A Critical Review on Expansive Soils Including the Influence of Hydrocarbon Pollution and the Use of Electrical Resistivity to Evaluate their Properties

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Abstract. This paper reviews the studies on expansive soil with a main focus on failure mechanism, financial losses, mineralogy, determination of swelling parameters and others. Effect of hydrocarbon pollution on geotechnical properties of expansive soil was presented. The paper discussed the assessment of electrical response of contaminated swelling soils. Wide extend of expansive grounds around the world and the serious impact created on infrastructures requires to identify its influential aspects and the appropriate treatments. Also, it was found that petroleum product affect significantly on the basic properties of swelling soils such as gradation, consistency, compaction, swelling and others, and electrical resistivity can be employed to reveal the electrical characteristics of polluted expansive soil.

1. Introduction
Expansive soil is a soil that significantly exhibits swell potential and shrinkage potential in relation to change in moisture content. Once soil hydrates, it becomes sticky, heavy, and its volume increases considerably as a result to absorbing large quantities of water. However, when it dehydrates it shrinks and becomes very hard causing noticeable cracks near the ground surface with maximum width may be up to 20 mm or more [1-3]. Practically, expansive soils can be observed in moist soil where a high plasticity clay can show problematic behaviour or in arid/semi-arid environments where soils have even moderate expansive index can lead to a pronounced damage [3]. Influential aspects of such soil that required to be identified are; failure mechanism, origin and the distribution around the world, structural damage, identification of mineral types and other aspects. However, the behaviour of expansive soil upon oil pollution is still not understood due to the lack in the related studies. In oil stations, soil pollution may occur due to the outflow of oil from broken tube lines or underground storage tanks of fuel or gas. In addition, oil leakage on the ground could be accidently occurred during transportation or during drilling processes in most circumstances [4]. Contamination with oil can be considered as a serious problem in geo-environmental engineering due to its effects on the atmosphere, groundwater and soil. Once the oil penetrates through the ground surface, an amount of it is trapped in the unsaturated zone, while the reminder of oil reaches the water table causing water pollution. The trapped amount evaporates to atmosphere and pollutes the air, vegetation and consequently affects the human health [5]. Many investigators studied the effect of oil products pollution on the geotechnical properties such as Atterberg limits, Max. dry density, hydraulic conductivity, shears strength, etc. for different types of soils.
However, investigations through expansive soil were not considered previously and need more detection. In recent years, Electrical Resistivity is considered as cost effective, non-destructive and quick method to investigate properties of soils. Many researchers have reported resistive response to soil petroleum pollution [6], but the relation between the degree of pollution and swelling index was not interpreted. The associated studies for polluted expansive soil are very limited and have not received sufficient attention in the literatures. To sum up, the main target of this research is to highlight the lack of knowledge about the behavior of expansive soil upon hydrocarbon pollution and the assessment of electrical resistivity for contaminated soil properties.

2. Expansive soil.
Expansive soil can cause a structural failure due to its seasonal volume variation and cautions should be taken pre and post construction of foundations and pavements [3,9]. The subsequent hardening and softening behaviour represented by the associated shrink-swell soil cycle can cause the structures founded on such soil to fail and damage civil infrastructures such as transportation, water supply, and sewage collection systems, as well as domestic, commercial, and industrial facilities. Damage in such facilities are clearly demonstrated by differential heave in roads and footpaths, inclined cracks in slab of basement and masonry walls, and breakage and fatigue in underground storage tank and buried pipeline [10]. It was reported that failure occurs when the volume alteration are irregularly distributed under the foundation, in such condition when the variation in water content of the soil around the edges of a building can lead to swelling pressure to develop beneath the outer border of the building while the water content beneath the center of the building will remain constant. Consequently, this will produce an end lift failure. In reverse, a center lift failure will result if swelling is localized beneath the center of the building or when shrinkage happens under the edges.

The American Society of Civil Engineers (ASCE) have weighed the harm due to expansive soil by 25% of all structures in the United States. The associated financial loss can be greater than that of floods, earthquakes and tornadoes [11]. Such the annual cost resulted from the hazardous foundation of the civil engineering structures rested on expansive soils is estimated at $1000 million in the United State, £150 million in the UK, and many billions of pounds worldwide [12-3]. Insurance companies in USA spend millions of dollars yearly to repair homes concerned with swelling clay derived from residual soils which can apply uplift pressures reach approximately 5,500 PSF, which can in turn cause significant damages to lightly-loaded wood-frame structures [1]. Example on occurred damage under such circumstances includes the residential zone of Akashat Mine near Al-Rubih city in the west of Iraq where tens of houses undergo from severe destruction due to soil swelling [13]. The parent materials that can be related to expansive can be classified into two main groups. The first group includes the igneous rocks in which the feldspar and pyroxene minerals decompose to form other secondary minerals and montmorillonite. The second group is called smectite group consist of the sedimentary rocks that comprise montmorillonite which in its role breakdowns and form expansive soils [14]. It is reported that expansive soils in Iraq are belong to the second group [15]. Generally, the minerals in the expansive clay have a very weak Van der Waals forces, their cation exchange capacity is very high (80-150 mg/100g) with extraordinary negative surface charge owing to isomorphs replacement, and possess a large specific area ranging between 400 m2/g and 900 m2/g [16]. Expansive soils are found throughout many regions of the world, particularly in arid and semi-arid regions, as well as where wet conditions occur after prolonged periods of drought. Their distribution is dependent on geology (parent material), climate, hydrology, geo-morphology and vegetation. Expansive soils occur and incur major construction costs around the world, with notable examples found in USA, Australia, India and South Africa [3]. In addition, many examples are found in the literature in the Arab Gulf area such as Al-Rawas in Oman and Al-Mamodi in Saudi Arabia. Al-Obaidy et al., 2016 [17] referred to presence of such soil in Iraq through reviewing the soil conditions in this country. Authors pointed that although in much Iraqi published work the existence of expansive clay is confirmed to be in middle and north of the country and some in the south, the most affected area with swelling clay is concentrated on the west.
3. Identification of mineral types for expansive soil

Several methods were employed to explore the clay mineral type in a natural expansive soil. Some of these methods were summarized as follows:

3.1 X-Ray diffraction

This method is an analytical technique which can chiefly provide information on a soil sample in which X-rays assembled at different angles and directed with slow rotation to show the intensity of the collected rays. The technique depends on Z direction of the sample which is influenced by exchange of central cations and the existence and size of the corresponding balancing cation [18].

3.2 Thermal inspection

This method is also called differential thermal analysis, in which the sample will be heated at a constant rate up to approximately 1000°C. The endothermic and exothermic effects occurring in the material are usually recorded by a proper device [19].

3.3 Chemical inspection.

Despite the developed technique to study clay, chemical analysis is still necessary for identification of clay minerals [20].

3.4 Dye adsorption

In this method, the soil sample is treated with acid, then the developed colours by the adsorbed dye are be influenced by the characteristic base exchange capacities of the different clay mineral group available [21].

3.5 Scanning electron microscope

It is a powerful technique to study the formation, texture and fabric of the clay tested sample. The high energy electron generates a variety of signals at the surface of the clay sample that expose the morphology, chemical composition, and crystalline structure of the sample [22].

4. Identification the degree of soil expansivity

The degree of soil expansivity was commonly assessed using a coefficient called the swell potential which is identified in the previous literature according to liquid limit, plasticity index or shrinkage limit. [16] presented tables for each individual characteristic based on associated references. Table 1 represents the degree of expansivity based on the above parameters.

| Swell Potential | Liquid Limit % | Plasticity Index % | Shrinkage Limit % |
|-----------------|----------------|--------------------|-------------------|
|                 | Chen 1965      | IS: 1948 & Gibbs    | Holts & Gibbs 1956|
| Low             | < 30           | <18                 | <12               |
| Medium          | 30-40          | 15-28               | 10-35              |
| High            | 40-60          | 25-41               | 23-32              |
| Very High       | >60            | >35                 | <10               |

5. Determination of the swelling index

There are two main geotechnical tests were applied in the former texts to determine the swelling index for the expansive soil; free swell test and oedometer test, a brief of those tests are given in the section below:
5.1 The Free swell index

The Bureau of Indian Standards (IS:2720, 1977) presented a free swell test in which two 10g identical soil samples passing sieve (425 mm) inundated in distilled water and kerosene for 24 hours after placing each sample in two graduated cylinders. The Free swell index \( FSI \) is calculated according to the following equation:

\[
FSI (%) = \left( \frac{V_d - V_k}{V_k} \right) \times 100\% \tag{1}
\]

\( V_d = \) reading of the graduated cylinder containing distilled water
\( V_k = \) reading of the graduated cylinder containing kerosene

According to IS: 1948-1970 the FSI can be considered as: low if it is less than 50%, medium if it equals to 50%-100%, high if it ranges between 100% and 200%, and very high if it is more than 200%.

5.2 Oedometer test

Oedometer test is a beneficial and common test in the geotechnical engineering. It is used to determine swelling parameters in soil sample such as swell pressure and swelling index. The swell pressure (Ps) can be defined as a required pressure for the swelling soil to consolidate back to its original volume before introducing the water [24]. The parameter Ps can be determined from the void ratio (\( e \)) - log effective stress (log'\( \sigma \)) relationship curve of the soil sample corresponding to the loading stage. The swelling index Cs which represents the slope of the unloading portion of the \( e \)-log'\( \sigma \) curve can be calculated as follows:

\[
Cs = \frac{\Delta e}{\Delta \log'\sigma} \tag{2}
\]

\( \Delta e \): Change in void ratio
\( \Delta \log'\sigma \): Change in effective stress

6. Oil contamination effect on expansive soil properties

Expansive soil is considered as problematic soils that lead to geotechnical and engineering challenges all over the world [26]. Behaviour of expansive soil due to oil products pollution is still obscure and unclear. Generally, clayey soils have complicated behaviour in the presence of organic liquids [27] and [37]. When oil spills, it moves down under gravity, spreads horizontally by migration then if find its way to change soil system properties [28]. It is necessary for geotechnical engineer to investigate the engineering behaviour of clayey and expansive soils in order to analyse the suitability of such polluted zone for civil engineering constructions in future [25]. There is a lack in studies and knowledge about oil contamination effect on expansive soil geotechnical properties. Daka, 2015 [24] have tried to fill the voids formed by deficiency in data of effect of oil on soils that contain montmorillonite This research highlights this gap of knowledge within this aspect.

7. Results of Previous Experimental Works on Contaminated Expansive Soil

Based on other researchers work, the following results have been taken out from their investigations: Harsh et al., 2016 [25] studied the impact of oil pollution on kaolinite clay and expansive soil (black cotton) properties. Outcomes of the expansive soil tests revealed that specific gravity decreased as oil content increased because the density of hydrocarbon is much lower than water. Liquid limit decreased as the percentage of oil pollution increased adversely to Daka, 2015 [24], whilst plastic limit and shrinkage limit increased due to oil addition. The study also examined the swelling potential variation due to oil contamination. Free swell index which is the important parameter to evaluate swelling potential increased with the addition of oil content. It was inferred that properties of expansive soil is more susceptible to deteriorate due to oil subjection and less reliable for any engineering project in vicinity of contaminated zone. Another study on the performance of petrol and diesel contamination on
black cotton soil which forms about 70% central India was conducted by Pusadkar and Bharambe, 2014 [29]. It was observed that Atterberg limits of polluted soil were increased. The maximum dry density, specific gravity, CBR, and swelling pressure were reduced. The research reported that the effect of contamination is quite similar to water by increasing inter-particle slippage. Few attempts reported that adding oil product can be used as a technique to stabilize swelling grounds. In Iraq, The hazard of soil contamination by petroleum product increases with the development of exploration, production and transportation [36]. Majeed, 2017 [28] studied the effect of various petroleum product on the expansive soil properties. The soil was obtained from karkuk city. Petroleum product such as: Kerosene, Gasoil, and Cut-back asphalt (MC-30) were added in different percentage (2, 4, 6, 8 and 10%) in order to improve the properties of expansive soil. It was concluded that for all petroleum products the addition of any percentage reduces the geotechnical properties values such as Atterberg limits, maximum dry unit weigh, free swell index and swell pressure which it in turn reduces the volumetric changes. Kerosene was the best petroleum product for treating expansive soil. Recently, Zeini and Al-Abdaly, 2020 [29] evaluated that fuel oil can be used as improvement agent for expansive soil properties. The study was conducted on swelling soils samples collecting from a region in the west desert of Iraq. Outcomes revealed that the (8%) of weight is the optimum percentage to reduce the swelling potential.

8. Use of electrical resistivity to assess expansive soil properties

Electrical resistivity can be defined as the ability of material to oppose the flow of electricity. It is considered as an attractive tool to monitor the subsurface and identifying changes in soil properties. It depends essentially on degree of saturation, porosity, clay content and temperature. Electrical resistivity property is widely employed recently for assessing the geotechnical parameters of soil, including the swelling index. However, under circumstances of leaking hydrocarbon products into expansive grounds, the usage of such technique in identifying the degree of contamination is still obscure and needs more investigation. Moreover, the effect of oil contamination on the swelling properties through an expansive characterized with high volume change upon drying or wetting with water was not considered. Although few recent attempts reported adding oil products as an improvement technique to stabilize an expansive ground [28], they did not interpret the relation between the degree of pollution and the swelling index for different expansive soils. Thus, the behaviour of such soil upon contamination with hydrocarbon products is still obscure and needs enhanced understanding. On the other hand, those conventional laboratory experiments still, in most circumstances, costly and require much effort and time to be performed. That is why some researchers functionalyzed the Electrical Resistivity ER method in their studies. Related to this topic, see Liu et al. [30]. The ER is economical, quick, non-destructive, and applicable for different soil types; its measurements can deliver beneficial information about moisture, densification, and salinity of the subsoil [31-33]. Moreover, the relationship between the electrical data and oil content can quickly establish. The ER of the petroleum substance in the soil is different in value from that of the water [6]. On the other hand, the ER is very useful in the evaluation of the degree of contamination as the electrical response will be altered concerning oil type and content [30]. Referring to the non-polluted expansive soil, the ER method was identified through previous literature with its high sensitivity to the mineralogical properties including montmorillonite and clay content [34]. Moreover, ER response can be used to correlate to the swell parameters such as swelling potential of expansive soils [35]. However, the electrical response of expansive soil and extending the correlation between ER and the swelling potential to include the percentage in the pollution with hydrocarbon substances was not taken into consideration in previous literature.

9. Statistics Results and Main Findings

According to the collected data and the associated sources of this study, it can be noticed that the majority of the researches have focused on the performance of various types of soil upon oil products contamination. However, few studies (about 10%) have referred to the influence of oil contamination on the behavior of the expansive soil, see figure. 1-a. Also, in many previous geophysical studies the electrical resistivity technique was functionalyzed in assessment the electrical response for different soil
types, only 15% of them were dedicated for the electrical response of uncontaminated expansive soil and about only 5% for contaminated expansive soil, see figure 1-b. Thus the electrical behavior of expansive soil upon addition of oil products is still obscure and need more investigation. The lack in related data highlighted the gap of knowledge within this topic.

![Different soil types](image1.png)

(a) Geotechnical studies upon contamination

![Different soil types](image2.png)

(b) Geophysical studies using ER method

**Figure 1.** Percentages of related studies

10. Conclusion
Expansive soil is a soil that exhibits swelling and shrinkage potential due to variation in moisture content resulted in structural failure in the civil infrastructures estimated by great financial loss annually. It is extended in many regions worldwide. Several methods were employed to identify mineral types and the degree of expansivity for expansive soil. Montmorillonite mineral is the main component of such soils. However, the effect of hydrocarbon pollution on the geotechnical properties of swelling soils did not receive sufficient attention in previous studies and still need more clarification. Few researches revealed that oil products can be used as improvement agent for expansive soil properties. Moreover, the positive relationship between electrical resistivity and oil content showed that such technique can be used as quick economic tool to investigate properties of contaminated expansive soil although the related researches in this field are very little. Finally, the obtained results of previous studies could be used as a guide in soil remediation concerning polluted ground and contribute to producing a reliable alternative to using costly, time and effort consuming conventional tests.

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