Study Simulation of Raft Foundation Using SAFE Software

Prepared By

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Abstract

Raft (mat) foundation design should be safe according to settlement. The most critical criteria and important value in the process of shallow foundation design is settlement. Raft foundation is posttensioned or reinforced slab on grade including all the concrete walls and columns inside the structure. Mat foundation decrease differential settlement while differential movement resisted by the concrete slab between position of loading. The soil-structure interaction issue is considered by a structure. Hence, the mat foundation behavior is more complicated in nature and usually computer modeling is used, the technique finite difference and finite element are the best solution for getting the accurate result. Understanding of the design variables on the reaction is the main factor to model mat foundation. In order to estimate the settlement beneath mat foundation 36 sample were modeled without considering the effect of water pressure beneath the raft foundation. The most effective parameters are the soil modulus of subgrade, and concrete modules of elasticity and the models show increasing of steel ration inside the raft had no effect on settlements and the extension of the raft from the edge of the columns had significant effect of the shape of the settlement.

Keywords: Finite element; Raft foundation; Settlement; Stress-strain

1. Introductions

In order to safely design mat (Raft) foundation, both bearing capacity and settlement shall be carefully examined. Bearing capacity needs to be investigated so that the foundation is safe against soil failure, while settlement shall be determined in order to be within the tolerant limit. It is generally believed that settlement is more critical than bearing capacity in designing shallow foundations. This can be seen no more clear than in pad or strip footing especially in these footings with width greater than 1.5 m which the maximum allowable settlement is limited to 25 mm (Terzaghi, Peck et al. 1996). For estimating the settlement of shallow foundation, forty different methods were reported (Douglas and French 1986). All these methods were clearly showed that the soil stiffness, applied pressure and foundation width are among the most effective factor that influencing the settlement of mat foundation.

The soil stiffness is measured using penetration resistance namely blow count from standard penetration test or tip resistance from cone penetration test(Das and Sivakugan 2007). However, the calculation of settlement is a complicated process particularly using finite element method FEM because the geometry and material of the building are generally complex. Therefore, the Empirical method can be found in literature so as to find the critical settlement. This empirical method has many disadvantages such as isolation of settlement-induced damage from other sources and lack of complete and measured analysis(Grant, Christian et al. 1974, Walhls 1981). These limitations are among the most effective factors that the numerical simulation shall be used in order to determine the settlement of the mat foundation (Augarde 1997, Potts and Addenbrooke 1997, Burd, Houlsby et al. 1998, Rots 2000). There are many challenges that shall be considered in using FEM. Firstly, the geometry of the foundation such as depth, length and width of the foundation. Secondly, the material properties such as modules of elasticity of concrete and soil modules of sub-grade. Finally, the boundary conditions (Roca 1997, Atamturktur, Hemez et al. 2012). These parameters are more precisely shall be used in case when the building and foundation are irregular as well as the material properties are randomly changed in all three directions (X, Y, Z). In addition, because of having the uncertainty in the interaction between foundation and supporting soil (Lourenço 2002, Lourenço 2006, Atamturktur, Hemez et al. 2012). The data collected in the site shall be incorporated to avoid the potential mistake in the inputting data parameters (De Sortis, Antonacci et al. 2005, De Stefano 2007, Gentile and Saisi 2007, Prabhu, Atamturktur et al. 2014). The value of settlement can be varied due to the variation in soil under mat foundation. So, the estimation of the mat foundation settlement is facing many challenges such as the history of stress-strain of the soil, the distribution of applied stress, the difficulty in getting undistributed samples of cohesion less soil and the influence of soil compressibility (Shahin, Jaksa et al. 2000). Types of settlement can be classified such as uniform settlement, tilt and non-uniform settlement. Each of these settlements can influence one type of structure. For example, uniform settlement is not very critical for buildings, while it has a significant impact on drainage or interface with utilities. However, the non-uniform settlement has a negative influence on the building structure that causes the structural distortion namely cracking of super structure and non-structural elements. Any movement in the structure can cause cracks in all floors of the buildings. Whereas, there are some structures that significantly affected by tilt settlement such as tank, towers and rigid structures(Basu and Salgado 2014, Altaie, Al-Ansari et al. 2015). The unexpected consolidation can lead to excessive or differential settlements. The stress-strain behavior of the soil can be variable from one place to another place and controlling such behavior is difficult to control. Therefore, simple design method shall be created so as to find the collapse limit and clearly represent the actual behavior of the soil(Osman and Bolton 2004). Standard penetration test (SPT) and cone penetration test (CPT) shall be used to estimate the settlement as well as oedometer and triaxial tests can be used to find the settlement of the soil, which are Laboratory test.(García-Palencia and Santini-Bell

2013, Partazian 2016). However, recently a very sophisticated method has been published in order to estimate the settlement of the mat foundation. The FEM is one of the advance methods for investigating settlement of the mat foundation.

1.1 Aim and objectives

The aim of this study is to determine settlement of mat foundation by using finite element method. The overall objective of the study is to investigate settlement behavior of mat foundation as well as to deter mine the effect of concrete modulus of elasticity, soil subgrade reaction, mat thickness, steel ratio and extension of mat foundation from edge columns on settlement then use a relation between these properties and settlement so as to discover which property have a great effect on mat settlement

2.1 METHODOLOGIES

In this study, the available finite element program Slab Analysis by the Finite Element Method (SAFE) 2016 is utilized to estimate the settlement beneath raft (mat) foundation, as well as the shape of the diagonal settlement. The properties of the analysis of this study are related to a structural of ten story and three bays by three bays raft foundation the load coming from 16 columns in with symmetrical bay of 9 meters as shown in appendix A. Bending moment is negligible because only axial loads are assumed. SAFE software is used to model mat foundation as two dimensional (2D) slabs on detached elastic spring support that is defined as soil modulus of subgrade reaction by using 4 node analyses. Thick plate FE is used to define mat foundation with shear deformation and bending moment capacities. For all case mesh size of 1.0 m x 1.0 m was found appropriate to run the model. Table (1 to 8) summarized raft properties for all cases.

3.1 Results and discussion

3.1.1 Thickness of raft foundation, T

The thickness of raft foundation of this study is presented in Table (1 to 8). The variation of data was from 700 mm to 1000 mm with a mean of 850 mm, standard deviation of 108 and COV of 0.127 as summarized in Table 1.

3.1.2 Concrete modulus of elasticity, E

The modulus of elasticity of this study is presented in Table (1 to 8). The data was varied from 18.2 GPa to 27.80 GPa with a mean of 22.86 GPa, standard deviation of 3.50 GPa and COV of 0.15 as summarized in Table 1.

3.1.3 Soil subgrade modulus, Ks

The Soil subgrade modulus of this study varied from $7.2*10^3$ kN/m^3 to $7.2*10^3$ kN/m^3 with average of $13.7*10^3$ kN/m^3, standard deviation of $5.30*10^3$ kN/m^3 and COV of 0.38 as presented in Table 1.

3.1.4 Steel Ratio, ρ

The value of steel ratio used in this study was from 0.0035 to 0.021 which is summarized in table (1 to 8). The statistical analysis of steel ratio was presented in table 1 and the mean, standard deviation COV was 0.53, 0.0065 and 0.0123 respectively.

3.1.5 Relationships Between Settlement and Raft thickness

The relationship between width of Raft thickness with Settlement by fixing concrete modulus of elasticity 21.019 GPa, soil subgrade modulus 7.20 $*10^3$ KN/m^3 were quantified using (Eq. 1) as shown in Figure 1. and the outline of the foundation was with the edge of the columns. The change in the X with Y was represented using relationship (Eq. 1) it can be seen that by increasing raft thickness**,** decreased Settlement and the model parameters A and B are summarized in Table 2. The coefficient of determination (R^2) for the relationship was 0.97 as summarized in Table 2.

$$\Delta = 4754.6\ T^{-0.713} \quad (1)$$

3.1.6 Relationships Between Settlement and Concrete modulus of elasticity

The change of Foundation settlement with changing of concrete modulus of elasticity presented in Eq.2 using Finite element method, by fixing of raft thickness 700 mm, soil subgrade modulus 7.20 $*10^3$ KN/m^3 as shown in Figure 2. The change in the X with Y was represented using relationship (Eq. 2) it is clear that by increasing modulus of elasticity the settlement decreased and the model parameters A and B are summarized in Table 2. The coefficient of determination (R^2) for the relationship was 0.89 as summarized in Table 2.

$$\Delta = 133.35\ E^{-0.359} \quad (2)$$

3.1.7 Relationships Between Settlement and Soil subgrade modulus

As Shown in Figure3 the soil subgrade modulus had a significant effect of decreasing settlement. It is clear that the increase of soil subgrade modulus decreased foundation settlement, fixing of raft thickness 700 mm and concrete modulus of elasticity 19.375 GPa. The change in the X with Y was represented using relationship (Eq. 3) and the model parameters A and B are summarized in Table 2. The coefficient of determination (R^2) for the relationship was 0.98 as summarized in Table 2.

$$\Delta = 128.56\ ks^{-0.551} \quad (3)$$

3.1.8 Relationships Between Settlement and Raft foundation steel ratio

The settlement of foundation had no affected by increasing the ratio of steel in the concrete it mean that there are no relation between settlement and steel ratio as shown in Figure 4.

3.1.9 Relationships Between Settlement and Extension of foundation

As represents in Eq. 4 the change of Settlement with changing of foundation outline by extending foundation from the edge of the columns, the value raft thickness 700 mm, concrete modulus of elasticity 21.019 GPa and soil subgrade modulus 7.20 $*10^3$ KN/m^3 as shown in Figure 4. The change in the X with Y was represented using relationship (Eq. 4) it is clear that the increase of foundation area lead to decrease settlement and the model parameters A and B are summarized in Table 2. The coefficient of determination (R^2) for the relationship was 0.96 as summarized in Table 2.

$$\Delta = 44.448\ e^{-0.00005\ Et} \quad (4)$$

3.1.10 Relationships Between Settlement and Diagonals settlement

Figure.5 represented the shape of diagonal settlement for deferent type of extension from the columns; it’s obvious that the settlement shape changed (decreased) with increasing extension and the shape of diagonal settlement become flatter step by step with increasing extension, that is mean the area of the foundation had significant effect of settlement.

3.1.11 Finite element mesh

Figure.6 and Figure.7 show the finite element mesh use to predict settlement the program automatically use soft mesh at the constrained load locations compare to the unloaded area.

4. Conclusions

In this Study, the effect of soil and concrete properties on settlement by using finite element program (SAFE) was investigated. Based on finite element data the following conclusion was reached:

1. Raft thickness had a moderate effect on raft settlement, increasing thickness 40% caused to reduce settlement 50%.
2. Both of concrete modulus of elasticity and soil subgrade reaction had a significant effete on reducing raft settlement. Concrete modulus of elasticity, soil subgrade reaction had a negative relationship with raft settlement.
3. Concrete raft steel ratio had a negligible effect on raft settlement
4. The extension of the raft foundation significantly affects settlement. More extension caused the shape of settlement flatter.
5. Based on the coefficient of determination (R^2). The linear and nonlinear models predicted the change of predicted settlement.

Recommendation

I recommend to compare two or more finite element software data in order to know the reliability of the software and adding seismic effect on the settlement by using different software in future work.

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Table 1. Statistical Variation of the study

	Statistical Parameters	T, (mm)	E, (GPa)	Ks *10^3, (kN/m^3)	ρ
Settlement	Range	700 - 1000	18.2 – 27.8	7.2 - 21	0.0035 – 0.021
	Mean (μ)	850	22.86	13.70	0.0123
	Std. Deviation (σ)	108	3.50	5.30	0.0065
	COV (%)	12.7	15	38	53

Table 2. Model parameters for the study

Depended Variable (Y-axis)	In depended Variable (X-axis)	A	B	R^2	No. of Data	Figure No.
Δ, mm	T, mm	4754.6	-0.713	0.97	7	Figure1
Δ, mm	E, GPa	133.35	-0.359	0.89	7	Figure2
Δ, mm	Ks, kN/m^3	128.56	-0.551	0.98	6	Figure3
Δ, mm	ρ	No relationship observed			5	Figure4
Δ, mm	Et, mm	44.448	-0.00005	0.96	8	Figure5

Table 3 Effect of Variation of Raft thickness on Settlement

Story	Columns (mm)	Raft thickness, T (mm)	Extension from columns, mm	E concrete, (Gpa)	Ks $*10^3$ (kN/m^3)	ρ	Δ (mm)
10	800X800	700	0	21.019	7.2	0.0035	45
		750					42.5
		800					40
		850					38
		900					38
		950					36
		1000					34.5

Table 5 Effect of Variation of concrete modulus of elasticity on Settlement

Story	Columns (mm)	Raft thickness, T (mm)	Extension from columns, mm	E concrete, (GPa)	Ks $*10^3$(kN/m^3)	ρ	Δ (mm)
10	800X800	700	0	18.2	7.2	0.0035	48
				19.375			45
				21.019			45
				23.025			42.5
				24.87			42.5
				25.742			42.5
				27.805			40

Table 6 Effect of Variation of soil Subgrade modulus on Settlement

Story	Columns, (mm)	Raft thickness, T (mm)	Extension from columns, mm	E concrete, (GPa)	Ks $*10^3$, (kN/m^3)	ρ	Δ (mm)
10	800X800	700	0	21.019	7.2	0.0035	45
					9		37.5
					12		32
					15		28
					18		26
					21		25

Table 7 Effect of Steel ratio on Settlement

Story	Columns, (mm)	Raft thickness, T (mm)	Extension from columns, mm	E concrete, (GPa)	Ks *10^3, (kN/m^3)	ρ	Δ (mm)
10	800X800	700	0	21.019	7.2	0.0035	45
						0.007	45
						0.0105	45
						0.014	45
						0.0175	45
						0.021	45

Table 8 Effect of Extension from columns on Settlement

Story	Columns, (mm)	Raft thickness, T (mm)	Extension from columns, mm	E concrete, (GPa)	Ks *10^3, (kN/m^3)	ρ	Δ (mm)
10	800X800	700	0	21.019	7.2	0.0035	45
			100				42.5
			200				40
			400				36
			600				31
			800				28.5
			1000				26
			1200				24

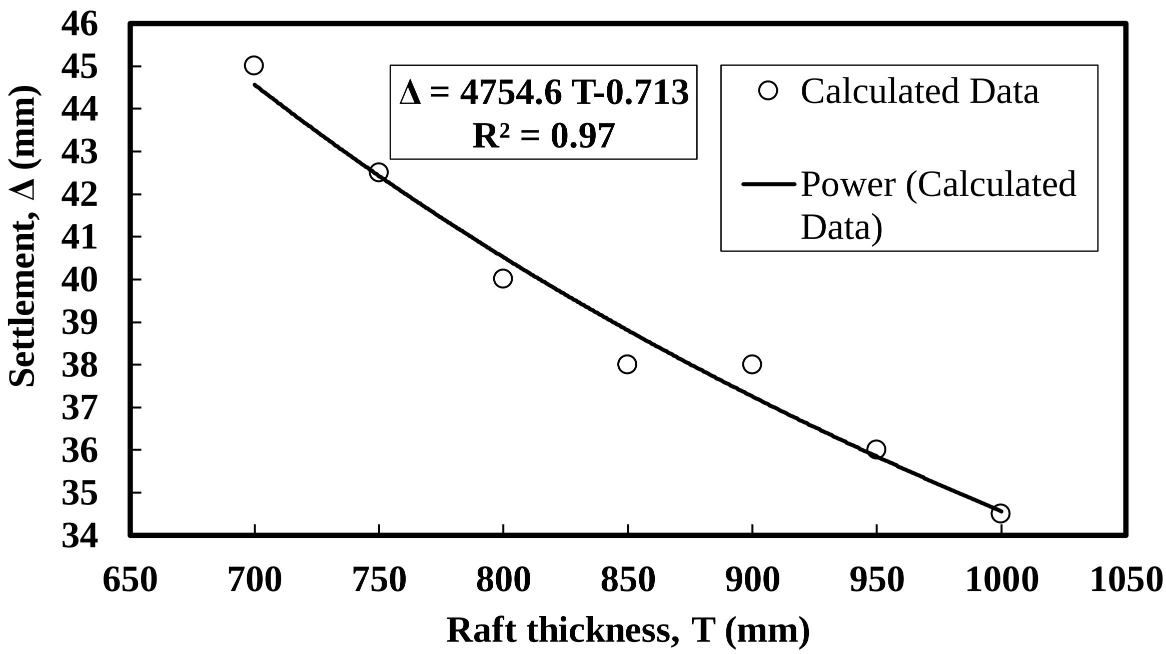

Figure 1: Settlement with Raft thickness

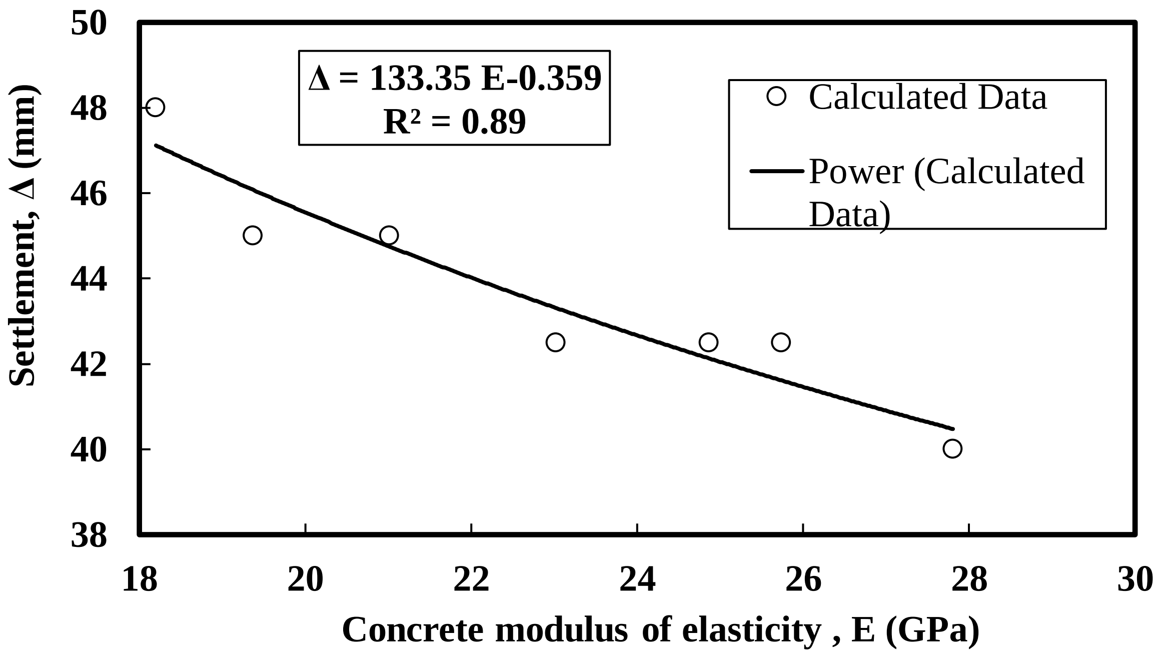

Figure 2: Settlement with Concrete modulus of elasticity

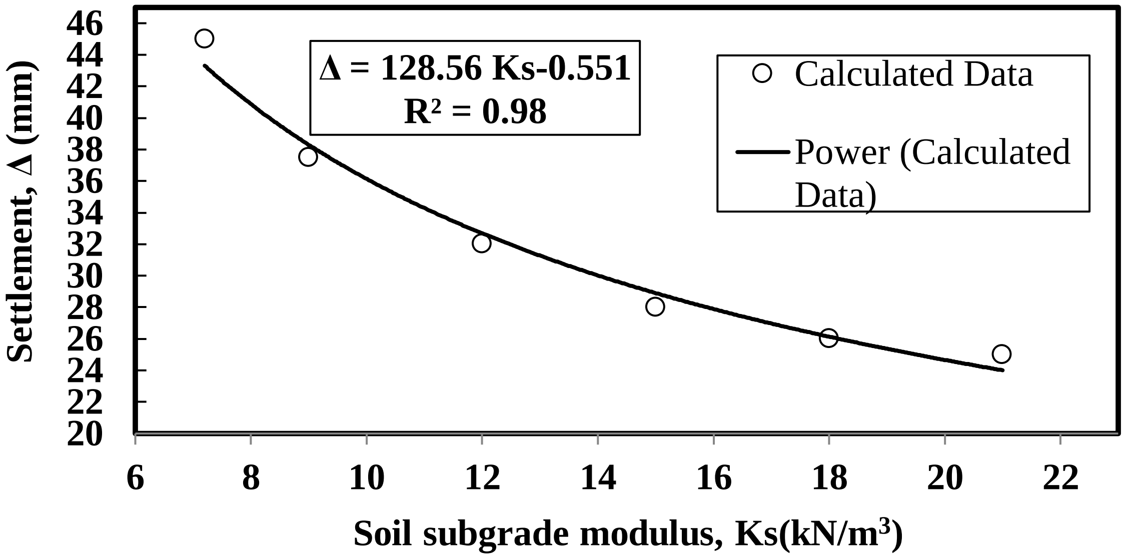

Figure 3: Settlement with Soil subgrade modulus

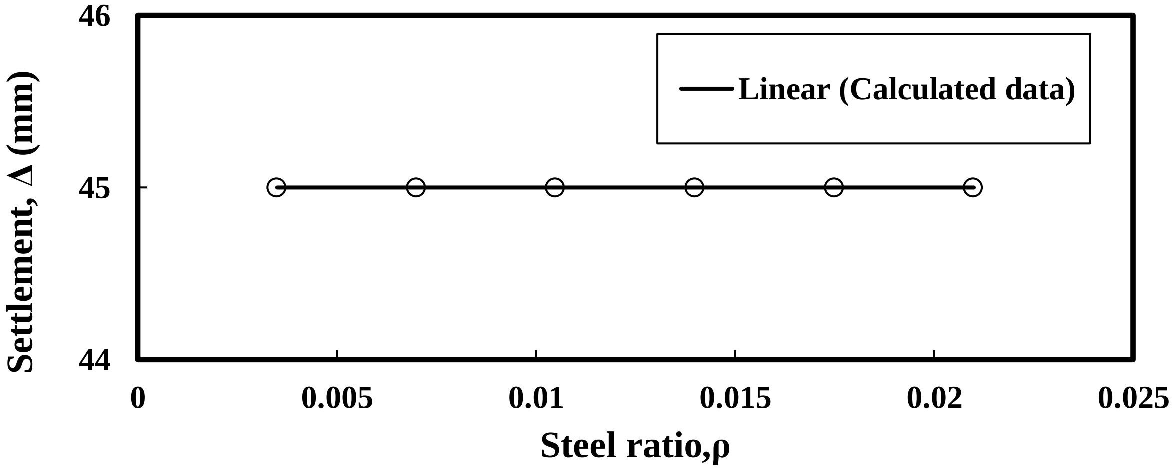

Figure 4: Settlement with Steel ratio

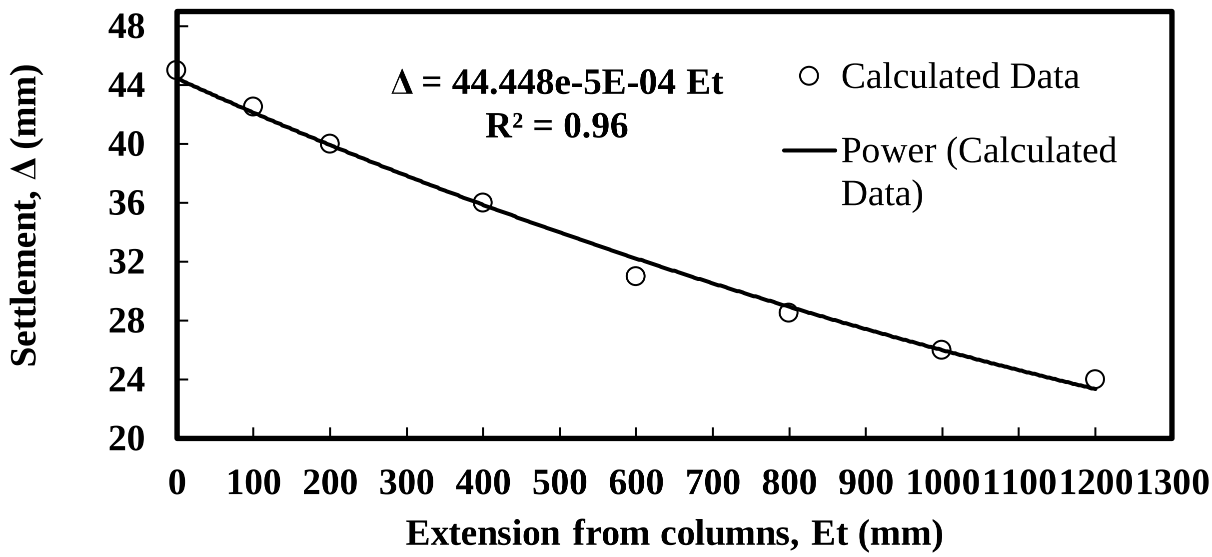

Figure 5: Settlement with Extension from columns

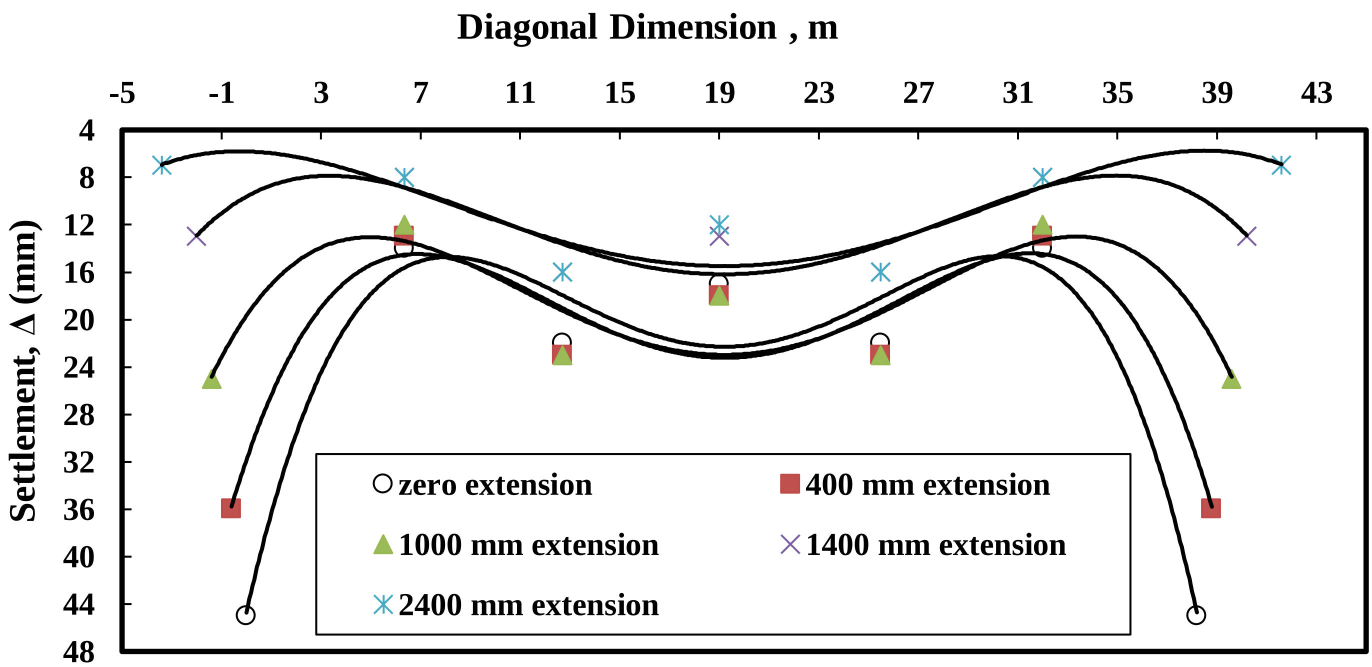

Figure 6: Settlement with Different type of extension from columns

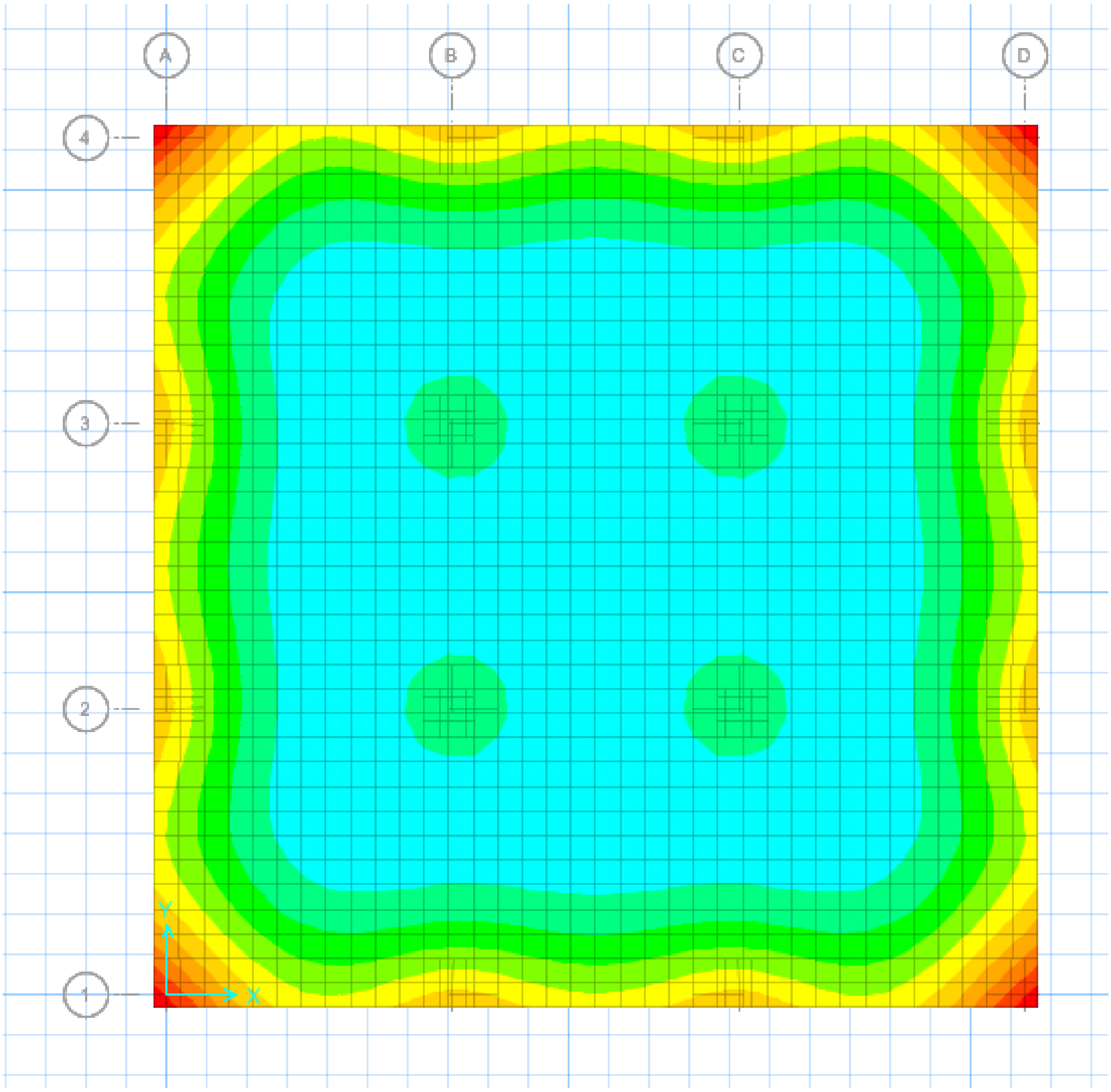

Figure 7: Finite element mesh used to predict raft settlement

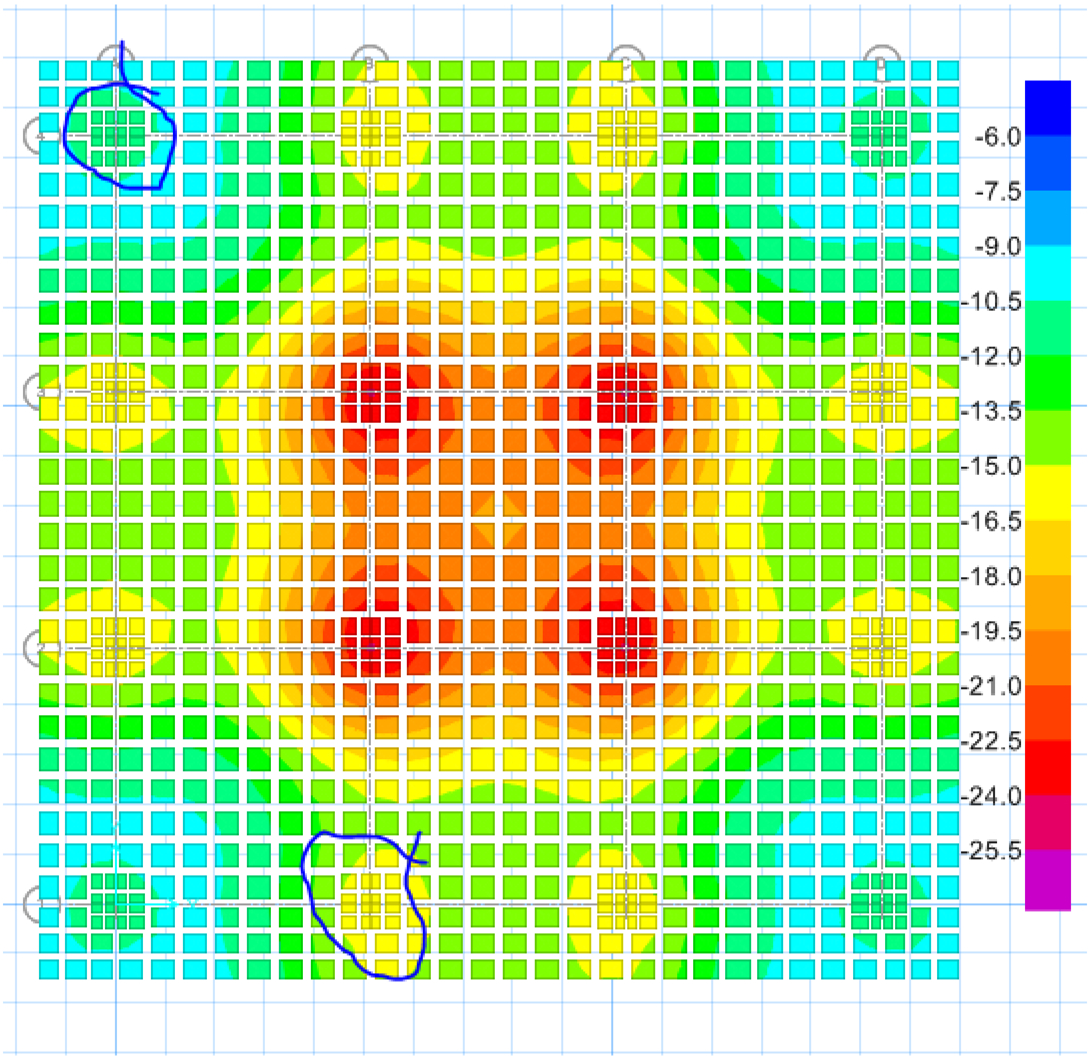

Figure 8: soft mesh used at concentrated load

Appendix A

3D model for 10 story building