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ORIGINAL CONTRIBUTION

Characterization of Coal Mine Overburden and Assessment as Mine Haul Road Construction Material

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Abstract This paper presents details of laboratory investigation carried out on coal mine overburden materials to check their suitability in base/sub-base of mine haul road pavement. In this investigation, strength characteristics of un- stabilized overburden materials are evaluated. Strength characteristics of overburden materials are obtained through laboratory tests by physical, mechanical, chemical and micro-structural analysis. The laboratory investigation shows untreated murrum, top soil and sub soil are not suitable to be used as mine haul road construction material. In this investigation, CBR method is used for layer thickness as well as cover thickness calculation. The paper also discusses the importance of various tests required for evaluation and assessment of mine haul road.

Keywords Pavement · Haul road design · California bearing ratio · Opencast mine

Introduction

A well stabilized haul road plays a vital role to maintain high productivity of a surface mine, because failure of such road leads to increase in air borne dust, reduced traffic mobility, increase in cycle time, increase in frequency of vehicle maintenance and fuel consumption. Stabilized haul road base is one of the most important components of mine haul road design. Based on the size of a surface coal mine, length of permanent haul road varies from 2 to 5 km. Apart from that, temporary haul roads or lumpy roads are also constructed from locally available material. The locally available material includes the overburden materials like sand stone, crushed gravel, morrum, top soil, sub soil and others based on their regional geological formation. Ulusay et al. [1] categorised the overburden material as heterogeneous with equal percentage of fine and coarse grains. The finer grains of sand, gravel, clay etc. are used as a filling material which does not contribute to the haul road stability whereas coarse grained is used as base and sub-base material. Tannant and Regensburg [2] mentioned that pot holes, sinking, rutting and settlement are major failure modes observed in mine haul roads. In a surface mine, cost of truck/dumper haulage contribute up to 50% of total mining cost [3].

Large capacity dumpers are used in surface mine to haul coal and overburden from mine to the stock yard and waste dump site respectively. Gross vehicular weight of large capacity dumpers can go up to 4000 kN and tire pressure to support the dumpers are typically in the range of 600 to 690 kPa [4]. Critical strain limit of mine haul road varies between 1500 and 2000 micro-strains [3]. Hence, mine haul roads should have sufficient bearing capacity and stiffness. Cost norm for 35 t dumper for a fixed thickness decreases from Rs. 602/m to Rs. 442/m when CBR value increases from 3 to 7% [5]. In this investigation, geotechnical properties of mine overburden materials are evaluated to check their suitability as haul road construction material. It is found that only untreated morrum is suitable as a sub-base material. Hence, commercial additive is required to improve the CBR of mine overburden materials for its use in sub-base and base course.

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Case Study

Coal mine A located in central part of India is considered in this study having annual production of about 15 Mt of coal and 7 Mm^3 of overburden. These material are transported by 80 t dumpers (make: Caterpillar) and 10 t dumpers (make: Tata) and uses bias and radial tyres respectively. The wear rate of bias and radial tyre is around 160 and 190 h/mm respectively, whereas the average life is around 6500 and 11,500 h respectively.

The length of mine haul road in this mine is around 8 and 2 km respectively and sub-base is constructed by mixture of sand and morrum in the ratio 2:3; and 45–63 mm size stone metal is laid over as a Water Bound Macadam (WBM). Finally, the freshly constructed mine haul road are compacted using 100 kN power roller. The haul roads in this mine is flexible type and are designed based on California Bearing Ratio (CBR) method. Figure 1 shows the haul road section. For dust suppression, mine management is using water sprinkling method due to frequent movement of dumpers as well as service vehicles.

Figure 2 shows the haul road condition of the mine with the problems like (a) pot holes and rutting, (b) material spillage from moving dumpers and dust generation, (c) excess sprinkling of water and deterioration of surface course. All the materials used for the construction of the haul road are the mine overburden material.

Materials and Methods

To access the suitability of the mine overburden material of this mine as a pavement material top soil and sub soil from the overburden are carefully sampled from different areas of waste dump for representative samples (Fig. 3). The samples are then placed in air tight packets in controlled environment and transported to the laboratory.

For all collected samples, specific gravity, particle size distribution, liquid limit, plastic limit, shrinkage limit, chemical compositions, optimum moisture content, maximum dry density, CBR, UCS, Tensile Strength, cohesion and angle of internal friction are determined. The specific gravity of overburden materials are determined using volumetric flask method (IS: 2720 part-III). Grain size distributions are carried out through a standard set of sieves following IS: 2720 part-IV. The material passing through 75 μm size is collected carefully and grain size distribution analysis is performed using hydrometer test. Atterberg limits of samples are determined as per IS: 2720 part-V and part-VI. Liquid limit is determined using standard liquid limit apparatus designed by Casagrande. Liquid limit is the minimum water content at which a part of material cut by a standard groove will flow together for a distance of 12 mm under an impact of 25 blows. Plastic limit is the minimum water content at which soil will begin to crumble when rolled into a thread of 3 mm diameter approximately. Shrinkage limit is the maximum water content at which reduction in water content will not decrease the volume of soil. Plasticity index is the difference of liquid limit and plastic limit. Chemical compositions of overburden materials are determined from EDX (Energy Dispersive X-ray) technique. The optimum moisture content (OMC) and maximum dry density (MDD) is determined by modified proctor test as per IS: 2720 part-VIII. In proctor mould, prepared samples are compacted in five layers and a rammer of weight 4.5 kg dropped from a height of 18 inches for compaction with 25 blows at each layers. The CBR test conducted as per IS: 2720 part-XVI, the samples are soaked for 4 days in water and allowed to drain for 15 min before test. Three different sets of CBR samples are prepared based on three period of curing, i.e. (1) immediate, (2) 7 days (3 days moist curing and 4 days soaking) and (3) 28 days (24 days moist curing and 4 days soaking). Two surcharge discs, each of weight 2.5 kg are placed on

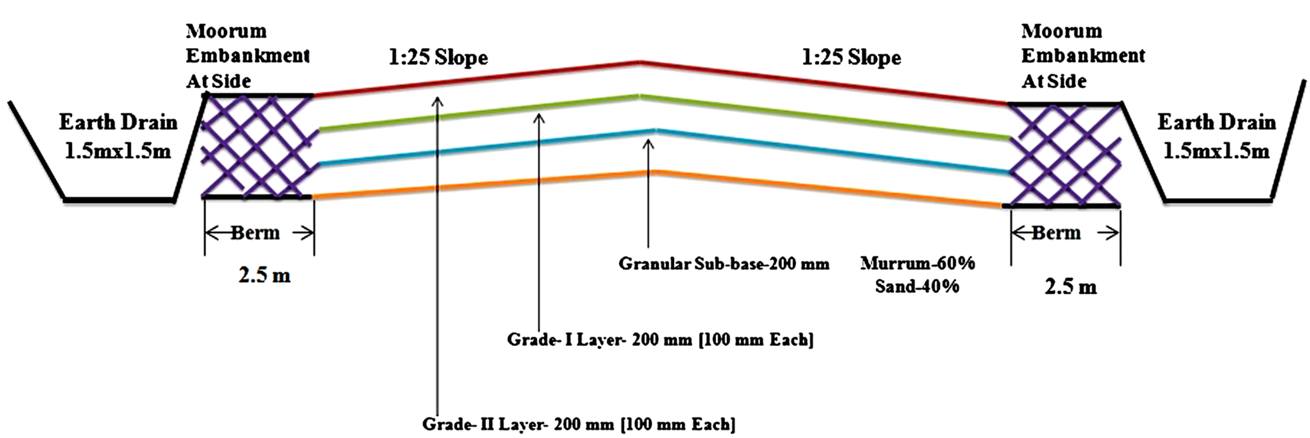


Fig. 1 Haul road pavement of study mine

Fig. 2 **a** Pot holes and rutting. **b** Material Spillage and upheave. **c** Excess sprinkling of water and deteriorated surface course

the sample with a plunger of 50 mm diameter penetrated at a rate of 1.25 mm/min during the test. The CBR is calculated using the two standard values of load and its corresponding penetration i.e. for 13.44 kN standard load penetration is 2.5 mm; for 20.16 kN standard load the penetration becomes 5.0 mm. The UCS tests (IS: 2720 part-X) samples of 38 mm diameter and 76 mm height are prepared and cured in humidity chamber at relative humidity >95% and temperature 30 ± 2 °C. The test has been carried out at a strain rate of 1.2 mm/min. The UCS

Fig. 3 Collection of Mine Overburden

test samples are prepared at optimum moisture content determined from the modified proctor compaction test. This is because the mine haul roads are continuously sprinkled with water and due to frequent movement of dumpers get compacted.

Material Characterization

The physical properties like specific gravity, Atterberg limits as liquid limit (LL), plastic limit (PL), plasticity index (PI) of overburden materials are shown in Table 1. Table 2 shows the chemical properties of murrum, sub soil and top soil. The specific gravity of top soil is found to be less than that of sub soil and murrum because of less iron content. Table 2 shows that the iron content in murrum, sub soil and top soil are 26.11, 9.83, and 5.89% respectively. Pandian [6] mentioned that the materials with high iron content have relatively high specific gravity. Table 2 shows that the compositions of CaO in murrum, sub soil and top soil are 0.65, 0.62 and 1.21% respectively which is low. Hence, natural binding cannot be expected and so some additive is required to enhance the pozzolanic reaction to increase the material strength.

The LL, PL, PI and SL reflect important geotechnical characteristics of volume change with addition of water. Figures 4 and 5 shows that the laboratory tested samples for plastic and shrinkage property respectively. Figure 4 shows that sub soil tested is non-plastic and hence its PL cannot be determined. Shrinking depends on soil characteristic and change in moisture but it is difficult to quantify. Theoretically, a moist soil can shrink until it reaches the shrinkage limit and it will not shrink if dry. Holtz and Gibbs [7] classified the volume change potential of geomaterial based on PI and SL value as shown in Table 3. The lower the shrinkage limit, the lower shrinkage potential [7, 8]. Hence, the overburden soil with negligible shrinkage limit will be best suited as a mine haul road material.

Particle size distribution reflects whether the material is poorly, medium or well graded and has strong influence on density. Murrum contained 37.4% gravel, sub soil contained 73.37% sand while top soil contained 56.88% silt and clay as shown in Fig. 6. As murrum contained higher percentage of gravel, its maximum dry density is highest while it is lowest for top soil as it contained higher percentage of silt and clay.

Figure 7a–c shows the morphology of murrum, sub soil and top soil, which indicate the presence of irregular shape of solid particles. These particles affect compaction

Table 1 Physical properties of different mine overburden materials

Property	Murrum	Sub soil	Top soil
Specific gravity	2.74	2.61	2.5
Gravel (>4.75 mm)	37.4	–	–
Sand (4.75–0.075 mm)	35.23	73.37	43.12
Silt and clay (<0.075 mm)	27.37	26.63	56.88
Liquid limit, LL (%)	46.1	24.6	32.78
Plastic limit, PL (%)	19.1	Non-plastic	16.15
Plasticity index, PI (%)	27	–	16.63
Shrinkage limit, SL (%)	15.13	20.83	19.61

Table 2 Chemical properties of different mine overburden materials

Constituents	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	MgO	TiO_2	Na_2O	MnO	LOI
Murrum	33.82	33.70	26.11	0.65	2.49	0.54	2.09	0.15	0.45	–
Sub soil	54.80	25.87	9.83	0.62	2.69	0.67	1.88	–	–	3.64
Top soil	51.48	26.96	5.89	1.21	1.71	0.59	2.37	–	–	9.79

Fig. 4 Plastic property of mine overburden material

Fig. 5 Shrinkage property of mine overburden material

Table 3 Volume change potential [7]

Volume change potential	Plasticity Index (%)		Shrinkage Limit (%)
	Arid area	Humid area	
Low	0–15	0–30	>12
Moderate	15–30	30–50	10–12
High	>30	>50	<10

behaviour [9, 10]. The micrograph is without any formation of cementitious compound confirms that these materials have low calcium content.

The engineering properties of a material such as UCS, tensile strength, CBR, cohesion, angle of internal friction are dependent on the moisture content and density (Table 4; Fig. 8a–c). Typically the higher the compaction the better is its geotechnical characteristics. Hence, it is necessary to achieve the desired degree of compaction which is necessary to meet the expected properties [11].

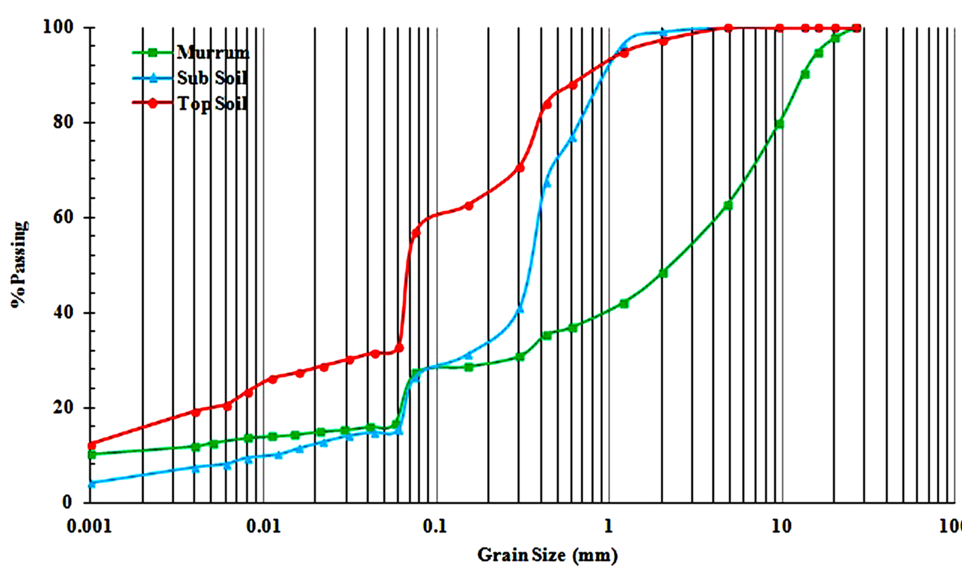
Compaction Characteristics

During compaction the density of soil is increased by application of mechanical energy such as tamping, rolling and vibration. In this process particles are forced to be closer and closer by reducing inter-particle air voids. The overall moisture content of all overburden samples varies between 6 and 11% and the highest OMC is 10.63% for murrum. The maximum dry density (MDD) of top soil is highest and equal to 2055 kg/m^3; whereas it is least for top soil with a value 1974 kg/m^3. The reason of less cohesion of top soil is due to its non-cohesive nature. Compaction curves obtained from modified proctor compaction test of various samples are shown in Fig. 9.

California Bearing Ratio

Mine haul road design based on CBR is well established and popular method for design of base and sub-base course of road pavement. CBR tests are carried out to characterize the untreated overburden materials. In un-soaked condition

Fig. 6 Grain size distribution curve of mine overburden



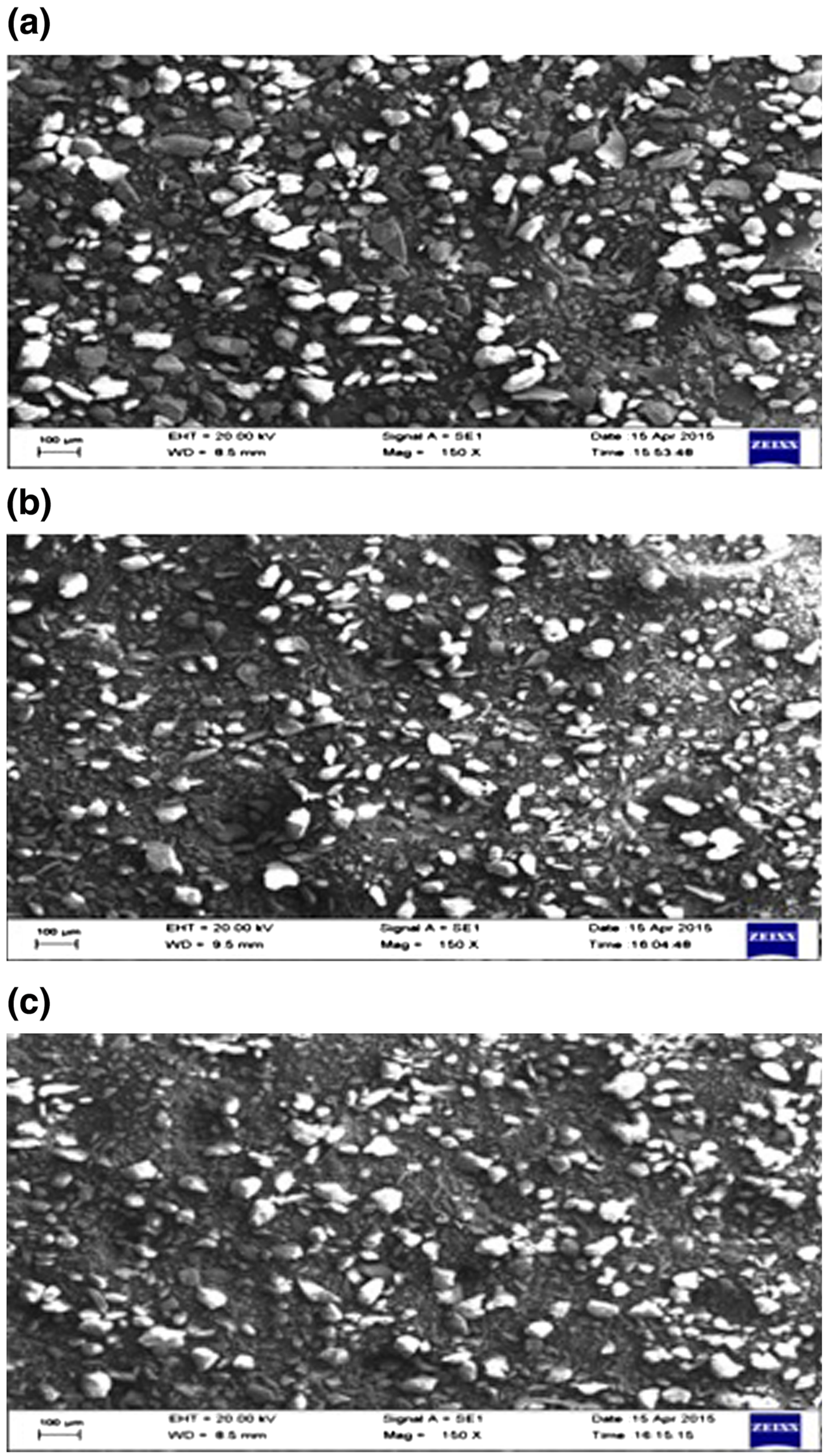


Fig. 7 **a** SEM of Murrum. **b** SEM of Sub Soil. **c** SEM of Top Soil

CBR values without additive varied between 4 and 39% as shown in Fig. 10a. In un-soaked condition CBR value is more than the soaked condition and it is due to the capillary forces created at optimum moisture content and MDD condition in addition to the friction resisting the penetration of the plunger [12].

However, when the samples are tested after 4 days of soaking, CBR values obtained are very low due to the destruction of the capillary forces as well as reduced frictional resistance as shown in Fig. 10b. Soaked condition is a conservative estimate, yet considered for worst scenario. The untreated mine overburden samples did not show any

Table 4 Engineering properties of different mine overburden materials

Property	Murrum	Sub soil	Top soil
OMC (%)	10.63	6.7	10.4
MDD (kg/m^3)	2055	1990	1974
CBR (un-soaked) (%)	39.3	8.5	4.7
CBR (soaked) (%)	18	2.1	1.7
UCS (kPa)	663.4	71.3	56.2
Young's modulus (MPa)	142.2	36.2	27.4
Cohesion (kPa)	38.9	22.2	20.6
Angle of internal friction (°)	37.1	36.7	36.2

appreciable strength values which classify the material unsuitable for sub-grade [13]. The general relationship between CBR and quality of sub-grade soil used in pavement construction is given in Table 5.

Unconfined Compressive Strength

The Unconfined compressive strength values of laterite, sub soil, top soil were 663.4, 71.3, 56.2 kPa respectively in unsoaked condition. The untreated mine overburden samples offered least resistance to external loading and also did not show any appreciable strength values. The values were very less in soaked condition which classify the material unsuitable for sub-grade as given in Table 6 [14]. Hence, it is essential to add additive to enhance UCS values. Figure 11 shows the failed samples exhibiting shear type failure.

Brazilian Tensile Strength

Tensile strength is an important property to predict the cracking behaviour of pavement, structures using stabilized soils [15]. The untreated mine overburden samples offered least resistance to external loading and also did not show any appreciable strength values. Low tensile strength generated lots of cracks and hence to avoid the crack formation additives are required to be added. Figure 12 shows the failed sample in brazilian tensile strength test.

Pavement Design Based on CBR Method

As discussed in "Material Characterization" section and shown in Table 4, the soaked CBR values of top Soil, subsoil and morrum are 1.7, 2.1 and 18% respectively. For 80t dumper deployed in studied mine, the pavement thickness is ascertained based on soaked CBR value. Here, for pavement design worst condition of water soaking is considered as the pavement is exposed to rain water as well as regular water sprinkling operations for dust suppression.

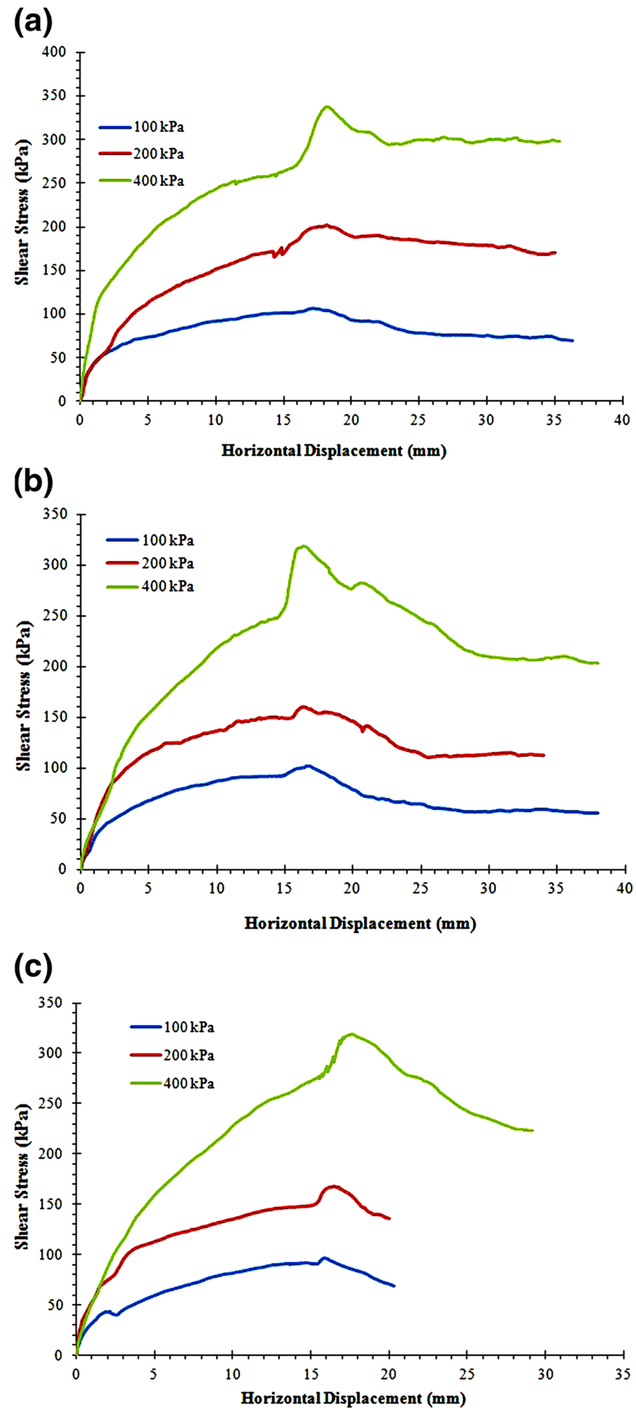


Fig. 8 **a** Shear strength characteristics of Murrum. **b** Shear strength characteristics of Sub Soil. **c** Shear strength characteristics of Top Soil

The gross vehicular weight (GVW) of 80t dumper is 160t with six numbers of wheels. The area of contact of the tyre is considered circular with its radius equal to the tyre width of 0.8 m. Tannant and Kumar [4] calculated the tyre pressure as given in Eq. (1).

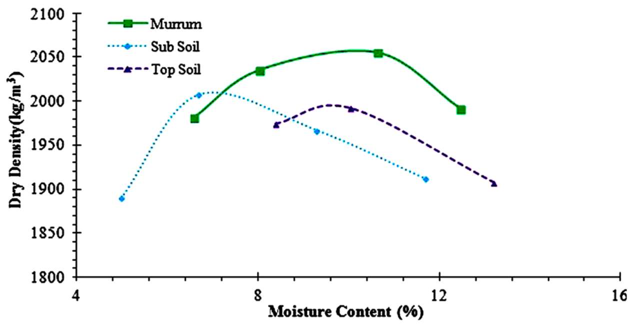


Fig. 9 Variation of dry density with moisture content

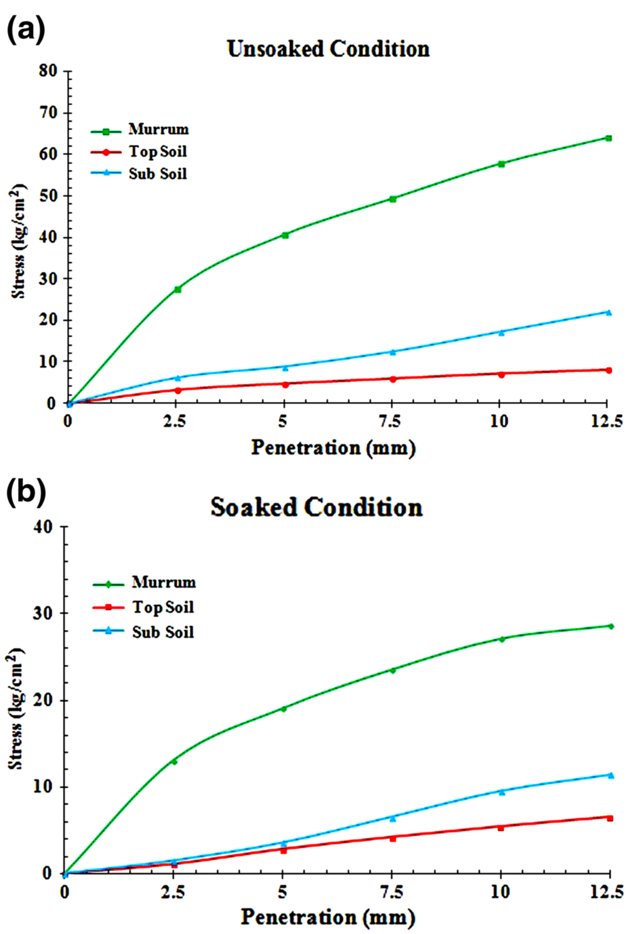


Fig. 10 **a** Stress and penetration relationship in un-soaked condition. **b** Stress and penetration relationship in soaked condition

$$\text{Tyre Pressure} = \frac{\text{Gross vehicular weight of Dumper}}{\text{Number of tyres} \times \text{Tyre foot print area}} \tag{1}$$

Using Eq. (1) the tyre pressure is 520 kPa. CBR cover-curve design method is widely used for design of flexible pavement [16]. In flexible pavement, the load transmission to the sub-grade is by lateral dispersion of the applied load with depth. The constituent layers and the overall depth is so designed that the stress and strain developed at all levels are within the material capabilities. Thompson [3] developed a statistical relationship given in Eq. (2) to determine pavement cover thickness above a material based on its CBR values [17]. The same technique can be used to determine the successive layers by keeping the higher CBR for top layer followed by lower layers.

$$Z_{CBR} = \frac{9.81 t_w}{P}\left[0.104 + 0.331 e^{(-0.0287 t_w)}\right]\left[2 \times 10^{-5\left(\frac{CBR}{P}\right)}\right]\left[\left(\frac{CBR}{P}\right)^{-\left(0.415 + P \times 10^{-4}\right)}\right] \tag{2}$$

where Z_{CBR} is layer thickness (m); t_w is truck wheel load (metric ton); P is tyre pressure (kPa); and CBR is California Bearing Ratio (%)

Based on Eq. (2) cover thickness above sub-grade is found to be 1.62 m for 2% CBR, whereas for sub-base of untreated morrum with 18% CBR, the layer thickness is found to be 0.42 m. Therefore, the cover thickness for sub-base becomes 1.20 m. It is also found that apart from morrum, no other mine overburden materials (i.e. top soil and sub soil) are found suitable for pavement design because of their low CBR values. Here for base course, morrum is required to be treated to improve its CBR from 18 to 40–50% or more with commercial additives like lime, cement, gypsum, RBI grade-81 and others cheaply and easily available. Using Eq. (2), layer thickness of base course having 40 and 50% CBR will be 0.18 m and 0.13 m respectively. As the material for surface course should ensure smooth ride with adequate skid resistance, high CBR and high bearing capacity the CBR value considered for surface course is 80 to 100%.

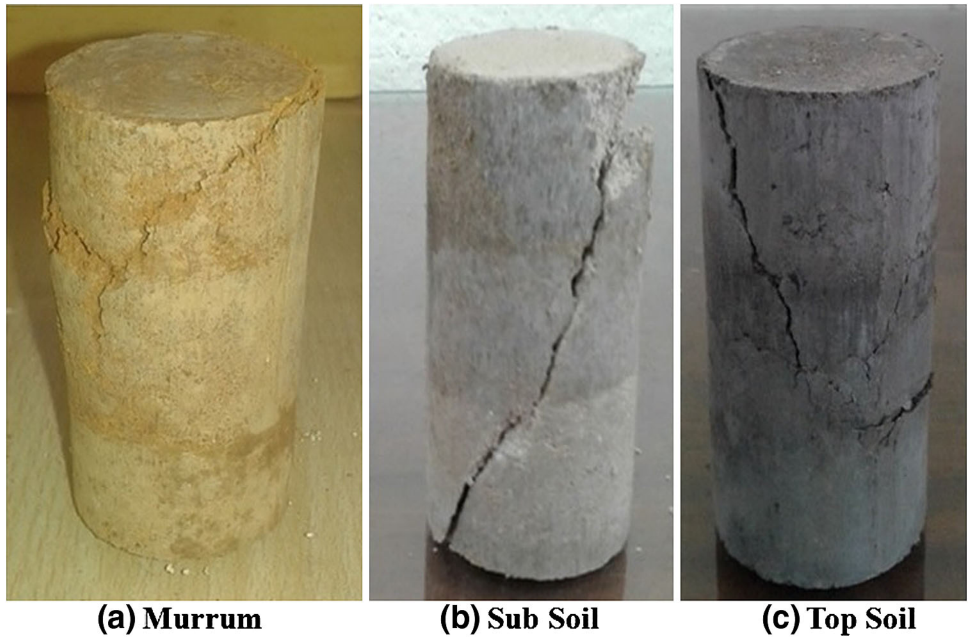
Table 5 Sub grade categorization based on CBR [13]

Quality of sub-grade	CBR (%)
Very poor sub-grade	0–3
Poor to fair sub-grade	3–7
Fair sub-grade	7–20
Good sub-grade	20–50
Excellent sub-grade	75

Table 6 Sub grade categorization based on UCS [14]

Quality of Sub-grade	UCS (kPa)
Soft sub-grade	25–50
Medium sub-grade	50–100
Stiff sub-grade	100–200
Very stiff sub-grade	200–380
Hard sub-grade	>380

Fig. 11 Failed samples after UCS test



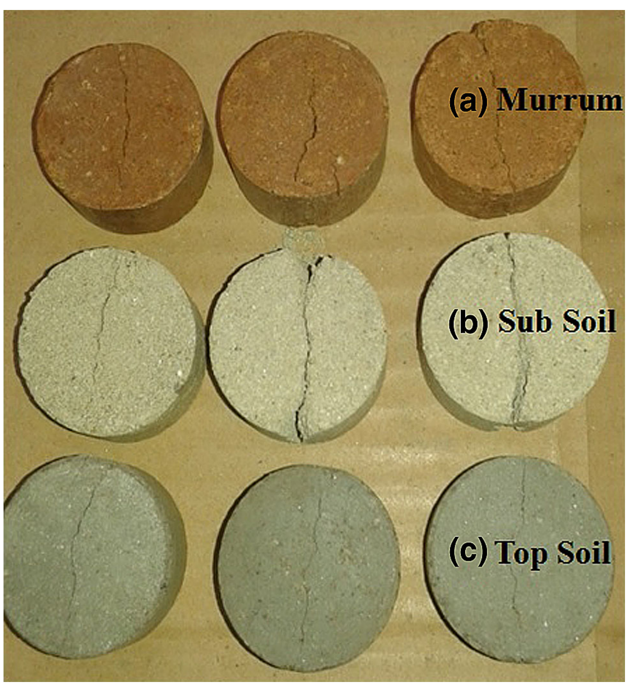


Fig. 12 Failed samples after Brazilian tensile strength test

Conclusion

Surface mine economics depends on the performance of haul road apart from other factors. The response of surface course depends on the layers beneath it. In the current investigation, performance of un-stabilized mine overburden materials are evaluated for haul road application. The following conclusions have been drawn from this study.

1. Overburden materials have major chemical constituents of silica 33.82–54.80%, alumina 25.87–33.70% and iron oxide 5.89–26.11%.
2. Top Soil, Sub soil and Morrum have high maximum dry density 1974, 1990, and 2055 kg/m^3 respectively and low optimum moisture content 10.4, 6.7 and 10.63% respectively.
3. Soaked CBR values of Top Soil, Sub-soil and Morrum are 1.7, 2.1 and 18% respectively.
4. Untreated Top soil and Sub soil are not suitable as haul road construction material as they posses low compressive strength and CBR value in soaked condition.
5. The CBR values of untreated top soil and sub soil are low (<3%) in soaked condition and hence those are unsuitable for road construction.
6. There is not much strength gain in the untreated top soil and sub soil with varying curing periods e.g. from 7 to 28 days.
7. Morphology of material confirms presence of irregular shape of solid particles, which affects the compactions whereas low calcium content does not support compaction. Hence, these haul road material requires some binding agents for their stability.
8. It is found that only untreated morrum is found suitable as a sub-base material. Hence, commercial additive is required improve the CBR of mine overburden materials to have potential as sub-base and base course material.

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