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Influence of Terrenoseal on Geotechnical Properties of Expansive Soil

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ABSTRACT

In this experimental work, Terrenoseal (*organo-silane*-based nano-chemical) is used to improve the swelling and shrinkage characteristics of expansive soil. Effects of Terrenoseal on soil are recognized by various soil laboratory experiments, like free swell index test, swell pressure test, consistency limits test and standard proctor test. Various analytical techniques, such as Thermo Gravimetric Analysis (TGA), wettability and contact angle, are performed in the laboratory to examine the physico-chemical properties of both untreated and treated soil samples. pH, Chemical Oxygen Demand (COD) and heavy-metal analysis were performed to investigate the effect of Terrenoseal on soil. Laboratory results demonstrate that the reduction in the swell pressure of treated soil samples by using a small concentration of nano-chemical was about 48% and the free swell index was reduced by about 49%. There was also an improvement in physico-chemical properties. Improvement in shrinkage limit of soil was found up to 36%. pH, heavy-metal analysis and Chemical Oxygen Demand of treated soil samples are within the acceptable limits.

KEYWORDS: Expansive soil, Swelling pressure, Terrenoseal, Wettability, Heavy-metal analysis.

INTRODUCTION

Expansive soils cause a huge challenge in civil-engineering construction and may spread over large areas. For example, expansive black cotton soil is available in more than twenty percent of the geographical region of India. Swelling and shrinking characteristics of these expansive soils on account of changes in season and moisture content often cause tremendous damage to structures. The presence of clay minerals, like montmorillonite, is responsible for such behavior of volume change. By large, these expansive soils can be recognized from their plasticity and high shrink-swell potential. Different techniques and methods, like the construction of deep piers, soil replacement, controlling moisture at a constant level and chemical soil stabilization, were suggested to reduce swelling and consequently prevent damage of buildings in expansive-soil areas.

The past trend shows that various studies have been conducted in the stabilization of expansive soils (Rice and Wilkins, 1977; Holtz, 1969; Basha et al., 2005; Darikandeh and Viswanadham, 2019; Al-Rawas and Al-Sarmi, 2005; Kumar and Solanki, 2019; Ta'negonbadi and Noorzad, 2019; Dennis Pere Alazigha, Buddhima Indraratna, Jayan S. Vinod and Heitor, 2017; Melese, 2022; Al-Zoubi, 2008; Tilak et al., 2014) by using various admixtures to reduce the swelling characteristics of soils. Due to mixing problems on site and solubility issues, the present study deals with the use of soluble nano-chemicals. Literature highlights that many nanomaterials, such as nano-clay, nano-silica, nano-copper, nano-carbon tubes, … etc., were used to reduce the swelling characteristics of expansive soils. In the last decades, technology has developed to reduce the swelling characteristics of expansive soils. Amongst these, the idea of nanotechnology was propounded by

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Feynman (1960). In recent research, this technology made fast and convincing progress. Several studies were carried out to improve the various engineering properties of clayey soil using SiO_2 nanoparticles and cement (Bahmani et al., 2014), carbon nanotubes and nano-silica (Majeed and Taha, 2013), nano-silica and lime (Iswarya and Satheeskumar, 2018), nano-SiO_2 (Changizi and Haddad, 2015), nano-$CaCO_3$, (Meng et al., 2017) and carbon nanotubes (Wang, 2016).

Here, Terrenoseal (*organo-silane*-based nano-chemical) is used to improve the shrinkage and swelling characteristic of expansive soils. Swelling is a separation of layers and penetration of water between these layers. The swelling of soil occurs due to water absorption and this water separates the layers within the soil particle structure. Different soils have layers separated by 0.5nm to 1.0nm. Most expansive soils have these layers separated more than other soils. Terrenoseal will react by penetrating between layers and make the gap hydrophobic; so when soil comes in contact with water, it cannot separate these layers, resulting in a reduction in swelling characteristics. Terrenoseal is reactive to all types of soil. Expansive soil, when treated with Terrenoseal, it gets stabilized and therefore, native soil can be used without soil replacement. The soil stabilization/improvement with Terrenoseal is a simple and relatively economical process.

MATERIALS

Expansive Soil

Samples of expansive soil were collected from Morsal, Navsari and Morbi regions in the State of Gujarat. The collected soil samples are black in colour due to the presence of iron, aluminum, … etc. compounds. Soil is highly argillaceous. The specific gravity of collected soil samples is 2.65 (Morsal), 2.8 (Navsari) and 2.6 (Morbi). The pH of the soil samples of Morsal, Navsari and Morbi regions is 7.6, 7.7 and 7.6, respectively. Magnesium concentrations of the soils of Morsal, Navsari and Morbi regions are 195mg/kg, 390mg/kg and 200mg/kg respectively. Iron concentrations of the soils of Morsal, Navsari and Morbi regions are 19500mg/kg, 33000mg/kg and 31000mg/kg, respectively. The collected samples were crushed by using a hammer and sieved through Indian Standard 4.75mm sieve.

Terrenoseal (*organo-silane*-based nano-chemical)

Terrenoseal is an *organo-silane*-based nano-product with a pale yellow colour, dispersible in water and having a density of 1.03gm/cc. It is reactive at room temperature to all siliceous compounds but the reaction is not violent. The product does not contain any heavy metals. The only metal present in the product is (7.5%) silicon. Terrenoseal (*organo-silane*-based nano-chemical) is procured from Tawata Technologies, Ahmedabad.

The Chemical Action of Terrenoseal on the Soil Surface

Terrenoseal (*organo-silane*-based nano-chemical) has four available reactive valencies. Silica (Si) of soil also has four valencies. One of these valencies of Terrenoseal is alkyl functionality which is not reactive under ambient conditions. The other three are alkoxy groups that can react with silicate-containing substrates, like sand, soil, … etc., as shown in Figure 1. One of the groups upon reaction gets polymerized. There are still two groups available, which can also react with -OH groups. Now, these -OH groups can be from another Terrenoseal molecule or another soil particle. So, when the soil is dry, all three groups react and become part of the soil, imparting hydrophobicity. The two groups will eventually react with available -OH groups to form Si-O-Si bonds. Si-O-Si is the strongest bond in nature. By reacting with soil, it will become permanent so that it cannot leach out, as shown in Figure 2.

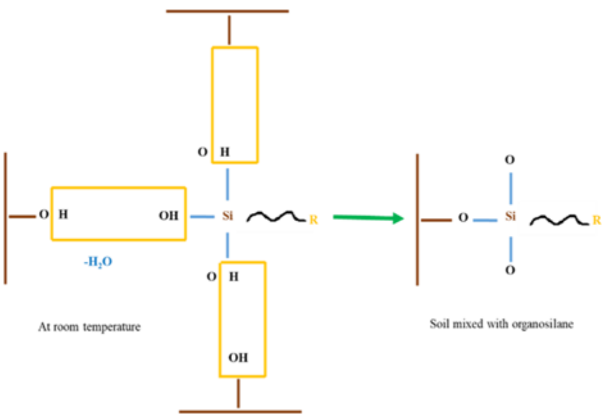

Figure (1): Soil-particle reaction mechanism with Terrenoseal reaction mechanism

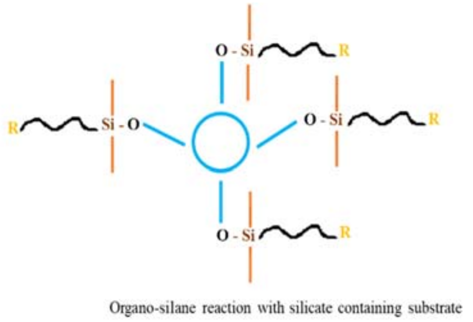

Figure (2): *Organo-silane* reaction with silicate-containing substrate

METHODOLOGY

Free swell index, Atterberg limits, compaction and swell pressure tests were conducted in a geotechnical laboratory as per IS code procedure. Samples of the soils were crushed by using a hammer and sieved through an IS 4.75 mm sieve in a geotechnical laboratory. The concentrated solution of Terrenoseal is then prepared by mixing 300 parts of water with 1 part of Terrenoseal with manual stirring until a homogenous mixture is produced. An important requirement of the technology is the wetting of each and every soil particle. By wetting the particles, the silane molecule has a chance to react with the soil. 1:300 dilution solution has enough molecules available for the smallest particles (clay and slit) to the sand particles. The above-mentioned solution was put to use in the treatment of the soil samples. This *organo-silane* will give effect only if the sample was at least once dried. The samples for consistency limits and free swell index were dried in an oven at 80˚C or air-dried for one-two days depending on site conditions. All the tests were performed three times and reported as per the average values obtained.

The infrared an (IR) spectroscopy technique was conducted using an infrared spectrometer which produces an IR spectrum. An IR spectrum can be visualized in a graph of infrared-light absorbance on the vertical axis *vs*. frequency or wavelength on the abscissa. Wettability tests were performed with a force tensiometer model with a penetration rate, plotted as a change in mass of the sample per second. The thermal analyses of soil specimens were carried out using Mettler thermal analyzer, TA4000, in the temperature range of 25–800°C. The measurement of contact angle was carried out using an optical tensiometer. In this test, the samples are developed under hydraulic presses which have 260 kg/cm^2 of maximum working pressure with a sample teflon holder with a diameter of 20mm.

pH and Chemical Oxygen Demand (COD) analyses of soil were performed as per American People Health Association (APHA), 23rd edition and IS 3025 (part 58): 2006/ reaffirmed 2017, respectively. Heavy-metal analysis was performed as per APHA 3111-B, 23rd Edn., 2017.

RESULTS AND DISCUSSION

Results and Discussion of Soil Investigation

Successive experiments were performed to investigate the properties of the soil samples in the soil laboratory and the outcomes are shown in Table 1, Table 2 and Table 3.

Table 1. Engineering and index properties of untreated and treated expansive soil of Morsal region

Soil tests with Indian Standard code referred	**Morsal, (untreated)-soil results**	**Morsal, (treated)-soil results**
Liquid-limit test (LL) (Indian Standard: 2720- part-5-1985)	62%	49%
Plastic-limit test (PL) (Indian Standard: 2720- part-5-1985)	26%	27%
Plasticity-index text (PI) (Indian Standard: 2720- part-5-1985)	36%	22%
Shrinkage-limit test (SL) (Indian Standard: 2720- part-6-1972)	11%	14%
Hydrometer test (Indian Standard: 2720- part-4-1985)	Gravel=8 % Sand=24%, silt= 19%, Clay=49%	Gravel= 7%, Sand=26%, Silt=22%, Clay=45%

Soil tests with Indian Standard code referred	Morsal, (untreated)-soil results	Morsal, (treated)-soil results
Standard proctor test (Indian Standard: 2720- part-7-1980)	Optimum Moisture Content(OMC) = 26.2 % and Maximum Dry Density (MDD) = 1.34gm/cm^3	Optimum Moisture Content(OMC) = 20.8% and Maximum Dry Density (MDD) = 1.71gm/cm^3
Free-swell test (Indian Standard: 2720- part-40-1970)	90%	49%
Swell-pressure test (Indian Standard: 2720- part-4-1977)	1.89 kg/cm^2	1.0 kg/cm^2
Soil classification (Indian Standard: 1498-1970)	CH (Cohesive soil)	CI (Cohesive soil)

Table 2. Engineering and index properties of untreated and treated expansive soil of Navsari region

Soil Tests with Indian Standard code referred	Navsari, (untreated)-soil results	Navsari, (treated)-soil results
Liquid-limit test (LL) (Indian Standard: 2720- part-5-1985)	71%	61%
Plastic-limit test (PL) (Indian Standard: 2720- part-5-1985)	28%	30%
Plasticity-index test (PI) (Indian Standard: 2720- part-5-1985)	43%	31%
Shrinkage-limit test (SL) (Indian Standard: 2720- part-6-1972)	11%	15%
Hydrometer test (Indian Standard: 2720- part-4-1985)	Gravel = 1%, Sand = 6%, Silt = 37%, Clay = 56%	Gravel=0%, Sand= 7%, Silt = 38%, Clay = 55%
Standard proctor test (Indian Standard: 2720- part-7-1980)	Optimum Moisture Content = 26.3% and Maximum Dry Density = 1.21 gm/cm^3	Optimum Moisture Content = 20.5% and Maximum Dry Density =1.56 gm/cm^3
Free-swell test (Indian Standard: 2720- part-40-1970)	118%	60%
Swell-pressure test (Indian Standard: 2720- part-4- 1977)	2.31 kg/cm^2	1.2 kg/cm^2
Soil classification (Indian Standard: 1498-1970)	CH (Cohesive soil)	CH (Cohesive soil)

Table 3. Engineering and index properties of untreated and treated expansive soils of Morbi region

Soil tests with Indian Standard code referred	Morbi, (untreated)-soil results	Morbi, (treated)-soil results
Liquid-limit test (LL) (Indian Standard: 2720- part-5-1985)	67%	58%
Plastic-limit test (PL) (Indian Standard: 2720- part-5-1985)	28%	30%
Plasticity-index test (PI) (Indian Standard: 2720- part-5-1985)	39%	29%

Soil tests with Indian Standard code referred	**Morbi, (untreated)-soil results**	**Morbi, (treated)-soil results**
Shrinkage-limit test (SL) (Indian Standard: 2720- part-6-1972)	12%	16%
Hydrometer test (Indian Standard: 2720- part-4-1985)	Gravel= 2%, Sand=15%, Silt= 30%, Clay=53%	Gravel=1%, Sand=17%, Silt=31%, Clay=51%
Standard proctor test (Indian Standard: 2720- part-7-1980)	Optimum Moisture Content = 21.2% and Maximum Dry Density = 1.4 gm/cm^3	Optimum Moisture Content = 17.4% and Maximum Dry Density = 1.69 gm/cm^3
Free-swell test (Indian Standard: 2720-part-40-1970)	72%	38%
Swell-pressure test (Indian Standard: 2720-part-4-1977)	1.76 kg/cm^2	0.91 kg/cm^2
Soil classification (Indian Standard: 1498-1970)	CH (Cohesive soil)	CH (Cohesive soil)

The above experimental results show that the decrease in plasticity index has resulted in the reduction in swelling pressure of the soils by 47%, 48% and 48% for Morsal, Navsari and Morbi soil, respectively. The free swell index of the soils was also decreased by 46%, 49% and 47% for Morsal, Navsari and Morbi soil, respectively. The effect of Terronoseal on all the soils has led to a significant reduction in swelling characteristics. This is due to the hydrophobic nature of Terronoseal. When added to the soil mass, the ingress of water in the crystalline structure is completely blocked, which can be correlated by the wettability test. The shrinkage limits of Morsal, Navsari and Morbi soils were increased by 27%, 36% and 33%, respectively, showing a decrease in the expansive characteristics of these soils. There was a significant increase in the Maximum Dry Density and a reduction in Optimum Moisture Content.

Results and Discussion of Instrumentation Techniques

Wettability Test Outcome of Morsal, Navsari and Morbi Soils

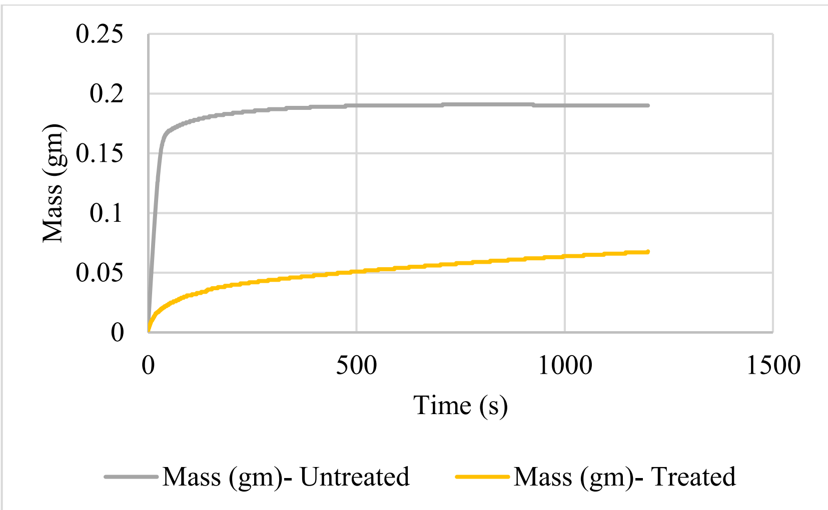

Figure (3): Wettability test for Morsal soil

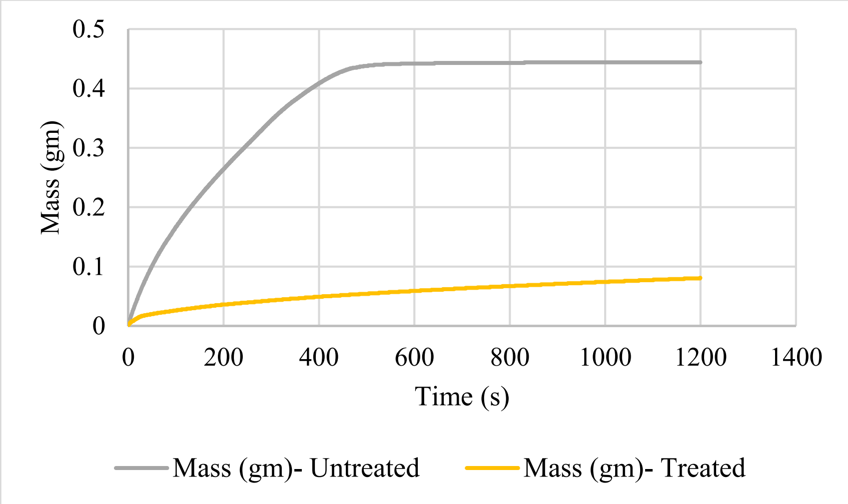

Figure (4): Wettability test for Navsari soil

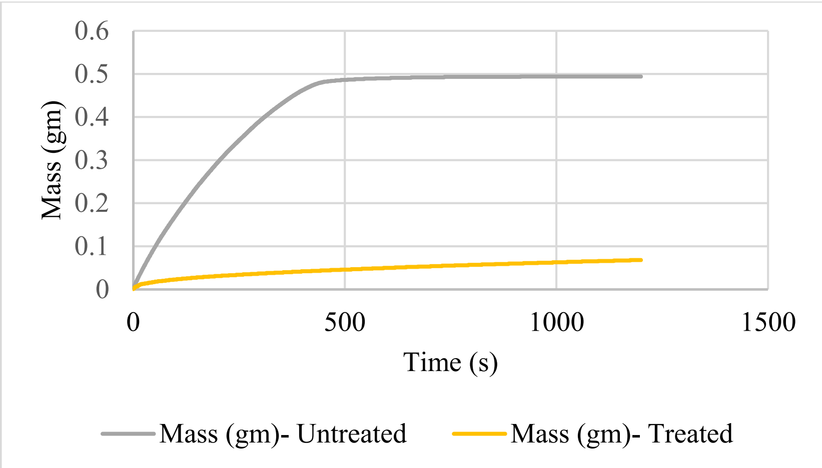

Figure (5): Wettability test for Morbi soil

All the clays are hydrophilic in nature; so when water was poured on a surface of the soil, it got spread on the surface, noting that soil surface silicate structure consists of –OH groups that make the surface of silicate water-loving. But, this Terrenoseal solution reverses the entire surface chemistry of silicate and monolayer develops over the surface of the soil with an alkyl group which modifies the soil's nature as water repellent. This supports the result for the wettability (absorption) test, as shown in Figure 3, Figure 4 and Figure 5. When water is poured on the dry treated surface of the soil, the water beads up on the treated-soil surface. Such action of silane remains permanent. The above experimental results show that treated-soil wettability reduces by 0.12 gram, 0.36 gram and 0.43 gram for Morsal, Navsari and Morbi soils, respectively.

Thermo-gravimetric (TGA) Analysis Test Outcome of Morsal, Navsari and Morbi Soils

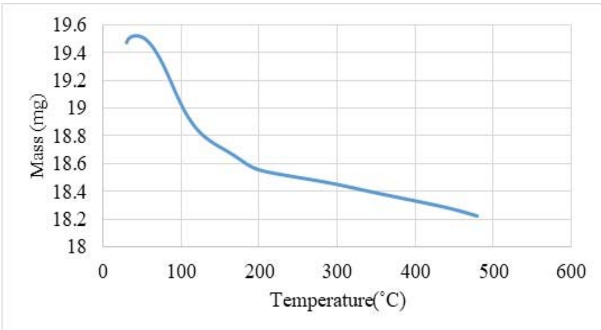

Figure (6): Thermo-gravimetric analysis test of Morsal untreated soil

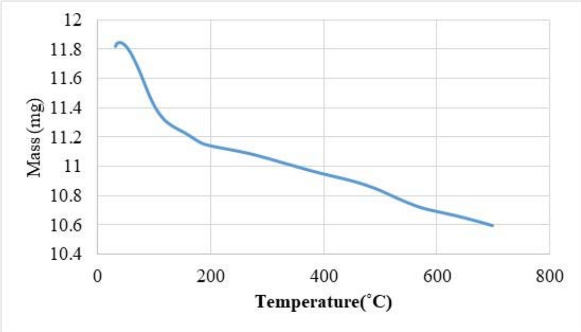

Figure (7): Thermo-gravimetric analysis test of Morsal treated soil

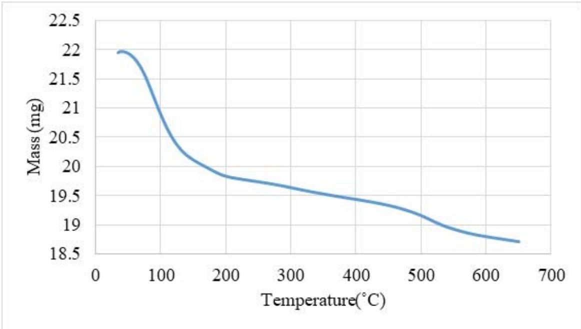

Figure (8): Thermo-gravimetric analysis test of Navsari untreated soil

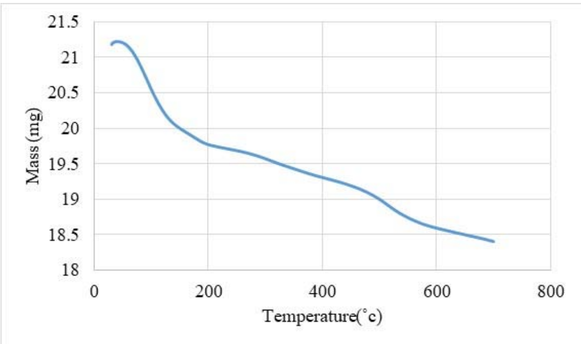

Figure (9): Thermo-gravimetric analysis test of Navsari treated soil

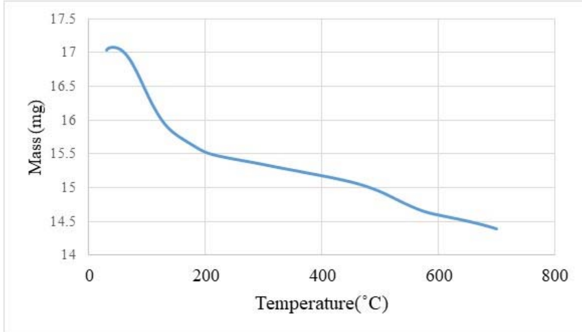

Figure (10): Thermo-gravimetric analysis test of Morbi untreated soil

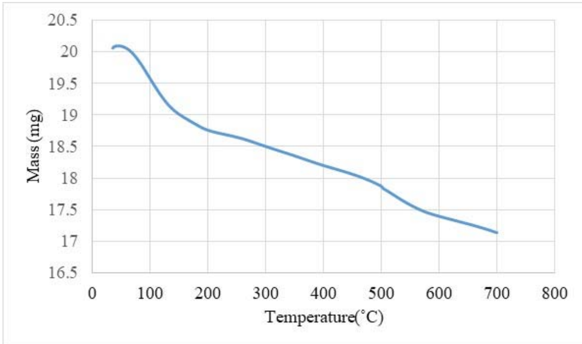

Figure (11): Thermo-gravimetric analysis test of Morbi treated soil

Thermo-gravimetric analysis shows two distinct regions, as shown in Figures 6-11. All soil samples have two distinct bands which show loss of water and loss of organic matter in the first band and the second band, respectively.

Contact Angle Analysis Test Results of Morsal, Navsari and Morbi Soils

Table 4. Contact angle test of untreated antreated expansive soils

Untreated Morsal	Treated Morsal	Untreated Navsari	Treated Navsari	Untreated Morbi	Treated Morbi
0˚ as untreated soil is hydrophilic	ϴ right = 137.36˚ ϴ left = 139.97˚	0˚ as untreated soil is hydrophilic	ϴ right = 125.38˚ ϴ left = 129.01˚	0˚ as untreated soil is hydrophilic	ϴ right= 138.46˚ ϴ left = 135.63˚

Contact-angle results in Table 4 show that untreated soil was hydrophilic, as the water is fully absorbed (making 0˚with soil surface) by the soil surface, but after the treatment, water is not absorbed by the soil surface, which confirms the hydrophobicity of the samples after treatment.

Results and Discussion of pH, Chemical Oxygen Demand (COD) and Heavy-metal Analysis of the Soils

Table 5. pH, chemical oxygen demand (COD) and heavy-metal analysis of the soils

Sr. No.	Parameters	Morsal (untreated)	Morsal (treated)	Navsari (untreated)	Navsari (treated)	Morbi (untreated)	Morbi (treated)	Referred test method
1	pH results at 27°C	7.6	7.6	7.7	7.8	7.6	7.7	American Public Health Association, 23rd edition 2017/4500- H+B
2	Chemical Oxygen Demand (COD) (gm/kg)	18.8	17.0	18.0	19.2	15.8	15.0	Indian Standard 3025 (part 58): 2006/ reaffirmed 2017
3	Arsenic (mg/kg)	1.21	1.1	1.29	1.3	1.2	1.1	American Public Health Association, 3111-B, 23rd Edn., 2017
4	Lead (mg/kg)	1.46	1.5	1.21	1.4	10.8	21.3	
5	Magnesium (mg/kg)	195	229	390	496	200	230	
6	Iron (mg/kg)	19500	20000	33000	38450	31000	34000	
7	Copper (mg/kg)	49.1	40.2	95.9	94.3	68.2	65.3	
8	Zinc (mg/kg)	28.8	25.4	68	67	25.8	23.1	

pH, COD and heavy-metal analysis test results of the soil samples shown in Table 5 indicate that the results are within the acceptable limits.

CONCLUSIONS

Index and engineering properties of expansive soil were studied with a view of improving the swelling characteristics of soil by utilizing Terrenoseal, where test outcomes conclude that:

- By adding 1 part of Terrenoseal in 300 parts of water, reductions of 49% and 48% were observed in free swell index and in swelling pressure, respectively.
- The shrinkage limit of the soil would increase up to 36%.
- The results of the standard proctor test observed a reduction in Optimum Moisture Content (OMC) and an improvement in Maximum Dry Density (MDD).
- In thermos-gravimetric analysis, treated (hydrophobic) soil has properties of retaining less water; so treated soil is expected to exhibit less water loss compared to untreated soil.
- Wettability and contact-angle test results confirm the hydrophobicity of the soil.
- The wettability test result shows that untreated soil is hydrophilic and the surface of the soil gets wet when it comes in contact with water. Further water migrates into the capillary pores because of capillary activity. However, treated soil is hydrophobic which does not get wet; so water migration in capillary pores is significantly reduced. The contact-angle test result confirms the hydrophobicity of the soil.
- The most important economic advantages of Terrenoseal technology are: (i) there is no

requirement of replacing an existing soil in the field after the treatment (ii) no special equipment is required and standard road construction equipment can also be used. Considering the same, any economic assessment should consider the cost of replacing native soil, transportation, the life cycle of the structure and the environmental factor.

- The use of Terrenoseal to improve the swelling and shrinkage characteristics of the expansive soil is found significant and from the outcomes, it can be concluded that Terrenoseal can be used as a permanent solution to enhance the index and engineering properties of expansive soils.

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