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Relationship between Depths of Bore Hole in a Site Investigation and Various Parameters

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Abstract: **Geotechnical investigation for a project is highly subjective. The spacing of borehole and depth of borehole depends on nature of project and loads transferred on to substratum. However the criterion of investigating a site to the depth where the increase in vertical stress due to footing is equal to 10% of the existing overburden pressure is well accepted among the geotechnical investigators. As per the criteria the minimum depth of bore hole for investigation varies with footing and soil characteristics. This paper examines and establishes the nature of relationship between D, depth of bore hole and those characteristics.**

I. INTRODUCTION

Geotechnical investigation is the most crucial part of any civil engineering project. The whole design of the project, selection of construction methods, sequence of construction execution pace and procedure largely depends on the outcome of soil investigation. In spite of this significance of the geotechnical investigation it is rarely attributed with its due importance in any civil engineering project. The reasons for this are mainly the complexity involved with soil stratums and largely uniform behavior of soils over small site covered by large number of medium size civil engineering projects.

There are various rationale decisions a Geotechnical investigator has to make, at the beginning and during the course of site investigation, to make the outcome of investigation: truly representative of the soil characteristics of the site, useful for rational design of the project and substantive to rely upon. The extent of geotechnical investigation, as widely acknowledged, depends on both the nature & size of the project and nature (type) of soil available at the site. As such a geotechnical investigation cannot be planned fully before actually carrying out some part of it, because nature of soil is not known before starting the investigation.

Normally a geotechnical investigator arrives at the site for investigation at least with a spacing of borehole and depth of borehole in mind. He can decide about the spacing of boreholes and depth of borehole, both however tentative, based on the nature of the project. The literature available to decide about spacing of borehole for project suggests the decision would be a subjective one, as every recommendation is a range rather than a discreet value. Our knowledge of geotechnical engineering also suggests that it couldn't be otherwise. But about deciding the depth of borehole there is unanimity about the criteria to be used.

II. DEPTH OF INVESTIGATION BORE HOLE

There is concurrence among geotechnical engineers about the criteria that the investigation boreholes should be taken up to a minimum depth where the increase in vertical stress due external load (footing, traffic etc) is not greater than 10% of the overburden pressure. This criterion is treated by the geotechnical engineering community as even conservative.

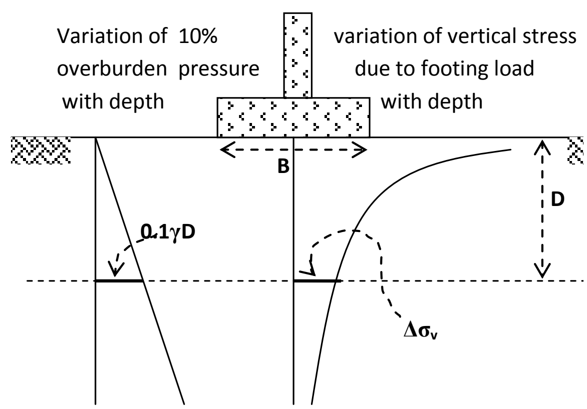


Fig.No.1. Illustration of concept of depth of investigation borehole

The pressure bulb which is the soil inside a bulb of isobar of 0.2q for any footing transferring a pressure intensity of q on to soil having a width of B extends up to a depth of 3B. This depth is considered as significant depth in the sense, the characteristics of soil with in this bulb determines the performance, both from settlement and shear failure criteria, of footing. It is identified that the soil outside this bulb has no considerable influence on the performance of footing. The bore hole depth criteria normally gives depth of bore hole greater than significant depth. Also by settlement calculations we can see that including layers of soil beyond depth D, borehole depth, will not increase total settlement by appreciable magnitude. The above two justifications have left the borehole depth criterion of "investigation boreholes should be taken up to a minimum depth where the increase in vertical stress due external load (footing, traffic etc) is not greater than 10% of the overburden pressure" unquestioned.

III.BOREHOLE DEPTH, D

Again the criterion - investigation boreholes should be taken up to a minimum depth where the increase in vertical stress due external load (footing, traffic etc) is not greater than 10% of the overburden pressure, implies at minimum depth of investigation borehole 10% of overburden pressure ($0.1\gamma D$) is equal to increase in vertical pressure ($\Delta\sigma_v$) due to footing pressure.

10% of overburden pressure = $(10/100)\ \gamma D = 0.1\gamma D$ (1)

Calculating increase in vertical pressure ($\Delta\sigma_v$) for a square footing of width B and transferring a pressure intensity of q units per unit area, using the approximate (2V: 1H) stress distribution method,

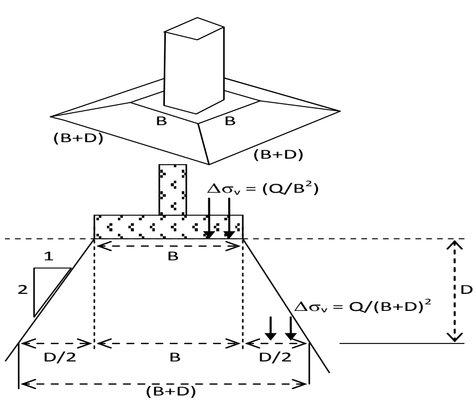


Fig.No.2. Illustration of concept of 2V: 1H stress distribution

Increase in vertical pressure ($\Delta\sigma_v$) at a depth D below the footing = total load on the footing/ area over which load is distributed at a depth

D = (pressure intensity transferred*Area of footing)/ $(B+D)(B+D)=qB^2/(B+D)^2$ (2)

{ for circular footing of diameter B and transferring a pressure intensity of q units per unit area ($\Delta\sigma_v$) = $\frac{\frac{q\pi B^2}{4}}{\frac{\pi(B+D)^2}{4}} = \frac{qB^2}{(B+D)^2}$ *which is same as that for square foundation as such depth of investigation bore hole for square and circular footings is same if B,q and γ are same for both. In this investigation only square and circular foundations are considered as they are the predominant type of footing in majority of medium scale projects.}*

As per Criterion of depth of investigation bore hole (1) and (2) are equal

Thereby

$$0.1\gamma D = \frac{qB^2}{(B+D)^2} \rightarrow D^3 + 2BD^2 + B^2D - \frac{10qB^2}{\gamma} = 0$$

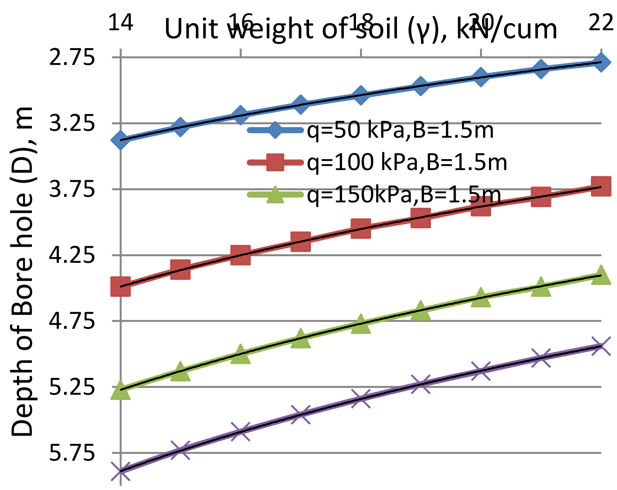
(3)

Solving which we can arrive at the depth of investigation borehole. We can notice here that the depth of investigation borehole D depends on footing characteristics (B and q) and soil characteristics (γ and q indirectly) as discussed earlier.

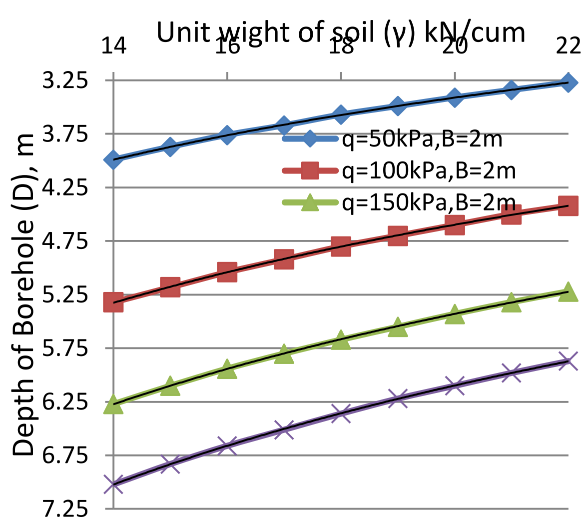
Solving of the above cubic equation is laborious and nomograms for determining D have been developed, which are cumbersome to use and as such are not popular. This paper tries to ease that job by presenting the depth of borehole in terms of a non dimensional number, for precise determination in the form of charts and for approximate conservative determination in the form of an equation.

Here we choose the non dimensional number qB/γ as D is directly related to q and B and is inversely related to γ . Calculations of D accurate to second decimal place is carried out using equation no (3) and the results are presented in the Table and graphs below.

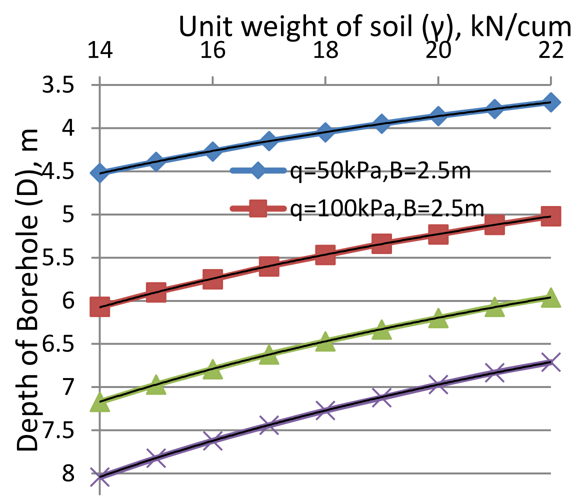
γ,kN/m³	→	14	16	18	20	22	14	16	18	20	22	14	16	18	20	22	14	16	18	20	22
B,m ↓		q=50 kPa					q=100 kPa					q=150 kPa					q=200 kPa				
1	D,m	2.66	2.52	2.4	2.3	2.21	3.51	3.33	3.18	3.05	2.94	4.11	3.9	3.73	3.58	3.45	4.58	4.36	4.17	4	3.86
	qB/γ	3.57	3.13	2.78	2.5	2.27	7.14	6.25	5.56	5	4.55	10.7	9.38	8.33	7.5	6.82	14.3	12.5	11.1	10	9.09
1.5	D,m	3.38	3.19	3.04	2.9	2.79	4.49	4.25	4.05	3.88	3.73	5.27	5	4.77	4.57	4.4	5.89	5.59	5.34	5.13	4.94
	qB/γ	5.36	4.69	4.17	3.75	3.41	10.7	9.38	8.33	7.5	6.82	16.1	14.1	12.5	11.3	10.2	21.4	18.8	16.7	15	13.6
2	D,m	3.99	3.76	3.57	3.41	3.27	5.32	5.04	4.8	4.6	4.42	6.27	5.94	5.67	5.43	5.22	7.02	6.66	6.36	6.1	5.87
	qB/γ	7.14	6.25	5.56	5	4.55	14.3	12.5	11.1	10	9.09	21.4	18.8	16.7	15	13.6	28.6	25	22.2	20	18.2
2.5	D,m	4.52	4.27	4.05	3.86	3.7	6.07	5.75	5.47	5.23	5.02	7.17	6.79	6.47	6.2	5.96	8.04	7.62	7.27	6.97	6.71
	qB/γ	8.93	7.81	6.94	6.25	5.68	17.9	15.6	13.9	12.5	11.4	26.8	23.4	20.8	18.8	17	35.7	31.3	27.8	25	22.7



Graph No.2 Relationship between D and γ for B=1.5m and q = 50, 100, 150 and 200 kPa

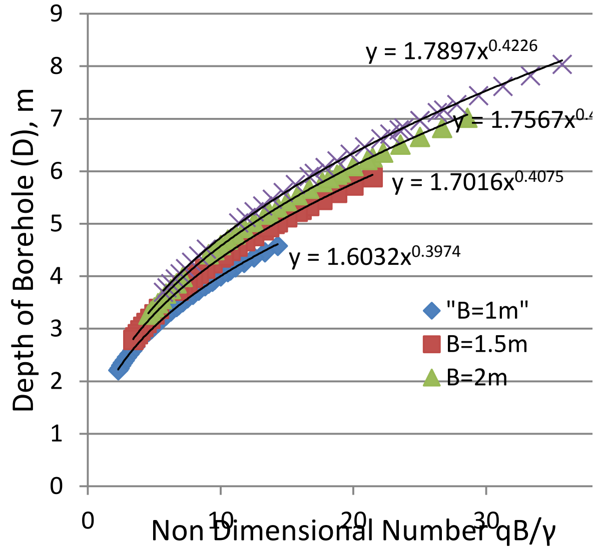


Graph 3 Relationship between D and γ for B=1.5m and q = 50, 100, 150 and 200 kPa



Graph No.4 Relationship between D and γ for B=2.5m and q = 50, 100, 150 and 200 kPa

The above charts even though are of great help in understanding the relationship between Depth of investigation borehole and various other parameters influencing it, arriving at depth of investigation borehole using these charts is as cumbersome(in the sense of number of charts, number of curves and interpolation for intermediate values and so on). To circumvent this difficulty we can plot the values of depth of investigation bore hole versus non dimensional number qB/γ. The plot is given below. Using of this graph is comparatively convenient and still gives reasonably correct values, provided we are ready to refer to four curves (for different values of footing width) of the graph and interpolate for intermediate values. Also we can use the four equations fitted by regression analysis which gives values of D accurate to +0.87% to -0.53% which is very much within the tolerable limits. However, even these equations will not avoid interpolation for intermediate values of footing widths. Again to overcome this last



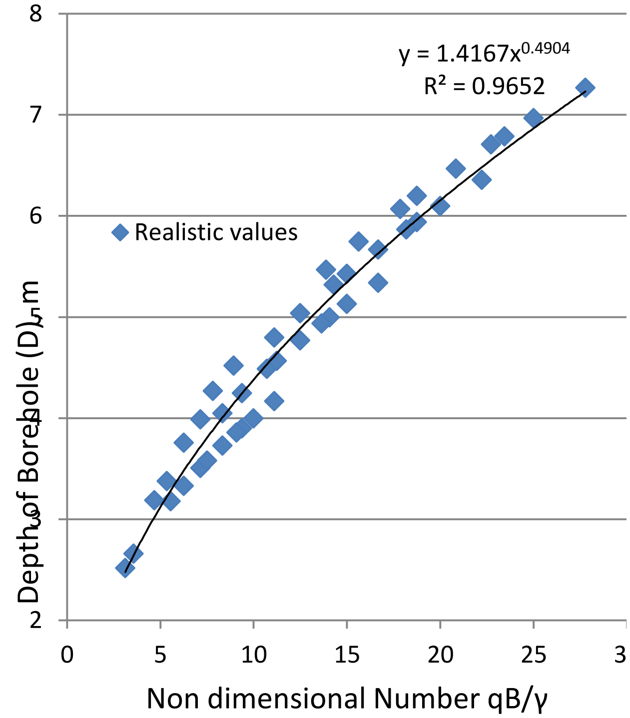
Graph No.5 Relationship between D and Non Dimensional Number (qB/γ) for different width square and circular footing

hurdle against simplicity of solution we can plot D versus non dimensional number qB/γ irrespective of footing width and fit an equation for the points. However at this point we should choose practically possible combinations of q, B and γ to make the solution more realistic. For example we can omit combination γ = 14 kN/m^3 and q = 200 kN/m^2. The plot of non dimensional number qB/γ versus D for possible realistic combinations of q, B and γ is given below.

The best fit equation for these points is

$$\boldsymbol{D = 1.42\left[\frac{qB}{\gamma}\right]^{0.49}} \quad \text{------------------------------------- (4)}$$

The equation (4) estimates D with + 10.81% and - 8.94% accuracy. While overestimation of D is not a problem, underestimation may lead to detrimental consequences. However if we consider the practicalities and economics of borehole drilling, 10% extra (maximum of 1m) drilling of borehole is a readily acceptable option (we can recall here the relative mobilization cost of equipment and drilling cost per unit depth). In such a circumstance equation (4) is of great help over other means available for determining the depth of investigation borehole.



Graph No.6 Relationship between D and Non Dimensional Number (qB/γ) for square and circular footing

IV.CONCLUSIONS

We can conveniently use equation $D = 1.42\left[\frac{qB}{\gamma}\right]^{0.49}$ for evaluating depth of investigation borehole, however for added safety always exploring to a depth 10% greater than the depth given by the equation.

We can conservatively, confidently on a safer side, use equation $D = 1.79\left[\frac{qB}{\gamma}\right]^{0.43}$ for evaluating depth of investigation borehole, which will be overestimating the values of D for footing of 1m size by 20% (Max overestimation being ~1m), for footing of 1.5m by 10% (Max overestimation being ~0.6m) and for footing of 2m width by 5% (Max overestimation being ~0.35m). For footing of 2.5m width the equation estimates D to an accuracy of ±1%. As such author recommends the equation $D = 1.79\left[\frac{qB}{\gamma}\right]^{0.43}$ as a safe bet for solving the problem under consideration.

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