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DEMONSTRATE AMES LABORATORY CAPABILITY IN PROBABILISTIC RISK ASSESSMENT (PRA)

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1. SUMMARY OF PRA WORK

1.1 Background

In response to the damage which occurred during the Three Mile Island nuclear accident, the Nuclear Regulatory Commission (NRC) has implemented a Probabilistic Risk Assessment (PRA) program to evaluate the safety of nuclear power facilities during events with a low probability of occurrence. The PRA can be defined as a mathematical technique to identify and rank the importance of event sequences that can lead to a severe nuclear accident [1.1].

In order that a PRA be performed, a model of the working plant may be developed using event trees and fault trees. An event tree would give insight into the combination of operator and equipment failures whereas a fault tree would lead to an estimate of the damage to the plant. PRA's can be performed for different events, both internal and external, that affect the function of the reactor. An example of internal events would be the malfunction of a pump in the secondary loop, whereas missile hits or an airplane crashing on the reactor are referred to as external events.

Another PRA application is the evaluation of nuclear containment buildings due to earthquakes. In order to perform a seismic PRA, the two conditional probabilities of ground motion and of structural failure of the different components given a specific earthquake are first studied. The first of these is termed probability of exceedance and the second as seismic fragility analysis. The seismic fragility analysis is then related to the ground motion measured in terms of "g" to obtain a plant level fragility curve [1.2].

At this stage it is necessary to differentiate between a seismic margin review and a PRA. A PRA consists of assessment of the risks associated with a large number of systems and components that make up the plant. A seismic margin review on the other hand focuses on the few components and systems in the plant whose failure would lead to severe core damage [1.3]. The seismic margin review forms an integral part of the PRA and is performed for few critical components such as the containment strength.

The existing seismic margin calculation methods were presented by Kennedy et al. [1.4], in a report prepared for the U.S. NRC. In the report, two methods to determine high confidence of low probability of failure capacity of components were examined. They were the conservative deterministic failure margin and the fragility analysis method. Both methods were applied to different components in a nuclear power plant. The analyses were performed by independent consultants and then compared to resolve the differences between two methods. A review of the calculations was expected to yield the basis for the different methods with regard to the assumptions and to lead to the selection of an appropriate method.

1.2 Previous Ames Laboratory Work

The conditional probability of failure of a containment vessel given the occurrence of a prescribed earthquake, which is termed the seismic fragility, forms an important part in the PRA of a nuclear power plant. Ames Laboratory has past experience in reliability analysis in characterizing the seismic resistance of steel containments [1.3]. The research which was performed during the 1980's and was sponsored by the U.S. NRC is summarized herein. The objective of the Ames

Laboratory research was to characterize the seismic resistance of steel containment vessels for six nuclear power plants (St. Lucie, Cherokee, Perry, WPPSS, Browns Ferry, and Watts Bar) by including a probabilistic description of the resistance of the vessel to a given level of seismic excitation, which was measured by the peak ground acceleration. Probabilistic descriptions of the occurrence and level of the earthquake and soil-structure interaction were not considered in the analysis.

A general review of structural reliability analysis by Advanced First Order Second Moment (AFOSM) methods and statistics of the various structural parameters were presented. Shell imperfections, which have a significant effect on shell buckling, were also described. The earthquake motion was taken to be a random process characterized by the peak ground acceleration. Several possible approaches for the prediction of the maximum values were reviewed: response spectrum; time integration; and random vibration. A method was presented to evaluate the sensitivity of the random resistance to the randomness of the individual parameters.

A random vibration approach was developed which characterizes the statistics of the maximum values of the structural response with an Extreme Value Type I distribution. The mean zero crossing rate was empirically reduced to match results of simulation studies and real earthquakes. The method was calibrated to the standard Newmark-Hall response spectrum with a peak ground acceleration of 1g. Both horizontal and vertical seismic components were combined to predict the mean and standard deviation of the maximum response. The method was generalized to multi-degree-of-freedom systems using principles of linear modal analysis. Results of the method compared favorably with simulation studies using real earthquake records.

Failure of the containment to perform its function was defined to occur when the maximum membrane strain in the shell reached twice the yield strain. This strain can be reached by loading along a fundamental loading path. However, because of the compressive stresses present during seismic activity, a bifurcation point may exist on the fundamental curve. Since no post-buckling analysis was performed, it was assumed that, if a bifurcation point was reached, buckling occurred along a secondary path with an associated strain exceeding twice the value of the yield strain. Hence, the seismic resistance was defined as the peak ground acceleration which causes the membrane strain to exceed twice yield -- either by the fundamental or secondary load path.

The structural analyses was performed using the finite difference method. The mean seismic resistance of each of the six containments was established. A sensitivity study established an approximate relationship between the seismic resistance and the basic random variables. Using AFOSM methods with the significantly random parameters, the fragility of the containment resistances was presented.

1.3 Current Participation

The past experience of Ames Laboratory can be extended to assist NRC with their PRA program by formulating a research plan to include a literature survey and by application to a specific containment. During the past year, a partial list of references was identified (Table 1.1) and efforts were made to collect them. However, in November of 1991, Ames Laboratory was contacted by NRC to be prepared to assist with the analysis of the San Onofre nuclear power plant containment. At that time, it was thought that the San Onofre containment would be a good

candidate to be used as a demonstration example for the fragility analysis. Accordingly, the focus of research was shifted to the San Onofre containment analysis

Much of the analysis of the San Onofre containment was completed and some of the results are presented in the following chapter.

In March 1992, NRC authorities contacted the research team and advised them that the San Onofre project was not forthcoming. Activities in the PRA were stopped.

1.4 References

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2. STRESS ANALYSIS

As discussed in the previous chapter, most of the effort in this project was devoted to the analysis of the San Onofre Unit 1 nuclear containment structure.

This section summarizes the stress intensities induced in the San Onofre Unit 1 nuclear containment structure for the load combinations specified for Levels A, B, C, and D in the NRC Standard Review Plan (SRP), Section 3.8.2 [2.1]. The structural analyses of the containment structure was first performed for each individual load case utilizing the BOSOR4 finite difference program and the results were combined to calculate the stress intensities for Design Conditions and Levels A, B, C, and D, which were compared to the allowable stress intensities from the American Society of Mechanical Engineers (ASME) Code.

2.1 Description of Axisymmetric Analytical Model

An axisymmetric finite-difference computer model was constructed to analyze the San Onofre Unit 1 nuclear containment structure using the BOSOR4 software. The entire steel containment structure and the sand-filled transition zone near the base of the containment were included in the model. Figure 2.1 shows the axisymmetric computer model, which is further described in the following subsections.

2.1.1 Modeling of the Containment Structure

The effect of various penetrations and structural discontinuities in the actual containment structure were ignored. The strength of the penetrated shell was assumed to be greater than the unpenetrated shell [2.2]. The variation in the shell wall thickness from 1.02 in. to 1.034 in. was ignored and the entire containment was modeled as a continuous shell structure with a uniform thickness of 1 in. In the meridional direction, a uniform mesh size of 1.7 in. was used for the portion of the containment between points A and B (surrounded by sand-filled transition zone, see Fig. 2.1). Between points B and C (the portion immediately above the grade level), the mesh size was 1.77 in. The mesh size was uniformly varied from 1.75 in. at point C, to 12 in., at point D. From point D to point E at the top of the containment shell, a uniform mesh size of 12 in. was used. The mesh size in the sand-filled transition zone and the region right above the grade level was relatively small compared to the rest of the shell in order to capture the bending of the shell in this region. The maximum mesh size used was 12 in., which is less than $\sqrt{rt/2}$ (14.5 in.) [2.2]. The boundary conditions at the base of the containment structure (where the shell enters the concrete cradle) were assumed to be totally fixed.

According to [2.3], the containment shell material is ASME Specification Type SA-516, Grade 70 steel. The material properties of the above steel at a temperature of 268°F (maximum accident temperature) were used in the analyses and are listed in Table 2.1 [2.3].

2.1.2 Modeling of the Sand-Filled Transition Zone

The sand around the containment structure was modeled as an elastic foundation. The BOSOR4 software treats an elastic foundation as a Winkler foundation which reacts normal to the shell surface; BOSOR4 substitutes an array of closely spaced springs oriented normal to the shell

surface. A constant elastic foundation modulus (lb/in³) is input for each of the BOSOR4 shell segments.

To permit a variation of the elastic foundation modulus of the sand in the sand-filled transition zone, the portion of the containment surrounded by the sand was modeled using 12 uniform size BOSOR4 shell segments (see Fig. 2.2). Only radial strain was assumed to exist in the sand zone. Hence, the elastic foundation modulus was evaluated for each of the 12 shell segments embedded in the sand zone using [2.4]

$$k_i = [(1-\nu)/(1-\nu-2\nu^2)]E/L_i \quad (2.1)$$

where, ν and E represent the Poisson's ratio and Young's modulus of the sand material; and L_i represents the thickness of the sand layer at the midpoint of the shell segment, i and in the direction normal to the shell surface (Fig. 2.2). The best estimate material properties of the sand are shown in Table 2.2 [2.3]. The Young's modulus corresponding to the dynamic condition of the sand-fill was used for ASME Level B, C, and D service limits, as the load combinations in these service limits include the dynamic seismic loads. The static value of the Young's modulus of sand was used for the load combinations for ASME Level A and Design Condition limits. Figure 2.3 shows the elastic foundation modulus curves from Eq. (2.1) used in the analyses.

2.2 Individual Load Cases

2.2.1 Dead Loads

The dead load of the containment structure was input as the normal and meridional components of pressure at different mesh points and a stress analysis was performed using the INDIC=0 option of BOSOR4 software. Figure 2.4 shows the meridional moment stress resultant (M_i) for static and dynamic conditions of the sand-fill. The peak value of M_i is reduced by almost 15% as the soil stiffness changes from the static to the dynamic value. The variation of the sand stiffness has negligible affect on force resultants, N_1 and N_2 in the meridional and circumferential direction, respectively. Under static sand conditions, the maximum meridional membrane stress of -448 psi occurred at the base of the structure (Elev. 14.0 ft.) and the maximum circumferential membrane stress of 491 psi occurred at Elev. 24.3 ft. The maximum extreme fiber stress of -998 psi occurred at Elev. 19.7 ft. in the meridional direction and the maximum extreme fiber stress of 525 psi occurred at Elev. 23.6 ft. in the circumferential direction.

2.2.2 Pressure

An uniform internal pressure of 52.2 psi generated by the postulated pipe break accident was used for assessment purposes as suggested by [2.3]. The stress analyses performed using INDIC=0 option of BOSOR4 resulted in equal meridional and circumferential membrane stresses at points remote from the base of the structure. The stress value was 22000 psi for both static as well as dynamic conditions of sand stiffness. Remote from the containment base, the BOSOR4 stress analysis yielded stress values similar to that obtained by simple shell theory ($pr/2t$). Extreme fiber stress in the circumferential direction in the vicinity of the sand zone were less than 22000 psi. On the other hand, a maximum extreme fiber stress of 32600 psi in the meridional direction occurred close to the grade level at Elev. 19.7 ft. Figure 2.5 shows the

meridional moment stress resultant (M_1) for static and dynamic conditions of the sand-fill. The peak value of M_1 is reduced by 20% as the sand stiffness changes from static to dynamic value

2.2.3 Temperature

A peak metal temperature of 268°F generated by the postulated pipe break accident was used for assessment purposes as suggested by [2.3]. The stress free temperature of the containment was assumed to be 68°F. The stress analysis was performed using INDIC=0 option of the BOSOR4 software. The maximum membrane stresses in the meridional and circumferential directions for the static sand stiffness were 2108 psi and -35225 psi at the base of the containment (Elev. 14.0 ft.). The maximum extreme fiber stresses in the meridional and circumferential directions were 30560 psi and -40780 psi at Elev. 19.7 ft. Figure 2.6 shows the meridional moment stress resultant (M_1) for static and dynamic conditions of the sand-fill. The peak value of M_1 is reduced by 15% as the sand stiffness changes from static to dynamic value.

2.2.4 Seismic Loading

Seismic loading is a special case of the nonaxisymmetric loading as discussed in Ref. [2.2]. A response spectrum analysis of the structure for a base excitation is performed by combining the modal responses to estimate the system maximum response. One approach to estimate the maximum response, R_{max} , for a particular degree of freedom or stress quantity is to combine the modal responses utilizing the Square Root of the Sum of the Squares (SRSS) method [2.5, 2.6, 2.7].

Despite the simplicity and practical advantages of the SRSS method, this method fails to take into account the effects of closely spaced frequencies on the overall response of a multi-degree of freedom system [2.8, 2.9]. Reference [2.9] suggests that modes should be considered to be closely spaced if their frequencies differ by less than 10%. If the modes are closely spaced, the SRSS method should be modified as follows:

$$R_{max} = \left[\sum_{k=1}^3 \left(\sum_{j=1}^m R_{kj}^2 + 2 \sum_{l=1}^p \sum_{r=1}^p |R_{kr} R_{rl}| \right) \right]^{1/2} \quad (2.2)$$

where p is the number of closely spaced modes, m is the total number of modes and k corresponds to the directions X, Y, and Z.

The response spectrum for Safe Shutdown Earthquake (SSE) was represented by the Housner spectrum (4% critical damping), scaled to 0.67g peak ground acceleration in the horizontal (X and Y) direction [2.3] (see Fig. 2.7). The vertical (Z) direction response spectrum was equal to two-thirds of the horizontal spectrum. The response spectrum for Operating Basis Earthquake (OBE) was represented by one-half of the Housner spectrum (2% critical damping), scaled to 0.67g peak ground acceleration in the horizontal (X and Y) direction [2.3] (see Fig. 2.7). The vertical (Z) direction response spectrum was equal to two-thirds of the horizontal spectrum.

The stresses in the structure were evaluated for the dynamic condition of the sand-fill. The stresses induced due to SSE and OBE were quite low as compared to pressure and temperature stresses. For SSE, the stresses (circumferential, meridional and shear) were less than 700 psi, and for OBE, the stresses were less than 300 psi.

2.3 Load Combinations

Section I.3 of the SRP 3.8.2 [2.1] requires that the design loading combinations be compilable with Subsection NE, Section III, Division 1 of the Code and Regulatory Guide 1.57 [2.10]. The pertinent load combinations for the Design Condition and Service Levels A, B, C, and D are listed in Tables 2.3 to 2.7. Table 2.8 defines the nomenclature used in Tables 2.3 to 2.7. In addition, Tables 2.3 to 2.7 refer to the specific SRP 3.8.2 loading combination numbers.

Subsection NE of the ASME Code (Table NE 3221.1) has established allowable stress intensities for the Design Conditions and Service Level A, B, C, and D as listed in Tables 2.3 to 2.7. Allowable stresses depend upon the stress classification, i.e., primary membrane, primary bending or secondary stresses and their combinations (Table 2.8).

The stress intensities were evaluated at all the mesh points for each of the load combinations and were compared to the corresponding allowable stress intensities prescribed by the ASME Code. The calculated maximum stress intensity for each load combination is listed in Tables 2.3 to 2.7. The calculated maximum stress intensities were less than the allowable values for all the load combinations except for load combination SRP (iii)(a)(3) under Level A Service Limits. The maximum calculated stress intensity in this case was 73985 psi at a point 3 in. below the grade level. The stresses in the shell (particularly the bending stresses) in the sand zone near the grade level are very much influenced by the sand stiffness. It should be noted that all the analyses were performed using the sand stiffness curves shown in Fig. 2.3, which assume that the sand near the grade level develops the full static or dynamic value of stiffness (E_{static} of 48600 psi and E_{dynamic} of 20800 psi). Generally, the sand near the grade level can be expected to have lower stiffness due to lower degree of compaction near the grade level.

A sensitivity analysis for the sand stiffness near the grade level was performed for the Level A load combination, SRP (iii)(a)(3), using the foundation modulus curves shown in Fig. 2.8. Curve 1, which is identical to curve A in Fig. 2.3, assumes the sand near the grade level to be at its full static value. In curves 2 and 3, the sand stiffness near the grade level was arbitrarily reduced using straight lines. Figure 2.9 shows the variation of the meridional inner fiber stress near the grade level obtained using sand stiffness curves 1 and 3. It can be seen that the maximum meridional inner fiber stress using curve 3 is about 17% less than that obtained using curve 1. Figure 2.10 shows the variation of the calculated inner fiber stress intensity near the grade level, for Level A load combination, SRP (iii)(a)(3). From this figure, it can be clearly seen that the maximum stress intensity obtained using curve 3 is lower than the ASME Code allowable value. Hence, the acceptability of the containment design is significantly dependant upon the sand properties.

2.4 Summary and Conclusions

The San Onofre Unit 1 nuclear containment structure was analyzed for the combined effects of dead load, pressure and thermal loads generated by postulated pipe break accident, SSE and

OBE. The maximum stress intensities for various load combinations specified for Design Conditions and Service Levels A, B, C, and D in SRP 3.8.2 were evaluated and compared with the allowable stress intensities from the ASME Code.

All the calculated maximum stress intensities were within those specified by the code, except for the case of Level A Service Limit, load combination SRP (iii)(a)(3). These results were based on the assumption of a uniform sand stiffness in the transition zone. A sand stiffness sensitivity study near the grade level showed a significant variation in the peak stresses with sand stiffness. Under actual in-place conditions, the sand stiffness near the grade level may be sufficiently low so as to produce stresses which satisfy the ASME code. However, actual in-situ tests should be performed to evaluate the actual variation of sand stiffness in the sand zone.

2.5 References

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APPENDIX A BOSOR4 AND BOSOR5 MODIFICATIONS

A.1 Modal Participation Factor (BOSOR4)

BOSOR4 software calculates eigenvalues, eigenvectors, generalized mass and modal participation factors for each vibration mode for a modal analysis performed with $INDIC = 2$. In BOSOR4 output, values of the modal participation factor were incorrect. This was discovered during the solution of the sample problem shown in Fig. A.1. The sample problem consists of an axisymmetric cylinder of length 80 in. and diameter 8 in. The material data are as follows: modulus of elasticity, E of 3,000 ksi; Poissons ratio, ν of 0.3; and, mass density, ρ of 0.000728 lb-sec²/in⁴. The sample problem was analyzed with BOSOR4 software using a total of 5 equally spaced mesh points. Hand calculations were also performed to evaluate the modal participation factors using the mode shapes from BOSOR4 software. The problem was also run on the finite element software ANSYS [A.1]. The ANSYS model consisted of 5 equally spaced nodes connected by axisymmetric straight shell elements (STIFF 61). The results of the modal participation factor calculation were compared as shown in Table A.1. In this table, the value of circumferential wave number, N , represents the direction of the ground motion. The horizontal ground motion in X and Y directions is represented by $N = 1$ and -1 , while $N = 0$, represents vertical ground motion in Z direction. For $N = 1$, it is clear that the modal participation factor from BOSOR4 is about 1/2 of the ANSYS and hand calculation values. Moreover, for all three values of N , (i.e., $N = 1, 0$ and -1) the values of the modal participation factors from BOSOR4 are quite different than the corresponding values obtained from ANSYS or hand calculations. The sample problem was repeated with different boundary conditions at the two ends of the cylinder and the above observations were confirmed.

When the BOSOR4 source code was studied, two errors were discovered in the calculation of the modal participation factor:

1. For $N = 0$ and -1 , BOSOR4 calculates incorrect values of the modal participation factor (variable `AMPLTD` in subroutine `LOCAL` of `MODE` library).
2. The BOSOR4 software introduces a factor of 1/2 in the modal participation factor calculation (variable `GAMP` in subroutine `MODE` of `MODE` library).

The errors in subroutines `LOCAL` and `MODE` of `MODE` library were corrected. In addition, FORTRAN lines were incorporated into subroutine `OUT2` of `B4POST` library to inform the user that the values of the modal participation factors are based on the modified version of BOSOR4 software. The above changes are documented in detail within the BOSOR4 source code in subroutines `LOCAL` and `MODE` of `MODE` library, and `OUT2` of `B4POST` library. The modified source code of the above subroutines is shown in Table A.2.

The sample problem shown in Fig. A.1 was rerun on the modified version of the BOSOR4 software and the correct values of the modal participation factor (see Table A.1, hand calculations) were obtained.

A.2 Modal Stress Resultants and Stresses Output

For a modal analysis (INDIC=2), BOSOR4 software does not calculate the Fourier coefficients for the modal stress resultants and modal stresses. These quantities are required for a seismic analysis. BOSOR4 was modified to calculate these coefficients for each of the modes of vibration and at each mesh point of the computer model. When the modified BOSOR4 software is run, it creates an additional output file named as FILE14.DAT which contains the modal stress resultants and stresses as well as the geometrical properties of the structure.

Figure A.2 shows a chart explaining the basic format of FILE14.DAT along with the names of all the quantities in it. Table A.3 lists the names of the subroutines and libraries of BOSOR4 source code where modifications were made for creating FILE14.DAT.

A.3 Effective Uniaxial Strain and Plastic Strain Output

BOSOR5 software has an option with which the user can specify if strains should be written to the output file. If this option is chosen, BOSOR5 writes the strain quantities at all the mesh points of all the segments.

The BOSOR5 source code was modified (FLOW subroutine of PLAST library) so that, in addition to the above output, a separate output file called RESULT.DAT is created during the modified BOSOR5 run. The RESULT.DAT file contains the strain quantities (plastic meridional and circumferential strain and effective uniaxial strain) at all the mesh points where plastic straining

occurs. The effective plastic strain ϵ_p is defined as $\epsilon_p = \sqrt{\frac{2}{3} \epsilon_{ij}^p \epsilon_{ij}^p}$, where ϵ_{ij}^p is the plastic component of the total ϵ_{ij} [A.2]. These quantities are printed out at all the loadsteps requested by the user during the POST-SETUP input session of BOSOR5.

A.4 References

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Table 1.1 List of Related Literature

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Table 2.1 Material Properties of SA-516, Grade 70 Steel Corresponding to the Peak
Sphere Metal Temperature of 268°F (2.3)

Minimum yield strength	S_y	34,000 Psi
Minimum ultimate tensile strength	S_u	70,000 Psi
Allowable stress intensity	S_{mc}	19,250
Design stress intensity	S_{m2}	22,700 Psi
Young's Modulus	E	29.2 E + 06 Psi
Coefficient of thermal expansion		6.14 E-06 in/in/°F
Poisson's ratio	ν	0.3
Density		0.284 lb/in ³

Table 2.2 Best Estimate Material Properties of the Sand

Young's modulus, E_{static}	48,600 Psi
Young's modulus, $E_{dynamic}$	50,800 Psi
Poisson's ratio, ν	0.35

Table 2.3 Design Conditions

SRP Reference Number	Description*	Design Allowable Stress Intensity Limit			Maximum Calculated Stress Intensity	
		Type*	Limit	Value (psi)	Value (psi)	Elev. (ft)
(i)	Not applicable					
(ii)	$D+L+P_a+T_a+R_a$ ($P_a=52.2$ psi, $T_a=68^\circ\text{F}$)	P_m	$1.0 S_{mc}$	19,250	15,715	14.0

*Definition of variables in the column is given in Table 2.8.

Table 2.4 Level A Service Limits

SRP Reference Number	Description*	Design Allowable Stress Intensity Limit			Maximum Calculated Stress Intensity	
		Type*	Limit	Value (psi)	Value (psi)	Elev. (ft)
(iii)(a)(1)	Not applicable					
(iii)(a)(2)	Not applicable					
(iii)(a)(3)	D+L+P _a +T _a +R _a (P _a =52.2 psi, T _a =68°F)	P _m	1.0 S _{mc}	19,250	15,715	14.0
(iii)(a)(3)	D+L+P _a +T _a +R _a (P _a =52.2 psi, T _a =268°F)	P _L +P _b +Q	3.0 S _{m1}	68,100	73,985	19.7

*Definition of variables in this column is given in Table 2.8.

Table 2.5 Level B Service Limits

SRP Reference Number	Description*	Design Allowable Stress Intensity Limit			Maximum Calculated Stress Intensity	
		Type*	Limit	Value (psi)	Value (psi)	Elev. (ft)
(iii)(b)(1)	$D+L+P_a+T_a+R_a+E$ ($P_a=52.2$ psi, $T_a=68^\circ\text{F}$, $E=\text{OBE}$)	P_m	$1.0 S_{mc}$	19,250	15,900	14.0
(iii)(b)(1)	$DL+P_a+T_a+R_a+E$ ($P_a=52.2$ psi, $T_a=268^\circ\text{F}$, $E=\text{OBE}$)	P_L+P_b+Q	$3.0 S_{m1}$	68,100	67,723	19.6
(iii)(b)(2)	Not applicable					
(iii)(b)(3)	Not applicable					
(iii)(b)(4)	Not applicable					

*Definition of variables in this column is given in Table 2.8.

Table 2.6 Level C Service Limits

SRP Reference Number	Description*	Design Allowable Stress Intensity Limit (psi)			Maximum Calculated Stress Intensity	
		Type*	Limit	Value (psi)	Value (psi)	Elev. (ft)
(iii)(c)(1)	$D+L+P_a+T_a+R_a+E'$ ($P_a=52.2$ psi, $T_a=68^\circ\text{F}$, $E'=SSE$)	P_m	$1.2 S_{mc}$ or $1.0 S_y$ (greater of two)	34,000	16,175	14.0
(iii)(c)(2)	Not applicable					
(iii)(c)(3)	Not applicable					

*Definition of variables in this column is given in Table 2.8.

Table 2.7 Level D Service Limits

SRP Reference Number	Description*	Design Allowable Stress Intensity Limit (psi)			Maximum Calculated Stress Intensity	
		Type*	Limit	Value (psi)	Value (psi)	Elev. (ft)
(iii)(d)(1)	D+L+P _a +T _a +R _a +Y _r +Y _i +Y _m +E (P _a =52.2 psi, T _a =68°F, E'=SSE)	P _m	S _i	To be performed		
(iii)(d)(2)	Not applicable					

*Definition of variables in this column is given in Table 2.8.

Table 2.8 Nomenclature

P	Stress Intensity (difference between the algebraically largest and smallest principal stresses, twice the maximum shear stress)
P_m	General primary membrane stress intensity. (Average stress across an entire section of a vessel. Not self limiting. Gross deformation occurs if this stress exceeds yield. An example is general membrane stress in a cylinder or sphere with internal pressure. Temperature stresses are <u>not</u> included. Therefore, the temperature is set equal to zero in Tables 2.3 to 2.7 in those cases for which P_m is checked. These stresses are checked at the shell middle surface.)
Q	Secondary stress intensity (Self-limiting. An example is the stresses due to the bending stress resultants M_1 , M_2 , M_{12} for pressure on seismic loading. All thermal stresses are secondary.)
P_L	Local primary membrane stress intensity. (A stressed region may be considered local if the distance over which the membrane stress intensity exceeds $1.1 S_{mc}$ does not extend in meridional direction more than $(rt)^{1/2}$. Typically self-limiting like a secondary stress but redistribution takes place only after large deformations. An example is the local membrane stress near a gross structural discontinuity such as shell intersections at the springline or at a penetration. Membrane stresses near the base of the containment may be considered in this category.)
P_b	Primary bending stress intensity (same as P_m except bending stress. An example is the center of a flat plate with lateral pressures.)
S_y	Yield stress, ASME Table I.2.0.
S_{mc}	Allowable stress intensity, ASME Table I.10.0.
S_{m1}	Allowable stress intensity, ASME Table I.1.0.
S_t	Allowable stress intensity, 85% of the allowable stress intensity specified in Appendix F.
D	Dead loads.
L	Live loads including all loads resulting from platform flexibility and deformation, and crane loading if applicable, equal to zero for this containment.
T_o	Thermal effects and loads during start-up, normal operating or shutdown conditions, based on the most critical transient or steady-state condition.
R_o	Pipe reactions during start-up, normal operating or shutdown conditions, based on the most critical transient or steady-state condition, equal to zero for this containment.
P_o	External pressure loads resulting from pressure variation either inside or outside containment.

Table 2.8 Nomenclature (continued)

E	Loads generated by the operating basis earthquake including sloshing effects, if applicable.
E'	Loads generated by the safe shutdown earthquake including sloshing effects, if applicable.
P _a	Pressure load generated by the postulated pipe break accident including P _o , pool swell and subsequent hydrodynamic loads. For this containment, accidental spray actuation is included in this category.
R _a	Pipe reactions under thermal conditions generated by the postulated pipe break accident including R _o , pool swell, and subsequent hydrodynamic reaction loads, equal to zero for this containment.
P _s	All pressure loads which are caused by the actuation of safety relief valve discharge including pool swell and subsequent hydrodynamic loads, equal to zero for this containment.
T _s	All thermal loads which are generated by the actuation of safety relief valve discharge including pool swell and subsequent hydrodynamic thermal loads, equal to zero for this containment.
R _s	All pipe reaction loads which are generated by the actuation of safety relief valve discharge including pool swell and subsequent hydrodynamic reaction loads, equal to zero for this containment.
Y _r	Equivalent static load on the structure generated by the reaction on the broken pipe during the design basis accident, equal to zero for this containment.
Y _j	Jet impingement equivalent static load on the structure generated by the broken pipe during the design basis accident, equal to zero for this containment.
Y _m	Missile impact equivalent static load on the structure generated by or during the design basis accident, such as pipe whipping, equal to zero for this containment.

Table A.1 Modal Participation Factor for the First
Mode of Vibration of the Cantilevered Beam
in Fig. A.1

Circumferential Wave No. N	Modal Participation Factor		
	BOSOR4	Hand Calculation	ANSYS
1	0.8125	1.625	1.558
0	0.6463	0	6.548E-05
-1	0.00105	1.625	1.558

Table A.2 Modified Source Code of LOCAL, MODE and OUT2 Subroutines of BOSOR4

```

C=DECK    LOCAL
SUBROUTINE LOCAL(IW,IS,HC,I5,FN,F,C,B,PSTS,BMODE,NSEG,THERM,
1PFXD,INDIC,TIO,IALL,IVEC,SMODE,TMODE,IPOINT,IDIST,IANALY,
1 ILOOP,IPOS,PALL,FF,RHF,RHFIX,RVAR,RFIX,XSINGL)
DOUBLE PRECISION H,HPAST,HI,C1,C2,C3,W,U,V,R,RD,FK1,FK2,CURD
DOUBLE PRECISION UD,VD,WD,WDD,CHI,PS
DOUBLE PRECISION F

C
C   CALLED FROM MODE, WHICH IS CALLED FROM MAIN.
C   CALCULATES MODE SHAPE FOR BUCKLING AND VIBRATION MODES.
C   ALSO CALCULATES STRESS RESULTANTS OR STRESSES FOR
C   NONSYMMETRIC
C   LINEAR STRESS ANALYSIS (INDIC=3). LOCAL DOES THIS FOR CURRENT
C   SHELL SEGMENT AND FOR CURRENT HARMONIC.
C   IN LINEAR STRESS ANALYSIS DISPLACEMENTS, STRESS RESULTANTS,
C   AND STRESSES ARE SUPERPOSED. FORCES AND MOMENTS IN DISCRETE
C   RINGS ARE ALSO CALCULATED, ALTHOUGH THESE ARE NOT SUPERPOSED
C   UNTIL LATER.
C
C   MODE SHAPE IN EACH SHELL SEGMENT CALCULATED ALONG WITH MODAL C
STRES
DIMENSION F(1),C(I5,14),B(I5,5),PSTS(I5,3),BMODE(IALL,9)
DIMENSION SMODE(9000),TMODE(9000),IDIST(1000),XSINGL(3000)
DIMENSION THERM(I5,8),TIO(I5,4),Z(100),T(100)
DIMENSION PFXD(I5,3),IW(1000),HC(1),FF(*),IPOS(*),PALL(*)
DIMENSION RHF(*),RHFIX(*),RVAR(*),RFIX(*)
COMMON/NOHARM/NHARM
COMMON/ALLRNG/NTOT,IPRE
COMMON/SHEL/ISHL(95),IWAL(95),ITHK(95),IARC(95),ILOAD(95)
COMMON/INTRVL/INTVAL(95),IOUT,NDIST,NCIRC,NTHETA
COMMON/XTRSS/SIG1I,SIG1O,SIG2I,SIG2O,TAUI,TAUO,SIGE1,SIGEO
COMMON/IDZREF/IZREF(95)
COMMON/FICTP/IFICT
COMMON/SFLAG/MONOQ
COMMON/STRSEG/ISTRSS(95)
REAL N10,N20
COMMON/ISTUFB/KK,I5TOT,IC,NUNK,KLAP,ICALL
REAL N1,N2,N12,M1,M2,MT,K1,K2,K12
COMMON/INTRG/NSTATN(95),IRING(95,20)
COMMON/AMPFAC/OMEGDR,YLATRL,YAXIAL,BDAMP,AMPLTD,GAMP(200)
COMMON/RESTRT/IREST
COMMON/RGTEMP/TNR(98),TMR(98),TMRX(98)
COMMON/DRGTEM/TNRFIX(98),TMRFIX(98),TMXFIX(98)

C
N = FN
IK = 1
N10 = 0.0

```


Table A.2 (continued)

```

N20 = 0.0
CHI0 = 0.0
IF (ISTRSS(IS).EQ.1) CALL GASP(T,I5,3,ITHK(IS))
C  RETRIEVE REFERENCE SURFACE LOCATION
IF (ISTRSS(IS).EQ.1) CALL GASP(Z,I5,3,IZREF(IS))
ITOT = I5TOT - 2*(IS-1)
LINDX = IPOS(3)
IF (ILOOP.EQ.2) LINDX = IPOS(6)
LINDX3 = LINDX + IVEC - 1
C
INDX = IPOS(9)
IF (ILOOP.EQ.2) INDX = IPOS(12)
INDX3 = INDX + IVEC - 1
C
TIN = 0.
TOUT = 0.
HI = HC(1)
C  START LOOP OVER CURRENT SEGMENT MESH POINTS.
DO 110 I=1,I5
IF (ISTRSS(IS).NE.1) GO TO 5
IF (INDX.EQ.0) GO TO 5
TIN = TIO(I,1)*PALL(INDX3)
TOUT = TIO(I,2)*PALL(INDX3)
IF (ILOOP.NE.1) THEN
    TIN = TIO(I,3)*PALL(INDX3)
    TOUT = TIO(I,4)*PALL(INDX3)
ENDIF
C
5  CONTINUE
H = HC(I)
HPAST = HI
HI = 2.*H-HPAST
ITOT = ITOT + 1
II = I5TOT + I + 1
I3M = IW(II - 1)
I0 = IW(II)
I3P = IW(II + 1)
I2M = I0-2
I1M = I0-1
I1P = I0+1
I2P = I0+2
IF ((I3P-I0).EQ.(IC+NUNK-KLAP)) I1P = I0 + IC + 1
IF ((I3P-I0).EQ.(IC+NUNK-KLAP)) I2P = I0 + IC + 2
C  DISPLACEMENTS AND DERIVATIVES FOR VARIABLE SPACING MESH
C
C1 = (HPAST-HI)*(HI + H)/(16.*HPAST*H)
C2 = (HI + H)*(HPAST + H)/(4.*HPAST*HI)
C3 = - (HPAST-HI)*(HPAST + H)/(16.*HI*H)

```

Table A.2 (continued)

```

W = C1*F(I3M) + C2*F(I0) + C3*F(I3P)
U = (F(I2M) + F(I1P))/2.
V = (F(I1M) + F(I2P))/2.
IF (IREST.EQ.2) V = - V
R = B(I,1)
RD = B(I,2)
FK1 = B(I,3)
FK2 = B(I,4)
CURD = B(I,5)
CURD = 0.0
RS = R
RDS = RD
CURV1 = FK1
CURV2 = FK2

C
C   AMPLITUDE FACTOR FOR HARMONIC DRIVING AT THE RESONANT
C   FREQUENCY.
C
C   FIND INTEGRAL OF Y*M*PHI. M*PHI IS STORED IN TMODE.
C
C.....
C   PLEASE NOTE: THIS SECTION OF SUBROUTINE "LOCAL" WAS MODIFIED (1/92)
C   BY THE RESEARCH TEAM OF STRUCTURAL ENGINEERING DEPARTMENT
C   (CIVIL ENGINEERING) AT IOWA STATE UNIVERSITY, SO THAT
C   THE PROGRAM CALCULATES CORRECT VALUES OF "MODAL PARTICIPATION
C   FACTORS" FOR CIRCUMFERENTIAL WAVE NUMBER (N) = -1, 0 AND 1.
C   THESE MODIFICATIONS CHANGE THE PARTICIPATION FACTOR RESULTS
C   OR "VIBRATION PROBLEMS" PERFORMED WITH INDIC = 2 ONLY.
C   FOR BETTER UNDERSTANDING OF THE CHANGES MADE IN THE PROGRAM,
C   THE FORTRAN LINES OF ORIGINAL VERSION OF THE PROGRAM ARE
C   PRESENTED BELOW. THEN EACH OF THE MODIFICATIONS MADE IN THESE
C   LINES ARE EXPLAINED.
C
C-----
C LINE      FORTRAN
C NO.      LINE
C-----
C 1      IF (INDIC.NE.2) GO TO 7
C 2      IF (IABS(N).GT.1) GO TO 7
C 3      IF (N.EQ.0) GO TO 6
C 4      AMPLTD = AMPLTD +XSINGL(I1M)*1. +XSINGL(I0)*R*FK2
C        +XSINGL(I1P)*RD
C 5      IF (I.EQ.1) AMPLTD=AMPLTD +XSINGL(I3M)*R*FK2 +XSINGL(I2M)*RD
C 6      IF (I.EQ.15)AMPLTD=AMPLTD +XSINGL(I3P)*R*FK2 +XSINGL(I2P)*1.
C
C 7      NOTE...THE ABOVE FORMULA IS FOR LATERAL FORCED MOTIONS
C ONLY...
C

```

```

C 8      GO TO 7
C 9      6 CONTINUE
C
C 10     AMPLTD = AMPLTD +XSINGL(I1M)*1. -XSINGL(I0)*RD
C        +XSINGL(I1P)*R*FK2
C 11     IF (I.EQ.1) AMPLTD=AMPLTD -XSINGL(I3M)*RD +XSINGL(I2M)*R*FK2
C 12     IF (I.EQ.I5)AMPLTD=AMPLTD -XSINGL(I3P)*RD *XSINGL(I2P)*1.
C
C 13     NOTE...THE ABOVE FORMULA IS FOR AXIAL FORCED VIBRATIONS
C ONLY.
C
C 14     7 CONTINUE
C
C-----
C
C 1      FROM LINES 2 & 3, IT IS CLEAR THAT FOR "N" = -1 & 1, THE PROGRAM
C        CALCULATES THE VARIABLE "AMPLTD" USING THE FORMULA GIVEN IN
C        LINES 4, 5 & 6. FROM THEORY, FOR "N" = -1, THE FORMULA FOR
C        CALCULATING THE VALUE OF "AMPLTD" SHOULD BE DIFFERENT.
C        HENCE
C        THE FOLLOWING FORTRAN LINE WAS ADDED BETWEEN LINES 3 & 4 OF
C        THE ORIGINAL CODE, SO THAT THE PROGRAM DOES NOT USE THE
C        SAME FORMULA FOR CALCULATING THE VALUE OF "AMPLTD".
C
C        IF (N.EQ.-1) GO TO 999
C
C
C 2      THE FOLLOWING FORTRAN LINES WERE ADDED BETWEEN LINES 8 &
C        9 OF THE ORIGINAL CODE, SO THAT FOR "N" = -1, THE PROGRAM C
C        USES THE CORRECT FORMULA FOR CALCULATING THE VALUE OF C
C        "AMPLTD".
C
C 999 AMPLTD = AMPLTD -XSINGL(I1M)*1. +XSINGL(I0)*R*FK2
C        +XSINGL(I1P)*RD
C        IF (I.EQ.1) AMPLTD=AMPLTD +XSINGL(I3M)*R*FK2 +XSINGL(I2M)*RD
C        IF (I.EQ.I5)AMPLTD=AMPLTD +XSINGL(I3P)*R*FK2 -XSINGL(I2P)*1.
C        GO TO 7
C
C
C 3      FOR "N" = 0, i.e. FOR AXIAL FORCED VIBRATIONS, THE PROGRAM
C        CALCULATES THE VALUE OF "AMPLTD" USING THE FORMULA GIVEN
C        BY LINES 10, 11 & 12 OF THE ORIGINAL CODE.
C
C      — FOLLOWING ERROR WAS IDENTIFIED IN LINE 10
C
C
C        /_____> should be "0" (ZERO)
C        /

```

Table A.2 (continued)

```

C
C      /
C      AMPLTD = AMPLTD +XSINGL(I1M)*1. -XSINGL(I0)*RD +XSINGL(I1P)*R*FK2
C
C
C
C
C      — FOLLOWING ERRORS WERE IDENTIFIED IN LINE 12
C
C
C
C
C
C
C
C
C
C
C      should be "0" (ZERO) < ____ \
C
C
C
C
C      IF (I.EQ.I5)AMPLTD=AMPLTD -XSINGL(I3P)*RD *XSINGL(I2P)*1.
C
C
C
C
C      should be "+" < ____ /
C
C
C
C
C      THE ABOVE ERRORS IN LINES 10 & 12 WERE FIXED.
C
C
C .....
C      END OF THE ABOVE EXPLANATION
C .....
C
C      IF (INDIC.NE.2) GO TO 7
C      IF (IABS(N).GT.1) GO TO 7
C      IF (N.EQ.0) GO TO 6
C      IF (N.EQ.-1) GO TO 999
C      AMPLTD = AMPLTD +XSINGL(I1M)*1. +XSINGL(I0)*R*FK2 +XSINGL(I1P)*RD
C      IF (I.EQ.1) AMPLTD=AMPLTD +XSINGL(I3M)*R*FK2 +XSINGL(I2M)*RD
C      IF (I.EQ.I5)AMPLTD=AMPLTD +XSINGL(I3P)*R*FK2 +XSINGL(I2P)*1.
C
C
C      NOTE...THE ABOVE FORMULA IS FOR LATERAL FORCED MOTIONS ONLY...
C
C      GO TO 7
C
C      999 AMPLTD = AMPLTD -XSINGL(I1M)*1. +XSINGL(I0)*R*FK2 +XSINGL(I1P)*RD
C      IF (I.EQ.1) AMPLTD=AMPLTD +XSINGL(I3M)*R*FK2 +XSINGL(I2M)*RD
C      IF (I.EQ.I5)AMPLTD=AMPLTD +XSINGL(I3P)*R*FK2 -XSINGL(I2P)*1.
C      GO TO 7

```

Table A 2 (continued)

6 CONTINUE

C

AMPLTD = AMPLTD +XSINGL(I1M)*0. -XSINGL(I0)*RD +XSINGL(I1P)*R*FK2
 IF (I.EQ.1) AMPLTD=AMPLTD -XSINGL(I3M)*RD +XSINGL(I2M)*R*FK2
 IF (I.EQ.I5)AMPLTD=AMPLTD -XSINGL(I3P)*RD +XSINGL(I2P)*0.

C

C NOTE...THE ABOVE FORMULA IS FOR AXIAL FORCED VIBRATIONS ONLY.

C

7 CONTINUE

C

US = U
 VS = V
 WS = W
 UD = (F(I1P) - F(I2M))/H
 VD = (F(I2P) - F(I1M))/H
 IF (IREST.EQ.2) VD = -VD
 C1 = -.5/HPAST
 C3 = .5/Hi
 C2 = -C1 -C3
 WD = C1*F(I3M) + C2*F(I0) + C3*F(I3P)
 C1 = 1./(HPAST*H)
 C2 = -2./(HPAST*Hi)
 C3 = 1./(Hi*H)
 WDD = C1*F(I3M) + C2*F(I0) + C3*F(I3P)
 CHIO = 0.
 N10 = 0.
 N20 = 0.
 CHI = WD - FK1*U
 CHIS = CHI

C STRAINS AND CHANGES IN CURVATURE

E1 = UD + W *FK1 + CHIO*CHI
 FMUL = 0.0
 K1=WDD-FK1*UD-CURD*U-FMUL*E1*FK1
 IF (R.GT.0.0) GO TO 10
 PS = - CHI
 E2 = E1
 E12 = 0.0
 K2 = K1
 K12 = 0.0
 GO TO 20

10 PS = W*FN/R - FK2*V

E2 = - V*FN/R + U*RD/R + W*FK2
 E12 = VD - V*RD/R + U*FN/R + CHIO*PS
 K2=-PS*FN/R+CHI*RD/R-FMUL*E2*FK2
 K12 = - CHI*FN/R + PS*RD/R + VD*FK2

20 CONTINUE

C

C IN THE FOLLOWING THE CONDITION INDIC.NE.2 WAS ADDED TO GET STRESS

Table A.2 (continued)

C RESULTANTS FROM THE MODAL ANALYSIS THIS WAS DONE BY FOUAD AND C RAMA

C

IF (INDIC.NE.3. AND. INDIC.NE.2) GO TO 70

C

C STRESS AND MOMENT RESULTANTS.

N1 = C(I,1)*E1 + C(I,2)*E2 + C(I,3)*K1 + C(I,4)*K2

N2 = C(I,2)*E1 + C(I,5)*E2 + C(I,6)*K1 + C(I,7)*K2

M1 = C(I,3)*E1 + C(I,6)*E2 + C(I,8)*K1 + C(I,9)*K2

M2 = C(I,4)*E1 + C(I,7)*E2 + C(I,9)*K1 + C(I,10)*K2

N12 = C(I,11)*E12 + C(I,12)*K12*2.

MT = C(I,12)*E12 + C(I,13)*K12*2.

C

IF (ILOOP.EQ.1) THEN

N1 = N1 + THERM(I,1)*PALL(INDX3)

N2 = N2 + THERM(I,2)*PALL(INDX3)

M1 = M1 + THERM(I,3)*PALL(INDX3)

M2 = M2 + THERM(I,4)*PALL(INDX3)

ELSE

N1 = N1 + THERM(I,5)*PALL(INDX3)

N2 = N2 + THERM(I,6)*PALL(INDX3)

M1 = M1 + THERM(I,7)*PALL(INDX3)

M2 = M2 + THERM(I,8)*PALL(INDX3)

ENDIF

IF (I.EQ.1.OR.I.EQ.I5) GO TO 30

GO TO 70

30 IF (R.GT.0.0) GO TO 40

GO TO 70

C

C

CORRECTION ADDENDS FOR EDGE STRESS RESULTANTS CALCULATED.

C

40 F1 = 0.5*RD*H/R

F2 = 0.5*FN*H/R

CN1 = - N2*F1 - N12*F2 + 0.5*N10*CHI*H*FK1

CN12 = N12*F1 + N2*F2 + 0.5*N20*PS*H*FK2

CM1 = -M2*2.*F1 + MT*2.*F2 - N1*CHI0*H - N10*CHI*H

IF (I.EQ.I5) GO TO 50

GO TO 60

50 CN1 = - CN1

CN12 = - CN12

CM1 = - CM1

60 N1 = N1 + CN1

N12 = N12 + CN12

M1 = M1 + CM1

N2 = N2 + C(I,2)*CN1/C(I,1)

M2 = M2 + C(I,9)*CM1/C(I,8)

70 CONTINUE

C

C THESE WERE ADDED BY FOUAD AND RAMA

Table A.2 (continued)

```

C      USING = SNGL(U)
      WSING = SNGL(W)
      VSING = SNGL(V)
      WRITE(14,*) USING,VSING,WSING,N1,N2,N12,M1,M2,MT,C(I,14)

C
C
      IF (ISTRSS(IS).EQ.1) GO TO 80
      IF (ISTRSS(IS).EQ.2) GO TO 85
      IF (MONOQ.EQ.1.AND.ISTRSS(IS).EQ.0) GO TO 85
C      BMODE CONTAINS GLOBAL QUANTITIES
      BMODE(ITOT,1) = U
      BMODE(ITOT,2) = V
      BMODE(ITOT,3) = W
      IF (INDIC.NE.3) GO TO 110
      BMODE(ITOT,4) = N1
      BMODE(ITOT,5) = N2
      BMODE(ITOT,6) = N12
      BMODE(ITOT,7) = M1
      BMODE(ITOT,8) = M2
      BMODE(ITOT,9) = MT
      GO TO 90
C      STRESS CALCULATES INNER AND OUTER FIBER STRESSES OF
C      MONOCOQUE AND SEMI-SANDWICH CORRUGATED SHELLS.
80      IF (ISTRSS(IS).EQ.1) CALL STRESS(E1,E2,E12,K1,K2,K12,T(I),Z(I),
      1IS,I,TIN,TOUT,CURV1,CURV2)
      BMODE(ITOT,1) = U
      BMODE(ITOT,2) = V
      BMODE(ITOT,3) = W
      BMODE(ITOT,4) = SIG1I
      BMODE(ITOT,5) = SIG1O
      BMODE(ITOT,6) = TAU1
      BMODE(ITOT,7) = SIG2I
      BMODE(ITOT,8) = SIG2O
      BMODE(ITOT,9) = TAUO
C
      GO TO 90
85      CONTINUE

      BMODE(ITOT,1) = U
      BMODE(ITOT,2) = V
      BMODE(ITOT,3) = W
      BMODE(ITOT,4) = E1
      BMODE(ITOT,5) = E2
      BMODE(ITOT,6) = E12
      BMODE(ITOT,7) = K1
      BMODE(ITOT,8) = K2
      BMODE(ITOT,9) = K12

```

Table A.2 (continued)

```

C
90  CONTINUE
    IF (I.NE.IRING(IS,IK)) GO TO 100
C   CALCULATE HOOP FORCE, IN-PLANE MOMENT, OUT-OF-PLANE MOMENT
C   AND TORQUE IN DISCRETE RING.
    IF (ILOOP.EQ.1)
      1CALL RINGF(IK,KK,RS,RDS,CURV1,CURV2,FN,US,VS,WS,CHIS,FF,
      1 PALL(LINDX3),NTOT,NHARM,IVEC,RHF,TNR,TMR,TMRX,IPOS(1),PALL,RVAR)
    IF (ILOOP.EQ.2)
      1CALL RINGF(IK,KK,RS,RDS,CURV1,CURV2,FN,US,VS,WS,CHIS,FF,
      1 PALL(LINDX3),NTOT,NHARM,IVEC,RHFIX,TNRFIX,TMRFIX,TMXFIX,
      1 IPOS(4),PALL,RFIX)
    IK = IK + 1
    KK = KK + 1
100  CONTINUE
C   PERFORM SUPERPOSITION FOR THIS PARTICULAR AXIAL STATION
C
    INEXT = IDIST(IPOINT)
    NNDIST = NDIST
    IF (NDIST.EQ.0) NNDIST = 1
    NNCIRC = NCIRC
    IF (NCIRC.EQ.0) NNCIRC = 1
    IF (ILOOP.EQ.1)
      1CALL SPOSE(ICALL,I,ITOT,IALL,FN,BMODE,PSTS,CHIS,
      1SMODE,TMODE,I5,NTHETA,IPOINT,INEXT,IOUT,NDIST,NCIRC,IS,IANALY,
      1 IVEC,N1,N2,IPOS(7),PALL,NNDIST,NNCIRC)
    IF (ILOOP.EQ.2)
      1CALL SPOSE(ICALL,I,ITOT,IALL,FN,BMODE,PFXD,CHIS,
      1SMODE,TMODE,I5,NTHETA,IPOINT,INEXT,IOUT,NDIST,NCIRC,IS,IANALY,
      1 IVEC,N1,N2,IPOS(10),PALL,NNDIST,NNCIRC)
C
    IF (ITOT.EQ.INEXT) IPOINT = IPOINT + 1
110  CONTINUE
    I5TOT = I5TOT + I5 + 2
C   STORE PRESTRESS QUANTITIES FOR BUCKLING ANALYSIS (INDIC=4)
    RETURN
    END

C=DECK   MODE
        SUBROUTINE MODE(M3,NVEC,IALL,SMODE,TMODE,BMODE,RHF,RHFIX,
        1 RVAR,RFIX,ILOOP,BBB)
C
C   CALLED FROM MAIN.

```


Table A.2 (continued)

C MODE SHAPE OR DISPLACEMENTS AND STRESSES CALCULATED FOR C BUCKLING
AND VIBRATION OR LINEAR STRESS ANALYSIS.. INPUT C EIGENVECTOR IS F,
C OUTPUT IS U,V,W, AND STRESS RESULTANTS. THESE ARE NORMALIZED IN
C BUCKLING AND VIBRATION PROBLEMS (EIGENVECTORS) AND DIMENSIONAL
C IN LINEAR NONSYMMETRIC STRESS PROBLEMS.
C DISPLACEMENTS AND STRESS RESULTANTS OBTAINED FOR NVEC
C EIGENVALUES
C

```
DOUBLE PRECISION F
DOUBLE PRECISION XX
DIMENSION XX(3000),FF(6250),XSINGL(3000)
DIMENSION F(3000),BMODE(IALL,9),BBB(10000),DS(1000),IW(1000)
DIMENSION SMODE(9000),TMODE(9000),X(1000),IDIST(1000)
COMMON/AMPFAC/OMEGDR,YLATRL,YAXIAL,BDAMP,AMPLTD,GAMP(200)
COMMON/RESTR/IREST
COMMON/AMPFC2/IMPFI(200)
COMMON/RGTEMP/TNR(98),TMR(98),TMRX(98)
COMMON/ALLRNG/ NTOT,IPRE
COMMON/NLINS/NSTART,NFIN
COMMON/SEGS/NSEG,M2,I5(95),I2,I2G
COMMON/DSPACE/IDS
COMMON/STRHD/NSHEAD
COMMON/OUTP/NPRT
COMMON/INSTAB/INDIC
COMMON/NOHARM/NHARM
COMMON/SMOAD/IMOAD(100),IPMODE(95),IPSM(95)
COMMON/NCONDS/NCOND
COMMON/WAVES/N0,N,NMIN,NMAX,INCR
COMMON/IDEIG/IDMODE(500),NVECTL,EIGENW(500)
COMMON/TWORHS/ITWO,IDMOD2(200)
COMMON/LOADHM/NLPOS(95),LAB(95),IDAB(95),ILPOS(12,95),PALL(6000)
COMMON/ISTUFB/KK,I5TOT,IC,NUNK,KLAP,ICALL
COMMON/LOCATN/ILOCP,ILOCB,IROWCP(98),IROWCB(98),IIWP,IIWB
COMMON/GMASS/GM(500)
COMMON/INTRVL/ INTVAL(95),IOUT,NDIST,NCIRC,NTHETA
COMMON/SHEL/ISHL(95),IWAL(95),ITHK(95),IARC(95),ILOAD(95)
COMMON/GLOBAL/IDZ,IZRING(98),ISAVE(20),INOTE
DIMENSION RHF(*),RHFIX(*),RVAR(*),RFIX(*)
COMMON/RESPO2/ANALY,WSPEC(40)
COMMON/NVVIB/NVIB
CHARACTER*20 WORD1(3)
CHARACTER*36 WORD2(3)
DATA WORD1(1),WORD1(2),WORD1(3)/
1 'HARMONIC EXCITATION ',
1 'RANDOM EXCITATION ',
1 'SHOCK          '/
```

C DATA WORD2(1),WORD2(2),WORD2(3)/

Table A.2 (continued)

```

1 'N*g/(OMEGA**2 * BETA)
1 'SQRT[OMEGA*SPEED/(2*BETA)]g/OMEGA**2'
1 '2*N*g/OMEGA**2
C
C THIS WAS ADDED BY FOUAD AND RAMA
C
C WRITE(14,*)NVEC
C
10 FORMAT(1P9E13.4)
II = I2 + 2*NSEG
M32 = M3*2
C RECOVER GLOBAL EQUATION NO.S CORRESPONDING TO W.
CALL GASP(IW,II,3,IIWB)
C RECOVER ELEMENTAL ARC LENGTHS DS.
CALL GASP(DS,I2,3,IDS)
IF (INOTE.EQ.1) CALL GASP(BBB,ISAVE(1),3,ISHL(1))
IF (INDIC.NE.3) GO TO 82
C FIND ARRAY X CORRESPONDING TO MERIDIONAL DISTRIBUTION. STRESSES
C OR STRESS RESULTANTS ARE PRINTED OUT FOR THESE MERIDIONAL C STATIONS
20 CALL IFIND(IDIST,X)
40 CONTINUE
K = NTHETA*NCIRC*9
IF (K.LE.9000) GO TO 50
NTHETA = 2*NTHETA/3
GO TO 40
50 CONTINUE
IF (NDIST.EQ.0) GO TO 65
DO 60 I = 1,9000
60 SMODE(I) = 0.
65 CONTINUE
IF (K.EQ.0) GO TO 75
DO 70 I=1,K
70 TMODE(I) = 0.
75 CONTINUE
C BEGIN LOOP OVER NO. OF EIGENVALUES FOR EACH HARMONIC N IN
C STABILITY OR VIBRATION ANALYSIS.
C BEGIN LOOP OVER NUMBER OF HARMONICS IN NONSYMMETRIC STRESS
C ANALYSIS
80 CONTINUE
IF (IREST.NE.2) GO TO 82
IANALY = ANALY
WRITE(6,81) WORD1(IANALY), WORD2(IANALY)
81 FORMAT(/ DYNAMIC RESPONSE ANALYSIS...//
1' N = LOAD FACTOR (NUMBER OF GRAVITIES)/
1' g = ACCELERATION OF GRAVITY'/
1' OMEGA = NATURAL FREQUENCY IN RADIANS/SEC'/
1' BETA = DAMPING COEFFICIENT'/
1' PARTICIPATION FACTOR:/'

```

Table A.2 (continued)

```

1' P/2 = integral(mass*mode*(base motion)/[2*(generalized mass)]
1'/
1' RESPONSE TO 'A20/
1' FORMULA FOR MULTIPLIER,m(i) = 'A36)
C
  WRITE(6,76)
76 FORMAT(/' FREQUENCY PARTICIPATION LOAD FACTOR DAMPING
1 SPECTRAL MULTIPLIER AMPLITUDE/'
1 ' (HERTZ) FACTOR, P/2 (N) COEFFICIENT
1T DENSITY (m) FACTOR=m*P/2')
C
82 CONTINUE
DO 250 II=1,NVEC
  AMPLTD = 0.
  IF (IREST.NE.2.OR.INDIC.NE.3) GO TO 85
  FREQU = EIGENW(NVECTL+II)
  CALL RESFAC(FREQU,FMULT,FNGVAL,DAMPNG,SPECD)
  AMPLTD = GAMP(NVECTL+II)*FMULT
  WRITE(6,83) FREQU, GAMP(NVECTL+II), FNGVAL, DAMPNG, SPECD, FMULT,
1 AMPLTD
83 FORMAT(1PE12.4,1PE16.4,1PE16.4,1PE14.4,1PE13.4,1PE13.4,1PE14.4)
85 CONTINUE
  IF (INDIC.EQ.3) GO TO 90
  FN = FLOAT(N)
  GO TO 100
90 FN = FLOAT(NSTART + (II-1)*INCR)
C RECOVER THE SOLUTION VECTOR F
100 CONTINUE
  IF (ILOOP.EQ.1) CALL GASP(F,M32,3,IDMODE(NVECTL+II))
  IF (ILOOP.EQ.2) CALL GASP(F,M32,3,IDMOD2(NVECTL+II))
105 FORMAT(/' NVEC,II,M3,M32,IDMODE(II),F(IM3),IM3=1,M3)=' 5I7/
1 (1P10E12.3))
C
  IF (INDIC.EQ.2) CALL GASP(XX,M32,3,IMPFI(NVECTL+II))
C
  IF (INDIC.NE.3) GO TO 110
110 WMAX = 0.0
  KK = 1
  ISTOT = 0
  IC = 4
  NUNK = 7
  KLAP = 4
  ICALL = 1
  IF (INDIC.EQ.3) GO TO 210
C
C NORMALIZE EIGENVECTOR (BUCKLING AND VIBRATION PROBLEMS ONLY,
C INDIC.NE.3.)
J = 1

```

Table A.2 (continued)

```

      I = 0
120  I = I + 1
      IF (J.GT.NCOND) GO TO 140
      IF (I.EQ.IROWCB(J)) GO TO 130
      GO TO 140
130  I = I + IC
      IF (I.GT.M3) GO TO 150
      J = J + 1
140  FI = F(I)
      WMAX = AMAX1(ABS(FI),WMAX)
      IF (I.GE.M3) GO TO 150
      GO TO 120
150  CONTINUE
      IF (WMAX.EQ.0.) WMAX = 1.
      DO 160 I=1,M3
160  F(I) = F(I)/WMAX
      DO 170 I=1,M3
      Fi = F(I)
      IF (ABS(FI).EQ.1.0) GO TO 180
170  CONTINUE
      GO TO 200
180  IF (FI.GT.0.) GO TO 200
      DO 190 I=1,M3
190  F(I) = - F(I)
200  CONTINUE
      FMULPY = 1.0
      IF (N.EQ.0) FMULPY = 2.0
      IF (INDIC.NE.2) GO TO 210
      GM(NVECTL+II) = FMULPY*3.1415927*ABS(GM(NVECTL+II)/WMAX**2)
C
      DO 205 I = 1,M3
      XSINGL(I) = SNGL(XX(I))*FMULPY*3.1415927/WMAX
205  CONTINUE
210  IPOINT = 1
      ITOT = 1
      ITOTL = 0
      IF (INOTE.GT.1) CALL GASP(BBB,ISAVE(1),3,ISHL(1))
      IADD = 2
      DO 240 I=1,NSEG
C
C      MODAL DISPLACEMENTS AND STRESSES FOR EACH SEGMENT FOUND IN
C      LOCAL.
C
      ISI = I5(I)
220  IPOS = 43*ITOTL + 1
      IEND = IPOS + 43*ISI - 1
      IF (IEND.LT.10000) GO TO 230
      IF (INDIC.NE.4) CALL GASP(BBB,ISAVE(IADD-1),1,ISHL(IADD-1))

```

Table A.2 (continued)

```

      CALL GASP(BBB,ISAVE(IADD),3,ISHL(IADD))
      ITOTL = 0
      IADD = IADD + 1
      GO TO 220
230  CONTINUE
      CALL LOCAL(IW,I,DS(ITOT),I5I,FN,F,BBB(8*I5I+IPOS),BBB(22*I5I+IPOS)
1,BBB(33*I5I+IPOS),BMODE,NSEG,BBB(IPOS),BBB(36*I5I+IPOS),INDIC,
2BBB(39*I5I+IPOS),IALL,II,SMODE,TMODE,IPOINT,IDIST,IANALY,
3 ILOOP,ILPOS(1,I),PALL,FF,RHF,RHFIX,RVAR,RFIX,XSINGL)
      ITOT = ITOT + I5I
      ITOTL = ITOTL + I5I
240  CONTINUE
C
C
C
C
C.....
C
C      IF (INDIC.EQ.2) GAMP(NVECTL+II)=ABS(AMPLTD)/(GM(NVECTL+II))
C
C.....
C
C      PLEASE NOTE: THE ABOVE FORTRAN LINE WAS MODIFIED (1/92) BY THE
C      RESEARCH TEAM OF STRUCTURAL ENGINEERING
C      DEPARTMENT (CIVIL ENGG.)
C      AT IOWA STATE UNIVERSITY, SO THAT THE PROGRAM CALCULATES
C      THE CORRECT VALUES OF "MODAL PARTICIPATION FACTORS" FOR
C      VIBRATION PROBLEMS PERFORMED WITH INDIC = 2.
C
C      THE CORRESPONDING FORTRAN LINE IN THE ORIGINAL CODE WAS
C
C      IF (INDIC.EQ.2) GAMP(NVECTL+II)=ABS(AMPLTD)/(2.*GM(NVECTL+II))
C
C
C.....
C
C
C      IF (INDIC.EQ.2) WRITE(14,*)
1EIGENW(NVECTL+II),GM(NVECTL+II),GAMP(NVECTL+II)
C
C      IF (INDIC.NE.4.AND.INOTE.GT.1)
1CALL GASP(BBB,ISAVE(IADD-1),1,ISHL(IADD-1))
C      IF (INDIC.EQ.3.AND.II.LT.NVEC) GO TO 250
C
C      IF (INDIC.NE.4.AND.INOTE.EQ.1)
1CALL GASP(BBB,ISAVE(IADD-1),1,ISHL(IADD-1))
C      NN = IALL*3
C      STORE MODE SHAPES

```

Table A.2 (continued)

```

      IF (INDIC.NE.3) CALL GASP(BMODE,NN,1,IMOAD(II+NVIB))
      IF (INDIC.NE.3) GO TO 250
      NN = IOUT*9*NDIST
      IF (IREST.NE.2) GO TO 247
      IF (IANALY.EQ.1) GO TO 247
      IF (NN.EQ.0) GO TO 244
      INBEG = IOUT*NDIST*3 + 1
C   WRITE(6,*)' IANALY,IOUT,INBEG,NDIST,NN=',
C   1      IANALY,IOUT,INBEG,NDIST,NN
      DO 243 I = INBEG,NN
C   WRITE(6,*)' I,SMODE(I)=' ,I,SMODE(I)
C   IF (MOD(I,IOUT).EQ.0) WRITE(6,*)' NEW COLUMN...'
      243 SMODE(I) = SQRT(SMODE(I))
      244 NK = NTHETA*NCIRC*9
      IF (NK.EQ.0) GO TO 247
      INBEG = NTHETA*NCIRC*3 + 1
      DO 245 I = INBEG,NK
      245 TMODE(I) = SQRT(TMODE(I))
      247 CONTINUE
C   STORE MERIDIONAL STRESS OR STRESS RESULTANT DISTRIBUTIONS.
C   STORE CIRCUMFERENTIAL DISTRIBUTIONS
C   STORE RING LOADS
      NN1 = IOUT*NDIST*9
      NN2 = NTHETA*NCIRC*9
      NN3 = NTOT*NHARM*4
C
      IF (ILOOP.EQ.1) THEN
        IMOAD(100) = 0
        IF (NN1.NE.0) CALL GASP(SMODE,NN1,1,IMOAD(100))
        IMOAD(99) = 0
        IF (NN2.NE.0) CALL GASP(TMODE,NN2,1,IMOAD( 99))
        IMOAD(96) = 0
        IF (NN3.NE.0) CALL GASP(FF,  NN3,1,IMOAD( 96))
        ELSE
          IMOAD(98) = 0
          IF (NN1.NE.0) CALL GASP(SMODE,NN1,1,IMOAD( 98))
          IMOAD(97) = 0
          IF (NN2.NE.0) CALL GASP(TMODE,NN2,1,IMOAD( 97))
          IMOAD(95) = 0
          IF (NN3.NE.0) CALL GASP(FF,  NN3,1,IMOAD( 95))
        ENDIF
C
      250 CONTINUE
      RETURN
      END

```

Table A.2 (continued)

```

C=DECK      OUT2
      SUBROUTINE OUT2(NVEC ,NTOT,BMODE,SMODE,TMODE,EGV,ILOOP)
C   CALLED FROM READIT, WHICH IS CALLED FROM MAIN
C   ESSENTIAL OUTPUT FROM CURRENT CASE IS PRINTED.
COMMON/INTRVL/ INTVAL(95),IOUT,NDIST,NCIRC,NTHETA
COMMON/ITERS/ITER
COMMON/SMOAD/IMOAD(100),IPMODE(95),IPSM(95)
COMMON/SHEL/ISHL(95),IWAL(95),ITHK(95),IARC(95),ILOAD(95)
COMMON/FORCES/V(98),HF(98),FM(98)
COMMON/INSTAB/INDIC
COMMON/SEGS/NSEG,M2,I5(95),I2,I2G
COMMON/WAVES/N0,N,NMIN,NMAX,INCR
COMMON/LSTEPS/ISTEP
COMMON/SFLAG/MONOQ
COMMON/EIGENV/P,OMG2,RHO
COMMON/TEMTUR/TEMP,DTEMP
COMMON/STEPS/STEP,STEP1(98),STEP2(98),STEP3(98)
COMMON/DETER/DET,NEX
COMMON/GMASS/GM(500)
COMMON/IDEIG/IDMODE(500),NVECTL,EIGENW(500)
COMMON/ROTATN/OMEGA,DOMEGA
COMMON/AMPFAC/OMEGDR,YLATRL,YAXIAL,BDAMP,AMPLTD,GAMP(200)
COMMON/NVVIB/NVIB
COMMON/IOCHOZ/IOYES(50),IOSEG(95)
DIMENSION BMODE(1000,9),SMODE(9000),TMODE(9000),EGV(50),X(1000)
DIMENSION VERT(98),HORIZ(98),FMOM(98)
K = INDIC + 3
GO TO (10,20,50,90,200,210,220),K
10  CONTINUE
C   INDIC = -2 - - LOAD INCREASED IN STEPS UNTIL DETERMINANT CHANGES
C   SIGN. THEN INDIC CHANGED TO - 1.
C
      CALL OUTLOD(INDIC,ITER,DET,NEX,P,TEMP,V,HF,FM,NTOT,OMEGA)
      GO TO 230
20  CONTINUE
C   INDIC = - 1 - - STABILITY ANALYSIS WITH NONLINEAR PREBUCKING
C   AND SEARCH FOR MINIMUM BUCKLING LOAD WITH CIRCUMFERENTIAL
C   WAVENUMBER,N.
C
      CALL OUTLOD(INDIC,ITER,DET,NEX,P,TEMP,V,HF,FM,NTOT,OMEGA)
      WRITE (6,30)
30  FORMAT(////15X,82H PREBUCKLING DISPLACEMENTS AND STRESS
1RESULTANTS.
1CORRESPONDING TO CRITICAL LOAD      )
      CALL OUTPEE(IPMODE(1),IARC,I2,I5,NSEG,BMODE,0)
      IF (IOYES(4).EQ.1) GO TO 230
      WRITE (6,40)N
40  FORMAT(////19H BUCKLING MODE FOR 17,23H CIRCUMFERENTIAL WAVES      1).

```

Table A.2 (continued)

```

      CALL OUTBUC(IMOAD(1),IARC,I2,I5,NSEG,BMODE,INDIC)
      GO TO 230
50  CONTINUE
C   AXISYMMETRIC NONLINEAR STRESS ANALYSIS
      GO TO 230
90  CONTINUE
C   INDIC = 1,2, OR 4--BUCKLING AND VIBRATION ANALYSES IN WHICH
C   MANY EIGENVALUES AND EIGENVECTORS FOR EACH N MAY BE OBTAINED.
C
      IF (INDIC.EQ.1.OR.INDIC.EQ.4) WRITE (6,100)
100  FORMAT(/33H BUCKLING LOADS AND MODES FOLLOW  )
      IF (INDIC.EQ.2) WRITE (6,110)
110  FORMAT(/24H VIBRATION MODES FOLLOW  )
      WRITE (6,120)N
120  FORMAT(/35H CIRCUMFERENTIAL WAVE NUMBER, N = 17/)
      WRITE (6,140)(EIGENW(NVECTL+I),I=1,NVEC)
140  FORMAT(' EIGENVALUES ='/(1P10E12.3))
      IF (INDIC.EQ.2) WRITE(6,145)(GM(NVECTL+I),I=1,NVEC)
145  FORMAT('/ GENERALIZED MASS ='/(1P10E12.3))

C.....
C
C   THE FOLLOWING LINES WERE ADDED (1/92) BY THE RESEARCH TEAM OF
C   STRUCTURAL ENGINEERING DEPARTMENT (CIVIL ENGG.) AT IOWA STATE
C   UNIVERSITY.
C
C
      IF (INDIC.EQ.2) WRITE(6,9991)
9991 FORMAT(/54H PLEASE NOTE: THE FOLLOWING VALUES OF PARTICIPATION 1)
      IF (INDIC.EQ.2) WRITE(6,9992)
9992 FORMAT(54H FACTORS ARE BASED ON THE MODIFIED VERSION OF THE 1)
      IF (INDIC.EQ.2) WRITE(6,9993)
9993 FORMAT(54H BOSOR4 SOFTWARE, WHICH IS INSTALLED ON AMES LAB 1)
      IF (INDIC.EQ.2) WRITE(6,9994)
9994 FORMAT(54H CADVAX. )
      IF (INDIC.EQ.2) WRITE(6,9995)
9995 FORMAT(/54H THE MODIFICATIONS WERE MADE BY THE RESEARCH TEAM 1)
      IF (INDIC.EQ.2) WRITE(6,9996)
9996 FORMAT(54H OF STRUCTURAL ENGINEERING DEPARTMENT (CIVIL ENGG.) 1AT
)
      IF (INDIC.EQ.2) WRITE(6,9997)
9997 FORMAT(54H IOWA STATE UNIVERSITY. THE MODIFICATIONS WERE MADE 1IN
)
      IF (INDIC.EQ.2) WRITE(6,9998)
9998 FORMAT(54H SUBROUTINES "LOCAL" & "MODE" OF MODE LIBRARY. )
C
C

```


Table A.2 (continued)

```

C.....
C
C
  IF (INDIC.EQ.2) WRITE(6,147) (GAMP(NVECTL+I),I=1,NVEC)
147  FORMAT(' PARTICIPATION FACTORS=/(1P10E12.3))
      DO 190 I=1,NVEC
      NVECTP = NVECTL + I
      EGV(I) = EIGENW(NVECTP)
      IF (INDIC.NE.1) GO TO 170
      PRESS = P + (EGV(I) - 1.)*STEP
      TEMPT=TEMP+ (EGV(I) - 1.)*DTEMP
      OMEGAX = OMEGA + (EGV(I) - 1.)*DOMECA
      IF (NTOT.EQ.0) GO TO 170
      DO 150 J=1,NTOT
      VERT(J) = V(J) + (EGV(I) - 1.)*STEP1(J)
      HORIZ(J)= HF(J)+ (EGV(I) - 1.)*STEP2(J)
150  FMOM(J) = FM(J)+ (EGV(I) - 1.)*STEP3(J)
      WRITE (6,160)I
160  FORMAT(/45H CRITICAL LOAD COMBINATION FOR EIGENVALUE NO.  I3,      119H
FOLLOWS      /)
      CALL OUTLOD(INDIC,ITER,DET,NEX,PRESS,TEMPT,VERT,HORIZ,FMOM,NTOT,
      1 OMEGAX)
170  CONTINUE
      IF (IOYES(4).EQ.1) GO TO 190
      WRITE (6,180)I
180  FORMAT(/30H MODE SHAPE FOR EIGENVALUE NO.  I3,9H FOLLOWS  )
      CALL OUTBUC(IMOAD(I+NVIB),IARC,I2,I5,NSEG,BMODE,INDIC)
190  CONTINUE
      GO TO 230
200  CONTINUE
C   INDIC = 2 -- VIBRATION MODES
      GO TO 90
210  CONTINUE
C   INDIC = 3 -- LINEAR NONSYMMETRIC STRESS ANALYSIS
      NNDIST = NDIST
      IF (NDIST.EQ.0) NNDIST = 1
      NNCIRC = NCIRC
      IF (NCIRC.EQ.0) NNCIRC = 1
      CALL OUTNON(OUT,NDIST,NCIRC,NTHETA,IMOAD,INTVAL,MONOQ,SMODE,
      1TMODE,X,ILOOP,NNDIST,NNCIRC)
      GO TO 230
220  CONTINUE
C   INDIC = 4 -- BUCKLING WITH NONSYMMETRIC PRESTRESS OR WITH
C   PRESTRESS ANALYSIS BYPASSED
      GO TO 90
230  CONTINUE
      RETURN
      END

```

Table A.3 Modified Libraries and Subroutines of BOSOR4
Source Code for Creating FILE14.DAT.

	BOSOR4 Library	Subroutines
1.	B4READ	READIT
2.	GEOM	GEOMTY
3.	RFIVE	RFIVE
4.	WALL	CFB2
5.	MODE	MODE, LOCAL

Figure 2.1 Axisymmetric Finite-Difference Computer Model of San Onofre Nuclear Containment Structure on BOSOR4 Software.

Figure 2.2 Modeling Details of the Sand Filled Transition Zone. (Refer to Fig. 2.1 for Points A and B)

Figure 2.3 Variation of Elastic Foundation Modulus in the Sand Zone, for Static and Dynamic Values of Sand Stiffness

Figure 2.4 Variation of Meridional Moment Stress Resultant (M_1), for Static and Dynamic Values of Sand Stiffness, Under Dead Load

Figure 2.5 Variation of Meridional Moment Stress Resultant (M_1) Along the Arc Length, for Static and Dynamic Values of Sand Stiffness, Under Internal Pressure (52.2 psi)

Figure 2.6 Variation of Meridional Moment Stress Resultant (M_1) Along the Arc Length, for Static and Dynamic Values of Sand Stiffness, Under Peak Metal Temperatures (268°F)

Figure 2.7 Horizontal Response Spectrum for Safe Shutdown Earthquake

Figure 2.8 Elastic Foundation Modulus Curves (for the Sand Zone) Used in Foundation Stiffness Sensitivity Studies

Figure 2.9 Variation of the Meridional Inner Fiber Stress Near the Grade Level for Sand Stiffness Curves 1 and 3, and Level A Load Combination (SRP (iii)(a)(3))

Level A: Inner fiber Stress Intensity

Figure 2.10 Variation of Inner Fiber Stress Intensity Near the Grade Level for Sand Stiffness Curves 1 and 3, and Level A Load Combination (SRP (iii)(a)(3))

Figure A.1 Sample Problem Used in Calibration of BOSOR4 Program

Problem Title

Total no. of Segments

No. of Mesh Points in Segment-1

Arc Length Global Radial Coordinate Meridional Curvature Distance between internal surface and reference surface

(for first mesh point of Segment-1)

•

(repeated till last mesh point of Segment-1)

Repeated for rest of the segments

Thickness, at first mesh point of Segment-1

•

repeated till last mesh point of Segment-1

Min. no. of Circumferential Waves Max. no. of Circumferential Waves Increment for Circumferential Waves

Global axial coord Global radial coord

(for first mesh point of Segment-1)

•

repeated till last mesh point of last Segment

No. of Eigenvectors

u	v	w	N ₁	N ₂
N ₁₂	M ₁	M ₂	M _T	C(1,14)
SIG11	SIG10	SIG21	SIG20	TAU11
TAU10	SIG1	SIG0		

Displacements, stress resultants and stresses
(for first mesh point of first segment and for first eigenvector corresponding to the min. no. of circumferential waves)

•

(repeated till last mesh point of last segment and for first eigenvector corresponding to the min. no. of circumferential waves)

Repeated for rest of the eigenvectors for min. no. of circumferential waves

Eigenvalue Generalized Mass Modal Participation Factor

(for first eigenvector corresponding to the min. no. of circumferential waves)

Repeated till max. no. of circumferential waves is reached

Figure A.2 Format of FILE14.DAT Created During Vibration Analysis (INDIC=2)
Option of the BOSOR4 Program

**DATE
FILMED**

6 / 23 / 94

END