Construction of Optimal Railway Formation and Foundations - A Civil Engineer's Approach

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Synopsis:

While selecting a foundation type most often it has been observed that there is no co-ordination between structural and geotechnical designers. The structural engineer feels that in overall design of structure the role of geotechnical engineer is very limited and of least importance, the former expects that later one should give him Safe Bearing Capacity after that he will start designing whereas the later one expects from the former the forecasted load and foundation dimension before starting calculations of Safe Bearing Capacity. The reason behind these conflicts is that both of them have confined themselves in the boundaries of structural and geotechnical terminology and they forgets that basically they are Civil Engineers. This trust deficit and lack of co-ordination leads to over conservative design and factor of safety goes upto 8 or 9 which costs to the tax payers hard earned money indirectly. In this paper an effort had been made to review the basic concepts of soil mechanics so that fundamental mistakes done in design/construction of railway formation and foundation could be avoided. This paper will help in understanding the very basic concepts of soil mechanics. How investment of a less than 1% of the total cost of project in geotechnical investigations and design, could save upto 8-10% of overall cost with safe and timely completion of projects.

Introduction:

Construction of railway formation, ROB/Bridge foundations projects are big projects and take years to complete. The construction engineers are always in pressure to complete the work and they takes the help of geotechnical and structural consultants at various stages. Most of the times it happens that there is no conversation and exchange of data between structural, geotechnical and construction engineers and each of them works in isolation and design there portion conservatively which ultimately makes the structure over safe sometimes with factor of safety 8 to 9. In the subsequent Para few basic concepts of soil mechanics have been discussed which emphasizes the need of close co-ordination among geotechnical, structural and construction engineers and enables the railway construction engineer to cross check the consultancy reports.

1. Determination of Bearing Capacity:

The most crucial element in design is computing bearing capacity. The most commonly used Terzaghi's bearing capacity equation is given below considering General Shear Failure

$$q_u = c'N_c + qN_q + 0.5\Upsilon' BN_\Upsilon$$ For Strip footing

$$q_u = 1.3c'N_c + qN_q + 0.4\Upsilon' BN_\Upsilon$$ For Square footing

$$q_u = 1.3c'N_c + qN_q + 0.3\Upsilon' BN_\Upsilon$$

For Circular footing

In case of local shear failure the shear strength parameters to be used are:

$$c'_m = \frac{2}{3}c'$$

$$\varphi'_m = \tan^{-1}(\frac{2}{3}tan\varphi')$$

The issues related with determination of Bearing Capacities are:

i. **Footing Dimension:**
The bearing capacity of any soil is determined based on the type of footing and its width (dimension). When the dimensions of foundation is asked by geotechnical engineer the arguments of structural engineers are, "if we know the type and dimension of footing then what is need of safe bearing capacity and geotechnical engineer". The solution is very simple the ***determination of bearing capacity is an iterative process and a civil engineer with ordinary prudence can determine it by following the simple steps.***

ii. **Type of Stress Analysis (Total/Effective)**
While carrying out stress analysis it is extremely important to choose appropriate testing, appropriate parameter for corresponding analysis whether total or effective stress. The summary of parameters, test and type of analysis is given in Table 1.

Table 1: Type of analysis with corresponding parameters

	Total Stress Analysis	Effective Stress Analysis
Parameters	c , φ	c' , φ'
Type of test	Unconfined Compressive Strength (UCS) or Unconsolidated Undrained (UU)	Consolidated Undrained (CU) Consolidated Drained (CD)
Overburden Pressure	Total overburden pressure to be considered $q = \Upsilon D_f N_q$	Total overburden pressure to be considered $q = \Upsilon' D_f N_q$
Density (Υ)	Bulk/Saturated density to be considered	Submerged density to be considered

Effective stress analysis is preferred over total stress analysis and the determination of shear strength parameters (c', φ') takes considerable time upto one week with proper instrumentation and experienced geotechnical engineer and. ***If geotechnical report is delivered within one or two days of sample supply then it simply means the proper testing has not been carried out.***

iii. **Effect of Water table**
Water table correction is applied when the water table is in close proximity of foundation and it reduces the surcharge and ultimately the bearing capacity. If in a geotechnical report water table correction is applied in effective stress analysis then it means correction has been applied twice and the safe bearing capacity has been

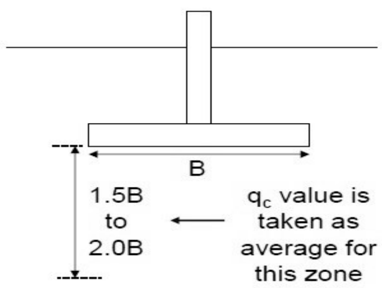
reduced to about half. ***This mistake/overlook would cost almost twice the cost of foundation construction***

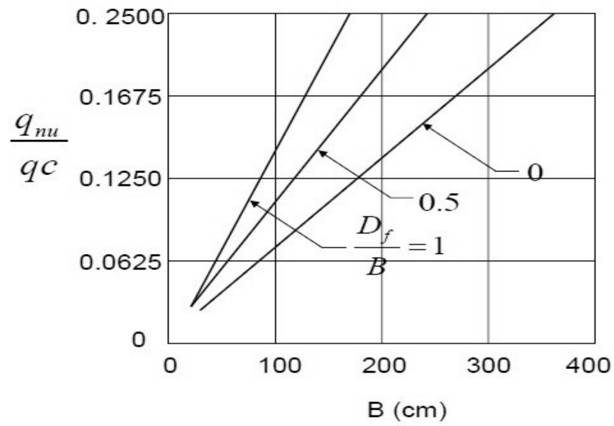
iv. Use of Correlations between SPT value and Bearing Capacity

Peck, Hansen and Thornburn (1974) & IS:6403-1981 recommended the use of the design charts for the determination of Nc, Nq and N_γ which is very easy and thus bearing capacity can be determined quickly, but dealing with soil is not as simple as dealing with steel and therefore the design charts proposed on the basis of studies done in some part of Japan and USA may not be applied directly as it may lead to over conservative or may end up with unsafe design. ***Therefore for important structures it is always better to carry out some tri-axial test, determine the shear strength parameters and then calculate bearing capacity factors (Nc, Nq and N_γ)***

v. Use of Correlations between CPT value and Bearing Capacity, IS 6403-1981

Cohesion less Soil:





The static cone resistance, q_c(kg/cm^2)is used to determine the bearing capacity factor, N_γ from the correlation given by Schmertmann (1975),

$$N_\gamma \cong \frac{q_c}{0.8}$$

From N_γ, φ the value of N_q can be obtained from the chart given by Peck, Hanson and Thornburn (1974).

Cohesive Soil:

$$q_{nu} = c_u.N_c.s_c.d_c.i_c$$

Soil Type	Point Resistance Values (qc) kg-f/cm^2	Range of Un-drained Cohesion (kg-f/cm^2)
Normally consolidated clays	$q_c < 20$	q_c /18 to q_c /15
Over consolidated clays	$q_c > 20$	q_c /26 to q_c /22

2. Determination of Stress

i. **The shape effect of footing**

The pressure bulb for different shape of footing is different and hence stress level at any point below the footing is directly dependent on the shape of footings

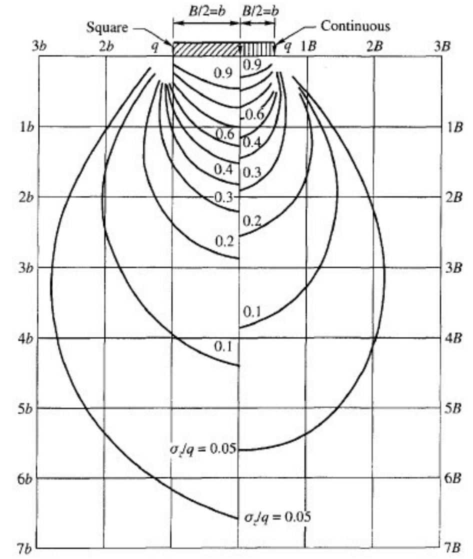


Fig: Pressure isobars based on Boussinesq equation for square and continuous footings (*Geotechnical Engineering by V.N.S. Murthy*)

ii. **The selection of method for stress calculation**

One can prefer any of the methods for calculation of stress at some depth as per his convenience and suitability

a) Boussinesq,
b) Westergard,
c) Newmark and
d) Approximate methods

Boussinesq, Westergard and Newmark method give the stress value at a depth depending on the depth at which it is calculated but in actual practice it is not necessary that the soil profile is same throughout the depth. ***Therefore while designing foundations of important structures for stress calculation, the soil profile and properties are required and it can be obtained through geotechnical investigations***

3. **Determination of Settlement**

The settlement analysis predicts two things (1) the magnitude of settlement and (2) the rate at which the settlement shall take place. The settlement analysis is performed in three sequential steps (1) determination of profile and properties of soil, (2) pressure before and after loading and (3) settlement determination and prediction of time-settlement relation.

The total settlement consists of three sequential differential settlements, the immediate settlement which occurs due to application of load, primary consolidation which occurs due to dissipation of pore water and secondary consolidation which occurs due to rearrangement of soil particles. For different type of foundation and soils the methodology of calculating settlement is different. Some of the methods are described in subsequent paras.

i. Immediate Settlement

Elastic settlement:

$$S_e = \int_0^H \varepsilon_z dz = \frac{1}{E_s}\int_0^H (\Delta\sigma_z - \mu_s\Delta\sigma_x - \mu_s\Delta\sigma_y)dz$$

E_s = Modulus of elasticity
H = Thickness of soil layer
μ_s = Poisson's ratio of soil

Elastic settlement for Flexible Foundation:

$$S_e = \frac{qB}{E_s}(1-\mu_s^2)I_f$$

I_f = influence factor: depends on the rigidity and shape of the foundation
E_s = Average elasticity modulus of the soil for (4B) depth below foundation level

ii. Settlement due to Primary Consolidation

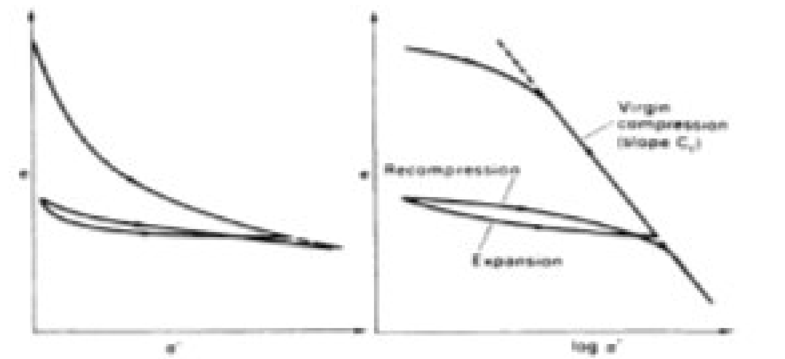


Fig: Settlement (change in void ration) vs load graph in various stages
(Ref: Craig's Soil Mechanics)

For NC Clay $(\sigma_c' < \sigma_o' < \sigma_o' + \Delta\sigma_{av}')$ $Sc = \frac{C_c H_c}{1+e_o}\log\left(\frac{\sigma_o' + \Delta\sigma_{av}'}{\sigma_o'}\right)$

For OC clay $(\sigma_o' + \Delta\sigma_{av}' < \sigma_c')$ $Sc = \frac{C_s H_c}{1+e_o}\log\left(\frac{\sigma_o' + \Delta\sigma_{av}'}{\sigma_o'}\right)$

For OC clay $(\sigma_o' < \sigma_c' < \sigma_o' + \Delta\sigma_{av}')$ $Sc = \frac{C_s H_c}{1+e_o}\log\left(\frac{\sigma_c'}{\sigma_o'}\right) + \frac{C_c H_c}{1+e_o}\log\left(\frac{\sigma_o' + \Delta\sigma_{av}'}{\sigma_c'}\right)$

Where, σ_o' = Average effective vertical stress before construction

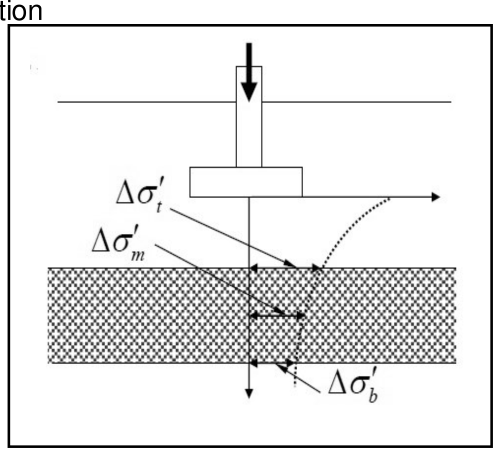
$\Delta\sigma_{av}'$ = Average increase in effective vertical stress

σ_c' = Effective pre-consolidation pressure

e_o = Initial void ratio of the clay layer

C_c = Compression Index

C_s = Swelling Index



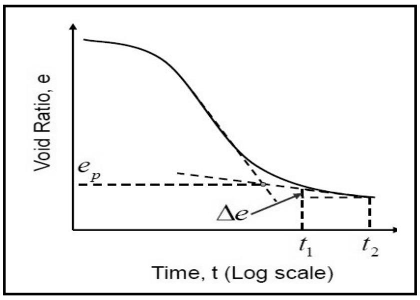
H_c = Thickness of the clay layer

$$\Delta\sigma'_{av} = \frac{1}{6}(\Delta\sigma'_t + 4\Delta\sigma'_m + \Delta\sigma'_b)$$

The important thing to be looked in the report is whether proper type of equation has been used for virgin compression, unloading or reloading stages. The consolidation oedometer test is to be carried out on undisturbed sample which takes upto a week, If the report submitted without undisturbed sample or just in a day or two of sample submission, indicates fake data.

iii. **Settlement Due to Secondary Consolidation**

$$S_s = \frac{C_\alpha H_c}{1+e_p}\log\left(\frac{t_2}{t_1}\right)$$



Where, C_α=Secondary Compression Index = $= \dfrac{\Delta e}{\log(t_2/t_1)}$

e_p = Void ratio at the end of primary consolidation

H_c = Thickness of Clay Layer

Secondary consolidation settlement is more important in the case of organic and highly-compressible inorganic clays.

In the determination of consolidation settlement, it is assumed that the structural load is applied simultaneously but in actual practice the structural load increases gradually with the pace of construction process. Therefore for the proper analysis of consolidation settlement, the duration and the activity schedule should be known, which is not available most of the time or not provided by the client.

Conclusions

With the above brief discussion an effort has been made to review basic concepts of soil mechanics which will help the construction engineers to figure out some of the fundamental mistakes carried out by consultants.

References:

1. Geotechnical Investigations for Structural Engineers (GISE) workshop carried out @ IIT Gandhinagar by Dr. Amit Prashant.
2. Theoretical Soil Mechanics by Karl Terzaghi
3. Craig's Soil Mechanics by R. F. Craig