Standard Method of Test for

The California Bearing Ratio

AASHTO Designation: T 193-99 (2003)

1. SCOPE

1.1. This test method covers the determination of the California Bearing Ratio (CBR) of pavement subgrade, subbase, and base/course materials from laboratory compacted specimens. The test method is primarily intended for but not limited to, evaluating the strength of cohesive materials having maximum particle sizes less than 19 mm ($^3/_4$ in.).

1.2. When materials having maximum particle sizes greater than 19 mm ($^3/_4$ in.) are to be tested, this test method provides for modifying the gradation of the material so that the material used for tests all passes the 19.0-mm ($^3/_4$-in.) sieve while the total gravel 4.75-mm (No. 4) to 75-mm (3-in.) fraction remains the same. While traditionally this method of specimen preparation has been used to avoid the error inherent in testing materials containing large particles in the CBR test apparatus, the modified material may have significantly different strength properties than the original material. However, a large experience base has developed using this test method for materials for which the gradation has been modified, and satisfactory design methods are in use based on the results of tests using this procedure.

1.3. Past practice has shown that CBR results for those materials having substantial percentages of particles retained on the 4.75-mm (No. 4) sieve are more variable than for finer materials. Consequently, more trials may be required for these materials to establish a reliable CBR.

1.4. This test method provides for the determination of the CBR of a material at optimum water content or a range of water content from a specified compaction test and a specified dry unit mass. The dry unit mass is usually given as a percentage of maximum dry unit mass from the compaction tests of T 99 or T 180.

1.5. The agency requesting the test shall specify the water content or range of water content and the dry unit mass for which the CBR is desired.

1.6. Unless specified otherwise by the requesting agency, or unless it has been shown to have no effect on test results for the material being tested, all specimens shall be soaked prior to penetration.

1.7. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 145, Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
- T 2, Sampling of Aggregates
- T 87, Dry Preparation of Disturbed Soil and Soil Aggregate Samples for Test

- T 88, Particle Size Analysis of Soils
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
- T 265, Laboratory Determination of Moisture Content of Soils

3. SIGNIFICANCE AND USE

3.1. This test method is used to evaluate the potential strength of subgrade, subbase, and base course material, including recycled materials for use in road and airfield pavements. The CBR value obtained in this test forms an integral part of several flexible pavement design methods.

3.2. For applications where the effect of compaction water content on CBR is small, such as cohesionless, coarse-grained materials, or where an allowance is made for the effect of differing compaction water contents in the design procedure, the CBR may be determined at the optimum water content of a specified compaction effort. The dry unit mass specified is normally the minimum percent compaction allowed by using the agency's field compaction specification.

3.3. For applications where the effect of compaction water content on CBR is unknown or where it is desired to account for its effect, the CBR is determined for a range of water content, usually the range of water content permitted for field compaction by using the agency's field compaction specification.

3.4. The criteria for test specimen preparation of self-cementing (and other) materials, which gain strength with time, must be based on a geotechnical engineering evaluation. As directed by the engineer, self-cementing materials shall be properly cured until bearing ratios representing long-term service conditions can be measured.

4. APPARATUS

4.1. *Molds*—The molds shall be cylindrical in shape, made of metal, with an internal diameter of 152.40 ± 0.66 mm (6.0 ± 0.026 in.) and a height of 177.80 ± 0.46 mm (7.0 ± 0.018 in.) provided with an extension collar approximately 50 mm (2.0 in.) in height and a perforated base plate that can be fitted to either end of the mold. (See Figure 1.) It is desirable to have at least three molds for each soil to be tested.

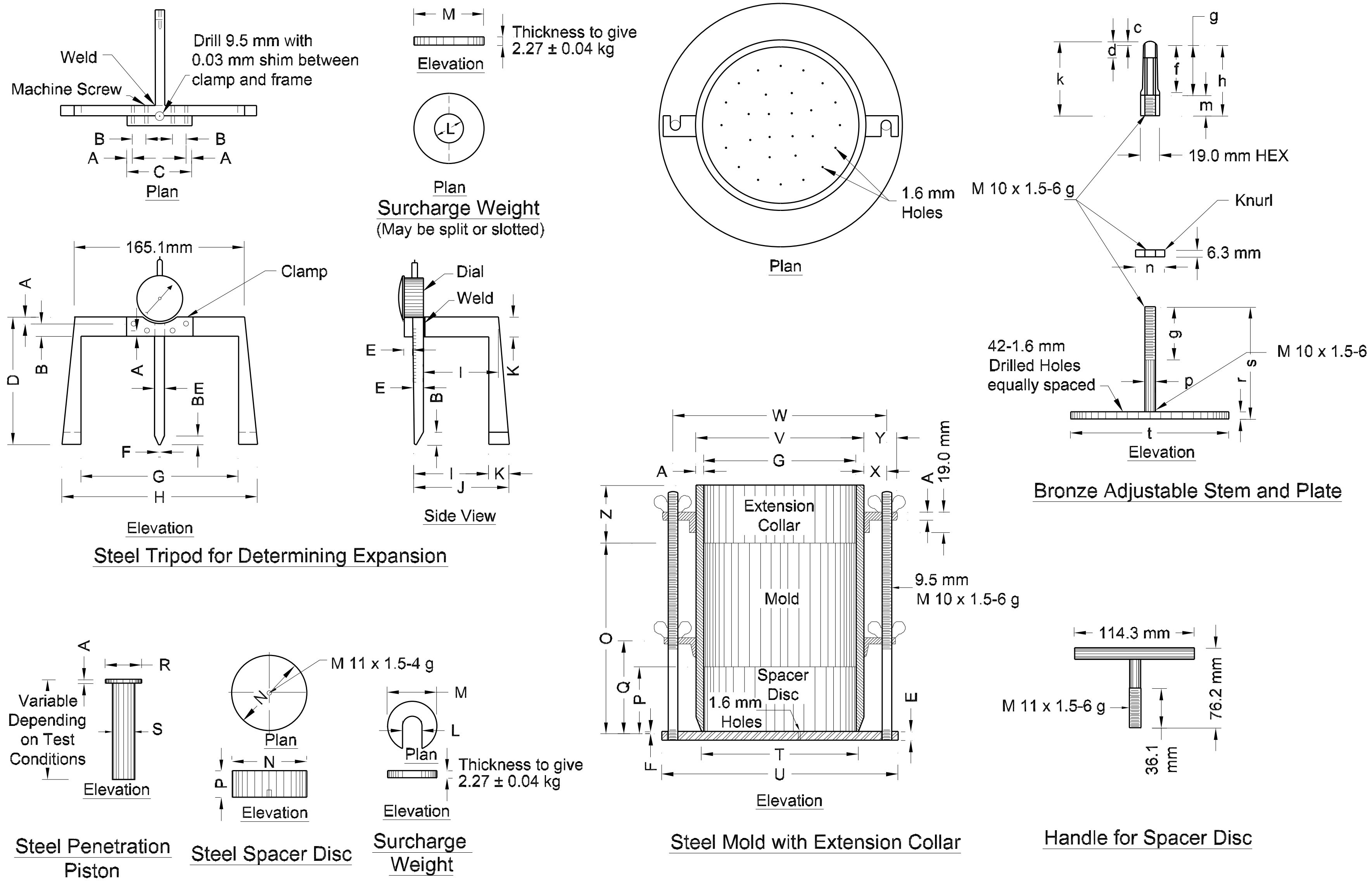


Figure 1—California Bearing Ratio Apparatus

Table of Measurements

	TRIPOD FOR DETERMINING EXPANSION											SURCHARGE		SPACER DISC	
MATERIAL	STEEL **													STEEL **	
DIMENSION	A	B	C	D	E	F	G	H	I	J	K	L*	M*	N*	P
METRIC, mm	6.3	12.7	63.5	120.6	9.5	1.6	152.4	190.5	76.2	95.2	19.0	54.0	149.2	150.8	61.37
TOLERANCE, mm													1.6	0.8	0.25
ENGLISH, in.	$\frac{1}{4}$	$\frac{1}{2}$	$2\frac{1}{2}$	$4\frac{3}{4}$	$\frac{3}{8}$	$\frac{1}{16}$	6	$7\frac{1}{2}$	3	$3\frac{3}{4}$	$\frac{3}{4}$	$2\frac{1}{8}$	$5\frac{7}{8}$	$5\frac{15}{16}$	2.416
TOLERANCE, in.													$\frac{1}{16}$	$\frac{1}{32}$	0.01

	MOLD WITH EXTENSION COLLAR														PISTON		
MATERIAL	STEEL**														STEEL**		
DIMENSION	A	E	F	G*	O	P	Q	T*	U***	V*	W	X	Y	Z	A	R	S*
METRIC, mm	6.3	9.5	1.6	152.40	177.80	61.37	88.9	158.0	238.1	165.1	212.7	23.8	33.3	50.8	6.3	69.8	49.63
TOLERANCE, mm				0.66	0.46	0.25											0.13
ENGLISH, in.	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{16}$	6	7	2.416	$3\frac{1}{2}$	$6\frac{7}{32}$	$9\frac{3}{8}$	$6\frac{1}{2}$	$8\frac{3}{8}$	$\frac{15}{16}$	$1\frac{5}{16}$	2	$\frac{1}{4}$	$2\frac{3}{4}$	1.954
TOLERANCE, in.				0.026	0.018	0.01											0.005

	ADJUSTABLE STEM AND PLATE														
MATERIAL	BRONZE														
DIMENSION			c	d	e*	f	g	h	k	m	n*	p*	r	s	t
METRIC, mm			5.6	11.9	3.2	46.04	50.8	69.8	75.4	19.0	28.6	9.5	6.3	107.9	149.2
TOLERANCE, mm															1.6
ENGLISH, in.			$\frac{7}{32}$	$\frac{15}{32}$	$\frac{1}{8}$	$1\frac{13}{16}$	2	$2\frac{3}{4}$	$2\frac{31}{32}$	$\frac{3}{4}$	$1\frac{1}{8}$	$\frac{3}{8}$	$\frac{1}{4}$	$4\frac{1}{4}$	$5\frac{7}{8}$
TOLERANCE, in.															$\frac{1}{16}$

Figure 1—*Continued*

4.2. *Spacer Disk*—A circular spacer disk made of metal 150.8 ± 0.8 mm ($5^{15}/_{16}$ ± $^{1}/_{32}$ in.) in diameter and 61.37 ± 0.25 mm (2.416 ± 0.01 in.) in height. (See Figure 1.)

Note 1—When using molds having a height of 177.80 mm (7.0 in.) (Figure 1), a spacer disk height of 61.37 mm (2.416 in.) is needed to obtain a thickness of compacted specimen that conforms to the thickness: 116.43 mm (4.584 in.) of specimens in T 99 and T 180.

4.3. *Rammer*—A rammer as specified in either T 99 or T 180.

4.4. *Apparatus for Measuring Expansion*—This consists of a swell plate with adjustable stem (Figure 1) and a tripod support for a dial indicator (Figure 1). The swell plate is made of metal, 149.2 ± 1.6 mm ($5^{7}/_{8}$ ± $^{1}/_{16}$ in.) in diameter and is perforated with 1.6-mm ($^{1}/_{16}$-in.) diameter holes. The tripod used to support the dial indicator is arranged to fit the mold extension collar.

4.5. *Indicators*—Two dial indicators: each indicator shall have a 25-mm (1-in.) throw and read to 0.02 mm (0.001 in.).

4.6. *Surcharge Weights*—One annular metal weight with a center hole approximately 54.0 mm ($2^{1}/_{8}$ in.) in diameter and several slotted or split metal weights, all 149.2 ± 1.6 mm ($5^{7}/_{8}$ ± $^{1}/_{16}$ in.) in diameter and each having a mass of 2.27 ± 0.04 kg (5 ± 0.10 lb) (Figure 1) (Note 2).

Note 2—When using split weights, the mass of the pair shall be 2.27 ± 0.04 kg (5 ± 0.10 lb).

4.7. *Penetration Piston*—A metal piston of circular cross-section having a diameter of 49.63 ± 0.13 mm (1.954 ± 0.005 in.) area = 1935 mm^2 (3 $in.^2$) and not less than 102 mm (4 in.) long. (See Figure 1.)

4.8. *Loading Device*—A compression-type apparatus capable of applying a uniformly increasing load up to a capacity sufficient for the material being tested at a rate of 1.3 mm/min. (0.05 in./min.), used to force the penetration piston into the specimen.

4.9. *Soaking Tank*—A soaking tank suitable for maintaining the water level 25 mm (1 in.) above the top of the specimens.

4.10. *Drying Oven*—A thermostatically controlled drying oven capable of maintaining a temperature of 110 ± 5ºC (230 ± 9ºF) for drying moisture samples.

4.11. *Moisture Content Containers*—As specified in T 265.

4.12. *Miscellaneous*—Miscellaneous tools such as mixing pans, spoons, straightedge, filter paper, balances, etc.

5. SAMPLE

5.1. The sample shall be handled and specimen(s) for compaction shall be prepared in accordance with the procedures given in T 99 or T 180 for compaction in a 152.4-mm (6-in.) mold except as follows:

5.1.1. If all material passes a 19.0-mm ($^{3}/_{4}$-in.) sieve, the entire gradation shall be used for preparing specimens for compaction without modification. If there is material retained on the 19.0-mm sieve, the material retained on the 19.0-mm sieve shall be removed and replaced by an equal amount of material passing the 19.0-mm sieve and retained on the 4.75-mm (No. 4) sieve obtained by separation from portions of the sample not otherwise used for testing.

5.1.2. *Bearing Ratio at Optimum Water Content*—From a sample having a mass of 35 kg (75 lb) or more, select a representative portion having a mass of approximately 11 kg (25 lb) for a moisture-density test and divide the remainder of the sample to obtain three representative portions having a mass of approximately 6.8 kg (15 lb) each.

5.1.3. *Bearing Ratio for a Range of Water Content*—From a sample having a mass of 113 kg (250 lb) or more, select at least five representative portions having a mass of approximately 6.8 kg (15 lb) each for use in developing each compaction curve.

6. MOISTURE-DENSITY RELATION

6.1. *Bearing Ratio at Optimum Water Content*—Using the 11-kg (25-lb) portion prepared as described in Section 5.1, determine the optimum moisture content and maximum dry density in accordance with the compaction method specified, either T 99 or T 180. A previously performed compaction test on the same material may be substituted for the compaction test just described, provided that if the sample contains material retained on the 19.0-mm ($^3/_4$-in.) sieve, soil prepared as described in Section 5.1 is used (Note 3).

Note 3—Maximum dry unit mass obtained from a compaction test performed in a 101.6-mm (4-in.) diameter mold may be slightly greater than the maximum dry unit weight obtained from compaction in the 152.4-mm (6-in.) compaction mold or CBR mold.

6.2. *Bearing Ratio for a Range of Water Content*—Using the 6.8-kg (15-lb) specimens prepared as described in Section 5.1, determine the optimum moisture content and maximum dry density in accordance with the compaction method specified, either T 99 (Method D) or T 180 (Method D) except that the CBR molds shall be used and each specimen shall be penetrated for CBR determination. In addition, the complete moisture-density relationship for 25-blow and 10-blow per layer compactions shall be developed and each test specimen compacted shall be penetrated. Perform all compaction in CBR molds. In cases where the specified unit mass is at or near 100-percent maximum dry unit mass, it will be necessary to include a compactive effort greater than 56 blows per layer (Note 4).

Note 4—A semilog plot of dry unit mass versus compactive effort usually gives a straight-line relation when compactive effort in J/m^3 ($ft\text{-}lb/ft^3$) is plotted on the log scale. This type of plot is useful in establishing the compactive effort and number of blows per layer needed to bracket the specified dry unit mass and water content range.

6.2.1. If the soaked CBR is to be determined, take a representative sample of the material, for the determination of moisture, at the beginning of compaction of each specimen and another sample of the remaining material after compaction of each specimen. Use T 265 to determine the moisture content. If the unsoaked CBR is to be determined, take a moisture content sample in accordance with T 99 or T 180 if the average moisture content is desired.

7. PROCEDURE

7.1. *Bearing Ratio at Optimum Water Content*:

7.1.1. Normally, three specimens must be compacted so that their compacted densities range from 95 percent (or lower) to 100 percent (or higher) of the maximum dry density determined in Section 6.1.

Note 5—Generally about 10, 30, and 65 blows per layer are suitable for compacting specimens 1, 2, and 3, respectively. More than 56 blows per layer are generally required to mold a CBR specimen to 100 percent of the maximum dry density determined by T 99 (Method D); this is due to the sample for the moisture-density test being reused, while the sample for the CBR specimen is mixed and compacted only once.

Note 6—Some laboratories may prefer to test only one specimen which would be compacted to maximum dry density at optimum moisture content as determined by either T 99 or T 180.

7.1.2. Clamp the mold to the base plate, attach the extension collar and weigh to the nearest 5 g (0.01 lb). Insert the spacer disk into the mold and place a coarse filter paper on top of the disk.

7.1.3. Mix each of the three 6.8-kg (15-lb) portions prepared in Section 5.1.2 with sufficient water to obtain the optimum moisture content determined in Section 6.1.

7.1.4. Compact the first of the three portions of soil-water mixture into the mold, using three equal layers and appropriate rammer if maximum density was determined by T 99 or five equal layers if maximum density was determined by T 180, to give a total compacted depth of about 125 mm, compacting each layer with the lowest selected number of blows in order to give a compacted density of 95 percent or less of the maximum density.

7.1.5. Determine the moisture content of the material being compacted at the beginning and end of the compaction procedure (two samples). Each moisture sample shall have a mass of at least 100 g for fine-grained soils and 500 g for coarse-grained soils. Determination of moisture content shall be done in accordance with T 265, Laboratory Determination of Moisture Content of Soils.

7.1.6. Remove the extension collar, and using a straightedge, trim the compacted soil even with the top of the mold. Surface irregularities should be patched with small-sized material. Remove the spacer disk, place a coarse filter paper on the perforated base plate, invert the mold and compacted soil and place on the filter paper so the compacted soil is in contact with the filter paper. Clamp the perforated base plate to the mold and attach the collar. Determine the mass of the mold and specimen to the nearest 5 g (0.01 lb).

7.1.7. Compact the other two 6.8-kg (15-lb) portions in accordance with the procedure in Sections 7.1.4 through 7.1.6, except that an intermediate number of blows per layer should be used to compact the second specimen and the highest number of blows per layer shall be used to compact the third specimen.

7.2. *Bearing Ratio for a Range of Water Content*:

7.2.1. Prepare specimens in accordance with Section 6.2. Perform all compaction in the CBR molds. Each specimen used to develop the compaction curves for the 10-blow, 25-blow, and 56-blow per layer compactive efforts shall be penetrated. In cases where the specified unit mass is at or near 100 percent maximum dry unit mass, it will be necessary to include a compactive effort greater than 56 blows per layer.

8. SOAKING

8.1. Place the swell plate with adjustable stem on the soil sample in the mold and apply sufficient annular weights to produce an intensity of loading equal to the mass of the subbase and base courses and surfacing above the tested material. The total mass shall be a minimum of 4.54 kg. Additional mass shall be added in increments of 2.26 kg.

8.2. Place the tripod with dial indicator on top of the mold and make an initial dial reading.

8.3. Immerse the mold in water to allow free access of water to top and bottom of the specimen. During soaking, maintain the water level in the mold and the soaking tank approximately 25 mm (1 in.) above the top of the specimen. Soak the specimen 96 hours (four days).

Note 7—A shorter immersion period (not less than 24 hours) may be used for soil-aggregate materials that drain readily if tests show that the shorter period does not affect the test results. For some clay soils, a soaking period greater than 4 days may be required.

8.4. At the end of 96 hours, make a final dial reading on the soaked specimens and calculate the swell as a percentage of the initial sample length:

$$\text{Percent swell} = \frac{\text{Change in length in mm during soaking}}{116.43\ \text{mm}} \times 100 \qquad (1)$$

8.5. Remove the specimens from the soaking tank, pour the water off the top and allow to drain downward for 15 minutes. Care shall be taken not to disturb the surface of the specimens during removal of the water. After draining, remove the surcharge weights and perforated plates.

Note 8—The mass of the specimens may be determined after draining when it is desired to determine the average wet density of the soaked and drained material.

9. PENETRATION TEST

9.1. *Application of Surcharge*—Place a surcharge of annular and slotted weights on the specimens equal to that used during soaking. To prevent displacement of soft materials into the hole of the surcharge weights, seat the penetration piston with a 44 N (10-lb) load after one surcharge weight has been placed on the specimen. After seating the penetration piston the remainder of the surcharge weights shall then be placed around the piston.

9.2. *Seating Piston*—Seat the penetration piston with a 44 N (10-lb) load, then set both the penetration dial indicator and the load indicator to zero.

9.3. *Application of Load*—Apply the loads to the penetration piston so the rate of penetration is uniform at 1.3 mm (0.05 in.)/min. Record the load when the penetration is 0.64, 1.27, 1.91, 2.54, 3.81, 5.08, and 7.62 mm (0.025, 0.050, 0.075, 0.100, 0.150, 0.200, and 0.300 in.). Load readings at penetrations of 10.16 and 12.70 mm (0.400 and 0.500 in.) may be obtained if desired.

Note 9—The moisture content of the upper 25 mm (1 in.) may be determined after testing if desired. Moisture samples shall weigh at least 100 g for fine-grained soils and 500 g for granular soils.

10. CALCULATIONS

10.1. *Stress-Strain Curve*—Plot the stress-strain (resistance to penetration-depth of penetration) curve for each specimen as shown in Figure 2. In some instances, the initial penetration takes place without a proportional increase in the resistance to penetration and the curve may be concave upward. To obtain the true stress-strain relationships, correct the curve having concave upward shape near the origin by adjusting the location of the origin by extending the straightline portion of the stress-strain curve downward until it intersects the abscissa. (See dashed lines.)

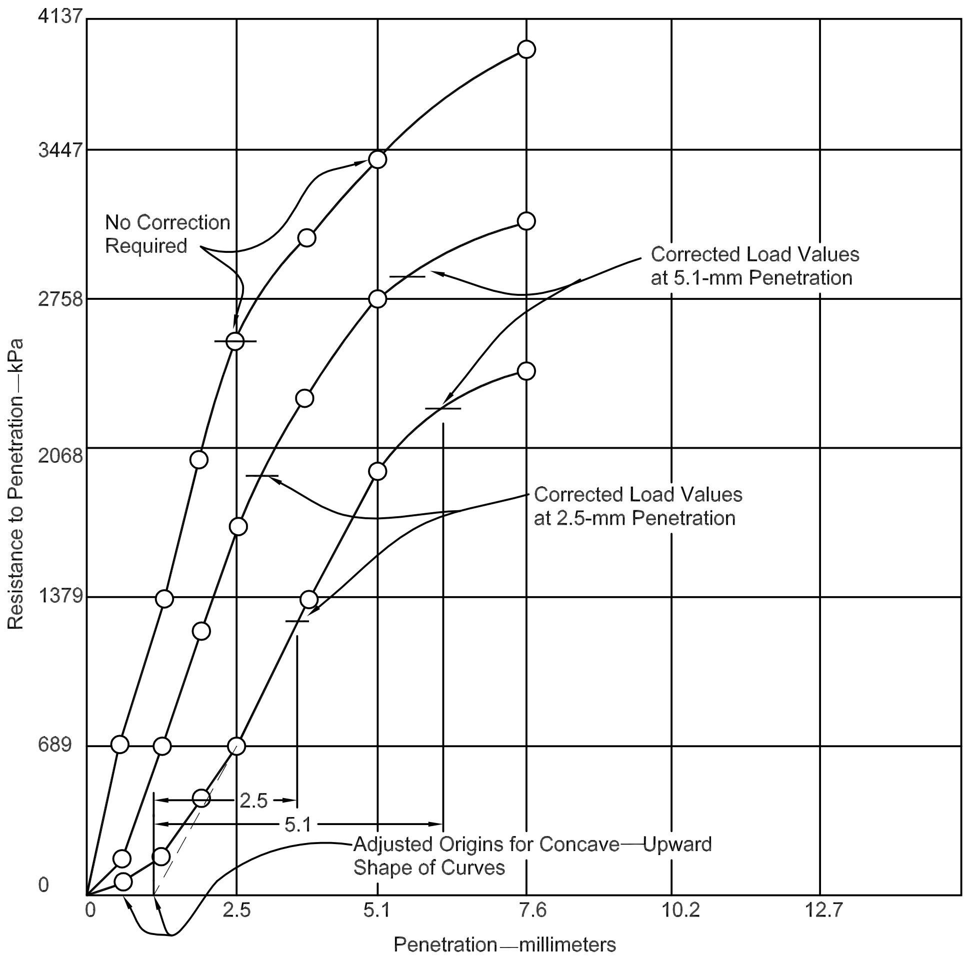


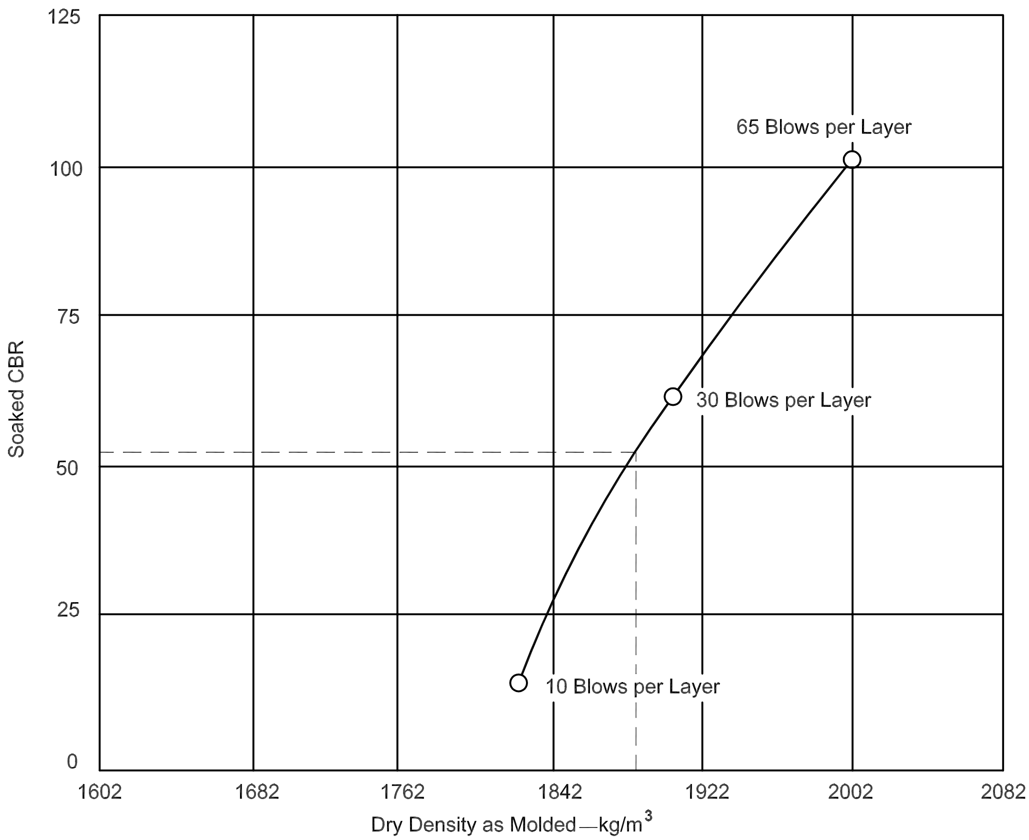
Figure 2—Correction of Stress-Strain Curves

10.2. *California Bearing Ratio*—The corrected load values shall be determined for each specimen at 2.54 and 5.08 mm (0.10 and 0.20 in.) penetration. California Bearing Ratio values are obtained in percent by dividing the corrected load values at 2.54 and 5.08 mm (0.10 and 0.20 in.) by the standard loads of 6.9 and 10.3 MPa (1000 and 1500 psi), respectively, and multiplying these ratios by 100.

$$\text{CBR} = \frac{\text{Corrected load value}}{\text{Standard load}} \times 100$$

10.2.1. The CBR is generally selected at 2.54 mm (0.10 in.) penetration. If the ratio at 5.08 mm (0.20 in.) penetration is greater, the test shall be rerun. If the check test gives a similar result, the ratio at 5.08 mm (0.20 in.) penetration shall be used.

10.3. *Design CBR for One Water Content Only*—Using the data obtained from the three specimens, plot the CBR-Dry Density as Molded relation as shown in Figure 3. The design CBR may then be determined at the desired percentage of the maximum dry density, normally the minimum percentage compaction permitted by the agency's compaction specifications.



Example:

Given: Maximum dry density by T 99 = 1986 kg/m^3

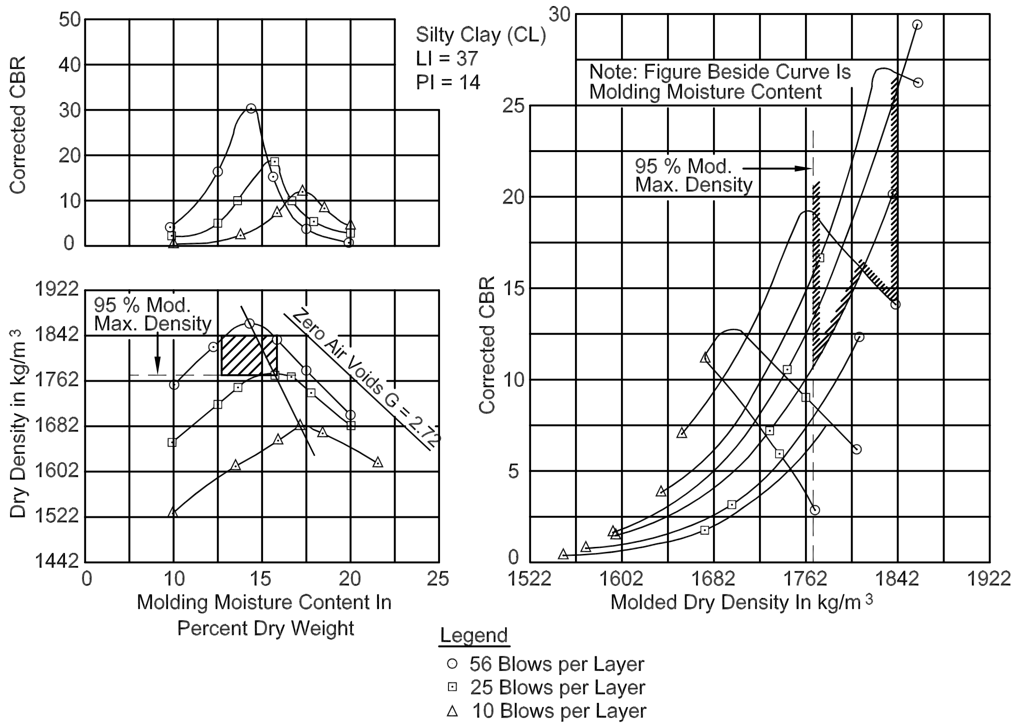
Find : The CBR at 95 percent of the above maximum dry density.

Solution: 95 percent of 1986 kg/m^3 = 1887 kg/m^3
At 1887 kg/m^3 > the CBR is 52.

Note: 1 pcf = 16.02 kg/m^3

Figure 3—Dry Density Versus CBR

10.4. *Design CBR for Water Content Range*—Plot the data from the tests at the three compactive efforts as shown in Figure 4. The data plotted as shown represents the response of the soil over the range of water content specified. Select the CBR for reporting as the lowest CBR within the specified water content range having a dry unit mass between the specified minimum and the dry unit mass produced by compaction within the water content range.



Note: Surcharge = 50-lb soaking and penetration. All samples soaked top and bottom four days. All samples compacted in five layers, 10-lb rammer, 18-in. drop in CBR mold.

Figure 4—Determining CBR for Water Content Range and Minimum Dry Unit Weight

11. REPORT

11.1. The report shall include the following information for each specimen:

11.1.1. Compaction effort (number of blows per layer).

11.1.2. Dry density as molded percent.

11.1.3. Moisture content as molded percent.

11.1.4. Swell (percent of original length) percent.

11.1.5. California Bearing Ratio percent.