This is an abridged version. for the full paper, see bosor5.papers/1986.usersmanual.pdf

BOSOR5—PROGRAM FOR BUCKLING OF COMPLEX, BRANCHED SHELLS OF REVOLUTION INCLUDING LARGE DEFLECTIONS, PLASTICITY AND CREEP

D. Bushnell

Lockheed Applied Mechanics Laboratory, Department 93–30, Building 255, 3251 Hanover Street, Palo Alto, California 94304, USA

from: STRUCTURAL ANALYSIS SYSTEMS, Vol. 2, A. Niku-Lari, editor, Pergamon Press, 1986, pp. 55-67

ABSTRACT

BOSOR5 performs axisymmetric collapse and nonsymmetric bifurcation buckling including elastic-plastic material behaviour and creep. It does not supercede BOSOR4, as it has no modal vibration capability or linear nonsymmetric stress analysis capability. It will handle segmented or branched, multimaterial, stiffened shells. The wall may be layered. Smeared stringers and smeared or discrete rings are permitted to go plastic. Only static analysis is performed by BOSOR5. The strategy for solution of the nonlinear prebuckling problem is such that the user obtains reasonably accurate answers even if very large load or time steps are used. This strategy is based on a subincremental iteration method in which the size of the subincrement is automatically determined so that the change in stress is less than a certain prescribed percentage of the effective stress. Discrete rings of arbitrary cross section are considered to be assemblages of thin rectangular elements. The input is interactive as with BOSOR4.

THEORETICAL BACKGROUND AND PROGRAM OVERVIEW

BOSOR5 is based on finite difference energy minimization; trigonometric variation is assumed for the circumferential variable; Newton's method is used to solve nonlinear prestress equilibrium; inverse power iterations with spectral shifts are used for eigenvalue extraction; Lagrange multipliers are used for constraint conditions; BOSOR5 is based on thin shell theory.

BOSOR5 has been widely used since 1974. In 1983 extensive user-friendly features were added to the VAX version to make provision of input data easy and reliable. An interactive input session generates a completely annotated file that can be used for documentation and for input for future similar cases. A MODIFY utility makes updating a case much easier than before. These features are essentially the same as those described in connection with BOSOR4. (See the paper on BOSOR4 in Volume 2 for details.)

The complex segmented and branched shells of revolution may have various meridional geometry, wall construction, boundary conditions, ring reinforcements, stringer reinforcements, and types of loading. Pressure and surface traction may vary along the meridian; temperature may vary along the meridian and through the thickness. Line loads may be applied at discrete ring centroids. Each load may have its own quasi-static variation in time, so that sequential loadings, such as a thermal cycle followed by an external pressure, may be applied. In this way fabrication effects followed by service loads can be simulated with BOSOR5. Examples of this are given below. All loads must be axisymmetric.

BOSOR5 is currently in widespread use and is maintained by the developer. Notices of bugs found are distributed to all known users. BOSOR5 has been thoroughly checked out by comparisons with other known solutions, tests, and by extensive use at many different institutions the world over for about 10 years. The characteristics and status of BOSOR5 are similar to those of BOSOR4. Therefore, the reader is referred to Table 1 in the paper on BOSOR4 for details on restrictions, language, documentation, I/O, hardware, size, availability, and maintenance of BOSOR5.

FIELD OF APPLICATION

BOSOR5 performs the following analyses:

1. a nonlinear stress analysis for axisymmetric behaviour of axisymmetric shell systems (moderately large deflections, elastic-plastic, creeping material). Axisymmetric collapse is a special case of this type of analysis.

2. an eigenvalue analysis in which the eigenvalues represent buckling loads of axisymmetric shell systems subjected to axisymmetric loads. Eigenvectors correspond to axisymmetric and to nonaxisymmetric buckling modes.

BOSOR5 will handle segmented and branched shells with the same geometries as those handled by BOSOR4. (See Fig. 1 in the paper on BOSOR4.)

ASSUMPTIONS, METHOD, DISCRETIZATION, USER-FRIENDLY FEATURES OF BOSOR5

The governing assumptions on which BOSOR5 is based are the same as those on which BOSOR4 is based, except that the material can creep and can go plastic (with elastic unloading). The plasticity model is von Mises yield and associated flow law with isotropic strain hardening. Deformation theory is used for the in-plane shear modulus, which is needed in the analysis governing nonaxisymmetric bifurcation buckling. The strains are assumed to be small.

The method and discretization scheme are the same as in the case of BOSOR4, except that the presence of nonlinear and irreversible material behaviour necessitates the use of the principle of virtual work rather than the principle of minimum potential energy; there is no kinetic energy involved, since BOSOR5 handles only statics problems; and a double-iteration loop is required during the prebuckling analysis phase because both nonlinear geometric (moderately large deflection) and nonlinear material behaviours are present.

Details of the analysis are presented in references 1-4.

The discretization scheme in BOSOR5 is identical to that in BOSOR4. Figure 2 in the paper on BOSOR4 gives details.

The user-friendly features described in the paper on BOSOR4 also apply to BOSOR5. Please see Tables 3, 4, and 5 in the paper on BOSOR4 for details.

EXAMPLES OF APPLICATION

DETAILED EXAMPLE CASE: The style of input and files generated with use of BOSOR5 are so similar to those generated with use of BOSOR4 that no such example will be repeated here. Please see Tables 4 and 5 of the paper on BOSOR4.

However, BOSOR5 input/output are a bit different from BOSOR4 I/O. With BOSOR5 the user executes the pre- main-, and postprocessors explicitly. (With BOSOR4 these three processors are all executed by the user's typing the one command BOSORALL). The explicit execution of each processor in BOSOR5 is better because more computer time is required to solve problems in which both geometric and material nonlinearity are present, and loading history is often important because of path dependence in problems involving plasticity. Therefore, the user generally wants to be able to interact with the analysis more often than is the case with BOSOR4, in which only geometric nonlinearity is present.

With BOSOR5, data that determine the state of the plastically deformed shell at each load step are saved, so that the user may restart the mainprocessor analysis at any load step for which this state has been determined in a previous run. The nature of nonlinear problems treated with BOSOR5 makes frequent use of the restart feature the rule rather than the exception that the use of this feature tends to be with BOSOR4.

BUCKLING OF INTERNALLY PRESSURIZED SHELLS: Ellipsoidal and torispherical heads with internal pressure can buckle because the material in the knuckle region is drawn in toward the axis of revolution as the internal pressure is increased. This deformation is displayed in Fig. 1. The material in the knuckle region is therefore under a biaxial stress field that is tensile in the meridional direction and compressive in the circumferential direction. The buckling mode consists of wrinkles in the knuckle region, as shown in Fig. 2. BOSOR5 calculates the axisymmetric prebuckled state and the lowest bifurcation pressure. Both geometric and material nonlinearity must be included to solve problems of this type accurately. Extensive comparisons with tests performed at the University of Liverpool, the University of Manchester, and in France are given in references 8, 9 and 10. In reference 10 this interesting problem is described in detail.

BUCKLING OF A WATER TANK: In 1972 in Belgium a large water tank collapsed upon being filled for the first time. The geometry of the tank is shown in Fig. 3(a). Failure appeared to be due to meridional buckles that formed in the conical region represented by Segment 9 in Fig. 3(b). This region was subjected to high meridional compression combined with circumferential tension, just the opposite of the biaxial stress state in the internally pressurized ellipsoidal head shown in Fig. 2. Accordingly, the buckles were long in the circumferential direction and short in the meridional direction, in contrast to the wrinkles displayed in Fig. 2. Figure 3(c) shows the axisymmetric prebuckling deformation of the tank predicted by BOSOR5 at the predicted bifurcation buckling load factor, $\lambda = 1.8$ times the load present at the moment of collapse. The prediction is higher than the actual because no allowance is made in the BOSOR5 model for geometric imperfections or welding prestresses. Figure 3(d) shows a redesigned tank and predicted axisymmetric deformations at load factors $\lambda = 1.0$ and at the predicted bifurcation buckling load factor, $\lambda = 2.65$.

AXISYMMETRIC COLLAPSE OF ROCKET BOOSTER STAGE: Figure 4 shows the rather complex rocket interstage geometry. The basically cylindrical shell is under uniform axial compression. Figure 5 displays the multi-segment model treated with BOSOR5. Plastic collapse with increaseing axial compression V occurs because of the large amount of meridional bending caused by the inward excursion of the axial load path in the region of the joint at Station 176. This rocket interstage was tested and failed at a load within 1% of the critical load predicted with BOSOR5.

MODELING FABRICATION EFFECTS WITH BOSOR5: The BOSOR5 program has been used for calculation of bifurcation buckling of cold-bent and welded ring-stiffened

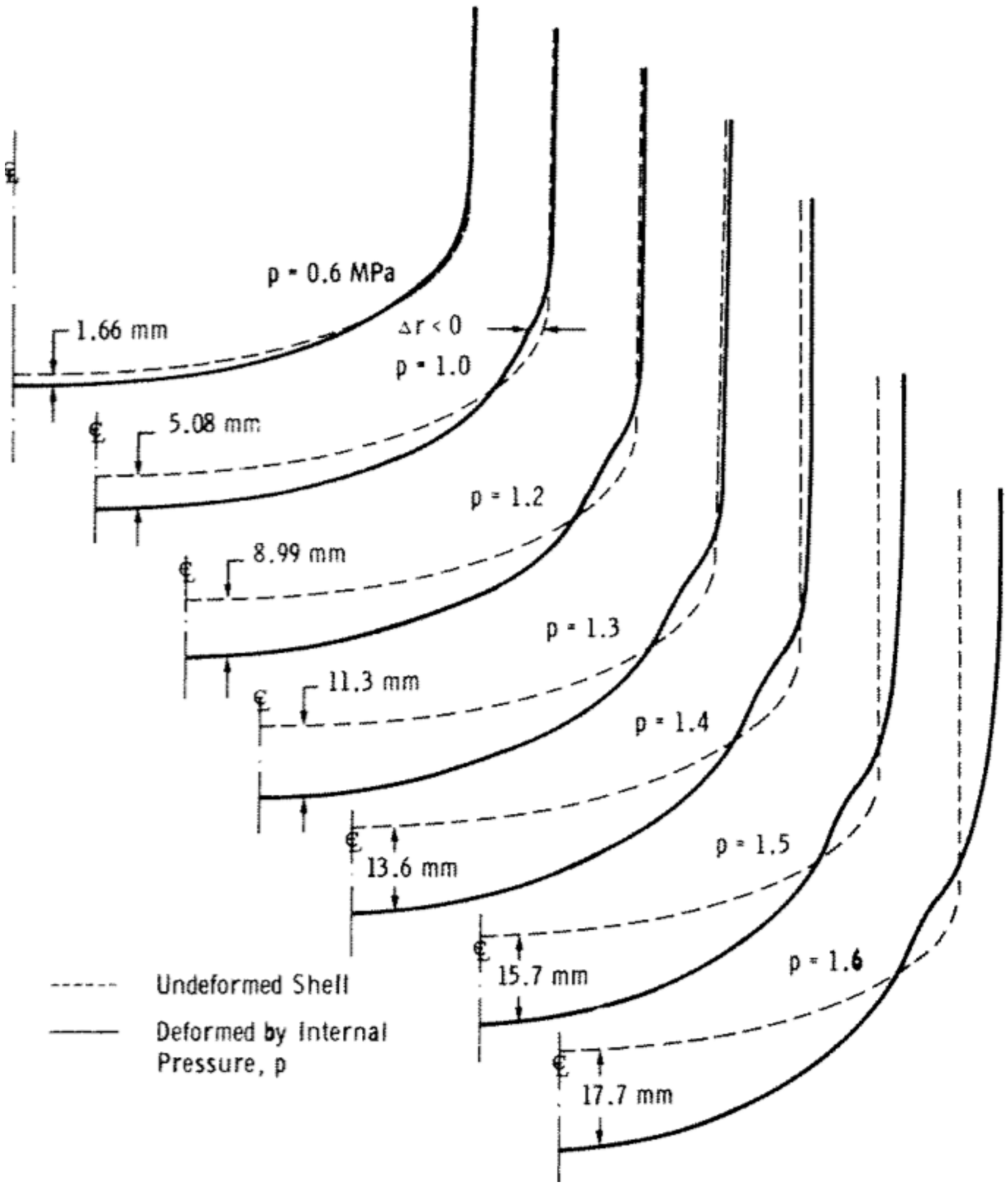

Fig. 1 Axisymmetric deformations predicted by BOSOR5 for an internally pressurized ellipsoidal pressure vessel head. Elastic-plastic bifurcation buckling is caused by the relatively narrow band of circumferential compression that occurs in the knuckle region. Accurate predictions of incipient buckling require the inclusion of both nonlinear geometric and material behavior in the simulation. (from STRUCTURAL ANALYSIS SYSTEMS, Vol. 2, A. Niku-Lari, editor, Pergamon Press, pp. 55-67, 1986)

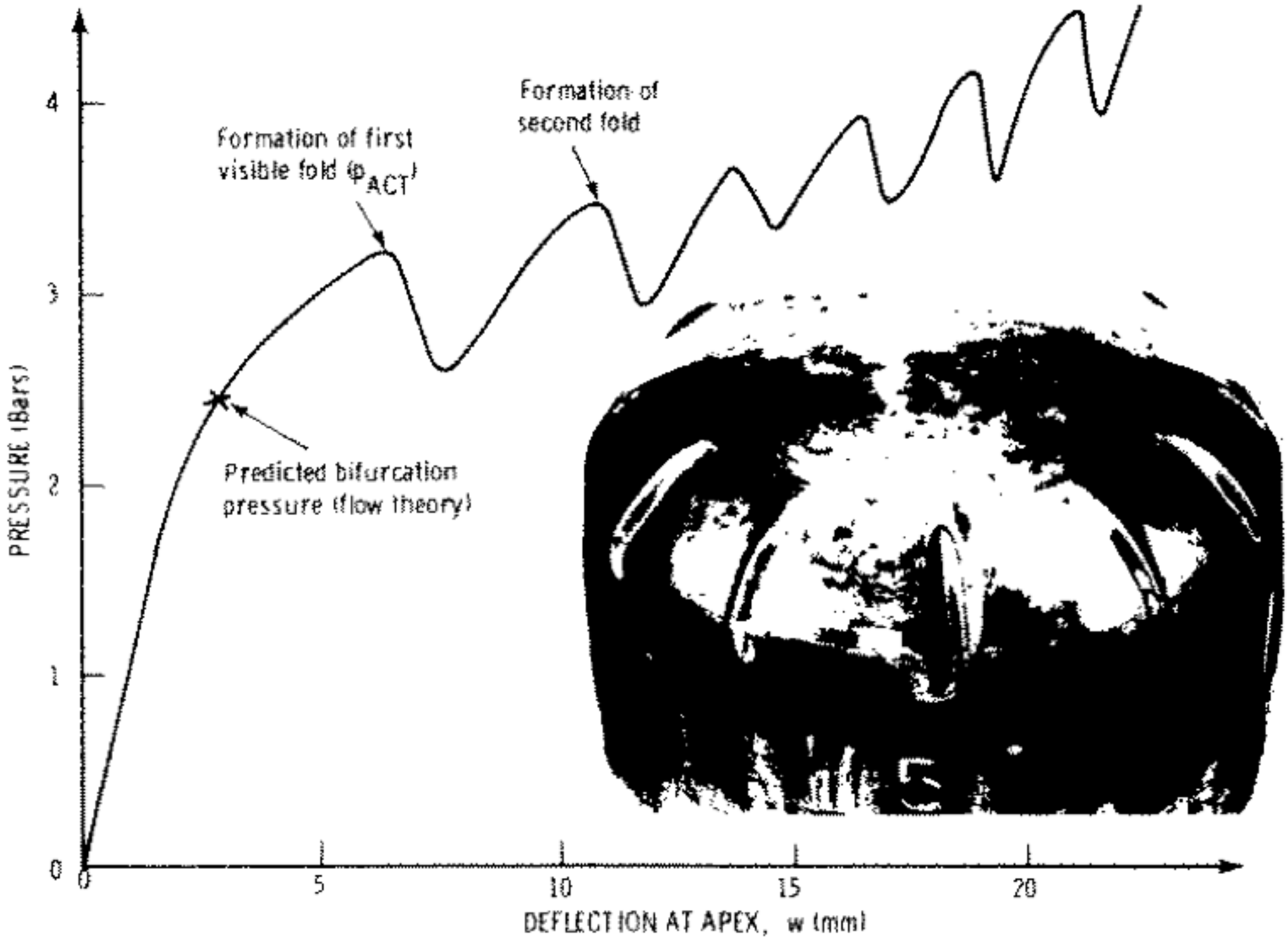

Fig. 2 Pressure-deflection curve for an internally pressurized ellipsoidal pressure vessel head. BOSOR5 predicts the behavior up to the bifurcation point. In the photograph the ellipsoidal head is in the far post-buckled stage. BOSOR5 does not predict post-bifurcation behavior. (from STRUCTURAL ANALYSIS SYSTEMS, Vol. 2, A. Niku-Lari, editor, Pergamon Press, pp. 55-67, 1986)

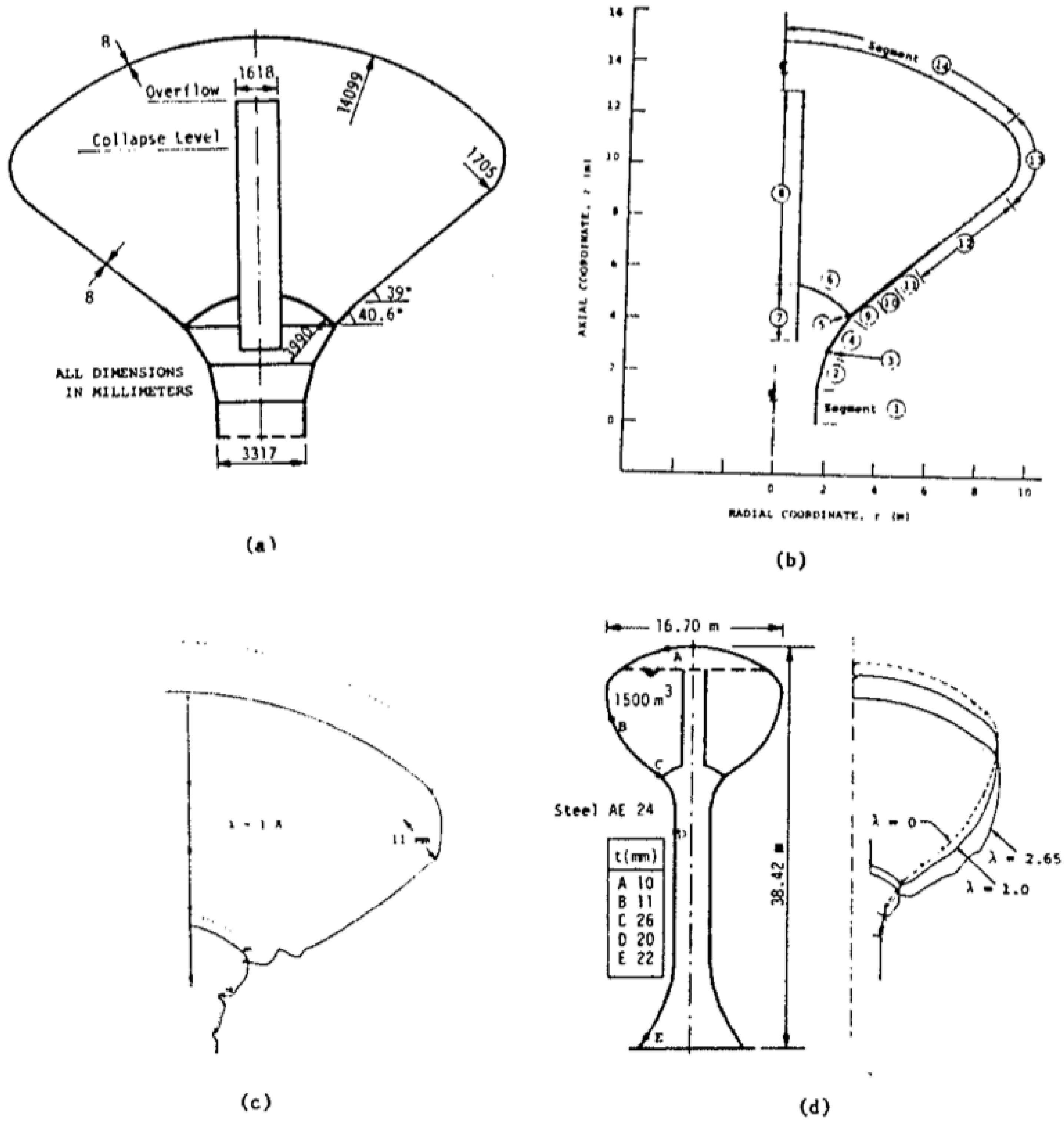

Fig. 3 Large steel water tanks and BOSOR5 models of them: (a) geometry of the original tank that failed in 1972; (b) BOSOR5 segmented and branched model of this tank; (c) BOSOR5 prediction of the axisymmetric deformation just before the predicted collapse; (d) the redesigned tank and deformation predicted by BOSOR5. (from STRUCTURAL ANALYSIS SYSTEMS, Vol. 2, A. Niku-Lari, editor, Pergamon Press, pp. 55-67, 1986)

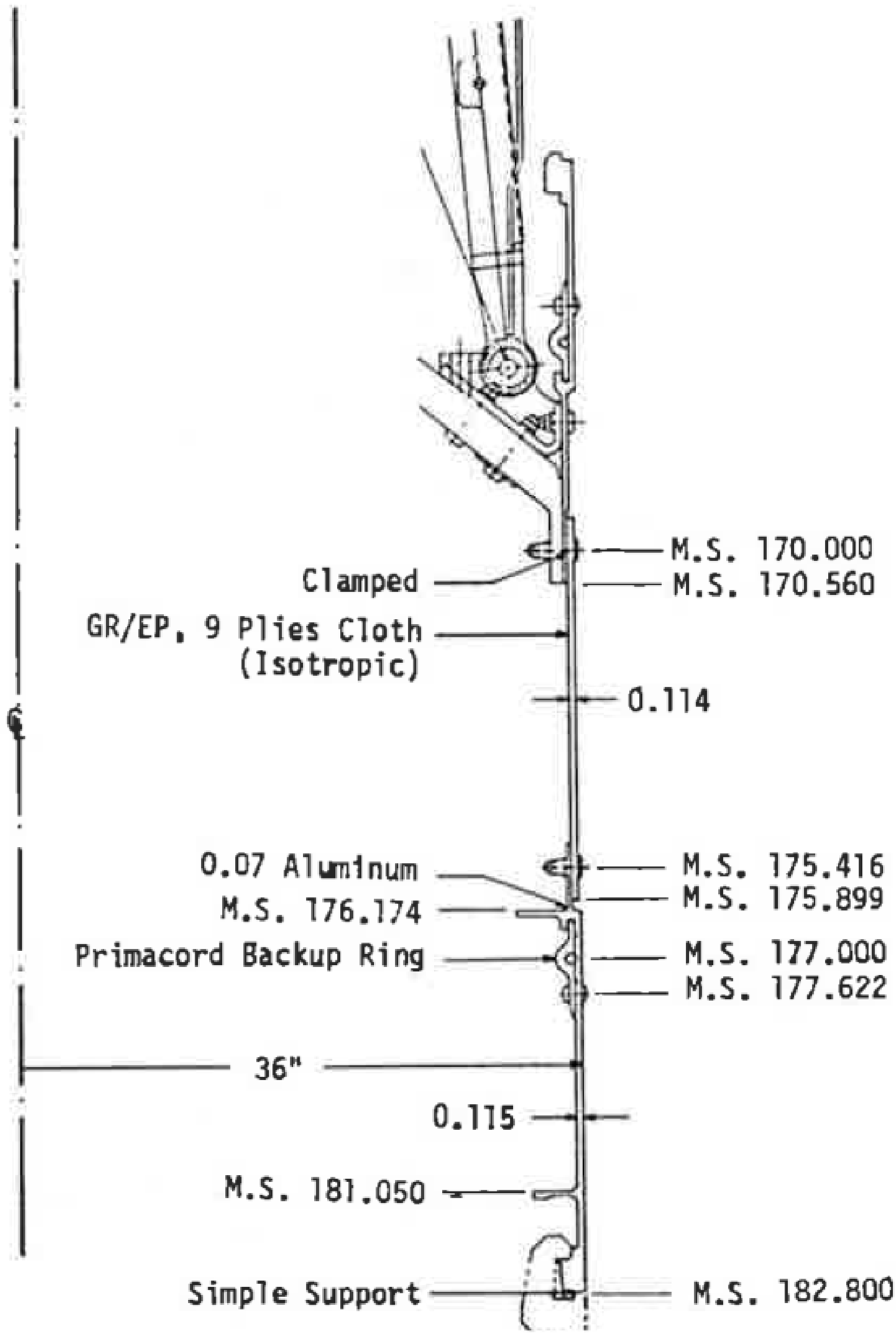

Fig. 4 Complex rocket inter-stage subjected to axial compression during launch. A stability problem arises from the eccentricity of the axial load path at Station MS 176. (from STRUCTURAL ANALYSIS SYSTEMS, Vol. 2, A. Niku-Lari, editor, Pergamon Press, pp. 55-67, 1986)

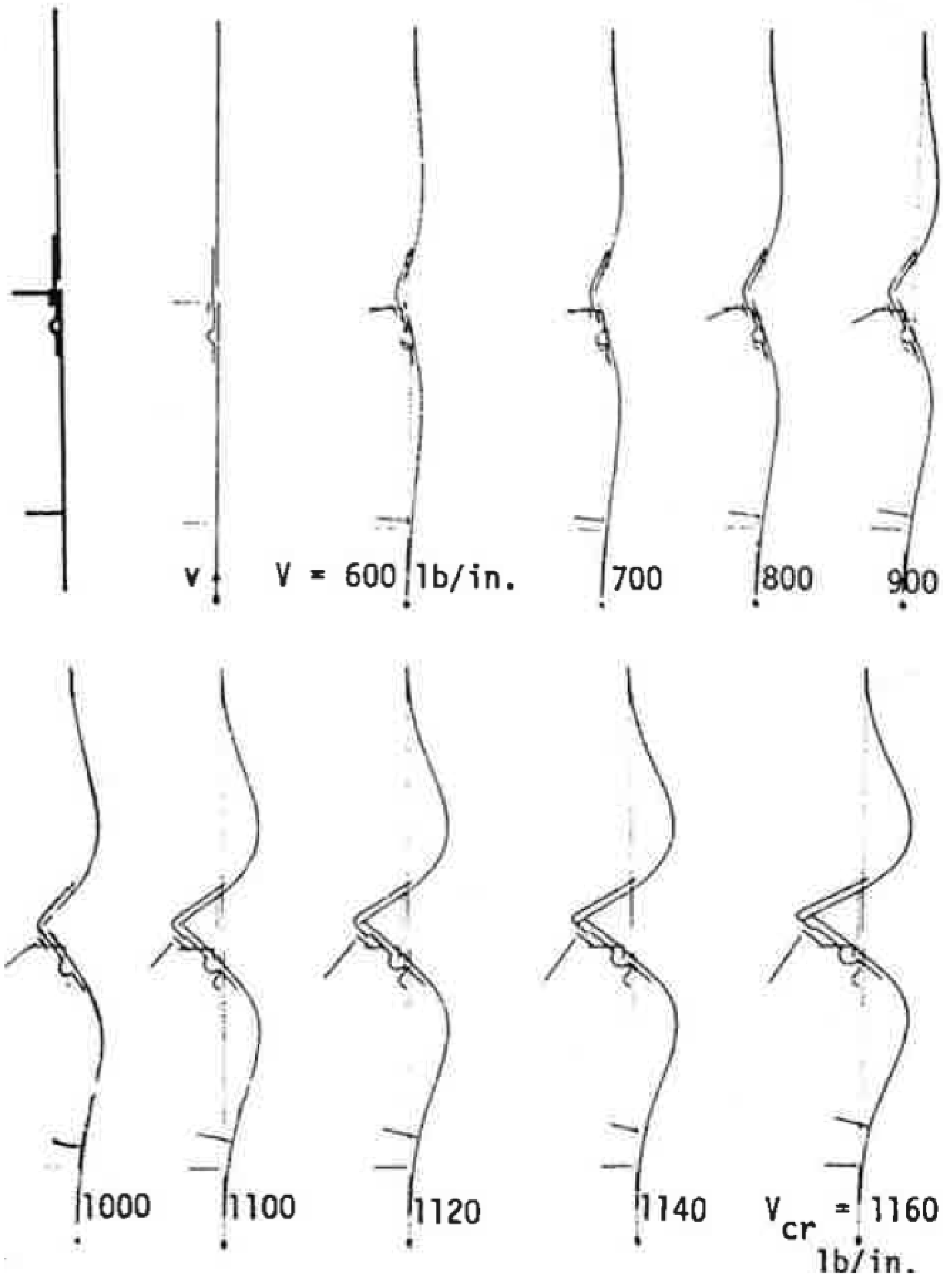

Fig. 5 Discretized, segmented BOSOR5 model and deformed profiles of the axially compressed rocket interstage with increasing axial compression, V. (from STRUCTURAL ANALYSIS SYSTEMS, Vol. 2, A. Niku-Lari, editor, Pergamon Press, pp. 55-67, 1986)