

Parametric Study on Settlement of Isolated Footings

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Abstract
Foundation is defined as that part of the structure which transfers the load from superstructure to the soil. When the soil is loaded by weight of the structure built on it, due to its compressibility soil compacts & the settlement of foundations occurs. Present study is focused out to determine the effect of various parameters affecting settlement of the foundation. A 4-storied building is considered for settlement calculation. The building is modeled & analyzed in E-TABS software to get final load acting on the footings. The minimum depth of the foundation (D_{min}) & the sizes of the footings were computed for isolated footings. For settlement calculations 3 types of soils were considered i.e. Dense Sand, Stiff Clay & Gravely Soils. The parameters were varied for these soil types & the settlements for depths lesser than minimum depth of foundation & greater than minimum depth of foundation are calculated. Further the settlements are also computed using SAFE software. The E-TABS analyzed file is being imported to SAFE software & the settlement were tabulated. Based on these analysis & calculations, the effects of Elastic Modulus of soil (E), Shape of foundation & Depth of foundation $(D_f$) in all three soils were observed.
Keywords: Superstructure, Compressibility, Dense Sand, Stiff Clay, Gravely Soils, SAFE, E-TABS.

1. INTROCTION
When the soil due to its compressibility compacts the settlement of foundations occurs. When soil is loaded the water presents in the expulses out resulting in decrease in the volume change there will be arrangement of the soil particles in the air voids created by expulsion of the water from voids. This arrangement reflects as a volume change leading to compression of the soil resulting in settlement whether the soil is moist or dry is central to predicting the amount of settlement to expect in a given foundation areas with moist soils will have more foundation settlement than dry areas. This can even cause damage to structure.

2. MODELING & ANALYSIS
A 4- story building is taken for the settlement computation of isolated footing & the building is modeled in E-TABS software and analyzed to get reactions on each footing. The general data considered for the modeling is given below.

Grade of Concrete	=	M_{20}
Grade of Steel	=	Fe415
Live Load	=	1.5 kN/m^2
Floor Finish	=	1 kN/m^2
Brick Wall	=	230 mm thick
Slab	=	150 mm thick
Beam	=	230 mm X 300 mm
Column	=	300mm X 450mm
Floor Height	=	3m
Type of Support	=	Pinned
Density of Concrete	=	25 kN/m^3
Density of Brick wall including plaster	=	20 kN/m^3

The building is modeled and analyzed in E-TABS as per IS456-2000 for the load combination of (DL+LL). End reactions of individual column were obtained and 10% of load of column was added as self-weight of footing to get total load acting on each footing. From these final reactions taken from E-TABS model the footings are divided into 5 groups to compute the settlement calculation. The groups are made depending on the load coming on footings and are as follows.

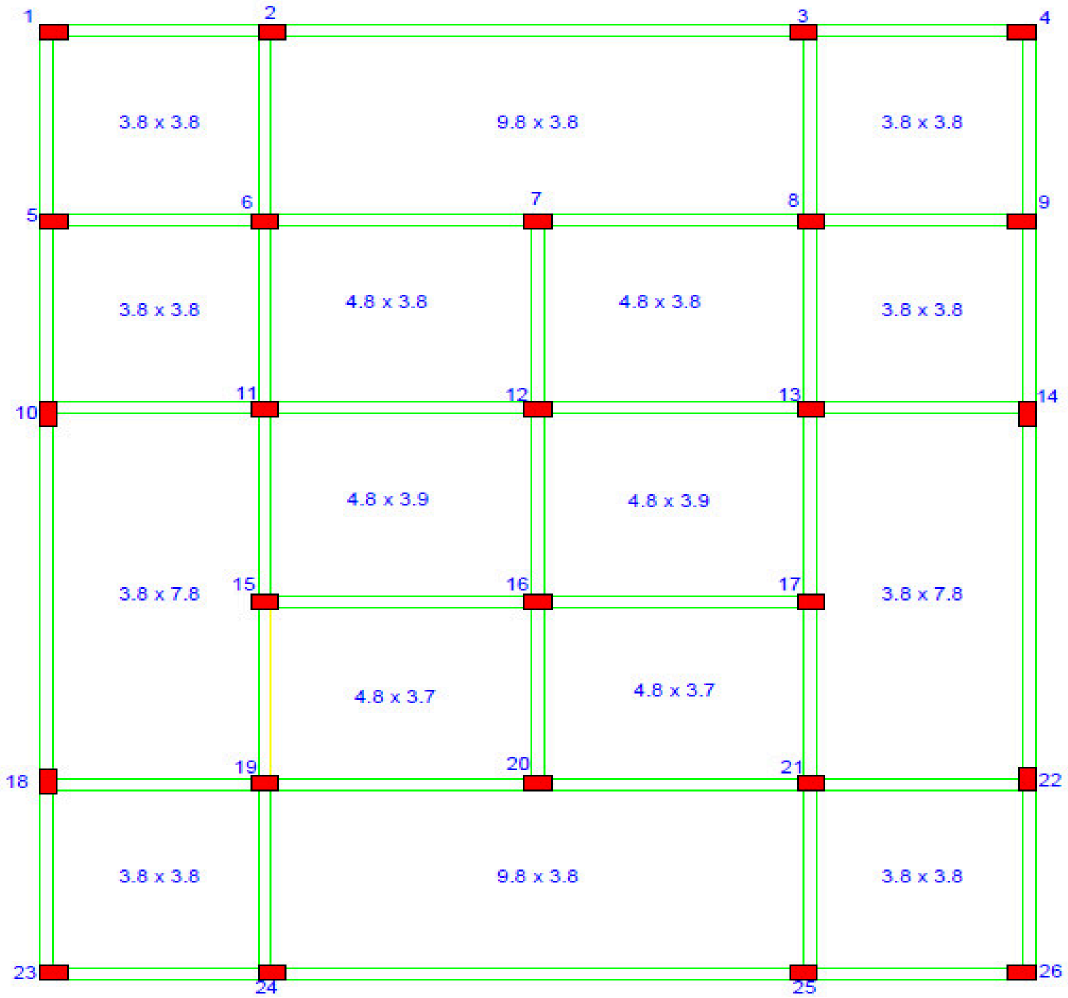

Figure number 1 Typical Floor Plan

Table number 1 Grouping of Footings

GROUP NO.	COLUMN NO.	FINAL LOAD CONSIDERED (kN)
1	1, 4, 23, 26	600
2	5, 9	900
3	10, 14, 18, 22	1200
4	2, 3, 6, 7, 8, 11, 13, 15, 17, 19, 20, 21, 24, 25	1400
5	12, 16	1500

Settlement Parameters

For analysis of settlement of the soil for isolated footings three different types of soils are considered and the variation of the settlement of soil is studied. The three soils considered are namely Dense Sand, Stiff clay & Gravely Soil. The different parameters considered for these soils are given below.

Table number 2: Settlement Parameters.

PARAMETER	DENSE SAND	STIFF CLAY	GRAVELY SOIL
Weight Density	20 kN/m^3	18 kN/m^3	20 kN/m^3
SBC	440 kN/m^2	150 kN/m^2	245 kN/m^2
Angle of Friction	38	30	35
Voids Ratio	0.5	0.6	0.35
Specific Gravity	2.65	2.8	2.7
Poison's Ratio	0.25	0.25	0.25
Young's Modulus	60 kPa	75 kPa	150 kPa

Depth & Size of Foundation

Minimum depth of foundation $D_{min} = \frac{SBC}{\gamma}\left(\frac{1-sin\theta}{1+sin\theta}\right)^2$

For the settlement calculation of the footings the final depths considered for each of the soil is given below.

Table number 3: Depth of Foundation for Different Soils.

TYPE OF SOIL	DEPTH LESSER THAN MIN. DEPTH (In M)	DEPTH GREATER THAN MIN. DEPTH (In M)
Dense Sand	1.00	1.50
Stiff Clay	0.75	1.00
Gravely Soil	0.80	1.00

$$Area\ of\ the\ Footing\ required = \frac{Load\ on\ the\ Footing}{SBC\ of\ Soil}$$

The size of the footings are calculated for Square,Rectangle with (L/B) ratio 1.5 & Rectangle with (L/B) ratio 2. The size of footing for different loads and shapes are calculated and tabulated below.

Table number 4: Sizes of Footing for Dense Sand.

LOAD (kN)	SQUARE B x B (m)	RECTANGLE (L/B=1.5) B x L (m)		RECTANGLE (L/B=2) B x L (m)	
	B (m)	B (m)	L (m)	B (m)	L (m)
600	1.20	1.00	1.50	0.85	1.70
900	1.50	1.20	1.80	1.10	2.20
1200	1.70	1.35	2.10	1.20	2.40
1400	1.80	1.50	2.25	1.30	2.60
1500	1.90	1.60	2.40	1.30	2.60

Table number 5: Sizes of Footing for Stiff Clay.

LOAD (kN)	SQUARE B x B (m)	RECTANGLE (L/B=1.5) B x L (m)		RECTANGLE (L/B=2) B x L (m)	
	B (m)	B (m)	L (m)	B (m)	L (m)
600	2.00	1.65	2.50	1.45	2.90
900	2.50	2.00	3.00	1.75	3.50
1200	2.90	2.40	3.60	2.00	4.00
1400	3.10	2.50	3.75	2.20	4.40
1500	3.20	2.60	3.90	2.25	4.50

Table number 6: Sizes of Footing for Gravely Soil.

LOAD (kN)	SQUARE B x B (m)	RECTANGLE (L/B=1.5) B x L (m)		RECTANGLE (L/B=2) B x L (m)	
	B (m)	B (m)	L (m)	B (m)	L (m)
600	1.60	1.30	1.95	1.45	2.90
900	2.00	2.00	3.00	1.75	3.50
1200	2.25	2.40	3.60	2.00	4.00
1400	2.40	2.50	3.75	2.20	4.40
1500	2.50	2.60	3.90	2.25	4.50

3. SETTLEMENT CALCULATION

SAFE software helps us to model, analyze and design various types of foundation. This software gives us option of importing files from other analysis software such as E-TABS. The analysis file from E-TABS software is imported to SAFE software to analyze it for settlement.

Data for the analysis of the footings considered is as follows:

Modulus of elasticity = 60000 kN/m² For Dense Sand
= 75000 kN/m² For Stiff Clay
= 150000 kN/m² For Gravely Soil
Poisson's ratio = 0.25
Weight per unit volume of concrete = 24 KN/m³
Thickness of footing = 1000 mm
Allowable bearing capacity = 440 KN/m² For Dense Sand
= 150 KN/m² For Stiff Clay
= 245 KN/m² For Gravely Soil
Minimum yield stress of rebar Fy = 415 N/mm²
Concrete strength Fck = 20 N/mm²
Subgrade Modulus = 8000 KN/m³ For Dense Sand
= 3000 KN/m³ For Stiff Clay
= 4900 KN/m³ For Gravely Soil

Using this data the footings are modeled & analyzed in SAFE Software & the settlements are tabulated for each of the footings.

Table number 7: Settlements for Dense Sand.

LOAD (kN)	SQUARE (mm)		RECTANGLE(L/B=1.5) (mm)		RECTANGLE(L/B=2) (mm)	
	1 m Depth	1.5 m Depth	1 m Depth	1.5 m Depth	1 m Depth	1.5 m Depth
600	49.80	48..53	46..60	41.34	32.53	31..18
900	49.00	47.60	45.00	43.64	31.20	29.84
1200	51.22	49.90	46.60	45.24	32..56	31.21
1400	56.87	55.50	53.70	52.40	36.12	34.82
1500	53.00	51.70	44.90	43.53	34..80	33.43

Table number 8: Settlements for Stiff Clay.

LOAD (kN)	SQUARE (mm)		RECTANGLE(L/B=1.5) (mm)		RECTANGLE(L/B=2) (mm)	
	0.75 m Depth	1 m Depth	0.75 m Depth	1 m Depth	0.75 m Depth	1 m Depth
600	61.10	57.56	60.11	56.56	59.72	55.80
900	61.03	57.40	62.50	58.94	62.43	58.50
1200	61.84	58.31	60.84	57.30	64.43	60.54
1400	68.93	65.38	70.97	67.42	69.93	66.00
1500	67.51	63.86	68.75	65.21	65.87	61.95

Table number 9: Settlements for Gravely Soil.

LOAD (kN)	SQUARE (mm)		RECTANGLE(L/B=1.5) (mm)		RECTANGLE(L/B=2) (mm)	
	0.8m Depth	1m Depth	0.8m Depth	1m Depth	0.8m Depth	1m Depth
600	38.20	36.58	36.80	35.24	36.52	34.95
900	36.66	35.07	37.20	35.60	36.15	34.60
1200	38.10	36.51	34.92	38.10	38.36	36.78
1400	42.41	40.83	42.97	41.40	41.47	39.88
1500	40.46	39.07	36.72	40.66	39.94	38.36

4. RESULTS & DISCUSSIONS

Effect of Modulus of Elasticity (E) of the Soil on Settlement:

As the 3 soils considered here have different Modulus of Elasticity values the settlement values also varies. The Modulus of Elasticity & the Settlement are inversely proportional to each other. Dense Sand and Stiff clay have undergone settlements more than 50mm when the depth of the foundation provided is less than minimum depth of foundation. As the Modulus of Elasticity value for gravely soil is high the amount of settlement for the footings provided is small and it is in the range of 25 to 30 mm only.

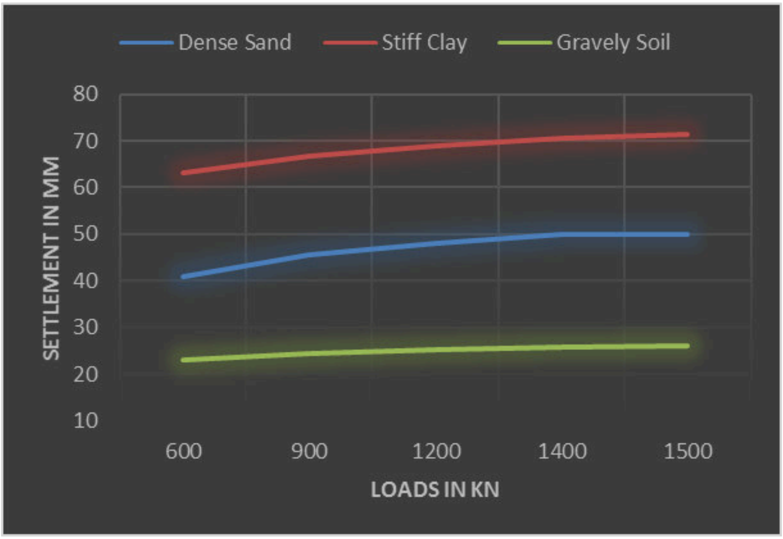

Figure number 2: Effect of Modulus of Elasticity (E) on Settlement

Effect of Shape of Foundation on Settlement:

The settlement of the foundation also varies with the shape of the foundation. In this case study 3 types of shapes of the foundation are considered, Square, Rectangle with (L/B=1.5) & Rectangle with (L/B=2) but the variation observed is very small in amount. The Square footings undergo larger amount of settlement as compare to rectangle footings. In rectangle footing also footings having higher (L/B) ratios undergo lesser amount of settlement as compared to footings having smaller (L/B) ratios.

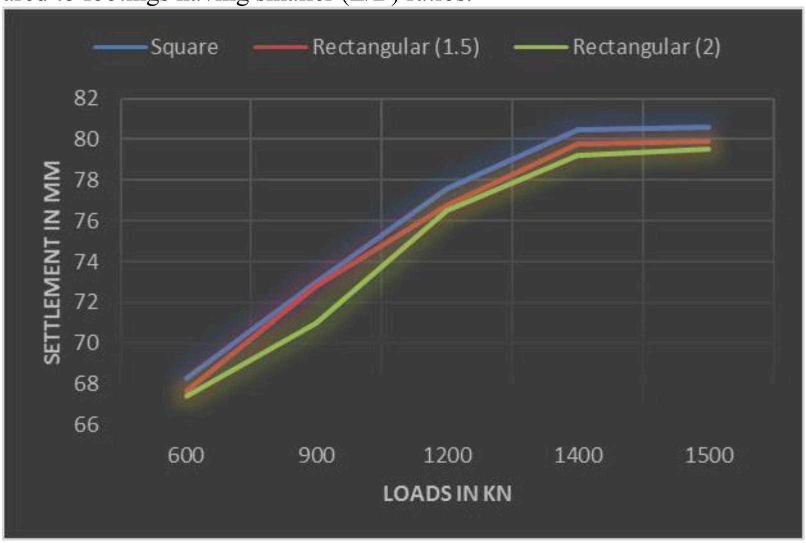

Figure number 3: Effect of Shape of Foundation on Settlement

Effect of Depth of Foundation on Settlement:

The settlement of the foundation varies significantly with the Depth of the Foundation. In this case study the depth of the foundation is provided lesser and greater than minimum depth of foundation. The amount of settlement occurred is lesser when the depth provided is greater than minimum depth of foundation as compared to depth of the foundation provided lesser than minimum depth of foundation.

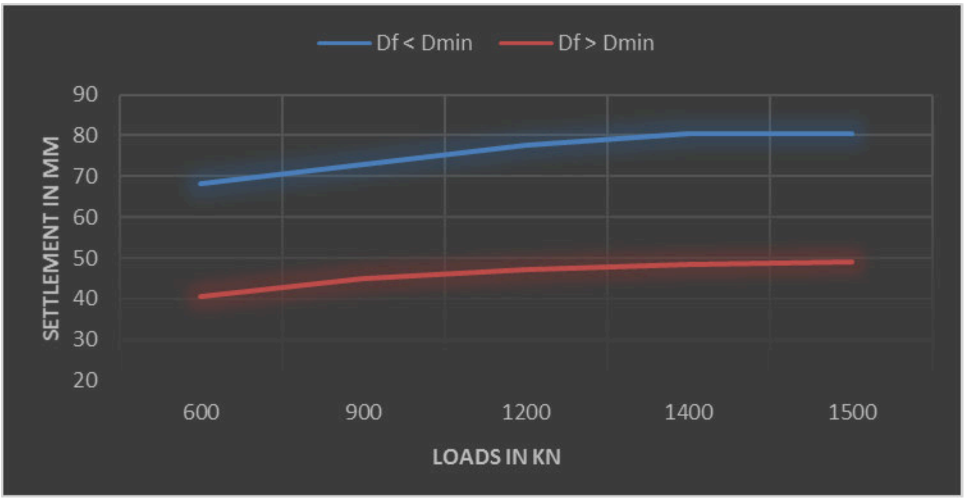

Figure number 4: Effect of Depth of Foundation on Settlement

5. CONCLUSION

- It is seen that depth of the foundation and settlement are inversely proportional to each other. Whenever the depth of the foundation is provided lesser than minimum depth of foundation the settlement is more. So it is advisable that the depth of the foundation should be kept more than minimum depth of foundation.
- There is not much significant variation seen in the settlement values for square shape footings and rectangular shape footings but rectangular footings gives lesser settlement values as compared to square footings.
- The settlement values for the stiff clay soil are high as compared to gravelly soil it is advisable to change the type of footing provided. For these soils having low SBC values Raft foundation turns out be economical and safe.

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