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PERSPECTIVE

Comparative study of the foundation model of a 220 kV transmission line tower with different footing steps - Finite element analysis

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Abstract

Transmission line towers are structures commonly used to support the phase conductors and shield wires of a transmission line. The present work describes the analysis of the superstructure and substructure of a 220 kV transmission line tower. The tower is a self-supporting three-dimensional type and designed for a height of 33.25 m, which is the usual height of supporting conductors to transmit power one point to another in Andhra Pradesh. The superstructure of the transmission line tower has been analyzed considering wind loads as per codal provisions IS 802:2002. Reactions obtained from the results in each leg of a transmission line tower at the base have been considered as forces for the finite element analysis of the substructure system. The analysis has been carried out using Ansys Workbench by considering the finite element analysis concept with solid 65 as an element for concrete footsteps and a truss element for steel sections. Various parameters like deformation & stresses are observed in the stub angle section and foundation system with five footing steps to study the compare the results between different footsteps of a foundation model. Numerical analysis, such as the finite element method, has enabled the prediction of stresses of the foundation of the transmission line tower.

Keywords: Base reactions, Finite element analysis, Soil structure analysis, Concrete footing steps, Stub angle.

Introduction

Recently, there has been growing interest in the use of transmission line towers for carrying electrical power from one corner to another corner of the world. Transmission lines are, as of today, a lot of overhead conduits and a ground wire which carry the electrical energy as high voltage current. Supporting structures are built at spans to keep these lines at an unmistakable range from the beginning. These structures are known as transmission posts or towers. The structure engineer is endowed with the testing position of planning and developing transmission structures to help weighty conductor loads in open climates with a serious extent of unwavering quality.

They discussed that the commonly used transmission line tower systems are the poles and the lattice frame system. The poles can be economical for a relatively shorter span and lower voltage. The approach that Lattice frame systems are being used for carrying the high voltage conductor. The lattice tower members typically consist of steel or aluminum angle sections. The primary members of the lattice tower are the leg, horizontal, cross arms and bracing members. They carry the vertical and shear loads on the tower and transfer them to its foundation. Secondary or redundant bracing members are used to provide intermediate support to the primary members to reduce their unbraced length and increase their load-carrying capacity D. G. Fink *et al.* (1978), S. J. Fang(1999).

All the authors came to the conclusion that "Most of the latticed towers presently in service around the world were analyzed as a space truss. Each member of the lattice tower is assumed to be pin-connected at its joints carrying only the axial load and no moment (linear ideal truss analysis). The tower is designed to carry either axial compression or

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tensile force. The full-scale transmission line tower tests give larger deflection than the theoretical linear elastic analysis. Also, it was found that almost 25% of the towers tested failed below the expected loads and often at unexpected locations. Additionally, the results showed that the local buckling occurred as a result of the bending moment caused by unbalanced deformation as well as axial compression" S. Roy (1984), W. Peterson (1962), M. Marjerrison (1968), B.-W. Moon (2009);.

Several researches developed numerical and theoretical models to represent the transmission line tower. Developed non-linear numerical analysis using finite element method to study the behavior of the main leg members of the tower Prasad Rao and Kalyanaraman (2001).

He has modeled and analyzed the superstructure and presented the results. The results are used in this paper for analysis of foundation model Ch. Sudheer *et al.* (2013), Sudheer Choudari *et al.* (2019).

Development of foundation Model

A foundation model with different step sizes has been developed for predicting the deformations and stresses in the concrete foot steps and stub angle steel section at the top of the finite element foundation model. Development of model involves various stages, which are discussed in the following sections:

Methodology

The foundation has been modeled by using Ansys Workbench version 18 in the present work by performing Finite Element Analysis.

For the foundation model, concrete material values of Young modulus, Poisson's ratio, density, and ultimate tensile strength have been used from the experimental analysis. Steel material was also considered from the experimental data with the following parameters: Young modulus, Poisson's ratio, density, ultimate tensile strength, and Strain life criteria.

Finite element (FE) model

FE model with boundary conditions is shown in Figure 1. The foundation has been modeled using solid 65 element. The stub angle at the top of the footing embedded into the concrete has been modeled using Link 180. These elements have 3 degrees of freedom at each node. The link element is well selected for large rotation or large strain non-linear application.

The bottom of FE foundation model is a fixed edge constraining all displacements. A pressure load of 0.15 MPa was applied on the bottom surface of FE foundation model to represent the soil which undergoes a vertical deformation of 40 mm considering soil modulus of 9000 kN/m^3.

To represent the support condition as fixed, all degrees of freedom (Ux, Uy, Uz) have been restrained. The

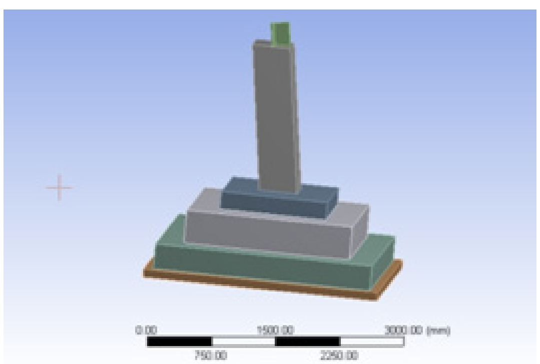

Figure 1: Finite Element foundation model of transmission line tower

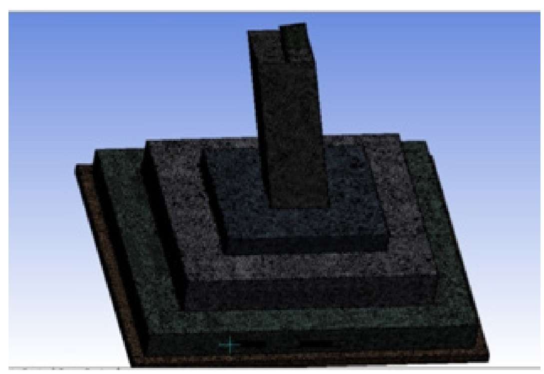

Figure 3: Meshing diagram of finite element foundation model with stub angle section

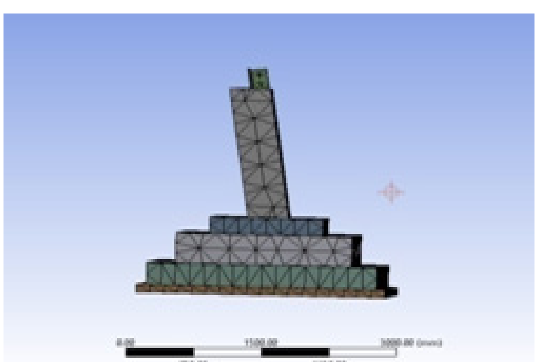

Figure 2: Meshing diagram of finite element foundation model with stub angle section (160 mm mesh size)

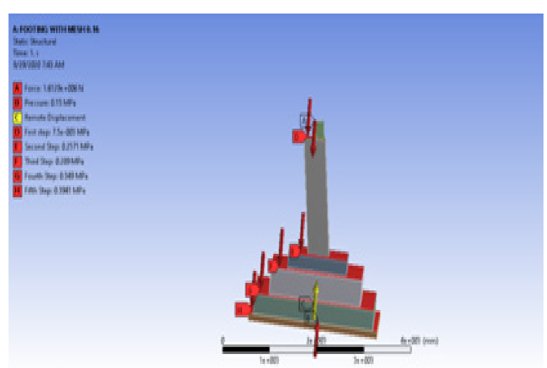

Figure 4: Forces acting on the finite element foundation model with stub angle section (10 mm mesh size)

transferred loads on the FE foundation model were found from the geometric condition of the transmission line tower subjected to the lateral loads and cable load on the tower structure. Load is applied on the top of stub angle as axial compression.

Rx= -3.2416e+005N, Ry=-1.58e+006 N which are the load obtained at the base of each leg of a transmission line tower analyzed separately.

The foundation selected for the analysis has the dimensions of the first concrete footing step 2550 x 2550 x 300 mm, the second concrete footing step 1950 x 1950 x 400 mm, the third concrete footing step 1250 x 1250 x 200 mm, the fourth concrete footing step 710 x 710 x 1700 mm, respectively connecting to the stub angle equal section 200 x 25 x 2204 mm (Figures 2 and 3).

The foundation with different footing steps is discretized using mesh sizes ranging from 10 to 200 mm. A load of Rx= -3.2416e+005N, Ry=-1.58e+006 N is applied incrementally as 50 load steps on the top of the stub angle and is shown in Figure 4.

Newton–Raphson method has been used to facilitate the non-linear analysis for solution convergence, i.e., force Convergence, moment convergence, and displacement convergence. In the non-linear analysis Von Mises yield criteria is used in this analysis. A number of studies have been conducted on the foundation model to estimate the number of elements in each direction which gives a constant deformation.

The details of the foundation model are presented in Table 1.

Validation

The details of the validation model are presented in Table 2, whereas the results of the validation model are presented in Table 3.

The comparative analysis between the example considered manual calculation and Software for the validation model is presented in Table 3.

The validation model is shown in Figure 5 and the loads acting on the model is presented in Figure 6. Also, deformation & stresses obtained in the foundation model with footing steps are presented in Figures 7-11. Results obtained from the analytical calculations (Ref 19: NPTEL Problem 1) are compared well with the results obtained from the finite element model.

Table 1: Details of the finite foundation model

Member type	*Dimension*	*Grade*
Stub angle section	200 x 25 x 2204 mm	FE415
First concrete footing step	1714 x 1714 x 712.4 mm	M25
Second concrete footing step	1250 x 1250 x 213.83 mm	M25
Third concrete footing step	1950 x 1950 x 401 mm	M25
Fourth concrete footing step	2550 x 2550 x 299 mm	M25
PCC concrete bed	2750 x 2750 x 100 mm	53 Grade Cement

Table 2: Details of the validation model

Member type	*Dimension*	*Grade*
First concrete footing step	400 x 400 x 330 mm	M25
Second concrete footing step	1250 x 1250 x 650 mm	M25
	Loads acting on the member	
Size of the first concrete step footing	600 N	
Upward thrust on the bottom footing	0.294 MPa	

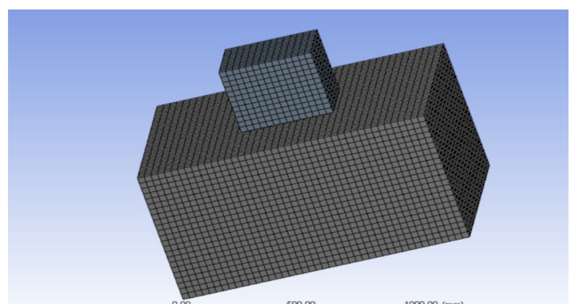

Figure 5: Validation model

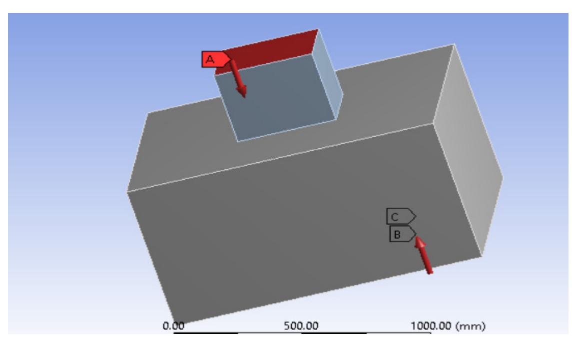

Figure 6: Loads applied on the validation model

Table 3: Results of validation model considered

Member Type	*Deformation (mm)*		*Von Mises stresses (MPa)*	
	Analytical calculations (NPTEL Problem)	*Analytical model (Ansys workbench)*	*Analytical calculations (NPTEL Problem)*	*Analytical Model (Ansys workbench)*
First concrete footing step	-4.22e-5	-4.333e-5	0.10271	0.10571
Second concrete footing step	-1.388e-5	-1.486e-5	0.00358	0.00458

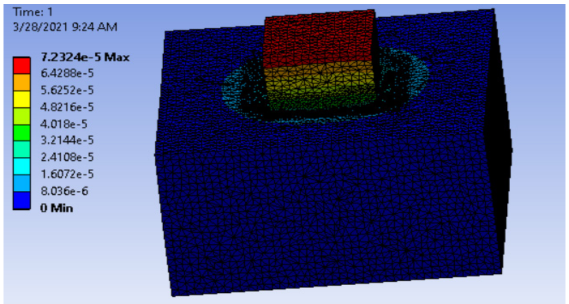

Figure 7: Deformation in validation model

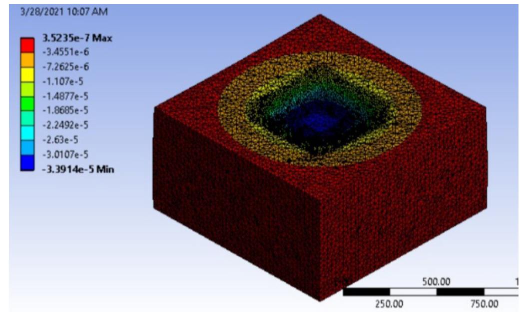

Figure 11: Vertical deformation of second concrete footing step of validation model

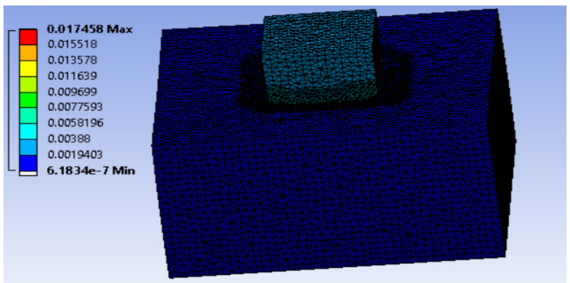

Figure 8: Von Mises stress in validation model

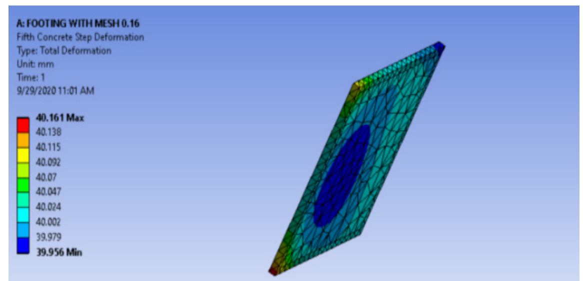

Figure 12: Deformation of first footing step of FE foundation model for the mesh size of 0.16 m

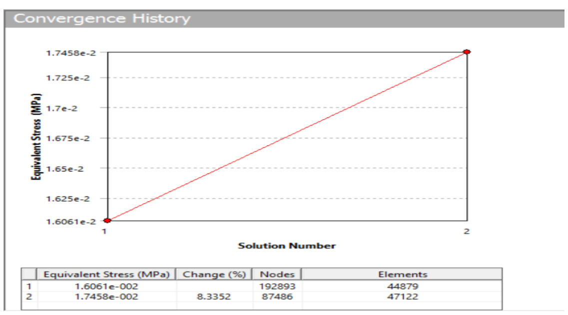

Figure 9: Stress convergence of validation model

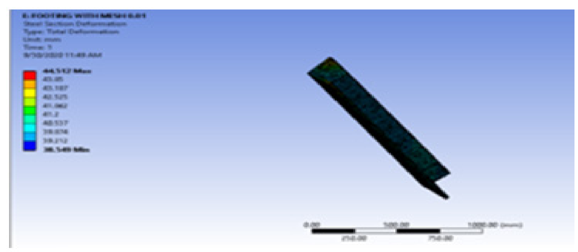

Figure 13: Deformation of stub angle section of FE foundation model for the mesh size of 0.01 m

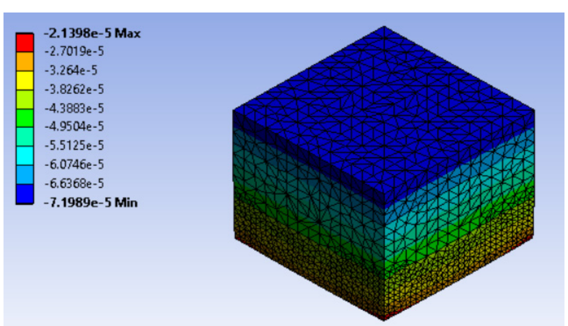

Figure 10: Vertical deformation of first concrete footing step of validation model

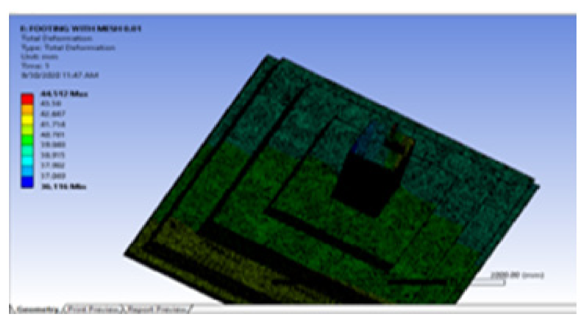

Figure 14: Total deformation of the footing model for the mesh size of 0.01 m

Results and Discussion

Finite element analysis has been carried out on foundation model with stub angle section after meshing and loading the model. The following parameters are considered for the foundation model of 220 kV transmission line tower.

Deformation

Deformation observed in stub angle section and concrete footing steps for different mesh sizes are evaluated to study the behavior of the foundation model considering soil-structure interaction at the base of the footing.

Table 4: Values of deformation of concrete foundation model with different footing steps for different mesh sizes

Deformation of foundation model										
Mesh Size(m) / Member type	*0.01*	*0.02*	*0.03*	*0.04*	*0.05*	*0.06*	*0.07*	*0.08*	*0.09*	*0.1*
Total deformation	44.512	44.681	44.409	44.193	44.004	43.772	43.721	43.659	43.496	43.635
Stub angle steel section	44.512	44.681	44.409	44.193	44.004	43.772	43.721	43.659	43.496	43.635
first footing step	42.022	42.132	42.177	42.13	42.12	42.121	42.101	42.084	42.075	42.086
second footing step	40.542	40.148	40.167	40.154	40.144	40.147	40.14	40.138	40.139	40.14
third footing step	40.859	40.041	40.084	40.023	40.019	40.033	40.018	40.013	40.017	40.017
fourth footing step	41.158	40.185	40.083	40.106	40.11	40.096	40.109	40.129	40.11	40.108
fifth footing step	41.308	40.256	40.09	40.17	40.173	40.158	40.17	40.192	40.17	40.167
Mesh / Member type	*0.11*	*0.12*	*0.13*	*0.14*	*0.15*	*0.16*	*0.17*	*0.18*	*0.19*	*0.2*
Total	43.695	43.59	43.832	43.784	43.703	43.683	43.682	43.466	43.465	43.364
stub angle steel section	43.695	43.59	43.832	43.784	43.703	43.683	43.682	43.466	43.465	43.364
first step concrete	42.079	42.074	42.075	42.07	42.054	42.053	42.053	42.032	42.032	42.032
second step concrete	40.139	40.137	40.137	40.137	40.135	40.133	40.133	40.131	40.131	40.13
third step concrete	40.017	40.016	40.016	40.016	40.016	40.016	40.015	40.015	40.015	40.016
fourth step concrete	40.107	40.108	40.106	40.106	40.105	40.104	40.104	40.103	40.103	40.101
fifth step concrete	40.167	40.167	40.163	40.164	40.16	40.161	40.158	40.159	40.158	40.155

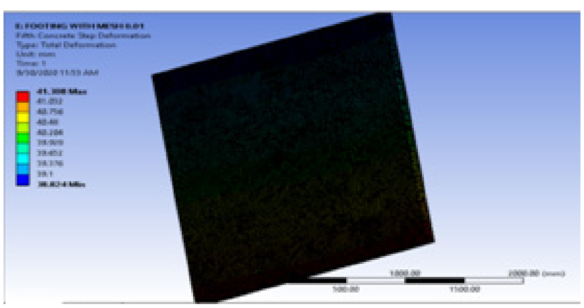

Figure 15: Deformation of fifth concrete footing step of the footing model for the mesh size of 0.01m

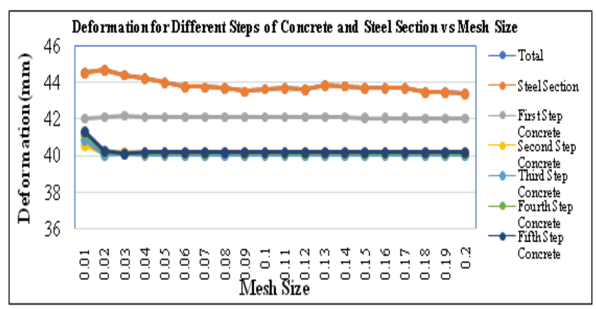

Figure 16: Variation of Deformation of stub angle steel section and footing steps of FE foundation model with different mesh sizes

The values of the deformation observed in different elements are presented in Table 4 for different mesh sizes. From the results, it is observed that the deformation observed in the stub angle steel section and five concrete footing steps are 44.681, 42.132, 40.148, 40.041, 40.185, and 40.256, respectively.

From Figures 12-16, it is observed that maximum deformation is found at the middle of the foundation model with a maximum value of 42.132 mm.

However total deformation of the foundation model with footing steps along with stub angle section is observed to be maximum at 44.681 mm at Node number 445 for 20 mm mesh size. As values observed are consistent and meet the convergence criteria with 20 mm mesh size, the footing model with 20 mm mesh size is considered as standard model.

Stresses

The finite element analysis results show good agreement with analytical calculations. Figures 17-19 show the Von Mises Stresses occur at the bottom face of the foundation model having five footing steps with stub angle section.

The Von Mises stresses are observed in the Stub angle section. The first, second, third, fourth and fifth step footings of the standard model are 1834.8, 634.26, 147.19, 130.27, 23.146, and 5.0547 N/mm^2, respectively by considering the convergence criteria.

The variation of Von Mises stresses with different mesh sizes is drawn for the stub angle section and five different footing steps and is presented in Figure 19 and Table 5.

Von Mises stresses observed to be a maximum of 1834.8 N/mm^{2}at node number 72 in the Stub angle section.

Table 5: Stresses in Stub angle steel section and concrete footing steps with different mesh sizes

Von mises stresses of foundation model										
Mesh Size(m) / Member type	*0.01*	*0.02*	*0.03*	*0.04*	*0.05*	*0.06*	*0.07*	*0.08*	*0.09*	*0.1*
Stub angle steel section	2481	1834.8	1287.8	1214.7	1208.8	1128.4	1047.2	1048.3	988.68	962.9
First concrete footing step	960.07	634.26	514.5	449.24	363.79	335.49	332.62	300.64	268.26	272.99
Second concrete footing step	175.15	147.19	108.38	117.99	75.564	78.61	63.149	61.03	45.955	51.706
Third concrete footing step	216.69	130.27	80.38	86.112	70.436	49.42	53.13	53.428	45.15	44.69
Fourth concrete footing step	35.735	23.146	19.07	15.492	13.382	12.041	11.363	10.087	9.9492	8.917
Fifth concrete bed	8.7622	5.0547	4.0022	3.0607	3.34	2.7809	2.5844	2.6271	2.5147	2.4607
Mesh Size(m) / Member type	*0.11*	*0.12*	*0.13*	*0.14*	*0.15*	*0.16*	*0.17*	*0.18*	*0.19*	*0.2*
Stub angle steel section	965.72	934.16	1106.4	1133.2	1157.9	1126.5	1126.5	1133.6	1133.6	1121.2
First concrete footing step	270.21	238.98	231.58	227.83	203.87	196.88	196.86	191.85	191.85	187.75
Second concrete footing step	51.875	45.121	48.401	49.927	47.969	40.333	40.328	37.905	37.905	37.964
Third concrete footing step	38.355	36.019	40.078	37.841	39.489	38.177	38.5	41.546	41.548	36.246
Fourth concrete footing step	8.3753	8.1119	7.7081	7.8342	6.4667	6.6216	6.1225	6.2842	6.1222	5.8147
Fifth concrete bed	2.4409	2.3046	2.2507	2.3036	2.2918	2.2651	2.1985	2.2932	2.1239	2.1714

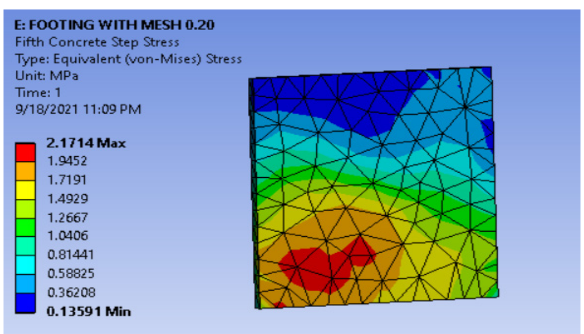

Figure 17: Von mises stress of fifth concrete foot step of FE foundation model for mesh size of 0.20 m

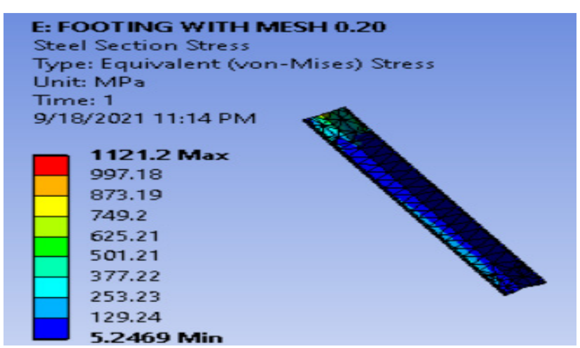

Figure 18: Von mises stress of steel stub angle section of FE foundation model for mesh size of 0.20 m

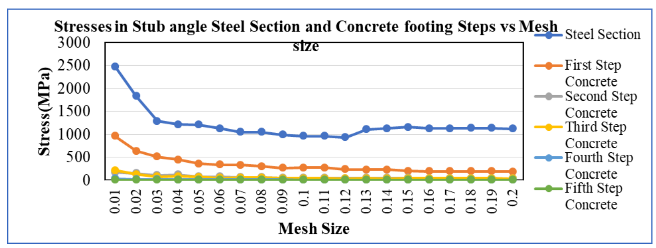

Figure 19: Variation of VonMises of stub angle steel section and footing steps of FE foundation model with different mesh sizes

Whereas for the foundation model with five different footing steps, the maximum Von Mises stresses observed are 634.26 N/mm^2 at node number 11442, 147.19 N/mm^2 at node number 62499, 130.27 N/mm^2 at node number 94234, 23.146 N/mm^2 at node number 112118 and 5.0547 N/mm^2 at node number 207546, respectively.

Von Mises stress in footing steps was observed to be decreased considerably as the mesh size increased.

Conclusion

The following are the conclusion

- The analytical results (manual) are compared well with the values obtained from finite element analysis of the foundation model with 5 footing steps along with stub angle section.
- The foundation model with a mesh size 20 mm shown better deformation values when compared to the foundation model with other different mesh sizes.
- A variation of 5 to 10% in the values of deflection has been observed for the foundation model with different mesh sizes.
- Using finite element analysis by Ansys, a solution for

foundation model with different mesh sizes can be analyzed with footing steps easily considering soil-structure interaction.

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