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Numerical Evaluation of Bearing Capacity of Shallow Foundation Resting on Sandy Soil Based on Shear Criteria and Settlement Criteria

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Abstract—*Based on two criteria i.e shear criteria and settlement criteria, the bearing capacity of sandy soil is evaluated and minimum of these two values is taken as allowable bearing capacity of shallow foundation. The result showed that with the increase in footing size B (1m to 6m) of the square shallow foundation, the bearing capacity from shear criteria (SBC) increases whereas the bearing capacity from settlement criteria (Q) decreases with the same footing size. Using different parameters such as φ, N and at different settlements SBC and Q are determined at different conditions and the result showed that Q is minimum in maximum cases and hence it is taken as the allowable bearing capacity from design point of view of the foundation.*

1. INTRODUCTION

Foundation is an integral part of a structure whether it may be a building, bridge and dam etc. The function of the foundation is to receive the load from the superstructure and transmit it to the underlying soil or rock. Soil is used as a construction material for various civil engineering structures. Structure on a ground with adequate bearing capacity is one of the basic requirements for the stability of a structure. Design of foundation consists of two different parts: one is the ultimate bearing capacity of soil below foundation and second is the acceptable settlement that a footing can undergo without any adverse effect on superstructure. Ultimate bearing capacity means the load that the soil under the foundation can sustain before shear failure; while, settlement consideration involves estimation of the settlement caused by load from superstructure which should not exceed the limiting value for the stability and function of the superstructure. In other words, the design of the foundation is based on two criteria. Shear failure criteria: A foundation must be safe against the shear strength failure or soil rupture. An adequate factor of safety is provided to preclude bearing capacity failure, as soil rupture is common referred to. According to experimental results from foundations resting sand (vesic ,1973), the mode of failure likely to occur in any situation depends on the size of the foundation and relative density of soil.

Settlement criteria: The settlement of a foundation, especially the differential settlement, must be within the permissible limit. According to the criteria, the foundation shall not settle more than the safe or tolerable magnitude of settlement such that the anticipated settlement due to the applied pressure on the soil should not be detrimental to the stability of the foundation.

These two criteria are independent and have to be dealt with separately. The bearing capacity value to be determined should minimum of these two values for the design requirement of a foundation.

The smaller value of bearing capacity is referred to as allowable bearing pressure of soil.

2. METHODOLOGY

Analysis on sand is taken place for the evaluation of bearing capacity for a square shallow foundation.

The size of the foundation is taken from 1m to 6m.

The foundation is considered to be resting on soil surface. So the depth is taken to be zero.

Bearing capacity of a square footing resting on sand on ground surface based on,

- Shear criteria
- Settlement criteria

Shear criteria-

For shear criteria, we usually follow Terzaghi's classical theory for bearing capacity evaluation in which bearing capacity factors are determined. These factors depends on angle of internal friction (φ).

Terzaghi's bearing capacity equation is given by,

$$SBC= (cN_c+qN_q+0.5B\gamma N_\gamma)/F \quad (1)$$

F= factor of safety which is usually taken as 1.5.

Nc, Nq and Nγ are the bearing capacity factors. As the foundation is resting on surface, so other factors except Nγ are of no use or Nc and Nq are taken zero.

$$SBC=0.5B\gamma N_\gamma/F \quad (2)$$

Where,

$$N\gamma = 0.5\left(\frac{Kp}{(cos\varphi)^2}1\right)tan\varphi \quad (3)$$

Kp=frictional angle of resistance.

With the increase in bearing capacity factors and the angle of internal friction, the safe bearing capacity of soil increases.

Settlement criteria-

According to the settlement criteria, the net soil pressure that can be imposed on the base without the settlement exceeding the permissible values as given in IS:1904-1948 to be determined for each structure and type of soil,that is safe bearing pressure. Also the settlement value evaluated from Standard penetration test depends on angle of internal friction. The bearing capacity of the soil in settlement criteria can be evaluated using the equation given by IS 6403-1976 for a settlement of 40mm,

$$Q = (N-3)(\frac{(B+0.3)}{2B})^2W \quad (4)$$

For other settlement values the equation can be given as,

$$Q = \frac{1.764SN^{1.4}}{B^{0.75}} \quad (5)$$

For the comparison between shear criteria and settlement criteria, an analytical method or a computer software is used which gives accurate results as per our requirements. MATLAB is a tool that can be used to solve the problems for this comparison.

3. RESULT AND DISCUSSION

Based on shear criteria and settlement criteria, bearing capacity of shallow foundation resting on sand surface is evaluated. Width of the footing is considered to be 1m to 6m. A square footing is taken into consideration which is resting on the surface. First of all the angle of frictional resistance and the standard penetration values are determined from the relation,

$$N = \frac{(\varphi-20)^2}{12} \quad (6)$$

Table 1: Relation between angle of friction and SPT N value

Angle of friction(φ)	Standard penetration resistance value(N)
28	5.3333
30	8.3333
32	12
34	16.3333
36	21.3333
38	27

Corresponding to the N value, angle of frictional resistance and N_γ are found out in the above table. From the values of Nγ, corresponding bearing capacity value of the sandy soil is found out which is given in the table below.

Table 2: Value of Nγ from SPT N- value

SPT (N) value	Angle of frictional resistance	N_γ
5	27.2460	15.192
10	30.9545	22.15
15	33.4164	28.45
20	35.4919	48.10
25	37.3205	68.9
30	38.9737	88.5

Using the same frictional angle and N value comparison between shear criteria and settlement criteria is done. To justify the criteria and finding the safe bearing capacity of soil, Terzaghi's theory of bearing capacity for sand resting on the surface is used. The equation is given by,

$$SBC = 0.5B\gamma N\gamma$$

Table 3: Bearing capacity of soil in shear criteria

Width(m)/Nγ	15.192	22.15	28.45	48.10	68.9	88.5
1	151.92	221.5	284.5	481	689	885
2	303.84	443	569	962	1378	1770
3	455.76	664.5	853.5	1443	2067	2655
4	607.68	886	1138	1924	2756	3540
5	759.6	1107.5	1422.5	2405	3445	4425
6	911.52	1329	1707	2886	4134	5310

the above tabulation calculated for the bearing capacity of soil is plotted in the graph.

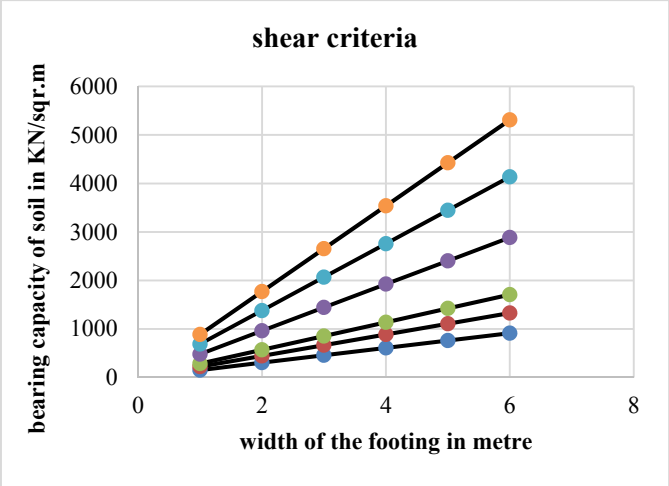


Fig. 1: Variation of SBC with B

From shear criteria,it is clear that the bearing capacity of soil increases with the increase in width of the footing.

From the settlement criteria bearing capacity of the soil is determined by standard penetration resistance value (N).

Table.4: SPT N value corresponding to the angle of friction

Angle of friction(φ)	Standard penetration resistance value(N)
28	5.3333
30	8.3333
32	12
34	16.3333
36	21.3333
38	27

Using the above N value, the bearing pressure of soil with respect to the settlement is determined. IS 1904-1986 provides the equation for the determination of the bearing pressure which is given by,

$$Q = (N-3)\left(\frac{(B+0.3)}{2B}\right)^2 W$$

Where W is the water reduction factor usually taken as 0.From the above equation, bearing pressure of the soil is determined which is given in the table below.

Table 5: Bearing capacity of soil in settlement criteria

Width (B)	N=5.3333	N=8.3333	N=12	N=16.3333	N=21.3333	N=27
1	27.30719	62.41694	105.3293	156.0429	214.5592	280.878
2	21.36909	48.84403	82.42481	122.1105	167.9021	219.7995
3	19.5513	44.68905	75.41325	111.7231	153.6193	201.102
4	18.67271	42.68082	72.02433	106.7024	146.716	192.0649
5	18.15524	41.49803	70.02837	103.7455	142.6501	186.7423
6	17.81431	40.71875	68.71331	101.7972	139.9713	183.2355

Corresponding graph is plotted wrt to the settlement criteria which is given below,

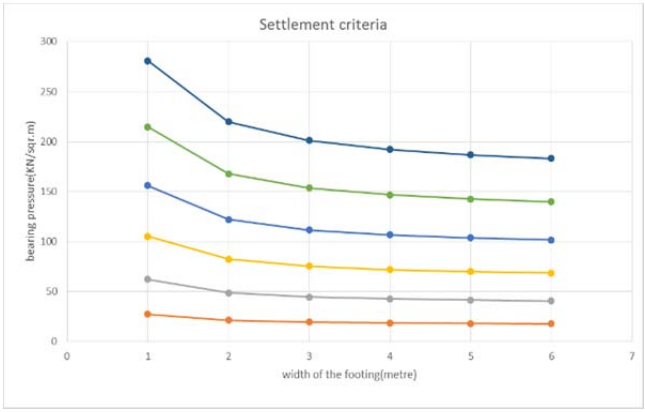


Fig. 2: Variation of Q with B

From the above graph, it is very much clear that the bearing pressure is decreasing with the width of the footing which is completely contradictory to the shear criterion. Minimum of these two criteria will be the allowable bearing capacity which is safe from design point of view.

A next case is considered at a constant width B=5m,SBC and Q are evaluated taking SPT N value from 10 to 50 at a gap of 5 and settlement S=10 to 50mm at a gap of 5mm. using both shear and settlement criteria bearing capacity values are evaluated which is presented in the graph below.

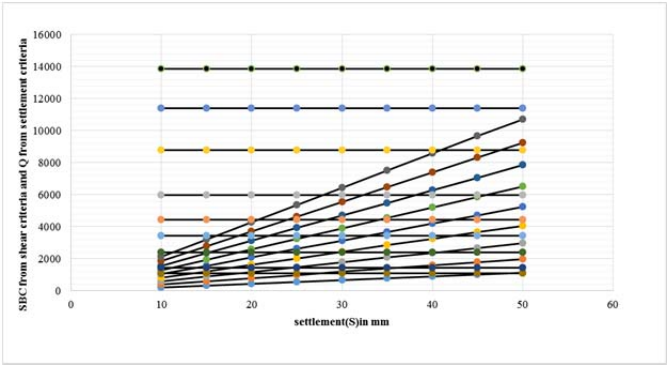


Fig. 3: Variation of SBC and Q w.r.t. S

In the above graph, SBC remains constant for each settlement value with a constant width where Q increases gradually with increasing settlement. Whatever the effect of settlement may be on SBC and Q, SBC becomes predominant over Q and Q

can be taken as the allowable bearing capacity of sandy soil.For more convenience, the bearing capacity values from both the criteria are taken at some particular settlement values (i.e. S=25mm, 45mm and 50mm) at a constant width of the footing i.e B=5m with standard penetration value (N) from 10 to 50 at a gap of 5 number of blows.The results are shown below through graphs.

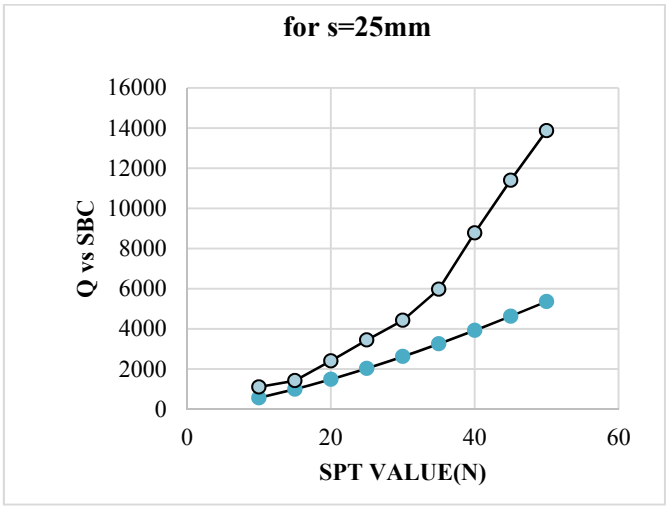
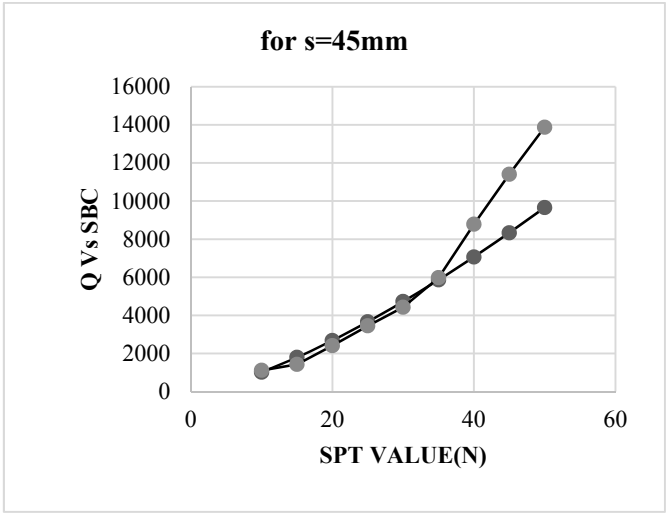
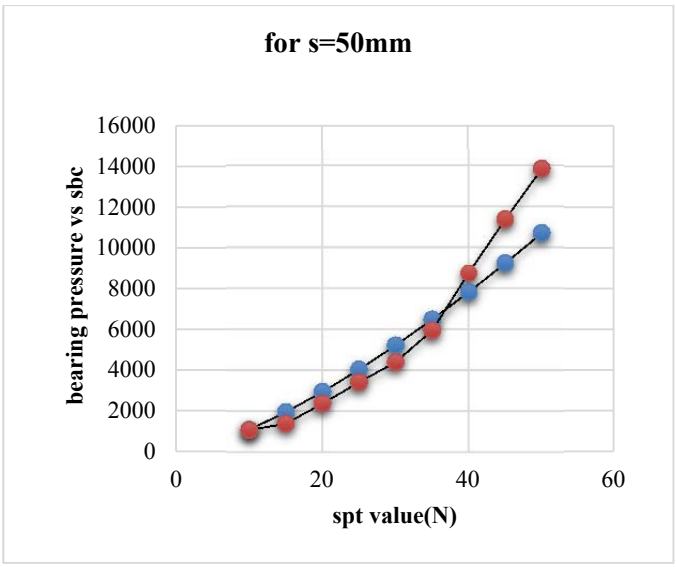


Fig. 4: Comparison of SBC and Q w.r.t N at S=25mm, 45mm and 50mm and B=5m





In each case SBC is predominant over Q with some variations for each settlement value. for a small settlement of 25mm SBC predominates over Q from the starting point of N to the end but in the later cases i.e in case of S=45mm and 50mm initially Q predominates over SBC upto N=30 to 40 n then occurs vice versa.

4. CONCLUSION

A no of parameters are taken to determine the allowable bearing capacity of the square shallow foundation resting on sandy soil. All the evaluations are done assuming that the footing is resting on the surface.

Following are the summarized results of present work

- The bearing capacity (SBC) of the square footing increases with the increasing footing size where the bearing pressure (Q) decreases with the increasing footing size.
- At a constant width, from the angle of friction N values are determined .using this N value and settlement S again both SBC and Q are determined. It is found that SBC remains constant with the increasing N value but Q increases with increasing N value.
- At some particular settlement values and constant footing width, with the increasing no of blows both SBC and Q are found where SBC is greater than Q.
- Again different sizes of the footing with different settlement values are considered at N from 15 to 50 at a gap of 5 blows and found that both values of SBC and Q increases but SBC values are predominant over Q.
- Again it is also found that even if there is an increase in SBC and Q, somewhere the values come closer and somewhere the difference is much more to compare with respect to the increasing N values.

- Whatever the case is, SBC coming greater than Q. hence it can be concluded that the bearing capacity from settlement criteria can be taken as allowable bearing capacity for the design of shallow foundation resting on sandy soil.

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