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Oil Contaminated Soil as Potential Applicable Material in Civil Engineering Construction

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Abstract:
Subsurface and ground water contamination with chemicals from industrial and agricultural sources poses environmental problems. Apart from constituting health risk to both human and animals (terrestrial and aquatic), it is a source of deterioration to physical, chemical and geotechnical properties of the soil.
The reuse of contaminated soil as civil engineering materials is seeing as one of the effective alternative methods of disposing contaminated soil. However, this is subject to either the containment of the agent of contamination in soil or effective remediation of the contaminated soil. The geomechanic and geotechnical behaviour of oil contaminated soil is therefore reviewed to ascertain their potential reuse as engineering material. This is explored in relation to the current state of oil contamination in Nigeria.
It is was reported that there was reduction in shear strength and stress-strain behaviour of low plastic and high plastic clays, significant reduction in permeability, strength and compressibility of the contaminated soil, reduction in maximum dry density (MDD) and optimum moisture content (OMC) and increase in liquid and plastic limits of the soil. It is also revealed that the maximum dry density and thus the compaction characteristics of the oil contaminated soil structure depend on the type and viscosity of the pore fluid. Other factors include the nature of the soil particles in relation to its mechanical and physicochemical properties and the presence of any organic or inorganic materials.
However, irrespective of these constraints, contaminated soil can still be applied as reused materials as discussed especially in hot-mix asphalt production, concrete production and sandcrete block production.
Keywords: Soil, Oil, Contamination, Reuse, Geotechnical properties.

1. Introduction

Soil is seeing and taken as a key component of natural ecosystems because sustainability of environment depends largely on the sustainable soil ecosystem (Adriano *et al*, 1998), therefore of important is its functionality in the balance of nature.
Soil and water contamination have been environmental problem that is facing the whole regions of the world. The source of contamination which may be either natural or anthropogenic is a very important factor which governs the nature and extent of the contamination. The anthropogenic sources are environmental pollution which results from human exploration of nature for either long term or short term benefits and this has of global concerns. Organic and inorganic contaminants concentration in soil though associated with biological and geochemical cycles are influenced as shown in figure1a and 1b by anthropogenic activities such as natural resources exploration, agricultural practices, industrial activities and waste disposal methods (Ndiokwere and Ezehe, 1990; Zauyah, *et al*., 2004; Usman, *et al*., 2002; Eja *et al*., 2003; Ebong, *et al*., 2007). Other sources include the open dump site, underground storage facilities, atomic power generating plants and the likes. Therefore, contaminated soil can be classified as solid waste of non hazardous type (Meegoda, *et al.*, 1992) as well as hazardous waste depending on the nature of the wastes and so it is of importance that it is restored to its pristine state before use or reuse due to its functionality in the balance of eco-system. This has made it to be of greater concern not only to the environmentalists and hydrologists but also to the geotechnical engineers.

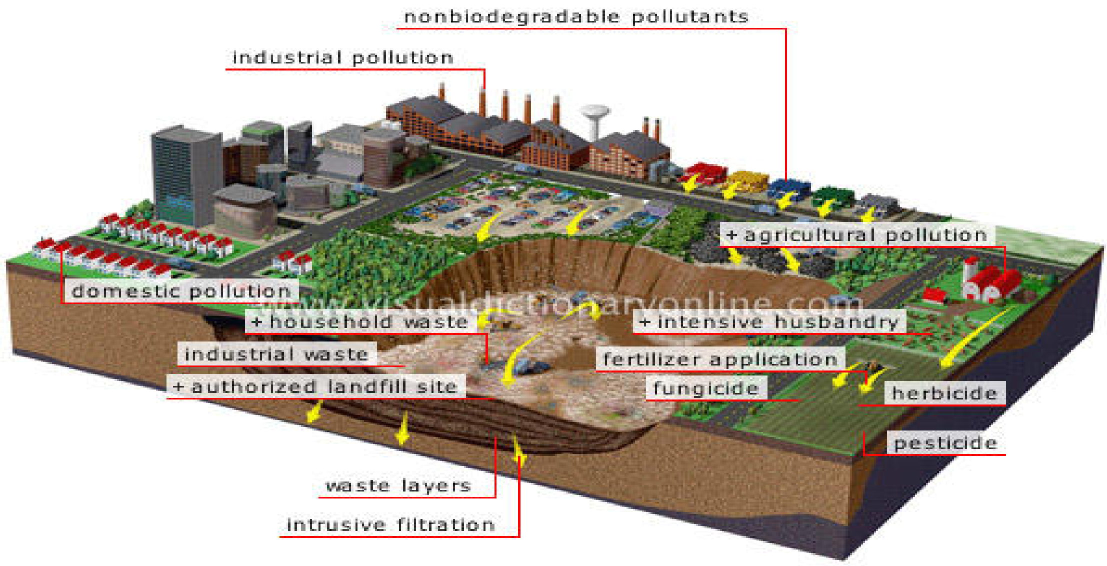

Figure 1a: Various Sources of Pollution to the Environment

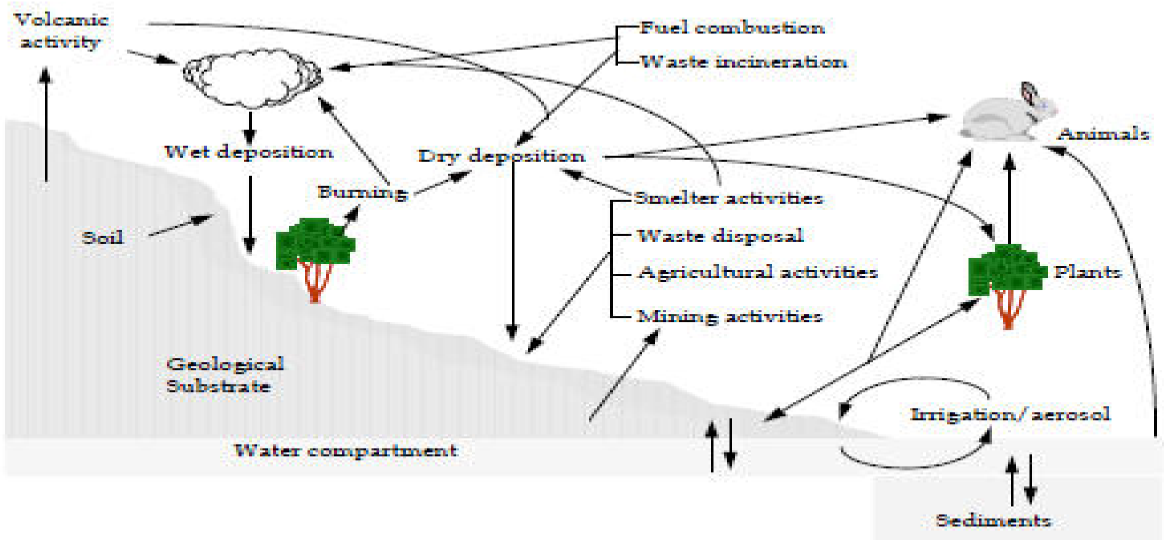

Figure 1b: A General Biogeochemical Cycle of Trace Elements
Source: (Lombi, *et al.*, 1998.)

Consequently, soil pollution is of economic importance because:

(i) Human, terrestrial and aquatic lives are at health risk resulting from the ingestion of contaminants in water, inhalation of its particulate matter, dermal contact with chemical wastes, eye sour and irritation from its gaseous emission.

(ii) Vegetation extinction due to high toxicity of land (Figure2b).

(iii) Abandonment of contaminated soil as brown field, that is, abandoned and uncultivated land (Figure 2a and 2b). This is from author's field survey of crude oil contaminated area in Ebubu township of Eleme Local Government Area of River State, Nigeria.

(iv) Indiscriminate disposal of the soil without any concern of its remediation and reuse as engineering material for road and building construction.

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Figure 2a: Oil Spill Site with Oil oasis out after excavation

Figure 2b: Nature of Soil and Vegetation after contamination with Crude Oil

Pollutants commonly found as a source of pollution to soil include but not limited to the following: heavy metals such as Lead, Nickel, Chromium, Arsenic, Mercury, Zinc and many other, hydrocarbons, halogenated organic compounds, non-chlorinated pesticides and herbicides, nitrogen compounds and radionuclide. Of importance among these pollutants to soil pollution in Nigeria are the heavy metals, petrochemical hydrocarbons, herbicides and pesticides. From the report "Selecting Remediation Techniques for Contaminated Sediments" EPA identified a wide range of contaminants present in sediments (EPA, 1993a) and grouped the contaminants into eight categories:

- Polynuclear aromatic hydrocarbons (PAHs)
- Pesticides (such as DDT)
- Chlorinated hydrocarbons (such as PCBs)
- Mononuclear aromatic hydrocarbons (benzene and its derivatives)

- Phthalate esters
- Metals (such as mercury and lead)
- Nutrients
- Other contaminants, such as cyanides and organo-metals

The 1998 National Quality Survey of EPA revealed that the most frequent chemical indicators for the highest level of sediment contamination were PCBs, mercury, organochlorine pesticides, and PAHs, with PCBs and PAHs being the most frequent. These chemicals are very toxic and tend to bioaccumulate in fatty tissues and are mostly derivative of Crude Oil. It is estimated that several million pounds of PCBs have entered the environment worldwide during the 50 years of its production (Abramowicz et al, 1992).

2. Remediation of Contaminated Soil

Beneficial reuse of contaminated soil can only be actualized after effective remediation is carried out to restore it to either its pristine state or a state at which the concentration of the contaminant cannot cause pollution, that is, it does not reach the threshold point set as standard for pollution to occur. The fundamental objectives of any remediation technique according to Atlas (1995) are reduction of actual or potential environmental threat and reduction of potential risk such that the unacceptable risks are reduced to acceptable levels which in turn depends on the expected use of the site after remediation since different risk targets can be associated with different end uses (Ukoli, 2003). Remediation of contaminated site is actualized through one or more of the following approaches:

(a) Modification of the contaminant to a less toxic form,
(b) Destruction and removal of the contaminants and
(c) Isolation of the contaminants from target by interrupting their transportation pathway.

Based on these approaches, remediation technnologies can be categorised into physical, chemical and biological remediation and can be grouped into two namely in-situ and ex-situ based on the methodological approach.

2.1 Remediation Technologies

The potential reuse of contaminated soil as construction materials has been seeing as one of the best alternative means of its disposal; however, since soil to be recycled or reuse must be classified as non-hazardous according to New Jersey Department of Environmental Protection (Meegoda *et al*, 1998), it needs to be treated to ensure its decontamination to the acceptable level.

Soil remediation technologies, in recent years, have gained considerable importance in view of deteriorating soil environment in many parts of the world, especially in regions and places where development activities are taking place at a faster pace as compared to earlier times (Bhandari et al., 2007).

Depending on the nature of contamination, a range of remediation technologies have been developed and are being practiced all over the world. Most of these technologies are known to have been based on biological, physical, chemical, physico-chemical, thermal or combinations of several of these (treatment trains). These technologies are broadly categorised into In-situ and Ex-situ technologies. Both in-situ (i.e., without soil excavation and transportation) and ex-situ (with excavation and transportation, if necessary) approaches have been in vogue (Prasad, 2008).

Ex-situ methods involve excavation of effected soils and subsequent treatment at the surface; this method includes Land farming, Incineration, Solidification and Stabilization (Amro, 2004). The traditional remediation approach, used almost exclusively on contaminated sites from the 1970s to the 1990s, consists primarily of soil excavation and disposal to landfill "dig and dump" and groundwater "pump and treat".

In situ technologies involves the treatment of sub-soil either by biological means such as contaminant degradation by microorganisms, chemical-physical processes which include Bioventing, Air Sparging, Soil Air Suction Extraction, Bioremediation or combination of the two processes and this has been used extensively in the USA (Encyclopaedia Wikipedia, 2008) or in-situ solidification/stabilization treatment which involves the addition of chemicals binding medium such as Portland cement and quicklime to encapsulate contaminated sediments and/or convert them into less soluble, less mobile, or less toxic forms. In situ treatment of contaminated soil is considered a possible cost-effective and eco-system supportive treatment option. However, the in-situ technique of remediation is more effective on sandy soil than in soil contains clay (Amro, 2004).

In situ treatment approach is advantageous for the following reasons:

(i) The contaminated soils are left in place without mobility thereby reducing the chance of further contamination from re-suspension of contaminants that are bound to the fine particles in the soil sediment.

(ii) There is reduction in the physical contact and exposure with the contaminated soil.

(iii) Reduction in the volatilization and irretrievable escape of the volatile organic compounds to the atmosphere of contaminants that are brought to the surface.

(iv) Absence of extensive long-term monitoring required for disposal facilities that handle contaminated sediments (e.g., landfills).

(v) Finally, it is the more cost-effective technological approach of treating contaminated soil.

Meanwhile, its disadvantage lies in its less effectiveness in complete remediation of the contaminants which is due to many factors including the following: low soil permeability, subsurface heterogeneities, contaminant distribution, obstructions to treatment zones, and process control limitations depending on the type of in-situ technology under consideration. Some of these processes the detail of which could be found in *Site Remediation Technologies: A Reference Manual by Government of Canadian (2003)* are:

2.1.1 Soil Vacuum Extraction

Also known as soil vapour extraction (SVE), this technology reduces concentrations of volatile contaminants in the subsurface. It involves applying a vacuum to the subsurface to enhance the volatilization of contaminants and to transport them to the surface. Use of SVE is limited to permeable unsaturated materials like sands, gravels and coarse silts, and to situations where the contaminants are volatile. One major disadvantage of SVE is the need to treat air emissions (off-gases) containing contaminants extracted from the subsurface. Another disadvantage is that a site containing contaminants with varying volatilities may require technologies other than, or in combination with, SVE to achieve remediation.

2.1.2 Pneumatic/Hydraulic Fracturing:

This method is used extensively in petroleum industry to fracture reservoirs of low permeability and enhance recovery of hydrocarbons. Preliminary investigations regarding this remediation process has suggested that this approach could be used on contaminated soil and rock. Fracturing is used to enhance pump-and-treat systems, or improve SVE in low permeability soils. Soil or rock matrices are forced opened by fracturing through the injection of pressurized air (for pneumatic fracturing) or fluid (for hydraulic fracturing) into a low permeability material to generate fractures. In addition, slurry of granular material (sand) and gel could be introduced into the newly-formed fractures to keep them open as highly permeable channels both for delivering remediating materials and r recovering of contaminants by enhanced pump-and-treat or enhanced SVE.

2.1.3 Thermal Treatment

The aim of thermal treatment is to heat soil *in-situ* to desorb and volatilize contaminants in the subsurface.

1. *Volatilization:* This method involves injection of hot fluid (hot water, air or steam) into the contaminated soil, radio frequency heating, and electrical resistance heating of contaminated soil. Volatilized contaminants are treated by any of the off-gas treatment technologies after subsurface extraction.
   Targeted contaminants in this process are compounds such as aliphatic (straight chained hydrocarbon) and aromatic (ringed hydrocarbon) fractions of jet fuels and gasoline, and chlorinated compounds which volatilize between 80°C and 300°C.
   One disadvantage of thermal heating is that it does not remove non-volatile organics or metals from the subsurface.

2. *Vitrification:* is another thermal treatment which is used to convert contaminated soils into chemically inert crystalline glassy materials instead of removing the contaminants from the soil. When the soil is heated to as high as 3600°C by passing electric current through electrodes inserted in a contaminated

soil, silicates present in the soil melt to form a glass matrix, contaminants are pyrolyzed, and metals are volatilized at this temperature. The contaminated soil is then converted into a solid material resembling granite at the end of the process. This innovative technology reveals low exposure to contaminants and no need for excavation as the benefits of *in-situ* treatments. An important advantage is the stable, glass-like material resulting from this approach.

2.1.3 Bioremediation

This process of remediation includes the following:

(1) *Natural Attenuation:* Natural attenuation refers to a decrease in the amounts of contaminants at a site as a result of natural processes. These processes are classified as biotic (biological) or abiotic (non-biological). This is bioremediation which occurs without any human intervention apart from monitoring. It is based on natural conditions and behaviour of soil indigenous microorganisms. In this process, micro-organisms consume the contaminants as a growth substrate (ie. food) in the presence of oxygen and other nutritional requirements. For natural attenuation to occur and be successful, a suitable environment must exist for the microbial population to flourish. Natural attenuation applies mainly to organic compound contaminants such as BTEX, PAHs and selected chlorinated hydrocarbons. The technology is likely not useful for situations involving free product or residual NAPL

(2) *Biostimulation:* This is the catalysis of natural attenuation process with the addition of nutrients and other substances to serve as source of energy for the indigenous microbial populations. This process includes:

   a. *Bioventing:* bioventing is a modified SVE which overcomes the limitation of off-gas treatment associated with SVE. It involves the delivering of oxygen to the subsurface to stimulate aerobic biodegradation of contaminants by microorganisms. Injection and extraction wells (similar to vent and extraction wells for SVE) aerate the subsurface. Unlike SVE, which stresses a high air flow for contaminant volatilization, Bioventing may be enhanced by adding substrates to the subsurface which however, is sometimes difficult to do.

   b. *Bioslurping:* is an innovative technology which relies on a suction tube to remove free product floating on the water table and to ventilate the soil. This ventilation resembles bioventing in that it enhances *in-situ* volatilization and biodegradation of contaminants. Contaminant vapours that reach the surface are discharged directly to the atmosphere, or treated.

(3) *Bioaugumentation or Land Treatment:*

This approach involves controlling of key environmental conditions such as pH, soil moisture content, temperature, oxygen, and nutrient concentration which affect biodegradation.It may entail introduction of genetically altered or engineered exogenic microorganisms(GEMs) which are capable of detoxifying a particular contaminant in the contaminated soil (Biobasics, 2006). Addition of amendments or bulking materials to the soil may enhance its water holding capacity, increase its air permeability, and or acts as a carbon source for the microorganisms. However, this approach is applicable only to biodegradable contaminants (e.g. polyaromatic hydrocarbons (PAHs) and pentachlorophenols (PCPs).

Majorly the process is more of redox reaction in which microbes use chemical contaminants in the soil as source of energy via metabolism in the presence of electron acceptor and thereby convert it to metabolites which is less toxic to the soil environment. For instance, petroleum hydrocarbons can be broken down by the microorganism through aerobic respiration in the presence of oxygen to form Carbon IV oxide and water. In this case, hydrocarbon losses electrons and is oxidized while oxygen gained electrons and is reduced (Nester *et al.*, 2001).

2.1.3 Solidification/Stabilization (S/S)

One major physico-chemical remediation process that has gained much emphasis in geotechnical engineering is solidification and stabilization (S/S). Solidification/Stabilization (S/S) is increasingly being used in the treatment of contaminated soil at brownfields sites (Wilk and Kruszewski, 2006). This process involves mixing a binding reagent with contaminated material such as soil, sludge, sediment, etc. S/S treatment protects human, terrestrial and aquatic lives and the environment from harmful effect of the contaminants by immobilizing contaminants within the treated material and at the same time improves the potency of the materials as construction materials. Immobilization is accomplished by changing the physical characteristics of the treated material and by chemically stabilizing the contaminants within the treated material. The type of binding materials employed depends on the the following factors:

i) Type and nature of contaminated materials

ii) The nature of contaminants

iii) Extent of the contamination

iv) intended reuse purpose and plan for the remediated material

v) Cost-effectiveness

Some of the binding materials which can be used in S/S process include cement, lime, asphalt, lime-pozzolan additives, cement-pozzolans additives etc.

According to Wilk and Kruszewski, (2006), most people recognize portland cement as a generic material principally used in concrete, but it has also been a versatile S/S binding reagent with the ability to both solidify and stabilize a wide variety of hazardous constituents. In fact, portland cement-based mix designs have been applied to a greater variety of wastes than any other S/S binding reagent.

However the selection of the binding agent should be based on its potency to:

a) chemically bind free liquids;
b) reduce the permeability of the waste form;
c) encapsulate waste particles by surrounding them with an impermeable coating;
d) chemically fix hazardous constituents by reducing their solubility; and,
e) reduce the toxicity of some contaminants.

Also the leachability of the contained contaminants should be ascertained using batch equilibrium adsorption test and diffusion test according to EPA’s directive.

3 Crude Oil-Soil Contamination

Soil can be contaminated with crude oil or petroleum products from varieties of sources which range from onshore and offshore crude oil exploration, pipeline leakages and vandalization, tanker accidents, discharge from coastal facilities, natural seepage, underground storage facilities leakage and onsite oil spillage. In some cases, oil washed ashore causes contamination of shoreline soils while surrounding soils of the processing plants become contaminated during the process (Evgin *et al*, 1992).

Hydrocarbon liquid during exploration, spills, and leakage percolates and infiltrates into the soil pores under gravity thereby saturating the soil in its pathway and thereafter reaches the underground water (Pamukcu and Hijazi, 1992). Within the capillary layer of the vadoze zone of ground soil, the liquid can further spread laterally as a result of its migration once it reaches the groundwater.

Recent increase in petroleum exploration and refining activities coupled with other operations of petroleum companies in Niger Delta region of Nigeria have allowed recurring contamination of its soil, creeks, swamps, river and streams (Okpowasili, 1996 and Onifade *et al.*, 2007) A total of 2005 oil spill incidents were reported in Nigeria by oil companies between 1976 and 1986 with an estimated total quantity of oil spilled being 2,038,711 barrels (Ifeadi and Nwankwo, 1987). Between January and June, 1998 alone Nigeria recorded three different oil spills of approximately 60,800 barrels of crude oil (Adepoyigi, 1998). On January 13, 1998, 40,000 barrels of light crude oil spilled from MPN’s (Mobil Producing Nigeria Unlimited) Idoho production platform, Qua Iboe terminal South Eastern Nigeria (Oil and Gas Publication [OGP], 1998a). Figure 2a and 2b is an example of oil spill in Eleme township of Eleme Local Government Area of River State. On March 26, 1998 there was spillage in which 26,000 barrels of crude oil were lost; leading to stoppage of crude oil production at Jones Creek by

Shell Petroleum Development Company, SPDC (OGP, 1998a). On 1st May 2010 a ruptured ExxonMobil pipeline in the state of Akwa Ibom spilled more than a million gallons into the delta over seven days before the leak was stopped. Over the last 50 years, foreign oil companies have spilled over 1.5 million tons of oil here, but there have been no legal convictions against them, and no compensation for spill victims. The Niger Delta is now one of the most polluted places in the world (Jadin, 2010).
Cumulative concentrations of petroleum hydrocarbons commonly are referred to as total petroleum hydrocarbons (TPH). Many different analytical techniques including gravimetric, immunoassay, and gas chromatography (GC) have been used to measure TPH in soil and water. None of the techniques measure the entire range of petroleum hydrocarbons. Several aromatic hydrocarbons are known or suspected human carcinogens and are classified as priority pollutants regulated by the U.S. Environmental Protection Agency (USEPA) (Office of the Federal Register, 2002). The BTEX compounds and 16 PAHs appear on The Clean Water Act Priority Pollutant list of 126 chemical substances (Office of the Federal Register, 2002). Benzene and PAHs are ranked sixth and ninth, respectively, on the 2001 Comprehensive Environmental Response, Compensation, and Liability Act Priority List of Hazardous Substances. Benzene often is the main ground-water contaminant of concern at petroleum release sites because of its high toxicity and mobility (as compared to other petroleum hydrocarbons). Plumes of benzene and other BTEX compounds have been detected in ground water near crude oil spills. At a site in Bemidji, Minn., benzene concentrations as great as 6.8 mg/L were detected in ground-water samples collected 16 years after 1.7 million Litres of crude oil were spilled in 1979 (Cozzarelli *et al.*, 2001).

4 Soil Contamination and Geotechnical Properties

Contamination of soil will definitely affect its geotechnical properties (Meegoda, *et al.,* 1998) and therefore to implement the contamination management plan of which reuse of contaminated soil is one, it is pertinent to assess the behaviour of soil under the influence of the contaminants. Lateritic soil as residual soil varies in physico-chemical properties depending on the clay content, a chemically active soil particles, present in it. Based on the environmental characteristics coupled with clay particles mineralogy, the behaviour of clay as soil material is always affected to a variable degree (Habib-ur Rahman, eta al, 2007). Such environmental characteristics include the pore fluids, their properties and types of ion present therein (Tuncan and Pamukcu, 1992).

Benson et al. (1998) reported that due to shortage of land for development, the need to develop contaminated and abandoned land i.e., brown-fields is strongly felt however, the prolonged contamination can partially or fully replace the soil pore fluid by chemicals, thereby changing the shear strength and stress-strain behaviour of soils (Meegoda and Ratnaweera, 2008). In this regard, examining the influence of chemical contaminants on shear strength and stress-strain behaviour and understanding the underlying mechanisms is important. Several researchers have studied the influence of chemical contaminants on shear strength by replacing pore water with chemicals. Moore and Mitchell (1974) attributed observed changes in shear strength to variations in electromagnetic forces. Ladd and Martin (1967) as well as Evans *et al.* (1986) did not observe a significant variation in shear strength or stress-strain behaviour. Sridharan and Rao (1973, 1979) attributed the observed increase in shear strength to a decrease in dielectric constant of pore fluid. Evgin and Das (1992) studied the stress-strain behaviour of loose and dense sands when saturated with water and oil. Significant reductions in the angle of friction were observed for sands when oil was used as the pore fluid coupled with sudden increase in the volumetric strain upon full saturation with oil. Also, finite element analysis of the foundation built on the contaminated sand experienced increase in settlement. Similar results were observed by Nasr (2009) in experimental and theoretical studies of the behaviour of strip footing on oil contaminated sand with oil content ranges from 0 to 5% in respect to weight of dry soil. A significant decrease in bearing capacity and bearing capacity factor (Nȣ) with increase in oil content as well as increase in settlement and settlement factor of the footing with increasing depth of contaminated sand was recorded. It was clearly stated that the factor that controls the behaviour of footing on oil contaminated sand is the type of oil. Heavy motor oil affects the bearing capacity of the footing more than the light gas oil in the absence of any other factors. Thus, the geotechnical behaviour of oil contaminated soil is a function of its viscosity.

Bearing capacity of unsaturated oil contaminated sand as carried out by Shin and Das (2001) with varying oil content from 0 – 6%, a drastic reduction in bearing capacity of soil was observed. In their further study, a significant reduction in shear strength parameters of the sand was noted (Shin, *et al.,* 2002). Geotechnical properties of Kuwaiti Sand contaminated with crude oil were examined. The results showed an increase in compressibility and particles attaining a closer packing possibly due to lubrication. In fact, a reduction in angle of friction (Ø) from 32° to 30° was observed for specimen prepared at a relative density of 60% and mixed with 6% of heavy crude oil corresponds to a decrease in Nɣ from 30.22 to 20.4 which correspond to 25% reduction in the bearing capacity (Al-Sanad et al., 1995; Al-Sanad and Ismael, 1997).

Rahman *et al.*, (2010) investigated the influence of oil contamination on the geotechnical properties of Basaltic Residual soil by artificially contaminating soil with engine oil in step concentration of 4% of the dry weight of soil sample. It was discovered that oil contamination enhances the liquid and plastic limits of the soil. There was reduction in maximum dry density (MDD) and optimum moisture content (OMC) of the soil compare to uncontaminated soil with increase in oil content as shown in figure 3.

This might result from the formation of thick envelope of oil around the soil particles which acts as cushion and therefore prevents inter-particles interwoven contact which thereby promotes increased slippage as oil quantity and viscosity increases and which consequently reduces the shear strength and compressibility of the contaminated soil. This same trend was noted by Shal *et al.,* (2003).

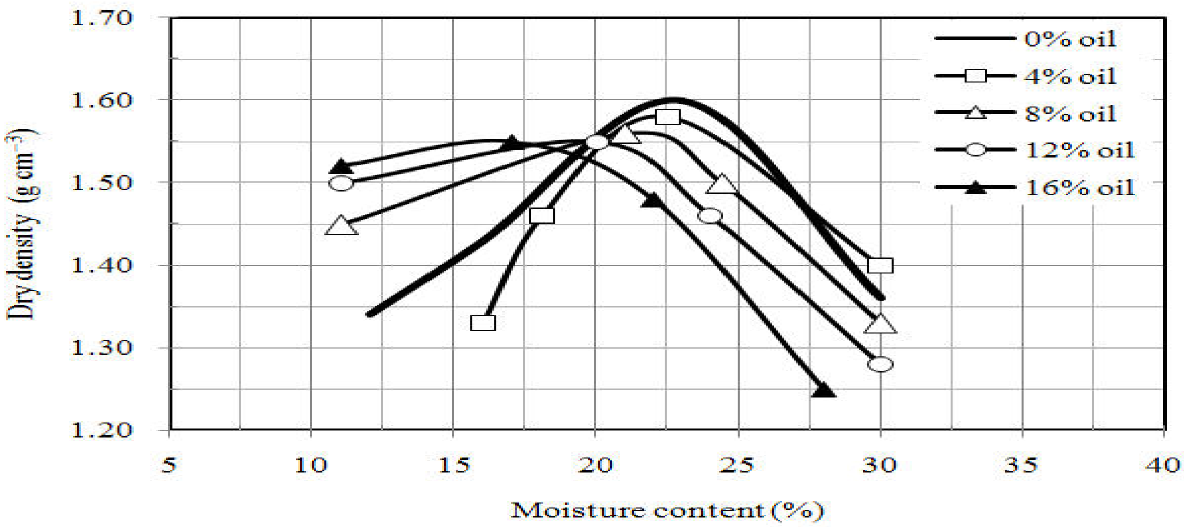

Figure 3: Compaction Characteristics of Oil-Contaminated Basaltic Residual Soil
Source: Rahman *et al.,* (2010)

In another research development, Meegoda *et al.,* (1997) stated that the geotechnical behaviour of contaminated soil depends on the nature of soil, nature and viscosity of contaminant liquid. Improvement in the compaction characteristics of soil contaminated with non polar liquids was attributed to the lubricating action until all the soil particles are completely coated. In the presence of polar organic liquids, the soil structure becomes dispersed which consequently leads to low MDD. But if the liquid viscosity is high enough, the dispersed structure is masked and this tends to improve the compaction characteristics. The compressibility behaviour of oil contaminated fine grained soil of low plasticity and high plasticity was studied by Meegoda and Ratnaweera (1994), it was concluded that the mechanical and physicochemical factors control the compressibility.

Extensive laboratory testing program carried out by Mashalah *et al.,* (2007) on the effect of crude oil contamination on the properties of soil from Bushehr Beach of South Iran revealed that upon contamination with 0 – 16% of crude oil by weight of dry soil samples, there is significant reduction in permeability and strength of the soil. However, no uniform effect inferred on the shear strength parameter even though there is final decrease in the peak shear strength in all studied samples and this was associated to the nature of soil sample used which is a deposited soil. Ratnaweera and Meegoda (2006) however attributed the observed reduction in shear strength and stress-strain behaviour of low plastic and high plastic clays to a combination of two mechanisms:

(i) Reduction in frictional properties at particle contacts resulting from changes in mineral-pore fluid-mineral interaction which might be due to the lubrication occurring at particle contacts leading to a reduction in maximum past consolidation pressure. This function can be quantified as function of pore fluid viscosity.
(ii) Changes in the physicochemical interaction which results from changes in the dielectric constant of the pore fluid.

Meanwhile, investigation by Vipulanandan and Elesvwarapu (2008) of the effect of kerosene contamination on the index properties and compaction characteristics of clayed soil when it is contaminated with kerosene at incremental rate of 2.5% up to 7.5% by dry weight of soil sample shows that liquid limit of the soil increased by 75% while the plasticity index increased by 60% upon the addition of 7.5% kerosene. However, the maximum dry density of the soil reduces by 6% with corresponding increase in optimum moisture content as the degree of kerosene contamination increases.

The effective porosity is a required parameter for mass flow rate calculations in groundwater hydrogeology and movement of contaminants through clay liners. It is also an important soil parameter in geotechnical engineering. In fine grained soils, there exist void spaces in individual soil grains in addition to the unconnected voids, holding fluid by interfacial forces. This makes the effective porosity depend on the physico-chemical interactions of the soil-pore-fluid electrolytic system. (Meegoda and Ratnaweera, 2008). Stephens *et al.* (1998) compared effective porosity values calculated from field tracer tests to that estimated from particle-size distributions and soil-water characteristic curves in the laboratory on three different textured samples and found to have poor correlation. The effective porosity of a soil is defined as the ratio of total volume of effective pores to the total volume of the soil matrix. The effective porosity of a soil is always less than or equal to the total porosity; the movement of solutes through porous media (soils and rocks) occurs through these interconnected pores, thus the seepage velocity and hence the effective element of contaminant transport through a porous medium depends on effective porosity (Meegoda and Ratnaweera, 2008).

5 Beneficial Reuse of Contaminated Soil

Oil contaminated soil should still find its use as construction materials though it is classified as hazardous waste material unless it is restored to its pristine state. Some of the major possible ways of reusing contaminated soil are discussed below.

1) *Subgrade Material in Road Construction.* Borrow pit materials are commonly used as road construction material. Brown field can as well be used once it is screened of boulders and larger soil particles and blended in such a way that variation in soil type from one truck load to another is avoided (Shan and Meegoda, 1998). However, leachability of contaminants into the saturated zone of ground must be guided and prevented as this can interfere with quality of underground water.
2) *Production of Soilcrete Bricks and Tiles.* Blocks commonly used in constructing non load bearingwalls are produced from the mixture of sand cement. Similarly, soilcrete bricks are made from the mixture of soil and cement. Eventhough they are weaker in strength compare to the sandcrete block, they can still be used in non load bearing walls and in construction of low cost building. Contaminated soil can as well be used like original soil in making soilcrete bricks in which leaching and escaping of volatile organic contaminants are prevented with the use of ceramic tiles and plastering (Shan and Meegoda, 1998). If it thoroughly burnt during firing some of the contaminants might be destroyed through this incineration process. Also, encapsulation and immobilization of contaminants can be achieved by using contaminated soil in production of ceramic tiles.
3) *Production of Concrete Mixture.* Researches on the use of soil in concrete production have been limited to the use of contaminated recycled concrete as aggregate in producing fresh concrete

(Kreijger, 1980). Contaminated soil could be used as sand replacement material in producing non load bearing concrete such as partition wall, blinding concrete in civil engineering construction works. The reduction in strength and increase in setting time initiated by the presence of clay materials can be cater for by increasing the cement content or by using polymer modified cement.

4) *Production of Asphalt Concrete.* Hot Mix Asphalt (HMA) and Cold Mix Asphalt (CMA) Concrete are road construction composite materials which consist of coarse aggregate or gravel retained on sieve No 4, fine aggregate or sand with sizes passing sieve No 4 but retained on sieve No 200. Mineral filler such as lime or crush stone dust passing sieve No 200 and asphalt cement typically in the following percentage ratio 50:40:5:5. Without compromising its quality and performance, 5 – 10% waste materials such as recycled asphalt pavements, tyre rubber, petroleum contaminated soil, polythene waste, ore slag, municipal solid waste ash and glass can be added to HMA (Collins, 1992; Flyan, 1992; Czarnecki, 1989).

6 Conclusion

Irrespective of the depth of contamination and the nature of contaminants especially the organic contaminants, it is a well established fact that the contamination will definitely altered the physico-chemical properties of the soil and thus its geotechnical properties. Therefore, it is highly pertinent to ensure adequate assessment of the impact of the geotechnical properties of the said contaminated soil before any civil engineering project will be constructed most especially when it involves shallow foundation since the angle of friction and cohesion of the soil on which the ultimate bearing capacity and stress-strain relationship depend are affected adversely as this is case of oil contamination considered.

Meanwhile, despite the reduction in the values of geotechnical properties of the contaminated soil, it can still be used in all the useful areas of application discussed as reused materials especially in hot-mix asphalt production concrete production and sandcrete block production. However, leachability test or diffusion test is one important test that should be carried out to ascertain the rate of the leaching of the petrochemical substances from the final products formed.

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