SIMPLIFIED MODELING FOR WIND TURBINE MODAL ANALYSIS USING NASTRAN

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ABSTRACT

A simplified finite element model of the Mod-0 wind turbine tower is described. Use of this model greatly reduces the computer time required for modal analysis. The model provides good accuracy in predicting tower frequencies and mode shapes as long as the tower bending mode shape resembles the first bending mode shape of a cantilever beam. Several applications where the simplified model was used for modal analysis are described.

INTRODUCTION

To reduce computing time and cost and, more importantly for us, to reduce turn-around time from overnight to daytime runs, a detailed finite element model of the Mod-0 wind turbine tower was reduced to six beam elements (stick model). This paper explains the method used to calculate the properties of the beam elements in the stick model, examines the accuracy of the stick model in predicting natural frequencies and mode shapes, compares computer times, and describes several applications where the stick model was used.

TOWER MODELS

Detailed Model

A detailed NASTRAN model of the Mod-0 tower was constructed for structural and modal analysis. A side view of this model is shown in figure 1(a). This view shows rails for an elevator that have since been removed from the tower. This model, which includes the conical transition section at the top of the tower, consisted of 143 nodes and 309 elements. Of these elements, 197 were bar elements (CBAR), 88 were rod elements (CROD), and 24 were plate elements (CQUAD2 and CTRIA2).

Simplified Model

The simplified or stick model of the tower consisted of just six NASTRAN bar elements. This model is shown in figure 1(b). In order to calculate the bar element properties, the detailed model was divided into six sections or bays. A gravity vector was applied to determine the weight of each bay. This weight determined the area used in each bar element of the stick model. The bending and torsional stiffnesses of each bar were selected so that a bending load or torque produced the same deflection or rotation, respectively, in the bar as it did in the bay that the bar represented.

The remainder of the wind turbine (bedplate, drive train and blades) was also modeled with bar elements. The complete model with the stick tower is shown in figure 2. Details of the bedplate and blade models are given in ref. 1. The drive train model details are given in ref. 2.

RESULTS AND DISCUSSION

Comparison of Natural Frequencies and Mode Shapes

Table I compares the measured natural frequencies for the tower alone with those predicted by both the detailed and stick models. The agreement is very good for the first bending modes. For the second bending mode, the stick model predicts a much higher frequency.

Figure 3 compares mode shapes predicted by the detailed and stick models. For the first bending mode (figure 3(a)) the agreement is good. However, for the second bending mode (figure 3(b)) the agreement is poor. Because of the poor agreement for the second bending frequency and mode shape, it is concluded that the stick model will not provide accurate results when the tower mode shape resembles a cantilever beam second bending mode shape like that shown in figure 3(b).

In table II results are presented for the complete wind turbine model with rigid blades. The natural frequencies predicted using the stick tower model are in reasonably good agreement with those predicted using the detailed tower model. The fourth mode is one of combined tower and bedplate bending. Figure 4 shows the mode shapes for the three bending modes given in table II. For the first two modes (figure 4(a) and 4(b)) the agreement is good. There is some difference for the combined tower/pod bending mode (figure 4(c)). All three mode shapes were normalized with respect to the deflection at the hub.

From the results of table II and figure 4 it is concluded that the stick model will provide accurate results in modal analysis for tower torsional modes and tower bending modes when the tower mode shape resembles a cantilever beam first bending mode shape.

Comparison of Computer Times

Some representative computing times are given in table III for modal analysis of the complete wind turbine using both the detailed and stick tower models. The NASTRAN code gives an estimate of symmetric real decomposition time. When the stick tower model is used, this time is very small. Of greater concern are CPU and total time. For this representative case, the model with the detailed tower requires 17 times as much CPU time and about 8 times as much total computer time.

APPLICATIONS

The wind turbine model with a stick tower was first used to determine the effect of the yaw drive stiffness on system natural frequencies. The yaw drive was modeled as a bar element at the top of the tower. The analysis showed that a pod yaw mode frequency, that was initially close to two per revolution, could be significantly increased by using a double yaw drive. The Mod-0 wind turbine was subsequently modified to include a double yaw drive.

Other applications of this simplified model include studies to determine the effect of blade weight on system natural frequencies, and the effect of the tower/bedplate attachment location on frequencies and mode shapes. In addition, the natural frequencies, mode shapes, and generalized masses obtained from the simplified model with rigid blades were used as input to Lockheed's REXOR program for determining blade loads.

CONCLUSIONS

From the results obtained using a simplified model of the Mod-0 tower, it is concluded that a tower of this type can be modeled as a simple cantilever beam for modal analysis. However, this model should be limited to tower torsional modes and tower bending modes where the mode shape resembles a cantilever beam first bending mode shape.

REFERENCES

1. Chamis, C. C.; and Sullivan, T. L. : Free Vibrations of the ERDA-NASA 100 kW Wind Turbine. NASA TM X-71879, 1976.

2. Sullivan, T. L.; Miller, D. R.; and Spera, D. A.: Drive Train Normal Modes Analysis for the ERDA/NASA 100-Kilowatt Wind Turbine Generator. NASA TM-73718, 1977.

DISCUSSION

Q. Why not use a Guyan reduction to simplify your NASTRAN model?

A. A Guyan reduction is a satisfactory means of reducing degrees of freedom for modal analysis. However, the stick model has even fewer degrees of freedom than you would obtain by a Guyan reduction. In addition, while the stick model discussed in the paper was based on a detailed finite element model of the tower, a stick model can also be constructed from an engineering drawing of a tower.

Q. Did you consider shear deformations in your model? Perhaps this would account for the discrepancy in the higher tower bending modes.

A. No, the model did not consider shear deformations. We are presently investigating the effect of shear deformation.

Q. What is the preparation time required to perform a stick model analysis?

A. The time required to prepare a stick model of a tower from a detailed tower model should be less than 8 manhours.

Q. Are you looking at towers with guy wires, pinned joints or damping?

A. No, but the modeling method described is amenable to structures with guy wires, pinned joints and damping.

TABLE I. - MOD-0 TOWER NATURAL FREQUENCIES, Hz

Mode	Measured	Predicted	
		Detailed Model	Stick Model
1st bending-1	4.7	4.8	4.9
1st bending-2	5.1	5.2	5.0
2nd bending-2	9.4	9.2	20.1

TABLE II. - COMPLETE MOD-0 PREDICTED NATURAL FREQUENCIES, Hz

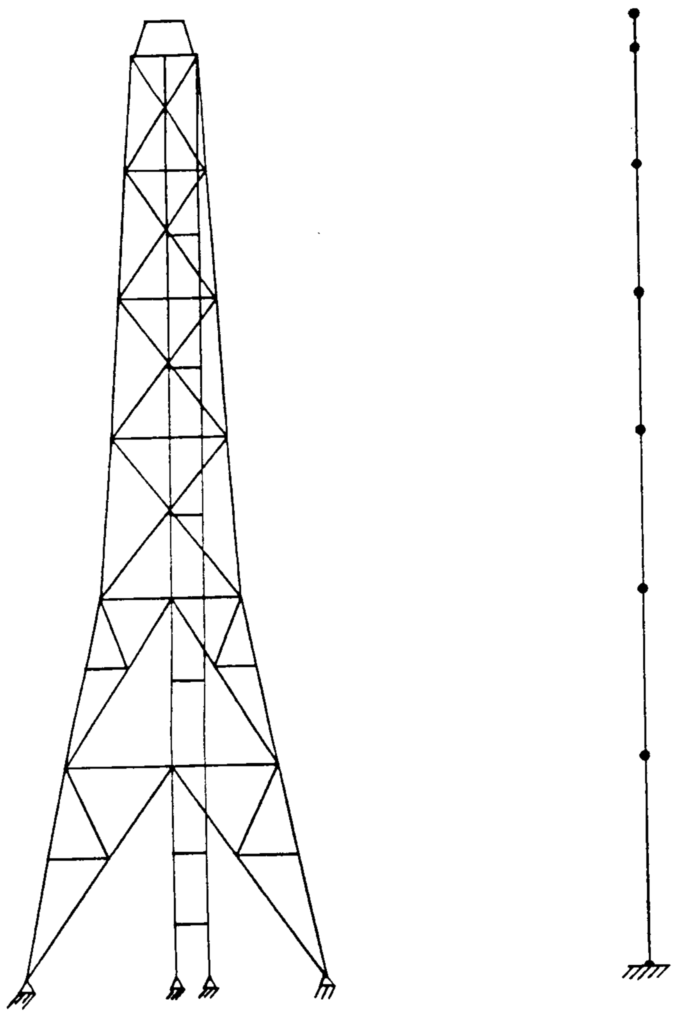
Mode	Detailed Model	Stick Model
Tower torsion	1.3	1.3
Tower 1st bending[a]	2.0	2.1
Tower 1st bending[b]	2.2	2.4
Tower/pod bending	3.8	3.9

[a]Motion at top of tower parallel to drive shaft
[b]Motion at top of tower normal to drive shaft

TABLE III. - COMPUTER TIME COMPARISONS

Computer Time	Detailed Model	Stick Model
Symmetric real decomposition time estimate, sec.	67	1
CPU time - 4 modes[a], min.	12.0	0.7
Total computer time - 4 modes[a], min.	24.4	3.2

[a]For the detailed model, 5 eigenvalues were extracted. One was a local mode.



(a) Detailed model (143 nodes; 309 elements).

(b) Stick model (8 nodes; 7 elements).

Figure 1. - Mod-0 tower models.

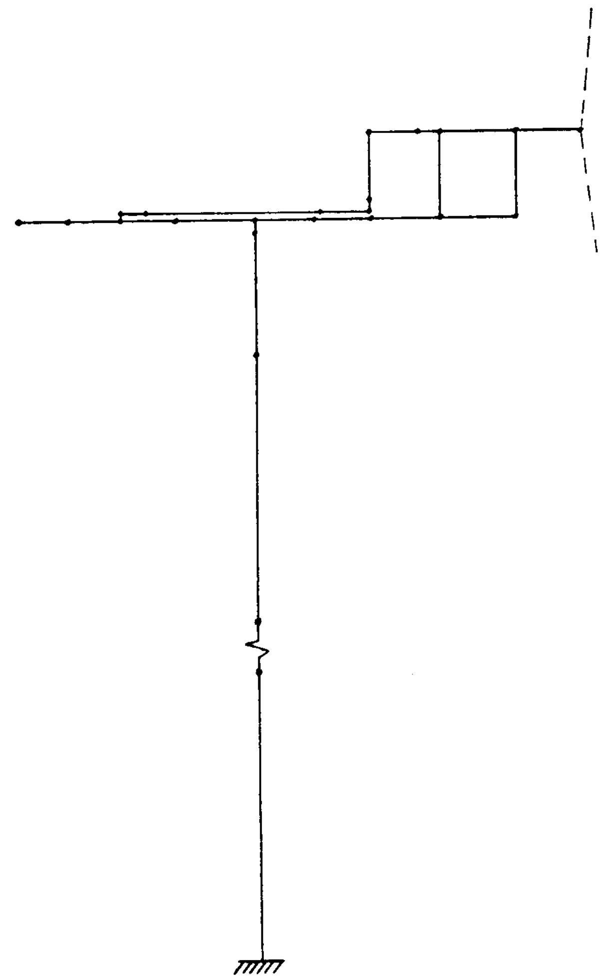


Figure 2. - Complete model with stick tower.

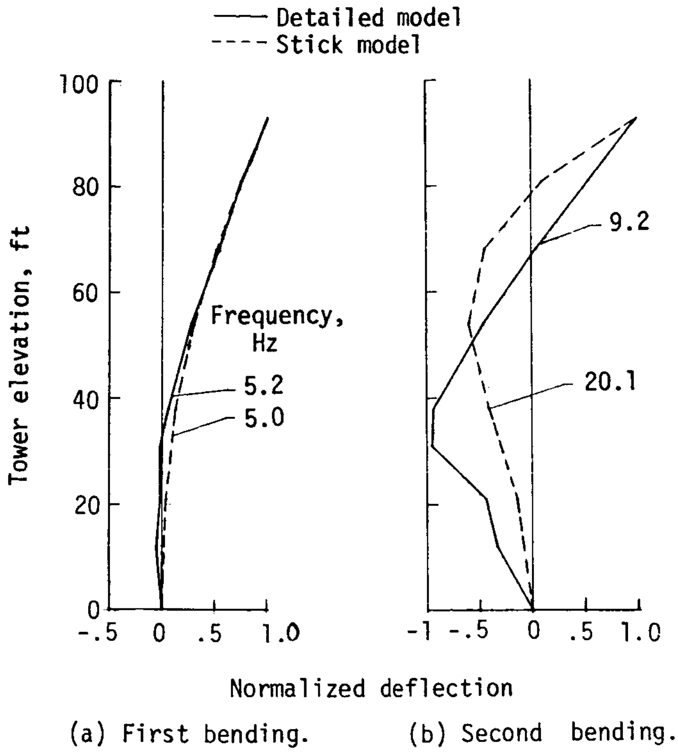


Figure 3. - Comparison of detailed and stick tower model mode shapes for tower only.

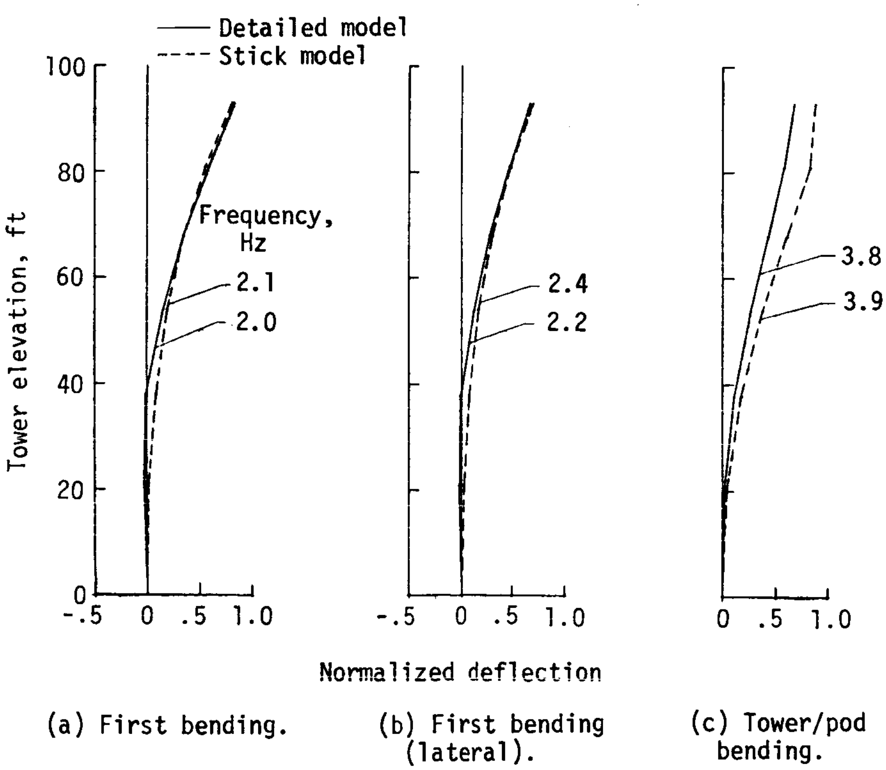


Figure 4. - Comparison of detailed and stick tower model mode shapes for complete system.