University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq
Volume 28 Number 9 September 2022

Experimental Investigation of Crack Initiation and Growth in Concrete Slabs Placed Directly on Clayey Soil

Ahmed Assim Abdullah *
PhD Student
College of Engineering
Gaziantep University
Gaziantep-Turkey
ehitusinseneer@gmail.com

Prof. Dr. Hanifi Çanakcı
Professor
College of Engineering
Hasan Kalyoncu University
hanifi.canakci@hku.edu.tr

ABSTRACT

The main objective of this study is to examine the impact of moisture concrete of clayey soil on the concrete slabs placed directly over it. This experimental study presents the mechanical properties of the concrete slab when placed on different clayey soil moisture content ranging from 0% to the optimum moisture content of 35%. The tests were performed on soil concrete specimens of 25*30*50 mm exposed to sprayed water curing conditions for 28 days. Tests of compressive strength, ultrasonic pulse velocity, crack depth and crack width were investigated through this paper. An ejection relationship between compressive strength of concrete and water content in the soil was observed, with a 26% increase with water increasing from 0% to 35%. The opposite was observed in the ultrasonic pulse velocity test, with a decrease of 58% from 0% to the highest water content ratio. As for crack depth and width, it recorded the highest depth and lowest width at 0% water content due to the increased susceptibility of the soil to the absorption of water from the concrete when it's totally dry. The experiment has shown that the soil moisture content is considered as a critical factor in controlling concrete cracking, and its variation has considerable implications for concrete crack growth.

Keywords: clay, compressive strength, ultrasonic pulse velocity, crack depth, crack width.

التحقيق في بدأ ونمو الشقوق في الالواح الخرسانية الموضوعة مباشرة على التربة الطينية

أحمد عاصم عبد الله *
طالب دكتوراه
كلية الهندسة
جامعة غازي عنتاب
غازي عنتاب-تركيا

حنفي جاناكجي
استاذ
كلية الهندسة
جامعة حسن كاليونكو

الخلاصة

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2022.09.07

Article received: 20/5/2022
Article accepted: 7/8/2022
Article published: 1/9/2022

تعتبر الاسس من اهم الاجزاء الانشائية لما لها من اهمية في اسناد المنشأ وتوزيع الاحمال . خلصت هذة الدراسة الى معاينة منطقة التلاصق بين الاسس الكونكريتية والتربة مختبرياً بتغيير المحتوى الرطوبي للتربة من الصفر وصولا للحد الاقصى وبظروف معالجة تحد من اضافة او فقدان الرطوبة من الكتلة الكونكريتية الممثلة للاساس داخل القالب وبمدة لاتزيد عن 28 يوم . وبعد المعاينة الدقيقة تم الكشف عن وجود تشققات شعرية غير ظاهرية بأبعاد واعماق مختلفة بتغيير المحتوى الرطوبي للتربة . هدفت هذة الدراسة بأستخدام الفحوصات المختبرية كفحص الانضغاط للنماذج الكونكريتة و بأستخدام سرعة الموجات فوق الصوتية واجهزة المايكروسكوب الى دراسة مدى تأثير التشققات الشعرية في الكتلة الكونكريتية للجزء الملامس للتربة على قوة الانضغاط وتعيين المحتوى الرطوبي المناسب للتربة للحد من تأثيرات التشققات في الاسس بفعل فقدان الرطوبة ووجد ان زيادة المحتوى الرطوبي للحد الاقصى تسبب في اضافة الماء للخرسانة وبأستخدام تربة ذات محتوى رطوبي ضعيف تسبب في امتصاص الماء من الخرسانة مما اثر سلباً على قابلية التحمل للانضغاط و زيادة في عمق التشققات في منطقة الاتصال بين التربة والاساس .

الكلمات الرئيسية: الطين ، قوة الضغط، سرعة النبض بالموجات فوق الصوتية، عمق الشق الخرساني ، عرض الشق الخرساني.

1. INTRODUCTION

In order to sustain, maintain, and defend a structure, its foundation must be considered. The foundation's quality must be replicated today because of the advancements in construction. In a natural disaster, such as an earthquake, flood, or severe wind, the foundations will hold and distribute the structure's weight and keep the structure safe. The moisture content of the ground soil should be controlled so that not to penetrate the structure and weaken it. The clay soil has a property that makes it not an ideal choice to construct above without stabilization or treatment **(Coduto, 1999)**. The clay soil tends to expand and absorb large amounts of water, foundations can shift up or down **(Das and Sobhan, 2013)**. It's possible that this shift will eventually cause the foundation to crack. Improvements to clayey soils usually necessitate a variety of ground improvement methods. A standard method is the use of stone columns, which are inserted vertically into clayey soils. This method was used by **(Al-Kubaisi, 2018)** to investigate how the stone columns affected the circular footings and see how they affected them. When the column length was increased, the results showed that the bending moment, the settlement, and the vertical stresses all decreased.

On the other hand, the horizontal stress and the shear force both increased. Using chemical additives is yet another method that can be utilized., **(Ardakani and Rajabi, 2021)** For soil enhancement, varying percentages of sepiolite were utilized. To investigate the effects of sepiolite on clayey sand soil, tests of Atterberg limits, compaction, compressive strength, pH, direct shear, and permeability were performed. It was discovered that filling the pores with sepiolite additive increased the strength by three times, as well as the permeability, liquid limits, and plastic limits. **Singh and Singh, 2022** Overall load bearing capacity of clayey & sandy soils improved significantly when pin piles were inserted to a shallow depth, according to research. **Gupta and Kumar, 2022** Improved clayey soil by using varied proportions of Fly ash plus Jute Fibers. Results from the tests of proctor compaction and the unconfined compressive strength, California Bearing Capacity of clayey soil indicated a significant increase in mechanical properties of the soil treated with fly ash and jute fibers.

Furthermore, **(Miraki et al., 2022)** Researchers studied the mechanical qualities, such as strength and durability, of alkali-activated ground granule blast furnace slag (GGBS) plus volcanic ash (VA), and found that both materials can be utilized to stabilize clayey soils. In order to increase the uniformity, compaction, and shear strength of clayey soils, hydrated lime can be used. The hydrated lime can be utilized to improve clayey soil because the treated samples exhibited an increase in consistency, strength, and compaction properties **(Abdalla and Salih, 2020).**

As water content increases over the ideal level, clayey soil's strength and stiffness decline noticeably. **(Dhakal, 2012).** It is essential to study how concrete structures crack and shrink, especially those outside structures that get heavy loads repeatedly. The long-term properties of the natural soils are affected by how wet and cold they are **(Tang et al., 2021)**.

Due to the high importance of soil-structure interaction on the analysis of the structure, large number of studies carried out in the literature to investigate the effects of soil on the structure. The study of (Fontan et al., 2011) has shown the effects and complexity of soil-structure interaction on the reinforced bridge and how it is essential to take into account the soil properties to avoid any damage. And due to the normality of clayey soil, which is considered a nonlinear and heterogeneous material, **(Frank and Thepot, 2005 and Viladkar et al., 2006)** have studied the nonlinear effects on the stiffness of the soil under the foundations. **Jahangir et al., 2013** investigated the analytical model of soil-structure interaction to study the effects of the shrinkage of the soils on the buildings. **Zolghadr Jahromi, 2009** investigated the considerable effect of soil-structure interaction on the various civil engineering structures design. Also, **(Fenton and Griffiths 2002)** showed the critical role of soil structure interaction on the response of the coupled system. In this regard, **(Elachachi et al., 2004 and Elachachi et al., 2012)** studied the influence of soil-structure interaction on the embedded pipe networks.

Although the little effects of the soil-structure interaction have been studied widely, few types of research focused on the variability of soil properties on the structure **(Kamel Bezih et al., 2015)**. This variability considers a complex character as it can vary with time and space.

It is necessary to consider the properties of soil and its variability due to its significant influence to the behavior of the structure, as the random and nonlinear behavior can result in insufficient reliability levels **(Kamel Bezih, 2015).** When the soil's nonlinear behavior is considered, the interaction between the soil and the structure can reliably cause the reinforced concrete structure to fail. **Shakir and Zhu 2009** tested the shear strength of the clay-concrete interface where two types of concrete were used; smooth and rough surface concrete with a fixed number of dry materials and different water proportions. The results indicated that the shear strength increased by increasing water content, especially in rough surface concrete. **Canakci 2011** looked into the friction between organic soil and building materials at the interface (concrete, wood, and metal). Three samples of soil with a fixed amount of water were put through a direct shear test (0 percent, 25 percent, 50 percent, and 75 percent). They used three different normal forces and the maximum shear stress at a strain rate of 10%. The results showed that the organic soil's water content, the surface's roughness, and the type of material should be considered when studying the friction angle between the organic soil and the building materials. **Ramseyer 2015** Researchers looked at what happened when a concrete slab was put on the ground in a controlled environment. They wanted to know how the slab would work when it was exposed to the environment on top and the moist ground on the bottom. Different kinds of concrete were used (normal strength concrete, high strength concrete, concrete with shrinkage reducing, and concrete with calcium sulfoaluminate cement). Tests were done to examine how the joints moved, how the temperature and humidity changed over the slab's depth, and how the material behaved. The

results showed that both the normal-strength and high-strength concrete had cracks, which grew after 600 days. While concrete made with calcium sulfoaluminate cement had been very reliable and didn't shrink, wrap around, or crack over time. When shrinkage is reduced in the concrete mix, it has a small effect at a young age and a negligible effect on long-term sectional stability. **Djamila 2018** The effect of adding admixtures like limestone powder, granulated slag, and natural pozzolana on the correlation (R2) with both compressive strength and pulse velocity of self-compacted concrete (SCC) that has been cured for 3, 7, 28, and 90 days was studied. The results showed that a good correlation factor can be made for the relationship for both compressive strength and pulse velocity, such as (R2 = 0.85) when adding granulated slag and (R2 = 0.72) when adding stone powder. However, the correlation was lowest when adding pozzolana (R2 = 0.69).
In this experimental study, the effects of different water content in the clayey soil on the mechanical and physical properties of concrete slabs that are placed directly above it to investigate the better water content that leads to minimizing damage to the foundation and the concrete structure. Tests of compressive strength and tensile strength to investigate the effects on mechanical properties and the ultra-sonic pulse velocity to investigate the cracks initiation, growth, depth, and width inside concrete samples with varying soil water content from zero to 35% with an increment of 5%.

2. MATERIALS AND EXPERIMENTAL WORKS

2.1 Materials

2.1.1 Clayey soil

The soil used to treat in this study was collected from the Gaziantep University campus (TURKEY). The soil is classified according to **(ASTM D2487-2017)** as CL. The particle size distribution of the soil was shown in **Fig. 1.**
Table 1 shows some engineering properties that were obtained during the laboratory tests performed to the soil.

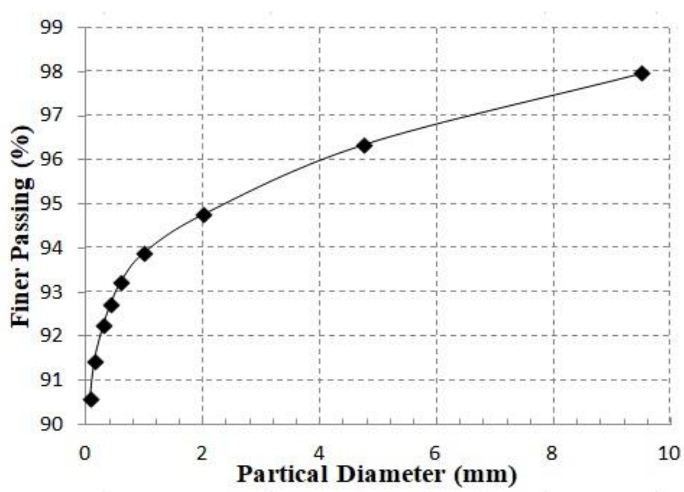


Figure 1. Particle size distribution of soil.

Table 1. Some engineering properties of the untreated soil.

Properties of untreated soil	Results
Liquid limit (LL) %	41
Plastic limit (PL) %	25
Plasticity index (PI) %	16
Specific gravity, GS	2.77
Classification (USCS)	CL
Swelling potential %	3.58

2.1.2 Cement

Ordinary Portland cement (PC CEM, I 42.5R) that complies with TS EN 197-1 was utilized for this investigation. This standard is mainly based on the European EN 197-1 standard. Its specific gravity was 3.15 grams per cubic centimeter, and its specific surface area was 326 square meters per kilogram. Concrete was made with its help; this was an important component. **Table 2** contains information about the cement's physical and chemical qualities

Table 2. Properties of plain Portland cement (CEM I 42.5R).

Composition	Percentage (%)
SiO_2	19.79
Al_2O_3	3.85
Fe_2O_3	4.15
CaO	63.84
MgO	3.22
SO_3	2.755

2.1.3 Aggregate

River gravel with a maximum size of 16 mm was used as a coarse aggregate, while the mixture of natural sand with a maximum size of 4 mm was used as a fine aggregate. Nature sand and river gravel had a specific gravity of 2.66 and 2.72 and a fineness modulus of 2.79 and 5.68, respectively. The sieve analysis results of natural aggregates are presented in **Fig. 2** and **Table 3.**

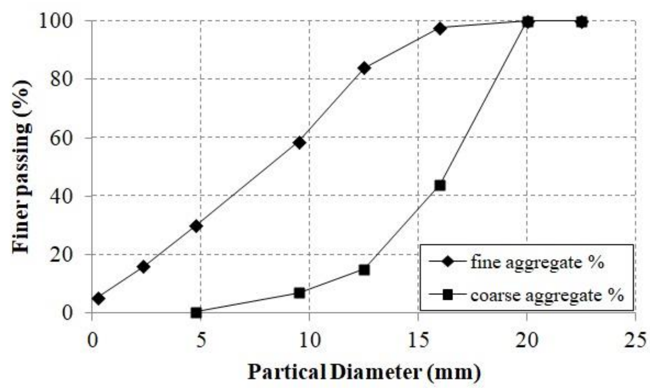


Figure 2. Particle size distribution of soil.

Table. 3. Physical properties and sieve analysis of the aggregate.

Sieve size (mm)	Fine aggregate %	Coarse aggregate %
16	100	100
8	99.7	31.5
4	94.5	0.4
2	58.7	0
1	38.2	0
0.5	24.9	0
0.25	5.4	0
Fineness modulus	2.79	5.68
Specific gravity	2.66	2.72

2.2 Experimental works

In this experimental study, eight mixtures of concrete were cast directly over the clayey soil in 50*25*30 cm wooden molds, **Fig. 3**. The soil was collected from Gaziantep university campus, cleaned and sieved to pass through sieve no. 4, and oven dried at 105℃ for 24 hr to get the fully dry condition. The dried soil was placed at the bottom of the molds at a depth of 10 cm. Compacted layer with different water contents ranged between 0% optimum moisture content, which was found to be 35% with a 5% increment for each sample. The concrete cast using a laboratory pan mixer of 30 Lt capacity and placed at a depth of 20 cm in three layers each layer compacted with a steel rod to remove the excess of air, the process of sample preparation is shown in **Fig. 3**. The samples were cured by sprayed water following ASTM C192/C192 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. The samples were labeled according to the water content of the soil; for example, M2 5% CWC referred to the sample content of 5% in the clay soil, and CWC referred to Clay Water Content. All the samples were then demolded after the curing period of 28 days to be tested for the following tests:

Figure 3. Soil-concrete sample preparation in wooden molds.

2.2.1 Compressive Strength

To determine the compressive strength, a testing machine with a capacity of 3000 KN was used to examine 150 mm by 150 mm cubes and 100 mm by 50 mm cylinders. The procedure is followed ASTM C 39. The experiment was carried out on two cubes measuring 150 mm by 150 mm and two cylinders measuring 100 mm by 50 mm for each mix at the age of 28 days to investigate the effects of variation of water content of the soil on the compressive strength of concrete. The cubic and cylindrical concrete samples were taken from the concrete slab using a coring cutting machine as shown in Fig. 4. The compressive strength was determined by taking the average value of the compressive forces exerted by two cubes two cylinders at each testing age. It is known that the higher water content in concrete leads to lower compressive strength. According to this fact, the change of soil water content will significantly affect the compressive strength by absorption of excess water from concrete in case of dry and low water content soil, which leads to an increase in its compressive strength and vice versa.

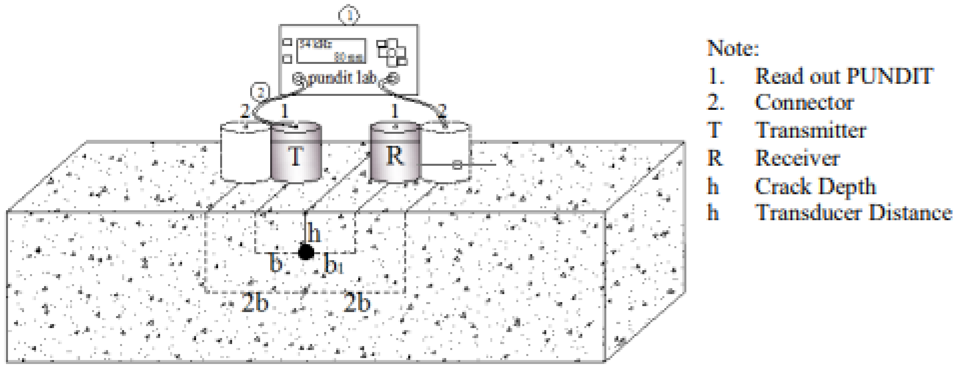
Figure 4. The coring cutting machine.

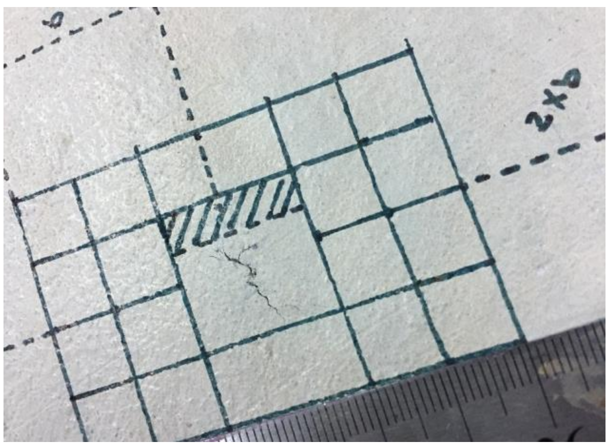
2.2.2 Ultrasonic pulse velocity (UPV)

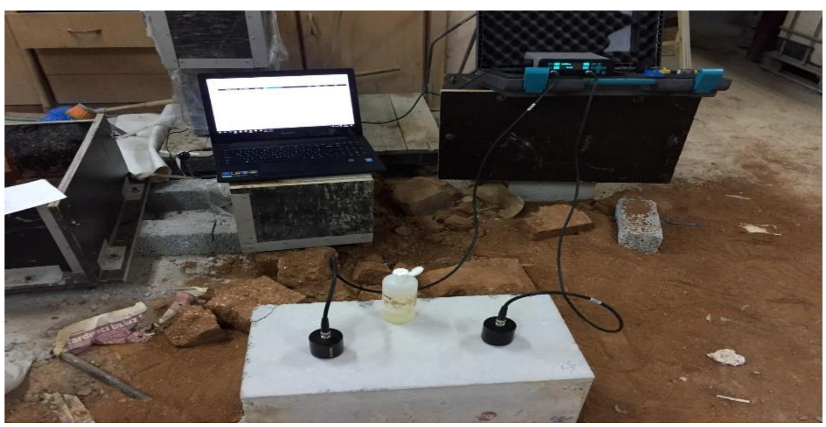
It has proven possible to measure structural damage using non-destructive testing methods. Ultrasonic pulse velocity measurements are used to evaluate the structural integrity of the most common constructions (UPV). Using ultrasound and flight time to evaluate the depth of surface opening cracks is discussed in this paper. When it comes to real-world applications, this strategy comes in handy quite a bit. It's low-cost, quick, and straightforward to perform, so you can see how quickly the cracking has spread.

2.2.3 Surface opening cracks depth by ultrasonic method

Several deterioration mechanisms, including repeated loading, differential settlement, and drying shrinkage, can cause surface opening cracks in concrete. While surface cracks may just damage the concrete's looks in certain situations, in most cases they are a sign of structural distress or diminished endurance. Diffraction BS 1881: Part 203 was used in this investigation to determine the non-destructive depth of cracks. By using PUNDIT tool, the crack depth investigated by the indirect method to measure the time of wave travelling from the transmitter to the receiver which are placed at equal distance from the surface crack line that is b, then the transmitter and receiver were placed on distance of 2b to obtain the second wave propagation measurement, **Fig. 5**. One side of the crack is exposed to stress waves, while the other side is monitored by a sensor placed at an angle to the crack. As seen in **Fig. 5**, Mechanical pulses, such as those delivered by ultrasound equipment, can produce stress waves.


pundit lab
T
R
h
b
b1
2b
2b
Note:
1. Read out PUNDIT
2. Connector
T Transmitter
R Receiver
h Crack Depth
h Transducer Distance





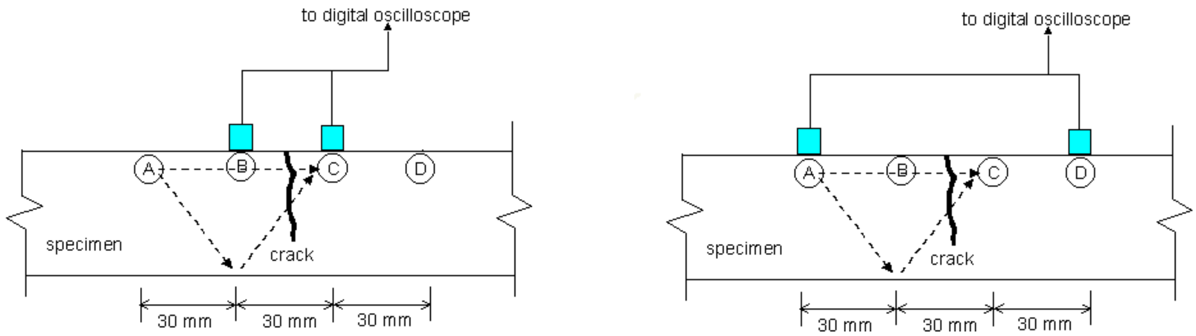


Figure 5. Crack depth measurement by the ultra-sonic method.

2.2.4 Crack width by microscope

This study used a portable Microscope to measure open surface crack width in concrete slabs after 28 days of curing.

3. RESULTS AND DISCUSSIONS

3.1 Compressive strength

In **Figs. 6 and 7**, concrete cubes and cylinder core samples were tested for compressive and tensile strength at 28 days old. 0 percent and 35 percent clay water content, respectively, yielded two series of concrete with early compressive strengths of roughly 22 and 30 MPa, **Fig. 8** shows the concrete sample after failure due to compression. A study found that the compressive strength of concrete decreased when laid on clay with a low water content percentage because of the lack of capillary water (Drying shrinkage). Drying shrinkage is the contraction of a hardened concrete mix caused by the loss of capillary water. High tensile stress results from shrinking, and decreased compressive strength is the result. Many research and investigations have shown that curing concrete properly is the best way to prevent shrinkage and generate a high degree of desirable characteristics in concrete. A 26 percent decrease in compressive strength was observed between zero and optimal moisture content. **Fig. 9** shows the linear relationship between UPV and compressive strength, with an R2 value of 0.96 showing a correlation between the two.

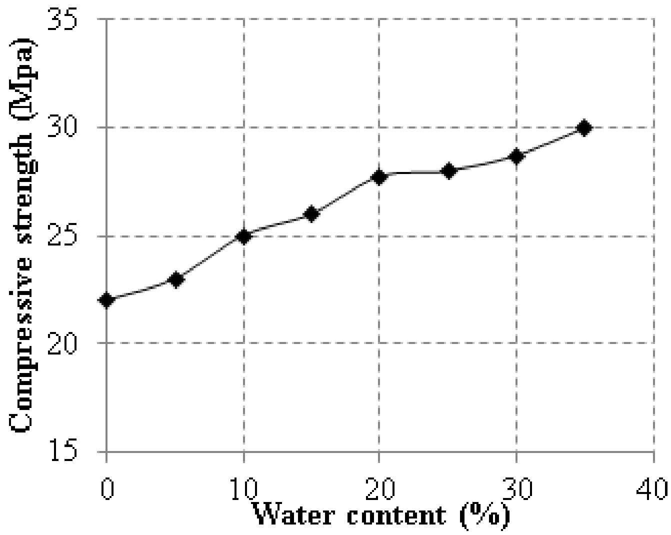


Figure 6. Compressive strength values of cubic concrete specimens cured for 28 days.

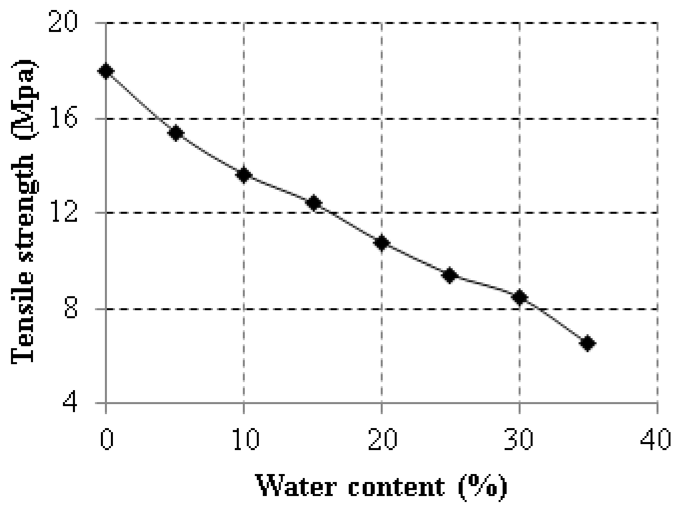


Figure 7. Tensile strength values of cylinder concrete specimens cured for 28 days.

Figure 8. The concrete cubic sample after failure due to compression.

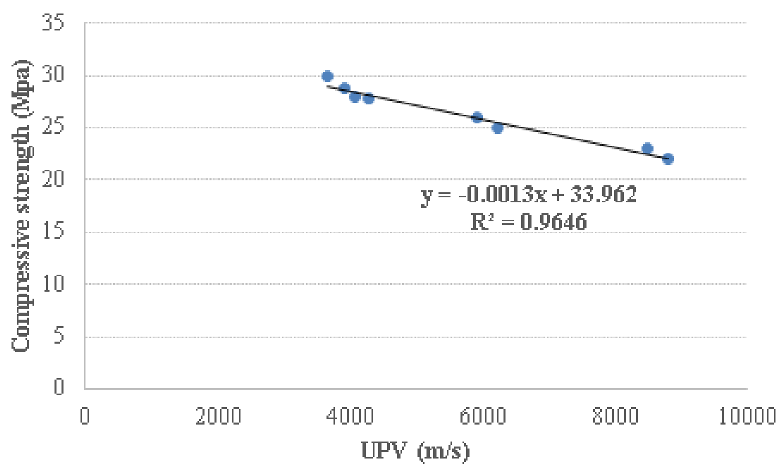


Figure 9. Relationship between UPV and compressive strength.

3.2 Ultrasonic Pulse Velocity (UPV)

The UPV values of the 28-day-cured concrete specimens are shown in **Table 5 and Fig. 9**. Eq. (1) was used to calculate the UPV. According to the results, specimens with low clay water content showed an increase in the UPV, while specimens with a higher water ratio mixture showed the lowest UPV of concrete. For instance, the mixture of 5% water content recorded 8480 m/s, while the 20% water content mixture was 4277 m/s, Because of increased capillary void volume and concrete cracking due to the presence of the high amount of cracks that leads to an increase the time of wave transition inside the concrete, this has happened to **(Khademi et al., 2016)** and these results agree with **(Parihar et al., 2022)** on the reinforced concrete as they found that the presence of steel bars increases the velocity of UP more than in the plain concrete. The total loss in UPV was 58% between the zero and optimal water content. A correlation between UPV with water content is depicted in **Figure 10.**

$$c = 0.2/(T_d - 0.6) \times 10^{-6} \quad (1)$$

Table 5. Results of UPV for each water content ratio.

Mix	UPV m/s
M1 0% CWC	8787
M2 5% CWC	8489
M3 10% CWC	6219
M4 15% CWC	5928
M5 20% CWC	4277
M6 25% CWC	4068
M7 30% CWC	3925
M8 35% CWC	3666

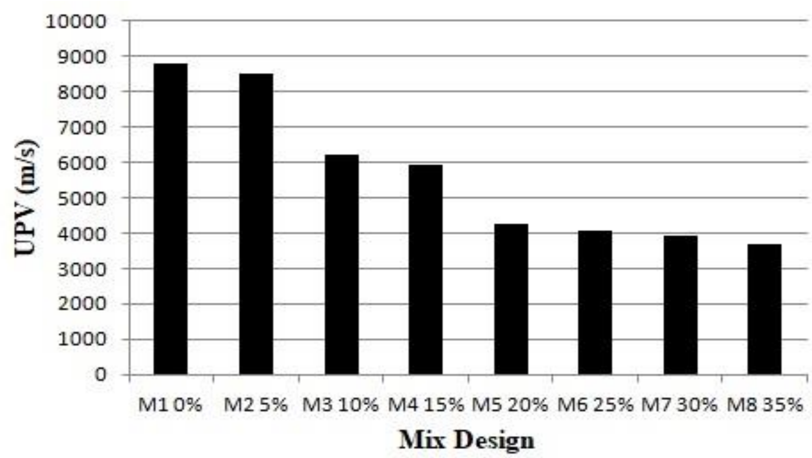


Figure 9. UPV values for concrete specimens cured for 28 days.

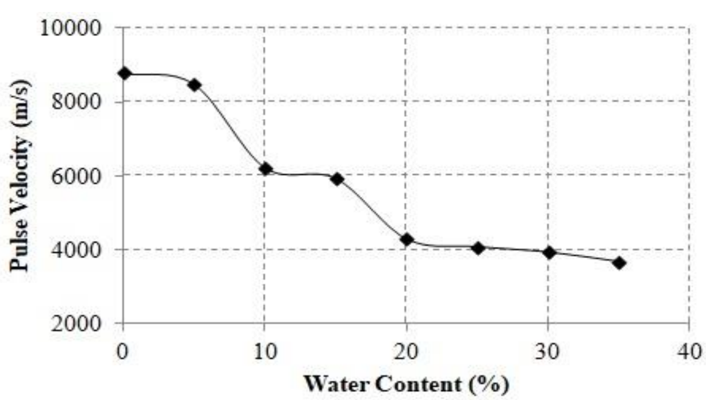


Figure 10. Relationship between UPV and water content of clayey soil.

3.3 Crack Depth

The results of the crack depth of concrete is reported in **Table 6** and plotted in **Fig. 11**. It can be found that there is an inverse relationship between the crack depth and water content. There is nearly a 98% reduction in the crack depth between zero and optimum moisture content mixtures. The crack depth showed to be highest at 0% soil water content, due to the high-water absorption from the concrete mixture by the soil leaving cracks. In contrast, these cracks started to decrease by increasing the soil water content as the absorption capacity decreased. The study of **(Li and Singh, 2021)** it was found that the variation of moisture content is related to the crack depth in a parabolic fashion.

Table 6. Crack depth for each water content ratio.

Mix	Crack Depth (cm)
M1 0% CWC	4
M2 5% CWC	3.15
. M3 10% CWC	3.05
M4 15% CWC	2.15
M5 20% CWC	2.1
M6 25% CWC	1.25
M7 30% CWC	0.35
M8 35% CWC	0.05

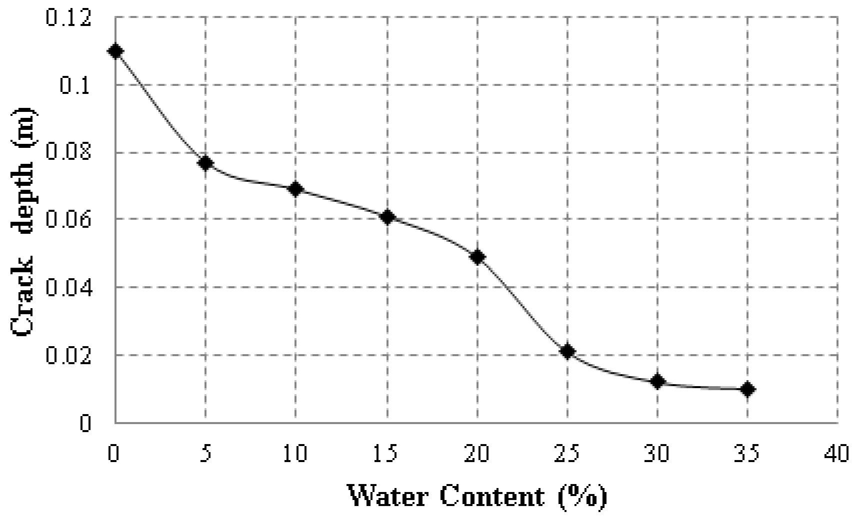
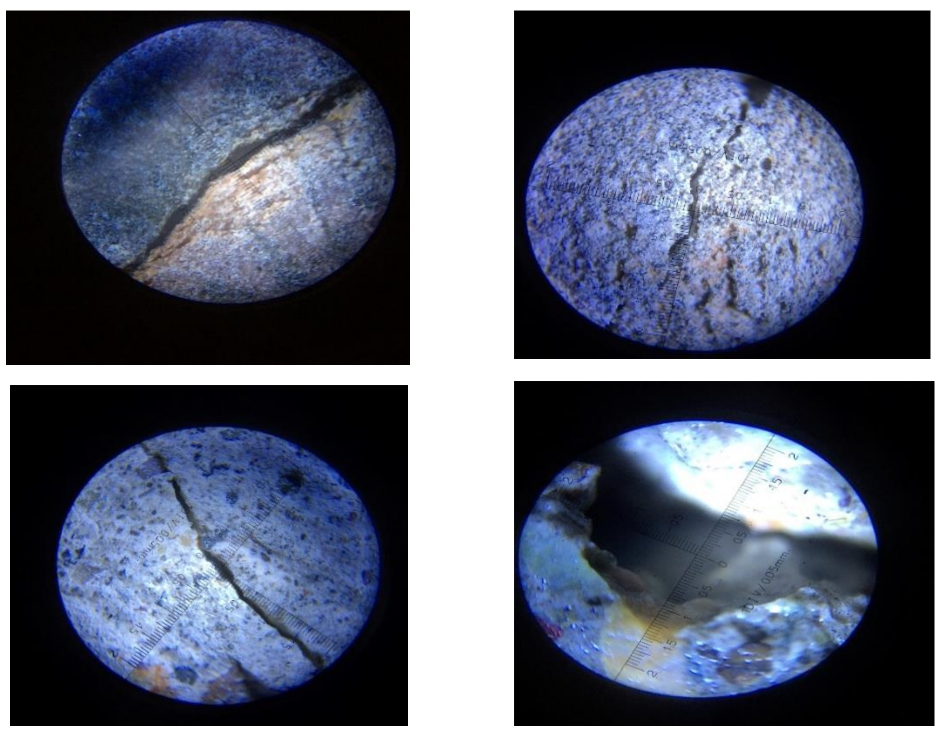


Figure 11. Relationship between crack depth and water content of the clayey soil.

3.4 Crack width by microscope

The crack width was investigated using a manual microscope for all the concrete mixtures. The results are shown in **Fig. 12** which indicated that the crack width ranged between 2 and 10.5 mm for the lowest and highest clay water content, respectively. This is due to the highest water loss leading to increased voids and cracks.



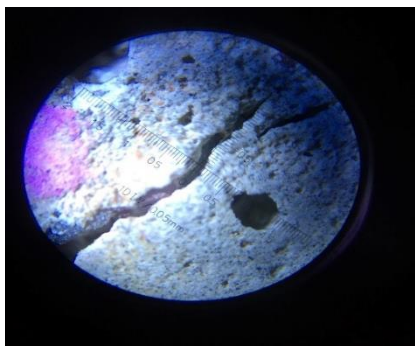


Figure 12. The crack width by microscope.

5. Conclusion

This experimental study aimed to investigate the effects of water content variation from zero to the optimum moisture content of clayey soil on the cracks growing in concrete placed directly above it. The following paragraphs conclude the gained results.

1. The compressive strength of concrete samples taken from the concrete slabs was noticed to be directly affected by the changing water content of the clayey soil. The compressive strength decreased by about 26% when the water content increased from zero to 35% due to the soil's high water absorption when it is dry.
2. The UPV for the 28 days cured concrete samples was recorded to be the highest with the lowest water content in soil, the sample with 35% water content recorded the lowest UPV with a reduction of 58%.
3. Also, for the crack depth, the minimum depth showed at the maximum water content, which is 35%, and a total reduction in crack depth was found to be nearly 98% while increasing the water content from zero to 35%.
4. Furthermore, the crack depth for the concrete placed over clayey soil varied between 2 and 10 mm when the water content inside the clayey soil increased from zero to the optimum moisture content.

REFERENCES

Abdalla, T. A., & Salih, N. B. (2020). Hydrated Lime Effects on Geotechnical Properties of Clayey Soil. *Journal of Engineering*, *26*(11), 150-169.

Al-Kubaisi, O. K. I. (2018). Prediction of the Effect of Using Stone Column in Clayey Soil on the Behavior of Circular Footing by ANN Model. *Journal of Engineering*, *24*(5), 86-97.

Ardakani, S. B., & Rajabi, A. M. (2021). Laboratory investigation of clayey soils improvement using sepiolite as an additive; engineering performances and micro-scale analysis. *Engineering Geology*, *293*, 106328.

ASTM C 39, 2018. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. American Society for Testing and Materials, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428.

ASTM C 597, 2016. Standard Test Method for Pulse Velocity through Concrete. American Society for Testing and Materials, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428.

ASTM C192, 2016. Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. American Society for Testing and Materials, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428.

ASTM D2487, 2017 Edition, December 15, 2017 - Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).

Bezih, K., Chateauneuf, A., Kalla, M., & Bacconnet, C. (2015). Effect of soil–structure interaction on the reliability of reinforced concrete bridges. *Ain Shams Engineering Journal*, *6*(3), 755-766.

Canakci, H., Yavuz, H. E., Celik, F., & Gullu, H. (2013, July). Interface friction between organic soil and construction materials. International Balkans Conference on Challenges of Civil Engineering.

Coduto, D. P. D. P. (1999). *Geotechnical Engineering: Principles and Practices* (No. Sirsi) i9780135763803).

Das, B. M., & Sobhan, K. (2013). *Principles of Geotechnical Engineering*. Cengage Learning.

Demir, İ., Sevim, Ö., & Tekin, E. (2018). The effects of shrinkage-reducing admixtures used in self-compacting concrete on its strength and durability. *Construction and Building Materials*, **172**, 153-165.

Dhakal, S. K. (2012). Stabilization of very weak subgrade soil with cementitious stabilizers, MSc thesis, Louisiana State University, US.

Elachachi, S. M., Breysse, D., & Denis, A. (2012). The effects of soil spatial variability on the reliability of rigid buried pipes. *Computers and Geotechnics*, *43*, 61-71.

Elachachi, S. M., Breysse, D., & Houy, L. (2004). Longitudinal variability of soils and structural response of sewer networks. *Computers and geotechnics*, *31*(8), 625-641.

Fenton, G. A., & Griffiths, D. V. (2002). Probabilistic foundation settlement on spatially random soil. *Journal of Geotechnical and Geoenvironmental Engineering*, *128*(5), 381-390.

Fontan M, Ndiaye A, Breysse D, Bos F, Fernandez C. Soil–structure interaction: parameters identification using particle swarm optimization. Comput Struct 2011; 89:1602–14.

Frank R, Thepot O. Etude en petites de´formations de l’interaction entre une fondation superficielle et une conduite enterre´e. Rev Eur Ge´nie Civ 2005;9–10(9):1095–109.

Grim, R. E. (1953). *Clay mineralogy*. Mcgraw-Hill Book Company, Inc; New York; Toronto; London.

Gupta, A., & Kumar, M. (2022). Clayey soil stabilization using flyash and jute fibre. *Materials Today: Proceedings*, *48*, 1205-1210.

Jahangir E, Deck O, Masrouri F. An analytical model of soil-interaction with swelling soil during droughts. Comput Geotech 2013; 54:16–32.

Khademi, F., Akbari, M., Jamal, S., 2016. Prediction of concrete compressive strength using ultrasonic pulse velocity test and artificial neural network modeling. Roman. J. Mat. 46 (3), 343–350.

Li, T., & Singh, A. (2021). Influence of crack on the damping properties of recycled concrete. *Construction and Building Materials*, *311*, 125324.

Miraki, H., Shariatmadari, N., Ghadir, P., Jahandari, S., Tao, Z., & Siddique, R. (2022). Clayey soil stabilization using alkali-activated volcanic ash and slag. *Journal of Rock Mechanics and Geotechnical Engineering*, *14*(2), 576-591.

Parihar, H. S., Shanker, R., & Singh, V. (2022). Effect of variation of steel reinforcement on ultrasonic pulse velocity prediction in concrete beam. *Materials Today: Proceedings*.

Shadravan, S., Ramseyer, C., & Kang, T. H. K. (2015). A long term restrained shrinkage study of concrete slabs on ground. *Engineering Structures*, 102, 258-265.

Shakir, R. R., & Zhu, J. (2009). Behavior of compacted clay-concrete interface. *Frontiers of Architecture and Civil Engineering in China*, 3(1), 85-92.

Singh, J., & Singh, S. (2022). Influence of pin piles entrenched in clayey and sandy soil. *Materials Today: Proceedings*, *48*, 1117-1122.

Tang, C. S., Zhu, C., Cheng, Q., Zeng, H., Xu, J. J., Tian, B. G., & Shi, B. (2021). Desiccation cracking of soils: A review of investigation approaches, underlying mechanisms, and influencing factors. *Earth-Science Reviews*, *216*, 103586.

Viladkar MN, Karisiddappa Bhargava P, Godbole PN. Static soil–structure interaction response of hyperbolic cooling towers to symmetrical wind loads. Eng Struct 2006; 28:1236–51.

Zolghadr Jahromi, Z. Partitioned analysis of nonlinear soil–structure interaction. Ph.D., Department of Civil and Environmental Engineering, Imperial College London, London; 2009. 331 p.