SOIL MECHANICS IA-EECQ 3171

BACHELOR OF ENGINEERING IN CIVIL ENGINEERING

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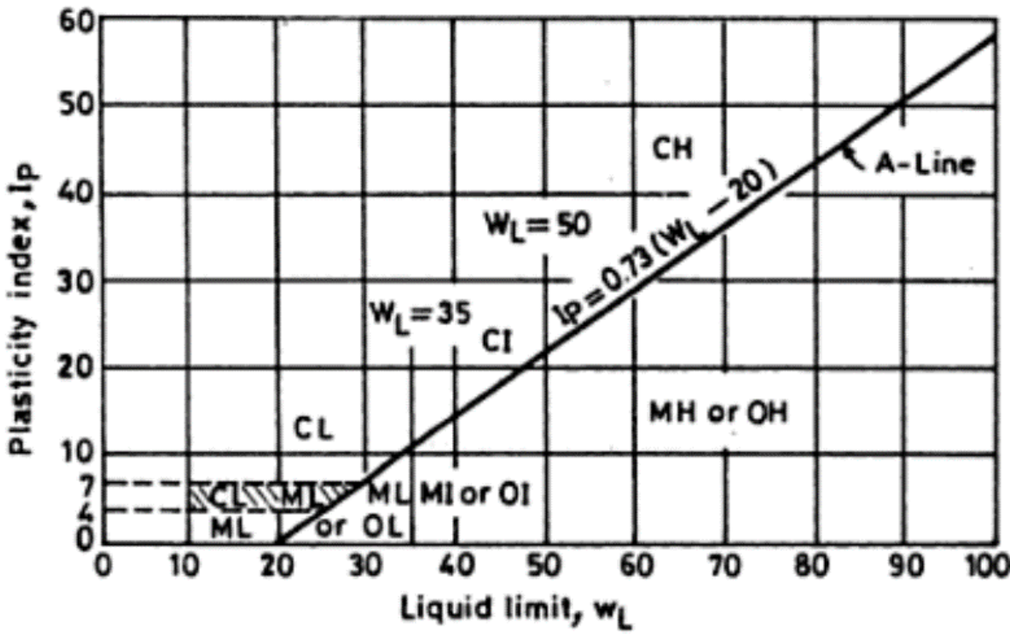
Soil Classification System

- **Unified Classification System**
  - Is the most popular classification system and combines gradation and plasticity.
  - Soils are placed in a group
  - Each group is denoted by a letter symbol representing main and qualifying terms
  - The liquid and plastic limits are used to classify fine-grained soils using th plasticity chart shown
  - The axes of plasticity chart are plasticity index and liquid limit
  - The diagonal line on the chart is known as the A-Line
  - The letter denoting the dominant size fraction is placed first in the group symbol



Plasticity Chart

Unified Classification System Cont’

- SILT (M) plots below the A-line and CLAY (C) plots above the A-line
- If a soil has a significant content of organic matter, the suffix O is added as the last letter of the group symbol.
- A group symbol may consist of two or more letters,
- For example
  - SW – Well-graded SAND
  - SCL – Very clayey SAND (clay of low plasticity)
  - CIS – Sandy CLAY of intermediate plasticity
  - MHSO – Organic sandy SILT of high plasticity
- Silts exhibit plastic properties over a lower range of water content than clays of the same liquid limit
- SILT or CLAY is qualified as gravelly if more than 50% of the coarse fractions is of gravel size and as sandy if more than 50% of the coarse fraction is of sand size
- Fine-grained soils have very high liquid limit if organic matter content is high
- Peats have usual have very high to extremely high liquid limits
- Any cobbles or bouders (particles retained in BS test sieve 63 mm) are removed before classification tests are done but their percentages in the sample are noted

Unified Classification System Cont'

- Mixtures of soil and boulders or cobbles can be indicated by using the letters Cb (COBBLES) or B (BOULDERS) joined by a + sign to the group symbol for the soil, the dominant component being written first.
- For example
  - GW+Cb $\Rightarrow$Well-graded GRAVEL with COBBLES
  - B + CL $\Rightarrow$ Boulders with CLAY of low plasticity
- In general, a classification system is useful in developing an understanding of the nature of different soil types in a manner that is understood internationally.

Unified Classification System Cont'

Dominant soil	Group symbol	Qualifying terms	
GRAVEL	G	Well-graded	W
SAND	S	Poorly graded	P
		Uniformly	Pu
		Gap graded	Pg
FINE SOIL, FINES	F	Of low plasticity (LL<35%)	L
SILT (M-SOIL)	M	Of interm plasticity (LL: 35-50)	I
CLAY	C	Of high plasticity LL: 50-70	H
		Of very high plasticity (LL: 70-90)	V
-		Of extremely high plasticity (LL>90)	E
-		Of upper plastic range (LL>35%)	U
PEAT	Pt	Organic (may be a suffix to any group)	O

Soil Compaction

- Soil compaction is the process of increasing the density of a soil by packing the particles closure together with a reduction of air.
- Loose soil for fills and embankments are placed in lifts of between 75 and 450mm in thickness and each layer is compacted with rollers, vibrators or rammers to a specified specification
- Medium cohesive soils are compacted by rolling
- Cohesionless soils (sand and some gravels) are compacted by vibration
- Degree of compaction of a soil depends on
  - Moisture content
  - Amount of compactive effort
  - Nature of soil
- The effect of compaction are
  - Increase in density of the soil
  - Increase in shear strength
  - Increase in bearing capacity through increase in shearing resistance
  - Decrease the tendency for settlement
  - Decrease in permeability of the soil

Soil Compaction Cont’

- Soil compaction may be static or dynamic (ramming, vibration or rolling)
- Ramming pounds the soil particles, pushing or packing them together and forces the air out of the voids
- The vibratory action sets the soil particles in motion then rearranges them into a denser packing
- The compaction characteristics of a soil can be assessed by means of standard laboratory tests

Soil compaction tests

- Soil compaction tests are used to
  - determine the soil moisture-density relationship
  - evaluate a soil for its suitability for constructing fills and embankments
- The existence of a relationship between moisture content and dry density was established by Proctor in 1933
  - For a particular compactive effort used, there is a particular moisture content at which a particular soil attains its maximum dry density
  - Such a moisture content is referred to as Optimum moisture content (OMC)
- The tests are done in accordance to specific standards

Soil compaction tests Cont'

- The standards used are:
  - (a) BS 1377 part 4, 1990 has 3 compaction procedures

(i) **Standard Proctor test** – the volume of the mould is 1 litre (1000 cm^3)

- the moist homogeneously mixed fine-grained soil passing 5 mm BS test sieve (Sieve no. 4) is compacted by a 2.5 kg rammer falling freely through a height of 300 mm,
- the soil is compacted in 3 layers each layer receiving 25-27 blows with the rammer.
- Each test is done with a regular measured increase in water (from dry to wet).
- At the end of each test, a small amount of the wet soil is taken for moisture content determination

(ii) **Modified Proctor test** - the volume of the mould is 1 litre (1000 cm^3)

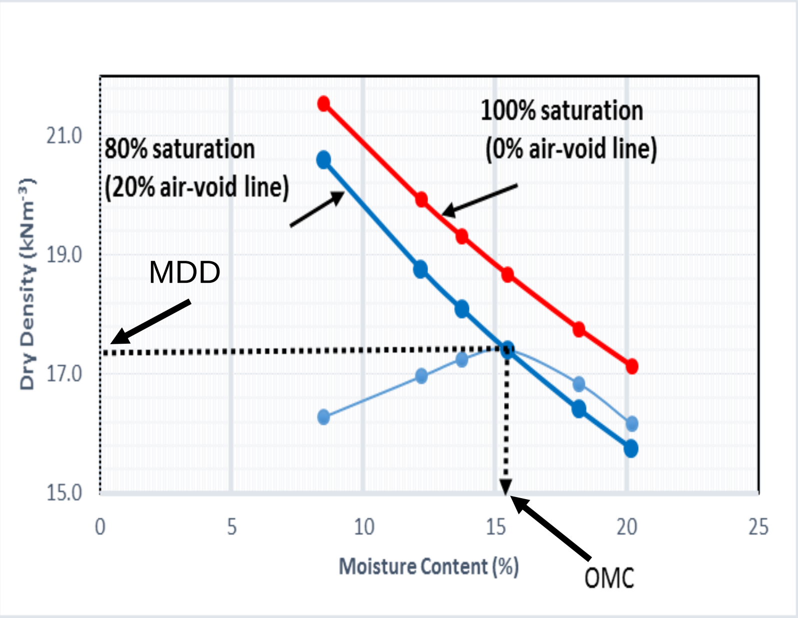
- the moist homogeneously mixed coarse-grained soil passing 20 mm BS test sieve is compacted by a 4.5 kg rammer falling freely through a height of 450 mm
- the soil is compacted in 5 layers each layer receiving 25-27 blows with the rammer, and the above is repeated

Soil compaction tests Cont'

- The standards used are:
  - (a) BS 1377 part 4, 1990 has 3 compaction procedures cont'
    - **(iii) Vibrating hammer test** – the soil passing 37.5 mm BS test sieve is compacted in 3 layers in a 2.3 litre mould using a circular tamper fitted in the vibrating hammer, each layer is compacted for 60 seconds.
  - (b) ASTM D-698 and AASHTO T-99 are equivalent to the Standard Proctor procedure
  - (c) ASTM D-1557 and AASHTO T-180 are equivalent to the Modified Proctor Procedure

Moisture Content-Dry Density Relationship

- Addition of water to soil particles brings soil particles together by coating them
- At low moisture content, soil stiff - difficult to compact
- Increase in water lubricates the soil particles bringing them together due to increased workability
- Density is increased under a given compactive effort
- When air content is minimum due to increase in water content, dry density becomes maximum
- Moisture content corresponding to this maximum dry density (MDD) is Optimum moisture content (OMC)
- Addition of water beyond OMC reduces the dry density because extra water occupies



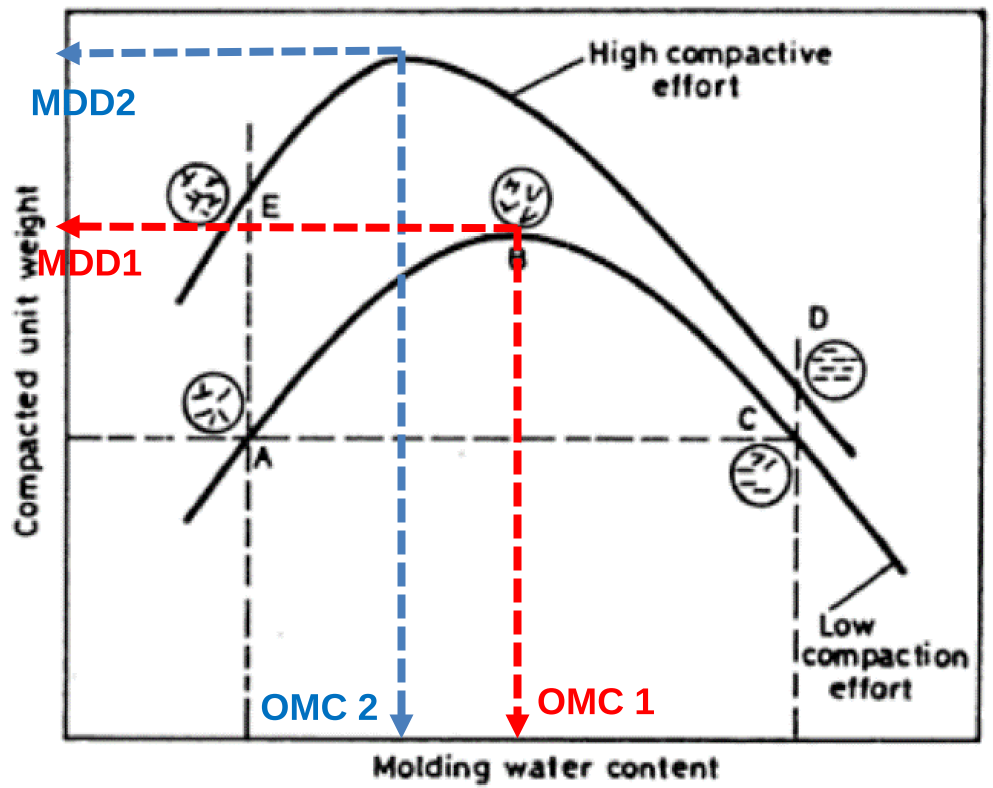
Saturation line is a line showing the relationship between moisture content and dry density at a constant degree of saturation.

It is given by $\gamma_d = \frac{\gamma_w\, G_s}{1+\frac{wG_s}{S_r}}$

from $\gamma_d = \frac{\gamma_w\, G_s}{1+e}$ since $wG_s = eS_r$

Effect of compactive effort

- High values of MDD are achieved by greater compactive effort at low OMC ie Modified Proctor test (4.5 kg rammer)
- Low values of MDD are achieved by lighter compactive effort at higher OMC ie Standard Proctor test (2.5kg rammer)



Example 1

- An earth embankment is compacted at a water content of 18% to a bulk unit weight of 19.2 kNm^{-3}. If the specific gravity of the sand is 2.7, find the void ratio and the degree of saturation of the compacted embankment
- Solution
  - Water content = 18%, Bulk unit wt. = 19.2 kNm^{-3} and Gs = 2.7
  - $Dry\ unit\ weight, \gamma_d = \frac{\gamma}{(1+w)} = \frac{19.2}{1+0.18}$ = 16.27 kNm^{-3}
  - But Dry unit weight, $\gamma_d = \frac{\gamma_w G_s}{1+e} \Rightarrow$ 16.27= $\frac{9.81x2.7}{1+e} \Rightarrow$ e = 0.628
  - Also wG_s = $eS_r \Rightarrow S_r = \frac{wG_s}{e} = \frac{0.18\ x\ 2.7}{0.628}$ = 77.39%

Example 2

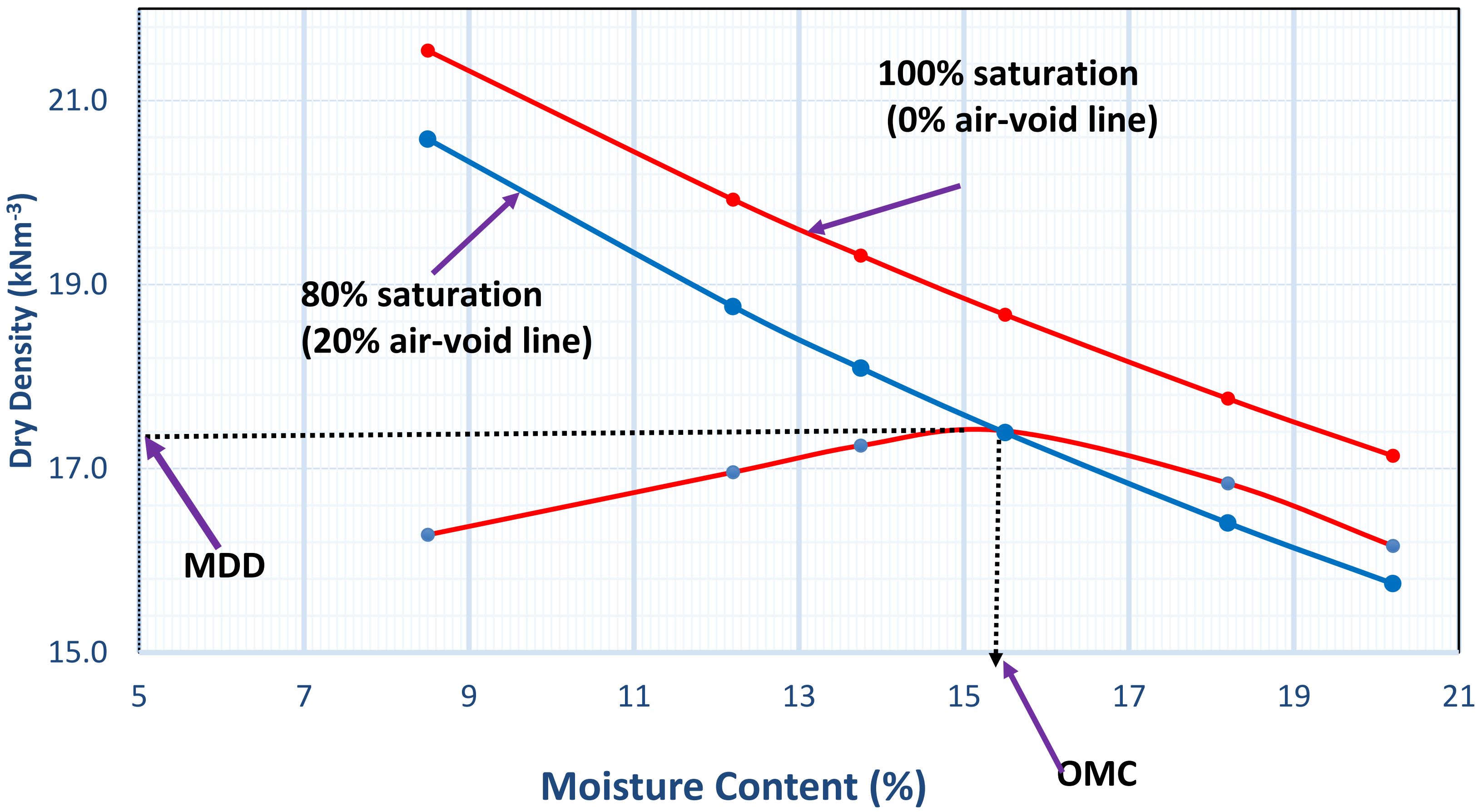
- The table below show Standard Proctor test results was done on an expansive clay sampled on sub grade of a road alignment. If present moisture content was given as 7.5%. Find MDD and OMC of the subgrade soil. Also, draw the air void lines on the compaction graph at 100% and 80% degree of saturation. NOTE: Weight of the soil is 2500g.

% water added	2	4	6	8	10	12
Vol. of water in ml	50	100	150	200	250	300
Bulk Unit Wt (kNm^{-3})	17.66	19.03	19.63	20.11	19.90	19.42
Moisture Content (%)	8.5	12.2	13.75	15.5	18.2	20.2
Dry Unit Wt (kNm^{-3}), $\gamma_d = \frac{\gamma}{(1+w)}$	16.28	16.96	17.25	17.41	16.84	16.16

Example 2 solution

% water added	2	4	6	8	10	12
Vol. in ml	50	100	150	200	250	300
Bulk Unit Wt (kNm^{-3})	17.66	19.03	19.63	20.11	19.90	19.42
Moisture Content (%)	8.5	12.2	13.75	15.5	18.2	20.2
Dry Unit Wt (kNm^{-3})	16.28	16.96	17.25	17.41	16.84	16.16
$S_r = 80\%, \gamma_d = \dfrac{\gamma_W G_s}{1 + \dfrac{wG_S}{S_r}}$	20.58	18.76	18.09	17.39	16.41	15.75
$S_r = 100\%, \gamma_d = \dfrac{\gamma_W G_s}{1 + \dfrac{wG_S}{S_r}}$	21.54	19.92	19.32	18.67	17.76	17.14

Example 2 solution



In-situ or field compaction

- In-situ or field compaction is necessary any time a construction job requires soil as a foundation structure
- Small to large earth moving equipment such as self-propelled Scrapers, Graders, Bull dozers or Crawler tractors, compactors and trucks are used
- Effective compaction is achieved by use of appropriate equipment.
- The thickness of the layers which can be properly compacted depends on
  - Soil type
  - Method of compaction
  - Moisture content
  - Equipment of compaction

In-situ or field compaction Cont'

- Soil compaction can be achieved by different means such as
  - Tamping
  - Kneading action ⇒ Sheepfoot Roller
  - Vibration
  - Impact
- Compactors operating on the tamping, kneading and impact principle are effective in cohesive soils while those operating on vibratory principle are effective in cohesionless soils

Types of compaction equipment

- The primary types of compaction equipment are
  - Rollers
  - Rammers
  - Vibrators
- The most common types of equipment are rollers
- Rollers are further classified as
  - Smooth-wheeled
  - Pneumatic-tyred
  - Sheepfoot
  - Grid

Types of compaction equipment

- Vibrators are classified as
  - Vibrating drum
  - Vibrating pneumatic
  - Vibrating plate
  - Vibroflot
- Relative Compaction (RC)
  - Is the ratio of the field dry density to laboratory maximum dry density expressed as a percentage
  - $RC = \frac{Field\ Dry\ Density\ (FDD)}{Laboratory\ Maximum\ dry\ density\ (MDD)}$ X 100%
  - It is a measure of the maximum dry density specified to be achieved in the field

Relative Compaction

- A layer of an embankment of a foundation has a RC specified by a specific design standard
- Each layer of a road pavement has a RC specified by a design standard
- For example, according to Kenya Road Design Manual (RDM) part III, 1987,
  - Sub grade layer must achieve 100% RC
  - Sub base layer must achieve 95% RC
  - Base layer must achieve 95% RC

Determination of field dry density

- The determination of field dry density (FDD) can be done by
  - Sand Replacement Method.
  - Core Cutter method.
  - Rubber Balloon Method
  - Nuclear gauge (Moisture Density) Method
- Sand Replacement and Core Cutter methods (Handout).
- Laboratory work

Some Types of Construction Equipment

- Read and makes on the following construction equipment
  - Crawler tractor (Bull dozer or Dozers)
  - Motor Grader
  - Scrappers
  - Vibrating Steel wheeled drum compactors
  - Sheepfoot compactors
  - Pneumatic-tyred compactors
  - Trenchers
  - Backhoes
  - Tippers

The California Bearing Ratio (CBR)

- CBR is a penetration test for evaluation of the mechanical strength of road sub grades and base courses (Sub base and Base)
- It was developed by California Dept. of Transportation, USA
- Its done in accordance to BS 1377 part 4, 1990
- The test is done by measuring pressure required to penetrate a soil sample with a plunger of standard area
- The measured pressure is then divided by the pressure required to achieve an equal penetration on a crushed rock material

The California Bearing Ratio (CBR) Cont'

- CBR is normally determined at a penetration of 2.5mm and 5.0mm top and bottom of the moulded sample
- Table 3 below shows the standard force-penetration relationships for 100% CBR
- Penetration vs load data is collected till failure occurs

Penetration (mm)	Force (Pressure), kN
2.0	11.5
2.5	13.2
4.0	17.6
5.0	20.0
6.0	22.2
8.0	26.3

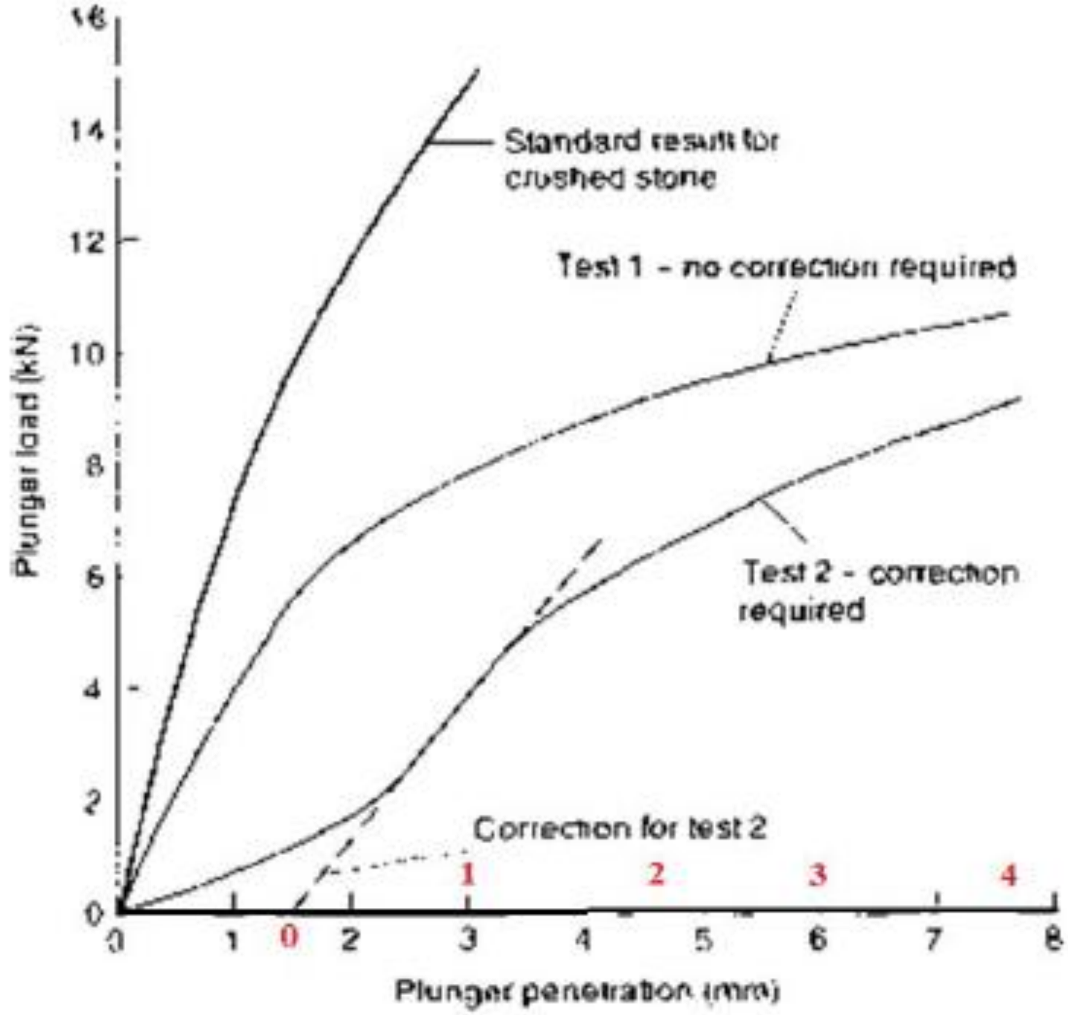
- A graph of Penetration vs load is drawn from where the load corresponding to 2.5mm and 5.0mm penetration is read

The California Bearing Ratio (CBR) Cont'

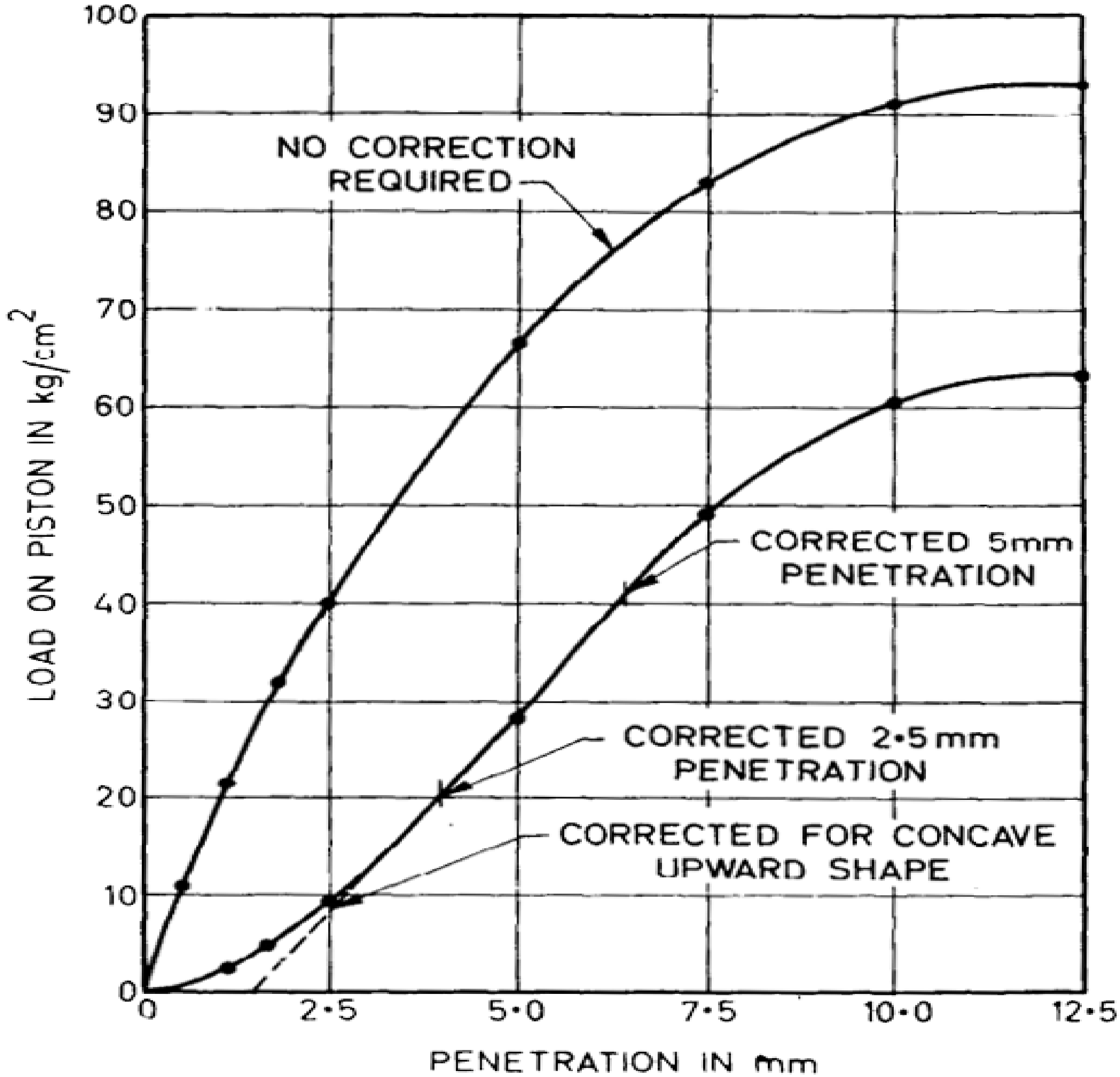
- The CBR value is given by :
  - $CBR\ value = \frac{Max.load\ at\ \ either\ \ 2.5\ or\ 5mm\ penetration}{Standard\ Load\ at\ either\ \ 2.5\ or\ 5\ mm\ penetration}$ X 100%
- The highest CBR value is reported as a percentage including its penetration. That is, the CBR value is x% at y mm penetration.
- Note that the normal type of CBR curve is convex upward (Test 1). However, if the initial part of the curve is concave upward (Test 2), a correction is done.
- For a curve to be corrected, a tangent is drawn on the straight part of the curve. Where the tangent cuts the x-axis becomes the origin of the x-axis and all measurements are measured from there.

The California Bearing Ratio (CBR) Cont’

- CBR curve correction



The California Bearing Ratio (CBR) Cont'



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Thank you