SUMMARY AND CONCLUSIONS

7.1 GENERAL

The major thrust in this study was the evaluation of soil performance in changed environment due to interaction with petroleum hydrocarbons. To characterize the effect, three soils with different classification viz. S-1 (CL), S-2 (CH) & S-3 (SP) to cover a broad spectrum of field situations and four most commonly used petroleum hydrocarbons based oils viz. UEO, diesel, gasoline and kerosene were used. Geotechnical properties of each type soil contaminated with petroleum hydrocarbons at varying concentrations were evaluated. Geotechnical properties of soils changed due to contamination. Some of the properties were found altered to cast an adverse effect on the stability, strength and design of structure where the contaminated soil encountered as a supporting medium or construction material. Subsequently, the contaminated soils were decontaminated using sodium dodecyl sulphate (SDS) as surfactant for soil washing. The reclamation potential of SDS washing technique was also evaluated. The findings/conclusions that emerge from synthesis of results presented in this thesis and available information in the literature are summarized in the following sections.

7.2 EFFECTS OF CONTAMINATION

- Geotechnical properties of soils, and hence, their behaviour get modified in presence of petroleum hydrocarbons as pore fluid. The extent of modification is dependent on the type of soil and characteristics of contaminants.
- The soil gradation becomes coarser upon contamination. The liquid limit and plasticity index for fine-grained soils increase upon contamination with
petroleum hydrocarbons except kerosene oil in which an inverse effect is observed.

- Soil classification for clays with low compressibility (CL) changes due to change in grain size distribution and Atterberg’s limits.
- Maximum dry density decreases and OMC increases for fine-grained soils contaminated with petroleum hydrocarbons. There is an improvement in the compaction characteristics for the sand up to 6% of degree of contamination.
- Unconfined compressive strength of fine-grained soils increase due to contamination with petroleum hydrocarbons. However, failure in the clays in the contaminated state commences at lower strain. Clays with low compressibility exhibit brittle failure (strain 7% to 10%) when degree of contamination in the soil is greater than 3 percent.
- Undrained shear strength of clays increases upon contamination. The rate of increase in the shear strength value is higher for soils with higher plasticity characteristics.
- Angle of internal friction (ϕu) for sand decreases with degree of contamination. The effect is predominant in the case of UEO and least with gasoline. Consequently, shear strength and safe bearing capacity in shear failure decreases for granular soil contaminated with petroleum hydrocarbons.
- Consolidation settlement for soils contaminated with petroleum hydrocarbons increases due to increase in the value of compression index. The percentage increase in the consolidation settlement for fine-grained soils ranges between 35 to 50 percent.
- Skempton’s co-relation between liquid limit and compression index is modified to be applicable for contaminated soil also. The modified equation is given as
  \[ C_L = 0.007 \left(1 + 0.12 \log \frac{\mu_C}{\mu_W} \right) (W_L - 10) \]  
  (7.1)
  Where \( \mu_C \) and \( \mu_W \) are absolute viscosity of contaminating fluid and water respectively. \( W_L \) is the liquid limit of soil expressed in percentage.
- The safe allowable bearing pressure over contaminated land decreases on account of increased settlement in fine-grained soils and decrease in the shear strength in granular soils. The structure already constructed will experience distress like cracks upon subsequent contamination of land.
• Permeability of fine-grained soils increases upon contamination with petroleum hydrocarbons whereas it decreases in the sand. The rate of increase in permeability in clays was found to be inversely proportional to Kinematic viscosity of petroleum oils i.e. maximum with gasoline and minimum with U.E.O. In the case of sand, maximum and minimum decrease in the co-efficient of permeability is with U.E.O. and gasoline, respectively.

• Swelling characteristics in fine-grained soils increase significantly upon contamination with petroleum hydrocarbons. However, clays do not exhibit any swelling with kerosene. A higher swelling results into greater swelling pressure and differential settlement.

• CBR of coarse-grained soil increases up to 6% contamination level and thereafter decreases sharply. The maximum value of CBR is found at 3% degree of contamination.

7.3 INTERACTION MECHANISM

Soil properties got modified due to physical, physico-chemical interaction between soil and contaminant. Following indirect inference has been drawn to explain the observed variations.

• Important parameters in the physical interaction are viscosity, density and surface tension of contaminating oils. Since the Kinematic viscosity and surface tension are maximum for UEO and minimum for gasoline, therefore, extreme effect has been observed for these two.

• Physical interaction is predominant in the case of granular soils where as physico-chemical interaction may take place in fine-grained soils. For soils with high plasticity chemical interaction overrides the physical interaction.

• For non-polar organic contaminating fluid, the dielectric constant is the important parameter to bring the changes in the thickness of diffuse double layer in clayed soils. Smaller value of the dielectric constant for petroleum oils increases the thickness of diffuse layer and consequently structure of clays tend to be more flocculated.
7.4 DECONTAMINATION OF SOILS

Decontamination of soils for the reclamation of contaminated land is necessary not only from engineering point of view to restore the original properties but also from environmental concern to check the contamination spread up to ground water and in adjacent areas. Following significant points have been concluded from the decontamination studies.

- Contaminants are held more strongly with fine-grained soils in comparison to coarse-grained soil.
- The optimum concentration of SDS required varies with type of soil and degree of contamination in the soil. Optimum concentration of surfactant (SDS) increases with degree of contamination in soils. Higher dose are required for fine-grained soils in comparison to coarse-grained soils. For fine-grained soils optimum dose increases with plasticity of soil.
- A thumb rule regarding optimum concentration of surfactant SDS could be arrived. The percentage weight of surfactant SDS required is the half and one-third of the degree of contamination in fine-grained soils and granular soils, respectively.
- The surfactant (SDS) washing technique is effective for all the types of soils contaminated with petroleum hydrocarbons. The reclamation potential of SDS in restoring the original properties of the soil comes out to be 95 percent on an average basis.