DETERMINATION OF N_Υ VALUES THROUGH MODEL TEST ON YAMUNA SAND AND BADARPUR SAND

A Dissertation Submitted in Partial Fulfilment of the Requirement for the Award of Degree of

MASTER OF TECHNOLOGY

IN

GEOTECHNICAL ENGINEERING

BY

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CERTIFICATE

This is to certify that the dissertation title **"Determination of N_Y values through model test on Yamuna sand and Badarpur sand"** based on and guidance in the academic session 2016-17. To the best of my belief and knowledge, **"Determination of N_Y values through model test on Yamuna sand and Badarpur sand"** submitted by **Mr. SUBHANKAR DEBNATH, Roll. No. 2K15/GTE/17**, in partial fulfilment for the award of degree of Master of Technology in **Geotechnical Engineering,** run by Department of Civil Engineering in Delhi Technological University during the year 2015-2017, is a bona fide record of student's own work carried out by him under my supervision and the matter embodied in dissertation has not been submitted for the award of any other degree or certificate in this or any other university or institute.

Prof. K C TIWARI

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CANDIDATE'S DECLARATION

I do hereby certify that the work presented is the report entitled **"DETERMINATION OF N_γ VALUES THROUGH MODEL TEST ON YAMUNA SAND AND BADARPUR SAND"** in the partial fulfilment of the requirements for the award of the degree of "**Master of Technology**" in **Geotechnical Engineering** submitted in the Department of Civil Engineering, Delhi Technological University, is an authentic record of my own work carried out from January 2017 to July 2017 under the supervision of **Prof. K C Tiwari** and **Dr. Amit Srivastava** Department of Civil engineering.

I have not submitted the matter embodied in the report for the award of any other degree or diploma.

Date: 31/07/2017

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Introduction

1.1 General

The most important geotechnical structures are the foundations, which transfer the load to the soil subgrade from the superstructures. The load carrying capacity of the soil per unit area is known as bearing capacity, based on which the foundation of structures is designed. There are mainly three factors on which present calculations of bearing capacity of a soil is based on. These are N_c, N_q and N_γ which depends on internal friction angle (φ) of soil.

Various researchers reveal that the failure surface below footing for general shear failure is divided into rigid zone and shear zone. There are many conventional methods of study which reveal the predefined failure zone and failure slip surface for determination of failure load on the footing based on which the list of bearing capacity factors is given. The use of predefined failure zones and slip surfaces leads to conservative results for the determination of bearing capacity factors. To overcome this problem many researchers also tried iterative computational procedures based on limit equilibrium method, upper bound and lower bound method, method of characteristics incorporated with finite element methods. The analyses of bearing capacity factors based on these studies are convergent for the values of N_c and N_q, but in case of N_γ the results are divergent. None of this methods give exact solution for N_γ values. As a result, along with various methodologies N_γ values can be found with considerable differences whereas the values of N_c and N_q from different studies are very closely spaced. Table :1 shows the difference of N_γ values as per few well known equations.

Table 1 Difference of N_γ values

Φ	Terzaghi (1943)	Meyerhoff (1963)	Vesic (1973)	Bolton and Lau(1993)	Soubra (1999)	Zhu (2001)
15	2.5	1.1	2.6	3.17	1.95	1.309
20	5	2.9	5.39	5.97	4.49	3.367
25	9.7	6.8	10.8	11.6	9.81	7.684
30	19.7	15.7	22.4	23.6	21.5	17.579
35	42.4	37.15	48.028	51	49	40.2
40	100.4	93.7	109.4	121	120	97.926
45	297.5	262.3	271.74	324	327	263.75

Table :1 gives a short view about the differences of N_γ values between Terzaghi, Meyerhoff, Vesic, Bolton and Lau, Soubra and Zhu with respect to Φ ranging from 15̊ to 45̊. It can be observed that the variation increases with the increase in Φ value. These are some well-known equations based on profound mathematical methodologies but the behavior of soil does not exactly follow any mathematical model. In case of soil its behavior varies with soil to soil. Thus in this study two different type of soil is chosen with a Φ value more than 35 and the ultimate bearing capacity is observed with model test. N_γ values calculated from ultimate bearing capacity is compared with profound studies on bearing capacity factor N_{Υ}. Three type of model footing (rectangular, circular and square) are used in these model tests and through load settlement curve the ultimate bearing capacity of soil is observed and N_γ values analyzed from it with respect to equations of Terzaghi, Vesic and Soubra. The N_γ values observed from model tests are compared with several well-known equations listed in Table:2 and an equation is suggested based on our observed data.

1.2 Objective of the Present study

a. Calculate N_γ values for two locally available sand - Yamuna sand and Badarpur sand from model study using square, circular and rectangular model footing.
b. Compare the N_γ values with various studies according to their method of considerations.
c. Propose a new approach to find bearing capacity factor N_γ based on experimental values.
d. Check the variations of data of new approached model equation with considered well established equations.

1.3 Chapter outline

The thesis arranged in five chapters. Concise information about each chapter is as follows. Chapter 1 is Introduction. This chapter gives an introduction about the bearing capacity. Chapter 2 is about Literature review. This chapter gives a brief review of relevant literature on the work carried out by different investigators. Chapter 3 discussed about Problem statement and methodology. This chapter introduces the problem concerned in the thesis. The concise expressions of bearing capacity factors and bearing capacity for surface footings are presented in the chapter. Chapter 4 states about Result and Discussion. The chapter deals with the results obtained from the bearing capacity analysis by model tests on sand. The presentation of tests is expressed as load settlement curves for each one. The bearing capacity factors for square, circular, rectangular footings are presented in tabular and graphical forms. Chapter is Summary and conclusions. This chapter presents an overall sum-up of the work carried out and brings out the salient conclusions. The scope for future studies work has also been included.

Chapter 2

Literature Review

2.1 General

The work on bearing capacity was started long ago in 19^{th} century by **William John Macquorn Rankine** (1885) to overcome the problem of uneconomical design of foundation. The bearing capacity theories proposed by various researchers helped in considerable reduction in cost of foundation and prevention of failure of structures due to loads coming from superstructures. The earlier theories were mostly conservative in nature. The widely accepted ground breaking theory of bearing capacity of strip footing was proposed by **Karl Von Terzaghi** in 1943, following his footsteps many researchers have contributed substantially for the development of foundation design, so that it can take safely the loads of various structures, which are the hallmark of civilization of mankind.

The main strength of soil against failure due to bearing of load is accredited to the shear strength parameters of soil viz. cohesion of soil (C) and internal friction between the particles of soil governed by angle of internal friction (ϕ). The bearing capacity theories proposed by most of the researchers in most of the case are based on limit equilibrium consideration of the soil. The bearing capacities of various types of footings in several conditions are reviewed through the following subsections.

2.2 Studies based on bearing capacity theories

Rankine's W. J. M. (1857) Rankine proposed a stress field solution that predicts active and passive earth pressure, soil is assumed to be cohesion-less, wall frictionless, soil-wall interface is vertical, the failure surface on which the soil moves is planar, and the resultant force is angled parallel to the backfill surface. The theory proposed was too approximate and is only used for academic purposes.

Rankine's theory assumes that failure will occur when the maximum principal stress at any point reaches a value equal to the tensile stress in specimen subjected to tension at failure. The bearing capacity given by Rankine is as follows

$$q_{ult} = \frac{1}{2} \times \gamma \times b \times N_\gamma + \gamma \times D_f \times {N_q}^2$$

$$N_\gamma = \frac{1}{2} \times \sqrt{N_\emptyset}\left({N_\emptyset}^2 - 1\right)$$

$$N_\emptyset = \tan^2\left(\frac{\pi}{4} + \frac{\phi}{2}\right)$$

Prandtl (1920) studied the problem of incipient plastic flow considering the indentation of a semi-infinite body by a flat rigid punch under conditions of plane strain. Prandtl investigated the plastic failure in metals when punched by hard metals. This theory was extended to punching of rigid footing into soil leading to shear failure in plastic equilibrium state. By considering the equilibrium of the plastic zone, Prandtl (1920) obtain the expression for ultimate bearing capacity,

$$q_{ult} = c \times \cot\phi \times \left(N_\phi \times e^{\pi \times \tan\phi} - 1\right)$$ (This expression is for c-φ soil)

$$q_{ult} = (\pi + 2)c = 5.14c$$ (This expression is for cohesive φ=0 soil)

$$N_\phi = \tan^2(45 + \phi/2)$$

Terzaghi (1943) further extended Prandtl's-Reissner analyses to make them applicable to actual soil foundation problems. He considered the case of rough foundation bases resting on a soil mass that possesses weight. He developed a general bearing capacity equation for a uniformly loaded strip footing. His theory is widely accepted and most of the researchers give emphasis on his work. The bearing capacity formula given by Terzaghi is as follows

$$q_u = CN_c + qN_q + 0.5\gamma BN_\gamma$$

Here C, q, γ and B are the cohesion, surcharge ($q = \gamma D_f$), unit weight and width of base of footing respectively, D_f is the depth of footing. N_c, N_q, $N\gamma$ are the bearing capacity factors defined as functions of angle of internal friction (ϕ).

Brinch Hansen (1960) modified the equation of Terzaghi by introducing five new factors that effects the bearing capacity of strip footing, they are as follows

a) Shape factor (s).
b) Depth factor (d).
c) Inclination factor (i).
d) Ground factor (g).
e) Base factor (b).

The bearing capacity equation proposed by Brinch Hansen by taking into account the effect of the factors mentioned above is as follows.

$$q_{ult} = CN_c s_c d_c i_c g_c b_c + qN_q s_q d_q i_q g_q b_q + 0.5\gamma B N_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma$$

Hansen defined the bearing capacity factors as follows

$$\mathrm{N_\gamma} = 1.5(\mathrm{N_q} - 1)\tan \emptyset'$$

$$\mathrm{N_c} = (\mathrm{N_q} - 1)\cot \emptyset'$$

$$\mathrm{N_q} = \tan^2\left(\frac{\pi}{4} + \frac{\emptyset}{2}\right)^2 e^{\pi \tan \emptyset'}$$

Meyerhof (1963) extended Terzaghi's analysis of the plastic equilibrium of the surface footing to shallow and deep foundations, considering the shear strength of soil above base level of foundation. A failure mechanism for both shallow and deep foundation was proposed. Equation of bearing capacity proposed by him is as follows.

$$q_{ult} = CN_c s_c d_c i_c + qN_q s_q d_q i_q + 0.5\gamma B N_\gamma s_\gamma d_\gamma i_\gamma$$

$$\mathrm{N_\gamma} = 1.4(\mathrm{N_q} - 1)\tan \emptyset'$$

$$\mathrm{N_c} = (\mathrm{N_q} - 1)\cot \emptyset'$$

$$\mathrm{N_q} = \tan^2\left(\frac{\pi}{4} + \frac{\emptyset}{2}\right)^2 e^{\pi \tan \emptyset'}$$

Vesic (1973) assumed identical failure surfaces to Terzaghi's but the angle made by the edge of the rigid zone with the surface horizontal was taken as (45 + φ/2) instead of φ. Bearing capacity factors N_c and N_q are identical to those of Meyerhof's and Hansen, ie. N_c proposed by Prandtl (1920) and Nq proposed by Reissner (1924). The Nγ given by Vesic is a simplified form of the recommendations of Caquot and Kerisel (1948).

$$N_c = \left(N_q - 1\right)\cot \emptyset$$

$$\mathrm{N_q} = \tan^2\left(\frac{\pi}{4} + \frac{\emptyset}{2}\right)^2 e^{\pi \tan \emptyset'}$$

$$N_\gamma = 2\left(N_q + 1\right)\tan \emptyset$$

Bolton M.D. and Lau C. K. (1993) used the method of characteristics to establish consistent factors for the vertical bearing capacity of circular and strip footings on soil which satisfies a linear (c, ϕ) Mohr-Coulomb strength criterion. This produces zones within which equilibrium and plastic yield are simultaneously satisfied for given boundary stresses. The principle of superposition was followed for computation of bearing capacity factors N_c, N_q and N_γ, for strip and circular footings. The values to be adopted for bearing capacity factors are tabulated as functions of ϕ.

Michalowski R. L. (1996) used the kinematic approach of limit analysis for estimation of bearing capacity factor N_γ of strip footing. The analysis leads to an upper bound on true limit load when calculation of the three terms in bearing capacity formula is consistent with one collapse mechanism. The optimization of chosen failure mechanism was carried out to yield a minimum value of collapse load. The influence of dilatancy angle on N_γ was also considered in the analysis. A closed-form approximation of obtained N_Υ values was suggested for practical purpose.

Zhu et al. (2001) computed the value of N_γ using the method of triangular slices. Base angle (ψ) of the rigid wedge used for the analysis is taken for three cases as (a) $\psi = \phi$, the internal frictional angle. (b) $\psi = \phi/2+45^\circ$ (c) for minimum value of ψ. The location of the critical failure surface is presented and the numerical solution of the N_γ is approximated by using simple equations. Influence of base angle on the N_γ is also investigated.

Kumar J. (2003) used the method of characteristics for determination of the bearing capacity factor $N\gamma$ of a rough strip footing. The analysis was performed by considering a curved non plastic wedge under the foundation base bounded by curved slip lines being tangential to the base of the footing at its either edge and inclined at an angle $\pi/4 - \varphi/2$ with the vertical axis of symmetry. All of the calculations were performed first by using forward difference technique and subsequently by using the central difference technique which increased the accuracy of computation.

Ukritchon et al. (2003) presented the numerical upper- and lower-bound solutions for the determination of bearing capacity factor N_γ of a surface strip footing on a frictional soil. Linear programming and finite-element spatial discretization is used to solve limit analysis of perfect plasticity, assuming a linear Mohr-Coulomb failure envelope with associated flow within the soil and along the soil-footing interface.

Hjiaj et al. (2004) carried out the numerical limit analyses for the determination of N_γ values of smooth and rough strip footings. The soil was modelled as cohesion less frictional obeying the Mohr–Coulomb yield criteria. The N_γ values for different friction angle was reported in tabular format. An approximate analytical expression for the determination of N_γ values was also suggested in this study.

Ausilio E., and Conte E. (2005) analyzed the influence of groundwater on the bearing capacity of shallow foundations using kinematic approach of limit analysis. Analysis was carried out by considering the footing rests on a soil where the water table is at some depth below the footing base. The effect of submergence of the soil below the footing on bearing was analyzed by performing a parametric. Finally, a simple approximation of the theoretical solution derived from the study was suggested for practical purposes.

Griffiths et al. (2006) presented a probabilistic study on the interference of two parallel rough rigid strip footings on a weightless soil with a randomly distributed un-drained shear strength parameters. The problem is studied using nonlinear finite element analysis from random finite element method within the Monte Carlo network. The nonlinear finite element analysis is merged with random field theory. he lognormal distribution and an exponentially decaying spatial correlation length are used for modeling the variability of undrained shear strength. The estimated bearing capacity statistics of isolated and two footings cases are compared and the effect of footing interference discussed. Although interference between footings on frictionless materials is not very great, the effect is shown to be increased by soil variability and spatial correlation length.

Lyamin et al. (2007) did rigorous analyses to obtain the values of shape and depth factors for its use in bearing capacity computations in sand. The bearing capacities of various geometries placed at varied depths are determined and consequently the shape and depth factors are ascertained and compared with the bearing capacities of strip footings located on the ground surface for the same soil properties (unit weight and friction angle). In addition to revisiting the terms in the traditional bearing capacity equation a simpler and different form of the bearing capacity equation, that does not require an assumption of independence of the self-weight and surcharge effects is used.

Yang F. and Yang J.S. (2008) investigated the bearing capacity factor Nγ of rough strip footing using rigid block upper bound limit analysis with a revised failure mechanism of subsoil. The velocity discontinues were assumed to occur in both radial and tangent directions. With the proposed mechanism upper bound formula for solution of bearing capacity factor N_γ was presented.

Georgiadis K. (2009) performed the element analyses of strip footings for the determination of un-drained bearing capacity of foundations on or near slopes taking into account the effect of parameters such as the distance of the footing from the slope, the slope height, or the soil properties. Based on the obtained results the design charts, equations, and a design procedure for the calculation of the un-drained bearing capacity factor N_c was presented.

Chapter 3

Methodology

3.1 Problem Statement

The bearing capacity of a footing is the maximum pressure that the underlying soil can withstand. This study is based on finding out bearing capacity factor N_γ of Yamuna sand and Badarpur sand and comparing them with N_γ of other research studies. Three sets of model footing plates with each sets having three sizes are used to find ultimate bearing capacity of both sand, and N_γ is calculated from those values using 3 equations.

Equation 1 Terzaghi $N\gamma = [tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\, tan\, \varphi)} + 3]\, tan(1.34\varphi)$

Equation 2 Vesic $N\gamma = 2[tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\, tan\, \varphi)} + 1]\, tan\, \varphi$

Equation 3 Soubra $N\gamma = [1.347\, tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\, tan\, \varphi)} - 0.162]\, tan(1.343\varphi)$

These equations are based on three different methodologies. Terzaghi's equation is based on limit equilibrium method. Vesic's equation is based on method of characteristics and Soubra's equation is based on upper bound method. N_γ value is calculated from ultimate bearing capacity based on each of these equation and compared with the formulas using same methodology in their concept.

3.2 Selection of Model

The model tests are designed to be done in UTM. The maximum size of the model test box was designed as per the maximum space available on the deck of UTM so the model box can fit there. The box is made of ply wood of 1" thickness and the inner dimensions are kept as 45cm X 60cm X 40cm as shown in fig:1.

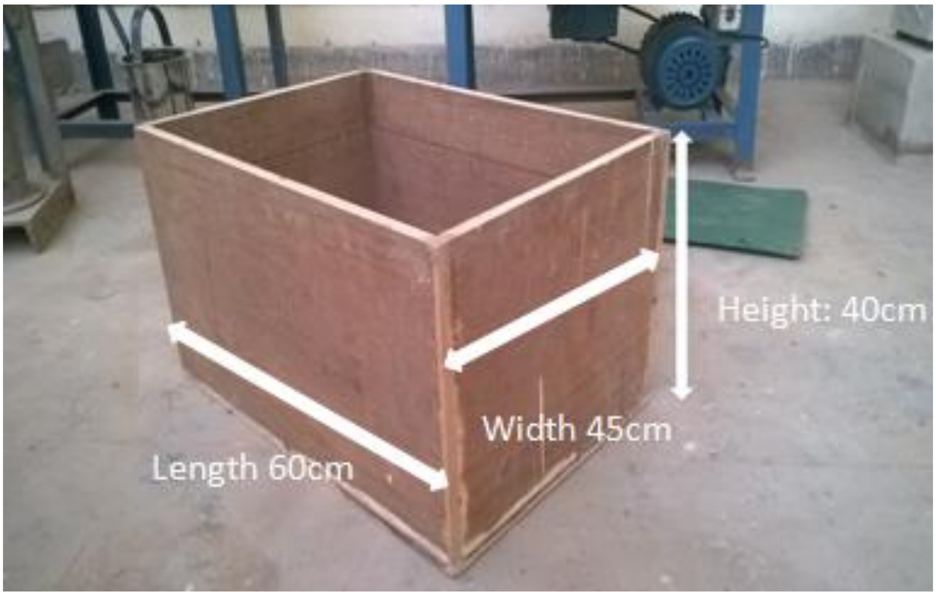


Figure 1 model box

The model footing plate sizes are calculated based on Bousseneqs equation such that the 0.1q pressure bulb generated from the loading cannot cross the sides of the model box to avoid the stress concentration.

Three types of model footing are chosen with 3 set of sizes:

- Square footing
  a. 5cmX5cm
  b. 8cmX8cm
  c. 10cmX10cm

- Circular footing
  a. 5cm diameter
  b. 7.5cm diameter
  c. 10cm diameter

- Rectangular footing
  a. 5cmX7cm
  b. 7.5cmX10.5cm
  c. 10cmX14cm

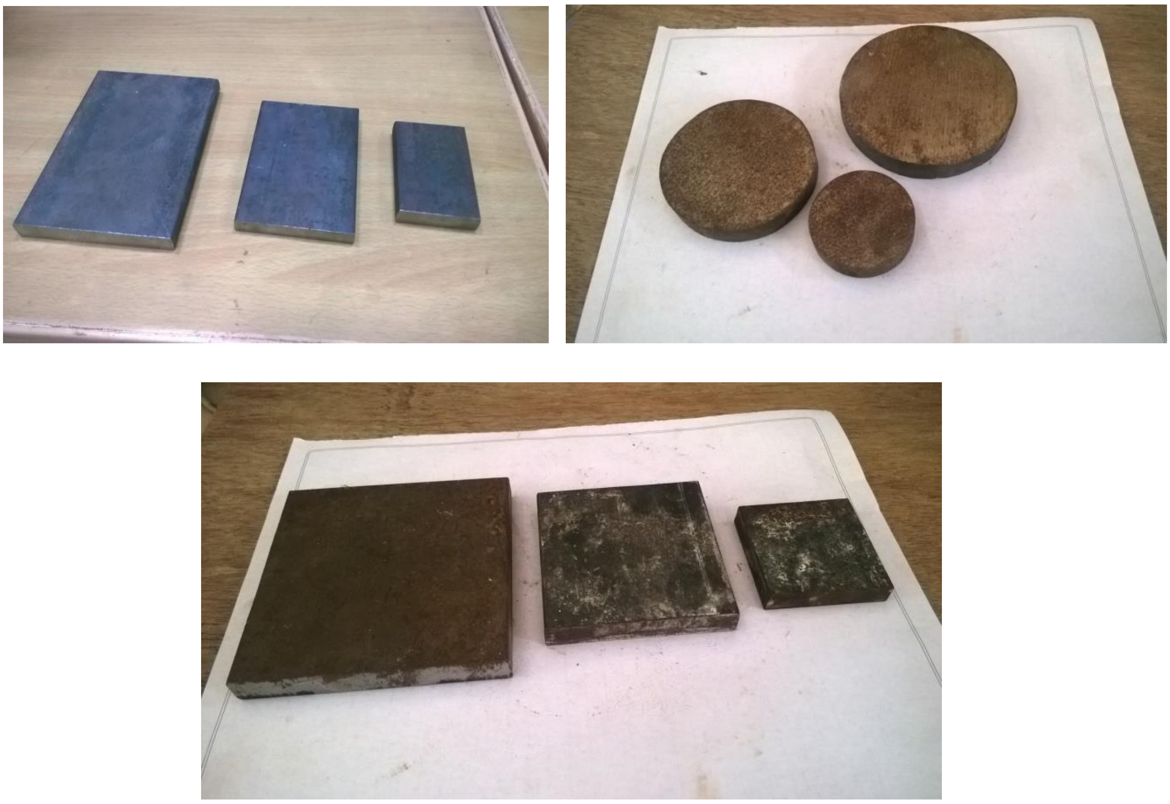


Figure 2 Rectangular, circular and square model plates

The model plates are mild steel iron plates of 12mm thickness with rough surfaces.

Two locally available sand, Badarpur sand and Yamuna sand are used as media of the tests. Badarpur sand is a course sand and on the other hand Yamuna sand is relatively finer one.

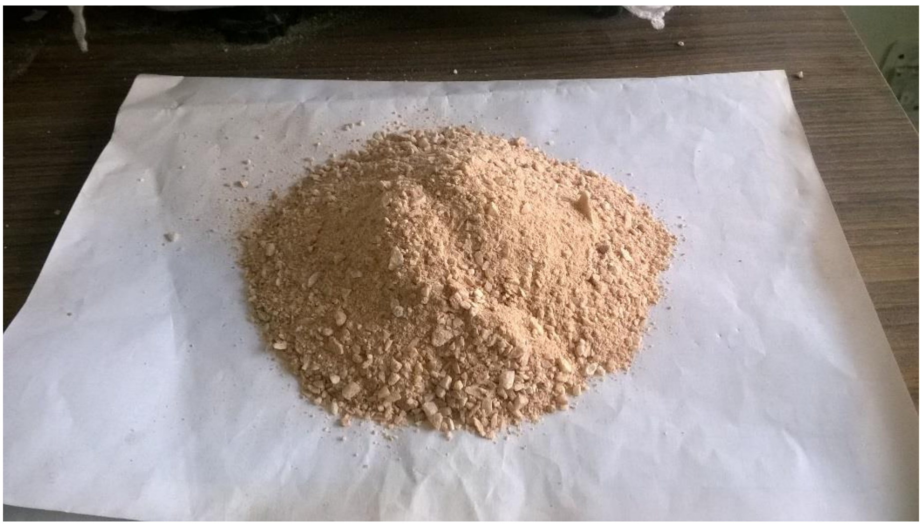


Figure 3 Badarpur sand

Figure 4: Yamuna sand

3.3 Model test arrangements

The model test arrangements are done in UTM (5000KN capacity) in concrete lab. Due to some limitations the measurement of loads is done by proving ring of 50 KN capacity. The loading rate is fixed to 0.1KN/mm and dial gauge is used to measure the displacement. The weight of the sand to be fit in the given volume of the model box at 100% relative density is calculated, then placed and compacted in the model box.

The model footings are placed as surface footings. The footing are placed over compacted sand and over that proving ring along with cylindrical portion at bottom is placed. Special attention is given to check the horizontally leveled surface of the footing and the verticality of proving ring. Then the upper cyllindrical portion of the UTM is fixed to the top of proving ring. The hydraulic jack below the UTM provide upward movement with a fixed loading rate. The proving ring gives the shear resistance of the sand against this movement and the dial gauge gives reletive settlement at that time.

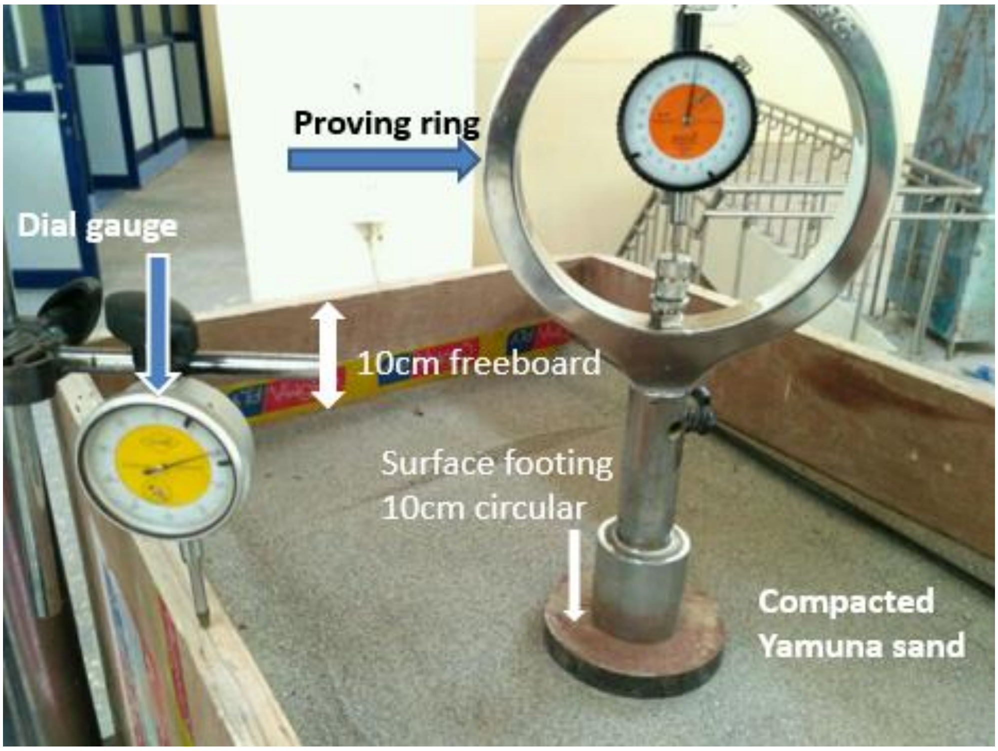


Figure 5 Test setup

The proving ring used is of 50 KN capacity. The calibrations of proving ring is certified by NCCBM.

3.4 Equations used to find Nɣ values

Table 2 Equations used to find Nɣ values

Sl. No.	Author	Model
1.	Terzaghi (1943); fitted expression; limit equilibrium	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)}+3]\tan(1.34\varphi)$
2.	Taylor(1948); limit equilibrium	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)}-1]\tan(\frac{\pi}{4}+\frac{\varphi}{2})$
3.	Caquot and kerisel (1953); fitted from Ukritchon et al.(2003); method of characteristics	$N\gamma = [1.413\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)}+1.794]\tan(1.27\varphi)$
4.	Biarez et al. (1961); equilibrium	$N\gamma = 1.8[\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)}-1]\tan\varphi$

	method	
5.	Meyerhof (1963); semi empirical based on limit equilibrium	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) e^{(\pi \tan\varphi)} - 1] \tan(1.4\varphi)$
6.	Hu(1964); fitted model; equilibrium limit	$N\gamma = [1.901 \tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) e^{(\pi \tan\varphi)} + 0.27] \tan(1.285\varphi)$
7.	Booker (1969); method of characteristics	$N\gamma = 0.1045 e^{(9.6\varphi)}$
8.	Hansen and Christensen (1963); fitted model; method of characteristics	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) e^{(\pi \tan\varphi)} - 1] \tan(1.33\varphi)$
9.	Abdul-Baki and Beik (1970); fitted model; limit equilibrium	$N\gamma = [1.752 \tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) e^{(\pi \tan\varphi)} + 0.186] \tan(1.32\varphi)$
10.	Davis and Booker (1971); fitted model; limit equilibrium	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) e^{(\pi \tan\varphi)} + 2.33] \tan(1.316\varphi)$
11.	Vesic (1973); approximation based on Caquot and kerisel (1953) analysis using the method of characteristics	$N\gamma = 2[\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) e^{(\pi \tan\varphi)} + 1] \tan\varphi$
12.	Chen (1975); upper bound limit analysis	$N\gamma = 2[\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) e^{(\pi \tan\varphi)} + 1] \tan(\frac{\pi}{4}+\frac{\varphi}{5}) \tan\varphi$
13.	Chen (1975); fitted model from mechanics two values; upper bound limit analysis	$N\gamma = [1.45 \tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) e^{(\pi \tan\varphi)} + 0.754] \tan(1.41\varphi)$
14.	Salencon et al. (1976); fitted model; limit equilibrium	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) e^{(\pi \tan\varphi)} - 1] \tan(1.405\varphi)$
15.	Craig and Pariti (1978); fitted model; limit equilibrium	$N\gamma = [2.22 \tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) e^{(\pi \tan\varphi)} + 0.22] \tan\varphi$
16.	Spangler and Hardy (1982); approximation from Terzaghi's mechanism	$N\gamma = 1.1[\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) e^{(\pi \tan\varphi)} - 1] \tan(1.3\varphi)$
17.	Simone and Restaino (1984); method of characteristics	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) e^{(\pi \tan\varphi)} - 1] \tan(1.341\varphi)$
18.	Bolton and Lau(1993); method of characteristics	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) e^{(\pi \tan\varphi)} - 1] \tan(1.5\varphi)$
19.	Bolton and Lau (1993); fitted model from original values of	$N\gamma = [1.274 \tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) e^{(\pi \tan\varphi)} + 3.736] \tan(1.367\varphi)$

	method of characteristics	
20.	Frydman and Burd (1997); fitted model; finite difference analysis	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} + 1]\tan(1.4\varphi)$
21.	Michalowski (1997); upper bound limit analysis	$N\gamma = e^{(0.66+5.11\tan\varphi)}\tan\varphi$
22.	Paolucci and Pecker (1997); fitted model; upper bound limit analysis	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} + 1]\tan(1.71\varphi)$
23.	Soubra (1999); fitted model; upper bound analysis	$N\gamma = [1.347\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} - 0.162]\tan(1.343\varphi)$
24.	Ueno et al. (2001); fitted mode; method of characteristics	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} - 1]\tan(1.436\varphi)$
25.	Wang et al. (2001); fitted model one; upper bound limit analysis	$N\gamma = 1.2[\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} + 4.6]\tan(1.436\varphi)$
26.	Zhu et al. (2001); case 1; limit equilibrium	$N\gamma = [2\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} + 1](\tan\varphi)^{1.35}$
27.	Zhu et al. (2001); case 2; limit equilibrium	$N\gamma = [2\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} + 1]\tan(1.07\varphi)$
28.	Cassidy and Houlsby (2002); fitted model; method of characteristics	$N\gamma = [0.85\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} - 3.884]\tan(1.716\varphi)$
29.	Dewaikar and Mohapatra (2003); fitted model; limit equilibrium based on Terzaghi's model	$N\gamma = [1.626\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} + 2.019]\tan(1.373\varphi)$
30.	Kumar (2003); fitted model; method of characteristics	$N\gamma = [0.96\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} + 0.508]\tan(1.352\varphi)$
31.	Kumar (2003); fitted model; upper bound analysis	$N\gamma = [1.379\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} - 0.461]\tan(1.337\varphi)$
32.	Ukritchon et al.(2003); fitted model from mean value; lower and upper bound analysis	$N\gamma = [1.279\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} - 3.057]\tan(1.219\varphi)$
33.	Hijaj et al. (2005); lower and upper bound analysis	$N\gamma = e^{[\pi/6(1+3\pi\tan\varphi)]}(\tan\varphi)^{\frac{2\pi}{5}}$
34.	Martin (2005); fitted model; method of characteristics	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} - 1]\tan(1.338\varphi)$
35.	Smith (2005); method of characteristics	$N\gamma = 1.75[\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{[(0.75\pi+\varphi)\tan\varphi)} - 1]\tan\varphi$
36.	Kumar and Kauzer (2007);	$N\gamma = [1.012\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} - 0.226]\tan(1.426\varphi)$

	lower;upper bound analysis	
37.	Lyamin et al. (2007); lower and upper bound method	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} - 0.6]\tan(1.33\varphi)$
38.	Kumar and Khatri (2008); fitted model; lower bound finite element linear programming	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} - 1]\tan(1.26\varphi)$
39.	Salgado (2008); approximation model from Martin (2005)	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} - 1]\tan(1.32\varphi)$
40.	Yang and yang (2008); fitted model; upper bound limit analysis	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} + 1]\tan(1.396\varphi)$
41.	Jahanandish et al. (2010); fitted model zero extension line method	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} + 1]\tan(1.5\varphi)$
42.	Kumar and Khatri (2011); fitted model; lower bound with finite element and linear programming	$N\gamma = [\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)e^{(\pi\tan\varphi)} - 5.115]\tan(1.577\varphi)$

This table is taken from "Quality assessment of soil bearing capacity factor models of shallow foundations" by Motra et al.

Chapter 4

Result and Analysis

4.1 Tests on soil

The practical part of the project starts with some basic engineering properties test of selected sand and to classify the type of the soil. The engineering properties of any soil is the most basic part on which accuracy of analysis of any project depends. Errors in this step leads to drastically variations in results. Thus to calculate the basic engineering properties of soil one should be very much careful.

4.1.1 Sieve analysis

Sieve analysis is used to be done to find out the gradation of the soil through particle size distribution curve. A set of sieves IS 4,8,16,30,40,50, 100 and 200 are used in this test. Soil sample of nearly 1kg is used for this test each time. Particle size distribution curve for Yamuna and Badarpur sand are shown in fig 7 and fig 8 respectively.

4.1.1.1 Yamuna sand

Yamuna sand is a fine uniform sand with a gray appearance. 1Kg of oven dry sand is used for the sieve analysis. The sieve used are as per IS:383,1970. The particle size distribution curve for sieve analysis is shown in Fig:6. The results I got are as follows: D_{10} = 0.15, D_{30} =0.2, D_{60} = 0.3, C_u = 2, C_C =0.889. So, it is a poor graded uniform sand.

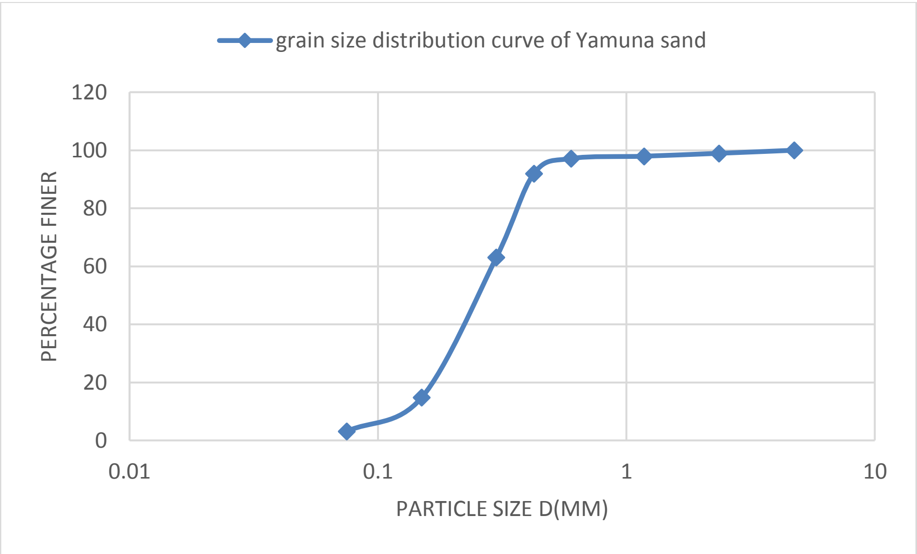


Figure 6 Yamuna sand grain size distribution

4.1.1.2 Badarpur sand

Badarpur sand is a course grained sand with light orange appearance. 1Kg of oven dry sand is used for the sieve analysis. The sieve used are as per IS:383,1970. The particle size distribution curve for sieve analysis is shown in Fig:7. The results I got are as follows: D_{10} = 1.2, D_{30} = 1.75, D_{60} = 4.8, C_u = 4, C_C = 0.52. So, it is poorly graded course sand.

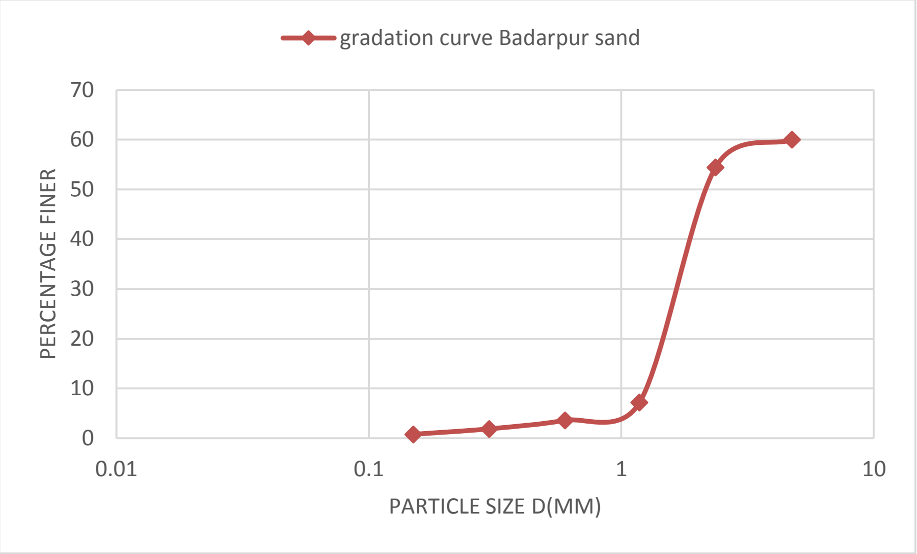


Figure 7 Badarpur sand grain size distribution

4.1.2 Specific Gravity test

Specific gravity of sand is tested using Pycnometer method. The specific gravity of Yamuna sand is 2.65, and for Badarpur sand, it is 2.7.

4.1.3 Relative Density test

The relative density test needs a mould of 3000cc with bottom plate and also with clamping arrangement with which it can be clamped on a 75cmX75cm vibrating table vibrating at 3600rpm. It also needs a surcharge weight of 140gm/cm2. The mould is first clamped in vibrating table and the collar is attached with it. Then sand is poured in it and surcharge is placed on the top and the whole system is vibrated up to 6-7 minutes.

Relative density test is done to find out the maximum and minimum density of fully dry sand and this test is very important for the project work because in the model box the soil have to be placed at that desired density. The test was conducted in IIT Delhi where in Foundation engineering lab the instrument is placed. The details of relative density test apparatus are shown in Fig:8.

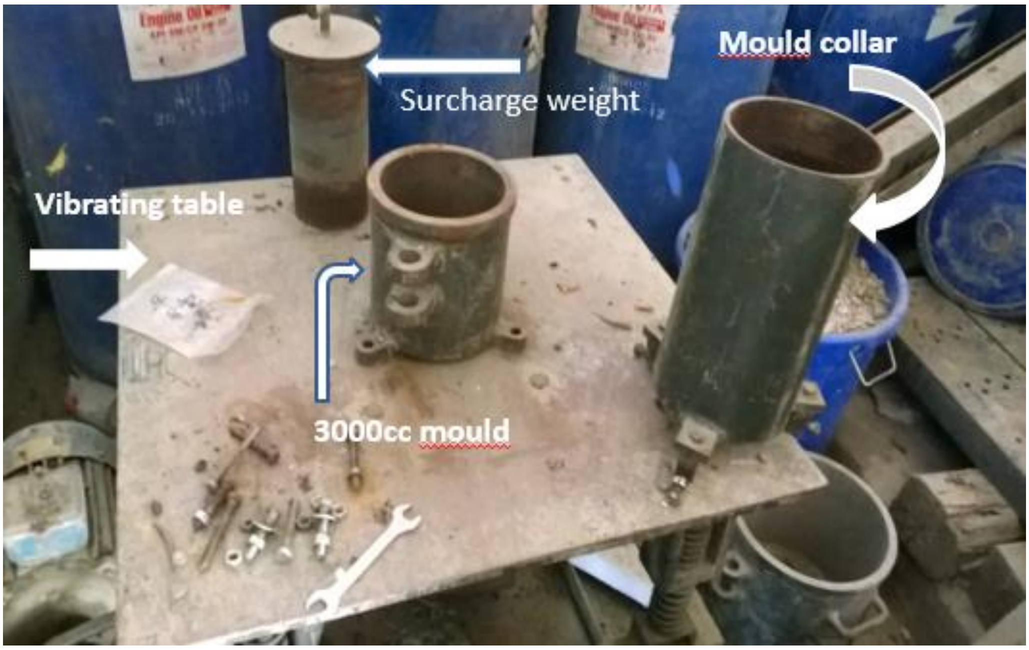


Figure 8 Relative density test apparatus

4.1.3.1 Yamuna sand

Table 3 Relative density test for Yamuna sand

Type of condition	Wt. of mould + sand (kg)	Wt. of empty mould(kg)	Volume of mould (cc)	Density (g/cc)
loose	14.380	10.35	3004.15	1.341
compacted	15.480	10.35	3004.15	1.707

The unit weight of Yamuna sand at relative density 100% = 17.07KN/m^3 and at the loosest condition the relative density is 1.341KN/m^3.

4.1.3.2 Badarpur sand

Table 4 Relative density test for Badarpur sand

Type of condition	Wt. of mould + sand (kg)	Wt. of empty mould(kg)	Volume of mould (cc)	Density (g/cc)
loose	**14.070**	**10.35**	**3004.15**	**1.238**
compacted	**15.610**	**10.35**	**3004.15**	**1.7509**

The unit weight of Badarpur sand at relative density 100% =1.7509KN/m^3 and at the loosest condition the relative density is 1.238KN/m^3.

4.1.4 Direct Shear test

Shear failure occurs in soil when shear stresses induced due to applied compression load exceed the shear strength of soil. In other words, shear stress is the principle engineering property that controls the stability of the soil under loading condition. Therefore, to find out shear parameters cohesion (C) and angle of internal friction (φ), we have to be very careful because all the bearing capacity factors are depending on φ. Little experimental errors in finding shear parameters can lead to drastically change in results of the study.

4.1.4.1 Yamuna sand

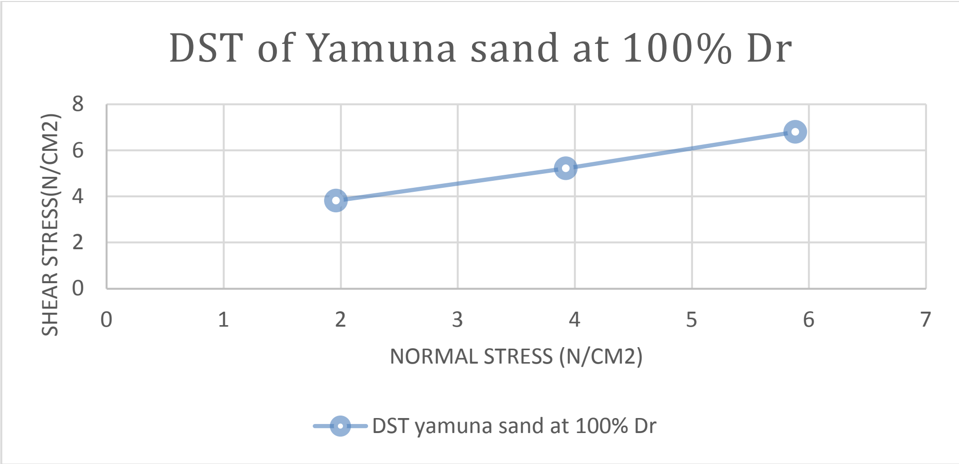


Figure 9 Direct shear test for Yamuna sand at relative density =100%

The angle of internal friction φ observed is 38° in case of Yamuna sand and cohesion C=2.2KPa. Direct shear test results for the Yamuna sand are shown in Fig.9

4.1.4.2 Badarpur sand

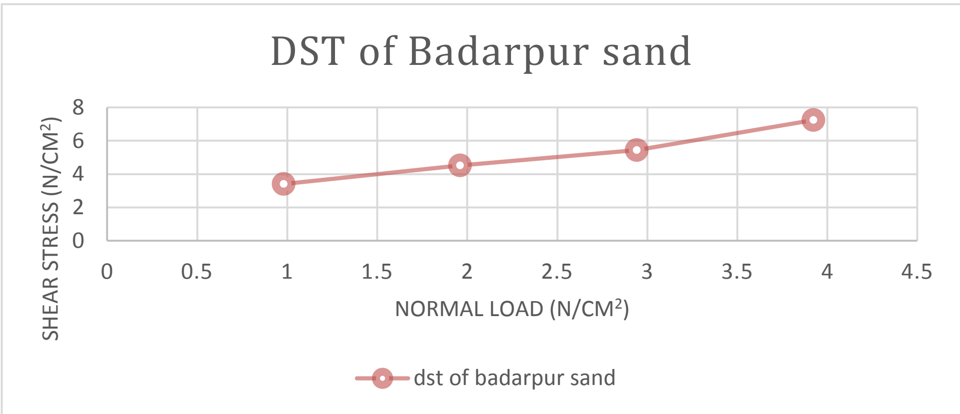


Figure 10 Direct shear test of Badarpur sand at relative density =100%

The angle of internal friction φ observed is 47° in case of Badarpur sand and cohesion C=2.3KPa. Direct shear test results for the sand are shown in Fig.10.

As per the results, the sand are not totally free from clay or silts which results the presence of cohesion component in these cases.

4.2 Tests on model

To conduct tests on model, the model box is filled with dry sand at specific compaction so that 100% relative density can be achieved. The model box is filled up to a height of 30 cm and 10 cm is kept as freeboard. For Yamuna sand total 140.945Kg is compacted in the model box in the desired dimensions and incase of Badarpur sand the weight of sand require is 144.570Kg.

The model footing plates are placed on surface and special consideration have been taken to check the horizontality of the plate and verticality of the loading arrangement along with proving ring. The proving ring gives the loading value and dial gauge gives the relative settlement. To plot load settlement curves both the values have to be taken simultaneously.

4.2.1 Pictures of shear failures of sand

Figure 11 Shear failure of Yamuna sand at 5cmX5cm sq. plate

Figure 12 7.5 cm circular surface footing

Figure 13 Shear failure on 7.5cm circular footing

Figure 14 Shear failure of Yamuna sand under 7.5cm circular footing

Figure 15 Shear failure of Yamuna sand under 10cmX14cm footing

Figure 16 Shear failure of Yamuna sand under 10cmX14cm footing

Figure 17 Shear failure of Badarpur sand under 10cmX10cm footing

Figure 18 Shear failure of Badarpur sand under 8cmX8cm footing

Figure 19 Shear failure of Badarpur sand under 10cm circular footing

Figure 20 Shear failure of Badarpur sand under 7.5cm circular footing

Figure 21 Shear failure of Badarpur sand under 5cm circular footing

4.2.2 Rectangular footing

4.2.2.1 Yamuna sand

4.2.2.1.1 Size 1 rectangular

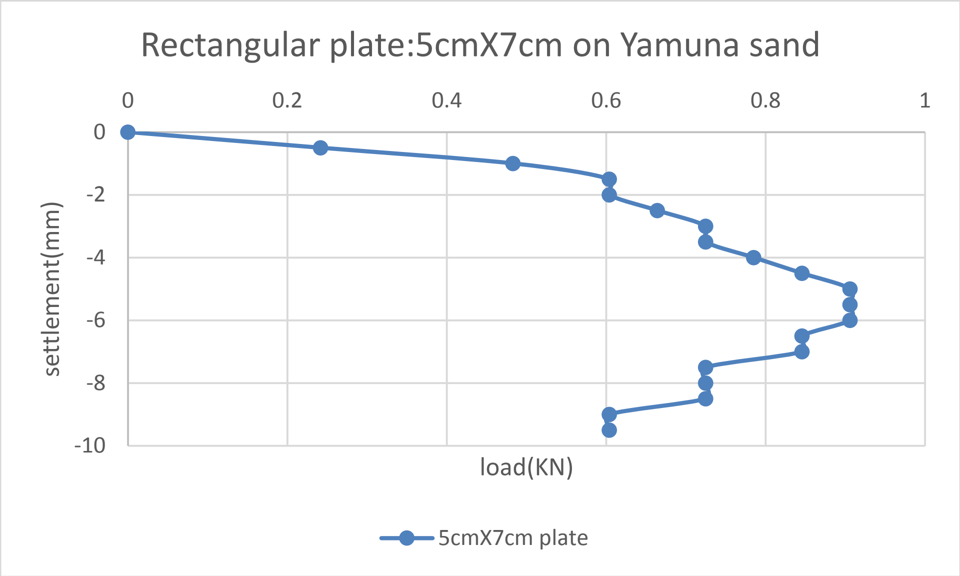


Figure 22 Model test on Yamuna sand : 5cmX7cm rectangular plate

4.2.2.1.2 Size 2 rectangular

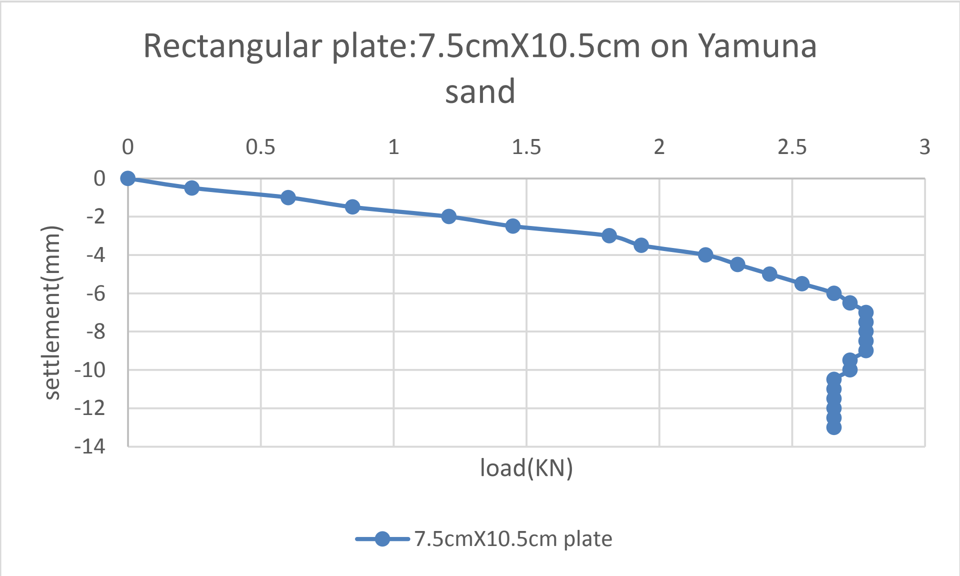


Figure 23 Model test on Yamuna sand : 7.5cmX10.5cm rectangular plate

4.2.2.1.3 Size 3 rectangular

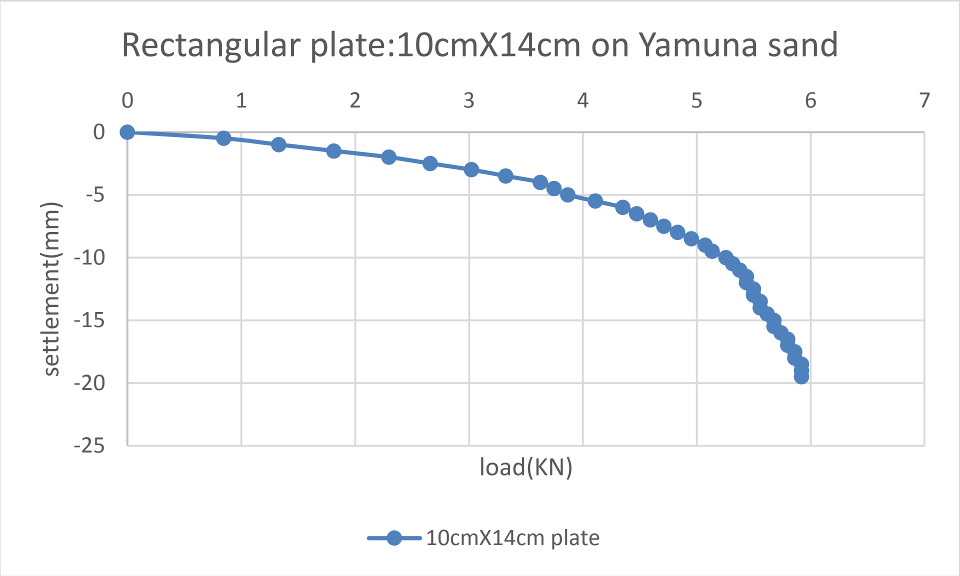


Figure 24 Model test on Yamuna sand : 10cmX14cm rectangular plate

4.2.2.2 Badarpur sand

4.2.2.2.1 Size 1

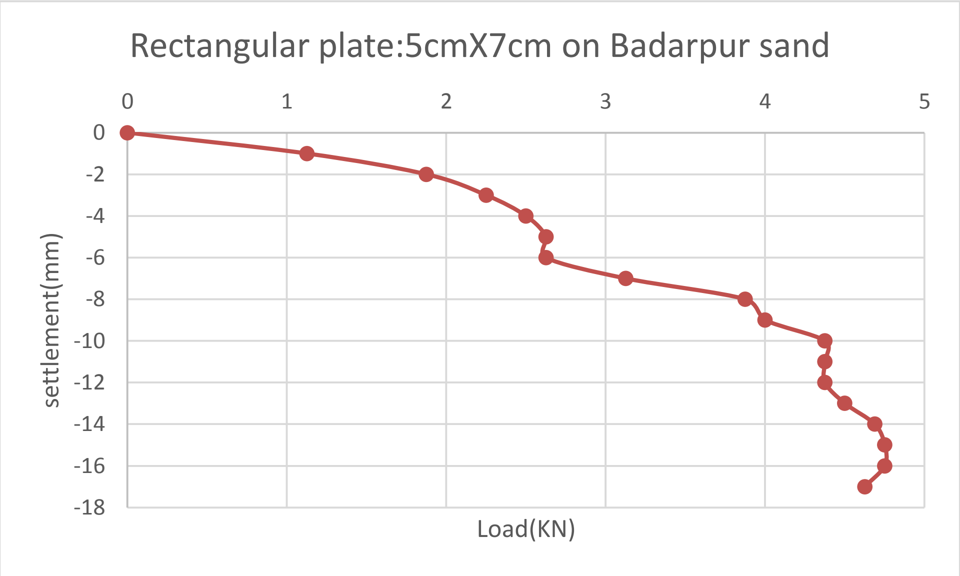


Figure 25 Model test on Badarpur sand : 5cmX7cm rectangular plate

4.2.2.2.2 Size 2

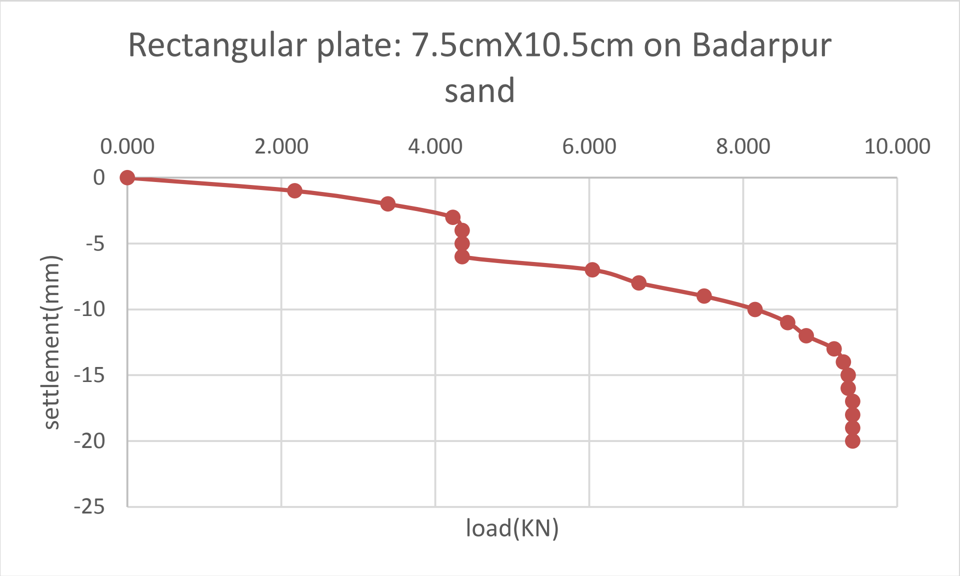


Figure 26 Model test on Badarpur sand : 7.5cmX10.5cm rectangular plate

4.2.2.2.3 Size 3

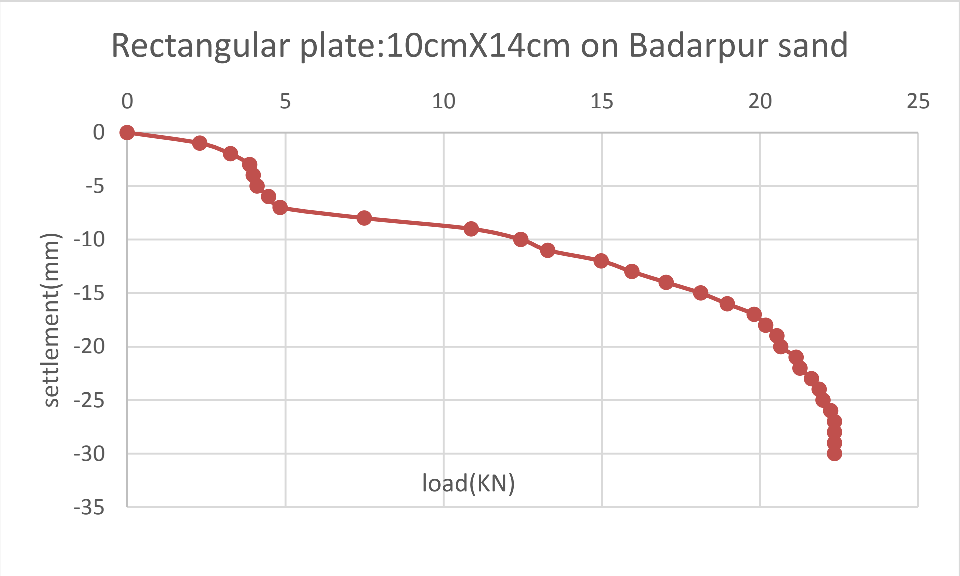


Figure 27 Model test on Badarpur sand : 10cmX14cm rectangular plate

4.2.3 Square footing

4.2.3.1 Yamuna sand

4.2.3.1.1 Size 1

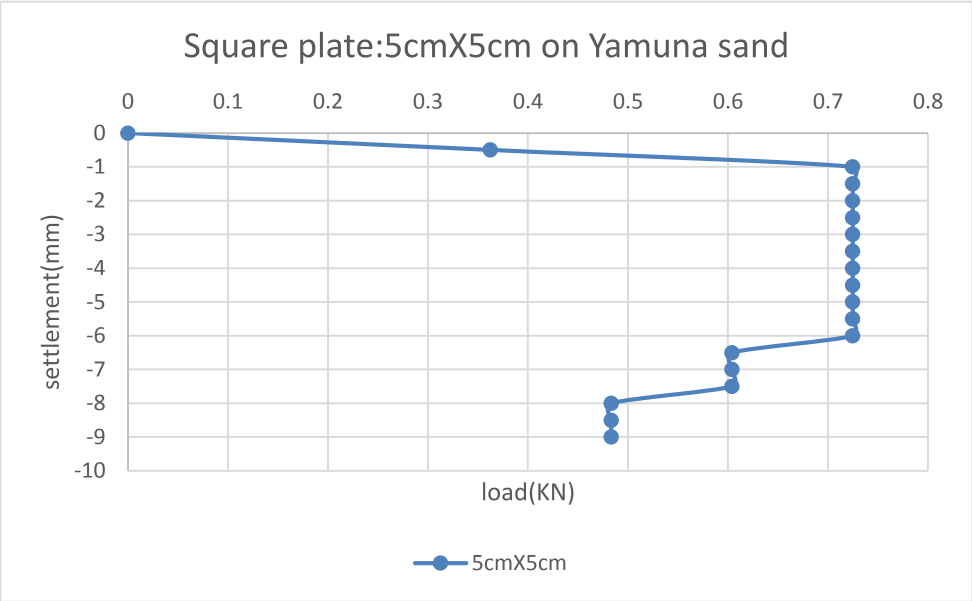


Figure 28 Model test on Yamuna sand : 5cmX5cm square plate

4.2.3.1.2 Size 2

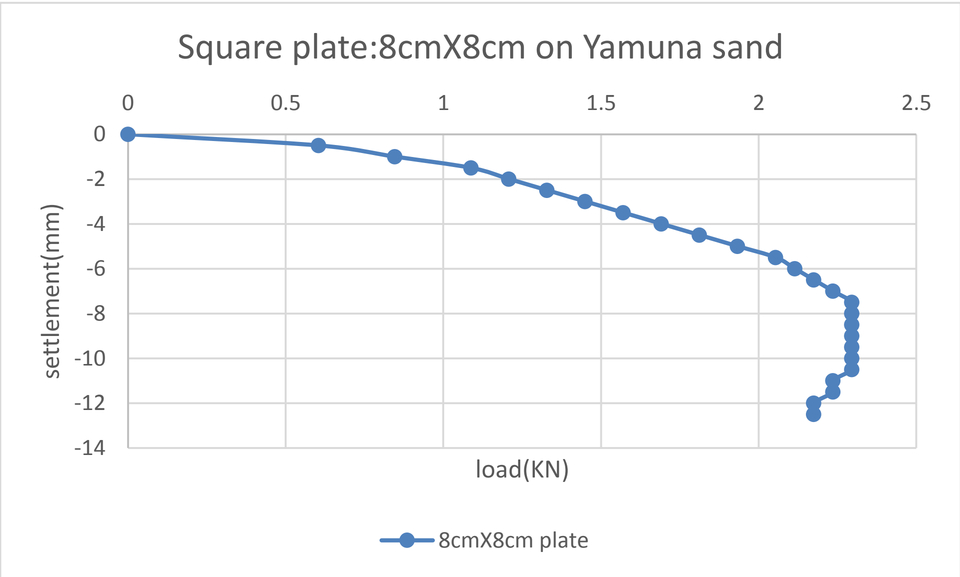


Figure 29 Model test on Yamuna sand : 8cmX8cm square plate

4.2.3.1.3 Size 3

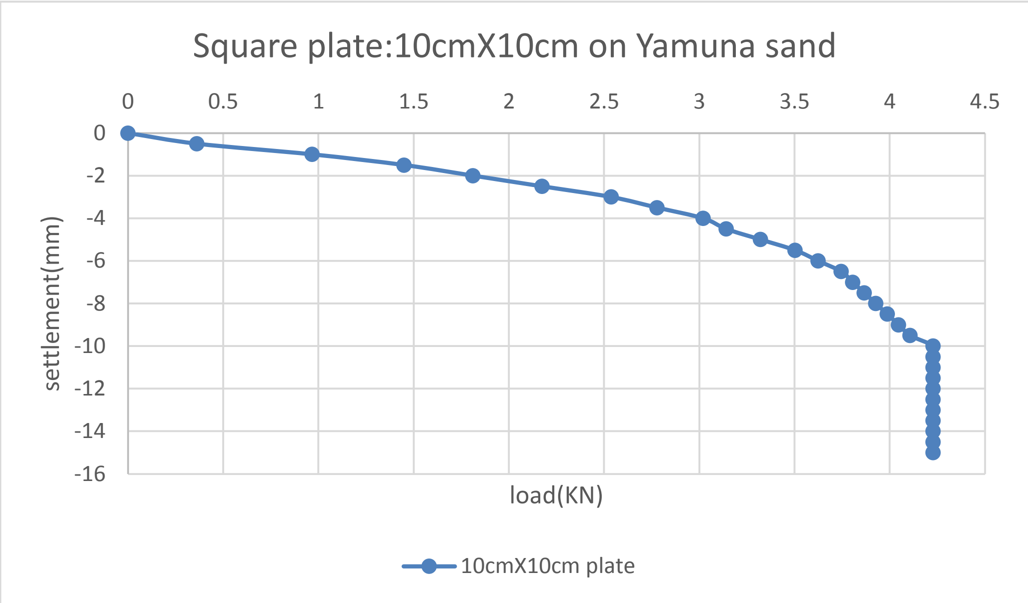


Figure 30 Model test on Yamuna sand : 10cmX10cm square plate

4.2.3.2 Badarpur sand

4.2.3.2.1 Size 1

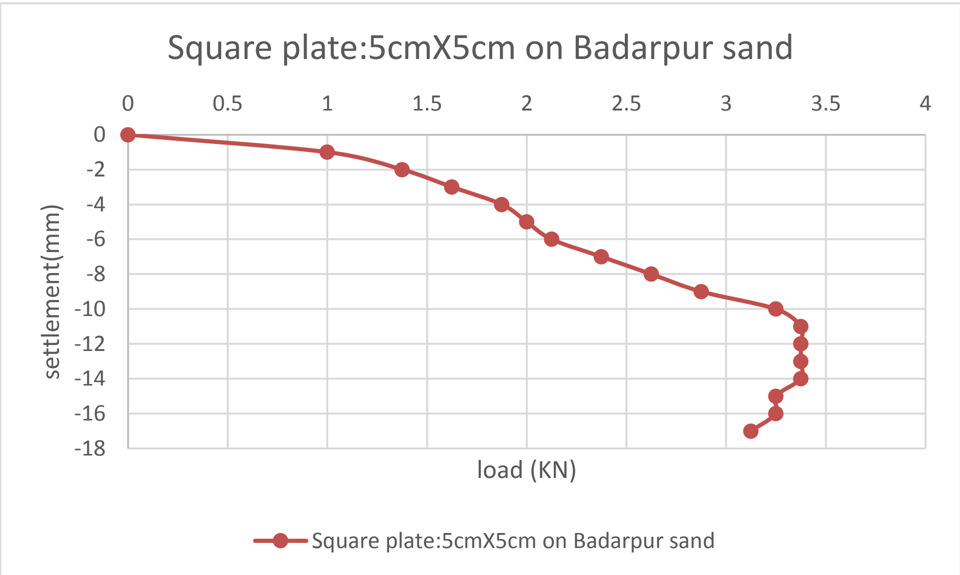


Figure 31 Model test on Badarpur sand : 5cmX5cm square plate

4.2.3.2.2 Size 2

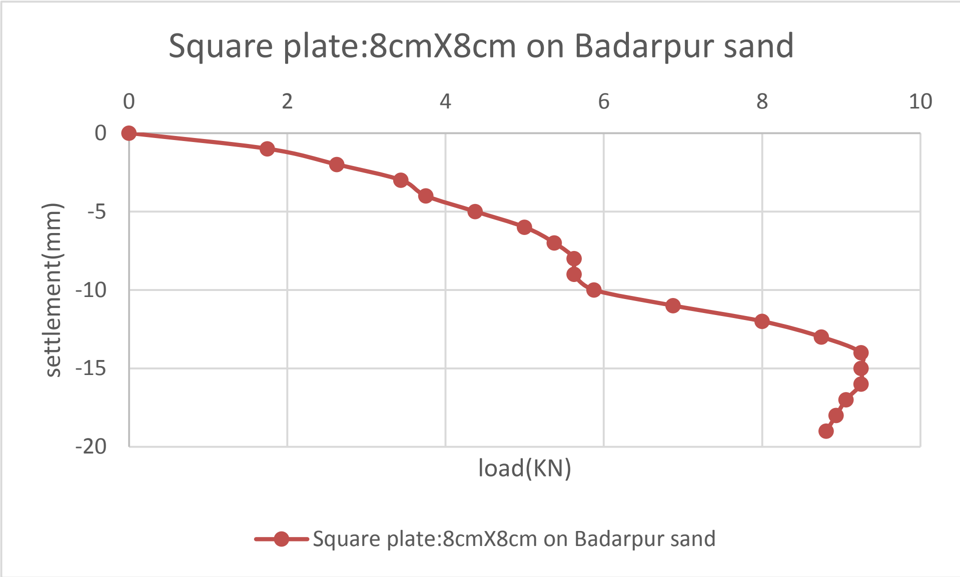


Figure 32 Model test on Badarpur sand : 8cmX8cm square plate

4.2.3.2.3 Size 3

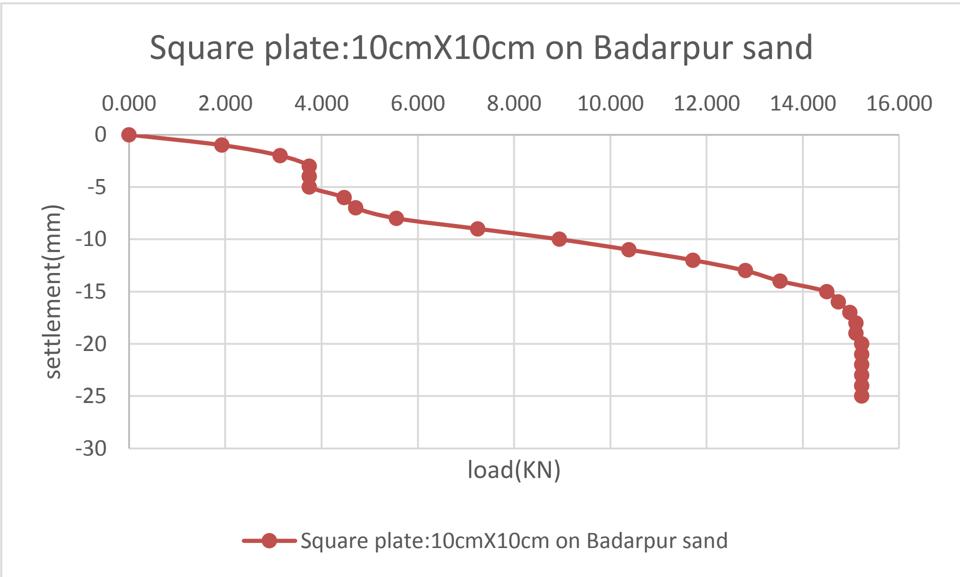


Figure 33 Model test on Badarpur sand : 10cmX10cm square plate

4.2.4 Circular footing

4.2.4.1 Yamuna sand

4.2.4.1.1 Size 1

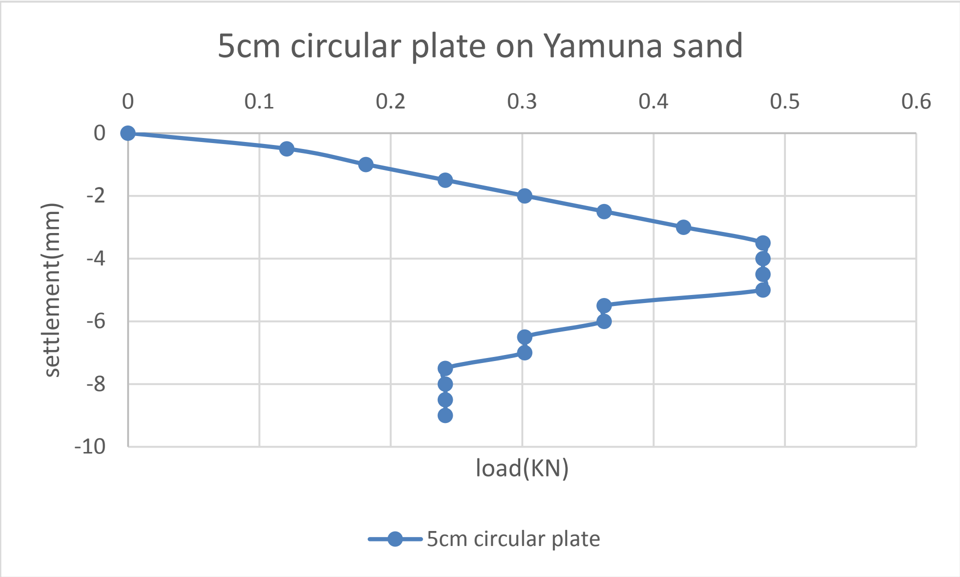


Figure 34 Model test on Yamuna sand : 5cm circular plate

4.2.4.1.2 Size 2

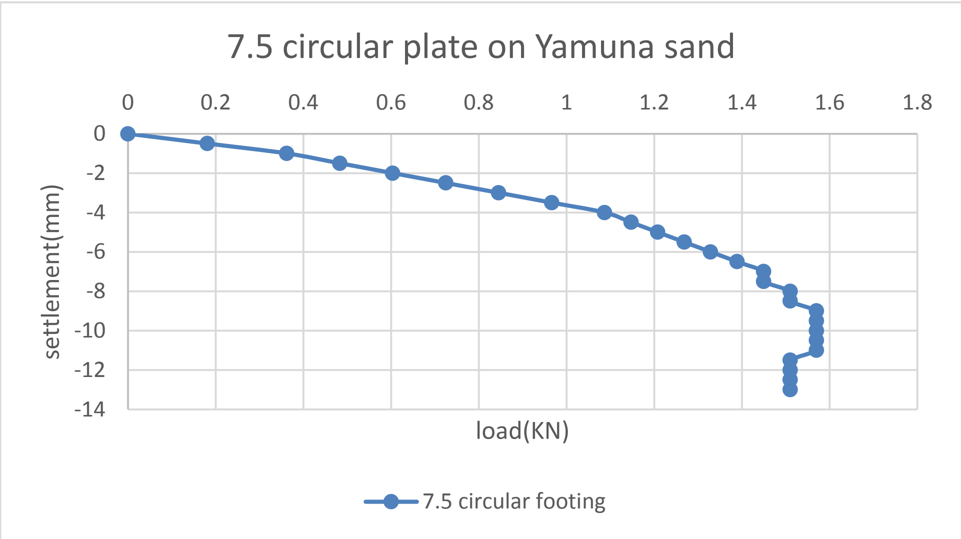


Figure 35 Model test on Yamuna sand : 7.5cm circular plate

4.2.4.1.3 Size 3

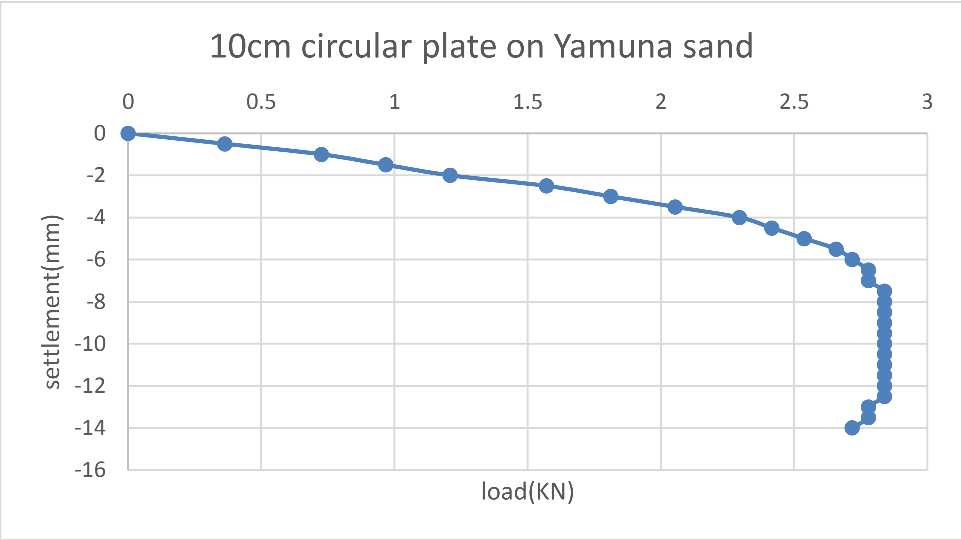


Figure 36 Model test on Yamuna sand : 10cm circular plate

4.2.4.2 Badarpur sand

4.2.4.2.1 Size 1

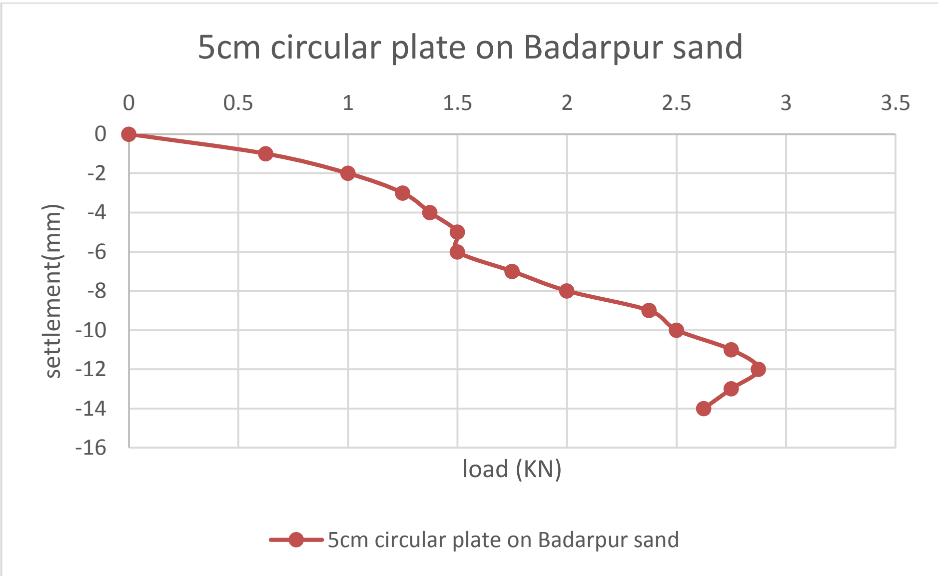


Figure 37 Model test on Badarpur sand : 5cm circular plate

4.2.4.2.2 Size 2

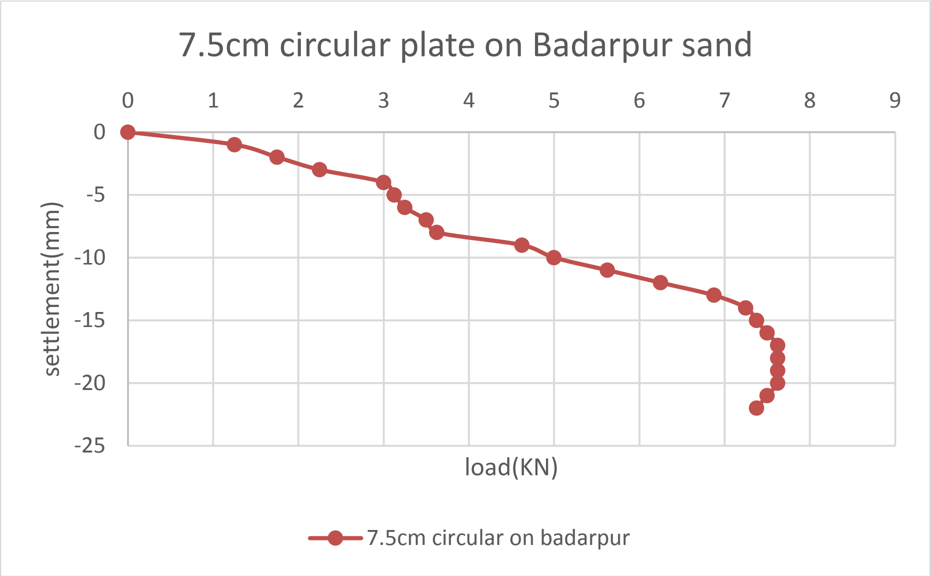


Figure 38 Model test on Badarpur sand : 7.5cm circular plate

4.2.4.2.3 Size 3

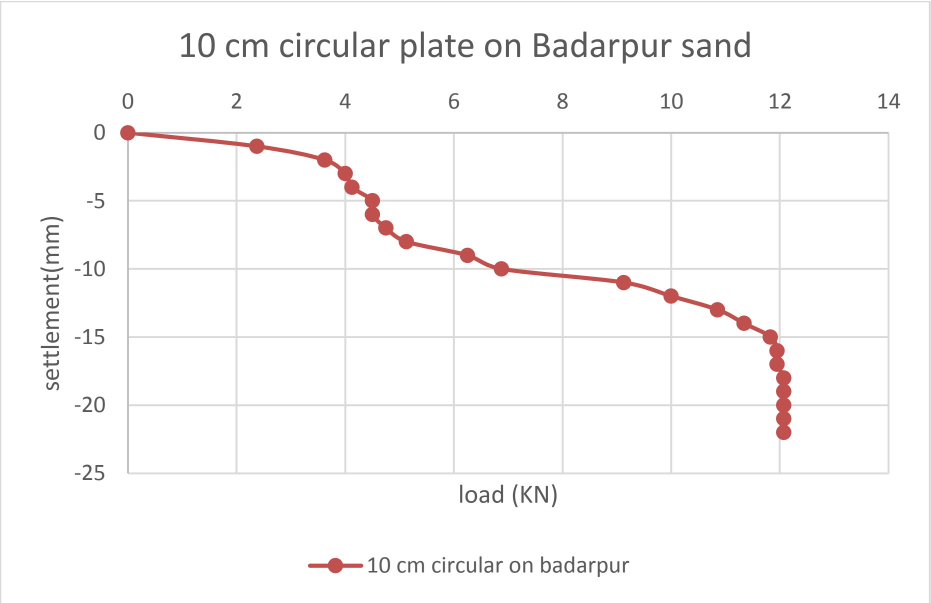


Figure 39 Model test on Badarpur sand : 10cm circular plate

Fig:22 to Fig:39 shows the load settlement curves on model tests. Model test on these sand gives true general shear failure. Heaving can be observed in both cases and surface cracks are also there. Fig:13, 15, 16 shows heaving of Yamuna sand and Fig:17, 18, 19, 20 shows formation of surface cracks in case of Badarpur sand. Best result of failure can be seen in case of 10cmX14cm rectangular plate on Yamuna sand where heaving of sand along with distinct surface cracks can be observed in Fig:15, 16.

The load settlement curve for 5cmX7cm rectangular, 5cmX5cm square or 5cm circular plate on Yamuna sand gives very steep step wise load settlement curve as shown in Fig:22, 28, 34. It is due to lesser failure load value, the variation of which is not distinctly readable with 50KN proving ring. If a proving ring of 5KN or 10KN capacity was used, we would have get a load settlement curve with smooth flow.

Tests on Badarpur sand gives a typical two step shear failure curve. As it is happening nearly all of these tests and follows a pattern, it cannot be neglected as any error in the experiment. In nearly all of the cases Fig:25, 26, 27; 31, 32, 33; 37, 38, 39 we can see the scenario. It may be a result of poor surface compaction because the step can be seen at a settlement of nearly 5-7mm. Thus one can say the mode of failure happening in Badarpur sand is local failure followed by general shear failure. However, the concept of plate load test to find failure load at a settlement of 10% width of plate is used. The formation of stepwise load -settlement curve leads to adoption of lesser load value as failure load.

4.3 Chart for failure points and corresponding N_Υ value

Failure load has been determined as per plate load test. In these tests the corresponding load of 10% settlement of the plate diameter of circular plate or side of square plate is considered. In case of rectangular footing 10% settlement of width is considered to check the failure load. The N_γ value is calculated with respect to three formulas considering three different methodologies. The list of N_γ values calculated using the Terzaghi, Vesic and Soubra are shown below in Table:5 and Table:6. It can be seen that the N_γ values calculated using the equation of Vesic vary too much for both kind of sand. The values based on Terzaghi and Soubra on Badarpur sand comes with a close variation.

4.3.1 Yamuna sand

Table 5 Chart for failure points and corresponding N_Υ values for Yamuna sand

Type	Dimension (cm)	Q(KN)	q_u (KN/m^2)	N_γ based on Terzaghi	N_γ based on Soubra(1999)	N_γ based on Vesic(1973)
Square	5X5	0.725	290	334.214	333.124	185.239
	8X8	2.296	358.75	334.891	334.21	283.786
	10X10	4.229	422.9	361.975	361.43	352.444
Circular	5	0.483	245.9898	273.5358	272.082	13.157
	7.5	1.45	328.2128	396.689	395.72	223.103
	10	2.839	361.4727	362.541	361.814	232.351
Rectangular	5X7	0.906	258.857	284.936	284.045	154.356
	7.5X10.5	2.779	352.888	361.538	360.945	231.618
	10X14	5.256	375.428	379.8	301.556	268.639

4.3.2 Badarpur sand

Table 6 Chart for failure points and corresponding N_Υ value for Badarpur sand

Type	Dimension(cm)	Q(KN)	q_u(KN/m^2)	N_γ based on Terzaghi	N_γ based on Soubra(1999)	N_γ based on Vesic(1973)
Square	5X5	2	800	525.715	788.066	
	8X8	5.625	878.906	469.475	633.445	116.602
	10X10	9.25	925	441.4288	572.604	181.08
Circular	5	1.5	763.943	563.5959	913.395	
	7.5	3.5625	806.385	483.518	716.719	
	10	6.875	875.352	494.004	668.905	86.512
Rectangular	5X7	2.625	750	555.998	744.494	137.983
	7.5X10.5	6.5625	833.333	518.821	644.494	269.794
	10X14	12.445	888.893	463.198	557.437	291.255

4.4 Comparison of N_γ value with other standard equations

In this part the Nɣ values determined from model tests are compared with various formulas regarding in the same area. These formulas are tabulated in Table.1. In the section below, the values are compared with those formulas regarding their concerned methodologies. In this theses, the model tests are analyzed with three common equations, Terzaghi, Vesic, Soubra. Terzaghi equation is based on limit equilibrium method, Vesic's equation is based on method of characteristics and Soubra's equation is based on upper bound method. Here a comparison is shown with various equations related to these three concern methodologies with our relevant analysis.

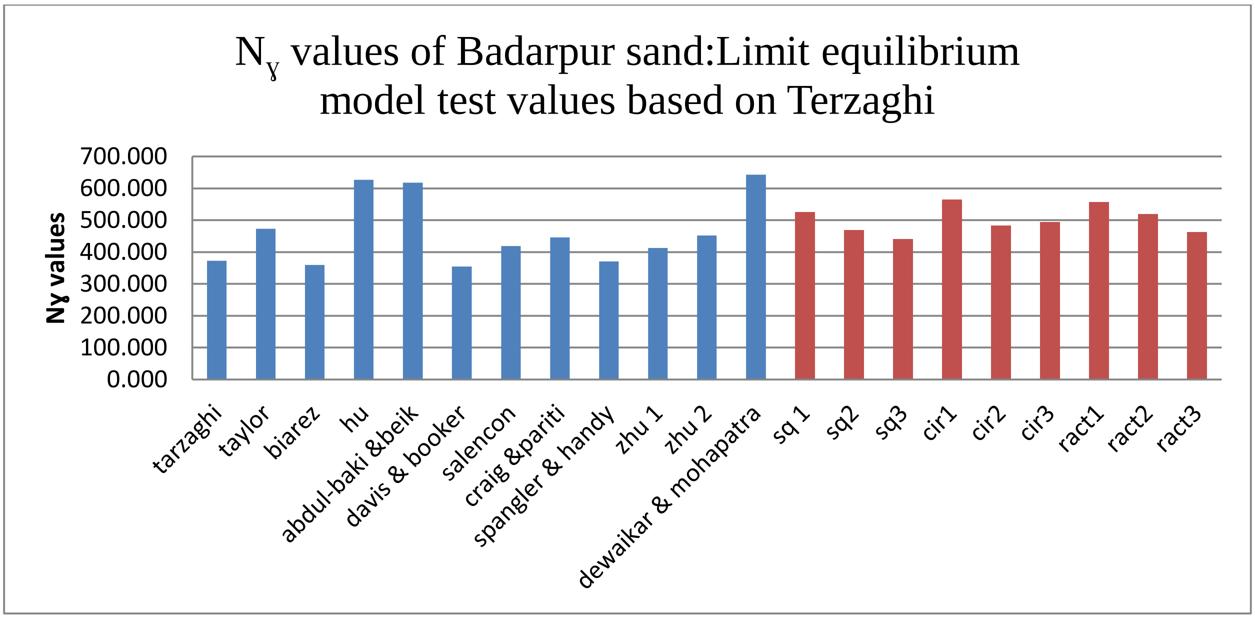


Figure 40 N_Υ values of Badarpur sand: limit equilibrium model test values based on Terzaghi.

Fig: 40 gives the variation of observed Nɣ values of Badarpur sand with respect to several equations based on limit equilibrium method. The Nɣ values observed here are analyzed with respect to Terzaghi's equation. Variation of our observed value have less than 20% variation with Taylor, Hu, Abdul-Baki and Beik, Salencon, Craig and Paritti, Zhu 2. The equations of Terzaghi, Biarez, Spengler and Handy, Dewaikar and Mohapatra gives Nɣ values within a variation of 35%. Only Davis and Booker gives results with a variation of

41%. So, these equations give close results of Nɣ values with our observed results. Among these equations only Hu, Abdul Baki and Beik, Dewakar and Mohapatra gives higher values of Nɣ and other equations give Nɣ values lesser than our observed studies.

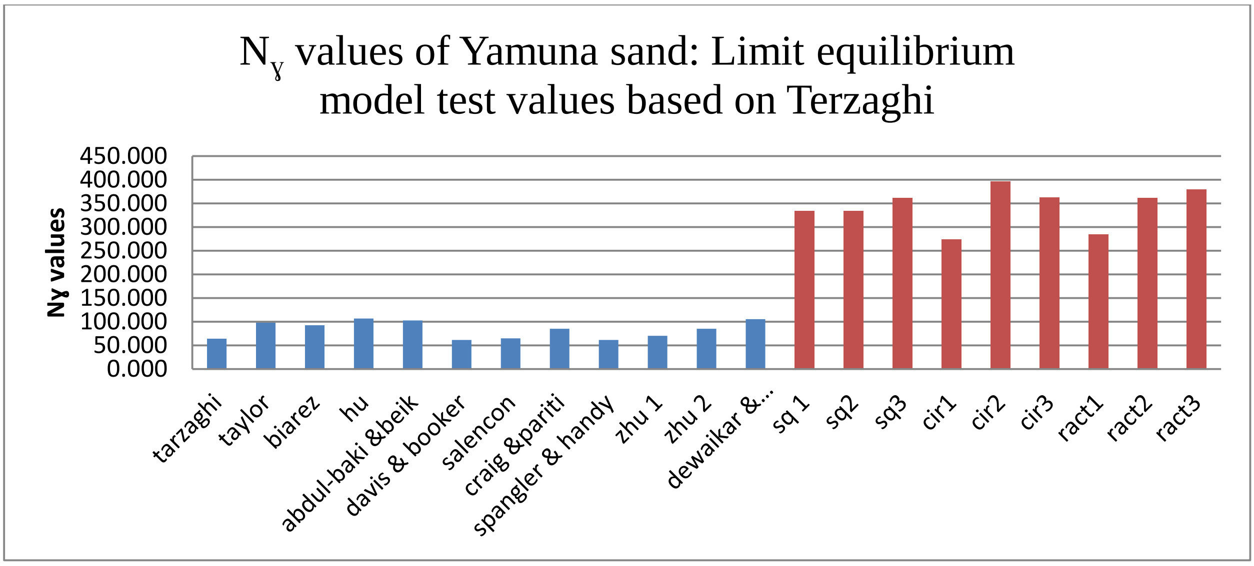


Figure 41 N_γ values of Yamuna sand: Limit equilibrium model test values based on Terzaghi

Fig: 41 gives the variation of observed Nɣ values of Yamuna sand with respect to several equations based on limit equilibrium method. The Nɣ values observed here are analyzed with respect to Terzaghi's equation. Variation with the equations of Terzaghi, Davis & Booker, Salencon, Spangler & Handy is huge and it is more than 400%. Experiment gives nearly double values of Nɣ than that of Hu, Abdul Baki & Beik, Dewaikar & Mohapatra & Taylor. The variation of results with Biarez, Craig & Paritti, Zhu1, Zhu 2 is 270% to 390%.

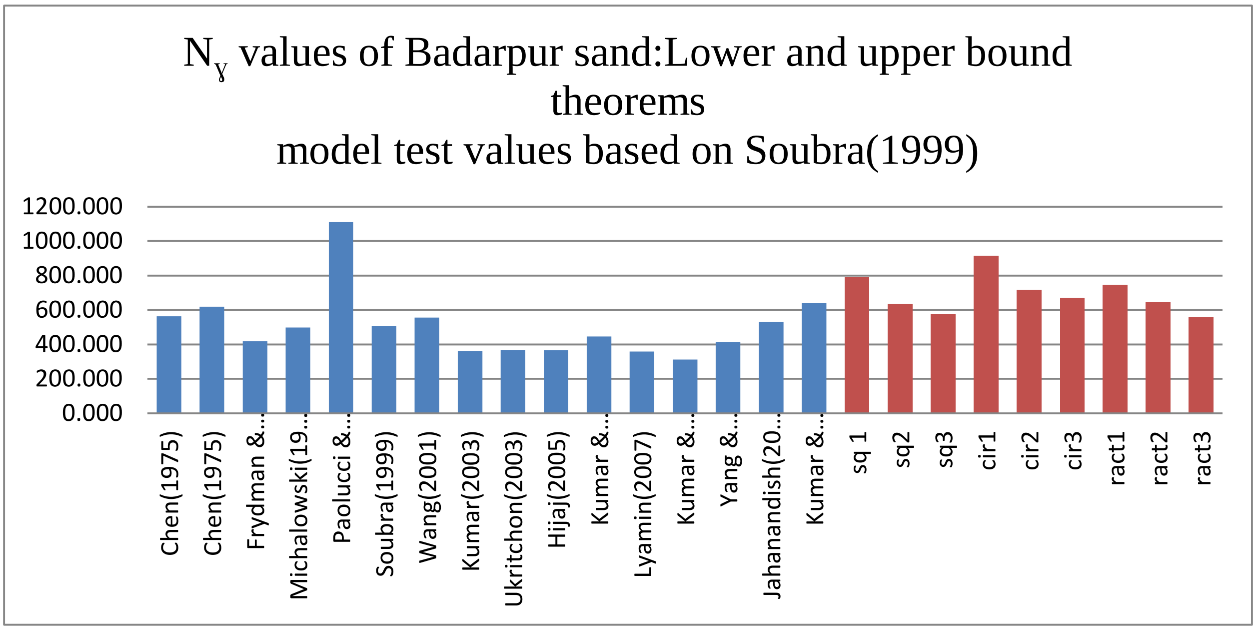


Figure 42 N_γ values of Badarpur sand: Lower and upper bound theorems model test values based on Soubra(1999)

Fig. 42 gives the variation of observed Nɣ values of Badarpur sand with respect to several equations based on upper bound and lower bound method. The Nɣ values considered here are analyzed with respect to Soubra based on upper bound method. Variation of observed Nɣ values is within 20% with Chen (1975) and Kumar & Khatri (2011). Among these equations, only the equation of Poucchi & Packer (1997) gives a result higher than the average of our observed value. All other equations give Nɣ value lesser than that. The equations with 20~40% variation are Chen (1975) Michelowski (1997), Soubra (1999), Wang (2001), Jahanandish (2010). The variation is more than 80% with Ukritchon (2003), Hijaj (2005), Lyamin (2007), Kumar & Khatri (2008). Whoever it can be state that the equations base on lower and upper bound methods give much conservative values.

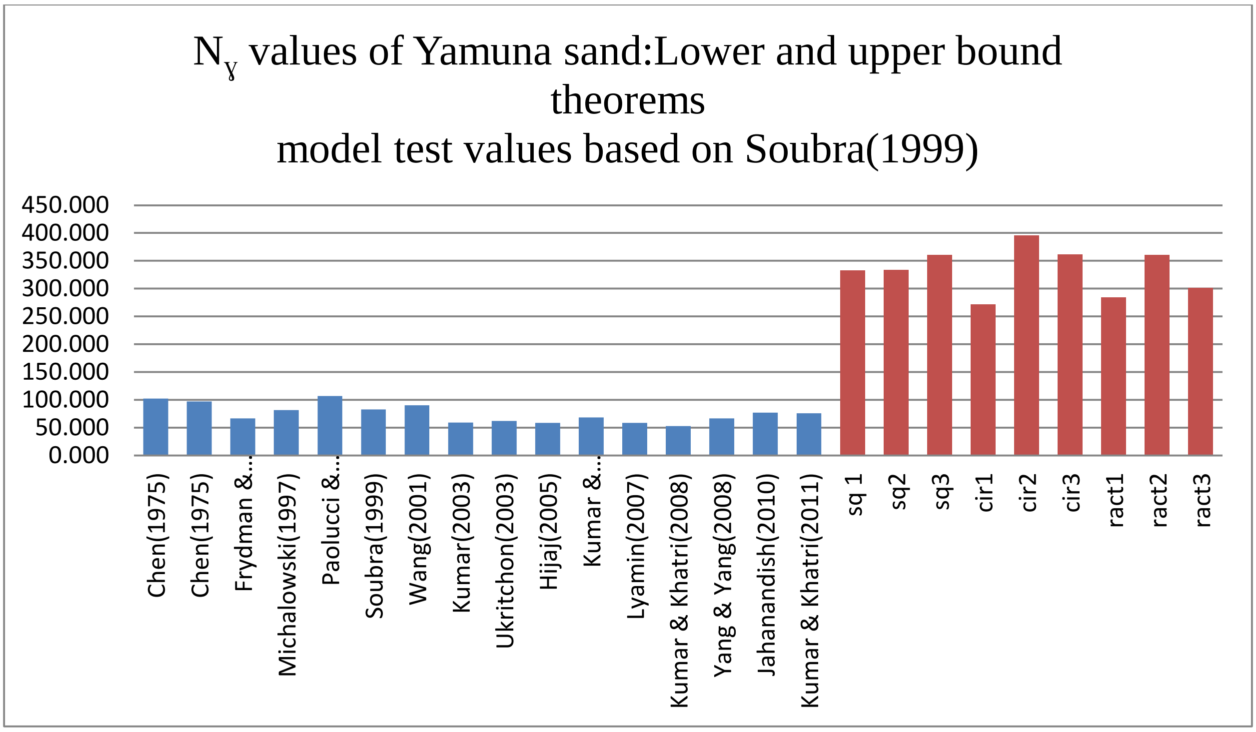


Figure 43 $N_{ɣ}$ values of Yamuna sand: Lower and upper bound theorems model test values based on Soubra(1999)

Fig. 43 gives the variation of observed Nɣ values of Yamuna sand with respect to several equations based on upper bound and lower bound method. The Nɣ values considered here are analyzed with respect to Soubra based on upper bound method. It gives similar results as per Fig. 30. The observed Nɣ values are with very higher side compared with other equation considered. The variation of result is more than 400% in case of Frydnan and Burd (1997), Kumar (2003), Ukritchon (2003), Hijaj (2005), Lyamin (2007), Kumar & Khatri (2008), Yang and Yang (2008). With the average values of Nɣ analyzed based on Soubra (1999). Observed average values are nearly double than Chan (1975), Panlucchi & Packer (1997). In case of Michaloski (1997), Soubra (1999), Wang (2001), Kumar & Kowzer (2007) Jahanandish (2010), Kumar and Khatri (2011) the variation of average Nɣ values is from 260%~400%.

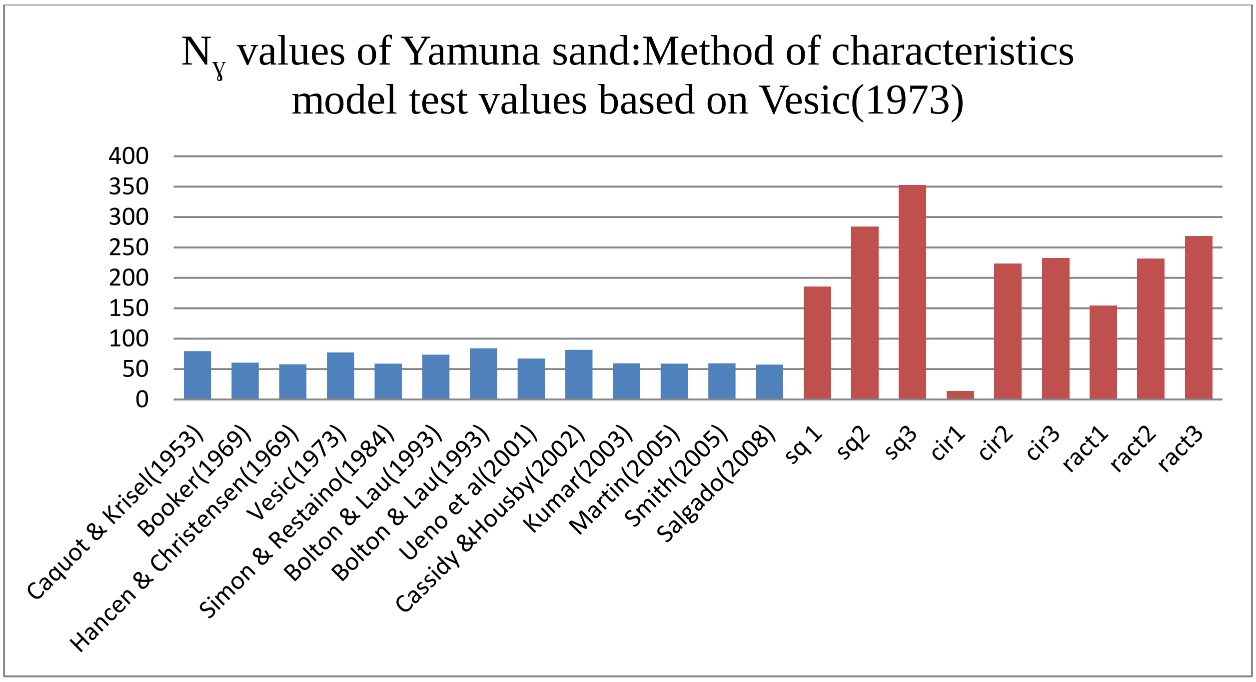


Figure 44 $N_ɣ$ values of Yamuna sand: Method of characteristics model test values based on Vesic(1973)

Fig. 44 gives variation of observed Nɣ values of Yamuna sand with respect to several equations based on method of characteristics. The Nɣ values considered here are analyzed with respect to Vesic's equation. The Vesic's analysis give irregular results of experimental observations. Average Nɣ value based of Vesic's equation for Yamuna sand is 216.077. All these conventional equations based on method of characteristics gives lesser values than the observed one with the variation of 156~276%.

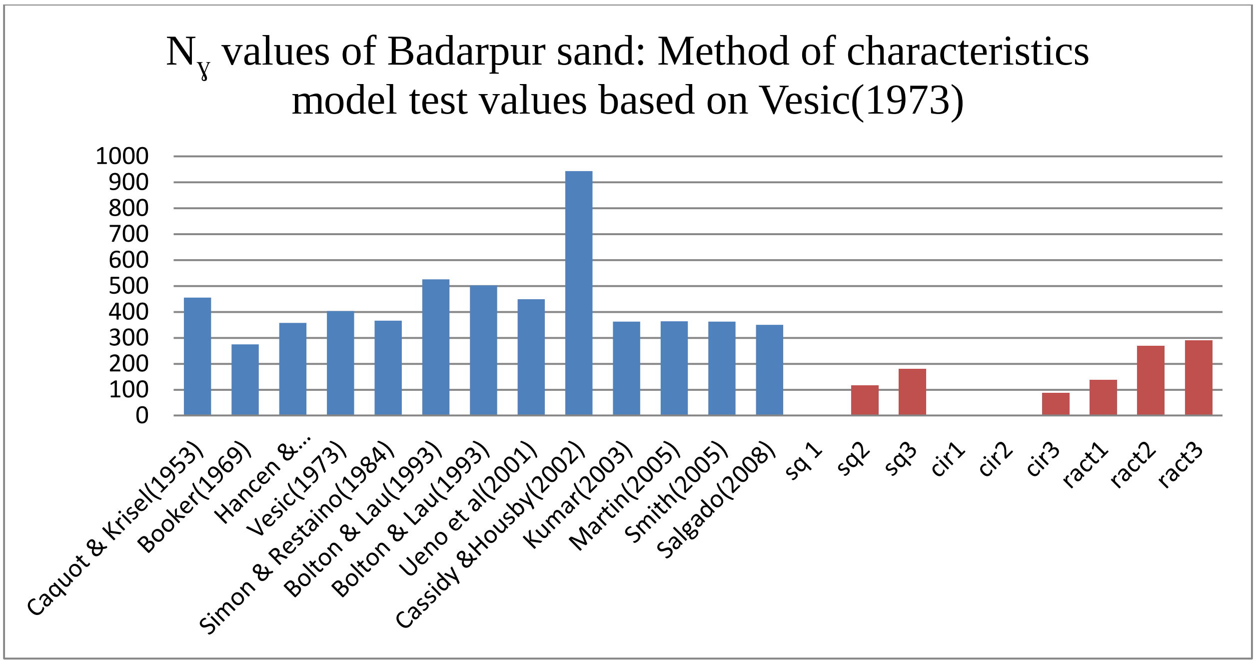


Figure 45 $N_ɣ$ values of Badarpur sand: Method of characteristics model test values based on Vesic(1973)

Fig. 45 gives variation of observed Nɣ values of Yamuna sand with respect to several equations based on method of characteristics. The Nɣ values considered here are analyzed with respect to Vesic's equation. The Vesic's equation gives irregular results of experimental observations. The average Nɣ value based on Vesic's equation of Badarpur sand is 180.537. It is lesser than any of the equation based on method of characteristics. In the case of 5cmX5cm square footing, 5cm circular footing and 7.5cm circular footing Vesic's equation gives negative Nɣ values. The equations used here vary 30% to 65% with our results. Only the equation of Cassidy and Housdy vary 80% with observed equation.

The experimental observations based on Terzaghi and Soubra gives Nɣ values with close range. The Nɣ values we get from these equations from both Yamuna sand and Badarpur sand follows a consistency. But Nɣ values calculated from Vesic's equation gives inconsistent data itself.

However, for Badarpur sand analysis with respect to Terzaghi's equation and Soubra's equation gives results which are in a close range with other equations based on limit equilibrium method and upper and lower bound method. But the Nɣ value we get from those equations are a bit higher side.

In case of Yamuna sand the experimental value analyzed by any of those 3 equations gives the value 2 to 4 times higher than the conservative equations. In this case also the analysis based on Terzaghi's equation and Soubra's equation give consistent results but analyzes based on Vesic's equation gives a totally inconsistent result. However, unlike the Badarpur sand here the average N_γ value analyzed is on the upper side with respect to other equations based on method of characteristics.

4.5 Generation of formula

The N_Υ values up to $\varphi=30^\circ$ is with nominal variation. The variation of results come after it. therefore, I decided to use the average values of N_Υ based on Terzaghi, Vesic, and Soubra, up to $\varphi=30^\circ$ and plot the values of N_Υ obtained from physical test based on Terzaghi, for both Yamuna and Badarpur sand. I use the steps for each type of footing used and get 9 set of variation there. I got 9 graphs along with 9 best fitting curve formula. Those formulas are used to generate N_Υ values up to $\varphi=0^\circ$ to 50°. The average values of those formulas are taken from $\varphi=30^\circ$ to 50°. These values are plotted in a graph and the best fitting curve gives an exponential variation for it.

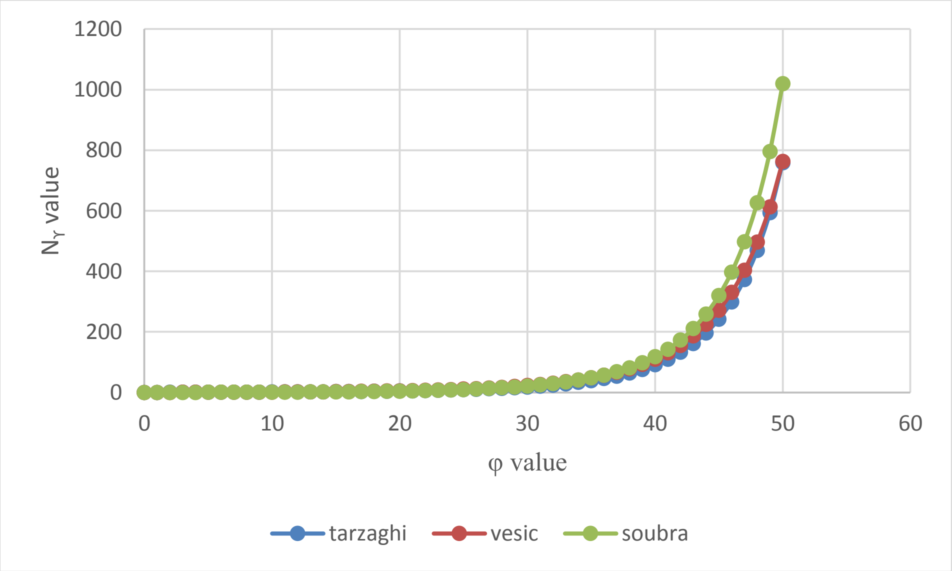
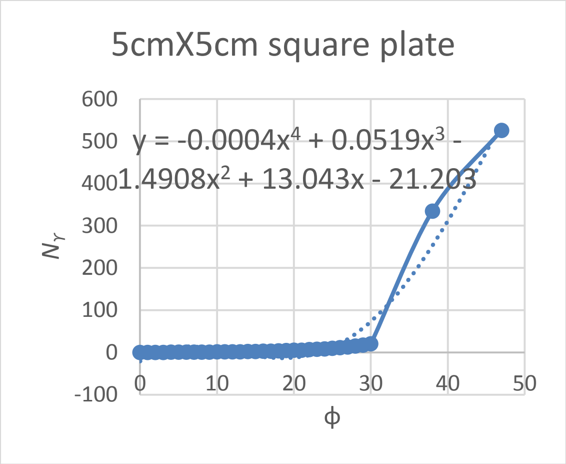


Figure 46 N_Υ values of Terzaghi, Vesic and Soubra with respect to angle of internal friction φ



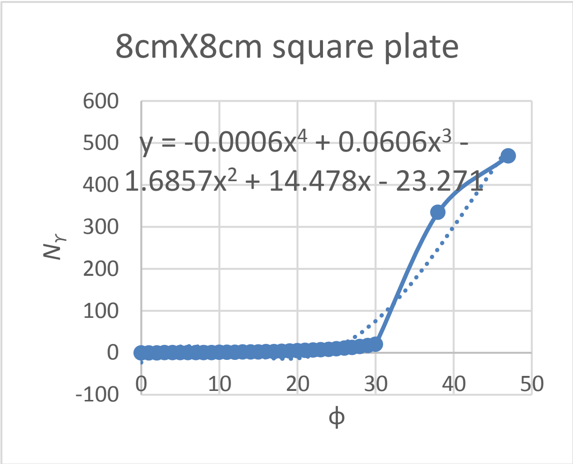
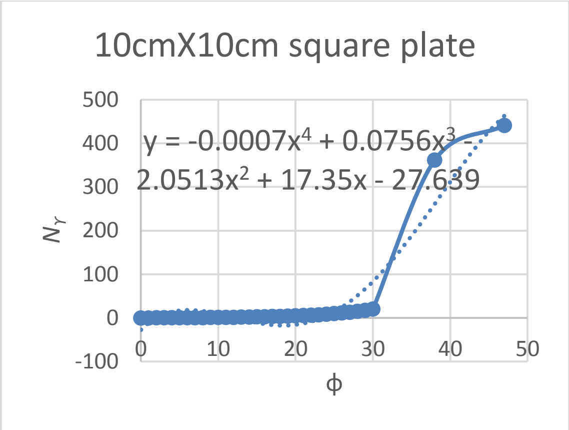


Figure 47 Curve fitting for 5cmX5cm plate

Figure 48 Curve fitting for 8cmX8cm plate



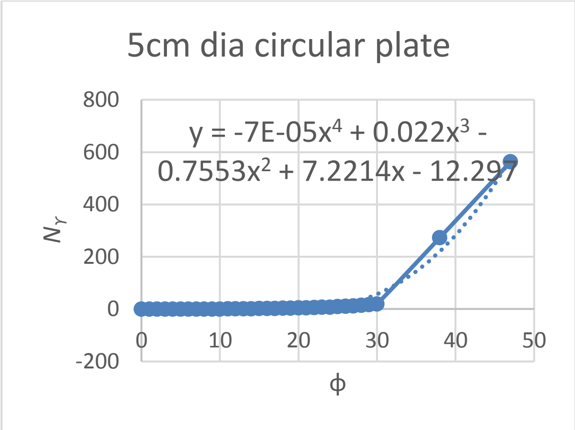
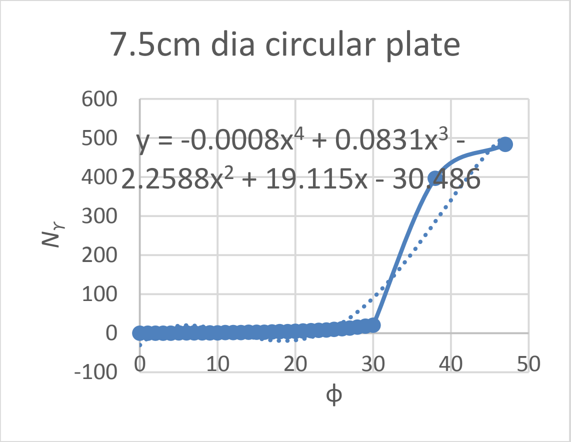


Figure 49 Curve fitting for 10cmX10cm plate

Figure 50 Curve fitting for 5cm circular plate



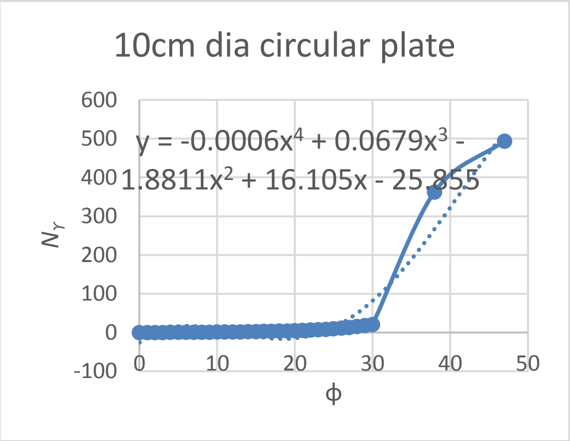
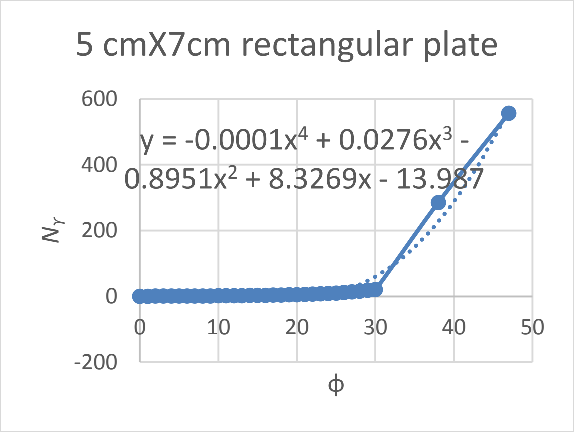


Figure 51 Curve fitting for 7.55cm circular plate

Figure 52 Curve fitting for 10cm circular plate



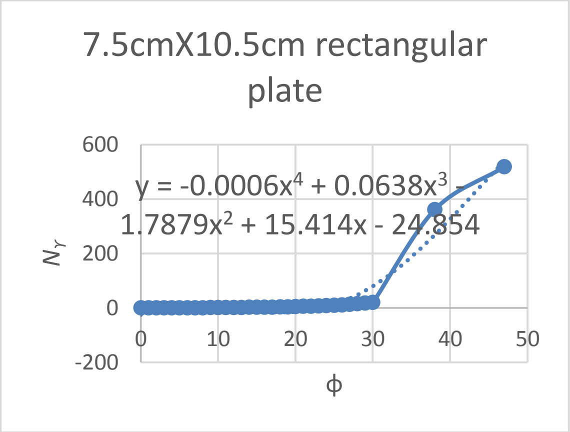


Figure 53 Curve fitting for 5cmX7cm plate

Figure 54 Curve fitting for 5cmX7cm plate

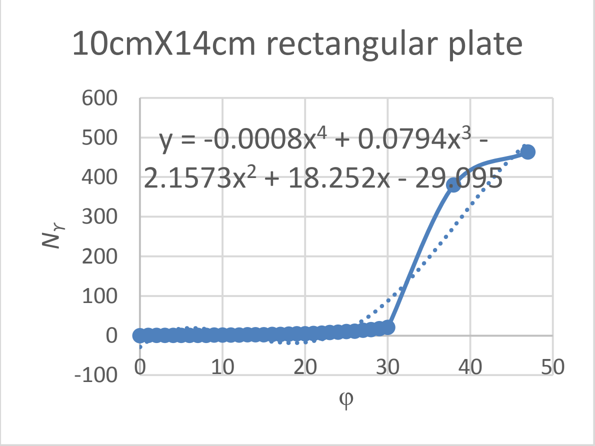


Figure 55 Curve fitting for 5cmX7cm plate

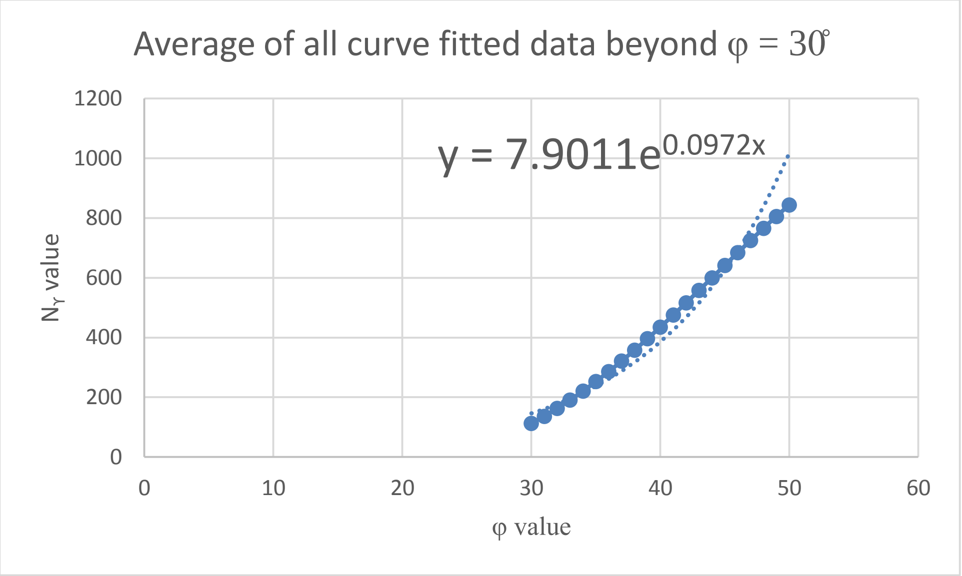


Figure 56 Average of all curve fitted data beyond φ = 30̊

Curve fitting can be done in various ways, like exponential curve, 3̊ cubical curve, 4̊ polynomial curve etc. but all of the equations used to find Nɣ values is used to be exponential so far. However, several ways have been tried to form equation in this pattern.

I have used 9 set of Nɣ values based on two points that is φ = 30̊ and φ = 47̊. To make an equation minimum 3 points are needed and to form exponential in needed more. To make best fit curve I use average points Terzaghi, Vesic and Soubra up to φ = 30̊ because up to φ = 30̊ the variations between them are not much. If Nɣ of one sand along with average values of Terzaghi, Vesic and Soubra is used then we can get an exponential curve as best fit curve. In this way we can get 9 set of equations from best fit curve for each of these sand and an average exponential curve can be found by averaging those results. Likewise, we can get equations for Nɣ values for each of Yamuna sand & Badarpur sand. But the variation using those equations with our observed result is more than 40%. The variation is more in case of cubical curve consideration.

Then along with the average Nɣ values from Terzaghi, Vesic and Soubra, the Nɣ values observed from experiments & analyzed based on Terzaghi is used together. 9 no. of model plates were used and the Nɣ values corresponding each model plates for Badarpur & Yamuna sand are used with average Nɣ values with 4̊ polynomial best fit curve, when exponential curve cannot be predicated with these values. This way 9 set of 4̊ polynomial best fit curve is generated. Φ values from 0~50 are fed in those equations and average values of those equations are find out. Than the average $N\gamma$ values for Φ=30̊ to Φ=50̊ is separated and plotted. The best fit curve from this values gives an exponential equation and the results for that occasion are within a range of 20% variation with the observed data. This equation along with the plotting is shown in fig. 56 and fig. 57.

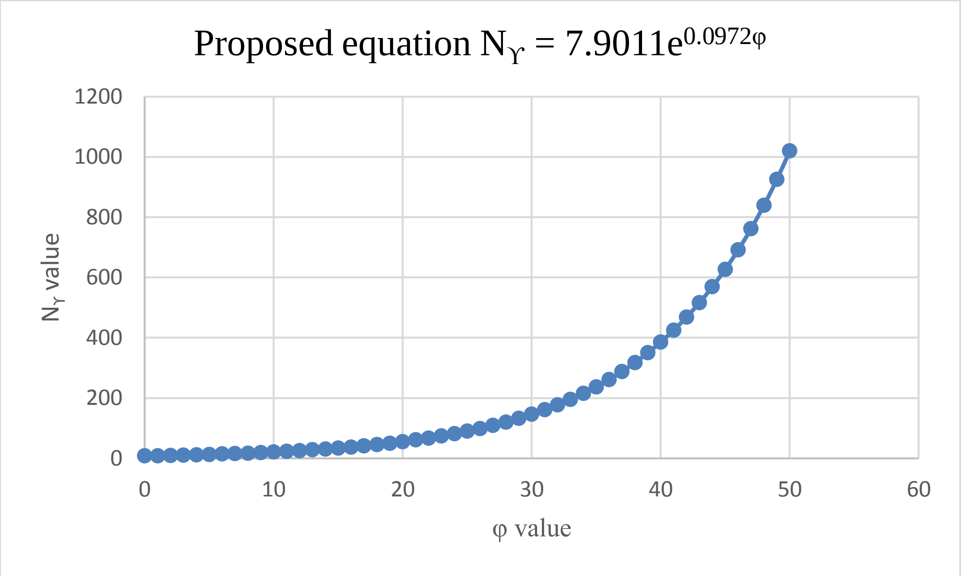


Figure 57 proposed equation

As the result of this test it can be represented that the proposed equation for N_Υ is

Equation 4

$$N\gamma = 7.011e^{0.0972\varphi}$$

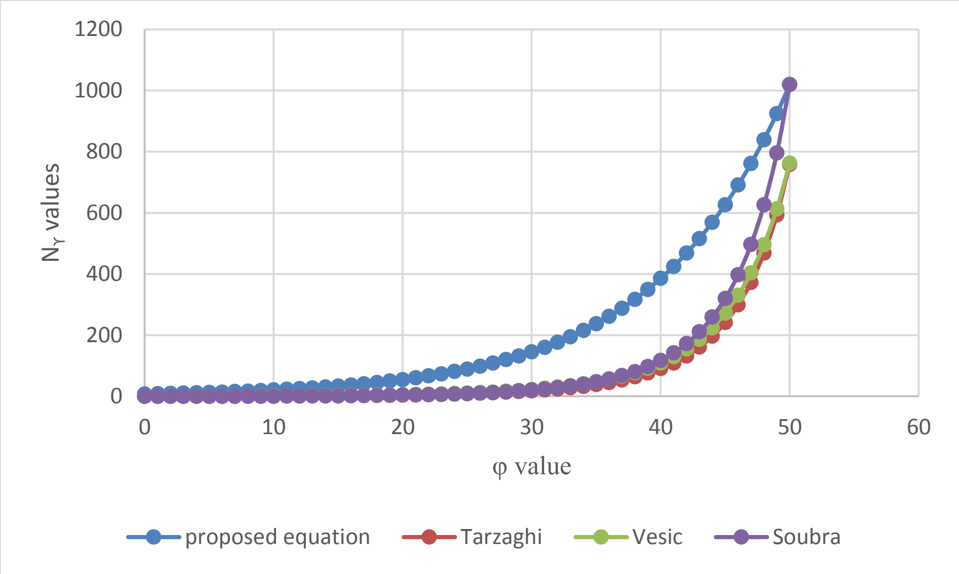


Figure 58 comparison of proposed equation with Terzaghi, Vesic and Soubra

The proposed equation is not a universal equation. It shows the bearing capacity factor N_Υ vary a lot with Terzaghi Vesic and Soubra from $\varphi = 30^{\circ}$ and that is the mix case of two locally available sand. According to this study the proposed equation gives higher values of N_Υ with respect to φ than these three equations. However, at $\varphi = 50^{\circ}$ Soubra's equation coincide with proposed equation.

4.6 Assumptions

- Soil mass is homogeneous and isotropic
- Shear strength is represented by Terzaghi's equation to generate proposed equation.
- Ground surface is horizontal.
- The loading on the model plate is perfectly vertical.
- Soil has same density in all depth.
- Shear failure of model is general shear failure type.

4.7 Variation of data

4.7.1 Variation of N_Υ values of Yamuna sand with proposed equation.

Table 7 Variation of N_Υ values of Yamuna sand with proposed equation.

type of footing	experimental Yamuna sand (N_Υ) based on Terzaghi	experimental Yamuna sand (N_Υ) based on Vesic	experimental Yamuna sand (N_Υ) based on Soubra	proposed value (N_Υ)	variation with Terzaghi (%)	variation with Vesic (%)	variation with Soubra (%)
Square 5cmX5cm	334.214	185.239	333.124	317.539	5.251	-41.664	4.908
Square 8cmX8cm	334.891	283.785	334.214	317.539	5.464	-10.630	5.251
Square 10cmX10cm	361.975	352.444	361.430	317.539	13.994	10.992	13.822
Circular 5cm	273.536		272.082	317.539	-13.858		-14.316
Circular 7.5cm	396.689	223.103	395.720	317.539	24.926	-29.740	24.621
Circular 10cm	362.541	232.103	361.814	317.539	14.172	-26.906	13.943
Rectangular 5cmX7cm	284.936	154.356	284.045	317.539	-10.268	-51.390	-10.548
Rectangular 7.5cmX10.5cm	361.538	231.618	360.945	317.539	13.856	-27.059	13.669
Rectangular 10cmX14cm	379.800	268.638	301.556	317.539	19.607	-15.400	-5.034

Table.7 shows the variation of N_Υ values of Yamuna sand between proposed equation and experimental observations analyzed with Terzaghi, Vesic and Soubra. The analyzes based on Terzaghi and Soubra are within a range of 20% except the case of 7.5cm circular plate test. But the variation with Vesic is very much.

4.7.2 Variation of N_Υ values of Badarpur sand with proposed equation

Table 8 Variation of N_Υ values of Badarpur sand with proposed equation.

type of footing	experimental Yamuna sand based on Terzaghi	experimental Yamuna sand based on Vesic	experimental Yamuna sand based on Soubra	proposed value	variation with Terzaghi	variation with Vesic	variation with Soubra
Square 5cmX5cm	525.715		788.066	761.585	-30.971		3.477
Square 8cmX8cm	469.475	116.602	633.445	761.585	-38.356	-84.690	-16.825
Square 10cmX10cm	441.429	181.08	572.604	761.585	-42.038	-76.223	-24.814
Circular 5cm	563.596		913.395	761.585	-25.997		19.933
Circular 7.5cm	483.518		716.719	761.585	-36.512		-5.891
Circular 10cm	494.004	86.512	668.905	761.585	-35.135	-88.641	-12.169
Rectangular 5cmX7cm	555.998	137.983	744.494	761.585	-26.995	-81.882	-2.244
Rectangular 7.5cmX10.5cm	518.821	269.794	644.477	761.585	-31.876	-64.575	-15.377
Rectangular 10cmX14cm	463.198	291.255	557.437	761.585	-39.180	-61.757	-26.806

Table.8 shows the variation of N_Υ values of Badarpur sand between proposed equation and experimental observations analyzed with Terzaghi, Vesic and Soubra. The analyzes based on Soubra is within a range of 20% except square 10cmX10cm plate and rectangular 10cmX14cm plate. The variation with Terzaghi in this case is much more and it nearly 40%. Proposed equation of this study gives N_Υ values on the higher side. The variation with Vesic in this case is more than 80% in some cases.

Chapter 5

5.1 Conclusion

1. The proposed equation is only applicable for $\varphi > 30^{\circ}$, because the best fitted curves adopted are 4° curve and the average values considered to make the proposed equation taken beyond $\varphi = 30^{\circ}$.

2. The variation of N_Υ values of proposed equation with Vesic is far too much in both the cases of Badarpur and Yamuna sand.

3. The variation of N_Υ values of proposed equation with experimental data analyzed based on Terzaghi and Soubra in case of Yamuna sand is within 15% except the case of 7.5 cm circular footing.

4. The variation curve in exponential form instead of polynomial equation can be achieved if only one experimental data of one type of sand is used and rest are taken from average values of Terzaghi, Vesic and Soubra. In that way we can get one equation for each type of sand. But the variation of results with experimental values are too much. This approach gives far better results than that.

5. The variation of N_Υ values of proposed equation with experimental data analyzed based on Terzaghi in case of Badarpur sand is at an average more than 30%. Terzaghi's equation gives lesser N_Υ values than our proposed equation.

6. The variation of N_Υ values of proposed equation with experimental data analyzed based on Soubra in case of Badarpur sand is within 20% except square plate of 8cmX8cm and rectangular plate of 10cmX14cm.

7. N_Υ values derived from experimental data based on Soubra gives lesser values in maximum case than the proposed equation in case of Badarpur sand.

8. The load settlement curves of Badarpur sand gives a typical two step failure pattern in most cases. The first failure can be observed within a settlement of 5mm. It may be a result of lesser compaction at the surface which leads to local shear failure follows by general shear failure.

9. If the first failure is ignored and a continuous load settlement curve is obtained with some adjustment to the test data, then Badarpur sand gives higher failure load which leads to obtaining higher N_{Υ} values by test results with the analysis of Terzaghi, Vesic and Soubra. Then the range of variation decreases from current observations.

5.2 Abbreviation

sl. No.	notations	meaning
1	Nc, Nq, Nϒ	Bearing capacity factors
2	ϒ	Unit weight of soil
3	ϕ	Angle of internal friction
4	c	Cohesion
5	D10	Percentage finer than 10%
6	D30	Percentage finer than 30%
7	D60	Percentage finer than 60%
8	Cu	Coefficient of uniformity
9	Cc	Coefficient of curvature
10	Q	Ultimate load
11	qu	Ultimate bearing capacity
12	sq 1	5cmX5cm footing plate
13	sq 2	8cmX8cm footing plate
14	sq 3	10cmX10cm footing plate
15	cir 1	5cm circular footing plate
16	cir 2	7.5cm circular footing plate
17	cir 3	10cm circular footing plate
18	ract 1	5cmX7cm footing plate
19	ract 2	7.5cmX10.5cm footing plate
20	ract 3	10cmX14cm footing plate

Chapter 6

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