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Research Article

Shrinkage Module of Soil Samples with Different Cement Content

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Abstract. The differences in soil's body mass during shrinkage over time have changes in soil physical properties which provide an important reason to check the design of underground foundations in expansive soils. In this paper, a state-of-art of the soil heat stress-strain relationship prediction methods is checked using soil engineering laboratory experiments and Matlab R2013b numerical modelling. The shrinkage of soils with different cement content of (0%, 2%, 4%, 6% and 8%) with the same water content of 20 percent in room temperature for 24 hours, are critically reviewed in terms of their predictive shrinkage along with their strengths and flexural behaviour. The review highlights the prediction methods present to determine the effect of heat stress on the shrinkage of soil samples with different cement content after classifying the soils into clay, silt and sand depending on their particle size using sieve and hydrometer experiments. The results of the soil engineering laboratory experiments showed that as the cement content increases, the shrinkage of soil decreases as a result of increased elasticity in soil. The numerical analysis using finite element method in Matlab R2013b shows that as the cement content increases the displacement in the soil sample decreases and that the soil sample with 8% cement content has more resistance to shrinkage and less displacement than the soil with 6% cement, which has less resistance to heat stresses and more displacement.

Keywords: Soil Samples, shrinkage, temperature, displacement, cement content, numerical analysis.

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1. Introduction

Expansive soils absorb large quantities of water after rainfall or due to local site changes such as leakage from water supply pipes or drains, therefore becoming sticky and heavy [1]. Conversely, they can also become stiff when dry, resulting in shrinking and cracking of the ground [8]. This hardening-and-softening behaviour is known as shrink-swell behaviour [19]. When supporting lightly loaded structures, the effect of significant changes in shrinkage of soils with high shrink-swell potential can be severe [20]. Hence, it is important to provide analysis to reliably estimate the volume change behaviour of soils with different cement content in field [11].

Significant advances were made during the last half century towards the prediction of the heave and the shrinkage related to volume change of soils [15]. The soil moisture varies due to environmental changes or, other factors have a significant influence on the soil movement changes with time [18]. For this reason, information related to the soil movement over time is of practical interest for both the reliable design of foundations for structures on expansive soils and the assessment of pre wetting and controlled wetting mitigation alternatives for expansive soils [2].

Local earth materials contain different types of soils classified according to their particle size to clay, silt or sand. The soil picked from the earth's surface and used for the shrinkage tests will be classified by the sieve and hydrometer experiment to determine their particle size distribution. The tested soil will have an addition of 0, 2, 4, 6, and 8% of cement. The water content used in the soil compositions is 20% of the soil mass weighed. By the addition of water and cement, the soil will have different porosity and elasticity. The soil samples will be tested numerically using Matlab modelling to analyse the displacement and heat resistance of the soil samples with different cement content. After classifying th soils, we do the shrinkage experiment for soil samples with different cement content to investigate the flexural strength of the soil samples.

2. Materials and Methods

2.1. Collection and classification of soil

Soil samples were collected from earth's surface at the university campus, which is located in Kingswood, New South Wales, in a field plot of $6 \times 6\ m^2$. The soil is classified as silt, sand, clay with moderate to high shrink–swell potential. The soil is to be classified by combining the results of sieve and hydrometer experimental results together in a graph that shows the diameter of the soil particle and percent finer [6].

The sieve test or the grain size analysis is commonly used in soil classification. The standard grain size test defines the relative proportion of different soils depending on the particle size [3]. The results of the sieve experiment are plotted in graph presenting the curves of grain size distribution which are used to determine the suitability of soil for constructions and estimation of soil-water movement.

Another soil classification experiment was conducted according to the Australian Standards [4] called the hydrometer experiment. In the hydrometer experiment the method used is to measure the specific density of soluble soils with particle size between 0.075 mm to 0.0002 mm with the relative density of water [9]. With combining the results obtained from the two experiments we get the grain size distribution graph for the classification of the soil materials picked from earth's surface.

3. Results

3.1. Sieve experiment results

In the sieve experiment, Soils are divided into groups based on their sizes of the particle grains in the soil mass. To distinguish their sizes we use sieves. The sieves permit smaller particles to fall through and retain the larger particles on the sieve. Sieves used were of different diameter sizes such as 2.36 mm, 1.18 mm, 600 micro metres, 425 micro metres, 300 micro metres, 150 micro metres, 75 micro metres. Only the soil particles that have passed to the pan were graphed for grain size distribution curve and taken as soil sample for the hydrometer test.

Table 1: Results of sieve experiment.

Sieve diameter (mm)	Mass of empty sieve (g)	Mass of sieve + soil retained (g)	Soil retained (g)	Percent retained	Percent passing
2.36	432.97	432.97	0	0	100
1.18	383.66	383.66	0.08	0.070	99.93
0.6	348.82	348.82	1.11	0.971	98.96
0.425	381.27	381.27	1.38	1.208	97.752
0.3	323.01	323.01	3.35	2.932	94.82
0.15	304.09	304.09	17.53	15.344	79.476
0.075	290.14	290.14	69.44	60.78	18.76
Pan	271.80	271.80	21.2	18.55	Nil

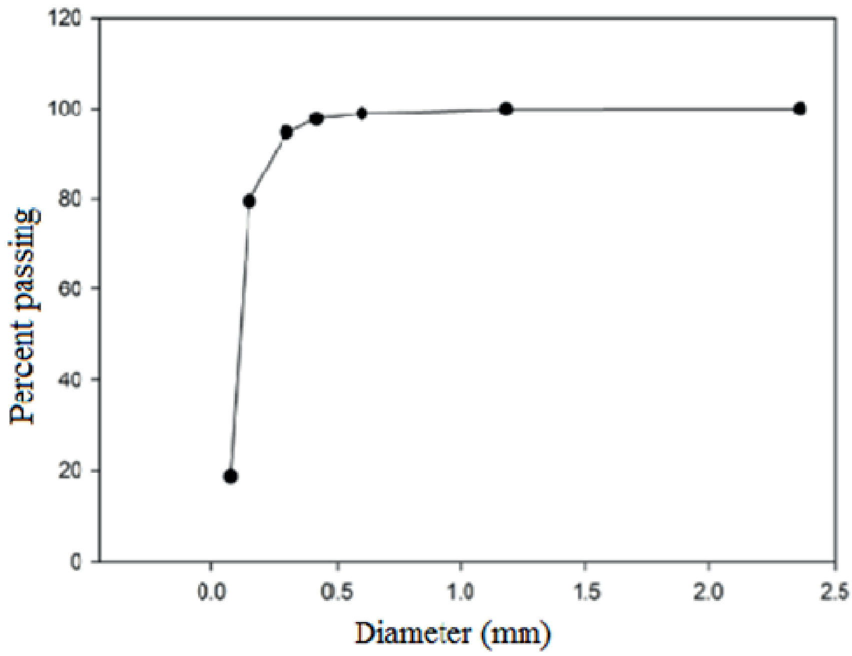

Figure 1: Grain size distribution curve for sieve test.

3.2. Hydrometer experiment results

The results of the hydrometer test shows that there maybe error in the percent finer passing in hydrometer as it shows the percent finer is not less than 20 percent, which is a bit different from the sieve grain size distribution graph, this may be because of the sieve test errors in accuracy and precision of soil grain size distribution and as well the hydrometer test had fluxuations on surface of water which disturbed the hydrometer reading and in was decreasing instead of increasing with time.

Table 2: Results of hydrometer experiment.

Time (minute)	Hydro-meter reading (g/l) Rh	Meniscus corrected Hydrome-ter reading (g/l) R'h	Temp (degree celcius)	Rc	F1	F2	F3	Particle size D (F1*F2*F3) (micro-metre)	Percent finer by mass (P = (0.65/ Mo)*Rc* (Gs/Gs–1)*100)	K (Percent finer by total mass)
0.5	27	25	24.2	24.99	3.58	1.301	14.14	65.85	100.00	18.55
1	27	25	24.2	24.99	3.58	1.301	10	46.57	100.00	18.55
2	26.9	24.9	24.2	24.88	3.59	1.301	7.07	32.74	99.62	18.48
4	26	24	24.2	23.98	3.6	1.301	5	23.41	96.01	17.81
8	26	24	24.2	23.98	3.6	1.301	3.54	16.57	96.01	17.81
15	25	23	24.2	22.98	3.61	1.301	2.58	12.11	92.00	17.07
30	23	21	24.2	20.98	3.67	1.301	1.83	8.73	84.00	15.58
60	22.5	20.5	24.2	20.48	3.68	1.301	1.29	6.17	81.99	15.21
120	21	19	24.2	18.98	3.71	1.301	0.91	4.39	75.99	14.1
240	20	18	24.2	17.98	3.73	1.301	0.65	3.15	71.99	13.35
1440	17	15	24.2	14.98	3.8	1.301	0.29	1.29	59.97	11.12

Table 3: Results of addition of K values from the hydrometer experiment to the particle diameter of the sieve experiment.

Particle diameter (mm)	Percent Passing
2.36	100
1.18	99.93
0.6	98.96
0.425	97.756
0.3	94.82
0.15	79.476
0.075	18.7
0.06585	18.55
0.04657	18.55
0.03274	18.48
0.02341	17.81
0.01657	17.81
0.01211	17.07
0.00873	15.58
0.00617	15.21
0.00439	14.1
0.00315	13.35
0.00129	11.12

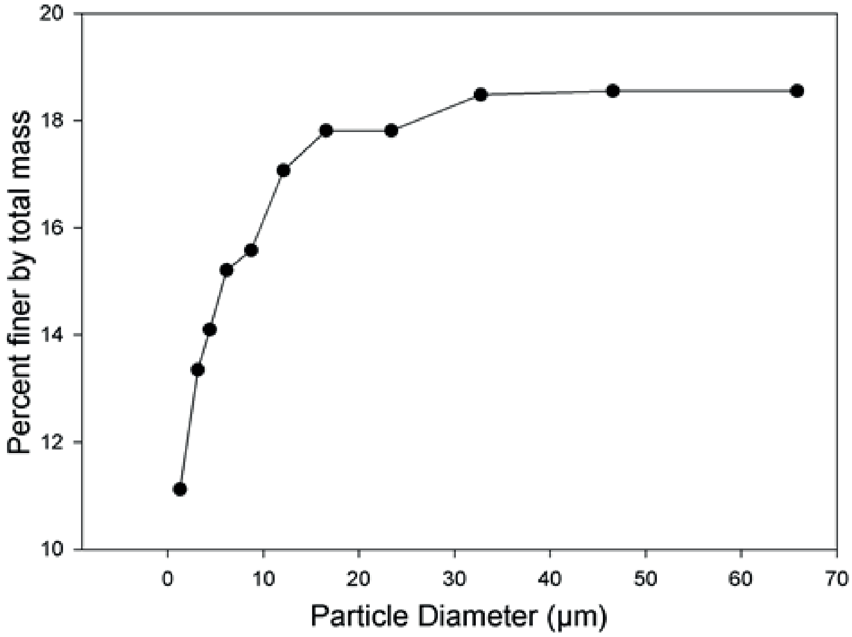

Figure 2: Grain size distributions for hydrometer experiment.

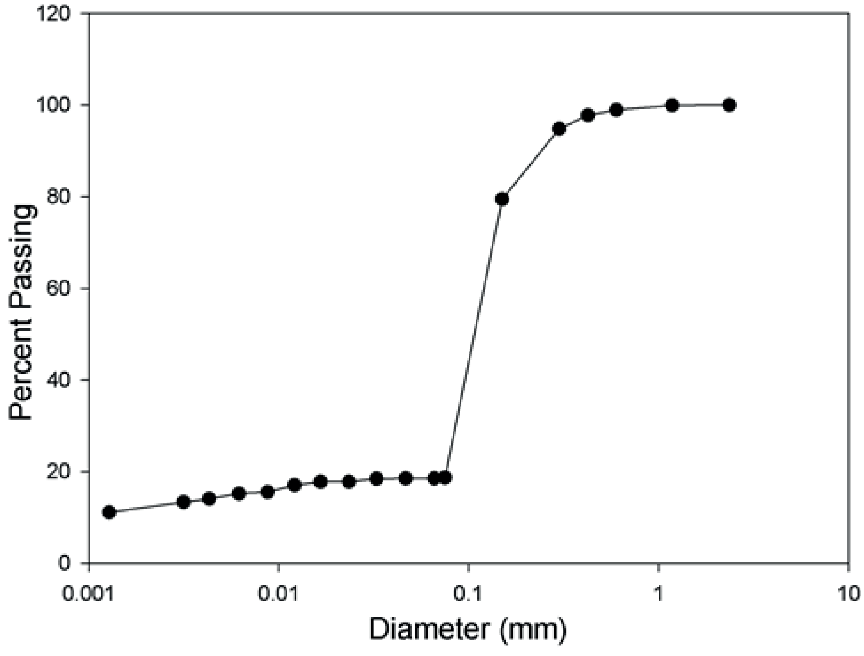

Figure 3: Grain size distributions for the soil classification test from the percent passing in sieve experiment extended by addition of K (percent finer by total mass) values from the hydrometer experiment.

3.3. Results of soil classification test

Addition of K and D values from the hydrometer results to the sieve result, we obtain the grain size distribution graph for soil classification. From the results of the soil classification tests presented in Figure 3, and the scale based on particle size of soil illustrated in Figure 4, the mean value for the diameter of soil particle is 0.295 mm, mean value of percent of soil passing

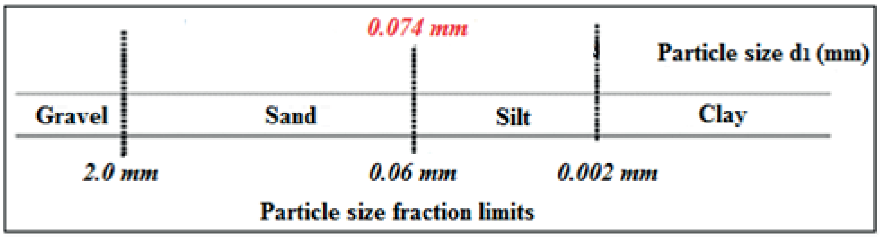

Figure 4: Soil classification scale based on particle size of local earth materials [11].

is 41.95%, and the local earth materials consist of Clay = 11% silt = 40% sand = 49%. D10 (the diameter of ten percent soil particles passing) is 0.00128 mm, D30 (the diameter of thirty percent soil particles passing) is 0.09 mm and D60 (the diameter of sixty percent soil particles passing) is 0.13 mm.

3.4. Formatting of mathematical components

Coefficient of uniformity:

$$Cu = D60/D10 \tag{1}$$

$$Cu = D60/D10 = 0.13/0.00128 = 101.56,$$

Coefficient of curvature:

$$Cc = (D30)^2/(D60.D10) \tag{2}$$

$$Cc = [(D30)^2/(D10*D60)] = [(0.09)^2/(0.00128*0.13)] = 48.67.$$

3.5. Preparation of shrinkage experiment

The preparation of soil samples for shrinkage experiment using the Australian Standards [5] are illustrated in Figure 5. The soil samples were mixed with different percentages of cement such as (0%, 2%, 4%, 6% and 8%) making five soil samples with standard water content of 20% for each soil sample. Oil was spread on the surfaces of the troughs to minimise the cracking of the soil samples when it shrinks longitudinally. The different soil samples were put into five troughs and the soil surfaces were made smooth to test them in shrinkage test at room temperature for 24 hours.

3.6. Shrinkage experiment results

The linear shrinkage value of specimen with various cement content and 20% water is determined by: LS = Ls/L × 100. Whereas, LS is linear shrinkage. Ls is the longitudinal shrinkage of the specimen in mm, L is the length of the trough, which is 250 mm.

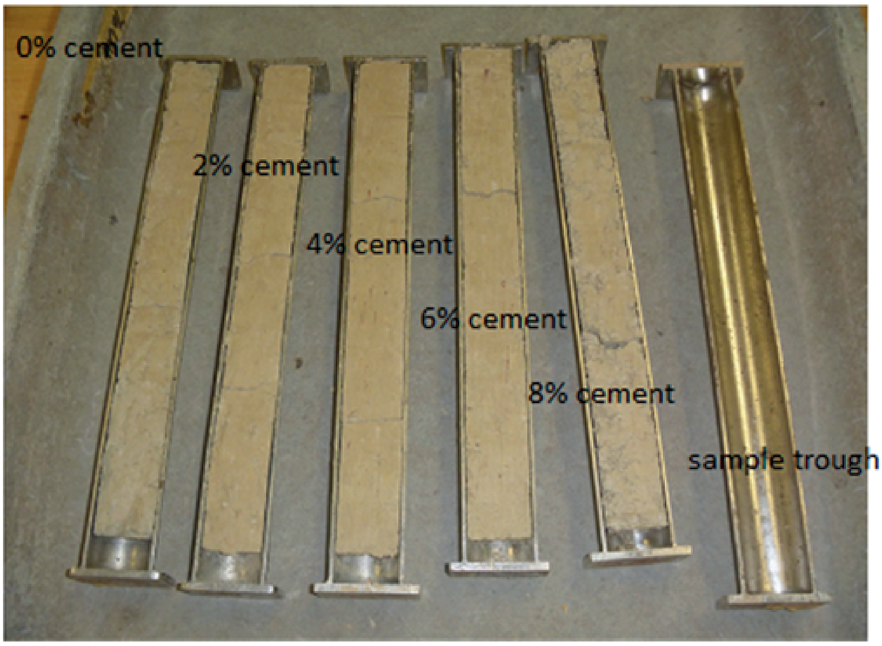

Figure 5: Shrinkage experiment of soil sample with different cement content in soil engineering laboratory.

Table 4: Results of shrinkage experiment.

Cement content percentages	Longitudinal shrinkage (mm)	Linear shrinkage
0.0000	15.0000	6.0000
2.0000	12.7000	5.0800
4.0000	12.4000	4.9600
6.0000	12.1000	4.8400
8.0000	11.8000	4.7200

The soil shrinkage results show increased mass strength of soil by the addition of more cement. There is a linear relationship between the longitudinal shrinkage and linear shrinkage of soil. The results also show the mean value for longitudinal shrinkage of soil samples is 12.8 mm, whereas the mean value for linear shrinkage is 5.12 mm. The volume change in soil samples is less with increasing cement content in soil samples as it increases the elasticity of the body mass of soil samples [12].

3.7. Matlab R2013b analysis

Using the partial differential equation (PDE) in Matlab modelling toolbox can produce instant solution to analytical numerical models. These models of soil samples allow in depth the prediction of soil deformation and stress-strain relationship by analysis and simulation [17]. These numerical simulations of the experimental set up were modelled using finite element method. The selected input parameters for the analysis are listed in Table 5. Details of numerical modelling resulting from the Matlab application shows the five various thermal displacements of the soil samples illustrated in Figures 7–11.

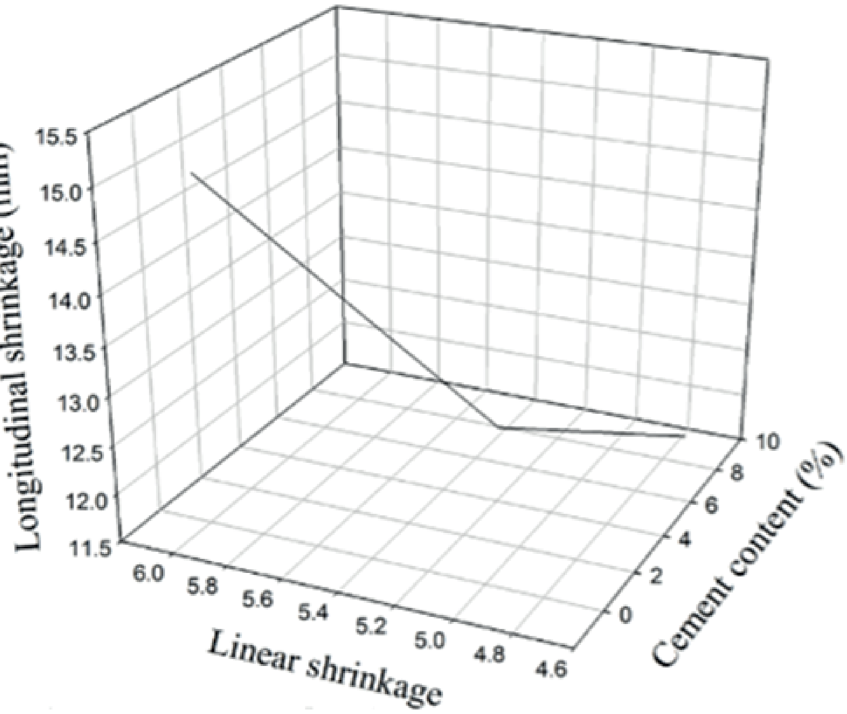

Figure 6: 3D Shrinkage behaviour for selected specimen with various cement content and 20% water.

Table 5: Shows the selection of input values of parameters used in Matlab R2013b modelling.

Selection	**Parameter**	**Value**
PDE specification	Modulus of Elasticity Nu Kx Kv Rho	[0.71, 1.77, 4.43, 8.87, 22.18] kPa 0.31 0 0 0.0091kg
Neumann Boundary	g_1 g_2 q_{11},q_{12} q_{21}, q_{22}	26.749*y 25.72*y*23 0 0
Dirichlet Boundary	(h_{11}, h_{12}) (h_{21}, h_{22}) r_1 r_2	1 1 2 2

The Neumann boundary conditions for heat stress at room temperature is 23°C was converted to 26.749 watt/metre/k [w/(m.k)]. The outer temperature is 22.11°C = 25.72 [w/(m.k)], which is used in calculating g_2, and the heat transfer coefficient is 50. While, the Dirichlet boundary condition include rectangular module which has four edges with dimensions of (0, 25) mm, (0, 250) mm, whereas Poisson's ratio = N_u, volume-force x-direction = K_x, volume-force y-direction = K_v and the density = Rho.

3.8. Numerical analysis results

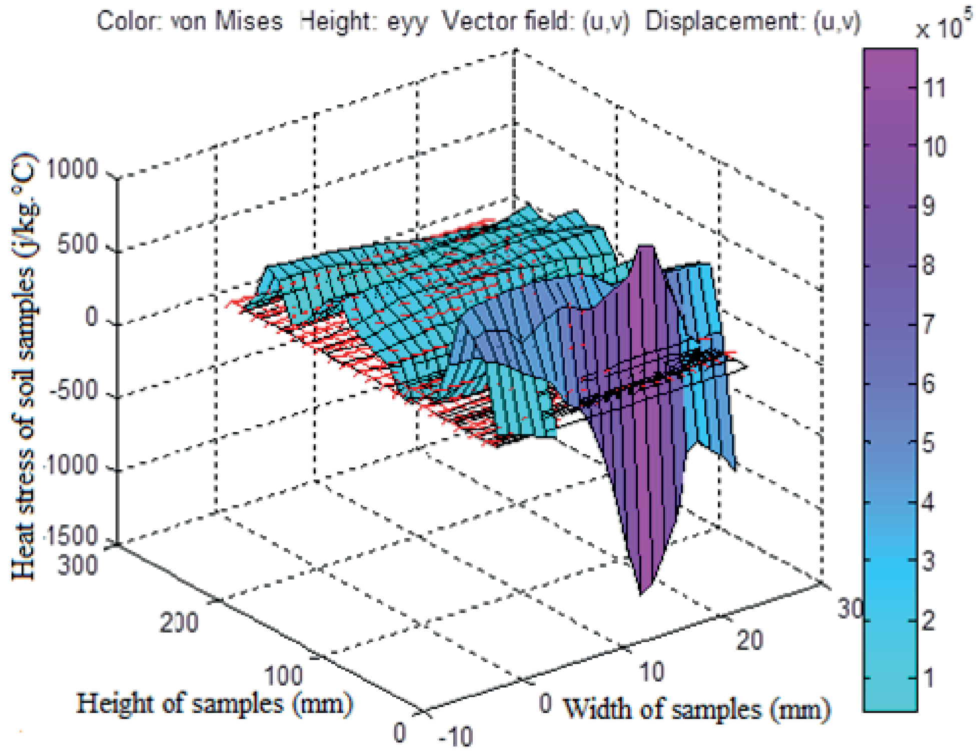

Figure 7: Displacement of soil sample with 0% cement.

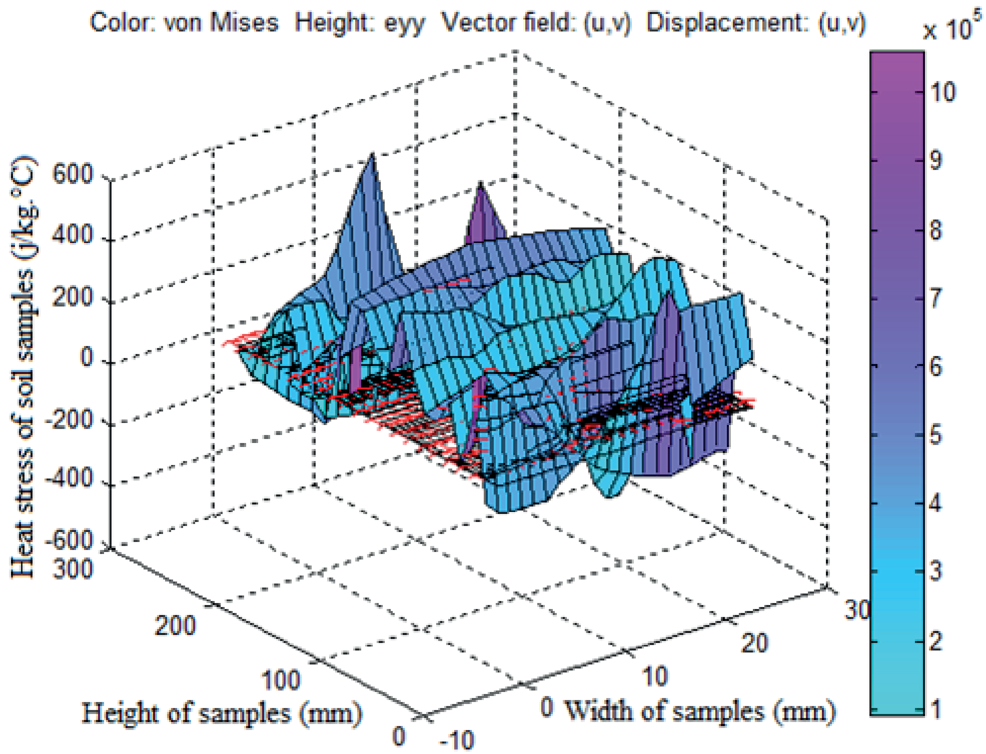

Figure 8: Displacement of soil sample with 2% cement.

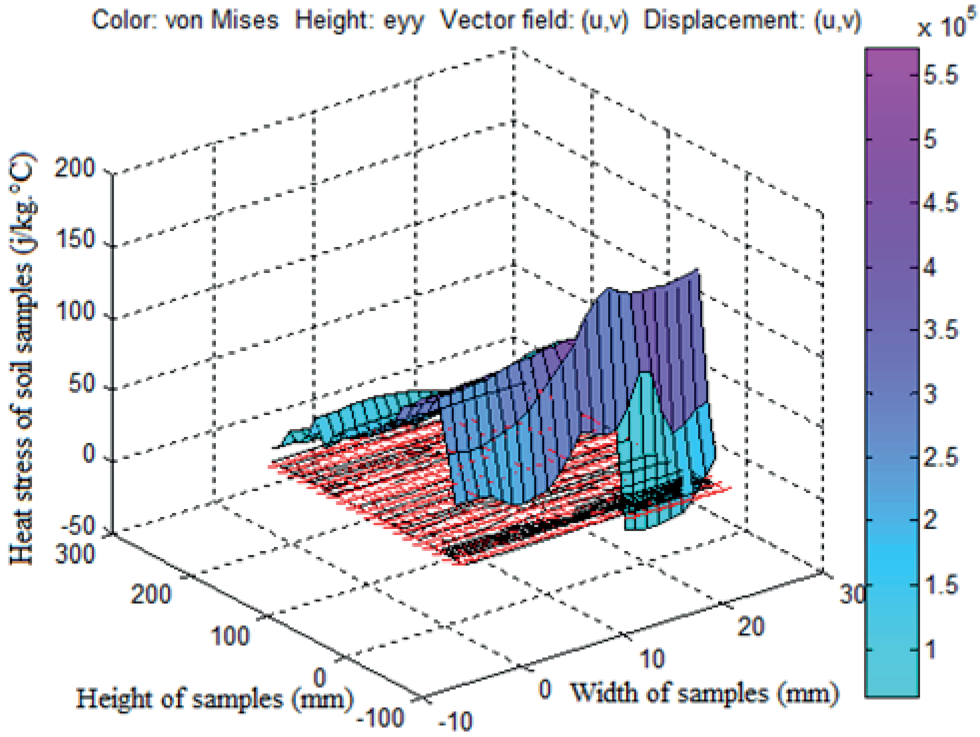

Figure 9: Displacement of soil sample with 4% cement.

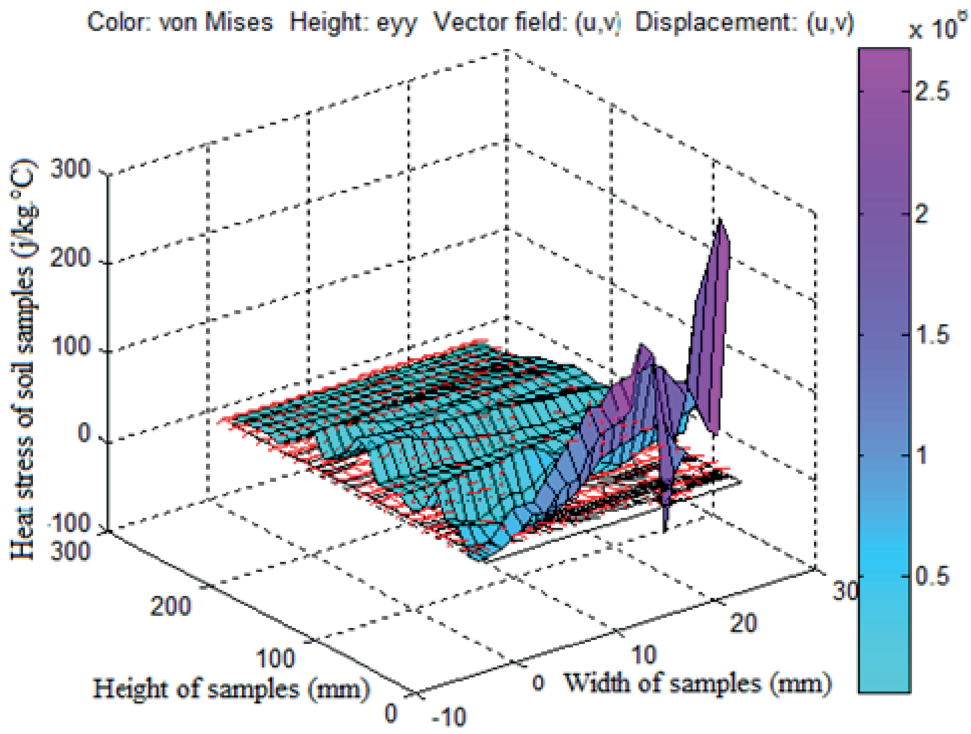

Figure 10: Displacement of soil sample with 6% cement.

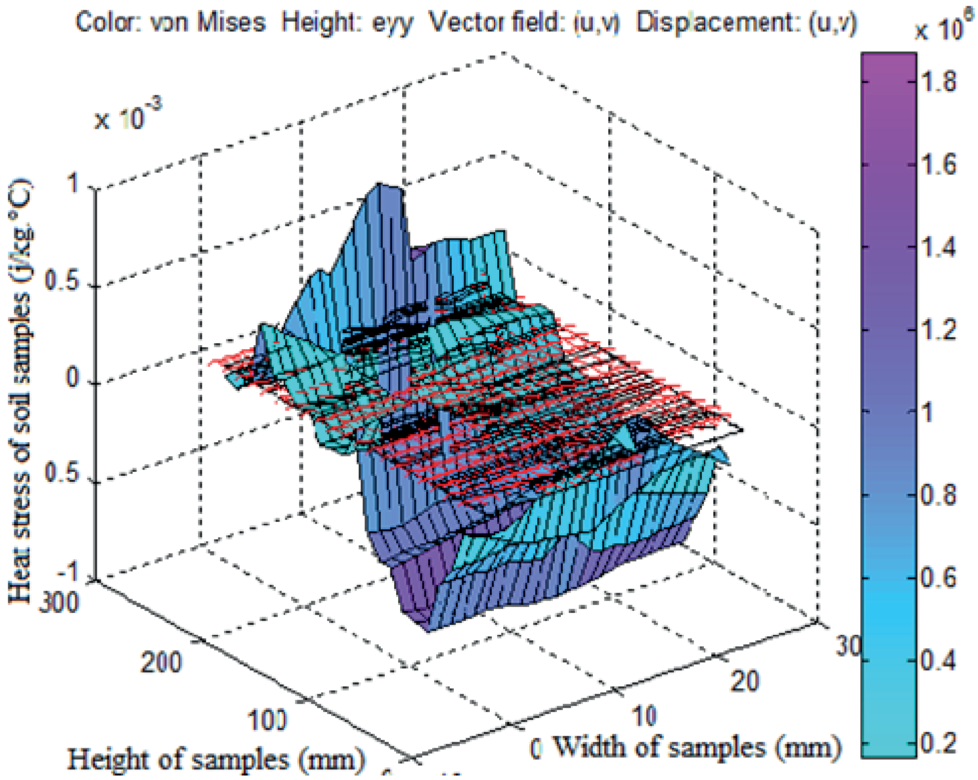

Figure 11: Displacement of soil sample with 8% cement.

4. Discussion

The results of the soil classification experiments showed different particle sizes of soil materials picked from earth's surface. With the partially saturated soil, the types of soil are changed and have a different porosity and elasto-plasticity [14]. With the addition of cement to soil samples, the strength of the soil composition increases [13]. That is because cement reacts with water to form bonds within the soil configuration [10]. The elasticity of soil samples rise as the chemical bond between the cement, water and soil is formed in the exothermal reaction of hydration [7]. As the cement content in soil increases, the elasticity of the samples increases by 2.5 so as the soft clayey soil has elasticity of 0.71 kPa, then, adding 2% cement to soil mass causes an increase to the elasticity by 2.5*0.71 KPa = 1.77 kPa [16].

The results of the shrinkage experiment showed that there is a linear relationship between the addition of cement and displacement. As the cement content increases in the soil, the shrinkage decreases. The numerical analysis of Matlab R2013b modelling showed the soil samples with different shear strains along their structural planes. The displacement of the 8% cement sample is less than the displacement of the soil sample with 6% cement content. The numerical analysis show that as the cement content increases, the displacement in the soil sample decreases. The deformations in the positive and negative directions of z-axis showed that the soil sample with 8% cement had more resistance to tensile and compressive shear stresses along its body mass than the soil sample with 6% cement and the other samples. As the cement content increases in the soil samples, the strains decrease.

The shrinkage behaviour of the soil samples with different cement content in the numerical analysis showed that the swelling and shrinking of water had an effect on the deformation behaviour in the z-axis as the cement increases, the hydration reaction between cement and water in the soil increases consequently. This affects the shrinkage behaviour of the soil that is shown in 0% cement content soil as it had more displacement and least resistance to heat stress than the other soils. Inversely, as the cement content increases the soil samples would have less strain along its x-y plane and more resistance to compressive and tensile shear stresses.

5. Conclusion

This article has investigated the influence of the addition of cement on the shrinkage of five samples of soil with different cement content. The soil materials picked from earth's surface have been classified according to their particle size. Then the soils were mixed with 20% water and different cement content of (0%, 2%, 4%, 6% and 8%) then were experimented in laboratory in shrinkage experiment and then numerically modelled in Matlab R2013b and compared the results of the two methods and found that as the cement content increases the displacement in the soil sample decreases and that the soil sample with 8% cement content has more resistance to shrinkage, tensile and compressive shear strains with less displacement than the soil with 6% cement, which has less resistance to heat stresses and more displacement.

The work presented in this paper led to the following conclusions:

- In soil classification test, the soil materials were classified by their particle size into Clay = 11% silt = 40% sand = 49, as shown in the grain size distribution from the soil classification experiments presented in Figure 3.
- The elasto-plasticity of soil changes by the addition of water as it modifies the particle size of soils that have been tested in shrinkage experiment.
- Results of the shrinkage experiment of soil trough samples with different cement content shows a linear relationship between the cement content and shrinkage, as the cement content increases the shrinkage of soil samples decreases.
- Numerical analysis of Matlab software indicated various shear strains in soil samples, the soil sample with 8% cement had more resistance to heat stresses along its body mass, and less displacement than the other soil samples with less cement content.
- The soil sample with 8% cement had more resistance to tensile and compressive shear stresses resulted from heat temperature than the other samples with less cement content.

Competing Interests

The authors declare no competing interests.

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Author Contribution

Mohannad Sabry has performed the experimental work and prepared the manuscript. He did the sieve, hydrometer and shrinkage experiments in soil engineering laboratory. Professor Chin Leo from the University of Western Sydney has supervised the experiments, Mohannad Sabry has discussed the experimental data among all authors.

Notations

g_1: heat boundary condition in room temperature

g_2: heat boundary condition for outer temperature

q_{11},q_{12}: spring constants front and back side of trough

q_{21}, q_{22}: spring constants side-ways of troughs

(h_{11}, h_{12}): weighs for front and back side of the structure

(h_{21},h_{22}): weighs for side-ways of the 2-D rectangular trough

r_1: displacements in front radius of the trough

r_2: displacements in back radius of the trough

K: percent finer by total mass

Cc: coefficient of curvature

Cu: coefficient of uniformity

L: length of trough

Ls: longitudinal shrinkage

LS: linear shrinkage in mm

E: elasticity

N_u: poisson's ratio

K_x: volume-force x-direction

K_y: volume-force y-direction

Rho: density

w/(m.k): watt/metre/kelvin

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