Comparative Study on Settlement Analysis of Shallow Foundation for Cohesive Soil

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Abstract. The surcharge due to building and roads affects the subsurface and ground behaviour and causes the settlement problem. The settlement problem is more effective when structure built on expansive soil. Because of settlement resulting damage and repair work may cost a considerable high amount, an accurate modelling of subsurface condition and prediction of ground-structure interaction can help to avoid such a foundation problem. In this study, settlement analysis by using conventional method and two-dimensional finite element (2D FEM) modelling are both carried out and the results are compared. Settlement analysis by using the conventional approach is performed for the particular geometry by using Terzaghi's one-dimensional consolidation theory. The compressibility coefficient involved in the formula is determined from consolidation test data. Thereafter settlement results are presented as settlement prediction on-time rate for comparison purpose. Then after 2D FEM analysis is performed for the same soil data and soil model is generated using FEM computer program. The results obtained from the analysis are compared with conventional method results. Terzaghi's equation, which is used in the conventional approach, is a logarithm function whereas 2D FEM analysis based on linear function according to Hook's law of linear elastic stress-strain relationship. Three different soil layers, which have different E and γ value determined for each layer and thickness of each layer is considered. The number variable affecting the results restrained comparison between conventional and 2D FEM settlement to be qualitative.

Keywords: Settlement, FEM analysis, Consolidation settlement, 1D settlement, Cohesive soil

1 Introduction

Since the primitives edge human basic need for shelter is not changed. For the inhabitation human need safe and resourceful land. But due to modern civilization and industrialization; population increase which demands more resouces for their inhabitation. So human forced to utilize even expansive site for their settlement. This brings the construction and development of a new structure for human occupancy. The construction of new structures on expansive site causes settlement of ground which leads to the vertical sinking of structure. When soil mass is subjected to a compressive force, its volume decreases, this indicated the compressibility of soil. Because of this compressibility property of soil, any/all foundation of structure starts its vertical, downward movement due to a volume decrease of the soil sinking under an applied load. This sinking of the foundation of structure into the soil is known as the settlement of a foundation. Settlement of subsoil causes damage to the structure that needs costly and unwieldy corrective measurements and permanency problems, sometimes of vigorous importance. The more precise settlement estimates are made the more effective planning and designing of construction sites are executed. The settlement analysis presented in this is aiming to compare the conventional methods to predict settlement of shallow foundation with computer-aided software. In this study spread type, the shallow foundation is to be considered. A spread footing or simply footing is a type of shallow foundation used to transmit a load of an isolated column or that of a wall to the subsoil. This is the most common type of foundation. The base of the column or wall is enlarged or spread to provide individual support for the load. Fig. 1. shows some typical spread footing.

Fig. 1. Typical Spread Footings

The main objective of this research to study the settlement of shallow foundation at Majura gate, Surat site with conventional methods and compare the same by creating a 2D computer-aided model by a finite layered method. In this regard, a 2D grid model will be constructed by using MIDAS GTS software for settlement prediction for a particular site, under the assumption of uniformly distributed load. A conventional method namely; “Final settlement using change in void ratio” is used to determine the settlement of shallow foundation rested on cohesive layered soil. MIDAS GTS finite element software, the main tool utilized for analysis. Considering the geometry condition and material property, 2D settlement analysis is carried out in vertical section using MIDAS GTS and visualized. Then the results obtained by both the approaches are compared.

2 Settlement Analysis

The settlement is categorized as total settlement and differential (uneven) settlement. Total settlement states the uniform vertical sinking of the entire structure, developed due to the weight of the structure and imposed loads. Differential or uneven settlement can occur if the loads on the structure are unequally distributed, variations in the soil properties or due to construction-related variations. The amount of settlement that a building can tolerate known as, the "allowable" settlement which depends on its size, type and intended use. In this paper, a total settlement is to estimate, which includes elastic settlement and consolidation settlement determination.

The succeeding are the required steps in settlement analysis:

a) Collection of relevant information: site location plan where the structure is constructed.
b) Determination of a subsoil profile: determination of soil properties up-to desired depth.
c) Stress analysis: vertical stress determination using the Boussinesq equation.
d) Estimation of settlements: In case of clayey soil the total settlement will

$$S= Si+Sc \tag{1}$$

e) Estimation of the time rate of settlements: Terzaghi's one-dimensional consolidation theory is used to find out time rate settlement. Based on the Terzaghi's theory, the total settlement at any time *'t'* is given by

$$St = Si + U.Sc \tag{2}$$

2.1 Settlement Calculation

The settlement analysis is carried out for an administrative building to be constructed in Dr S. & S. S. Ghandhy College. This institution is located at Majura gate, the south-west zone of Surat city. The building is rested on single strip type shallow footing. Dimension and water table location is indicated in Table 1.

Table 1. Features of Footing

Item	Size
Dimension of footing	3.0 m X 4.0 m X 3.0 m
Thickness of footing	1.25m
Dimension of column	0.4 X 0.7 m
Depth of water table	4.5 m deep from G.L

Two major geological formations encountered in this area, upper brownish black clay and yellow soil formation up to 12 m depth. The brownish-black clay is expansive in nature and shows variation according to seasonal change. Yellow soil is situated at about 9m depth from the ground surface. This yellow soil is firm and does not show any effective variation in its nature. The engineering properties of soil is indicated in Table 2.

Table 2. Engineering properties of soil (Majura gate)

Depth From G.L. (m)	w (%)	Density (kN/m^3)		Particle Size Analysis				IS Soil	G	Shear Parameters	
		Bulk	Dry	Gravel %	Sand %	Silt %	Clay %			C (kN/m^2)	Ø (deg)
2	21	18.1	15.0	0	44	42	14	MI-CI	2.59	19	28
2	14	17.8	15.6	8	53	24	15	SC	2.54	24	25
4	15	18.2	15.9	0	35	54	11	MI-ML	2.52	5	30
9	14	18.5	16.2	0	61	33	6	SM	2.55	5	31

In this study stress develop due to rectangular footing load is to be determined using the Boussinesq equation. Stresses are found out at the centre of footing (Fig. 4.3) using equation;

$$\sigma_z = 4.I_N * Q \quad (3)$$

Where I_N is depend on L/z and B/z.

Stresses develop due to applied load (considering simple static case) is determined at every 1.2m interval; given in Table 3.

Table 3. Developed Stresses

Depth of Soil Layer	m=2z/B	n=L/B	I_0	I = $4.I_0$	Stress intesity(Δp) (kN/m^2)
3	0.75	0.75	0.1372	0.5489	77.3798
4.2	1.05	0.75	0.1572	0.6287	88.6388
5.4	1.35	0.75	0.1672	0.6686	94.2603
6.6	1.65	0.75	0.1722	0.6888	97.1093
7.8	1.95	0.75	0.1749	0.6995	98.6132
9	2.25	0.75	0.1764	0.7054	99.4462
10.2	2.55	0.75	0.1772	0.7088	99.9298
11.4	2.85	0.75	0.1777	0.7109	100.2231
12.6	3.15	0.75	0.17	0.7122	100.4079

			81		
13.8	3.45	0.75	0.17 83	0.7131	100.5285
15	3.75	0.75	0.17 84	0.7137	100.6096

2.2 Settlement Estimation

The proposed site located at Majura gate is an open ground no structure is existed in past. So the site is considered as normally consolidated. When the load is applied to the soil it starts compressing and shows immediate settlement. When immediate settlement is completed then due to the dissipation of pore water consolidation settlement occurs as the water table is at 4.50m depth from the ground surface. Here the site is near to the river bed so there is a considerable effect on water level fluctuation. Subsoil data for settlement calculation is given below Table 4.

Table 4. Soil Data for Settlement Calculation

Particulars	**Data**
Bearing capacity	140.98 kN/m^2
Specific gravity	2.59
Void ratio	0.63
Pressure bulb height	8.0m
Compression index	0.18
Coefficient of volume change	0.0002 m^2/kN
Pre-consolidation pressure	135.33 kn/m^2
Effective overburden pressure	102.90 kN/m^2
Load at mid of compressible layer	38.08 kN/m^2
Modulus of elasticity (assumed)	192600
Poisson's ratio	0.3
Influence factor (I) (from Table 2 in IS 8009,Pt-I)	0.8
Influence factor for Rigidity R_f	0.80
Correction factor for depth D_f	0.75
Factor λ for normally consolidated clay	1.0

According to IS 8009 (part -1) - 1976 clause 9.2.2.2; If the clay is not pre-compressed, that is, in a simple static, the final settlement is estimated by using change in void ratio method only. Static load for settlement calculation is taken as S.B.C of filling layer as surcharge loading. Settlement estimated using void ratio method is given below: (Table 5)

Table 5. Estimation of Final Settlement

Type of Settlement	Estimated Value
Immediate Settlement (S_i)	27.52 mm
Consolidation Settlement(S_c)	71.03 mm
Total settlement (S)	59.03 mm

According to IS 1904-1976 clause 16.3.4 table 1; permissible maximum settlement for R.C.C Isolated foundation on plastic clay is 75 mm. The estimated value of the settlement is within the permissible limit.

3 Time Rate Settlement

Terzaghi's theory for the determination of the rate of consolidation of a saturated soil mass subjected to a static load. Depending upon the rate of consolidation final settlement is being estimated. Final settlement calculation based on U degree of consolidation and time factor Tv. To determine the rate of consolidation, a test is carried out. From consolidation test results co-efficient of consolidation is calculated by using Square root of time fitting method.

3.1 Determination of Co-efficient of Consolidation

The square root of time fitting method: Here a curve plotted between dial gauge reading and the square root of time to determine the coefficient of consolidation.

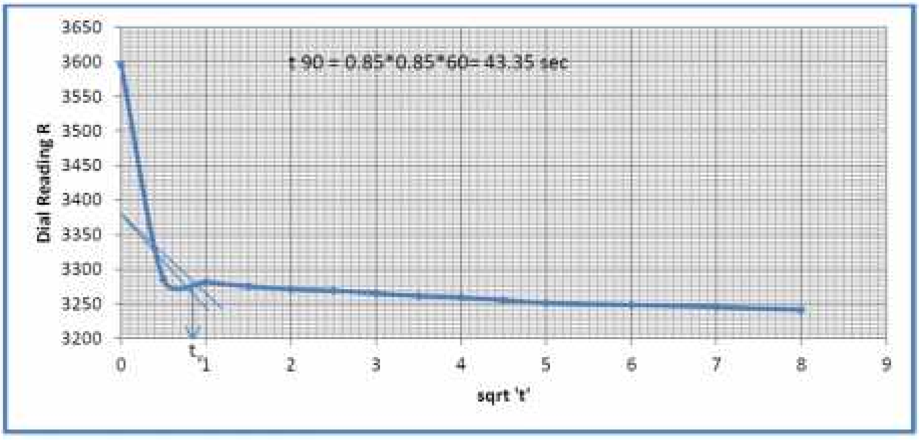

Fig. 2. Typical Square Root of Time Plot

A curve is to be plotted to determine time t_{90} and the average value of C_v is calculated.(See Fig.2)

3.2 Determination of Time Rate Settlement

Necessary values to determine time rate settlement is obtained and then settlement is to be found by equation (2). Settlement obtain is shown in Table 6.

Table 6. Time Rate Settlement

Degree of Consolidation U (%)	Time Factor T_v	Total Settlement S_t (mm)	Time (days)
10	0.008	7.10	4
20	0.031	14.21	16
30	0.071	21.31	36
40	0.126	28.41	63
50	0.197	35.52	99
60	0.287	42.62	144
70	0.403	49.72	202
80	0.567	56.82	284
90	0.848	63.93	425
95	1.163	67.48	583

4 Finite Layered Analysis

MIDAS GTS is a total, state-of-the-art solution, which has been developed through integrating all the functionality necessary for structural analysis for geotechnical and tunnel engineering. Real situations may be modelled either by a plane strain or an axisymmetric model in 2D or 3D. The program uses a convenient graphical user interface that enables users to quickly generate a geometry model, finite element mesh, finite element pre and post-processing mode and report generation based on a representative vertical cross-section of the situation at hand.The steps followed in 2D settlement analysis are described as follows.

1. General setting: Here in this study the 2D model is selected. Default unit systems are chosen.
2. Creating the geometry model: by accurately entering values a geometry model is generated.
3. Mesh generation: Finite element mesh is generated assigning the size control for each edge. Then each sectional area is meshed using auto mesh planner area option in MIDAS GTS.
4. Assigning the model material property: The material properties assign are given in Table 7.

Table 7. Material Properties

Parameter	Sand with silt	Silty clay	Sand with clay
Material model	Mohr- coulomb	Mohr- coulomb	Mohr- coulomb
Unit weight (kN/m^3)	17.8	18.2	18.5
Poisson's ratio	0.3	0.3	0.3
Young's modulus (kN/m^2)	19600	17000	39200
Cohesion(kN/m^2)	24	5	7
Friction angle (deg)	**25**	**30**	**30**

5. Applying load and boundary condition: In this soil model, three types of boundary conditions are assigned. The first condition is ground support which is given to all mesh set. The second condition is Non Consolidation condition applied to the footing. Third drain condition is applied at below footing and also at depth of 3.0m i.e below the fill layer.

   The load is applied in the form of a uniformly distributed load. The filling layer is not considered in the model instead of that it is considered as surcharge loading of value 140.98 kN/m; which is applied at first layer called silty clay layer, by using pressure load option of the program. The column load of 1000kN/m is also applied as a pressure load at top of the footing. The final model generated after assigning material property, boundary condition and load application with mesh sets is shown in Fig. 3.

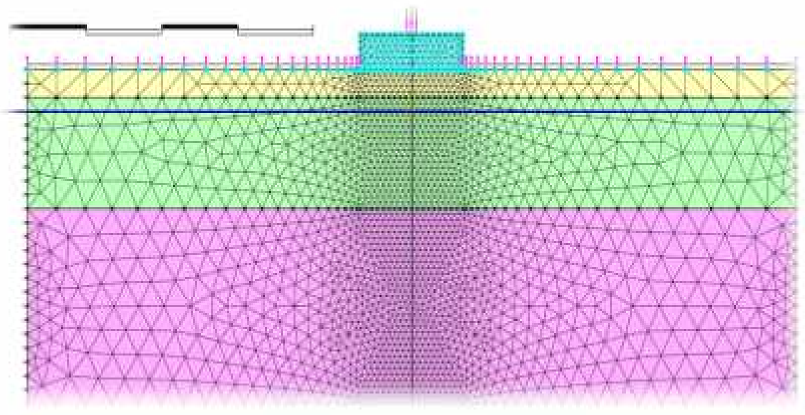

Fig. 3 Geometry Model With Load And Boundary Condition.

6. Define construction stages for analysis: While defining construction stages the water level is defined in the initial stage only. As this work is regarding settlement

analysis in long term stage only time period is defined. The time period is taken of 730 days.

7. Post-processing and Result Evaluation: while using MIDAS GTS, one can obtain node wise results after calculation. In this study, the selected node is node no 90 which indicates the depth of the calculated value of pressure bulb depth i.e 2 x width of footing. Initially, as there is no load on soil so no displacement takes place. But when the footing is constructed and column load is applied then stresses and settlement developed (Fig.4 and Fig. 5). As shown in the figure the maximum stresses are developed below the footing. As depth increases the stresses are decreases.

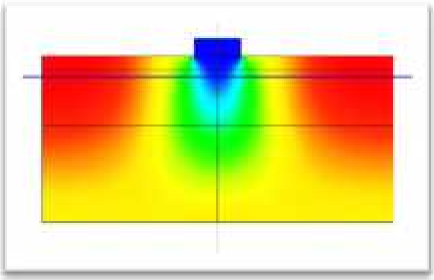

Fig. 4 Displacements in 2D Footing Stage

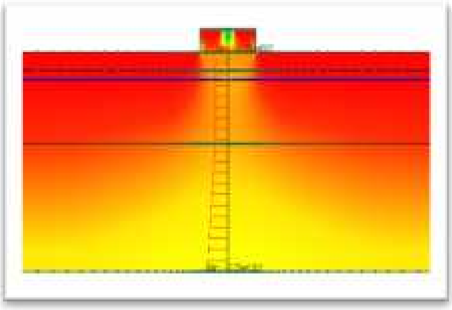

Fig. 5 Stresses in 2D Footing Stage

In the case of the surcharge construction stage, the stresses and displacement both are approximately the same as that of the 2D footing stage because the load applied in surcharge is less than column load.

5 Result and Discussion

For the duration obtain by conventional approach (i.e 584 days) settlement is calculated by FEM analysis. The maximum settlement obtained is 48.6mm at 284 days and then after the settlement is going to decrease for the mentioned duration. The settlement value for 584 days by FEM analysis is 41.3mm.

As shown in fig.9 in conventional method result settlement increasing with time, but for the same time settlement value for FEM approach is decreasing. The maximum settlement from the conventional method is 67.47mm achieve in approximately 583 days and from FEM approach for with column load condition settlement is 48.6mm achieved in approximately 284 days whereas from FEM approach for surcharge load only it is 35.13 mm at 425 days.

The difference in settlement patterns can be explained by the parameters used in the calculation. In the analysis work, the soil parameter values are used based on the bore log chart provided. In 2D FEM analysis the continuity of the layers can be followed only in two directions i.e width and depth only. In 2D FEM analysis ground is treated as permeable elastic solid, and the pore fluid coupled with the solid is based on the conditions of compressibility and continuity. The equation used in the conventional method the main parameter affecting the settlement the coefficient of compressibility and initial stresses as a logarithm function whereas in 2D FEM analysis settlement is related to the applied load and Young's modulus of each soil layer. 2D FEM analysis is based on linear function according to Hook's law of linear elastic stress-strain relationship.

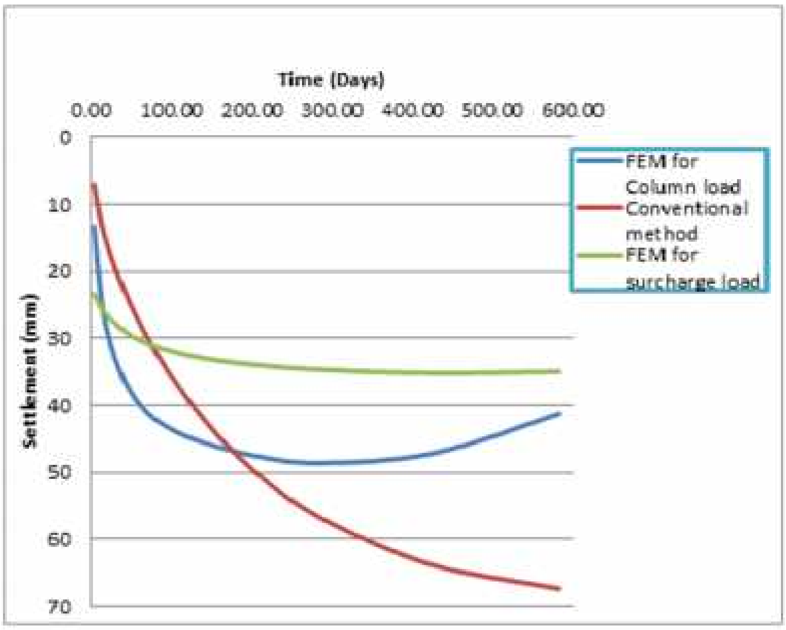

Fig.6 Time v/s Settlement Curve

Figure. 6 shows the settlement results obtained from both the approaches. In this time period is taken as a comparison parameter as obtained in time rate settlement analysis. The reason for selecting this parameter is that the settlement is time-dependent and the curve obtained from the result clearly indicates the stages of settlement.

6 Conclusion

It is important for settlement predictions to know the best explanation of the soil profile stress history, whether using traditional or FEM analytical methods. 2D FEM analysis is carried out for two load conditions, first for surcharge load only and second for column load only; the result obtained are 1.15-1.25 and 1.60-1.70 times respectively lesser than conventional approach results. According to the thickness of layers and distribution of compressible layers, FEM values are closer to expected. The over-all results of this study also indicate the fact that most conventional methods used to compute settlement of foundations on cohesive soils over predict.

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