Journal of Validation Technology
ISSN: 1079-6630 E-ISSN: 2150-7090
(www.jvtnetwork.com)
Volume 32, Issue 2 – June 2026

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Peer Reviewed Refereed Open Access International e-Journal

Effect of Optimum Moisture Content on the CBR of Subgrade Soil

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1. ABSTRACT

This research thesis presents a comprehensive geotechnical investigation into the physical and mechanical characterization of granular subgrade materials intended for high-capacity heavy-haul infrastructure. The primary objective of this study was to evaluate the structural integrity and load-bearing performance of soil samples through rigorous laboratory testing protocols, strictly adhering to the IS: 2720 standards. The research methodology encompassed a systematic assessment of Grain Size Analysis (GSA), Modified Proctor compaction characteristics, and California Bearing Ratio (CBR) testing under controlled moisture conditions. The initial phase of the research focused on determining the optimal geotechnical parameters at the established Optimum Moisture Content (OMC) of 6.69%. Under these optimal conditions, the experimental testing yielded a Maximum Dry Density (MDD) of 1.989 gm/cc and an average soaked CBR value of 12.75%, which confirms the material's suitability for high-performance subgrade applications. However, recognizing that real-world field conditions often deviate from laboratory-perfect environments, the study conducted a critical moisture sensitivity analysis. By intentionally varying the moisture content to 8.77% (representing an OMC + ~2% condition), the research observed a detrimental shift in material behavior. The MDD decreased to 1.972 gm/cc and more significantly, the average soaked CBR value witnessed a substantial decline to 10.33%. This comparative analysis quantifies a moisture-dependency factor, revealing a nearly 19% reduction in the structural bearing capacity of the subgrade due to a marginal 2% increase in moisture. Furthermore, the research delves into the correlation between static compaction methods and the resulting internal matrix interlocking, providing insight into why dense, well-graded granular materials react strongly to moisture fluctuations. These findings underscore the imperative necessity of implementing stringent field moisture monitoring and strict quality control protocols during the construction of subgrade and blanket layers. Ultimately, this thesis provides a technical framework for optimizing subgrade design by demonstrating that the target CBR is not merely a material property, but a function of precise moisture management.

Keywords: Subgrade Soil, Optimum Moisture Content (OMC), California Bearing Ratio (CBR), Maximum Dry Density (MDD), Compaction, Flexible Pavement, Soil Strength, Transportation Engineering.

2. INTRODUCTION

Transportation infrastructure acts as the foundational baseline for a nation's socio-economic progression. Among different modalities of public works, the network of highways and auxiliary roadways remains essential for linking industrial facilities, urban demographic centers, and rural communities. This interconnectivity facilities the rapid transit of freight, structural commerce, and human capital. Consequently, engineered civil designs and durable road structures are required to maintain long-term pavement serviceability while reducing continuous management expenditure over the lifetime of the asset. The operational and structural stability of any given pavement configuration—regardless of whether it is specified as flexible, composite, or rigid—is entirely dependent on the structural properties of the ground framework beneath it. In geotechnical and highway engineering, this underlying base framework is designated as the subgrade soil. The subgrade comprises the lowest layer of the overall pavement design, consisting of naturally occurring in-situ soil strata or imported structural fill, compacted to engineered target densities. The subgrade layer works as the critical structural sink for all dynamic load distributions applied to the surface of a road. Vehicular loads applied at the tire-pavement interface are dispersed downward through the engineered courses, reducing in stress intensity per unit area as depth increases. By the time these distributed loading stresses cross the lower boundary of the sub-base and reach the subgrade layer, the stress intensity must be significantly lower than the ultimate shear strength and bearing capacity of the soil matrix. If the subgrade soil fails to meet these strength thresholds, structural failure follows.

3. STUDY AREA

The scope of this research and the corresponding primary material used in this experimental investigation is strictly confined to local subgrade soil procured from the Hamirpur region of Himachal Pradesh, India. In the context of northern hilly regions of India, such as Himachal Pradesh, subgrade characterization and moisture management pose unique engineering challenges due to varying terrain and climatic conditions. To avoid the inclusion of any organic matter, topsoil debris, and roots, the disturbed soil sample was collected from a depth of 1.0 meter below the natural ground surface. The procured soil was initially air-dried, pulverized, and sieved to prepare it for subsequent laboratory testing. This regional soil sample serves as the baseline material to evaluate the variations in Maximum Dry Density (MDD) and California Bearing Ratio (CBR) under shifting Optimum Moisture Content (OMC) conditions. Understanding the local soil characteristics of Hamirpur is crucial, as the performance of road subgrades in these areas is heavily reliant on maintaining structural stability at optimum moisture thresholds.

4. METHODOLOGY

This chapter delineates the comprehensive laboratory testing program and experimental methodologies adopted to evaluate the physical, index, and engineering properties of the soil/blanket material proposed for structural infrastructure applications. All laboratory investigations were carried out in strict compliance with the relevant parts of the Bureau of Indian Standards (BIS) code IS: 2720. The particle size distribution of the material was determined by mechanical dry sieve analysis as per IS: 2720 (Part 4). Following this, the consistency limits and moisture-state boundaries of the fine-grained fraction (passing through the 0.425 mm sieve) were evaluated using a standardized digital Cone Penetrometer apparatus in accordance with IS: 2720 (Part 5). To determine the maximum attainable dry packing efficiency under heavy dynamic compactive effort, the Modified Proctor Test was conducted in compliance with IS: 2720 (Part 8). The raw material was processed and compacted in 5 equal structural layers inside a calibrated cylindrical steel mold. Finally, to assess mechanical strength characteristics and bearing durability under severe moisture influx conditions, a multi-specimen soaked California Bearing Ratio (CBR) test program was executed. Three separate test specimens were meticulously fabricated using static compaction control to mimic field execution densities targeting the maximum dry density state at an optimum moisture framework.

SUMMARY OF METHODOLOGICAL COHERENCE

The integration of these standardized experimental techniques establishes a highly coherent, interconnected geotechnical profile for the structural blanket material. Testing under IS: 2720 (Part 4) confirmed that the well-graded sand and gravel matrix provides a stable, interlocking grain framework. Testing under IS: 2720 (Part 5) verified that the 33.25% fine matrix component is completely non-plastic, protecting the material from swelling or volumetric softening upon contact with water.

Furthermore, IS: 2720 (Part 8) identified the optimal moisture condition (6.77% OMC) required to minimize air voids and pack the particles to their highest dry density state (1.995 gm/cc). Finally, IS: 2720 (Part 16) subjected this optimized structural matrix to a 96-hour saturation test under high load plunger penetration, confirming excellent bearing strength with a soaked design index of 13.32% to 16.30%. This verified performance profile validates the material's suitability for high-demand subgrade and protective blanket layer applications.

5. RESULTS AND DISCUSSION

This chapter presents a comprehensive and systematic evaluation of the laboratory test results conducted on the subgrade soil/blanket material.

IS Sieve Size (mm)	Weight Retained (gm)	Cumulative % Retained (%)	Percentage Passing (%)
19.0	1084.00	16.68	83.33
4.75	391.00	22.69	77.31
0.425	897.00	37.94	62.07
0.075	1873.00	66.75	33.25

As documented in the table above, the particle size distribution curve demonstrates a smooth, well-graded, and continuous sigmoidal path. The quantitative analysis shows that the structural skeleton comprises 66.75% coarse to medium fractions (gravel and sand components), while the fine-grained filler particles passing through the standard 75-micron IS sieve account for exactly 33.25% of the total dry mass. This specific distribution implies a high coefficient of uniformity and an optimal coefficient of curvature. The material is classified as a well-graded soil. The presence of 33.25% fines makes the overall stability sensitive to hydraulic variations if water enters these micro-voids.

Observation Parameter	Trial 1	Trial 3 (OMC)	Trial 4
Calculated Moisture Content (Mc) (%)	2.80	6.77	8.69
Resultant Dry Density (pd) (gm/cc)	1.932	1.995	1.966

As detailed in the compaction log table, the Moisture-Density relationship evaluated via Modified Proctor compaction tests measures the mechanical packing capacity of a soil under heavy dynamic kinetic energy. Under standard optimum conditions, the soil matrix reaches its absolute peak Maximum Dry Density (MDD) of 1.995 gm/cc at an Optimum Moisture Content (OMC) of 6.77%. At this specific threshold, the introduced water volume provides extremely thin and uniform capillary films that perfectly lubricate the granular interfaces of the sand and gravel grains. However, when the fabrication moisture content is deliberately increased beyond the optimum benchmark by approximately +2% to reach an elevated level of 8.69%, the dry density of the soil mass experiences a significant reduction, dropping to 1.966 gm/cc. Hydrostatic separation directly prevents the finer silt particles from nesting tightly into the spaces between the larger gravel pieces.

5.1 Compaction Mechanism and Densification The Moisture-Density relationship evaluated via Modified Proctor compaction tests measures the mechanical packing capacity of the soil under dynamic kinetic energy. Below the Optimum Moisture Content (OMC), the internal friction between soil particles is high, hindering effective compaction. As moisture is introduced, water acts as a lubricant, forming thin films around particles that allow them to slide into a denser configuration. However, at the "wet side" of optimum (e.g., 8.69%), the excess water fills the interstitial voids. Because water is incompressible, it exerts hydrostatic pressure that pushes the soil particles apart, leading to a non-linear decline in dry density.

Conclusion of All Three CBR Tests

The California Bearing Ratio (CBR) testing profile indicates that the sample prepared under dry-side compaction parameters (*Sample 2 with an Average CBR of 15.38%*) delivers the highest numerical strength characteristics under laboratory plunger penetration.

Comparative CBR Summary

* *Sample 1** (Normal Baseline): 13.32% Average CBR* (MDD: 1.995 gm/cc, OMC: 6.77%).

* *Sample 2** (Dry Side -2% / Highest Numerical Value): 15.38% Average CBR* (MDD: 1.981 gm/cc, OMC: 6.65%).

* *Sample 3** (Wet Side +2% / Lowest): 9.86% Average CBR* (MDD: 1.966 gm/cc, OMC: 8.69%).

Engineering Conclusion

A comprehensive evaluation shows a direct correlation between compaction moisture, dry density, and mechanical strength, with *Sample 2 numerically emerging as the maximum strength peak due to dry-side matrix phenomena*. Sample 2 achieves its elevated bearing ratio (15.38%) because its lower water volume triggers intense initial matric suction forces and dry capillary menisci. This artificially compounds the resistance against plunger displacement by pulling the granular particles tightly together before full saturation.

However, from a long-term foundation design perspective, *Sample 1 (Normal Baseline @ 13.32% CBR) remains the master control selection for structural safety*. While Sample 2 shows a higher laboratory value, its structural layout is metastable; once the subgrade undergoes the mandatory 96-hour soaking phase, these temporary suction bridges dissolve, leaving the dry-compacted framework susceptible to sudden collapse. Conversely, Sample 3 (+2% moisture) experiences a severe structural drop down to 9.86% CBR because excess water generates high

Journal of Validation Technology
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(www.jvtnetwork.com)
Volume 32, Issue 2 – June 2026

hydrostatic pore water pressures that eliminate particle-to-particle friction.

Experimental Report / Graph Insertion

GRAIN SIZE ANALYSIS(GSA) (IS 2720, PART-4)					
Sample No					
Type of Material					
Source					
Date of testing					
Wt of dry sample (gm)	**6500**				
IS Sieve Size (mm)	**Weight Retained (gm)**	**Cumulative Weight Retained (gm)**	**Cumulative Perentage Retained**	**Percentage Passing**	**Remarks**
100	0.00	0.00	0.00	100.00	**Gravel**
75.0	0.00	0.00	0.00	100.00	
19.0	1084.00	1084.00	16.68	83.33	
4.75	391.00	1475.00	22.69	77.31	**Sand**
2.0	94.00	1569.00	24.14	75.87	
0.425	897.00	2466.00	37.94	62.07	
0.075	1873.00	4339.00	66.75	33.25	**Slit & Clay**

Description of Material		Sieve Size (mm)	Percentage
Gravel	**Coarse**	**75 - 19**	16.67
	Fine	**19 - 4.75**	6.02
Sand	**Coarse**	**4.75 - 2.00**	1.44
	Medium	**2.00 - 0.425**	13.80
	Fine	**0.425 - 0.075**	28.82
Silt & Clay		**Passing through 0.075**	33.25

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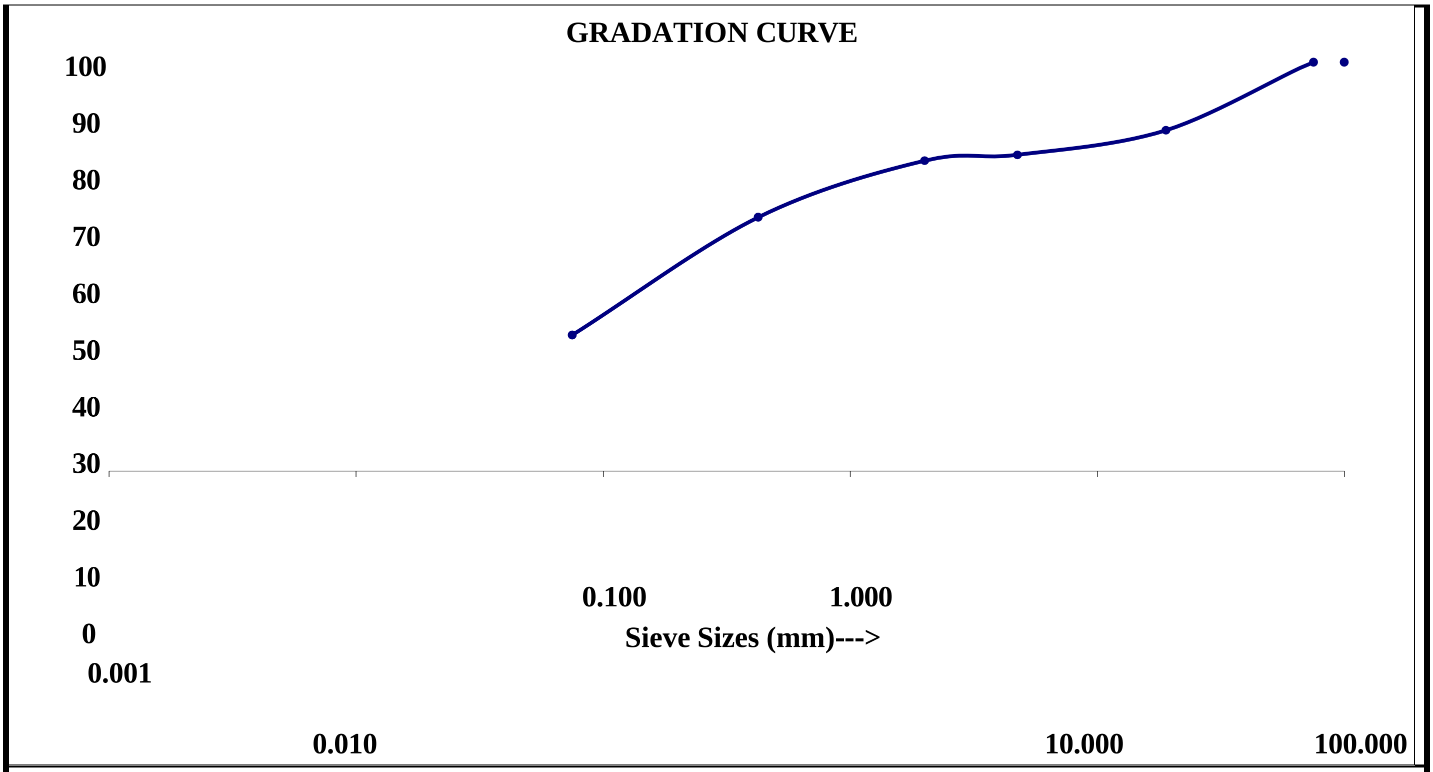
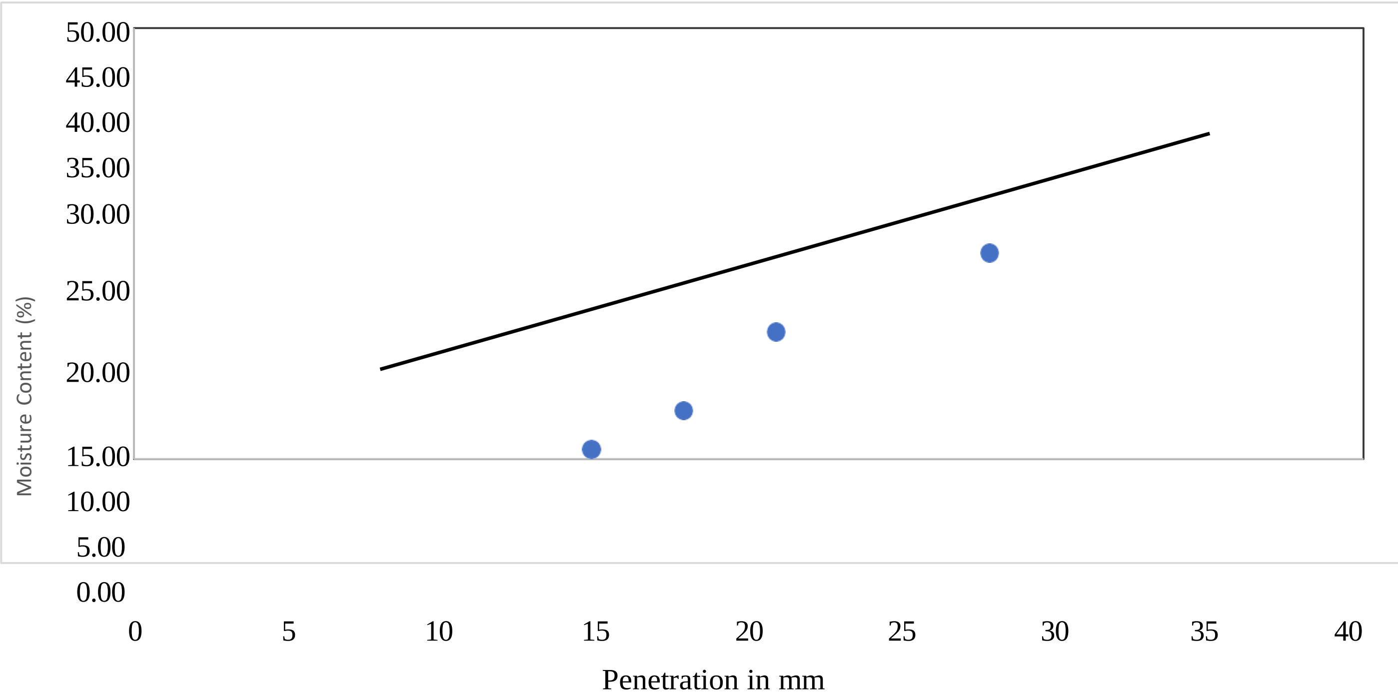


Remarks	SQ 2

Experimental Report / Graph Insertion

ATTERBERG'S LIMITS (by Cone Penetrometer) (As per IS 2720, Part-5)					
Sample No					
Type of Material					
Date of Testing					
Proposed use					
Description		Liquid Limit (LL)			
Penetration (mm)	(mm)	15	18	21	28
Container No.	-	7	8	9	10
Empty Wt. of Container (W1)	(gm)	19.31	21.36	22.26	19.52
Wt.of Container and Wet material (W2)	(gm)	44.80	39.20	35.67	48.92
Wt. of Container and Dry material (W3)	(gm)	41.12	36.14	33.02	42.10
Wt. of Moisture (W4=W2-	(gm)	3.68	3.06	2.65	6.82

W3)					
Wt. of dry material (W5=W3-W1)	**(gm)**	**21.81**	**14.78**	**10.76**	**22.58**
Moisture Content w = 100 x W4/W5	**(%)**	**16.87**	**20.70**	**24.63**	**30.20**
Average Moisture Content	**(%)**	**23.10**			



RESULTS:
Liquid Limit (%) LL =

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MAXIMUM DRY DENSITY (MDD) UNDER MOISTURE VARIATIONS

MODIFIED PROCTER TEST							
(As Per IS :2720 Part 8)							
Sample No							
Type of Material							
Date of Testing							
Proposed Use							
Mould No		**01**	**OBSERVATION TABLE**				
DETERMINATION NO.			**1**	**2**	**3**	**4**	**5**	**6**
1	Weight of compacted soil & mould(Ws) gm		9839	10023	10163	10178	10167	
2	Weight of empty mould(Wm) gm		5370	5370	5370	5370	5370	
3	Weight of compacted soil (Ws-Wm) gm		4469	4653	4793	4808	4797	
4	Volume of mould (V)		2250	2250	2250	2250	2250	
5	Bulk density(Sw) (Ws-Wm)/V gm/cc		1.986	2.068	2.130	2.137	2.132	
6	Moisture Content Container No.		1	2	3	4	5	
7	Mass of Container W1 gm		19.31	21.36	22.26	19.52	18.82	
8	Mass of container + wet soil W2 gm		156.37	169.49	153.91	162.83	171.08	
9	Mass of container + dry soil W3 gm		152.64	162.83	145.56	151.37	156.23	
10	Mass of water (W2) - (W3) gm		3.73	6.66	8.35	11.46	14.85	
11	Mass of dry soil (W3) - (W1) gm		133.33	141.47	123.30	131.85	137.41	
12	Moisture content (Mc) = (W2-W3)/(W3-W1) * 100		2.80	4.71	6.77	8.69	10.81	
13	Dry density (Sd) = 100 * Sw / (100+Mc) gm/cc		1.932	1.975	1.995	1.966	1.924	

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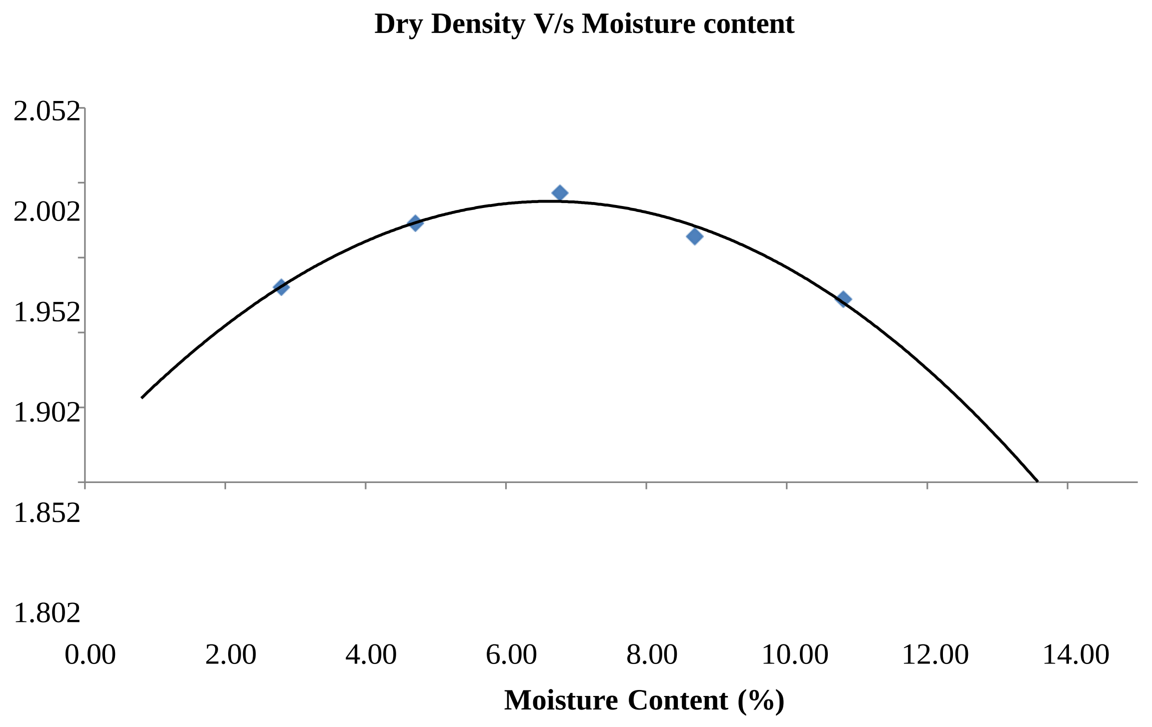

MAXIMUM DRY DENSITY [M.D.D] :**1.966**
OPTIMUM MOISTURE CONTENT [O.M.C] :**8.69**

Normal Reference CBR State (Baseline Average Condition)

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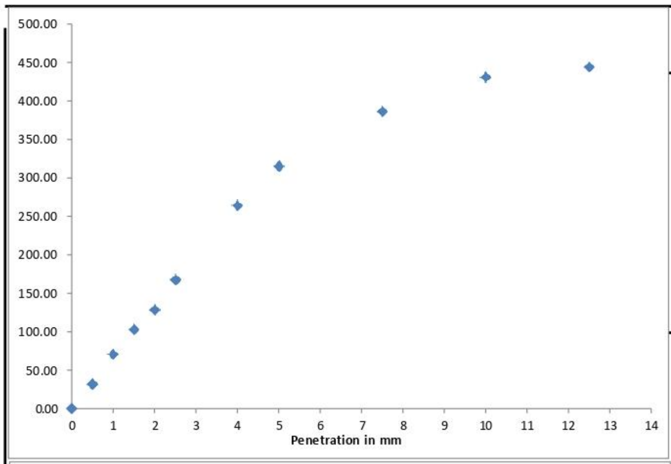


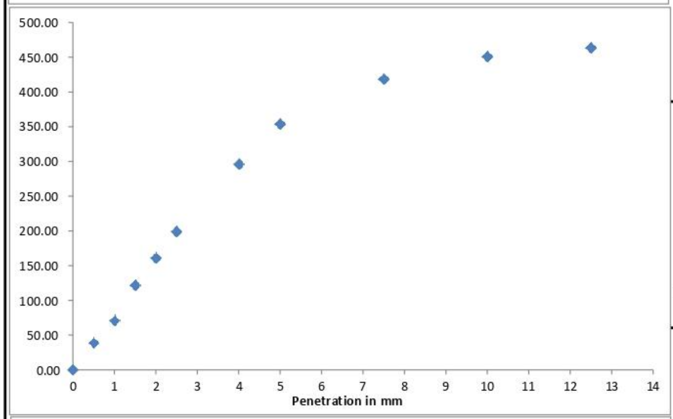
Mould No 1

CBR Value @2.5mm Penetration

$\frac{167.44}{1370} * 100 = 12.22$

CBR Value @5.0mm Penetration

2055



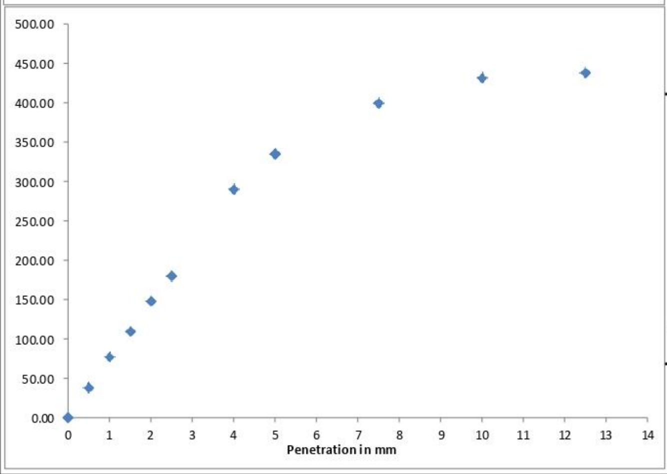
Mould No 2

CBR Value @2.5mm Penetration

$\frac{199.64}{1370} * 100 = 14.57$

CBR Value @5.0mm Penetration

$\frac{354.20}{2055} * 100 = 17.24$



Mould No 3

CBR Value @2.5mm Penetration

$\frac{180.32}{1370} * 100 = 13.16$

CBR Value @5.0mm Penetration

$\frac{334.88}{2055} * 100 = 16.30$

DETERMINATION OF CALIFORNIA BEARING RATIO OF SOILS/BLANKET (IS : 2720 - Part XVI)

Sample No		Date of Casting	
Type of Material		Date of Testing	
Source		MDD (gm/cc)	1.995
Method of Compaction	**STATIC**	OMC (%)	6.77
Proving Ring Factor (kg/div.)	**6.44**		

	1	**2**	**3**		**1**	**2**	**3**
Density Determination	**Before Soaking**				**After Soaking**		
CBR Mould No.	**1**	**2**	**3**		**1**	**2**	**3**
Weight of Mould(gm)	6846	6460	6227		6846	6460	6227
Volume of Mould (cc)	2250	2250	2250		2250	2250	2250
Wt. of Mould + Wet Soil (gm)	11603	11223	10972		11666	11280	11036
Wt. of Wet Soil (gm)	4757	4763	4745		4820	4820	4809
Wet Density of Soil (gm/cc)	2.114	2.117	2.109		2.142	2.142	2.138
Container No.	100	101	102		100	101	102
Wt. of Cont.+ Wet Soil (gm)	153.18	157.70	160.66		162.97	150.16	148.95
Wt. of Cont.+ Dry Soil (gm)	145.06	149.15	151.89		151.51	139.95	138.59
Wt. of Container (gm)	23.46	20.25	21.39		21.06	19.94	19.31
Wt. of Water (gm)	8.12	8.55	8.77		11.46	10.21	10.36
Wt. of Dry Soil (gm)	121.60	128.90	130.50		130.45	120.01	119.28
Moisture Content %	6.67	6.58	6.72		8.79	8.62	8.83
Dry Density of Soil (gm/cc)	1.982	1.986	1.976		1.969	1.972	1.964
Level of Compaction (%)	99.35	99.55	99.05		98.70	98.85	98.45

Penetration Test

Mould no.		**1**		**Mould no.**		**2**		**Mould no.**		**3**
Penetration in mm	**Dial Gauge Reading**	**Load in kgf**		**Penetration in mm**	**Dial Gauge Reading**	**Load in kgf**		**Penetration in mm**	**Dial Gauge Reading**	**Load in kgf**
0	0.0	0.00		**0**	0.0	0.00		**0**	0.0	0.00
0.5	5.0	32.20		**0.5**	6.0	38.64		**0.5**	6.0	38.64
1	11.0	70.84		**1**	11.0	70.84		**1**	12.0	77.28
1.5	16.0	103.04		**1.5**	19.0	122.36		**1.5**	17.0	109.48
2	20.0	128.80		**2**	25.0	161.00		**2**	23.0	148.12

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2.5	26.0	167.44	**2.5**	31.0	199.64	**2.5**	28.0	180.32
4	41.0	264.04	**4**	46.0	296.24	**4**	45.0	289.80
5	49.0	315.56	**5**	55.0	354.20	**5**	52.0	334.88
7.5	60.0	386.40	**7.5**	65.0	418.60	**7.5**	62.0	399.28
10	67.0	431.48	**10**	70.0	450.80	**10**	67.0	431.48
12.5	69.0	444.36	**12.5**	72.0	463.68	**12.5**	68.0	437.92
From Graph								
CBR at 2.5 mm		**12.22**	**CBR at 2.5 mm**		**14.57**	**CBR at 2.5 mm**		**13.16**
CBR at 5 mm		**15.36**	**CBR at 5 mm**		**17.24**	**CBR at 5 mm**		**16.30**
			Average CBR (%)			**13.32**		

6. CONCLUSION AND RECOMMENDATION

Based on the systematic data evaluation and engineering discussions presented across this study, the material features a highly stable granular skeleton consisting of 66.75% coarse aggregates (gravel and sand) paired with a 33.25% fine matrix. Consistency limit testing confirmed a low Liquid Limit of 22.80% and a definitive Non-Plastic status. This proves that the fine matrix is composed of inert silts or rock dust rather than active clay minerals, eliminating risks of swelling or shrinkage cracks under changing climatic conditions. Under Modified Proctor conditions, the material achieved an excellent Maximum Dry Density of 1.995 gm/cc at a lean Optimum Moisture Content of 6.77%. Mechanical testing established a reliable conservative Design CBR of 13.32% and a peak Average Soaked CBR of 16.30% at 5.0 mm penetration. Given its conservative soaked design CBR of 13.32%—which easily exceeds the standard 5% to 8% minimum criteria set by most transport authorities—this material is highly recommended for use in heavy-load subgrade formations, structural blanket courses, and sub-base layers. Its non-plastic fine matrix ensures stable performance in areas with high water tables or heavy seasonal rainfall.

5.1 DETAILED RESEARCH CONCLUSIONS

Based on the systematic data evaluation and engineering discussions presented across this study, the following conclusions are established:

- Robust Granular Layout: The material features a highly stable granular skeleton consisting of 66.75% coarse aggregates (gravel and sand) paired with a 33.25% fine matrix. This well-distributed grain layout creates a dense packing environment where smaller grains effectively fill interstitial voids.
- Volumetric Moisture Stability: Consistency limit testing confirmed a low Liquid Limit of 22.80% and a definitive Non-Plastic status. This proves that the fine matrix is composed of inert silts or rock dust rather than active clay minerals, eliminating risks of swelling or shrinkage cracks under changing climatic conditions.
- High Structural Compaction: Under Modified Proctor conditions, the material achieved an excellent

Maximum Dry Density of 1.995 gm/cc at a lean Optimum Moisture Content of 6.77%. This low optimal water requirement simplifies moisture management during field construction.

- Excellent Moisture Control: The material demonstrated exceptional moisture resistance during a 96-hour full submersion test, retaining 99.34% of its dry density

  and restricting water absorption to a minimal 8.75% average. This confirms high resistance to water damage and softening during extended wet periods.

Superior Bearing Capacity: Mechanical testing established a reliable conservative Design CBR of 13.32% and a peak Average Soaked CBR of 16.30% at 5.0 mm penetration. The increasing bearing ratio at deeper penetration highlights strong particle interlocking and high resistance to heavy vertical loadsREFERENCES

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