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Vibration Control and Optimization in Composite Structural Elements by Use of Add-On Viscoelastic Materials.

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13. ABSTRACT *(Maximum 200 words)*
The findings of the research supported by ARO Grant DAAl03-88-K-0013 to the University of Florida are summarized. The focus of the study was in three areas :

<a> development of new and efficient models for accurate prediction of structural damping ability,

<b> development and application of new strategies to the associated optimization problem, i.e., damping layer redistribution for maximizing damping subject to static stiffness, stress, weight and frequency constraints, and,

<c> experimental quantification for comparison with analytical predictions.

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This report summarizes the findings of the research supported by ARO Grant DAAL03-88-K-0013 to the University of Florida. In the present study, the feasibility and effectiveness of viscoelastic damping materials for the vibration control of composite structural elements were examined. The representative problem chosen for this study was the optimization of add-on constrained viscoelastic damping treatment applied to arbitrarily laminated composite plate and beam elements. The focus of the study was in three areas :

<a> development of new and efficient models for accurate prediction of structural damping ability,

<b> development and application of new strategies to the associated optimization problem, i.e., damping layer redistribution for maximizing damping subject to static stiffness, stress, weight and frequency constraints, and,

<c> experimental quantification for comparison with analytical predictions.

(1) Research in analysis and optimization was conducted by Drs. Sun and Hajela of the University of Florida. They were assisted in their efforts by doctoral candidates V. S. Rao and C.-Y. Lin.

The main objective of this phase was to develop an efficient finite element analysis program for the analysis of viscoelastically damped composite beams and plates. A special-purpose, stand-alone finite element analysis code, UFPAC, ideally suited to analyze such structures was developed. The program contains a library of elements considered to be most appropriate for modeling laminated composite beams and plates. Emphasis was placed on the efficiency of the finite element model since it had to be combined with optimization algorithms which usually require a large number of functional evaluations. The ability to model the effect of structural prestress on the overall damping ability is also included in the analysis. Structural prestress, such as the centrifugal stiffening caused in helicopter rotor blades are significant, and can cause considerable change in stiffness and damping ability. The finite element implementation of the modal strain energy based approach was modified for efficiently predicting the damping ability about prestressed configurations. In previous progress reports the finite element model was shown to be accurate and is believed to be an improvement upon existing models available for the analysis of such structures. Details of the two-dimensional analysis were summarized in previous progress reports, and the appropriate publications were also submitted.

An example problem showing the effect of prestress on loss factors and mode shapes of a tapered graphite/epoxy beam modeled by using the laminated plate element is included at the end of this report. The figures 1-8 shown are a two dimensional array of heights (deflections) and do not reflect the actual shape of the beam. However, it clearly shows the different bending and twisting mode shapes, and the dominant effect that prestress has on the response characteristics of a structure. In fact, when the inplane loads are sufficiently large they govern the flexural behavior of the member, and the effect of the material properties is relatively small. The prestress considered in this case is caused by a steady state rotation as shown on page 6. The details of the analysis applied to a generally laminated composite plate, and results from the three-dimensional model are currently being prepared for publication and will be made available after completion.

The development efforts in the area of optimization methods were focussed in two directions. In the first approach, new strategies in optimal design were combined with the analysis tools described in the preceding paragraphs for predicting damping in laminated composites subjected to viscoelastic damping treatments. The optimal design problem is of multi-criterion nature and the design space is characterized by a mix of integer, discrete and continuous design variables. The feasible directions method based global criterion approach, with a branch-and-bound strategy to account for discrete variables, was introduced as a solution to this problem. Results from this study were presented in publication number 11 in Item 1 included after this section. However, the approach was found to be deficient from the standpoint of increased computational effort with increasing dimensionality of discrete/integer design variables, and like other mathematical programming algorithms, susceptible to convergence to a local optimum.

As a second approach, genetic algorithms, which have been discussed in previous progress reports, were combined with the analytical methods to design optimal damping layer configurations. This approach has been shown to be versatile in its operation in a discrete design space, and further, is less susceptible to convergence to a local optimum. Two distinct strategies have been implemented to account for the multi-criterion nature of the design, and to obtain a family of Pareto solutions in a single run of genetic search. The results are encouraging and are discussed in publications 1 and 4 included under Item 1.

(2) Supporting experimental research was conducted by Dr. R. F. Gibson at Wayne State University, Detroit, Michigan. He has been assisted by post-doctoral Research associate Dr. Raju Mantena and Graduate Assistant M. L. Anantha Murthy.

The major objective of the experimental phase was to provide verification of the results predicted by the analytical model. Experimental study consisted of fabricating and testing simple composite geometries such as beams and plates subjected to add-on constrained viscoelastic damping treatments. The focus was on the design of appropriate specimen configurations and fixtures for preloading the specimens, and measuring damping about preloaded configurations. The design of the loading fixtures and specimens have been discussed in previous progress reports. Damping measurement were made for several taped and untaped composite specimens with and without preload. In each case, the experimental results showed reasonably good agreement with the analytical predictions. In the preloaded case, the comparisons can be made up to first-ply failure beyond which point the increase of damping due to damage seen in the experimental results is not accounted for in the finite element model. Experimental results also confirmed that the effect of boundary conditions on the overall damping ability is significant in the case of surface damping treatments. The experimental method used in this research was a frequency domain based damping measurement technique. The method was developed previously by the principal investigator. The details regarding the experimental technique and other pertinent references are available in publication number 2 in Item 1. An independent three-dimensional finite element analysis of un-preloaded beams was also conducted at Wayne State University. Results from this analysis have been discussed in different publications which have been submitted with the progress reports.

Item 1. MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP

1. C.-Y. Lin and P. Hajela, "Genetic Algorithms in Structural Optimization Problems with Discrete and Integer Design Variables", in review for Journal of Engineering Optimization.

2. P. R. Mantena, R. F. Gibson, and S. J. Hwang, "Optimal Constrained Viscoelastic Tape Lengths for Maximizing Damping in Laminated Composites", to be published in AIAA Journal in 1991.

3. P. Hajela and C.-Y. Lin, "Genetic Search Strategies in Multicriterion Optimal Design", Proceedings of the II Pan American Congress of Applied Mechanics, Valparaiso,Chile, January 1991.

4. P. Hajela and C.-Y. Lin, "Genetic Search Strategies in Multicriterion Optimal Design", Proceedings of the 32nd AIAA/ASME/ASCE/ASC SDM meeting, Baltimore, MD, April 1991.

5. V. S. Rao, B. B. V. Sankar, and C. T. Sun, "Constrained Layer Damping of Composite Beams Subjected to Initial Stresses", Proceedings of the 5th technical conference of the American Society of Composites, East Lansing, Michigan, June 10-13, 1990.

6. P. R. Mantena and R. F. Gibson, "Constrained Layer Damping Treatments for Vibration Control in Composite Structural Elements", Proceedings of the 5th technical conference of the American Society of Composites, East Lansing, Michigan, June 10-13, 1990.

7. R. F. Gibson, " Damping Characteristics of Composite Materials and Structures", Presented at the 6th Annual ASM/ESD Advanced Composite Conference, Detroit, Michigan, Oct. 8-11, 1990 and Submitted to Journal of Materials Engineering.

8. C. T. Sun, B. V. Sankar and V. S. Rao, " Damping and Vibration Control of Unidirectional Composite Laminates Using Add-on Viscoelastic Materials", 139(2), pp. 277-287, 1990.

9. Gibson, R. F., "Dynamic Mechanical Properties of Advanced

Composite Materials and Structures", The Shock and Vibration Digest, Vol 22, No. 8, pp. 3-12, August 1990.

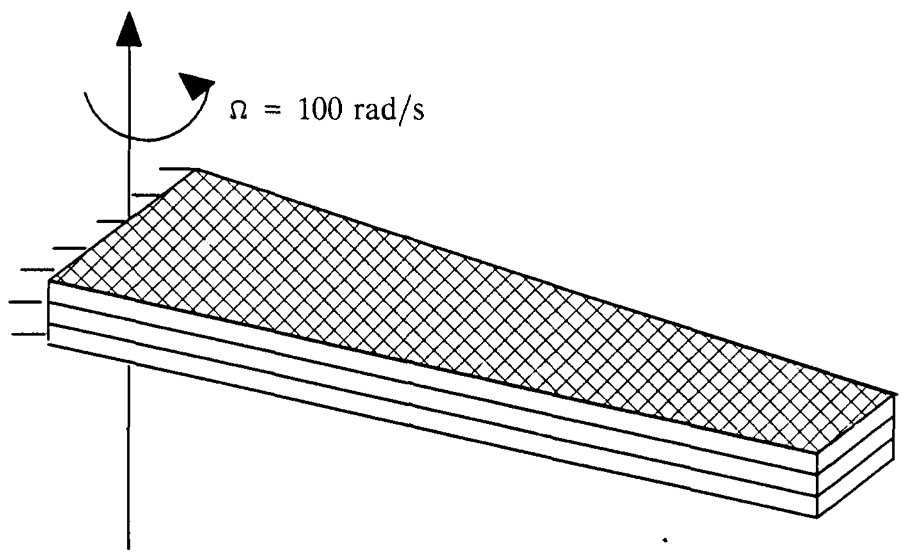
10. P. R. Mantena, "Vibration Control of Composite Structural Elements with Constrained Layer Damping Treatments", PhD Dissertation, University of Idaho, July 1989.

11. C.-J Shih, "Optimum Design of Laminated Composite Structures for Enhanced Damping Characteristics", PhD Dissertation, University of Florida, April 1989.

Item 2. SCIENTIFIC PERSONNEL SUPPORTED

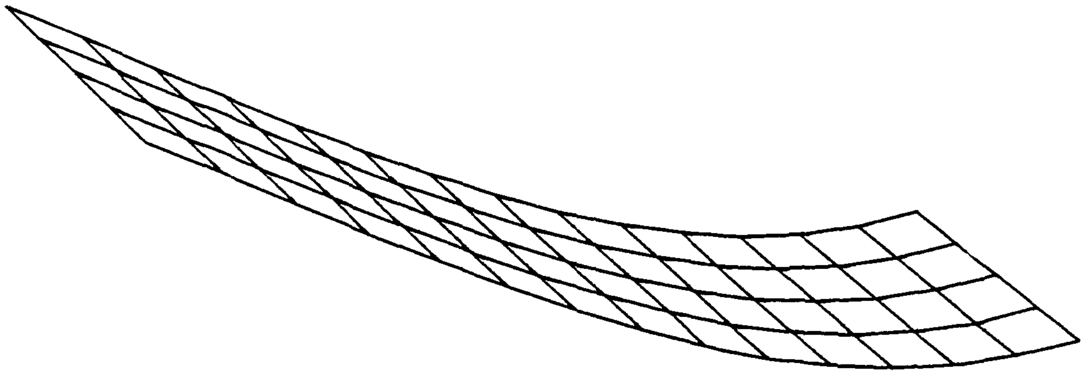
1. Mr. V. S. Rao, Graduate Research Assistant, University of Florida.
2. Mr. C.-Y. Lin, Graduate Research Assistant, University of Florida.
3. Dr. C. J. Shih, Graduate Research Assistant University of Florida.
4. Dr. P. R. Mantena, Post-Doctoral. Research Associate, Wayne State University.
5. Mr. M. L. Anantha Murthy, Graduate Research Assistant, Wayne State University.

EXAMPLE PROBLEM -



$[0]_{20}$	ply thickness 0.000127 mm	E_1	= 127.90 GPa
Length	1 m	E_2	= 10.27 GPa
width	0.05 m (fixed end)	G_{12}	= 7.31 GPa
	0.02 m (free end)	υ_{12}	= 0.24
		υ_{23}	= 0.20

Frequency = 4.83 Hz
loss factor = 0.005



Frequency = 17.7 Hz
loss factor = 0.00051

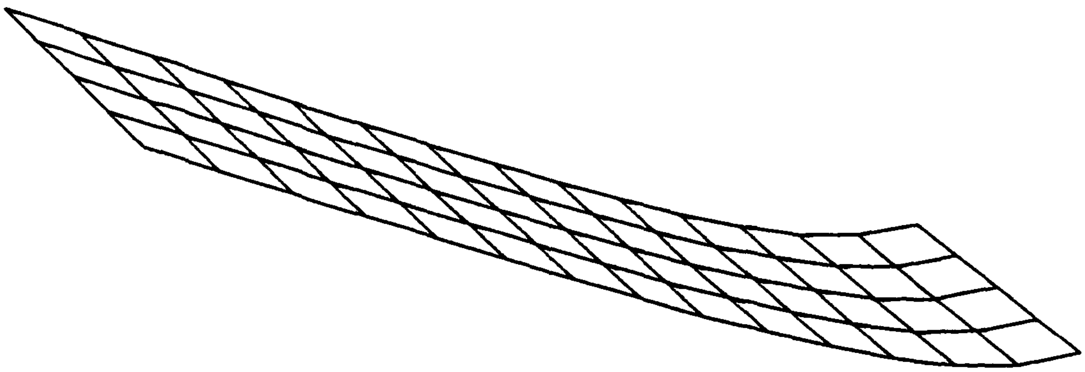


Figure 1. Mode shape of un-prestressed (top) and prestressed (bottom) tapered laminated composite beam (Mode 1)

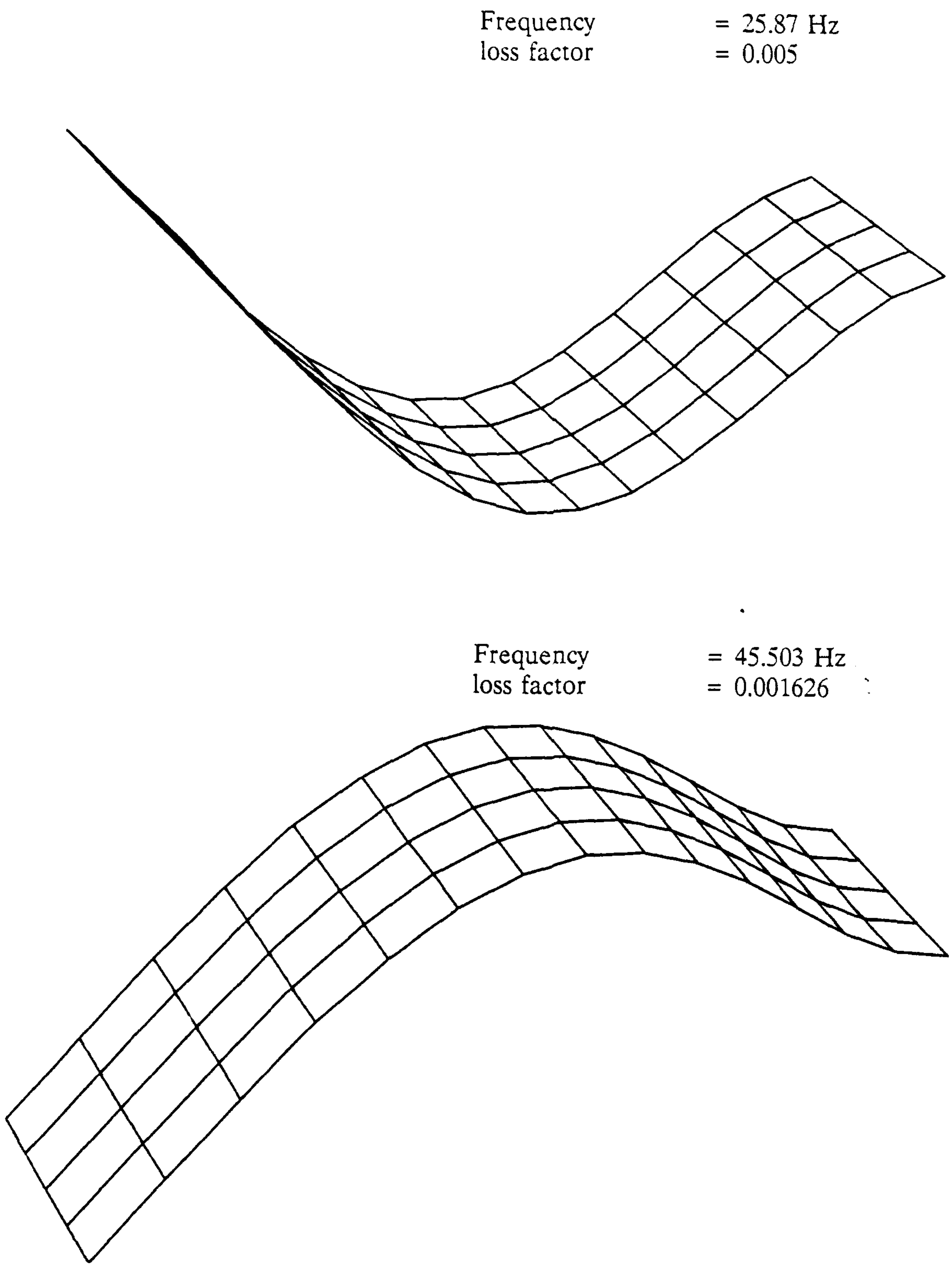


Figure 2. Mode shape of un-prestressed (top) and prestressed (bottom) tapered laminated composite beam (Mode 2).

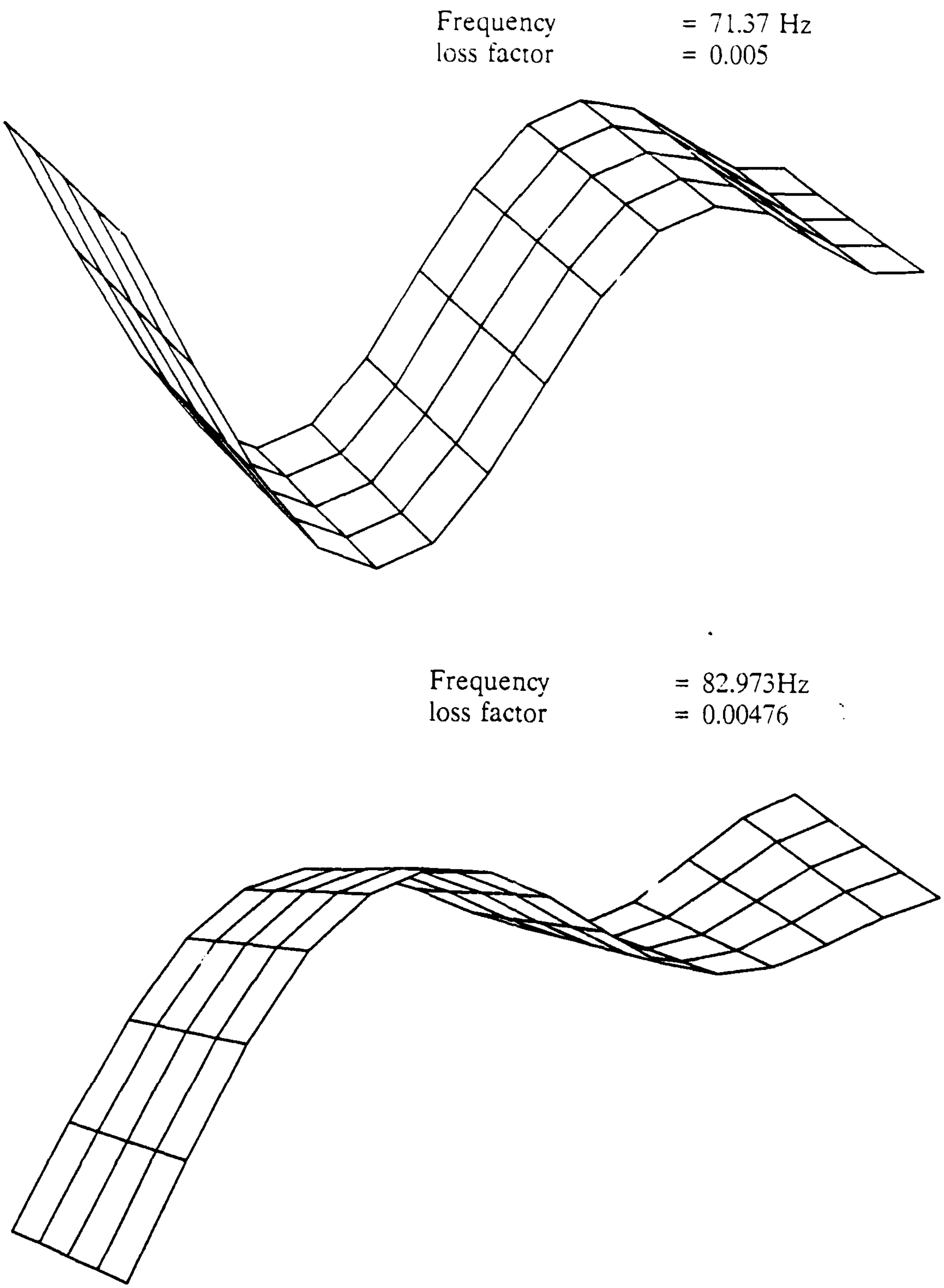


Figure 3. Mode shape of un-prestressed (top) and prestressed (bottom) tapered laminated composite beam (Mode 3)

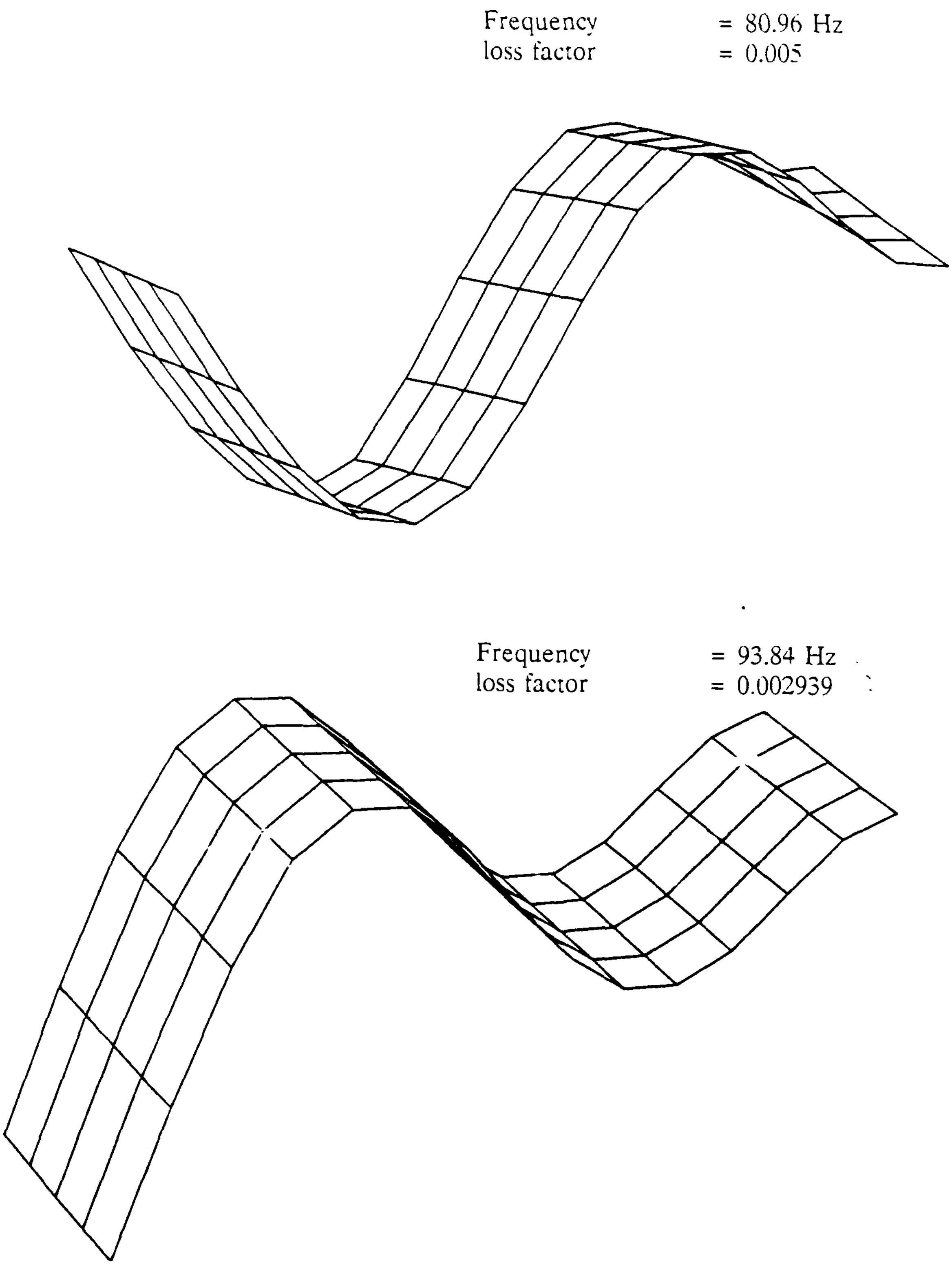


Figure 4. Mode shape of un-prestressed (top) and prestressed (bottom) tapered laminated composite beam (Mode 4)

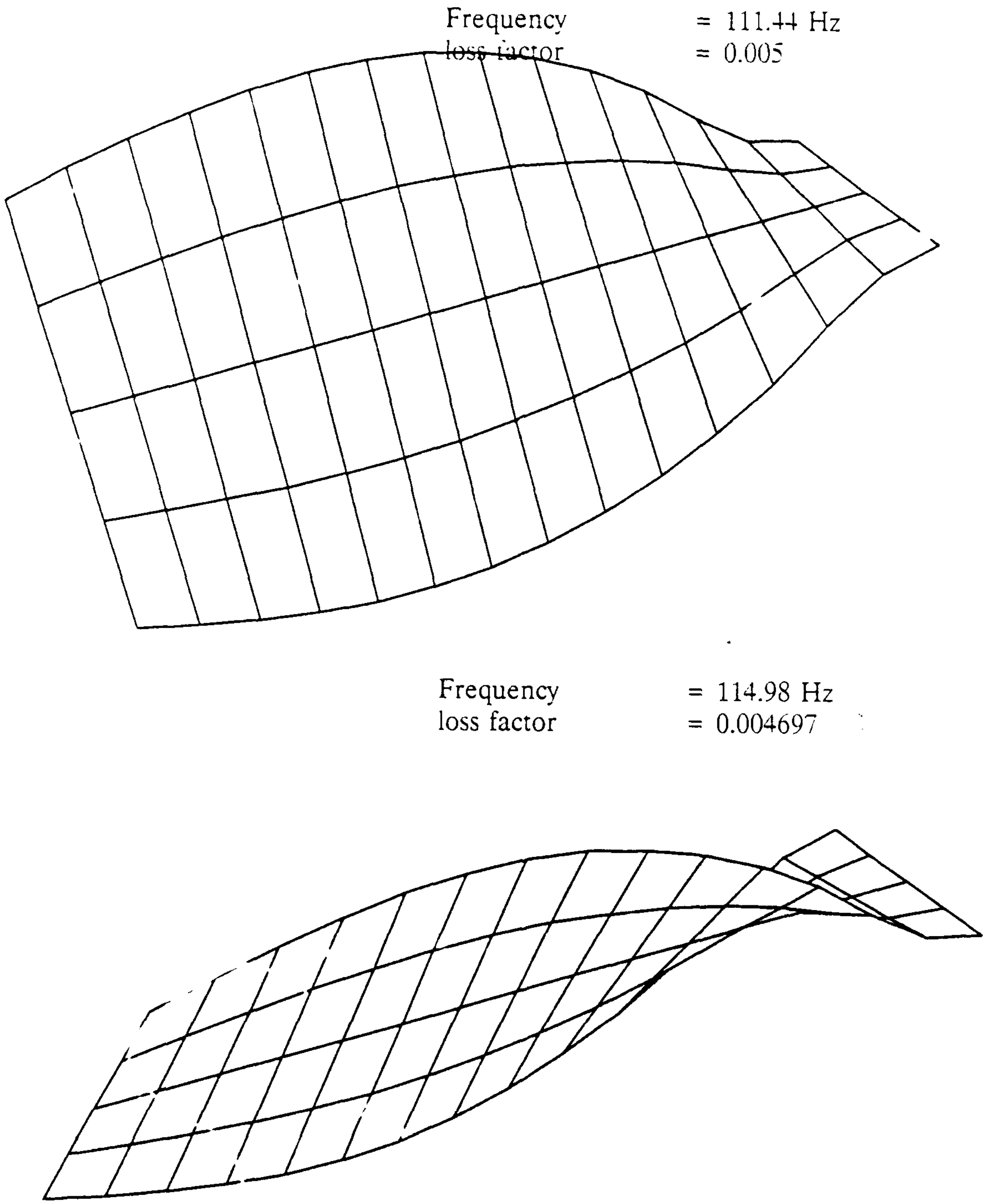


Figure 5. Mode shape of un-prestressed (top) and prestressed (bottom) tapered laminated composite beam (Mode 5)

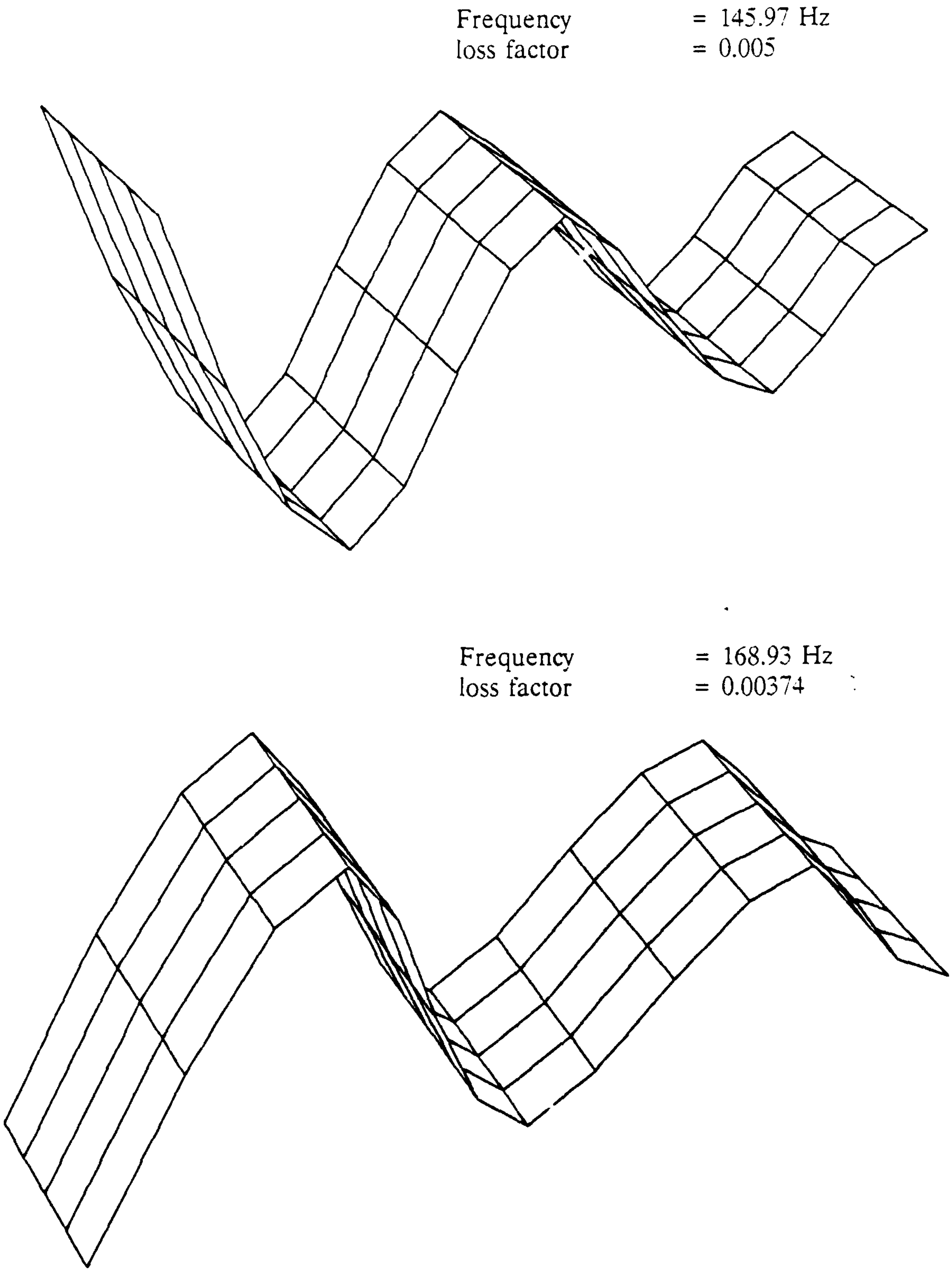


Figure 6. Mode shape of un-prestressed (top) and prestressed (bottom) tapered laminated composite beam (Mode 6).

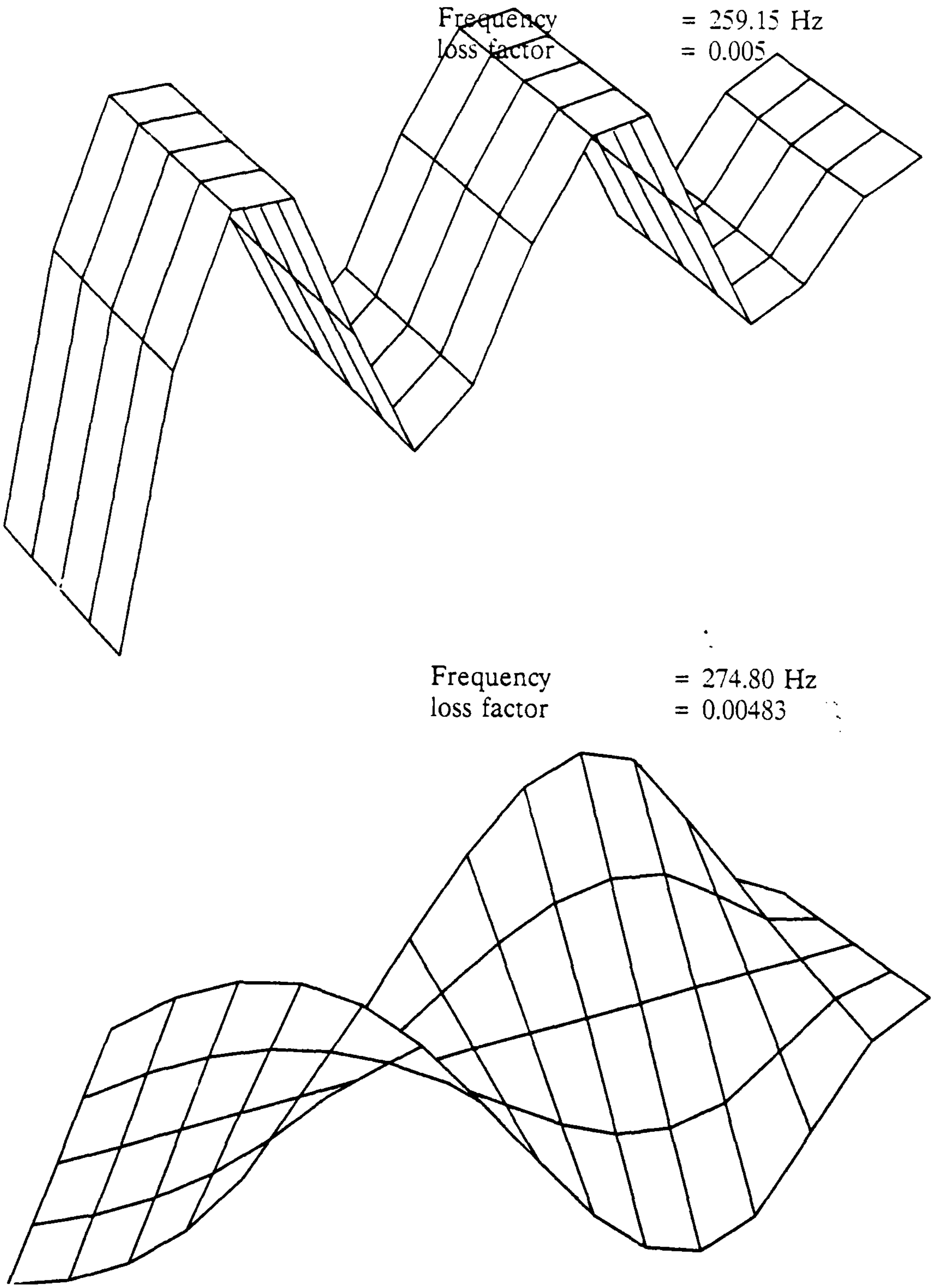


Figure 7. Mode shape of un-prestressed (top) and prestressed (bottom) tapered laminated composite beam (Mode 7)

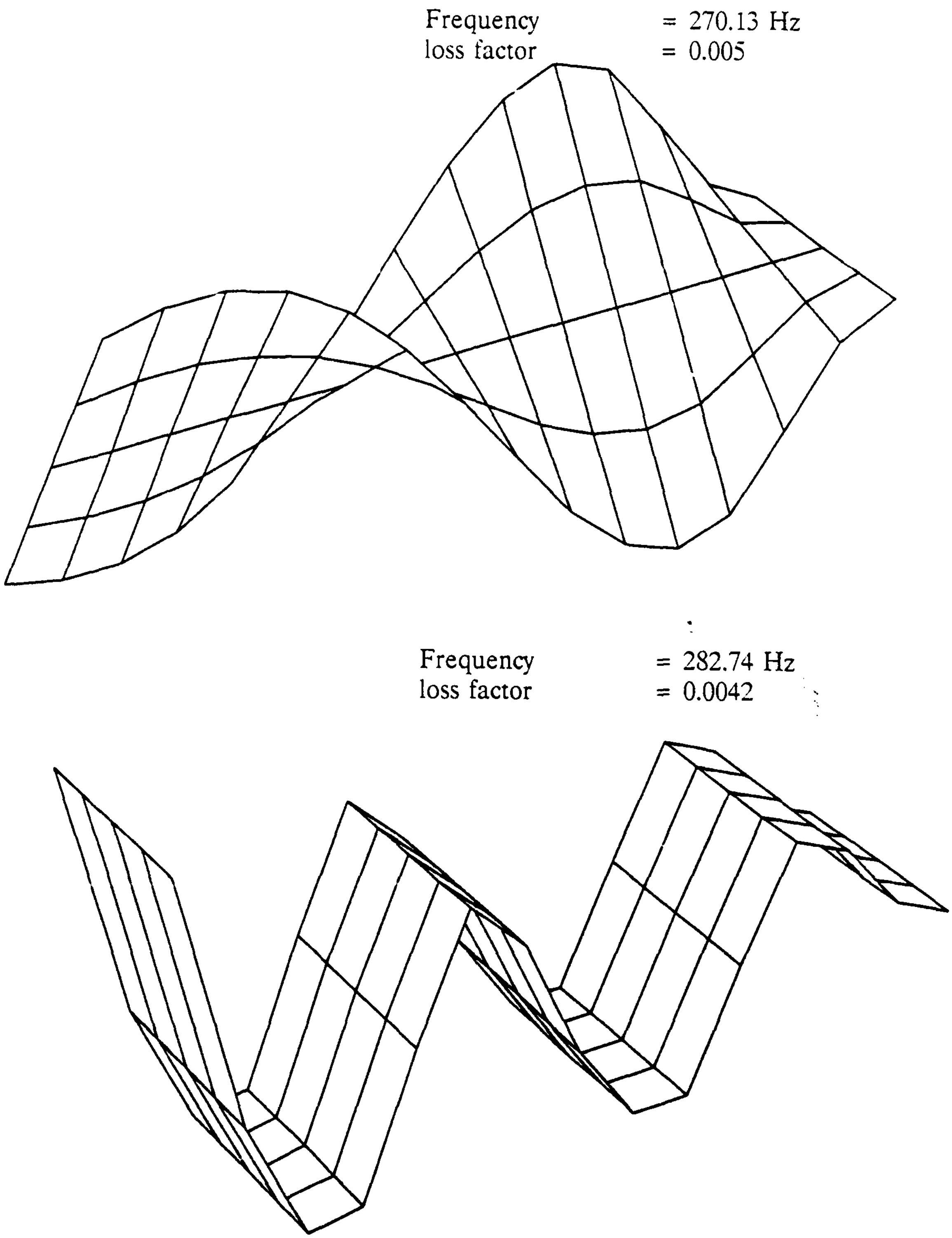


Figure 8. Mode shape of un-prestressed (top) and prestressed (bottom) tapered laminated composite beam (Mode 8)