

## Research Paper

# Prediction of unconfined compressive strength of geopolymer stabilized clayey soil using Artificial Neural Network



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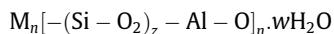
## ABSTRACT

Viability of Artificial Neural Network (ANN) in predicting unconfined compressive strength (UCS) of geopolymer stabilized clayey soil has been investigated in this paper. Factors affecting UCS of geopolymer stabilized clayey soil have also been reported. Ground granulated blast furnace slag (GGBS), fly ash (FA) and blend of GGBS and FA (GGBS + FA) were chosen as source materials for geo-polymerization. 28 day UCS of 283 stabilized samples were generated with different combinations of the experimental variables. Based on experimental results ANN based UCS predictive model was devised. The prediction performance of ANN model was compared to that of multi-variable regression (MVR) analysis. Sensitivity analysis employing different methods to quantify the importance of different input parameters were discussed. Finally neural interpretation diagram (NID) to visualize the effect of input parameters on UCS is also presented.

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## 1. Introduction

Geopolymer technology is a recent field of research interest in concrete science and engineering and is gaining increasing attention for utilization of industrial by products such as FA and GGBS. Any pozzolanic material containing source of silica and alumina that is readily dissolved in the alkaline solution acts as a source of geopolymer precursor species and lends itself to geopolymerization [1]. Geopolymerization involves the poly-condensation reaction of geopolymeric precursors i.e. alumino-silicate oxide with alkali polysilicates yielding polymeric Si–O–Al bond as shown below [2–4].



where M is the alkaline element, z is 1, 2 or 3 and n is the degree of poly-condensation [4]. It is worthwhile to mention that the micro-structure of the end product formed after geopolymerization is totally different from that of pozzolanic reactions since pozzolanic reaction yields calcium silicate hydrate and/or calcium alumino-silicate [5].

Review of literature reveals that limited research have been carried out on soil stabilization by geopolymer binder. In recent past,

FA based geopolymer was successfully used by some researchers for improvement of clayey soil [6–9]. However, in most of the cases, the specimens were cured either at elevated temperature or at ambient temperature for a prolonged period, sometimes up to one year. Zhang et al. [10] studied the feasibility of metakaolin based geopolymer as a next generation soil stabilizer. GGBS-based geopolymer binder shows very high strength within hours and yet doesnot require elevated temperature curing [11,12]. Till date, rare literatures are reported on the effectiveness of GGBS-based geopolymer soil stabilization. Only recently, Yaolin et al. [13] investigated the effect of several alkali activators on the stabilization efficacy of GGBS treated marine soft clay. Detail investigation on role of parameters such as binder content, alkali to binder ratio and molar strength of alkali affecting mechanical properties of GGBS based geopolymer stabilized soil is yet to be explored.

In the present study, an effort has been made to stabilize clayey soil by GGBS based geopolymer. Source materials such as FA and blend of GGBS + FA were also incorporated in the present study to compare the stabilization efficacy among them and were reported via 28 day UCS. For optimal and effective stabilization, ANN based UCS predictive model was developed. Prediction efficacy of developed ANN model was compared with that of MVR model. Sensitivity analysis was employed to understand the effect and to quantify the importance of different input geopolymer mix parameters on the predicted UCS of stabilized specimens.

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**Table 1**  
Engineering properties of clayey soils.

Soil type	Liquid limit	Plastic limit	Plasticity index	MDD <sup>a</sup> in kN/m <sup>3</sup>	OMC <sup>b</sup>	d <sub>10</sub> in micron	d <sub>50</sub> in micron	d <sub>90</sub> in micron	Classification	
									USCS	AASHTO
S1	116.27	27.81	88.46	14.112	23.89	0.835	1.568	2.505	CH	CH
S2	82.15	25.69	56.46	15.288	19.26	6.473	9.245	18.34	CH	CH
S3	37.68	23.61	14.07	16.562	19.05	54.889	51.475	66.59	CL	CL

<sup>a</sup> Maximum dry density.

<sup>b</sup> Optimum moisture content.

## 2. Experimental procedure

### 2.1. Material used

Three different types of soil designated as S<sub>1</sub>, S<sub>2</sub> and S<sub>3</sub> in the present study were undertaken. The soils were collected from three different locations in Silchar city within 2 m of the ground surface. The engineering properties of the soils conforming to relevant Indian Standard Code of Practice are presented in Table 1. Commercially available ultra-fine GGBS and ASTM class F fly ash collected from thermal power plant at Farakka (India) was used as source material. The chemical and physical characteristics of GGBS and FA are presented in Table 2. Sodium hydroxide was chosen in the present study as alkali activator because of its greater capacity to liberate silicate and aluminate monomers [14]. Commercial grade sodium hydroxide (NaOH) pallets with purity 98%, specific gravity 2.13 and molecular weight 40 were used in the present study. Sodium silicate is often used along with sodium hydroxide for alkali activation as the presence of sodium silicate in sodium hydroxide is believed to enhance the reaction kinetics of geopolymerization [15]. In the present study, sodium silicate (Na<sub>2</sub>SiO<sub>3</sub>) combined with sodium hydroxide was used only in few cases to produce variations in some of the experimental variables, details of which will be dealt in subsequent sections. Sodium silicate used in the study had a specific gravity of 1.5, 97% purity and a molecular weight (Na<sub>2</sub>SiO<sub>3</sub>·5H<sub>2</sub>O) equal to 212. The alkali solution was prepared with tap water one day prior to use.

### 2.2. Methodology

The requisite quantity of clay soil weighed to the nearest gram was oven dried for 24 h at 110 ± 5 °C and then thoroughly mixed with source materials in a kitchen appliance until a uniform mix was obtained. Amount of binder were varied as a percentage of dry weight of soil solids from 4–50% for GGBS, 4–20% for FA and blend GGBS + FA. Molar concentration of alkali solution (M) used in the present study were 4 M, 8 M, 10 M, 12 M and 14.5 M. Alkali solution was added to the mix and the mixing was continued for 15 min. In literature, a mixing time of 10–20 min is reported for obtaining a homogeneous mix with the same alkali solution [10,13,16]. Ratio of alkali solution to binder by weight (A/B) was also selected as an experimental variable and the values of A/B were 0.45, 0.65 and 0.85. Review of literature reveals that researchers had considered A/B ratio in the range of 0.25–0.66 for geopolymer synthesis [16–18]. However, in the present study values of A/B ratio were varied from 0.45 to 0.85 to achieve wide variation in

**Table 2**  
Chemical and physical properties of source materials.

Source material	CaO	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	SO <sub>3</sub>	MgO	SiO <sub>2</sub>	Specific surface area in m <sup>2</sup> /kg
GGBS	34	20	2	0.8	8	35	800
FA	0.67	22.63	5.3	0.41	0.16	66.39	300

Na/Al ratio for geopolymer synthesis. Samples were compacted manually at a consistency of plastic limit with a tempting rod to eliminate air voids in PVC molds having diameter 38 mm and height 76 mm. Since the samples were compacted manually, it was found that at a consistency of plastic limit, desired workability for homogeneous compaction was possible. The prepared samples in molds were kept in laboratory for 24 h and then cured continuously in water for 28 days. After curing, samples were air dried at room temperature for one hour before testing. The 28 day UCS of the specimens was determined according to IS: 2720 (Part 10) [19]. Average test results of three specimens were reported as the UCS of the specimen.

### 2.3. Na/Al and Si/Al ratios

Previous research on geopolymer reveals that reaction kinetics of geopolymer synthesis are controlled by the atomic ratio of Na to Al (Na/Al) and Si to Al (Si/Al) in the mix and governs the strength of the product formed after geopolymerization [4,5,20,21]. Therefore, in the present study Na/Al and Si/Al for individual mixes were considered as experimental variables. Source of Na is NaOH and Na/Al ratio increases with increase in M and A/B in the mix. GGBS and FA are the source of Si and Al and Si/Al is constant for a particular binder. Again, for a particular binder, Na/Al ratio is independent of the binder percentage in the mix (but depends upon the relative proportion of the binders in a blended mix i.e. GGBS + FA). An example of calculation procedure of Na/Al and Si/Al is briefly explained in Appendix A. Calculated values of Na/Al and Si/Al of mixes with various combinations of M and A/B are presented in Tables 3 and 4. To examine the role of variation in Si/Al value on UCS, sodium silicate along with sodium hydroxide as secondary source of Si in the form of alkali activator was introduced in some mixes while maintaining a constant Na/Al ratio. Three different Na/Al ratios were chosen and for each value of Na/Al, variation in Si/Al was done accordingly as shown in Table 5.

### 2.4. Experimental results

28 day UCS of stabilized soil specimens with various combinations of the experimental variables are presented in Appendix B. Experimental results indicated the potential role of all the

**Table 3**  
Calculated Na/Al and Si/Al ratios at different M and A/B for GGBS and FA.

Molar concentration, M	Alkali to binder ratio, A/B	Na/Al		Si/Al	
		GGBS	FA	GGBS	FA
4	0.45	0.39	0.34	1.49	2.49
8	0.45	0.69	0.61	1.49	2.49
12	0.45	0.93	0.82	1.49	2.49
14.5	0.45	1.05	0.93	1.49	2.49
12	0.65	1.34	1.18	1.49	2.49
14.5	0.65	1.52	1.34	1.49	2.49
12	0.85	1.75	1.55	1.49	2.49
14.5	0.85	1.98	1.75	1.49	2.49

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