Quick settlement computation of shallow foundations using soil index & plasticity characterisitics

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ABSTRACT
The aim of study is to establish fairly reliable forecast of consolidation parameters for alluvial deposits and finally total settlement at a specified time by passing statistically not acceptable tests with reference to time and cost both. New approach is evolved for quick analysis and to assess sensitivity of structure at a site for settlement. The derived parameters and approach is quick and economical. Empirical model is prepared to predict the settlement of shallow foundations incorporating soil index and plasticity characteristics. The model incorporates the computation of over consolidation ratio, time rate settlement, magnitude of settlement and differential settlement of foundations. The model will be useful for foundation design incorporating the differential settlement of foundations.

Key Words
Alluvial Deposits, Empirical model, Foundation Settlement, Shallow foundations, Soil Consolidation, Soil Properties.

1 INTRODUCTION

In the selection and design of foundation system, it is important to determine the types and properties of the soil. In a detailed investigation, the conventional approach is to perform subsurface investigation being to obtain for a sufficient number of soil samples which are then tested in the laboratory to obtain the necessary soil properties including consolidation parameters. The basic index properties are water content, dry density, void ratio, consistency limits. Consolidation tests are expensive and time consuming. In order to obtain realistic values, special sampling and testing techniques and testing systems are required. It is required to conduct these tests with the utmost accuracy and to adopt realistic and suitable procedures to evaluate and interpret the results obtained. However, the group of tests performed to obtain index properties of soil is relatively inexpensive and simple. They do not require much time or any sophisticated testing system. Hence, it is very useful to develop empirical correlations for estimating the consolidation properties with soil index properties. The industrial growth and real estate activity in decade has been very fast. There are very few qualified equipped agencies to serve the sectors demand for soil investigations in time and at affordable price. The test for normal range of stress takes a more time. This constrain and normal practice to test typical one or two samples for a soil strata of approximately 3000 m^3 of the soil per unit could be statically unacceptable and occasionally misleading particularly for alluvial stratified layered deposits. Thus the expected accuracy of results and predicted final settlement or its time rate is highly variable. The aim of study is to establish fairly reliable forecast of consolidation parameters and finally total settlement at a specified time by passing statistically not acceptable tests with reference to time and cost both. New approach is evolved for quick analysis and to assess sensitivity of structure at a site for settlement. The derived parameters and approach can be new, quick and economical.

2 SUBSOIL CHARACTERISTICS

The study area is divided in to 10 zones of Surat City and SUDA (Surat urban development authority) situated in Gujarat state of India. Six zones are of Surat Municipal Corporation and 4 zones of SUDA. The subsoil characteristics of each zone are studied in detail from large number of datasets. A datasets containing index and consolidation parameters are used to conduct a statistical study to determine suitable correlations for estimating consolidation response. This statistical analysis is carried out in order to obtain the most suitable and practically applicable relationships. This database can provide information regarding trends, relationships and statistical properties, a mechanism whereby test results can be checked and provides geotechnical information for preliminary design purposes. The soil characteristics of each zone are studied up to a depth of 8 m. This depth is stress zones for shallow foundations. Generally for multistoried buildings foundations are located at 3 to 4 m depth in the study region. The average soil properties up to depth of 8 m are shown in Table 1.

The consolidation characteristics such as compression index and compression ratio of west zone Surat are found less compared to other zones. The coarse-grained soil is predominant in west zone Surat. The properties covered in the table are liquid limit , plastic limit , plasticity index , void ratio, dry unit weight , water content , % finer , compression index and compression ratio.

Table 1 Average range of Subsoil characteristics for study area

Soil Properties	Most Range
Liquid Limit (w_L)	30 – 60
Plastic Limit (w_p)	20 – 30
Plasticity Index (I_p)	15 – 30
Void Ratio (e_0)	0.6 – 0.9
Dry unit weight kN/m^3 (γ_d)	14 – 16
Water Content (w)	15 – 30
Porosity (n_0) %	40 – 46
% Fines	60 – 90
Clay %	20 – 30
Silt %	40 – 60
Compression Index (C_c)	0.24 - 0.37
Compression Ratio ($C_{c'}$)=Cc/1+e_0	0.14 – 0.18
Soil Classification	Low to High Compressible Fine Grained Soil
Differential Free swell	10 – 80
Mineralogy	Montmorillomite & Kaolinite

3 STATISTICAL SUMMARY OF SUBSOIL CHARACTERISTICS AND EMPIRICAL CORRELATIONS

Statistical summary of parameters such as mean, median, and standard deviation, coefficient of variance, skew ness, kurtosis and range are studied of all zones. This statistical analysis is done with the software statistixl. Statistical summary of subsoil characteristics of all zone of Surat and SUDA shows that mean value range of liquid limit 38.5 – 51 %, plastic limit 20 – 25 %, plasticity index 20 – 27 %, void ratio 0.7 - 0.77 %, dry unit weight 15.2 - 16.0 gm/cc, water content 19 - 23 and % finer 55 - 84. Coefficient of variance for most soil properties in all zones found below 30% except very few cases. The lower values of skewness and kurtosis in all zones indicate symmetry of data. Table 2 shows statistical summary of index properties of Surat and SUDA. Various methods and empirical correlations are available to predict consolidation parameters are used for study area for determination of compressibility parameters. It is found that use of empirical correlations for consolidation parameters can not be generalized for all places and all soils. Empirical correlations should be used only after verifying its feasibility for particular region and type of soils. Consolidation test is expensive, and its reliability is also poor due to sampling disturbances. Time to investigate adds more time to finalize soil report. Normally soil report excludes the consolidation tests in the study area. In such cases empirical correlations are very useful to estimate consolidation settlement of shallow foundations. Laboratory test results of the study area used for deriving new correlations. New correlations are proposed for prediction of compression index and compression ratio using liquid limit, plasticity index, water content, void ratio and porosity for alluvial deposits of study area as shown in Table 2. Correlations are obtained using soil plasticity characteristics having higher value of correlation coefficient.

Table 2 New Correlations

Correlation	Correlation Coefficient (R^2)
C_c = 0.0061 w_L – 0.0024	0.8435
C_c = 0.4066 e_0 – 0.0415	0.7223
C_c = 0.0082 Ip+ 0.0915	0.7862
C_c = 0.0107 n_0 – 0.1818	0.7115
C_c = 0.0091 w + 0.0522	0.77
C_c' = 0.0022 w_L + 0.0478	0.9063
C_c' = 0.0029 Ip + 0.0833	0.8579
C_c' = 0.0035 w + 0.0631	0.6735

Correlations obtained using soil plasticity characteristics having higher value of correlation coefficient in compare to other soil properties. These correlations are use for prediction of compression index and compression ratio for different zones of Surat and SUDA region. Statistical summary of predicted values of compression index and compression ratio for Surat and SUDA are shown in table 4. New correlations derived for compressibility parameters of soil using index and plasticity properties are used for all zones of Surat and SUDA region. Experimental results are studied for soil index and consolidation properties. Available test datasets of Surat and SUDA gave reasonably good correlation coefficient between soil plasticity and compression characteristics. Initially liquid limit and plasticity index are used separately for determining compression characteristics of alluvial soil. The average values of compressibility parameters are computed from values obtained using liquid limit and plasticity index correlations. From detail study of results, it is found that both parameters of soil may improve the correlation coefficient. The further study is carried out for determining consolidation parameters of soil using single or both parameters of soil. Large numbers of datasets of study area are used from S V National Institute of Technology and different agencies for deriving correlations of consolidation parameters. Empirical correlations are proposed for over consolidation ratio, coefficient of consolidation with soil plasticity characteristics. Correlations are also proposed for compression index and compression ratio using single or both parameters. Validations of new correlations are done with existing consolidation test datasets of other region. The proposed correlations derived by author for compressibility parameters of alluvial soil of above mention properties with correlation coefficient 0.75 and more are as follows for shallow foundations.

The ratio of pre-consolidation pressure and present overburden pressure is known as over consolidation ratio (OCR). Based on OCR soils are classified as normally consolidated, over consolidated or under consolidated. Selection of consolidation parameters such as compression index (C_C), Recompression index (C_r) or coefficient of volume change (m_v) is on the basis of OCR for computing consolidation settlement. The correlations are also suggested by researchers to obtain Pre-consolidation pressure and Nagaraj and Murthy (1994), Chetia and Bora (1998) etc.

Based on the test data of study area following relation is derived for over consolidation ratio

Over consolidation ratio

$(OCR) = 1.85 - 0.007\ p_o - 0.225\ (e/e_L)$ $R^2=0.793$ ....(1)

The rate of settlement of the soil layer takes place is essential from design consideration. This can be determined using coefficient of consolidation Cv. To obtain Cv it is essential to conduct a routine one-dimensional consolidation test. The various time fitting curves are available to evaluate Cv. This is time consuming process. Curve fitting procedures available in the literature are not completely satisfactory in evaluating Cv and hence large variation is obtained in the evaluated values by different procedures. Generally square root time fitting or Log time fitting curves are use for evaluation of Cv. The rate of settlement is directly related to the rate of excess pore pressure dissipation. Coefficient of consolidation C_V is useful in the determination of the time required for a finite percentage of consolidation to occur. The coefficient of consolidation Cv generally decreases as the liquid limit of soil increases. The range of variation of C_V for given liquid limit is very high. C_V varies with both level of stress and degree of consolidation. For practical site settlement calculations, measure C_V relative to loading range applicable to site, and then assume this value to be constant. In the present study coefficient of consolidation is correlated with liquid limit and plasticity index of soil. It is observed that Cv for alluvial soil is giving higher value of correlation coefficient with plasticity index than to liquid limit. The correlation of Cv with liquid limit is also quite satisfactory.

Based on the test data of study area following correlations are derived for coefficient of consolidation

Coefficient of consolidation using liquid limit

$(C_v) = 10^8\ w_L^{-6.7591}$ cm^2/sec $R^2=0.7867$ ....(2)

Coefficient of consolidation using plasticity index

$(C_v) = 7.7525\ Ip^{-3.1025}$ cm^2/sec $R^2=0.9156$ .... (3)

Compression ratio using liquid limit

$(Cc') = 0.0032\ w_L + 0.0004$ $R^2=0.7806$ ...... (4)

Compression ratio using liquid limit and plasticity index

$(Cc') = 0.002\ w_L + 0.001\ Ip + 0.037$ $R^2=0.8674$ ... (5)

Fig 1(a) shows comparison of measured and predicted compression ratio from liquid limit and plasticity index.

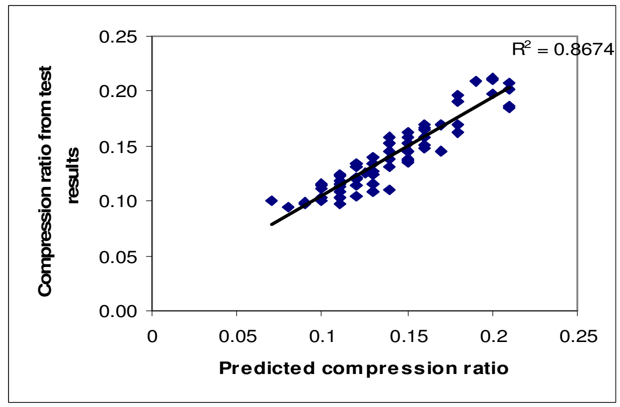

Fig 1 (a) Comparison of measured and predicted Compression ratio

Comparison of measured and predicted compression index using ANN (Artificial Neural Network) is shown in fig 1 (b).

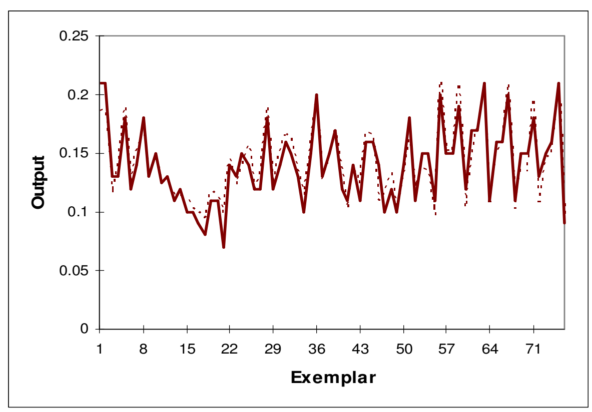

Fig 1 (b) Comparison of measured and predicted compression index Using ANN

MSE	0.000141866
MAE	0.009728118
Min Abs Error	2.11004E-05
Max Abs Error	0.030127471
r	0.931366511

The software neurosolution5 was utilized for training, testing and cross validation. Various architectures of ANN along with numerous training algorithms were tried till satisfactory results were obtained.

The comparison of compression ratio from measured 135 numbers test data from literature and using above empirical correlation liquid limit and plasticity index both are determine. It is found that the values obtained using empirical correlations are close to consolidation test data. Compression ratio of soil is giving higher value of correlation coefficient with liquid limit and plasticity index both. Table 3 shows statistical comparison of compression ratio using test datasets of other region from literature and empirical correlation using liquid limit and plasticity index.

Table 3 Statistical summary of compression ratio from test data and correlation

Parameter	Cc’ from test data	Cc’ from correlation W_L & Ip
Mean	0.175	0.178
Median	0.167	0.172
Std Error	0.004	0.003
Std Dev.	0.043	0.039
COV.	24.391	21.312
Sum	23.609	24.582
Minimum	0.103	0.126
Maximum	0.296	0.280
Range	0.193	0.154
Count	135.000	135.000
Skewness	0.678	0.823
Kurtosis	-0.151	-0.151

4 EMPIRICAL MODEL FOR COMPUTATION OF SETTLEMENT OF SHALLOW FOUNDATIONS

Empirical model is proposed using Visual Basic Program to predict the settlement of shallow foundations incorporating soil index and plasticity characteristics. The model incorporates the computation of over consolidation ratio, time rate settlement, magnitude of settlement and differential settlement of foundations. The model will be useful for foundation design incorporating the differential settlement of foundations. This model is proposed to obtain settlement of shallow foundation for fine grained alluvial deposits of same subsoil range. In this model input parameters are soil index & plasticity characteristics for obtaining settlement of foundations. The soil index and plasticity characteristics in addition to geometrical foundation parameters and load on the foundation are required to obtain settlement using this empirical model. The program is also prepared for predicting contact pressure between soil and footing (Safe or Allowable bearing Pressure) from input of required parameters. For Prediction of total and differential settlement soil properties and geometrical parameters used as input parameters are % finer, bulk unit weight of soil (γ) water content (w) , liquid limit (w_L), plasticity index (Ip), specific gravity of soil grains (G) , standard penetration resistance (N) , width of footing (B), length of the footing (L), depth of the footing (D) , degree of consolidation (U). Model computes area of footing, safe load on the footing with dry unit weight of soil (γ_d), void ratio (e) , thickness of the compressible layer (H), void ratio at liquid limit (e_L) ,existing over burden pressure (p_o), over consolidation ratio (OCR). Magnitude of settlement is determined using compression ratio of soil. The soil for which plasticity index is not known Cc′ is determined using liquid limit. When liquid limit (w_L) and plasticity index (Ip) both are known compression ratio is determine using both parameters. Recompression index is taken as 10% of compression ratio.

For determining magnitude of settlement of normally consolidated soil geometrical factor is taken as 0.7 and for over consolidated soil taken as 0.5. Depth factor (D_f) and Rigidity factor (R_f) are taken as 0.8 in computation of magnitude of settlement. Modulus of elasticity is assumed or computes using standard penetration resistance (N) in this model. The total settlement of the foundation is taken as sum of corrected immediate settlement and corrected consolidation settlement. The model also incorporates differential settlement between two footings or two edges. Angular distortion is computed by giving center to center distance between two footings. If computed settlement is exceed the permissible settlement it highlights the values. These computations are used to check differential settlement for structural member of frame. The empirical model also includes computation of time rate settlement. Coefficient of consolidation is to be determined using liquid limit, if plasticity index is not known. When plasticity index of soil is known coefficient of consolidation (Cv) is computed on using plasticity index. The model incorporates single drainage or double drainage. The output of time rate settlement is obtained in days.

5 CONCLUSION

Empirical model is prepared to obtain settlement of shallow foundation for preliminary design. In this model input parameters are soil index and plasticity characteristics with some basic soil properties and geometrical dimensions. Model computes parameters such as over consolidation ratio. Coefficient of consolidation, compression ratio, immediate settlement, consolidation settlement and differential settlement. This model is enable the designer to decide safe bearing capacity or permissible bearing capacity which ever governs the design, Critical differential settlement zones in a structure to proportion foundations or stiffen structure and indicate critical sample site to minimize errors in transfer or remolding of samples collected by driller.

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