

APPENDIX A

California Bearing Ratio Design Methodology

The CBR is the basis for determining the thickness of soil and aggregate layers used in the design of roads and airfields in the theater of operations. A soil's CBR value is an index of its resistance to shearing under a standard load compared to the shearing resistance of a standard material (crushed limestone) subjected to the same load.

CBR DESIGN METHODOLOGY

The CBR design methodology has four major parts:

- Evaluate the soil to determine its engineering characteristics (gradation, Atterberg limits, swell potential, Proctor test (CE 55 compaction test) and CBR test). These tests are performed by a Materials Quality Specialist, Military Occupational Speciality (MOS) 51G or a soils testing laboratory according to standard testing procedures (see *TM 5-530*).
- Evaluate the laboratory data to determine the initial design CBR value and the compactive effort to be applied during construction.
- Evaluate all soil data to determine the final design CBR and construction use of the soil or aggregate.
- Determine the thickness of the soil layer based on the final design CBR and the road or airfield use category (see *TM 5-330*).

This appendix focuses on the second and third parts of the methodology.

CBR Design Flowchart

The CBR Design Flowchart (see *Figure A-1, pages A-2 and A-3*) is a useful tool when determining the initial and final design CBR values.

Step 1 - Look at the Compaction Curves. For CBR analysis, soils are classified into one of three soil groups:

- Free-draining.
- Swelling.
- Nonswelling.

The compaction curve on page 1 of a Department of Defense (DD) Form 2463 gives an indication as to the group in which a particular soil falls. A U-shaped compaction curve indicates a free-draining soil. A bell-shaped compaction curve indicates that the soil is either a swelling or a nonswelling soil.

Step 2- Look at the Swell Curve. To distinguish between a swelling and nonswelling soil, look at the swell data plotted on a DD Form 1211. If the percent of swell exceeds 3 percent for any soil moisture content, the soil is classified as a swelling soil. If the percent of swell never exceeds 3 percent, the soil is nonswelling.

Step 3- Find the Peak of the CE 55 Curve. The maximum dry density is found at the

Schematic 1

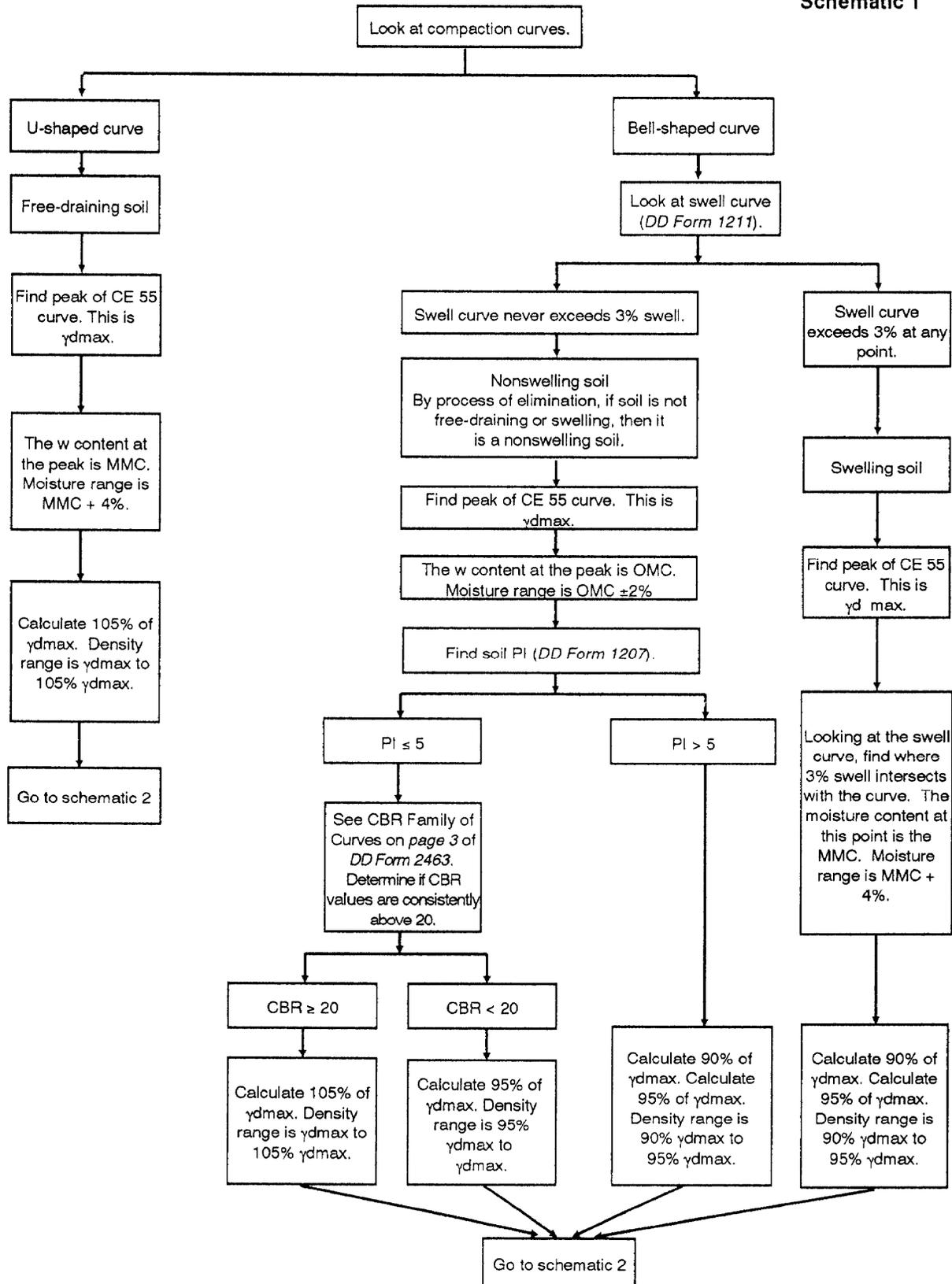


Figure A-1. CBR design flowchart.

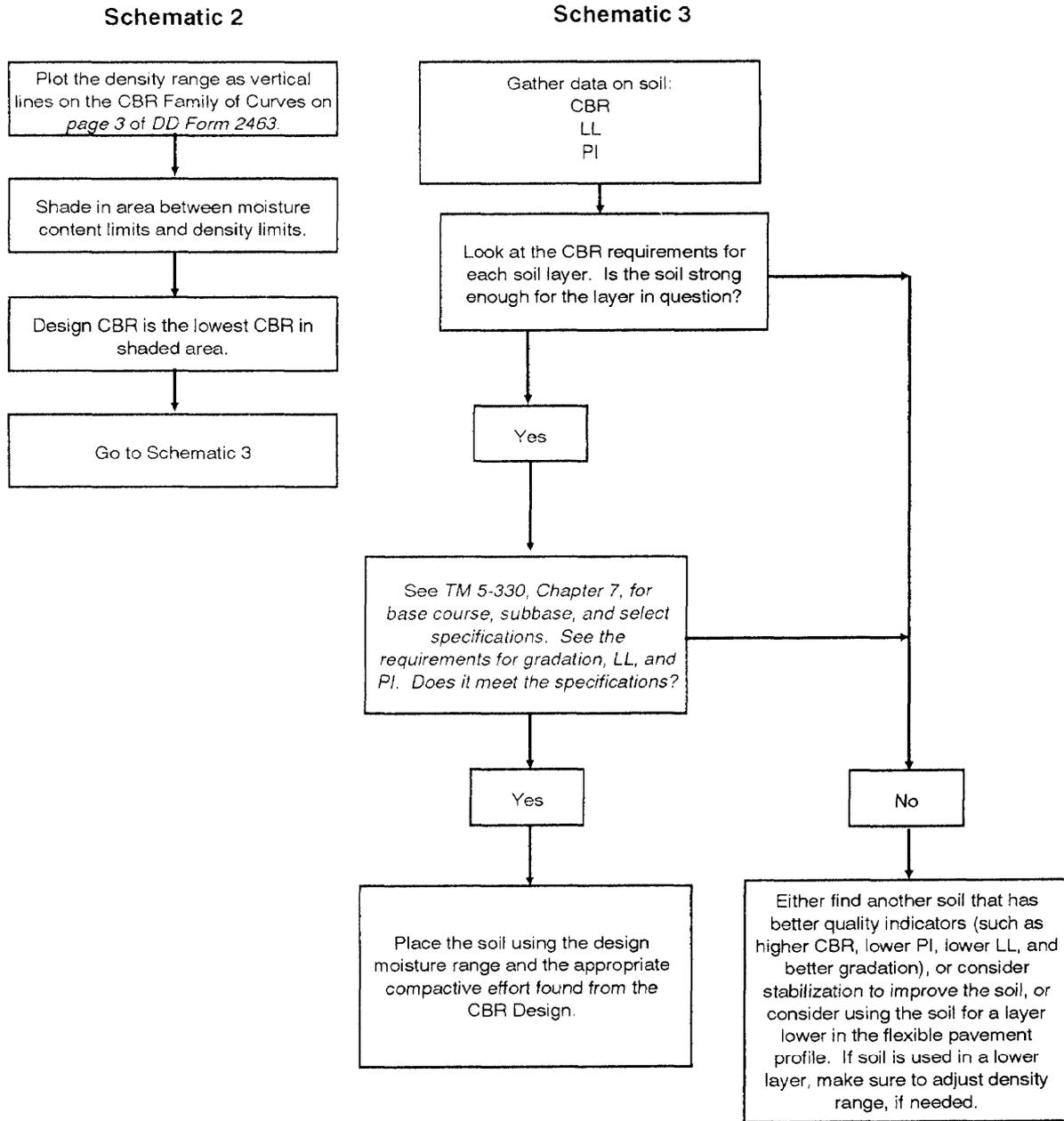


Figure A-1. CBR design flowchart (continued).

peak of the CE 55 curve. For free-draining soils, the peak of the curve occurs at the point of the curve where there is no increase in dry density with an increase in moisture.

Step 4 - Determine the Design Moisture Range. The design moisture range is influenced by the soil group.

- Free-draining soils. The moisture content that corresponds to the maximum dry density is the MMC. The design moisture range is $MMC + 4$ percent. For example, if the maximum dry density occurred at 13 percent soil moisture, the MMC would equal 13 percent and the design moisture range would be 13 to 17 percent soil moisture.
- Swelling soils. Army standards permit no more than 3 percent swell to occur after a soil has been placed and compacted. Therefore, swelling soils must be preswelled to a moisture content that will result in 3 percent or less swell. The moisture content at which 3 percent swell occurs is called the MMC. The design moisture range for a swelling soil is $MMC + 4$ percent. The moisture content corresponding to the maximum dry density is not considered for swelling soils.
- Nonswelling soils. The moisture content that corresponds to the maximum dry density is the OMC. The design moisture range is $OMC \pm 2$ percent. For example, if the OMC is 12 percent, the design moisture range would be 10 to 14 percent.

Step 5 - Find the Soil Plasticity Index.

This step applies to nonswelling soils only. Noncohesive soils ($PI \leq 5$) can be compacted to greater densities than cohesive soils ($PI > 5$). If the soil is cohesionless, look at the CBR Family of Curves on page 3 of a DD Form 2463 to determine the compactive effort.

Step 6 - Determine the Density Range.

The theater-of-operations, standard compaction range is 5 percent, unless otherwise

stated. The maximum dry density is the basis for determining the density range (compactive effort).

- Free-draining soils. They are compacted to between 100 percent and 105 percent maximum dry density.
- Swelling soils. They are compacted to between 90 and 95 percent of maximum dry density.
- Nonswelling soils.
 - $PI > 5$. Cohesive nonswelling soils are compacted to between 90% and 95% of maximum dry density.
 - $PI \leq 5$ and $CBR < 20$. cohesionless, nonswelling soils having CBR values below 20 are compacted to between 95 percent and 100 percent maximum dry density.
 - $PI \leq 5$ and $CBR \geq 20$. cohesionless, nonswelling soils having CBR values ≥ 20 are compacted to between 100 percent and 105 percent maximum dry density.

Step 7 - Plot the Density Range. Draw vertical lines on the CBR Family of Curves on page of a DD 2463, corresponding to the density range determined in previous steps. Circle the moisture values that correspond to the moisture range determined in earlier (five moisture values should be circled).

Step 8 - Determine the Initial Design CBR. Using the CBR Family of Curves, find where each moisture curve, within the moisture range, enters and exits the density-range limit lines drawn in previous step. Find the CBR value corresponding to the lowest entrance or exit point of each curve. This is the initial design CBR.

Step 9 - Gather the Soil Data. The CBR is not the only criteria used when determining where to place a soil in the road or airfield design. Criteria for the LL, the PI, and the grain-size distribution must also be satisfied. Subbase and select material criteria are found in *Table A-1*. Base-course gradation requirements are found in *Table A-2*.

Step 10 - Determine the Final Design CBR. Using the initial design CBR value,

Table A-1. Recommended maximum permissible values of gradation and Atterberg limit requirements in subbases and select materials.

Material	Maximum Design CBR		Size, Inches		Gradation Requirements Percent Passing				Atterberg Limits			
	Air-fields	Roads	Air-fields	Roads	No 10		No 200		LL		PI	
					Air-fields	Roads	Air-fields	Roads	Air-fields	Roads	Air-fields	Roads
Subbase	50	50	3	2	50	50	15	15	25	25	5	5
Subbase	40	40	3	2	80	80	15	15	25	25	5	5
Subbase	30	30	3	2	100	100	15	15	25	25	5	5
Select Material	Below 20	20	3	3	-	-	25	-	35	35	12	12

Table A-2. Desirable gradation for crushed rock, gravel, or slag and uncrushed sand and gravel aggregates for base courses.

Sieve Designation	Percent Passing Each Sieve (Square Openings) By Weight				
	Maximum Aggregate Size				
	3-Inch	2-Inch	1 1/2-Inch	1-Inch	1-Inch Sand-Clay
3-inch	100				
2-inch	65-100	100			
1 1/2-inch		70-100	100		
1-inch	45-75	55-85	75-100	100	100
3/4-inch		50-80	60-90	70-100	
3/8-inch	30-60	30-60	45-75	50-80	
No 4	25-50	20-50	30-60	35-65	
No 10	20-40	15-40	20-50	20-50	65-90
No 40	10-25	5-25	10-30	15-30	33-70
No 200	3-10	0-10	5-15	5-15	8-25

determine if the soil material is suitable for use as a base, subbase, select, or subgrade layer material. Next, look at the gradation requirements for use in that layer. Finally, look at the LL and the PI criteria. If a soil material meets all the criteria for use in a soil layer, then it can be placed in that layer. If it fails to meet all criteria for its intended use, consider using the material in another layer. The final design CBR is determined by the criteria that the soil material meets. The following examples illustrate this point:

- A soil material has an initial design CBR value of 65. Based on CBR value, this material is suitable for use in a base-course layer for a road. The maximum aggregate size is 1.5 inches. When evaluating the soil against the base-course criteria in *Table A-2, page A-5*, we find that the percent passing the Number 40 sieve is 6 percent, which is less than the minimum allowable for use as a base course. Therefore, we cannot use the material as a base course, but perhaps it can be used as a subbase. By evaluating the soil against the CBR 50 subbase criteria (see *Table A-1, page A-5*), we find that the soil material meets all criteria. The final design CBR for this soil would be CBR 50. It would be used as a CBR 50 subbase.
- A soil material has an initial design CBR of 37. We are considering the use of this material as a subbase. There are no criteria for a CBR 37 subbase; therefore, we will use the following rule:
 - If a soil material meets the criteria of the next higher subbase, the final design CBR will be the same as the initial design CBR.
 - If a soil material fails to meet the criteria of the next higher subbase but meets the criteria of a lower subbase or select material, the initial design CBR will be adjusted downward to the maximum CBR value of the layer at which all criteria were met, which becomes the final design CBR.

In our example, if the soil material met the CBR 40 subbase criteria, the final design CBR would be 37 and the road or airfield would be designed with a CBR 37 subbase layer. If the soil failed to meet the CBR 40 subbase criteria but did meet the CBR 30 subbase criteria, the final design CBR would be 30 and the road or airfield would be designed with a CBR 30 subbase. If the soil failed to meet both the CBR 40 and CBR 30 subbase criteria, the material would be evaluated against the select material criteria. If it met the select criteria, the final design CBR would be 20.

CBR DESIGN PRACTICAL EXERCISE

In preparation for an airfield construction project in support of a Marine Corps exercise, a soil sample was obtained from Rio Meta Plain, Venezuela. The soil was tested, and the test results are presented in *Figures A-2 through A-9, pages A-7 through A-14*. Using the USCS, the soil was classified as a (GM-GC) (see *Figure A-2, and Figure A-3, page A-8*).

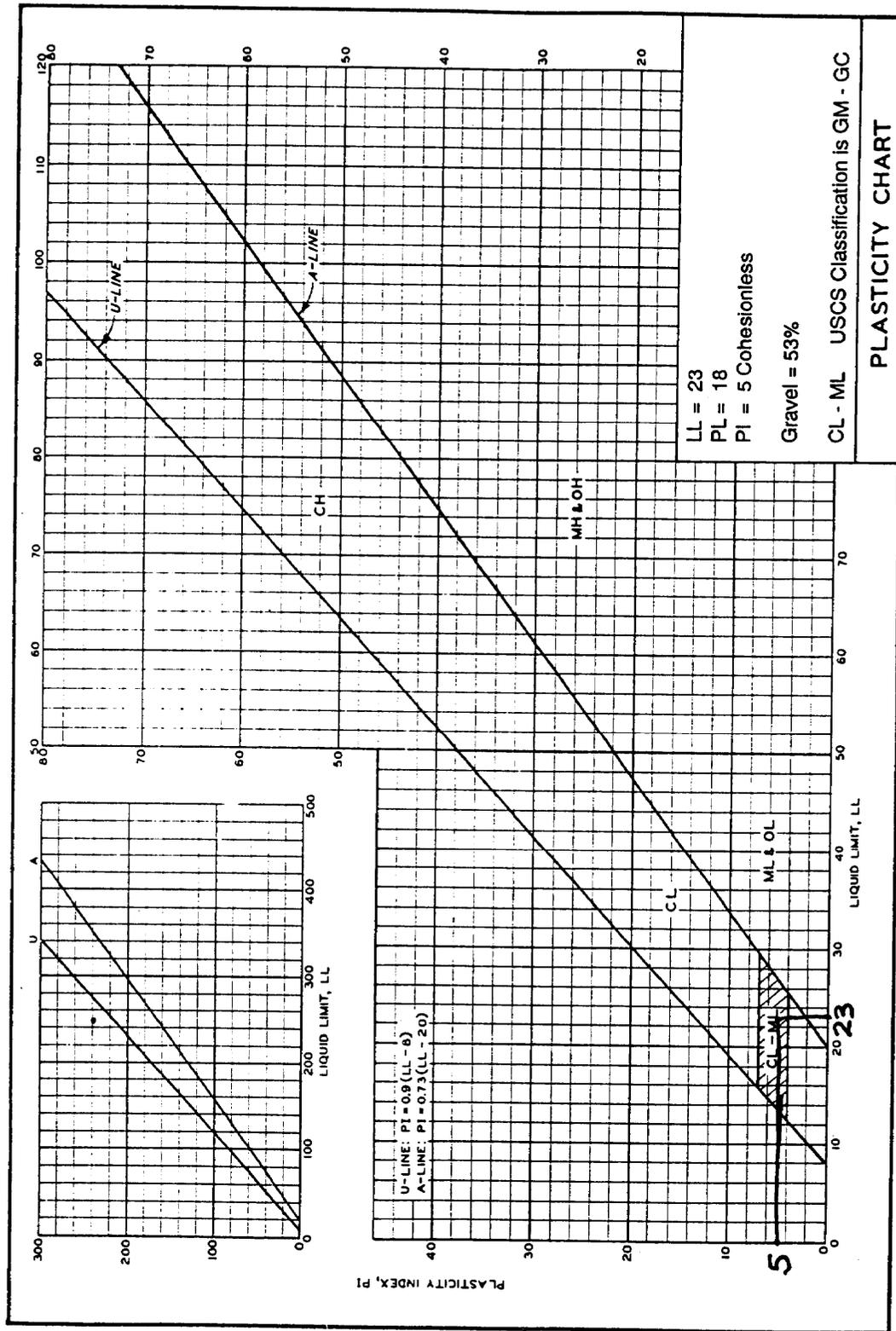
What are the initial and final design CBRs of this soil? Where will this soil be placed in the airfield design?

Looking at the density-moisture curve on *Figure A-4, page A-9*, we see that the compaction curve is bell-shaped (Step 1); therefore, the soil is either swelling or nonswelling. The swell data is shown in *Figure A-5, page A-10*. Swelling never exceeds 3 percent at any point on the curve (Step 2). The soil is nonswelling.

Maximum dry density occurs at 125 pcf (*Figure A-2, page A-7*), and the OMC is 11.3 percent. The design moisture range is 9.3 to 13.3 percent (Steps 3 and 4).

The LL and PL were determined to be 23 and 18, respectively. $PI = LL - PL (23 - 18 = 5)$; therefore, the soil is cohesionless. We must look at the CBR Family of Curves to determine the compactive effort (Step 5).

Figure A-6, page A-11, shows the CBR Family of Curves. Note that while some values exceed 20, most of the data points are clustered below 20. Thus, we will compact



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Figure A-3. Plasticity chart plotted with Rio Meta Plain soil data.

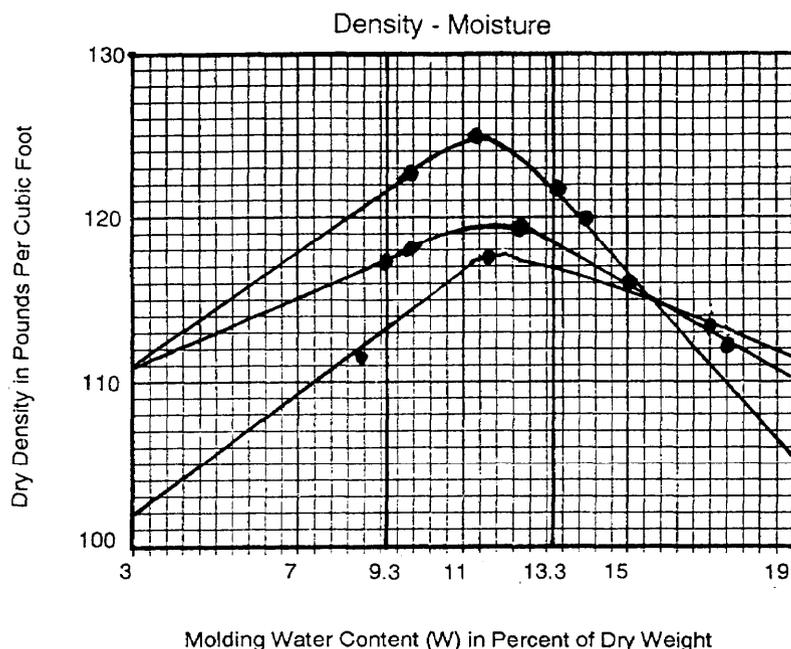


Figure A-4. Density-moisture curve for Rio Meta Plain soil.

this soil to a density between 95 percent and 100 percent maximum dry density or between 118.75 and 125 pcf (Step 6). When plotted on the density-moisture curve with the moisture range (9.3 to 13.3 percent), the specification block is formed (see *Figure A-7, page A-12*).

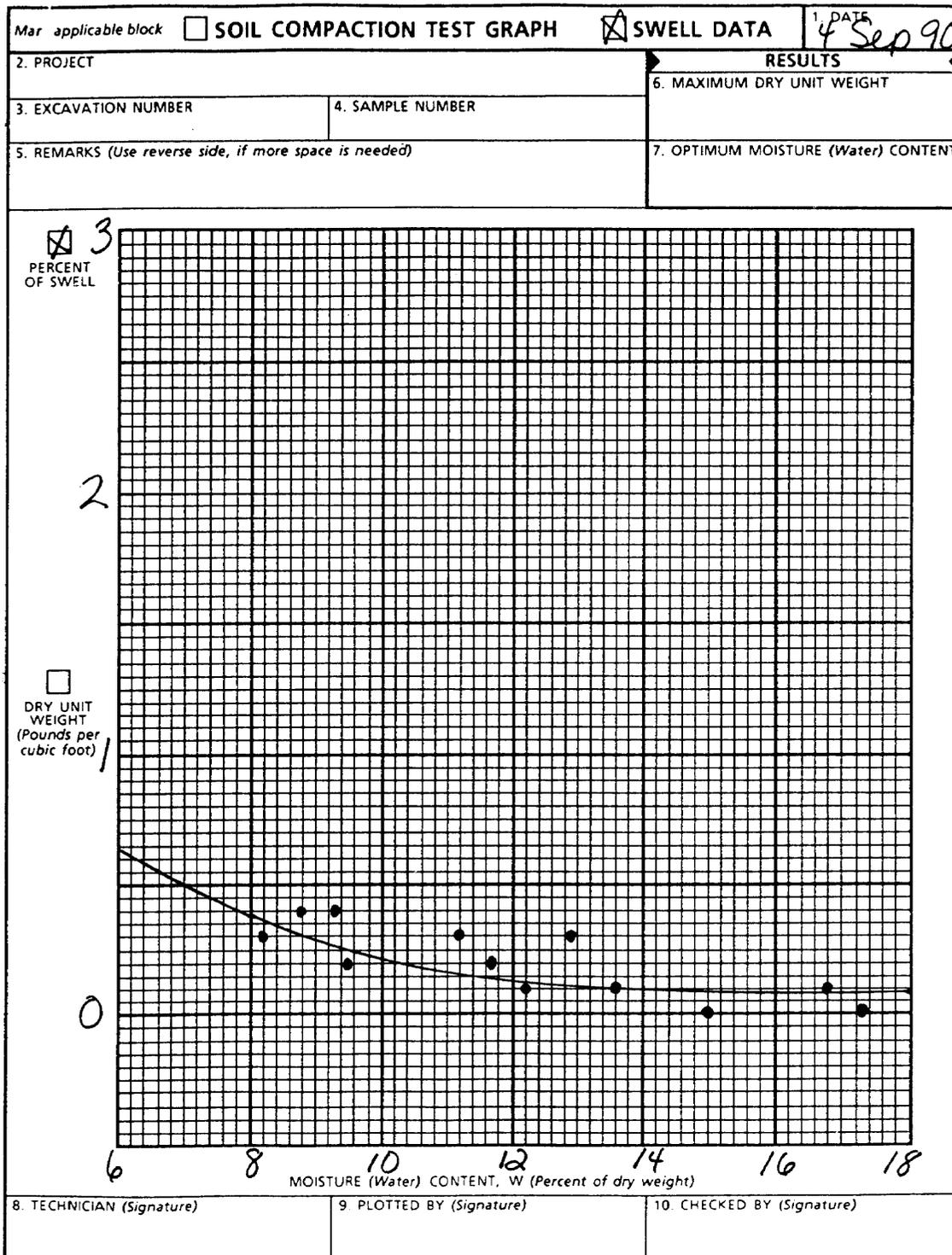
The CBR Family of Curves, *Figure A-8, page A-13*, shows the density range superimposed on the curves and the moisture range values circled (in this case we've circled the moisture values 9-13) (Step 7). Following each moisture curve in our range and marking where it enters and exits the density limits, we find that the lowest CBR value occurs at the point where the 13 percent moisture curve exits the 118.75 pcf density limit line. Interpolating between the 13 percent and 14 percent moisture curves, 13.3 percent moisture results in an assured CBR value of 7.5 (see *Figure A-9, page A-14*) (Step 8).

The initial design CBR of this soil is 7.5. Because of the low CBR, we can consider this soil material for use as select material if it meets the criteria of *Table A-1, page A-5*. Looking at DD Form 1207 (*Figure A-7, page*

A-12), we first check the maximum aggregate size and see that it is 2 inches. The maximum allowable aggregate size (see *Table A-1 page A-5*, for a select material used in the construction of an airfield is 3 inches; therefore, our soil meets this criteria. Next, we check for the percent passing the Number 200 sieve and find that the percent passing the Number 200 sieve is 23 percent. From *Table A-1, page A-5*, we find that the select criteria allows up to 25 percent of the material to pass the No 200 sieve; therefore, our soil meets this criteria. Finally, we must evaluate the LL and PI of our soil against the select criteria in *Table A-1, page A-5*. When we do this, we find that our soil's PI of 23 and LL of 5 meet the requirements.

The final design CBR of the soil is 7.5, and it is suitable for use as a select material.

The final portion of the CBR design process is to determine the thickness of the road or airfield structure based on the CBR values of the subgrade, select, subbase, and base-course materials available for use in the construction effort. This is discussed in detail in *TM 5-330*.



DD Form 1211, DEC 86

Previous editions are obsolete.

Figure A-5. Swelling curve for Rio Meta Plain soil.

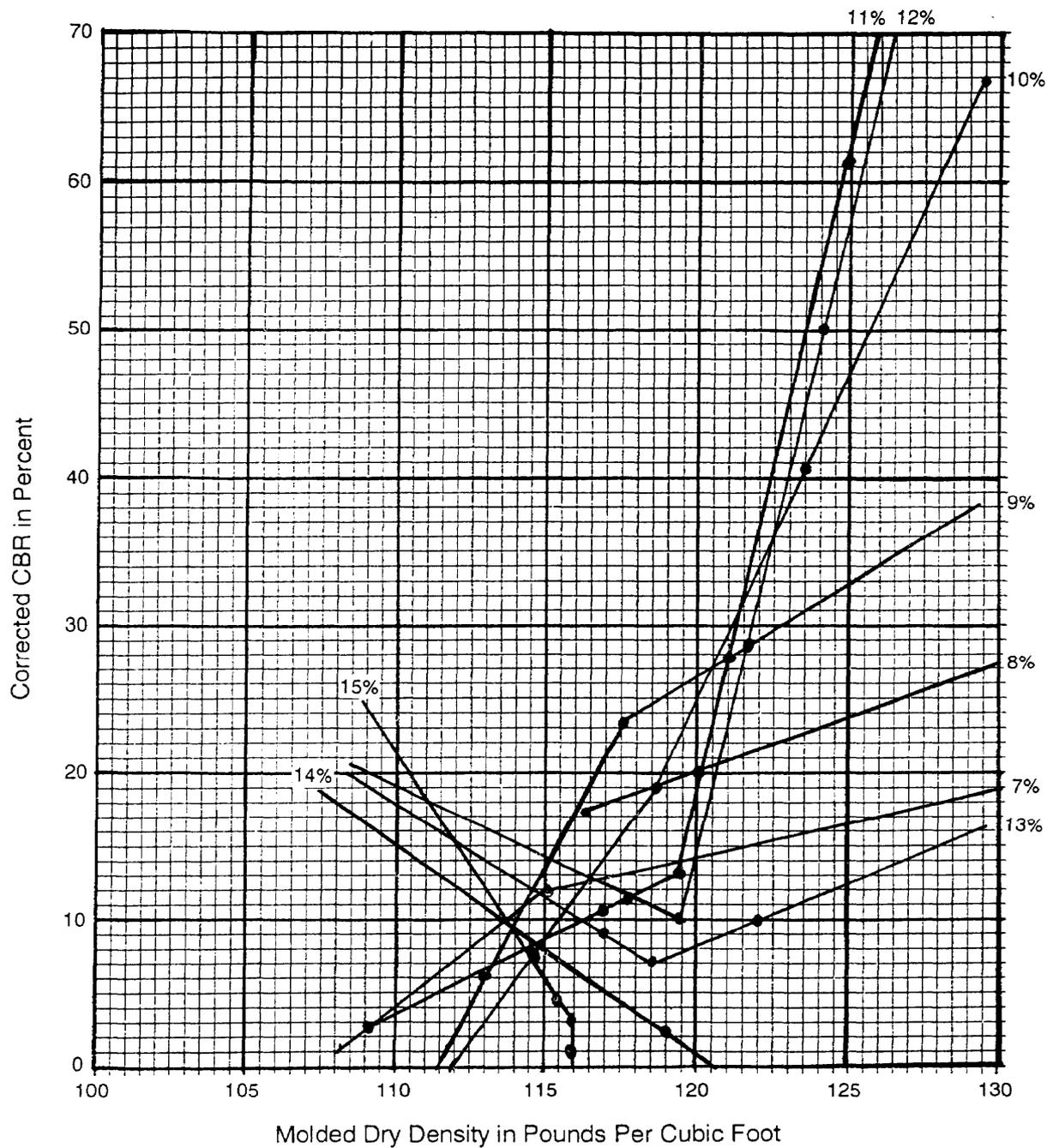


Figure A-6. CBR Family of Curves for Rio Meta Plain soil.

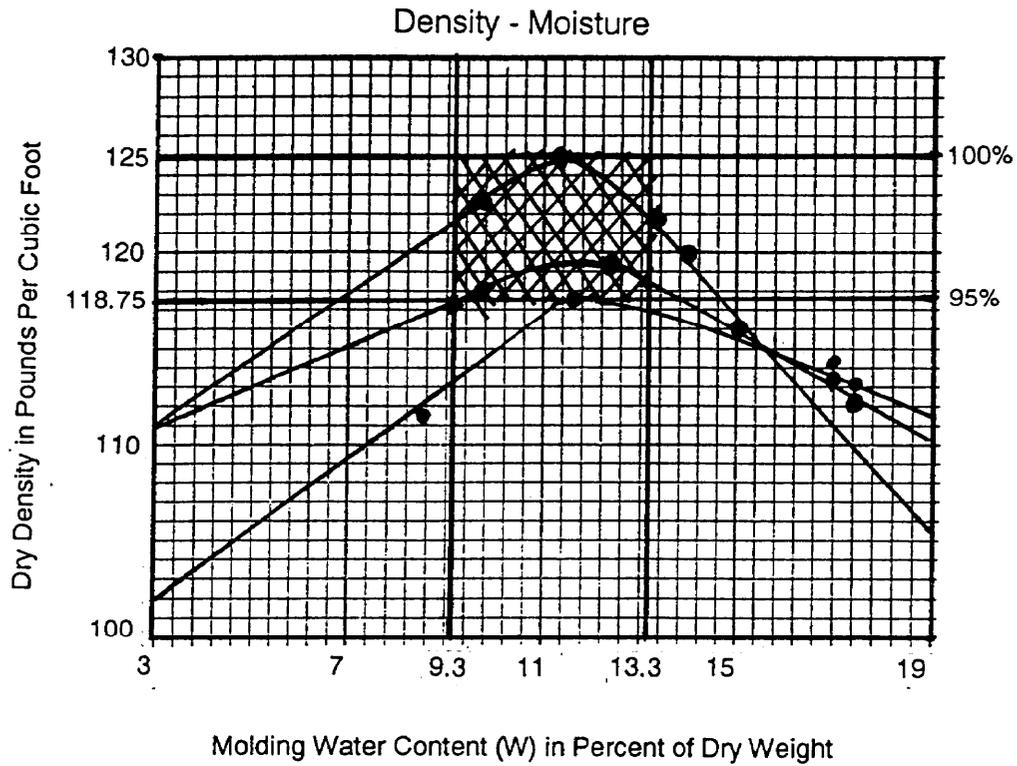


Figure A-7. Density-moisture curve for Rio Meta Plain soil with density and moisture ranges plotted.

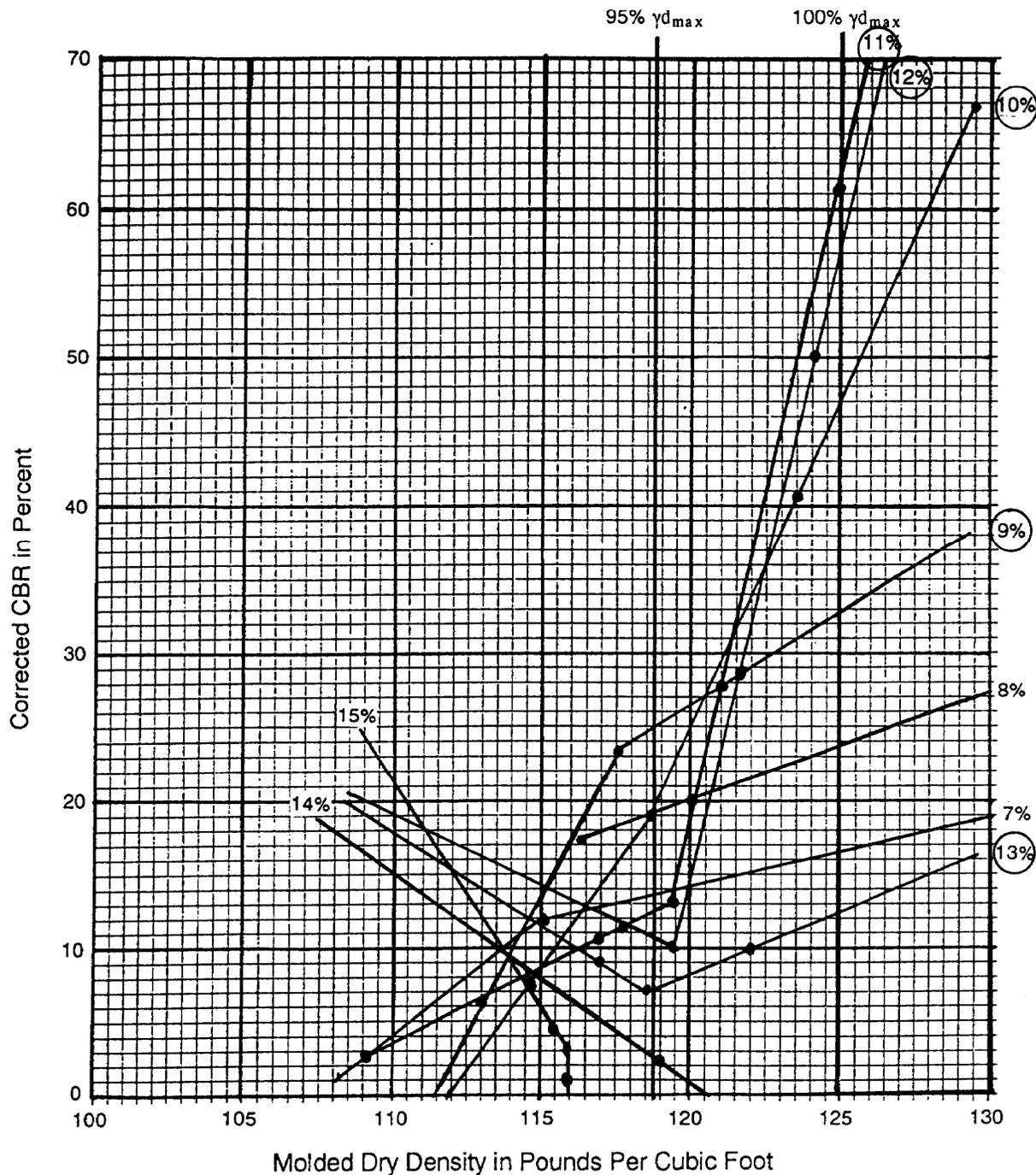


Figure A-8. CBR Family of Curves for Rio Meta Plain soil with density range plotted.

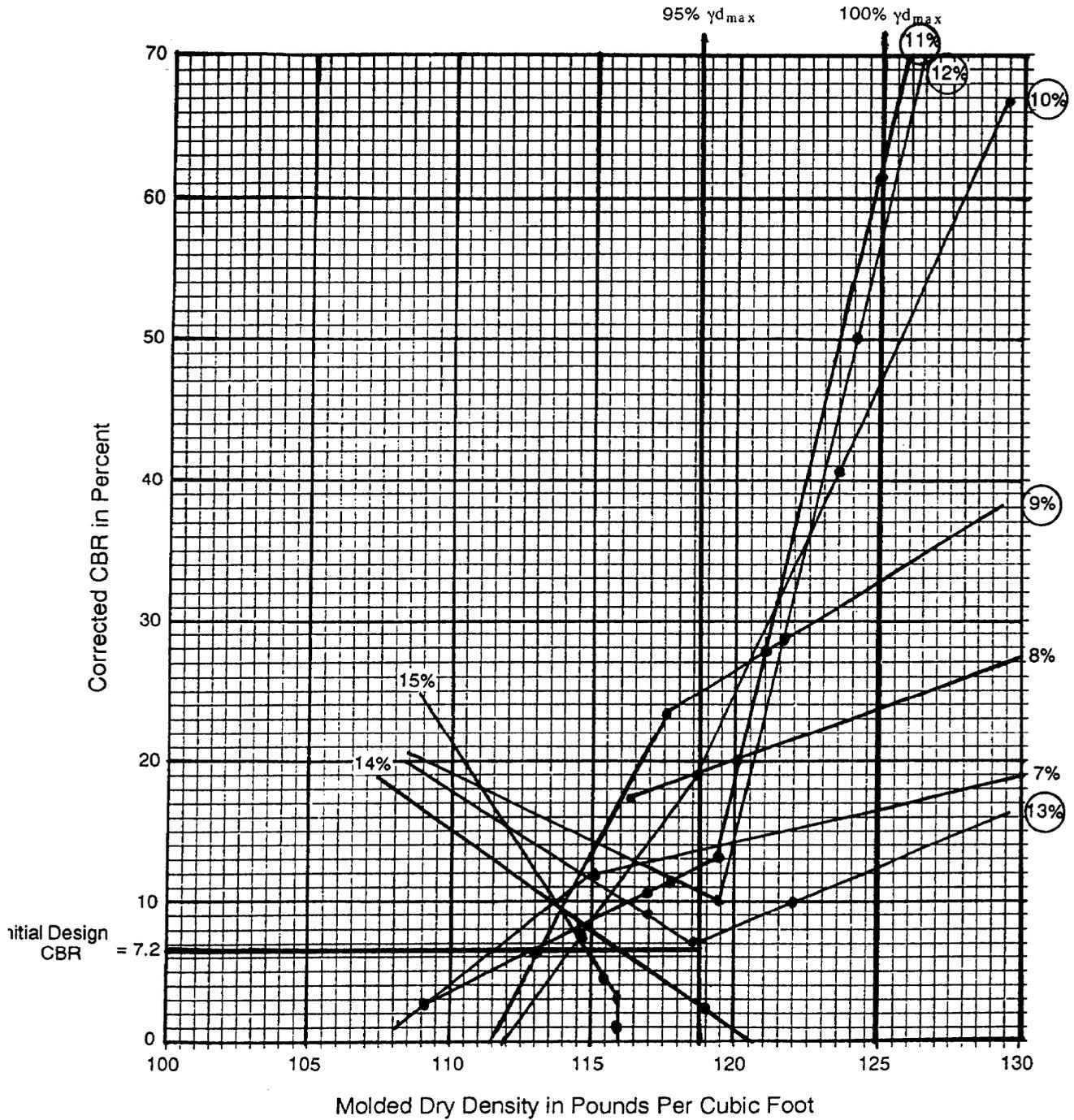


Figure A-9. Design CBR from Rio Meta Plain soil from CBR Family of Curves.