0.611 | 0.608 | 0.592 | 0.589 | 0.588 |
| 6.50 | 0.635 | 0.635 | 0.634 | 0.631 | 0.628 | 0.625 | 0.622 | 0.605 | 0.601 | 0.600 |
| 6.75 | 0.646 | 0.647 | 0.646 | 0.644 | 0.641 | 0.637 | 0.634 | 0.617 | 0.613 | 0.612 |
| 7.00 | 0.656 | 0.658 | 0.658 | 0.656 | 0.653 | 0.650 | 0.647 | 0.628 | 0.624 | 0.623 |
| 7.25 | 0.666 | 0.669 | 0.669 | 0.668 | 0.665 | 0.662 | 0.659 | 0.640 | 0.635 | 0.634 |
| 7.50 | 0.676 | 0.679 | 0.680 | 0.679 | 0.676 | 0.673 | 0.670 | 0.651 | 0.646 | 0.645 |
| 7.75 | 0.685 | 0.688 | 0.690 | 0.689 | 0.687 | 0.684 | 0.681 | 0.661 | 0.656 | 0.655 |
| 8.00 | 0.694 | 0.697 | 0.700 | 0.700 | 0.698 | 0.695 | 0.692 | 0.672 | 0.666 | 0.665 |
| 8.25 | 0.702 | 0.706 | 0.710 | 0.710 | 0.708 | 0.705 | 0.703 | 0.682 | 0.676 | 0.675 |
| 8.50 | 0.710 | 0.714 | 0.719 | 0.719 | 0.718 | 0.715 | 0.713 | 0.692 | 0.686 | 0.684 |
| 8.75 | 0.717 | 0.722 | 0.727 | 0.728 | 0.727 | 0.725 | 0.723 | 0.701 | 0.695 | 0.693 |
| 9.00 | 0.725 | 0.730 | 0.736 | 0.737 | 0.736 | 0.735 | 0.732 | 0.710 | 0.704 | 0.702 |
| 9.25 | 0.731 | 0.737 | 0.744 | 0.746 | 0.745 | 0.744 | 0.742 | 0.719 | 0.713 | 0.711 |
| 9.50 | 0.738 | 0.744 | 0.752 | 0.754 | 0.754 | 0.753 | 0.751 | 0.728 | 0.721 | 0.719 |
| 9.75 | 0.744 | 0.751 | 0.759 | 0.762 | 0.762 | 0.761 | 0.759 | 0.737 | 0.729 | 0.727 |
| 10.00 | 0.750 | 0.758 | 0.766 | 0.770 | 0.770 | 0.770 | 0.768 | 0.745 | 0.738 | 0.735 |
| 20.00 | 0.878 | 0.896 | 0.925 | 0.945 | 0.959 | 0.969 | 0.977 | 0.982 | 0.965 | 0.957 |
| 50.00 | 0.962 | 0.989 | 1.034 | 1.070 | 1.100 | 1.125 | 1.146 | 1.265 | 1.279 | 1.261 |
| 100.00 | 0.990 | 1.020 | 1.072 | 1.114 | 1.150 | 1.182 | 1.209 | 1.408 | 1.489 | 1.499 |

Table 11.2 Variation of F_2 with m' and n'

| n' | m' | | | | | | | | | |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|--------|-------|
| | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 |
| 0.25 | 0.049 | 0.050 | 0.051 | 0.051 | 0.051 | 0.052 | 0.052 | 0.052 | 0.052 | 0.052 |
| 0.50 | 0.074 | 0.077 | 0.080 | 0.081 | 0.083 | 0.084 | 0.086 | 0.086 | 0.0878 | 0.087 |
| 0.75 | 0.083 | 0.089 | 0.093 | 0.097 | 0.099 | 0.101 | 0.104 | 0.106 | 0.107 | 0.108 |
| 1.00 | 0.083 | 0.091 | 0.098 | 0.102 | 0.106 | 0.109 | 0.114 | 0.117 | 0.119 | 0.120 |
| 1.25 | 0.080 | 0.089 | 0.096 | 0.102 | 0.107 | 0.111 | 0.118 | 0.122 | 0.125 | 0.127 |
| 1.50 | 0.075 | 0.084 | 0.093 | 0.099 | 0.105 | 0.110 | 0.118 | 0.124 | 0.128 | 0.130 |
| 1.75 | 0.069 | 0.079 | 0.088 | 0.095 | 0.101 | 0.107 | 0.117 | 0.123 | 0.128 | 0.131 |
| 2.00 | 0.064 | 0.074 | 0.083 | 0.090 | 0.097 | 0.102 | 0.114 | 0.121 | 0.127 | 0.131 |
| 2.25 | 0.059 | 0.069 | 0.077 | 0.085 | 0.092 | 0.098 | 0.110 | 0.119 | 0.125 | 0.130 |
| 2.50 | 0.055 | 0.064 | 0.073 | 0.080 | 0.087 | 0.093 | 0.106 | 0.115 | 0.122 | 0.127 |
| 2.75 | 0.051 | 0.060 | 0.068 | 0.076 | 0.082 | 0.089 | 0.102 | 0.111 | 0.119 | 0.125 |
| 3.00 | 0.048 | 0.056 | 0.064 | 0.071 | 0.078 | 0.084 | 0.097 | 0.108 | 0.116 | 0.122 |
| 3.25 | 0.045 | 0.053 | 0.060 | 0.067 | 0.074 | 0.080 | 0.093 | 0.104 | 0.112 | 0.119 |
| 3.50 | 0.042 | 0.050 | 0.057 | 0.064 | 0.070 | 0.076 | 0.089 | 0.100 | 0.109 | 0.116 |
| 3.75 | 0.040 | 0.047 | 0.054 | 0.060 | 0.067 | 0.073 | 0.086 | 0.096 | 0.105 | 0.113 |
| 4.00 | 0.037 | 0.044 | 0.051 | 0.057 | 0.063 | 0.069 | 0.082 | 0.093 | 0.102 | 0.110 |
| 4.25 | 0.036 | 0.042 | 0.049 | 0.055 | 0.061 | 0.066 | 0.079 | 0.090 | 0.099 | 0.107 |
| 4.50 | 0.034 | 0.040 | 0.046 | 0.052 | 0.058 | 0.063 | 0.076 | 0.086 | 0.096 | 0.104 |
| 4.75 | 0.032 | 0.038 | 0.044 | 0.050 | 0.055 | 0.061 | 0.073 | 0.083 | 0.093 | 0.101 |
| 5.00 | 0.031 | 0.036 | 0.042 | 0.048 | 0.053 | 0.058 | 0.070 | 0.080 | 0.090 | 0.098 |
| 5.25 | 0.029 | 0.035 | 0.040 | 0.046 | 0.051 | 0.056 | 0.067 | 0.078 | 0.087 | 0.095 |
| 5.50 | 0.028 | 0.033 | 0.039 | 0.044 | 0.049 | 0.054 | 0.065 | 0.075 | 0.084 | 0.092 |
| 5.75 | 0.027 | 0.032 | 0.037 | 0.042 | 0.047 | 0.052 | 0.063 | 0.073 | 0.082 | 0.090 |
| 6.00 | 0.026 | 0.031 | 0.036 | 0.040 | 0.045 | 0.050 | 0.060 | 0.070 | 0.079 | 0.087 |
| 6.25 | 0.025 | 0.030 | 0.034 | 0.039 | 0.044 | 0.048 | 0.058 | 0.068 | 0.077 | 0.085 |
| 6.50 | 0.024 | 0.029 | 0.033 | 0.038 | 0.042 | 0.046 | 0.056 | 0.066 | 0.075 | 0.083 |
| 6.75 | 0.023 | 0.028 | 0.032 | 0.036 | 0.041 | 0.045 | 0.055 | 0.064 | 0.073 | 0.080 |
| 7.00 | 0.022 | 0.027 | 0.031 | 0.035 | 0.039 | 0.043 | 0.053 | 0.062 | 0.071 | 0.078 |
| 7.25 | 0.022 | 0.026 | 0.030 | 0.034 | 0.038 | 0.042 | 0.051 | 0.060 | 0.069 | 0.076 |
| 7.50 | 0.021 | 0.025 | 0.029 | 0.033 | 0.037 | 0.041 | 0.050 | 0.059 | 0.067 | 0.074 |
| 7.75 | 0.020 | 0.024 | 0.028 | 0.032 | 0.036 | 0.039 | 0.048 | 0.057 | 0.065 | 0.072 |
| 8.00 | 0.020 | 0.023 | 0.027 | 0.031 | 0.035 | 0.038 | 0.047 | 0.055 | 0.063 | 0.071 |
| 8.25 | 0.019 | 0.023 | 0.026 | 0.030 | 0.034 | 0.037 | 0.046 | 0.054 | 0.062 | 0.069 |
| 8.50 | 0.018 | 0.022 | 0.026 | 0.029 | 0.033 | 0.036 | 0.045 | 0.053 | 0.060 | 0.067 |
| 8.75 | 0.018 | 0.021 | 0.025 | 0.028 | 0.032 | 0.035 | 0.043 | 0.051 | 0.059 | 0.066 |
| 9.00 | 0.017 | 0.021 | 0.024 | 0.028 | 0.031 | 0.034 | 0.042 | 0.050 | 0.057 | 0.064 |
| 9.25 | 0.017 | 0.020 | 0.024 | 0.027 | 0.030 | 0.033 | 0.041 | 0.049 | 0.056 | 0.063 |
| 9.50 | 0.017 | 0.020 | 0.023 | 0.026 | 0.029 | 0.033 | 0.040 | 0.048 | 0.055 | 0.061 |
| 9.75 | 0.016 | 0.019 | 0.023 | 0.026 | 0.029 | 0.032 | 0.039 | 0.047 | 0.054 | 0.060 |
| 10.00 | 0.016 | 0.019 | 0.022 | 0.025 | 0.028 | 0.031 | 0.038 | 0.046 | 0.052 | 0.059 |
| 20.00 | 0.008 | 0.010 | 0.011 | 0.013 | 0.014 | 0.016 | 0.020 | 0.024 | 0.027 | 0.031 |
| 50.00 | 0.003 | 0.004 | 0.004 | 0.005 | 0.006 | 0.006 | 0.008 | 0.010 | 0.011 | 0.013 |
| 100.00 | 0.002 | 0.002 | 0.002 | 0.003 | 0.003 | 0.003 | 0.004 | 0.005 | 0.006 | 0.006 |

Table 11.2 (continued)

| n' | m' | | | | | | | | | |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | 4.5 | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 | 10.0 | 25.0 | 50.0 | 100.0 |
| 0.25 | 0.053 | 0.053 | 0.053 | 0.053 | 0.053 | 0.053 | 0.053 | 0.053 | 0.053 | 0.053 |
| 0.50 | 0.087 | 0.087 | 0.088 | 0.088 | 0.088 | 0.088 | 0.088 | 0.088 | 0.088 | 0.088 |
| 0.75 | 0.109 | 0.109 | 0.109 | 0.110 | 0.110 | 0.110 | 0.110 | 0.111 | 0.111 | 0.111 |
| 1.00 | 0.121 | 0.122 | 0.123 | 0.123 | 0.124 | 0.124 | 0.124 | 0.125 | 0.125 | 0.125 |
| 1.25 | 0.128 | 0.130 | 0.131 | 0.132 | 0.132 | 0.133 | 0.133 | 0.134 | 0.134 | 0.134 |
| 1.50 | 0.132 | 0.134 | 0.136 | 0.137 | 0.138 | 0.138 | 0.139 | 0.140 | 0.140 | 0.140 |
| 1.75 | 0.134 | 0.136 | 0.138 | 0.140 | 0.141 | 0.142 | 0.142 | 0.144 | 0.144 | 0.145 |
| 2.00 | 0.134 | 0.136 | 0.139 | 0.141 | 0.143 | 0.144 | 0.145 | 0.147 | 0.147 | 0.148 |
| 2.25 | 0.133 | 0.136 | 0.140 | 0.142 | 0.144 | 0.145 | 0.146 | 0.149 | 0.150 | 0.150 |
| 2.50 | 0.132 | 0.135 | 0.139 | 0.142 | 0.144 | 0.146 | 0.147 | 0.151 | 0.151 | 0.151 |
| 2.75 | 0.130 | 0.133 | 0.138 | 0.142 | 0.144 | 0.146 | 0.147 | 0.152 | 0.152 | 0.153 |
| 3.00 | 0.127 | 0.131 | 0.137 | 0.141 | 0.144 | 0.145 | 0.147 | 0.152 | 0.153 | 0.154 |
| 3.25 | 0.125 | 0.129 | 0.135 | 0.140 | 0.143 | 0.145 | 0.147 | 0.153 | 0.154 | 0.154 |
| 3.50 | 0.122 | 0.126 | 0.133 | 0.138 | 0.142 | 0.144 | 0.146 | 0.153 | 0.155 | 0.155 |
| 3.75 | 0.119 | 0.124 | 0.131 | 0.137 | 0.141 | 0.143 | 0.145 | 0.154 | 0.155 | 0.155 |
| 4.00 | 0.116 | 0.121 | 0.129 | 0.135 | 0.139 | 0.142 | 0.145 | 0.154 | 0.155 | 0.156 |
| 4.25 | 0.113 | 0.119 | 0.127 | 0.133 | 0.138 | 0.141 | 0.144 | 0.154 | 0.156 | 0.156 |
| 4.50 | 0.110 | 0.116 | 0.125 | 0.131 | 0.136 | 0.140 | 0.143 | 0.154 | 0.156 | 0.156 |
| 4.75 | 0.107 | 0.113 | 0.123 | 0.130 | 0.135 | 0.139 | 0.142 | 0.154 | 0.156 | 0.157 |
| 5.00 | 0.105 | 0.111 | 0.120 | 0.128 | 0.133 | 0.137 | 0.140 | 0.154 | 0.156 | 0.157 |
| 5.25 | 0.102 | 0.108 | 0.118 | 0.126 | 0.131 | 0.136 | 0.139 | 0.154 | 0.156 | 0.157 |
| 5.50 | 0.099 | 0.106 | 0.116 | 0.124 | 0.130 | 0.134 | 0.138 | 0.154 | 0.156 | 0.157 |
| 5.75 | 0.097 | 0.103 | 0.113 | 0.122 | 0.128 | 0.133 | 0.136 | 0.154 | 0.157 | 0.157 |
| 6.00 | 0.094 | 0.101 | 0.111 | 0.120 | 0.126 | 0.131 | 0.135 | 0.153 | 0.157 | 0.157 |
| 6.25 | 0.092 | 0.098 | 0.109 | 0.118 | 0.124 | 0.129 | 0.134 | 0.153 | 0.157 | 0.158 |
| 6.50 | 0.090 | 0.096 | 0.107 | 0.116 | 0.122 | 0.128 | 0.132 | 0.153 | 0.157 | 0.158 |
| 6.75 | 0.087 | 0.094 | 0.105 | 0.114 | 0.121 | 0.126 | 0.131 | 0.153 | 0.157 | 0.158 |
| 7.00 | 0.085 | 0.092 | 0.103 | 0.112 | 0.119 | 0.125 | 0.129 | 0.152 | 0.157 | 0.158 |
| 7.25 | 0.083 | 0.090 | 0.101 | 0.110 | 0.117 | 0.123 | 0.128 | 0.152 | 0.157 | 0.158 |
| 7.50 | 0.081 | 0.088 | 0.099 | 0.108 | 0.115 | 0.121 | 0.126 | 0.152 | 0.156 | 0.158 |
| 7.75 | 0.079 | 0.086 | 0.097 | 0.106 | 0.114 | 0.120 | 0.125 | 0.151 | 0.156 | 0.158 |
| 8.00 | 0.077 | 0.084 | 0.095 | 0.104 | 0.112 | 0.118 | 0.124 | 0.151 | 0.156 | 0.158 |
| 8.25 | 0.076 | 0.082 | 0.093 | 0.102 | 0.110 | 0.117 | 0.122 | 0.150 | 0.156 | 0.158 |
| 8.50 | 0.074 | 0.080 | 0.091 | 0.101 | 0.108 | 0.115 | 0.121 | 0.150 | 0.156 | 0.158 |
| 8.75 | 0.072 | 0.078 | 0.089 | 0.099 | 0.107 | 0.114 | 0.119 | 0.150 | 0.156 | 0.158 |
| 9.00 | 0.071 | 0.077 | 0.088 | 0.097 | 0.105 | 0.112 | 0.118 | 0.149 | 0.156 | 0.158 |
| 9.25 | 0.069 | 0.075 | 0.086 | 0.096 | 0.104 | 0.110 | 0.116 | 0.149 | 0.156 | 0.158 |
| 9.50 | 0.068 | 0.074 | 0.085 | 0.094 | 0.102 | 0.109 | 0.115 | 0.148 | 0.156 | 0.158 |
| 9.75 | 0.066 | 0.072 | 0.083 | 0.092 | 0.100 | 0.107 | 0.113 | 0.148 | 0.156 | 0.158 |
| 10.00 | 0.065 | 0.071 | 0.082 | 0.091 | 0.099 | 0.106 | 0.112 | 0.147 | 0.156 | 0.158 |
| 20.00 | 0.035 | 0.039 | 0.046 | 0.053 | 0.059 | 0.065 | 0.071 | 0.124 | 0.148 | 0.156 |
| 50.00 | 0.014 | 0.016 | 0.019 | 0.022 | 0.025 | 0.028 | 0.031 | 0.071 | 0.113 | 0.142 |
| 100.00 | 0.007 | 0.008 | 0.010 | 0.011 | 0.013 | 0.014 | 0.016 | 0.039 | 0.071 | 0.113 |

Table 11.3 Variation of I_f with L/B and D_f/B

| L/B | D_f/B | I_f | | |
|-------|---------|---------------|---------------|---------------|
| | | $\mu_s = 0.3$ | $\mu_s = 0.4$ | $\mu_s = 0.5$ |
| 1 | 0.5 | 0.77 | 0.82 | 0.85 |
| | 0.75 | 0.69 | 0.74 | 0.77 |
| | 1 | 0.65 | 0.69 | 0.72 |
| 2 | 0.5 | 0.82 | 0.86 | 0.89 |
| | 0.75 | 0.75 | 0.79 | 0.83 |
| | 1 | 0.71 | 0.75 | 0.79 |
| 5 | 0.5 | 0.87 | 0.91 | 0.93 |
| | 0.75 | 0.81 | 0.86 | 0.89 |
| | 1 | 0.78 | 0.82 | 0.85 |

Table 11.5 Representative Values of Poisson's Ratio

| Type of soil | Poisson's ratio, μ_s |
|--------------|--------------------------|
| Loose sand | 0.2–0.4 |
| Medium sand | 0.25–0.4 |
| Dense sand | 0.3–0.45 |
| Silty sand | 0.2–0.4 |
| Soft clay | 0.15–0.25 |
| Medium clay | 0.2–0.5 |

Table 11.4 Representative Values of the Modulus of Elasticity of Soil

| Soil type | E_s | |
|------------|-------------------|---------------------|
| | kN/m ² | lb/in. ² |
| Soft clay | 1,800–3,500 | 250–500 |
| Hard clay | 6,000–14,000 | 850–2,000 |
| Loose sand | 10,000–28,000 | 1,500–4,000 |
| Dense sand | 35,000–70,000 | 5,000–10,000 |

Consolidation Settlement

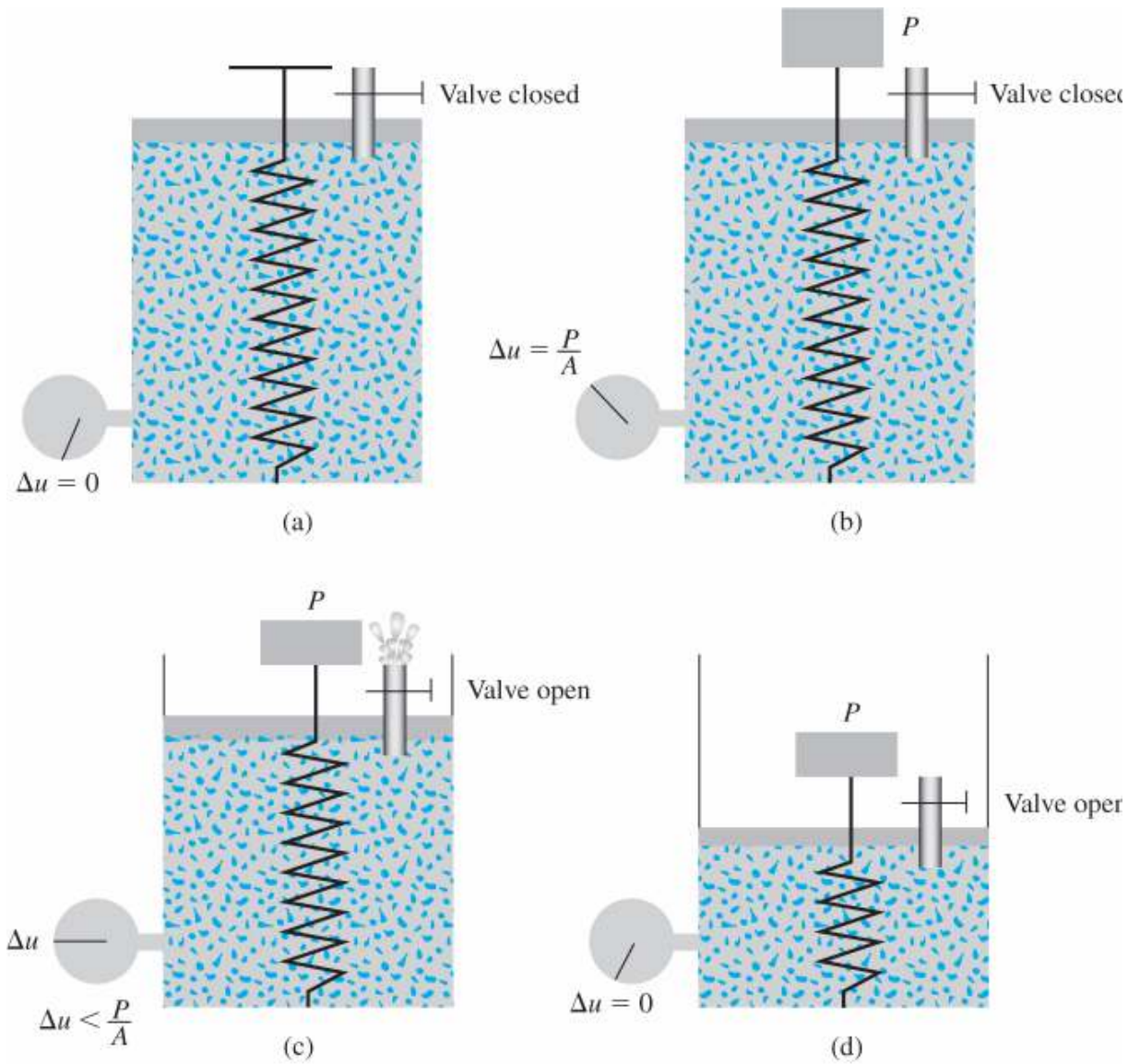


Figure 11.5 Spring-cylinder model

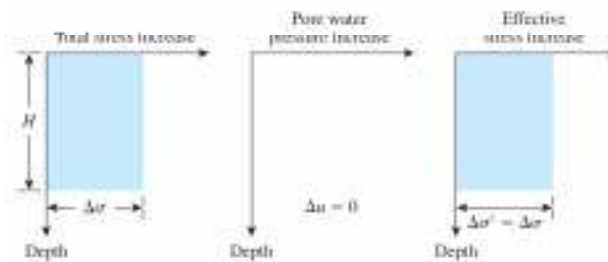
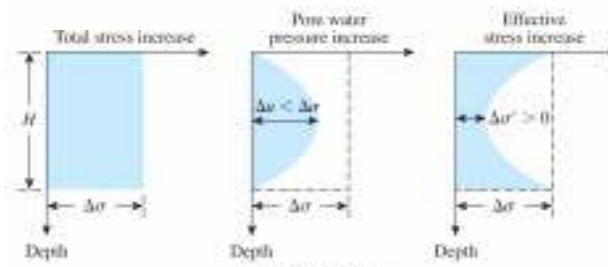
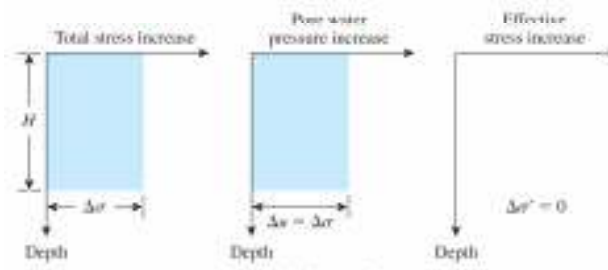
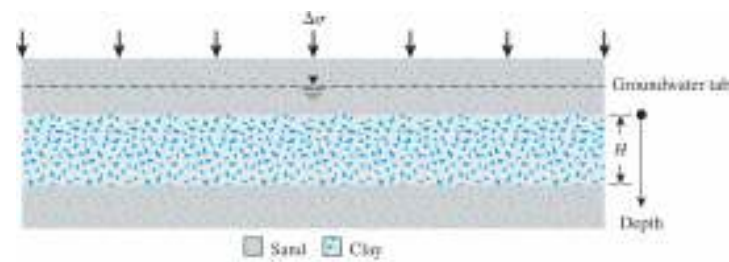
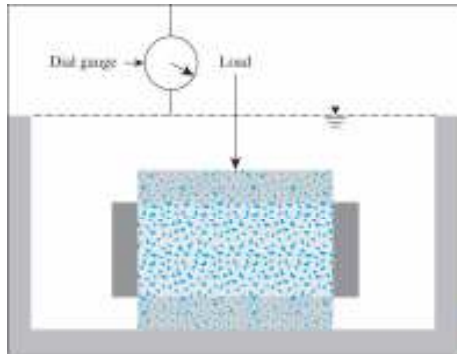


Figure 11.6 Variation of total stress, pore water pressure, and effective stress in a clay layer drained at top and bottom as the result of an added stress, $\Delta\sigma$

One-Dimensional Laboratory Consolidation Test



Porous stone
 Soil specimen
 Specimen ring

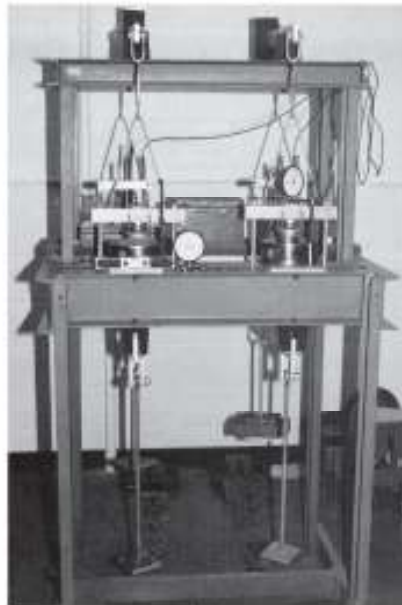
(a)

Figure 11.7

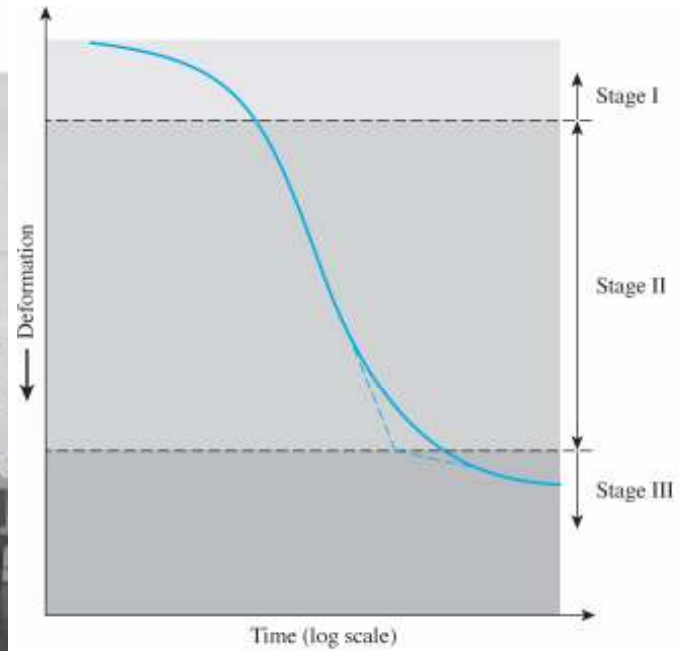
(a) Schematic diagram of a consolidometer; (b) photograph of a consolidometer; (c) a consolidation test in progress (right-hand side) (Courtesy of *Briga M. Dax, Henderson, Nevada*)



(b)



(c)



- Stage I: Initial compression
- Stage II: Primary consolidation
- Stage III: Secondary consolidation

Figure 11.8

Time-deformation plot during consolidation for a given load increment

One-Dimensional Laboratory Consolidation Test...contd

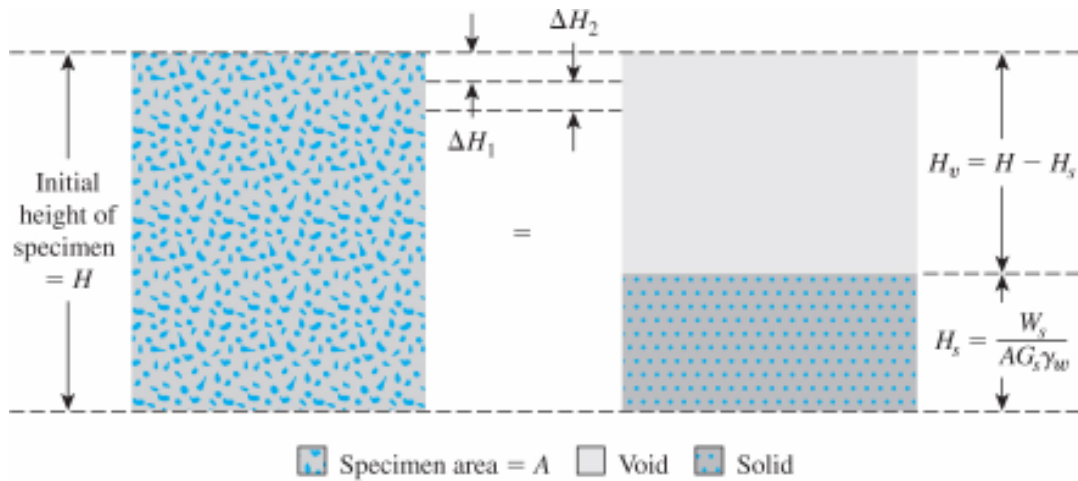


Figure 11.9 Change of height of specimen in one-dimensional consolidation test

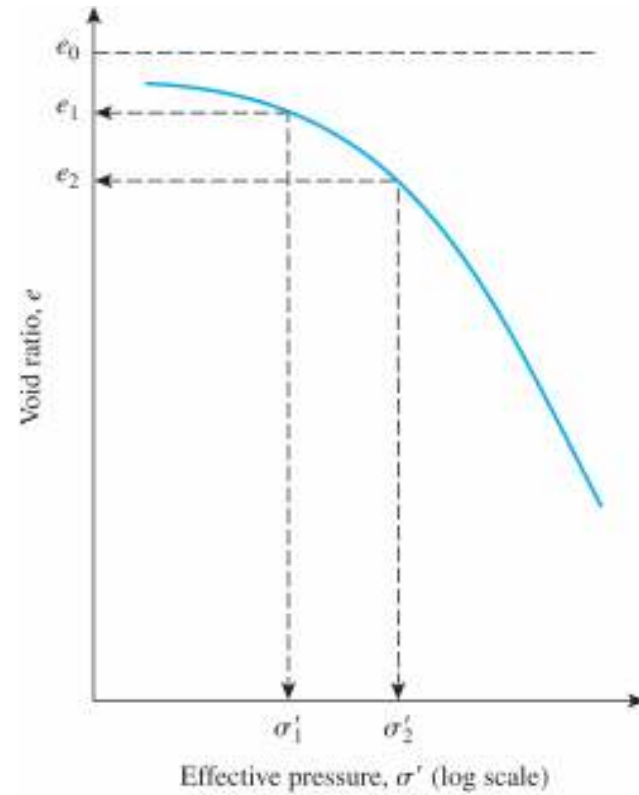


Figure 11.10 Typical plot of e against $\log \sigma'$

Normally Consolidated and Overconsolidated Clays

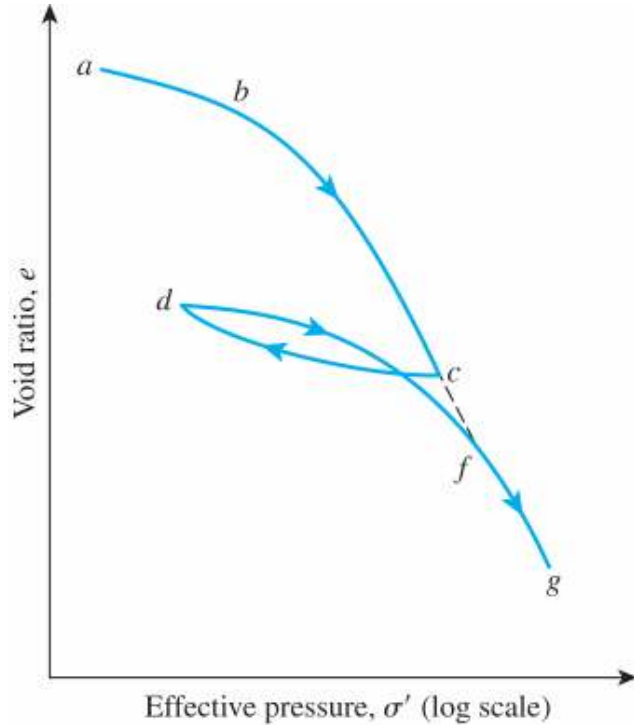


Figure 11.12 Plot of e against $\log \sigma'$ showing loading, unloading, and reloading branches

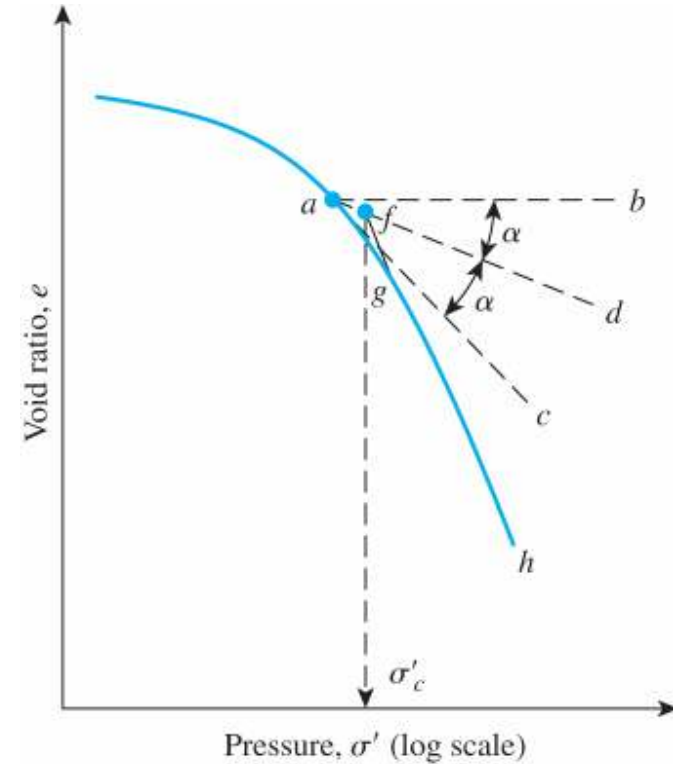


Figure 11.13 Graphic procedure for determining preconsolidation pressure

Normally Consolidated – whose present effective overburden pressure is the maximum pressure that the soil was subjected to in the past

Overconsolidated – whose present effective overburden pressure is less than that which the soil experienced in the past. The maximum effective past pressure is called the preconsolidation pressure

$$\text{Over Consolidation Ratio (OCR)} = \frac{\sigma'_c}{\sigma'}$$

σ'_c = preconsolidation pressure of the specimen

σ' = present effective vertical pressure

Effect of Disturbance on Void Ratio – Pressure Relationship

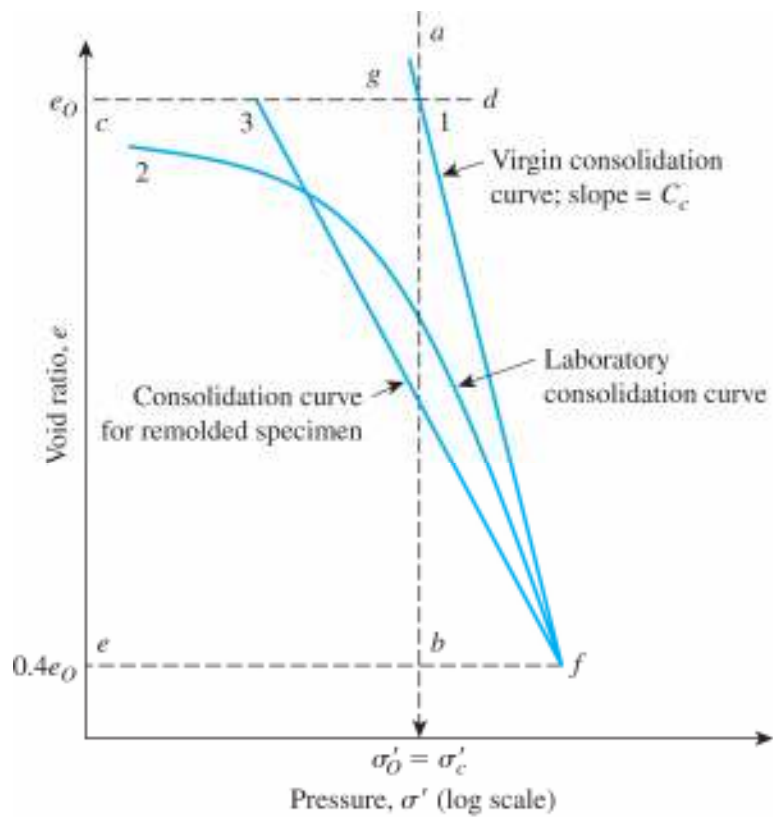


Figure 11.14 Consolidation characteristics of normally consolidated clay of low to medium sensitivity

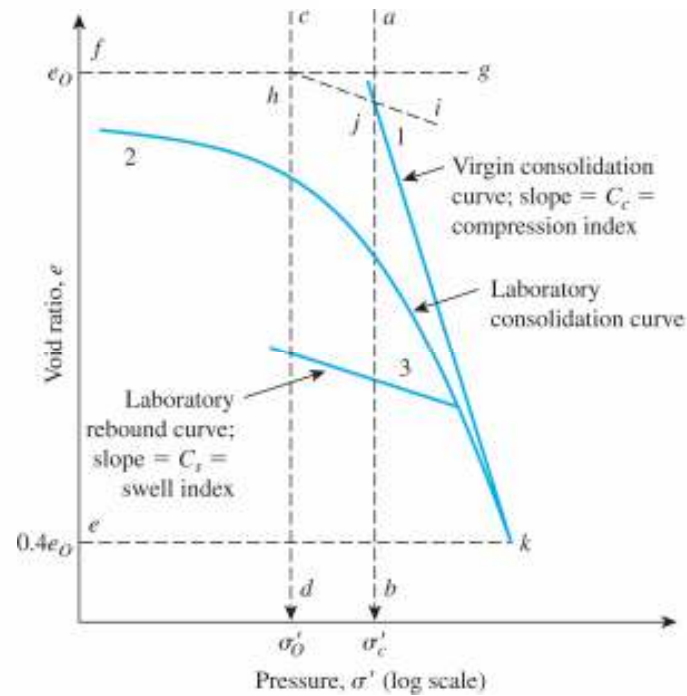


Figure 11.15 Consolidation characteristics of overconsolidated clay of low to medium sensitivity

Calculation of Settlement from One-Dimensional Primary Consolidation

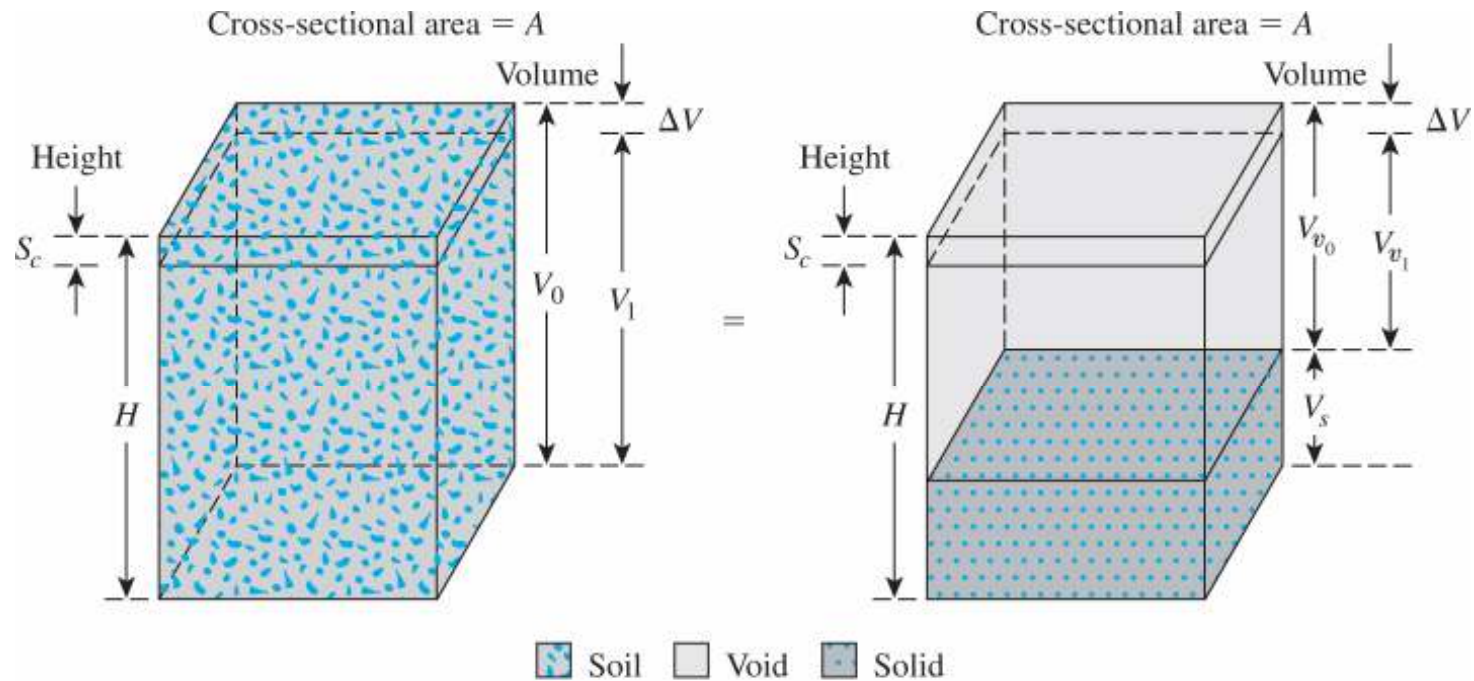


Figure 11.16 Settlement caused by one-dimensional consolidation

$$S_e = \frac{C_c H}{1 + e_0} \log \left(\frac{\sigma'_0 + \Delta\sigma'}{\sigma'_0} \right)$$

$$\text{If } \sigma'_0 + \Delta\sigma' \leq \sigma'_c \quad S_e = \frac{C_s H}{1 + e_0} \log \left(\frac{\sigma'_0 + \Delta\sigma'}{\sigma'_0} \right)$$

$$\text{If } \sigma'_0 + \Delta\sigma' > \sigma'_c \quad S_e = \frac{C_s H}{1 + e_0} \log \frac{\sigma'_c}{\sigma'_0} + \frac{C_c H}{1 + e_0} \log \left(\frac{\sigma'_0 + \Delta\sigma'}{\sigma'_c} \right)$$

Compression Index (C_c) and Swell Index (C_s)

$$C_c = 0.009(LL - 10) \dots \dots \dots \text{Skempton (1944)}$$

$$C_s \approx \frac{1}{5} \text{ to } \frac{1}{10} C_c$$

Table 11.6 Correlations for Compression Index, C_c *

| Equation | Reference | Region of applicability |
|---------------------------|-----------------|---|
| $C_c = 0.007(LL - 7)$ | Skempton (1944) | Remolded clays |
| $C_c = 0.01w_N$ | | Chicago clays |
| $C_c = 1.15(e_o - 0.27)$ | Nishida (1956) | All clays |
| $C_c = 0.30(e_o - 0.27)$ | Hough (1957) | Inorganic cohesive soil: silt, silty clay, clay |
| $C_c = 0.0115w_N$ | | Organic soils, peats, organic silt, and clay |
| $C_c = 0.0046(LL - 9)$ | | Brazilian clays |
| $C_c = 0.75(e_o - 0.5)$ | | Soils with low plasticity |
| $C_c = 0.208e_o + 0.0083$ | | Chicago clays |
| $C_c = 0.156e_o + 0.0107$ | | All clays |

Table 11.7 Compression and Swell of Natural Soils

| Soil | Liquid limit | Plastic limit | Compression index, C_c | Swell index, C_s |
|--------------------------|--------------|---------------|--------------------------|--------------------|
| Boston blue clay | 41 | 20 | 0.35 | 0.07 |
| Chicago clay | 60 | 20 | 0.4 | 0.07 |
| Ft. Gordon clay, Georgia | 51 | 26 | 0.12 | — |
| New Orleans clay | 80 | 25 | 0.3 | 0.05 |
| Montana clay | 60 | 28 | 0.21 | 0.05 |

Secondary Consolidation Settlement

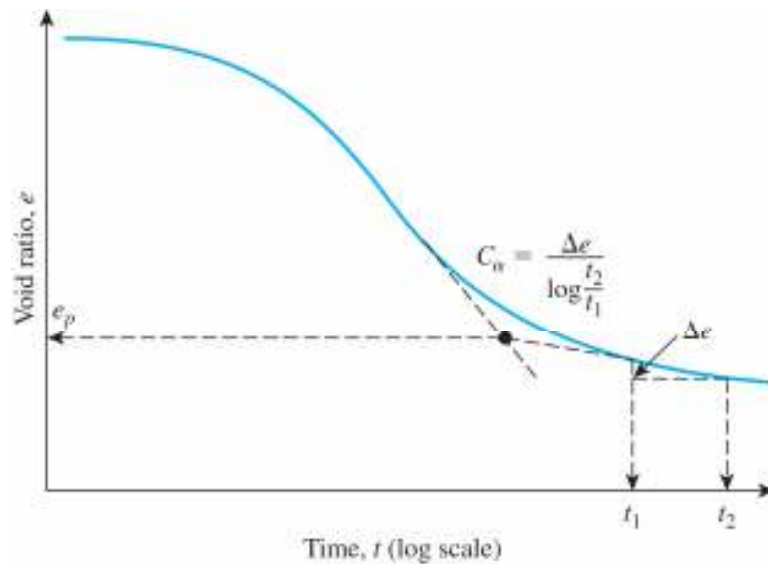


Figure 11.20 Variation of e with $\log t$ under a given load increment and definition of secondary consolidation index

$$S_s = C'_\alpha H \log \left(\frac{t_2}{t_1} \right)$$

$$C'_\alpha = \frac{C_\alpha}{1 + e_p}$$

$$C_\alpha = \frac{\Delta e}{\log t_2 - \log t_1} = \frac{\Delta e}{\log(t_2/t_1)}$$

C_α = secondary compression index

Δe = change of void ratio

t_1, t_2 = time

e_p = void ratio at the end of primary consolidation

H = thickness of clay layer

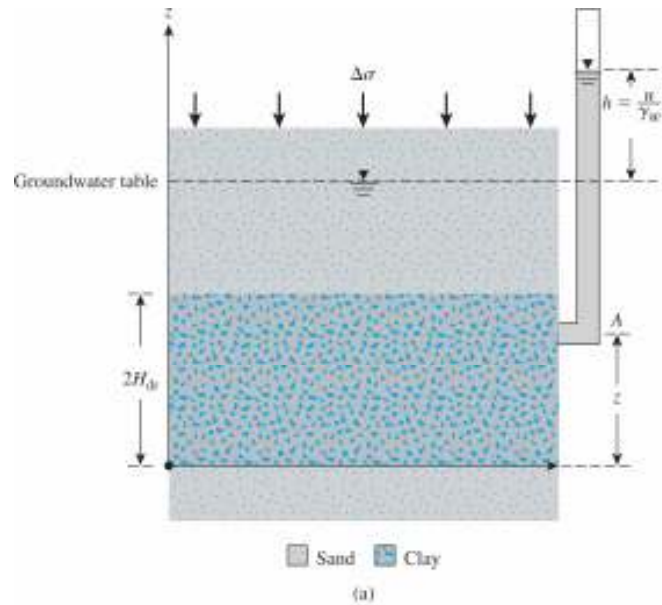
Magnitudes of C'_α

Overconsolidated clays = 0.001 or less

Normally consolidated = 0.005 to 0.03

Organic Soil = 0.04 or less

Time Rate of Consolidation



$$T_v = \text{Time Factor} = \frac{c_v t}{H_{dr}^2}$$

$$\text{For } U = 0 \text{ to } 60\%, T_v = \frac{\pi}{4} \left(\frac{U\%}{100} \right)^2$$

$$\text{For } U > 60\%, T_v = 1.781 - 0.933 \log(100 - U\%)$$

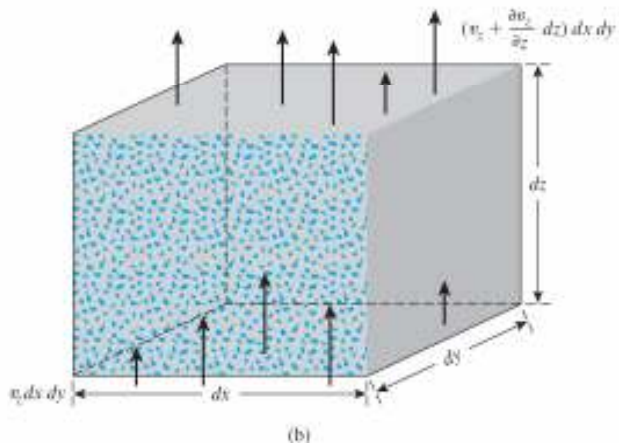


Figure 11.22
 (a) Clay layer undergoing consolidation;
 (b) flow of water at A during consolidation

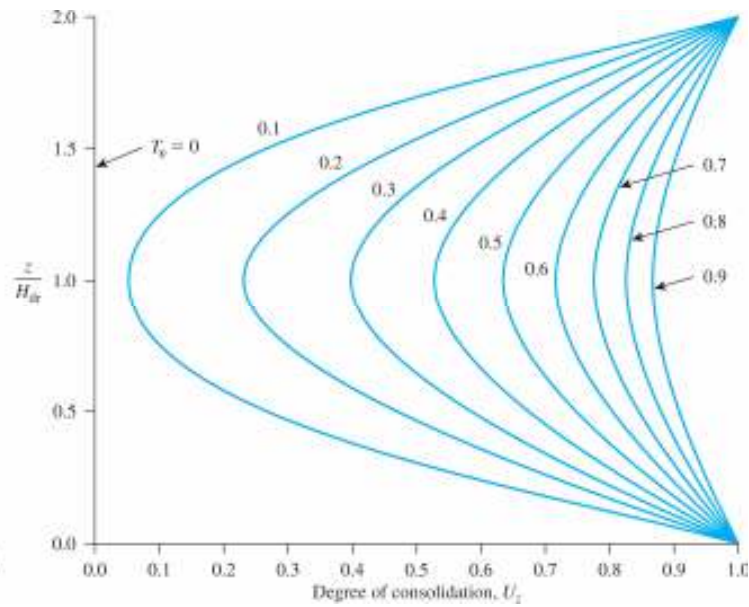
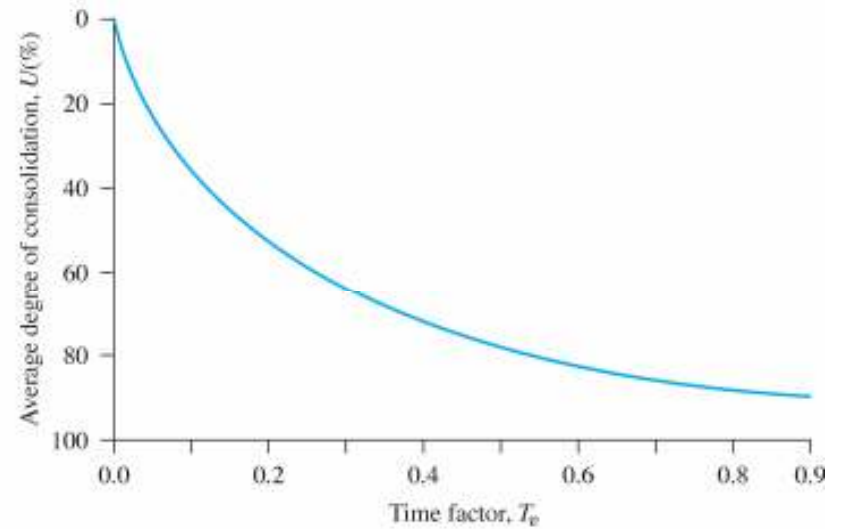
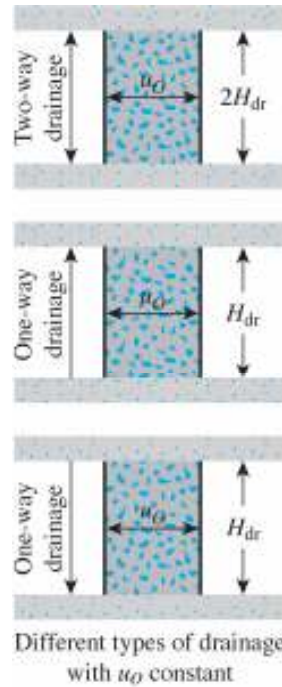


Figure 11.23
Variation of U_z with T_v and z/H_{dr}



Different types of drainage
with u_0 constant

Figure 11.24 Variation of average degree of consolidation with time factor, T_v (u_0 constant with depth)

Table 11.8 Variation of T_v with U

| U (%) | T_v | U (%) | T_v | U (%) | T_v | U (%) | T_v |
|---------|---------|---------|--------|---------|-------|---------|----------|
| 0 | 0 | 26 | 0.0531 | 52 | 0.212 | 78 | 0.529 |
| 1 | 0.00008 | 27 | 0.0572 | 53 | 0.221 | 79 | 0.547 |
| 2 | 0.0003 | 28 | 0.0615 | 54 | 0.230 | 80 | 0.567 |
| 3 | 0.00071 | 29 | 0.0660 | 55 | 0.239 | 81 | 0.588 |
| 4 | 0.00126 | 30 | 0.0707 | 56 | 0.248 | 82 | 0.610 |
| 5 | 0.00196 | 31 | 0.0754 | 57 | 0.257 | 83 | 0.633 |
| 6 | 0.00283 | 32 | 0.0803 | 58 | 0.267 | 84 | 0.658 |
| 7 | 0.00385 | 33 | 0.0855 | 59 | 0.276 | 85 | 0.684 |
| 8 | 0.00502 | 34 | 0.0907 | 60 | 0.286 | 86 | 0.712 |
| 9 | 0.00636 | 35 | 0.0962 | 61 | 0.297 | 87 | 0.742 |
| 10 | 0.00785 | 36 | 0.102 | 62 | 0.307 | 88 | 0.774 |
| 11 | 0.0095 | 37 | 0.107 | 63 | 0.318 | 89 | 0.809 |
| 12 | 0.0113 | 38 | 0.113 | 64 | 0.329 | 90 | 0.848 |
| 13 | 0.0133 | 39 | 0.119 | 65 | 0.304 | 91 | 0.891 |
| 14 | 0.0154 | 40 | 0.126 | 66 | 0.352 | 92 | 0.938 |
| 15 | 0.0177 | 41 | 0.132 | 67 | 0.364 | 93 | 0.993 |
| 16 | 0.0201 | 42 | 0.138 | 68 | 0.377 | 94 | 1.055 |
| 17 | 0.0227 | 43 | 0.145 | 69 | 0.390 | 95 | 1.129 |
| 18 | 0.0254 | 44 | 0.152 | 70 | 0.403 | 96 | 1.219 |
| 19 | 0.0283 | 45 | 0.159 | 71 | 0.417 | 97 | 1.336 |
| 20 | 0.0314 | 46 | 0.166 | 72 | 0.431 | 98 | 1.500 |
| 21 | 0.0346 | 47 | 0.173 | 73 | 0.446 | 99 | 1.781 |
| 22 | 0.0380 | 48 | 0.181 | 74 | 0.461 | 100 | ∞ |
| 23 | 0.0415 | 49 | 0.188 | 75 | 0.477 | | |
| 24 | 0.0452 | 50 | 0.197 | 76 | 0.493 | | |
| 25 | 0.0491 | 51 | 0.204 | 77 | 0.511 | | |

Coefficient of Consolidation

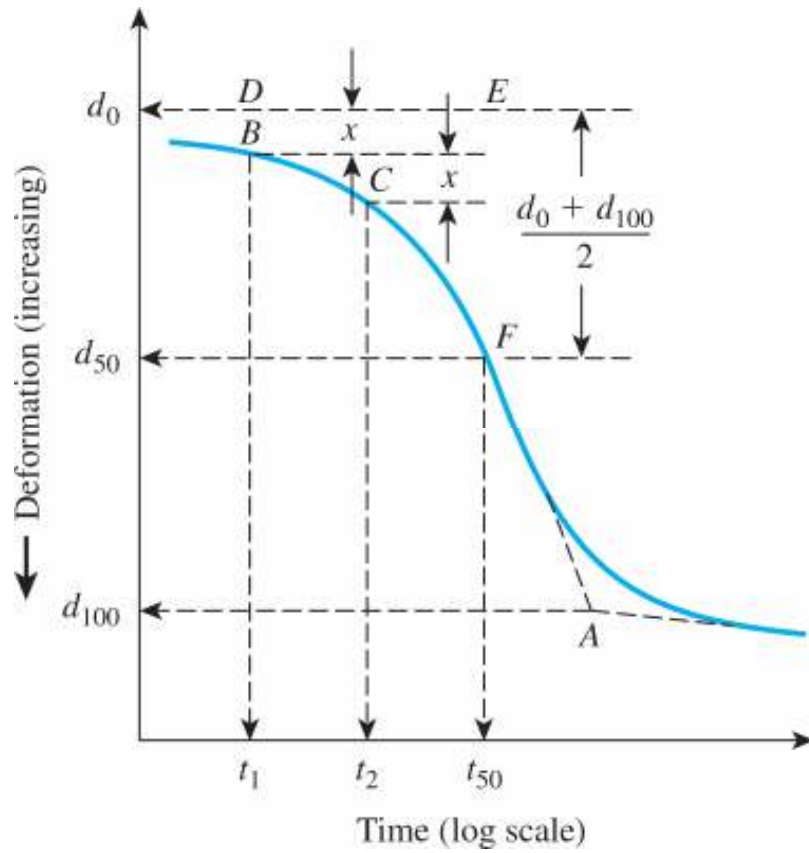


Figure 11.25
Logarithm-of-time method for determining coefficient of consolidation

$$c_v = \frac{0.197 H_{dr}^2}{t_{50}}$$

Table 11.9 Comparison of c_v Obtained from Various Methods*

| Soil | $c_v \times 10^4 \text{ cm}^2/\text{sec}$ | | | |
|--------------------------------|--|--------------------------|----------------------------|-----------------------------|
| | Range of pressure σ' (kN/m ²) | Logarithm-of-time method | Square-root-of-time method | Early stage log- t method |
| Red earth | 25–50 | 4.63 | 5.45 | 6.12 |
| | 50–100 | 6.43 | 7.98 | 9.00 |
| | 100–200 | 7.32 | 9.99 | 11.43 |
| | 200–400 | 8.14 | 10.90 | 12.56 |
| | 400–800 | 8.10 | 11.99 | 12.80 |
| Brown soil | 25–50 | 3.81 | 4.45 | 5.42 |
| | 50–100 | 3.02 | 3.77 | 3.80 |
| | 100–200 | 2.86 | 3.40 | 3.52 |
| | 200–400 | 2.09 | 2.21 | 2.74 |
| | 400–800 | 1.30 | 1.45 | 1.36 |
| Black cotton soil | 25–50 | 5.07 | 6.55 | 9.73 |
| | 50–100 | 3.06 | 3.69 | 4.78 |
| | 100–200 | 2.00 | 2.50 | 3.45 |
| | 200–400 | 1.15 | 1.57 | 2.03 |
| | 400–800 | 0.56 | 0.64 | 0.79 |
| Illite | 25–50 | 1.66 | 2.25 | 2.50 |
| | 50–100 | 1.34 | 3.13 | 3.32 |
| | 100–200 | 2.20 | 3.18 | 3.65 |
| | 200–400 | 3.15 | 4.59 | 5.14 |
| | 400–800 | 4.15 | 5.82 | 6.45 |
| Bentonite | 25–50 | 0.063 | 0.130 | 0.162 |
| | 50–100 | 0.046 | 0.100 | 0.130 |
| | 100–200 | 0.044 | 0.052 | 0.081 |
| | 200–400 | 0.021 | 0.022 | 0.040 |
| | 400–800 | 0.015 | 0.017 | 0.022 |
| Chicago clay (Taylor, 1948) | 12.5–25 | 25.10 | 45.50 | 46.00 |
| | 25–50 | 20.10 | 23.90 | 31.50 |
| | 50–100 | 13.70 | 17.40 | 20.20 |
| | 100–200 | 3.18 | 4.71 | 4.97 |
| | 200–400 | 4.56 | 4.40 | 4.91 |
| | 400–800 | 6.05 | 6.44 | 7.41 |
| | 800–1600 | 7.09 | 8.62 | 9.09 |

Methods for Accelerating Consolidation Settlement

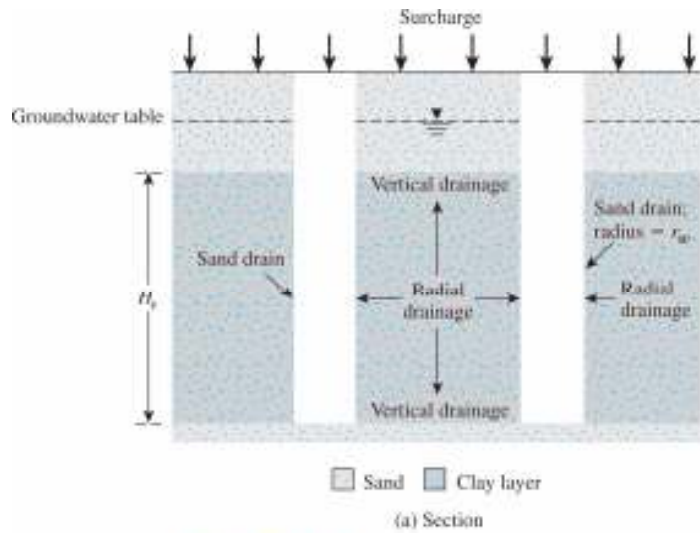


Figure 11.35 Sand drains

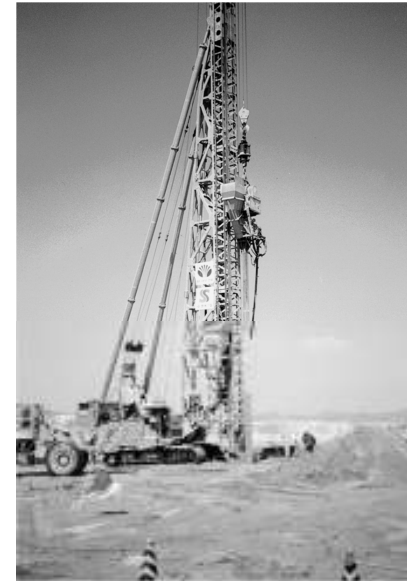
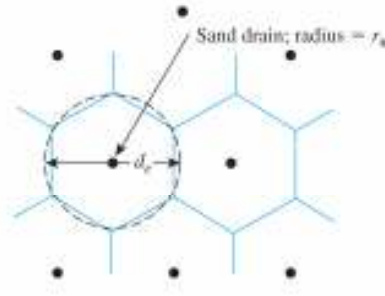


Figure 11.37 Prefabricated vertical drain (PVD)

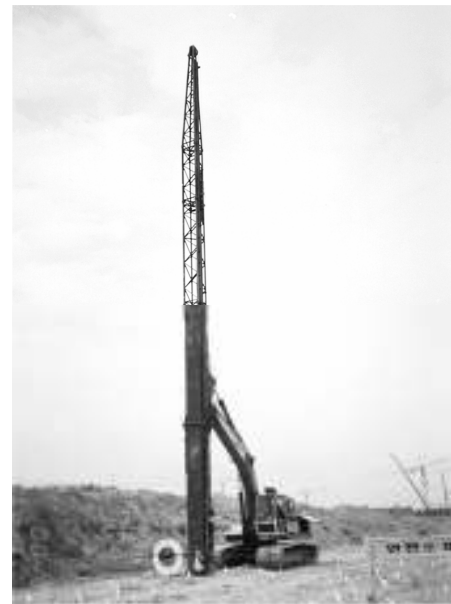


Figure 11.38 Installation of PVDs in progress (Courtesy of E.C. Shin, University of Incheon, South Korea)

Precompression

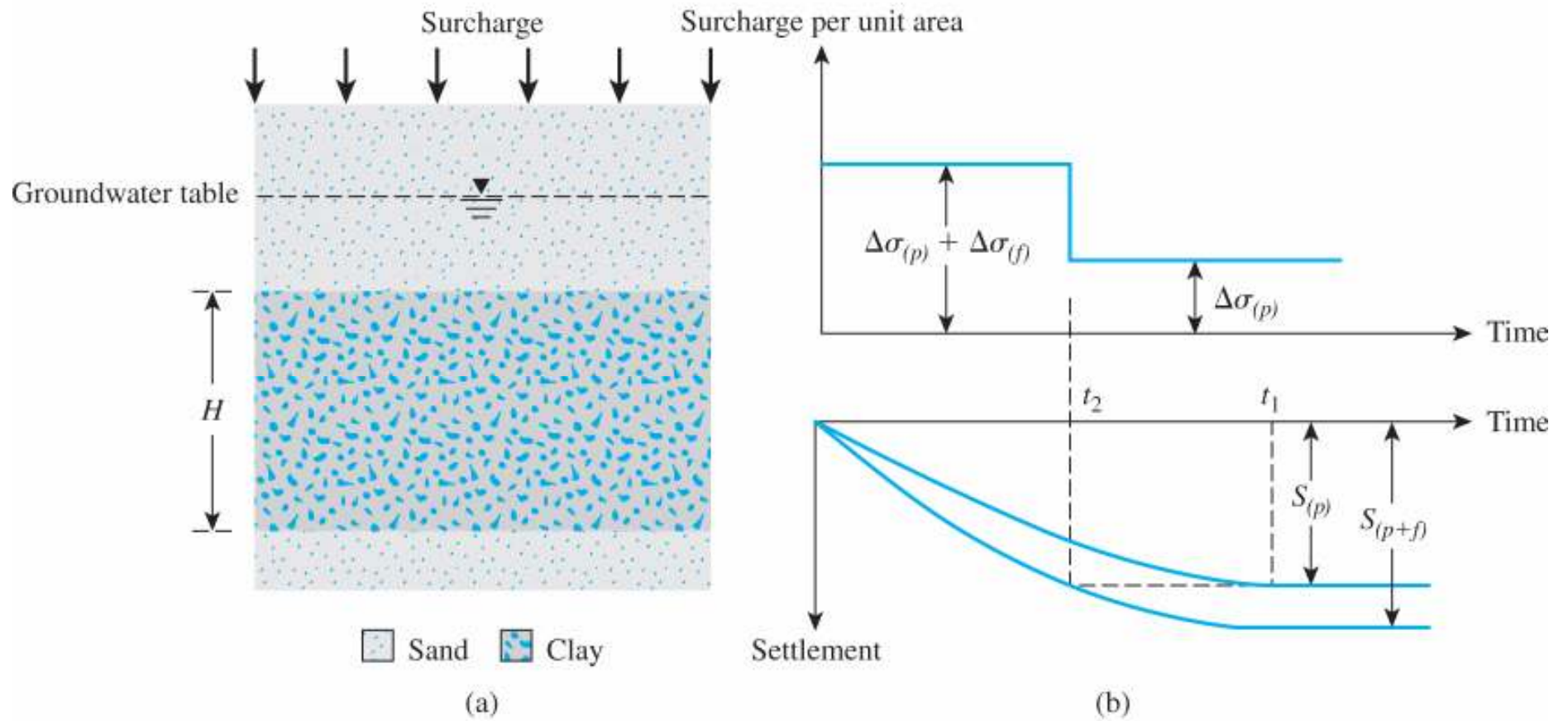


Figure 11.39 Principles of precompression