Stabilization Technique for local soils using Fly-Ash, Gypsum and Chemical additives in Rural housing and Infrastructure

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Abstract- Increased construction activity and continued dependence on conventional materials is leading to inadequate availability of natural and conventional construction materials. The creation and expansion of rural civic infrastructure in terms of roads, housing, civic and social facilities necessitates the search for alternate building materials and making use of readily available cost effective materials such as industrial wastes. The availability of good earth is often challenging, many a times, the procurement of locally available soils suitable for construction involves large lead distances. In this technical paper, stabilization techniques with two industrial wastes namely Gypsum and Fly-ash have been used on locally available soils. Fly-ash Gypsum stabilized soil mix has been further experimented by using chemical additives; calcium chloride /sodium silicate. The optimum percentages of fly-ash, gypsum and chemical additives were obtained based on strength tests. Significant improvement in CBR and strength of the soil is reported for soil stabilized with Fly-ash Gypsum and chemical additives.

Keywords – soil stabilization, Fly-ash Gypsum stabilized soil, chemical additives, calcium chloride /sodium silicate

I. INTRODUCTION

Housing and all weather roads to access the basic amenities is the prerequisite for Nation's development. In India, increase in population and shortage of construction materials resulted in acute shortage of housing as well as civic infrastructure in terms of quantity and quality. The 'Working Group on Rural Housing' constituted by the Planning Commission of India has estimated the housing shortage at 40 million households until the end of the twelfth plan period. Taking incremental shortage and natural calamities, estimated housing shortage for the people below poverty line would be 39.30 million for the period 2012-17. To meet this demand, 7-8 houses per 1000 population need to be built. To fulfill the housing demand the requirement for conventional building materials is huge and it needs 125 million tons of cement, 14 million tons of steel and gigantic stacks of bricks to meet the housing shortage. Similarly to construct all weather low volume roads in Indian villages, gigantic volumes of good sub grade soil and sub base material as granular sub base (GSB) layer is required.

For housing (bricks) and road (subgrade and GSB) construction activity, soil accounts for about 75% of the total cost and due consideration should be given to its strength. The quality of bricks available and its preparation in different parts of the country vary depending on the quality of the material used. Bricks manufactured from the native soils of the rural areas are not satisfying the specifications of Class-III brick laid down by BIS. As the availability of conventional material alone cannot meet the demand, there is need to utilize locally available materials. The locally available materials may not satisfy the specifications of good brick earth and soil-sub grade, and in such cases stabilization of the locally available materials becomes essential. The understanding of physical, mechanical and chemical properties of the industrial wastes such as Fly-ash and Gypsum helps in understanding the chemistry of soil-industrial waste mix during its stabilization process. In the present work, two industrial wastes; Gypsum and Fly-Ash are used to improve the properties of soil obtained from the quarry sites of Warangal District (Telangana State, India) and are examined for their effective use in brick manufacturing and also sub grade and sub base material in flexible pavements. The strength characteristics of the stabilized soil are further studied with chemical additives; Calcium chloride and Sodium Silicate.

II. MATERIALS FOR SOIL STABILIZATION

A. *Fly-ash*

A fine, glassy powder recovered from the gases of burning coal during the production of electricity, is fly ash. The fly ash particles consist primarily of silica, alumina and iron. In India, power generation from thermal plants is highly dependent on combustion of high-ash fed coal. The current yearly generation of fly-ash is more than 150 million tons (Central Electricity Authority 2011-12). The disposal of fly ash through conventional methods is a major concern. According to the estimates and studies, 1 MW of power generation from a thermal plant requires approximately one acre of land for the disposal of the fly-ash generated. Due to consistent efforts, utilization of fly-ash reached from 9.63% in 1996-97 to 54.5% during 2011-12 and efforts are made for 100% utilization (CEA, Annual Report 2011-12). Of the total fly-ash generated currently about 8.5% is used in roads and embankments and 5% in bricks and tile manufacturing.

Indian fly-ashes are characterized by higher concentration of SiO_2 (49-65%) and Al_2O_3 (16-29%) and lower contents of CaO (1-4%) and Fe_2O_3 (4-10%). Fly ash is pozzolanic in nature and the reactivity of fly ash is largely dependent on their glass content, specific surface area and other mineral phases present. It has been reported that the Indian fly-ash is more crystalline with relatively less glass content. The fly-ash particles are of 45 μm size with specific surface area ranging from 300-600m^2/kg. It is also observed that utility of fly-ash in structural fills and road layers is a function of particle size distribution and specific surface area.

The use of fly-ash and lime in soil stabilization started a long ago in the year 1957 at Purdue University, Indiana through a joint Highway research project. It is reported that when small amounts of hydrated lime (4%-6%) and fly ash (up to 40%) in the presence of water and aggregates such as sandy soils, aggregates, slag, crushed stones aggregates and sand in controlled quantities improves its strength characteristics significantly. This discovery opened the gates for application of fly-ash in base course and sub base course of road component layers. Barnes (1997) reported that the pozzolanic reactivity of fly ash mainly depends on the amounts of silica and alumina, presence of moisture and free lime, and fineness of the fly ash. The calcium in self-cementing fly ashes is mostly in the form of crystalline compounds of aluminates and silicates, which account for hydration characteristics that are more like Portland cement rather than lime. The initial formation of cementitious reaction products is due to the hydration of tricalcium aluminate, which Ferguson and Leverson (1999) report is the cause of problems during long compaction delay times. The strength gain during periods over 28 days is mostly attributed to the pozzolanic reactions between calcium oxide and the aluminous and siliceous contents in the soil. Many researchers experimented with industrial wastes like fly-ash, blast furnace slag, rice husk ash (Niranjan et al, 1992) gypsum, for the soil stabilization and grouting and its application in embankments, base and sub base component layers and building blocks. The Institute for Solid Waste Research & Ecological Balance (INSWAREB, 2015) is commercially manufacturing building blocks using fly-ash, lime and gypsum under the name Falg-Bricks.

When Fly-ash (0-25%) and rice husk ash (0-15%) was added to expansive clays, significant improvement in strength characteristics (100%), CBR (47%) and reduction in swell properties were observed (Brooks, 2009). The use of fly-ash in base and sub base courses of pavement layers along with fine aggregates and coarse aggregates in the presence of lime has shown significant improvement in CBR value. Different soils ranging from ML-CH have been treated with fly-ash in Iowa State University for the stabilization of fine grained pavement sub grades. Soil testing revealed that soil compaction characteristics, compressive strength, wet/dry durability, freeze/thaw durability, hydration characteristics, rate of strength gain, and plasticity characteristics are affected by the addition of fly ash (Iowa State University, 2005).

The process of adding and monitoring the mixing water during the stabilization operation is one of the most important steps in the construction process. In a mixing plant setup, general suggestions for addition of water are that it should be between 80% and 110% of the optimum moisture content, based on the moisture-density relationship of the stabilized mixture, to obtain proper density at time of compaction (ACAA, 1991). The Fly ash used in the study is obtained from National Thermal Power Corporation (NTPC), Ramagundam. The properties of Fly-Ash are given below

Table 1 Properties of Fly-Ash

Chemical Constituent	%
SiO_2	65.08
Al_2O_3	21.85
Fe_2O_3	4.07
CaO	4.09
Loss on Ignition	2.6
Moisture Content	0.5

Specific Gravity of Fly-ash	2.24

B. Gypsum

Gypsum ($CaSO_4.2H_2O$) a hydrated calcium sulphate, is a byproduct generated as waste during the manufacture of Ammonium phosphate fertilizer, phosphoric acid and hydraulic acid. Currently gypsum generation from all sources (industrial by product and mineral extraction) is about 4.5 million tons per annum (Indian Minerals Year Book, 2013). Gypsum is widely used in construction industry because of its special property of losing three-fourth of the combined water of crystallization when moderately heated (calcined) to about 130^oC. In presence of water gypsum can be spread out, cast or moulded to any desired surface or form. On drying, it sets into a hard rock-like form. The BIS specification (IS: 10170-1982, reaffirmed 1995) lays down a minimum 70% content of $CaSO_4.2H_2O$ and maximum limit of 0.75% Na, 1.0% F and 15% free moisture on dry basis for by-product gypsum. The material should pass through 2 mm sieve, but 50% of material should also pass through 0.25 mm (60 mesh) sieve. The purity of phospho-gypsum ranges from 77 to 98% $CaSO_4.2H_2O$. The gypsum used in the study is obtained from Visakhapatnam. The properties of Gypsum are given below:

Table 2 Properties of Gypsum

Chemical Constituent	%
CaO	31.6
SO_3	42.4
SiO_2	2.8
Soluble Salts	0.12
Fraction retained on 300 micron sieve	6.3

C. Chemical Additives

Sodium Silicate and Calcium Chloride are procured from the standard manufacturers.

D. Soil

The soil used for laboratory studies is from quarry site for brick manufacturing site, Warangal district located at a distance of 10 km from Kakatiya Institute of Technology and Science (KITS), Warangal institute campus. The general properties of soil are determined at KITS engineering laboratory as per IS specifications and are summarized as in Table-1.

Table 3 Engineering Properties of soil

Property	Parametric Value
Specific gravity of Solids	2.6
Grain Size Analysis (%)	
Gravel	2.0
Sand	69.40
Fines	28.60
Atterberg Limits (%)	
Liquid Limit	28.60
Plastic Limit	22.70
Shrinkage Limit	19.20
IS Classification of Soil	SC
Compaction Characteristics (IS Light Compaction)	
Maximum Dry Density (kN/m^3)	18.93
Optimum Moisture Content OMC (%)	10.60
Unconfined Compressive Strength(kN/m^2)	204

III. LABORATORY INVESTIGATION AND RESULT

A. *Fixation of Gypsum and Fly Ash:* The soil is mixed with varying proportions of Gypsum (0 to 10%) at increments of 2% and the composition characteristics are determined. Unconfined Compression tests are carried out on different soil – gypsum specimens prepared at MDD and corresponding OMC's after 3 days of curing. Results of the tests are presented in the following Table 4.

Table 4 Composition and Strength Characteristics of Soil-Gypsum

1	Gypsum Content (%)	0%	2%	4%	6%	8%	10%
2	Optimum Moisture Content	10.6	11.72	11.93	12.18	12.46	12.84
3	Maximum Dry Density MDD (kN/m^3)	18.93	19.68	19.91	19.72	19.62	19.54
4	Unconfined Compressive Strength (kN/m^2) after 3 days of curing	204	525	671	497	472	466

The optimum percentage of Gypsum is fixed on the basis of UCC test values. The soil is treated with arrived percentage of Gypsum (4%) and is mixed with various proportions of fly ash (0-30%). The optimum percentage of the same is fixed on the basis of pozzolanic effect. The test results are tabulated in Table 5.

Table 5 Compaction and UCC test results of Soil Gypsum fly-ash mixes.

Sl.No	Description						
1	Fly ash Content (%)	0%	10%	15%	20%	25%	30%
2	Optimum Moisture Content (%)	11.93	13.20	13.42	13.56	13.64	13.77
3	Maximum Dry Density MDD (kN/m^3)	19.91	19.62	19.41	19.23	18.64	18.20
4	Unconfined Compressive Strength (kN/m^2) after 3 days of curing	671	923	1003	1092	876	647

The strength characteristics of Gypsum (4%) - Fly ash (20%) soil mix are further studied with the addition of varying percentage of calcium chloride /Sodium silicate. The results are presented in the Table 6

Table: 6 Compaction and Strength characteristics of Soil Gypsum Fly-ash mix with chemical additives

		Calcium Chloride					Sodium Silicate			
1	Chemical Additive (%)	0%	0.5%	1.0%	1.5%		0%	0.5%	1.0%	1.5%
2	Optimum Moisture Content (%)	13.56	13.68	13.79	13.93		13.56	13.76	13.95	14.02
3	Maximum Dry Density MDD (kN/m^3)	19.23	19.12	19.07	18.96		19.23	19.02	18.96	18.78
4	Unconfined Compressive Strength (kN/m^2) after 3 days of curing	1092	2948	3982	2987		1092	1264	1458	1153

B. *Preparation of Blocks*

Standard moulds of size 19cm X 9cm X 18cm are fabricated with a marking at 9cm height. The soil passing through 4.75 mm sieve is compacted at its OMC and corresponding maximum dry density in the mould till the height of the mould comes down to the marked level while pressing the wet block. Soil blocks are casted from Gypsum mixed soils, Soil-Gypsum-Fly ash with and without chemical additives at the predetermined proportions. The cast blocks are cured for 7 days and 14 days and tested for compressive strength and water absorption. Results are presented in the Table 6.

Table 6 Compressive Strength of Stabilized Blocks

	Mix Proportions'	Compressive Strength in kN/m^2		
		7 Days	14 Days	Air Dried
1	Soil	--	--	2600
2	Soil+ Gypsum	3286	3680	4156
3	Soil+ Gypsum+ Fly-Ash	4876	5264	5728
4	Soil+ Gypsum+ Fly-Ash+ $CaCl_2$	12836	14264	17622
5	Soil+ Gypsum+ Fly-Ash+ Sodium Silicate	5538	6148	7684

C. Test on Soil and Soil Gypsum-Fly-ash–chemical additive mixes for use in flexible pavement: CBR Value

Soil is tested for its use as sub grade and sub base course materials in flexible pavements. Adopting heavy compaction testing procedures, California Bearing Ratio (CBR) mould is prepared for the combinations of soil, soil +Fly-Ash+ Gypsum and soil +Fly-Ash+ Gypsum + chemical additive mixes. Test results are presented below Table 7.

	Mix Proportions	CBR Value in %			
		UnSoaked	Soaked	7 day curing	14 day curing
1	Soil	3.84	2.18	-	-
2	Soil+ Gypsum	4.53	2.96	4.92	5.58
3	Soil+ Gypsum+_ Fly Ash	5.12	3.54	5.98	6.36
4	Soil+ Gypsum+ Fly-Ash+ $CaCl_2$	6.28	4.12	7.26	7.74

D. Effect of Improved CBR on overall composition of pavement overlays

For the construction of rural roads, Indian Roads Congress has brought out Rural Road Manual IRC SP: 20-2002 for design and construction. However, there are situations in many states across the country, where the prescribed standard material many a times is not available involving large lead distances and resulting in longer haulage and higher costs. If the locally available native materials are materials, including marginal and reclaimed materials are modified using stabilizing techniques, it could be possible to reduce the cost of road construction.

Normally the traffic volumes on rural roads would be minimum and curve "F" may be selected. For sub grade soils with poor CBR value less than 3%, overall thickness of the pavement would be in the range of 750mm-800mm. By adopting in-situ soil stabilizing techniques as revealed in the experimental investigation the CBR value can be increased significantly and overall pavement thickness could be reduced to 350 mm - 450mm. By adopting in-situ soil stabilization techniques at the sub-grade level the CBR value can be significantly improved to 7% - 8% and where in Granular Sub Base (GSB) overlay can be placed on the compacted subgrade with reduced thickness. Similarly, in sub base course, 50% reduction in Wet Macadam Mix (WMM) /Water Bound Macadam (WBM) over lay thickness can be achieved.

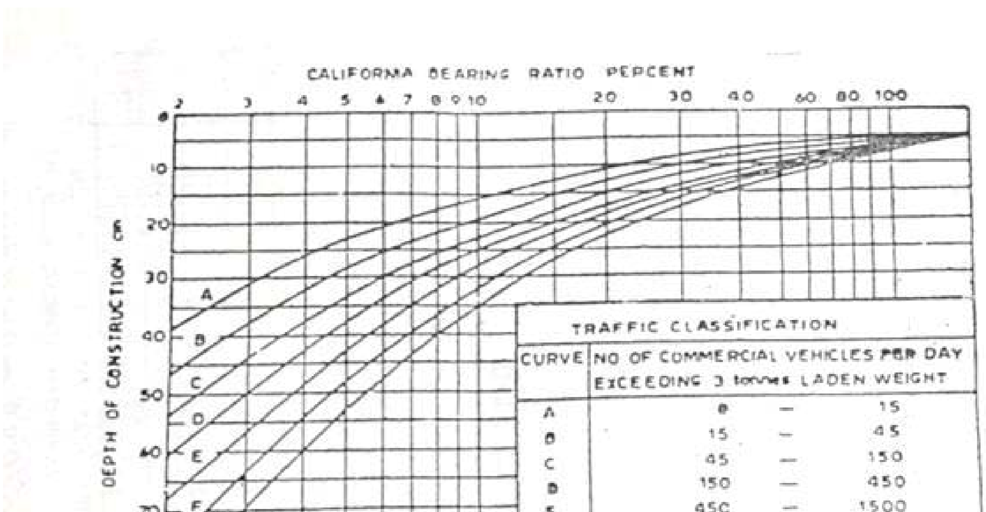

Figure 1: CBR Design Chart (Recommended by IRC)

IV. CONCLUSION

1. The compressive strength of soil increased by 60% with the addition of gypsum up to optimum percent of 4% and then decreases. Hence Gypsum may be used to improve the strength of soils blocks.

2. Addition of Fly-Ash to soil Gypsum Mix results in improvement of Compressive strength by 120% up to certain value (20% in the present study)and then decreases. Hence Fly-ash Gypsum Mix may be used for obtaining better quality bricks.
3. The properties of soil-Gypsum-fly ash mix improves with the addition of calcium chloride and sodium silicate (1%)
4. Out of the two chemical additives; calcium chloride gives significant compressive strength improvement in Soil-Gypsum-Fly ash mix.
5. The combination of Gypsum 4% and Fly-ash (20%) in soil with little quantity of calcium chloride (1%) result in maximum block compressive strength (about 17622 kN/m^2) in the dry condition.
6. The air dried stabilized blocks should be given protective coating as they found to have less water absorption resistance.
7. Stabilization of sub grade soil by fly-ash (20%) + Gypsum (4%)+ Calcium Chloride(1%) significantly improve the CBR value and can be effectively implemented in local soils which will significantly reduce the overall thickness of component layers.

Authors Remarks:

In this research work an attempt is made by the authors to make of use of locally available soils stabilized with industrial waste and chemical admixtures. Experimental analysis revealed significant improvement in soil strength and CBR value by the addition of Flay-ash and Gypsum and with marginal percentage of chemical additives. Such stabilized soils can be effectively used in brick making industry and rural road construction with less dependence on conventional materials. The optimum percentages given are suitable and applicable for the soil tested. Such method can be adopted and locally available soils and building materials can be tested to find the optimum mix to suit to the local conditions. The objective of the research is to demonstrate and propagate the use of low cost technologies for their effective use in rural areas. District Authorities and other governmental agencies involved in execution of rural housing and infrastructure should encourage and adopt with the help of local technical institutions.

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