The Structural Analysis of Power Transmission Towers Using Different Materials

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August 29, 2023

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Abstract. Transmission towers serve the crucial role of transmitting power across extended distances via cables. Variations in environmental conditions across diverse regions impact material strength, potentially leading to structural impairment and failure. This research aims to investigate the properties of different materials and their impact on tower strength. 3D tower models were designed using software and analyzed through Ansys APDL. Mechanical APDL was likely chosen due to its advanced analysis capabilities, customization options, and suitability for handling large and complex structural models like transmission towers. Material properties were modified while maintaining consistent load, surface area, ground installation, and element dimensions. Comparative analysis reveals that steel power transmission towers exhibit minimal deformation (0.60883E-3 mm) in the x-direction, contrasting significantly with aluminum's greater deformation (1.7395E-3 mm) under the same conditions. This discrepancy is attributed to steel's superior attributes, encompassing hardness, yield strength, toughness, elongation, tensile strength, fatigue resistance, corrosion resistance, malleability, plasticity, and creep resistance. In conclusion, the research establishes steel as the optimal material for power transmission towers due to its enhanced structural integrity under identical loading and design parameters, ensuring reliable and efficient power transmission.

Introduction

Transmission towers play a vital role in efficiently distributing power across diverse regions, each characterized by unique environmental conditions that can potentially induce structural damage. Ensuring the sustained integrity of these towers necessitates the adoption of designs and materials that effectively mitigate deformation and enhance load-bearing capacity under equivalent operational stresses [1]. Parametric analysis is crucial for assessing the forces exerted on various tower components, taking into account the inherent variations in material properties [2]. Highlighting the paramount importance of reliability underscores the imperative of preempting catastrophic failures [3].

The comprehensive evaluation of multiple tower designs, facilitated by NE-NASTRAN and Ansys, identifies robust configurations under comparable conditions while emphasizing the intricate interplay of stress and strain in non-linear behaviors. Rigorous testing protocols subject diverse tower prototypes to a gamut of loads, encompassing tensile, compressive, and residual static forces, with Ansys instrumental in precisely quantifying deformation [4]. A specific comparative analysis of two designs distinguished by differing widths but identical ground areas draw on mathematical expressions to define properties and node placements, subsequently integrated into Ansys APDL for meticulous node delineation. Towers are secured at endpoints and subjected to exhaustive testing to gauge deformation, stress distribution, and strain [5]-[7].

In light of the projections by Li et al. [8], which foresee a growing demand for transmission tower materials due to ongoing power grid expansion, favoring trends that prioritize ecological sustainability, robustness, and resource efficiency. Addressing the prediction of tower failures, Albermani et al. [9] accentuate its necessity, considering the cost and time implications of full-scale testing. As a result, judicious material selection capable of withstanding diverse environmental challenges emerges as a pivotal strategy in averting tower failures, drawing insights from the research mentioned above.

Methodology

Firstly, commence the process by creating a steel transmission tower within Solidworks. Subsequently, initiate Ansys APDL and utilize the Import function to incorporate an IGES file. Proceed to the preferences section and designate the analysis type as structural. In the preprocessor phase, the option for the element type and introduce the element type 2-node 188. Access the material properties via the dropdown menu, and navigate to the materials models section. Within the structural category, designate isotropic and outline the material characteristics by the provided information. Specifically, the modulus of elasticity for Steel is 200 GPa, while Aluminum exhibits a value of 70 GPa [10].

TABLE 1. PROPERTIES OF STEEL AND ALUMINUM

Sr. No	Material used	Modulus of Elasticity (GPa)	Poisson Ratio
1	Steel	200	0.33
2	Aluminum	70	0.33

The Poisson ratio remains consistent, and the dimensions for element type and the distance between surfaces remain identical for both towers. Proceed to the sections tab, select beam, and proceed to define common sections for steel following the provided specifications. Within the "beam tool" tab, opt for the L-section sub-type, specifying a width of 0.1 and both thickness values set at 0.002, and associate the material ID as 1. Similar selections are made for Aluminum, as the aim is to analyze deformations across distinct material types. Within the meshing tab, select all to generate nodes and elements. The resulting elements and nodes for the steel tower are depicted below. Furthermore, it's noteworthy that this study employs uniform dimensions, nodes, elements, and load parameters for both power transmission towers. Subsequent sections will delve into the modeling and analysis specifically concerning aluminum.

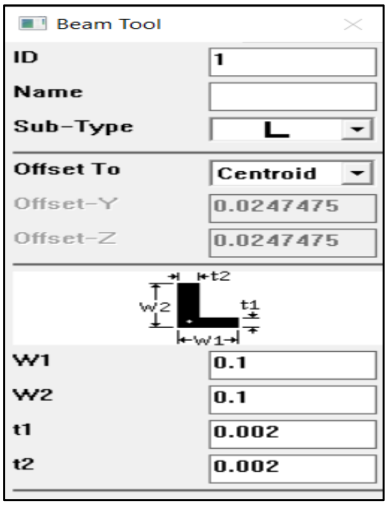

Figure 1. Element Dimensions for Steel and Aluminum in m.

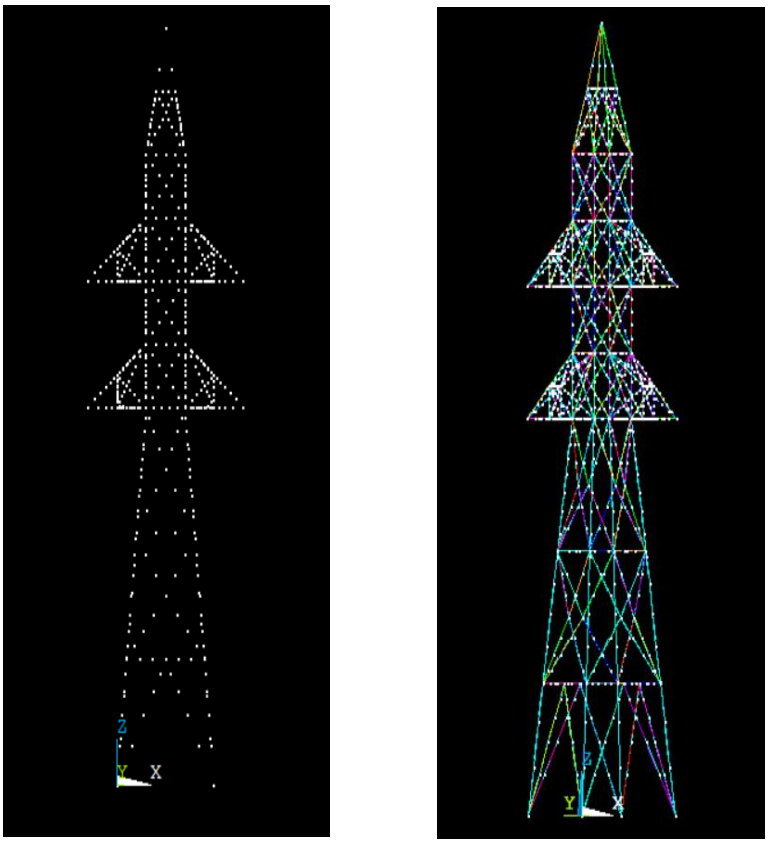

Figure 2. Nodes Elements and of the Steel Tower.

Commence by designing a transmission tower within Solidworks, opting for Aluminum material. Subsequently, proceed to Ansys APDL. Employ the import function within APDL to bring in an IGES file. Within the preferences tab, designate the analysis type as structural. In the preprocessor phase, choose the Element type and incorporate the 2-node 188 element type. Access the material properties from the dropdown menu and select the materials models. Within the structural segment, options for isotropic and specify the material characteristics as illustrated below. Specifically, the modulus of elasticity for the Aluminum alloy stands at 70 GPa.

Move to the "sections tab" and select beam, then proceed to define common sections following the provided specifications. Within the beam tool tab, the option for the L-section sub-type sets the width at 0.1 and both thickness values at 0.002. As depicted in Figure 1, associate the material ID with the value 1. Within the meshing tab, select all to generate nodes and elements. The resulting elements and nodes for the Aluminum tower are presented below.

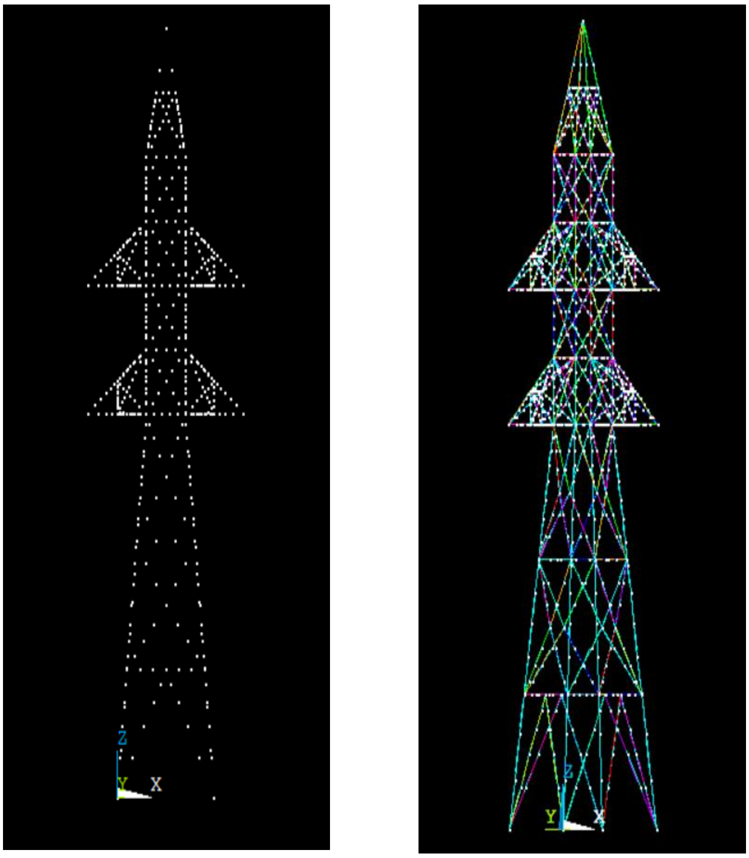

Figure 3. Nodes and Elements of Aluminum Tower.

Within this section, we shall undertake a comprehensive assessment of various parameters through the application of Boundary Conditions. In the "Load" tab, uniformly apply the load for both steel and aluminum configurations. Subsequently, finalize the process by setting "All degrees of freedom" to zero and configuring load values at distinct nodes, as illustrated below.

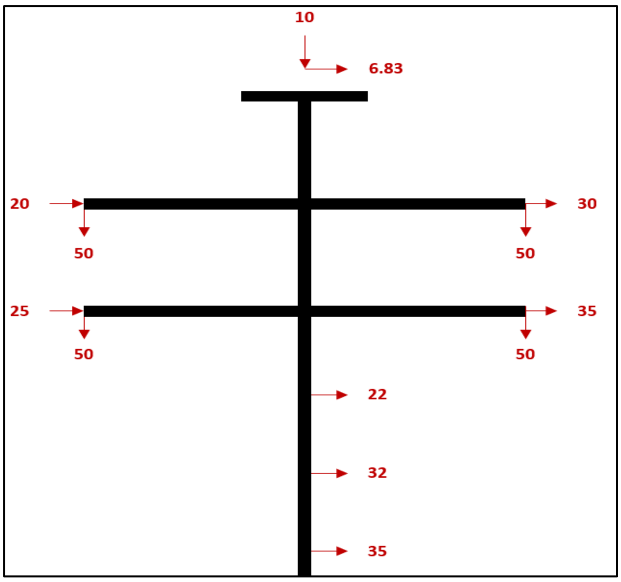

Figure 4. Load tree (N) for Steel and Aluminum.

Upon the successful application of the load, proceed to the solve phase to ascertain the properties and resulting deformations. The loads and the resultant deformations of the steel transmission tower are presented in the subsequent illustration.

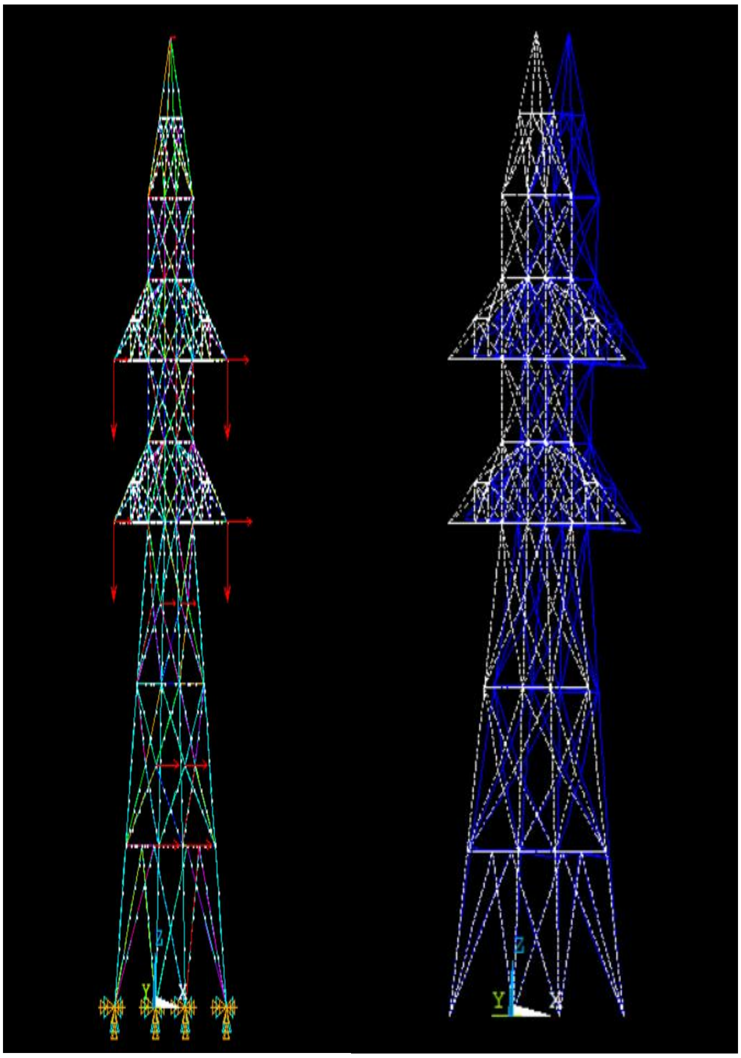

Figure 5. Loaded and deformed steel

Conclusive outcomes have been achieved, with Ansys computing deformations, Von Mises stresses, and elastic strains, facilitating direct comparison of the structural strengths between the two towers. The computation of total deformation in Ansys is performed using the formula as outlined by Gardezi et al. [1].

$$d = \sqrt{x^2 \; + y^2 \;\; z^2} \qquad (1)$$

In the context of deformations, x, y, and z represent the respective directional shifts along the axes. Various approaches exist for evaluating Von Mises stresses. The formula employed to compute Von Mises stress within Ansys is delineated as follows [8].

$$\sigma' = \sqrt{\frac{1}{2}}\;[(\sigma_3 - \sigma_1)^2 + (\sigma_1 - \sigma_2)^2] \qquad (2)$$

Equivalent strain can be determined through multiple methodologies. The approach embedded within the Ansys software involves the utilization of the subsequent formula [8].

$$\varepsilon_{eq} = \frac{1}{1+v}\sqrt{(1/2[(\varepsilon_3 - \varepsilon_1)^2} + (\varepsilon_2 - \varepsilon_3)^2 + (\varepsilon_1 - \varepsilon_2)^2)] \qquad (3)$$

The analysis process for Aluminum mirrors that of steel. The deformed structure is depicted in the accompanying figures.

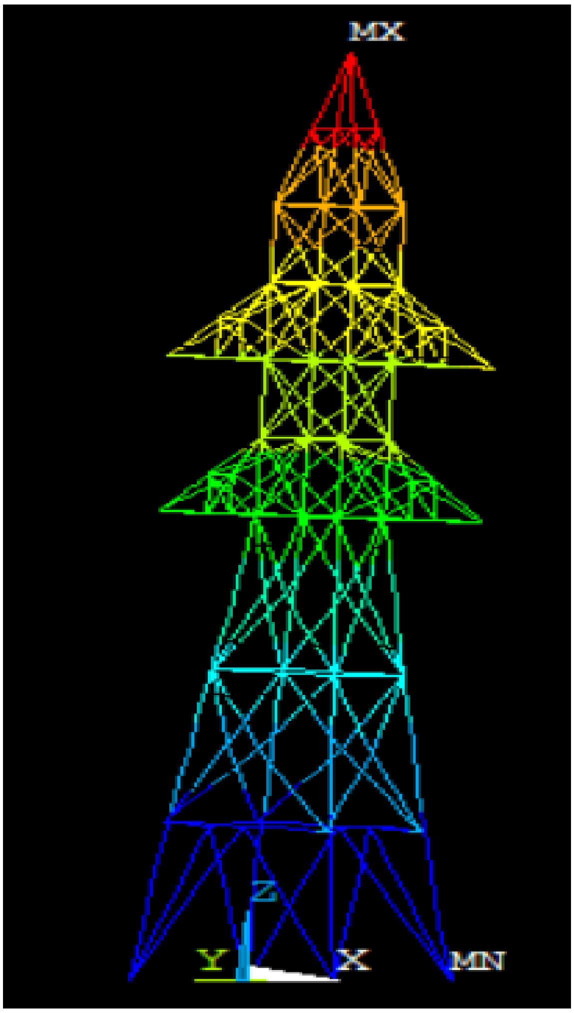

Figure 6. Deformed Aluminum

RESULTS & DISCUSSIONS

Upon the manipulation of numerous parameters encompassing deflections along all three axes, stresses, and strains for both transmission towers, a comprehensive comparison has been undertaken. The summarized findings are presented in Table 1, as illustrated below.

TABLE 2. 3D DEFLECTION AND STRAIN OF STEEL AND ALUMINUM TRANSMISSION TOWER

Degree of Freedom (DOF)	Steel Transmission Tower	Aluminum Transmission tower
DOF x(mm)	0.60883E-3	1.7395E-3
DOF y (mm)	10.963E-3	31.322E-3
DOF z (mm)	5.7290E-3	-0.16369E-3
Strain (mm/mm)	0.61152E-3	1.7472E-3

The aforementioned table and its corresponding outcomes highlight a notable trend: deformations in Aluminum towers along the x-axis, y-axis, and z-axis, as well as strains, surpass those observed in steel towers under equivalent design conditions, loads, Poisson ratios, element dimensions, ground area utilized for installation, and surface separation distances. As a result, the preference should lean towards steel power transmission towers, given their comparatively superior performance. Furthermore, The specific convergence criteria employed in the research are not detailed in the provided information. Convergence criteria in structural analysis establish thresholds for parameters like displacements, forces, or energies, ensuring that the simulation achieves stable and accurate results. The choice of convergence criteria is vital for reliable analysis outcomes.

CONCLUSION

Steel transmission towers can be preferred over Aluminum due to the following reasons.

1. Steel is harder than aluminum.
2. The majority of malleable tempers and alloys of aluminum are more susceptible to denting, dinging, or scratching when compared to steel.
3. Steel is strong as well as less likely to warp, bend or deform underweight, heat, or force.
4. Steel is naturally 2.5 times denser than aluminum

Future studies can be conducted in the following areas

1. Towers designs can be changed.
2. Loads conditions can be changed.
3. Element dimensions can be changed.
4. A dynamics load can be applied.
5. Transmission towers with different physical parameters can be tested.

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Glossary

Nodes x y z

NODE	UX	UY	UZ	USUM
1	0.0000	0.0000	0.0000	0.0000
2	0.17395E-002	0.31322E-005	-0.16369E-003	0.17472E-002
3	0.52079E-004	-0.27274E-005	-0.36295E-004	0.63537E-004
4	0.17228E-003	-0.31465E-005	-0.61953E-004	0.18311E-003
5	0.32844E-003	-0.23209E-005	-0.80478E-004	0.33816E-003
6	0.49941E-003	-0.93407E-006	-0.94272E-004	0.50824E-003
7	0.67171E-003	0.59065E-006	-0.10496E-003	0.67986E-003
8	0.83709E-003	0.20052E-005	-0.11364E-003	0.84477E-003
9	0.99089E-003	0.31775E-005	-0.12101E-003	0.99825E-003
10	0.11308E-002	0.40507E-005	-0.12755E-003	0.11380E-002
11	0.12560E-002	0.46144E-005	-0.13354E-003	0.12631E-002
12	0.13669E-002	0.48861E-005	-0.13915E-003	0.13739E-002
13	0.14640E-002	0.48981E-005	-0.14448E-003	0.14711E-002
14	0.15486E-002	0.46893E-005	-0.14958E-003	0.15558E-002
15	0.16219E-002	0.43002E-005	-0.15449E-003	0.16293E-002

16	0.16851E-002	0.37695E-005	-0.15919E-003	0.16926E-002
17	0.20257E-002	-0.11624E-005	-0.17664E-003	0.20334E-002
18	0.17927E-002	0.30042E-005	-0.16606E-003	0.18004E-002
19	0.18478E-002	0.22616E-005	-0.16853E-003	0.18555E-002
20	0.19049E-002	0.11157E-005	-0.17112E-003	0.19126E-002
21	0.19642E-002	-0.14945E-006	-0.17382E-003	0.19719E-002
22	0.23183E-002	-0.13717E-005	-0.18454E-003	0.23257E-002
23	0.20876E-002	-0.17257E-005	-0.17836E-003	0.20952E-002
24	0.21480E-002	-0.19436E-005	-0.18001E-003	0.21555E-002
25	0.22066E-002	-0.19090E-005	-0.18159E-003	0.22140E-002
26	0.22634E-002	-0.16978E-005	-0.18310E-003	0.22708E-002
27	0.26201E-002	0.72560E-006	-0.18937E-003	0.26269E-002
28	0.23736E-002	-0.91669E-006	-0.18543E-003	0.23809E-002
29	0.24315E-002	-0.36501E-006	-0.18635E-003	0.24386E-002
30	0.24919E-002	0.18419E-006	-0.18731E-003	0.24990E-002
31	0.25548E-002	0.60232E-006	-0.18832E-003	0.25617E-002
32	0.29199E-002	-0.51641E-007	-0.19139E-003	0.29262E-002
33	0.26797E-002	0.62695E-006	-0.18977E-003	0.26864E-002
34	0.27395E-002	0.50273E-006	-0.19018E-003	0.27461E-002
35	0.27994E-002	0.35012E-006	-0.19058E-003	0.28059E-002
36	0.28595E-002	0.16627E-006	-0.19099E-003	0.28659E-002
37	0.35438E-002	0.37466E-006	-0.71172E-004	0.35445E-002

NODE	UX	UY	UZ	USUM
38	0.29820E-002	-0.22290E-006	-0.17939E-003	0.29874E-002
39	0.30662E-002	-0.25446E-006	-0.16316E-003	0.30705E-002
40	0.31803E-002	-0.61204E-007	-0.14120E-003	0.31834E-002
41	0.33350E-002	0.32848E-006	-0.11145E-003	0.33368E-002
42	0.29203E-002	0.17965E-006	0.51065E-004	0.29207E-002
43	0.29827E-002	0.29066E-006	0.38841E-004	0.29830E-002
44	0.30671E-002	0.42144E-006	0.22325E-004	0.30672E-002
45	0.31812E-002	0.54986E-006	-0.16851E-007	0.31812E-002
46	0.33355E-002	0.60271E-006	-0.30259E-004	0.33356E-002
47	0.26156E-002	-0.79784E-006	0.50159E-004	0.26161E-002
48	0.26759E-002	-0.98649E-006	0.50341E-004	0.26764E-002
49	0.27367E-002	-0.83974E-006	0.50522E-004	0.27372E-002
50	0.27978E-002	-0.50093E-006	0.50703E-004	0.27983E-002
51	0.28591E-002	-0.11336E-006	0.50884E-004	0.28595E-002
52	0.23213E-002	0.14877E-005	0.51117E-004	0.23218E-002
53	0.23753E-002	0.14396E-005	0.50942E-004	0.23758E-002
54	0.24312E-002	0.10623E-005	0.50759E-004	0.24317E-002
55	0.24895E-002	0.46127E-006	0.50568E-004	0.24901E-002
56	0.25508E-002	-0.22103E-006	0.50368E-004	0.25513E-002
57	0.20198E-002	-0.18632E-005	0.49473E-004	0.20205E-002
58	0.20838E-002	-0.19182E-005	0.49831E-004	0.20844E-002
59	0.21469E-002	-0.10975E-005	0.50174E-004	0.21475E-002
60	0.22080E-002	0.24476E-007	0.50502E-004	0.22086E-002
61	0.22663E-002	0.10002E-005	0.50816E-004	0.22669E-002
62	0.17432E-002	0.51276E-005	0.46975E-004	0.17438E-002
63	0.17935E-002	0.39309E-005	0.47432E-004	0.17941E-002
64	0.18457E-002	0.24090E-005	0.47909E-004	0.18463E-002
65	0.19004E-002	0.75512E-006	0.48408E-004	0.19010E-002
66	0.19581E-002	-0.77750E-006	0.48929E-004	0.19587E-002
67	0.0000	0.0000	0.0000	0.0000
68	0.52493E-004	-0.11948E-005	0.21973E-004	0.56919E-004
69	0.17554E-003	-0.12566E-006	0.34463E-004	0.17889E-003
70	0.33540E-003	0.19792E-005	0.40979E-004	0.33790E-003
71	0.50998E-003	0.43584E-005	0.43886E-004	0.51189E-003
72	0.68528E-003	0.65655E-005	0.44750E-004	0.68677E-003
73	0.85281E-003	0.83623E-005	0.44586E-004	0.85402E-003
74	0.10078E-002	0.96452E-005	0.44030E-004	0.10088E-002

NODE	UX	UY	UZ	USUM
75	0.11481E-002	0.10395E-004	0.43460E-004	0.11489E-002
76	0.12728E-002	0.10640E-004	0.43087E-004	0.12736E-002
77	0.13825E-002	0.10440E-004	0.43009E-004	0.13832E-002
78	0.14779E-002	0.98606E-005	0.43256E-004	0.14786E-002
79	0.15604E-002	0.89750E-005	0.43816E-004	0.15610E-002
80	0.16311E-002	0.78508E-005	0.44653E-004	0.16318E-002
81	0.16917E-002	0.65503E-005	0.45723E-004	0.16923E-002
82	0.17498E-002	0.53514E-006	0.21008E-003	0.17623E-002

83	0.17448E-002	0.42619E-005	0.91548E-004	0.17472E-002
84	0.17464E-002	0.28412E-005	0.12954E-003	0.17512E-002
85	0.17478E-002	0.16052E-005	0.16146E-003	0.17553E-002
86	0.17489E-002	0.82407E-006	0.18805E-003	0.17590E-002
87	0.17551E-002	0.52410E-006	0.35031E-003	0.17898E-002
88	0.17506E-002	0.45949E-006	0.23410E-003	0.17662E-002
89	0.17518E-002	0.37251E-006	0.26420E-003	0.17716E-002
90	0.17533E-002	0.33228E-006	0.30199E-003	0.17791E-002
91	0.18800E-002	0.63154E-006	0.20992E-003	0.18917E-002
92	0.18662E-002	0.67444E-006	0.22552E-003	0.18798E-002
93	0.18501E-002	0.61807E-006	0.24366E-003	0.18661E-002
94	0.18314E-002	0.46218E-006	0.26472E-003	0.18504E-002
95	0.18096E-002	0.25566E-006	0.28914E-003	0.18325E-002
96	0.17843E-002	0.15371E-006	0.31744E-003	0.18124E-002
97	0.20196E-002	0.21199E-005	0.49510E-004	0.20202E-002
98	0.19842E-002	0.21898E-005	0.90409E-004	0.19863E-002
99	0.19548E-002	0.17330E-005	0.12412E-003	0.19588E-002
100	0.19305E-002	0.12239E-005	0.15196E-003	0.19365E-002
101	0.19104E-002	0.84946E-006	0.17499E-003	0.19184E-002
102	0.18938E-002	0.65693E-006	0.19408E-003	0.19037E-002
103	0.18802E-002	-0.22459E-007	0.20991E-003	0.18919E-002
104	0.19844E-002	-0.21239E-005	0.90559E-004	0.19864E-002
105	0.19550E-002	-0.15161E-005	0.12418E-003	0.19590E-002
106	0.19308E-002	-0.79875E-006	0.15190E-003	0.19367E-002
107	0.19107E-002	-0.27418E-006	0.17487E-003	0.19187E-002
108	0.18940E-002	-0.21956E-007	0.19397E-003	0.19039E-002
109	0.18663E-002	-0.14258E-006	0.22563E-003	0.18799E-002
110	0.18501E-002	-0.17632E-006	0.24389E-003	0.18661E-002
111	0.18313E-002	-0.10096E-006	0.26504E-003	0.18504E-002

NODE	UX	UY	UZ	USUM
112	0.18095E-002	0.87780E-007	0.28949E-003	0.18325E-002
113	0.17843E-002	0.34599E-006	0.31772E-003	0.18124E-002
114	0.17496E-002	0.38936E-007	0.21009E-003	0.17622E-002
115	0.17505E-002	0.72203E-007	0.23429E-003	0.17661E-002
116	0.17517E-002	0.33621E-006	0.26432E-003	0.17715E-002
117	0.17533E-002	0.71891E-006	0.30187E-003	0.17791E-002
118	0.17429E-002	-0.49715E-005	0.46991E-004	0.17435E-002
119	0.17447E-002	-0.36362E-005	0.91510E-004	0.17471E-002
120	0.17464E-002	-0.20744E-005	0.12936E-003	0.17511E-002
121	0.17478E-002	-0.85430E-006	0.16122E-003	0.17552E-002
122	0.17488E-002	-0.15327E-006	0.18787E-003	0.17589E-002
123	0.23256E-002	0.72227E-006	0.22364E-003	0.23363E-002
124	0.23224E-002	0.13518E-005	0.98727E-004	0.23245E-002
125	0.23234E-002	0.10452E-005	0.13869E-003	0.23276E-002
126	0.23243E-002	0.79605E-006	0.17217E-003	0.23307E-002
127	0.23250E-002	0.68541E-006	0.20018E-003	0.23336E-002
128	0.23307E-002	0.46445E-006	0.37559E-003	0.23608E-002
129	0.23263E-002	0.80087E-006	0.24945E-003	0.23397E-002
130	0.23274E-002	0.70326E-006	0.28198E-003	0.23444E-002
131	0.23289E-002	0.46200E-006	0.32303E-003	0.23512E-002
132	0.24653E-002	0.73056E-006	0.22361E-003	0.24754E-002
133	0.24504E-002	0.78542E-006	0.24052E-003	0.24622E-002
134	0.24331E-002	0.72371E-006	0.26015E-003	0.24469E-002
135	0.24129E-002	0.54146E-006	0.28292E-003	0.24294E-002
136	0.23894E-002	0.28792E-006	0.30931E-003	0.24094E-002
137	0.23622E-002	0.12885E-006	0.33992E-003	0.23866E-002
138	0.26154E-002	0.12563E-005	0.50196E-004	0.26159E-002
139	0.25778E-002	0.12639E-005	0.93726E-004	0.25795E-002
140	0.25463E-002	0.10633E-005	0.13016E-003	0.25496E-002
141	0.25200E-002	0.86005E-006	0.16048E-003	0.25251E-002
142	0.24982E-002	0.73107E-006	0.18560E-003	0.25051E-002
143	0.24802E-002	0.69160E-006	0.20640E-003	0.24888E-002
144	0.24654E-002	-0.11009E-006	0.22358E-003	0.24755E-002
145	0.25779E-002	-0.59957E-006	0.93729E-004	0.25796E-002
146	0.25463E-002	-0.29628E-006	0.13012E-003	0.25496E-002
147	0.25201E-002	-0.67424E-007	0.16039E-003	0.25252E-002
148	0.24983E-002	0.33674E-007	0.18550E-003	0.25052E-002

NODE	UX	UY	UZ	USUM
149	0.24803E-002	0.10895E-007	0.20632E-003	0.24889E-002

150	0.24505E-002	-0.27269E-006	0.24056E-003	0.24623E-002
151	0.24331E-002	-0.32991E-006	0.26028E-003	0.24470E-002
152	0.24129E-002	-0.25353E-006	0.28314E-003	0.24294E-002
153	0.23894E-002	-0.38009E-007	0.30958E-003	0.24094E-002
154	0.23622E-002	0.26278E-006	0.34016E-003	0.23866E-002
155	0.23255E-002	-0.93758E-007	0.22368E-003	0.23362E-002
156	0.23262E-002	-0.29203E-006	0.24966E-003	0.23396E-002
157	0.23273E-002	-0.85401E-007	0.28212E-003	0.23444E-002
158	0.23289E-002	0.45788E-006	0.32291E-003	0.23512E-002
159	0.23211E-002	-0.11300E-005	0.51157E-004	0.23216E-002
160	0.23223E-002	-0.85075E-006	0.98588E-004	0.23244E-002
161	0.23233E-002	-0.36332E-006	0.13843E-003	0.23275E-002
162	0.23242E-002	-0.17157E-007	0.17189E-003	0.23306E-002
163	0.23249E-002	0.73144E-007	0.20002E-003	0.23335E-002
164	0.23161E-002	0.20077E-006	-0.37174E-003	0.23458E-002
165	0.23177E-002	-0.90102E-006	-0.23375E-003	0.23295E-002
166	0.23172E-002	-0.46035E-006	-0.27632E-003	0.23336E-002
167	0.23167E-002	-0.12383E-006	-0.31304E-003	0.23378E-002
168	0.23164E-002	0.92832E-007	-0.34462E-003	0.23419E-002
169	0.23142E-002	0.13465E-006	-0.57249E-003	0.23840E-002
170	0.23158E-002	0.26607E-006	-0.40284E-003	0.23506E-002
171	0.23154E-002	0.33419E-006	-0.44435E-003	0.23576E-002
172	0.23148E-002	0.34791E-006	-0.49962E-003	0.23681E-002
173	0.23162E-002	0.33006E-006	-0.37171E-003	0.23458E-002
174	0.23149E-002	0.14857E-006	-0.49959E-003	0.23682E-002
175	0.23155E-002	0.17360E-006	-0.44429E-003	0.23577E-002
176	0.23159E-002	0.23796E-006	-0.40277E-003	0.23506E-002
177	0.23185E-002	0.21807E-005	-0.18454E-003	0.23258E-002
178	0.23165E-002	0.46742E-006	-0.34463E-003	0.23420E-002
179	0.23168E-002	0.69981E-006	-0.31306E-003	0.23379E-002
180	0.23173E-002	0.10519E-005	-0.27632E-003	0.23337E-002
181	0.23178E-002	0.15439E-005	-0.23372E-003	0.23296E-002
182	0.24735E-002	0.75766E-006	-0.37170E-003	0.25013E-002
183	0.25844E-002	0.55686E-006	-0.23380E-003	0.25950E-002
184	0.25545E-002	0.47081E-006	-0.27106E-003	0.25689E-002
185	0.25292E-002	0.46508E-006	-0.30259E-003	0.25472E-002

NODE	UX	UY	UZ	USUM
186	0.25076E-002	0.52347E-006	-0.32939E-003	0.25292E-002
187	0.24892E-002	0.62679E-006	-0.35223E-003	0.25140E-002
188	0.24576E-002	0.89070E-006	-0.39171E-003	0.24886E-002
189	0.24385E-002	0.89974E-006	-0.41581E-003	0.24737E-002
190	0.24155E-002	0.76174E-006	-0.44484E-003	0.24561E-002
191	0.23878E-002	0.49018E-006	-0.47981E-003	0.24355E-002
192	0.23544E-002	0.18605E-006	-0.52192E-003	0.24116E-002
193	0.24736E-002	-0.16006E-006	-0.37167E-003	0.25014E-002
194	0.24577E-002	-0.30061E-006	-0.39173E-003	0.24887E-002
195	0.24385E-002	-0.31412E-006	-0.41585E-003	0.24738E-002
196	0.24156E-002	-0.18367E-006	-0.44488E-003	0.24562E-002
197	0.23879E-002	0.61477E-007	-0.47984E-003	0.24356E-002
198	0.23545E-002	0.28586E-006	-0.52192E-003	0.24117E-002
199	0.26202E-002	0.70554E-007	-0.18937E-003	0.26270E-002
200	0.25845E-002	0.16629E-007	-0.23378E-003	0.25951E-002
201	0.25546E-002	0.66635E-007	-0.27101E-003	0.25690E-002
202	0.25293E-002	0.97548E-007	-0.30251E-003	0.25473E-002
203	0.25078E-002	0.69056E-007	-0.32932E-003	0.25293E-002
204	0.24894E-002	-0.21078E-007	-0.35217E-003	0.25141E-002
205	0.17403E-002	-0.93880E-007	-0.34567E-003	0.17743E-002
206	0.17397E-002	0.24350E-005	-0.21150E-003	0.17525E-002
207	0.17399E-002	0.15596E-005	-0.25307E-003	0.17582E-002
208	0.17401E-002	0.79301E-006	-0.28888E-003	0.17639E-002
209	0.17402E-002	0.23794E-006	-0.31953E-003	0.17693E-002
210	0.17387E-002	-0.27709E-007	-0.53684E-003	0.18197E-002
211	0.17401E-002	-0.32218E-006	-0.37547E-003	0.17801E-002
212	0.17398E-002	-0.34439E-006	-0.41506E-003	0.17886E-002
213	0.17393E-002	-0.14312E-006	-0.46759E-003	0.18010E-002
214	0.17404E-002	0.45702E-006	-0.34563E-003	0.17744E-002
215	0.17402E-002	0.69197E-006	-0.37547E-003	0.17803E-002
216	0.17399E-002	0.61067E-006	-0.41509E-003	0.17887E-002
217	0.17393E-002	0.20395E-006	-0.46763E-003	0.18011E-002
218	0.17398E-002	-0.23222E-005	-0.16371E-003	0.17475E-002
219	0.17399E-002	-0.17020E-005	-0.21100E-003	0.17527E-002
220	0.17401E-002	-0.10017E-005	-0.25259E-003	0.17583E-002
221	0.17402E-002	-0.37913E-006	-0.28858E-003	0.17640E-002

222	0.17403E-002	0.10919E-006	-0.31940E-003	0.17694E-002

NODE	UX	UY	UZ	USUM
223	0.18903E-002	0.83587E-006	-0.34506E-003	0.19216E-002
224	0.19926E-002	-0.11643E-005	-0.21801E-003	0.20045E-002
225	0.19652E-002	-0.74719E-006	-0.25216E-003	0.19813E-002
226	0.19420E-002	-0.23770E-006	-0.28097E-003	0.19622E-002
227	0.19221E-002	0.22149E-006	-0.30561E-003	0.19463E-002
228	0.19051E-002	0.58103E-006	-0.32679E-003	0.19329E-002
229	0.18753E-002	0.10141E-005	-0.36400E-003	0.19103E-002
230	0.18572E-002	0.10177E-005	-0.38692E-003	0.18971E-002
231	0.18353E-002	0.81594E-006	-0.41465E-003	0.18816E-002
232	0.18089E-002	0.43119E-006	-0.44817E-003	0.18636E-002
233	0.17770E-002	0.12118E-007	-0.48853E-003	0.18429E-002
234	0.18905E-002	-0.34703E-006	-0.34503E-003	0.19217E-002
235	0.18754E-002	-0.64636E-006	-0.36398E-003	0.19104E-002
236	0.18573E-002	-0.76903E-006	-0.38691E-003	0.18971E-002
237	0.18353E-002	-0.67738E-006	-0.41465E-003	0.18816E-002
238	0.18089E-002	-0.38540E-006	-0.44817E-003	0.18636E-002
239	0.17770E-002	-0.32992E-007	-0.48853E-003	0.18429E-002
240	0.20259E-002	0.19952E-005	-0.17664E-003	0.20336E-002
241	0.19926E-002	0.12367E-005	-0.21799E-003	0.20045E-002
242	0.19652E-002	0.84376E-006	-0.25213E-003	0.19813E-002
243	0.19421E-002	0.56237E-006	-0.28094E-003	0.19623E-002
244	0.19223E-002	0.28682E-006	-0.30557E-003	0.19465E-002
245	0.19053E-002	-0.16084E-007	-0.32676E-003	0.19331E-002
246	0.0000	0.0000	0.0000	0.0000
247	0.52011E-004	0.30989E-005	-0.36281E-004	0.63491E-004
248	0.17324E-003	0.43992E-005	-0.61763E-004	0.18397E-003
249	0.33084E-003	0.45948E-005	-0.80056E-004	0.34041E-003
250	0.50324E-003	0.41521E-005	-0.93624E-004	0.51189E-003
251	0.67673E-003	0.33787E-005	-0.10413E-003	0.68470E-003
252	0.84295E-003	0.24727E-005	-0.11268E-003	0.85045E-003
253	0.99719E-003	0.15563E-005	-0.12000E-003	0.10044E-002
254	0.11372E-002	0.70122E-006	-0.12653E-003	0.11442E-002
255	0.12622E-002	-0.54843E-007	-0.13257E-003	0.12691E-002
256	0.13724E-002	-0.69606E-006	-0.13828E-003	0.13794E-002
257	0.14688E-002	-0.12203E-005	-0.14375E-003	0.14758E-002
258	0.15525E-002	-0.16337E-005	-0.14902E-003	0.15596E-002
259	0.16247E-002	-0.19467E-005	-0.15410E-003	0.16320E-002

NODE	UX	UY	UZ	USUM
260	0.16867E-002	-0.21719E-005	-0.15900E-003	0.16942E-002
261	0.17921E-002	-0.28855E-005	-0.16607E-003	0.17997E-002
262	0.18469E-002	-0.25273E-005	-0.16855E-003	0.18546E-002
263	0.19042E-002	-0.14198E-005	-0.17113E-003	0.19119E-002
264	0.19640E-002	0.19609E-006	-0.17382E-003	0.19717E-002
265	0.20881E-002	0.31792E-005	-0.17836E-003	0.20957E-002
266	0.21484E-002	0.34420E-005	-0.18001E-003	0.21560E-002
267	0.22070E-002	0.31696E-005	-0.18158E-003	0.22144E-002
268	0.22637E-002	0.26691E-005	-0.18309E-003	0.22711E-002
269	0.23737E-002	0.16598E-005	-0.18542E-003	0.23810E-002
270	0.24316E-002	0.10300E-005	-0.18634E-003	0.24387E-002
271	0.24920E-002	0.42864E-006	-0.18731E-003	0.24990E-002
272	0.25549E-002	0.33561E-007	-0.18832E-003	0.25618E-002
273	0.29200E-002	0.83906E-006	-0.19139E-003	0.29263E-002
274	0.26799E-002	0.32315E-006	-0.18977E-003	0.26866E-002
275	0.27396E-002	0.49983E-006	-0.19017E-003	0.27462E-002
276	0.27995E-002	0.62707E-006	-0.19058E-003	0.28060E-002
277	0.28596E-002	0.73132E-006	-0.19098E-003	0.28660E-002
278	0.29821E-002	0.92257E-006	-0.17939E-003	0.29875E-002
279	0.30663E-002	0.92564E-006	-0.16317E-003	0.30707E-002
280	0.31805E-002	0.79566E-006	-0.14118E-003	0.31836E-002
281	0.33351E-002	0.53027E-006	-0.11141E-003	0.33370E-002
282	0.29202E-002	0.36860E-006	0.51102E-004	0.29206E-002
283	0.29825E-002	0.35661E-006	0.38883E-004	0.29828E-002
284	0.30668E-002	0.35995E-006	0.22357E-004	0.30669E-002
285	0.31809E-002	0.38453E-006	-0.14237E-007	0.31809E-002
286	0.33353E-002	0.41758E-006	-0.30293E-004	0.33355E-002
287	0.26757E-002	0.14020E-005	0.50377E-004	0.26762E-002
288	0.27365E-002	0.12426E-005	0.50558E-004	0.27370E-002
289	0.27978E-002	0.92162E-006	0.50740E-004	0.27982E-002
290	0.28591E-002	0.58244E-006	0.50921E-004	0.28595E-002

291	0.23750E-002	-0.89061E-006	0.50981E-004	0.23756E-002
292	0.24310E-002	-0.43058E-006	0.50797E-004	0.24316E-002
293	0.24894E-002	0.16344E-006	0.50606E-004	0.24899E-002
294	0.25507E-002	0.77586E-006	0.50405E-004	0.25512E-002
295	0.20833E-002	0.23804E-005	0.49869E-004	0.20839E-002
296	0.21464E-002	0.14870E-005	0.50212E-004	0.21470E-002

NODE	UX	UY	UZ	USUM
297	0.22077E-002	0.22214E-006	0.50541E-004	0.22083E-002
298	0.22662E-002	-0.80508E-006	0.50856E-004	0.22667E-002
299	0.17932E-002	-0.41144E-005	0.47452E-004	0.17938E-002
300	0.18455E-002	-0.27170E-005	0.47933E-004	0.18461E-002
301	0.19003E-002	-0.10009E-005	0.48436E-004	0.19009E-002
302	0.19581E-002	0.73903E-006	0.48962E-004	0.19587E-002
303	0.0000	0.0000	0.0000	0.0000
304	0.51800E-004	0.13848E-005	0.22024E-004	0.56305E-004
305	0.17455E-003	0.80132E-006	0.34496E-004	0.17792E-003
306	0.33434E-003	-0.73666E-006	0.40962E-004	0.33684E-003
307	0.50899E-003	-0.25934E-005	0.43810E-004	0.51088E-003
308	0.68442E-003	-0.43891E-005	0.44620E-004	0.68589E-003
309	0.85210E-003	-0.59146E-005	0.44415E-004	0.85328E-003
310	0.10073E-002	-0.70718E-005	0.43832E-004	0.10082E-002
311	0.11476E-002	-0.78324E-005	0.43251E-004	0.11484E-002
312	0.12725E-002	-0.82104E-005	0.42882E-004	0.12732E-002
313	0.13822E-002	-0.82432E-005	0.42821E-004	0.13829E-002
314	0.14777E-002	-0.79797E-005	0.43095E-004	0.14783E-002
315	0.15601E-002	-0.74720E-005	0.43691E-004	0.15608E-002
316	0.16309E-002	-0.67710E-005	0.44571E-004	0.16315E-002
317	0.16914E-002	-0.59236E-005	0.45688E-004	0.16920E-002
318	0.99247E-004	-0.28168E-007	-0.56304E-007	0.99247E-004
319	-0.17986E-004	0.25615E-004	-0.27143E-004	0.41429E-004
320	-0.33900E-004	0.58359E-004	-0.50419E-004	0.84244E-004
321	-0.14620E-004	0.62392E-004	-0.50487E-004	0.81581E-004
322	0.34244E-004	0.39438E-004	-0.30950E-004	0.60711E-004
323	0.10372E-003	-0.44371E-005	0.31336E-003	0.33011E-003
324	0.10223E-003	-0.14337E-004	0.20215E-003	0.22699E-003
325	0.10074E-003	-0.13558E-004	0.96958E-004	0.14047E-003
326	0.53635E-003	-0.78267E-005	0.25613E-003	0.59442E-003
327	0.19419E-003	0.23824E-004	0.27829E-003	0.34018E-003
328	0.28773E-003	0.24910E-004	0.26420E-003	0.39142E-003
329	0.39486E-003	0.69456E-005	0.26346E-003	0.47473E-003
330	0.10270E-002	0.59504E-005	0.18622E-003	0.10438E-002
331	0.87325E-003	0.79104E-006	0.20888E-003	0.89788E-003
332	0.70777E-003	-0.57579E-005	0.23356E-003	0.74533E-003
333	0.10272E-002	-0.57469E-005	-0.30304E-003	0.10709E-002