Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan Vol. 25 No. 3-2020
ISSN:1813-1786 (Print) 2313-7770 (Online)

The Structure Optimization and Analysis of the Power Transmission Towers

S. A. R. Gardezi[1], M. M. A. Bhutta[2]

[1] Department of Mechanical Engineering, University College of Engineering & Technology, BZU Multan, Pakistan,
[2] Department of Mechanical Engineering, University of Engineering & Technology, Lahore, Pakistan.

[1] ss3096939@gmail.com

Abstract- As transmission towers support transmission lines used to transmit the electric load to the farther areas, any structural failure of towers can cause alarming situation. Therefore, there is a need to increase the structural strength of these towers; one such method is through the reliable design of towers. The purpose to conduct this research is to compare the static strength of two 3-D transmission towers of different designs. In first tower, load distribution is preferred vertically while in second tower, it is preferred horizontally. These towers have 221 and 282 nodes and consist of 519 and 735 elements respectively. Material features and element dimensions are same as the purpose here is to compare only the strength of towers of different designs. These nodes and elements are modeled in Ansys APDL software. On applying the same force, deformation can be compared. Transmission tower #1 has a less deformation of 0.374778 mm along the y-direction while the transmission tower #2 has more deformation that is 1.402760 mm. The deformation in first tower is less; it has a compact size; it is easy to design, and less material is used in the fabrication of this tower. It is concluded that the first transmission tower can bear the same load with less deformation. Therefore, it is an attractive and suitable choice while selecting the design of transmission tower.

Keywords- **:** 3-D Transmission tower, Truss Analysis, Structural Analysis, Ansys APDL Software, Comparison of Towers.

I. Introduction

Transmission towers are made of many types of trusses bolted through gussets. They must be safe and reliable otherwise it can waste the capital [1]. Parametric study is normally used to determine the forces in the secondary braising members of a tower along with non -linear analysis [2, 3]. It is required to use minimum material having maximum capability to bear the load. Hence, it is required to use such a design that may experience relatively lower deformation under the same applied forces, same distance between the ground and the lowest load-acting point and same area required for the installation of transmission towers.

Reference [4] states that the transmission towers must be reliable; otherwise, severe danger can occur in case of tower failure. Authors used NE-NASTRAN programming to model the tower and ANSYS for simulation. This research was conducted on many full-scale transmission towers. Comparatively stronger towers with same boundary conditions were identified. Moreover, it was concluded that stress is significant in the non-linear behavior of elements. Reference [5] designed and fabricated the transmission towers with different designs. By applying a tensile and compressive force, these towers were tested. All the tests were done under normal conditions. By using ANSYS software, deformation was measured. Residual static load condition was obtained to investigate the condition of tower while designing. Maximum dynamic condition has also been investigated by some authors, as presented in [6-9]. For this, two transmission towers of different designs were chosen; one design having less width than the other. The ground area for the installation of both transmission towers was same, however, width along the height was designed to vary with different degree. First of all, the material properties and dimensions of L-beam were defined. Nodes locations were found according to given data by using mathematical expressions. All nodes of transmission tower were defined on Ansys software and modeled elements on Ansys Mechanical APDL 17.0 software. All legs of both transmission towers were fixed in all directions. In one tower, force was applied along the height of the tower while in the other, it was applied along the width of the tower. Then, transmission towers were analyzed by applying the same load and results were deduced by comparing deformation, stress, and strain. Full-scale testing was performed on the three-dimensional structure. The load condition was static. The above features were the same in both towers;

only design of towers was different. Nodal values were generated by using formex formulation. Comparison of all four towers was made and presented in [10].

Reference [11] discussed that the prediction of the failure of transmission tower is necessary. It is conducted based on structural failure prediction because the full-scale testing or forensic analysis is very expensive and time-consuming.

Collapse analysis on 400 kV transmission tower was carried out [12] and failure of tower at different elevations was evaluated with a purpose to determine the failure mechanics due to the load of freezing rain and to modify the design of the tower to increase the load bearing capacity and to prevent from collapse. For this, openness program was chosen for modeling and dynamic analysis of tower. After removing members, capacity to demand ratio was calculated. The critical areas, where failure can occur with relatively higher probability, were investigated through impact factor and capacity to demand ratio. One tower was provided with diaphragm while other was not. The failure mode was noticed, and it was found that the deformations in the diagonal bracings of tower having no diaphragm were relatively larger [13].

Reference [14] conducted a research on five transmission towers whose voltage ranges from 220 kV to 400 kV. Failures were studied and observed using the full-scale testing. The tower members were constructed using beam column. NE-NASTRAN software was used for modeling the tower. The software is changed from NE-NASTRAN to ANSYS APDL in this research. Failure was predicted and modifications were recommended.

As it is much important to know the failure of transmission tower in view of economic and social concerns, therefore, this research work is necessary in order to select a particular design of towers among various available options and to avoid any tower failure.

II. METHODOLOGY

Material characteristics like modulus of elasticity (E), poison ratio of steel, element type, element dimensions, ground area used for installation, distance between surface and lowest nodal point and load applied are same in both type of towers.

Modeling and analysis of both transmission towers are discussed in different sections.

2.1. Modeling of 1st Transmission Tower:

First of all, open the Ansys software APDL. From the preferences tab, select the structural because this research deals with the structural analysis. From the pre-processor tab, select the element properties and define element behavior as E= 2x105 MPa and poison ratio= 0.3. Elements were considered to behave elastically, as has been done in [15]. Define the element dimensions. Element is beam 2-node 188. The length of L-beam on both sides is 0.1 mm with thickness of 0.002 mm. The dimensions of beam are given below.

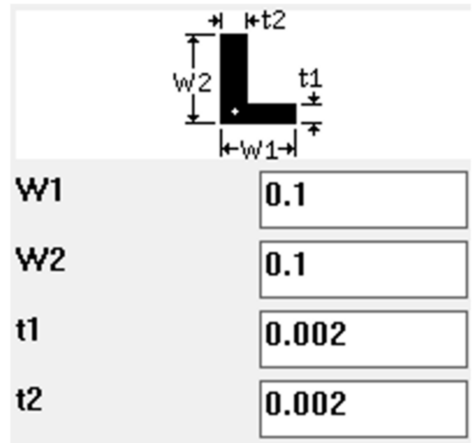


Figure 1. Element dimensions (mm)

Nodes are defined and calculated using mathematical formulae by using the height of transmission tower i.e. 75 ft. and ground area i.e. 10x10 ft^2. Define all the nodes and elements of the front side by using an active coordinates system.

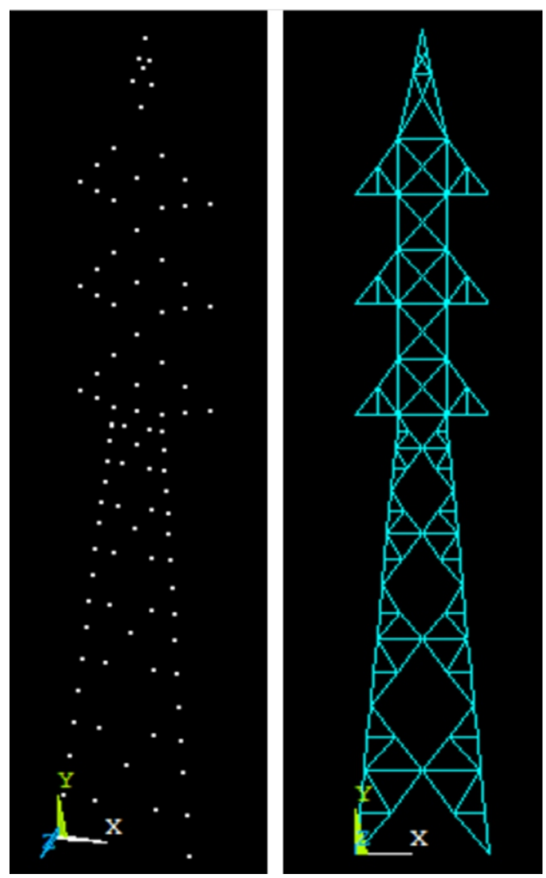


Figure 2. Nodes & elements of the front side

Nodal points of back side of transmission tower are found by using the points of front side. Front and back sides are same with the variation of Z-coordinates. X and Y-coordinates are used which are already used in front side. As the back side of tower is at the distance of 10 feet from the front side. For finding Z-coordinates of back side using front side, the formula is

$$Zb + Zf = -10 \qquad (1)$$

Where
Zf is the z-coordinate of front side
Zb if the z-coordinate of back side
-ve sign indicates that both sides are in -ve Z-axis. Magnitude 10 indicates the sum of Z-points from the origin.
The number of back side nodes are less than that of front side by the number of points where load will be applied. Nodes & elements of the back side modeled in ANSYS APDL are given below:

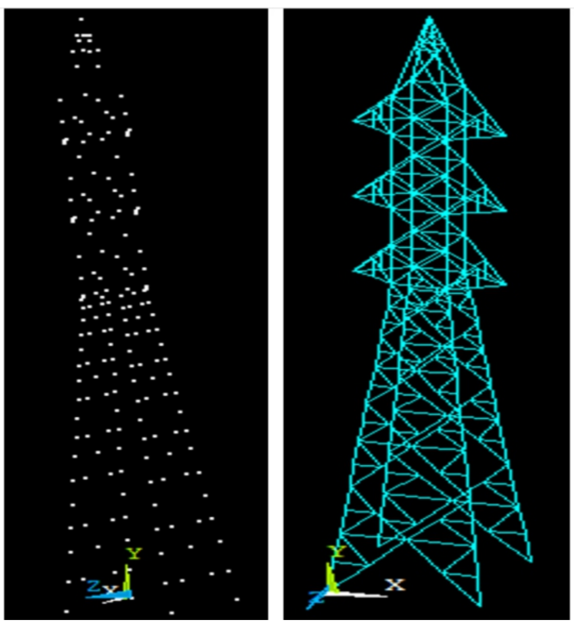


Figure 3. Front and back side nodes and elements

Then, right side nodal points are defined. Right side is same as front side with the variation of axis. X-nodal points of front side is converted into Z-nodal points of right side. Z-nodal points of front side are converted into X-nodal points of left side. For X-nodal values of right side, same procedure is used as in finding Z nodal points of back side. And then X-nodal points of right side are calculated as shown in Fig.4 and various view of 1st transmission tower are shown in Fig.5.

2.2. *Modeling of 2nd Transmission Tower*

Procedure for defining material behavior, material properties, element dimensions is same as in 1st transmission tower. As both towers are to be compared, therefore, ground area used for installation

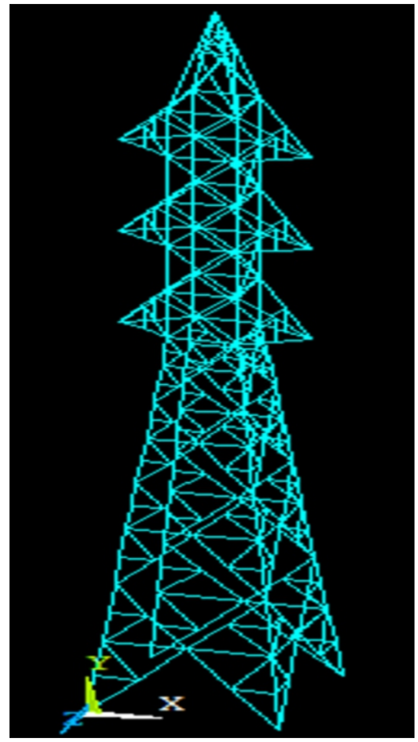
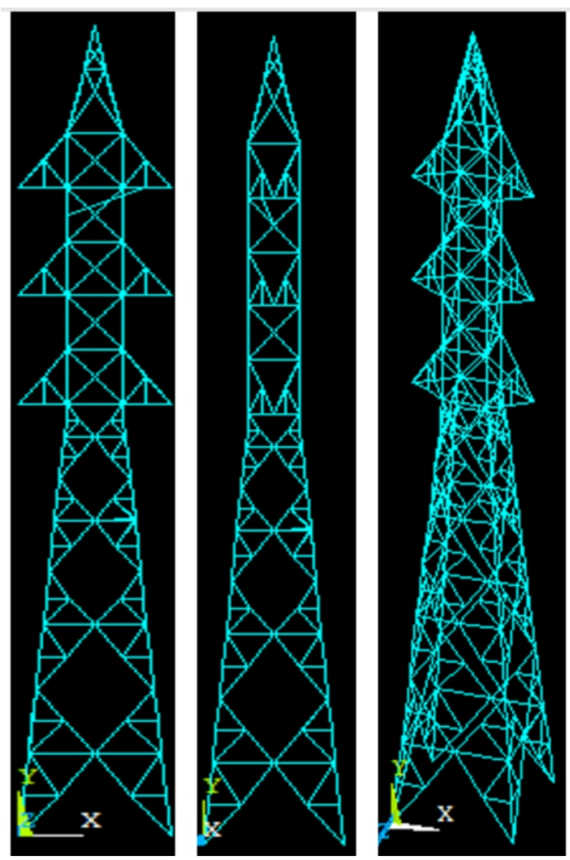


Figure 4. Front, back and right-side elements



Front view Side view Isometric view
Figure 5. Views of 1st transmission tower

and height for both are kept same. Define all the nodes and elements of the front side by using an active coordinates system. All these nodes are given in glossary. Define all these nodes in ANSYS APDL modeling. By drawing lines between required nodes, elements are defined. Front side is ready.

Nodal points of back side of transmission tower are found by using the points of front side. Front and back sides are same with the variation of Z-coordinates. X and Y-coordinates are used which are already used in front side. As the back side of tower is at the distance of 10 feet from the front side. For finding Z-coordinates of back side by using front side, Eqn. (1) is used.

Nodes & elements of the back side modeled on ANSYS APDL are shown below:

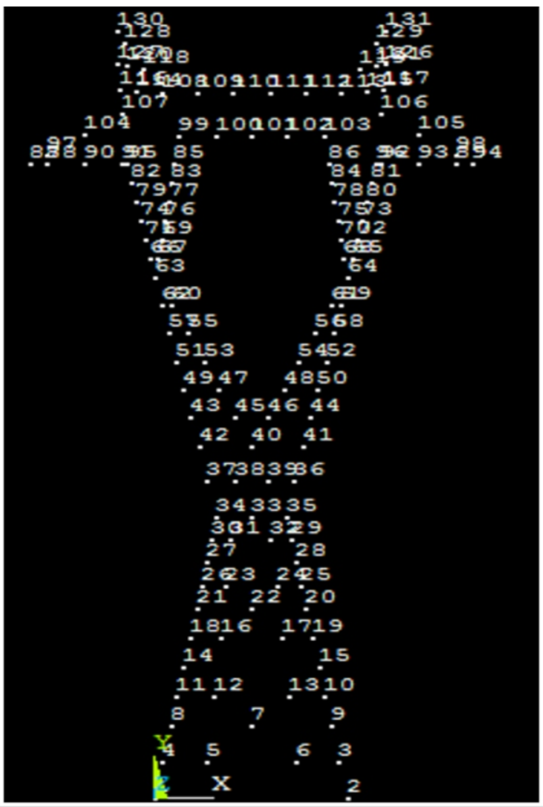
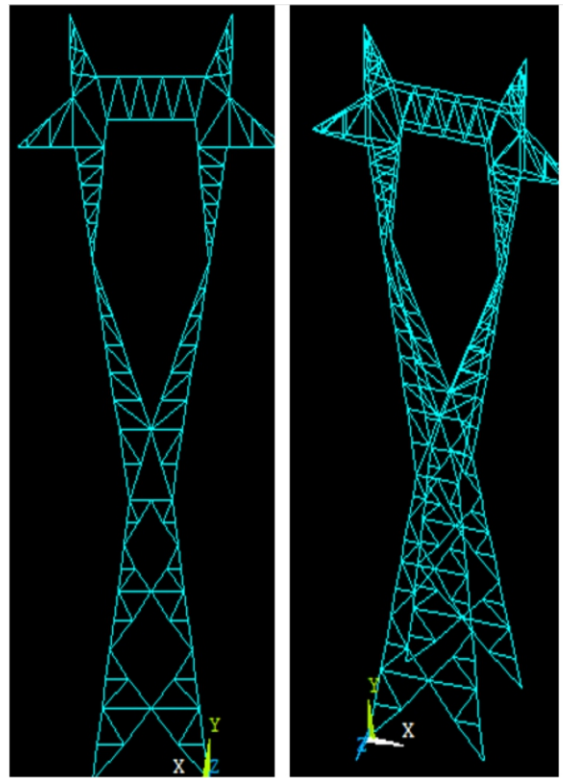


Figure 6. Nodes of tower

Then, right side nodal points are defined. Right side is same as front side with the variation of axis. X-nodal points of front side is converted into z-nodal points of right side. Z-nodal points of front side are converted into X-nodal points of left side. For X-nodal values of right side, same procedure is used as in finding Z-nodal points of back side. And then X-nodal points of right side are calculated.

Left and right sides vary in X-nodal values as front and back sides vary in Z-values. To calculate X-values for right side (Xr), first of all, transmit Z of front into X of left side (Xl) followed by the application of Eqn. (1) by replacing Z with X.



Front view Isometric view

Figure 7. Front and Backside elements

Following above mentioned modelling techniques, various views of 2nd transmission tower have been modeled and represented in Figures 8-10 respectively.

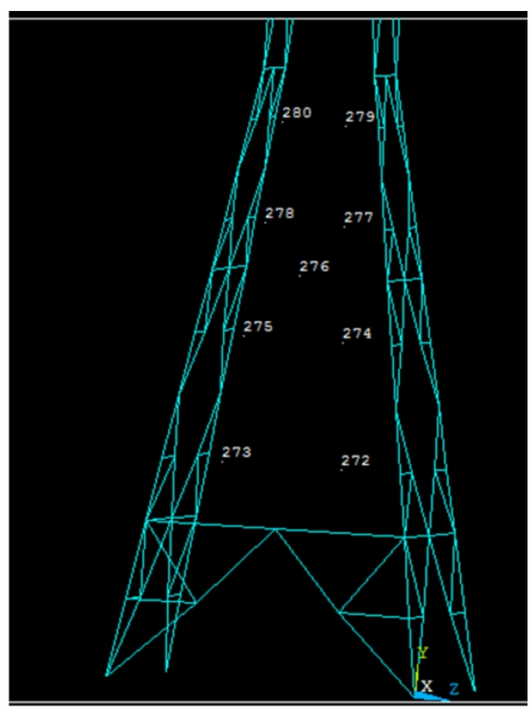
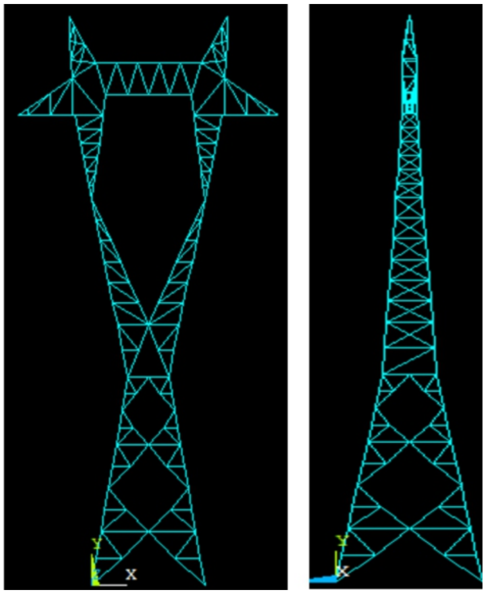


Figure 8. Left Side Modelling



Front view is same as back view

Left side view is same as right side view

Figure 9. Different views of 2nd transmission tower

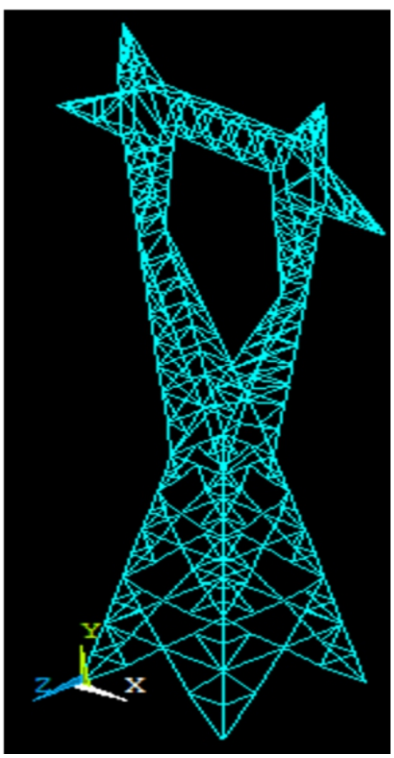


Figure 10. Isometric view of 2nd transmission tower

2.3 Analysis of 1st Transmission Tower:

Fixed support will be provided to all four legs of the tower. Force is applied due to the weight of wires. Load condition values are shown below in Fig.11.

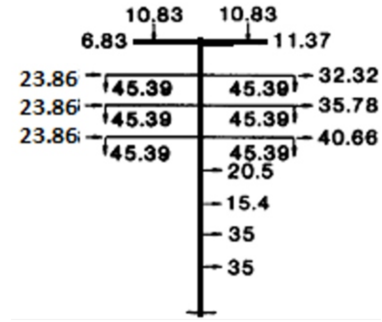


Figure 11. Load condition

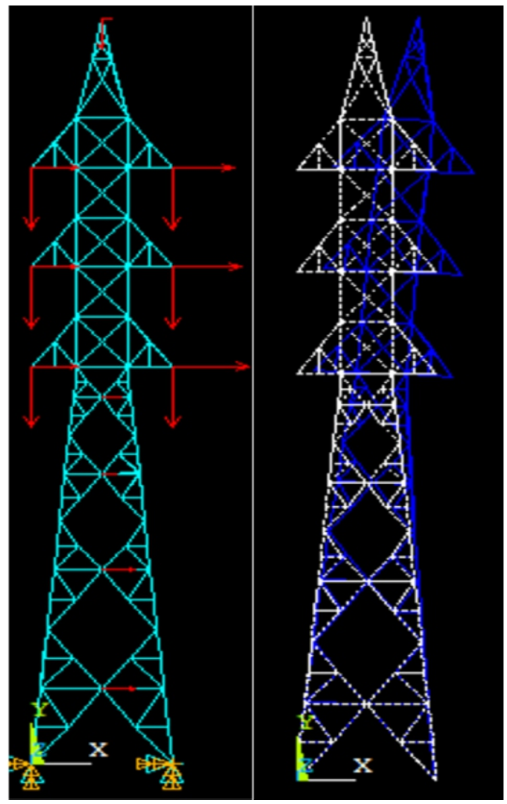


Figure 12. load and deformed shape of 1st transmission tower

After applying load, ANSYS calculates the total deformation, von-mises stress and elastic strain in the tower, as represented in Figure 13. These three parameters can be found to compare the strength of tower.

1. Total deformation

$$\sqrt{x^2 + y^2 + z^2} \quad (2)$$

Where x, y and z are directional deformations along X, Y and Z axis respectively.

2. Von-Mises stress

Von-Mises stress can be found by many methods. The method which is programmed in ANSYS APDL software is by using this formula [16].

$$\sqrt{\frac{1}{2}[(\sigma_3-\sigma_1)^2+(\sigma_2-\sigma_3)^2+(\sigma_1-\sigma_2)^2]} \quad (3)$$

3. Equivalent strain (εe)

Equivalent strain can be found by many methods. The method which is programmed in ANSYS APDL software is by using this formula given in [16].

$$\frac{1}{1+V}\sqrt{(\frac{1}{2}[(\varepsilon_3-\varepsilon_1)^2+(\varepsilon_2-\varepsilon_3)^2+(\varepsilon_1-\varepsilon_2)^2]} \quad (4)$$

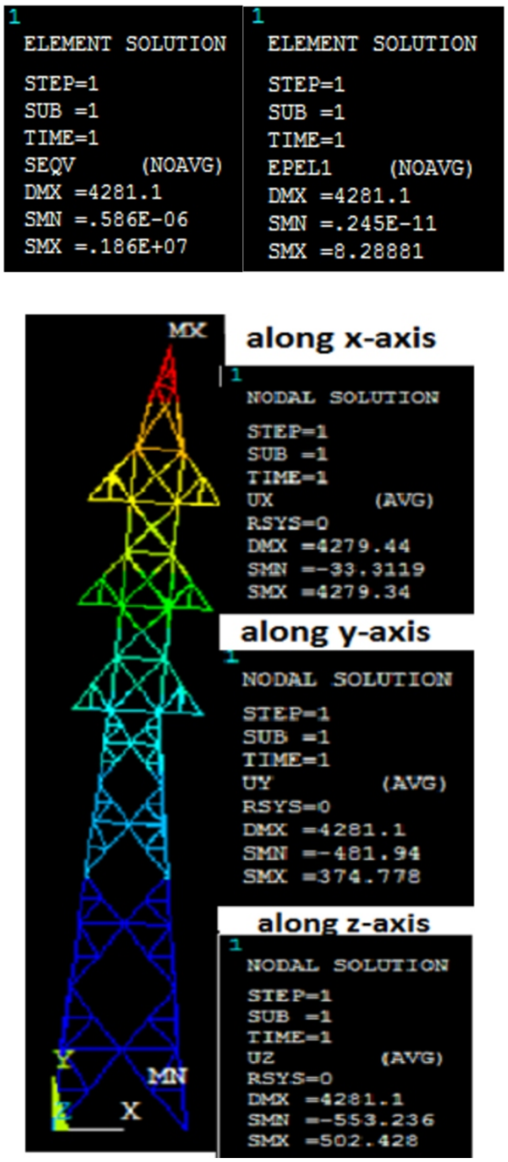


Figure 13. Deformation, stress, and strain of 1st transmission tower

2.4 Analysis of 2nd Transmission Tower:

Load conditions are the same as applied in the 1st transmission tower.

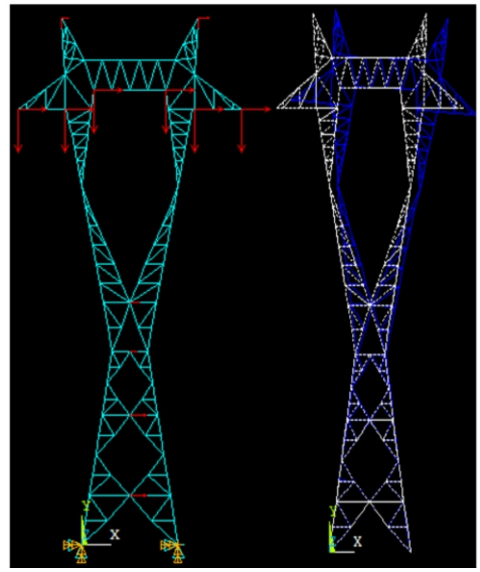


Figure 14. Load conditions and deformed shape of 2nd transmission tower

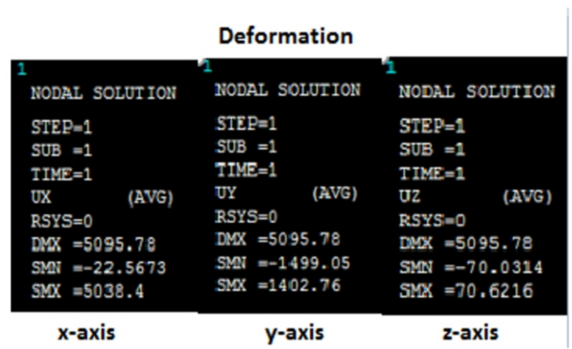


Figure 15. Deformation along x, y, and z-axis in 2nd transmission tower

2.5. Comparison of Results

After calculating various parameters such as deflections along all three axes, stresses and strains for both transmission towers, a comparison has been conducted, as listed in Table 1 and graphically shown in Figure 16.

Table 1 Comparison of deformations, stress, and strain in both towers

	1st transmission tower	**2nd transmission tower**
DOF x (mm)	4.27944	5.0384
DOF y(mm)	0.374778	1.40276
DOF z (mm)	4.2811	5.09578
Stress (Mpa)	1.86e03	0.0027728e6
Strain	0.00828881	0.01235695

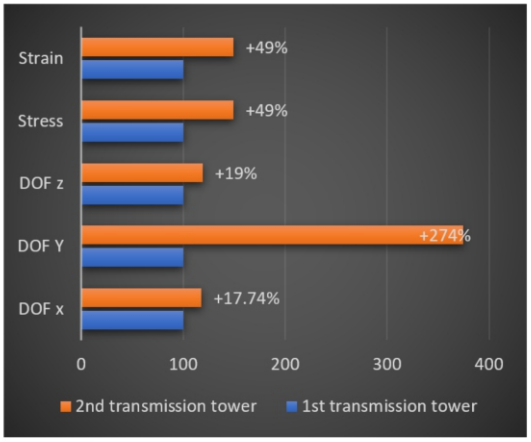


Figure 16. Comparison of deformations, stress, and strain in both towers

From Figure 16, it can be noted that all parameters i.e. deformation, stress and strain are higher in 2nd tower than the 1st one. From modeling perspective, it can also be noted that 2nd design is complex and requires relatively more material.

III. Results & Discussions

Deformation in 2nd transmission tower is found to be greater than that of the 1st transmission tower (about 17.74%, 274.00% and 19.00% comparatively higher along X-axis, Y-axis and Z-axis respectively. Similarly, stress and strain observed in 2nd tower is also greater (about 49.00% in both cases respectively) than that of 1st tower. This can be attributed to two reasons; firstly, area normal to the applied forces is smaller in case of second transmission tower and secondly, there is a hollow portion in the center of second tower. One more reason is that the elements are crowded in first tower which is not so in second tower. As first tower is compact, it is beneficial to install it as it will occupy less ground area. Moreover, as the number of members in second tower are higher than the first tower, more material will be used for fabrication and hence the cost will be higher too. Along with increased cost, second transmission tower is difficult to fabricate due to complex design. Hence, first transmission tower must be preferred.

IV. Future Scope

i. The effect of material properties on the failure of transmission tower can be analyzed.
ii. Tower designs can be analyzed dynamically.
iii. Effect of gravity can also be included in the analysis of both transmission towers.
iv. Analysis can be done by varying element dimensions.
v. Effect of the distribution of load on varying (either more or less) nodal points can also be evaluated.
vi. Transmission towers having more than 1 material properties can be designed so that different amount of stresses can be observed in different parts as per requirement.
vii. Transmission towers having relatively less ground area required for installation can be designed.

V. Conclusion

1st transmission tower must be preferred to 2nd transmission tower due to following reasons:

i. Less material used
ii. Low cost
iii. Easy design
iv. High strength
v. Minimum deformation
vi. Stresses felt are minimum

Although both transmission towers have these parameters in common:

i. Material characteristics
ii. Element type
iii. Element dimensions
iv. Ground area used for installation
v. Distance between surface and lowest nodal point
vi. Load applied

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GLOSSARY

First transmission tower
Front side nodes

NODE	X	Y	Z
1	0.0000	0.0000	0.0000
2	10.000	0.0000	0.0000
3	0.30118	3.7637	-0.30118
4	9.6989	3.7637	-0.30118
5	2.6505	3.7637	-0.30118
6	7.3495	3.7637	-0.30118
7	0.60220	7.5275	-0.60220
8	9.3978	7.5275	-0.60220
9	5.0000	7.5275	-0.60220
10	0.84308	10.539	-0.84308
11	9.1569	10.539	-0.84308
12	2.9215	10.539	-0.84308
13	7.0785	10.539	-0.84308
14	1.0840	13.550	-1.0840
15	8.9160	13.550	-1.0840
16	1.3248	16.561	-1.3248
17	8.6752	16.561	-1.3248
18	3.1624	16.561	-1.3248
19	6.8376	16.561	-1.3248
20	1.5657	19.572	-1.5657
22	8.2416	21.980	-1.7584
23	8.4343	19.572	-1.5657
24	3.3792	21.980	-1.7584
25	6.6208	21.980	-1.7584
26	1.7584	21.980	-1.7584
27	5.0000	19.572	-1.5657
28	1.9511	24.389	-1.9511
29	8.0489	24.389	-1.9511
30	2.1439	26.798	-2.1439
31	7.8561	26.798	-2.1439
32	3.5720	26.798	-2.1439
33	6.4281	26.798	-2.1439
34	2.3366	29.207	-2.3366
35	7.6934	29.207	-2.3366
36	5.0000	29.207	-2.3366
37	2.4907	31.134	-2.4907
38	7.5093	31.134	-2.4907
39	3.7454	31.134	-2.4907
40	6.2546	31.134	-2.4907
42	2.6449	33.061	-2.6449
43	7.3551	33.061	-2.6449
44	2.7991	34.989	-2.7991
46	7.2009	34.989	-2.7991
47	3.8995	34.989	-2.7991
48	6.1005	34.989	-2.7991
49	2.9532	36.916	-2.9532
50	7.0468	36.916	-2.9532
51	5.0000	36.916	-2.9532
53	3.0766	38.458	-3.0766
54	6.9234	38.458	-3.0766
55	4.0383	38.458	-3.0766
56	5.9617	38.458	-3.0766
57	3.2000	40.000	-3.2000
58	3.2000	45.000	-3.2000
59	3.2000	50.000	-3.2000
60	3.2000	55.000	-3.2000
61	3.2000	60.000	-3.2000
62	3.2000	65.000	-3.2000
63	6.8000	40.000	-3.2000
64	6.8000	45.000	-3.2000
65	6.8000	50.000	-3.2000
66	6.8000	55.000	-3.2000
67	6.8000	60.000	-3.2000
68	6.8000	65.000	-3.2000
69	5.0000	40.000	-3.2000
70	0.0000	40.000	-5.0000
71	1.6000	40.000	-4.1000
72	8.4000	40.000	-4.1000
73	10.000	40.000	-5.0000
74	1.6000	42.500	-4.1000

75	5.0000	42.500	-3.2000
76	8.4000	42.500	-4.1000
77	5.0000	47.500	-3.2000
78	0.0000	50.000	-5.0000
79	1.6000	50.000	-4.1000
80	8.4000	50.000	-4.1000
81	10.000	50.000	-5.0000
82	1.6000	52.500	-4.1000
83	5.0000	52.500	-3.2000
84	8.4000	52.500	-4.1000
85	5.0000	57.500	-3.2000
86	0.0000	60.000	-5.0000
87	1.6000	60.000	-4.1000
88	8.4000	60.000	-4.1000
89	10.000	60.000	-5.0000
90	1.6000	62.500	-4.1000
91	5.0000	62.500	-3.2000
92	8.4000	62.500	-4.1000
93	5.0000	69.000	-3.9200
94	4.2800	71.000	-4.2800
95	5.7200	71.000	-4.2800
96	5.0000	72.333	-4.5200
97	4.6400	73.000	-4.6400
98	5.3600	73.000	-4.6400
99	5.0000	75.000	-5.0000

Back side nodes

NODE	X	Y	Z
100	0.0000	0.0000	-10.000
101	0.30110	3.7637	-9.6989
102	0.60220	7.5275	-9.3978
103	0.84308	10.539	-9.1569
104	1.0840	13.550	-8.9160
105	1.3248	16.561	-8.6752
106	1.5657	19.572	-8.4343
107	1.7584	21.980	-8.2416
108	1.9511	24.389	-8.0469
109	2.1439	26.798	-7.8561
110	2.3366	29.207	-7.6634
111	2.4907	31.134	-7.5093
112	2.6449	33.061	-7.3551
113	2.7991	34.989	-7.2009
114	2.9532	36.916	-7.0468
115	3.0766	38.458	-6.9234
116	3.2000	40.000	-6.8000
117	3.2000	45.000	-6.8000
118	3.2000	50.000	-6.8000
119	3.2000	55.000	-6.8000
120	3.2000	60.000	-6.8000
121	3.2000	65.000	-6.8000
122	10.000	0.0000	-10.000
123	9.6989	3.7637	-9.6989
124	9.3978	7.5275	-9.3978
125	9.1569	10.539	-9.1569
126	8.9160	13.550	-8.9160
127	8.6752	16.561	-8.6752
128	8.4343	19.572	-8.4343
129	8.2416	21.980	-8.2416
130	8.0469	24.389	-8.0469
131	7.8561	26.798	-7.8561
132	7.6934	29.271	-7.6634
133	7.5093	31.134	-7.5093
134	7.3551	33.061	-7.3551
135	7.2009	34.989	-7.2009
136	7.0468	36.916	-7.0468
137	6.9234	38.458	-6.9234
138	6.8000	40.000	-6.8000
139	6.8000	45.000	-6.8000
140	6.8000	50.000	-6.8000
141	6.8000	55.000	-6.8000
142	6.8000	60.000	-6.8000
143	6.8000	65.000	-6.8000
144	2.6505	3.7637	-9.6989
145	7.3495	3.7637	-9.6989
146	5.0000	7.5275	-9.3978
148	2.9215	10.539	-9.1569
149	7.0785	10.539	-9.1569
150	3.1624	16.561	-8.6752
151	6.8776	16.561	-8.6752
152	5.0000	19.572	-8.4343
153	3.3792	21.980	-8.2416
154	6.6208	21.980	-8.2416
155	3.5720	26.798	-7.8561
156	6.4281	26.798	-7.8561
157	5.0000	29.207	-7.6634
158	3.7454	31.134	-7.5093
159	6.2546	31.134	-7.5093
160	3.8995	34.989	-7.2009
161	6.1005	34.989	-7.2009
162	5.0000	36.916	-7.0468
163	4.0383	38.458	-6.9234
164	5.9617	38.458	-6.9234
165	5.0000	40.000	-6.8000
166	1.6000	40.000	-5.9000
167	8.4000	40.000	-5.9000
168	1.6000	42.500	-5.9000
169	5.0000	42.500	-6.8000
170	8.4000	42.500	-5.9000
171	5.0000	47.500	-6.8000
172	1.6000	50.000	-5.9000
173	8.4000	50.000	-5.9000
174	1.6000	52.500	-5.9000
175	5.0000	52.500	-6.8000
176	8.4000	52.500	-5.9000
177	5.0000	57.500	-6.8000
178	1.6000	60.000	-5.9000
179	8.4000	60.000	-5.9000
180	1.6000	62.500	-5.9000
181	5.0000	62.500	-6.8000
182	8.4000	62.500	-5.9000
183	5.0000	69.000	-6.0800
184	4.2800	71.000	-5.7200
185	5.7200	71.000	-5.7200
186	5.0000	72.333	-5.4800
187	4.6400	73.000	-5.3600
188	5.3600	73.000	-5.3600

Left and right side nodes

NODE	X	Y	Z
189	9.6989	3.7637	-2.6505
190	9.6989	3.7637	-7.3495
192	9.3978	7.5275	-5.0000
193	9.1569	10.539	-2.9215
194	9.1569	10.539	-7.0785
195	8.6752	16.561	-3.1624
196	8.6752	16.561	-6.8376
197	8.4343	19.572	-5.0000
198	8.2416	21.980	-3.3792
199	8.2416	21.980	-6.6208
200	7.8561	26.798	-3.5720
201	7.8561	26.798	-6.4281
202	7.6634	29.207	-5.0000
203	7.5093	31.134	-3.7454
204	7.5093	31.134	-6.2546
205	7.2009	34.989	-3.8995
206	7.2009	34.989	-6.1005
207	7.0468	36.916	-5.0000
208	6.9234	38.458	-4.0383
209	6.9234	38.458	-5.9617
210	6.8000	47.500	-5.0000
211	6.8000	57.500	-5.0000
212	6.0800	69.000	-5.0000
213	5.4800	72.333	-5.0000
214	0.30110	3.7637	-2.6505
215	0.30110	3.7637	-7.3495
216	0.60220	7.5275	-5.0000
217	0.84308	10.539	-2.9215
218	0.84308	10.539	-7.0785
219	1.3248	16.561	-3.1624
220	1.3248	16.561	-6.8376
221	1.5657	19.572	-5.0000

Second transmission tower
Front side nodes

NODE	X	Y	Z
1	0.0000	0.0000	0.0000
2	10.000	0.0000	0.0000
3	9.5876	2.5775	-0.41240
4	0.41240	2.5775	-0.41240
5	2.7062	2.5775	-0.41240
6	7.2938	2.5775	-0.41240
7	5.0000	5.1550	-0.82480
8	0.82480	5.1550	-0.82480
9	9.1752	5.1550	-0.82480
10	8.8452	7.2175	-1.1548
11	1.1548	7.2175	-1.1548
12	3.0774	7.2175	-1.1548
13	6.9224	7.2175	-1.1548
14	1.4848	9.2800	-1.4848
15	8.5152	9.2800	-1.4848
16	3.4074	11.342	-1.8148
17	6.5926	11.342	-1.8148
18	1.8148	11.342	-1.8148
19	8.1852	11.342	-1.8148
20	7.8552	13.405	-2.1448
21	2.1448	13.405	-2.1448
22	5.0000	13.405	-2.1448
23	3.7043	15.054	-2.4086
24	6.2957	15.054	-2.4086
25	7.5914	15.054	-2.4086
26	2.4086	15.054	-2.4086
27	2.6724	16.703	-2.6724
28	7.3276	16.703	-2.6724
29	7.0638	18.351	-2.9362
30	2.9362	18.351	-2.9362
31	3.9681	18.351	-2.9362
32	6.0319	18.351	-2.9362
33	5.0000	20.000	-3.2000
34	3.2000	20.000	-3.2000
35	6.8000	20.000	-3.2000
36	7.2700	22.500	-3.3300
37	2.7300	22.500	-3.3300
38	4.1000	22.500	-3.3300
39	5.9000	22.500	-3.3300
40	5.0000	25.000	-3.4600
41	7.7400	25.000	-3.4600
42	2.2600	25.000	-3.4600
43	1.8840	27.000	-3.5640
44	8.1160	27.000	-3.5640
45	4.1673	27.000	-3.5640
46	5.8327	27.000	-3.5640
47	3.3347	29.000	-3.6680
48	6.6653	29.000	-3.6680
49	1.5080	29.000	-3.6680
50	8.4920	29.000	-3.6680
51	1.1320	31.000	-3.7720
52	8.8680	31.000	-3.7720
53	2.5020	31.000	-3.7720
54	7.4980	31.000	-3.7720
55	1.6693	33.000	-3.8760
56	8.3307	33.000	-3.8760
57	0.75600	33.000	-3.8760
58	9.2440	33.000	-3.8760
59	9.6200	35.000	-3.9800
60	0.83667	35.000	-3.9800
61	9.1633	35.000	-3.9800
62	0.38000	35.000	-3.9800
63	0.40000	37.000	-4.0840
64	9.9960	37.000	-4.0840
65	10.246	38.330	-4.1532
66	-0.24604	38.330	-4.1532
67	0.16959	38.330	-4.1532
68	9.8305	38.330	-4.1532
69	0.33604	39.667	-4.2284
70	9.6640	39.667	-4.2284
71	-0.49796	39.667	-4.2284
72	10.498	39.667	-4.2284
73	10.748	41.000	-4.2920
74	-0.74800	41.000	-4.2920
75	9.4980	41.000	-4.2920
76	0.50200	41.000	-4.2920
77	0.66758	42.330	-4.3612
78	9.3324	42.330	-4.3612

79	-0.99804	42.330	-4.3612
80	10.998	42.330	-4.3612
81	11.250	43.670	-4.4308
82	-1.2500	43.670	-4.4308
83	0.83404	43.670	-4.4308
84	9.1660	43.670	-4.4308
85	1.0000	45.000	-4.5000
86	9.0000	45.000	-4.5000
87	-6.5000	45.000	-5.0000
88	-5.6887	45.000	-4.9157
89	15.689	45.000	-4.9157
90	-3.6888	45.000	-4.7078
91	-1.6887	45.000	-4.5000
92	11.689	45.000	-4.5000
93	13.689	45.000	-4.7078
94	16.500	45.000	-5.0000
95	-1.5000	45.000	-4.5000
96	11.500	45.000	-4.5000
97	-5.6887	45.596	-4.9157
98	15.689	45.596	-4.9157
99	1.2490	47.000	-4.5000
100	3.1245	47.000	-4.5000
101	5.0000	47.000	-4.5000
102	6.8755	47.000	-4.5000
103	8.7510	47.000	-4.5000
104	-3.6888	47.064	-4.7078
105	13.689	47.064	-4.7078
106	11.689	48.532	-4.5000
107	-1.6887	48.532	-4.5000
108	0.31125	50.000	-4.5000
109	2.1867	50.000	-4.5000
110	4.0622	50.000	-4.5000
111	5.9378	50.000	-4.5000
112	7.8133	50.000	-4.5000
113	9.6888	50.000	-4.5000
114	-0.95100	50.153	-4.5172
115	10.951	50.153	-4.5172
116	-1.8133	50.305	-4.5344
117	11.813	50.305	-4.5344
118	-0.61325	51.773	-4.7000
119	10.613	51.773	-4.7000
120	-1.4755	51.926	-4.7172
121	11.476	51.926	-4.7172
122	11.938	52.079	-4.7344
123	-1.9378	52.079	-4.7344
124	-1.5377	53.547	-4.9000
125	11.538	53.547	-4.9000
126	-2.0000	54.434	-5.0000
127	12.000	54.434	-5.0000

Back side nodes

NODE	X	Y	Z
128	10.000	0.0000	-10.000
129	0.0000	0.0000	-10.000
130	9.5876	2.5775	-9.5876
131	0.41240	2.5775	-9.5876
132	2.7062	2.5775	-9.5876
133	7.2938	2.5775	-9.5876
134	5.0000	5.1550	-9.1752
135	0.82480	5.1550	-9.1752
136	9.1752	5.1550	-9.1752
137	8.8452	7.2175	-8.8452
138	1.1548	7.2175	-8.8452
139	3.0774	7.2175	-8.8452
140	6.9224	7.2175	-8.8452
141	1.4848	9.2800	-8.5152
142	8.5152	9.2800	-8.5152
143	3.4074	11.342	-8.1852
144	6.5926	11.342	-8.1852
145	1.8148	11.342	-8.1852
146	8.1852	11.342	-8.1852
147	7.8552	13.405	-7.8552
148	2.1448	13.405	-7.8552
149	5.0000	13.405	-7.8552
150	3.7043	15.054	-7.5914
151	6.2957	15.054	-7.5914
152	7.5914	15.054	-7.5914
153	2.4086	15.054	-7.5914
154	2.6724	16.703	-7.3276
155	7.3276	16.703	-7.3276
156	7.0638	18.351	-7.0638
157	2.9362	18.351	-7.0638
158	3.9681	18.351	-7.0638
159	6.0319	18.351	-7.0638
160	5.0000	20.000	-6.8000
161	3.2000	20.000	-6.8000
162	6.8000	20.000	-6.8000
163	7.2700	22.500	-6.6700
164	2.7300	22.500	-6.6700
165	4.1000	22.500	-6.6700
166	5.9000	22.500	-6.6700
167	5.0000	25.000	-6.5400
168	7.7400	25.000	-6.5400
169	2.2600	25.000	-6.5400
170	1.8840	27.000	-6.4360
171	8.1160	27.000	-6.4360
172	4.1673	27.000	-6.4360
173	5.8327	27.000	-6.4360
174	3.3347	29.000	-6.3320
175	6.6653	29.000	-6.3320
176	1.5080	29.000	-6.3320
177	8.4920	29.000	-6.3320
178	1.1320	31.000	-6.2280
179	8.8680	31.000	-6.2280
180	2.5020	31.000	-6.2280
181	7.4980	31.000	-6.2280
182	1.6693	33.000	-6.1240
183	8.3307	33.000	-6.1240
184	0.75600	33.000	-6.1240
185	9.2440	33.000	-6.1240
186	9.6200	35.000	-6.0200
187	0.83667	35.000	-6.0200
188	9.1633	35.000	-6.0200
189	0.38000	35.000	-6.0200
190	0.40000	37.000	-5.9160

191	9.9960	37.000	-5.9160
192	10.246	38.330	-5.8468
193	-0.24604	38.330	-5.8468
194	0.16959	38.330	-5.8468
195	9.8305	38.330	-5.8468
196	0.33604	39.670	-5.7772
197	9.6640	39.670	-5.7772
198	-0.49796	39.670	-5.7772
199	10.498	39.670	-5.7772
200	10.748	41.000	-5.7080
201	0.50200	41.000	-5.7080
202	9.4980	41.000	-5.7080
203	-0.74800	41.000	-5.7080
204	0.66758	42.330	-5.6388
205	9.3324	42.330	-5.6388
206	-0.99804	42.330	-5.6388
207	10.998	42.330	-5.6388
208	11.250	43.670	-5.5692
209	-1.2500	43.670	-5.5692
210	0.83404	43.670	-5.5692
211	9.1660	43.670	-5.5692
212	1.0000	45.000	-5.5000
213	9.0000	45.000	-5.5000
214	-5.6887	45.000	-5.0843
215	-3.6888	45.000	-5.2922
216	-1.6887	45.000	-5.5000
217	-1.5000	45.000	-5.5000
218	11.500	45.000	-5.5000
219	11.689	45.000	-5.5000
220	13.689	45.000	-5.2922
221	15.689	45.000	-5.0843
222	-5.6887	45.596	-5.0843
223	15.689	45.596	-5.0843
224	1.2490	47.000	-5.5000
225	3.1245	47.000	-5.5000
226	5.0000	47.000	-5.5000
227	6.8755	47.000	-5.5000
228	8.7510	47.000	-5.5000
229	-3.6888	47.064	-5.2922
230	13.689	47.064	-5.2922
231	11.689	48.532	-5.5000
232	-1.6887	48.532	-5.5000
233	0.31125	50.000	-5.5000
234	2.1867	50.000	-5.5000
235	4.0622	50.000	-5.5000
236	5.9378	50.000	-5.5000
237	7.8133	50.000	-5.5000
238	9.6888	50.000	-5.5000
239	-0.95100	50.153	-5.4828
240	10.951	50.153	-5.4828
241	-1.8133	50.305	-5.4656
242	11.813	50.305	-5.4656
243	10.613	51.773	-5.3000
244	-1.4755	51.926	-5.2828
245	11.476	51.926	-5.2828
246	-1.9378	52.079	-5.2656
247	11.938	52.079	-5.2656
248	-1.5377	53.547	-5.1000
249	11.538	53.547	-5.1000
250	-0.61325	51.773	-5.3000

Left side nodes

NODE	X	Y	Z
251	0.41240	2.5775	-2.7062
252	0.41240	2.5775	-7.2938
253	0.82480	5.1550	-5.0000
254	3.2000	20.000	-5.0000
255	1.1548	7.2175	-3.0774
256	1.1548	7.2175	-6.9224
257	1.8148	11.342	-3.4074
258	1.8148	11.342	-6.5926
259	2.1448	13.405	-5.0000
260	2.4086	15.054	-3.7043
261	2.4086	15.054	-6.2957
262	2.9362	18.351	-3.9681
263	2.9362	18.351	-6.0319
264	9.5876	2.5775	-2.7062

Right side nodes

NODE	X	Y	Z
265	9.5876	2.5775	-7.2938
266	9.1752	5.1550	-5.0000
267	8.8452	7.2175	-3.0774
268	8.8452	7.2175	-6.9224
269	8.1852	11.342	-3.4074
270	8.1852	11.342	-6.5926
271	7.8552	13.405	-5.0000
272	7.5914	15.054	-3.7043
273	7.5914	15.054	-6.2957
274	7.0638	18.351	-3.9681
275	7.0638	18.351	-6.0319
276	6.8000	20.000	-5.0000
277	-1.5000	45.000	-5.0000
278	-1.6887	45.000	-5.0000
279	11.689	45.000	-5.0000
280	11.500	45.000	-5.0000
281	8.7510	47.000	-5.0000
282	1.2490	47.000	-5.0000