Optimisation of haul road dimension with lime induced overburden composite material

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Abstract **— The current share of coal in India's installed electricity generation of 343789 MW is about 57%. India produced 662.792 MT in 2016-17 with a projected output of 1 billion tonnes by 2020. The majority of it would be sourced from high capacity open cast mines. It needs large HEMMs that need rugged, strong and hence, durable haul roads. Haul road construction materials have not matched to the increasing capacities of heavy earth moving machineries. Conventional materials for construction of haul roads include either the mine overburden or locally available sand, gravel and/or clay. As observed, those do not provide adequate ground stability resulting in excessive stress and strain on the haul road layers. This study developed and evaluated waste byproduct based alternate haul road construction material for better performance. The developed material constitute mine overburden, fly ash, and lime of varying percentages. Their physico-mechanical properties were determined. The lime and fly ash content and curing period was observed to have direct co-relation with the strength of the developed composite materials. The composition with 27.5% fly ash, 64.2% OB and 8.3% lime exhibited maximum UCS at 3.14 Mpa and CBR at 77.08%. The critical strain limit for the haul road was determined for an operating coal mine. The best composition was evaluated to determine the maximum strain values for both static and cyclic loading conditions. The haul road dimensions were optimised for minimum adverse effect on the surface course to keep the strain limits below the critical value. The developed composite materials with enhanced geotechnical properties exhibit strong potential to replace the conventional materials in the layers underlying the surface course as well as enhance the effective utilization of fly ash**

Keywords— Mine Overburden, Cyclic Loading, Critical Strain, composite Material

I. Introduction and Background

Coal is still the most popular resources for energy. These days there has been increasing activity to enhance the extraction of coal through surface mines. Traditionally surface excavation is a major mechanism to extract mineral in large geometric quickly and efficiently. The transportation of coal and overburden material is a main economic activity of the mine and its performance has a strong bearing on the mine economics. The transportation takes place on haul road whose life varies between a few months to full life of the mine (years). The transportation cost of a surface coal mine is about 50% of the total operating cost (7).The larger the mine capacity, the more robust the haul road should be. The over-lying earth material and coal are loosened, and shifted to facilitate coal extraction.

During the past 30 years, surface mine haulage equipment has developed from tiny capacity 20 tons to vehicles that transport as much as 400 tons. Unfortunately, the design of roads this equipment must traverse has not advanced at the same rate. There has been very little focus on developing the safety as well as the performance parameters of the haul roads. There are frequent cases of continuous haul road maintenance that adversely affect the mine cost. One of the major reasons of frequent problems occur due to unsuitable haul road construction materials as well as its thickness. Thus a need for the development of suitable materials for haul road design is strongly felt. Normally in an open cast mine the length of permanent haul road varies between 3 to 5 km. They are used for ferrying the overburden material as well as the extracted coal and other minerals. The average stripping ratio (overburden to coal) during the last three decades in India was 2.67m^3/t (18). Though there are attempts to reclaim the mined out area with filling by the waste dumps, the measures do not often accommodate all the displaced overburden. One of the major environmental challenges is to manage the huge volume of overburden generated in these opencast mines.

At present axle loads from 80 t to 170 t ply on haul roads in India with a few mines having larger sizes. A good haul road ensures reduced breakdown of vehicles with increased rate of availability, reduced cost of maintenance, reduced fuel consumption, better safety, increased tyre life, etc. Haul road is a multi-layered structure. A haul road design has two main aspects, structural and geometric designs. The geometrical design of haul road deals with physical dimensions such as width, cross-slope, ditch height and safety berm height. The structural design of haul road is basically the determination of the thickness of various layers of a haul road for a particular combination of construction materials and load configuration. The objective of both the design is to provide a safe, efficient, smooth and vehicle friendly ride to the haul trucks and other vehicle without excessive maintenance through its designed life. Typically, the upper layer consists of the strongest material. Applied load, sub-grade strength, pavement thickness, and layer strength influence the structural performance of haul road. Loading induces strain in the layers. The vertical compressive strains decrease with increasing depth thus permitting use of material of different gradation as well as construction process.

Typically, the coal deposits of India are overlain by a mixture of clay, soil, sandstone, shale stones, etc. making the material highly heterogeneous. Most mine operators use the loose overburden material for the haul road construction. Overburden consists of alluvium, laterite, sandstone, carbonaceous shale, coal bands, clays etc. A proper utilization of this overburden material will ensure the effective utilization of the mining lease area, reduce the transportation cost and improve the overall sustainability of the mine. Thermal power plants are commissioned near to the surface coal mines. These plants produce huge quantities of fly ash that adversely affect environment. Increasing the usage of fly ash in haul road would reduce the problem. Fly ash rich in silica, is a good void filling material. In presence of binding agent, it exhibits pozzolanic behavior.

Potential application of fly ash alone or soil stabilized with fly ash or fly ash and admixtures for road construction has been reported by a number of researchers (5, 9, 10, 13). The enhancement of mechanical strength of fly ash with addition of lime has been reported elsewhere (1, 6, 8, 11). There exist many reports on successful usage of fly ash in pavement (20, 21) and limited investigation of it on haul road (15, 16).

There exists strong potential of surface coal mine overburden for use as underground backfill material due to favorably compared values of bulk density, porosity/percolation rate, etc (17). The untreated top soils and sub soils of a coal mine had low compressive strength and low CBR value i.e. less than 3% (19). In another report, it was observed that 62% fly ash with 30% mine overburden and 8% clinker content exhibited highest strength values at 1.14 MPa at 28 days curing and the mixture was recommended suitable for base or sub-base layers (22).

The investigation consists of numerical analysis with both conventional material as well as the developed composite material at different thickness i.e. base and sub-base layers. The surface course remained the strongest material and hence not changed or replaced. The conventional material was replaced with composite material at both base and sub-base layers though at different stages.

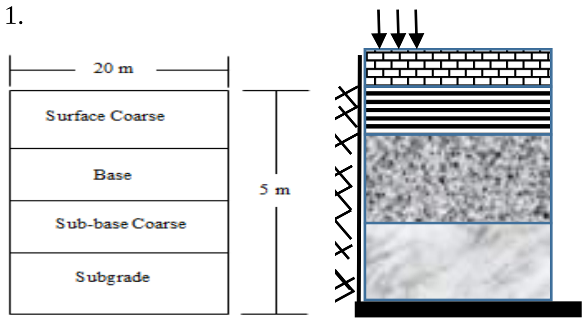
In this investigation fly ash based composite material has been developed and evaluated for its efficiency in haul road construction material. A composite material is made from two or more constituent ingredients with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The composite materials consist of a mixture of fly ash, overburden and lime. The experimental investigation involved 15 to 50% fly ash, 85 to 50% overburden, and 2 to 9% lime. The material strength values obtained varies from 0.71 to 3.14 MPa between 7 and 56 days curing period respectively. The maximum strength value was obtained for a composition of 27.5%, 64.2%, and 8.3% at 56 days. This developed material has been evaluated for the haul road application.

The strength parameters of the developed material cured for 7 to 56 days were evaluated. The details of such experiments are discussed elsewhere (14). The fly ash and overburden material used are available from a nearby power plant and surface coal mine of Odisha respectively. The additive selected was commercially available superior grade quick lime. The chemical characterization of overburden, lime, and fly ash are given below (Table 1).

Table-1: Chemical compositions of fly ash, mine overburden and lime (14)

Constituents (%)	Fly ash	Mine Overburden	Lime
SiO_2	50.88	49.8	0.92
Al_2O_3	34.78	28.49	0.29
Fe_2O_3	6.31	8.32	0.45
CaO	0.52	1.09	75.82
K_2O	1.42	0.39	--
MgO	0.51	1.23	3.94
TiO_2	2.95	0.69	--
Na_2O	0.2	--	--
P_2O_5	--	--	0.04
SO_3	--	--	0.55
LOI	2.4	10	17.99

A cross-section of the haul road considered is shown in the figure 1.



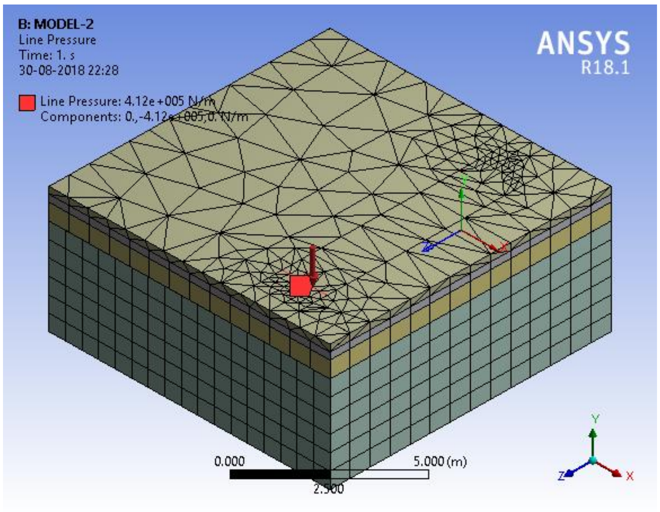


Fig 1: Haul Road Structure, Modelling and Image of Loading on surface

II. Critical Strain Analysis

Critical vertical strain is the maximum vertical strain that the haul road structures experience at failure due to loading. It depends on the number of passes by dumpers over a year. The empirical relation is critical strain, $\varepsilon = {80000}/{N^{0.27}}$ where ε is the allowable strain limit in microstrain and N is number of load repetitions i.e. number of passes (4). There are reports that the relation ε is valid between 50000 and 5000000 passes for any surface mine (4). This was also favorably confirmed for 2000 micro-strain in SA mines (2). It is determined that the number of passes a line on the haul road surface would experience is 10 every 12 minutes assuming the mine operates 6 hours a shift with 3 shifts per day for 300 days in a year.

The total production of a case study mine is 7 million tonnes of coal with average stripping ratio of 2.67 i.e. an annual material transportation of 26 MT. The road is proposed to remain stable for 5 years without any major maintenance work. So total load of coal carried over the road is 130 million tonnes. The number of passes a line of haul road surface would experience over a period of time is determined.

Dumper capacity used= 80 T

Number of passes of loaded trucks on the road = 130000000/80= 1625000

Critical strain= 80000/(1625000)$^{0.27}$= 1683 µm

III. Tyre Pressure

The surface course experience line loading due to the dumper wheel. The simulation was carried out with a pay load of 80T with gross vehicular weight of 160T (24). The dumper experiences 67% load on read axle and 33% on front axle. The number of tyres in a dumper are at front 2 and back 4 (2x2) with tyre width at 0.8m.

Diameter of contact area of Tyre = Width of the Tyre

$$Tyre\ Pressure = \frac{Gross\ Vehicular\ Weight}{Number\ of\ tyres * Tyre\ Foot\ Print\ Area}$$
= 520 KN/m^2

The surface experience line loading and it is determined for axisymmetric configuration as below.
Total load on 3 tyres= 520*3= 1560KN/m2
Total load on the rear tyres= 1560*0.67*1.6*1= 1672KN/m
Total load on the front tyre= 1560*0.33*0.8*1= 412 KN/m

IV. Simulation

The haul road geometry was discretized in four layers (Fig.1). The geometrical parameters of construction material for the layers were considered in decreasing order with surface coarse with stiffest material. The design was evaluated with both conventional as well as the best developed composite material with varying layer thickness. Attempt has also been made to reduce the total thickness of the haul road without exceeding the critical vertical strain limit. The surface coarse thickness and its material properties remained the same. The haul road models were developed in SOLID WORKS 2016 and imported to ANSYS R18.1 for simulation.

The simulation of haul road loading was carried out in axisymmetric condition with 10m wide and variable depth (Table-2) with permissible deformation in the lateral direction. The simulation for maximum strain was carried out with surface coarse, base course, sub-base course and sub-grade layers at 0.25m, 0.25m, 0.45m and 3.0m respectively. The elastic modulus values for conventional material in decreasing order at different layers considered were 200, 100, 50 and 50 MPa (12). The elastic modulus value of the developed composite material obtained was 142 MPa. An uniform Poission ratio value of 0.4 was considered for all the layers (12). The maximum strain values exhibited with conventional material curve 3909 µm and 4377 µm static and cyclic loading respectively. It is observed that there was little change in strain values when the thickness of subgrade beyond 1.5m. So in subsequent simulation the thickness of subgrade was maintained as 1.5m. The results of the simulation carried out are discussed in following section.

Table-2: Different Thickness and Material Properties of the Haul Road

Construction Materials	Layer E (MPa), t (m)							
	Surface		Base		Sub-base		Subgrade	
	E	t	E	t	E	t	E	t
Conventional Material	200	0.25	100	0.25	50	0.45 to 1.2	50	3
Replaced with Developed Material	200	0.25	100	0.25	142	0.45 to 1.2	50	3
Alternate Layout with Developed Material	500	0.25	142	0.7 to 1.45			50	1.5

Results and Analysis

The maximum strain in static loading using the conventional material obtained was 3909 µm. It decreased by 53% to 1833 when the ratio of sub-base thickness to total thickness changed from 0.11 to 0.22. The critical strain reduced to 1344 µm when the ratio was 0.25. The strain values exhibited higher magnitude from 4377 µm to 2344 µm for the ratio of 0.11 to 0.25 when cyclic loading on the haul road was applied. When the composite material was used in sub-base for static loading, the maximum strain drastically reduced from 1008 µm to 508 µm for the ratio from 0.11 to 0.25 respectively. However, the behaviour was more adverse in cyclic loading that showed the maximum strain value at ratio of 0.25 to be 1134 µm (Figure 2). These values were much below the critical strain limit of 1683 µm.

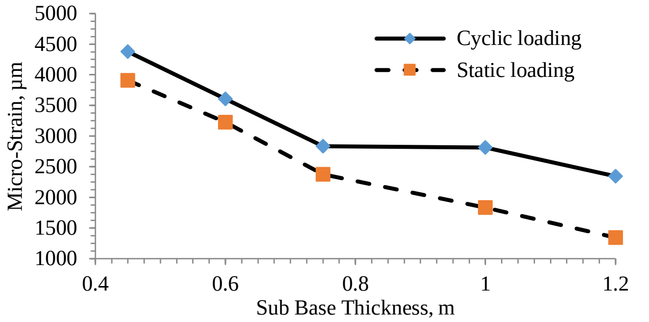


Fig. 2: Static vs Cyclic Behaviour with Conventional material

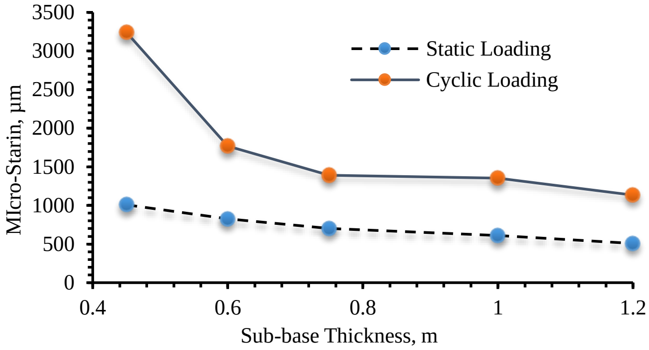


Fig.3: Static vs Cyclic Behaviour with Composite material

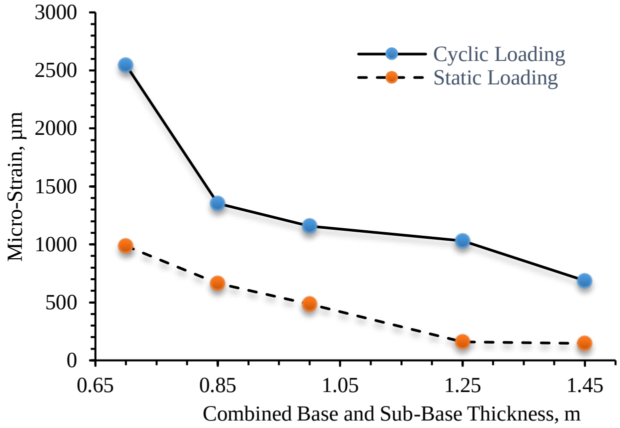


Fig 4: Static vs Cyclic Behaviour with proposed layout and material

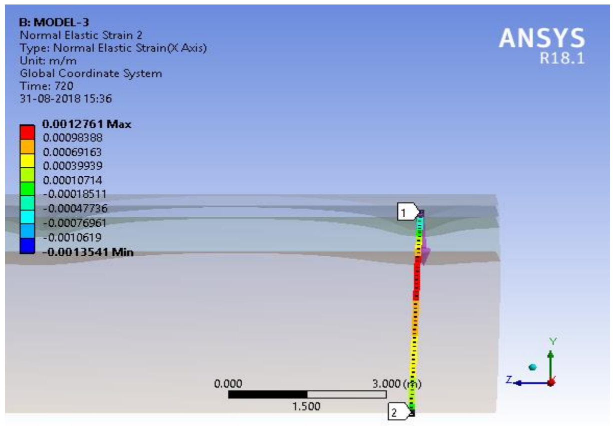


Fig 5: Image of the simulation with proposed layout

The vertical compressive strain due to use of developed composite material in the sub-base exhibit encouraging results though with total thickness at 4.7m (Fig. 3). Hence, a few modified haul road structural design were simulated with composite material to reduce the total thickness. The composite material was used in base and sub-base with varying thickness from 0.7 to 1.45m and the total vertical strain were determined. It is observed that the maximum vertical strain produced was very low i.e. 986 µm for static loading condition. The strain values at the static loading further reduced by 85% i.e. from 986 to 146 µm for a ratio from 0.28 to 0.46 respectively. Similar values for cyclic loading are from 2546 µm to 687 µm. The analysis also shows that at a ratio of 0.28, the maximum strain is more than the critical strain. However, the vertical strain falls below the critical strain from the ratio of 0.36 to 0.46. The stress on the surface due to axle loading penetrated the layers with reduced intensity though that fills the interface between the sub-base and subgrade. It was observed that the layers produced resilience immediately after the loss in the load intensity due to high modulus value of composite material (figure 4). This phenomenon results in producing reduced vertical strain.

V. Conclusion

The surface coal mine haul road is a multi layered structure. Its behavior has a major influence on the productivity and economics of mining operations. Mines conventionally use the over burden or local material to construct the haul road that often exhibit poor performance. The maximum critical vertical strain developed in the haul road structure for a 80T dumper is about 2000 micro-strain. High strength engineering material has been developed with over burden, fly ash, and lime. Numerical simulation of an existing coal mine with different layer thickness as well as construction material exhibited reduced vertical strain. The optimum haul road dimension obtained was 0.25m surface course, 0.8m base and sub-base combined followed by 1.5m sub-grade layer with maximum critical strain value of 1500µm. The developed material exhibit higher potential for haul road application. It has strong potential to reduce the total thickness of the haul road structure and hence cost of mining.

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