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Design and construction rules committee for the EFR -Current status and development

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ABSTRACT

The Design and Construction Rules Committee (DCRC) was set up by the European Design and Construction Companies (FRAMATOME, NNC, SIEMENS, ANSALDO) in order to evolve mutually agreed design and construction rules for the European Fast Reactor. This paper reviews some of the DCRC work carried out since the work presented in 1993 at the Post Smirt 12 Conference seminar on Construction Codes and Engineering Mechanics and highlights some future activities with respect to on going collaboration on Codes and Standards for the Fast Reactor.

INTRODUCTION

The investigation of high temperature design methods and criteria for future Fast Reactor Designs has been established within the European Fast Reactor (EFR) project since its inception and the responsibility for establishing good design practice and methods was passed to the EFR Associates Design and Construction Rules Committee (DCRC). The DCRC is a joint group of experts from the partner companies of EFR Associates, which was set up in 1987 with the objective of evolving mutually agreed design and construction rules for the metal structures of the next fast reactor to be built in Europe. All partners consider that the RCC-MR code [1] which is mainly based on the experience gained in France with the construction of Superphenix constitutes a sound basis for the common design and construction rules and the experience of the other partners in the field of Fast Reactor design and construction is to be taken into account in the further work performed by the DCRC. The design and construction of EFR is to be based on the RCC-MR with extensions and modifications recommended by the DCRC on topics not covered by the RCC-MR or for which there are deviations in the practices of the companies. The DCR Committee also provides two specialist subgroups on materials and fabrication (plus chemistry and metallurgical aspects) and seismic design with the responsibility of studying specific topics in these specialist areas and reporting the results to DCRC.

The D & C companies submit proposals to the committee and its subgroups on chosen topics and following evaluation and discussion a conclusion is sought recommending an extension or modification to the rules of RCC-MR or to retain the existing RCC-MR rule. If a consensus cannot be reached the differences are identified and explained and the significance to design of EFR described. The work is presented in a concluding report to be used in conjunction with RCC-MR in the design of EFR. A compendium of the recommendations is issued periodically which provides a summary of the recommendations made and to be used with the RCC-MR code.

The DCRC has established links with the experts of the European Research and Development organisations and also with the European Commission DGXI Working Group on Codes and Standards (WGCS) committee. For the latter the DCRC members represent their companies on this committee or on one of its subgroups and this provides an important link of mutual benefit and provides a review forum for many of the ongoing CEC studies in the high and low temperature design field.

RESULTS OF DCRC WORK

The DCRC Collaboration has been very successful with over twenty five concluding reports on different topics issued to date. A list of some of the completed reports is given in table 1. The results from some of these have been reported previously in earlier Smirt Conferences [2,3]. In some cases a revision of a report has been issued where a further advance has been made rather than issuing a new document and some of the topics have up to three or four revisions.

In this paper a review of selected topics not covered in previous Smirt Conferences will be discussed. These topics are as follows:

- new advances on design rules for weldments
- new advances on elastic fatigue and creep/fatigue
- treatment of ratcheting
- topics on seismic design
- topics on material and fabrication issues

Alongside these it is proposed to provide a brief review of some of the main recommendations made by the DCRC many of which have now been formally introduced into the RCC-MR.

DESIGN RULES FOR WELDMENTS

Progress has been made on the design rules to be used for weldments. Some interim recommendations are now available concerning weldment factors to be used for 316L (N) stainless steel used on the major primary circuit components, Carbon steel used for the roof and plug, Mod 9Cr1Mo steel used for the Steam Generator Unit (SGU) and also some guidance is given on the treatment of Bi-metallic weldments in design.

A list of the factors derived for similar welded joints are shown in Tables 2 & 3. Their derivation has been discussed in previous papers [2,3].

Dissimilar metal weldments between the above austenitic and ferritic materials are to be used in the EFR between the Steam Generator Unit (SGU) nozzle and the secondary pipework (Mod 9Cr 1Mo - 316L(N)) and between the Roof and some primary circuit structures (Carbon Steel - 316L(N)). The upper transition joint on the SGU operates at about 500°C and the lower at about 370°C, whereas the primary circuit transition joints generally operate at less than 150°C. Three types of transition joint are mainly used in design:

direct welding of two heterogeneous base materials
welding after buttering
use of a transition piece

For the latter the buttering of the base metal may also be applied prior to welding the transition piece. A transition piece has the advantage of including a material with an intermediate thermal expansion coefficient that can be used to reduce thermal stresses from thermal cycling.

Filler metals between austenitic and ferritic transition joints are usually either austenitic steels or Ni based alloys. Under fatigue or Creep/fatigue loading conditions failure usually occurs on the ferritic side of the joint which is valid whether or not buttering is used. The welding sequences, processes and conditions must be chosen carefully to avoid hot cracking in the filler metal and cold cracking either in the martensitic diluted region or in the HAZ. Post weld heat treatment is used to temper the hard martensitic regions so that acceptable levels of hardness, strength and toughness are achieved although care is needed to avoid undue softening elsewhere. An important advantage of buttering is that the stresses near the fusion line from solidification shrinking and due to differential expansion of the austenitic and ferritic parts of the joint can be minimised.

In the RCC-MR there is only general advice to designers on the deformation concentrations which can occur under cyclic conditions due to the differences in material properties. However following discussions concerning the different practices used by the designers in the different countries the DCRC recommended the introduction of the following additional guidance for designers:

to locate dissimilar metal weldments in areas of low primary stress, low thermal cyclic stress and where creep effects are as small as possible.

for as-welded (undressed) weldments if possible these should not be used in load bearing applications under elevated temperature conditions

design limits applied to dissimilar metal weldments should be the same or lower than those of the weakest similar welded joint of the parent materials.

ELASTIC FATIGUE AND CREEP/FATIGUE

Further progress has been made concerning the methods to be used for elastic fatigue and creep/fatigue evaluation. The DCRC recommends the fatigue and creep/fatigue procedures of RCC-MR. Fatigue curves and cyclic stress strain data recommended by the DCRC for 316L(N) steel have now been incorporated into the latest edition of the RCC-MR code. Additional work has also been completed on the procedures for treatment of thermal striping and vibrations a summary of which is given in the following paragraphs:

Thermal striping is the effect of a rapid random oscillations of surface temperature which usually occurs in the mixing zone of coolant streams of different temperature inducing a corresponding fluctuation of surface strains in the metal. The loading is characterised by large numbers of loading cycles under strain controlled conditions which can add to the damage caused by other loadings. There are no specific rules in RCC-MR for thermal striping and the general fatigue and creep/fatigue rules are applied. The DCRC concluded that a specific fatigue curve was required to apply the general method which takes account of the strain controlled nature of the loading. New design fatigue curves were therefore derived using the definition of equivalent strain used in RCC-MR which cover situations up to 10^9 cycles (see Fig.2).

The treatment of vibration loadings however is done on the basis of load control rather than strain control. Consequently for this type of loading a further fatigue curve was needed. The DCRC recommended specific stress controlled curves for 316L(N) steel derived from the RCC-MR strain controlled curve, lowered by factors to account for mean stress effects when the loading exceeds the yield stress, and extrapolated to higher cycles using a constant slope (see Fig.1)

For combinations of thermal striping and vibrations a procedure was recommended in which the fatigue usage fraction is calculated as the sum of three parts:

$$V = V1 + V2 + V3$$

V1 is obtained using the total strain range based on the sum of the total strain components due to thermal striping and vibrations and the maximum total strain components induced by level A cycles. The strain controlled fatigue curve is used to obtain the damage fraction.

V2 is obtained using the total strain range obtained from the sum of the thermal striping and vibration loadings. If a less conservative addition can be justified this can be used. The stress controlled fatigue curve is used. The number of cycles is the smaller of the remaining numbers of thermal striping or vibration loading cycles.

V3 is obtained using the total strain range for the numbers of cycles not taken into account previously whether thermal striping or vibration and the corresponding curve is used for the analysis.

The DCRC also concluded on the use of the procedure in RCC-MR concerning zones with geometrical discontinuities and it was agreed to use the procedure recommended by the R & D organisations replacing the elastoplastic Von Mises strain range by the maximum strain difference during the cycle. The method may be used under low and high temperature conditions provided creep is negligible and multiaxial out-of-phase loading is excluded.

DESIGN OF TUBEPLATES

Improvements have been made in the methods used for the design of tubeplates. Methods for dealing with flat and dished thick tubeplates have been prepared by the DCRC and are reported in a previous Smirt Conference [3]. The methods are appropriate for use on the designs of SGU and IHX of EFR. Recommendations are made using the axisymmetric equivalent solid plate modelling technique in which this region is replaced by a homogenous solid plate. The method can be used under non-creep and under creep conditions. The equivalent solid plate is assumed to behave isotropically in planes perpendicular to the axes of the perforations and use is made of the elastic constants E^* and v^*. In the direction parallel to the axis of the perforations, an effective Young's Modulus E' takes account of the reduction in cross sectional area. The equivalent solid plate stresses are determined using Finite Element analyses and an approach similar to ASME A8000 is used but with some specific changes. The method is prepared for triangular and circular pitch perforation patterns the latter of interim status.

Further work is underway by the DCRC to make use of a recent study carried out by the European Commission WGCS group on flat tubeplates which investigated amongst other topics the elastic constants and the multipliers needed for circular pitch perforation patterns.

The values of E^* and v^* were assessed using 3-D finite element calculations (with a limited number of perforations included in the model) and the results compared with deflections from axisymmetric model solutions. Correction factors for the moments were derived from the comparison between the 2-D and 3-D calculations as a function of the radius and angular position and following a review of factors for triangular, square and other pitch patterns, the multiplication factors for peak stress for the circular pattern were established as a function of their circumferential position

The results showed that a good estimation of the effective E^* value was obtained from the average of the values for triangular and square pitch and the effective poissons ratio v^* was shown to be slightly higher than that of the square pattern in the pitch direction. Stress multipliers to assess peak stresses were defined for an intermediate case (between triangular and square pitch) such that they can be assessed every 15°. Also stress multipliers for triangular pattern with ligament efficiency 0.6 and 0.7 are provided.

METHODS FOR ASSESSMENT AGAINST RATCHETING

The work on the evaluation of suitable diagrams to assess ratcheting in cylindrical structures of FBR's has continued for many years in Europe and elsewhere and DCRC has been looking at the potential of the different European procedures developed both in France and the UK. The present method of RCC-MR is to use the efficiency diagram derived mainly from specific torsion - tension testing on 316L(N) type steel. This method however is best suited to situations where reasonable levels of primary loading occur with a secondary stress. Where primary stresses are generally small and secondary stresses can be large as is the case at the Sodium surface of FBR's an alternative approach is needed.

There is a requirement therefore to consider a simplified diagram approach which can be used in the EFR for problem such as those experienced at the Sodium free Level. The methods currently being investigated are those developed previously in the UK as part of the UK FBR programme mainly at Leicester University and which have been subsequently extended within the work program of the WGCS. A separate paper is given elsewhere on this work at this Smirt Conference [4] (an Interaction Diagram is shown in Fig. 3). The other possible method is one being developed in France by CEA [5]. The DCRC have been working to obtain a direct comparison of all available procedures against a specific design benchmark of a free level type loading. The work has not yet been concluded but it is expected that one of these methods will be recommended for this type of loading.

Other methods have been developed such as the Shakedown Method developed in the UK for elevated temperature structures which use elastic finite element results supported by a post processor to indicate whether ratcheting will occur under specified loadings. Shakedown methods are valuable in eliminating the possibility of ratcheting without the complexity and expense of full inelastic analysis. The shakedown analysis short cuts the route taken by inelastic analysis by moving immediately to a prediction of the steady cyclic state. A further benefit in high temperature applications is the ability to produce assessments of creep/fatigue damage which are potentially less pessimistic than assessments made by traditional code routes.

The Shakedown method is a general purpose approach which has been examined by the DCRC [2] and recommended for use on EFR. This method can cope with the free level and other loadings and in principle a whole range of different component and element types can be dealt with. A study reported in the last Smirt considered the application of the method to the tubeplate [6]. Some recent developments are also given in a paper on the application of the Shakedown method to piping completed under a study contract let by the CEC WGCS [7]. The DCRC proposes to incorporate the results of these cases in its work.

Recent improvements have been made by DCRC to the recommended Shakedown method by incorporating a higher value of K1 for 316L(N) steel at elevated temperatures. The value of K1 is derived from load controlled tests and conservatively used along with the minimum material yield in the definition of the shakedown yield surface. This recommendation has been made following a detailed examination of a the available creep fatigue test behaviour by the R & D organisations which showed that cyclic softening was not apparent at temperatures up to 550°C. Use of the revised value of K1 (see Fig.4) allows greater range of acceptable residual stress fields for satisfaction of the ratcheting criteria however further optimisation of the residual stress distribution to minimise creep damage is more likely to obtain an acceptable creep/fatigue damage value.

REVIEW OF SEISMIC DESIGN METHOD

Progress has been made in the field of seismic design with the help of the expert sub group on seismic design (SDG), examining such topics as design and analysis methods, input data, soil structure interaction, seismic qualification and monitoring. The main progress is in the review of partner practices and recommendation of harmonised approaches where this is possible. A brief outline of some of the work performed and conclusions reached are given in the following paragraphs:

Work has been carried out to review and compare the different methods used for modelling and analysis of structures in the partners countries. Methods applicable to both isolated and non-isolated structures were covered and many of the methods of solution of the equations of motion and modelling approaches used were shown to be common. The review covers the modelling of the building, the mechanical components such as the vessels and heat exchangers and the piping system. Further work is underway to examine simplified methods used for piping, in particular the methods based on strain quantities rather than stress. The DCRC SDG will make use of some recent CEC WGCS studies completed on the topic.

A review of the site independent input data for the preliminary seismic design under SSE loading was made in order to provide a recommendation which can fulfil the requirements of the individual partner countries. A recommendation was formulated based on the UK and USNRC Spectra implemented by performing separate calculations using these free field input spectra acting at the ground surface and enveloping the resulting floor response spectra.

Soil Structure Interaction procedures used in the partner countries have been reviewed and no essential differences in the national practices was found. Recommendations were formulated concerning the methods to be used for the generic site calculations. Standard methods (ie. Finite Element model of upper structure, impedance functions,soil springs followed by either Modal Response Method, Modal Time History, etc.) are to be used for the preliminary and final building concepts. The final building concept should then be evaluated using refined methods such as the frequency domain analysis method for verification. For site specific calculations both should be used.

A state of the art review of the expected developments in seismic isolation was carried out in order to identify possible options for the EFR design. For horizontal isolation a preference was expressed for high damping steel laminated rubber bearings because of their simplicity, compactness, predictability, stable characteristics and large achievable capacity. For vertical isolation of the reactor block helical springs with viscodampers were considered most appropriate. It was also concluded that qualification programmes for the single device and for the system should be established and to meet the objective of plant standardisation a unique set of isolator/damper characteristics should be selected possibly as a compromise between different design constraints.

Other aspects investigated includes the seismic methods used for the core, consistent set of data for seismic studies, seismic monitoring and instrumentation and criteria and methods used for qualification by testing. For these last two topics a review of national practices was carried out and suggestions were put forward for consideration when such programmes were needed. The work on the core seismic methods included a review of the methods used in the partner countries and served to identify areas for further R & D. The study on consistent set of data was performed in order to identify and propose a methodology for ensuring consistency of data across the different partner organisations and countries.

MATERIAL, FABRICATION AND ENVIRONMENTAL CONSIDERATIONS

Significant progress has also been made on a number of material and fabrication issues including recommendations on design data for 316L(N), Mod 9Cr 1 Mo steel and Carbon steel. The work has also covered areas such as procurement and acceptance of materials, fabrication and inspection rules, quality assurance, standards to be used, allowable types of welds and the treatment of issues associated with corrosion which includes a corrosion checklist for designers. Some of this information has been reviewed in previous papers [2,3] and much of the material property data has been introduced into the 1993 edition of RCC-MR. Table 4 gives an indication of the data established by DCRC for 316L(N) and Mod 9Cr1Mo Steels.

Presently design codes do not include design procedures for consideration of corrosion, especially stress corrosion cracking despite the fact that such cracking has in the past led to significant outage of power plants. It was recognised therefore that some guidance is required for designers to help them with material selection and to raise awareness of potential problems with respect to corrosion. A review of the national practices was performed and a corrosion cracking checklist formulated based on this practice. The checklist covers normal chemistry operating conditions and abnormal chemistry conditions. For the latter the designer should seek advice from corrosion specialists.

Present work in relation with material aspects concern the update of material properties for Mod 9Cr1Mo and Carbon steels. For Mod 9Cr1Mo steel, a complete revision of RCC-MR material properties group 18s should be proposed following the work undertaken by R & D organisations and in the frame of the WGCS. It concerns in particular the update of allowable stresses, fatigue and creep/fatigue properties (including the symmetrisation factor Ks) as well as creep laws. For Carbon steels, the work undertaken concerns tensile and creep data and low cycle fatigue properties. The materials concerned are grades similar to A48, A42 and A37 and modifications recommended take account of recent European standards.

CONCLUDING REMARKS

The DCRC continues to work towards the establishment of a common set of design rules for the next European Fast Reactor. Where possible the DCRC has made full use of recommendations from R & D organisations and the results of studies performed by the European Commission Committee on Codes and Standards (WGCS) to further their understanding and improve their recommendations. A brief synthesis of some of the recommendations made since the last paper published in 1993 Post Smirt Seminar has been included in the paper together with a review of some of the main recommendations made by DCRC many of which have been introduced into the latest edition of the RCC-MR.

ACKNOWLEDGEMENTS

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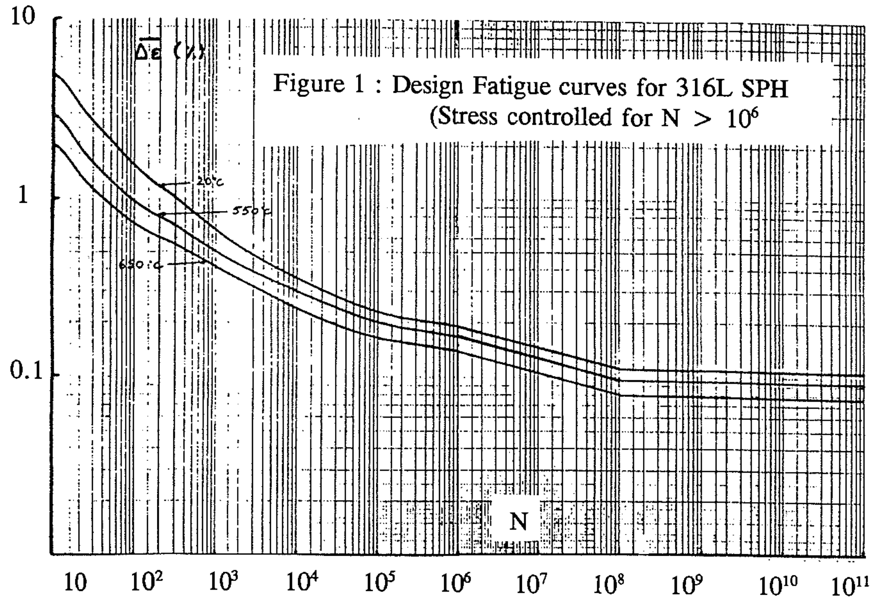

Figure 1 : Design Fatigue curves for 316L SPH (Stress controlled for $N > 10^6$)

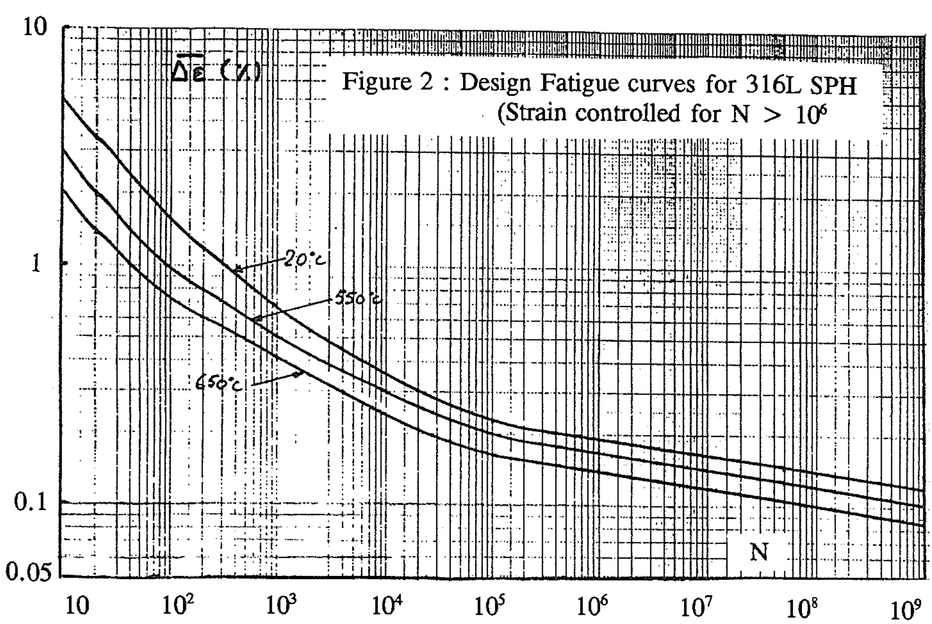

Figure 2 : Design Fatigue curves for 316L SPH (Strain controlled for $N > 10^6$)

DCRC Concluding Reports	RCC-MR				new
	confirm	clarify	modify	addition	
No.1 :Negligible creep curve for 316L SPH			x		
No.2 :Derivation of allowable design stresses Sm and St	x				
No.3 :Irradiation effects on mechanical properties of 316L SPH				x	
No.4 :Sodium effects on mechanical properties of material under normal reactor conditions		x			
No.5 :Design rules for welds			x		
No.6 :Elastic fatigue and creep fatigue rules			x		
No.7 :Shakedown design rules for fast reactor application					x
No.8 :Physical properties of 316L SPH and Mod 9Cr1Mo				x	
No.9 :Design methods for tubeplates			x		
No.10:Buckling Analysis			x		
No.11:Design properties of Mod 9Cr1Mo				x	
No.12:Strain Based creep-fatigue assessment for inelastic analysis					x
No 13:Leak before Break procedure for sodium boundary components					x
No.14:Standards to be used in the EFR project		x			
No.15:Preheat.postheat and stress relief treatments				x	
No.16:List of Base materials and related weldments for EFR				x	
No.17:Interaction Diagrams for ratcheting (in preparation)				x	
No.18:Generic ground motion for site independent seismic studies of EFR				x	
No19:Allowable types of welded joint			x		
No.20:Rules for prevention of Elastic Follow- up				x	
No.21:Selection of Austenitic stainless steels in relation to Intercrystalline corrosion		x			
No.22:Soil structure Interaction analysis of EFR				x	
No.23:Corrosion cracking checklist				x	
No.24:Guidance document on Dissimilar welds				x	
No.25:Complimentary specifications for EFR				x	
N0.26:Design properties of carbon steels - Tensile and creep data				x	
No.27:Design properties of carbon steels - Low cycle fatigue (in preparation)				x	

Table 1 : List of DCRC Concluding Reports

Material	RCC-MR Weldment Factor	Value
316L(N)	J_r J_f	(table 3) 1.25
Mod 9Cr 1Mo	J_m J_t J_r J_f	1.0 0.9 0.9 1.25
Carbon Steel	J_m	1.0

Table 2 : Weldment Factors recommended by DCRC

t(h) θ (°C)	1	10	3.10	10^2	3.10^2	10^3	3.10^3	10^4	3.10^4	10^5	3.10^5
425											
450	1	1	1	1	1	1	1	1	1	1	1
475	0,96	0,96	0,96	0,97	0,97	0,97	0,97	0,98	0,98	1	1
500	0,93	0,92	0,93	0,94	0,94	0,94	0,95	0,96	0.97	0,99	1
525	0,89	0.88	0,89	0,91	0,91	0,91	0,92	0,94	0.96	0.99	1
550	0.85	0,84	0,85	0,88	0,88	0,90	0,91	0,93	0,96	0.99	1
575	0,82	0,81	0,81	0,86	0,87	0,89	0,90	0,93	0,96	1	1
600	0,78	0,78	0.79	0,84	0,85	0,88	0,90	0,93	0,97	1	1
625	0,77	0,77	0,78	0,82	0,84	0.87	0,90	0,94	0,97	1	1
650	0.76	0.76	0,78	0,81	0,83	0.86	0,90	0,94	1	1	1
675	0,76	0,76	0.78	0,80	0,84	0,87	0,90				
700	0.76	0.76	0.78	0,80	0,83						

Table 3 : Recommended values of J_r for 316L SPH welds

Material	Property	Ammended	New	No Change
316L (N)	A3.1S			
	Negligible creep curve	x		
	Sm, St			x
	Fatigue curves	x		
	Cyclic curves, Kε, Kv	x		
Mod 9cr 1Mo	A3.18S			
	Physical properties	x		x
	Tensile properties			x
	Sm, St			x
	Fatigue curve		x	
	Cyclic curves,Kε, Kv		x	
	Creep/fatigue Interaction		x	
	Creep rupture			x

Table 4 : DCRC material data evaluations for RCC-MR (316L(N) & Mod 9Cr1Mo steels)

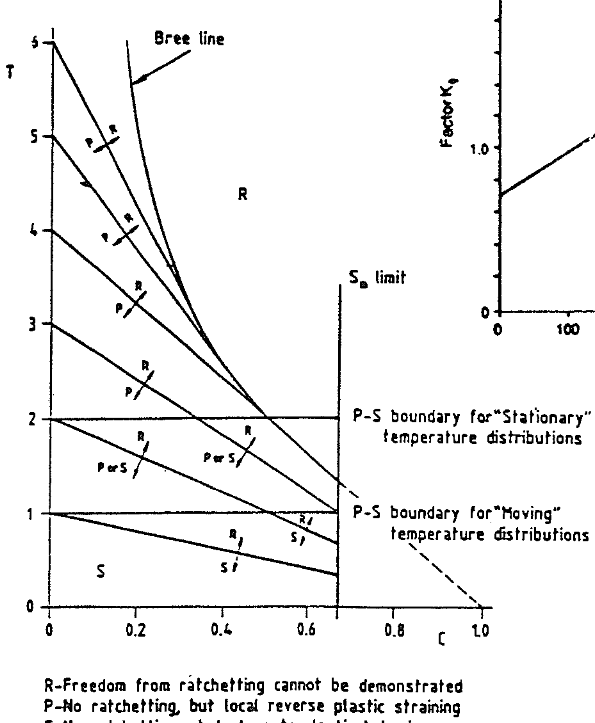

Figure 3 : Ratcheting Interaction Diagram

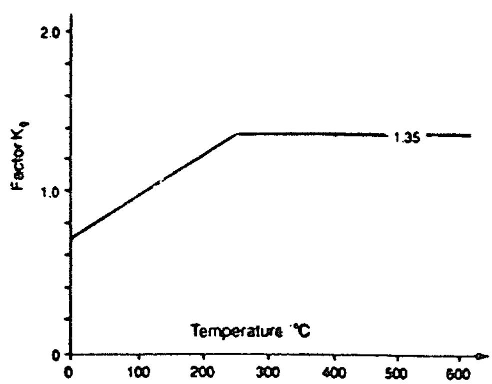

Figure 4 : K1 value - Shakedown Method