VALIDATION OF WATER TABLE CORRECTION FACTOR APPLIED TO BEARING CAPACITY OF FOOTING AS RECOMMENDED BY IS 6403, USING FEM BASED SOFTWARE

MAJOR PROJECT REPORT

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

BACHELOR OF TECHNOLOGY

(CIVIL)

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DEPARTMENT OF CIVIL ENGINEERING

GURU NANAK DEV ENGINEERING COLLEGE, LUDHIANA

CERTIFICATE

We hereby certify that the work which is being presented in the major project report entitled "**VALIDATION OF WATER TABLE CORRECTION FACTOR ON BEARING CAPACITY OF FOOTING RECOMMENDED BY IS 6403 USING FEM BASED SOFTWARE**" by "SAURAV SHARMA, SHIVAM KUMAR SINGH, TARANPREET SINGH, TWINKLE DEVI, UJJWAL KUMAR SINGH, VISHAL DAS" in partial fulfilment of requirements for the award of degree of B.Tech. (CIVIL) submitted in the Department of Civil Engineering at GURU NANAK DEV ENGINEERING COLLEGE, LUDHIANA under PUNJAB TECHNICAL UNIVERSITY, KAPURTHALA is an authentic record of my own work carried out during a period from August 2021 to December 2021 under the guidance Dr. PRASHANT GARG. The matter presented in this project report has not been submitted by me in any other University / Institute for the award of any Degree or Diploma.

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CHAPTER - 1

INTRODUCTION

1.1 GENERAL:

Bearing capacity is the capacity of soil to support the loads that are applied to the ground above. It depends primarily on the type of soil, its shear strength and its density. It also depends on the depth of embedment of the load – the deeper it is founded, the greater the bearing capacity. Where there is insufficient bearing capacity, the ground can be improved or alternatively the load can be spread over a larger area such that the applied stress to the soil is reduced to an acceptable value less than the bearing capacity.

1.1.1 METHODOLOGY:-

In this project we are going to validate the water table correction given by IS 6403:1981 using a fem based software called PLAXIS 2D and propose a correction factor if required to normalize the values of bearing capacity of a particular soil at different water table conditions. The method suggested by IS 6403:1981 is going to be used in this project for all manual calculations and all the values of constants will be taken from the same code mentioned above. As for the software based calculations, the PLAXIS 2D software available in the computation laboratory of Civil department in Guru Nanak Dev Engineering college is going to be used. The detailed usage of the above mentioned software is discussed below in Chapter 3. All the tables and graphs are to be done on MS Excel using appropriate formulae. MS Office 2007 is going to be used in this particular project.

1.2 BEARING CAPACITY OF SOIL:-

i. **Ultimate bearing capacity:** the maximum vertical pressure that can be applied to the ground surface, at which point a shear failure mechanism develops in the supporting soil

ii. **Allowable bearing capacity:** this is the ultimate bearing capacity divided by appropriate factors of safety; the factors may be further increased in order to limit settlements in an appropriate way.

1.2.1 HOW TO CALCULATE BEARING CAPACITY:-

There are various methods of calculating bearing capacity, for example:-

- Presumptive Analysis
- Analytical Methods
- Plate Bearing Test
- Penetration Test
- Modern Testing Methods
- Centrifuge Test

Among these an analytical method of calculating bearing capacity of soil provided in IS 6403:1981 is going to be used in this project.

1.3 Overview of IS 6403:1981:-

Three types or failure of soil support beneath the foundations have been recognized, depending upon the deformation associated with the load and the extent of development of failure surface.
They are: a) general shear failure, b) local shear failure and c) punching shear. The choice of which method of analysis is best suited in a given situation is difficult to make, because only limited teat data are available on full sized foundation to verify the reliability of the computed bearing capacity. However guidelines given in relevant clauses may be used for guidance.

1.3.1 Soil with cohesion and angle of shearing resistance:-

The following formulae shall be used for calculate the ultimate net bearing capacity in the case of strip footings:

a. In case of general shear failure, $q_u = cN_c + q(N_q - 1) + \frac{1}{2}B\gamma N_\gamma$
b. In case of local shear failure, $q'_u = cN'_c + q(N'_q - 1) + \frac{1}{2}B\gamma N'_\gamma$

The values of ***Nc, Nq, Nγ, N'c, N'q, N'γ***, are provided in the code.

1.3.2 The ultimate net bearing capacity obtained in 1.3.1 for strip footing shall be modified to take into account, the shape of the footing, inclination of loading, depth of embedment and effect of water table, the modified bearing capacity formulae are given as under:

a. In case of general shear failure,

$$q_u = cN_c s_c d_c i_c + q(N_q - 1)s_q d_q i_q + 0.5\, B\gamma N_\gamma s_\gamma d_\gamma i_\gamma W'$$

b. In case of local shear failure,

$$q'_u = cN'_c s_c d_c i_c + q(N'_q - 1)s_q d_q i_q + 0.5\, B\gamma N'_\gamma s_\gamma d_\gamma i_\gamma W'$$

The values of ***Nc, Nq, Nγ, N'c, N'q, N'γ***, s_q, d_q, i_q, $s_c, d_c, i_c, s_\gamma, d_\gamma, i_\gamma$ are provided in the code.

1.3.3 Effect of water table:-

a) If the water table is likely to permanently remain at or below a depth of (D_f + B) beneath the ground level surrounding the footing then W' = 1.
b) If the water table is located at a depth D_f or likely to rise to the base of the footing or above then the value of W' shall be taken as 0.5.
c) If the water table is likely to permanently got located at depth $D_f < D_w < (D_f + B)$ then the value of W' be obtained by linear interpolation.

This water table correction given by IS 6403:1981 is to be verified using PLAXIS 2D software in this project.

1.4 PLAXIS 2D:-

- PLAXIS 2D is a powerful and user-friendly finite-element package intended for 2D analysis of deformation and stability in geotechnical engineering and rock mechanics.
- PLAXIS is used worldwide by top engineering companies and institutions in the civil and geotechnical engineering industry. Applications range from excavations, embankments, and foundations to tunneling, mining, and reservoir geomechanics.

- PLAXIS is equipped with a broad range of advanced features to model a diverse range of geotechnical problems, all from within a single integrated software package. Simulate various soil and rock behavior such as: dynamics for loading modeling, PlaxFlow for time-dependent groundwater analysis, and Thermal for analysis of heat flow on the hydraulic and mechanical behavior of soil.
- Efficiently create models with a logical geotechnical workflow. Define everything from complex soil profiles or geological cross-sections to structural elements, such as piles, anchors, geotextiles, and prescribed loads and displacements. Import geometry and automatically mesh to create a finite element mesh almost immediately.
- Bentley's geotechnical applications are backed by world-class expertise and used worldwide to support producing safer structures and environments for all. Strengthen your solutions with the digital workflows and trusted computation of PLAXIS.

1.4.1 Basic features of PLAXIS 2D:-

- **Proven 2D Geotechnical Analysis**
  Take advantage of robust and reliable settlement, stress, and safety analysis. For more than 25 years, industry leaders have chosen this software.
- **Comprehensive Soil Material Library**
  Use a comprehensive soil material library of more than 40 materials to accurately model the behavior of anything ranging from soft soil to hard rock.
- **Conduct Dynamic Analysis**
  Perform dynamic analysis to analyze the effects of man-made or natural seismic vibration in soil or structures.

1.4.2 Advantages of PLAXIS 2D:-

1. **A Combination of Methods**
   With PLAXIS, you are able to analyze with state-of-the-art solver and the most accepted FEM and LEM methods backed by dozens of verification studies and constitutive models. With Bentley geotechnical software you can handle common and complex geotechnical analysis of soil or rock slopes using either the limit equilibrium

method (LEM) or the finite element method (FEM). Three-dimensional LEM analysis allows you to solve directly for the safety factor of a trial slip surface, until you find the critical one.

For instance, PLAXIS includes many advanced material models besides standard models like the linear elastic – ideal plastic model with Mohr-Coulomb failure criterion. The advanced material models involve specific features such as stress-dependency of stiffness, strain-hardening / softening, memory of pre-consolidation, critical state, anisotropy, creep, swelling and shrinkage. With those advanced models, users are able to simulate the behaviour of soils and rocks more realistically and get more accurate results from their calculations.

2. **Digital Workflows**

   PLAXIS is developed with your geotechnical challenges in mind, so you will work confidently at each stage of your geotechnical analysis project.

   - **Soil and Calibration Geometry** - Access a logical geotechnical workflow and user-friendly graphical user interface to facilitate fast and efficient model creation.
   - **Analysis Calculation** - Calculate with confidence by accessing various trusted methods and provide realistic assessment of stresses, forces, and displacements in soil and structures.
   - **Results Output** - Leverage powerful and versatile post-processing and display forces, displacements, stresses, and flow data in contour, vector, and iso-surface plots in various ways.

3. **Solutions -** Next to the basic 2D and 3D PLAXIS version, users can utilize PLAXIS world-class set of modules to address offshore, groundwater flow, temperature effects and effects of seismic vibrations.
4. **Advanced Expertise** - Bentley's thought leadership team continually advances applications with valuable expertise and knowledge. You will find tons of tips and tricks, knowledge base and technical discussions at Bentley Communities.
5. **Interoperability** - PLAXIS can integrate with many Bentley applications including ProjectWise and STAAD to produce flexible results. Here is an example. Engineers can now design and analyze deep foundations and apply results post-processing and evaluate relevance for STAAD - Pro, thanks to the interoperability between STAAD-Pro and PLAXIS 3D through ISM technology.

1.5 OBJECTIVES:-

- To determine the bearing capacity of soil for Strip footing by varying water table position using IS code and PLAXIS 2D.
- To compare the results of water table correction factors, as calculated using IS code and PLAXIS 2D.
- To find out the relationship between water table correction factor with width of footing and depth of water table.

CHAPTER - 2

ANALYTICAL STUDIES

GENERAL:

The bearing capacity of soil depends upon many parameters as soil properties, size of footing, shape of footing and position of water table. The angle of load applied also effect the bearing capacity of soil. As per Indian Standard, three components are considered to determine the bearing capacity. The footing is considered at the top of soil so that overburden pressure may be zero. Soil is also taken as sandy soil so that bearing capacity due to cohesion may be neglected. The following parameters are taken for the present study.

2.1 SOIL PROPERTIES:-

Type – Sand

Unit weight, γ = 18 kN\m^3

Cohesion index, C = 0

Angle of fiction, ϕ = 30°

2.2 PROPERTIES OF FOOTING:-

Type – strip footing

Length, B = 6 m

Depth, D_f = 0 to 12 m with increment of 0.5m

2.3 CALCULATIONS:-

For, ϕ = 30°,

Table 2.1 Values of constants

	N	**S**	**d**	**i**
c	30.14	1.0	1.69	0
q	18.40	1.0	1.0	0
γ	22.40	1.0	1.0	4

All data given in table 2.1 has been collected from IS 6403:1981.

2.3.1 CALCULATING BEARING CAPACITY:-

The formula mentioned in section 1.3.2 is going to be used for farther calculations.

$$\boldsymbol{q_{nu} = cN_c s_c d_c i_c + \gamma D_f (N_q - 1) s_q d_q i_q + 0.5\, B\gamma N_\gamma s_\gamma d_\gamma i_\gamma W'}$$

Since, i_c and i_q are equal to 0 the effective part of the above equation remains as follows:-

$$q_u = 0.5\, B\gamma N_\gamma s_\gamma d_\gamma i_\gamma W'$$

$$q_u = 0.5 * 6 * 18 * 22.4 * 1 * 1 * 4 * W'$$

$$q_u = 4838.4 * W'$$

For, D_w = 0.5 m

W' = 0.5 + (0.5*0.5)/6 = 0.54

$$q_u = 4838.4 * 0.54 = 2613\ kNm^{-2}$$

Similarly for, different depths of water table, the values of bearing capacity has been tabulated below in table 2.2

Table 2.2: Bearing Capacity and water correction factor

Depth of water table D_w(m)	**W'**	**q_{nu} (kN\m^2)**
0.5	0.54	2613.17
1	0.583	2820.78
1.5	0.625	3024
2	0.66	3193.79
3	0.75	3628.79
4	0.83	4015.86
5	0.92	4451.32
6	1	4838.4
7	1	4838.4

8	1	4838.4
9	1	4838.4
10	1	4838.4
11	1	4838.4
12	1	4838.4

The Fig. 2.1 shows, change in q_{nu} with respect to the depth of the water table. It is observed that bearing capacity of soil increases with the increase in depth of water table i.e. as water table goes down; bearing capacity of soil decreases linearly up to the width of footing and beyond the depth of footing from bottom of footing, water has no effect on bearing capacity.

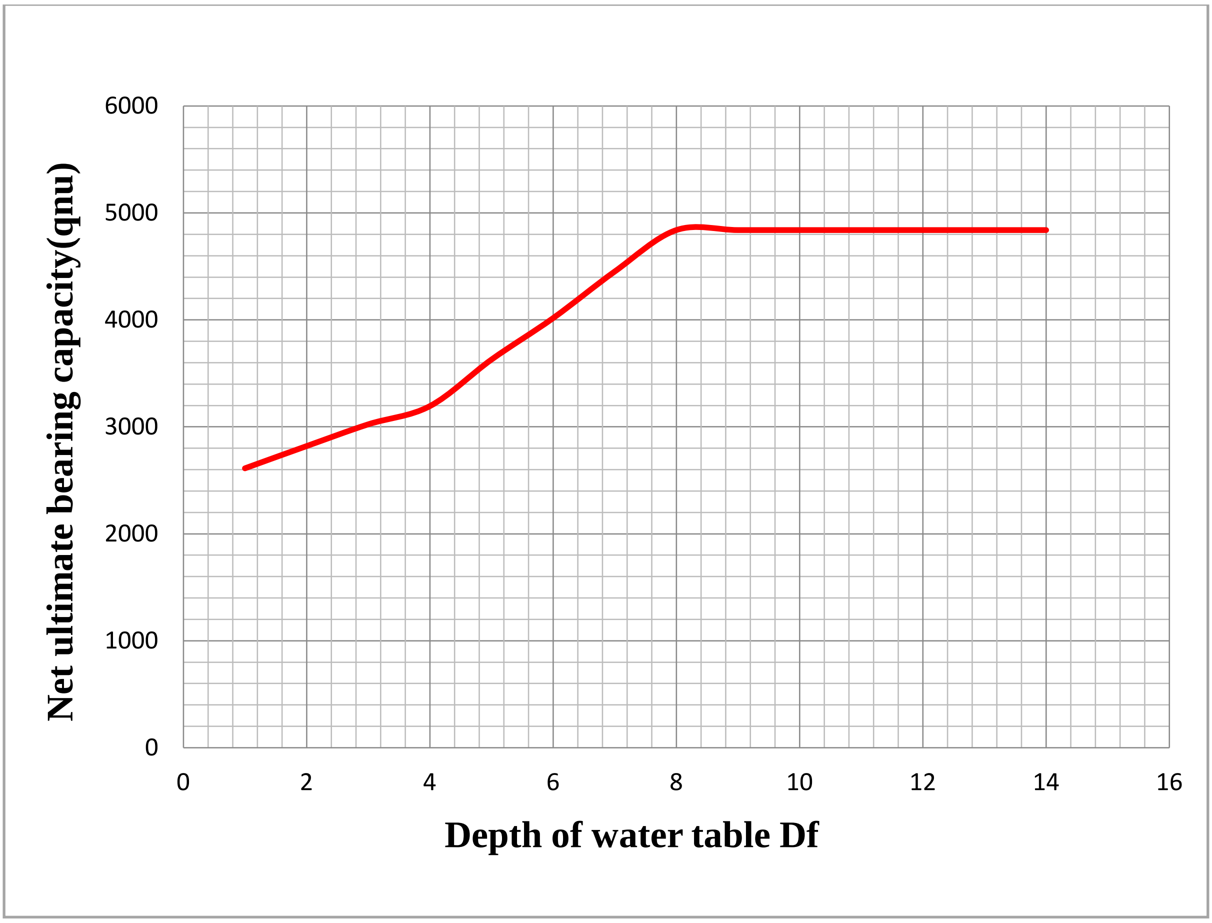

Fig. 2.1 Change in net ultimate bearing capacity with respect to depth of water table

CHAPTER 3

NUMERICAL STUDY

3.0 GENERAL:

PLAXIS is finite Element method based software specifically used for Geotechnical problems. Real world problems may be simulated in Plaxis 2D and results may be obtained with a satisfactory level of tolerance. The software is validated many times with the experimental results by many researchers. The software is also used in to analyze many complex problems as Foundation (Pile raft) of Burj Khalifa, Dubai is also analyzed using Plaxis 3D. In present study, Plaxis 2D is used. A strip footing with footing width as 5m is taken for study so that Plain strain condition may prevail. Model of strip footing on sand is created in Plaxis and Plastic analysis is performed. The step by step procedure of analysis is described as below.

3.1 SETTING UP THE PROJECT:-

1. Selecting the new project options a new project has been created.

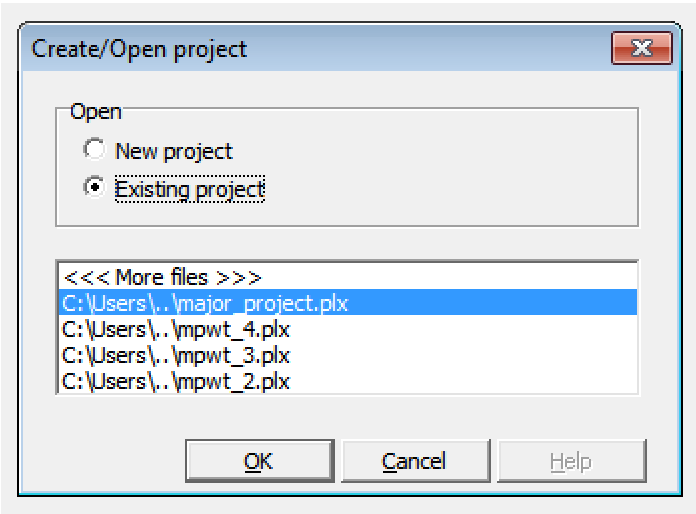

Fig. 3.1 Create a project

2. Then in the general settings option in the project tab the title of the project has been set to **”major_project”** (as per convenience) in the project section.
3. In the general section model has been set to plain strain and elements to 15 – Node.

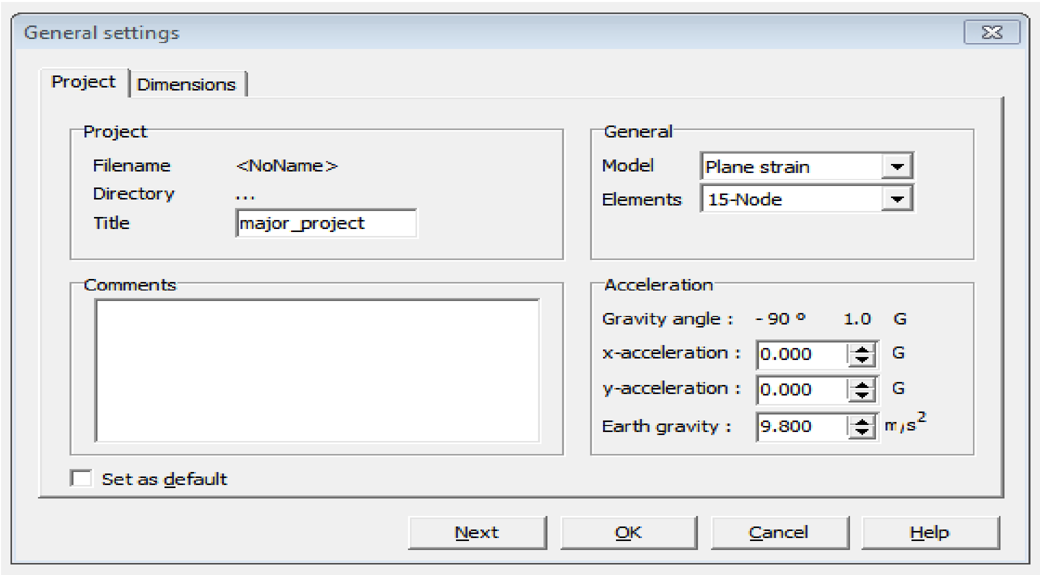

Fig. 3.2 Project settings

4. The others are selected by default.
5. In the dimensions tab the units has been set to SI units and time was set to day.
6. And the other details can be seen in Fig. 3.3.

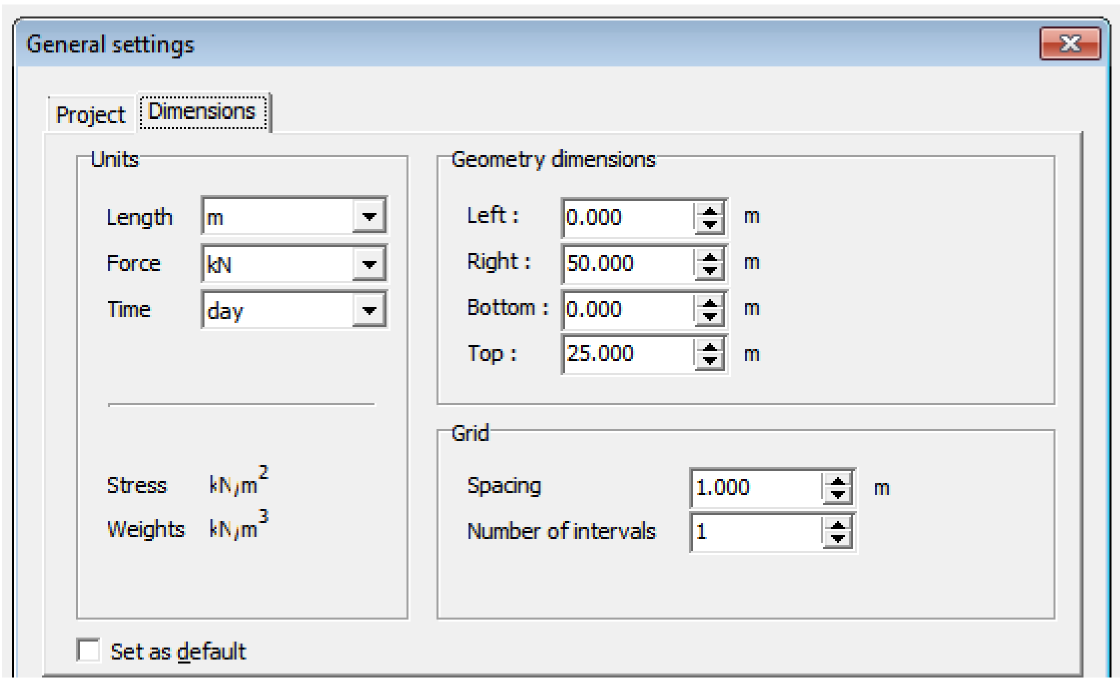

Fig. 3.3 Dimensions

7. Then the material was set to sand with Identification – lesson 1 – sand, Material model – Mohr – Coulomb and Material type – Drained in the material set section.
8. In general properties section $\gamma_{\mathbf{unsat}}$ and $\gamma_{\mathbf{sat}}$ has been set to 18 kN/m^3 and 20 kN/m^3 respectively.
9. Permeability is set by default as shown in the Fig. 3.4.

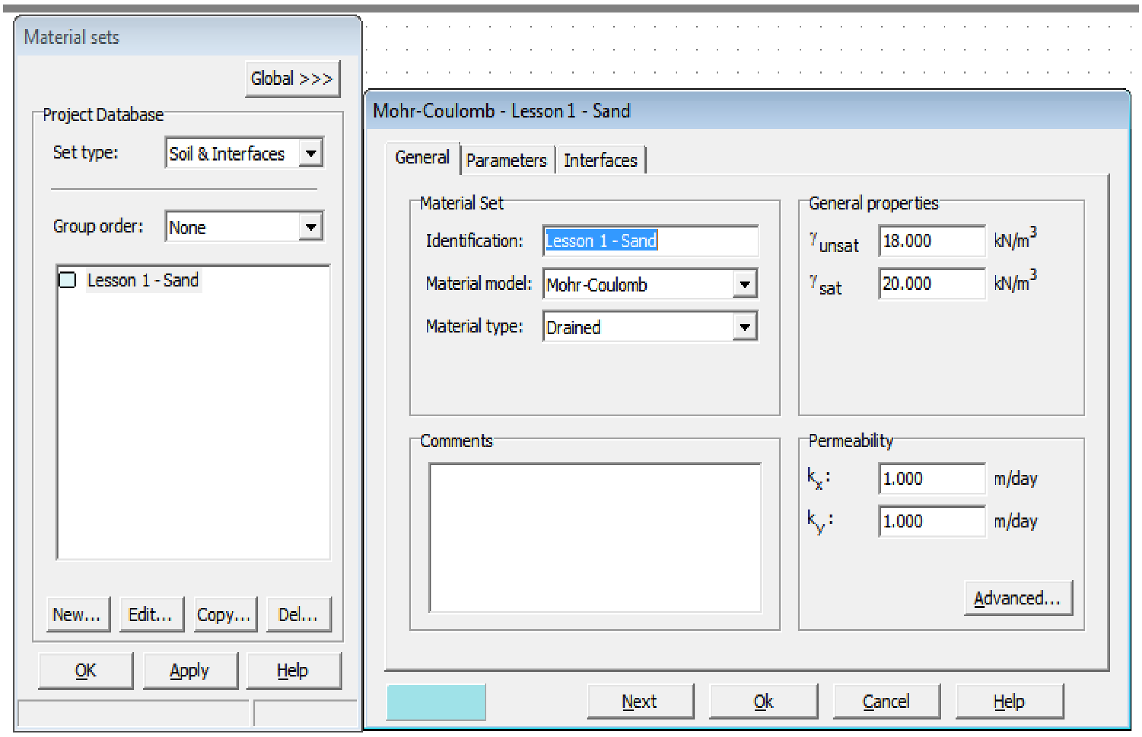

Fig. 3.4 General settings

10. In the parameters tab Modulus of elasticity has been set to 1.3 * 10^4 kN/m^2, Poisson's ratio (ν) to 0.3 and ϕ to 30. And the rest are calculated according to our inputs.

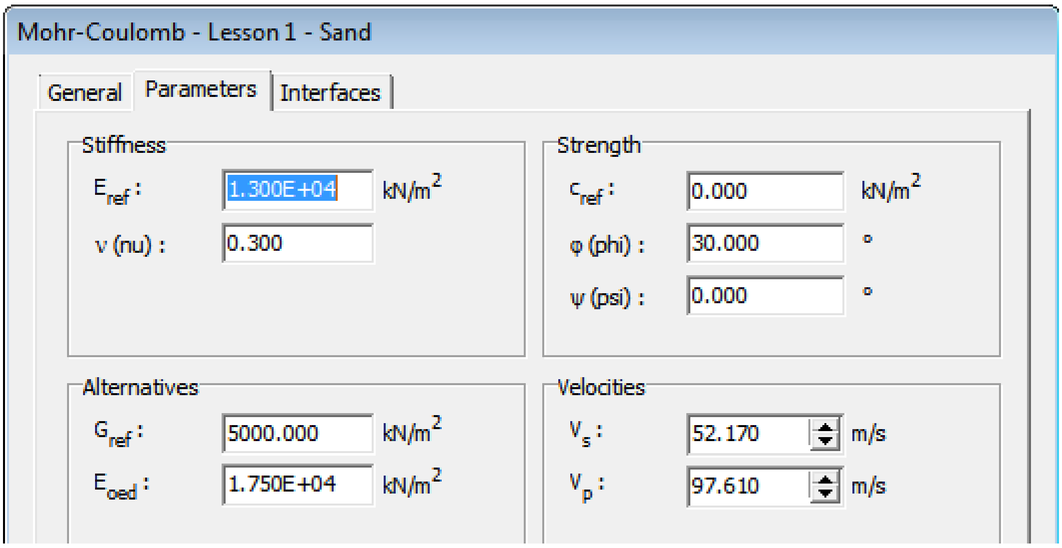

Fig. 3.5 Parameters

3.2 CREATING THE MODEL:-

1. A 45 m wide and 15 m high soil model was created this particular soil is to be analyzed by the software during calculations.
2. Upon that a 6 m bearing plate was constructed right in the middle as shown in fig. 3.6.

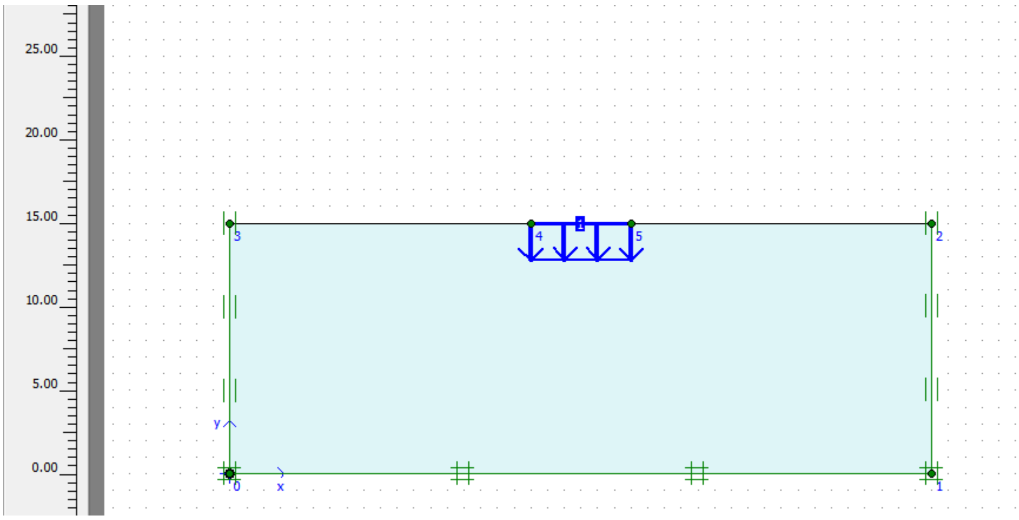

Fig. 3.6 The model

3. Then after selecting the whole model the **"MESH"** tool was used to create a mesh which is the root of computations in these types of software, i.e. shown in fig. 3.7 below.

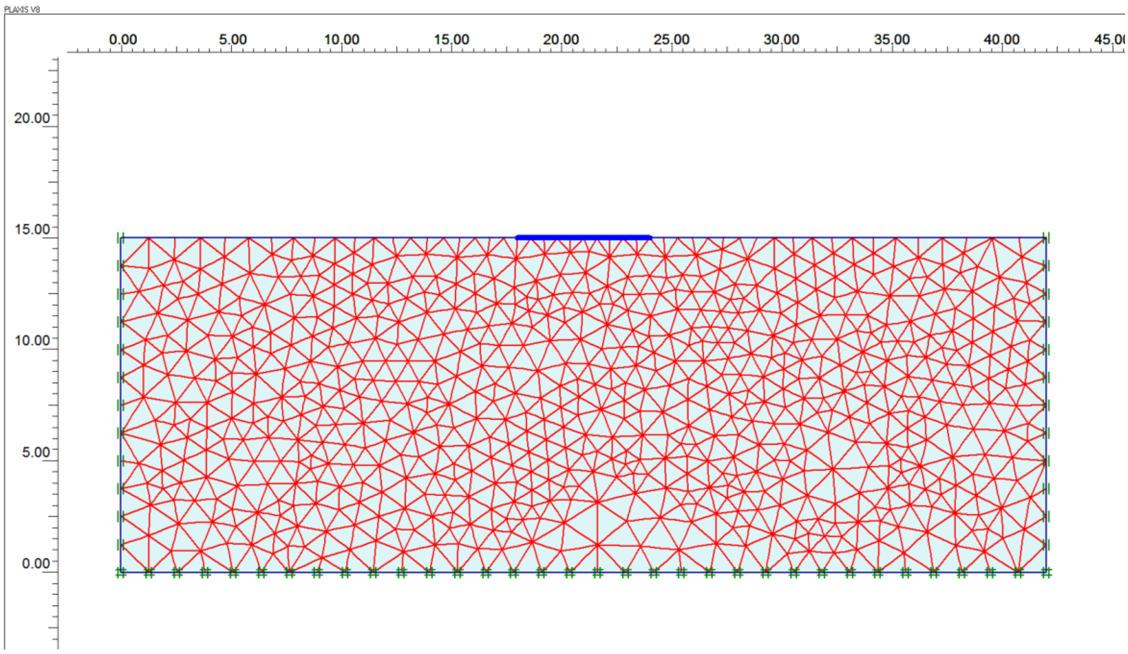

Fig.3.7 Mesh before deformation

3.3 CALCULATIONS

1. In the calculations tab calculation type selected as plastic the rest was by default.

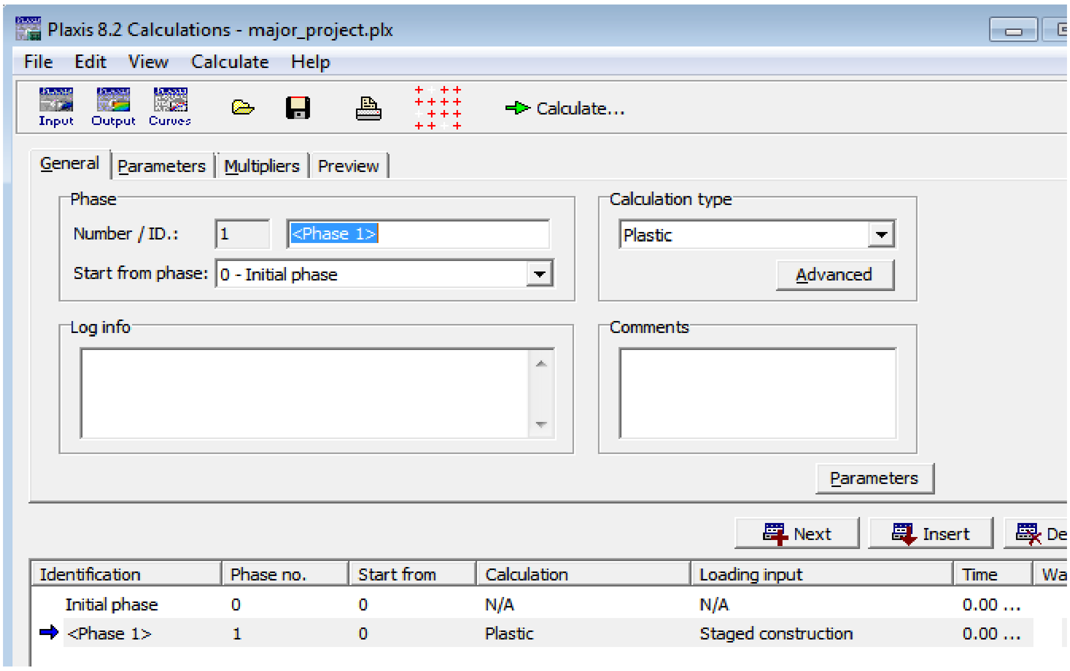

Fig.3.8 Calculations panel

2. In the parameter tab additional step was raised up to 400 for better results and the rest was default.
3. Then the calculate button was clicked on.
4. The below fig. shows on going calculations.

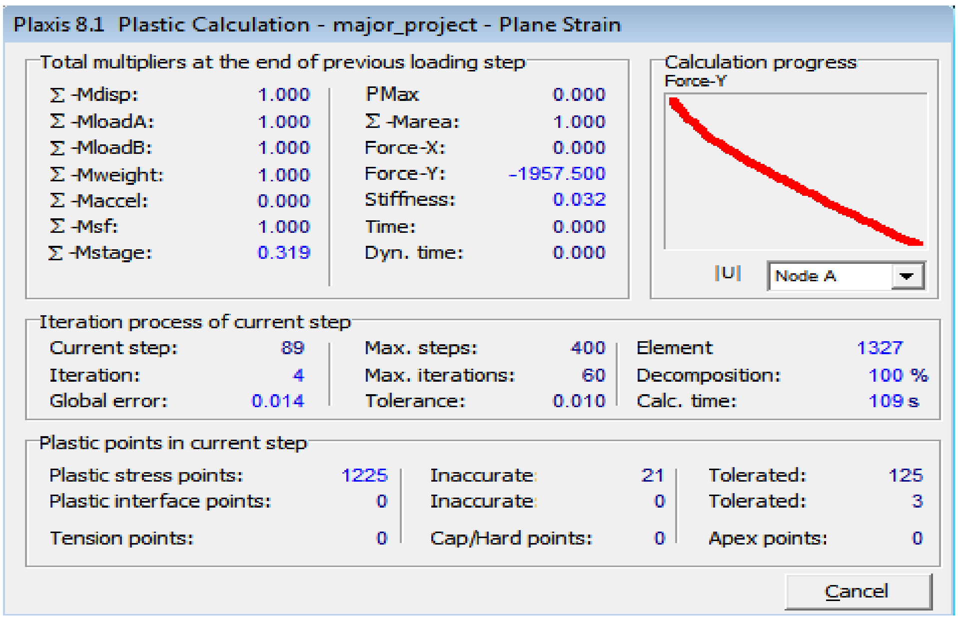

Fig.3.9 Ongoing calculations

3.4 RESULTS

1. The limit of displacement was set to 1 m so the simulation would terminate as soon as the displacement reaches 1 m.
2. The actual displacement shown by the simulation is shown in fig. 3.10.
3. **Viewing output results**

   The outcomes of the computation procedure may be seen in the Output programme once it has been completed. The stresses and displacements in the whole geometry as well as any cross section of the model, if appropriate, may be shown in the output window. An individual may look after the deformed mesh at the conclusion of the designated calculation procedure in the output module, which includes a display of the maximum displacement at the lower end. Similarly, choosing total displacements from the Deformation option will display total displacements of all nodes as arrows with a relative magnitude indicator. Selecting shadings in the same box will display colour shadings of total displacements. In addition, at the colour borders, an index with the displacement values is displayed. Contours can be selected from a box in the toolbar plot, which displays contour lines of total displacements. The Deformations option also provides for the depiction of incremental displacements in addition to overall displacements. These displacements aid in the visualisation of a potential failure mechanism.

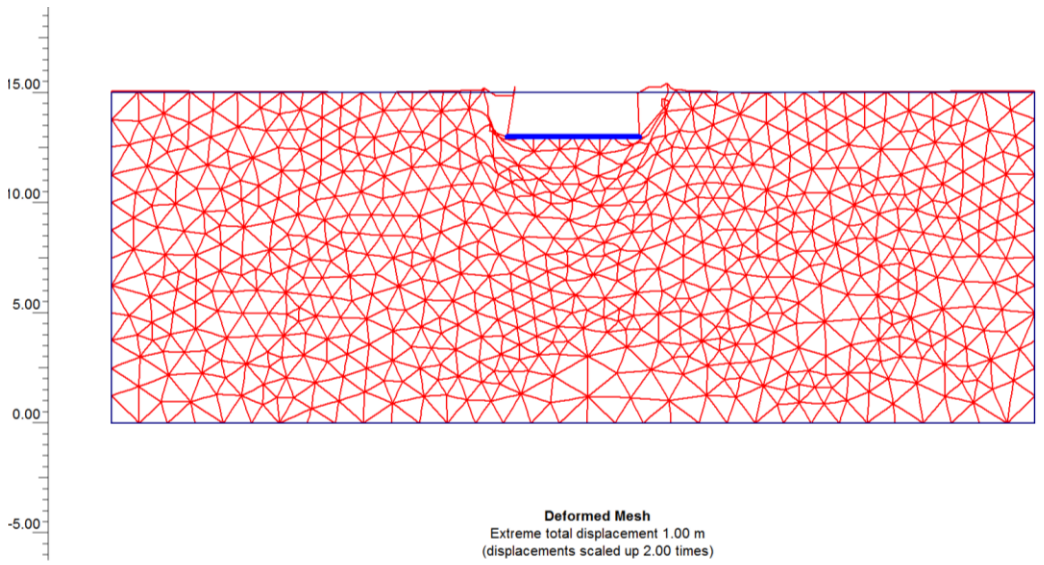

Fig. 3.10 Deformed mesh

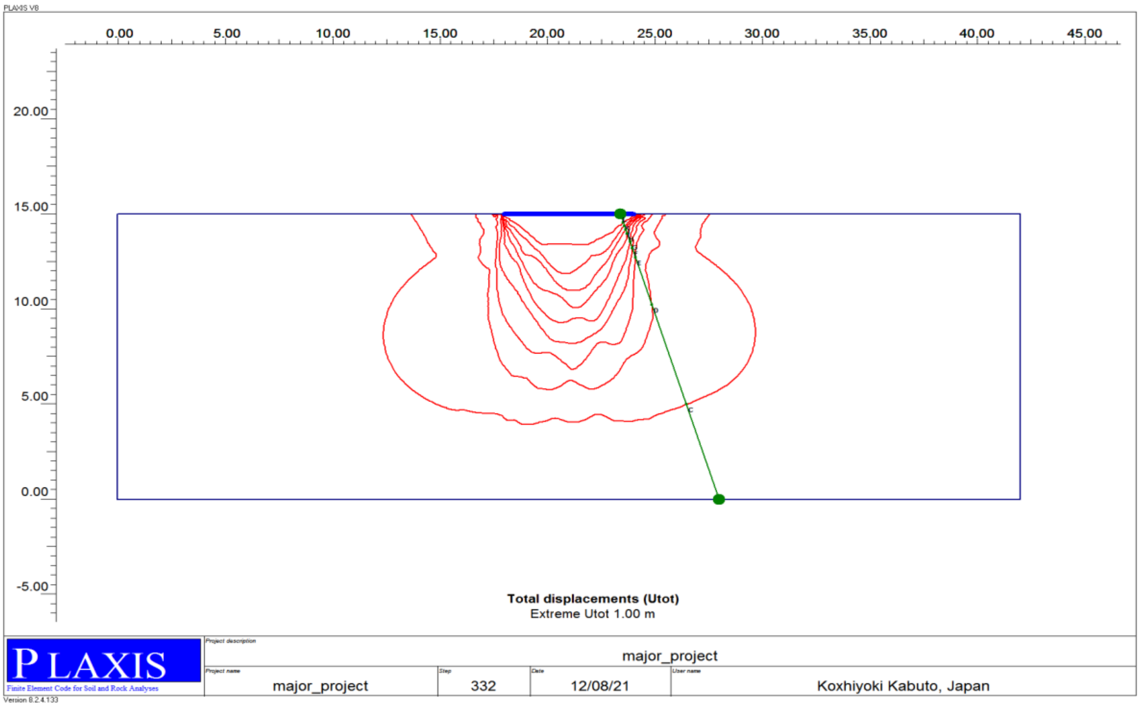

Fig. 3.11 Contour lines of total displacement

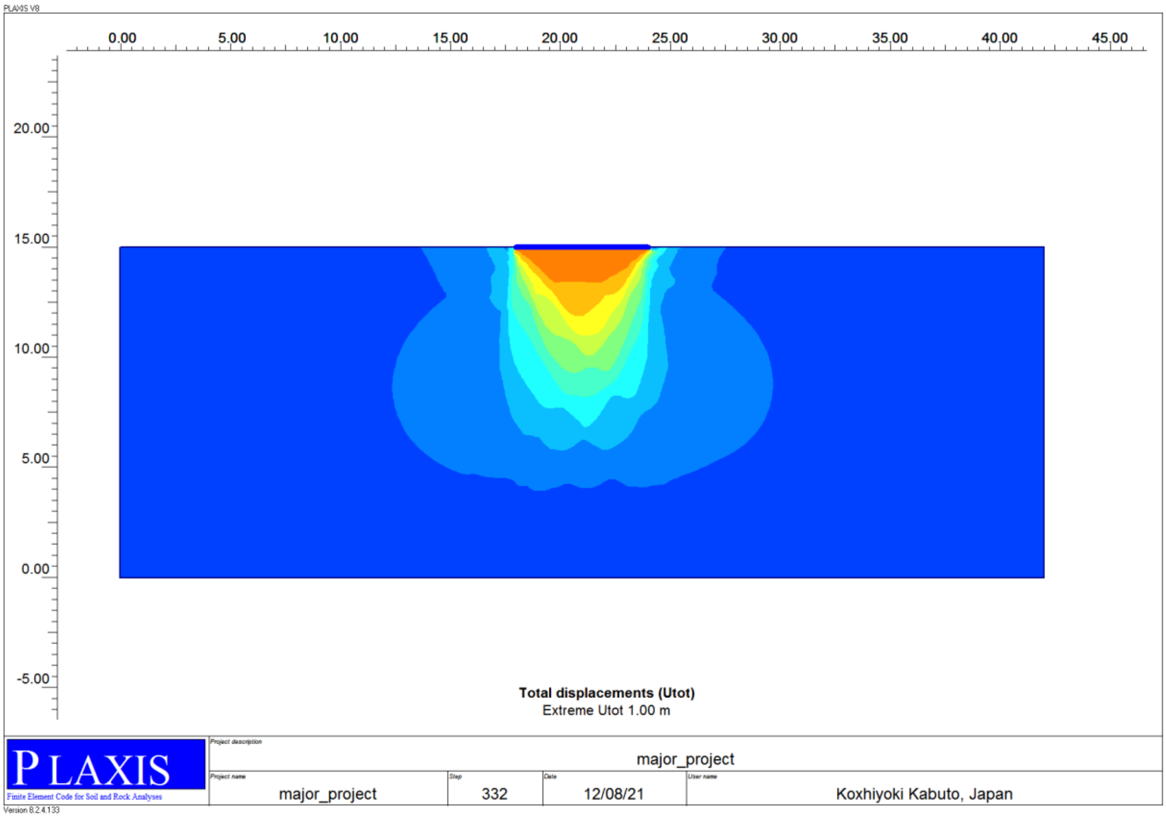

Fig. 3.12 mean shading of total displacement

4. Curve generation

Curve generation is a step on which our study results rely. While generating the curve, individuals have to make a choice between X-Y scatter. On the X axis one can choose displacement, velocity, multiplier, pore pressure and many more. In the same way on the Y axis displacement, multiplier, force etc can be chosen as shown in fig. 4.1. Also the curve can be inverted as per the requirement. In our current work, graphs with an inverted axis are used. To construct a curve, we should select a node for which we want displacement data, or stress points. Now to construct the load displacement curve in our present study choose force and displacement as shown in the dialog box below.

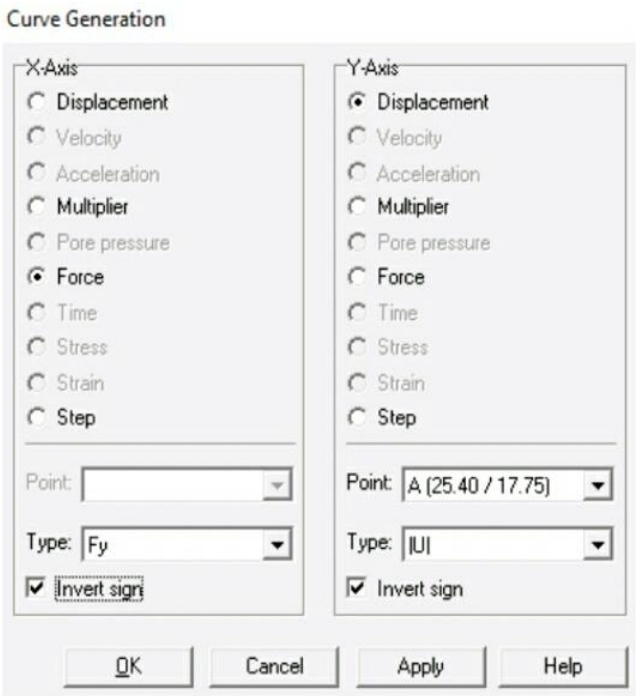

Fig. 3.13 Curve generation dialog box

5. All the load settlement curves (displacement vs. load in kN) are given below.

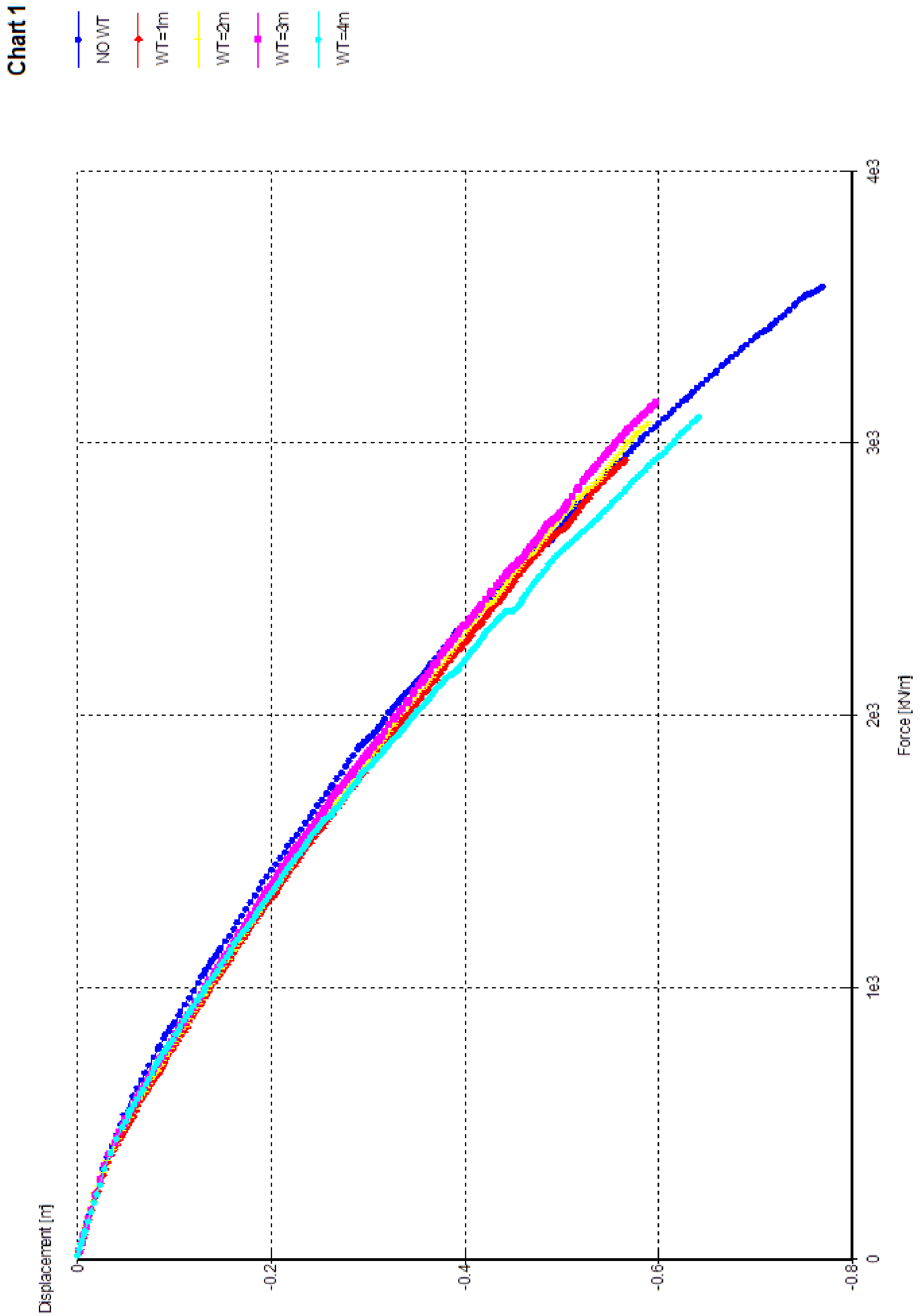

Fig. 3.14 Load settlement curve for $D_w = 0 - 4m$

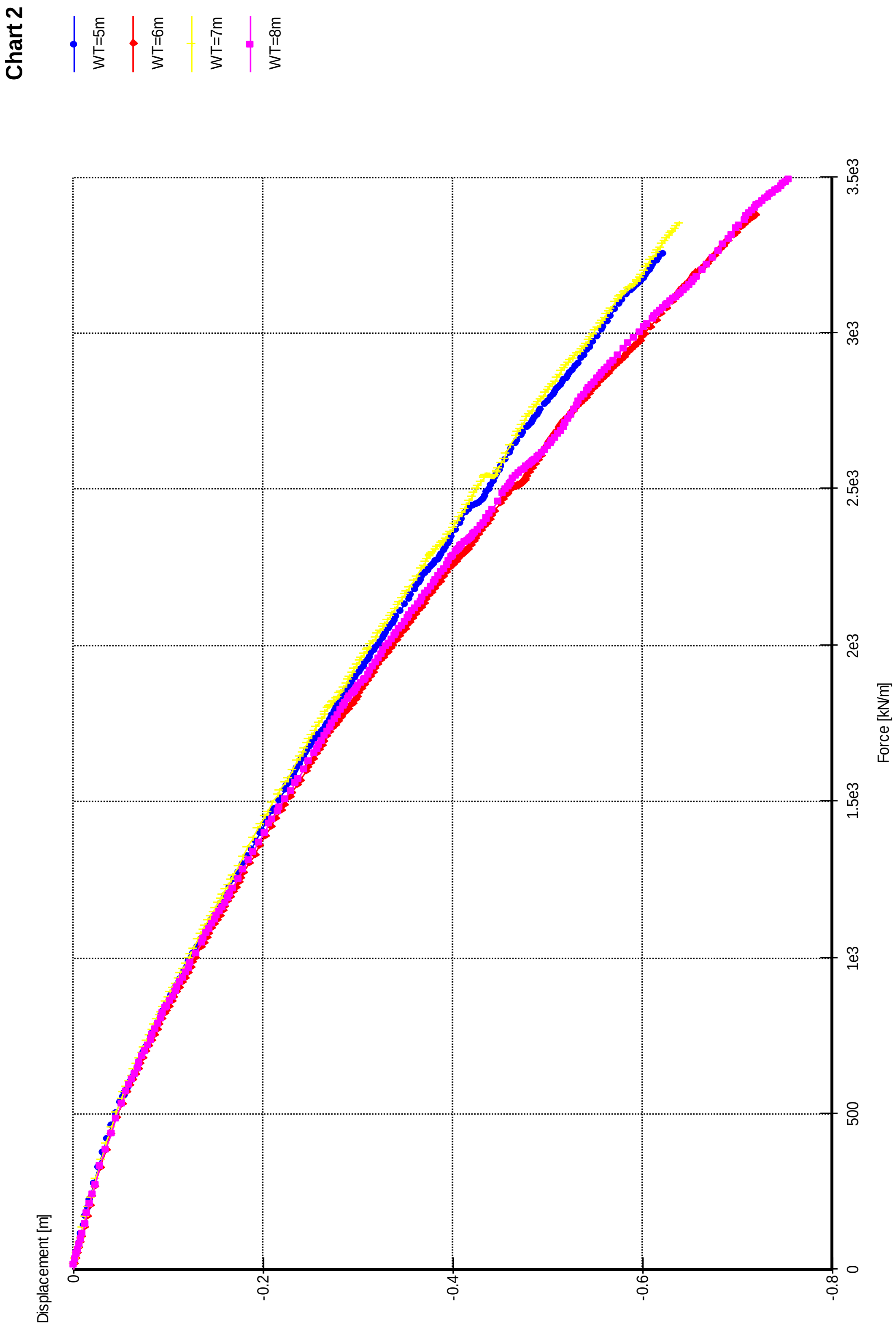

Fig. 3.15 Load settlement curve for $D_w = 5 – 8m$

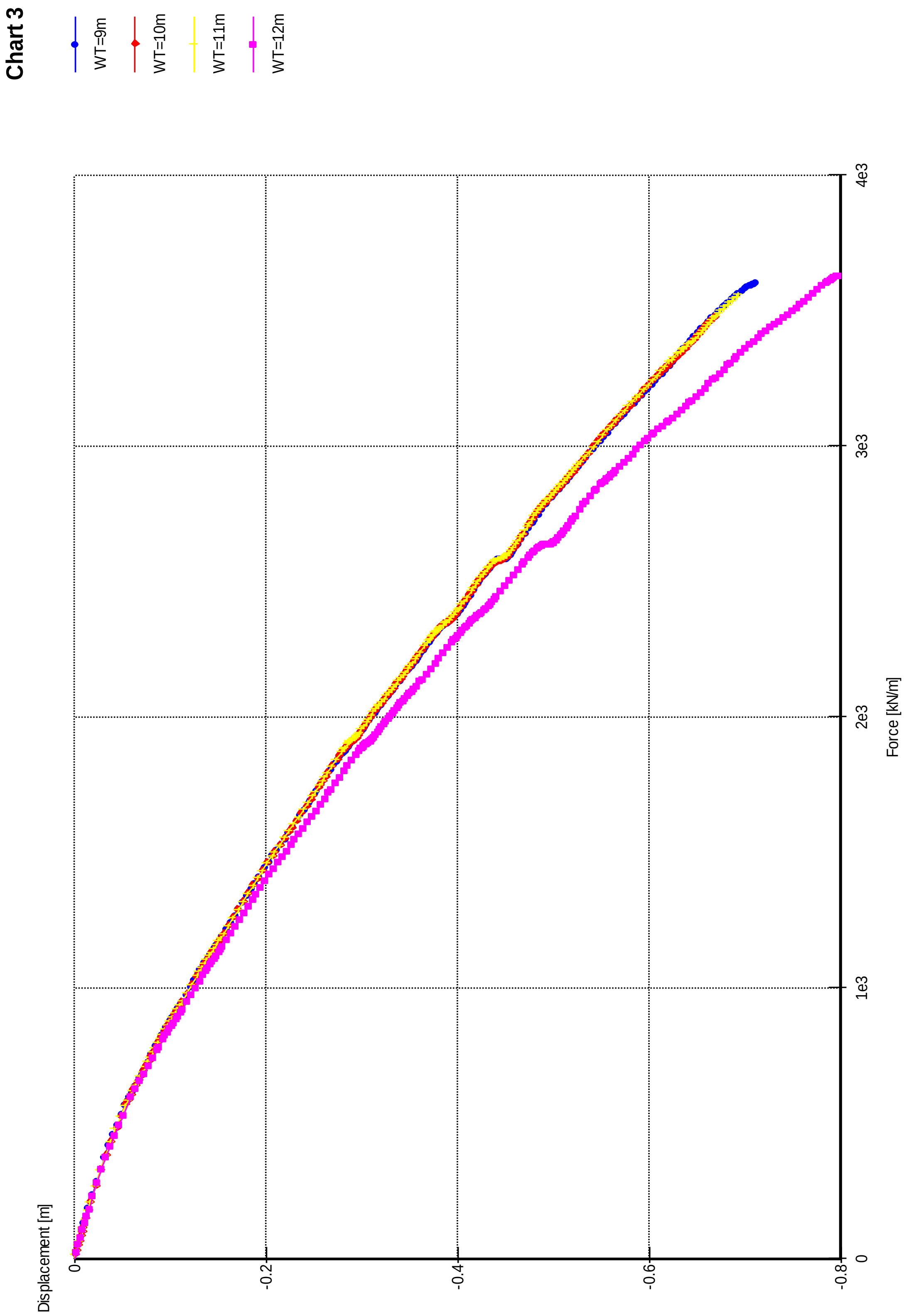

Fig. 3.16 Load settlement curve for $D_w = 9 - 12$m

CHAPTER 4

RESULT AND DISCUSSION

4.0 GENERAL:

The bearing capacity of soil for strip footing resting on the top of sandy soil is determined by varying water table depth. The depth of water table is varied from bottom of footing to two times of footing width. All soil and footing parameters are kept constant. The bearing capacity is calculated at different position of water table. The results are listed below.

4.2 BEARING CAPACITY:

The bearing capacity of sandy soil for strip footing is tabulated in table 4.1. It is observed that bearing capacity go on increasing as water table goes down in both cases. The similar findings are observed when BC is calculated by Plaxis. As per Indian Standard, Bearing capacity increases up to a depth equal to width of footing and beyond this there is no effect of water table on bearing capacity. As per Plaxis, Bearing capacity increases if water tables goes down up to a depth of 1.5 times the width of footing. After 1.5 B, the depth of water table has no effect on bearing capacity.

Table 4.1: Results of Bearing Capacity using IS Code & Plaxis

dw (m)	w	Analytical q_{nu} (kN/sq m	Plaxis q'_{nu}	w'(water Correction factor) Plaxis	w'(water Correction factor) IS code	1 + dw/B	% error
0.5	0.54	2613.17	2840	0.554688	0.540	1.083	8.680262
1.0	0.583	2820.78	3150	0.615234	0.583	1.167	11.67124
1.5	0.625	3024	3260	0.636719	0.625	1.250	7.804233
2.0	0.66	3193.34	3510	0.685547	0.660	1.333	9.916263
3.0	0.75	3628.79	3840	0.75	0.750	1.500	5.820397
4.0	0.83	4015.86	4330	0.845703	0.830	1.667	7.822484
5.0	0.92	4451.86	4830	0.943359	0.920	1.833	8.493978
6.0	1.0	4838.4	5000	0.976563	1	2.000	3.339947
7.0	1.0	4838.4	5030	0.982422	1	2.167	3.959987
8.0	1.0	4838.4	5060	0.988281	1	2.333	4.580026
9.0	1.0	4838.4	5100	0.996094	1	2.500	5.406746
10.0	1.0	4838.4	5120	1	1	2.667	5.820106
11.0	1.0	4838.4	5120	1	1	2.833	5.820106
12.0	1.0	4838.4	5120	1	1	3.000	5.820106

The Variation of Bearing capacity with depth of water table is also represented in fig 4.1. It is also observed that Plaxis 2D over estimate the bearing Capacity as compared to calculated using Indian standard at all position of water table. But the % error is up to 11.6% which is within 15% and shows a good compatibility.

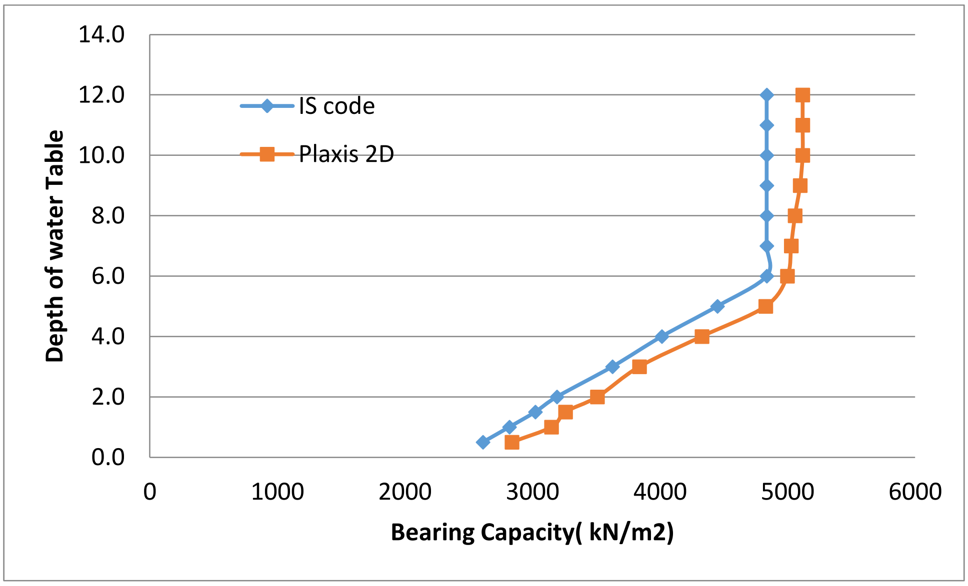

Fig: 4.1: Bearing Capacity with depth of water table

4.3 WATER CORRECTION FACTOR:

Water correction factor is calculated using IS 6402 and Plaxis 2D. Water correction factor is minimum i.e.0.5 when water table touches the footing and it increases as water table goes down, It became 1 if water table goes down to a depth of B from bottom of footing. Similar trend is observed in the value of water table correction factor when calculated with Plaxis. The only difference is the It become one after a depth of 1.5B from the bottom of footing.

4.4 WATER CORRECTION FACTOR RELATION WITH DEPTH OF WT:

The variation of water table correction factor with depth of water table and footing width ($1+d_w/D$) is shown in Fig 4.2. It is observed that water table correction factor increases with increase in depth of water table. It is also observed that the slope of water correction with depth of water changes at a depth of B and 1.5B. Therefore the linear relation was found as below

For $d_w \leq B$

$$W' = 0.506(1+d_w/D_f)$$

If $B<d_w\leq 1,5B$

$$W' = 0.041(1+d_w/D_f)+0.89$$

If $d_w> 1.5B$

$$W'=1$$

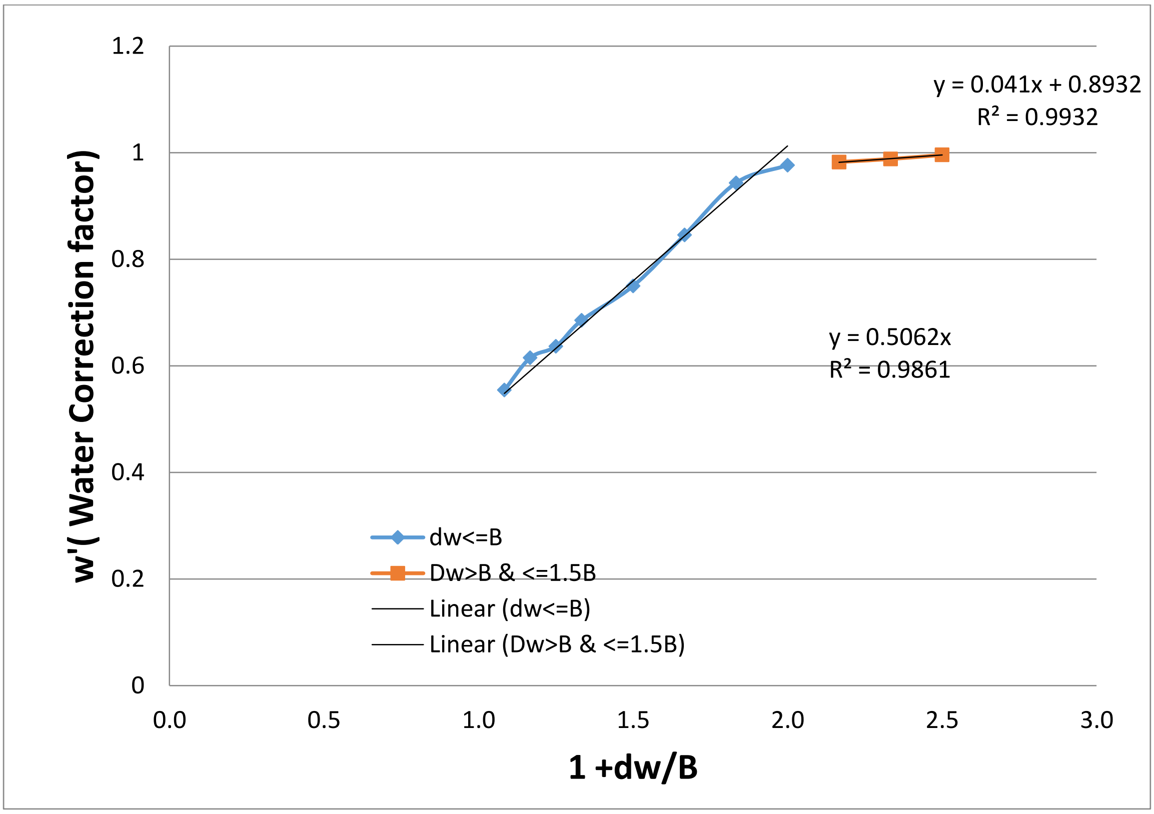

Fig: 4.2: water correction variation with depth (Plaxis)

The water correction factor as calculated using PLAXIS 2D has a small variation with respect to Indian Standard.

CHAPTER 5

CONCLUSION

The aim of present study is to check if the relation of water correction factor with depth of water table is same as recommended by Indian Standard and that of calculated with Plaxis 2D. If it differs, the aim is to develop a new modified relation of water correction factor with depth of water table in terms of width of footing. The minor differences are observed and new relationship is developed. The following conclusions are drawn from the present study with limitation of study.

1 Bearing capacity of soil for strip footing is calculated and similar trends are observed from both of method. Bearing capacity increases in both cases with water table depth. The results from Plaxis is over estimated but within a limit of 12%. It is concluded that Plaxis may be used with a good accuracy to determine the bearing capacity of soil.

2 Water correction factor as calculated using Plaxis has a small variation with respect to that of Indian Standard. As per IS code water correction factor varies upto a depth equal to width of footing while As calculated using Plaxis, Water correction factor varies upto a depth equal to 1,5 times of footing width.

3 A relationship between water table correction factor with depth of water table and width is developed as below:

For $d_w \leq B$

$$W' = 0.506(1+d_w/D_f)$$

If $B<d_w\leq 1,5B$

$$W' = 0.041(1+d_w/D_f)+0.89$$

If $d_w > 1.5B$

$$W'=1$$

LIMITATIONS:

- The study is carried out only on fixed parameter of soil. The properties of soil are kept constant.
- The study is limited to strip footing only.

FUTURE SCOPE:

1 The study should be carried out on the different soil.

2 The study should also be expended by varying parameters of soil.

3 The shape and size of footing should also be varied to find the relation of water correction factor with width of footing.

4 Experimental study may also be carried out to validate the result obtained by PLAXIS.

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