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Chemical and Geotechnical Properties of Expansive Soil Stabilized with Fly Ash and Geotextiles

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Abstract : Expansive Sub-grade soil improvement is one of the primary and major processes in the construction of any highway. Roads on black cotton soil often fail due to swelling and shrinking of such soil which makes stabilization mandatory. As flyash is available at very lower cost it can be used for stabilization of expansive soils for various uses. This present research aims to utilize the fly ash in road application. In this research index, engineering, chemical properties of virgin soil has been studied. In addition, chemical analysis is done for soil and fly ash mixture. Flyash is added to the soil with 10%, 20%, 30%, 40%, and 50% by weight of soil. The soil falls under CI category. It has 50% free swell index. The CBR of soil is 13.6% and it reduces to 2.66% when soaked. Shear strength of soil is 42.06 kpa at its optimum moisture content of 15% with maximum dry density of 1.658 g/cc. This study indicates that plasticity index, free swell index, pH, and cation exchange capacity, are decreasing with the addition of fly ash and total soluble solids, calcium carbonate content are increasing with the addition of fly ash. To ascertain the soil composition, XRD analysis has been done.
Keywords : Subgrade, Flyash, Plasticity index, Free swell index, pH, Cation exchange capacity, XRD analysis, Total soluble solids, Calcium carbonate content, Geotextile, CBR, MRA.

1. Introduction

In general Clays exhibit undesirable engineering properties. These to have low shear strengths and to lose shear strength further upon wetting or other physical changes. They can be plastic and compressible and they expand when wetted and shrink when dried. Some types expand and shrink greatly upon wetting and drying – a very undesirable characteristics. Clayey soils can creep over time under a load, especially when the shear stress is depending its shear strength, making them prone to sliding. They develop large lateral pressures. These tend to have low resilient modulus values. For these reasons, clays are generally poor materials for foundations. The annual cost of damage done to non-military engineering structures constructed on expansive soils is estimated at $220 million in the United Kingdom and many billions of dollars are worldwide. Flyash was successfully used for stabilizing expansive clays. The strength characteristics of flyash stabilized clays are measured by means of unconfined compressive strength (CBR) or California Bearing Ratio (CBR) values. Based upon the soil type, the effective flyash content for improving the engineering properties of the soil varies between 15 to 30%[1,2,3,4,5,6,7].

Geosynthetics is a class of geomaterials that are used to improve soil conditions for a number of applications. They consist of manufactured polymeric materials used in contact with soil materials or pavements to act as a separator and reinforcing material like steel bars in concrete. Geosynthetics has been increasingly used in geotechnical and environmental engineering for the last 5 decades. Over the years, these had helped designers and contractors to solve several types of engineering problems where the use of conventional construction materials would be restricted or considerably more expensive. There are a significant number of geosynthetic types and geosynthetic applications in geotechnical and environmental engineering[8,9,10,11,12,13,14,15].

In this study, characteristics of soil stabilized with flyash are studied. In addition reinforcing effects of geosynthetics are also studied. AMultiple Regression model that could predict CBR value based on Atterberg's limit, OMC, MDD, Flyash content, and number of layers of geotextile has also been developed[16,17,18,19,20].

2. Methodology and Materials

2.1 Methodology

Methodology mainly consists of three parts. Part 1 includes identification of problems in construction of roads in black cotton soil, review of literatures, collection of soil and flyash. Part 2 and part 3 are laboratory works which are mainly focused on determination of index, engineering, chemical properties of soil and chemical properties of soil and flyash mixture. Methodology is graphically represented by figure 1.

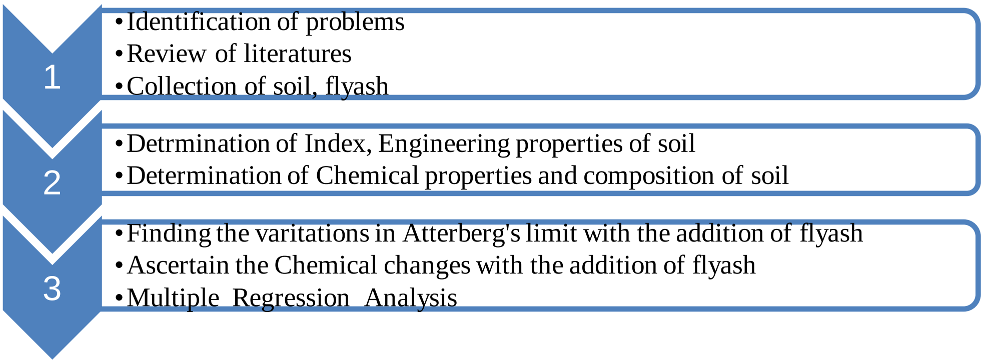


Figure1. Methodology

2.2 Materials

2.2.1 Collection of Soil

Soil for this research work is collected from Cheranmaanagar, Coimbatore, Tamilnadu state, India. The locations are 11.0542^{0}, 77.0183^{0}. The soil sample was present at depth of 4 feet from ground level. The soil sample used for analysis is clay. The laboratory investigations confirm that the soil falls under the category Clay with Intermediate Compressibility.

2.2.2 Collection of flyash

Fly ash is obtained from Mettur Thermal Power Plant, Tamilnadu state which belongs to class F.

2.2.3 Chemical composition of flyash.

Mineral composition of fly ash was obtained from mettur thermal power plant and is as follows.

Table 1.Composition of flyash

S.no	Constituents	%
1	MgO	0.57
2	Al_2O_3	24.12
3	SiO_2	52.55
4	K_2O	0.965
5	P_2O_5	0.72
6	CaO	2.65
7	Loss on Ignition	18.18

Table 2. Properties of geotextile

Property	Values
Tensile Strength (MD) kN/m	28.5
Tensile Strength (CD) kN/m	26.5
Elongation (MD) %	30
Elongation (CD) %	27
Trapezoid Strength (MD) N	320
Trapezoid Strength (CD) N	320
Puncture Strength (N)	370
Apparent Opening Size (mm)	0.075
Water Permeability (Flow Rate)	9.5 l/m2/s
Mass Per unit Area (gsm)	140

2.3 Geotextile

Geotextile for this research is manufactured by Techfab India with the following specifications.

3. Laboratory Investigations on Index and Engineering Properties

This elaborates the various index and engineering properties of soil namely natural moisture content, specific gravity, liquid limit, plastic limit, shrinkage limit, grain size distribution, optimum moisture content, maximum dry density, unconfined compressive strength, CBR test and free swell test etc.Table.3 gives the index and Engineering properties of the soil.

Table 3. Properties of soil

S.no	Properties	Result	Remarks
1	Natural Moisture Content	8.69%	-
2	Specific Gravity	2.71	-
3	Sieve Analysis % of Gravel % of sand % of Silt % of Clay	2.1% 30.5% 22.1% 45.3%	-
4	Differential Free Swell Index	50%	Degree of expansion is high
5	Liquid Limit (W_L)	47%	
	Plastic Limit (W_P)	17%	
	Shrinkage Limit (W_S)	12%	Degree of expansion is marginal
	Flow Index (I_f)	22	
	Plasticity Index (I_P)	30%	Swelling potential is high
	Toughness Index (I_t)	1.36	Since (I_t) > 1.0 Soil nor friable at Plastic state.
	Liquidity Index(I_L)	-27 %	Since (I_L) < 0 Very Stiff
	Consistency Index (I_C)	127.7 %	Since (I_C) >100 Very Stiff
	Soil Classification	CI	Clay of intermediate Compressibility
	Activity (A)	0.53	A < 0.75 Soil is Inactive
6	Optimum Moisture Content	15%	-
	Maximum Dry Density	1.658 g/cc	-
7	Unconfined Compressive Strength (q_u)	84.12 kN/m^2	-
	Cohesion (C_u)	42.06 kN/m^2	-
8	CBR unsoaked CBR soaked	12.88% 2.68 %	-

3.1Standard Proctor's Compaction Test (light compaction)

The Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) is determined by conducting standard proctor's test as per IS: 2720 (Part 7) – 1980. This test has been conducted for soil with 0%, 10%, 20%, 30%, 40%, and 50% of flyash along with single and double layer of geotextile. Geotextile has cut into plan dimension of proctor mould and placed at the end of each soil layer. Table 4 gives the comparison of OMC and MDD.

Table 4.Comparisons of OMC and MDD

S.no	% of Flyash added	Zero layer of reinforcement		Single layer of reinforcement		Double layer of reinforcement	
		OMC in %	MDD in g/cc	OMC in %	MDD in g/cc	OMC in %	MDD in g/cc
1	0	15	1.658	14.41	1.649	14.36	1.621
2	10	14.93	1.678	14.11	1.669	14.08	1.657
3	20	13.45	1.642	13.09	1.6304	13	1.618
4	30	12.2	1.628	12	1.617	12.17	1.612
5	40	10.76	1.611	10.4	1.603	10.28	1.584
6	50	9.7	1.593	9.26	1.580	8.967	1.564

Table 5. Comparison of UCC Strength

S.no	Flyash content	UCC in KN/sq.m	Cohesion in KN/sq.m
1	0	84.12	42.06
2	10	97.27	48.635
3	20	126.85	63.425
4	30	106.82	53.41
5	40	84.02	42.01
6	50	78.81	39.405

3.2Unconfined Compressive Strength

The unconfined compressive strength and cohesive strength is obtained by conducting Unconfined Compressive Strength test. The test is conducted as per IS:2720(Part 10)-1991 for soil with 0%, 10%, 20%, 30%, 40%, and 50% of fly ash. Table 5 gives the comparison of UCC strength and cohesion.

3.3Determination of CBR

For any pavement design, CBR is the prime factor which determines the thickness of each pavement layer. CBR (unsoaked& soaked) test is done as per IS2720 part 16. For soil with 0%, 10%, 20%, 30%, 40%, and 50% of flyash mixtures soaked and unsoaked tests have been done. For soil with 0%, 10%, 20%, 30%, 40%, and 50% of flyash mixtures along with the inclusion of single and double layer of geotextiles, soaked CBR tests have been done. Spacing in-between the geotextiles is kept arbitrarily 42mm (±5mm). Table 6 and 7 gives the results of unsoaked and soaked CBR.

Table 6.Results of UnsoakedCBR test

S.no	Flyash content in %	CBR in %
1	0	12.88
2	10	16.1
3	20	17.17
4	30	16.46
5	40	15.38
6	50	14.31

Table7.Results of Soaked CBR test

S.no	% of Flyash added	Soaked CBR without reinforcement	Soaked CBR with single layer of reinforcement	Soaked CBR with double layer of reinforcement
1	0	2.68	3.57	6.44
2	10	3.22	3.75	6.8
3	20	4.29	6.08	10.73
4	30	3.57	4.83	7.87
5	40	2.86	3.93	5.72
6	50	2.68	3.22	5.37

4. Laboratory investigation on chemical properties

Chemical analyses are very much important to ascertain the mechanism behind the stabilization and also to know influence of various chemical parameters such as total soluble solids, pH, Cation Exchange Capacity, calcium carbonate content, and soluble sulphates. The mechanism can be found from XRD analysis.

These analyses are carried out for soil with 0%, 10%, 20%, 30%, 40%, and 50% addition of flyash.

4.1 Total soluble solids

Total soluble solids indicate the amount of presence of soluble salts and other soluble materials present in soil. This test is done in accordance with IS 2720 part 21 (Gravimetric analysis) and also indirectly determined using TSS analyzer. Results from both the tests are tabulated. It is observed that there is no significant change in soluble solids concentration from both the tests.

4.2 Calcium carbonate ($caco_3$) content

The $CaCO_3$ content can be found from volumetric analysis of soil-flyash mixture blended with 0.1 N HCL against 1N NaOH as per IS 2720 part 23 (1976).

Table .9 shows the amount of calcium carbonate present.

Table .8 total soluble solids

S.no	% of Flyash added	Soluble solids (ppm) (analyzer)	Soluble solids (ppm) (IS method)
1	0	102.2	101
2	10	110.9	110
3	20	125.5	125
4	30	133.7	133
5	40	140.1	141
6	50	145.9	146

Table .9 Amount of calcium carbonate present

S.no	% of Fly ash added	Calcium carbonate (% by weight)
1	0	20
2	10	20.7
3	20	21.3
4	30	22
5	40	22.8
6	50	23.5

4.3 Determination of pH

The pH of the samples were determined using the method of Eades and Grim specified by IS 2720 part 26, which involves mixing the solids with pure water (1:5 solid: water), periodically shaking samples, and then testing with a pH meter after 1 hour.

Table .10 pH of soil with Fyash

S.no	% of fly ash added	pH
1	0	8.89
2	10	8.72
3	20	8.52
4	30	8.43
5	40	8.38
6	50	8.33

Table .11Cation Exchange Capacity of soil with flyash

S.no	% of Fly ash added	CEC (meq/100g)
1	0	89.683
2	10	80.011
3	20	76.884
4	30	74.573
5	40	73.169
6	50	72.931

4.5 Cation Exchange Capacity (CEC)

CEC represents the exchangeable cations present in soil. There are two methods available to determine CEC namely Chapman method (IS 2720 part 24: 1974) and Soil Society of America (compulsive exchange) method. Tests are conducted based on above mentioned methods and there are no much difference is observed between the results from both methods.

4.6 Soluble Sulphate Determination

Three methods are specified by IS 2720 part 27 to determine total soluble sulphates namely precipitation method, volumetric method, and calorimetric method. The last two methods are being subsidiary methods; precipitation method is used in this analysis.

It is observed that sulphate present in the soil is 0.012% by mass. This shows only a trace of sulphate is present and there is no sulphate present in flyash. Hence this test not conducted for soil-flyash mixture as the influence of sulphate on the stabilization process of this particular soil is nil.

4.7 XED Analysis

XRD analysis was done to know the mineralogical composition of soil. This test was carried out in Avinasilingam University, Coimbatore, tamilnadu state, India. The mineralogical composition of soil is as shown in table .12 and the XRD output is shown in figure 2.

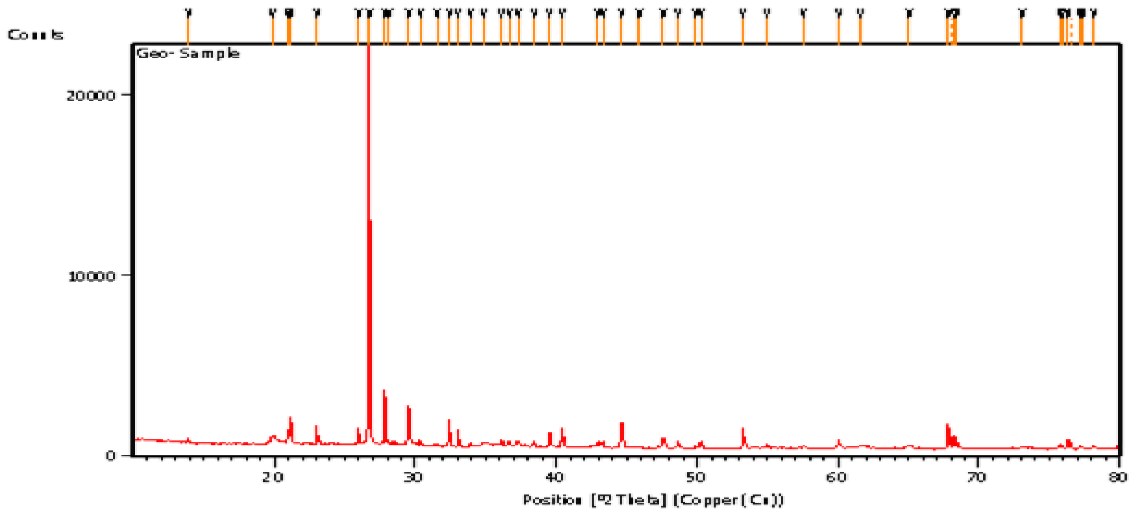


Figure .2 Output of XRD Analysis

Details of minerals present and their D spacing is given in table 12.

Table. 12 Minerals and D spacing

S.no	Mineral	D Spacing (10^{-10}m)
1	Quartz	3.34
2	Mica	3.20
3	Felds	3.02
4	Kaolinite	4.2
5	Illite	2.23
6	Chlorite	1.38

5. Discussion on Results

5.1 Variations in OMC and MDD

The variation of optimum moisture content and maximum dry density with the addition of flyash and inclusion of geotextile layers can be observed from figure 3 to 5.

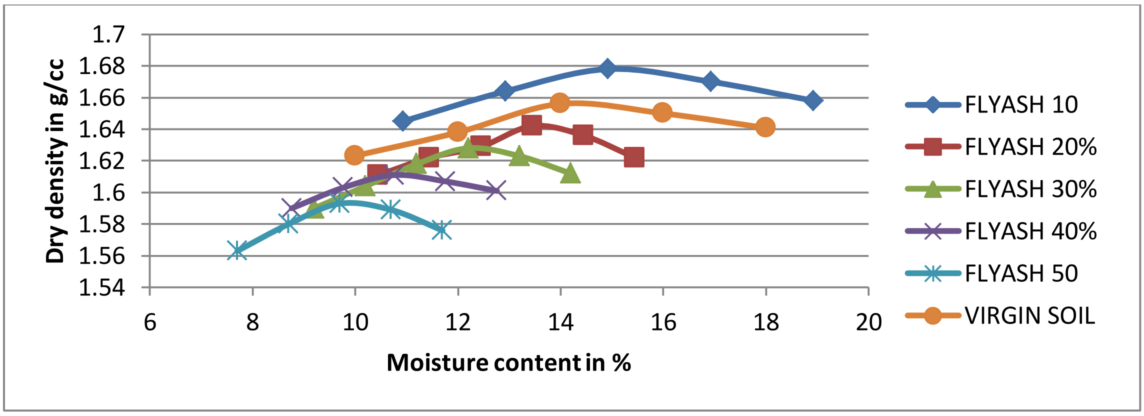
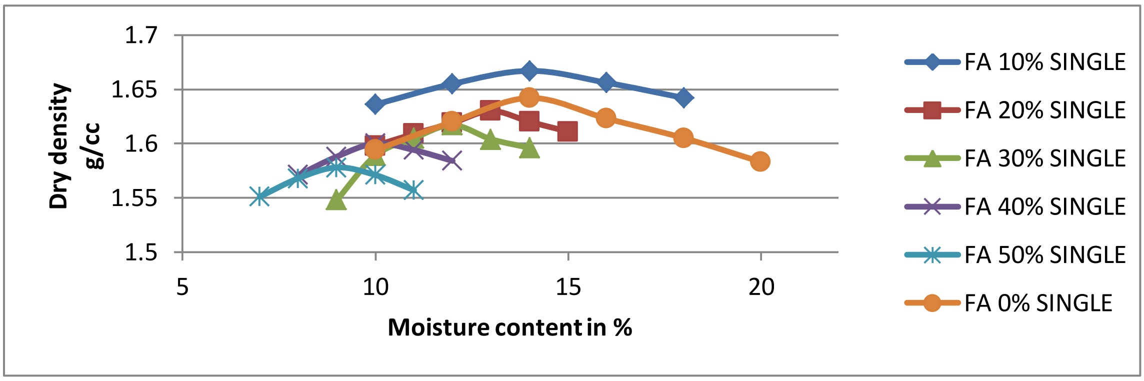


Figure 3.Variation of OMC&MDD with addition of Flyash



The geotextile is chemically inert and has low specific gravity than soil and flyash mixtures. Thus inclusion of geotextile does not cause change in OMC but MDD is decreasing when compared with soil-flyash mixture.

Figure 4.Variation of OMC &MDD with addition of flyash and single layer of geotextile

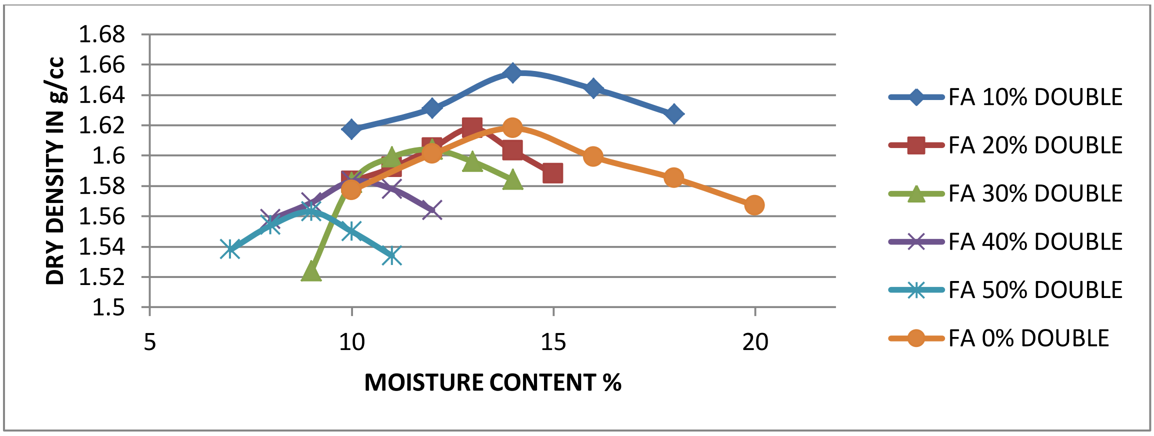


Figure 5. Variations of OMC &MDD with addition of flyash and dual layers of geotextile

5.2 variations in Ucc strength

The variation of unconfined compressive strength with fly ash content is given in Figure 6 for standard proctor density.

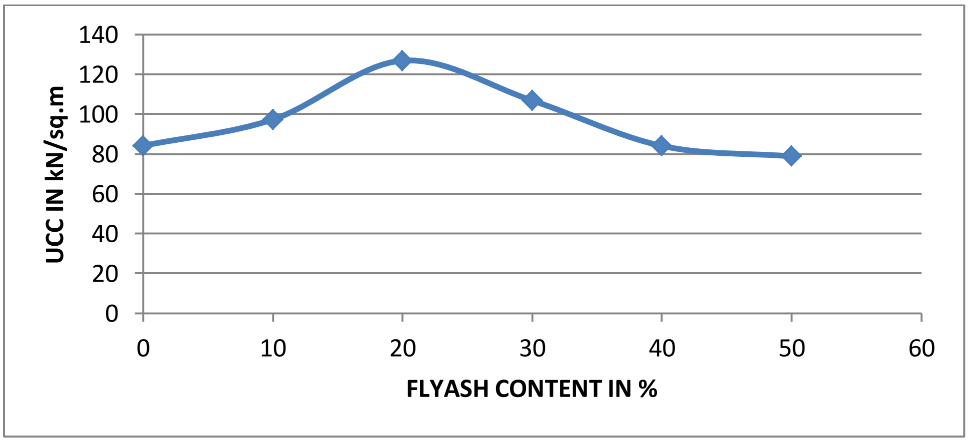


Figure 6. Variations in UCC strength with the addition of flyash

4.3 Variations in CBR

The reactions behind the variations in CBR values with the addition of flyash are same as that of the variations in UCC strength. The increases in CBR values with the inclusion of geotextile are mainly due to the reinforcing effects of geotextile. Lateral restraint and tensioned membrane effects of geotextile contribute to the increase in CBR. Figure 7 and 8 shows that the variations in CBR.Table13 give the percentage increase in CBR with the inclusion of geotextiles.

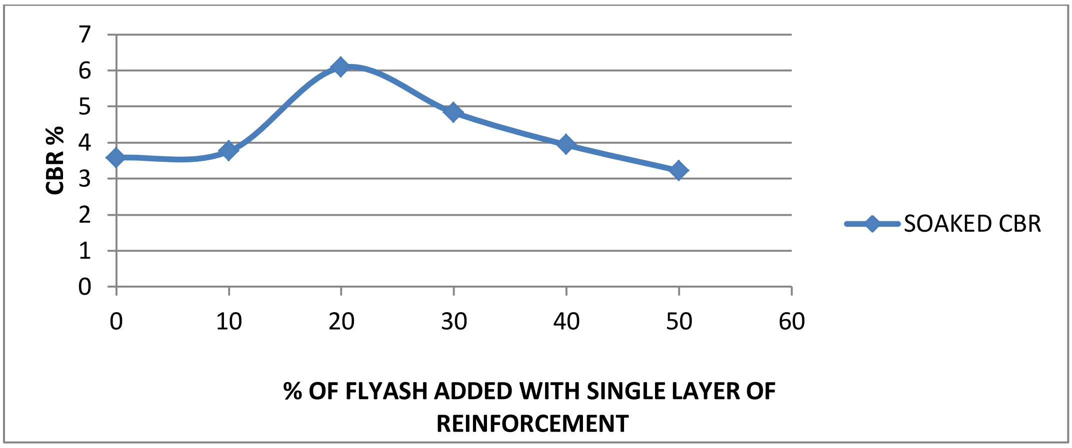


Figure 7 Variations in CBR with the addition of flyash and single layer of geotextile

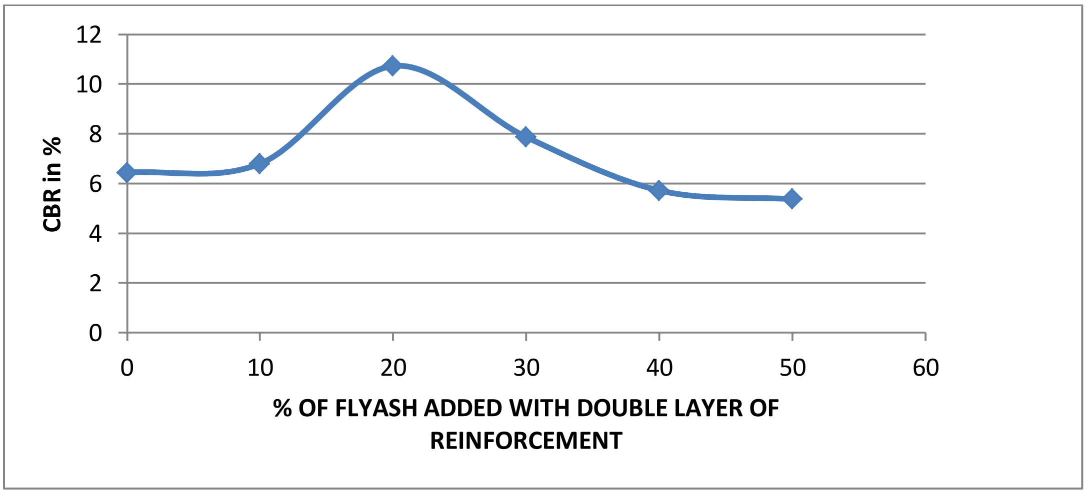


Figure 8. Variations in CBR with the addition of flyash and double layer of geotextile

Table 13. % increase in CBR with inclusion of geotextile with respect to the flyash stabilized subgrade

S.no	% of flyash added	% increase in soaked CBR with single layer of reinforcement	% increase in soaked CBR with double layer of reinforcement
1	0	33.20	140
2	10	16.45	111.8
3	20	41.72	150.1
4	30	35.29	120.44
5	40	37.41	100
6	50	20.14	100.37

5.3 Variation of Atterberg's limit with the addition of fly ash

Variation of Atterberg's limits with addition of flyash can be observed from figures 9 to 11. Liquid limit, plastic limit, plasticity index are decreasing with the addition of flyash.

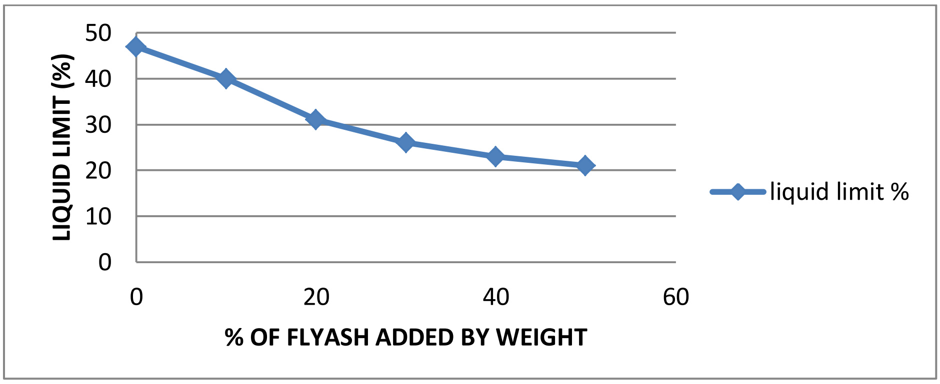


Figure .9 Variation of liquid limit with the addition of fly ash

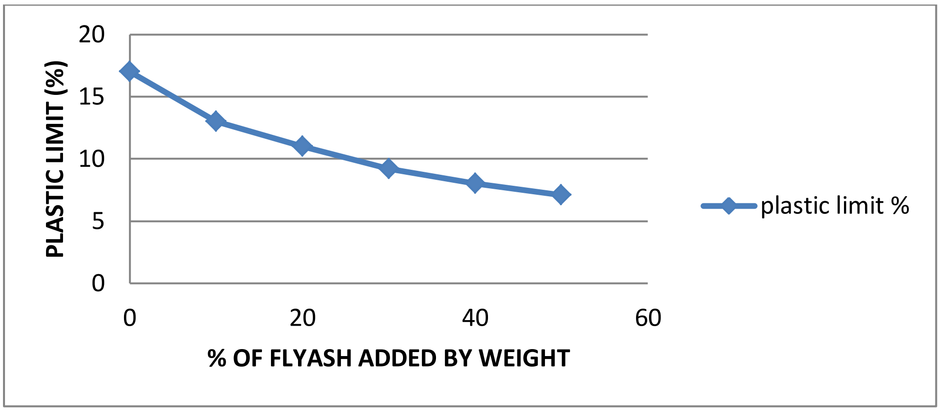


Figure .10 Variation of Plastic limit with the addition of fly ash

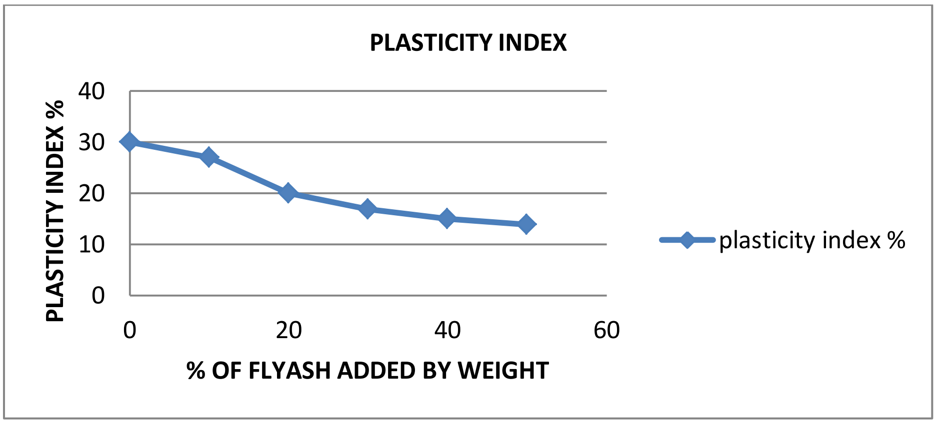


Figure .11 Variation of Plasticity Index with the addition of fly ash

Table 14 summarizes the percentage reduction in Atterberg's limit and graphically represented by figures 12, 13 and 14.

Table .14 Summary of percentage reduction in Atterberg's limit

S.no	%of Flyash added	% Reduction in Liquid limit	% Reduction in Plastic limit	% Reduction in Plasticity index
1	0	0	0	0
2	10	14.89	23.52	10
3	20	34	35.3	33.33
4	30	44.68	45.8	44
5	40	51.06	52.9	50
6	50	55.31	58.23	53.66

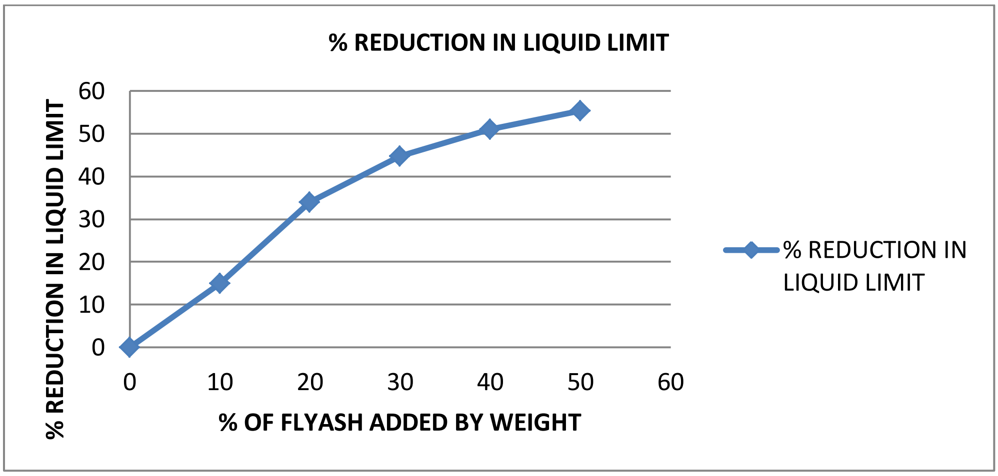


Figure .12 Percentage Reduction in Liquid Limit

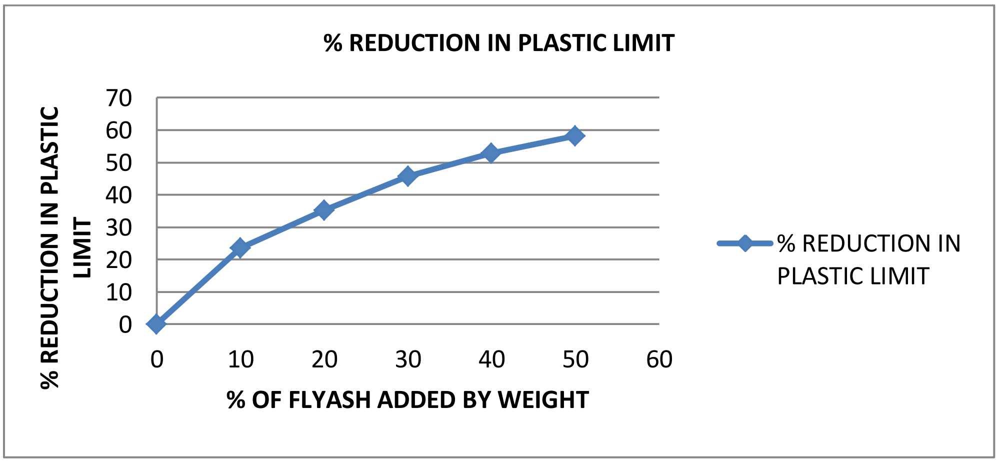


Figure .13 Percentage Reduction in Plastic Limit

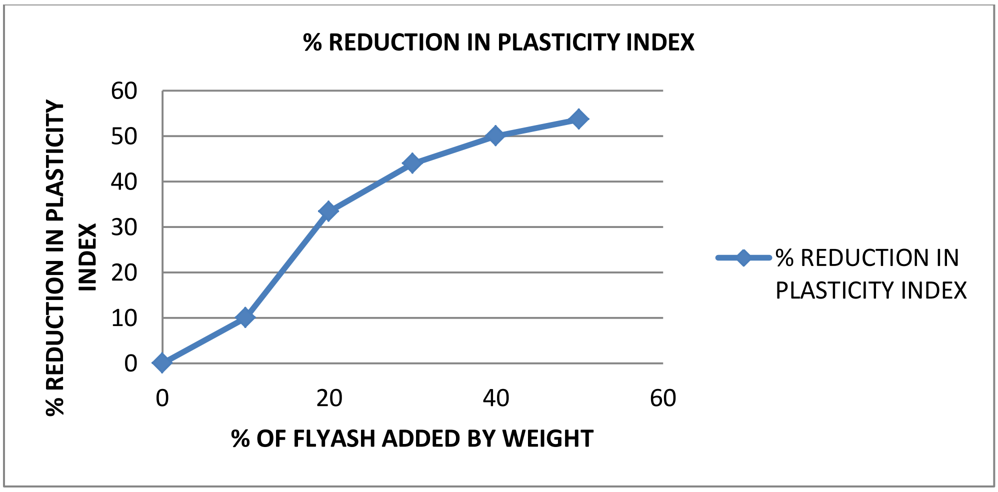


Figure .14 Percentage Reduction in Plasticity Index

5.4 variations in total soluble solids with the addition of fly ash

Total soluble solids increases with addition of flyash. The increased soluble solid content with addition of flyash indicates that amount of flyash available for cementing actions. This gives a positive result, which shows in figure 15.

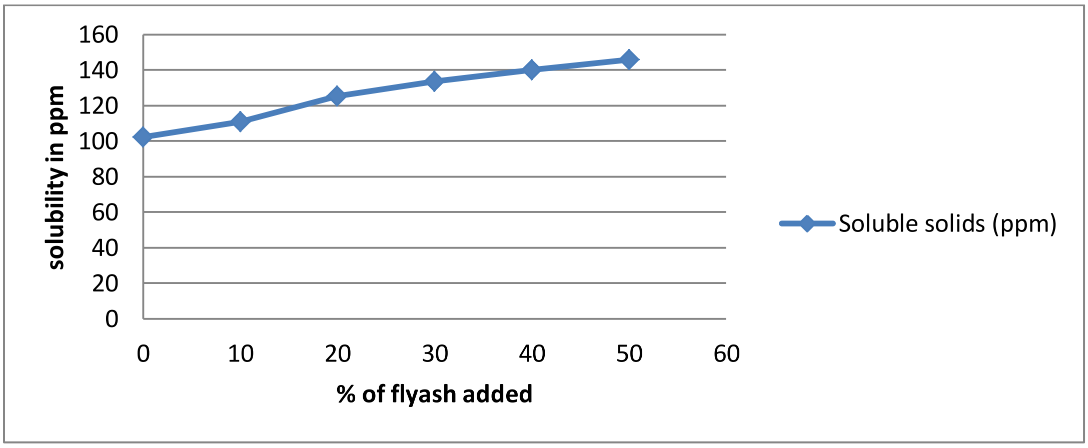


Figure .15 variations of total soluble solids with the addition of fly ash

5.5 Variations in calcium carbonate (caco$_3$) content

Calcium carbonate acts as a binding material and it increases with the increase in fly ash content in soil. This content may vary with respect to time since cementaneous process is a long time chemical reaction.

The variation of $CaCO_3$ with the addition of flyash is sown in figure 16.

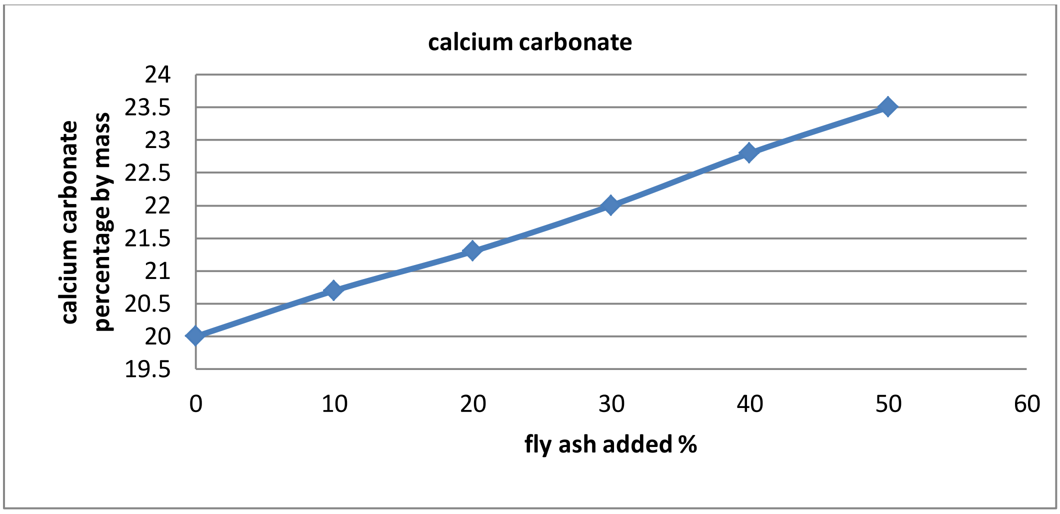


Figure .16 Variation of caco$_3$ with the addition of flyash

5.4 Effect of fly ash on ph of soil

The pH of soil is an indirect measure of Cation Exchange Capacity of soil. pH is directly proportional to CEC in alkaline state. CEC and pH are indirectly proportional to strength of soil.

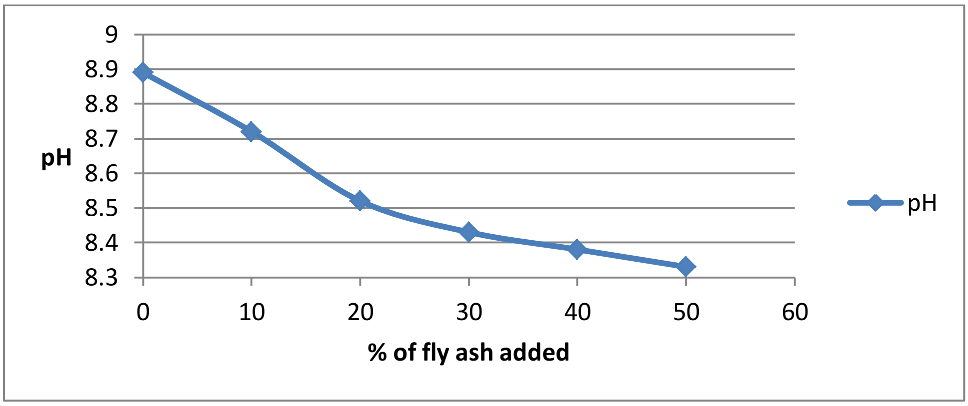


Figure .17 Variation of ph with the addition of flyash

5.6 Effect of flyash on cation exchange capacity of soil

Cation exchange capacity indicates amount of exchangeable ions adsorbed on clay surface. CEC fixes the double layer thickness of clay. Plasticity index is directly proportional to the double layer thickness. A decrease in CEC is observed with the addition of flyash to soil.

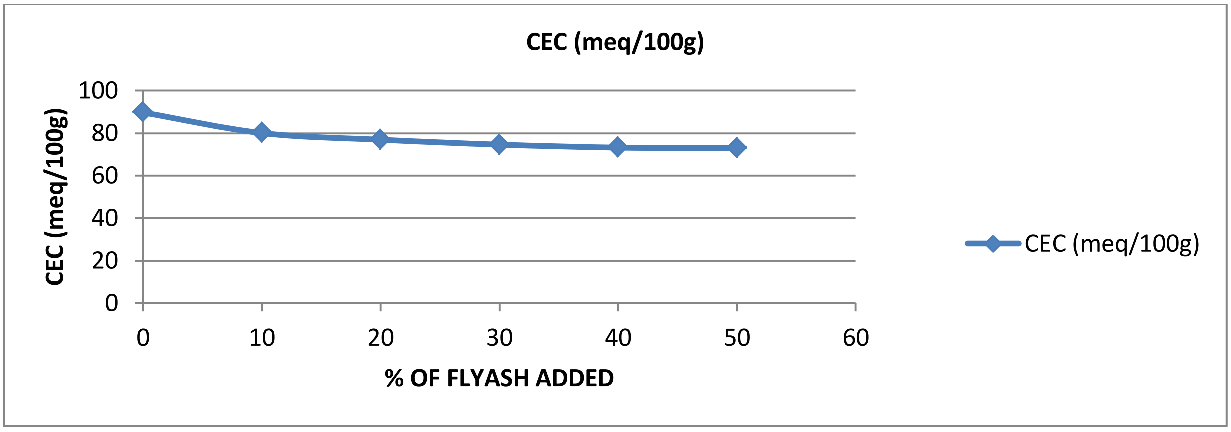


Figure .18 Effect of flyash on cation exchange capacity of soil

5.7 Variation in differentialfree swell

Differential free swell has a trend of decreasing due to decrease in plasticity index. It indirectly indicates that swell pressure may also be reduced.

The variation of DFS with the addition of flyash is shown in figure.19.

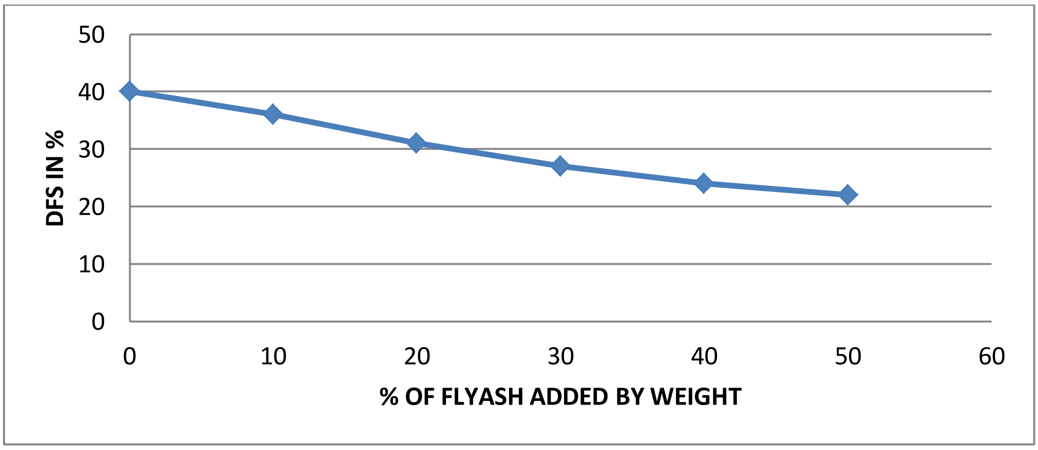


Figure .19 variation of dfs with the addition of flyash

6. Multiple Regression analysis modelling

5.1 Aim of modelling

The ultimate motto of regression analysis is to develop an equation which could have the capacity to find CBR value based upon some input parameters**.**

The ambition of ANN modelling is to develop an ANN model to predict CBR value and also to study the effect of number of neurons in hidden layer with different algorithms.

5.2 Development of Multiple regression models

Multiple regressionsare regression with two or more independent variables on the right-hand side of the equation. Multiple regressioncan be adopted if more than one cause is associated with the effect we wish to understand. For the development MRA model, MS-Excel 2007 software has been used.

5.2.1Inputs and output

Two models 1) Artificial Neural Network (ANN) model 2) Multiple Regression Analysis(MRA) model have been developed to predict the soaked CBR values of reinforced flyashstabilizedsoil .Both the models have been developed by taking, Atterberg's limits, % of flyash added, OMC (%) and MDD (kN/m^3), number of geotextile layers as input variables and soaked CBR (%) as output variable.

5.2.2Summary of output

Using MS-Excel 2007, regression analysis has been done and the following relationship is obtained with a co-efficient of correlation(R^2) 0.8878.

$$CBR= 0.09895X_1 -0.2171X_2 +0.0451X_3+2.737X_4-55.785X_5+1.979X_6+63.483$$

Here,

X_1= % of flyash added,
X_2= Liquid limit,
X_3=Plastic limit,
X_4= OMC,
X_5= MDD,
X_6= No. of geotextile layers.

5.3.2Effect of training algorithm

As stated earlier, at the end of training a set MSE and R values are obtained. This process is repeated until the maximum R value and minimum MSE has reached for the particular algorithm. The values are tabulated in table 15.

Table15.Effect of training algorithm

S.no	Algorithm	R value	MSE
1	Quasi-Newton back propagation	0.88712	$1.083x10^{-4}$
2	Bayesian regulation back propagation	0.85190	$4.983x10^{-5}$
3	Conjugate gradient back propagation with Powell-Beale restarts	0.94122	$3.776x10^{-7}$
4	Conjugate gradient back propagation with Fletcher-Reeves updates	0.81167	$7.339x10^{-6}$
5	Conjugate gradient back propagation with Polak-Ribiére updates	0.85819	$2.964x10^{-9}$
6	Gradient descent back propagation	0.94862	$9.985x10^{-9}$

7	Levenberg-Marquardt back propagation	0.98695	$8.0242x10^{-11}$
8	One-step secant back propagation	0.92335	$1.388x10^{10}$
9	Scaled conjugate gradient back propagation	0.96904	$1.946x10^{-6}$

From table 6.1 we can infer that Levenberg-Marquardt back propagation shows maximum R value of 0.98695 and minimum MSE value of $8.0242e^{-11}$ and hence Levenberg-Marquardt back propagation can be used although it consumes higher memory usage compared to any other algorithm. When there is a constraint to memory usage Scaled conjugate gradient back propagation can be employed.

5.3.3Effect on number of neurons in hidden layer

Keeping the percentage of data allotted for training and testing as constant, numbers of neurons are varied and R value is noted. Randomness is observed between R value and numbers of neurons.The values can be read from table 16 and figure 20.

Table16.Relationship between number of neurons and r values

Number of neurons	**Percentage of data allotted and R value**		
	10%-10%	**15%-15%**	**20%-20%**
2	0.9334	0.9736	0.8340
4	0.7812	0.8712	0.6725
6	0.8573	0.6698	0.9745
8	0.9223	0.7845	0.9421
10	0.8125	0.9869	0.7967
15	0.8823	0.4356	0.5698
20	0.9461	0.5739	0.8883
25	0.9388	0.7866	0.8934
30	0.7174	0.4358	0.8352

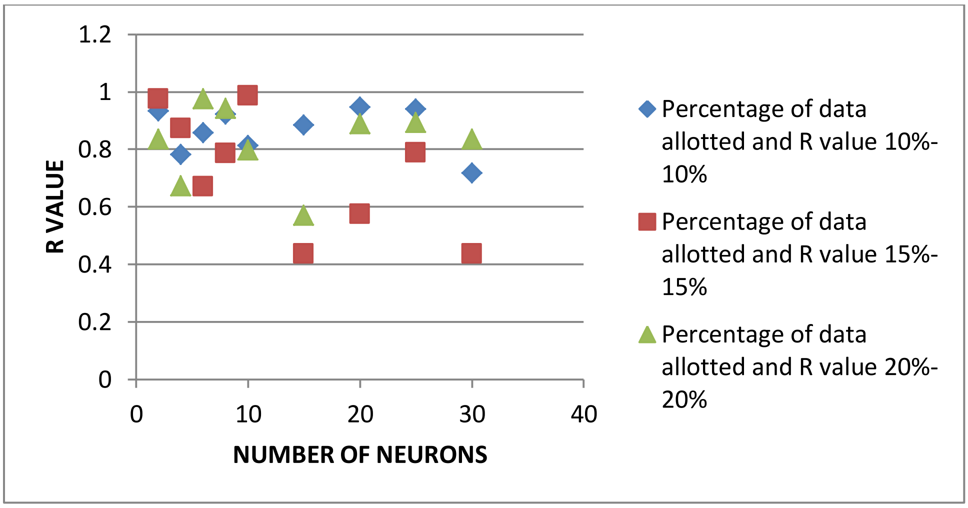


Figure 20.Effect on number of neurons in hidden layer

7. Conclusion

Based on the laboratory, experimental investigations on stabilization and computational modelling, the following conclusions can be drawn.

1. The decrease in OMC and MDD with the addition of flyash is mainly due to reduction in CEC and thickness of double layer.
2. The addition of geotextile layers reduces the MDD but OMC remains almost unchanged.
3. Maximum UCC strength of 126.85 kN/sq.m, Maximum unsoaked CBR of 17.17% and Maximum soaked CBR of 4.29% are obtained at flyash content of 20% by weight. Hence 20 % of flyash content is optimum for stabilization purposes.
4. Soaked CBR of subgrade soil is further increased with inclusion of geotextile layers. Soaked CBR value has increased to 6.08% with single layer of geotextile while 10.73% of soaked CBR has obtained for two layers of geotextile.
5. The liquid limit of untreated soil was 47%. It has decreased to 26% at 30% addition of flyash. On further addition of flyash, liquid limit has finally reduced to 21%.
6. The plasticity index of untreated soil was 30%. It has decreased to 13.9% at 50% addition of flyash.
7. The percentage reduction of plasticity index is 53.6% attained at 50% addition of flyash.
8. It is observed that there is no significant change in soluble solids concentration from IS testing method and TDS analyzer.
9. Total soluble solids increases from 102.2 ppm to 145.9 ppm by adding flyashupto 50%.
10. $CaCO_3$ content is increased to by adding 50% flyash to soil.
11. Only a trace of sulphate is present in soil.
12. pH value of virgin soil is 8.89 which shows soil is slightly alkaline and ph is reduced to 8.33 with the addition of 50% flyash.
13. CEC is decreased to 72.931 meq/100g with the addition of 50% flyash and IS testing method and Soil Society of America gives almost same results.
14. The MRA produces R^2value of 0.8878 isapplicable for CI category of clays and properties of reinforcement remains the same.

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