International Refereed Journal of Engineering and Science (IRJES)
ISSN (Online) 2319-183X, (Print) 2319-1821
Volume 5, Issue 11 (November 2016), PP.20-27

Mathematical Modelling of Swelling Pressure of Expansive Soil - Fly ash Mix Reinforced with Nylon Fibre

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Abstract: Expansive soils are a worldwide problem, causing extensive damage to civil engineering structures. Jones and Holtz estimated in 1973 that the annual cost of damage in the United States due to expansive soil movement was $2.3 billion. Utility of fly ash in expansive soil stabilization is established by accessing the extent of improvement achieved in relevant Engineering properties of expansive soil such as Plasticity, Compaction, Compression strength, CBR value and Swelling Index

This paper presents experimental results based on analysis of swelling pressure of expansive soil - Fly ash mix could be reduced by addition of randomly distributed Nylon fibres. The effect of addition of Nylon Fibres on compaction characteristics, swelling pressure is studied. Reinforcement content, varying from 0.25 % to 1.25 % by dry weight was added to stabilize the soil- flyash mixtures. Samples were prepared at optimum moisture content and maximum dry density and were cured for 3 day duration in the laboratory under controlled conditions.

The mathematical models have also been developed to correlate swelling pressure with different parameters. The developed mathematical model is adequate to represent the relationship and useful to predict the swelling pressure. Adequacy of developed mathematical model has also been tested by conducting different verification experiments. It is observed that difference between predicted and observed value of swelling pressure is lying within 10%.

A Mathematical model represented by response equation has been developed, considering only linear and quadratic effects of percentage of fibre reinforcement and length of fibres. The appropriate equation has been decided and coefficients have been determined using MATLAB software.

Keywords: Fly ash, HT Nylon 66 Fibre, Swelling Pressure, Mathematical Modelling

I. INTRODUCTION

Large quantity of ash is being generated at coal/lignite based Thermal Power Stations in the country, which not only requires large area of precious land for its disposal but is also one of the sources of pollution of both air and water.

Efforts are underway to improve the use of fly ash in several ways, with the geotechnical utilization also forming an important aspect of these efforts. In this paper, emphasis is made to investigate the utilization of fly ash in Expansive Soil stabilization. The fly ash percentage variation is made from 0 % to 50% with an increment of 5%. It is found that 30% of fly ash provides better results. Also an experimental investigation focused on evaluating the effectiveness of Nylon fiber in providing stable and improved quality of expansive soil-flyash mix reinforced with nylon fibre.

II. LITERATURE REVIEW

Hussein A. Elarabi (2004) considered internal stresses, environmental factors and state of stress main governing factor of swelling characteristic of expansive soils. Further emphasis that no one method of soil analysis estimates shrink-swell potential accurately, however could be predicted by examining a combination of physical, chemical and mineralogical properties. The factors influencing the shrinkage –swell potential is suggested to be broadly divided in three major groups namely, Soil characteristics that influence the basic nature of the internal stress of the field, Environmental factors that influence the change that may occur in the internal stress system and the state of stress.

According to Lee D Jones at el the critical characteristics of expansive soil is its ability to change volume with water content variation, essentially governed by clay mineral contents such as smectite. Swelling and shrinkage are not fully reversible processes, thus an shrinkage cracks formed due to drying may not gets closed perfectly causing bulk-out, further in-filled shrinkage cracks imparts heterogeneity to the soil resulting increase in swelling pressures.

Lakshmi Keshav et al. 2012 analyzes effect of fly ash on an expansive soil for flexible pavement design in terms of cost, dry density, CBR value, swell Index and liquid limit. Decrease in swelling index, liquid limit & plasticity, 1.64 times increase in CBR value and considerable saving in road construction are found to be effect of fly ash content on expansive soil.

Das Arindam and Sabyasachi Roy (2014) attributed shrinkage and swelling characteristic to the presence of minerals such as smecite, bentonite, montmorillonite, beidellite, vermiculite, attapulgite, nontronite, illite & chlorite and changes in moisture content. The distress to the rectangular slab foundation is found to be an result of moisture differentials within soils at the edge of the slab. It is found to be due to the studied effect of swelling and shrinking characteristics of expansive soil on Foundation. The shrink-swell capacity of expansive soils leads differential movement beneath foundations. Use of 2 to 8 % by weight of lime is recommended for effectively arrest swell and shrinkage with replacement of sodium and potassium ions with calcium significantly reduces the plasticity index of the soil.

Xu Jiawena et. al. (2005), have presented numerically controlled electrochemical contour evolution machining (NC-ECCEM) process using rotary tool. The geometric model, the modelling method and its numerical solution, regarding the NC-ECCEM process has also been introduced. Calculated results of the model were in line with the experimental results. The model presented will be helpful for the analysis process.

P. Asokan et. al. (2008), has developed multiple regression and ANN model to determine the optimal machining parameters in ECM for hardened steel using electrochemical machining. The multiple regression and ANN model were developed by authors to map the relationship between process parameters and objectives in terms of grade. The obtained average percentage deviation for the training data of the linear regression model, logarithmic transformation model, and ANN model, was 12.7, 25.6 and 3.03, respectively. While examining the average percentage deviation of three developed models, author observed that ANN model shows least percentage deviation. So it was reported, ANN is the best prediction model.

III. MATERIALS AND METHODS

Expansive soil is the material which exhibits swell & shrink under alternate wetting and drying situation. The sampled collected from Shri Shivaji Agriculture College Nagpur Road at Rahatgaon Amravati in plastic bags were then transported to the testing laboratory.

Table 3.1: Results from Series of Conventional Laboratory Tests

Sr. No.	**Properties**	**Value**
1	Specific Gravity, G	2.67
2	Grain Size Analysis	
	i) Sand	9%
	ii) Silt	19%
	iii) Clay	72%
3	Atterberg's Consistency Limits	
	i) Liquid Limit, W_L	72.46%
	ii) Plastic Limit, W_P	32.55%
	iii) Plasticity Index, PI	39.91%
	iv) Shrinkage Limit, SL	10.00%
4	Compaction Properties	
	Maximum dry density MDD	15.00 kN/m^3
	i) Optimum moisture content	27.00%
5	Swelling Pressure	
	i) Force Swell Index (FSI)	61.55
	ii)Swelling Pressure	217 Kn/m^2
6	IS classification of Soil	CH

3.1 Fly Ash

Fly ash is silt –size non cohesive material having a relatively smaller specific gravity than the normal soils. The samples identified for this study were collected from the Thermal power station at Koradi, Near Nagpur. The Physical properties of Fly Ash used are given in Table 3.2.

Table 3.2: Physical Properties of Fly Ash

Sr. No	Physical constituents	Unit	Value
1	Specific Gravity, G		2.00
2	Liquid Limit, WL	%	28.00
3	Plastic Limit , WP	%	None
4	Maximum Dry Density	kN/m^3	13.24
5	Optimum Moisture Content	%	24.00
6	Colour		Grey
7	Gravel		Nil
8	Sand	%	25.00

3.2 HT Nylon 66 Fibre

HT Nylon 66 Fibre is the material which on inclusions increased the strength of the fly ash specimens and changed their brittle behaviour into ductile behaviour. The physical properties of Fibres are given in Table 3.3.

Table 3.3: Physical Properties of Fibre

Properties	Value
Specific Gravity	1.14
Density	1140 Kg/m^3
Water Absorption	1.30%
Melting Point	260^0C
Elongation	15-28%
Tensile Strength	41 MPa
Modulus of Elasticity	445.70 Pa

3.3 Mix Proportions

Expansive Soil is mixed with 5 to 50% with the increment of 5% of fly ash by dry unit weight of the soil. Optimum mix proportion giving highest maximum dry density based on the results of standard proctor test were used for carrying out further study on influence of Nylon-66 fibre on various properties of expansive soil. Expansive soil, sly ash and Nylon-66 fibre mix with optimum dose of fly ash and varying percentage & length of fibres were prepared. The optimum dose of fly ash were close to 30% and Nylon-66 fibre percentage adopted are 0.25, 0.50, 0.75, 1.00 , 1.25 & 1.50 with length varying from 6 mm to 24 mm.

IV. RESULT AND DISCUSSION

4.1 Introduction:

Based on literature review and preliminary investigation three factors namely expansive soil, Flyash, HT Nylon66 are considered for investigation. A preliminary design of experiment using the orthogonal array (OA) was carried out in order to access the relative effect of these three parameter. Three levels of each factor were used in experimental design through an L9 orthogonal array. Table 4.1 shows the parameter and there values used at different levels.

Table 4.1: Factors and their levels

Sr. No.	Parameters	Level1	Level2	Level3
1	Length of Fibre	6mm	12mm	18mm
2	%age of Fibre	0.25	0.75	1.25

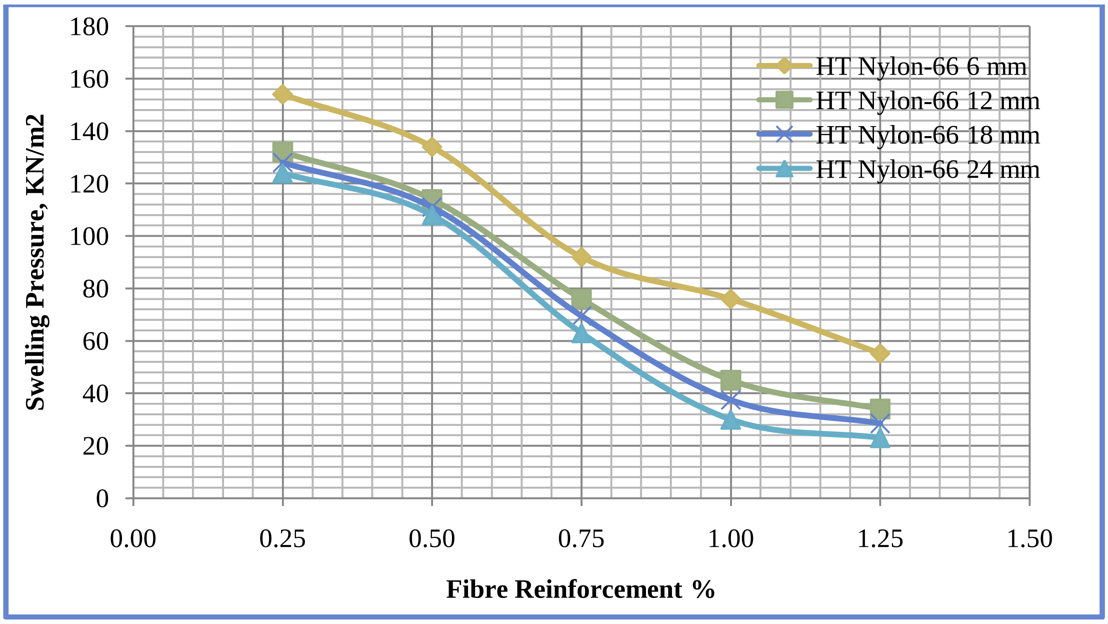

Figure 4.1: Improvement in Strength Characteristics of Expansive Soil-Fly Ash Mix in terms of Swelling Pressure with Different % of Randomly Distributed HT Nylon-66 Fibres

Table 4.2: Variation in Strength Characteristics of Expansive Soil-Fly Ash Mix in terms of Swelling Pressure with different % of Randomly Distributed HT Nylon-66 Fibres

Sr. No.	Designation	Reinforcement in Fly Ash-Expansive Soil Mix		Swelling Pressure KN/m^2				
		Fibre Length, mm	Fibre %	Sample 1	Sample 2	Sample3	Avg.	Swelling Pressure% Variation
1	OSFB 0.00		0	162.61	151.34	169.05	161.00	0.000
2	OSFB 0.25/6		0.25	160.16	167.08	144.76	157.33	-2.277
3	OSFB 0.50/6		0.50	136.68	139.36	125.96	134.00	-16.770
4	OSFB 0.75/6		0.75	92.92	86.48	96.6	92.00	-42.857
5	OSFB 1.00/6		1.00	68.04	77.52	82.08	75.88	-52.870
6	OSFB 1.25/6	6 mm	1.25	56.65	58.85	49.5	55.00	-65.839
7	OSFB 0.00		0	144.9	170.66	167.44	161.00	0.000
8	OSFB 0.25/12		0.25	139.92	118.8	137.28	132.00	-18.012
9	OSFB 0.50/12		0.50	121.98	117.42	102.6	114.00	-29.193
10	OSFB 0.75/12		0.75	82.08	68.4	77.52	76.00	-52.795
11	OSFB 1.00/12		1.00	49.05	40.5	45.45	45.00	-72.050
12	OSFB 1.25/12	12 mm	1.25	34.34	30.94	36.72	34.00	-78.882
13	OSFB 0.00		0	144.9	170.66	167.44	161.00	0.000
14	OSFB 0.25/18		0.25	129.32	128.8	125.88	128.00	-20.497
15	OSFB 0.50/18		0.50	111.98	111.42	109.6	111.00	-31.056
16	OSFB 0.75/18		0.75	69.25	72.13	68.62	70.00	-56.522
17	OSFB 1.00/18	18 mm	1.00	37.9	40.25	35.85	38.00	-76.398

Sr. No.	Designation	Reinforcement in Fly Ash-Expansive Soil Mix		Swelling Pressure KN/m^2				
		Fibre Length, mm	Fibre %	Sample 1	Sample 2	Sample3	Avg.	Swelling Pressure% Variation
18	OSFB 1.25/18		1.25	29.9	30.5	26.6	29.00	-81.988
19	OSFB 0.00		0	164.22	146.51	172.27	161.00	0.000
20	OSFB 0.25/24		0.25	127.72	112.84	131.44	124.00	-22.981
21	OSFB 0.50/24		0.50	98.28	113.4	112.32	108.00	-32.919
22	OSFB 0.75/24		0.75	66.15	57.33	65.52	63.00	-60.870
23	OSFB 1.00/24		1.00	31.8	30.9	27.3	30.00	-81.366
24	OSFB 1.25/24	24 mm	1.25	20.93	23.23	24.84	23.00	-85.714

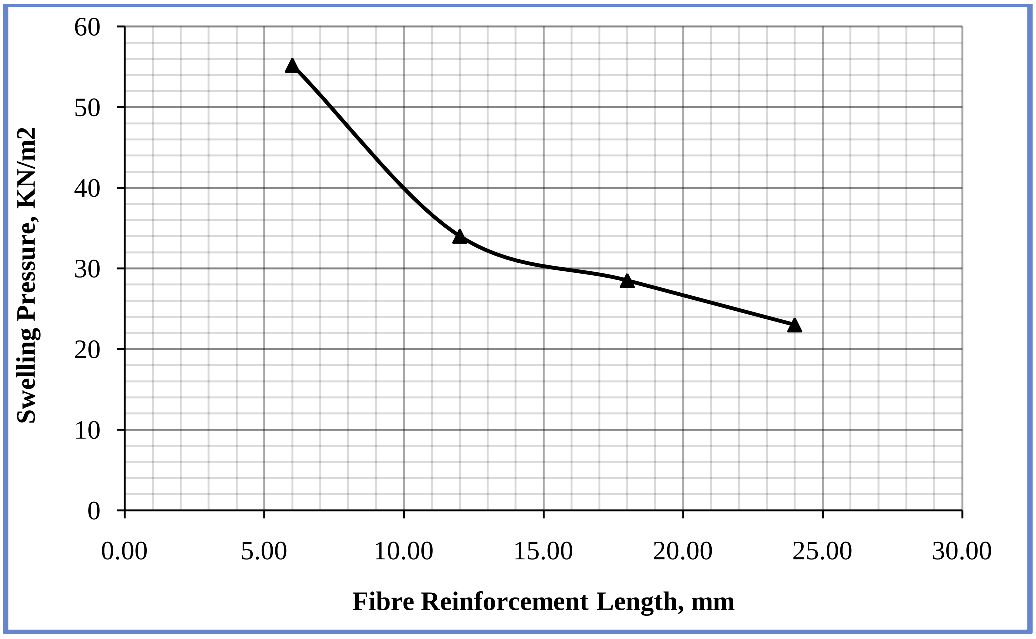

Figure.4.2: Improvement in Strength Characteristics of Expansive Soil-Fly Ash Mix in terms of Swelling Pressure with Different Length of Randomly Distributed HT Nylon-66 Fibres

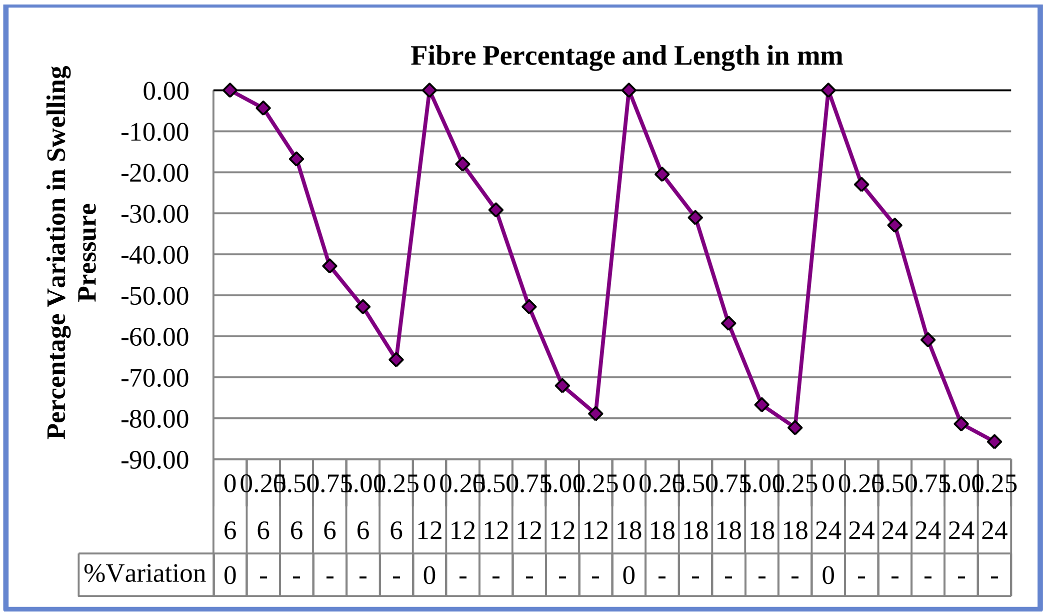

Figure 4.3: Percentage variation in Strength Characteristics of Expansive Soil-Fly Ash Mix in terms of Swelling Pressure with Different % of Randomly Distributed HT Nylon-66 Fibres

4.2 Development of Mathematical Models and Verification for Swelling Pressure of Expansive Soil - Flyash Mix Reinforced with Nylon Fibres

The mathematical models to represent the relationship among strength Characteristics and input parameters have been developed by regression analysis on the basis of L_9 orthogonal array of robust design. The response equation has been developed, considering only liner and quadratic effects of percentage of fibre reinforcement and length of fibres. The appropriate equation has been decided and coefficients have been determined using MATLAB software.

Mathematical Model for Swelling Pressure of Expansive Soil - Fly ash Mix Reinforced with Nylon Fibres has been developed for predication of Swelling Pressure Strength in terms of Fibre percentage and length of fibres.

$$\square_{sp} = 222.7798 - 6.94435 X_1 - 154.6664 X_2 + .2037 X_1^2 + 37.3332 X_2^2$$

Where,

σ_{sp} = Average Swelling Pressure in kN/m^2

X_1= Length of Fiber/Nylon in mm

X_2= Nylon Fibre %

Table 4.3: L9 Orthogonal Array Experimental design_Average Swelling Pressure

Experiment No.	Length of Fiber/Nylon in mm	Nylon Fibre %	Average Swelling Pressure in kN/m^2			
			Experimental value (Swelling Pressure)	Model value (Swelling Pressure)	Difference	Variation in %
1	6	0.25	154	152.11	1.89	1.22
2	6	0.75	92	93.45	-1.45	-1.57
3	6	1.25	55	53.45	1.75	3.18
4	12	0.25	132	132.45	-0.45	-0.34
5	12	0.75	76	73.78	2.22	2.92
6	12	1.25	34	33.78	0.22	0.65
7	18	0.25	128	127.45	0.55	0.43
8	18	0.75	70	68.78	0.72	1.04
9	18	1.25	29	28.78	-0.28	-0.98

From the above equation Swelling pressure has been predicated from the developed model and its reliability is verified with experimental values. These values are tabulated in Table 4.4 and its variation is represented in graphical format in figure 4.4. It is observed that differences between predicted and observed values are within 10%

Table 4.4: Verification of Experimental and Model values for Average Swelling Pressure in kN/m2

Experiment No.	Length of Fiber/Nylon in mm	Niylon Fibre %	Average Swelling Pressure in kN/m2			
			Experimental value (Swelling Pressure)	Model value (Swelling Pressure)	Difference	Variation in %
1	6	1.00	76	71.11	4.89	6.43
2	12	0	161	168.78	-7.78	-4.83
3	18	0	161	163.78	-2.78	-1.73
4	24	0	161	173.45	-12.45	-7.73
5	24	0.50	108	105.45	2.55	2.36

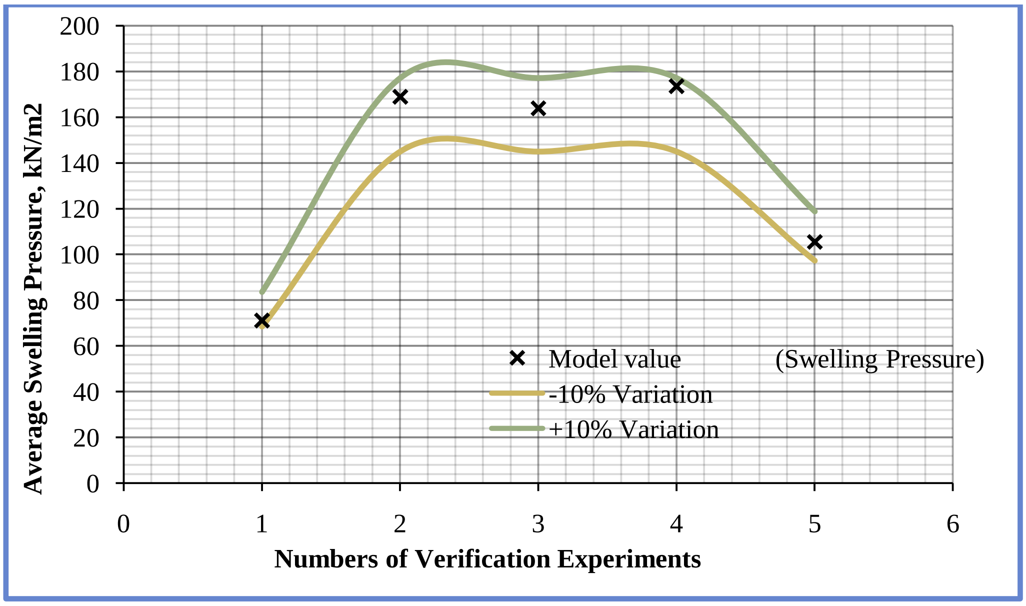

Figure 4.4: Validity of Mathematical Model of Average Swelling Pressure

V. CONCLUSION

This research work intended towards an experimental investigation on strength characteristics of expansive soil - flyash mix reinforced with nylon fibres. The experimental investigation is carried out composed of tests reflecting Plasticity, Compaction and swelling characteristics of expansive soil, expansive soil –flyash mix and expansive soil – flyash mix reinforced with nylon fibres. Influence of fly ash content on expansive soil, HT Nylon 66 fibre content on expansive soil –flyash mix is presented and analysed..The results are analysed using mathematical modelling and the response equations are developed.

- Optimum percentage of HT Nylon-66 fibres having significant effect on characteristics of expansive soil fly ash mix is 0.75% of 12 mm length.

- Swelling characteristics of expansive soil-fly ash soil mix scaled in the form of swelling pressure shows remarkable improvement of 85.714 %, with Swelling Pressure decreasing from 161 kN/m^2 to 23 kN/m^2 at HT Nylon 66 fibre content of 1.25 % of 24 mm length.

- The developed mathematical model is significant to represent the relationship and useful to predict the values for Swelling pressure

- Adequacy of developed mathematical model has also been tested by conducting different verification experiments and it is observed that difference between predicated and observed value of Swelling pressure is lying within 10%.

VI. ACKNOWLEDGEMENT

Author acknowledges the support given by SARALA Fibre Mumbai by providing various samples of Fibres. He is also thankful to Principal teaching and non-teaching staff B.N. COE Pusad, Dist Yavatmal (MS) for providing necessary experimental assistance from their research lab. The author is also thankful to Dr. Shirish Dhobe for his contribution in this research work.

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