RESEARCH ARTICLE

International Journal of Civil, Environmental and Agricultural Engineering

DOI: 10.34256/ijceae2011

Experimental Investigation on performance of silica fumes as a soil stabilizer for oil contaminated strata

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Received : 30th January 2020, Accepted : 24th April 2020

Abstract: Oil leakage is an environmental issue unnoticed in the present time. The problem of oil leakage and oil contamination is main concern for petroleum harvesting countries. Oil contamination in soil creates health issues in the area surrounding it. The nutrients in the soil get reduced significantly due to oil contamination which makes the land not suitable for cultivation. The oil produces hydrocarbons which makes the civil structures weak and out at risk. The most harmful effects of oil contamination are excessive settlement of structures, breakage of underground pipes, etc. In this project, we are trying to study the effects of oil contamination in the soil and also to find a sustainable solution for it. The soil is contaminated in the percentage from 0 to 20% and the tests on index and engineering properties have been conducted to find the effect of engine oil. In order to stabilize the oil contaminated soil, we use silica fumes as a stabilizing agent. The optimum percentage of silica fume is chosen based on the tests of Index and Engineering properties conducted on the soil with silica fumes. The percentage of oil where the soil properties need stabilization is known and the soil is stabilized with the optimum silica fume percentage.

Keywords: Soil stabilisation, Contaminated soil, Stabilising agent, CBR value.

1. Introduction

Large and heavy structures need a good foundation to carry the loads acting upon them. So the good foundation needs a good soil base. Soil base plays a vital role in construction. Before the designing of loads, initially it is made sure that the site is suitable for construction, based on the index and engineering properties of the soil. The bearing capacity of the soil determines the load carrying capacity of the structure. The soil profile determines the type of foundation. When the soil is remoulded or disturbed naturally or by human influence, might become unworkable. If the soil properties are altered and become unsuitable for further construction or environmental work, another site can be chosen. Due to scarcity of available land nowadays, there arises a need for stabilizing the soil to attain the required properties.

One such common problem encountered on soil nowadays is the disposal of waste oil into the open lands, which causes soil contamination and deterioration of the natural soil properties. The oil contamination of the soil mainly occurs due to the breakage of oil storage tanks, improper disposal of waste engine oil, pesticides, etc. The main concern over soil contamination is health risks from direct contact, secondary contact from the vapours evolving from the contaminated soil, and the contamination of underlying ground water which becomes unusable. The oil contamination in soil creates many problems for structures by inducing settlements, contaminating water table, stagnation of water on the surface. The cleaning process of soil contamination is a very costly and time consuming process, even though there are many ways to remove the contamination nowadays, like Phytoremediation, Mycoremediation, Bioremediation, Aeration of contaminated soil etc. The main pollutants causing soil contaminations are petroleum hydrocarbons, pesticides, solvents, lead and heavy metals. The issue of oil spills and oil leakage is often overlooked as the occurrence of this event.

To use the contaminated soil for construction purposes, we use stabilization as a solution. The oil present in soil, in due course of time reduces the index properties and the engineering properties of the soil. The oil contamination of soil affect the ground water, surface water and reduce the soil nutrients, which is available for the plants to grow which is responsible for their structural formation. The oil contamination reduces the soil fertility, bearing strength, permeability and causes liquefaction of soil. In order to reduce the effects of oil contamination on soil,we used silica fumes as a stabilizing agent. When the oil contaminated soil was stabilized with silica fumes, we observed that it improved the properties of soil. Silica fume is an admixture mainly used in concrete as a replacement for fly ash, to attain better strength compared to the one with fly ash.

2. Materials and Methodology

Material Collection and Curing

The soil sample was collected from Annakatti, Coimbatore, Tamil Nadu, from a depth of two meters. The soil collected was clay. The oil used for contamination was of grade 20-40 engine oil obtained from the shops near Ettimadai, Tamil Nadu. The oil obtained from the shops were mixed in a bucket and kept to get a homogeneous mix. The silica fumes used in this project was commercially available densified silica fumes.

Curing of Soil Sample

The soil is contaminated with the engine oil of grade 20-40 in clean tray with clean trowel by hand mixing for 10 minutes to get a uniform mix. The contaminated soil is allowed to be cured for 7 days and was covered to retain the moisture content.

Mixing Silica Fumes in Soil

Silica fumes were added in various percentages by weight of of soil. The soil was then thoroughly mixed with the silica fumes using a trowel by hand mixing for 10 minutes.

3. Results and Discussion

3.1. Uncontaminated Soil

The engine oil obtained was of grade 20W - 40 which is commonly used for motor vehicles and was found to have a specific gravity of 0.91and silica fumes used for the work are commercially obtained densified silica fumes of specific gravity 2.10. The index and engineering properties of uncontaminated soil is represented in table-**I**

Table-I index and engineering properties of uncontaminated soil

Experiments	**Results**
Liquid limit (%)	31.5
Plastic limit (%)	20
Plasticity index (%)	11.5
Soil Classification	**CL**
Specific gravity	2.69
OMC (%)	15.5
MDD(g/cc)	1.97
UCS (N/mm^2)	0.10
k (cm/s)	2.75x10^{-4}
CBR 2.5 mm(%)	1.5
CBR 5 mm(%)	1.79

3.2 Oil contaminated soil

The index and engineering properties of the soil contaminated with varying percentage (4%,8% and 12%) of engine oil are shown in table-**II**

Table-**II** index and engineering properties of oil contaminated soil

Table-II index and engineering properties of oil contaminated soil

EXPERIMENTS	4% OIL	8% OIL	12% OIL
Liquid limit (%)	32.5	34	36
Plastic limit (%)	21.2	22	24.1
OMC (%)	12.4	10.8	9.6
MDD (g/cc)	1.965	1.93	1.89
k (cm/s)	$2.64x10^{-4}$	$2.51x10^{-4}$	$2.37x10^{-4}$
CBR 2.5 mm (%)	1.7	2.42	2.20
CBR 5mm (%)	1.91	2.20	2.05
UCS (N/mm^2)	0.08	0.061	0.047

3.2.1 Effects of Oil Contamination on Atterberg limits of Soil

The Atterberg limits for the soil contaminated with varying percentages of oil were found out, as per IS specification. The results of the tests have been shown in fig.1 and 2

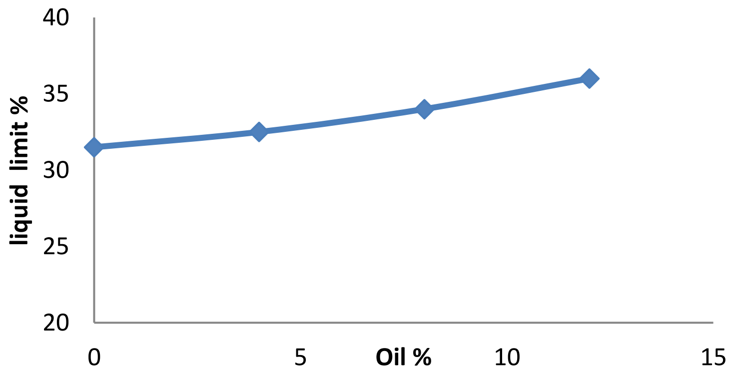

Fig.1 variations of plastic limit with varying oil %

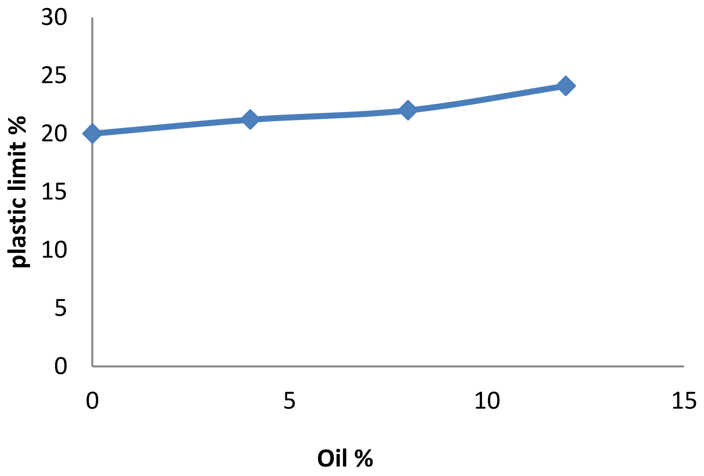

Fig.2 variations of plastic limit with varying oil %

In oil contaminated soil, more percentage of water is required to break the oil layer surrounding soil particle in order to attain liquid state and plastic state. Hence the liquid limit and plastic limit are higher for oil contaminated soil, as shown in fig.1and 2.

3.2.2 Effects of Oil Contamination on Compaction

Standard Proctor compaction test as per IS specification has been conducted for the soil contaminated with varying percentages of oil to find the optimum moisture content and maximum dry density. The compaction curves for the silica mixed soil have is given in fig.3

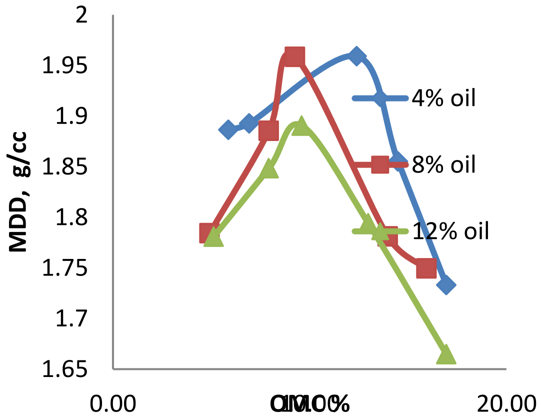

Fig. 3 compaction curves for varying SF %

In the case of oil contaminated soil, the optimum moisture content and maximum dry density decreases. The reason for decrease is, the oil surrounding the soil particle gets expelled when compacted. So less moisture content is required to attain maximum dry density.

3.2.3 Effects of Oil Contamination on UCS of Soil

The unconfined compressive strength of the oil contaminated soil was found to be decreasing with the increasing oil percentages which can be observed from the fig.4. The increased percentages of oil reduces the inter particle friction due to its lubrication effect. So the oil contaminated soil samples tend to failure in short duration and have low strengths.

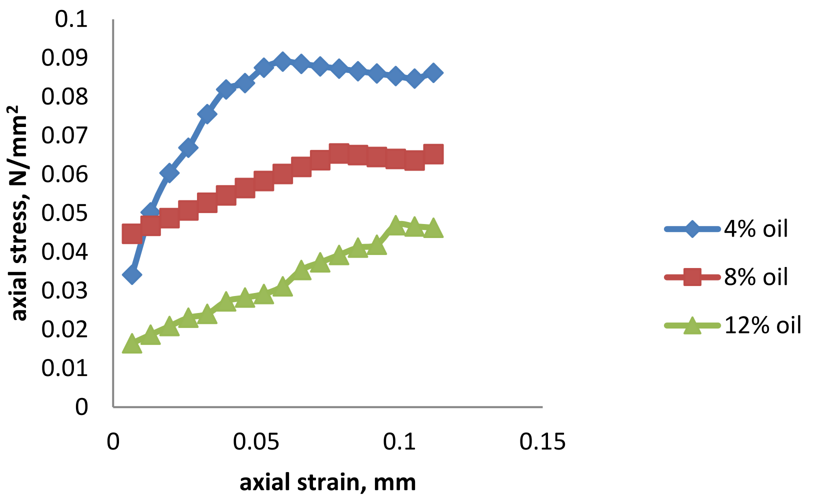

Fig. 4 Variations of Stress-Strain Curves of UCS of Soil with varying oil

3.2.4 Effects of Oil Contamination on Coefficient of Permeability

The coefficient of permeability of oil contaminated soils was found to have been decreased, which might be due to the clogging of pores in the soil by oil which forms a layer around the soil particle. The variations of k have been show in the fig. 5

3.2.5 Effects of oil on CBR Value

As per IS specification California Bearing Ratio test was conducted on oil contaminated soil samples. The soil samples were prepared at corresponding OMC and MDD. It was observed that there was an increase in CBR value at 8% of oil contamination. This increase is due to the increase in inter-particle shear resistance from clumping of soil particles. Beyond 8%, the oil creates a lubrication effect and the soil slide over each other and results in low CBR value.

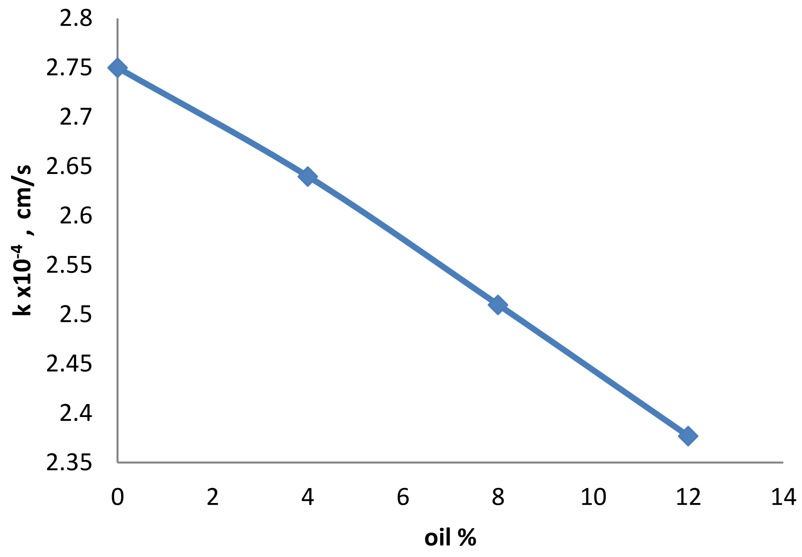

Fig. 5 Variations of k with varying oil %

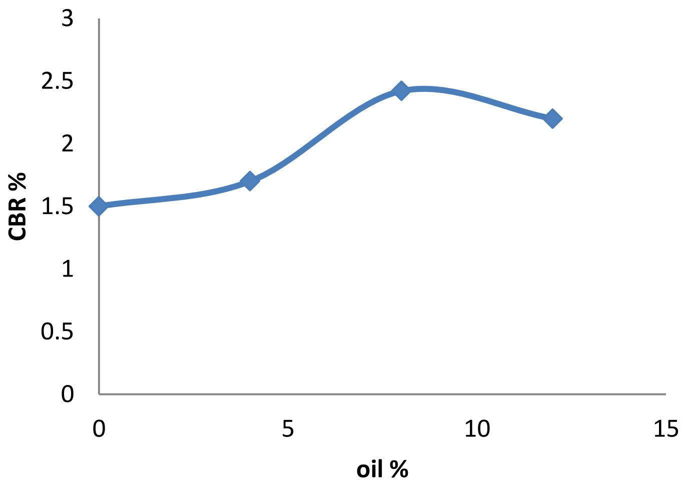

Fig. 6 Variations of CBR value with varying oil %

3.3 Stabilization of Oil Contaminated Soil

The tests for stabilization of oil contaminated soil were conducted and the corresponding results were obtained and are given in Table III,IV and V

Table III Properties of Soil contaminated with 4% Oil and Stabilized with varying percentages of Silica fumes

EXPERIMENTS	**4% OIL**	**5% SF**	**10% SF**	**15% SF**	**20% SF**
OMC (%)	12.4	13	14.1	15.2	16.8
MDD (g/cc)	1.965	1.93	1.91	1.87	1.84
k (cm/s) $x10^{4-4}$	2.64^{4}	2.66^{4}	2.70^{4}	2.71^{-4}	2.7^{-4}
CBR 2.5 mm (%)	1.7	1.75	1.83	1.89	1.93
CBR 5mm (%)	1.91	1.96	2.01	2.06	2.10
UCS (N/mm²)	0.08	0.09	0.105	0.11	0.12

Table IV Properties of Soil contaminated with 8% Oil and Stabilized with varying percentage of Silica fumes

EXPERIMENTS	**8% OIL**	**5% SF**	**10% SF**	**15% SF**	**20% SF**
OMC (%)	10.8	11.2	13	14.5	15.6
MDD (g/cc)	1.93	1.91	1.87	1.84	1.81
k (cm/s) $x10^{4-4}$	2.51	2.57	2.64	2.72	2.78
CBR 2.5 mm (%)	2.42	2.50	2.61	2.70	2.82
CBR 5mm (%)	2.20	2.28	2.37	2.45	2.56
UCS (N/mm²)	0.061	0.07	0.081	0.08	0.09

Table V Properties of Soil contaminated with 12% Oil and Stabilized with varying percentage of Silica fumes

EXPERIMENTS	12% OIL	5% SF	10% SF	15% SF	20% SF
OMC (%)	9.6	10.1	10.7	11.3	11.8
MDD (g/cc)	1.89	1.85	1.79	1.73	1.69
k (cm/s) x10^{-4}	2.37	2.41	2.47	2.52	2.56
CBR 2.5 mm (%)	2.20	2.29	2.37	2.45	2.53
CBR 5mm (%)	2.05	2.11	2.22	2.30	2.39
UCS (N/mm^2)	0.047	0.059	0.065	0.072	0.081

3.3.1 Effects of silica fumes in MDD and OMC of Oil Contaminated Soil

The optimum moisture content for oil contaminated soil is increased and maximum dry density is decreased which follows the regular pattern is shown in the above figures 7,8,9. The variation of compaction curves can be attributed to the formation of a metal complex by the reaction between silica and oil which reduces the oil content in the soil samples

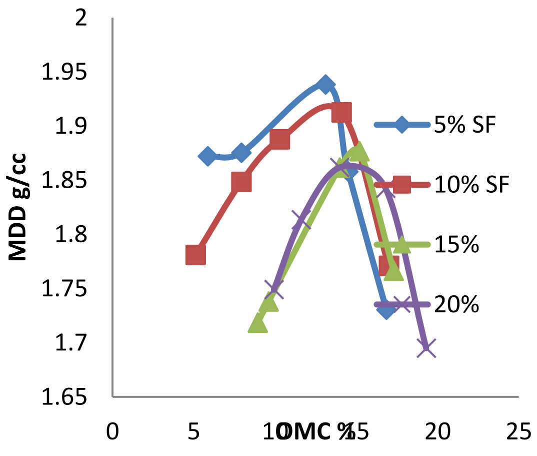

Fig. 7 Compaction curve for Soil with 4% oil with varying SF %

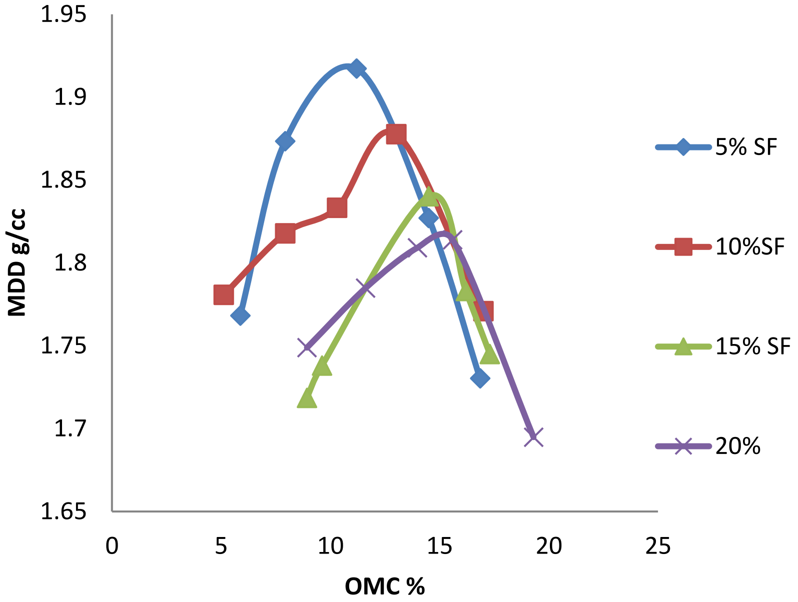

Fig 8 Compaction curve for Soil with 8% oil with varying SF%

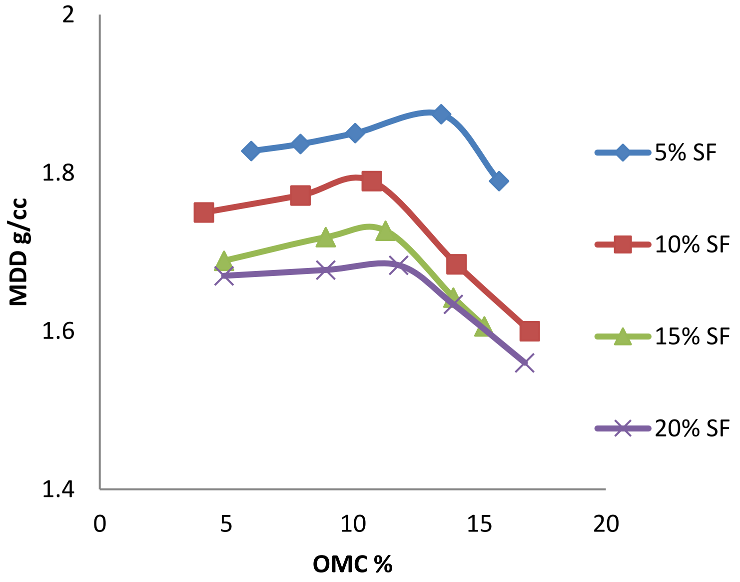

Fig.9 Compaction curve for Soil with 12% oil with varying **SF%**

3.3.2 Effects of silica fumes in UCS of Oil Contaminated soil

The addition of silica fumes have showed improvements in oil contaminated soil samples as the silica fumes possess pozzolanic properties which increases the internal cohesion between the soil particles. This causes the slight increases in the UCS of stabilized oil contaminated soils.The stress-strain curves for the tests conducted are given below in figures 10,11,12.

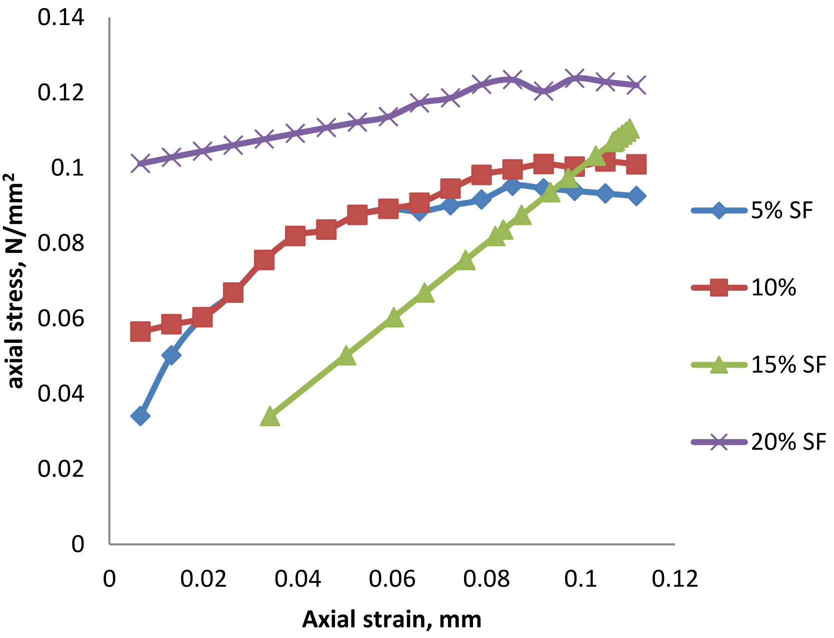

Fig 10 Variations of Stress-Strain curve of UCS of 4% oil contaminated with varying SF%

3.3.3 Effects of Silica Fumes on Permeability of Oil Contaminated Soil

In figure 13, showing the coefficient of permeability of oil contaminated soil stabilized with silica fumes; it can be observed that the permeability has slightly increased. This might be due to the formation of the stable metal complex which reduces the oil content in the soil sample. Since the clogging of pores of the soil samples have reduced due to the addition of silica fumes, there is a slight increase in the flow of water inside the soil sample, compared to oil contaminated soils.

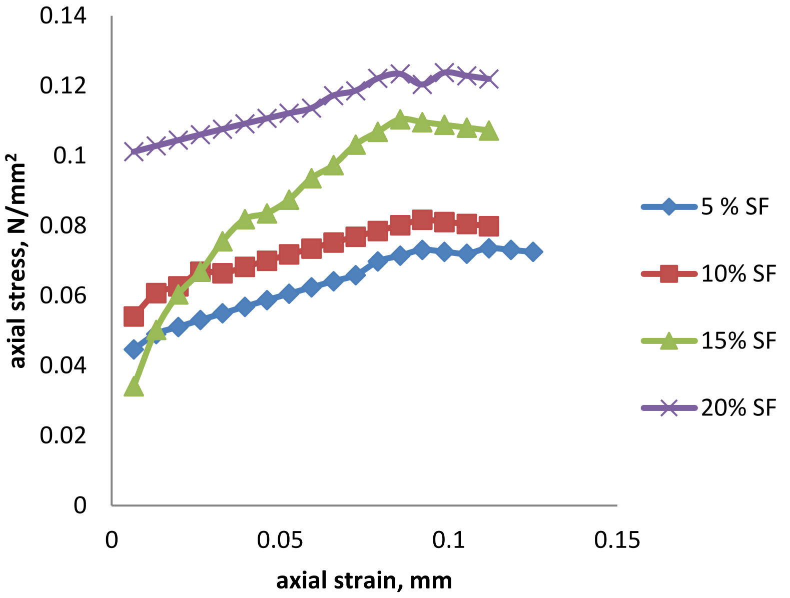

Fig 11 Variations of Stress-Strain curve of UCS of 8% oil contaminated soil with varying SF%

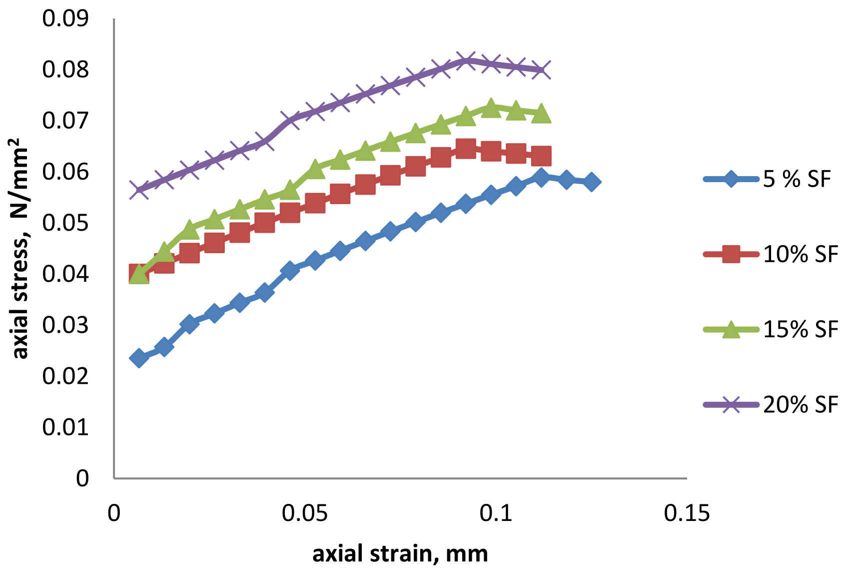

Fig 12 Variations of Stress-Strain curve of UCS of 12% oil contaminated soil with varying SF%

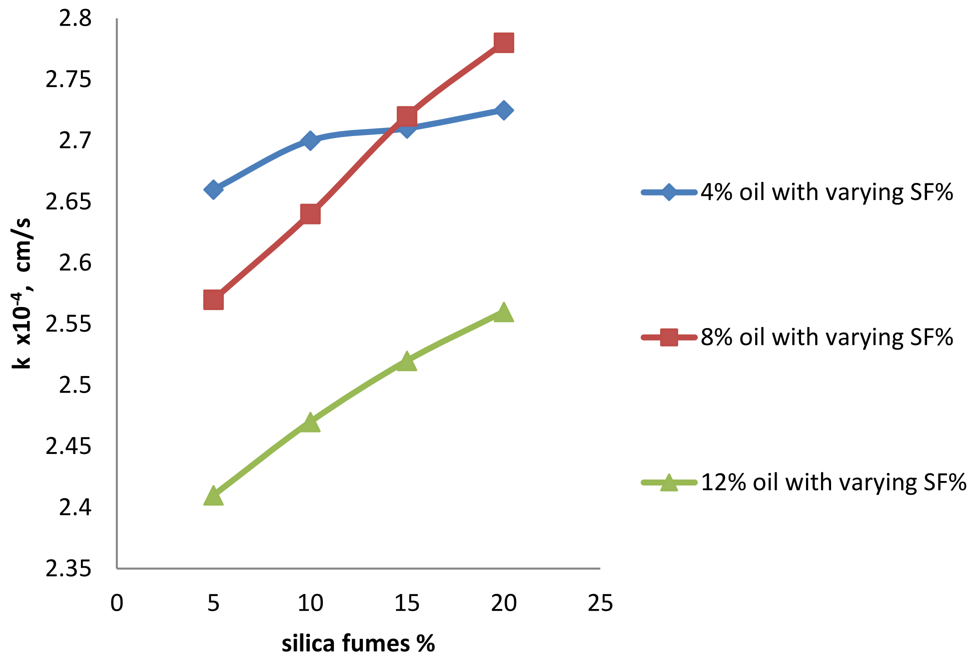

Fig. 13 Variations of k for varying oil % with varying SF %

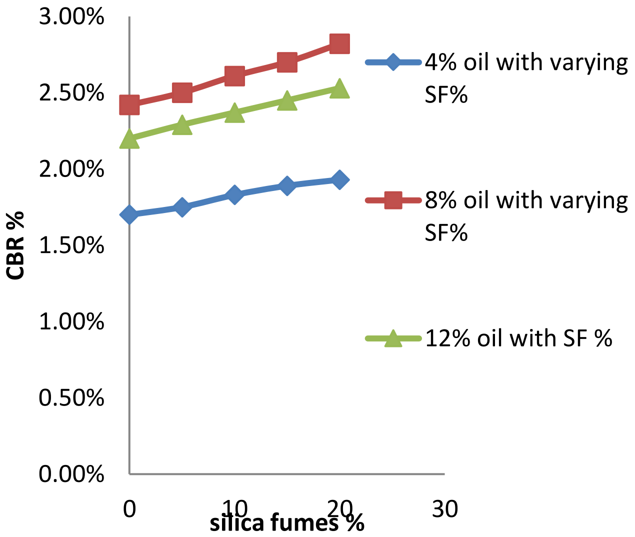

Fig. 14 Variations of CBR for varying oil % with varying SF%

3.3.4 Effects of silica fumes on CBR of oil Contaminated Soil

The varying percentages of silica fume in the oil contaminated soil gives an improved CBR value. This can be attributed to formation of stable complex formed by silica with oil which reduces the amount of oil in the soil sample. The silica fumes, thus contribute the slight increase in the CBR value.

IV. Conclusion

The following conclusions are observed from the series of tests conducted on soils mixed with silica fumes, oil contaminated soils and stabilized oil contaminated soil as per IS specification.

- The liquid limit for the soils mixed with varying percentages of silica fumes and oil contaminated soils have increased from 31.5% of virgin soil to 40% and 36% respectively.
- The plastic limit was also found to have increased from 20% of that of virgin soil to 28.2% and 24.1% with addition of silica fumes and oil contamination respectively.
- It was observed that OMC increases from 15.5 to 18% and MDD decreases from 1.97 to 1.81g/cc for soils mixed with varying percentages of silica fumes, whereas both OMC and MDD decreases from 12.4 to 9.6% and from1.96 to 1.89g/cc for oil contaminated soil.
- The OMC for the stabilized soil increases from 15.5 to 16.8% and the MDD decreased from 1.97 to 1.69g/cc
- It was observed that the soil has the maximum UCS of 0.19N/mm2 at 10% addition of silica fumes with the soil samples. In case of oil contaminated soil, the strength of the UCS samples have been reduced and reached a lowest value of 0.047 N/mm2 at 12% oil contamination. The UCS of the stabilized soils has showed some overall improvement, with 20% addition of silica fumes.
- The coefficient of permeability of silica mixed soil samples have reduced to 25% to that of virgin soil. The same pattern is seen in oil contaminated soil where k has reduced to 13% percentage to that of virgin soil. The stabilized soil samples showed slight increment in permeability.
- The CBR of silica fumes mixed with soil samples attain a maximum value of 1.5% for 2.5mm and 1.79% for 5mm at 5% addition of silica fume and decreases on higher percentage addition of silica fumes.
- The CBR for oil contaminated soil reached its maximum at 8% oil contamination with 2.42% and 2.20% for 2.5 and 5 mm respectively. The CBR value of the stabilized soils had improved with 20% silica fumes addition.

It was concluded that 20% addition of silica fumes to the oil contaminated soils have provided us better results so that the stabilized oil contaminated soil can be used for engineering works

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Acknowledgements: NIL

Conflict of interest: NIL

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