



A Study on Utilization of Mine Overburden as a Replacement of Base and Sub-base Layers on Rural Roads

Brajendra Nath, Sowmiya Chawla^(✉), and Randhir Kumar Gupta

Department of Civil Engineering, IIT(ISM), Dhanbad, Jharkhand, India
pranav.talkto@gmail.com, sowmiya_iitd@hotmail.com,
randhir@live.in

Abstract. The ever-increasing urbanization, globalization and population have led to construction of pavement in rural areas. It has been a cause of concern of depletion of natural resources at an alarming rate but also gradually becoming a challenge for sustainability. This paper presents the application of mine overburden (OB) dump material for replacing the natural aggregate in rural roads. OB dump also known as colliery spoil which is the solid residual material resulting from the mining of coal. It is likely to contain varying proportions of sandstone, shale, mudstone and coal fragments. These overburden can be used in various ways as a substitute for conventional material for rural roads. The coal producing countries (including India) accumulate large amounts of OB close to collieries. The existing coal mine overburden might be a good alternative for aggregate and provide a suitable base and sub base material in rural roads. Use of OB may provide an economical solution to reduce the transportation cost that has to be hauled from a long distance under such conditions also reduce the environmental influence caused by coal mining. In this present study the 1:3 scaled laboratory model tests have been carried out on an unpaved pavements with OB as base and sub-base layers. Monotonic as well as cyclic tests have been conducted using computer controlled pneumatic cyclic actuator. The tests were conducted with various soil conditions and loading patterns. A finite element analysis for monotonic loading has been done with different soil conditions. Based on the test results, it can be concluded that Dhanbad soil of subgrade CBR 3 gives better results than other subgrade of low CBR. The overburden aggregate shows similar behaviour to that of virgin aggregates. Therefore overburden dumps can be used as a replacement of base and sub-base layers for rural roads where the utility of low volume roads are high.

1 Introduction

Rural Roads are recognized as an infrastructure for the social, economic and agricultural growth of the country. Rural infrastructure has a direct link in improving livelihoods, health and productivity and reduced poverty. Rural roads constitute more than 80% of the total road network in India Fig. 1 and Table 1. Roads are a lifeline for rural communities, linking them to markets, education, health and other facilities. Better

roads provide improved market access which, in term results in favorable input and output prices and improving the economic condition of the rural poor.

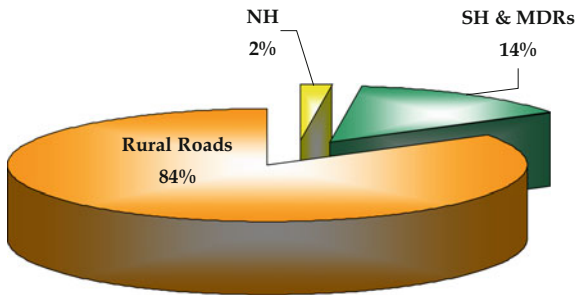


Fig. 1. Status of rural roads in India

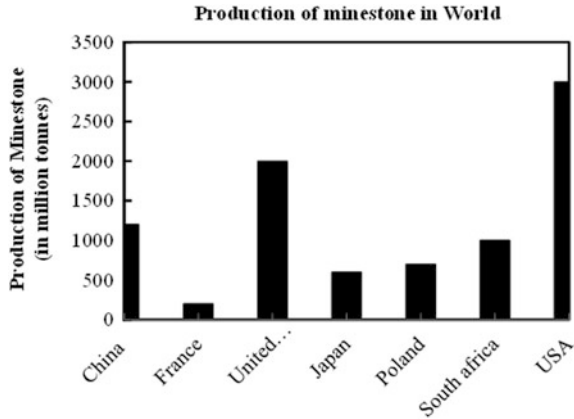
The Government of India in order to accelerate development and growth made huge investments in power, industry, transport and essential social services like education and health. Efforts were also made to improve the productivity of agriculture sector in the country. However benefits of all these investments were not reaching the majority of its population living in the rural areas. In the early 70s, planners decided to give a major thrust to the development of rural roads through investing in various schemes which had provisions to provide help for developing rural roads despite of that the rural roads development still lacked adequate planning and management and the need for National and State highways remained a priority in the successive years. To improve and maintain its usage alternative such as use of mine stone overburden in low volume and unpaved roads need to be explored. As most of the roads in the United States and the world are low-volume unpaved roads (Tingle and Jersey 2007), materials required for construction and maintenance of these roads put a huge burden on the environment every year. The possible use of mine stone overburden to replace natural and produced materials therefore could provide a better choice in environmental terms as compared to other materials such as sand, gravel and aggregate.

1.1 Production of Mine Waste

Coal is the most abundant fossil fuel resource present in India. Currently, India stands fourth in the world in terms of identified reserves. There are 44 major coalfields located in the Indian peninsular, in addition to 17 in the north-eastern region. In India production from opencast mining which currently accounts for 73.8% of total coal production. India has reached the forefront of the world coal scene, ranks fourth in total coal production and is the third largest coal producer from opencast mines. The average stripping ratio (overburden to coal) during the last three decades was 1.97 tonnes/m³ (Chalukya 2000). Increasing coal mining waste and the accelerating pace of industrialization have stretched the self-sustaining capacity of the ecosystem to the point where its delicate equilibrium is threatened. Table 1 and Fig. 2 gives a clear cut idea about the production of mine stone or OB dumps in worldwide and in India during the mining process.

Table 1. Total length of road network in India 32 lakh km

S.no	Road network in India	Length (km)
1	National highways (NH)	65,600 km (2.04%)
2	State highways and major district roads (SH and MDRs)	4,32,000 km (13.5%)
3	Rural roads	27 lakh km (84.4%)

**Fig. 2.** Production of mine stone in the world (after Krystyna M Skarzynska 1995)

Opencast excavation of coal deposits involves the removal of overlying soil and rock debris and their storage in overburden dumps. These overburden dumps change the natural land topography, affect the drainage system and prevent natural succession of plant growth resulting in acute problems of soil erosion and environmental pollution. The overburden consists of alluvial loose sand, gravel, shale and sandstone. Sandstone are sedimentary rocks consists of quartz and feldspar and found in various colours like white, grey, red, buff, brown, yellow and even dark grey. The specific gravity of sandstone varies from 1.85 to 2.7 and compressive strength varies from 20 to 170 N/mm². Its porosity varies from 5 to 25% (Sharzynska 1995a). There is various application of mine stone in railways, roadways, harbour, mining and hydraulic Engineering as described in (Sharzynska 1995b). The results on test sections with other base materials (sand, aggregate and quarry waste) can be found in Pokharel et al. (2010, 2011), and Yang et al. (2011).

2 Facility, Equipment and Test Preparation

Test facilities at the Indian Institute of technology ISM Dhanbad were used for this research. The material properties were determined at IIT ISM Dhanbad. A photographic view of the model test set-up is given in Fig. 3. To apply monotonic and cyclic loadings on the model, the tank was mounted on the loading frame of a cyclic Actuator with Computer Control System. The set up consists of specially fabricated rectangular

steel tank with the dimension of 120 cm × 80 cm × 60 cm and is made up of 6 mm thick steel plates and suitable angles acting as stiffeners for conducting model tests on low volume roads. The tank is fitted with Perspex sheet on both sides so that observers could visualize the failure of the pavement. The other two sides of the tank are smooth and rigid to create plane strain conditions in the tank. A Polythene sheet lubricated with oil on the wall to reduce friction and allow free vertical movement. The granular layer (sub base and base layer) and subgrade were compacted using a 10 kg steel hammer and a 20 kg specially manufactured sheep foot roller respectively.



Fig. 3. The typical model test

2.1 Instrumentation Used

Monotonic and cyclic loading were applied at the top of the pavement by a circular plate which was in turn connected to pneumatic load cell of the cyclic actuator. Model pavement were adequately instrumented to record important responses during the tests. The instrumentation consists of displacement transducer and pneumatic load cell to a computer controlled data acquisition system. A load cell of 20 kN capacity was used to measure the vertical load.

3 Test Procedure

3.1 Bed Preparation and Instrumentation

The subgrade soil bed was prepared as follows: first, the dry soil was sieved to remove foreign particles; a required amount of water was then mixed with the soil. The soil which was used in this study namely Dhanbad soil was mixed with water manually by bare feet in a 30-kg batch each in a large ceramic tub to break up any clods present base on a trial and error procedure. The soil was then filled up in separate cylindrical drums

and covered up with wet jute bags for 24 h for moisture equalization. At the bottom of the test tank, circular holes were provided at constant interval. These holes were covered with a layer of non-woven geotextile and subgrade soil was placed over it ensuring a drainage boundary at the bottom of the tank. The test tank was filled with required amount of subgrade soil and compacted in four layers to achieve desired density. Kneading compaction was carried out using a small specially manufactured sheep foot roller of 20 kg weight as shown in Fig. 4. After the compaction process samples were collected from three different location in plan and from four different depths at each location to monitor water content, dry density and undrained shear strength. The entire surface area was then covered with wet jute sheets and the soil bed was left in this condition for further 24-hour moisture equalization. The sub-base and base layer which consist of overburden aggregates were prepared and compacted in two layers by manual compaction to ensure uniformity. The required amount of moorum was added in granular layer to fill the gap between the aggregates.



Fig. 4. Kneading compaction using sheep foot roller

3.2 Loading System

The axle load in most states varies from 80 kN (18,000 lb) to 90 kN (20,000 lb) (Yoder and Witczak 1975). In this study, 1:3 scaled laboratory model test consist of single tire of 20 kN (4500 lb) is considered. The load is transferred to the pavement surface through a contact pressure of single tire. The tire contact pressure on the road is equal to the tire pressure, which is equivalent to 550 kPa. A circular loading plate was used to apply the wheel load on the laboratory model pavement section. The following

equation were used to determine the dimensions of the loading plate to simulate the effect of a wheel load (Yoder and wiczak 1975):

$$r_c = \sqrt{\frac{P}{P_c \pi}} \quad (1)$$

$$D = 2r_c \quad (2)$$

where, r_c is the radius of contact surface, P is the total load on the tire, P_c is the tire inflation pressure and D is the diameter of contact surface. In this study the thickness of the loading plate was 20 mm and the diameter of the loading plate was 124 mm.

3.3 Model Test Procedure

A total of 8 tests were conducted in two groups on pavement section. Group 1 was termed as monotonic test and Group 2 as Cyclic test. The pavement section consisted of Dhanbad soil as subgrade of depth 40 cm, overburden aggregate as sub-base and base of depth 15 cm and 5 cm respectively. The designed pavement section was according to the guidelines for the design of flexible pavements for rural roads (IRC SP: 72-2007). The above section was in a reduced laboratory model test of 1:3 scale. In Group 1 as termed as monotonic test, four tests were conducted on different soil condition of Dhanbad soil and in Group 2, four cyclic tests were conducted on subgrade of Dhanbad soil of CBR 2 of load 2.4 and 3.6 kN and CBR3 of load 2.4 and 3.6 kN.

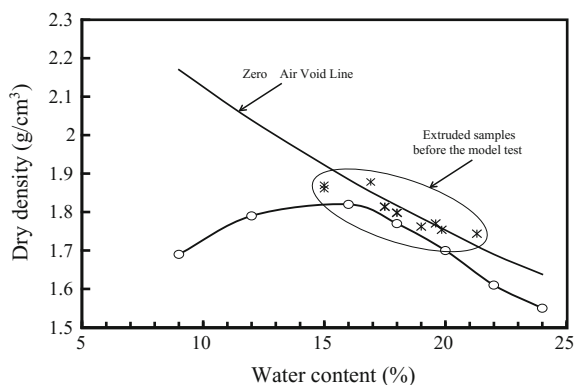
4 Material Properties

4.1 Subgrade

The locally available Dhanbad soil is used as a subgrade soil for this study which are classified as sandy silt of low plasticity. Important characteristics of the Dhanbad soil are summarized in Table 2. Standard Procter compaction and CBR tests on this soil were carried out in the Laboratory. The optimum moisture content and the maximum dry density were 16% and 18.8 kN/m³. The compaction curves are shown in Fig. 5. The grain size distribution of subgrade as shown in Fig. 6 has a D_{10} of about 0.18 mm, a D_{60} of about 0.82 mm and a uniformity coefficient of about 4.55. It can be concluded that soil is well graded soil (Table 3).

Table 2. Overburden of mining waste in India (in million tonnes)

	1999– 2000	2000– 2001	2001– 2002	2002– 2003	2003– 2004	2004– 2005	2005– 2006
<i>1. Coal</i>							
Production	300	310	323	337	356	377	407
overburden	1100	1135	1183	1235	1304	1383	1493
<i>2. Bauxite</i>							
production	7.1	7.99	8.59	9.87	10.92	11.96	12.34
overburden	4.3	4.84	5.20	6.0	6.6	7.2	7.5
<i>3. Limestone</i>							
Production	129	123.6	129.3	155.74	153.39	165.75	170.38
overburden	135	129.4	135.3	163.0	160.5	173.5	178.3
<i>4. Iron ore</i>							
Production	75	80.7	86.2	99.1	122.8	145.9	154.4
overburden	69.9	75.2	80.3	92.3	114.5	136	143.9
<i>5. Others</i>							
Production	7.5	5.02	4.91	7.82	8.32	9.24	9.44
Overburden	14.5	10.60	10.38	15.20	16.26	19.30	18.61

**Fig. 5.** Water content and dry density relationship of Dhanbad soil

5 Mine Overburden Aggregates

Mine overburden material named as sandstone brought from a mine overburden dump site in Jharia coalfield Dhanbad, Jharkhand, were used in this study as sub-base and base layers. Materials used for sub-base and base layer was a crushed aggregate of sandstone of sedimentary rock. The crushed aggregates are then sieved in reduced scale of 1:3 of gradation of sub base and base layer according to the code of rural roads manual (IRC SP:20-2002). The D_{10} and D_{60} sizes are approximately 11 and 28 mm respectively, giving a uniformity coefficient of 2.54. Therefore sub base can be

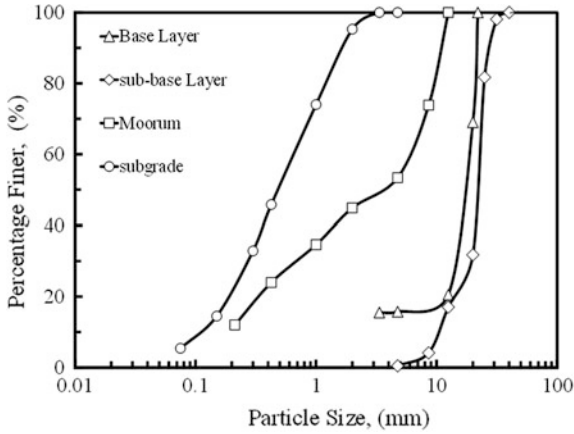


Fig. 6. Grain size distribution of various pavement layer materials

Table 3. Physical properties of subgrade soil

S. no	Properties	Dhanbad soil
1	Dry density (kN/m^3)	18.8
2	OMC (%)	16
3	Specific gravity	2.62
4	Coefficient of uniformity, C_u	4.55
5	Coefficient of curvature, C_c	0.978
6	D_{10} (mm)	0.18
7	D_{30} (mm)	0.38
8	D_{60} (mm)	0.82

classified as a uniform fine gravel. The specific gravity, water absorption, aggregate impact test, los angles abrasion test and slake durability were conducted as shown in Table 2. Aggregate impact value indicates a relative measure of the resistance of aggregate to impact. Bureau of Indian standards (BIS) for aggregate impact value are used to classify the stone aggregates with respect to toughness property. The aggregate impact value of soft aggregates for road construction is given in Table 4.

Table 4. Basic properties of mine stone aggregate

S. no	Properties	Minestone	Physical requirement of course aggregate for WBM for sub base and base course (IRC)
1	Specific gravity	2.28	2.5–3.2
2	Water absorption (%)	4.7	4.0
3	Aggregate impact test (AIV) (%)	36	50
4	Los Angeles abrasion test (%)	69	40
5	Slake durability test (%)	96	–

6 Finite Element Method

Finite Element Method (FEM) is a powerful tool to analyze engineering problems, the accuracy of which depends on several factors. First, the extent of meshing of the individual components. Second, incorporation of the parameters that has major influence on the problem. Finally, the interpretations of the result should be reasonable. Accordingly, the FEM is used in this study to perform a comparative analysis of the results obtained from the two methods i.e. experimental and FEM.

6.1 Material Properties

Material properties used for the FEM analysis is same as that for the experimental setup. The properties of each component is shown in Table 5.

Table 5. Material properties

	Soil layer	E (kPa)	μ	Y (kN/m ³)	C	ϕ
CBR < 0.16	Subgrade	100	0.49	18	4	0.1
	Sub-base	190	0.35	20	0.1	35
	Base	240	0.3	21	0.1	30
CBR = 0.2	Subgrade	100	0.49	18	4	0.1
	Sub-base	3800	0.35	20	0.1	35
	Base	5200	0.3	21	0.1	30

6.2 Finite Element Model

Finite Element Modelling of the experimental setup is done using the geotechnical analysis software, Midas GTS NX. A three-dimensional model of the subgrade, sub-base and base layers is loaded on top to get the load settlement profile of the base layer. The subgrade is modelled using elastic-plastic, Mohr-Coulomb constitutive relationship, the sub-base and base layers are modelled using elastic-plastic, Mohr-coulomb, effective stress (drained) relationship. Each layers of pavement are divided into proper element size using the auto mesh option. The FEM model is shown in Fig. 7.

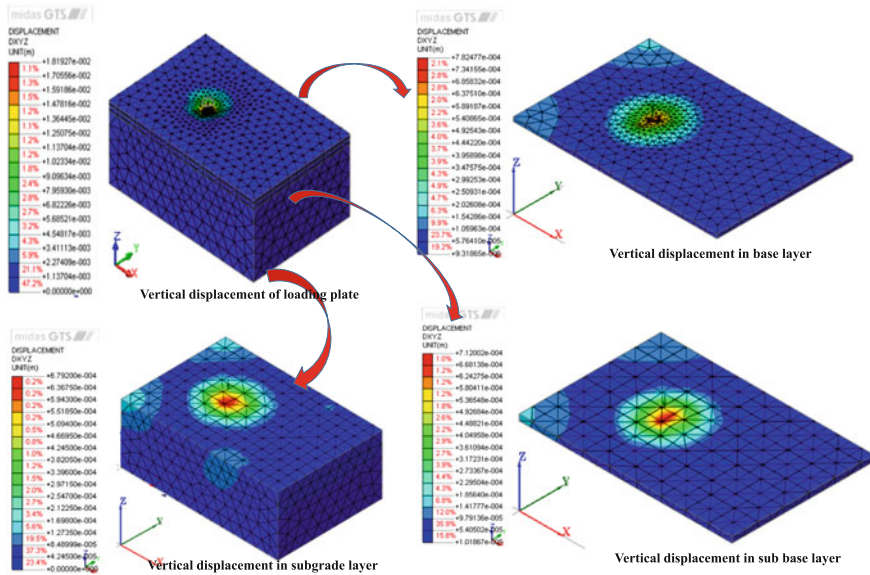


Fig. 7. Finite Element method test

6.2.1 Boundary Conditions

The use of proper boundary condition is the most vital part so as to represent the exact physical setting of the actual problem. Therefore, to obtain this several tools are used such as restraints to the nodes of boundary layer. In this study, roller supports is used for the vertical boundaries and the bottom boundary face is considered as fixed. The intermediate boundaries between the layers are set as drainage boundary.

6.2.2 Loading

A vertical load of 10 kN is applied on the plate with 10 load steps with a maximum of 350 iterations in each step. The loading is performed for twenty minutes and displacements for each loading step is obtained.

7 Results and Discussions

7.1 Monotonic Tests

A strain controlled monotonic test was conducted on an unreinforced pavement section. The result of this test was used to determine the magnitude of cyclic load to be applied during cyclic tests. During the monotonic test the loading was applied at the strain rate of 0.06 mm/sec. These tests were conducted to find out the effect of subgrade condition on the load settlement responses. Based on (Vesic 1963) the failure loads under monotonic loading for different soil conditions for unreinforced pavements were obtained as 4 kN and 6 kN respectively. A threshold stress level is defined as critical stress level is above CLRS, plastic deformation is non-terminating. Based on (Sharma 2007 and Sowmiya 2013) threshold stress ratio (TSR) has been obtained as 60% for low plasticity soils. Based on this cyclic load of 2.4 kN (TSR = 60%) of subgrade of CBR 2 and 3.6 kN (TSR = 60%) of subgrade of CBR 3 were used for different soil conditions of Dhanbad soil.

7.1.1 Effect of Subgrade CBR on Total Settlement

Figure 8 presents the effect of Subgrade soil CBR value on the total settlement of the pavement. From the results it is concluded that CBR of less than 2 shows the behavior of punching shear failure and local shear failure and CBR above 2 shows General shear failure.

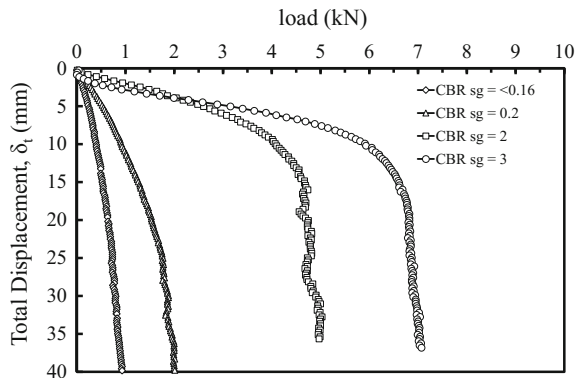


Fig. 8. Effect of subgrade soil CBR value on the load—settlement response

7.1.2 Effect of Compaction Energy on Total Displacement

Figure 9 presents the effect of compaction effort on the total displacement. It is concluded that the subgrade compacted with sheep foot roller gives better load carrying capacity than the subgrade compacted with hand kneading.

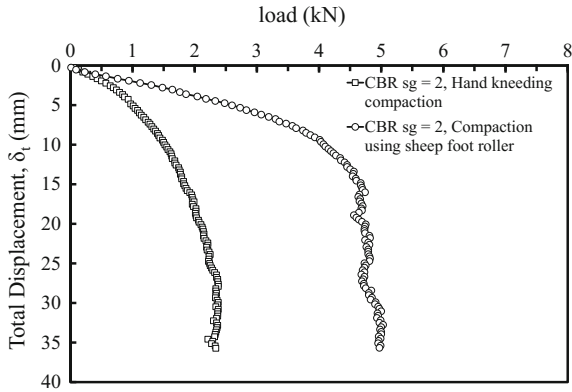


Fig. 9. Effect of compaction effort on the load—settlement response

7.1.3 Finite Element Prediction

Figure 10 presents the finite Element prediction of the comparison of load displacement curves of model test and numerical model. Both the model test and numerical test shows the similar behavior compacted with hand kneading and sheep foot roller. The compaction with hand kneading shows that soil is loosely packed and shows punching and local shear failure while compaction with sheep foot roller shows that soil is capable of taking the desired load for transportation with nature of General shear failure.

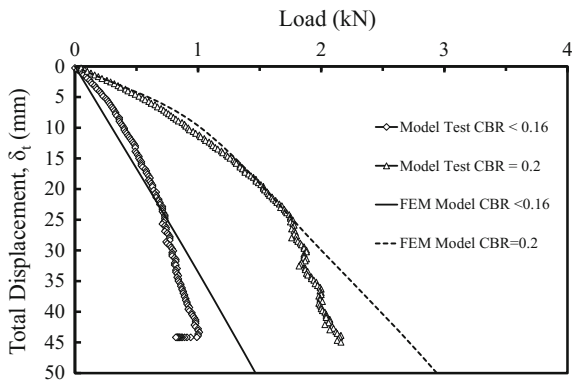


Fig. 10. Comparison of displacement in model test and FEM model

7.2 Cyclic Tests

The cyclic tests of pavement section was carried out on two different soil conditions of CBR 2 and CBR 3 of load 2.4 and 3.6 kN. For the subgrade of CBR 2 threshold stress ratio was taken as 60% as 2.4 kN of 4 kN failure load and cyclic tests were

conducted in four steps i.e. 1.2 kN (30% of failure load), 1.6 kN (40% of failure load), 2 kN (50% of failure load) and 2.4 kN (60% of failure load). Considering the Indian typical mixed traffic condition varying axle loads in a particular lane, the above load steps have been applied. For the subgrade of CBR 3 threshold stress ratio was taken as 60% as 3.6 kN of 6 kN failure load and cyclic tests were done in four steps i.e. 1.8 kN (30% of failure load), 2.4 kN(40% of failure load),3 kN(40% of failure load) and 3.6 kN (60% of failure load).

7.2.1 Loading Pattern of Cyclic Model Test

The actuator with load cell was placed over loading plate. A sinusoidal load pattern has been followed at an increasing magnitude of load cycle of 100 to 25,000 with frequency of 0.67 Hz (Perkins et al. 2012) has been applied with Dhanbad soil as subgrade with different soil conditions of 2.4 and 3.6 kN cyclic load was applied as shown in Figs. 11 and 12. Initially the stiffness of the model pavement was very low for low volume roads, therefore a slow frequency of 0.67 Hz was applied. A strain controlled loading was applied during monotonic tests while a stress controlled loading was applied during cyclic tests.

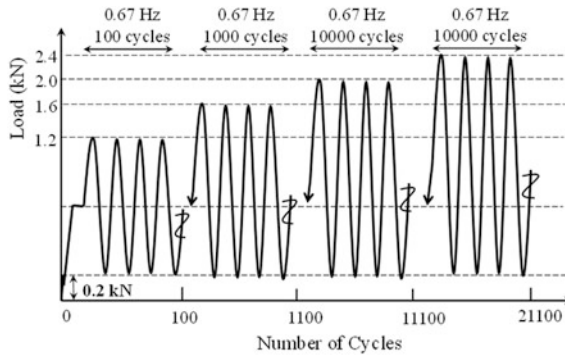


Fig. 11. Sinusoidal loading sequence of 2.4 kN

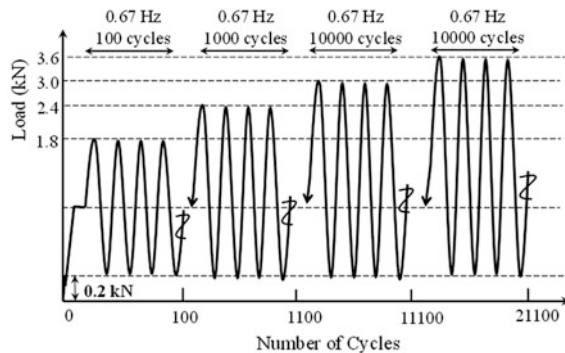


Fig. 12. Sinusoidal loading sequence of 3.6 kN

7.2.2 Effect of Subgrade CBR on Rut Depth

Figure 13 shows the typical initial cyclic loading pattern up to 1000 loading cycles of the model test results of CBR 3 with 3.6 kN. Figure 14 shows the model test section, the effect of subgrade CBR 2 and 3 on rut depth for cyclic load of 2.4 kN. The pavement section with subgrade CBR 2 shows more rut depth as compared to subgrade CBR 3 for different steps of loading pattern of 1.2, 1.6, 2.0, 2.4 kN respectively. It is due to the fact that CBR 3 is stiffer than CBR 2. The behavior of subgrade of CBR 3 shows the pattern of general shear failure while the CBR 2 shows the pattern of local shear failure.

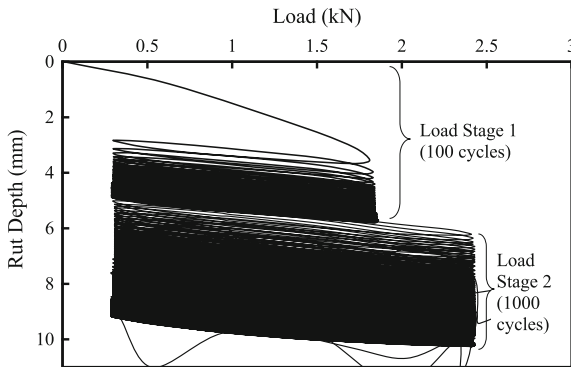


Fig. 13. Typical initial cyclic loading pattern up to 1000 loading cycles of the model test results of CBR 3 with 3.6 kN

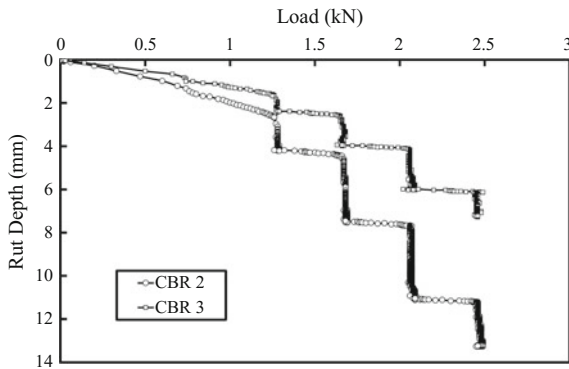


Fig. 14. Effect of subgrade CBR on rut depth for cyclic load of 2.4 kN

Figure 15 shows the model test section the effect of subgrade CBR 2 and 3 on rut depth for cyclic load of 3.6 kN. The pavement section with subgrade CBR 2 shows more rut depth as compared to subgrade CBR 3 for different steps of loading pattern of

1.8, 2.4, 3.0, 3.6 kN respectively. It is due to the fact that CBR 3 is stiffer than CBR 2. It is concluded that the behavior of subgrade of CBR 3 shows the pattern of general shear failure while the CBR 2 shows the pattern of local shear failure.

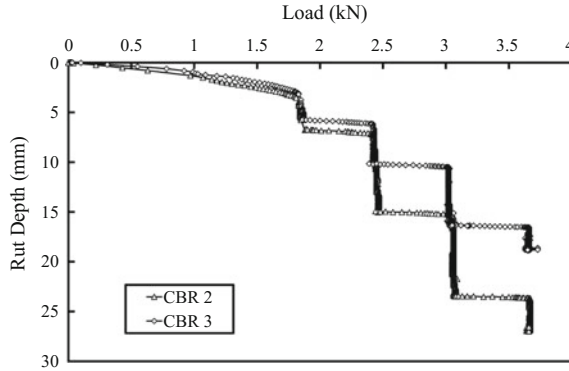


Fig. 15. Effect of subgrade CBR on rut depth for cyclic load of 3.6 kN

7.2.3 Effect of Cyclic Loads on Subgrade CBR

Figures 16 and 17 shows the effects of cyclic loads of 2.4 and 3.6 kN on subgrade CBR 2 and 3, respectively. It seems that, with same subgrade CBR 2 and different loading conditions the displacement is more in case of cyclic load of 3.6 kN than 2.4 kN. For the first 100 and 1000 cycles the rut depth is steep in both the cases. In third cycle of 10,000 the rut depth is increasing but constant in both the loading cases of same soil condition. In fourth cycle of 10,000, obviously the rut depth is increasing but constant in both the cases. The modulus of the pavement section has been changed due to increasing traffic loading. After 'n' number of traffic passes the pavement layers get compacted and the overall stiffness of the pavement section also increased. This is reason for the reduction in the incrementation of the rut depth with increasing the loading cycles.

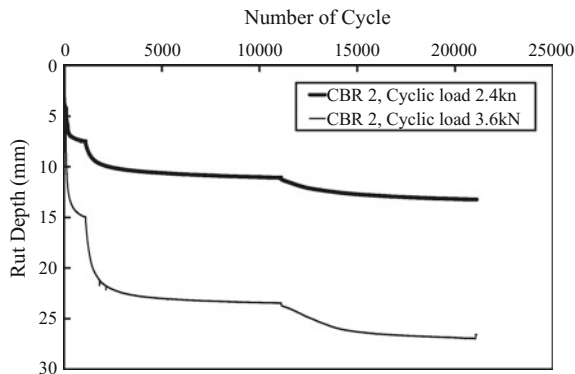


Fig. 16. Effect of cyclic loads of 2.4 and 3.6 kN on subgrade CBR 2

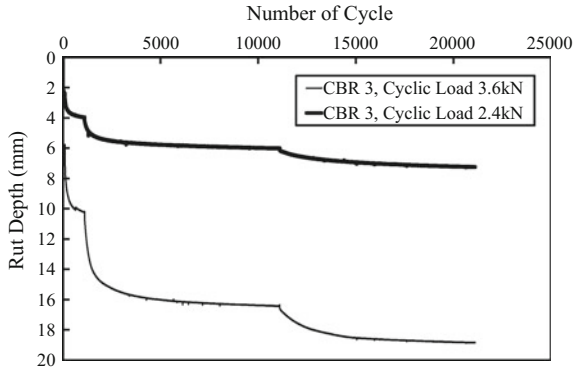


Fig. 17. Effect of cyclic loads of 2.4 and 3.6 kN on subgrade CBR 3

Figures 18 and 19 shows the effect of cyclic load 2.4, 3.6 kN on subgrade of CBR 2 and 3, respectively. For the first 100 cycles the rut depth is more in subgrade with CBR 2 than subgrade with CBR 3. For the second 1000 cycles the rut depth is steep in both the soil conditions. For the third 10,000 cycles rut depth is constant in both the subgrade of CBR 2 and CBR 3 but rut depth has increased significantly in subgrade of CBR 2. For the last 10,000 cycles rut depth is uniform in both the cases.

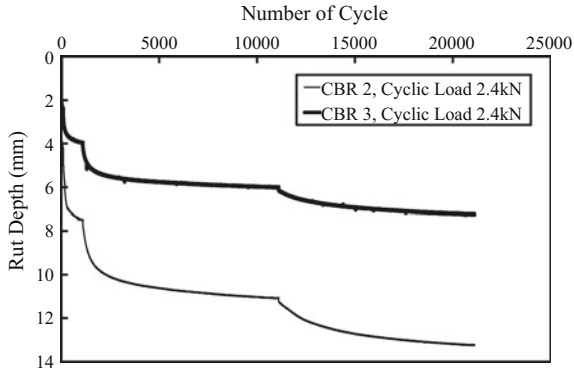


Fig. 18. Effect of cyclic load 2.4 kN on subgrade CBR of 2 and 3

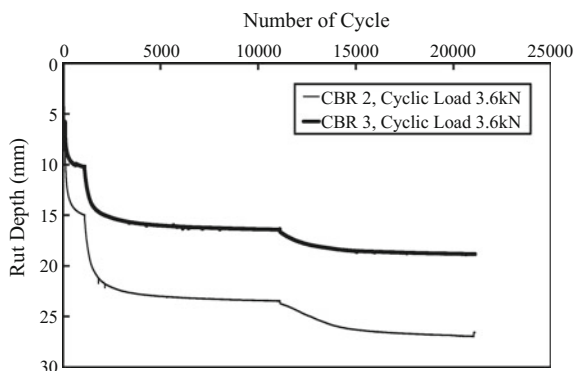


Fig. 19. Effect of cyclic load 3.6 kN on subgrade CBR of 2 and 3

8 Conclusion

This paper presents the results of the experiment conducted on reduced scale model test and numerical tests on sample test section that include mine stone overburden materials in base and sub base layer. The following conclusion can be drawn from this study that Mine stone overburden materials can be used as pavement materials for base and sub base courses in unpaved roads as sustainable alternative. Laboratory model test results shows that the subgrade condition will play a major role for the load settlement response of the pavement. This is the preliminary study of the behaviour of modelled rural pavement using overburden aggregates as a base as well as sub-base layer. Moreover, the detailed study has been needed to study the resilient behaviour as well as the breakage characteristics of the overburden aggregates.

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