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ASSESSMENT OF OPTIMUM FLYASH AND LIME FOR WEAK SUBGRADE IN THE DESIGN OF FLEXIBLE PAVEMENTS

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Abstract-The practice of treating soil with fly ash and lime is an attractive technique when the project requires improvement of the local soil for the construction of stabilized bases under pavements, as a support layer for shallow foundations, to strengthen slopes in slope stability problems, and to prevent sand liquefaction. Most of the time flexible pavement in India needs to be constructed over problematic and poor sub-grade. Such type of sub-grade has low CBR (California Bearing Ratio), which thereby increases the thickness of the pavement. Thus to increase the CBR of such soil we undertake the process of stabilization, thereby reducing the thickness of pavement. The following work was carried out in order to determine the effect of lime, Fly Ash and combination of both on the stabilization of weak soil and thereby effects on Maximum Dry Density (MDD), Optimum Moisture Content (OMC) and CBR of the sub-grade soil.

The soil to be treated was brought up from Sadeipalli near N.H-6, the Fly Ash from nearby 'HINDALCO' and Lime from local manufacturer. Various tests were carried out to determine the CBR and the other criteria like Liquid Limit, OMC, Plastic Limit, and UCS (Unconfined Compressive Strength) etc.

It was found that for sub-grade, a mix of 70% soil, 30% Fly Ash, and 3% lime gives the maximum CBR value i.e. 55.8%, 37.02% and 36.53% after 12, 7 and 4 days of curing respectively whereas the original CBR value of the weak soil was 2.29% after 4 days of curing. Similarly, the UCS of general soil was found to be 1.04 kg/cm2 whereas the average UCS of stabilized soil of different mixes after 7 & 12 days of curing were found to be 2.48 kg/cm2 & 3.23 kg/cm2 respectively. After the strength optimization was over, the feasibility and economic study was carried out for the various mixes considering major roads using the PWD schedule of rates, 2011-12, govt. of Orissa.

From that it was found that 70 % soil + 30% Fly Ash + 2% lime mix gives the maximum savings. But considering the allied factors, we have suggested the 70:30:3 mix of soil, Fly Ash, lime. The sub-grade with the optimized mix costs more than the conventional mix. Still if used along with the specified sub grade layer, the overall savings will be almost 20% as per standard govt. rates. After the cost prediction of different layers of pavement was done a generalized model for cost prediction was developed using SPSS software. It related cost, CBR (in %) and traffic (in msa) and developed a general equation using multiple regression analysis.

From the overall study, it was revealed that mixing only Fly Ash with soil doesn't improve the CBR. Lime alone is capable of providing considerable improvement towards strength. But as the prime motive is to maximize the use of fly Ash, it was always tried to use as much of Fly Ash as possible. The mix containing soil, lime and Fly Ash will maximize the utilizing the potential of Fly Ash. So it is advisable to use all the three together.

1. INTRODUCTION

Reliable road network is prime requirement for the progress of any country. Particularly for a vast & diverse country like India, it is utmost necessary to provide good connectivity to the rural areas so that complete social & economical progress can be achieved. So far the progress in this regard has been minimal. But now with government schemes like "Pradhan Mantri Gram Sadak Yojana" (PMGSY), NHAI Project-4 (Golden Quadrilateral Project, North South East West Corridor) the road construction scenario has taken a big leap forward. Still major hurdles like constraint of fund, lacks of good quality construction materials in the near vicinity considerably hampers the process. So the construction method should be such that with minimum expenditure it is possible to have good roads. Fly ash roads can provide a far better surface than conventional WBM roads due to the higher durability, which can be upgraded to a higher type of pavement at a later stage.

2. MATERIALS USED

2.1 Fly Ash

Fly Ash is used as sub base material collected from HINDALCO thermal power station.

2.2 Sand Soil

The sand soil is used as sub grade material for the test track. The properties obtained from the laboratory tests are furnished below in Table 2.1.

2.3 Lime

Lime brought from local manufacturer.

Table-2.1 Properties of Un-Stabilized Soil

Property	Soil
OMC (%)	13.3
CBR (%) (Heavy Compaction)	2.3
Liquid limit (%)	24.4
Plastic limit (%)	12.3
Plasticity index (%)	12
Unified soil classification	CL
Classified as per AASHTO	CL
Typical name	Inorganic clay of low plasticity

3. LABORATORY INVESTIGATION

3.1 Modified Proctor Test

The modified proctor test were carried out on un-stabilized and stabilized soils as per Indian Standards soil mixed with varying percentages of lime and fly- ash, with percentages of lime varying from 1% to 5% at steps of 1% by dry weight of soil and percentages of fly ash varying from 10 to 50% at steps of 10% by dry weight of soil. The dry-density content relations were plotted for each test. The optimum moisture content (OMC) and maximum dry density (MDD) at each lime- content and fly ash were evaluated.
The figure gives the variation of MDD with various lime-contents including fly ash. The maximum dry density for these soils decreases gradually with increase in lime-content and fly ash, which is due to the light weight of soil particles. The change in OMC was quite marginal for lime and soil combination but was significant for fly ash combination.

3.2 California Bearing Ratio (CBR) Tests

CBR test were conducted on un-stabilized and stabilized soils with different lime-content and fly ash as per Indian Standards. The maximum limit was 5%. Various samples were tested with different lime contents along with fly ash. Weight of soil at each percentage of lime-content required for the test was determined using the volume of the mould and corresponding MDD obtained from Modified Proctor Test. Soil sample and lime and fly ash were properly mixed, considering the required amount of water as per the OMC. The soil sample after mixing was filled in the mould and compacted through heavy compaction methodology. It was then cured for 4days (complete soaking), 7 days (3 days air curing + 4days soaking) and 12 days (8 days air curing + 4 days soaking) and the respective sample was tested in CBR testing machine. The CBR was determined at 2.5 mm and 5mm penetration and maximum of this was adopted as CBR value. CBR values at different lime-content and percentage increases in CBR with respect to un-stabilized soils were presented below. The CBR value of unstabilized soil was 2.3 %, this increased to 7.8, 18.80, 22.3, 35, 39.5 percent due to addition of 1, 2, 3, 4, 5 percent lime respectively and increased to
3.8, 4.2, 4.4, 4.9, 5.8 percent due to addition of 10, 20, 30, 40, 50 percent fly ash respectively. It shows that maximum improvement in CBR was observed when soil was stabilized with 70% soil, 30% fly ash and 3% limes.

Table-3.1 Variation of Maximum Dry Density and Optimum Moisture Content And % Increase of CBR with Lime Content

Lime content (%)	MDD (KN/m^3)	OMC (%)	Maximum CBR (%)	% incre
0	19.45	13.30	2.30	-
1	19.40	13.80	7.80	239. 13
2	19.30	14.00	18.80	717. 39
3	19.03	14.90	22.30	869. 56

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4	18.77	15.50	35.00	1421 .74
5	18.67	16.10	39.50	1617 .39

Table-3.2 Variation of Maximum Dry Density and Optimum Moisture Content And % Increase of CBR With Fly Ash Content

Fly ash content (%)	MDD (KN/m^3)	OMC (%)	Maximum CBR (%)	% Increase of CBR
0	19.45	13.3	2.3	-
10	18.93	14.9	3.8	65.22
20	18.47	15.3	4.2	82.61
30	17.93	16.5	4.4	91.31
40	17.01	18.3	4.9	113.04
50	16.10	20.4	5.8	152.17

Table 3.3 Variation of 4 days Soaked CBR Values With Both Lime and Fly Ash Content

Soil + Lime + fly ash content	90% soil + 10% flyash	80% soil + 20% fly ash	70% soil + 30% flyash	60% soil + 40% flyash	50% soil + 50% flyash	100% soil + lime 1%	100% soil + lime 2%	100% soil + lime 3%	100% soil + lime 4%	100% Soil + lime 5%
4 day soaked CBR (%)	3.8	4.2	4.4	4.9	5.8	7.8	18.8	22.3	35	39.5

Table-3.4 Variation of 4 days CBR Values With Both Lime and Fly Ash Content Including Curing Period

Soil + Lime + fly ash content	90% soil + 10% fly ash + 2% lime	90% soil + 10% fly ash + 3% lime	80% soil + 20% fly ash + 2% lime	80% soil + 20% fly ash + 3% lime	70% soil + 30% fly ash + 2% lime	70% soil + 30% fly ash + 3% lime	100% soil +3% lime
4 days CBR (%)	17.54	18.6	21.26	31.66	30.53	36.53	22.3

Table-3.5 Variation of 7 days CBR Values with both Lime and Fly Ash Content including Curing Period

Soil + Lime + fly ash content	90% soil+ 10% fly ash + 2% lime	90% soil+ 10% fly ash + 3% lime	80% soil+ 20% fly ash + 2% lime	80% soil + 20%fly ash + 3% lime	70% soil+ 30% fly ash + 2% lime	70% soil+ 30% fly ash + 3% lime	100% soil + 3% lime
7 days CBR (%)	16.56	25.33	25.33	34.5	33.1	37.02	20.46

Table-3.6 Variation of 12 days CBR Values with both Lime and Fly Ash Content including Curing Period

Soil + Lime + fly ash content	90% soil+ 10% fly ash + 2% lime	90% soil+ 10% fly ash + 3% lime	80% soil+ 20% fly ash + 2% lime	80% soil + 20%fly ash + 3% lime	70% soil+ 30% fly ash + 2% lime	70% soil+ 30% fly ash + 3% lime	100% soil + 3% lime
12 days CBR (%)	30.0	35.2	35.8	49.7	48.0	55.8	60.8

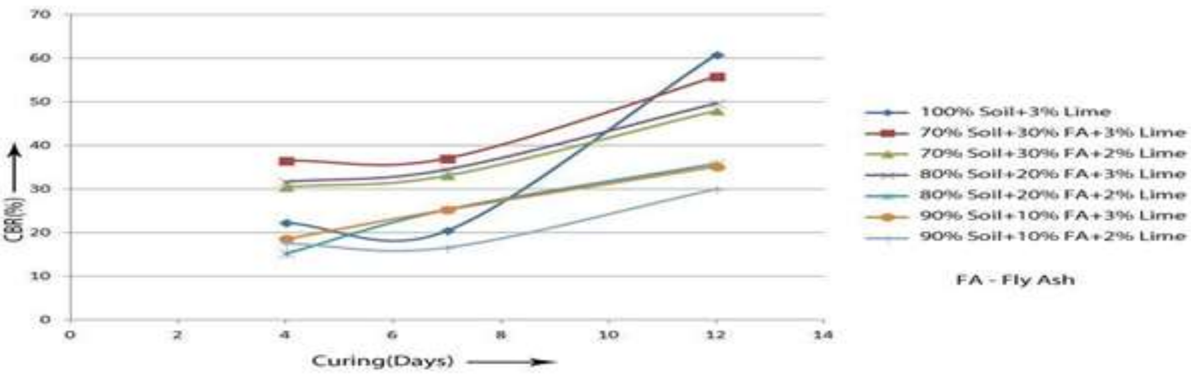

Fig. 3.1 Graph Showing CBR Vs. Days of Curing

3.3 UNCONFINED COMPRESSIVE STRENGTH

UCS is a quick test to obtain the shear strength parameters of cohesive (fine grained) soils either in undisturbed or remolded state

- The test is not applicable to cohesionless or coarse grained soils.
- The test is strain controlled and when the soil sample is loaded rapidly, the pore pressures (water with in the soil) undergo changes that do not have enough time to dissipate.
- Hence the test is representative of soils in construction sites where the rate of construction is very
- Fast and the pore waters do not have enough time to dissipate.
- The test results provide an estimate of the relative consistency of the soil as can be seen in Table.
- Almost used in all geotechnical engineering designs (eg. design and stability analysis of foundations, retaining walls, slopes and embankments) to obtain a rough estimate of the soil strength and viable construction techniques.
- To determine Undrained Shear Strength or Undrained Cohesion (Su or Cu) =q_u/2

Table 3.7 Classification of Clay

CLAY TYPE	UCS (Kg/cm^2)
Very Soft	< 25
Soft	25 – 50
Medium	50 – 100
Stiff	100 -200
Very Stiff	200 -400
Extreme	> 400

Table 3.8 Unconfined Compressive Strength for 7 days Curing Period

Soil + Lime + fly ash content	90% soil + 10%fly ash + 2% lime	90% soil+ 10% fly ash + 3% lime	80% soil+ 20% fly ash + 2% lime	80% soil + 20%fly ash + 3% lime	70% soil+ 30% fly ash + 2% lime	70% soil + 30% fly ash + 3% lime	100% soil + 3% lime
7 days UCS (kg/cm^2)	2.5	4.27	2.18	3.38	1.23	2	1.79

Table 3.9 Unconfined Compressive Strength for 12 days Curing Period

Soil + Lime + fly ash content	90% soil + 10% fly ash + 2% lime	90% soil + 10% fly ash + 3% lime	80% soil + 20% fly ash + 2% lime	80% soil + 20% fly ash + 3% lime	70% soil + 30% fly ash + 2% lime	70% soil + 30% fly ash + 3% lime	100% soil + 3% lime
12 days UCS (kg/cm^2)	4.122	4.212	2.6	3.707	2.4	2.91	2.66

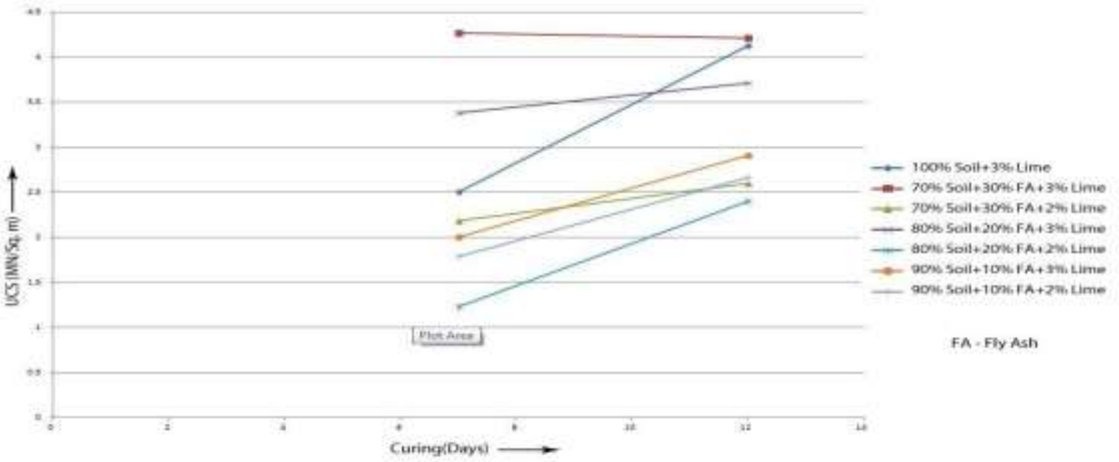

Fig. 3.1 UCS v/s Days of Curing

3.4 Elastic Modulus of Stabilised Soils

Laboratory determination of elastic modulus of chemically stabilized lateritic soil was beyond the scope of the present study. However, elastic modulus can be estimated from empirical relationship published in the literature. One approach is to assume lightly cemented materials to behave as unbound granular material. This approach is suggested by Austroads for modified granular materials to which small amounts of stabilizing agents are added to improve stiffness or to correct other deficiencies (e.g. by reducing plasticity). Elasticity modulus E_S of sub-base (assuming this to behave as unbound granular layer (in MPa), is given by IRC: 37-2001 as:

$$E_2 = 0.2 \times (h_2)^{0.45} \times E_3$$

Where h_2=thickness of sub-base layer in mm (considered as 200mm) and E_3 =modulus of underlying layer, i.e. sub-grade in MPa IRC: 37-2001 suggest the following relationship between elastic modulus of sub-grade and its CBR:

E (in MPa) = 10 x CBR (if CBR is less than 5%)

$= 17.6 \times CBR^{0.64}$ (if CBR is more than 5%)

Based on above correlations, elastic modulus of chemically stabilized soil of 500 mm thickness as sub-grade is estimated to lie between 133 and 167 MPa for sub-grade CBR of 7 to 10 percent.

3.5 Calculation Of Elasticity Modulus

Soil type: - S+FA+L = (90+10+2)

Design CBR – 22.5%

$E_1 = 17.6 \times 22.5^{0.64}$

$= 129.09$ MPa $= E_3$

Elasticity modulus of sub-base, $E_2 = 0.2 \times (h_2)^{0.45} \times E_3$

$= 0.2 \times (200)^{0.45} * 129.09$

$= 280.17$ MPa

Table-3.10 Tabulation for Modulus of Elasticity:

SOIL TYPE	DESIGN CBR (%)	MODULUS OF ELASTICITY (in MPa)	
		SUB-GRADE	SUB-BASE
Only soil	2.3	23	49.91
S+FA+L=(90+10+2)	22.5	129.09	280.147
S+FA+L=(90+10+3)	26.4	143.00	310.31
S+FA+L=(80+20+2)	26.9	144.70	314
S+FA+L=(80+20+3)	37.3	178.40	387.13

S+FA+L=(70+30+2)	36	174.39	378.42
S+FA+L=(70+30+3)	41.9	192.18	417.03
S+L=(100+3)	45.6	202.88	440.25

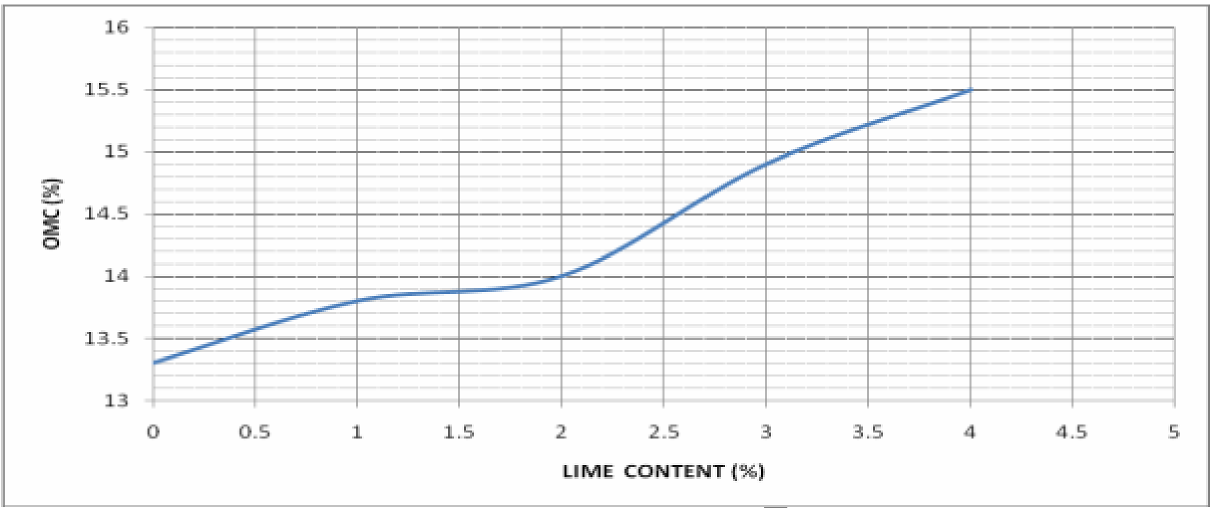

Fig. 3.2 OMC v/s LIME Content

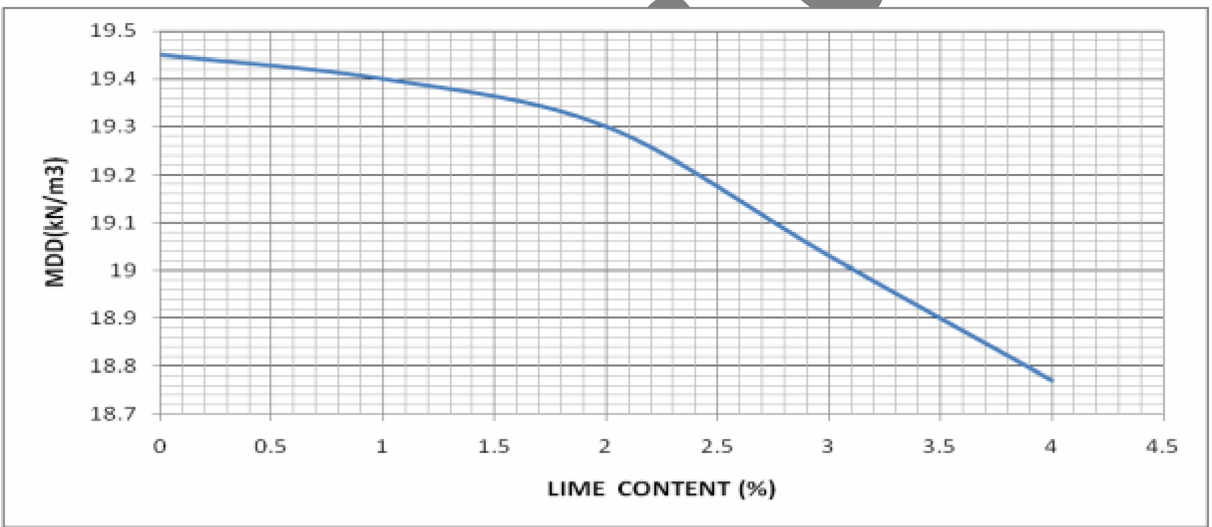

Fig. 3.3. MDD v/s LIME Content

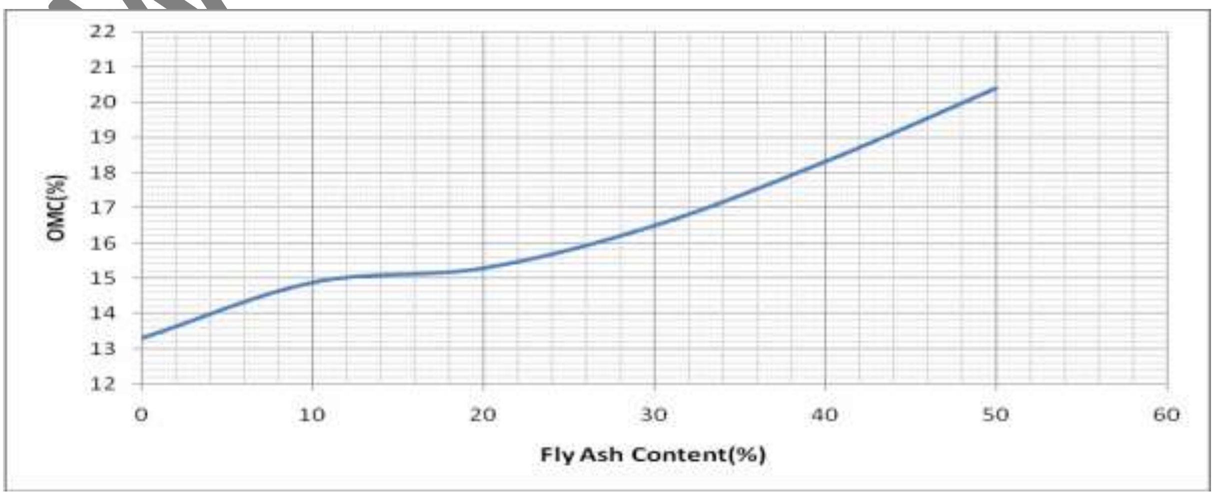

Fig. 3.4 OMC v/s FLY ASH Contant

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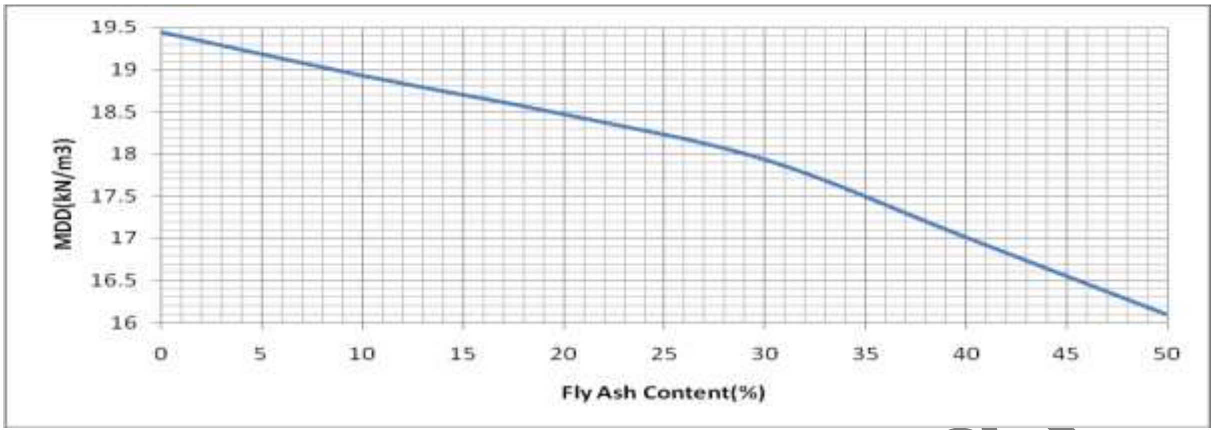

Fig. 3.5 MDD v/s FLY ASH Content

CONCLUSION

- The maximum dry density of the unstabilized soil was found to be 19.45 KN/m3 which thereby decreases with the addition of lime and fly ash due to their light weight. With the addition of lime in percentages of 1to5% at steps of 1% gives the value of M.D.D 19.40,19.30,19.03,18.77 and 18.67 KN/m3 respectively and with the addition of fly ash in percentages of 10 to 50 at steps of 10% gives the value of M.D.D 18.93,18.47,17.93,17.01 and 16.10 KN/m3 respectively.
- The Optimum Moisture Content of unstabilized soil was found to be 13.30% which thereby increases with the addition of lime and fly ash. For lime content of 1 to 5% at steps of 1% gives the value of OMC 13.8,14.0,14.9,15.5 and 16.1 % respectively and for fly ash content of 10 to 50% at steps of 10% gives the value of OMC 14.9,15.3,16.5,18.3 and 20.4 % respectively.
- The CBR value for the unstabilized soil was found to be 2.3% which increases with the addition of lime and fly ash. With the addition of lime in percentages of 1 to 5% at steps of 1% gives the value of CBR 7.8,18.8,20.3,35 and 39.5 % respectively and with the addition of fly ash in percentages of 10 to 50 at steps of 10% gives the value of CBR 3.8,4.2,4.4,4.9 and 5.8 % respectively. With the combination of both soil and fly ash as in S+L+FA(90+10+2), S+L+FA(90+10+3), S+L+FA(80+20+2), S+L+FA(80+20+3), S+L+FA(70+30+2), S+L+FA(70+30+3), S+L(100+3) are 13.0,35.2,35.8,49.7,48.0,55.8 and 60.8% respectively. Durability of the sub-grade is directly dependent on the CBR value. Hence, for a combination of 70:30:3 the maximum value of CBR is obtained that is 55.8%.
- It is recommended to use the above following combination so as to maximize the use of fly ash thereby reducing the cost of construction of roads.
- The UCS of the general soil was found to be 1.04 kg/cm2 whereas the average UCS after 7 days curing was found to be 2.48 kg/cm2and after 12 days of curing was found to be 3.23 kg/cm2. Hence with increase in strength of soil the UCS increases.
- The modulus of elasticity of soil is 24.64 MPa. With different combination of soil, lime and fly ash as in S+L+FA(90+10+2), S+L+FA(90+10+3), S+L+FA(80+20+2), S+L+FA(80+20+3), S+L+FA(70+30+2), S+L+FA(70+30+3), S+L(100+3) the value increases to 129.09,143,144.7,178.4,174.390,192.18 and 202.88 respectively.
- From the design and cost of sub-grade it was observed that the combination of 70% soil, 30% fly ash and 2% lime gives the maximum saving of 25.537 lakhs for 20 msa, 30.887 lakhs for 50 msa and 35.372 lakhs for 100 msa per km of road as compared to road using only soil sub-grade. The combination of soil and lime also gives more saving for 20 msa and 50 msa than the above combination but we recommend the combination of 70:30:2 because we have maximized the use of fly ash. But considering the following facts we recommend 70% soil, 30% fly ash and 3% lime for sub-grade which gives a net saving of lakhs for 20 msa, 26.753 lakhs for 50 msa, and 26.743 lakhs for 100 msa as compared to road using only soil in sub-grade.
- It was seen that with the addition of 1% extra lime in mix 70% soil, 30% fly ash and 3% lime the CBR increases from 48% to 55.8% that gives an increase of 16.25 %. Although the initial cost is a bit on the higher side but in the long run it will be cost effective owing to lower maintenance cost.
- As compared the combination of soil and lime it uses 30% of fly ash per km of road. So ultimately it will result in Saving of valuable land used for filling of flyash.
- Less pollution hazard from storage of flyash.

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