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# Eccentrically Loaded Strip Footing on Oil Contaminated Kanhan Sand

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***Abstract:* Onshore and offshore oil spills contaminate soil. In addition to environmental concerns for ground water pollution and other possible effects, the geotechnical properties of the contaminated soil such as the shear strength and the hydraulic conductivity are also altered. This paper presents previous research in progress to evaluate the ultimate bearing capacity of shallow foundations on WEO contaminated sand bed. The results of the tests reported here relate to the remaining two percentages of WEO. Results of direct shear tests for determining the soil friction angle are given. This paper also presents an experimental investigation aimed for understanding the behaviour of strip footing on oil-contaminated sand. Contaminated sand layers were prepared by mixing sand with the waste engine oil (WEO) content of 2 % and 3 % by weight of dried sand. A series of conditions, including uncontaminated cases, were tested by varying parameters such as the thickness of the contaminated sand layer, oil percentage and eccentricity of loading. The effects of eccentric loading on strip footing on uncontaminated and oil contaminated sand bed were studied in an experimental setup. Along with these, laboratory model test results for the ultimate bearing capacity of a surface strip foundation supported by Waste Engine Oil (WEO) contaminated sand are also presented. The load-settlement behaviour of foundation on uncontaminated and oil contaminated sand was also studied and compared in terms of BCR. Based on these test results, the effect of oil contamination in drastically reducing the bearing capacity ratio is discussed.***
***Keywords—Strip Footing; Sand; Waste Engine Oil (WEO); Eccentricity of Loading; Bearing Capacity Ratio (BCR).***

## I. INTRODUCTION

Rapid industrialisation means that large quantities of industrial waste are being discharged into surrounding areas, causing contamination of the soil. Leakage of pipelines, oil wells, underground storage tanks of gas station sand stranded oil spills are the major sources of surface contamination. Soil contamination with oil is a serious worldwide problem. During the last decade, the results of a number of studies related to the physical properties and behaviour of oil contaminated soil have been published. Oil and gas are the most significant sources of energy worldwide, and their importance increases due to the ever increasing global demand for energy. However, the main drawback with this type of energy is the severe damage they caused to the environment due to the enormous amount of oil spills and leakage during their production. Air, water, and land are being contaminated for short-term benefits by industrial, petrochemical, construction, and sanitary activities. This pollution is usually caused by wars, vandalism, terrorism, and theft, but can also be caused by accidental leakage, oil spillage, corroding pipelines, transporting petroleum, human error during production and separation process. Intentionally or unintentionally, oil spill contamination impacts the physical and chemical properties of the surrounding sand.

Meegoda and Ratnaweera in 1994 examined the compressibility of contaminated fine-grained soils by performing consolidation tests. Their finite-element analysis showed that the settlement of the foundation increases due to oil contamination. Al-Sanad *et al.* in 1995 and Al-Sanad and Ismael in 1997 found that oil contamination leads to decreased permeability and strength. Vesic in 1973 found that the the angle of friction and bearing capacity factor $N_\Upsilon$ got reduced due to oil contamination. Ghaly (2001) performed direct shear tests on oil-contaminated sands which showed a reduction in angle of friction with an increase in the oil percentage. Shin et al. (2002) reported a significant reduction in angle of friction with oil contamination. According to Ratnaweera and Meegoda (2006), the shear strength of granular soil decreases with an increase in pore fluid viscosity. Mashalah *et al.* (2007) carried an extensive laboratory testing program which shows that oil contamination induces a reduction in the permeability and strength of all soil samples.

Mhaske *et al.* (2017) carried out laboratory testing on eccentrically loaded strip footing on WEO contaminated sand showing the effect of 1 % WEO contamination, this study is the further extension of that experimental work. Land contamination is not only harmful for the subsurface water aquifers but is also a detriment to the buildings and structures on it. Any change in the engineering properties and behaviour of the soil strata may lead to a loss in the bearing capacity and an increase in the total or differential settlements of the foundation systems of structures. However, little information is available dealing with the effect of oil contamination of soil on the bearing capacity and settlement of shallow foundations. Therefore, the objective of the current study is to perform laboratory testing programs to determine the effects of oil contamination of sandy soil on the ultimate bearing capacity of a model strip footing. In addition, the comparison between uncontaminated and oil-contaminated sandy soil are studied.

## II. MATERIALS AND METHODS

### *A. Test Tank and Test Footing*

The apparatus used for the model tests is essentially a mild steel tank, 4 mm thick, 700 mm long, 400 mm wide, and 500 mm high with a steel base. The front long side was made of 20 mm thick glass, which allowed the sample to be seen during the preparation, to observe sand deformations during testing, and to minimize the friction between the tank wall and sand particles. The inside fixed walls of the tank are polished smooth to reduce friction with the sand as much as possible. Plain-strain conditions were considered for all model tests, therefore, the rigid footing was made of a rigid steel plate with a width of 100 mm, a thickness of 15 mm, and a length equal to the width of the tank to simulate a plain-strain strip footing. The grooves were made on the footing for centric and eccentric loading at e/B = 0.2 and 0.3 where e/B = ratio of eccentricity of loading to the width of footing. All tests were performed with the footing resting on the sand surface ($D_f$ = 0.0). A rigid loading frame was used to apply the vertical load to the model strip footing. Two dial gauges were used to measure the settlement of the footing with an accuracy of 0.01 mm.

### *B. Testing Material : Kanhan Sand, Oil*

Sand as a soil was used as fill material for the model tests. The particle size distribution was determined using the dry sieving method and results are shown in Fig. 1. Using the Unified Soil Classification System, the sand was determined to be poorly graded sand. All model tests were conducted at a relative density of 40 %. Direct shear tests were performed on specimens prepared at the same relative density used in the model tests with an estimated internal friction angle of 44°. The shear displacement during the tests was 1.0 mm/s. Some physical properties of the sand are given in Table I.

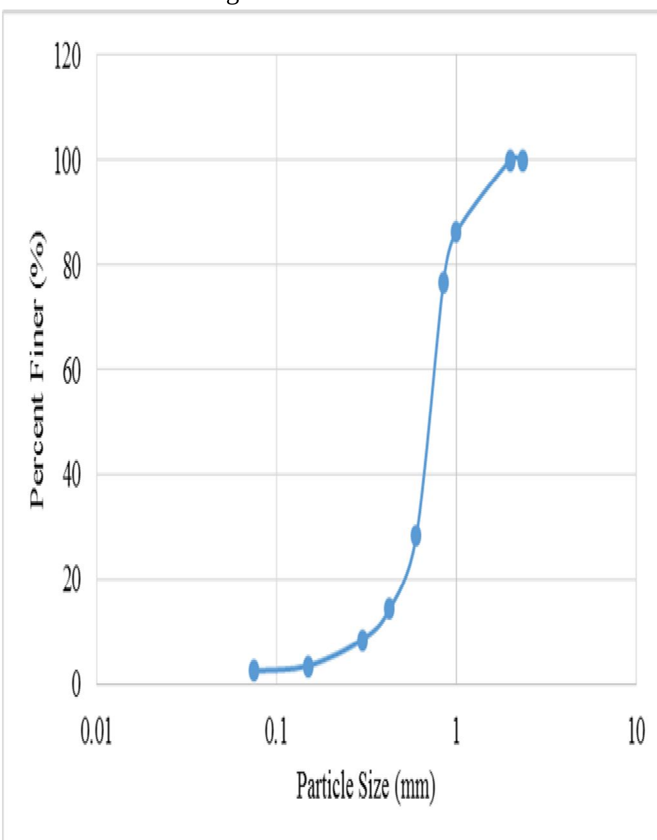


Fig. 1 Grain-size Distribution Curve of Test Sand

TABLE I

PHYSICAL PROPERTIES OF SAND

| Sr. No. | Physical Properties of Uncontaminated and Contaminated Sand | | | |
|---|---|---|---|---|
| | Properties | Uncontaminated Sand | 2% Oil Contaminated Sand | 3 % Oil Contaminated Sand |
| 1 | Specific Gravity (G) | 2.70 | 2.57 | 2.43 |
| 2 | $\Upsilon_{max}$ (kN/m$^3$) | 17.18 | - | - |
| 3 | $\Upsilon_{min}$ (kN/m$^3$) | 15.88 | - | - |
| 4 | Angle of internal friction, $\phi$ (DST) | 44 | 23 | 18 |
| 5 | Cohesion (kN/m$^2$) | 0.0 | 31 | 36 |
| 6 | Average grain size ($D_{60}$) (mm) | 0.82 | - | - |
| 7 | Effective grain size($D_{10}$) (mm) | 0.35 | - | - |
| 8 | Coefficient of uniformity ($C_u$) | 2.343 | - | - |
| 9 | Coefficient of curvature ($C_c$) | 1.472 | - | - |
| 10 | I. S. Classification | SP | - | - |

In experimental work, waste engine oil (WEO) from garage was used to contaminate the sand bed in the model tests. Oil added for contamination of sand worked as a softener which caused decrease in the friction between sand particles and strip bottom which further lead to decrease in bearing capacity of soil. Properties of waste of engine oil collected form Honda garage are shown in Table II.

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TABLE II: Properties Of Oil

| Oil | Properties | | |
|---|---|---|---|
| | Kinematics Viscosity ($m^2/s$) | Density ($kN/m^3$) | Specific Gravity |
| Waste Engine oil | 45 x $10^{-6}$ | 8.3 | 0.82 |

## III.METHODOLOGY

### *A. Preparation of Sand Bed*

While testing on uncontaminated sand, sand rainfall technique was used to fill the tank. The height of fall to achieve the desired relative density was determined prior by performing a series of trials with different height of fall. The sand was poured in the tank by sand rainfall technique keeping the height of fall as 50 cm to maintain the constant relative density 40% corresponding bulk density 16.31 $kN/m^3$ throughout the test. While testing on oil contaminated sand, uncontaminated sand at bottom was placed with the help of rainfall technique and then the oil contaminated sand layer for various depths, as per the depth of contamination to the width of footing ratio, was prepared by adding required percentage of waste engine oil in the sand in another container. This sand was placed inside the model box in 25 mm layers. For contaminated sand (moist sand), a raining technique for soil placement in the test tank was not suitable and did not provide uniformity in compaction. Therefore, the sand unit weight was controlled by pouring the pre-calculated weight of oiled sand into the box for each layer separately and then compacted to reach the required layer thickness. The length and width of contaminated sand layer was kept equal to the dimensions of an experimental tank and depth of contaminated sand layer was varied in an experimental investigations. Therefore, the unit weight of sand was controlled by pouring the precalculated weight of sand into the box for each layer separately, and the sand surface was levelled.

### *B. Experimental Procedure*

The vertical load tests were conducted on a model strip foundation as per IS: 1888-1982 to evaluate the ultimate bearing capacity. The sand bed was prepared and the strip footing was placed on the sand bed. The hydraulic jack was attached to the horizontal member of loading frame with the help of plates and nut bolts. The proving ring was attached to the bottom of the jack. One metal rod was connected to the bottom threads of proving ring and rested directly on the groove made on the strip footing.

Dial gauges were placed on the strip footing to measure the vertical displacement on application of vertical load. Fig. 2 shows experimental setup.

*1)* Contaminated sand
*2)* Uncontaminated sand
*3)* Stri
*4)* Test tank
*5)* Proving ring
*6)* Reaction beam

An experimental program was carried out to evaluate the effects of oil contamination on the performance of strip footing on sand bed. The research work aims to study the performance of strip foundation resting on uncontaminated and oil contaminated sand bed with respect to its various parameters under centric as well as eccentric loading. The theme of the project is to perform the model tests on strip foundation by varying its important parameter. Detailed experimental program of tests is given in Table III.

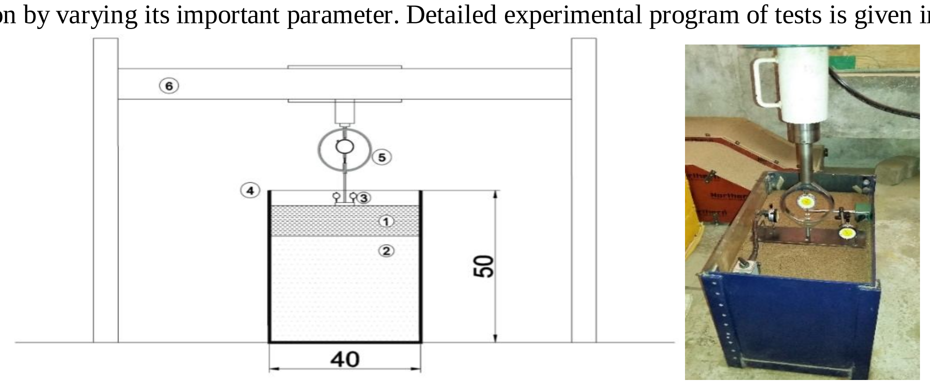


Fig. 2 Schematic Diagram of Test Setup for Vertical Loading used for Experimental Investigations with Actual Experimental Setup

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TABLE III

DETAILS OF PARAMETRIC STUDY IN EXPERIMENTAL INVESTIGATION

| Sr. No. | Details of Constant Parameters | | Details of Variable Parameters | |
|---|---|---|---|---|
| | Parameters | Description | Parameters | Description |
| 1 | Type of Footing | Strip Footing | Eccentricity to Width of Footing Ratio (*e/B*) | *e/B* = 0, 0.2, 0.3 |
| 2 | Type of Loading | Vertical | Percentage of Oil | 2 % , 3 % |
| 3 | Type of Soil | Kanhan Sand, Relative Density = 40 % | Depth of Contamination to Width of Footing Ratio (U/B) | U/B = 0.25, 0.5, 0.75, 1.0 |
| 4 | Type of Oil | Waste Engine Oil | - | - |
| 5 | Length of Contamination | Length of Contamination = 700 mm | - | - |
| 6 | Width of Contamination | Width of Contamination = 400 mm | - | - |

## IV. EXPERIMENTAL RESULTS

In this research, laboratory studies were conducted on model strip footing. The laboratory study would give an idea about the behaviour of strip footing on oil contaminated sand bed with loading eccentricity and depth of contaminated sand layer. During the experimental investigations, depth of contamination, eccentricity were augmented whereas the other parameters viz., dimensions of footing, type of soil, type of oil, length and width of contamination were kept constant. The model plate load tests were conducted on strip footing on uncontaminated and contaminated sandy soil bed prepared in experimental set-up and the load settlement curve was plotted for each test. The ultimate bearing capacities were determined from the load settlement curves.

Then ultimate bearing capacities of footing on oil contaminated sand were compared with that of footing on uncontaminated sand in terms of bearing capacity ratio.

### *A. Performance of Strip Footing on Uncontaminated Sand*

The results of the model plate load test are divided into two part according to loading condition viz., results for centric loading and eccentric loading. Both results are presented for different depths of contamination.

The load settlement curves for uncontaminated sand under centric and eccentric loading conditions were already published in the previous work of Mhaske *et al.* (2017). The ultimate bearing capacity for strip footing for centric loading conditions was found to be 185.0 kN/m$^2$. The ultimate bearing capacities for strip footing for eccentric loading conditions i.e. for e/B = 0.2 and 0.3 were found to be 105.25 kN/m$^2$ and 39.5 kN/m$^2$ respectively.

### *B. Performance of Strip Footing on Oil Contaminated Sand under Centric Loading*

The tests were conducted on model strip footing on prepared contaminated sand bed with 2 and 3 percentage of waste engine oil (WEO). The load settlement curves for strip footing corresponding to different depths of contaminated layer of sand bed (U) with respect to width of the model strip footing are drawn to determine the ultimate bearing capacities (UBC). The load settlement curves, only for *U/B* = 0.25, under centric loading condition for strip footing resting on uncontaminated and WEO contaminated sand bed is shown in Fig. 3. The ultimate bearing capacities are then determined and presented in Table IV.

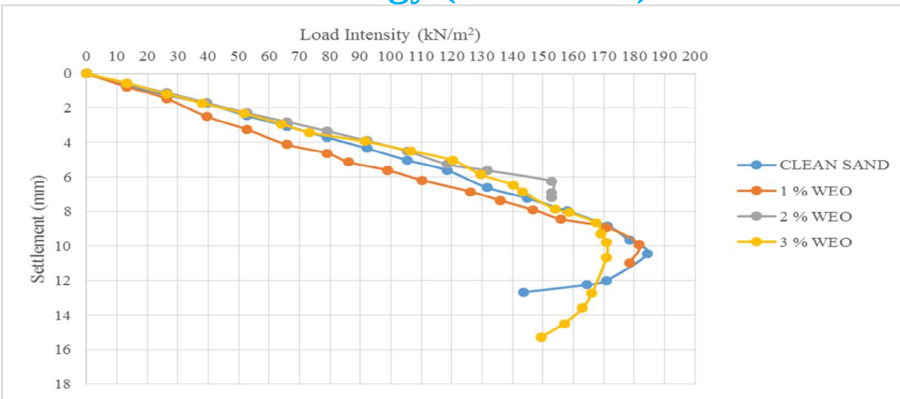



Fig. 3 Load Settlement Curves for Strip Footing on Uncontaminated and WEO Contaminated Sand under Centric Loading (*U/B* = 0.25 and *e/B* = 0)

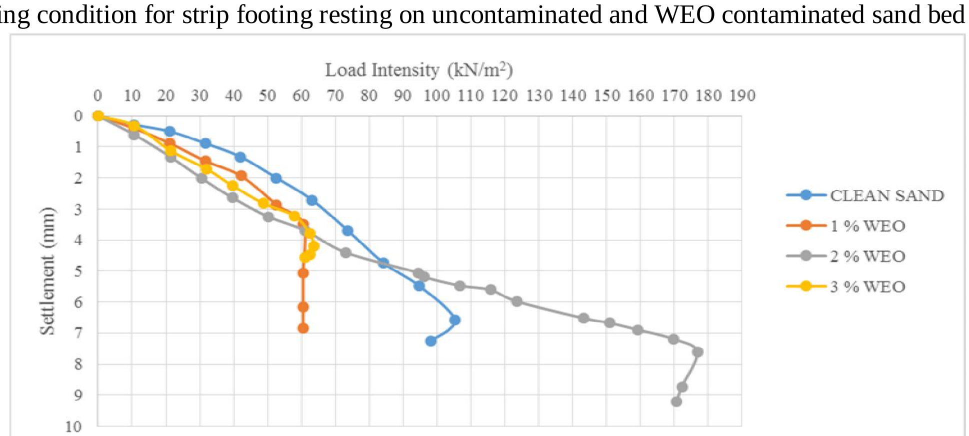
TABLE IV

ULTIMATE BEARING CAPACITIES AND BCR FOR STRIP FOOTING UNDER CENTRIC LOADING

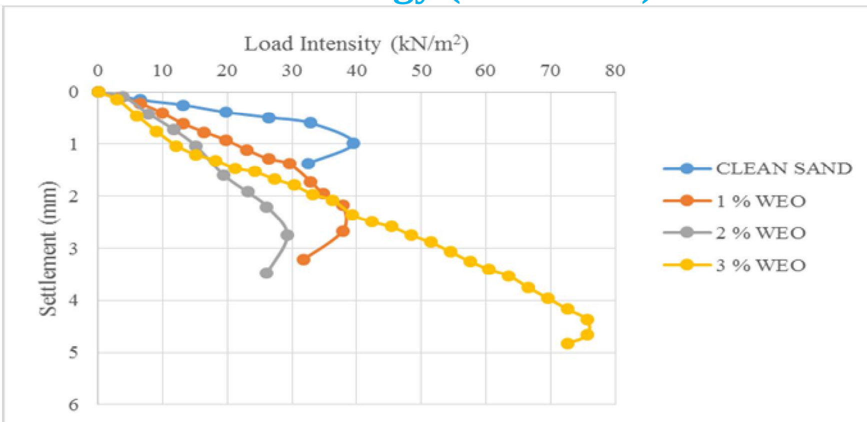
| Sr. No. | *U/B* | WEO Percentage | UBC (kN/m²) | BCR |
|---|---|---|---|---|
| 1 | 0.25 | 1 | 181.5 | 0.98 |
| | | 2 | 155 | 0.84 |
| | | 3 | 171 | 0.92 |
| 2 | 0.5 | 1 | 66.5 | 0.36 |
| | | 2 | 98.32 | 0.53 |
| | | 3 | 94.74 | 0.51 |
| 3 | 0.75 | 1 | 178.5 | 0.96 |
| | | 2 | 168.9 | 0.91 |
| | | 3 | 57.5 | 0.31 |
| 4 | 1.0 | 1 | 64 | 0.34 |
| | | 2 | 37.25 | 0.20 |
| | | 3 | 27 | 0.15 |

*C. Performance of Strip Footing on Oil Contaminated Sand Bed Subjected to Eccentric Loading*

The load settlement curves for eccentric loading for different depths of contaminated layer of sand bed (U) with respect to width of the model strip footing are drawn and UBC are determined. For different U/B ratios the load settlement behaviour for eccentric loading are determined and the ultimate bearing capacities are shown in the Table V. The load settlement curves, only for 0.25, under eccentric loading condition for strip footing resting on uncontaminated and WEO contaminated sand bed is shown in Fig. 4.




(a) For U/B = 0.25, e/B = 0.2




(b) For U/B = 0.25, e/B = 0.3

Fig. 4 Load Settlement Curves for Strip Footing on Uncontaminated and WEO Contaminated Sand under Eccentric Loading

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TABLE V

ULTIMATE BEARING CAPACITIES AND BCR FOR STRIP FOOTING UNDER ECCENTRIC LOADING

| Sr. No. | e/B | U/B | WEO Percentage | UBC (kN/m²) | BCR |
|---|---|---|---|---|---|
| 1 | 0.2 | 0.25 | 1 | 61 | 0.58 |
| | | | 2 | 177 | 1.68 |
| | | | 3 | 63.6 | 0.60 |
| | | 0.5 | 1 | 56 | 0.53 |
| | | | 2 | 62.01 | 0.59 |
| | | | 3 | 49.5 | 0.47 |
| | | 0.75 | 1 | 113.5 | 1.10 |
| | | | 2 | 33.3 | 0.32 |
| | | | 3 | 12.2 | 0.12 |
| | | 1 | 1 | 28.74 | 0.27 |
| | | | 2 | 21.5 | 0.20 |
| | | | 3 | 11.6 | 0.11 |
| 2 | 0.3 | 0.25 | 1 | 38.5 | 0.97 |
| | | | 2 | 29.5 | 0.75 |
| | | | 3 | 75.6 | 1.91 |
| | | 0.5 | 1 | 22.7 | 0.57 |
| | | | 2 | 21.17 | 0.54 |
| | | | 3 | 26.5 | 0.67 |
| | | 0.75 | 1 | 15.2 | 0.38 |
| | | | 2 | 15.2 | 0.38 |
| | | | 3 | 12.2 | 0.31 |
| | | 1 | 1 | 18.15 | 0.46 |
| | | | 2 | 21 | 0.53 |
| | | | 3 | 6.2 | 0.16 |

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*D. Summary and Discussion*

In the first set, strip footing on uncontaminated sand under centric as well as eccentric loading was tested. Then effect of depths of contaminated sand bed was studied for centric and eccentric loading. The ultimate bearing capacities of foundation were determined form load settlement curves. The results for performance of strip footing on contaminated sand bed were compared with footing on uncontaminated sand in terms of bearing capacity ratio (BCR).

Bearing capacity ratio (BCR) is the ratio of ultimate bearing capacity of strip footing on contaminated sand bed under centric or eccentric loading to the ultimate bearing capacity of strip footing on uncontaminated sand bed under centric or eccentric loading.

The effect of various parameters on the performance of strip footing on contaminated sand bed is discussed in following sections.

Direct shear tests were carried out to determine the influence of oil contamination on angle of internal friction and cohesion intercept of uncontaminated and contaminated test sand.

*1) Effect of Oil Contamination on Soil Properties:* Fig. 5 shows influence of percentage of oil contamination on cohesion, from which it is observed that the cohesion of sand increases with increase in the percentage of oil contamination.

Fig. 6 shows influence of percentage of oil contamination on angle of shearing resistance of sand from which it is observed that the angle of internal friction is significantly influenced by oil contamination and it decreases with increase in percentage of oil contamination.

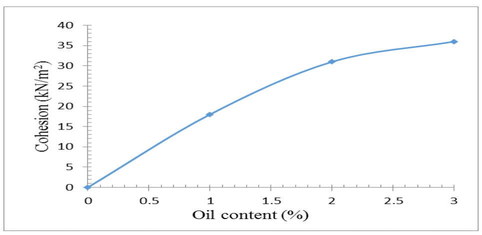



Fig. 5 Influence of Percentage of Oil Contamination on Cohesion

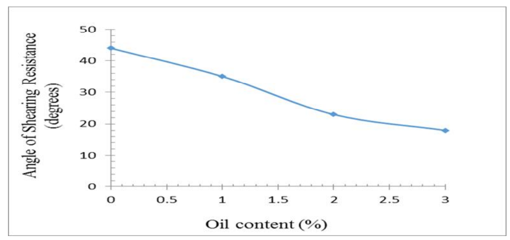
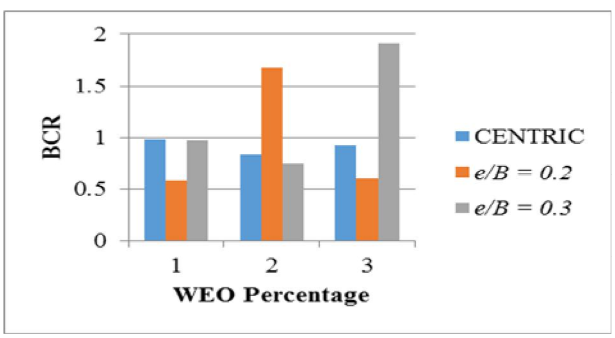
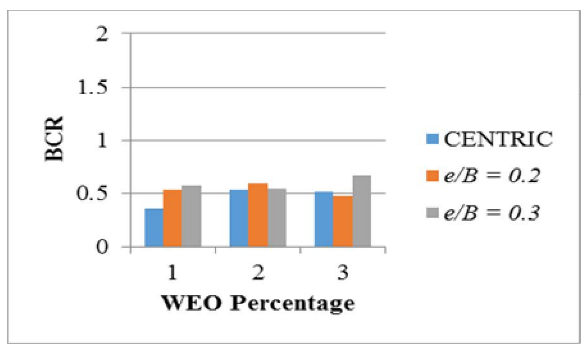



Fig. 6 Influence of Percentage of Oil Contamination on Angle of Shearing Resistance

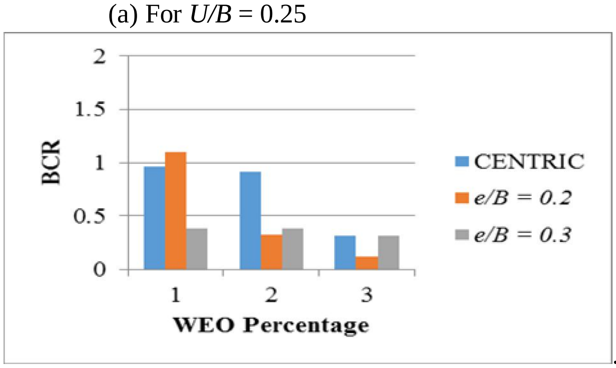
*2) Effect of Percentage of WEO:* Tests were carried out for three different percentage of waste engine oil (WEO) to study the effect of oil percentage on load-settlement response. This response was studied for centric as well as eccentric loading. Fig. 7 shows effect of percentage of WEO on BCR for strip footing.



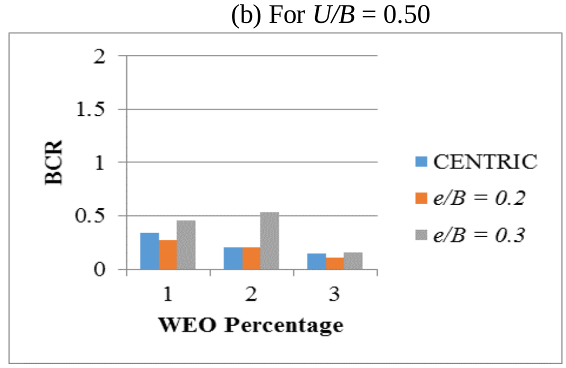

(a) For *U/B* = 0.25




(b) For *U/B* = 0.50




(c) For *U/B* = 0.75



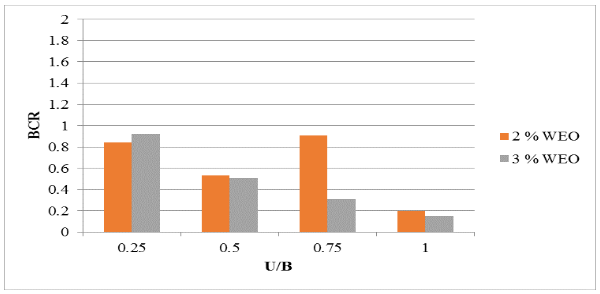

(d) For *U/B* = 1.0

Fig. 7 Effect of Percentage of WEO on BCR for Strip Footing

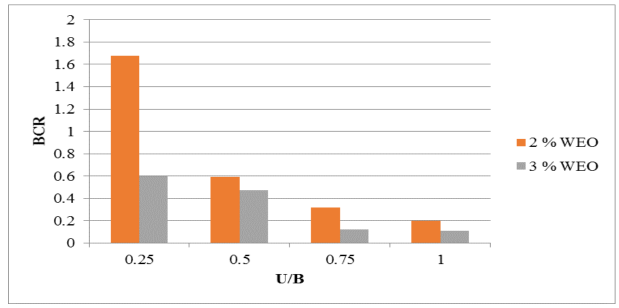
The bearing capacity ratio of strip footing subjected to centric loading deceases with increase in percentage of oil contaminating the sand. For e/B = 0.2, BCR deceases as oil percentage increases for U/B = 0.75 and 1.0 and maximum at 2 % for U/B = 0.25 and 0.50. For e/B = 0.3, no significant change in BCR except for U/B = 0.25 and BCR is maximum at 2 for U/B ratio equal to 0.75-1.0 and at 3 percentage of WEO for U/B ratio equal to 0.25 - 0.5. For eccentric loading BCR deceases as oil percentage increases for U/B equal to 0.75 and 1.0.

*3) Effect of Depth of Contamination:*In the present study, four different depths of contaminated sand bed were adopted and model plate load test was carried out on strip footing resting on contaminated sand bed. Variation of BCR with depth of contaminated sand layer was studied for centric and eccentric loading conditions along with the percentages of WEO.

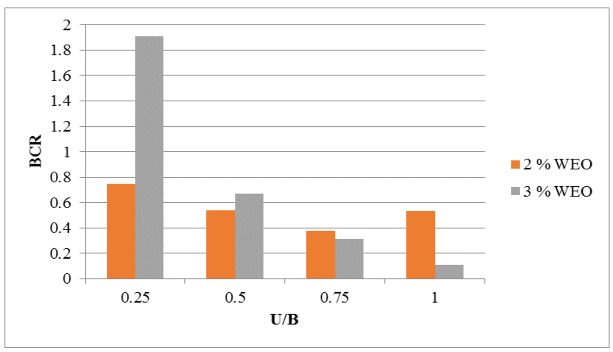
Fig. 8. shows the variation in BCR of strip footing with different depths of contamination to the width of footing ratio (U/B) for centric and eccentric loading for various percentages of WEO contaminated sand bed.




(a) Centric




(b) e/B = 0.2

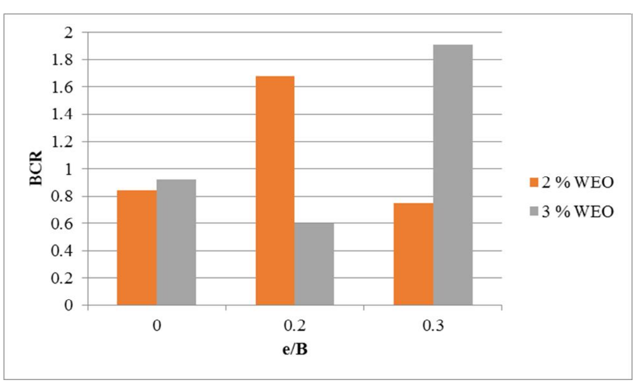



(b) e/B = 0.3

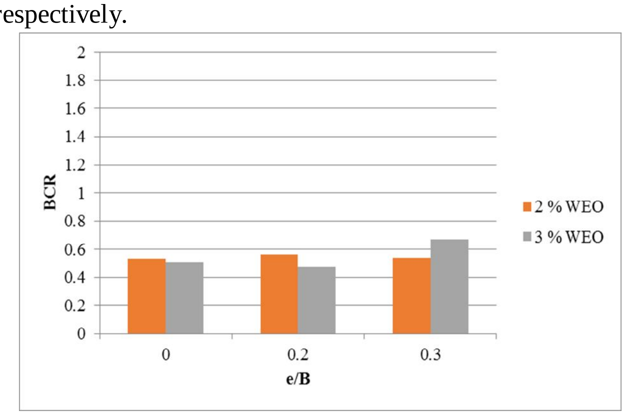
Fig. 8 Effect of *U/B* Ratio on BCR for Strip Footing Subjected to Centric and Eccentric Loading

The bearing capacity ratio of strip footing subjected to centric as well as eccentric loading deceases with the increase in the depth of contamination.

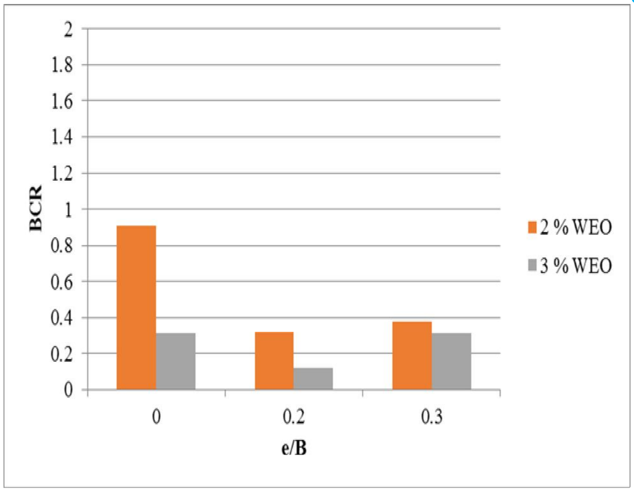
*4) Effect of Eccentricity of Load:*Tests were also conducted to study the effects of eccentricity of applied load on BCR of strip footing. Fig. 9 (a) to Fig. 9 (b) show the variation of BCR with respect to different e/B ratios for various percentage of waste engine oil (WEO) in the form of bar charts for U/B = 0.25, 0.50, 0.75, 1.00 respectively.



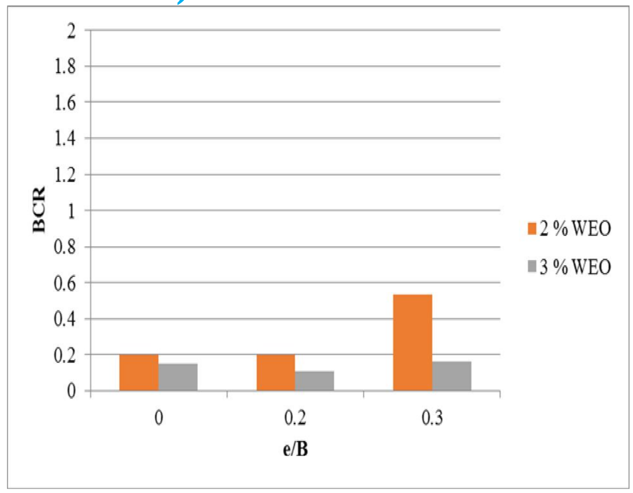

(a) For *U/B* = 0.25




(b) For *U/B* = 0.50




(c) For *U/B* = 0.75




(d) For *U/B* = 1.0

Fig. 9 Effect of *e/B* ratio on BCR for Strip Footing

## V. CONCLUSIONS

From experimental investigations, the following broad conclusions are drawn:

*A.* The angle of internal friction is significantly influenced by oil contamination. It decreases with increase in percentage of oil contamination.

*B.* The cohesion of sand increases with increase in the percentage of oil contamination.

*C.* The bearing capacity ratio of strip footing subjected to vertically centric loading decreases, in general, with increase in percentage of oil contaminating the sand bed.

*D.* The bearing capacity ratio of strip footing subjected to vertically centric as well as eccentric loading decreases, in general, with the increase in the depth of oil contaminated sand bed.

*E.* The ultimate bearing capacity of strip footing on uncontaminated as well as contaminated sand bed decreases, in general, with the increase in the load eccentricity.

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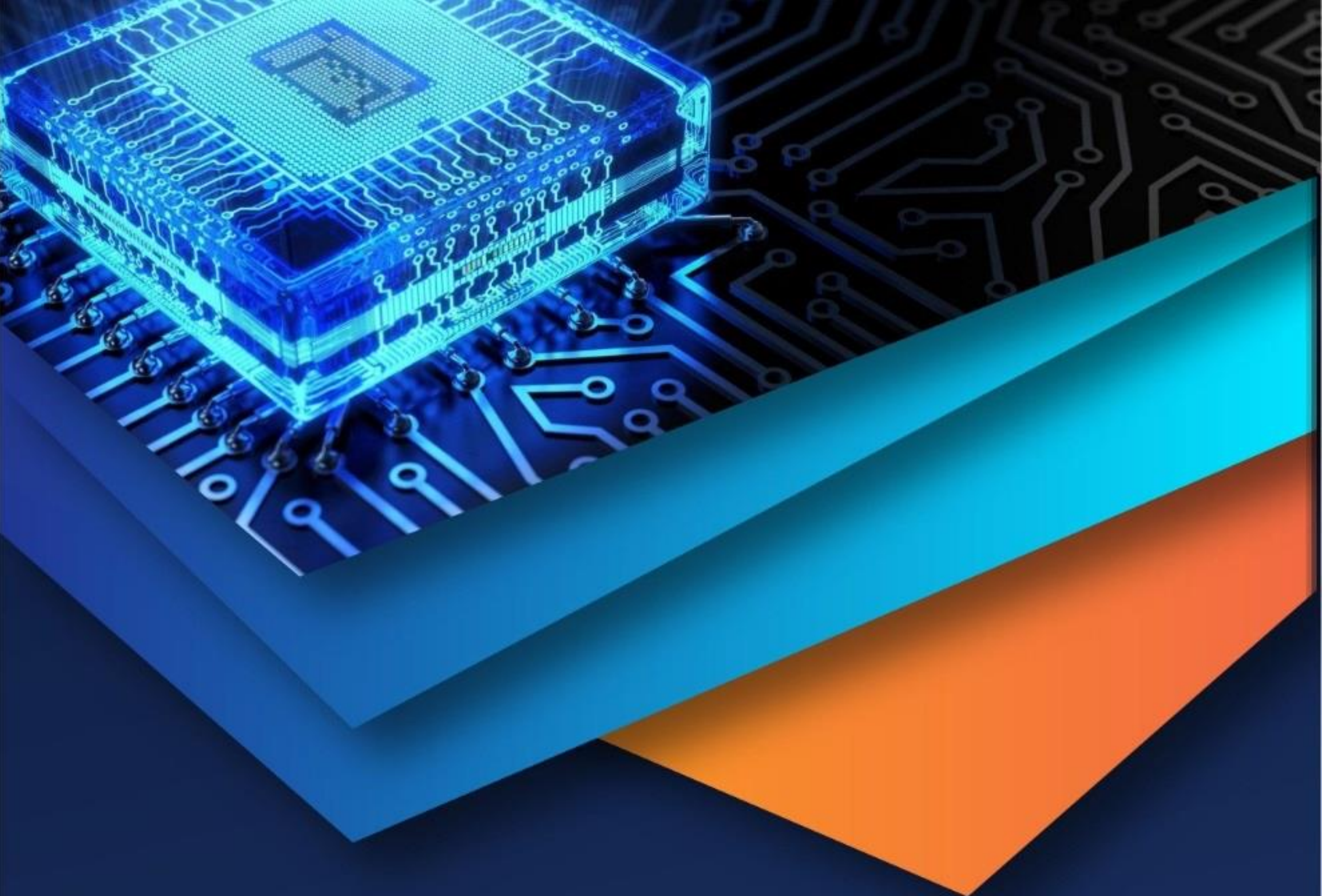


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