Vol. 05, No. 3 (2023) 525-538, doi: 10.24874/PES05.03.015

Proceedings on Engineering Sciences

www.pesjournal.net

EXPERIMENTAL STUDY ON SOFT CLAY SOILS TO IMPROVE SETTLEMENT AND ULTIMATE STRESS USING THERMOS MECHANICAL LOADS

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Received 10.03.2023.
Accepted 01.07.2023.
UDC – 620.172.21

Keywords:

Soft Clay Soils, Settlement, Ultimate Stress, Thermos Mechanical Loads

A B S T R A C T

*The electrothermal method was used to treat soft clay soil under load in this study. The experiment model was adopted to study settlement behavior. The effect of heat on settlement and maximum stress, of soft clay soils, were studied. The variables studied are the distance between the heaters, the heating time, and the temperature of the source. A model was used with dimensions (60 * 40 * 60) cm, and heaters were used in each model, and the power of each heater was 925 watts, and the number of models used was 37 models. The first examination was without heat treatment, and settlement was measured in it directly. As for the rest of the tests, heat treatment was used in it, and the tests were divided into two phases. The first stage is the heat treatment stage, and the second stage is the stage of placing the mechanical load on the soil. The mechanical load is weights placed on the soil through the footing. The tests were divided according to the research structure into three cases and according to the distance between the two heaters (20,30,40) cm. In each case, the tests are conducted according to the heating time, where the heating time was used (4,8,12) consecutive hours, and each time 4 tests were used at different temperatures (200,300,400,500) degrees Celsius. An improvement value of 99.8% in the settlement was obtained when the source temperature was 500°C, with a heating time of 12 hours, and the distance between the heaters was 20 cm. An improvement in maximum stress of 425% was obtained when the source temperature was 500 °C, the heating time was 12 h, and the distance between the heaters was 20 cm. The conclusions of the study are that the settlement decreases with increasing temperature and the ultimate stress increases with increasing temperature.*

1. INTRODUCTION

Soft clay soils make up much of the land in southern Iraq. It is necessary to strengthen this soil, especially in these places, to stimulate economic development and to create projects in various disciplines because the formation of projects on this soil is difficult. As a result, the technology used to improve these soils must be

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financially efficient, rapid, and durable (Abbas & Ali, 2020). Many regions of the world also have soft loamy soils, which have the maximum stress and lead to large settlements when loaded (Abu-Zrieg et al., 2001). Dirt properties can be improved by using various techniques, including chemical treatment, artificial soil reinforcement, removal, replacement with different filling materials, etc., to reduce excessive settlements and improve maximum stress (Kempfort & Gebreselassic, 2006). However, there are several things to consider when selecting a technique to measure the degree of improvement. It includes the area and volume of soil to be treated, soil type, access to raw materials, access to necessary equipment, disposal of waste and water pollution, effects on nearby structures, local experience, amount of time available, and cost (Lancaster-Jones et al., 1978; Joshi et al., 1994). Since 1955, the heat treatment method has been used only by the Soviets, and in particular in Russia and Ukraine, and the use has decreased due to high fuel prices (Mitchel, 1981). Clay-rich soil and stones form the basis for many towns, cities, transportation lines, and structures. Due to their capacity to contract or expand in response to variations in water content, the clays composed of montmorillonite pose a serious risk to technical construction. The underground water table's diffusional flow of moisture via the soil's pores, rainfall's gravity flux of water into the ground, and other sources might all play a role in the moisture shift. Soft soils require more damage than floods, volcanoes, tornadoes, earthquakes, or other natural disasters. By improving the soil or utilizing specific types of foundations, the detrimental effect of expansive soil on structures can be avoided or mitigated (Mitchel, 1969). Heat treatment was one of the suggested types of improvement techniques utilized to address the issue of building on expanding soil. Investigating the physical characteristics of the soft soil existing in particular locations of Iraq is vital to ascertain the remedies for reducing damages (Ozcan et al., 2003). The electric heating method was used recently in Korea, where a researcher used the heating method in one of the locations in Korea, and he used temperatures between (70 and 110) °C. The researcher obtained good results for the maximum stress and slump in the soil (Park et al. 2012) (Figure 1).

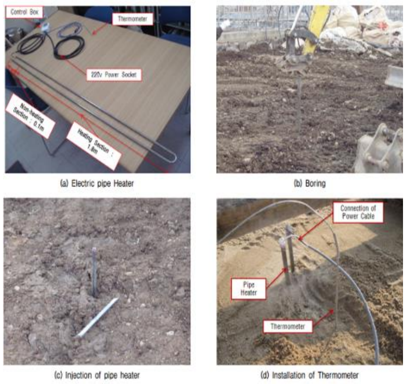

Figure 1. Soil improvement using Heaters (Park et al., 2012)

Also (Rahil, 2007; Rahil, 2019) (Figure 2) investigated fine clay's ultimate bearing capability and final settlement after thermal treatment. After combining Baghdad clay with enough water to give it a shear strength of 7 kPa, he conducted seven typical experiments on clay soil inside a square steel box with a length of 750 mm after heat treatment, two of which were used as a standard without treatment. for reference. This innovative gas-heating system uses wells to heat. Four square patterns of boreholes with 3.5 cm diameters, 30 cm lengths, and 3d, 4d, 5d, 6d, and 7d distances (d being the well diameter) were heated for six hours each. A 150 mm long, 20 mm thick square aluminum plinth was placed in the soft clay surface area and loaded monotonously until the settlement reached 10% of the foot width. The results showed that as spacing rises, bearing capacity increases and stability falls until a maximum limit (5d), when it declines and stability increases. 5d space has the best bearing capacity and settlement.

Figure 2. Soil improvement using Heaters (Rahil, 2019)

In this study, a model was used in which soft clay is used to study settlement behavior, and heat treatment is done with two heaters for each test. It put several variables in the treatment, which are the time factor, the distance between the heaters, and the change in the source temperature. The study aims to study the effect of heating on the settlement of the model, find out the optimal distance between the heaters and the base, and find out the optimum temperature.

2. MATERIAL OF METHODS

The research structure relied on heating the soft clay soil with heaters, as two heaters it can be used in each test at a specified distance. The distances between the two heaters it (20,30,40) cm, and in each of these distances, 4 tests were used, with a temperature of (200,300,400,500) degrees Celsius for each test, and a heating time of 12 hours. After heating the model the model is loaded with cumulative loads and settlement is measured.

2.1 Materials used in the model

Soft soil. The samples used in the investigation were taken from a site in the east of the city of Nasiriyah, which is located within the coordinates (31.05238, 46.20908). The ground was excavated to a level of 1.5 m to obtain this soil. Table 1 shows the types of soft soils used in this research. The USCS classification indicates that the soil is CL soil. Figure 3 shows the particle size.

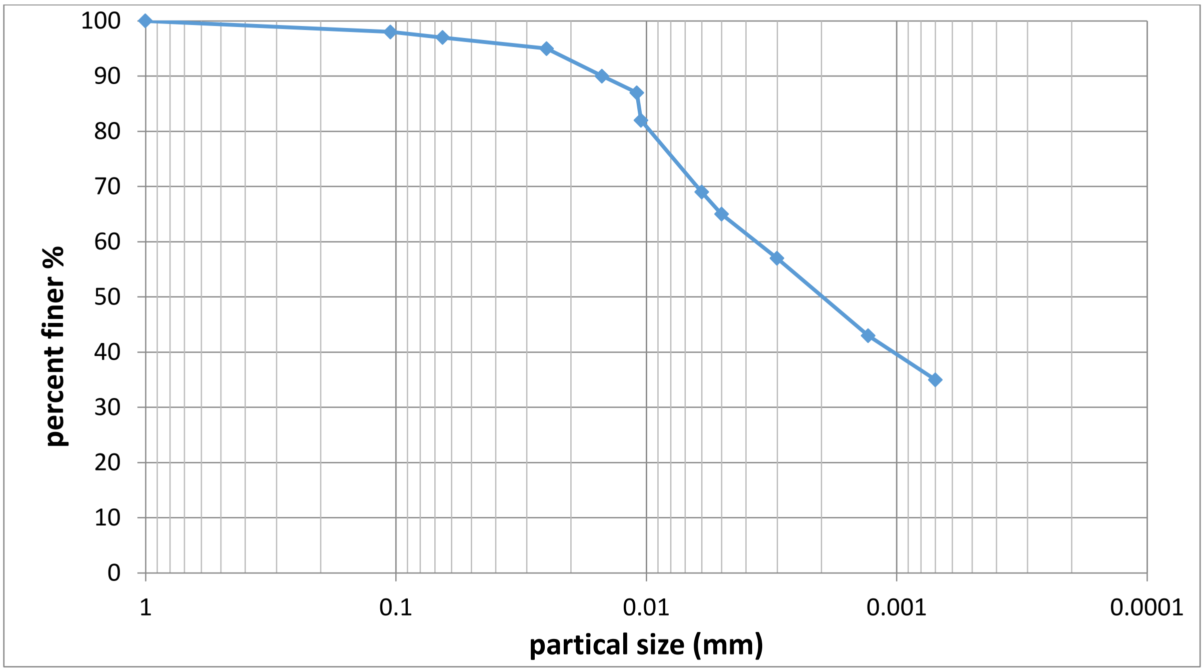

Figure 3. Grain size distribution curve for clay soil

Table 1. Physical properties of natural soil used

1 **Properties**	2 **Value**	3 **Specification**
4 **Initial water content (WC) %**	5 13%	6 --------------------
7 **Liquid Limit (L.L)**	8 % 46	9 ASTM D 4318 - 2003
10 **Plastic Limit (P.L)**	11 % 21	12 ASTM D 4318 - 2003
13 **Plasticity Index (I.P)**	14 % 25	15 -----------------
16 **Specific Gravity (Gs)**	17 2.60	18 ASTM D 854 - 2007
19 **Percent of Clay**	20 67	21 ASTM D 422 - 2006
22 **Percent of Silt**	23 27	24 ASTM D 422 - 2006
25 **Percent of Sand**	26 6	27 ASTM D 422 - 2006
28 **Unified Soil Classification System**	29 CL	30 ASTM D 2487 - 2006 31 (USCS)
32 **Optimum Moisture Content (O.M.C) %**	33 19	34 ASTM D 698 - 2007
35 **Maximum Unit Weight (kN/m^3)**	36 15.5	37 ASTM D 698 - 2007
38 **Shrinkage limit**	39 15	40

2.2 Heating system

To improve the soil, generate heat within the soil, and conduct sample tests, try to be as close as possible to what is happening in the field. A special heating system was made. This system has a powered panel with temperature control systems and sensors on the edge of the heater that plugs directly into the electrical panel. The heater is an electric heater with a length of 50 cm and a diameter of 1 cm with a maximum power of 925 watts connected to the heating system. As shown in Figure 3.

2.3 Preparation of soil bed and testing

Several tests of soil physical properties, including soil, liquid limits, plastic limits, and density tests, are performed before the preparation stage to ensure the effectiveness of the preparation procedures. it also performed a series of soils requiring a shear strength (C) of 40 kPa with a moisture content of 34%. The soil was moistened and mixed with water according to the moisture content. The moist soil was stored in airtight plastic bags for 2 days to ensure even moisture distribution (Rahil, 2007). Then, the soil was compacted in a cubic form, the dimensions of which are 60 cm x 40 cm x 60 cm, in the form of layers, and the thickness of each layer was 10 cm. Thirteen typical tests were then performed. The first model is without the use of heat. The following four models were investigated at different temperatures (200,300,400,500) °C and heaters were used. After that, the distance from the center of the base was changed. used four tests at the same temperatures as above and a distance of 15 cm from the center of the base for each variable. Then a distance of 20 cm from the center of the foundation was used. The mechanical load is an iron foundation with dimensions of 15 cm in length, 5 cm in width, and 2 cm in thickness. Various vertical loads are placed on it. These loads come from the foundation pressure via a pipe connected to it by a jack. The load cell is used to read the results through the Data Logger. Figure 3 shows the first stage of the test and Figure 4 shows the second stage of the test.

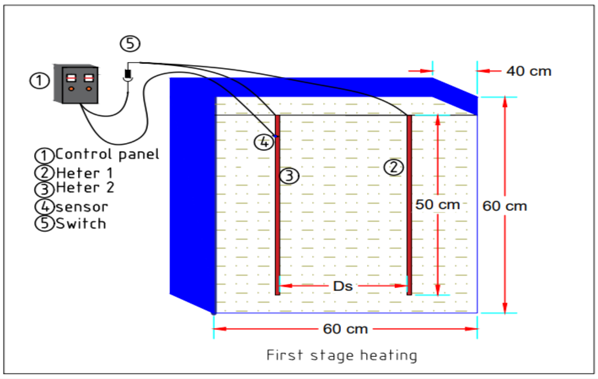

Figure 3. Dimension box test with installing heating system

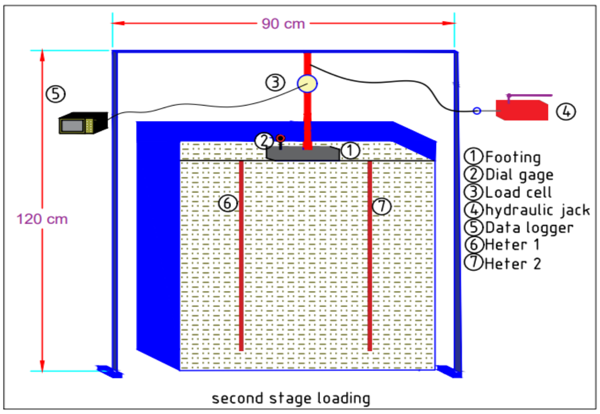

Figure 4. Preaper clay soil with installing statice load and heaters

3. RESULTS AND DISCUSSION

Depending on how one interprets Terzaghi's proposal (1943). The failure rate threshold is 10% of the baseline width in all model testing. The maximum amount of failure allowed in any of the model tests was 10% of the total width of the structure. Furthermore, load location was verified using standards from the American Society for Testing and Materials (ASTM), namely the 1195 and 1196 editions (Bowels, 1996). Soil is also characterized by the degree of cohesion, which is measured by Park (Park et al., 2012) Figure 5. That's what's on the plate, by the way.

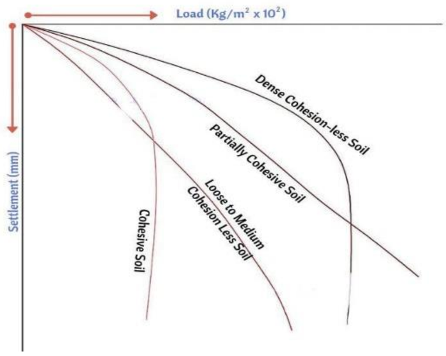

Figure 5. The change in the degree of soil cohesion according to the shape of the curve obtained from the plate load test

3.1 The Distance between the Heater and the Center of the Footing is 20 cm

The heaters were placed at a distance of 20 cm from the center of the footing and in the longitudinal direction, that is, the distance between the two heaters was 40 cm. In this case, the heaters in the models were run for different times for each model (4,8,12) hours, depending on the figure 5. Soil cohesion was rated for all tests. Figures 6, 7, and 8 are curves between stress and settlement for times (4, 8, and 12) hours, respectively.

4 models were tested at different temperatures (200,300,400,500) °C,

From Figure 6 and footing on what Terzaki said about the collapse when flattening 5 mm, the maximum stress of the model without the use of heating was very small and was about 42.5 kN / m2, after the application of heat there was a stress tolerance and the maximum stress tolerance is (44.5, 58, 68, 61) kN/m². For the tests (200, 300, 400, 500) ° C, respectively, also, based on the curve of the model without temperature, the failure occurred with a maximum stress of 42.5 KN / m2, and when compared with the tests models whose temperature was (200, 300, 400, 500) °C. the settlement at this point is (4.2, 2.6, 1.2, 0.9) mm, respectively, and the percentage of improvement it (16%, 48%, 76%, and 82%, respectively).

For Figure 7, which resulted from an increase in the heating time to 8 hours, the maximum stress is (48.5, 56.3, 65.6, 70) kN / m 2. (200, 300, 400, and 500 degrees Celsius, respectively, also, based on the curve of the model without temperature, the failure occurs with a maximum stress of 42.5 KN / m2, and when compared to the models whose temperature was (200, 300, 400, 500) degrees Celsius, the settlement at this point it (4.3, 2.4, 1, 0.9) mm, respectively, and the percentage of improvement in flattening it (14%, 52%, 80%, and .82%, respectively).

For Figure 8. Where is the maximum stress (79, 91, 102, 116) kN/m². For the tests (200, 300, 400, 500) degrees Celsius, respectively. Also, footing on the curve for the model without temperature, it can be noted that the failure occurred with a maximum stress of 42.5 kN/m², and when compared to models whose temperature was (200, 300, 400, and 500) °C. the decrease at this point was (1.5, 0.6, 0.5, 0.5) mm, respectively, and the percentage of improvement in the settlement was (70%, 88%, 90%, and 90%, respectively). This means that settlement is reduced by increasing the heating time and increasing the temperature of the heaters. Temperatures from the source.

For Figure 9 the settlement values are taken at different temperatures at all times. It is noted that the settlement values decrease with increasing temperatures as well as with increasing heating time.
For Figure 10, the maximum stress values increase with increasing temperatures and heating time. It is also noted from Figures 6 and 7 that the best value for settlement is 0.5 mm, and this value is when the heating time is 12 hours and the temperature is 500°C and 400°C. It is also noted that the best value for the maximum stress is 116 kN/m², and this also occurs when the temperature is 500 °C with a heating time of 12 hours.

It is also noted from Figures 6, 7, and 8 that all curves contain crumbs, and these crumbs increase with increasing temperatures and heating time. The reason for this is that the models, after heating, lose the amount of water they contain due to the exit of water vapor, as the place of water is replaced by voids, and these voids have not been settled, and the examination is carried out immediately. after heating. Referring to figure 5, the soil did not change its condition and remained somewhat cohesive in all shapes.

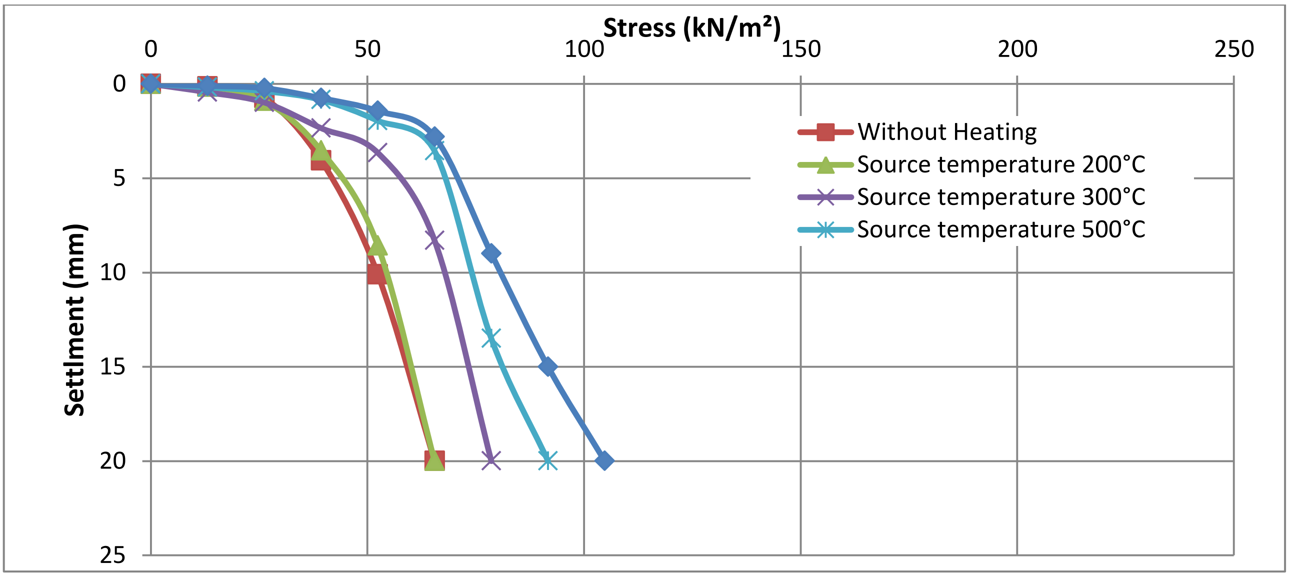

Figure 6. The relationship between stress and settlement when the heating time is 4 hours and the distance between the heater and the center of the base is

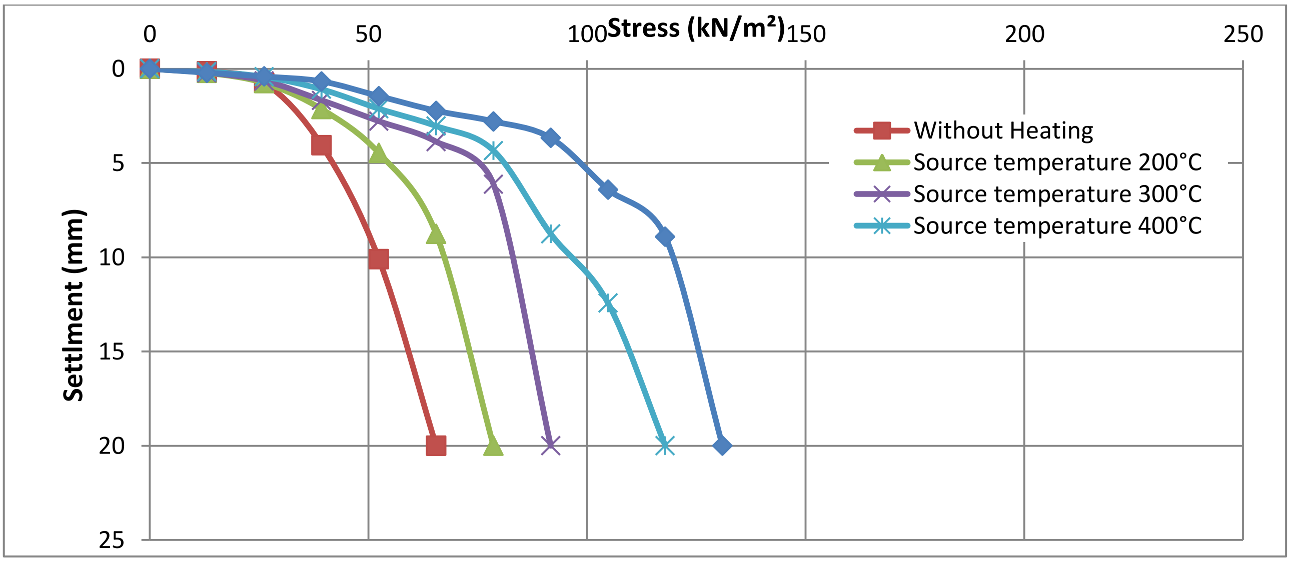

Figure 7. The relationship between stress and settlement when the heating time is 8 hours and the distance between the heater and the center of the base is 20 cm

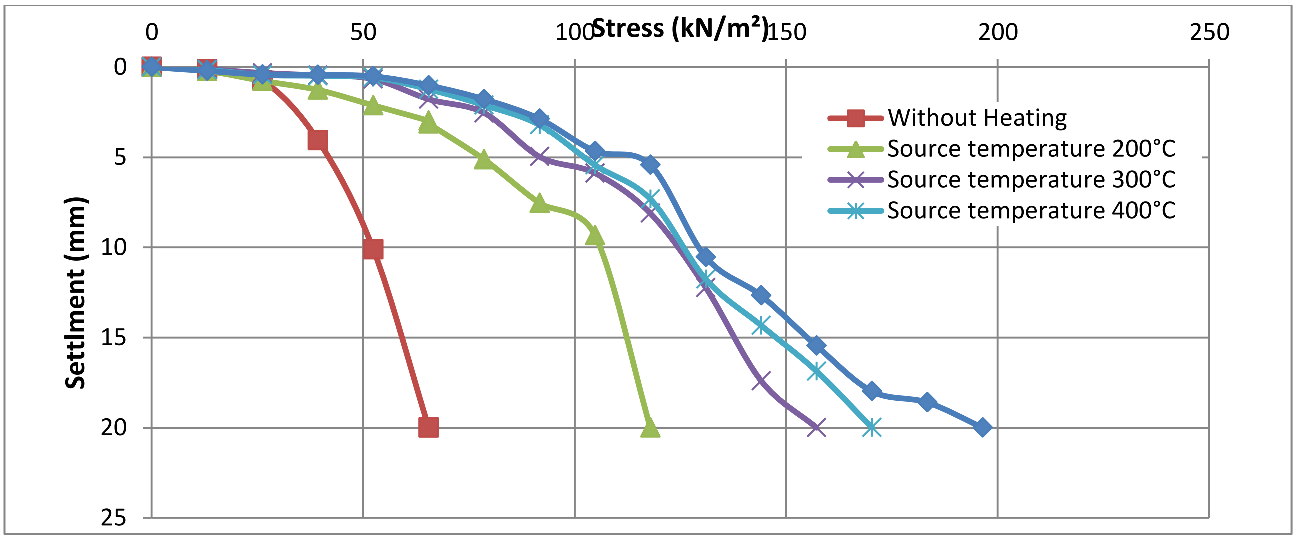

Figure 8. The relationship between stress and settlement when the heating time is 12 hours and the distance between the heater and the center of the base is 20 cm

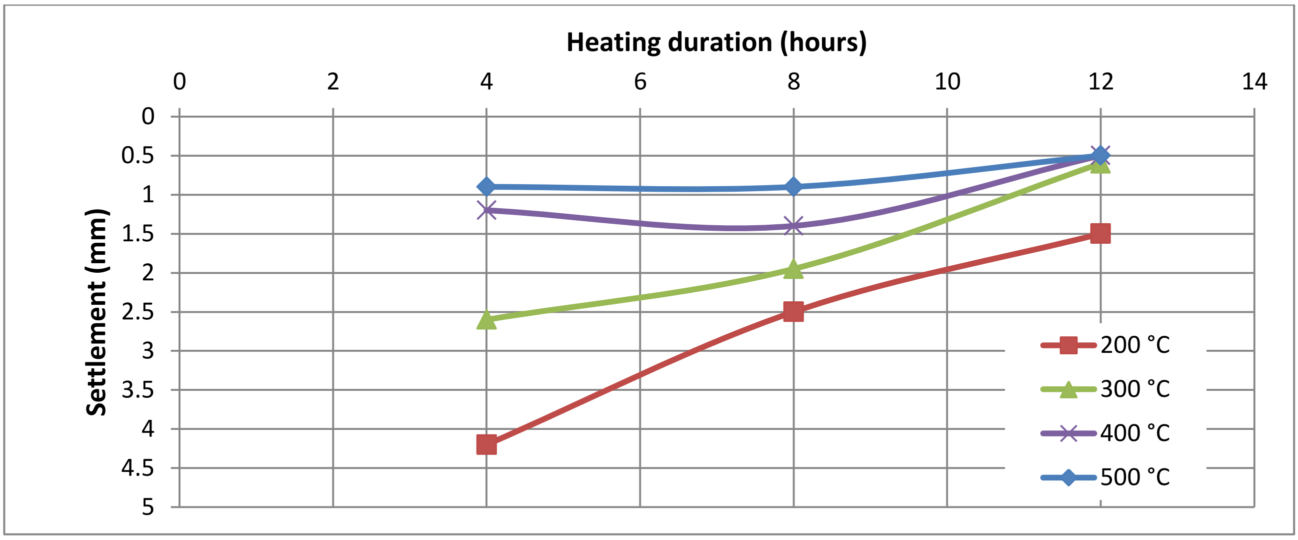

Figure 9. The relationship between settlement and heating time for temperatures (200,300,400,500) degrees Celsius

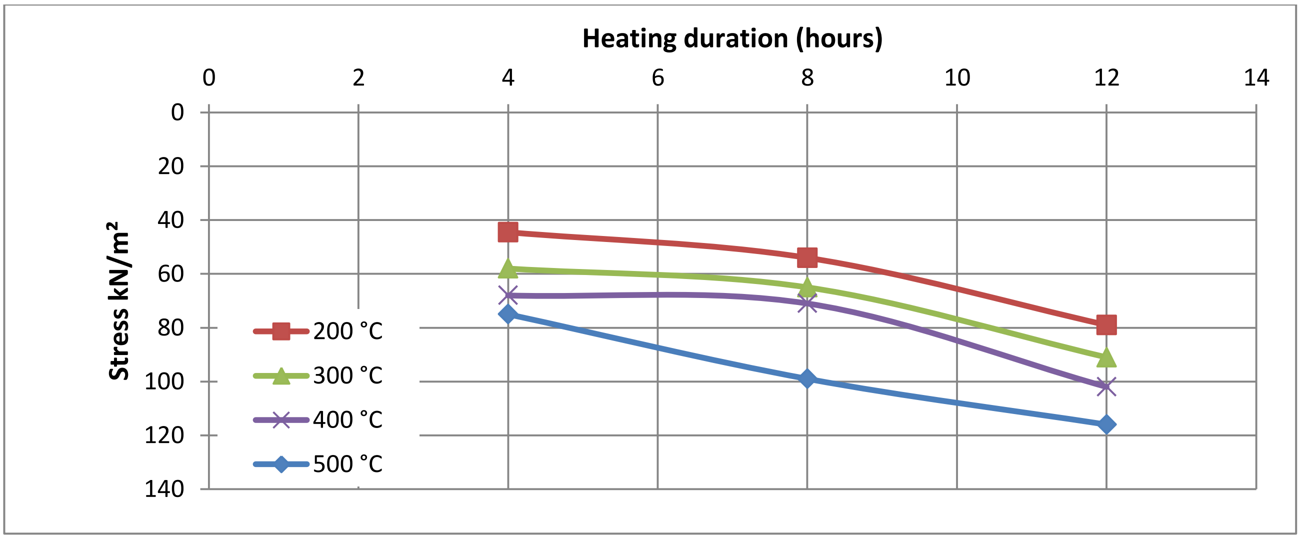

Figure 10. The relationship between the maximum stress and the heating time for temperatures (200,300,400,500) degrees Celsius

3.2 The Distance between the Heater and the Center of the Footing is 15 cm

The distance between the two heaters is approximately 15 cm from the center of the footing, and the rest of the variables are studied, including the duration of heating at different temperatures. And 12 models were tested, each of these models carries a constant heating time and constant temperature, and the time and temperature are changed for each model. As in the previous case

For Figure 11 and based on what Terzaki said about the failure when flattening 5 mm, the maximum stress of the model without using its heating is very small and was about 42.5 kN / m2, after applying heat the maximum stress (53, 49, 60, 71) kN/sqm. For the tests (200, 300, 400, 500) °C, respectively, also, footing on the curve of the model without temperature, the failure occurred with a maximum stress of 42.5 kN / m2, and when compared with models whose temperature was (200, 300, 400, 500) degrees Celsius. The settlement at this point was (2.7, 3.8, 2.9, 2.4) mm, respectively, and the percentage of improvement was (46%, 24%, 42%, and 52%, respectively). Noting that the percentage of improvement in settlement increases with increasing temperatures from the source as shown in Figure (11). It is noted that the highest percentage of improvement in settlement is when the model is heated by 500 degrees Celsius and that the differences between the rest of the other temperatures are slight. It is noted that all the curves in Figure (11) classify the soil within the composition of cohesive clay and as classified (Figure 5).

For Figure 12 by increasing the heating time to 8 hours after applying heat, the maximum stress is (66, 89, 95, 111) kN/m². For the tests (200, 300, 400, 500) degrees Celsius. Respectively, also, footing on the curve of the model without temperature, it can be noted that the failure occurred with a maximum stress of 42.5 kN/m², and when compared with the models whose temperature was (200, 300, 400, 500) degrees c. It is noted that the settlement at this point was (1.4, 1.2, 1.5, 1) mm, respectively, and the percentage of improvement was (72%, 76%, 70%, and 80%, respectively). It is noted that the soil in this case transformed after being heated from a cohesive substance to a less cohesive one.

For Figure 13, and by increasing the heating time to 12 hours after applying heat, the maximum stress is (80, 108, 117, 122) kN / m 2. For the tests (200, 300, 400, 500) degrees Celsius., respectively, also, based on the curve of the model without temperature, the failure occurred with a maximum stress of 42.5 kN/m², and when compared to the models whose temperature was (200, 300, 400, 500) °C. The settlement at this point was (0.9, 0.8, 0.75, 0.75) mm, respectively, and the percentage of improvement was (82%, 84%, 85%, and 85%, respectively). As the soil moved from a state of cohesion to a less dense cohesion for all tests.

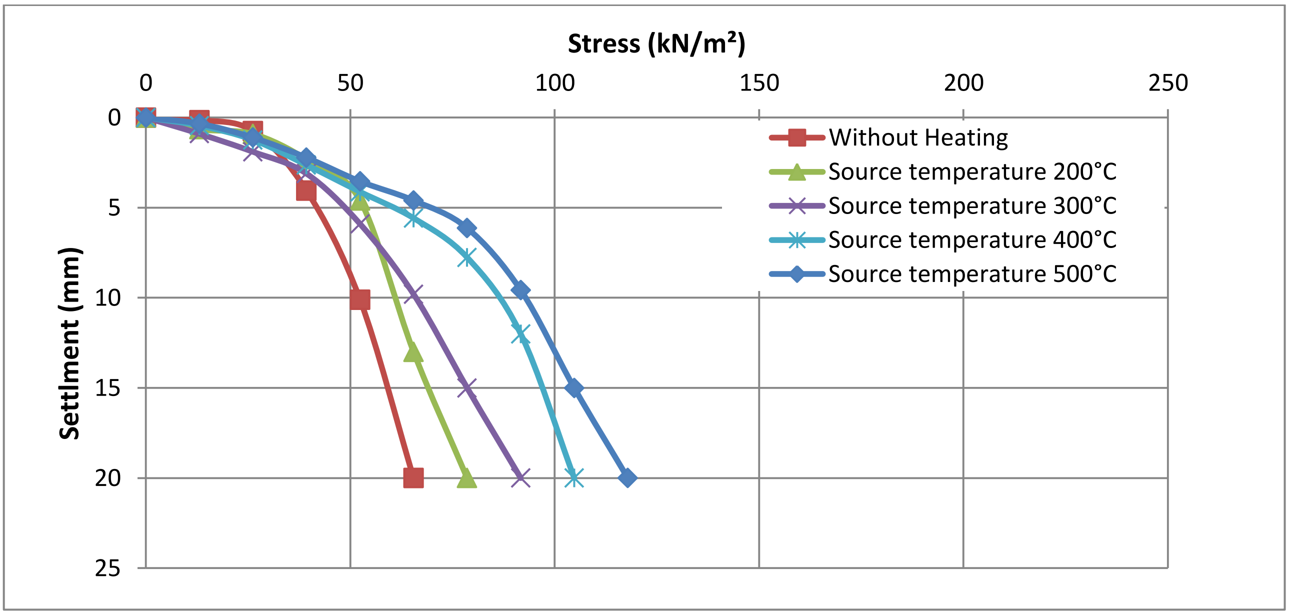

Figure 11. The relationship between stress and settlement when the heating time is 4 hours and the distance between the heater and the center of the base is 15 cm

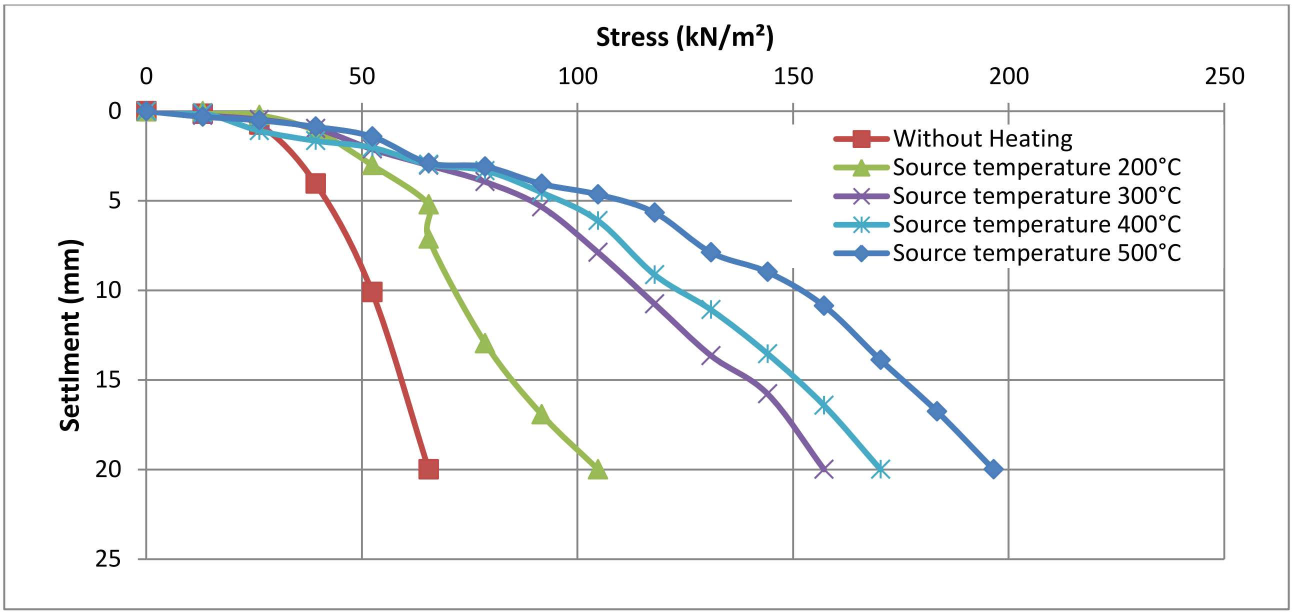

Figure 12. The relationship between stress and settlement when the heating time is 8 hours and the distance between the heater and the center of the base is 15 cm

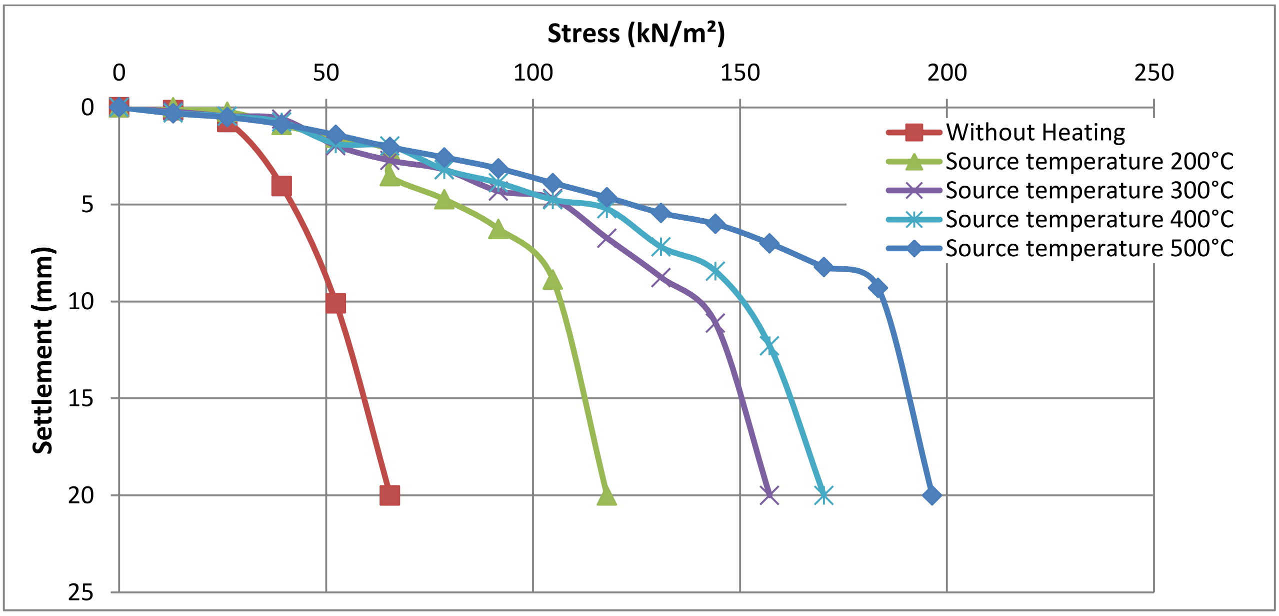

Figure 13. The relationship between stress and settlement when the heating time is 12 hours and the distance between the heater and the center of the base is 15 cm

All different times and settlement values and temperatures are taken. It is noted that the settlement value decreases with increasing temperature, as well as a significant increase in the maximum stress value with varying values. Referring to Figure 14, it is noted that the settlement values decrease with the increase in temperature as well as with the increase in the heating time; Also, concerning Figure 15, the maximum stress values increase with increasing temperatures and increasing heating time. It is also noted from Figures 14 and 15 that the minimum value for settlement is 0.75 mm, and this value is when the heating period is 12 hours and the temperature is 500 °C. It is also noted that the best value for the maximum stress is 112 kN/m², and this also occurs when the temperature is 500°C with a heating time of 12 hours. It is also noted from Figures (11), (12), and (13) that all curves contain crumbs, and these crumbs increase with increasing temperatures and heating time. The reason for this is that the models, after heating, lose the amount of water they contain due to the exit of water vapor, as they replace the place of water with voids, and these voids have not been settled, and the examination is carried out immediately after heating.

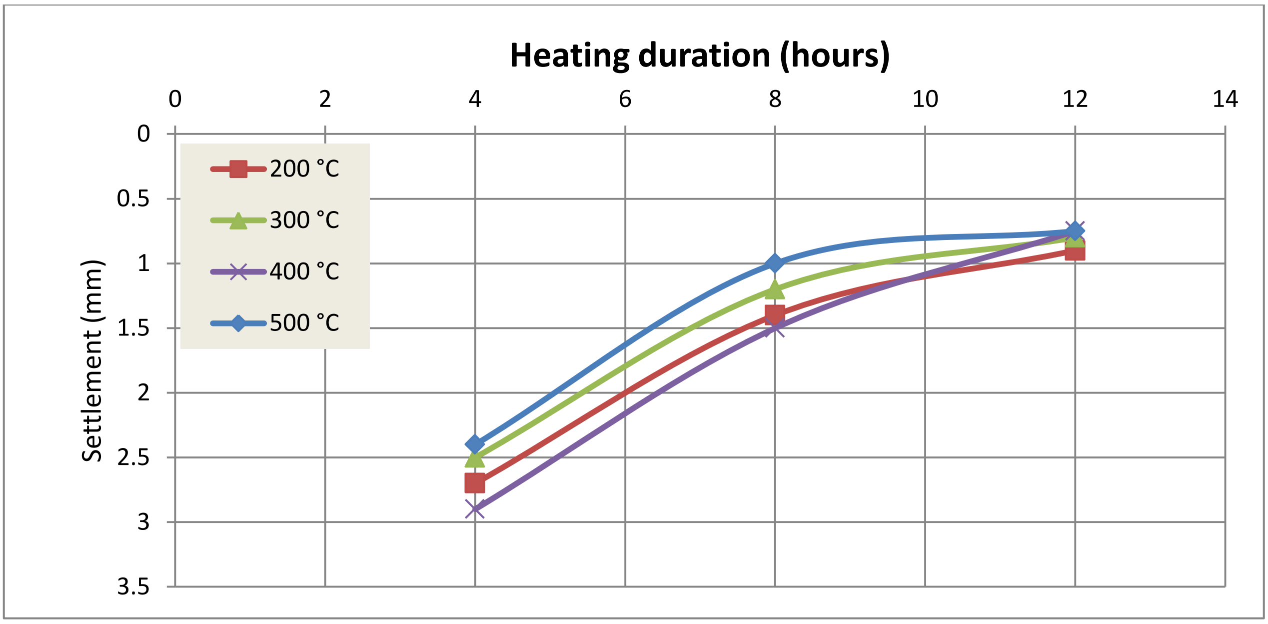

Figure 14. The relationship between the settlement and the heating time for temperatures (200,300,400,500) degrees Celsius

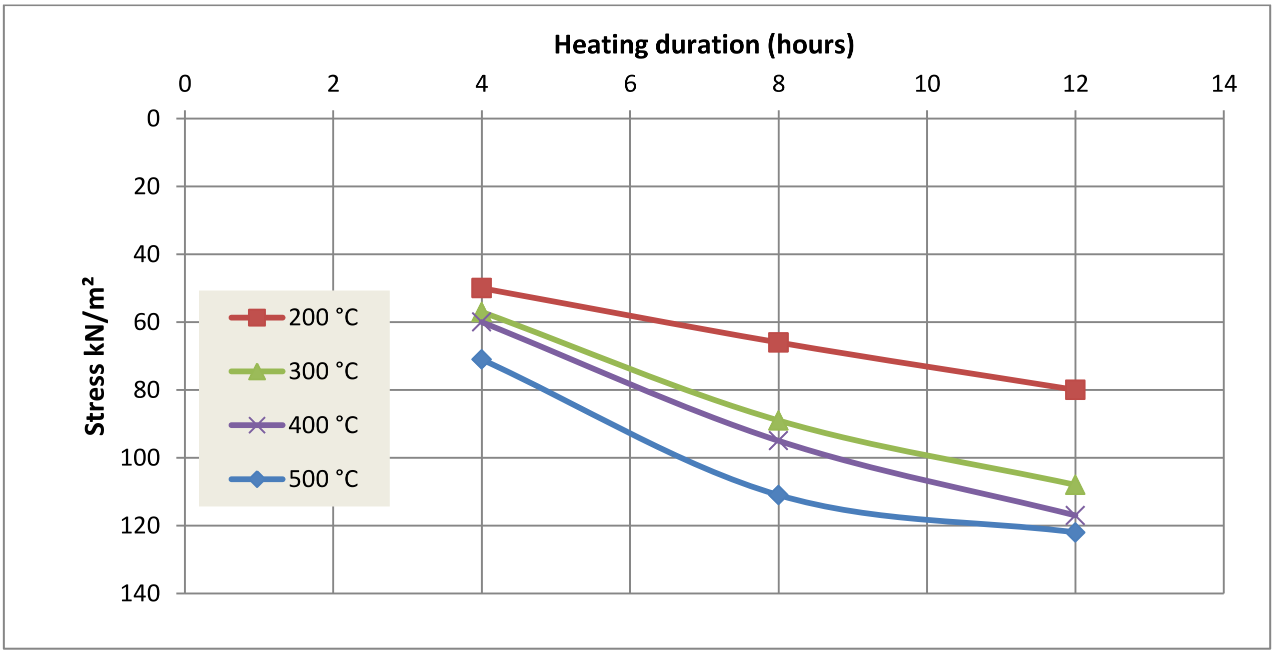

Figure 15. The relationship between the maximum stress and the heating time for temperatures (200,300,400,500) degrees Celsius

3.3 The Distance between the Heater and the Center of the Footing is 15 cm

Figure 16 and footing on what Terzaki said about the collapse when flattening 5 mm, the maximum stress of the model without the use of heating was very small and was about 42.5 kN / m2, after applying heat there was a stress tolerance and the maximum stress tolerance reached (52, 60, 73, 96) kN/sqm. For the tests (200, 300, 400, 500) °C, respectively, also, based on the curve of the model without temperature, it can be noted that the failure occurred with a maximum stress of 42.5 kN / m2, and when compared with the models whose temperature was (200, 300, 400, 500) °C. it can be noted that the settlement at this point was (2.9, 2.2, 1.5, 0.9) mm, respectively, and the percentage of improvement was (42%, 56%, 70%, and 82%, respectively). Noting that the percentage of improvement in subsidence increases with increasing temperatures from the source as shown in Figure 4. It is noted that the highest percentage of improvement in the settlement is when the model is heated by 500 °C and that the differences between the rest of the other temperatures are slight. It is noted the curves the curve in Figure 5 classifies the soil within the composition of less cohesion clay.

For Figure 17 and by increasing the heating time to 8 hours after applying heat, the maximum pressure was (49.9, 60, 69.9, 119) kN/m². For the tests (200, 300, 400, 500) °C., respectively, also, based on the curve of the model without temperature, it can be noted that the failure occurred with a maximum stress of 42.5 kN/m², and when compared with the models whose temperature was (200, 300, 400, 500°C. It is noted that the decrease at this point was (3.7, 2.5, 1.5, 0.9) mm, respectively, and the percentage of improvement was (26%, 50%, 70%, and 82%, respectively). It is noted that when the soil is heated to temperate and res (500, 400,300) °C, it changes after being heated and moves from a cohesive substance to a less dense cohesion. As for a temperature of roof 200 °C, it turns into less cohesion.

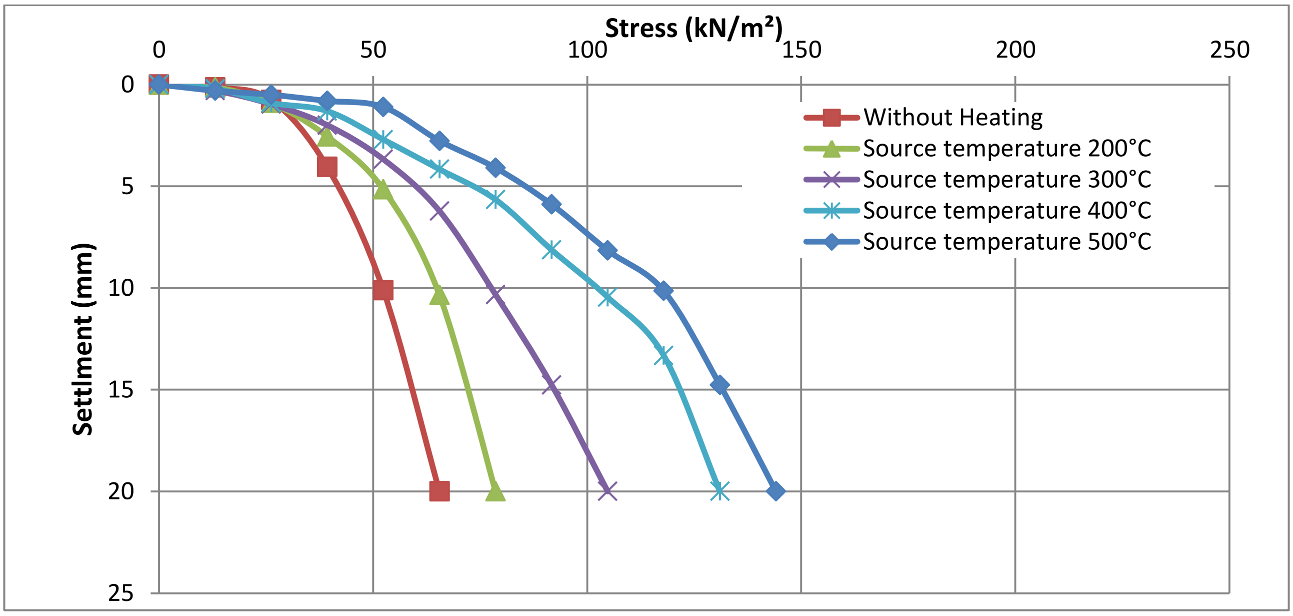

Figure 16. The relationship between stress and settlement when the heating time is 4 hours and the distance between the heater and the center of the base is 10 cm

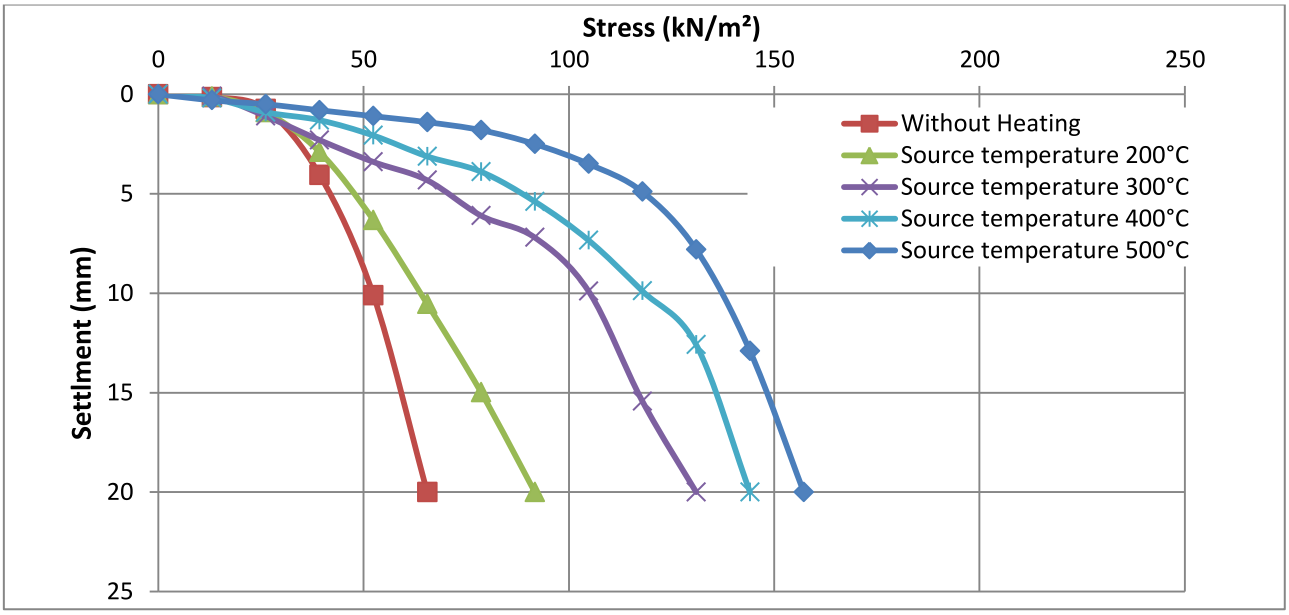

Figure 17. The relationship between stress and settlement when the heating time is 8 hours and the distance between the heater and the center of the base is 10 cm

For Figure 18 and by increasing the heating time to 12 hours after applying heat, the maximum stress was (72, 149.8, 170, 223) kN/m². For the tests (200, 300, 400, 500) °C., respectively, also, based on the curve of the model without temperature, it can be noted that the failure occurred with a maximum stress of 42.5 kN/m², and when compared with the models whose temperature was (200, 300, 400, 500) °C. It is noted that the settlement at this point was (1.1, 0.03, 0.02, 0.01) mm, respectively, and the percentage of improvement was (78%, 99.4%, 99.4%, 99.4%, respectively). It was observed that the soil moved from a state of cohesion to a partially cohesive soil for temperatures (500,400,300) °C. While it remained coherent at a temperature of 200 °C.

At all different times, values and temperatures are taken. It is noted that the settlement value decreases with increasing temperature, in addition to a significant increase in the maximum stress value with varying values. Referring to Figure 19, it is noted that the settlement values decrease with increasing temperature as well as with increasing heating concerning respect to Figure 20, the maximum stress values increase with increasing temperatures and increasing heating time. It is also noted from Figures 19 and 20 that the lowest value of the settlement is 0.01 mm, and this value is when the heating period is 12 hours and the temperature is 500 °C. It is also noted that the best value for the maximum stress is 223 kN/m², and this also occurs when the temperature is 500°C with a heating time of 12 hours.

It is also noted that the best value for the maximum stress is 223 kN/m², and this also occurs when the temperature is 500°C with a heating time of 12 hours. It is also noted from Figures, 16, 17 and 18 that all curves contain crumbs, and these crumbs increase with increasing temperatures and heating time. The reason for this is that the models, after heating, lose the amount of water they contain due to the exit of water vapor, as the place of water is replaced by voids, and these voids have not been settled, and the examination is carried out immediately after heating.

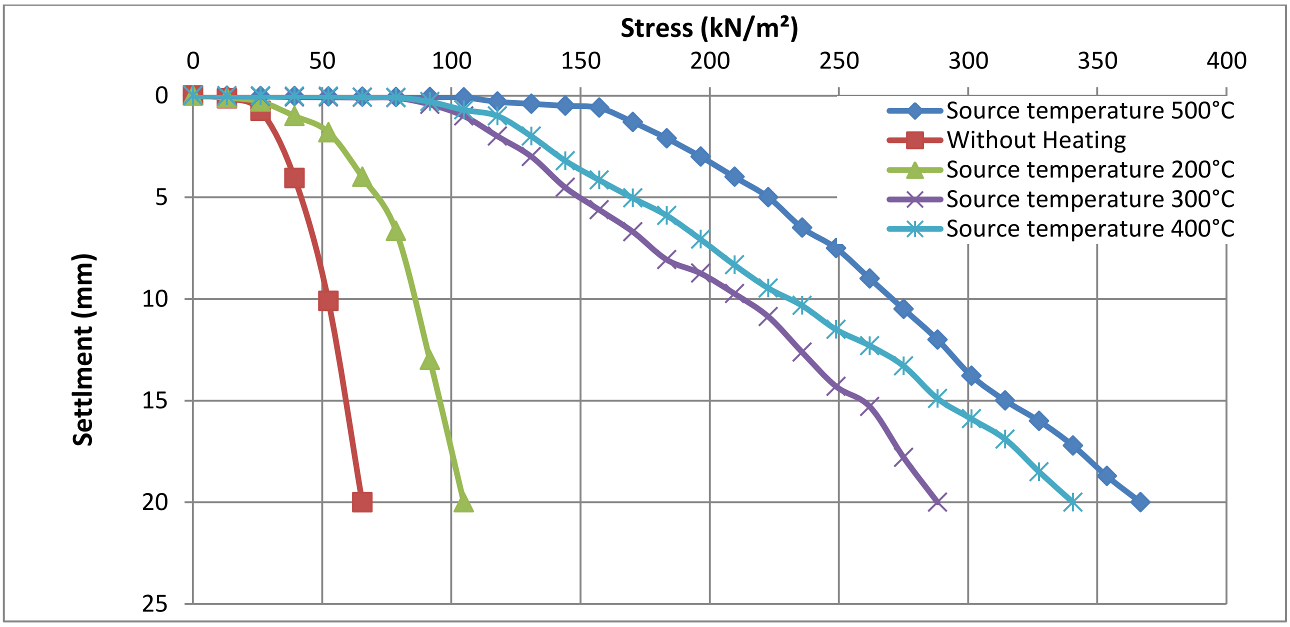

Figure 18. The relationship between stress and settlement when the heating time is 12 hours and the distance between the heater and the center of the base is 10 cm

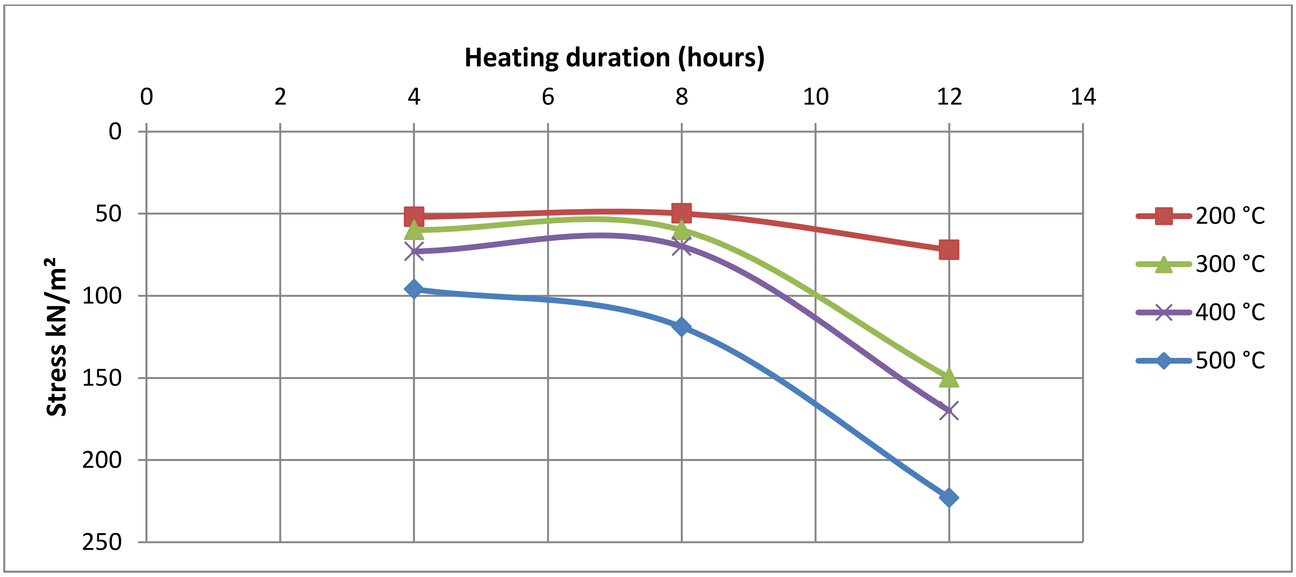

Figure 19. The relationship between the maximum stress and the heating time for temperatures (200,300,400,500) degrees Celsius

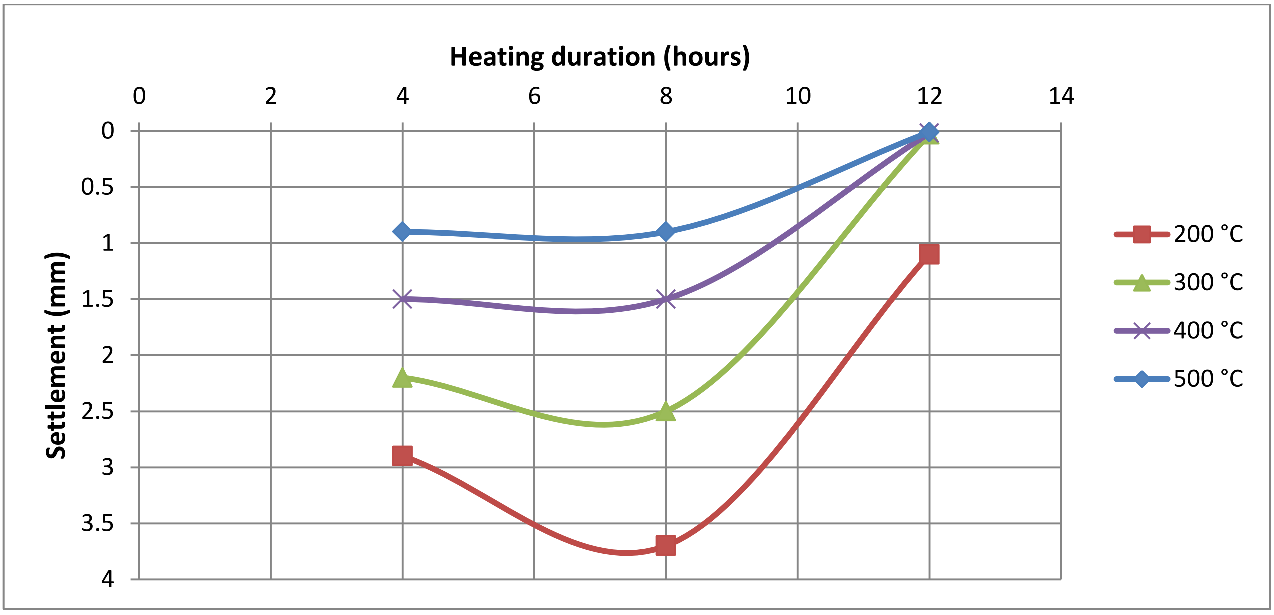

Figure 20. The relationship between the settlement and the heating time for temperatures (200,300,400,500) degrees Celsius

4. RESULTS OBSERVED DURING THE TESTS

Since the best settlement ratio occurred when the distance between the two heaters and the footing center was equal to 10 cm and when the temperature was 500 °C, we are now attaching pictures (Figure 21).

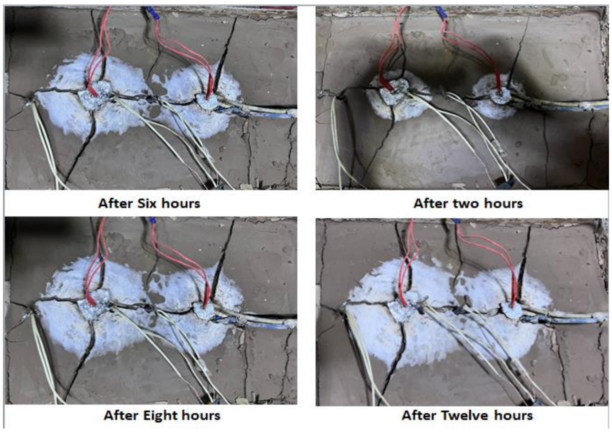

Figure 21. The shape of the soil after it has been heated at different times and at a temperature of 500 °C

Showing the shape of the model upon examination multiple times t is noted that the cracks increase with the increase of the heating time and that the width of the largest crack was 2 cm. By measuring the depth, it was found that the largest depth is 3 cm, as the cracks were in the surface layer only. It is also noted that there is a white layer surrounding the heater, and the diameter of this layer increases with the increase in the heating time, which indicates This region has lost its water content and also indicates that the heat transfer is in a diagonal direction, that is, it surrounds the heater from all sides and evenly.

5. CONCLUSION

Preliminary results from examining the results of empirical models are summarized in this paragraph. The following proposal may be considered for subsequent endeavours.

The settlement value increases with the increase in the source temperature and increases with the decrease in the distance between the heaters. It increases with the increase in the heating time as well, as the best settlement is when the distance between the heater and the heater is 20 cm, the temperature of the heater is 500 degrees Celsius, and the heating time is 12 hours, where the settlement improvement rate is 99.8%.

The value of the maximum stress increases with increasing temperature and decreasing the distance between the heaters, where the best improvement ratio for the maximum stress reaches 425% when the temperature is 500 °Cand the distance between the heater and the base center is 10 cm and the heating time is 12 hours

Cracks that occur in the soil due to heat are ineffective and are only on the surface.

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