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Research Paper

Improving Clay of Intermediate Plasticity for Rural Road Sub-Grades – A Case Study

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ABSTRACT

Many regions of the world are affected by soils with poor engineering properties. This has significant influence on infrastructure development of the region. Design and construction of civil engineering structures on such soils has always been a challenging task for engineers. Stabilization has been recommended and used to overcome the weakness of these soils and making the condition appropriate for construction of structures or laying of the roads. This paper presents a systematic experimental investigation undertaken to explore the possibility of using stabilizing materials for improving the engineering properties of soil of type clay with intermediate plasticity. Effectiveness of commonly used stabilizing materials viz. cement, lime, and fly ash is investigated. Further, using the CBR values of the soil obtained for different quantity of stabilizing material, the sub-grade of pavement for rural roads was designed following the guidelines recommended by Indian Road Congress. Cost estimation per km of sub-grade for rural road pavement is done for all the designed sub-grades. Cost analysis for sub-grades of rural road pavement shows that 2% cement is the most economical option for improvement of properties of such clays. However, combination of (4% lime & 4% fly ash) as stabilizing agent is more attractive because, without any noticeable increase in the cost, it also helps in protecting environment by (i) enabling significant disposal of fly ash, a non-decomposable waste material and (ii) reduction in cement consumption and in turn reduction in emission of harmful gases, which are released during cement production.

Keywords: Soil improvement; intermediate plasticity; rural pavement; sub-grade thickness; cost comparison

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1. Introduction

The soil in some regions of Morena District in the State of Madhya Pradesh, India primarily composed of clay with intermediate plasticity and exhibits poor engineering characteristics. Detailed studies has been reported on behavior of flexible pavements on such soils [Djellali, Ounis and Saghafi, 2013; Djellali et al., 2017]. In sub-grade construction for flexible rural road pavements, properties of such locally available poor soils can be improved by adding suitable stabilizing material in appropriate quantity. In recent years, the application of stabilizing materials like lime, cement, fly ash, etc has been investigated for variety of poor soils. Lime has been extensively used for stabilizing highly unstable plastic and swelling clay, such as black cotton (BC) soil. The lime enlarges the size of clay particles by coagulation, thereby changing the soil structure and stabilizing it by reducing its swelling tendencies. Lime stabilization has also been used for plastic clays. When lime is added to such clay, exchange of cation takes place and as a result decrease in plasticity of the clay occur [Katare, Pande and Jain, 2009]. Bandipally, Cherian and Arnepalli explained nicely the soil-lime interaction mechanism through thermo-gravimetric results [Bandipally, Cherian and Arnepalli, 2018]. Cherian and Arnepalli explained the role of clay mineralogy in lime stabilization [Cherian and Arnepalli, 2015]. Cement has also been used as stabilizing material, for increasing strength and durability of soil and also to minimize effect of moisture variation. Cement can be used to stabilize all soil types except highly organic soils [IRC: SP-89, 2010]. Number of reactions occurs when cement is added to the clayey soil. These reactions are flocculation, ion exchange, carbonation and pozzolanic reactions. During the hydration process free lime is produced. This free lime of high pH has the ability to react pozzolanically with soil and improves its strength and durability. This reaction continues as long as the pH is high enough, generally above 10.5 [Al-Rawas, Hago and Al-Sarmi, 2005]. The issue that may restrict use of cement is that cement hydration is fast and causes rapid hardening in stabilized layers. Therefore, a mellowing period may not be available in between mixing and compaction process. Cherian et al. described in detail the calcium absorption behavior of clay of distinct mineralogical composition [Cherian et al., 2018]. Another popular stabilizing material is fly ash which is a by-product obtained from burning coal during power generation. It is classified into class ‘C’ (self-cementing) and class ‘F’ (non-self cementing) fly ash. Fly ash acts as a pozzolano or filler to reduce the void spaces among larger size particles [Al-Rawas, Hago and Al-Sarmi, 2005]. Fly ash itself has less cementitious value but it reacts chemically and form cementitious compound in presence of moisture. Cementitious compound that formed, improves the strength and compressibility of soil.

Researchers carried out studies on applications of materials for stabilizing variety of soil like Black Cotton soil, inorganic clay of high plasticity, inorganic clay with medium plasticity, soft grained red soil, lateritic soil, highly weathered phyllite etc. Studies have been carried on use of stabilizing agents like lime [Magafu and Li. 2010; Olugbenga, Oluwole and Iyiole, 2010]; cement

[Oyediran and Kalejaiye, 2011; Mao and Miller, 2017]; stone dust [Mudgal, Sarkar and Sahu, 2014]; fly ash [Gyanen, Savitha and Krishna, 2013; Karthik et al., 2014] and natural fibres [Maity, Chattopadhyay and Mukherjee, 2018; Tripathi et al., 2020]. Some studies have been made on combination of stabilizing agents like lime + stone dust [Mudgal, Sarkar and Sahu, 2014]; lime + fly ash [Singh and Pani, 2014]; cement + copper slag [Shahiri and Ghasemi, 2017]; cement + magnesium slag [Amini and Ghasemi, 2019]; nano polymer stabilizer + Silica sand [Mousavi and Karamvand, 2017]; granulated blast furnace slag (GBS) + fly ash [Yadu and Tripathi, 2013]; fly ash + rice husk ash (RHA) [Brooks, 2009; Singhai and Singh, 2014]; and fly ash + moorum [Raut, Bajad and Khadeshwar, 2014]. Optimum moisture content (OMC), maximum dry density (MDD), Atterberg limits, California Bearing Ratio (CBR) values, unconfined compressive strength (UCS), shear strength etc are the properties of soil which were considered by the researchers to investigate the effectiveness of stabilizing materials. It can be concluded that study on application of stabilizing materials viz. (i) cement, (ii) lime, and (iii) fly ash, separately and in combination, for clay of intermediate plasticity is lacking.

Therefore, this study aims to explore the effectiveness of these materials for improving the properties of clay with intermediate plasticity. It also includes the cost analysis for arriving at the optimum quantity of stabilizing material that results into efficient solution for rural pavement construction. Quantity of these agents varied from 0 to 10% of soil mass. When used in combination, the agents are used in equal proportion. Variation in index properties like liquid limit, plastic limit, and plasticity index, and engineering properties like MDD, CBR values and swelling pressure are observed for assessing the suitability and effectiveness of the stabilizing agents for such type of clays.

2. Characterization of the Clay

The soil used in this experimental study was collected from Madhogarh village of Morena district in state of Madhya Pradesh, India. The soil samples were taken from a depth of 1.0 m to 2.0 m below the local ground level. The soil was cohesive in nature. A series of tests were conducted on the virgin clay for its classification and finding its index and engineering properties. Location of the clay is plotted in the plasticity chart as shown in Figure 1. The figure shows that soil may be classified as clay with intermediate plasticity and it is in close proximity of A-Line [IS 1498, 1970].

Table 1. Index & engineering properties of clay

Property	Value
Liquid Limit	36.7%
Plastic Limit	24.6%
Plasticity Index	12.1%
Specific Gravity	2.69
Optimum Moisture Content	14.7%
Maximum Dry Density	1.74 g/cc
California Bearing Ratio	2.40%
Swelling Pressure	0.33 kg/cm^2

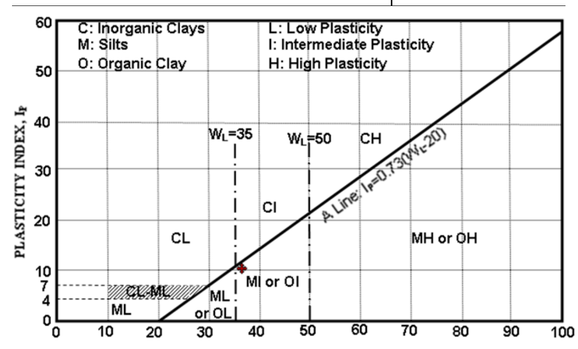

Figure 1. Location of the virgin clay in Plasticity Chart (marked by ✣) [IS 1498, 1970]

2.1 Need for Stabilization

In a flexible pavement, of rural roads, the sub-grade is the layer at base which ultimately receives the loads transferred through different layers of the pavement. It is essential that at no time, the soil sub-grade is over stressed and therefore it is necessary to have properly compacted and stabilized layer of sub-grade having adequate thickness. This design thickness of sub-grade depends upon its CBR. Due to very low CBR values, such clay may results in excessive design thickness of pavement sub-grades. Swelling potential of such clays may affect the durability of the pavement. It is therefore necessary to improve its properties before using for sub-grade of such pavements.

3. Stabilizing Materials Used

Cement, used in this study, is portland pozzolano cement (PPC) of Birla make. The specific gravity of cement is 3.10. The cement has mineral admixture and properties in the range as prescribed by Indian Standards, IS 1489 (Part 1). Lime used in the study is one which is commonly used for whitewashing. It is procured in the form of quick lime of class C (i.e. fat lime). Specific gravity of the lime is 2.2 and its pH value is 12. Fly ash, for this study is procured from Shree Singaji thermal power plant situated in Khandwa district of the state of Madhya Pradesh. The chemical composition and physical properties of the fly ash are shown in Table 2a and 2b respectively [Soni, Pandey and Sharma, 2017].

Table 2a. Chemical Composition of fly ash [32]

Characteristics	% (by weight)
Silica	55 - 65
Iron-oxide	5 - 7
Aluminum oxide	22 - 25
Calcium oxide	5 - 7
Magnesium oxide	< 1
Titanium oxide	< 1
Phosphorous	< 1
Sulphate	< 1
Alkali oxide	< 1

Table 2b. Physical properties of fly ash [32]

Physical property	Value
Specific Gravity	2.51
Initial Setting time	120 minute
Final Setting time	280 minute
Fineness (specific surface)	320 m^2/kg
Lime reactivity (Average compressive strength)	4 N/mm^2

4. Sample Preparation and Test Procedure

Effectiveness of stabilizing agents namely (i) lime; (ii) cement; and (iii) fly ash is investigated through properties like (a) plasticity index; (b) CBR value and (c) swelling pressure. Quantity of these agents varied from 0 to 10% of soil mass. The quantity of agents, when used alone, is varied as 2%, 5%, 8% and 10% respectively, making 12 numbers of such samples, as shown in Table 3. When used in combination, the agents are used in equal proportion i.e. in combination of (1%+1%); (2.5%+2.5%); (4%+4%) and (5%+5%) respectively.

The virgin clay got properly mixed with pre-decided quantity of the stabilizing agents as described above. OMC and MDD are then determined using standard Proctor test [IS 2720 (Part 7), 1987]. Then potable quality water is added in desired quantity and properly mixed by hand till the mixture becomes more or less uniform. To allow the mixture develop adequate stability, the test samples were cured in plastic containers for 28 days in laboratory at temperature around 30ºC, before performing the tests for index properties, CBR values and swelling pressure.

Test methods followed in the study for determining (i) Atterberg limits; (ii) OMC and MDD; (iii) CBR values and (iv) Swelling pressure are as prescribed in Indian Standards.

The details of test procedures is available in relevant publications [IS 2720 (Part 5), 1985; IS 2720 (Part 7), 1987; IS 2720 (Part 16), 1987; IS 2720 (Part 41), 1977]. The CBR tests are carried out at respective optimum moisture contents. Experimental setup and equipment used for different tests are shown in Figure 2. The tests are carried out for virgin clay and all the twenty four combinations of stabilized clay shown in Table 3 to determine its properties and investigate the effect of adding varying quantity of different stabilizing agents.

(a) Liquid Limit Test

(b) Test for OMC and MDD

(c) Test for CBR Value

(d) Test for Swelling Pressure

Figure 2. Experimental setup and equipment used

5. Results and Discussions

Liquid limit; plastic limit and plasticity index tests; standard Proctor test; CBR value test and swelling pressure test were conducted in the study for the virgin clay and the clay treated by varying the quantity of stabilizing materials. Summary of the results of this experimental study is presented in Table 3. Effect of stabilization and the quantity of stabilizing agent on engineering properties of the clay is discussed in following section.

5.1 Effect on Atterberg Limits

The Liquid Limit (LL) of virgin clay is 36.7%. It is observed from Figure 3(a) that mixing of stabilizing materials generally results into increase in LL. It is observed that in general LL increases with increase in quantity of stabilizing material. The value of LL increases to about 48% at 10% quantity of stabilizing materials, mixed separately or in combination. Increase is the maximum for combination of 5% (lime + fly ash) or 5% (cement + fly ash) in which case the LL increases to approximately 50%.

Plastic limit (PL) for virgin clay is 24.6%. Figure 3(b) shows that PL of soil increases with increase in quantity of stabilizing materials lime; cement; (lime + fly ash); or (cement + fly ash). The PL increases to about 45% for increase in quantity of these stabilizing materials from 0% to 10%. Further, for fly ash and (fly ash + cement), PL increases to maximum at 2% quantity of these stabilizing materials. The plasticity index (PI) for virgin clay is 12.1%. Figure 3(c) shows that plasticity index (PI) of soil undergoes sudden decrease when quantity of the stabilizing material increases to 2%. Thereafter, the values of PI remain more or less constant within the range of 2% to 6% for increase in quantity of stabilizing materials lime, cement, (lime + fly ash) and (lime + cement). When the clay is mixed with 2% fly ash, the PI dips to a minimum value of less than 2% and thereafter starts increasing with the value of PI reaches to about 20% at 10% quantity of fly ash. Similar trend is observed for combination of (cement + fly ash) but with lesser fluctuation.

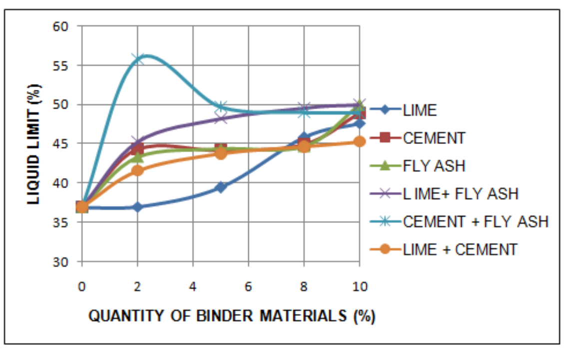

Figure 3a. Effect of stabilizing material on LL

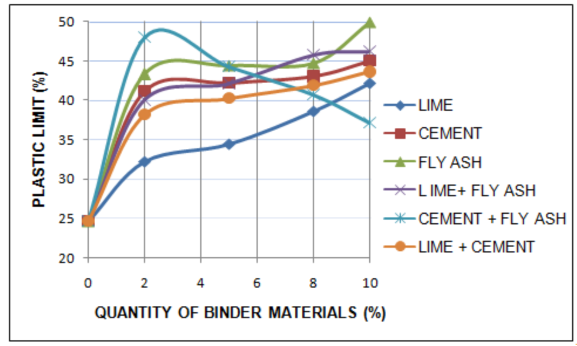

Figure 3b Effect of stabilizing material on PL

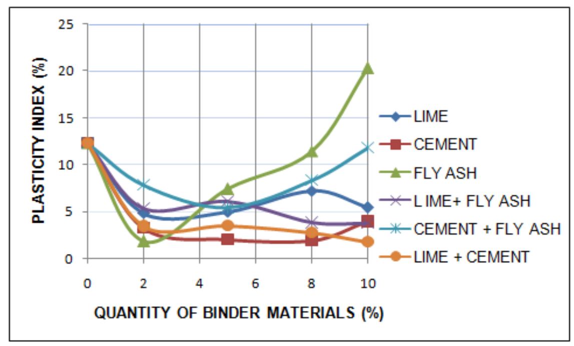

Figure 3c. Effect of stabilizing material on PI

5.2 Effect on OMC and MDD

Variation of OMC and MDD versus stabilizing material quantity is shown in Figure 4(a) and Figure 4(b), respectively. Figure 4(a) shows that value of OMC, in general increases when mixed with stabilizing materials. It is observed that except for fly ash, OMC increases with mixing of 2% stabilizing material. Increase is maximum for the clay treated with 2% lime and the increase is as high as 50%.

Table 3. Index and engineering properties of the clay

S. No.	Stabilizing Material and its Quantity	LL (%)	PL (%)	PI (%)	OMC (%)	MDD g/cc	CBR (%)	Swelling pressure (Kg/cm^2)
1	virgin clay	36.7	24.6	12.1	14.7	1.74	2.40	0.33
2	2% lime	37.0	32.2	4.8	22.7	1.64	32.40	0.16
3	5% lime	39.4	34.4	5.0	22.7	1.64	16.70	0.04
4	8% lime	45.8	38.6	7.2	22.7	1.63	22.00	0
5	10% lime	47.6	42.2	5.4	22.7	1.62	48.60	0
6	2% cement	44.3	41.1	3.2	20.7	1.74	21.96	0
7	5% cement	44.2	42.2	2.0	20.7	1.66	43.90	0
8	8% cement	44.9	43.0	1.9	18.4	1.75	66.40	0
9	10% cement	48.9	45.0	3.9	18.4	1.75	63.20	0
10	2% fly ash	43.3	41.5	1.8	12.7	1.74	2.60	0.24
11	5% fly ash	44.4	37.0	7.4	15.8	1.74	3.70	0.10
12	8% fly ash	44.7	33.3	11.4	16.7	1.71	4.20	0
13	10% fly ash	49.9	29.6	20.3	16.9	1.71	5.20	0
14	1% lime + 1% fly ash	45.3	40.0	5.3	20.7	1.7	40.20	0.19
15	2.5% lime + 2.5% fly ash	48.2	42.1	6.1	20.7	1.69	39.20	0.08
16	4% lime + 4% fly ash	49.6	45.8	3.8	20.7	1.67	20.90	0
17	5% lime + 5% fly ash	49.9	46.2	3.7	20.7	1.67	15.20	0
18	1% cement + 1% fly ash	55.8	48.0	7.8	18.7	1.69	15.20	0
19	2.5% cement+2.5% fly ash	49.7	44.3	5.4	18.7	1.71	62.70	0
20	4% cement + 4% fly ash	49.0	40.7	8.3	18.7	1.72	39.70	0
21	5% cement + 5% fly ash	48.9	37.1	11.8	18.7	1.73	89.90	0
22	1% cement + 1% lime	41.6	38.2	3.4	18.7	1.71	15.20	0
23	2.5% cement + 2.5% lime	43.7	40.2	3.5	18.7	1.7	68.30	0
24	4% cement + 4% lime	44.6	41.9	2.7	18.7	1.68	39.70	0
25	5% cement + 5% lime	45.3	43.6	1.7	22.1	1.62	88.90	0

OMC for the treated clay becomes more or less constant for increase in stabilizing material beyond 2%. For fly ash it becomes more or less constant when the stabilizing quantity is in the range of 5 to 10%. The increase in OMC for small amount of stabilizing materials may be due to increased demand of water by them. Further increase in quantity of stabilizing material from 2% to 10% the effect on OMC reduces water demand got offset by enlargement of size of clay particles due to coagulation. For the clay treated with 2% or 5% cement content, OMC is 20.7% but for 8% or 10% quantity of cement mixing, the OMC reduces to 18.4 %. At 2% to 8% of (cement

+ lime), OMC remains 18.7% and at 10% it increases to 22.1%.

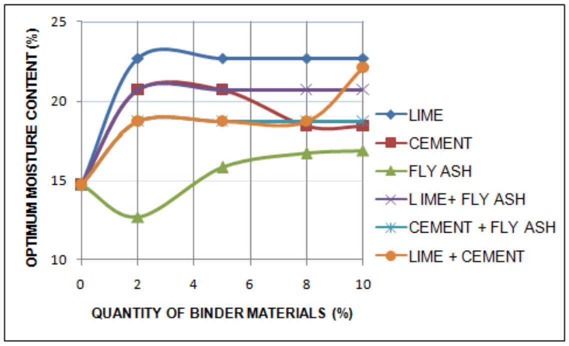

Figure 4a. Effect of stabilizing material on OMC

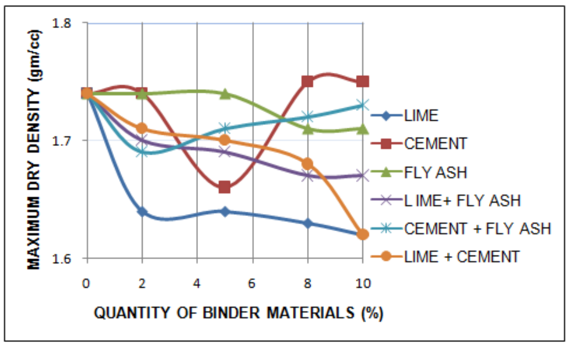

Figure 4b. Effect of stabilizing material on MDD

From Figure 4(b), it is observed that the effect of adding stabilizing material on MDD is less than 7%. Except for cement, the MDD of the clay, in general, decreases with increase in quantity of stabilizing material. The maximum decrease in MDD is of the order of about 7%. The decrease in MDD may be due to value of specific gravity for these stabilizing materials lesser than the clay. Increase in MDD is observed for cement mixing and the reason may be higher specific gravity of cement as compared to the clay.

5.3 Effect on CBR values

CBR of virgin clay is found to be 2.4%. Variation of CBR values with stabilizing material quantity is shown in Figure 5. It is observed that CBR value of the clay mixed with stabilizing materials cement, fly ash, (cement + fly ash) increases with increase in the quantity of these stabilizers. However, for combination of (fly ash + lime), CBR value increases only up to 2% quantity mixed in the clay and then decreases. It is observed from the graph that cement is also very effective for improving CBR value of the clay. CBR value shoots up to 21.96% by mixing of 2% quantity of cement.

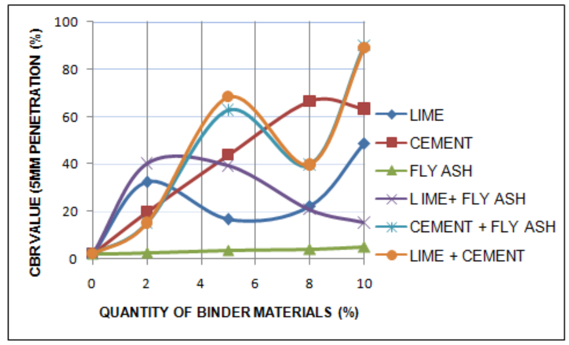

Figure 5. Effect of stabilizing material on CBR

In fact mixing of cement with clay is not a simple mixture of hydrated cement particles bonding together unaltered clay particles, but is a system in which both the clay and the hydrating cement combine through secondary reactions. Alteration dissolution of silica and alumina from both clay particles and amorphous constituent in the high pH environment causes alteration of the clay. The dissolved silica and alumina combine with calcium ions and form additional cementitious material which bonds adjacent clay particles together [Herzog and Mitchell, 1962]. Fly ash, when used alone, is observed to be least effective. However, it becomes quite effective when mixed in combination with lime. Mixing of 2% quantity of (lime + fly ash) increases CBR value of the clay to 40.2%. No increase in CBR is observed for further increase in quantity of (lime + fly ash). Fly ash is also quite effective when mixed in combination with cement. CBR value of the clay increases to 62.7% when it is treated by (2.5% cement + 2.5% fly ash).

5.4 Effect on Swelling Pressure of Soil

Swelling pressure, which indicates expansive nature of clay, has adverse effect on durability of pavements. Swelling pressure for virgin clay was found to be 0.33 Kg/cm^2. The plot between swelling pressure versus binding material quantity is shown in Figure 6.

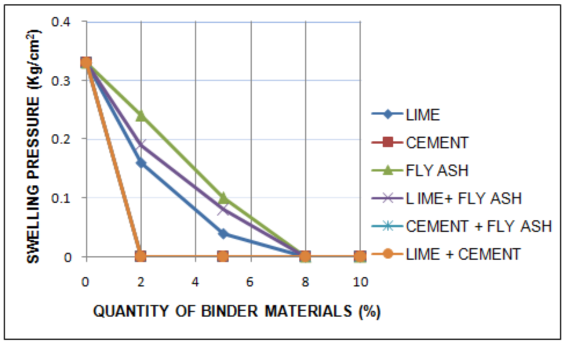

Figure 6. Effect of stabilizing material on swelling pressure

It is observed that stabilizing materials are effective in reducing the swelling pressure of such clay. Among the stabilizing materials considered in the paper, cement is found to be the most effective for reducing the expansive nature of the clay. Mixing of 2% of cement, when used alone, found to be enough to reduce the swelling pressure to zero. The clay-cement interaction explained in section 5.3 may be the reason for loss of swelling characteristic. Only 1% of cement content is found to be adequate, when used in combination with lime or fly ash, for reducing the swelling pressure from 0.33Kg/cm^2 to zero. A minimum of 8% lime need to be mixed with the clay to reduce its swelling pressure to zero. The addition of lime to clay causes an instantaneous rise in the pH of molding water resulting into increase in the reactivity of surface silica and alumina. The reactive hydrous silica and alumina then combine with calcium ions to form gradually hardening cementitious materials. The modified clay particles also lose their expansive nature [Herzog and Mitchell, 1962]. Mixing of a minimum 8% fly ash with the clay is required to bring the swelling pressure to zero. The pozzolanic and non-plastic characteristic of fly ash helps in improving the properties of the clay. Mixing of 8% (lime + fly ash) reduces the swelling pressure of the clay to zero.

6. Cost Analysis

The section of the pavement for the rural roads is designed as per the recommendations of Indian Road Congress [IRC SP:20, 2002]. The thickness of pavement is designed on the basis of projected number of Commercial Vehicles per day (CVPD) for the design life. This projected CVPD is estimated on the basis of CPVD at the time of study i.e. year 2016 and its growth rate. The required thickness of sub-grade for the clay mixed with different stabilizing materials in varying quantity is determined. CVPD value for rural roads in the locality is taken as 30; growth rate is considered as 6% and the design life as 20 years. Prevailing rates in the locality for material is considered for arriving at the cost per Km of sub-grade. In view of negative impact of swelling pressure on durability of rural roads, treated soil whose swelling pressure exceeds zero is not considered for the cost analysis. The detailed procedure for cost estimation of per km length of sub-grade for virgin and stabilized clay is described in Annexure-A. The cost is worked out for different quantity of stabilizing materials and the results of cost analysis are summarized in Table 4. Figure 7 shows the cost comparison between different options stabilization of the clay considered in the study. It can be observed that cost of sub-grade decreases significantly when the soil i.e. clay of intermediate plasticity, is treated with stabilizing materials. Figure 7 and Table 4 shows that fly ash, when mixed alone, is least effective in reducing the cost, however, when used in combination with lime or cement, it results in significant cost reduction.

It is observed from Figure 7 that on the basis of cost, two options may be considered as most efficient viz. (i) cement alone with 2% quantity and (ii) Combination of 4% lime & 4% fly ash. Quantity of fly ash for this option is computed as explained in Annexure-A. Quantity of fly ash that may be disposed per Km length of rural road pavement is worked out to be 15030 Kg. Both options reduce the cost of sub-grade to about one-sixth, though the cost is slightly higher for option (ii). The cost of option (ii) may further increase for locations far away from thermal power stations owing to additional cost involves in transportation of fly ash. However, second option seems to be more attractive as it also helps in protecting environment by (a) enabling disposal of fly ash, a non-decomposable waste material and (b) minimize or rather eliminates the use of cement for improvement of engineering properties of such clays and thus results into reducing emission of harmful gases which are released during cement production.

Table 4. Cost per Km of sub-grade for different stabilizing materials

	Stabilizing Material and its Quantity	CBR Value (%)	Swelling Pressure (Kg/cm^2)	Design Thickness of Sub-grade (mm)	Cost of Sub-grade per Km length (Rs.)
1	Virgin clay	2.4	0.33	370	396825
2	2% lime	32.4	0.16	---*	---*
3	5% lime	16.7	0.04	---	---
4	8% lime	22.0	0	30	101092
5	10% lime	48.6	0	30	118152
6	2% cement	19.9	0	30	68681
7	5% cement	43.9	0	30	129269
8	8% cement	66.4	0	30	199358
9	10% cement	63.2	0	30	241797
10	2% fly ash	2.6	0.24	---	---
11	5% fly ash	3.7	0.1	---	---
12	8% fly ash	4.2	0	260	308129
13	10% fly ash	5.2	0	210	255372
14	1% lime + 1% fly ash	40.2	0.19	---	---
15	2.5% lime + 2.5% fly ash	39.2	0.08	---	---
16	4% lime + 4% fly ash	20.9	0	30	69188
17	5% lime + 5% fly ash	15.2	0	50	130793
18	1% cement + 1% fly ash	15.2	0	50	86607
19	2.5% cement + 2.5% fly ash	62.7	0	30	83984
20	4% cement + 4% fly ash	39.7	0	30	116158
21	5% cement + 5% fly ash	89.9	0	30	137930
22	1% cement + 1% lime	15.2	0	50	102286
23	2.5% cement + 2.5% lime	68.3	0	30	105435
24	4% cement + 4% lime	39.7	0	30	148048
25	5% cement + 5% lime	88.9	0	30	171005

*Treated soil whose swelling pressure exceeds zero is not considered for the cost comparison.

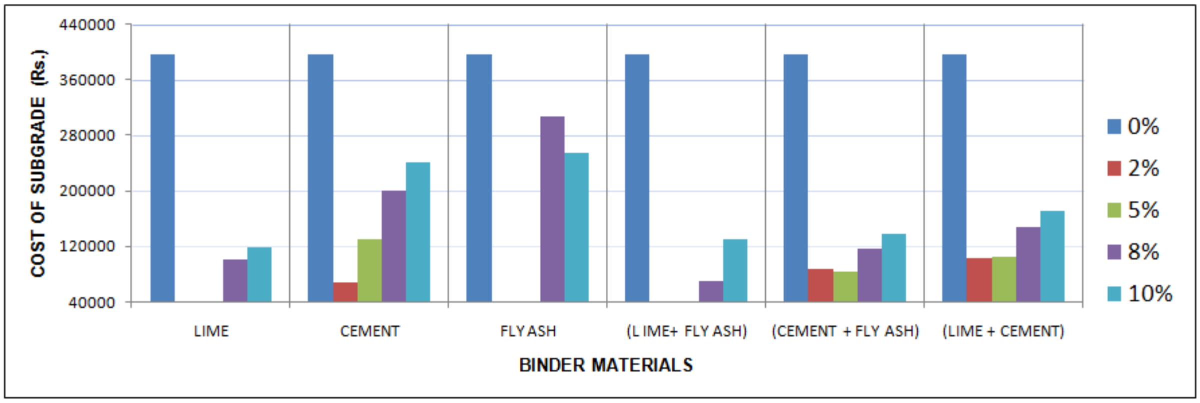

Figure 7. Comparison of cost of sub-grade for different stabilizing materials

It is observed from Figure 7 that on the basis of cost, two options may be considered as most efficient viz. (i) cement alone with 2% quantity and (ii) Combination of 4% lime & 4% fly ash. Quantity of fly ash for this option is computed as explained in Annexure-A. Quantity of fly ash that may be disposed per Km length of rural road pavement is worked out to be 15030 Kg. Both options reduce the cost of sub-grade to about one-sixth, though the cost is slightly higher for option (ii). The cost of option (ii) may further increase for locations far away from thermal power stations owing to additional cost involves in transportation of fly ash. However, second option seems to be more attractive as it also helps in protecting environment by (a) enabling disposal of fly ash, a non-decomposable waste material and (b) minimize or rather eliminates the use of cement for improvement of engineering properties of such clays and thus results into reducing emission of harmful gases which are released during cement production.

7. Conclusion

The value of CBR of sub-grade material for clay of intermediate plasticity is low. This necessitates increased section thickness and costly construction of rural roads in such locations. Stabilizing material may be used to improve the CBR values. A systematic experimental study is carried out to analyze the effectiveness and feasibility of lime, cement and fly ash, mixed separately and in combination, to improve the CBR value and other Engineering properties of local soil viz. clay of intermediate plasticity. Following are some conclusions drawn on the basis of this experimental study.

- Cement and lime is very effective in increasing CBR value of these clays. Mixing of only 2% quantity of cement or lime increases the CBR value by more than eight folds.
- Fly ash, when used alone for these clays, has very small impact on CBR value. When used in combination with lime or cement, it becomes very effective and for same increase in CBR value, reduces demand of lime or cement to less than half.
- Swelling pressure of such clays reduces when treated by any of the three stabilizing materials. Cement is most effective as only 2% quantity of cement alone eliminates the swelling pressure and only 1% is required when used in combination with lime or fly ash.
- Two options viz. (i) cement alone with 2% quantity and (ii) Combination of 4% lime & 4% fly ash found to be most efficient as far as cost analysis for rural road pavement is concerned.

- Combination of 4% lime & 4% fly ash may be better option as it also helps in protecting environment by (a) enabling disposal of fly ash, a non-decomposable waste material and (b) reduction in cement consumption and in turn reduction in emission of harmful gases, which are released during cement production.

8. References

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Annexure – A: Procedure for Cost Estimation of Sub-grade

Recommendations of IRC: SP: 20 (2002) are referred to work out the thickness of sub-grades for these rural roads. Thickness of sub-grades is decided by the CBR value and the projected number of commercial vehicles per day (CVPD) for the design life. Current CVPD for the locality, considering both directions, is 30. Prescribed growth rate is 6%. Therefore for design life of 20 years, the projected value of CVPD is 97. Thus the traffic classification for these rural roads is C (in which range of CVPD is 45 to 150). The recommended thickness of sub-grade for Traffic Classification C and known CBR value is given in Table A-1. Thickness of sub-grade is prescribed as 30mm for all the values of CBR above 20.

Table A-1 Recommended sub-grade thickness [IRC: SP: 20 (2002)]

CBR value	**2**	**3**	**4**	**5**	**6**	**7**	**10**	**15**	**20**
Thickness of sub-grade (in mm)*	370	330	260	210	175	150	98	50	30

*The values are for Traffic Classification C.

For the cost analysis, 1Km long stretch of pavement is taken. Cost of sub-grade only is considered for the cost comparison because thicknesses of other components of pavement are same irrespective of CBR values. Prevailing rates of different materials in the locality are assumed for the cost analysis. The rates considered are as shown in Table A-2. A sample calculation is presented for cost estimation of one Km stretch of sub-grade for the case when 8% lime is used as stabilizing material.

Table A-2 Unit rates of the materials

Material	**Clay**	**Cement**	**Lime**	**Fly ash**
Unit Rate	Rs. 143/- per cubic metre	Rs. 5.40 per Kg	Rs. 2.50 per Kg	Rs. 0.21 per Kg

CBR value is 22.0.	
For CBR value of 20 or above, thickness of sub grade	= 0.030m
MDD of virgin soil	= 1.74 gm/cc
MDD of treated soil	= 1.63 gm/cc
Length of pavement	= 1000m;
Width of pavement	= 7.5m;
Therefore total volume	= 225m^3
Total quantity =225x1630	= 366750 Kg
Quantity of lime = 366750x0.08	= 29340 Kg
Cost of lime=29340x2.5	= **Rs 73350**
Quantity of soil =366750x0.92	= 337410 kg
Volume of soil=337410/1740	= 194m^3
Cost of soil =194x143	= **Rs 27742**
Hence total cost of sub-grade for 1km stretch = (73350+27742)	**= Rs 101092**