NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2414

AN EXPERIMENTAL DETERMINATION OF THE CRITICAL BENDING MOMENT OF A BOX BEAM STIFFENED BY POSTS

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SUMMARY

An experimental determination of the critical bending moment of a box beam stiffened by posts is described and discussed. The experimental buckling load is in good agreement with that given by theory. Since appreciable distortion of the beam cross section occurred before the buckling load was reached, modification of post construction by the use of several ribs may be necessary for maintenance of the rectangular shape of the cross section.

INTRODUCTION

A theory for the stability of an idealized box beam stiffened by posts and subjected to pure bending was presented in reference 1. In that paper a trial design was made in which the box-beam compression cover would buckle with transverse nodes through the posts. The weight of post stiffening required to stabilize the compression cover was found to be very small compared with the weight of the compression surface, and a considerable saving of weight appeared to be obtained by the use of post stiffening rather than conventional rib-stringer construction if the amount of stiffening were adequate for actual box beams.

The idealized structure assumed in the theoretical analysis is different from an actual box beam stiffened by posts. For instance, actual box-beam covers are restrained by the webs; whereas the theory assumes that the covers are simply supported. The applied moment causes the box beam to bend; whereas the theory assumes that the covers are subjected to tensile and compressive loads but remain flat. An actual box beam may therefore buckle in a manner much different from the theoretically predicted behavior and the critical load may be materially changed.

In order to obtain some idea of the behavior of an actual box beam stiffened by posts, a box beam similar to that designed in reference 1 was constructed and tested. The details and results of the investigation are given in the present paper.

ANALYSIS OF BOX BEAM

The details and dimensions of the test specimen are shown in figure 1. The tension and compression covers of the box beam are of equal thickness and are riveted to two channels. Three rows of equally spaced posts connect the two covers. The weight of the posts, including all attachment material, is about 6 percent of that of the compression cover.

The theoretical buckling stress σ_{cr} of the box-beam compression cover may be determined by use of the theory of reference 1. Results of that theory which apply to the particular case of box beams with equally stiff tension and compression covers and having one to six rows of posts are shown by the curves of figure 2. The buckling-stress coefficient k for a box-beam compression cover which buckles with nodes along every chordwise line of posts is plotted in figure 2 as a function of L/b, the ratio of the spanwise spacing of the posts to the cover width (see dashed curve and use right-hand ordinate scale). The minimum values of the post-axial-stiffness parameter S required to obtain this mode of buckling are also plotted in figure 2 as a function of L/b (see solid curves and use left-hand ordinate scale).

The following quantities are used in the analysis of the test box beam:

Spanwise spacing of post, L, inches	6.0
Box width between rivet lines, b, inches	28.0
Thickness of covers, t, inches	0.365
Modulus of elasticity of beam material, E, psi	10.5×10^6
Poisson's ratio of beam material, μ	0.3
Flexural stiffness of covers, $D = \frac{Et^3}{12\left(1 - \mu^2\right)}$, pound-inches	46,760
Area of posts, A, square inches	0.1104
Length of posts, h, inches	6.23
Axial stiffness of posts, $F = \frac{AE}{h}$, pounds per inch	186,000
Moment of inertia of box-beam cross section, I, inches^4	192.2
Distance from middle plane of box beam to middle plane of covers, c, inches	2.933
Ratio of spanwise spacing of posts to cover width, L/b	0.214
Axial-stiffness parameter, $S = \frac{Fb^2}{\pi^2 D}$	316

From figure 2, the buckling-stress coefficient $k = \frac{b^2 \sigma_{cr} t}{\pi^2 D}$ is 23.8, corresponding to a cover buckling stress of 38,400 psi, provided the axial-stiffness parameter S is at least 300. The posts are thus seen to be theoretically adequate to stabilize the compression cover until the buckling stress is reached. With the use of this buckling stress and elementary beam theory, the critical bending moment is found to be 2,520,000 inch-pounds.

EXPERIMENTAL RESULTS

The box beam was subjected in the combined load testing machine of the Langley structures research laboratory to a pure bending moment which put the upper surface in compression (see fig. 3). Strains were measured at three locations on the outer surface of the compression cover, as shown in figure 4, to serve as a basis for detecting buckling.

The growth of the measured strains with applied moment is shown in figure 5. The buckling load was taken as the moment at which the strains in gages 1 and 3 reversed. This bending moment of 2,470,000 inch-pounds is only about 2 percent below the calculated moment of 2,520,000 inch-pounds. The structure continued to take load until failure occurred when several posts were crippled at a point about 8 percent above the strain-reversal buckling load.

The mode of buckling indicated by the behavior of the strains after strain reversal appears to be that predicted by the theory. The compression strains in gages 1 and 3 decreased while that in gage 2 increased. This behavior corresponds to superimposed buckles which are up in bays 1 and 3 and down in bay 2 and hence with transverse nodes through the intervening chordwise lines of posts (see fig. 6).

Although buckling load and pattern are significant in providing partial confirmation of the theory presented in reference 1, attention should also be focused upon the prebuckling behavior of the box beam. As the bending moment was increased, a downward deflection of the two covers relative to their edges was observed, the center deflection becoming of the order of the cover thickness. The deflection of the covers relative to their edges is not to be entirely unexpected and can possibly be explained by consideration of the factors that affect bending of the covers. Among the interacting factors are the Poisson effect which produces anticlastic curvature of the beam covers (reference 2) and secondary bending effects associated with hollow beams which make the covers deflect toward each other, the tension surface tending to straighten out and the compression surface tending to have greater curvature than the edges (reference 3). These effects are modified by the posts which transmit forces between the covers and maintain the depth of the box beam and by the end supports which maintain the rectangular cross sections of the ends of the box and clamp the ends of the tension and compression covers.

CONCLUDING REMARKS

Despite differences between the test specimen and the idealized structure used in the analysis, the experimentally determined critical bending moment was only about 2 percent below the calculated critical moment and buckling occurred, as predicted, with transverse nodes through the posts. The results of the test, however, show that significant prebuckling deformations may occur, namely, cross-sectional deformation due to downward dishing of the covers during bending. In actual wings, such cross-sectional deformation could be undesirable, and supplementary stiffening would be necessary to maintain the airfoil shape. For proportions similar to those tested a proper combination of posts and ribs may make a satisfactory design both from the viewpoint of deformations and strength. For some other proportions, posts alone may be adequate. In any case, consideration should be given to the possibility and importance of cross-sectional deformation in any application of stiffening by the use of posts.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., April 19, 1951

REFERENCES

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2. Timoshenko, S.: Theory of Elasticity. First ed., McGraw-Hill Book Co., Inc., 1934, pp. 221-226.

3. Reissner, Eric: Note on Some Secondary Stresses in Thin-Walled Box Beams. Jour. Aero. Sci., vol. 9, no. 14, Dec. 1942, pp. 538-542.

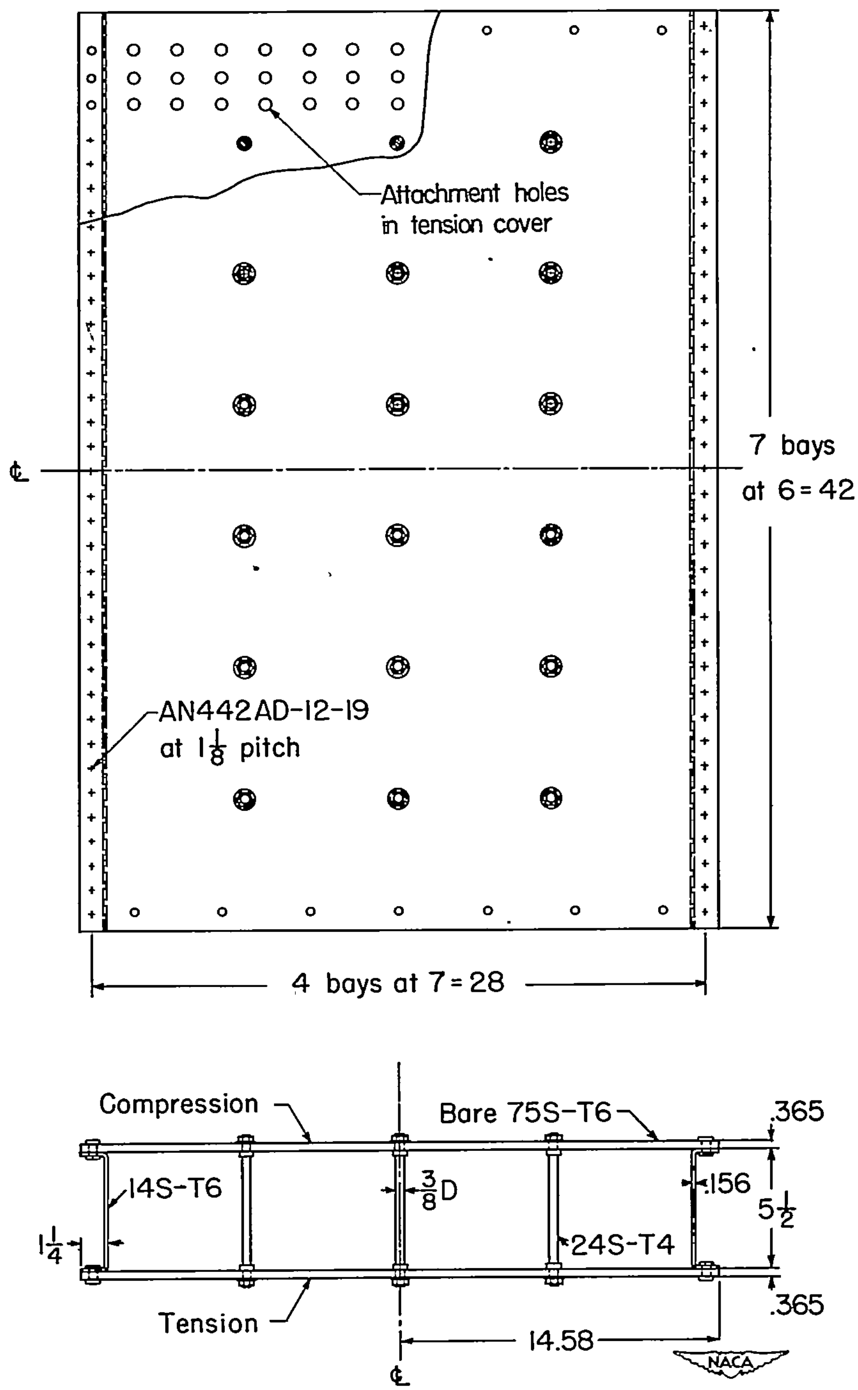

Figure 1.- Test box beam stiffened by posts.

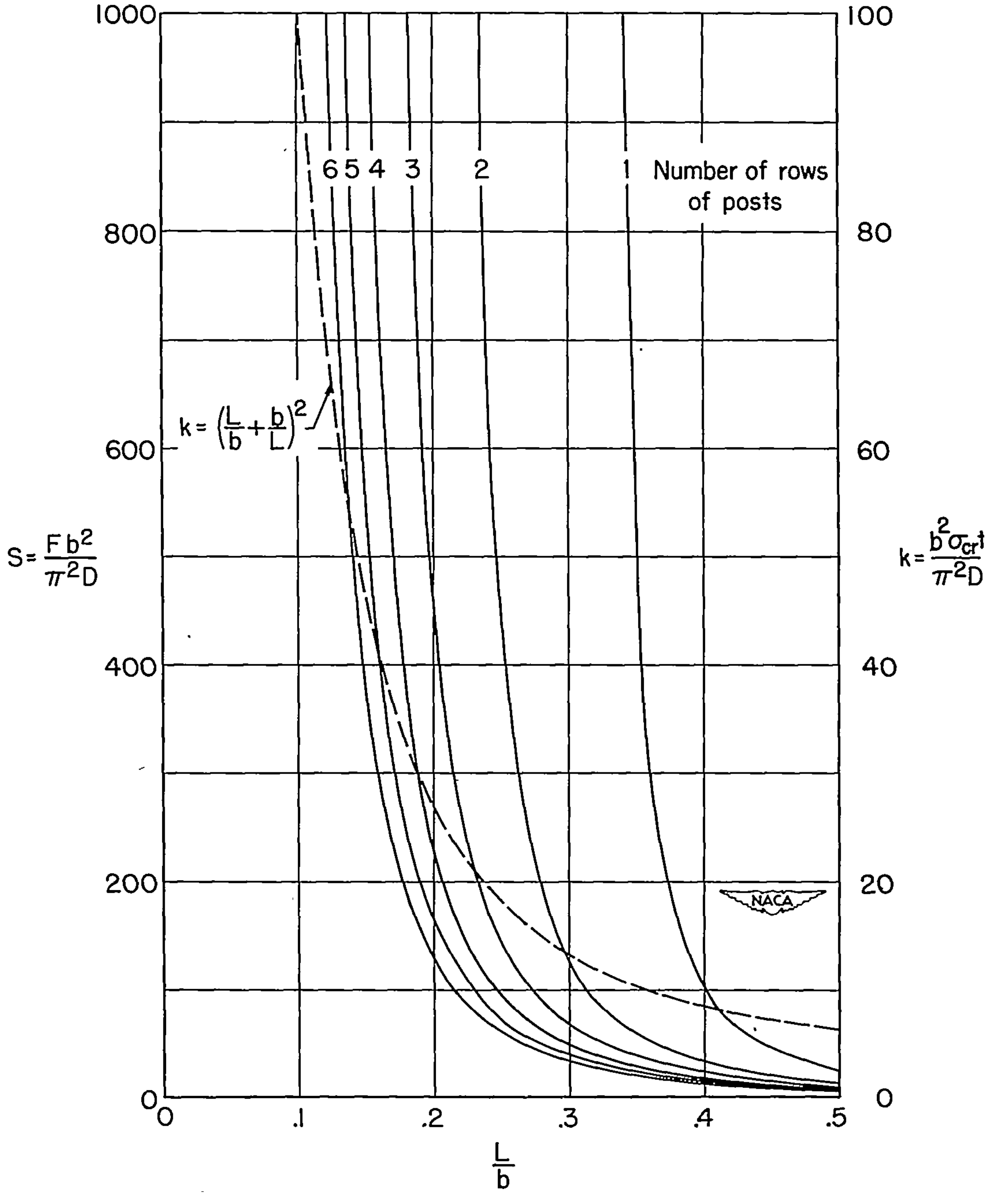

Figure 2.- Minimum post axial stiffness required for compression cover to buckle with transverse nodes through the posts (solid curves) and corresponding buckling-stress coefficient (dashed curve).

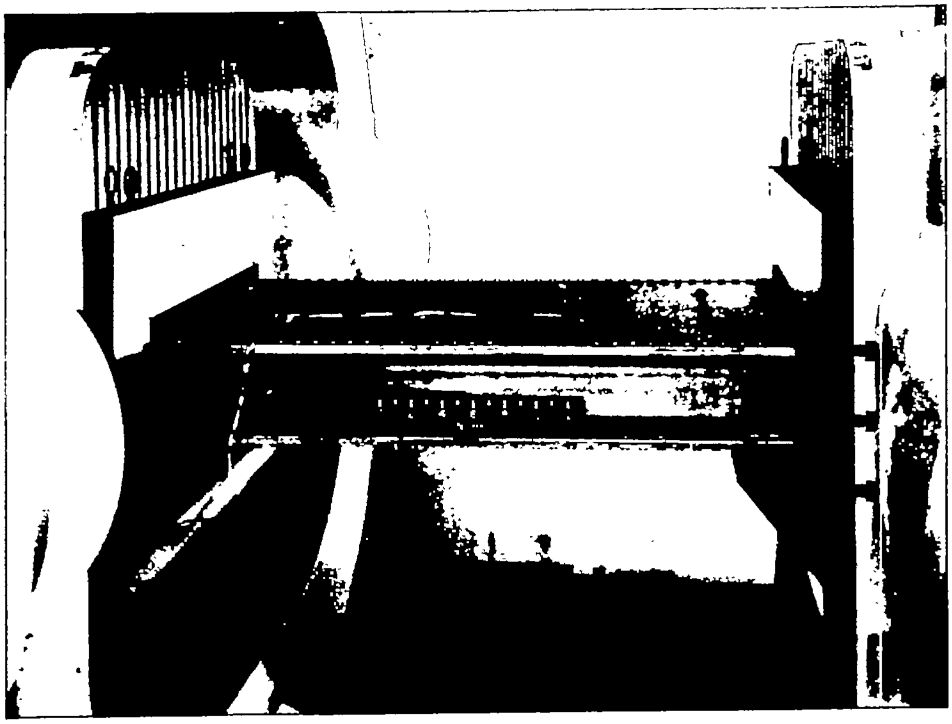

Figure 3.- Box beam mounted in combined load testing machine.

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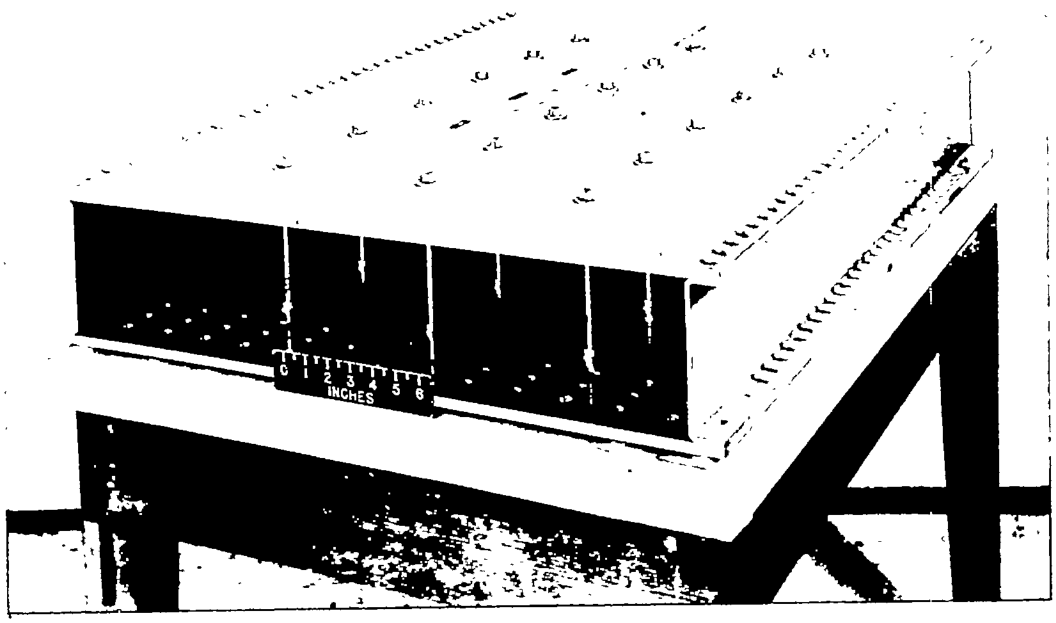

Figure 4.- Location of strain gages on box-beam compression cover.

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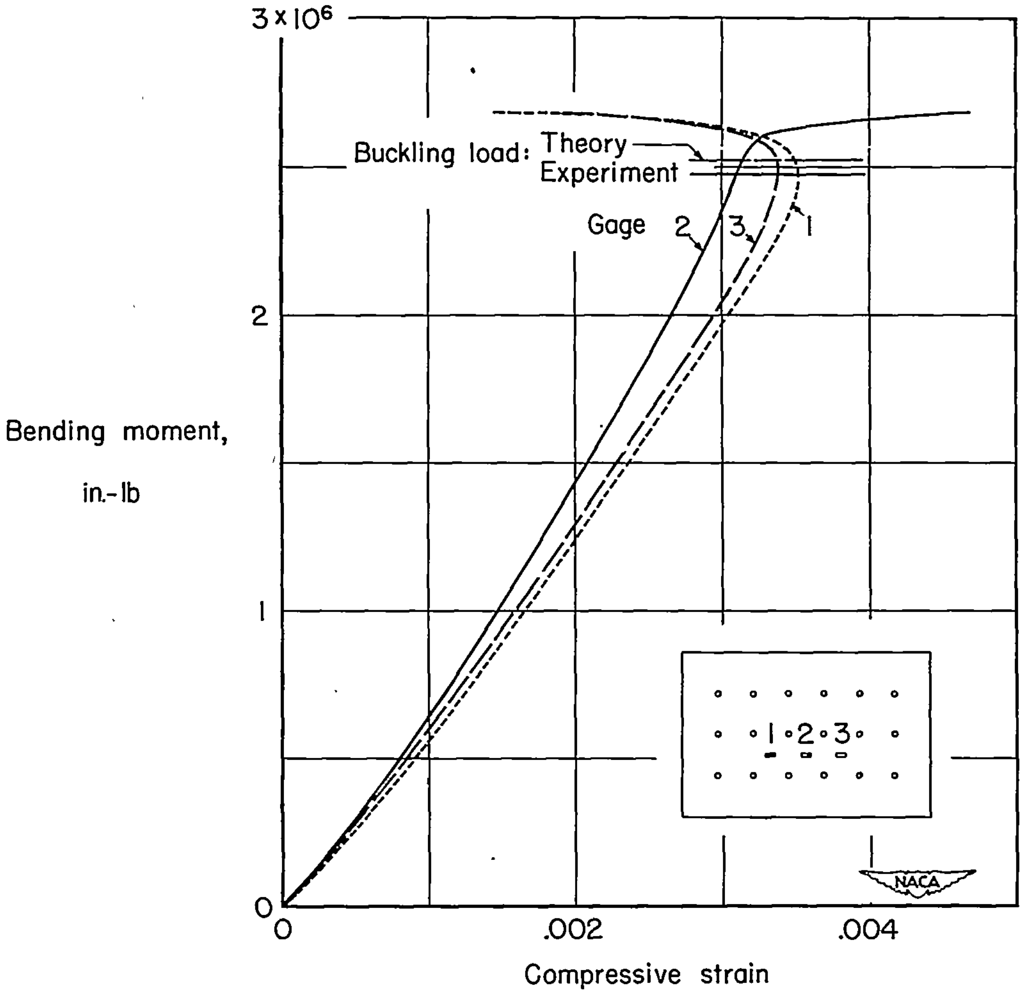

Figure 5.- Load-strain curves for compression cover of box beam stiffened by posts.

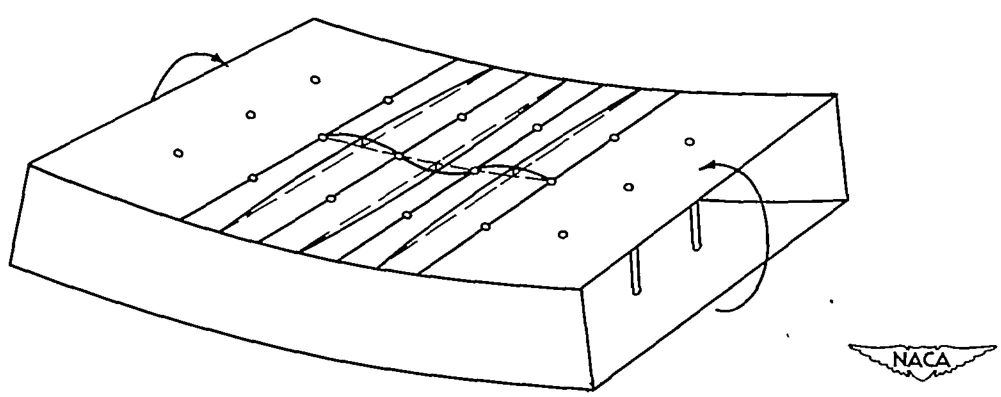

Figure 6.- Mode of buckling of the box beam.

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