



# Stabilization Of Swelling Soils Using Waste Material For Environmental Sustainability

Banothu Tirupatamma <sup>[1]</sup>, Darga Kumar, N. <sup>[2]</sup>

<sup>1, 2</sup>, JNT University Hyderabad, Telangana, India.

**Abstract** Expansive soils, prone to significant volume changes with moisture fluctuations, pose a considerable challenge in construction and infrastructure projects due to their potential to cause structural damage. Traditional soil stabilization methods, such as the use of cement can be costly and environmentally detrimental. In this paper utilization of waste materials, including fly ash, and lime as a sustainable alternative material for controlling the swelling behaviour of expansive soils is presented. Through laboratory experiments and analysis, the effects of waste materials on soil properties were evaluated. The results demonstrated that incorporating waste materials can effectively reduce the swelling pressure, swell potential and compression index of expansive soils. Increased moisture content enhanced the engineering properties, and provides an environmentally friendly solution for soil stabilization. This paper reveals the development of cost-effective and sustainable practices for improving the performance of expansive soils in construction.

**Key words:** Fly ash, lime, swelling soil, swelling pressure, swell potential.

## 1.0 Introduction

Expansive soils, known for their high plasticity and susceptibility to volume changes due to moisture variations present significantly and further poses challenges in construction and infrastructure development. These soils can cause severe structural issues, including foundation cracks, pavement deformations, and embankment failures. Conventional methods to reduce soil swelling, such as the use of lime or cement for stabilization, are often expensive and environmentally unfriendly. Recently, there has been increasing interest in utilizing waste materials to mitigate the swelling behaviour of expansive soils. Materials such as fly ash, rice husk ash, and recycled construction debris provide a sustainable alternative while also addressing the environmental concerns related to waste management. Integrating these materials into soil has shown potential to enhance its engineering properties, decrease swelling tendencies, and improve the long-term durability of soil structures. The application of waste materials in soil stabilization has been successfully implemented in various infrastructure projects, particularly in regions where expansive soils pose a significant risk.

These materials not only provide a cost-effective alternative to traditional stabilizers but also contribute to sustainability goals by reducing the reliance on virgin materials and minimizing waste. The control of swelling behaviour in expansive soils has been a critical area of research due to the severe structural issues these soils can cause. Traditionally, chemical stabilization methods, such as the use of lime and cement, have been employed to mitigate the swelling potential of expansive soils. However, these methods have raised concerns regarding their environmental impact and the high costs associated with them.

In recent decades, research has increasingly turned towards the use of industrial and agricultural waste materials as eco-friendly alternatives to traditional soil stabilizers. Waste materials such as fly ash, and Lime have gained attention due to their potential to enhance soil properties while mitigating environmental issues associated with waste disposal. Fly ash, a by product of coal combustion, has been extensively studied for its soil stabilization properties. Research by **Pandian and Nagaraj (1999)** demonstrated that the addition of fly ash to expansive soils significantly reduces their swelling potential while improving compressive strength.

Fly ash's pozzolanic properties, which lead to the formation of cementitious compounds in the presence of moisture, make it an effective stabilizer.

**Cokca (2001)** investigated the effects of fly ash, composed of silica, alumina, iron oxides, and unoxidized carbon, on expansive soils. Findings showed that increasing fly ash content reduces soil plasticity and swelling potential due to silt particle addition and flocculation reactions. Both high- and low-calcium Class C fly ashes were effective stabilizers, enhancing the geotechnical properties of expansive soils. **Nalbantoglu and Guchilmez (2002)** found a 15% fly ash mix significantly reduced soil swell potential after 30 days of curing. **Beeghly (2003)** showed that while lime effectively stabilizes soils, a combination of lime and fly ash is particularly beneficial for low-plasticity soils and reduce the cost of construction.

**Phanikumar and Sharma (2004)** reported that adding 20% fly ash reduces plasticity and Free Swell Index by 50%. Various studies also highlighted the effectiveness of fly ash combined with other materials, such as gypsum and lime. **Shahu et al. (2013)** found that factors like curing time, fly ash content, and dolime proportions significantly affect the stiffness and shear strength of copper slag fly ash dolime (CFD) mixtures used in flexible pavement base layers. An optimal mix of 80% copper slag, 20% fly ash, and 15% dolime demonstrated the best performance. After 28 days of curing, the mix showed high strength and resistance to wet/dry cycles. **Shahu et al. (2013)** explored a cost-effective method for stabilizing expansive soils in road construction without excavation, finding that using a cushioning layer of fly ash, GGBS, and lime is effective for black cotton soils. **Surya Narayanan Raju et al. (2015)** determined that stabilizing expansive soils with 20% fly ash provided the best results, reducing Free Swell Index (FSI), increasing Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR), and optimizing Atterberg limits for strength and swelling control.

**Raj et al. (2018)** found that specimens containing copper slag with 9% cement and cured for 28 days achieved the highest compressive and tensile strength. When copper slag and fly ash are mixed in optimal proportions and stabilized with 6% to 9% cement, they can be effectively utilized as granular material in the sub-base and base layers of road pavements. **Alex et al. (2018)** highlighted fly ash as a sustainable and cost-efficient stabilizer, which, when combined with lime, lowers the plasticity and swelling of expansive soils while boosting their strength and load-bearing capacity. **Jose et al. (2020)** observed that adding 15% fly ash to expansive soils reduced the Liquid Limit (LL) by 35.84%, decreased the Optimum Moisture Content (OMC) to 92.3%, and increased. **Anu et al. (2016)** studied the stabilization of soft clay using fly ash and lime stone dust, aiming to find the best mix for maximum strength and minimal swelling. Their tests showed that the ideal combination was 9% fly ash and 10% limestone dust, which provided optimal compaction and strength. **Zumarawi et al. (2016)** investigated the impact of fly ash on expansive soils in Sudan and found that adding 10% fly ash doubled the UCS and reduced the Free Swell Index (FSI), swell pressure, and swell potential by 50-70%. At 25% fly ash, a 90% reduction in swelling was achieved, greatly improving soil properties.

The literature suggests that the use of waste materials in controlling the swelling behaviour of expansive soils is feasible and beneficial. These materials offer a sustainable solution by improving soil properties, reducing environmental impact, and lowering costs associated with soil stabilization. Further research is needed to optimize the use of these materials and expand their application across different soil types and environmental conditions. This paper seeks to evaluate the effectiveness of lime and fly ash waste materials in mitigating the swelling behaviour of expansive soils.

## 2. Methodology of Experimental Work

The methodology includes material selection and preparation of expansive soil samples which are collected from a location known for high swelling potential. The samples were air-dried, pulverized, and sieved to remove particles larger than 4.75 mm. The waste materials selected for this study include fly ash, lime. These materials were chosen due to their availability, chemical composition, and potential to improve soil properties and control swelling of soil. Soil was mixed with varying percentages of fly ash (0%, 5%, 10%, 15%, 20% and 30%) and Lime (0%, 4%, 6%, and 8%) by weight of dry soil. The mixtures were thoroughly blended to ensure uniform distribution of the waste material within the soil. Laboratory tests such as sieve analysis (IS 2720-4-1985), liquid limit and plastic limit (IS2720-5-1985), free swell index (IS2720-40-1977), specific gravity (IS:2720 Part 2), standard compaction (IS2720-7-1980) and consolidation tests (IS 2720-Part XV) were conducted as per the standard test procedures presented in the respective Indian Standard Codes of Practice of Testing of Soil in the laboratory. This methodology ensures a comprehensive evaluation of the

potential for using waste materials in soil stabilization, contributing to the development of sustainable and cost-effective construction practices. The basic results of soil, fly ash and lime are presented in the Tables. 1 to 2.

**Table.1 Properties of soil**

S.NO	Properties	Values
1.	Specific gravity	2.62
2.	Free swell index	140
3.	% Fine fraction (silt and clay)	69.0
	% Sand	30.0
	% Gravel	1.0
4.	Liquid Limit (%)	78
	Plastic Limit (%)	38
	Plasticity Index (PI)	40
5.	Optimum Moisture Content (%)	22
	Maximum dry density (kN/m <sup>3</sup> )	15.25
6.	Soil classification	CH

**Table. 2 Properties of fly ash**

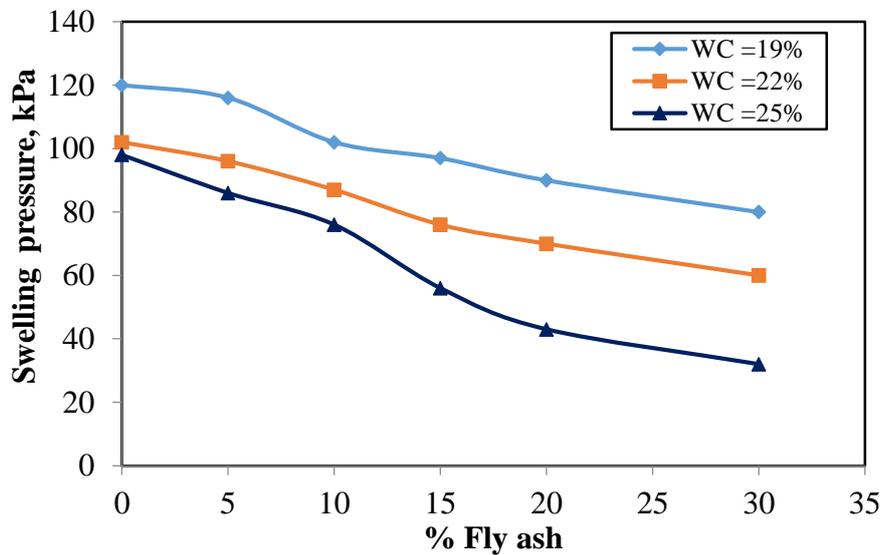
S.NO	Chemical /Physical properties	Value
1.	SiO <sub>2</sub> in %	48
2.	Al <sub>2</sub> O <sub>3</sub> in %	25
3.	Fe <sub>2</sub> O <sub>3</sub> in %	15
4.	Other Chemical constituents in %	3-5
5.	Specific gravity	1.96
6.	OMC in %	20.0
	MDD in kN/m <sup>3</sup>	13.30
7.	Fines in % (silt and clay)	21.0
	Sand in %	79.0
	Gravel in %	0%

## Lime

The proper selection and quantity of binders can effectively stabilize expansive soil. Lime was collected from Hyderabad and it is of hydrated lime (slaked lime) with 85% - 90% calcium hydroxide and 7% silica. Lime proportions of 0%, 4%, 6% and 8% by dry weight of the soil were added to clay soil.

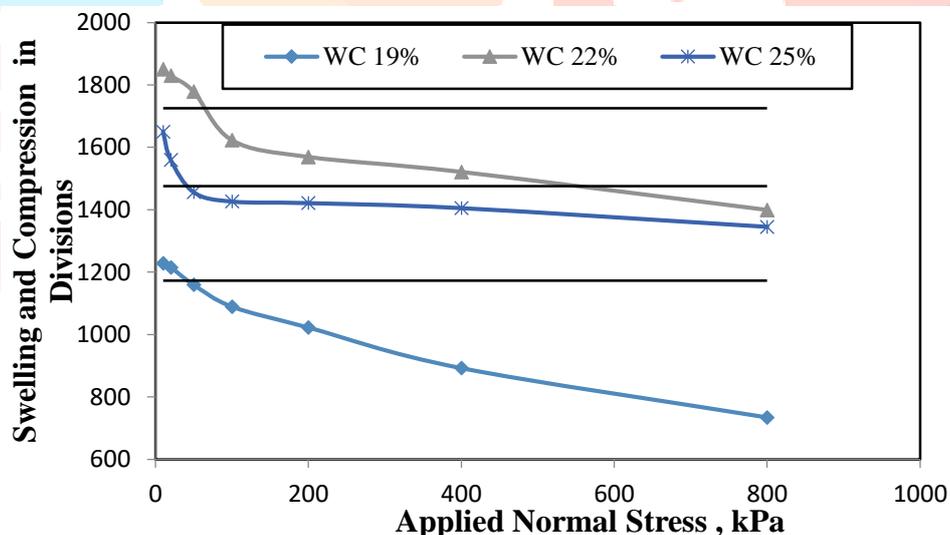
## 3. Results and Discussion

Soils with high plasticity typically exhibit elevated liquid limit values and are prone to both swelling and shrinkage. Structures built on such soils are likely to experience diagonal and vertical cracks due to these movements. These soils are characterized by significant swelling pressure and swell potential. To mitigate these issues, it is necessary to stabilize the soils using appropriate additives. Fig.1 shows that as the percentage of fly ash increases, the swelling pressure decreases for soil samples prepared at water contents of 19%, 22%, and 25%. Across all water contents tested, increasing fly ash leads to a reduction in swelling pressure. Additionally, increasing the water content further reduces the swelling pressure. For soil samples prepared at 19% water content, untreated samples show a swelling pressure of 120 kPa, which decreases to 80 kPa with 30% fly ash, marking a 33% reduction. Similarly, at 25% water content, the swelling pressure drops from 98 kPa without fly ash to 32 kPa with 30% fly ash, resulting in a 67% decrease.



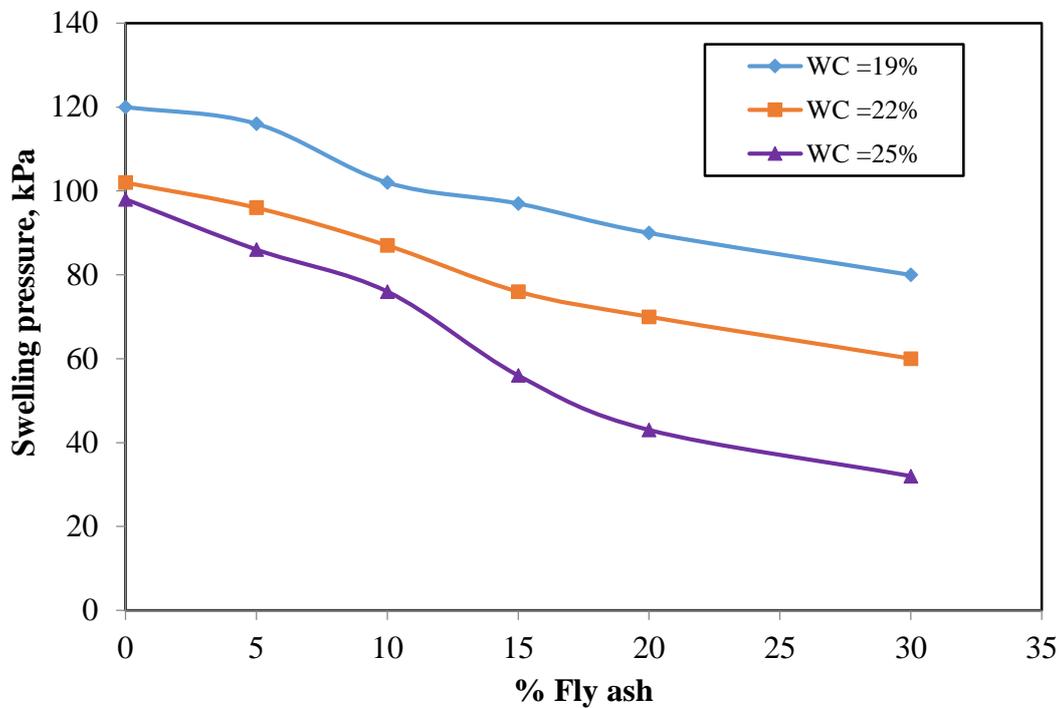
**Fig.1 Swelling and compression of untreated clay soil with different water contents**

Fig.2 presents the swelling and compression of soil under applied normal stress and treated with 10% of fly ash and prepared at 19%, 22% and 25% of water contents. From this figure it is observed that at seating load of 5 kPa, swelling is noticed initially and same was allowed freely to swell to its maximum. The sample prepared at 19% water content swollen from 1180 divisions to 1220 divisions. Similarly, the samples prepared at 22% and 25% water contents have swollen respectively from 1760 to 1810 divisions and 1480 to 1640 divisions. The swell potential observed for the sample prepared at different water contents such as 19%, 22% and 25% respectively are 3%, 2% and 1%. The respective swelling pressures at the water contents 19%, 22% and 25% are 50 kPa, 60 kPa and 35 kPa. At the initial stage, swelling is observed under the seating load due to low water content present in the soil. As the saturation occurs with the time the voids are filled with water and swelling took place.



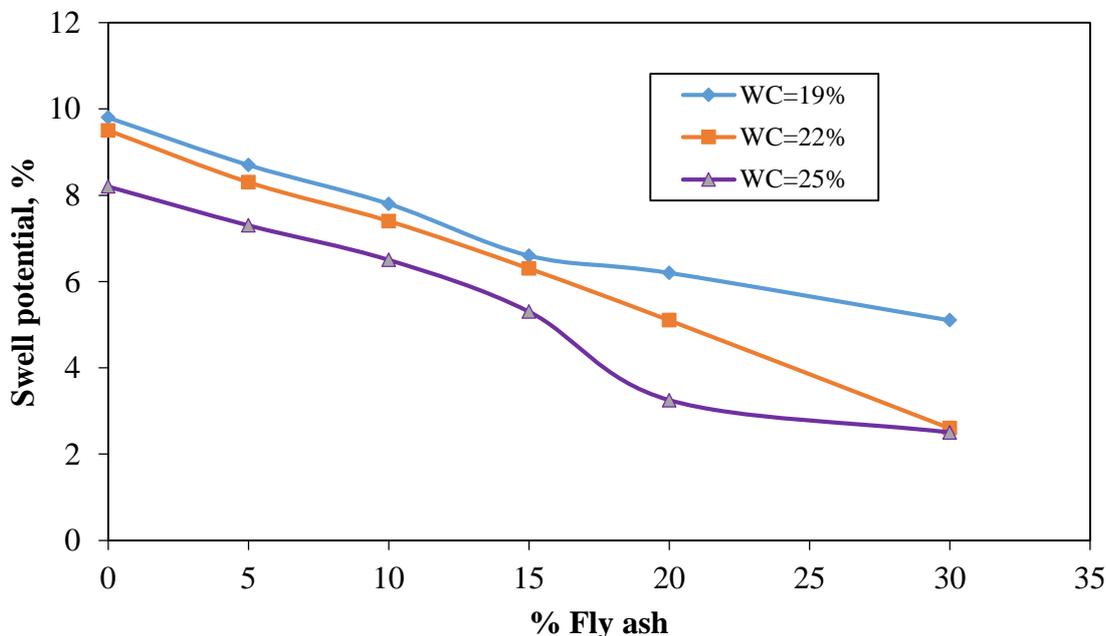
**Fig.2 Swelling and Compression of clay soil stabilized with 10 % fly ash under applied load**

Fig.3 presents the variation of swelling pressure with fly ash for samples prepared at water contents 19%, 22% and 25%. The fly ash proportions used are 0%, 5%, 10%, 15%, 20% and 30%. From this figure, it is observed that as the as the % fly ash increases, the swelling pressure is decreasing at all the moisture contents tested. Further, as the water content increases, the swelling pressure is decreasing. The swelling pressure of untreated and 30% fly ash treated soil samples prepared at 19% water content respectively are 120 kPa and 80 kPa. The decrease in swelling pressure when 30% fly ash added to sample at 19% water content is 33%. For the soil samples prepared at 25% water content with 0% fly ash and 30% fly ash showed the swelling pressures as 98 kPa and 32 kPa, the corresponding reduction in swelling pressure is 67%.



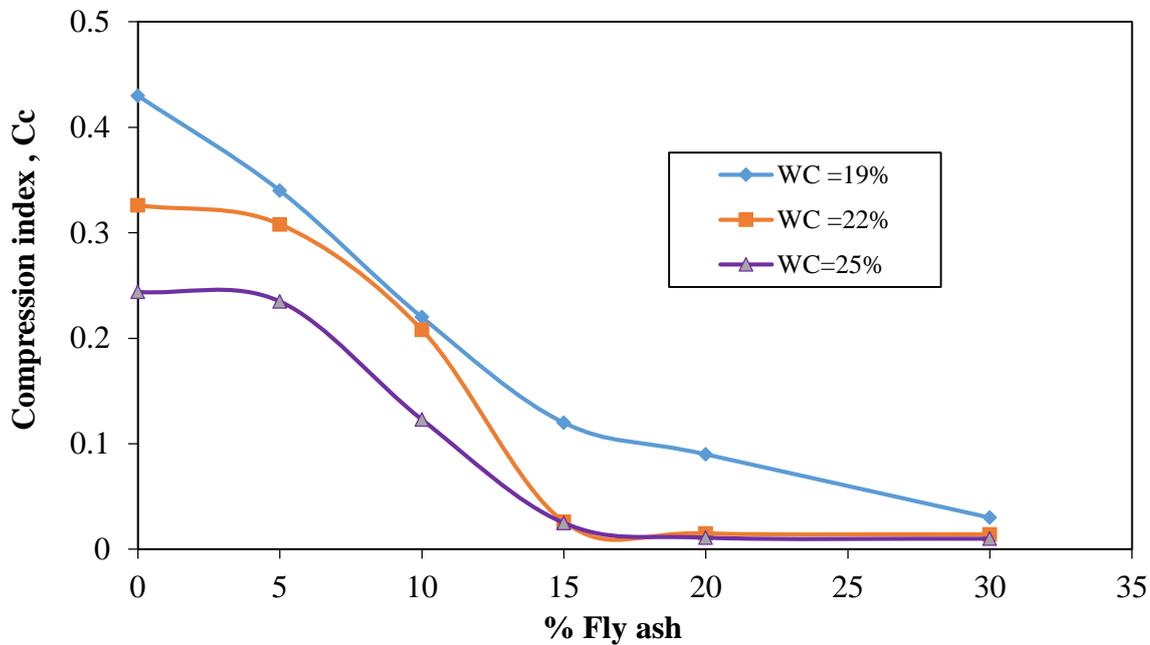
**Fig.3 Swelling pressure of clay soil stabilized with fly ash under applied load**

Fig.4 illustrates how the swell potential varies with the percentage of fly ash for samples treated with fly ash proportions ranging from 0% to 30% and prepared at water contents of 19%, 22%, and 25%. From this figure, it is observed that the swell potential is varying from highest 10% to lowest 2% almost. Especially, the soil sample treated with fly ash proportions of 0%, 5%, 10%, 15%, 20% and 30% and prepared at 25% water content showed decreased swell potential comparatively with the samples prepared at water contents 19% and 22%. The reduction in swell potential is about 75%. Hence addition of fly ash resulted in 75% reduction in swell potential.



**Fig.4 Variations of swell potential of clay with different moisture content**

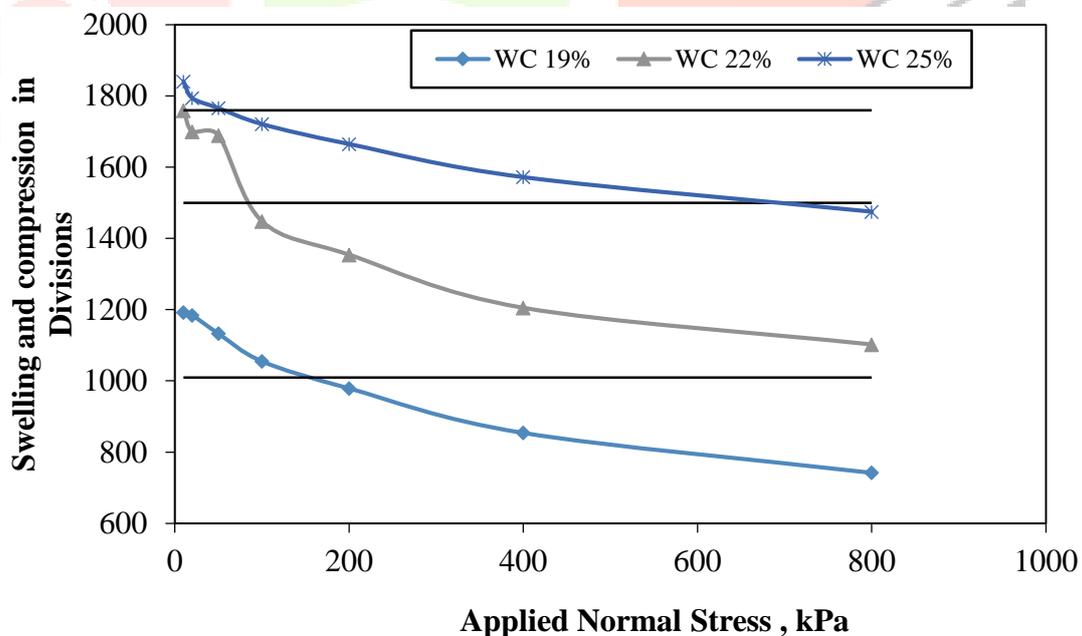
Fig.4.5 presents the variation of compression index with % of fly ash for samples tested at different water contents such as 19%, 22% and 25%. The fly ash proportions used are 0% to 30% at 5% increment. Here 0% fly ash is nothing but untreated soil. The figure shows that as the percentage of fly ash increases, the compression index decreases. Additionally, it is observed that with rising water content, the reduction in the compression index becomes more pronounced. It may be due to water absorption of the soil at less water content.



**Fig.5 Variation of compression index with lime at different water contents**

Fig.6 presents the swelling and compression under applied normal stress of 4% of Lime samples prepared at 19%, 22% and 25% of water contents from this figure it is observed that at seating load of 5 kPa, swelling is noticed initially and was allowed freely to swell to its maximum. The sample prepared at 19% water content swollen from 1000 divisions to 1200 divisions. Similarly, the samples prepared at 22% and 25% water contents have swollen respectively from 1500 to 1780 divisions and 1780 to 1810 divisions.

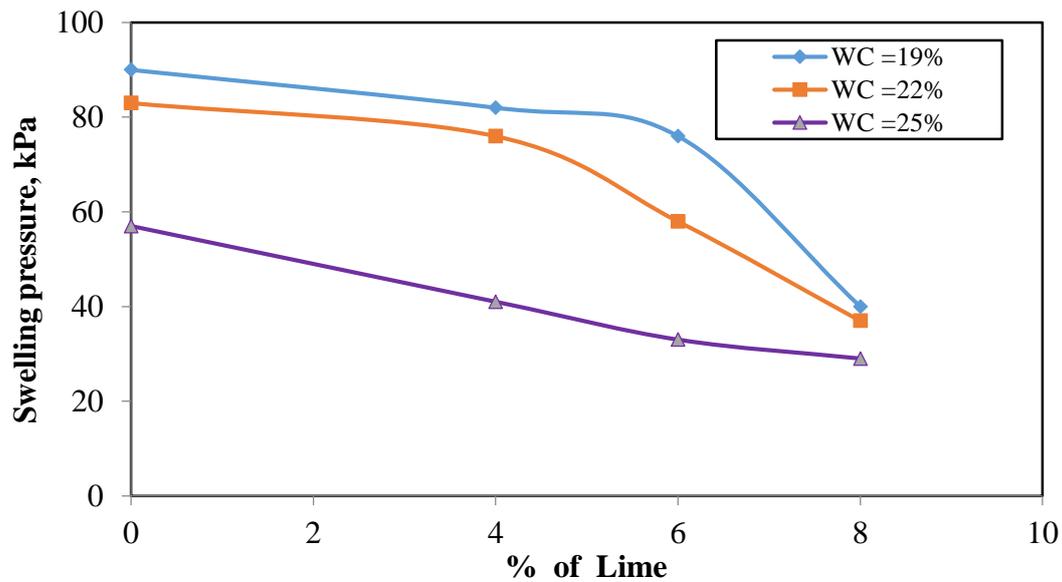
The swell potential observed for the sample prepared at different water contents such as 19%, 22% and 25% respectively are 2%, 1.8% and 1.6 %. The respective swelling pressures at the water contents 19%, 22% and 25% are 160 kPa, 80 kPa and 60 kPa. At the initial stage of clay sample swelling is observed under the seating load due to low water content present in the soil. As the saturation occurs with the time the voids are filled with water and swelling starts.



**Fig.6 Swelling and Compression of clay soil stabilized with 4% lime under applied load**

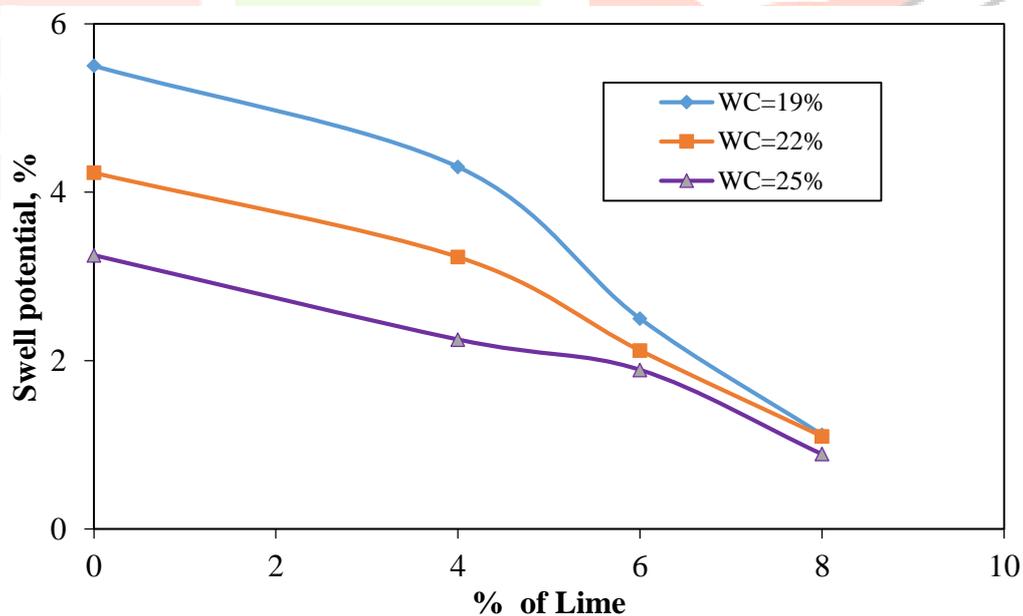
Fig.7 illustrates how the swelling pressure varies with the percentage of fly ash for samples prepared at water contents of 19%, 22%, and 25%. The fly ash proportions used are 0%, 5%, 10%, 15%, 20% and 30%. From this figure, it is observed that as the as the % fly ash increases, the swelling pressure is decreasing at all the moisture contents tested. Further, as the water content increases, the swelling pressure is decreasing. The swelling pressure of untreated and 30% fly ash treated soil samples prepared at 19% water content respectively are 90 kPa and 45 kPa. The decrease in swelling pressure when 30% fly ash added to sample at 19% water content is 50%. For the soil samples prepared at 25% water content with 0% fly ash and 30% fly

ash showed the swelling pressures as 58 kPa and 28 kPa, the corresponding reduction in swelling pressure is 54%.



**Fig.7 Swelling and Compression of clay soil stabilized with lime under applied load**

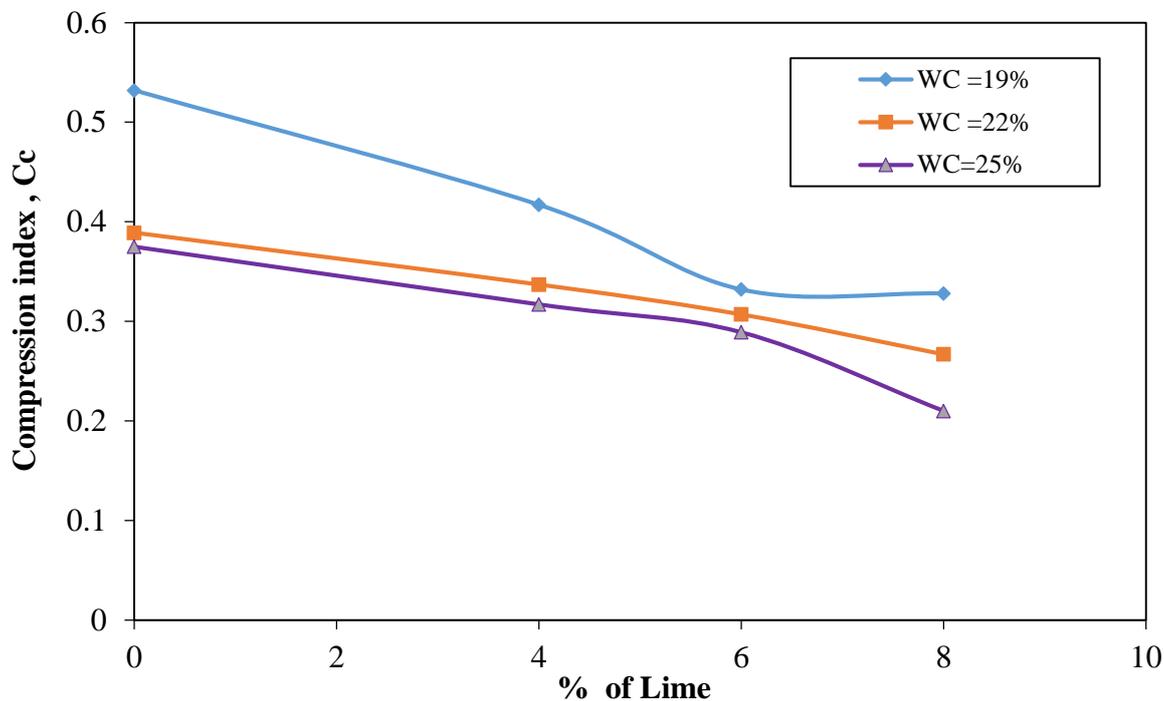
Fig.8 shows the variation in swell potential with the percentage of fly ash for samples treated with fly ash proportions ranging from 0% to 30%, and prepared at water contents of 19%, 22%, and 25%. From this figure, it is observed that the swell potential is varying from highest 5.8% to lowest 1.5% almost. Especially, the soil sample treated with fly ash proportions of 0%, 5%, 10%, 15%, 20% and 30% and prepared at 25% water content showed decreased swell potential comparatively with the samples prepared at water contents 19% and 22%. The reduction in swell potential is about 50%. Hence addition of fly ash resulted in 50% reduction in swell potential.



**Fig.8 Variation of swell potential with lime for different moisture contents**

Fig.9 presents the variation of compression index with % of fly ash for samples tested at different water contents such as 19%, 22% and 25%. The fly ash proportions used are 0% to 30% at 5% increment. Here 0% fly ash is nothing but untreated soil. The figure reveals that as the percentage of fly ash increases, the compression index decreases. Additionally, it shows that higher water content leads to a more pronounced reduction in the compression index. This effect may be attributed to the soil's water absorption at lower moisture levels. From the Fig.4.9, for sample prepared at 19% water content the compression index values are 0.54 and 0.36 respectively for 0% and 30% treated soils. The compression index at 19% water content when fly ash is varied from 0% to 30% is reduced to 66% on compression index value of 0.43. For sample

prepared at 22% water content the compression index values are 0.38 and 0.32 respectively for 0% and 30% treated soils. The compression index at 19% water content when fly ash is varied from 0% to 30% is reduced to 3% on compression index value of 0.38. For sample prepared at 25% water content the compression index values are 0.38 and 0.22 respectively for 0% and 30% treated soils. The compression index at 19% water content when fly ash is varied from 0% to 30% is reduced to 4% on compression index value of 0.38.



**Fig.9 Variation of compression index with lime at different water contents**

#### 4. Conclusion

As the percentage of admixtures fly ash and lime influence the swelling and compression index of soil, these values are reduced. The samples are prepared at 19%, 22% and 25% of water content at the seating load of 5kPa. In case of 0% to 15% fly ash, the swelling and compression index values observed are not causing drastic change. But in case of 15% to 30% of fly ash addition to clay soil caused substantial decrease in the swelling nature and compression index of clay. Hence, fly ash utilization in controlling the swelling and settlement of clay soil is effective. Fly ash utilization in clay helps in solving two issues optimization of construction cost and effective control of environmental issues in order to achieve environmental sustainability.

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