ANALYSIS OF THE NEW RCC-MRX METHODOLOGIES FOR CREEP-FATIGUE DAMAGE

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❑ BACKGROUND

RCC-MRx code has been developed for Sodium-cooled Fast Reactors (SFRs), experimental reactors and fusion reactors but can be used, on condition that the rules applicability is justified, for components for other nuclear installations including the other GEN IV and SMR reactors.

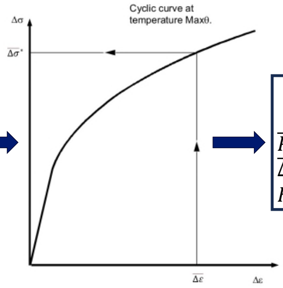
In the 2022 version, the RCC-MRx code introduced methodologies to calculate more precisely the creep-fatigue damage of a loaded structure, mainly focused on the computation of the creep usage fraction W. The latter is a variable used to quantify the creep damage.

The historical methodology used to calculate the creep-fatigue damage that is schematized on the figure below considers the following assumptions:

- The rebuild hysteresis loop is a curve without information on compressive or tensile stress,
- The holding time is considered as positioned at the point ($\overline{\Delta\varepsilon}$,$\overline{\Delta\sigma^*}$).

To catch the abovementioned phenomena, the recently introduced methodologies are proposed.

ELASTIC CALCULATIONS →



→

$$\sigma_k = \overline{P_{max}} + K_S \cdot \overline{\Delta S^*}$$

$\overline{P_{max}}$: a primary stress during the holding time
$\overline{\Delta S^*}$: an estimation of the secondary stress range
K_S: a symmetrisation coefficient

→ W

❑ RECENTLY INTRODUCED METHODOLOGIES

- **Methodology 1 : Compressive and tensile stress-strain hysteresis curve**
  This modification allows to consider a part of the cycle in compression or in tensile, using a new definition of the symmetrisation coefficient :

$$K'_S = min(K_S; \overline{\sigma_{max}}/\overline{\Delta\sigma^*})$$

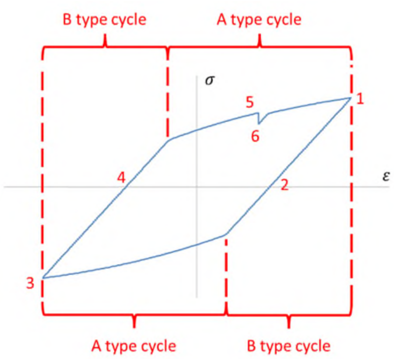
  So, it is possible to decrease the value of σ_k, whether the cycle is purely elastic

- **Methodology 2 : Holding time is not located at one of the extrema of the cycle**
  It allows to avoid the use of the point ($\overline{\Delta\varepsilon}$,$\overline{\Delta\sigma^*}$) in the rebuild hysteresis loop and to decrease the holding time stress. For example, it allows to compute a creep usage factor using the stress at the point 5 instead of the stress at the point 1 (see figure below).

- **Methodology 3 : Consideration of compression during the holding time**
  From experimental tests on austenitic stainless steels, it is well-known that a compressive stress is less damaging than a tensile stress for creep damage. To consider that effect, this methodology proposes a new way to determine σ_k, when the holding time is in compressive stress state :

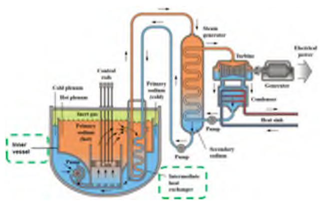
$$\sigma_k = 0.867 \cdot \sigma_k + 0.133 \cdot \frac{\sigma_k}{\sigma_{el\_h}} \cdot \frac{\sigma_k - \overline{P_{max}}}{\sigma_k} \cdot trace(\sigma_{el\_h})$$

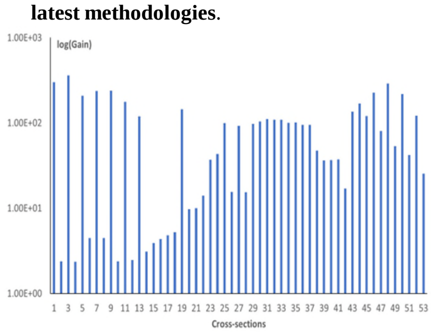
- **Methodology 4 : Use of R5 procedure, in case of the primary stress is neglected**
  The hysteresis cycle is split into two half-cycles: without creep and with creep. Concerning the creep damage, it is determined using a stress σ_k calculated in the half-cycle with creep. For example (see figure below), the holding time stress σ_5 at the point 5 is determined using the relative stress along the points 345 and the Neuber hyperbola. This stress is then used as the start of the holding time stress to calculate the stress σ_k.



❑ APPLICATIONS

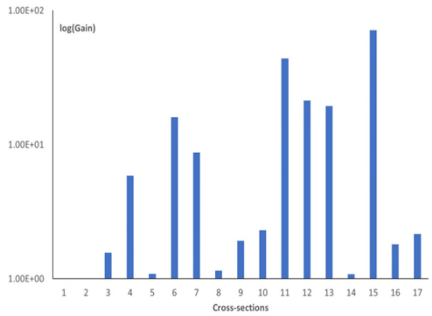
- **The Inner Vessel (IV)** and **the Intermediate Heat eXchanger (IHX)** are chosen to evaluate the recently introduced methodologies.
- The fatigue-creep analysis is carried out on several cross-sections of the structures.
- The **gain** is defined as the **ratio** between the creep damage fraction of the **historical methodology** and the one obtained from the **latest methodologies**.





- **For the IV**, the creep damage fraction W is considerably reduced using the third methodology, by **a factor of 10-100**.
- Concerning the most loaded cross-section obtained with the historical methodology, **the creep damage fraction W** is about **37 times smaller.**
- On some cross-sections, **the risk of creep damage** is even **reduced** to **"zero"**.

- **For the IHX**, the creep damage fraction W is considerably reduced using the third and fourth methodologies.
- Concerning the most loaded cross-section obtained with the historical methodology, **the creep damage fraction W** is about **8 times smaller.**
- For the component as a whole, **the creep damage fraction W** is **reduced by a factor of 2.5.**



❑ CONCLUSION

Recent improvements given to creep-fatigue methodologies have incorporated important aspects of creep phenomenon. As a result of that and based on the observations here presented, the recently introduced RCC-MRx methodologies of creep-fatigue are predictive and adapted to evaluate the creep-fatigue damage observed on SFR components. The assessment of creep-fatigue damage of innovative nuclear reactors – particularly to the GEN IV and SMR projects can be evaluated using the RCC-MRx Code, on condition that the rules applicability is justified. These methodologies can be used in the design of SMRs to demonstrate a more important lifetime of their components and consequently increase the performance of their plant.