Studies on Soil Heating Using Renewable Solar Energy

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Abstract. Soil heating is one of the methods of ground improvement from a shallow to moderate depth of problematic soils such as soft clay. The existing method of soil heating is done by open fire system, blowing of hot air from furnace, buried of fuels etc. These methods are considered as toxic or not an eco-friendly. In this investigation, an attempt was made to improve the remoulded soft clay using solar energy based soil heating. Solar energy is stored in battery backup and the same is used to heat the soil through hot air blower into the predrilled hole surround by soft clay placed in a rectangular box of initial water content at 85% LL of different type of soils (Natural Soil LL=80%, Kaolinite LL=30% and Bentonite LL=240%). While blowing hot air, the temperature of the soil at two different depths and two radical distances were recorded for varying time interval. The change in water content was also measured at different depths and distance from the source of heating unit in soils. Results indicated that even though the temperature at the sources is 300˚C, the temperature recorded in soil varies from 32˚C to 45˚C only, and at any given time. Further, at any time of heating, the reduction in water content was always higher for Kaolinite and least for Bentonite, and this may be because of poor drainage characteristic (or low permeable nature) of Bentonite where the rate of evaporation is less compared to free draining Kaolinite soil (high permeable nature).

Keywords: Soil Improvement; Soil Heating; Solar Energy; Vane Shear Strength

1 Introduction

Ground improvement techniques namely dewatering, compaction, column methods, soil reinforcement and thermal methods are often adopted to stabilize the clays to suit the design standards. In comparison with other soil improvement methods, thermal stabilization method produces immediate results. Thermal stabilization is defined as irreversible process which alters the physical and mechanical properties of clayey soil. Application of heat to the soil helps in accelerating the drainage of soil which leads to quicker consolidation and hence resulting in increase the strength of the soil. However, these changes will take place when soil is treated at temperature close to fusion. Soil heating is performed at the site using electrical method, pumping hot air and by heating non-toxic elements. The above methods of soil heating are costly, toxic and quite complex. Soil heating through solar energy will be cost effective, eco-friendly and promotes for sustainable development.

Finn (1951) investigated the effect of temperature on the consolidation characteristics of remoulded clay during primary compression, and found that the compression index increased at 4.4˚C and 21.2˚C. Cane Cekerevac and Lyesse Laloui (2004) studied the performance of kaolinite clay using temperature controlled triaxial apparatus. Temperatures applied were between 22˚C and 90˚C. The experimental program also includes triaxial tests at ambient and high temperature for different initial over consolidation ratios, consolidation tests at ambient and high temperatures, and drained thermal heating for different initial over consolidation ratios. Temperature effects were identified by comparing the results of tests performed at high temperature (90˚C) and at ambient temperature (22˚C). Temperature effects on the normal consolidation line (NCL) were examined by comparing ambient and high temperature. It was concluded that normal consolidation line is independent of temperature. It was observed that initial secant modules increases with increasing temperature. Yield limit shrinks with increase in temperature. They further reported that heating of the normally consolidated sample produces a contraction while over consolidated sample dilates. Stalin et al (2004) investigated the effect of initial moisture content on the behaviour of thermally cured three different clays. The initial moisture content on the index and strength properties of three thermally expansive clays was studied. They concluded that type of soil and initial moisture content play a crucial role in soil heating.

Joakim Laguros (1969) conducted the laboratory tests on moulded specimens of all four types of soils, such as kaolinite, illite, a montmorillonite and a montmorillonite-illite. In all four soils, the liquid limit decreased with an increase in temperature. The unconfined compressive strength data indicated an increase in strength with an increase in temperature except illite soil which deviated slightly from this tendency at higher temperatures. Ashwani Kumar (2010) investigated that the renewable energy sources and technologies have potential to provide solutions to the long-standing energy problems being faced by the developing countries. In this investigation, attempts are rare to study the effect of soil heating through solar based energy for varying soil type at the initial moisture content closed to liquid limit. Gulgun Yilmaz (2010) and investigated the effect of thermal treatment of kaolinite and bentonite soil on particle size, as well as water content, specific gravity, plasticity, activity index, swelling and compression index and strength properties. He concluded that kaolinite and Bentonite can be used as good stabilization materials if they are thermal treated kaolinite up to 400°C and Bentonite up to 500°C. In this investigation, attempts are made to study the influence of soil type on solar based heating technique.

2 Materials

One natural soil and two commercial soils were used. The natural soil was collected from Kishkinta, Chennai by making open trench at depth of 1.5m and two commercial soils namely Kaolinite and Bentonite were procured from Chennai local market. The properties of the soils are shown in Table 1. The natural soil and Bentonite are classified based on IS 1496-1970 as ‘CH’ type (Clay of high plasticity) and kaolinite is classified as ‘CL’ type (Clay of low plasticity). Soils of varying plasticity were selected in order to assess the effect of soil type in soil heating.

Table 1. Properties of soils used

Property	Natural soil	Kaolinite	Bentonite
Specific gravity	2.65	2.54	2.78
Liquid Limit (%)	80	30.32	240
Plastic Limit (%)	31	17.74	33
Plasticity Index (%)	49	12.58	207
Shrinkage Limit (%)	15	14.52	6.5
Sand (%)	5	3	0
Silt (%)	29	88	45
Clay (%)	66	9	55
Maximum Dry Density (g/cc)	1.47	1.83	1.52
Optimum Moisture Content (%)	30	18	24.25
UCC Strength (kN/m^2) (at OMC and γ_d max)	167.7	-	--
BIS Classification	CH	CL	CH

3 Experimental Programme

3.1 Components of Solar Heating Unit

Solar panels are used to convert the solar energy into electrical energy. The electrical energy obtained is again converted to heat energy for heating the soil mass. This experimental set up has following components.

Solar Panel. Solar panels generate free power from the sun by converting sunlight to electricity with no moving parts, zero emissions, and no maintenance. The solar panel, the first component of an electric solar energy system, is a collection of individual silicon cells that generate electricity from sunlight. The solar cell works in three steps:

- Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.
- Electrons (negatively charged) are knocked loose from their atoms, allowing them to flow through the material to produce electricity. Due to the special composition of solar cells, the electrons are only allowed to move in a single direction.

- An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.

The solar panel which was used in this investigation (see Fig. 1) has an output of maximum of 50 watts of 17 volts. Solar panel size is of 900 mm X 660 mm.

Fig. 1. View of Solar panel – 50 Watts (Size 900mm X660mm)

Battery. The batteries used are designed to be discharged and then re-charged hundreds or thousands of times. Battery receives current from solar panel array through charge controller.

Charge Controller. A charge controller or charge regulator is similar to the voltage regulator. It regulates the voltage and the passing of current from solar panels to the battery. Most panels give an output about 16 to 20 volts. So if there is no regulation the batteries will be damaged for overcharging.. Charge controller takes the output of the panel and feed current to the battery until the battery is fully charge.

Digital Temperature Indicator. A digital temperature indicator which comprises of standard type K thermocouple (UV 7030) and standard temperature indicator has been used to measure the temperature range which can be measured from 0 to 2000°C. Temperature has been read out using the digital display. Sensors used to record the temperature from the soil. Sensor which is used in this investigation can sense the temperature up to 400°C.

Thermocouple Switch Box. A single pole switch box is used to connect multiple probes or sensors to the thermocouple. Three numbers of sensors have been used for this study, which is connected to the thermocouple switch box in turn to the thermocouple. The temperature that is sensed by the sensors is connected in parallel. The temperature that is sensed by the sensors can be read out only in the digital temperature indicator.

Blower Unit with Perforated Pipe. Blower unit comprises of three numbers of heating coil connected in series along with a fan (placed behind heating coil). The blower unit is connected to a pipe of diameter 5cm and the perforations are made at the end of pipe along its periphery to enhance the transfer of heat.

Model Tank. The model tank of size 30cm x 30cm x 40cm, made up of acrylic was used (see Fig. 2). The hot air was blown from apparatus in the prepared soil sample through the perforated tubes that was inserted. The top portion of the tank was suitably covered such that hot air does not escape through the gaps available between perforated tubes and surrounding soil. Suitable arrangement was made to insert the perforated pipes in the soil without touching the bottom of the tank. For the laboratory model test 12mm size gravel was used as an intermediate layer between perforated tube and the remoulded soft clay. This gravel layer was used to enhance the dissipation of hot air throughout the soft clay bed radially and vertically. A geogrid was used as a separator along the outer circumference of the gravel layer. This prevents the gravel from mixing in the soft clay bed due to the self weight of gravel.

Procedure Adopted for Soil Heating. To understand the importance of soil heating in stabilization of soil, experiments were carried out in the model test setup for varying initial moisture content and change in soil medium. In order to compare the results of Natural soil, experiments were also conducted on Bentonite and kaolinite. For the experimental purpose the solar heating unit was arranged neatly. The solar panel was exposed to direct sunlight and the energy from the solar panel was received and taps the energy in the battery backup. After the battery was fully charged, the blower was connected to facilitate heating the clay bed. A square model tank of size 30x30x40cm was used in this investigation. The clay sample was mixed to known initial moisture content at 85% of liquid limit such that soil has no lumps and it was evenly mixed. Initially, clay was filled completely to a depth of 10cm, and then blower unit along with perforated pipe was positioned to centre of tank. The surrounding soil and perforated pipe was separated by a gravel (12mm size) layer guarded by geogrid along its peripheral surface. After positioning the perforated pipe, the clay was filled around to a depth of 20cm. The blower unit was connected to charge controller, battery and then to solar panel. The blower was switched on and the hot air starts moving into the soft clay bed through the perforated pipe. Sensors were used to sense the temperature at different places (Radial distance of 5cm and 10cm at a depth of 2.5cm and 5cm respectively (see Fig. 2). The temperature in soil was noted at regular time intervals till the end of the experiment. The experimental setup of soil heating was shown in

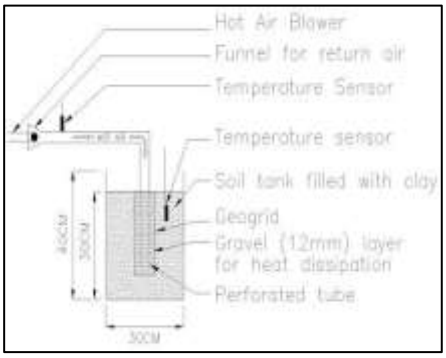

Fig. 3.

Fig. 2. Schematic view showing cross section of tank with sensor.

Fig. 3. Experimental set up of soil Heating

4 Results and Discussions

4.1 Temperature in Soil and Duration of Heating

During the process of soil heating through solar energy the temperature in soil surrounding the hot air blower pipe was recorded at different time interval for a maximum of 400 minutes for Natural soil (LL = 80%), Kaolinite (LL = 30%) and Bentonite (LL = 240%), for initial moisture content corresponding to 85% of their respective liquid limits. The temperature was recorded using thermal sensors that were placed at radial distance of 50mm and 100mm from the source of hot air blower pipe and at two different depths of 25mm and 50mm.

Fig 4, 5 and 6 present the variation of temperature in soil with duration of heating corresponding to 85% liquid limit of natural soil, Kaolinite and bentonite respectively, for a radial distance of 50 mm and 100 mm from the hot air blower and for the different depths. Even though the recorded temperature in soil is varying from 20^{o}C to 45^{o}C irrespective of soil, the time at which the temperature utilized is very high for natural soil and kaolinite, low for bentonite soil. It may be mentioning here that the liquid limit of natural soil and kaolinite are 80% and 30% respectively, but for bentonite the liquid limit is 240% Because of high amount of initial moisture content of bentonite, the temperature raises to only 35°C up to 50 minutes and thereafter the temperature recorded increases to maximum of 45°C. But for natural soil and kaolinite, the temperature recorded is 40°C in less than 50 minutes. This is mainly because of finer content of bentonite leading the slower rate of evaporation as a gain time. Because of its lower permeability as the permeability of bentonite is lower compared to natural soil and kaolinite, the rate of evaporation is also slower. But kaolinite and natural soil have coarse fractions, resulting in high temperature at the less time interval. The easiness with which the loss of water by heating is slow in heating compared to natural soil and kaolinite, at any distance from the hot air blower. At any duration of heating the temperature recorded in kaolinite and natural soil are higher and the lower is for bentonite as seen from Fig 7 and 8. This is mainly attributed to effect of type of soil and their coarseness.

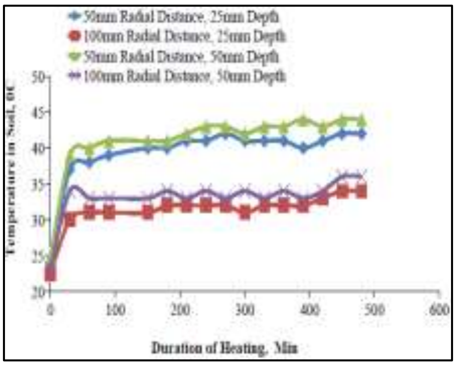

Fig. 4 Temperature in Soil Vs Duration of Heating in Natural Soil at 85% LL

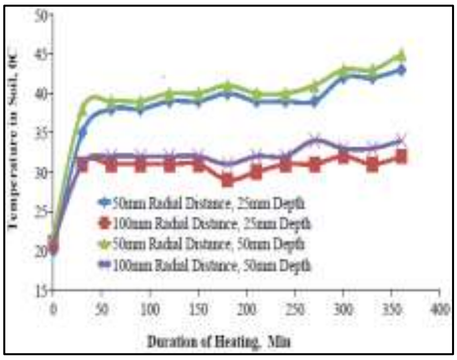

Fig. 5 Temperature in Soil Vs Duration of Heating in Bentonite at 85% LL

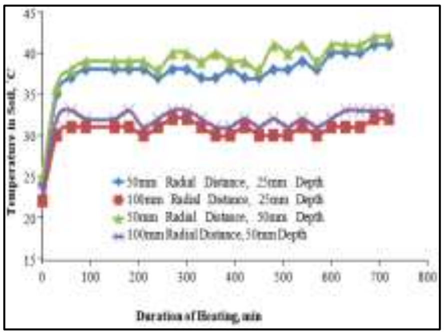

Fig. 6. Temperature in Soil Vs Duration of Heating in Kaolinite at 85% LL

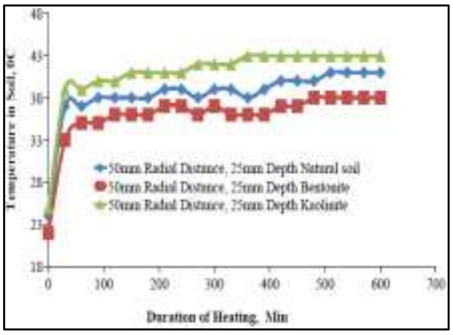

Fig.7. Temperature in Soil Vs Duration of Heating in all Soils for 85% LL at 50mm Radial Distance and 25 mm Depth

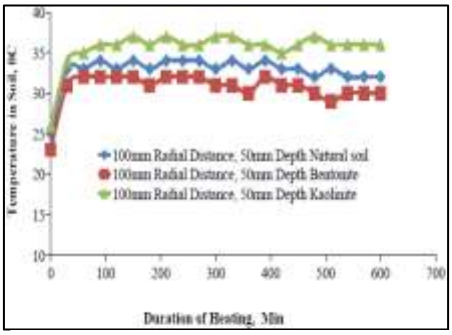

Fig. 8. Temperature in Soil Vs Duration of Heating in all Soils for 85% LL at 100mm Radial Distance and 50 mm Depth

The water content decreases steeply up to 30 minutes with time of heating and after which the reduction in water content is moderate (see Fig. 9) for two different depths and of radial distance. The variation in temperature in soil – duration of heating matches well with the reduction in water content with duration in heating. That is, the temperature fluctuation recorded in clay ranged between 33˚C and 45˚C. Mostly this case, the fluctuation in heating value with respect to time is hardly between 30˚C and 42˚C even for a total duration of 600 min.

Fig. 10 shows the water content reduction and duration of heating for Bentonite at 85% LL. Unlike natural soil, the moisture content in bentonite reduction is very steep with respect to duration of heating, may be because of high initial moisture content of 204% (85% of LL of Bentonite).

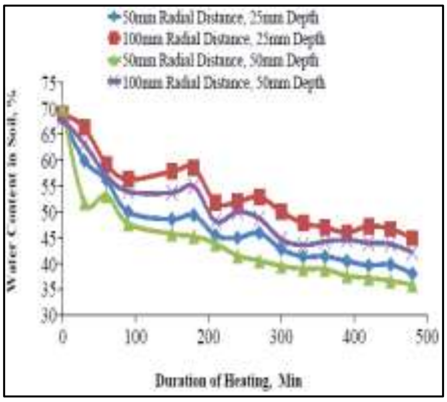

Fig.9 Water content in Soil Vs Duration of Heating in Natural soil at 85% LL

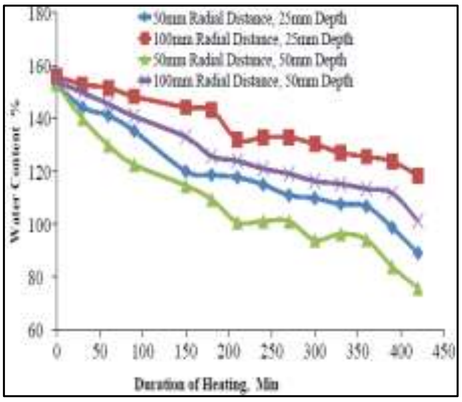

Fig.10 Water content in Soil Vs Duration of Heating in Bentonite at 85% LL

Fig. 11 presents the water content reduction with duration of heating for Kaolinite 85% liquid limit water content. The actual IMC before start of the test for each water content is 22.5 %, 25.5% and 30% (Table 2). From the particle size distribution, it is seen that kaolinite is having silt of 88% and clay of 9% and remaining are coarser fraction (Table 1). Because of the higher amount of silt sized particles, it would obviously have high permeability and in such cases the drying through hot air blown from inlet attracts more water towards the hot pipe before getting evaporated.

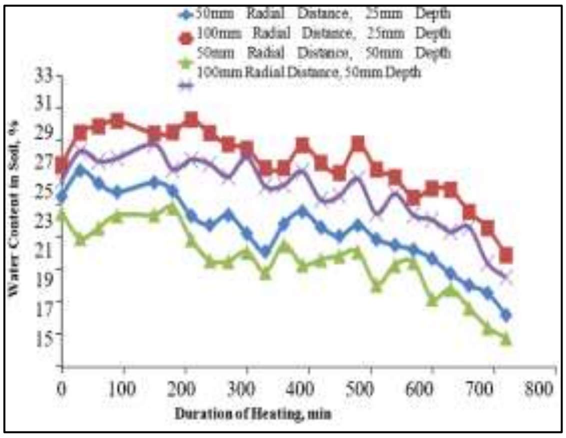

Fig. 11. Water content in Soil Vs Duration of Heating in Kaolinite at 85% LL

Effect of Soil Type and Water Content Reduction. Fig. 12& 13 present the effect of soil type on soil heating on the reduction in water content with duration of heating, for 50mm and 100mm distance and 25mm and 50mm depth. At any time of heating the reduction in water content is very steep for Bentonite and almost no change for kaolinite and little reduction in the beginning of heating for natural soil. As seen from the Table 2, the reduction in water content is relatively high for higher IMC for a given soil and at the same time for a given IMC, the percentage reduction is maximum for natural soil and lesser for Bentonite. The percentage reduction is maximum for natural soil and lesser for bentonite. The percentage reduction in water content is always high for kaolinite compared to natural soil and summarized as seen from Table 2. It is mainly because of the rate of evaporation of water content owing to the presence of coarse fraction has seen from Table 1.

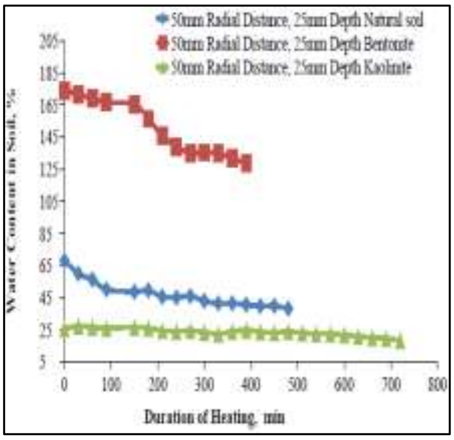

Fig. 12. Water content in Soil Vs Duration of Heating in all Soils for 85% LL at 50 mm Radial Distance and 25 mm Depth

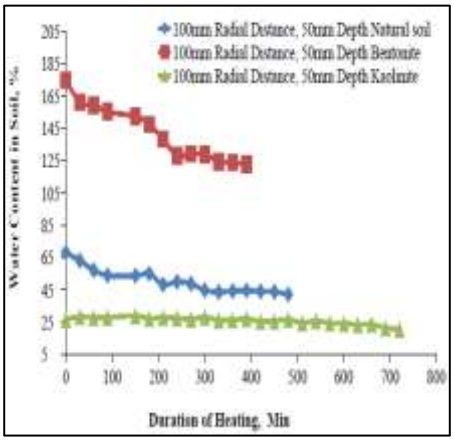

Fig. 13. Water content in Soil Vs Duration of Heating in all Soils for 85% LL at 100 mm Radial Distance and 50 mm Depth

T te e at
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Description	Water content (%)		
	Before heating	After heating	% reduction
Natural soil	8.80	18.78	113.41
Bentonite	6.56	17.56	167.68
Kaolinite	4.45	12.25	175.28

4.3 Effect of Soil Heating on Vane Shear Strength

Shear strength is one of the important engineering properties of soil, which is ultimately responsible for the stability of any structures. The soft clay normally would have undrained shear strength value ranging from 3 to 10 kN/m^2 only. The vane shear strength of Natural soil, Bentonite and Kaolinite are $6.56kN/m^2$, $7.48kN/m^2$ and $7.45kN/m^2$ respectively corresponding to 85% IMC of respective liquid limit water content. At the end of heating, the vane shear strength of Natural soil, Bentonite and Kaolinite are $17.56kN/m^2$,$18.24kN/m^2$ and $16.24kN/m^2$ respectively. The percentage of gain in strength of Natural soil, Bentonite and Kaolinite are 167.68%, 143.85% and 118% respectively (see Table 3). Even though the reduction in water content is high for kaolinite as seen from table 2, the gain of shear strength is lesser for kaolinite and least for bentonite, for a maximum duration of heating of 800 minutes. This is due to the fact here the reduction of water content in bentonite and natural soil could increase the undrained cohesion effectively compared to kaolinite.

The kaolinite soil is having only 9% clay content but the clay content for natural soil and bentonite are 66% and 55% respectively (Table 1). Because of more clay content present even though the reduction in water content for natural soil and bentonite are ranging from 167% to 175%, still the soil could gain maximum strength unlike kaolinite.

Table 3. Variation of vane shear strength of Natural soil, Bentonite and Kaolinite before and after heating at 85% LL

Description	Initial moisture content (%)	Vane shear strength in kN/m^2		% of gain in strength
		Before heating	After heating	
Natural soil	68	6.56	17.56	167.68
Bentonite	204	7.48	18.24	143.85
Kaolinite	25.5	7.45	16.24	118

5 Conclusions

Three different soils namely Natural soil, Bentonite and Kaolinite were subjected to soil heating process with a known IMC. Based on the analysis of temperature in soil, reduction in water content and vane shear strength, the following conclusions are drawn.

- Even though temperature at the source of heating is 300˚C, the temperature recorded in the soil varied between 30˚C to maximum of 43˚C only irrespective of duration of heating, type of soil and initial moisture content. This could be due to loss of heat energy in various means such as through soil cracks.
- At any time of heating, the temperature recorded at a depth of 50mm and 50mm radial distance is always higher than 50mm depths and 100mm radial distance. On the other hand, temperature recorded in soil at 25mm depth or 50mm or 100mm radial distance is always lower than the same distance at 50mm depths. This may be because when hot air is blowing in to the soft slurry soil sample, the heat energy is effectively dissipated over the surrounding soil at deeper depths and whereas at shallow depth, because of loss of heat through the surface cracks, there could not be effective heating of soil mass as reflected by the recorded temperature.
- At any time of heating, the temperature recorded for kaolinite is always higher than natural soil and bentonite, this is because of the presence of higher amount of coarser particles in kaolinite, the rate at which the water enters or drains out also increases and in the present case the rate of evaporation.
- Due to the high permeability nature of kaolinite, the heat energy is easily dissipated through the coarser particle pores compared to that bentonite and natural soil.
- The order of % gain in Vane shear strength is Natural soil > Bentonite > Kaolinite. Lower gain in strength for bentonite for higher IMC could be due to improper heating of soil mass because of poor permeability characteristics.

It is hence summarised the soil heating is highly influenced by the type of soil, an initial moisture content and irrespective of duration of heating.

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