

# Creep Fatigue Analyses of a Single Wall Redan According to the RCC-MR

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## 1. INTRODUCTION

This paper deals with the validation of the single wall redan (inner vessel) option for the SUPERPHENIX 2 LMFBR project, according to the requirements of the RCC-MR Code.

Former studies (BLAIX et al, 1987) dealt with the design of the structure with respect to :

- excessive deformation,
- instability (buckling phenomenon),
- progressive deformation.

To complete this validation, an assessment against creep-fatigue damage has been carried out using elastic and inelastic methods.

This paper presents the methods used and the results obtained. The approach has been to validate the design using elastic methods and support this with inelastic analysis to show the further safety margins that are available.

## 2. BACKGROUND

### 2.1 Description of the structure

On the SUPERPHENIX 2 project, the reactor inner vessel separates the central hot sodium pool containing the core assemblies and the intermediate heat exchangers inlets, from the cold sodium pool in which the intermediate heat exchangers outlets are located (figure 1).

The structure therefore contributes to the overall hydraulics of the reactor block, bears the intermediate heat exchanger pressure drop, and is subjected to the temperature differences between the hot plenum and the cold plenum (545°C and 395°C respectively at Nominal Steady State conditions).

The single wall inner vessel also features thirteen standpipes in which components such as intermediate heat exchangers and pumps are located. The presence of these standpipes results in a three-dimensional and nonaxisymmetric geometry which requires a 3-D analysis approach to verify.

### 2.2 Former studies

The single wall redan is subjected to the following loadings, in addition to the structure weight :

- a) operating conditions : pressure drop and temperature difference through thickness at nominal steady state,
- b) upset conditions : reversal of the temperature gradient through thickness, due to the case of reactor shutdown,
- c) pseudostatic pressures due to vertical and horizontal seismic loadings.

Earlier analyses (Blaix et al, 1987) were performed in order to validate the structure against any risk of excessive deformation, progressive deformation and buckling, in compliance with the RCC-MR rules.

Having satisfied this requirement it was necessary to complete the study with an analysis of the creep-fatigue damage under normal operating and upset conditions.

### 3. CREEP-FATIGUE ANALYSIS METHODOLOGY

In order to validate the redan against the risk of creep-fatigue damage elastic and inelastic analyses were performed as summarised in the following sections. The upper part of the redan (hot region) is mainly studied.

#### 3.1 Elastic analysis : three dimensional approach

a) Three dimensional elastic computations were performed using the Finite Element Method by means of the SYSTUS Code. The structure was modelled with eight-noded shell elements.

An angular sector was chosen, which represents half the distance between two heat exchangers (figure 2).

The resulting F.E. model was then subjected to a set of mechanical and thermal load cases, whose features were as follows :

. Mechanical loads :

- self weight of structures,
- hydraulic pressure drop,
- seismic loadings.

. Thermal loads (table 1) whose most significant are :

- a nominal steady state which is characterized by a 120°C temperature gradient through thickness,
- a cold transient characterized by a 60°C maximum inverse temperature gradient through thickness.

Stress calculations show the most highly loaded region to be located in the upper part of the redan, at the hot side of the connection with the heat exchanger standpipe.

In this region, some equivalent stress values were obtained as follows :

- . Nominal Steady State (P1) : 225 MPa (tensor in compression)
- . Cold transient (T3) : 100 MPa (tensor in tension)
- . Pressure and self weight loading : 50 MPa (tensor in tension)

This value is the maximum primary stress in the structure due to mechanical loads, and compares with a value of 10 MPa found elsewhere in the upper part of the redan.

b) A preliminary elastic creep-fatigue analysis was carried out to assess the overall creep-fatigue damage. This analysis was performed in two regions :  
.the upper part of the redan (away from the IHX connection),  
.the highly loaded region at the IHX connection.

The following load cycles were considered (table 1) :

Cycle A : P1 -> T2 -> T3 -> P3 -> P1

Cycle B : P1 -> P2 -> T2 -> T3 -> P3 -> P1

Cycle C : P1 -> P3 -> P1 -> T1 -> T2 -> T3 -> P1

The total dwell time during the plant life at full load was taken as 230 000 hours.

. For the upper part of the redan away from the IHX connection, the derived results were as follows :

Fatigue usage fraction : Vfat = 0.04  
Creep rupture usage fraction : Wcreep = 0.53

Therefore, for the major part of the inner vessel, i.e. away from the connection with the IHX, the creep and fatigue damage values (V,W) are located inside the allowable area on the creep-fatigue interaction diagram. From the RCC-MR rules, this region of the structure may be considered as validated towards creep-fatigue damage.

- For the connection with the IHX standpipe the following results are obtained :

	Cycle A	Cycle B	Cycle C
Temperature during dwell time (oC)	512	512	512
Maximum stress range ( MPa)	330	330	330
Number of occurrence	210	130	65
Mean primary stress $\bar{P}$ (MPa)	50	50	50
$\sigma_k = \bar{P} + K_s \Delta \sigma^*$ (MPa)	211	211	211
Dwell time per cycle ( hours )	487	487	974
V ( fatigue )	0.05	0.025	0.025
W ( creep )	1.81	1.12	1.13
Cumulated V fatigue		0.1	
Cumulated W creep		4	

The dwell times are calculated in order to maximize the damages induced by the most stressing cycles.

The above usage fractions suggested that close to the connection the creep-fatigue damage was unacceptable when using the elastic analysis route of RCC-MR.

However, a detailed analysis was then carried out, taking into account :

- the localised geometry of the connection,
- the new rules of the RCC-MR code (stress relaxation during hold time, new way of evaluation of  $\sigma_k$ ).

### 3.2 Elastic analysis : two dimensional localised approach

a) The chosen geometry is the upper connection between the redan and the IHX standpipe. It is composed of :

- the redan shell (30 mm thickness),
- the standpipe shell (20 mm thickness).

The study is performed by means of the SYSTUS Finite Element Code, using six or eight-noded thick axisymmetric elements. The F.E. model was subjected to the nominal steady state thermal loading, which was the most severe load case for this part of the structure.

Parametric computations were performed, modifying the geometry of the junction between the two shells in order to minimise stresses.

The localised geometry of the connection redan-standpipes was then revised, an alternative design obtained to minimise creep-fatigue damage.

The main features of this design were :

- . Thickness of the local redan shell increased to 35 mm in order to reduce the primary stress level in this region,
- . Suppression of any geometrical discontinuity on the hot face of the redan shell.

Using this geometry, stress computation show no additional stress concentration on the hot face of the redan in this region.

b) A final elastic creep-fatigue analysis was then performed, taking into account:

- The local thickening of the redan shell,
- The new rules allowed in the addenda of the RCC-MR code :
  - . Stress relaxation during hold time,
  - . A new way of evaluation of  $\sigma_k$  (figure 3).

This analysis led to the following usage fractions :

Fatigue usage fraction : Vfat = 0.076  
Creep rupture usage fraction : Wcreep = 0.804

These creep and fatigue damage values were within the allowable area of the creep-fatigue interaction diagram, and satisfy the RCC-MR requirements. The redan structure was therefore considered as validated towards creep-fatigue damage, by means of an elastic investigation.

However, a simplified inelastic analysis was performed, in order to determine the benefits of this kind of method.

### 3.3 Inelastic analysis

A three dimensional inelastic calculation was carried out for the transient loading cycle labelled C. The redan was idealised as a 3D ABAQUS shell element sector model based on the SYSTUS idealisation with additional refinements in areas close to connection with the IHX standpipe and VERO.

For the inelastic analysis it was necessary to prescribe thermal boundary conditions and calculate metal temperatures for the complete loading cycle. This was done in stages. The stress calculations were performed for one complete loading cycle starting and ending at the no-load condition P3 (see table 1).

The constitutive laws used to represent the material behaviour were derived from the creep strain hardening law and reduced cyclic stress-strain curves given in RCC-MR. The stress curves were interpreted in the form of a bi-linear kinematic hardening model.

Elastic, plastic and creep strains were calculated at different stages in the loading cycle and the overall stress-strain response obtained at different locations. A comparison was made with corresponding elastic results in terms of strain range and creep-fatigue damage.

The largest equivalent strain range in the upper part of the redan was 0.22 %. This was on the hot face at the junction between the redan and the IHX standpipe as given in the elastic analysis (position A, see figure 2). A comparison with elastic results shows an enhancement due to plasticity and creep of up to 20 %. The enhancement calculated from the elastic route of RCC-MR were also found to be conservative.

ELASTIC F.E. CALCULATIONS	INELASTIC F.E. CALCULATIONS	RCC-MR $\Delta \epsilon$
0.183 %	0.219 %	0.26 %

The creep strain during the full load operating period was small and stresses on the hot pool face were compressive. The calculated stress-strain response for position A is shown in figures 4 and 5. The result given is for the gauss point of the element nearest the uppermost part of the connection and corresponds to the position of highest mechanical stress.

The result does not include the effect of localised stresses at the connection. A cyclic shift of the stress-strain curve occurred after applying the one loading cycle.

A creep-fatigue damage assessment was performed using the inelastic route of RCC-MR and this showed a lower damage than obtained using the elastic RCC-MR

method. The values were up to 20 % lower than calculated from the elastic results.

A further assessment using the procedure for compressive creep given in the Addendum of November 1987 gave a negligible creep damage fraction at the most highly stressed position. The highest overall creep-fatigue damage using this method was 0.01.

**CONCLUSION**

The SUPERPHENIX 2 single wall redan has been validated against creep-fatigue damage, by means of an elastic investigation.

This method has used :

- A 3D overall approach, which has brought out :
  - . a highly loaded region located at the upper connection between the redan and the IHX standpipe,
  - . the importance of primary stresses and hold time temperature in that zone.
- A 2D localised analysis, which enabled to design a new local geometry.

A 3D inelastic analysis has been carried out which :

- gives a lower creep-fatigue damage than the corresponding elastic method,
- shows the elastic enhancement procedure in RCC-MR to be conservative and effect of creep strains to be small,
- gave compressive stresses on the hot pool face which, when assessed against the November 1987 Addendum of RCC-MR, gave negligible creep damage.

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**REFERENCES**

RCC-MR. Design and construction rules for mechanical components of FBR Nuclear islands. June 1985 Edition including November 1987 Addenda.

SYSTUS. Release VAX 228. User's Guide May 1986.

Ph. Terny, J.C. Blaix, R. Del Beccaro, "Design of the fast breeder reactor single wall inner vessel", paper E7/5, Volume E, Transactions of the 9th International Conference on Structural Mechanics in Reactor Technology, Lauzanne, 17-21 August 1987.

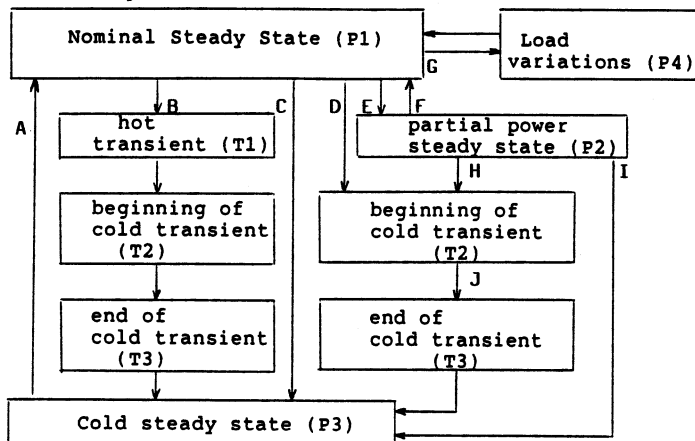
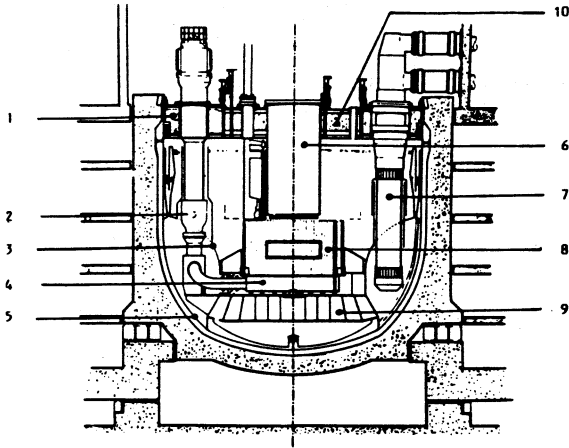


Table 1 Load cases for the 3D elastic analysis



- 1 - Roof Slab
- 2 - Primary Pump
- 3 - Inner Vessel
- 4 - Diagrid
- 5 - Primary Vessel
- 6 - Above Core Structure
- 7 - Intermediate Heat Exchanger
- 8 - Core
- 9 - Strongback
- 10 - Rotating Plugs

FIGURE 1

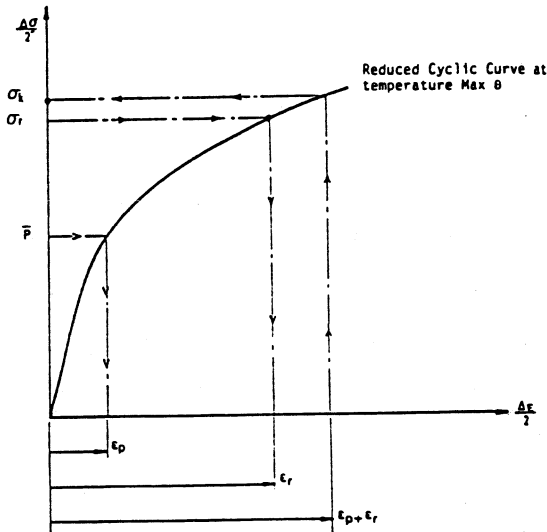


FIGURE 3

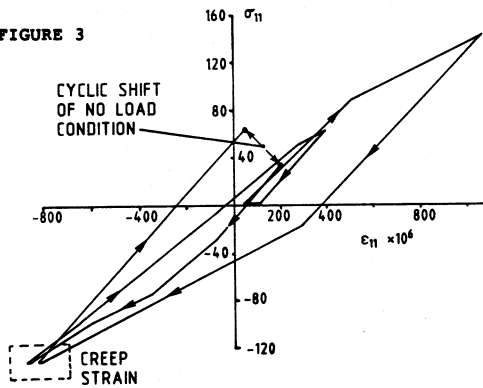


FIGURE 2

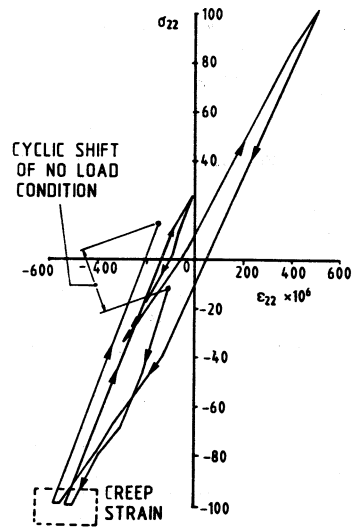
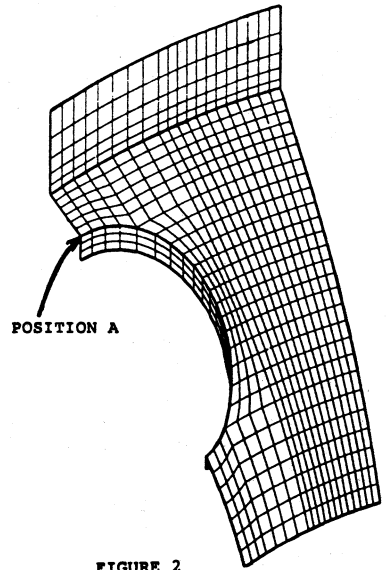


FIGURE 4

ELASTIC PLASTIC CREEP CALCULATIONS - STRESS STRAIN RESPONSE ON HOT POOL SURFACE (POSITION A)

FIGURE 5