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Experimental Study on the Influence of Alccofine-1203 and Phosphogypsum on the Strength Characteristics of Expansive Soil

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***Abstract:** Expansive soil is generally found in arid and semi-arid regions of the world. One of the main issues with these expansive soils is their swelling properties when their natural water content increases. The various swell-shrink tendencies of expansive soils cause numerous issues with the substructure and distress in infrastructures such as buildings, pavements, and breast walls, among others. Geotechnical engineers have worked hard to understand the behavior of expanding soil and implement appropriate management strategies. The current study aims to elucidate the efficacy of alcofine-1203 and Phosphogypsum (PG) powder in achieving the geotechnical properties of soil and improving its high swell, high shrink, and low bearing capacity, which have benefits for civil engineering. The combination of the two materials can be more beneficial when used as a stabilizing agent than using them individually. An experimental programme has calculated the effects of alcofine-1203 (3, 6, 9, and 12%) and Phosphogypsum (0.25, 0.5, 0.75, and 1.0%) on the Atterberg limits, optimum moisture content (OMC), unconfined compressive strength (UCS), maximum dry density (MDD), and other essential soil characteristics. Both admixtures were added independently and blended into the expansive soil. It was found that the liquid limit, plasticity index, optimum moisture content, and swelling behavior of the expansive soil have been greatly reduced with the addition of specified admixtures. UCS gradually increases from 46.4 kPa to 948 kPa after 56 days due to the combined effect of 12% alccofine and 1.0% Phosphogypsum reacting with soil, which plays a critical role when compared to the remaining admixture combination. Hence, the result concluded that the addition of 12% alccofine and 1.0% PG exhibited an essential improver of expansive soils, proved that adding the admixture is a potential stabilizer, and also proved that the problematic soil was transformed into the best soil. It also reduced the construction cost by making the best use of locally available materials.*

***Keywords:** Alccofine-1203, Expansive soil, Phosphogypsum, Shrinking, Swelling, Unconfined Compressive Strength.*

I. INTRODUCTION

Expansive soils are well known around the world for their volume change behavior in response to moisture fluctuation due to their intrinsic mineralogical behavior.

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It is typically consuming the expected impact to produce unwanted engineering behavior, such as low load bearing capacity, high shrink, swell potential, and high moisture susceptibility (F. H. Chen, 1975 & 1988, [7,8]). These types of soils are found mainly in arid and semi-arid regions in the world. They cover a major portion on the geographical area in the world such as Australia, Canada, China, India, South Africa, and the United States. In India has extensive track of expansive soils known as black cotton soil covers about 20% of the total land such soils are found extensively in Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Tamil Nadu and Puducherry. One of the most difficult soils for civil engineering to work with this expansive soil or black cotton soil, which expands and contracts as a result of changes in water flow (Azam et al., 2013, [4]). The foundations of structures built on expansive soil are seriously at risk. Due to its natural shrinking and swelling behavior (Abdullah et al., 1999, [1]; Mishra et al., 2008, [20]) when it reacts with water, this type of soils can generate uplift forces that significantly damage lightly loaded buildings such as sidewalks, basements, etc. (Selvamsagayaradja et al., 2021, [28]; K.S. Subba Rao, 2000, [16]). As a result, the problematic soils are distinguished by their severe hardness when dry and by their great swelling potential during the wetting process, and the damages from expansive soils is very common where the yearly loss exceeds annual rainfall in arid and semi-arid areas (Suresh et al., 2018, 2019, [32,33]). It has been estimated as a probable natural hazard, if not treated adequately can cause catastrophic to the structure and destruction to the human life. In order to achieve the desired strength, mechanical stabilization, such as compaction, and chemical admixture approach were utilized to strengthen the soil qualities, to regain the index properties of soil as well as its shrinking and swelling characteristics. Differential free swell has been performed on the soil and identified an 81% reduction in swelling potential and a change in a state of behavior of soil from plastic nature to brittle nature has been observed by (G. Ramakrishna et al., 2018, [12]). A study by (Suresh et.al., 2019, [33]) used the various proportions of alccofine and $CaCl_2$ admixtures to stabilize the clay soil as cohesive non swelling soils (CNS) cushions below the light weight structures and the optimum strength of expansive soil is obtained at 6% alccofine and 1% $CaCl_2$. On the other hand, $CaCl_2$ and $MgCl_2$, are hygroscopic materials and therefore perfectly suited for stabilizing expansive soils because they absorb water from the environment and prevent shrinkage cracks from appearing in expansive soils during the summer season (Mishra et al., 2008, [20]).

Additionally, the stiffness and strength qualities of soft soils can be increased by mixing waste materials and fibres with chemical agents (Fatahi et al., 2013, [10]; Fatahi and Khabbaz, 2012, [9]). According to (Hayder Hasan et al., 2016[14]), stabilizing expansive soils using bagasse ash and hydrated lime not only increases strength but also makes it easier to address environmental issues by reducing waste from the sugar industry. In order to manage the consolidation features of the expansive soil, (A.T. Manikandan & M. Moganraj 2014, [17]) found that the addition of bagasse ash and hydrated lime together is more efficient than the addition of bagasse ash alone. Hence, 3% of lime and 0.75% of sisal fibre content (K.R. Manjunath et al., 2013, [19]) can be considered as optimum percentages for black cotton soil to increases the CBR value. Many researchers used the industrial by-product material such as alccofine (Rajesh Prasad Shukla et al., 2016, [24]; Rakesh Kumar Dutta et al., 2019, [26]), using pond ash and alccofine (Mohd Fahiem Tahir & Er. Tripti Goyal, 2019, [21]), cement kiln dust, alccofine-1101 (Amit Talgotra & Er. Neeraj Sharma, 2017, [3]), marble dust, alccofine-1108 (Manish Kumar Soni & Sandeep Singh, 2019, [18]), as additives are becoming more popular due to their relatively low cost additionally CO_2, emission can be reduced significantly by the increased use of such supplementary cementing materials currently wasted in lagoons and landfill sites. The most important feature in the stabilization of clay soils is the ability of the stabilizer to provide a sufficient amount of calcium. The goal of this study is to stabilize expansive soil by enhancing its geotechnical properties and increase the compressive strength of compacted expansive soil using a combination of alccofine and Phosphogypsum (PG) as a binder, while avoiding the harmful health and environmental issues that can be induced due to the disposal of this material. Therefore, the combination of the two materials can be more beneficial when used as a stabilizing agent then using them individual. However, no research on the joint activation of Phosphogypsum (PG) and alccofine as stabilising agents for expansive soils has been published too far. The additives used have been chosen, focusing on waste reduction, economy, and its eco-friendly nature.

II. MATERIALS AND METHODOLOGY

A. Materials

Black Cotton Soil: The soil from Location 1, in the Puducherry region, India, was used for this investigation because of its high swell, shrink, and low load-carrying capacity. The soil has collected at a depth of 1.5 m below the ground level. It is dried and sieved through a sieve of 4.75mm size to remove gravel fraction if any. And it is conserved in the test center. The soil is classified as 'CH' as per IS Classification (IS 1498: 1970) which has inorganic clay of High Plasticity **(**Sridharan & Nagaraj, 2009, [31]**).** Table 1 shows the index and engineering properties of high swell and shrinks soil.

Table 1. Physical Properties of Soil

Properties of soil	Results
Specific gravity, (G_S)	2.27
Color of soil	Blackish Grey
Grain size distribution	
Clay (%)	67.9
Silt (%)	28.49
Sand (%)	03.61
Atterberg Limits	
Liquid Limit, (W_L) (%)	103
Plastic Limit, (W_P) (%)	37.78
Shrinkage Limit (W_S) (%)	01.82
Plasticity Index, (PI) (%)	65.22
Free swell index (FSI) (%)	125
Free swell ratio (FSR)	02.25
Water absorption (W_A) (%)	93.73
Swell potential (S) (%)	57.74
Cation exchange capacity (CEC) meq/100g	26.27
Specific surface area (SSA) m^2/g	01.021
Unified soil classification	CH
Compaction characteristics	
Optimum Moisture Content (OMC) (%)	36
Maximum Dry Density (MDD) (KN/m^3)	13.8
Unconfined compressive strength (UCS) kPa)	46.44
pH	02.78
Conductivity (mS/cm)	05.71

Alccofine: Alccofine 1203 is a fine cementitious Ground Granulated Blast Furnace Slag (GGBS) material that performs superior to all other mineral admixtures used and obtained from Counto Micro-Fine Product Private Limited, Goa, India. The majority of Ultra-fine slag products are used for high-performance soil stabilization purposes. Table 2 displays the physical and chemical characteristics of micro-fine slag.

Table 2. Physical and Chemical Properties of Ultra-Fine Slag

Properties	Results
Physical properties	
Specific gravity	2.9
Bulk density (kg/m^3)	680
Particle size distribution (mm)	
D10	1.5
D50	5.0
D90	9.0
D95	11.5
Chemical properties	
CaO	32.9 (%)
Fe_2O_3	1.9 (%)
MgO	7.98 (%)
Al_2O_3	21.6 (%)
SO_3	0.21 (%)
SiO_2	35.41 (%)

Phosphogypsum (PG): Phosphogypsum (PG) is the calcium sulphate hydrate formed as a by-product of the production of fertilizer from phosphate rock. It is mainly composed of gypsum ($CaSO_4 \cdot 2H_2O$). but also contains impurities of environmental concern such as residual acids, fluoride, heavy metals and naturally-occurring radionuclides. Impurity composition within Phosphogypsum can vary greatly depending on the source of phosphate rock used in phosphoric acid production and by treating phosphate ore (apatite) with sulfuric acid according to the following reaction:

$$Ca_5(PO_4)_3X + 5\,H_2SO_4 + 10\,H_2O \rightarrow 3\,H_3PO_4 + 5\,(CaSO_4 \cdot 2\,H_2O) + HX$$

where X may include OH, F, Cl, or Br

Approximately 4-6 tons of PG are generated per ton of phosphoric acid production.

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The continuous growth in the world population increases food production demand which requires an increase in phosphate fertilizer production resulting in an increase in PG content (Alaa M. Rashad 2017, [2]). Only 15% of world PG production is recycled as building materials, including cement retarder, building gypsum powder, gypsum board, filler in papermaking, fibre plasterboard, mine filling agent, and roadbed material (Siqi Zhao et al., 2017, [29]; Holanda et al., 2017, [11]). Approximately 85% of this by-product is still discarded into the ocean or river, or stored in ponds or leaps without purification. This disposal causes serious contamination. Reduction in the disposal of this by-product has economic and environmental benefits. It is also recycled as agricultural fertilizers or soil stabilization amendments and as set controller in the manufacture of Portland cement (Hanan Tayibi et al., 2009, [13]). Table 3 shows the oxides composition of Phosphogypsum.

Table 3: Oxide Composition of Phosphogypsum

Major elements	Result
SO_3	44.7
CaO	32.04
F	0.79
Na_2O	0.13
Cl	0.72
P_2O_5	0.67
SiO_2	0.43
Al_2O_3	0.24
MgO	0.14
Fe_2O_3	0.07
LOI	21.06

B. Methodology

The index and engineering characteristics of stabilized soils can be evaluated using a variety of tests. The current study is focused on analysing the physical properties, compaction, strength, and swell/shrink behavior. Experiments have been done on expansive soil using varying concentrations of Phosphogypsum (0.25, 0.50, 0.75, and 1.0%) and alccofine -1203 (3, 6, 9, and 12%). According to Indian Standards, the expansive soil sample's specific gravity, Atterberg limits, compaction, unconfined compressive strength (UCS), consolidation, and swelling characteristics of soil were all determined. The water absorption (W_A) of soil mixed with the admixtures Phosphogypsum and alccofine-1203 were added independently and blended into the combination of both admixtures with expansive soil. A water absorption (W_A) equation is developed and recommended by (Mokeagus J.A, 1978, [22]). Water absorption equation is $W_A = 0.91\ W_L$, where, W_L is liquid limit. The cation exchange capacity (CEC) of the blended soil-admixture samples was determined. The Cation Exchange Capacity (CEC) was created and is advised (Sridharan A & Nagaraj H.B, 2009, [31]).

III. RESULT AND DISCUSSION

The effect of Alccofine-1203 and Phosphogypsum (PG) on different properties of expansive soil was determined as per Indian standards and discussed in the following sections Atterberg limit, free swell index, compaction parameters, unconfined compressive strength, and free swell ratio.

A. Atterberg limits (LL, PL, PI): The influence of alccofine and Phosphogypsum on Atterberg limits of expansive soil is shown in Fig 1. Results show that liquid limit and plastic limit are decreased gradually and shrinkage limit increases; hence the difference between plastic limit and shrinkage limit is termed as shrinkage index and similarly the difference between liquid limit and plastic limit is the plasticity index. Plasticity index is reduced by about 66% and Shrinkage index is increased by about 53% when the soil is blended with 12% alccofine + 1% Phosphogypsum due to the pozzolanic reaction and the capacity of cation exchange of the blend when compared to the soil is blended with admixture individually from Table 4. Based on IS (1498) – 1970 classification the results proved that the index properties of natural soil are changed from high swell potential to medium swell potential due to the accumulation of 12% alccofine + 1% Phosphogypsum. (J. Mitchell, 1993, [15]) Suggested that plasticity is a good indicator of swell potential; that is, that a lower plasticity index reflects a lower swell potential. The addition of calcium chloride to soil increases the charge concentration (Ramanamurty, V & Praveen G.V, 2008, [27]).

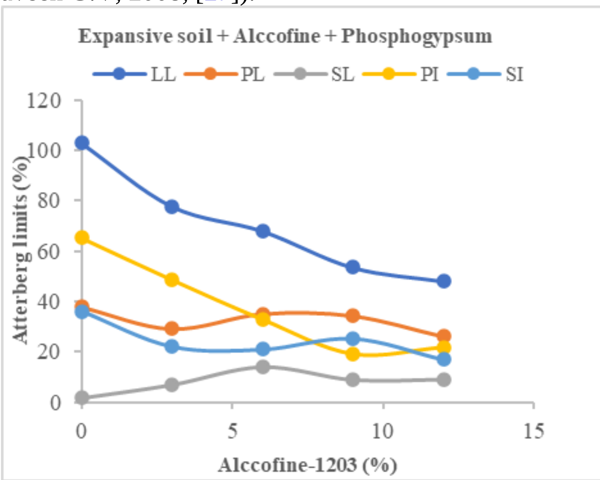

Fig. 1. Effect of Alccofine and Phosphogypsum on Atterberg limits

The compaction characteristics of treated and untreated soils are shown in Fig. 2 (a) and (b). The results of compaction show that the MDD is increased from 13.8 kN/m^3 to 17 .5 kN/m^3 and optimum moisture content is reducing from 36% to 15.6% with an increase of 12% alccofine and 1% Phosphogypsum binder; that is, for the sample which shows maximum strength. Similar behavior of MDD and OMC was observed Ground granulated blast furnace slag (GGBS) or industrial waste was used as stabilizing agents (Erdal Cokca, 2001, [6]; Phani Kumar & Sharma, 2004, [5]). An increase in dry density for a given compaction effect is desirable for use as construction materials as it indicates soil improvement was reported an increase in MDD and a decrease in the OMC with increasing alccofine (Sivapullaiah, 2004, [30]; Rajesh Prasad Shukla et al., 2015, [25]).

B. Free swell index (FSI): A swelling behavior of soil is blended with different percentages of alccofine and Phosphogypsum is presented in Table 4. The presence of montmorillonite minerals greatly influences the swelling properties of soil.

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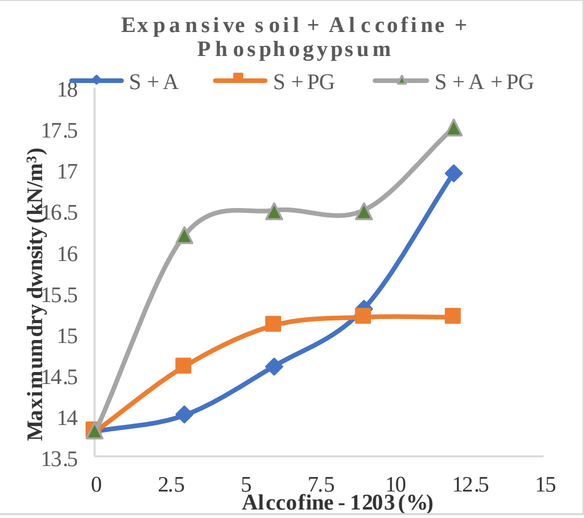
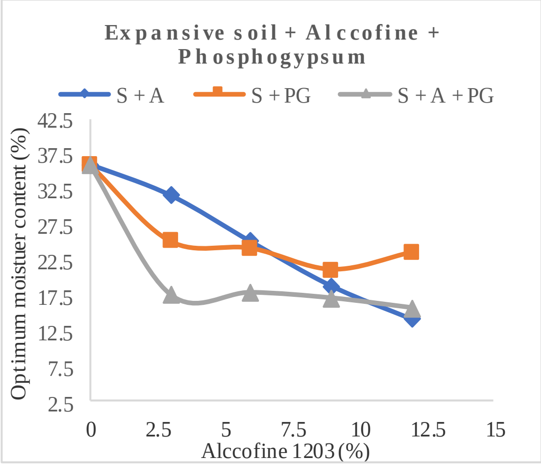
By adding these chemicals individually to the soil proves that the FSI is gradually dropped from 125% to 4.5% at 12% of alccofine and 38.89% at 0.75% of Phosphogypsum. Hence, the result shows that both admixtures were reduced the swell potential of soil from high swelling to low swelling and, also similar result is obtained when the soil is blended with the combined action of 12% alccofine + 1% Phosphogypsum as per IS 1498-1970 (Sridharan & Nagarajan, 2009, [31]). **S**imilar result is obtained by (Suresh & Murugaiyan, 2019, [33]) the swelling behavior is changed from high swelling to zero swelling at 6% alccofine and 1% $CaCl_2$ with intrinsic soil.



(a) Maximum dry Density (MDD)



(a) Optimum Moisture Content

Fig. 2. Compaction Characteristics of Treated and Untreated Soil

C. Free swell ratio (FSR): The free swell ratio method is very competitive, involving a very simple procedure, for the prediction of the swell potential of a soil. It is defined as the ratio of equilibrium sediment volume of 10 g oven-dried soil passing a 425 µm sieve in distilled water to that in kerosene.

$FSR = V_d/V_k$

The results show that the FSR value is reduced from 2.25 to 1.17 which means the swelling of soil is changed from high swelling to low swelling with the accumulation of 12% alccofine + 1% Phosphogypsum respectively. And also, the dominating clay mineral is changed from montmorillonite to mixture of kaolinite and montmorillonite (Prakash et al., 2009, [23]).

D. Cation Exchange Capacity: The exchangeable cations such as Ca, Mg, Na, and K determined displacing these from soil colloids with NH_4. This is done by Asian Enviro Labs Pvt. Ltd. Pallavaram, Chennai.

Table 4: Effects on Index and Engineering Properties of Soil Blended with Admixtures

Admixtures (%)	W_L (%)	W_P (%)	W_S (%)	PI (%)	SI (%)	G_S	FSI (%)	FSR	UCS (kPa)	MDD (kN/m³)	OMC %
0	103	37.78	1.82	65.22	35.96	2.27	125	2.25	46.4	13.8	36
A 3	77.8	29.17	7.05	48.63	22.12	2.44	81.25	1.81	89.5	14	31.6
A 6	68	28.78	5.4	39.22	23.38	2.46	25	1.25	118	14.6	25
A 9	60.5	20.44	11.32	40.06	9.12	2.42	13.63	1.13	150	15.3	18.7
A 12	42	31.18	17.95	10.82	13.23	2.64	4.5	1.05	172	16.95	14
PG 0.25	68.2	26.41	5.85	41.79	20.56	2.45	70.59	1.71	94	14.6	25
PG 0.50	60.5	32.18	0.97	28.32	31.21	2.53	66.67	1.67	110	15.1	24
PG 0.75	42	22.82	8.77	19.18	14.05	2.95	38.89	1.39	128	15.2	21
PG 1	66	29.09	5.93	36.91	23.16	2.88	44.4	1.44	83	15.2	23.5
A 3 + PG 0.25	77.8	29.17	7.05	48.63	22.12	2.31	82.35	1.82	81	16.2	17.5
A 6 + PG 0.50	68	35.09	14.14	32.91	20.95	2.79	66.67	1.67	120	16.5	17.8
A 9 + PG 0.75	53.5	34.28	9.06	19.22	25.22	2.61	44.4	1.44	135	16.5	17
A 12 + PG 1	48	26.14	9.16	21.86	16.98	2.68	16.67	1.17	155	17.5	15.6

Note: A = Alccofine; PG = Phosphogypsum; W_L = Liquid limit; W_P = Plastic limit; W_S = Shrinkage limit; PI = Plasticity index; SI = Shrinkage index; G_S = Specific gravity; FSI = Free swell index; FSR = Free swell ratio; UCS = Unconfined compressive strength; S = Swell potential; W_A = Water absorption.

3.5 Unconfined Compressive Strength (UCS):

The prepared soil sample of UCS test were conducted with alccofine and Phosphogypsum were added independently and blended to the expansive soil. It was performed on both natural soil and chemically treated soils.

The UCS value of natural soil is 46.4 kPa. The percentage of Alccofine-1203 (3, 6, 9, and 12%) and Phosphogypsum (0.25, 0.5, 0.75 and 1.0%)

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were added by dry weight of the soil. In addition, the effect of curing time on strength improvement was examined for a period of 0, 7, 14, 28, and 56 days. The optimum strength was noticed at 12% alccofine with 1% Phosphogypsum. The UCS strength is gradually increased from 46.4 kPa to 155 kPa, 229 kPa, 454 kPa, 706 kPa and 948 kPa at 0, 7, 14, 28, and 56days with the accumulation of 12% alccofine with 1% Phosphogypsum. And the result proves that the UCS strength was increased from 46.4 kPa to 948 kPa with 56 days of curing. Therefore, based on the unconfined compressive strength behavior with the addition of 12% alccofine and 1% Phosphogypsum binder is recommended as an optimum content of effectively stabilized to this expansive soil.

Table 5: Properties Obtained for Optimum Soil + alccofine + Phosphogypsum

Properties	**Natural soil**	**87% S + 12% A + 1% PG**
Specific gravity, (G_S)	2.27	2.68
Atterberg Limits		
Liquid Limit, (W_L) (%)	103	48
Plastic Limit, (W_P) (%)	37.78	26.14
Shrinkage Limit (W_S) (%)	01.82	9.16
Plasticity Index, (PI) (%)	65.22	21.86
Shrinkage Index, (SI) (%)	35.96	16.98
Free swell index (FSI) (%)	125	16.67
Free swell ratio (FSR)	02.25	1.17
Water absorption (W_A) (%)	93.73	43.68
Cation exchange capacity (CEC) meq/100g	26.27	45.52
Unified soil classification	CH	CI
Compaction characteristics		
Optimum Moisture Content (OMC) (%)	36	15.6
Maximum Dry Density (MDD) (kN/m^3)	13.8	17.5
Unconfined compressive strength (UCS) (kPa)	46.44	155

IV. CONCLUSION

In this investigation, several tests were carried out based on the laboratory tests, to study the impact of alccofine-1203 and Phosphogypsum on swelling characteristics and strength behavior of soil. The findings drawn from the data in this research are as follows:

1. The addition of alccofine-1203 and Phosphogypsum to the soil decreased the liquid limit and plasticity index while increasing the shrinkage limit. It is found that the addition of stabilizers causes flocculation of clay particles and increases the number of coarse particles which help in reducing the Atterberg limits.
2. The optimum moisture content (OMC) was found to decrease 36% to 15.6% while the maximum dry density (MDD) increases from 13.8 kN/m^3 to 17.5 kN/m^3 with a binding content.
3. Unconfined compressive strength (UCS) tests were conducted with alccofine-1203 and Phosphogypsum were added independently and blended to the expansive soils. It was performed on both natural and chemically treated soil. The UCS value for natural soil is 46.4 kPa. The maximum UCS strength was an increase from 46.4 kPa to 948 kPa with 56 days of curing with soil + 12% alccofine + 1% Phosphogypsum.
4. The swell behavior of soil; swell index is reduced from 125% to 16.67% and which means the swelling of soil is changed from high swelling to low-swelling with the accumulation of 12% alccofine + 1% Phosphogypsum respectively.

Based on the positive outcomes, it can be said that the expansive soil containing alccofine and Phosphogypsum is a useful cohesive non-swelling soil (CNS) for roads, sidewalks, and floorings. Hence the result concluded that the addition of 12% alccofine + 1% Phosphogypsum exhibited an essential stabilizer on a high swell, high shrink soil and poor bearing capacity soil thereby it was discovered that by addition of the admixture a problematic soil is converted to best soil.

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DECLARATION

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Conflicts of Interest/ Competing Interests	The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
Ethical Approval and Consent to Participate	We further confirm that any aspects of the work covered in this manuscript that has involved human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.
Availability of Data and Material/ Data Access Statement	The data that support the findings of this study are available from the corresponding author upon reasonable request.
Authors Contributions	V. Jaladevi: Conceptualization, Methodology, Writing-original draft. V. Murugaiyan: Visualization, Supervision and editing.

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