A Computer Program (ASMEN47) to Perform Assessment to the N-47 Elastic Creep-Fatigue Rules

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Abstract

The calculations leading to the fatigue assessment of a component operating in the creep regime based on the elastic route of ASME CCN47 [1] is computerised in the form of a program ASMEN47. The program works from a database which contains ORNL constitutive equations for some materials given in N47 [1]. For other high temperature materials, creep data in the form of the Bailey-Norton Law is used. The structure of the program is of a modular form using separate subroutines for stress relaxation, modified Poisson's ratio, Neubers correlation with the options of using time hardening or strain hardening theories for the relaxation calculations.

The elastic stress analysis results of a structure analysed at various time points (load cases) for a given load history is used as input data to this program. The user selects the onerous areas of the structure and the maximum strain ranges for the combinations of given load cycles are calculated by the program.

1. Introduction

Nuclear and fossil plant components operating in the elevated temperature regime are generally analysed by finite element method. The stress analysis results are then linearised and processed through the N47 [1] assessment procedure which is complex and time consuming. A computer program, ASMEN47 has been developed by Babcock Power Ltd for this purpose.

The paper describes the ASMEN47 program and its associated modules in some detail. Various flow diagrams are included to explain the program structure including the use of ORNL constitutive equations and the alternative Bailey-Norton law where appropriate. The program uses a material data bank, which is continuously being updated and is accessible simultaneously by other 'in-house' programs.

The limitations of applicability in terms of temperature limits, materials, number of cycles and locations in the structure are explained. The program has been tested against previously analysed AGR and PFR components which were assessed to the N47 elastic route through simplified longhand calculations, the results obtained are discussed.

All symbols used in this paper are defined in N47 [1].

2. Aims of the Program

The aims of the program are to speed up the calculation procedure, obtain the best level of design quality assurance and ensure correct application of all relevant clauses of the N47 elastic assessment route. The program also ensures correct material data transfer, a high level of accuracy and repeatability in the final results, and presentation in a form suitable for report documentation.

3. N47 Clauses Applied by the Program

The program covers the fatigue damage assessment given in clause T1432 of CCN47,[1] which is summarized as follows:-

For calculating the fatigue damage using elastic analysis, the maximum total equivalent strain, ε_t, for a loading cycle is used with the design fatigue curve to determine the number of design allowable cycles, N_d, where

$$\varepsilon_t = \frac{S^*}{S} K^2 \varepsilon_n + K \varepsilon_c + K_T \varepsilon_F \qquad (1)$$

The ε_n value is calculated using the method for determining the equivalent strain range, $\Delta\varepsilon_{equiv}$ (T1413 or T1414 [1]), using the elastic strain equations to determine strain components.

The creep strain, ε_c, caused by the load controlled stresses is determined from the isochronous stress-strain curve.

In calculating the peak thermal strain, ε_f, for a load cycle, the elastic equations are used with a modified value for Poisson's ratio determined by

$$\nu = 0.5 - (0.5 - \nu_e) \frac{3\,\overline{Sm}}{E\,\varepsilon_{ta}} \qquad (2)$$

where ν is greater than or equal to the elastic Poisson's ratio, ν_e.

For more accurate and less conservative determination of the total strain, ε_t, the first term of equation (1) is replaced with the value ε_m obtained by locating the intersection of the Neuber equation $\sigma.\varepsilon = S^* K^2 \varepsilon_n$ on the applicable time-independent composite isochronous stress-strain curve, fig. (1) (assuming the procedure of clause T1432(c)(1),[1] is followed).

4. Program Structure

4.1 Main Program

The program is written on a modular basis (figs. 2-7). The main program (fig.2) calculates ε_n for each load case combination using the method of T1414[1], omitting the local stress concentrations, creep strain and peak thermal strains. For each load case combination, ε_f is calculated using the equivalent strain method for corresponding peak stresses and modified Poisson's ratio. Subprogram PNUCAL (fig.3) is called to calculate ν_e, ν, E for each load case.

For each load case combination, ε_m is calculated by calling subprogram EMCAL (fig.4). The corresponding ε_t values are then calculated and output. The program arranges all ε_t values with their respective load combinations and allocates the specified number of cycles.

4.2 Subprogram PNUCAL

For each load case, PNUCAL extracts the elastic Poisson's ratio, ν_e, Young's modulus, E, and the allowable strain range, ε_{ta} from the databank. To calculate the modified Poisson's ratio, ν, the value of $3\overline{Sm}$ is first calculated for each load case. Subroutine SM3CAL (fig.5) is called for this purpose. $3\overline{Sm}$ is defined in T1325(d),[1], as follows :-

$$3\overline{Sm} = 1.5Sm + S_{rH} \quad (3)$$

$$\text{or } 3\overline{Sm} = S_{rH} + S_{rC} \quad (4)$$

where S_{rH} and S_{rC} are the hot and cold relaxation strengths respectively.

When only one extreme of the stress cycle is in the elevated temperature regime, eq. (3) applies. When both extremes of the stress cycle are in the elevated temperature regime, eq. (4) applies. Sm is the lowest stress intensity for a given temperature and is extracted from the databank. PNUCAL calls the stress relaxation programs to determine S_{rH} and S_{rC} for each load case, $3\overline{Sm}$ is then calculated, and hence ν.

4.3 Stress Relaxation Subroutines

N47 [1] specifies that S_{rH} and S_{rC} are determined by performing a pure uniaxial relaxation analysis starting with an initial stress of 1.5Sm and holding the initial strain for the time of service above 800°F.

The relaxation subroutines (figs.6&7) calculate the relaxation strengths using a forward creep technique with either time hardening or strain hardening theory, as user specified. For calculating successive creep strain intervals, isochronous stress-strain data for the material at each temperature are required. There are two options for supplying this data. If the material is type 304 or 316 steel, a subroutine containing ORNL constitutive equations [2] specifying the isochronous curves can be called. The other option requires the zero time isochronous stress-strain data to be user input for each temperature along with an appropriate Bailey-Norton (B-N) law for creep strain of the form

$$\varepsilon_c = A\ \sigma^n\ t^m \quad (5)$$

where σ is stress, t is time, and A,n,m, are material constants.

4.4 Subprogram EMCAL

For each load case combination, EMCAL calculates the ε_m value using the ε_n value calculated in the main program. This can be performed through either of the two routes available in EMCAL (fig 3). As described in section 4.3, these routes employ either ORNL constitutive equations or the B-N creep law.

For each load case combination, the composite zero time isochronous stress strain curve (fig.1) is generated. A value for S* is found by iteration. The Neuber equation is then solved by iteration to obtain ε_m.

4.5 Databank

The databank contains tables of data given in N47. These include E, S_{mt}, S_o, S_y (for materials S304, S316, 800H, 716H and 2¼Cr) and ν_e, S_m and ε_{ta} (S304, S316 and 800H only) over a wide temperature range. A simple retrieval subroutine,

incorporating the code recommended interpolation procedures, extracts relevant information from the databank.

4.6 Input/Output

Input data required are transient details with number of cycles, P+Q and peak stresses (F) for each load case; stress concentration factors (K and K_T); hot and cold temperatures for each case; material type; and relevant B-N equation parameters and zero time isochronous data (if applicable).

The output is in a form suitable for report documentation and includes data for S_m, ν , ν_e, S_{rH}, S_{rC}, $3\bar{S}_m$, E for each case with tabulated data for stress and strain components, as well as the strain ranges $\varepsilon_n, \varepsilon_m, \varepsilon_f$ and ε_t for each load case combination.

5. Limitations of Applicability of ASMEN47

One location only of a structure may be assessed at one time. The program allows service assessment in the creep regime as defined by N-47[1]. It can however, be applied to the entire loading histroy of a component including parts of the cycle occurring below the creep regime. At present, the program will run only for S304, S316 and alloy 800H. Extension of the program to include 9%Cr 1%Mo annealed and 2¼ Cr is in progress.

6. Verification of the Program

All verification work on the program has produced very acceptable results. Table (1) summarizes the results of a sample verification run of the program using data from the S316 Hartlepool spine analysis [3]. No peak stresses were present, the ε_m values calculated by ASMEN47 were less than the longhand calculated $(S^*/S)K^2\varepsilon_n$ values in every case and thus gave lower fatigue damage. Verification of the stress relaxation subroutines as independent modules has been carried out.

7. Conclusion

The results from the program are highly encouraging, and both time and cost effective. More accurate and less pessimistic results are obtained from the program than from longhand calculations, since it correctly applies all relevant clauses of the N47 [1] elastic route assessment.

Acknowledgement

The Authors wish to thank Babcock Power Ltd. for allowing the publication of this paper.

References

[1] ASME Boiler and Pressure Vessel Code, Code Case N47, Section III, Div. 1, 1983.

[2] The Generation of Isochronous Stress-Strain Curves, ASME Publication, 1972.

[3] Babcock Power Ltd report NEDR/07/193, "Hartlepool Nuclear Power Station Design Submission on Reactor 1 and Reactor 2 Boiler Support Spines", Issue 5, 1981.

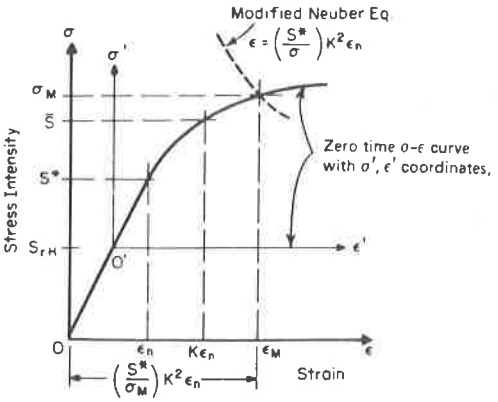

FIG. 1 Zero time composite stress-strain curve, [1].

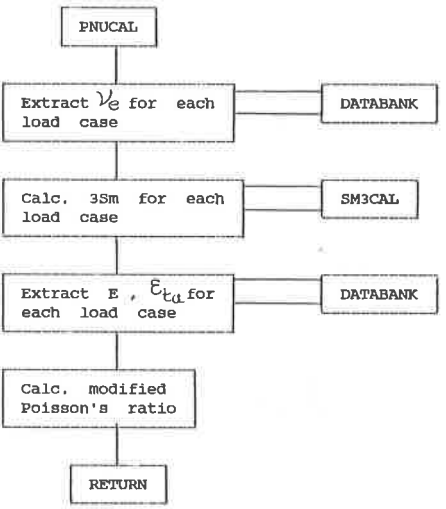

FIG. 3 Subprogram PNUCAL flowchart.

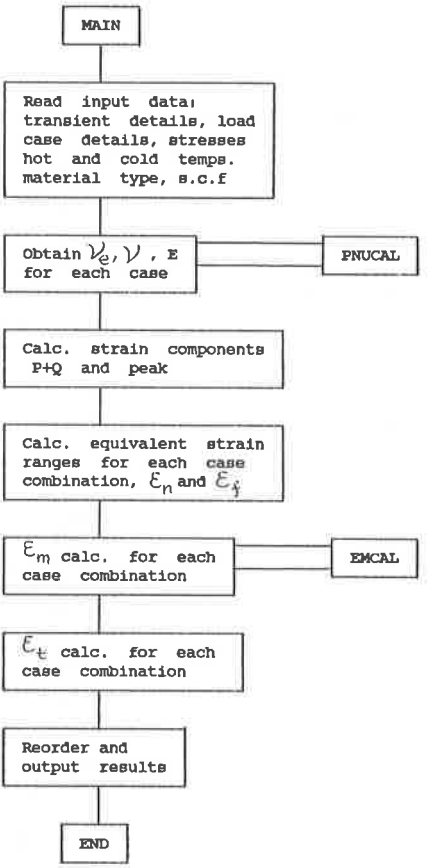

FIG. 2 Main program flowchart.

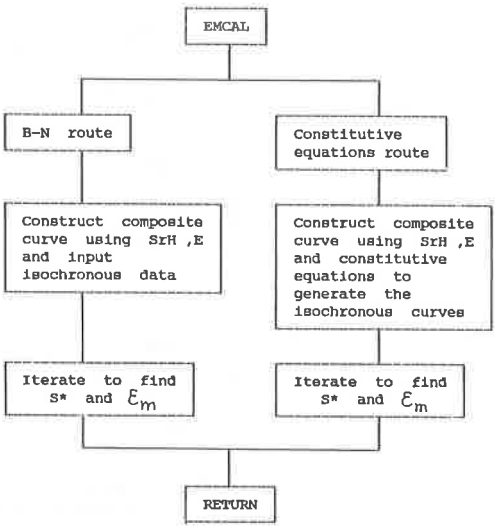

FIG. 4 Subprogram EMCAL flowchart.

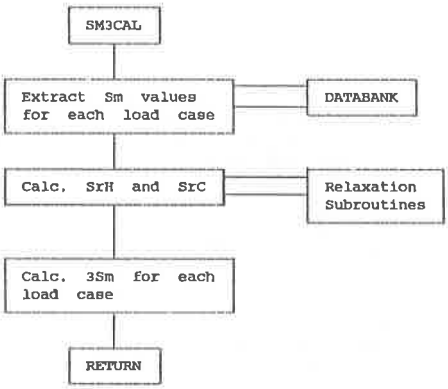

FIG. 5 Subroutine SM3CAL flowchart.

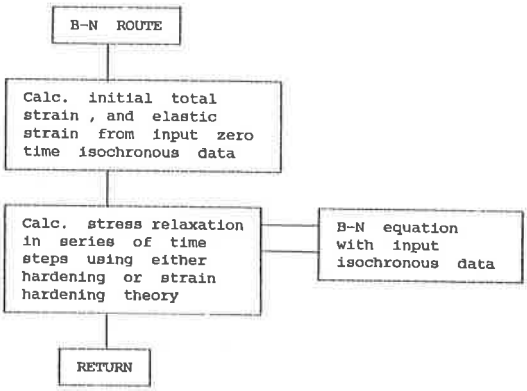

FIG. 6 Flowchart for stress relaxation using B-N equation.

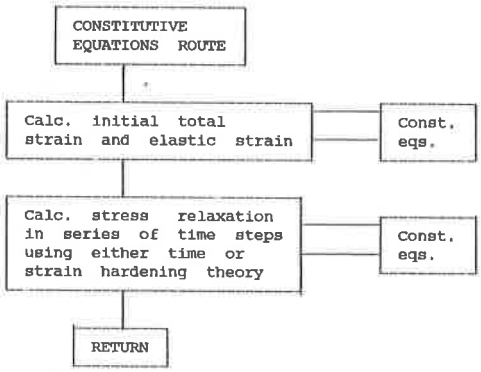

FIG. 7 Flowchart for stress relaxation using ORNL constitutive equations.

CYCLE	EN (DATA)	EN (PROG)	EM (DATA)	EM (PROG)
Depress/cold	0.677	0.6814	0.975	0.9177
Boiltrip/ cold	0.624	0.6294	0.899	0.7553
Boiltrip(8s)/ boiltrip(3600s)	0.224	0.1898	0.323	0.2278
100%MCR/ reatrip	0.143	0.1415	0.206	0.1698
100%MCR/ refuel1	0.113	0.1108	0.163	0.1329
100%MCR/ refuel2	0.093	0.0901	0.134	0.1092

(units millistrain)

TABLE(i) Comparison of program calculated values with longhand, simplified hand calculated values.