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INVESTIGATION OF THE GEOTECHNICAL CHARACTERISTICS OF CEMENT STABILIZED SAND FOR BACKFILLING BEHIND RETAINING WALLS

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ملخص البحث

يعتبر ضغط التربة الفعال الناتج عن تربة الردم هو الحمل الرئيسى المؤثر فى تصميم الحوائط الساندة. فيمكن استخدام الأرفف او الاجنحة الخرسانية فى هذه الحالة من أجل تصميم الحائط وضمان إتزانها. كما يمكن إستخدام الوحدات المنفصلة مثل أكياس الرمل وبلوكات الفوم أو يمكن إستخدام مادة أسمنتية تؤدى إلى بعض التلاحم للردم خلف الحوائط الساندة بهدف تقليل ضغط التربة الفعال المؤثر. يتضمن هذا البحث دراسة الخصائص الجيوتقنية للرمل بعد إضافة أسمنت بورتلاندى بنسب مختلفة تتراوح من 7% إلى 10% من وزن الرمل ومحتوى ماء – أسمنت من 1:1 إلى 2.5 :1 خلال عده أيام للمعالجة (1، 2، 7 و 28 يوم). كما يتضمن البحث مثال تطبيقى بإستخدام التحليل العددى تم فيه إستخدام الخصائص الجيوتقنية لخليط الرمل والأسمنت التى تم الحصول عليها من تجارب معملية مكثفة.

ABSTRACT

The geotechnical characteristics backfill material used behind retaining walls influentially govern the intensity of the created active lateral earth pressure, as it could be considered the dominant load acting on these walls. Sometimes walls of considerable height lacked ability to sustain adequate wall stability. In such case, the commonly measured to be taken is either to increase the wall and foundation dimensions or to use additional resisting elements (i.e. keys, shelves or wings). Nevertheless, discrete units (e.g. sand bags, foam blocks or gabions) and cementitious materials are different backfilling techniques deemed to reduce the lateral earth pressure acting on the retaining walls.

This research illustrates the improvement can be gained in geotechnical properties of clean sand after mixing with ordinary Portland cement. An intensive laboratory program was carried out to study the following parameters: cement percentages range from 7% to 10% by weight of dry sand, water-cement ratios range from 1:1 to 2.5:1 for several curing periods of 1, 2, 7 and 28 days. The results showed a creation of cohesion in sand-cement mix with slight change in angle of internal friction. The geotechnical properties of sand-cement mixture resulted from the laboratory experiments have been used in a numerical example to study the effect of different backfilling behind retaining walls.

Keywords: retaining walls, Portland cement, lateral earth pressure, Unconfined, Shear parameter.

1. INTRODUCTION

Well compacted sand and gravel are the common backfilling materials to be used behind retaining walls. This sort of backfill is generally characterized as non-cohesive and non-plastic soil, i.e. the soil cohesion is negligible and the soil shear strength is solely dependent upon the internal friction angle. It has been well recognized that the active lateral earth pressure can be decreased by increasing the soil shear parameters (C&φ). In accordance, the concept of using a cementitious material has been arisen, with a simple theme of mixing the conventional granular backfill with water and suitable cementitious binder. Lime and cement are the most common cementitious binders. Several efforts were exerted in finding out backfill material that can reduce the lateral earth pressure behind retaining walls. Among these efforts, the recent study intended to the idea of using Cement Stabilized Sand (CSS) behind retaining walls, through laboratory research, field research and parametric numerical application to study cement type and water ratios with different curing techniques.

2. BACKGROUND

Mixing clean sand with variable percentages of Portland cement yields to nonlinear increase in cohesion (Abdulla and Kiousiss, 1997). Meanwhile (Consoli; et al 2007) elaborated the influence of cement amount, moisture content and porosity on the strength of artificially cemented sandy soil. Their results indicated linearly increasing in unconfined compression strength by increasing cement content.

The unconfined compressive strength of different soil samples mixed with Portland cement and cured for 7 days showed increase in the peak axial stress and decrease in strain due to the addition of cement, the non-treated samples show a ductile behavior – bulging type of failures (Sariosseiri and Muhunthan, 2008). The same observations have been reported by (Shooshpasha and Shirvani, 2015) after stabilizing sandy soil with lime Portland cement.

(Alkarni and Elkholy, 2012) stated that adding Portland cement to dune sand with (5%- 7% - 9%) cement content by dry weight showed improvement in sand properties such as maximum dry density and shear parameters especially at cement content of 9% after three curing days.

Different researches studied the effect of adding more than one cementing agent with the hosting soil. Hamidi and Hooresfand, 2012 added 3% Portland cement combined with poly propylene fibers to clean sand, A Triaxial test was carried out after curing for 7 days. The results showed that, by adding fibers to sand-cement mixture, peak and residual shear strength increased and the brittle failure behavior became more ductile. (Ates, 2016) added of glass-fiber and white cement as a reinforcement to improve the mechanical properties of sandy soil was used. He found that, the best mixing percentage was 3% of glass fibers and 15% white cement for higher unconfined compressive strength, and he reported a reduction in failure displacement and increasing the brittle behavior of samples. Lemaire, et al 2013 treated silty soil with Portland cement and lime, and the samples were cured for long period of time. The results showed an immediate improvement in the unconfined compressive strength for the treated soil with 1% lime and 5% Portland cement.

Hashad and El-Mashad, (2013) used field tests and reported that, mixing the hosting soil with cement dust is the best among other materials (granular compacting soil, gabions, geogrid reinforcing) in reducing the lateral earth pressure on retaining wall, and improving seepage and permeability properties of sandy soil behind the wall. For road construction Pandey and Rabbani (2017) reported that, as the cement content increased, the dry density decreases and the moisture content increases. In addition, the unconfined strength increases especially with long periods of curing.

Several researches used numerical analysis to study the effect of using geofoams and shelves on reducing lateral earth pressure behind retaining walls, i.e. (Dave and Daska, 2015 and Khan; et al 2016)

3. EXPERMENTAL WORK AND RESULTS

An intensive laboratory program was planned to evaluate the unconfined compressive strength and direct shear tests of cement stabilized sand (CSS) with cement percentages of 7%, 8%, 9% and 10%) by weight of dry sand, Water-cement ratio (w/c) of 1:1, 1.5:1, 2:1 and 2.5:1) and curing period of 1, 2, 7 and 28 days. Pure sand was tested in the laboratory to determine the geotechnical properties as reference.

3.1. Pure sand properties

Laboratory tests were performed on clean sand and it is classified as poor graded medium to coarse sand according to the unified system. The average value of coefficient of curvature Cc is 1.034 while the average value of coefficient of uniformity is 2.494; grading curve is presented in figure (1). The average value of specific gravity Gs is 2.64. Modified Proctor compaction test indicate that, the maximum dry density of sand to be 18.3 kN/m^3 at 10% optimum moisture content. The direct shear test for sand at maximum dry density, the angle of internal friction is 33.60 degree.

3.2. Mix sample preparation

CSS samples were divided into two groups, the first one was (unconfined compression strength test) using cylinder molds of 150 mm diameter and height of 300 mm. the second group was for direct shear test using cubic specimens with dimensions of 100*100 mm and 20 mm high. Samples were stored in clean and dry place in natural atmosphere after preparation and cured using wet sponges on the top surface of samples to maintain samples moisture to avoid water evaporation until test day.

3.2.1. Mixing and remolding process

1. According to the sample dry weight, cement and water were estimated by weight.
2. Molds were cleaned and lubricated to minimize the side friction during extracting the samples.
3. In dry state, the required amounts of sand and cement were mixed in electric mixer for two to three minutes until homogeneous mix is reached. Then water was added to dry sand-cement mixture in electric mixer for three to four minutes until homogenous mix was reached.
4. The unconfined cylinders mold height was divided into 4 equal levels to ensure equal layers, and then the mixture was poured from the height of mold surface without compaction. Each layer was leveled before adding the next layer and the last layer was leveled by the surface.
5. In direct shear cubes mixture was poured in two equal layers about 1.0 cm per layer without compaction, and the last layer was leveled at the surface.

3.2.2. Samples extracting process

For curing days 2, 7 and 28 days samples were extracted from molds after two days, and wrapped in plastic stretches and labeled with number and test date. For curing one day, samples were extracted after one day and tested.

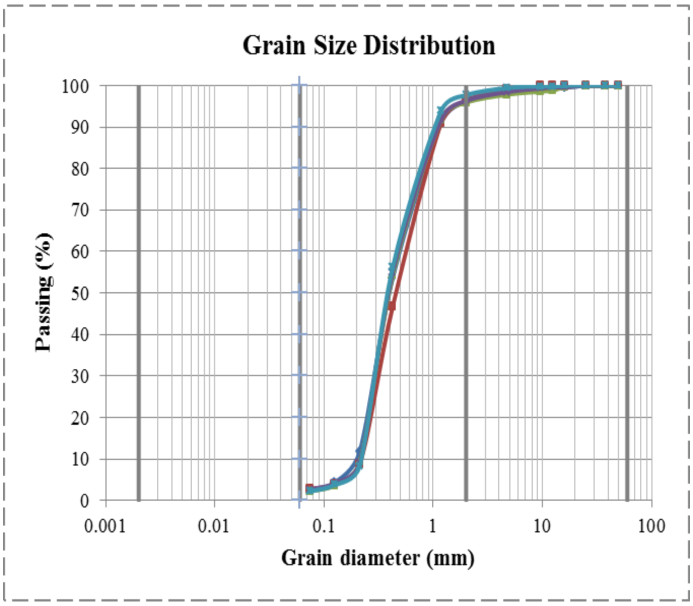

Figure (1): Pure sand grading curve

4. RESULTS

4.1. Unconfined compression strength test

Sixty four CSS samples were prepared to cover the range of cement contents, water-cement ratios, and curing days for the unconfined compression strength test. The unconfined compressive strength relation for different curing days with different cement contents and water-cement ratios are shown in figures from (2) to (5). This set of graphs clearly indicate that, unconfined compressive strength increase with the increase of cement amount, water-cement ratio and curing period.

Unconfined compressive strength increased in obvious values when increasing cement content from 7% to 10%. Also unconfined compressive strength increased with curing time. While water-cement ratio has shown different pattern, unconfined compressive strength increased for water-cement ratio up to (2:1), and then decreased with the increase of water-cement ratio. This is may be referred to the extra amount of water that didn’t help in strength as much it helped with the workability. Cement and sand mixtures absorb the required amount of water for chemical reactions but the extra amount of water weakened CSS samples. Regardless cement content (%) or curing period, it can be observed that the optimum water-cement ratio for maximum unconfined compressive strength is in the range of (1.5:1) and (2:1). As shown in figures from (6) to (9).

Experimental results showed that, there is an obvious increase in unconfined compressive strength of CSS samples for cement content from 7% to 9%, and any other increase in cement content afterward hasn’t significant influence on CSS strength except in the case of water-cement ratio of (1.50:1.0). Figures (10) to (13) present these observations.

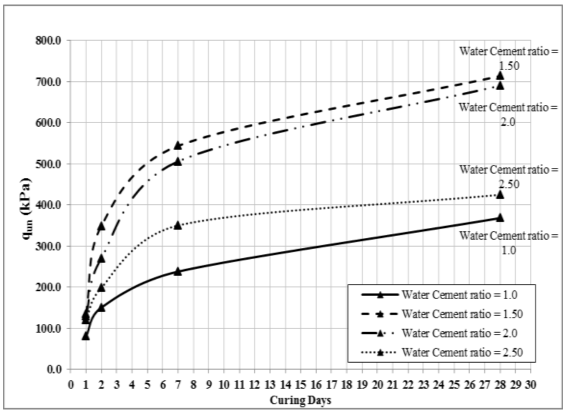

Figure (2): Unconfined compressive strength relationship with curing days at cement content of (7%) at different water-cement ratios

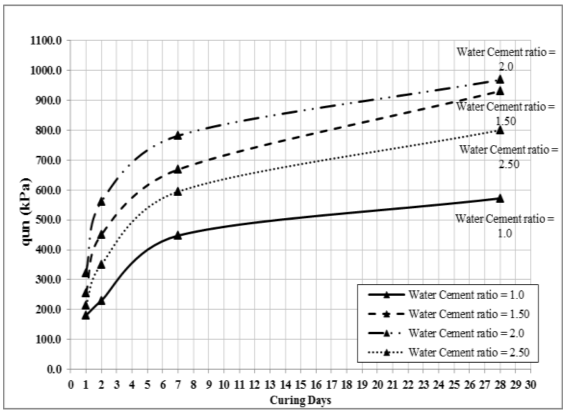

Figure (3): Unconfined compressive strength relationship with curing days at cement content of (8%) at different water-cement ratios

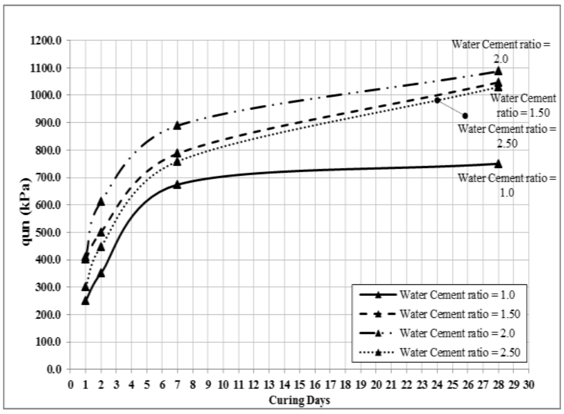

Figure (4): Unconfined compressive strength relationship with curing days at cement content of (9%) at different water-cement ratios

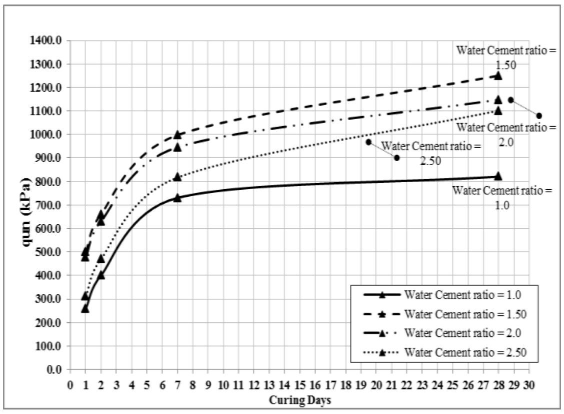

Figure (5): Unconfined compressive strength relationship with curing days at cement content of (10%) at different water-cement ratios

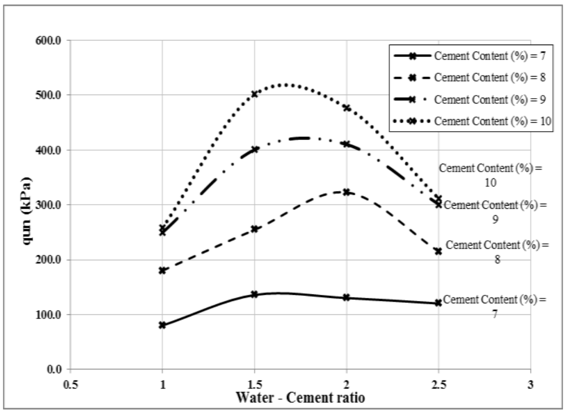

Figure (6): Unconfined compressive strength relationship with water-cement ratio at (1) curing day at different cement contents

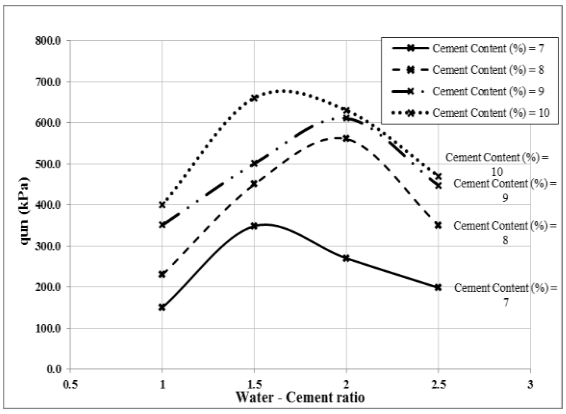

Figure (7): Unconfined compressive strength relationship with water-cement ratio at (2) curing days at different cement contents

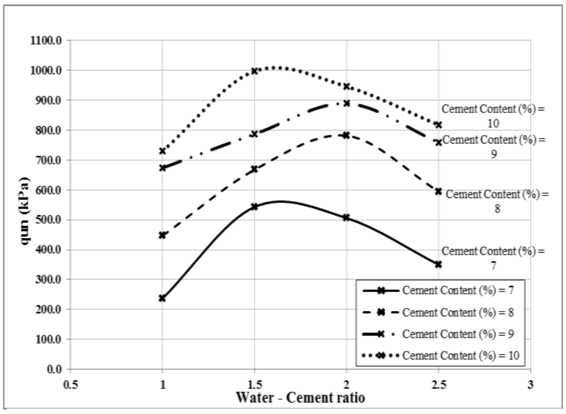

Figure (8): Unconfined compressive strength relationship with water-cement ratio at (7) curing days at different cement contents

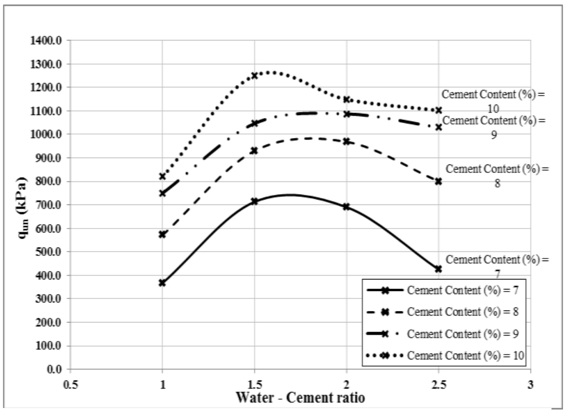

Figure (9): Unconfined compressive strength relationship with water-cement ratio at (28) curing days at different cement contents

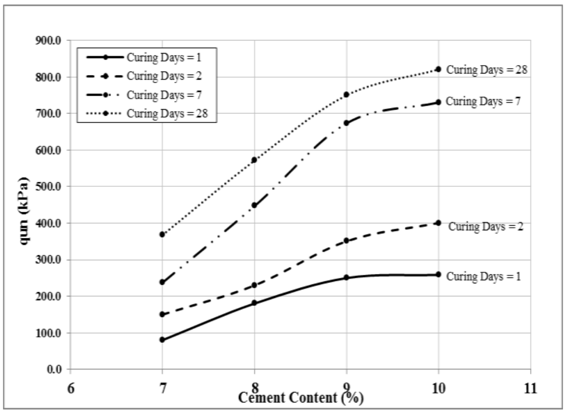

Figure (10): Unconfined compressive strength relationship with cement content at water-cement ratio of (1:1) at different curing days

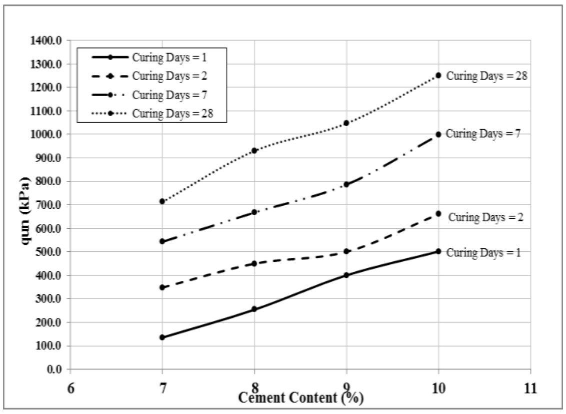

Figure (11): Unconfined compressive strength relationship with cement content at water-cement ratio of (1.5:1) at different curing days

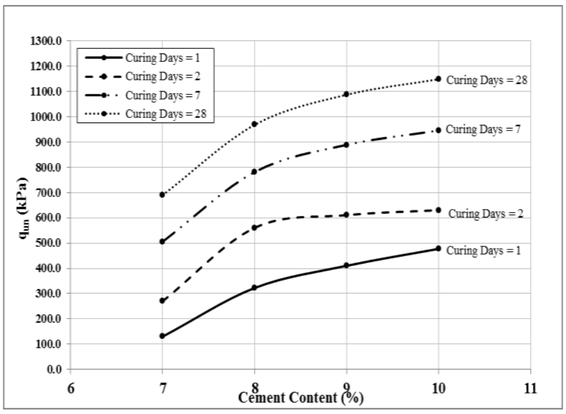

Figure (12): Unconfined compressive strength relationship with cement content at water-cement ratio of (2:1) at different curing days

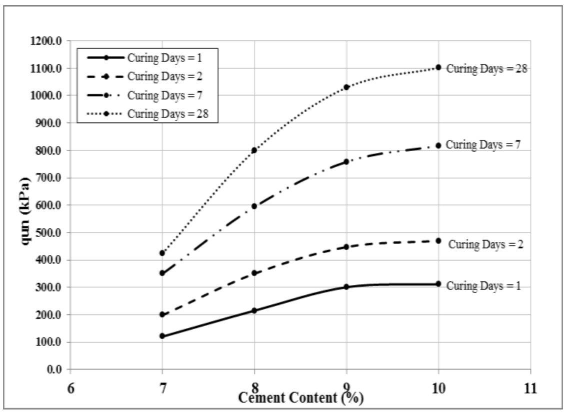

Figure (13): Unconfined compressive strength relationship with cement content at water-cement ratio of (2.5:1) at different curing days

4.2. Direct shear test

Direct shear tests were performed on CSS samples for two cement contents (8% and 10%) with one water-cement ratio (2:1) for three curing periods of 1, 2 and 7 days. Figure (13) shows that at cement content of 8% and water-cement ratio of (2:1); the cohesion intercept (c) after one curing day was 30.5 kN/m^2. Cohesion intercept increased to reach 60.8 kN/m^2 after seven days of curing. While the angle of internal friction (φ) hasn't expressed an increase through curing days, but it could be observed that with increasing curing days the angle of internal friction expressed reduction in value from 30.82° to 26.36°. However at cement content of 10% and water-cement ratio of (2:1), cohesion intercept was 10.5 kN/m^2 at the first day of curing then increased to reach 98.9 kN/m^2 at seventh day of curing. The angle of internal friction expressed the same behavior as at 8% cement content. The angle of internal friction reduced from 46.40° at one curing day to reach 33.02° after seven days of curing as shown in figure (14). Comparing the angle of internal friction (φ) of pure sand with CSS samples of 8% cement content and water-cement ratio of (2:1) after one day of curing, it was noticed a reduction of (φ) from 33.60° at raw sand to be 30.82° at 8% cement content. That could be a result of increasing the fines content in sand particles. While the angle of internal friction was 46.40° for CSS samples with 10% cement content after one day of curing. Direct shear test results are summarized in table (1).

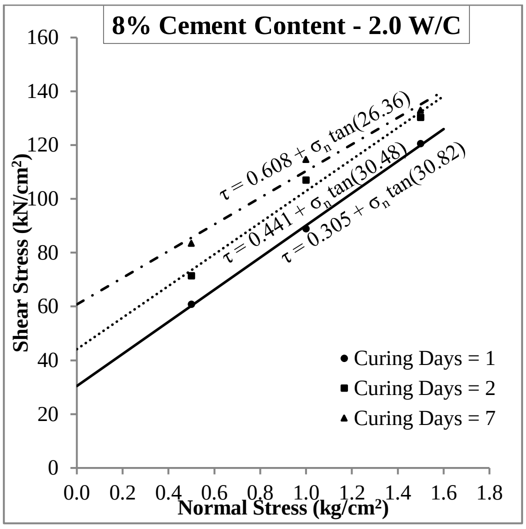

Figure (13): shear envelope of 8% cement content with (2.0:1) water-cement ratio after 1, 2 and 7 curing periods

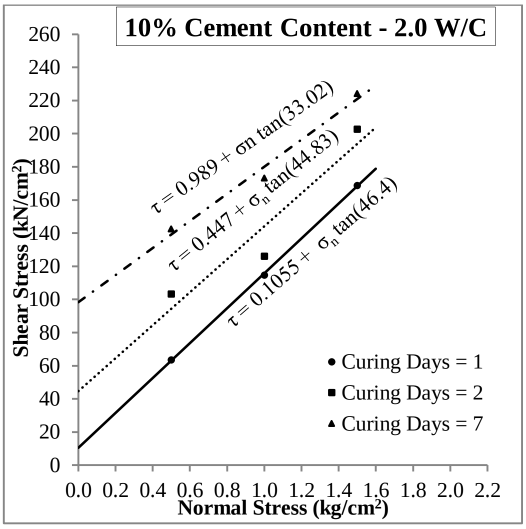

Figure (14): shear envelope of 10% cement content with (2.0:1) water-cement ratio after 1, 2 and 7 curing periods

Table (1): direct shear test results summary

CSS samples	8% CSS with 2:1 water-cement ratio			8% CSS with 2:1 water-cement ratio		
Curing periods	1	2	7	1	2	7
Cohesion intercept (kPa)	30.5	44.1	60.8	10.5	44.7	98.9
Th angle of internal friction (°)	30.82	30.48	26.36	46.40	44.83	33.02

5. NUMERICAL EXAMPLE OF RETAINING WALL WITH DIFFERENT BACKFILLING

A numerical study has been executed using (Plaxis 2D) on an example of existing retaining structure with 5.50 meter high and 1.0 meter base width subjected only to its own weight, to study the effect of backfilling material behind the wall. The study divided into two numerical models. The first model was established to simulate the retaining wall backfilled with compacted pure sand in 11 layer/0.50 meter per layer. The second one has been carried out with the same dimensions of the retaining wall backfilled with CSS material using the properties resulted from the laboratory experiments 11 layer/0.50 meters per layer, Plane-Strain model has been created to simulate the best dimensions of CSS fill as backfill behind the retaining wall. CSS cluster properties were defined using Mohr-Coulomb failure criterion as summarized in table (2). The retaining wall was defined as a linear elastic concrete material with density (ɤ) of 25 kN/m3 and modulus of elasticity (E) of 2.200E+07 kPa. Sensitivity analysis was carried out to determine the appropriate dimensions of the numerical model boundary condition as shown in figure (15) and (16)

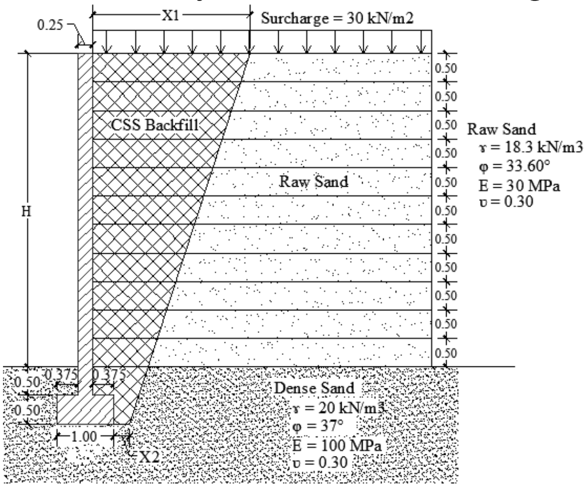

Figure (15): retaining wall dimensions

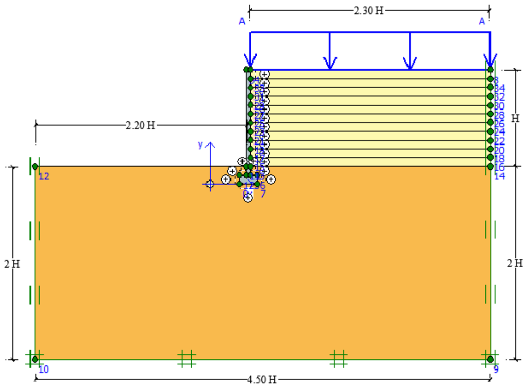

Figure (16): retaining wall model backfilled with pure sand backfill

Table (2) CSS fill material properties

Cement Content (%)	8			10		
Water-Cement ratio	2:1			2:1		
Curing Days	1	2	7	1	2	7
Bulk density, ɤ (kN/m^3)	17.70			19.30		
Angle of internal friction, φ (°) according to direct shear test	30.82	30.48	26.36	46.40	44.83	33.02
Cohesion, C (kN/m^2) according to direct shear test	30.50	44.10	60.80	10.60	44.70	98.90
Modulus of elasticity, E (MPa) according to stress-strain relation of direct shear test	115.0	147.7	200.2	110.3	180.0	200.7
Poisson ratio, υ	0.30			0.30		
Surcharge (kN/m2)	30					

5.1. Pure sand backfill

The properties of compacted raw sand as backfill behind the retaining wall could not be applied on more than 5 layers (0.50 meter per layer). Retaining wall model failed (due to the initiations of plastic points) after adding more than 5 layers of raw sand as shown in figure (17). To determine the factor of safety after adding the fifth layer, C-Phi reduction technique was used. The factor of safety (FOS) reached 1.4142.

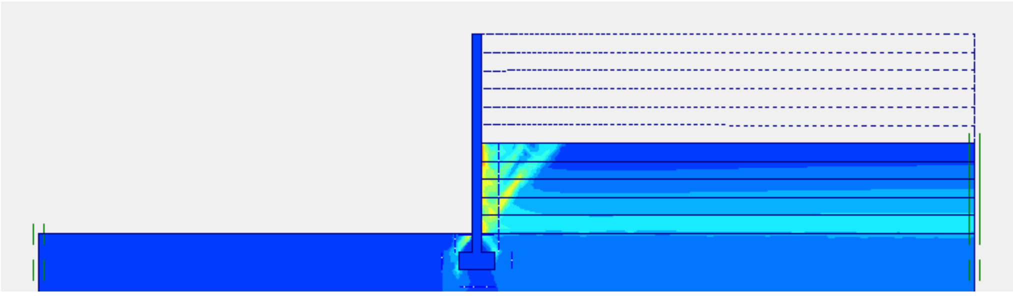

Figure (17): shear strain mode of using raw sand as backfill behind retaining wall up t to layer 5

5.2. CSS as backfill behind retaining wall-model

A numerical parametric study was carried out to detect the minimum width of CSS fill behind the retaining wall to assure the completion of backfill layers and the strength to carry 30 kPa surface surcharge with factor of safety (FOS) more than (1.25), as the minimum accepted value. The parameters were taking into consideration the horizontal distances (X1 and X2) presented in figure (15). The studied distance was taken as a ratio of free height of the wall (H = 5.50 m).

5.3. Results and discussion

Numerical parametric study showed that, the minimum horizontal distance of CSS backfill from the corner base of the retaining wall from the active side of the wall (X2) cannot be zero and should not be less than (0.05 H) and the minimum horizontal distance from the top of the wall (X1) should not be less than (0.50 H). The minimum factor of safety was found to be 1.2981 using 8% cement content at the combination of (X2=0.05 H) and (X1=0.50 H). Also figure (18) presents the relationship between the horizontal distance (X1) and FOS in different cases of (X2) using 8% CSS with water-cement ratio of (2:1).

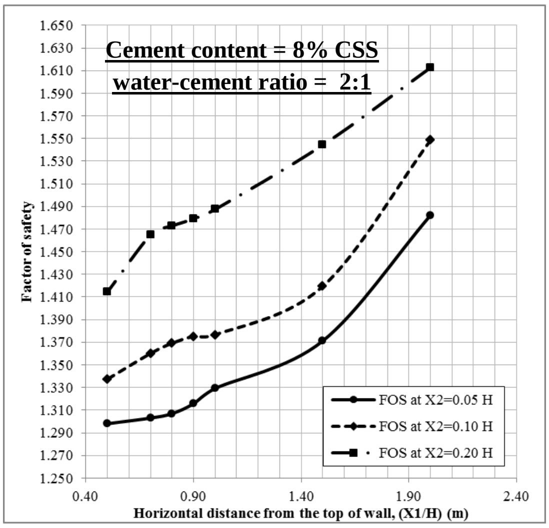

Figure (18): relationship between horizontal distance (X1) and FOS with different (X2)

6. CONCLUSIONS

1. To create Cementitious sand material, the best Portland cement mixing percentage is 9%, as any more increase shall have negligible effect on the unconfined compressive strength of the prepared mixture.
2. The optimum water-cement ratio that yields unconfined compressive strength is in the range of (1.5:1) and (2:1). Although water-cement ratio of (2.5:1) improved the workability of CSS mixtures. The unconfined compressive strength becomes less.
3. Curing period is an important parameter for CSS samples strength as samples gained most of its strength from day 2 to day 7 to reach its maximum strength at day 28. Also it was noticed that as the curing period increased, CSS samples cohesion parameter increased, while the angle of internal friction decreased.
4. The numerical parametric study using (Plaxis 2D). showed that the best dimensions for CSS backfill behind retaining wall (X1) and (X2) shouldn't be less than (0.50 H) and (0.05 H) respectively. As H is the free height of the wall.
5. The wall dimensions are important factors in choosing the backfilling, the wall with base width (≤ 0.20 H) can't support pure granular backfilling, but it can support CSS backfill with surface surcharge up to 30 kPa.

7. REFERENCES

[1] Abdulla, A.A., Kiousis, P.D (1997) "Behavior of Cemented Sands – Testing", International Journal for Numerical and Analytical Methods in Geomechanics vol. 21, 533-547.

[2] Consoli, N.C., Foppa, D., Festugato, L. and Heineck K.S., (2007) "Key Parameters for Strength Control of Artificially Cemented Soils", JOURNAL OF GEOTECHNICAL AND GEOENVIRONMENTAL ENGINEERING.

[3] Sariosseiri, F., Muhunthan, B. (2008) "Effect of cement treatment on geotechnical properties of some Washington State soils", Engineering Geology 104 119–125.

[4] Alkarni, A., Elkholy, S.M., (2012)"Improving geotechnical properties of dune sands through cement stabilization', Journal of Engineering and Computer Sciences, Qassim University, Vol. 5, No. 1, pp. 1-19.

[5] Hamidi, A., Hooresfand, M., (2012)" Effect of fiber reinforcement on triaxial shear behavior of cement treated sand", Geotextiles and Geomembranes 36.

[6] Hashad, A., El-mashad, M. (2013) "Assessment of soil mixing with cement kiln dust to reduce soil lateral pressure compared to other soil improvement methods", Construction Research Institute, National Water Research Center, Egypt.

[7] Lemaire, K., Deneele, D., Boneet, S. and Legret, M., (2013) "Effects of lime and cement treatment on the physicochemical, microstructural and mechanical characteristics of a plastic silt", Engineering Geology 166.

[8] T. N. Dave and S. M. Dasaka, (2014) "Surcharge Induced Earth Pressure Reduction on Rigid Retaining wall using EPS Geofoam," Tunneling and Underground Construction GSP 242 © ASCE,.

[9] Shooshpasha, I.,Shirvani, R.A., (2015) "Effect of cement stabilization on geotechnical properties of sandy soils", Geomechanics and Engineering ·

[10] Ates¸ A., (2016) "Mechanical properties of sandy soils reinforced with cement and randomly distributed glass fibers (GRC)", Composites Part B 96.

[11] Khan, R., Murty, D., Chauhan, V.B., (2016) "Reduction of lateral earth pressure on retaining wall using relief shelf: A numerical study," in International Conference on Soil and Environment, ICSE.

[12] Pandey,A., Rabbani, A., (2017) "Soil stabilisation using cement", International Journal of Civil Engineering and Technology.