Vermiremediation of Crude Oil Contaminated Soil for Application as Highway Subgrade Material

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Abstract- This research investigated the effectiveness of vermiremediation using Eudrilus eugeniaen to treat crude oil contaminated soil for potential use as subgrade material. Five soil samples were analyzed: natural soil, contaminated soil with zero number of earthworms (control) and contaminated soil with 10, 20 and 30 earthworms each contaminated with 75cl of crude oil per 10kg of soil respectively with the exception of the natural soil. The earthworms were then introduced into the soil samples after 24hrs of contamination and left for over a period of 16 weeks, moisture, feeding was maintained with leaves and plant roots. Total Petroleum Hydrocarbon (TPH), soil pH, soil texture and nutrient level were assessed before and after treatment. The initial total petroleum hydrocarbon present in the contaminated soil sample was 40,400 mg/kg. After remediation, TPH was reduced to 25,200mg/kg (37.62%) with 10 earthworms, 21,600mg/kg (46.53%) with 20 earthworms and 220,800mg/kg (48.51%) with 30 earthworms, making a total reduction of 19,600mg/kg. Geotechnical properties were conducted. Scanning Electron Microscopy (SEM) Analysis was also carried out on the contaminated soil sample and sample with 30 numbers of earthworms using BSH energy level. The study concluded that Eudrilus eugeniae shows potential for remediating crude oil contaminated soil achieving 48.51% level for 30 numbers of earthworms. Therefore, future research should explore higher earthworms' densities and utilize British standard heavy (BSH) compaction energy for shear strength tests to order to align with the requirement of federal ministry of works and housing general specification for road and bridges.

Indexed Terms- Vermiremediation, Crude Oil Contaminated Soil, Highway Subgrade Material, Geotechnical Properties, Endrullis Eugeniae, Total Petroleum Hydrocarbon (TPH)

I. INTRODUCTION

The modern world's interconnectedness, economic expansion, and social advancement depend heavily on the construction and maintenance of road networks. However, these processes often come at a high cost to the environment, particularly when contaminated material needs to be removed in order to develop and maintain roads. Hydrocarbons, heavy metals, pesticides, and diseases are among the hazardous substances that might be discovered in contaminated soil. These compounds have the potential to gravely harm ecosystems, the environment, and human health if left unchecked (Njoku, 2017).

Due to these challenges, research into innovative and ecologically friendly soil remediation techniques is becoming more and more important, especially considering the significant soil requirements of road construction projects. Recently, interest in vermiremediation has grown because of its potential.
One method used by nature to clean up damaged environments is bioremediation (Njoku, 2017). It encompasses all procedures and activities that are carried out to alter an environment through the use of living things to eliminate or detoxify environmental pollutants (Njoku, 2017). Biological agents are used in bioremediation to convert toxic chemical substances into non-hazardous forms. It involves adding organisms and nutrients, such as nitrogen and inorganic or organic phosphate, to the contaminated soil and is a rather inexpensive and efficient method of environmental cleanup microbial remediation/microremediation, phytoremediation, mycoremediation, zooremediation, and vermiremediation are examples of bioremediation procedures (Njoku, 2017)

Using earthworms to remove pollutants from the soil is known as vermicomposting. Studies on the possible application of earthworms have demonstrated their capacity to handle sewage sludge and contaminated land (Njoku, 2017). It has been found that a wide range of organic and inorganic contaminants, including pesticides, polycyclic aromatic hydrocarbons (PAH), crude oil, and heavy metals, can be tolerated by earthworms and either removed completely or assisted in their removal (Njoku, 2017). The author also outlined a few potential vermiremediation strategies, such as: direct application of earthworms to contaminated soils, co-application of earthworms to contaminated soils with another organic media such as compost, application of contaminated media to earthworms as part of a feeding regime, indirect use of earthworms through the application of vermidigested material.

The ultimate purpose of this research is to turn polluted soil into a sustainable and ecologically acceptable material for road construction by examining the viability and efficacy of vermiremediation. The combined strategy has the ability to address the logistical and environmental issues related to conventional soil restoration techniques while simultaneously encouraging the responsible and sustainable construction of infrastructure that is vital to the advancement of society. As such, it's a significant step in the direction of more environmentally friendly and sustainable road construction techniques in the future.

II. LITERATURE REVIEW

Soil contamination by crude oil

Crude oil is a rapid and convenient energy source that raises living standards and improves our quality of life. Around the world, it is naturally occurring in various places, especially the USA, Russia, Romania, Iran, Mexico, Iraq, Saudi Arabia, Kuwait, Libya, and Nigeria (Ahmed, 2020). An estimated billion tons of crude oil, natural gas, and its derivatives are produced year by the petroleum industry. Following further processing, all of these are turned into refined goods including lubricants, gasoline, diesel, and gasoline (Ahmed, 2020).

Hydrocarbons that are volatile liquids with different molecular weights and structures make up crude oil. It is classified according to the most common constituent inside its more than 17,000 hydrocarbons (Ahmed, 2020).

The three main hydrocarbons components present in crude oil are compiled and presented in table 2.1 Three main hydrocarbons component present in crude oil

1	Paraffins	Methane
		Ethane
		Octane
2	Naphthene	Benzene
		Toulene
		Xylene
3	PAH	Naphthalene
		Anthracene
		Benzopyene

(Ahmed, 2020).

One of the main environmental issues affecting terrestrial and aquatic environments is the contamination of crude oil. Nowadays, hydrocarbons derived from petroleum affect around 80% of land and are utilized as a source of energy in the chemical and oil sectors (Juanshan, 2020). Crude oil coats the soil's surface and keeps the carbon dioxide that soil organisms produce in place. By adhering the soil particles to one another, it also reduces the porosity of the soil. The quantity and kind of oil spilled determines the amount of loss (Juanshan, 2020).

Long-term stable PAH contact with soil causes a condition known as soil aging, which makes the soil resistant to all forms of treatment (Juanshan, 2020). The biological environment, plants, and human health may all be at danger if these pollutants seep into ground water from the soil (Juanshan, 2020). Therefore, it is critical to remove these dangerous materials from the soil in order to protect life from their lethal consequences. Furthermore, by cleaning up oil-contaminated areas, more land can be made accessible for habitation and farming. Many nations, like Kuwait, Lebanon, and some others, are creating their own plans to deal with the soil pollution caused by crude oil. Many techniques have been developed to extract crude oil from the polluted soil. For this, a rapid, eco-friendly, and economical approach is needed. The latest advancements in widely accepted remediation techniques for treating soil contaminated by crude oil are the main topic of this review.

Bioremediation

In order to treat contaminated sites and restore them to their original state, bioremediation is defined as a process that uses living organisms, primarily microorganisms, green plants, and their enzymes, to remove, degrade, mineralize, transform, and detoxify the hazardous components of environmental waste and environmental pollutants into harmless or less toxic forms (Tyagi, 2021). Chemical pollutants such pesticides, polyaromatic hydrocarbons, halogenated petroleum hydrocarbons, nitroaromatic chemicals, metals, and industrial solvents have all had their concentrations and toxicity reduced through the employment of the bioremediation process (Tyagi, 2021). Cometabolism, biotransformation kinetics, biotreatment, and biogeochemical modeling are among the fundamental research areas in the field of bioremediation. Field application research areas include biogeochemical assessment techniques, environmental attenuation, fate modeling, and cometabolic techniques (Tyagi, 2021).

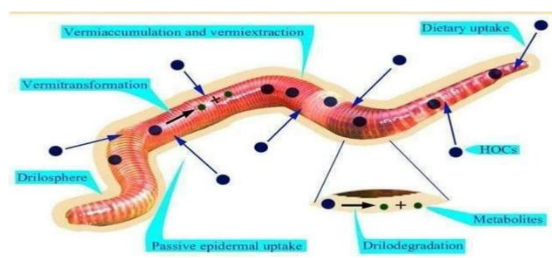
Both large- and small-scale uses of bioremediation have been effective; one notable example of bioremediation's use for the treatment of contaminants is the cleanup of the oil spill in Alaska (Tyagi, 2021). Sludge, waste streams, lagoons, soil, and contaminated groundwater can all be cleaned up using bioremediation procedures. Bioremediation techniques can be successfully implemented in contaminated fields by using appropriate engineering models or designs to create a favorable growth environment and by making optimal use of natural and engineered bacteria and their processes.

Remediation of organic contaminants by earthworms

Organic matters or substrates are generally known to be biodegradable through a biotransformation process known as mineralization or composting (Dada et al, 2021). When earthworms facilitate or speed up the process of natural composting of organic matter, it is referred to as vermicomposting. Vermicomposting is the process of biodegradation of organic matter through the interactions between earthworms and microorganisms (Dada et al, 2021). When the organic matter or substrate is a contaminant, the earthworm facilitated composting is described as vermiremediation.

The name "vermiremediation" combines two Latin words: vermis, which means worm and remedium, which means to remove or correct an ill. To the best of our knowledge, Edwards and Arancon (2006) as cited in the study of (Shi, 2020) were the first to use the phrase "vermiremediation" (according to study findings from Google Scholar and Web of Science) (Shi, 2020). Though Rodriguez-Campos et al. (2014) as cited in the study of (Shi, 2020) write that "earthworms are used for removing contaminants from the soil or when earthworms help to degrade nonrecyclable chemicals," it's possible that they were the first to define the phrase (Shi, 2020). This definition seems a little ambiguous, thus a thorough explanation was cautiously supplied here.

Vermiremediation is a type of earthworm-based bioremediation technology that gathers and extracts, transforms, or breaks down contaminants in the soil environment by utilizing the earthworms' life cycle (e.g., feeding, burrowing, metabolism, secretion) or their interactions with other abiotic and biotic factors (Shi, 2020). vermiextraction and vermiaccumulation, vermitransformation, and drilodegradation are some of the terminologies that may be used to characterize potential processes and mechanisms involved in Vermiremediation, according to the definition. The Figure below shows these procedures.



The word "vermiremediations" refers to a biological technology-based technique that employs earthworms to improve degradation and remove pollutants from contaminated locations all over the world (Almutairi, 2019). Earthworms in general, and Eisenia fetida in particular, are resistant to pollutants such as heavy metals and organic toxins found in soil. According to reports, this strategy uses earthworms to bioaccumulate pollutants in their bodies, which then, with the help of enzymes, biodegrade or bio-transform into safe products

(Almutairi, 2019). According to (Almutairi, 2019), residual, heavy, and hydrocarbons in contaminated soil are not always destroyed or removed by the vermiremediation process.

Geotechnical properties of contaminated soil. Hydrocarbon-contaminated soils:
According to the importance and necessity of fundamental information about hydrocarbon compounds and their presence in soil structures in assessing the geotechnical behavior of hydrocarbon-contaminated soils, this section aims at comprehensively reviewing the published scientific literature that discuss some aspects of hydrocarbon-contaminated soils, including hydrocarbon compounds, microstructures of hydrocarbon-contaminated soils, and available methods for determination of hydrocarbons in contaminated soils (Rajabi, 2018).

III. MATERIALS AND METHODOLOGY

Soil Samples and vermiremediation bed preparation:

The process began with the collection of representative soil samples from a designated area, and the soil specimens were then contaminated with crude oil. To replicate realistic contamination conditions, soil samples were uniformly contaminated with crude oil at predetermined amounts. There are four (4) samples in total, and each 10 kg of soil sample has 75 cl of crude oil contamination.

Figure 3.1 (A) Figure 3.1 (B) Figure 3.1 (C)

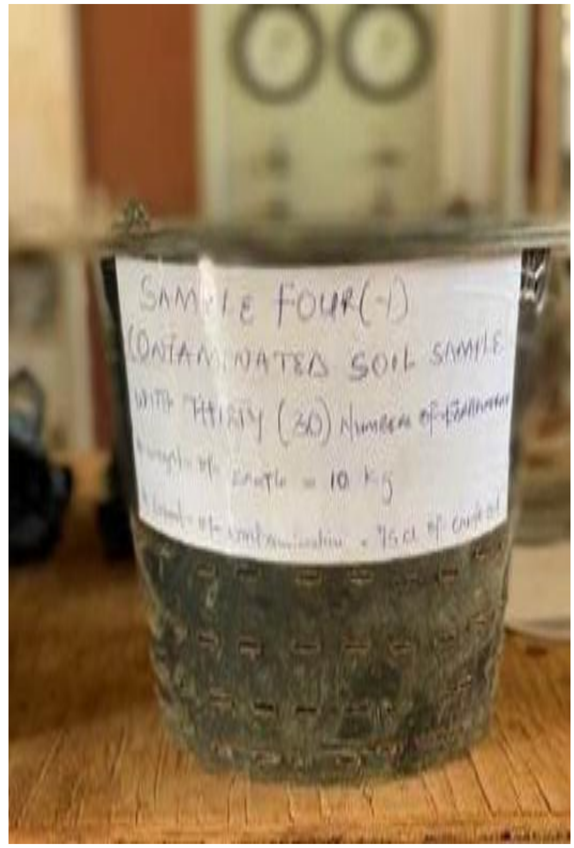


Figure 3.1 (D)

Figure 3.1 (E)

Earthworm Selection, preparation, introduction and maintenance

[Eudrilus eugeniae] were determined to be appropriate candidates for the remediation procedure. In order to guarantee uniformity and reproducibility, vermiremediation tests were carried out under carefully monitored laboratory conditions. Earthworms were then introduced in to the contaminated soil matrices, and the vermiremediation process was started in an environment that was closely observed.

Soil Property Analysis:

- Analyze the soil samples for various physical and chemical properties, such as texture, pH levels, nutrient levels, and total petroleum hydrocarbon (TPH) before and after vermiremediation.
- Evaluate changes in soil properties to assess the effectiveness of the vermiremediation process in improving the quality of the soil for highway subgrade applications.

Geotechnical Laboratory Test:

The geotechnical test Conducted are as follows;

Atterberg limit	- BS 1377(1990)
liquid limits (LL)	- BS 1377 (1990)
plastic limit (PL)	- BS 1377 (1990)
Plasticity Index (PI)	- BS 1377 (1990)

Compaction with three energylevels:

British Standard Light (BSL)

British Standard Heavy (BSH) West African Standard (WAS)

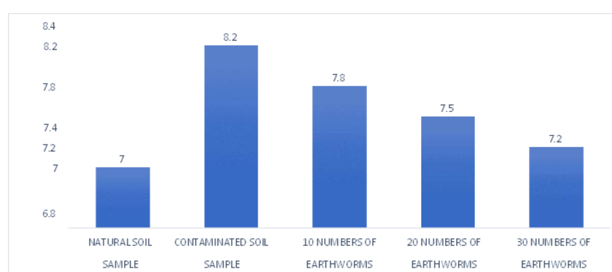
Compaction Characteristics: Maximum Dry Density (MDD) and Optimum Moisture Content (OMC)

California Bearing Ratio (CBR)	- BS 1377(1990)
Unconfined compressive strength (UCS)	- BS 1377 (1990)
Sieve analysis	- BS 1377 (1990)

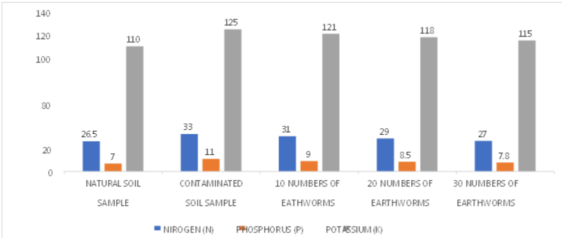
IV. DISCUSSION AND ANALYSIS OF RESULT

Soil property analysis

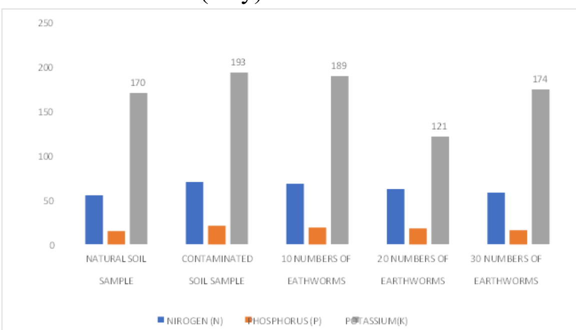
Soil PH Level



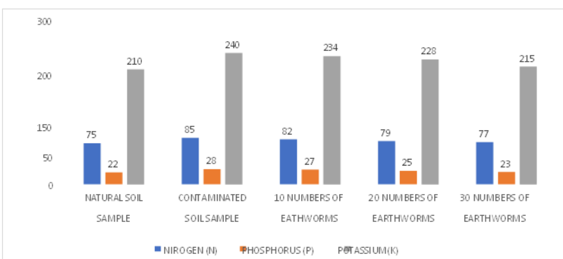
Soil nutrient level (sandy)



Soil nutrient level (silty)



Soil nutrient level (clay)



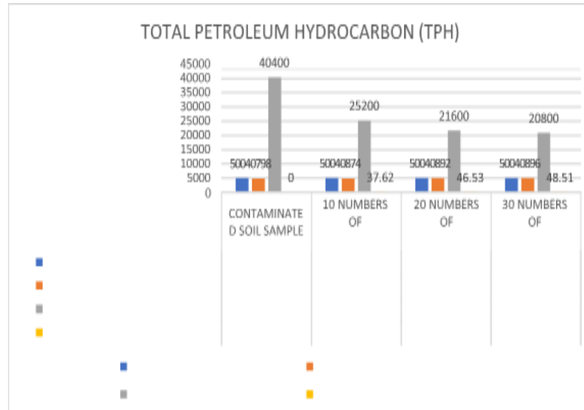
(Okafor, 2023), stated that petroleum contamination increases soil PH to alkaline and also increase total nitrogen, organic carbon content and relative amount of phosphorus.

Similarly in this research, the soil PH of the samples increases to alkaline due to the crude oil contamination and also the soil nutrient level for the different soil sample, for sandy, loamy and clay, have increase in nitrogen, phosphorus and potassium respectively.

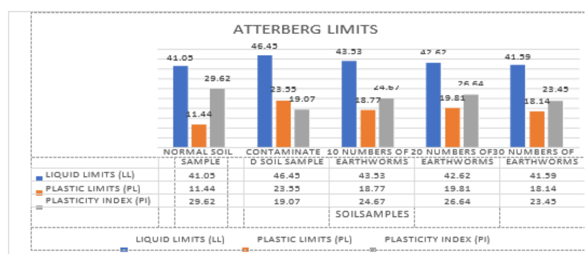
Therefore, the values for soil properties analysis are relatively high in contaminated soil sample, hence it significantly reduced in the remediated soil samples due to the earthworm's activity in the remediation process.

Total Petroleum Hydrocarbon (TPH)

The result below shows the analysis on the amount of Total Petroleum Hydrocarbon (TPH) present in the contaminated soil sample and the remediated soil samples carried out by gravimetric method.



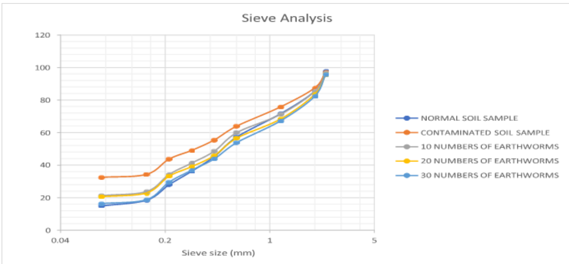
from the above result it can be seen that the earthworm's breakdown or reduces the concentration of the Total Petroleum Hydrocarbon (TPH) from 40,400mg/kg to 20,800 mg/kg which has total of 19,600 mg/kg reduction in TPH concentration due to the earthworms' life cycle.It also shows that, as the numbers of earthworms are increasing in the soil samples the vermiremediation is becoming more effective.



According to the findings of the Atterberg limits tests included in the study of (Ebadi, 2012), the plasticity index (PI) subsequently drops, the liquid limits (LL) rise with a light slope, and the plastic limits tend to increase distinctively as the oil content increases.

According to the Federal Government, general specification for road and bridges, liquid limit should be less than or equals to 50% plasticity index should be less than or equals to 35%. Hence the liquid limits and plastic limits for the soil samples are within the range of the general specification.

Sieve analysis



(Ijimdiya, 2011), stated that, as the oil content increased the grading modulus decreased. This is consistent with the characterization of particle size, since at higher grading modulus the soil particles have lower percentages of fines passing through BS No. 200 sieve. This implies that grading modulus is inversely related to the percentage of fines content.

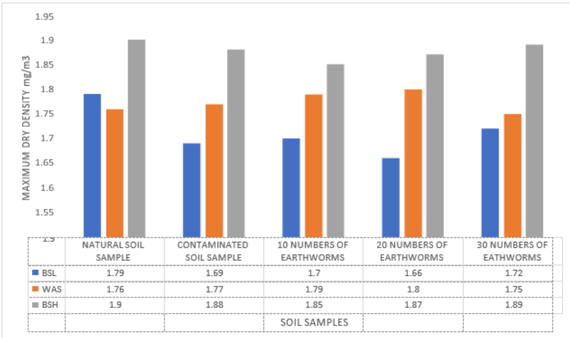
similarly, in this research it can be clearly seen that the contaminated soil sample have higher percentage passing through sieve No.:200 but subsequently dropping down in the soil samples with 10, 20 and 30 numbers of earthworm's remediation.

According to the Federal Ministry of works and Housing (FMWH) general specification for road and bridges the percentage passing through sieve No. 200mm or 0.075µm should be less than of equals to 35%. In this research, all the soil samples fall under group A-2-7 which is silty or clayey gravel and sand, according to the American Association of Highway and Transport Officials (AASHTO) soil classification system. The Group Index (GI) of the soil samples are 3 for normal soil sample, 7 for contaminated soil sample, 4 for 10 numbers of earthworm's remediation, 4 for 20 numbers of earthworm's remediation and 3 for 30 numbers of earthworm's remediation respectively. As the numbers of earthworms are increasing in the samples the group index is becoming low which means that, the lower the group index the better the result.

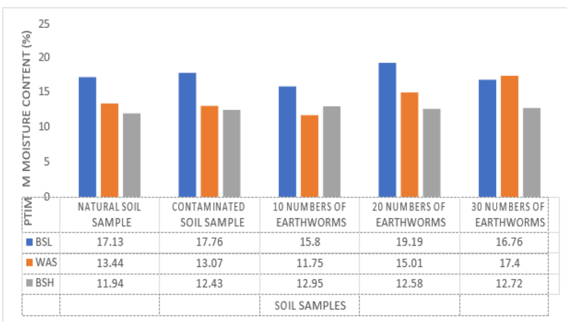
The soil samples are classified below, according to the American Association of Highway Transport Official (AASHTO) soil classification system.

SOIL SAMPLE	PERCENTAGE PASSING SIEVE NO. 200mm (%)	PLASTICITY INDEX (PI)	GROUP CLASSIFICATION	GROUP INDEX (GI)	FEDERAL GOV.T GENERAL SPECIFICATION	REMARK
NORMAL SOIL SAMPLE	15	29.62	A-2-7 (Silty or clayey gravel and sand)	3	Percentage passing ≤ 35% PI ≤ 35	Meets FGGS requirement
CONTAMINATED SOIL SAMPLE	32.55	19.07	A-2-7 (Silty or clayey gravel and sand)	7	Percentage passing ≤ 35% PI ≤ 35	Meets FGGS requirement
10 NUMBERS OF EARTHWORMS	21.35	24.67	A-2-7 (Silty or clayey gravel and sand)	4	Percentage passing ≤ 35% PI ≤ 35	Meets FGGS requirement
20 NUMBERS OF EARTHWORMS	20.65	26.61	A-2-7 (Silty or clayey gravel and sand)	4	Percentage passing ≤ 35% PI ≤ 35	Meets FGGS requirement
30 NUMBERS OF EARTHWORMS	16.35	23.45	A-2-7 (Silty or clayey gravel and sand)	3	Percentage passing ≤ 35% PI ≤ 35	Meets FGGS requirement

Compaction characteristics Maximum Dry Density (MDD)



Optimum Moisture Content (OMC)



(Salimnezhad, 2021), stated that, by the increase of oil content in soil, MDD and OMC values decrease. The oil presence reduces water absorption and dissipates applied energy, which leads to low compaction.

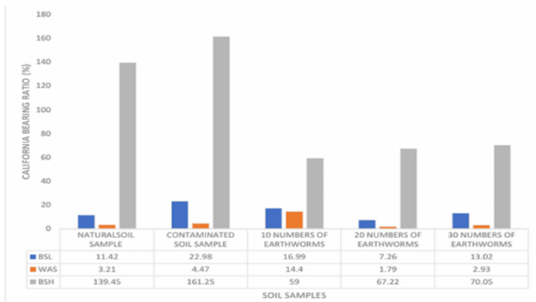
Similarly, in this research, the MDD decreases in the contaminated soil sample due to the crude oil contaminant but significantly increasing in samples with 10, 20 and 30 numbers of earthworm's remediation, however, the OMC increased in the contaminated soil sample but the values were decreasing in the remediated soil sample.

According to the Federal Ministry of works and Housing (FMWH) general specifications for road and bridges, maximum dry density should be minimum of 1.7Mg/m3 and optimum moisture content should be maximum of 18%. From the above result, it can be clearly seen that only contaminated soil sample (BSL) which have 1.69 Mg/m3 and 20 numbers of earthworms (BSL) which have 1.66 Mg/m3 have not meet the requirement. And for OMC it can also be clearly seen that all the energy level and soil sample have meet the requirement except 20 numbers of earthworms (BSL) which have 19.19%. However, based on this research I recommend the use of BSH because the results are sounder and more effective.

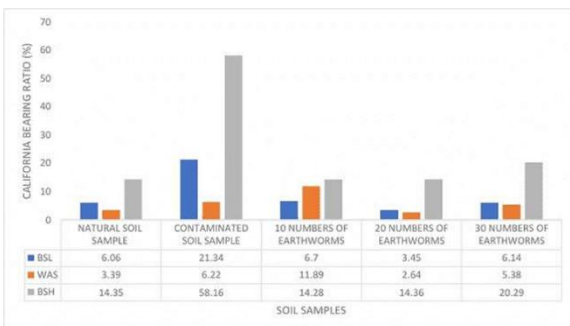
The table below shows the soil samples which failed to meet with the requirement for federal Gov.t general specification for road and bridges

SOIL SAMPLES	MAXIMUM DRY DENSITY (MDD)	OPTIMUM MOISTURE CONTENT (OMC)	FEDERAL GOV.T GENERAL SPECIFICATION	REMARK
Contaminated soil sample (BSL)	1.69mg/kg		MDD ≥ 1.7mg/kg OMC ≤ 18%	Failed in MDD
20 numbers of Earthworms (BSL)	1.66mg/kg		MDD ≥ 1.7mg/kg OMC ≤ 18%	Failed in MDD
20 numbers of earthworms (BSL)		19.19%	MDD ≥ 1.7mg/kg OMC ≤ 18%	Failed in OMC

California Bearing (CBR) Unsoaked and Soaked California Bearing Ratio (Unsoaked)



California Bearing Ratio (Soaked)



In this research the unsoaked and soaked CBR increases in contaminated soil sample and is decreasing in the sample with 10, 20 and 30 numbers of earthworm's remediation due to the effect of vermiremediation in the soil sample.

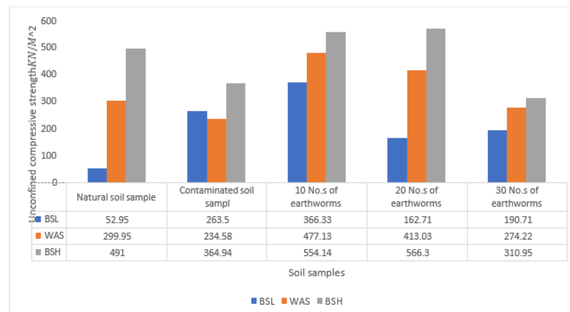
According to the Federal Ministry of works and Housing (FMWH) general specifications for roadand bridges the value for CBR should be greater than or equals to 15%. From figure 4.10 for unsoaked samples, it can be clearly seen that 30 numbers of earthworm's remediation meet with requirement. Similarly, from figure 4.11 For soaked samples, 30 numbers of earthworm's remediation meet with requirement. Therefore, based on this research I recommend the used of BSH for unoaked samples and soaked samples.

(Akinwumi, 2014), in his research, he concludes that the unsoaked CBR of the soil initially increased before it decreased while its soaked CBR decreased with increasing percentages of the crude oil in the soil.

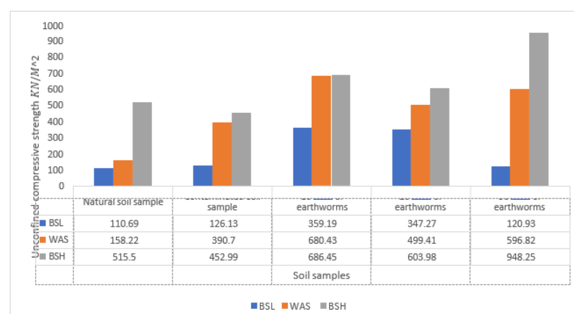
In this research the unsoaked and soaked CBR increases in contaminated soil sample and is decreasing in the sample with 10, 20 and 30 numbers of earthworm's remediation due to the effect of vermiremediation in the soil sample.

According to the Federal Government General Specification for road and bridges, the California Bearing Ratio (CBR) value for subgrade soil materials should be greater than or equals to 15%.

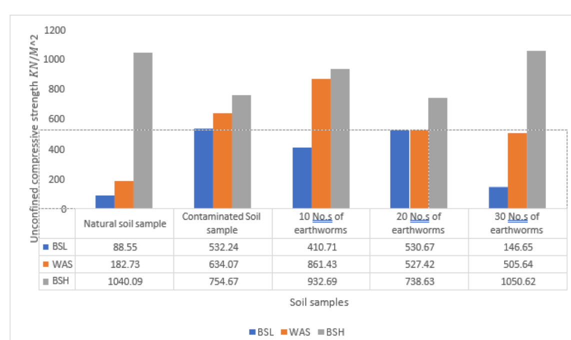
Unconfined Compressive Strength (UCS) UCS at 7 days



UCS at 14 days



UCS at 28 days



(Salimnezhad, 2021), stated that by increasing the oil content in soil, the UCS decreases. Moreover, oil cannot show the bonding and adhesive characteristics as a pore and inter-particle fluid. Because crude oil is a non- polar fluid, and its molecules cannot bond to water or charged surface of clay minerals. It will produce an immiscible phase in the soil-water system, which acts as a lubricant, and it decreases the cohesion and UCS of contaminated soil (Salimnezhad, 2021).

Similarly, in this research, most of the result particularly for BSH shows that the contaminated soil sample has decrease in UCS but increases subsequently in the sample with 10, 20 and 30 numbers of earthworm's remediation due to the effect of earthworms in the vermiremediation process.

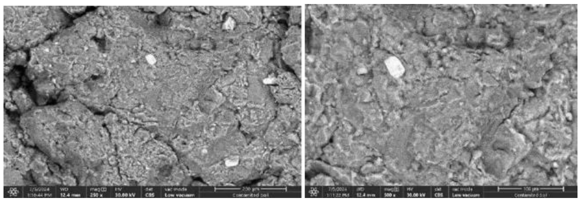
According to the Federal Ministry of works and Housing (FMWH) general specification for roadand bridges, it's specified that UCS in KN/m^2 should be greater than or equals to $200KN/m^2$. Fromthe result above it can be clearly seen that, at 7 days all the samples with their energy levels meetsthe requirement except normal sample BSL, 20 numbers of earthworms BSL and 30 numbers of earthworms BSL, at 14 days all the samples with their energy levels meets the requirement exceptnormal soil sample BSL and WAS, contaminated soil sample BSL and 30 numbers of earthwormsBSL, at 28 days all the samples with their energy levels meets the requirement except normal sample BSL and WAS. Therefore, based on this research I recommend the use of British StandardHeavy (BSH) for unconfined compressive strength (UCS)

The table below shows the UCS of soil samples that failed to meet with the Federal Government general specification for road and bridges.

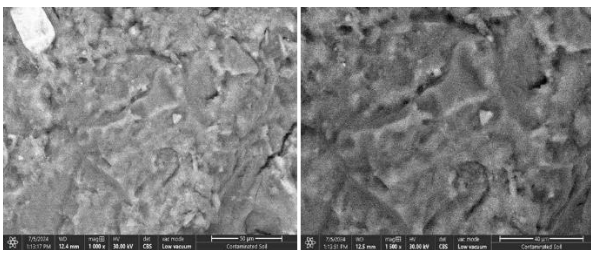
Soil sample	UCS at 7days	UCS at 14 days	UCS at 28 days	FGGS	Remark
Normal soil sample (BSL)	52.95KN/m2			UCS ≥ 200KN/m2	Failed at 7days
20 numbers of earthworms (BSL)	162.71KN/m2			UCS ≥ 200KN/m2	Failed at 7days
30 numbers of earthworms (BSL)	190.71KN/m2			UCS ≥ 200KN/m2	Failed at 7days
Normal soil sample (BSL)		110.69KN/m2		UCS ≥ 200KN/m2	Failed at 14 days
Contaminated soil sample (BSL)		126.13KN/m2		UCS ≥ 200KN/m2	Failed at 14 days
30 numbers of earthworms (BSL)		120.93KN/m2		UCS ≥ 200KN/m2	Failed at 14 days
Normal soil sample (WAS)		158.22KN/m2		UCS ≥ 200KN/m2	Failed at 14 days
Normal soil sample (BSL)			88.55KN/m2	UCS ≥ 200KN/m2	Failed at 28 days
30 numbers of earthworms (BSL)			146.65KN/m2	UCS ≥ 200KN/m2	Failed at 28 days
Normal soil sample (WAS)			182.73KN/m2	UCS ≥ 200KN/m2	Failed at 28 days

Scanning Electron Microscopy (SEM) Analysis

Scanning Electron Microscopy (SEM) analysis of contaminated soil sample and 30 numbers of earthworm's remediation compacted at their respective Optimum Moisture Content (OMC) of British Standard Heavy (BSH) energy level shows is figure 4.15 and figure 4.16. Form the SEM analysis, it was observed that, the working distance (WD) on contaminated soil sample and samplewith 30 numbers of earthworms at 1500 magnification and is 12.5mm and 14.6mm. this implies that as the working distance is increased, the beam divergence angle is decreased, which provide a greater depth of field. The depth of field refers to the zone in which the specimen appears acceptably in focus to the eye.

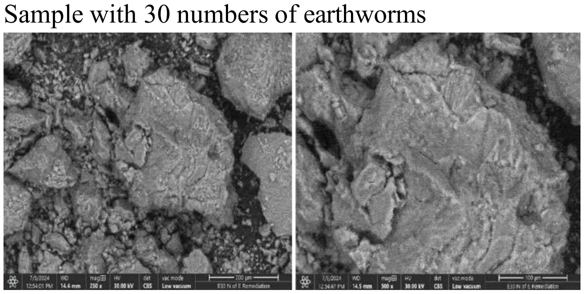


(A) Contaminated soil sample x 250 mag (B) Contaminated soil sample x 500 mag

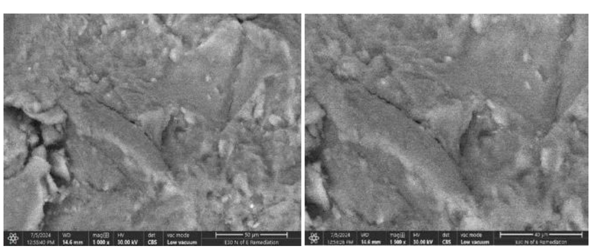


C) Contaminated soil sample x 1000 mag D) Contaminated soil sample x 1500 mag

Sample with 30 numbers of earthworms



(A) 30 numbers of earthworms x 250 mag (B) 30 numbers of earthworms x 500mg



C) 30 numbers of earthworms x 1000 mag D) 30 numbers of earthworms x 1500 mag

C) The major differences observed between Contaminated and soil sample with 30 numbers of earthworm's remediation at the various magnification is:

Surface Morphology
SEM images of contaminated soil at 1500 magnification often show changes in the surface morphology. Crude oil contamination can lead to the coating of soil particles with oil residues, resulting in altered surface textures. After remediation at 1500 magnification, SEM imagestypically show a more restored surface texture. Remediation processes aim to remove or degrade the oil contaminants, which can lead to the exposure of cleaner soil surfaces and a return to more natural surface characteristics.

Pore Spaces and Aggregation
The presence of crude oil can alter the soil's pore structure. Oil contamination may fill the pore spaces between soil particles or cause aggregation of particles, leading to a reduction in the visibleporosity in SEM images. This could result in a more compact or less porous appearance. Remediation processes often aim to restore the original pore structure by removing contaminantsand breaking down oil residues. SEM images of soil sample with 30 numbers of earthworm's remediation show restored pore spaces and a more natural arrangement of soil particles, reflectingimproved porosity and structure.

Particle Surface Coating
Contaminated Soil: SEM reveal the presence of hydrocarbon films or coatings on soil particles. The oil creates a distinct layer on the particle surface, which is often visible in high-resolution SEM images.

Remediated Soil: Following successful remediation, the coating of soil particles is reduced. SEM imagesshow cleaner particle surfaces with less evidence of oil-related residues.

CONCLUSION AND RECOMMENDATION

Conclusion
1. The ex-situ contamination method was successfully implemented, ensuring uniform distribution of crude oil in the soil sample. This method provided controlled conditions that are essential for reliable assessment of vermiremediation efficiency.
2. Vermiremediation demonstrated significant

efficiency in reducing crude oil contaminants in the soil. Earthworms played a crucial role in breaking down the hydrocarbons, leading to a measurable decrease in contaminant levels over time and the efficiency varied based on earthworm species and environmental conditions.
3. The study identified that species like Endrullis eugeniae were particularly effective in crude oil degradation. Optimal soil composition included a balance of nutrient level and maintaining moisture content support the earthworm activity and microbial processes.
4. Post-vermiremediation analysis showed that the soil met the physical and chemical standards required for highway subgrade material. Geotechnical properties, including Atterberg limits, compaction, California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS) and Sieve Analysis were within the acceptable range for use in highway subgrades, ensuring the remediated soil could be repurposed effectively.

These conclusions collectively suggest that vermiremediation is an effective, environmentally friendly approach for treating crude oil-contaminated soil, making it suitable for reuse in civil engineering applications.

Recommendations

The following recommendations are made in light of the study's aim regarding the vermiremediation of soil contaminated by crude oil in order to guarantee the thorough accomplishment of the objectives and fruitful results:

1) Vermiremediation using the earthworm species (Endrullis Eugenae) can be used for remediating crude oil contaminated soil as it potential, benefit a vital area which include environmental sustainability and infrastructure development.
2) In this research the level of remediation achieved is 48.51% for 30 numbers of earthworms. Therefore, for feature research I recommend the use of large number of earthworms in other to know the highest level of remediation the earthworms can achieve.

For the energy levels used in this research, i recommend the use of British Standard Heavy (BSH) on the shear strength parameter test carried out in this research, because the BSH results are sounder and more effective

Contribution to knowledge

These recommendations are essential to obtaining solid and trustworthy results from the vermiremediation research. Following these recommendations can help researchers advance our understanding of sustainable remediation methods and offer insightful information for real-world applications in the disciplines of civil and environmental engineering.

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