Strain Limits within the Scope of the Integrity Assessment of Piping Systems

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ABSTRACT

Allowable stresses in nuclear power plant piping resulting from loading conditions to be considered in Germany are determined on the basis of the German Safety Standards of the Nuclear Safety Standards Commission, KTA. The limitation of the different stress categories within the analysis of the mechanical behaviour is based on a linear elastic material behaviour. Because of the ductile material used in high energy nuclear piping, a more realistic assessment can be performed on the basis of allowable strains using elastic plastic material behaviour. In the present work comparison between the analysis of piping systems considering the elastic material model and the actual elastic plastic material behaviour is performed. The possibilities of allocating plastic strains to calculated elastic stresses is discussed. A parametric study on straight pipes with the actual elastic plastic material model under pure bending is the basis of deriving the elastic plastic strains for the calculated elastic stresses. Strain limits are suggested which correspond to the different stress categories. The aim is to utilize the deformation possibilities of ductile materials used in German nuclear piping and the allocation of maximum strains to different load categories.

Keywords: strain limit, ductile material, stress category

1 INTRODUCTION

The German Safety Standard for nuclear power plants, KTA, [1], requires different stress limits for different classes of components, different Design Levels and different materials. The limits are mainly derived from the ASME BPVC Section III, [2]. The stress limits change for different service levels, [3]. Stress limits are established for Design Level A, Level B, Level C, and Level D loadings, table 1. Design conditions loads lead to the required wall thickness of the vessel. Level A conditions are those referred to as normal conditions, Level B as upset conditions. Level A and B loadings occur during the normal operation conditions of the component. Stress limits for Level A and B are selected so that there is no damage. Level C stress limits permit large deformations in areas of structural discontinuity which may necessitate the removal of the component or support from service for inspection or repair of damage. Level D stress limits permit gross general deformations with some subsequent loss of dimensional stability and damage requiring repair, which may require removal of the component or support from service. The stress criteria in the ASME BPVC is based on the definition of the $S_m$ value which is a fraction of 1/3 of the tensile strength or 2/3 of the minimum yield strength $S_Y$. This means $S_m=S_Y/1.5$ for ferritic steels. For austenitic steels, $S_m$ is the lower of 1/3 minimum tensile strength or 90% of the minimum yield strength. The increase to 90% of yield strength is to allow for the strain-hardening characteristics of austenitic steel.

Guidelines on the evaluation of elastic stresses relative to BPVC defined failure modes as they relate to stress limits can be found in [4].
table 1: Failure modes and damage mechanisms by limitation of different types of stresses

<table>
<thead>
<tr>
<th>Loading Conditions</th>
<th>Service Loading Levels</th>
<th>Damages Covered</th>
<th>Type of stress to be considered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>0</td>
<td>• Excessive Deformation</td>
<td>Primary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Instability</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>A</td>
<td>• Progressive Deformation</td>
<td>Primary+Secondary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Fatigue</td>
<td>Primary+Secondary+Peak</td>
</tr>
<tr>
<td>Upset</td>
<td>A</td>
<td>• Excessive Deformation</td>
<td>Primary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Instability</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>• Progressive Deformation</td>
<td>Primary+Secondary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Fatigue</td>
<td>Primary+Secondary+Peak</td>
</tr>
<tr>
<td>Emergency</td>
<td>C</td>
<td>• Excessive Deformation</td>
<td>Primary</td>
</tr>
<tr>
<td>Faulted</td>
<td>D</td>
<td>• Instability</td>
<td>Primary</td>
</tr>
<tr>
<td>Test</td>
<td>P</td>
<td>• Excessive Deformation</td>
<td>Primary</td>
</tr>
</tbody>
</table>

For piping components and piping systems in nuclear power plants the values for $S_m$ are derived under the given stress versus strain curves of the used materials. Considering primary membrane stresses, where primary stresses are load controlled, the maximum allowable elastic stress leads to a small elastic plastic strain for materials with high ductility like the Material called X-6-CrNiNb18-10. Performing a simplified stress analysis for a straight pipe with given bending moment and internal pressure the KTA takes equation [1.1] to form the basis for simplified calculation following the DBR, Design by Rule Philosophy. The stress limits are derived from the different service conditions and are determined by $\alpha$ in [1.1].

Considering primary membrane and bending stresses for level D, the maximum allowable load leads to a elastic plastic strain. The stress for primary bending and membrane stress is assumed to be a fictitious elastic material behaviour

$$\sigma_l = B_1 \frac{d_s}{2S_c} p + B_2 \frac{d_s}{2t} M_{Il} \leq \alpha S_m$$  \[1.1\]

where $B_1$ and $B_2$ are stress indices given by the KTA, [1]. The different limitations for different load levels were derived from comparing the sustainability of integer piping components which were experimentally proved, [6]. All moments are added geometrically and divided by the moment of inertia against bending to obtain the moment-based stress. It is assumed that the torsional moment is considered conservative in this way.

As already mentioned there exists a good and well proven experimental basis to limit primary membrane and bending stresses in straight piping components. Consequently the limitation of the fictitious elastic reaction moments depends on the geometry of the different experimentally tested piping components and the used materials.

However, it is assumed that the commonly used limitation of stresses for level D at high loads with a low probability of occurrence does not take advantage of the high ductility and possibility of strain-hardening of current steels. Especially concerning the service loading level D for faulted conditions in the KTA allowing excessive deformation table 1. It should be possible to make a better use of the possibilities of deformation that the used materials offer. This could be reached by introducing strain limitation criteria for quasi static loads in dependence of the stress state.
2 STRAIN AS A LIMITATION CRITERION FOR ALLOWABLE LOADS

The three principle design elements usually considered as design criteria for piping components by the Design by Rule approach are the design method, the design load and the allowable stress, [7]. Especially when the design is following the Design-by-Analysis rules a structural strain is taken into account for the limitation of the loads. The structural strain is the strain in stress concentration free models. Even if the model is concentration free, depending on the load, the stress state evolves into various directions. It is due to the stress state whether or not the strain as a limitation criterion is possible.

The main problem when deriving criteria for strain limitation is the multiaxiality of the stress state. Depending on the stress state the local strain for a ductile material is restricted if the multiaxiality of the stress state is high.

The size effect is another problem concerning the introduction of a strain limit. When necking starts the strain differs despite the same geometrical relations of the diameter and the notch. In [13] several experimental investigations were performed on the size effect of different specimens of the same geometrical relations but different absolute dimensions. The material examined was the ferritic vessel steel 22NiMoCr37. There was a small size effect in this experiments. This could be ascertained when introducing a strain limit. Even if geometries have the same relations the strain is different during necking in dependence of the stress state and absolute dimensions of the component.

For the introduction of strain limits for piping components a method which shows the stress state in pipes is introduced. This leads to a predication for strain limits in pipes and piping systems. This paper deals with the basics of material mechanics -especially with the stress state- in a parametric study on straight pipes. The stress states and strains shown for these different pipes under different bending angles indicate whether or not the calculated stress states develop to low strain limitation in piping systems.

Comparing the limitation of stress and strain in a piping system will improve the load capacity of the examined piping system. However, this requires the actual elastic plastic material behaviour to be considered and to take strains into account as a criterion for limiting loads in straight pipes. When defining a limitation of strain on the basis of the stress state which results in limitation of loads, the material behaviour of the used steels should be known.

2.1 Material behaviour of steels with high deformation possibilities used in nuclear power plants

In Figure 1 the engineering stress versus strain curve is in contrast to the true stress versus strain curve. The difference between the curves results from the change in section area values when the tensile probe is loaded. In the engineering stress versus strain curve the cross sectional area change is not considered. Until the strain, where a three-axial stress state is formed, called $\varepsilon_g$, the true stress and strain curve is derived from the engineering curve by the formula [2.1]. The true stress versus strain curve and its derivation from a multiaxial stress state is described in detail in [10]. Figure 2 shows the technical and the true stress versus strain curve of a material called X-6-CrNiNb18-10, table 2. There is a great difference between the two kinds of stresses. The uniform strain $\varepsilon_p$, elongation without necking, of the material shows nearly 50%. The strain $\varepsilon_{limit}$ is 4%. The uniform strain not only depends on the material and temperature but also on the stress state or the absolute dimensions. When $\varepsilon_g$ is reached the probe begins to develop a multiaxial stress state in the necking region. For the present work the stress state in straight pipes under pure bending is important. Therefore the clearance of the stress state in the pipes is required.
\[ \sigma = \sigma_0 \cdot (1 + \varepsilon) \]  

**table 2: Values of tensile test, X-6-CrNiNb18-10**

<table>
<thead>
<tr>
<th>Temp C°</th>
<th>Direction</th>
<th>Sy MPa</th>
<th>Rp1.0 MPa</th>
<th>Rm MPa</th>
<th>E-Modul</th>
<th>A₀ %</th>
<th>Z %</th>
<th>( \varepsilon_g ) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>T</td>
<td>245</td>
<td>277</td>
<td>591</td>
<td>-</td>
<td>63.6</td>
<td>67.1</td>
<td>53.9</td>
</tr>
<tr>
<td>21</td>
<td>T</td>
<td>247</td>
<td>280</td>
<td>587</td>
<td>-</td>
<td>63.5</td>
<td>63.6</td>
<td>52.2</td>
</tr>
<tr>
<td>100</td>
<td>T</td>
<td>224</td>
<td>254</td>
<td>478</td>
<td>194100</td>
<td>46.6</td>
<td>67.7</td>
<td>34.1</td>
</tr>
<tr>
<td>230</td>
<td>T</td>
<td>206</td>
<td>232</td>
<td>417</td>
<td>179400</td>
<td>37.0</td>
<td>63.6</td>
<td>28.7</td>
</tr>
<tr>
<td>230</td>
<td>T</td>
<td>211</td>
<td>239</td>
<td>414</td>
<td>179300</td>
<td>37.4</td>
<td>62.4</td>
<td>27.4</td>
</tr>
<tr>
<td>300</td>
<td>T</td>
<td>202</td>
<td>233</td>
<td>410</td>
<td>179600</td>
<td>36.1</td>
<td>59.9</td>
<td>25.9</td>
</tr>
<tr>
<td>350</td>
<td>T</td>
<td>189</td>
<td>222</td>
<td>413</td>
<td>170300</td>
<td>28.3</td>
<td>50.5</td>
<td>23.8</td>
</tr>
<tr>
<td>350</td>
<td>T</td>
<td>188</td>
<td>219</td>
<td>416</td>
<td>167600</td>
<td>36.1</td>
<td>60.5</td>
<td>26.2</td>
</tr>
<tr>
<td>350</td>
<td>T</td>
<td>189</td>
<td>220</td>
<td>417</td>
<td>174400</td>
<td>35.2</td>
<td>61.2</td>
<td>-</td>
</tr>
</tbody>
</table>

**Figure 1: True and engineering stress versus strain curve, strain until rupture, \( \varepsilon \) is the technical strain, \( \varepsilon^* \) is the true logarithmic strain**
2.2 Multiaxiality of stress, stress state

The multiaxiality of the stress state causes great problems when deriving strain limits. A quantitative value for the consideration of the stress state was invented by the coefficient of multiaxiality of the stress state $q$ of Clausmeyer, [16]. Within $q$ the equivalent von Mises stress $\sigma_{\text{Mises}}$ is opposed to the hydrostatic stress, equation [2.2]. The lower $q$, the higher the multiaxiality of the stress state and the possibility of a spontaneous cleavage fracture is rising, Figure 3.

$$q = \frac{\sigma_{\text{Mises}}}{\sqrt[3]{3\sigma_m}}$$

[2.2]

The parabola of Mohr in Figure 3 shows the development of the stress state and the influence of the deformation on the material. If one of the circles cuts the line $R_e$ which is the real yield stress the material considered will deform irreversibly. If one of the circles cuts through the parable $\tau_0$ a ductile fracture will occur. So $\tau_0$ is the stress if a ductile fracture occurs. If the principle stresses $\sigma_1$ and $\sigma_3$ in Figure 3 are nearly the same and none of the circles cuts through the lines $\tau_{FB}$, they may reach $\sigma_T$ which is the cleavage fracture stress where $q$ is 0.31. A spontaneous cleavage fracture will occur without any plastic deformations. Consequently different stress states have different limit strains.
Figure 3: The envelope of Mohr

Figure 4 shows the stress state for different pipes with different diameters and different diameter ratios. Absolute diameters of 200 mm and 400 mm are examined. The diameter ratio from 1.1 to 1.4. The strain and stress state in the pipes was evaluated under a bending moment resulting in a bending angle up to 30°. In Figure 5 the coefficient of multiaxiality of the stress state q is plotted versus the diameter ratio. $\sigma_m$ is the hydrostatic stress. The calculated stress states q have the advantage of plastic deformations because they reach from 1.0 to 1.8 in Figure 4 and Figure 5. The maximum equivalent strains show values from 4.1% to 4.7%. In Figure 6 normalized stress ratios with isoparametric curves of q are given. $\xi$ is the normalized stress $\sigma_2/\sigma_1$ of the principle stresses $\sigma_1$, $\sigma_2$ and $\sigma_3$. $\eta$ is the normalized stress $\sigma_3/\sigma_1$ where $\sigma_1 > \sigma_2 > \sigma_3$. Along the isoparametric q curves the values of q are constant. The require $dq/d\xi\neq 0$ is met nearly everywhere and it is important for the existence of a unique solution of q. Only the curve $dq/d\xi=0$, the blue line does not result in a uniqueness of the solution for the multiaxiality of the stress state q in the Figure 6. The red line symbolizes the stress state with a high potential of cleavage fracture. If $0<q<0.31$ cleavage fracture occurs. $q<0.31$, will constrain the plastic deformation of the material. Therefore the tendency of deformation possibilities of a steel in the plastic regime can't be taken into account any more. For $q=0$ the hydrostatic stress state occurs. Theoretically, there is no plastic deformation any more. With increasing q, plasticity is increasing. For the uniaxial tension test the coefficient of multiaxiality is 1.73. For more detailed explanations see Roos [17] who provided a general overview on the stress state. The calculated values in Figure 6 give a clear impression of the dominating stress directions of the principle stresses while the isoparametric q curves show high values for the calculated normalized stress states. High values of q are equal to low triaxiality of the stress state.
Concerning the values of the stress states in Figure 4, 5, 6 and 13 of the examined straight pipes, it makes sense to introduce elastic-plastic limit strains into the KTA because there is no danger of a cleavage fracture occurring in straight pipes. However, this depends on the calculated stress state.
which is not given because $q$ is higher than 0.31. The question arises about the values of the strain limits in different loading levels. To answer this question additional parametric studies on straight pipes are performed.

![Diagram showing normalized stress states in straight pipes under pure bending at inner surface of the pipes with $D_a=400$ and $D_a=200$ and $D_a/D_i=1.1..1.4$, bending angle=30°, X-6-CrNiNb18-10, room temperature. Source of methodology, [17]](image)

**Figure 6:** Normalized stress states in straight pipes under pure bending at inner surface of the pipes with $D_a=400$ and $D_a=200$ and $D_a/D_i=1.1..1.4$, bending angle=30°, X-6-CrNiNb18-10, room temperature, source of methodology, [17]

![Diagram showing stresses and stress state in one straight pipe under bending and internal pressure $p_i=10$ MPa along the wall thickness, bending angle=30°, X-6-CrNiNb18-10, room temperature. $\sigma_a$= axial stress, $\sigma_R$= radial stress, $\sigma_u$= hoop stress.](image)

**Figure 7:** Stresses and stress state in one straight pipe under bending and internal pressure $p_i=10$ MPa along the wall thickness, bending angle=30°, X-6-CrNiNb18-10, room temperature, $\sigma_a$= axial stress, $\sigma_R$= radial stress, $\sigma_u$= hoop stress
2.3 Parametric studies on straight pipes under bending

The present FE-calculations are performed on the basis of great deviations with nonlinear material behaviour as shown above in Figure 2. For the present work the ferritic material X-6-CrNiNb18-10 and the austenitic material X-6-CrNiNb18-10 are examined. The ratio of the outer diameter D_a to the length is five. The ratio D_a/D_i ranges from 1.1 to 1.4 with a step width of 0.025 where D_i is the inner diameter. The examined diameters reach from 50 to 400 mm. step width is 25 mm. There is a good agreement shown for the validated calculation when comparing the FE-calculation with the experimental results in Figure 9.

Figure 9: Load versus deflection curve of a pipe with diameters, D_a=331mm, D_i=267mm, and wall thickness s=32mm, maximum bending angle possible=25°

The experimental results shown in Figure 10 are the basis for the performed parametric studies. Once the moment is calculated with equation [1.1], the elastic plastic strains occurring at the outer surface of
a pipe can be derived from the strains calculated in the parametric studies where the maximum strain is expected. Figure 10 also shows the experimental derived load versus strain curve for a straight pipe under pure bending. For the level D in the KTA the allowable stress can be calculated as 480 MPa. The assigned elastic-plastic strain is 2.2%, see Figure 10. The maximum strain measured was 4.2% with a bending angle of 25°. The bending angle was limited by the geometry of the bending machine. It was impossible to reach strains higher than 5% using the bending machine. The experiment leads to the idea of assigning the real elastic-plastic strains to the elastic stresses calculated with the formula [1.1] under bending and internal pressure. The real elastic-plastic strains shall be assigned to the elastic stresses calculated using the formula in [1.1].

\[
\varepsilon_{\text{Mises}} = \frac{1}{\sqrt{2(1+\mu)}} \sqrt{(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_1 - \varepsilon_3)^2 + (\varepsilon_2 - \varepsilon_3)^2}
\]  

[2.3]

In the present work the maximum longitudinal strain for Level D nearly corresponds with the equivalent plastic strain at high strain values Figure 11. To evaluate the elastic-plastic strain at the outer diameter of the calculated pipes, the equivalent plastic strain according to [2.3] is used.

Figure 10: Load versus strain curve of an austenitic pipe with diameter \(D_a=331\, \text{mm}, D_i=267\, \text{mm}, \) \(s=32\, \text{mm}\), experimental result, longitudinal strain, [8]

Figure 11: Load versus strain curve of a pipe with external diameter \(D_a=331\, \text{mm}, D_i=267\, \text{mm}, \) \(s=32\, \text{mm}\)
The parameter fields in Figure 12 are calculated for different outer diameters, different thicknesses of pipes, different materials and different temperatures. One parameter field consists of 195 FE-calculations. The data extracted from the fields are strain, reaction moment and bending angle after completing the FE-calculation. It will be stopped on reaching the required rotation angle given as a boundary condition. It can be seen from the maximum equivalent strains in Figure 12 for the different calculations that highest values are 5% strain for bending angles of 25°. On the basis of the calculated strain values surfaces of the same bending angles were determined. The surfaces are applied to interpolate equivalent strains under a provided moment and diameter ratio.

\[ \varepsilon_{\text{Mi}} \text{ in relation to } \frac{D_a}{D_i} \text{ and } M_{\text{B}} \]

\[ \varepsilon_{\text{Mi}} = f(q, \text{tension probe values}) \]  

\[ \varepsilon_{\text{lim}} = f(q, \text{tension probe values}) \]  

**Figure 12: Strain distribution values of straight pipes with analytically approximated values for austenitic steel X-6 CrNiNb18-10 at room temperature in dependence of the bending angle and the outer and inner diameter**

### 2.4 Different strain limits

The DIN EN 13445 standard describes a maximum allowable structural strain of 5 % for FE-analysis on the basis of an elastic ideally plastic material model for a limit load analysis where the structural strain is the strain in a stress concentration free model. If the yield strength is reduced by a factor of 1.2, the real strain in comparison to the ideally plastic strain nowhere reaches 5 %, however generally the values are much lower. The TRD, [9], technical rules for steam piping, suggests a limit strain for primary stresses of 0.2%. In KTA 3201.2 the limit for ratcheting -proceeding deformation despite constant stress amplitude- is 5% for base material and 2.5% for the weld. Measurements performed at the hot steam reactor, HDR, [11], showed maximum measured strains for blow down conditions of 2%. The examined material was a ferritic steel. In [12] Diem examined different pipe bends of austenitic and ferritic steels. The maximum measured strains are contrary to the maximum loads. For ferritic steels the minimum strain for critical moments was measured 2%, for austenitic steels 4%. In [13] limit strains of 20% are determined for a not notched nuclear vessel material for primary stresses. In [14] the proposal for limit strains was 2% for level D for ferritic steels. In [15] the plastic strains in a pipe system under different loading conditions were examined. The maximum equivalent strains were 1.25%. The examples for different strains show that there is a certain experimental experience considering strain limits. But a limit strain should only be applied depending on the stress state because the stress state is responsible for the deformation possibilities of materials with high ductile characteristics.
The problem with limit strains is the multiaxiality of the stresses, as shown above in Figure 3. However, as shown in Figures 4, 5, 6, 7, the stress states in straight pipes under pure bending guarantee the possibility for plastic deformation when the considered material shows ductile behavior. In the KTA the ductility and hence the possibility of a material to deform irreversible is guaranteed with the values of the notch bar impact required after the RSK-LL, [18]. For the base material the values in the upper shelf of the notch bar impact energy must be at least 100 J for ferritic and austenitic steels or higher.

2.5 Comparison between different limitation procedures used for limitation of admissible loads in piping systems

The piping system in Figure 13 is used for the examination of elastic-plastic strains in a real geometry. Herein the boundary conditions, the loads and the different used materials are shown. The red area is X-6-CrNiNb18-10, the yellow area is a 20MnMoNi5-5, the blue area represents the weld with NiCr70Nb. Room temperature is assumed. The internal pressure of the piping system is 23.1 MPa. The external force is 400kN for all FE-calculation. The model is build up with three dimensional elements. Four over the thickness of the wall of the piping system. The pressurizer connection and the thermo sleeve were modelled as exact as possible.

The reaction moments and the strains are evaluated at the cross sections shown in Figure 14 on the right side. The definition of integral plastic strains is shown on the left side of Figure 14. Integral plastic strains are middle equivalent strains over the whole cross section area.

![Examined pipe system](image-url)
Proceedings of the International Youth Nuclear Congress 2008

In Figure 15 the reaction moment on the load in the piping system is shown along the piping system. Two different material models are considered. One material model is derived from the actual elastic-plastic material behaviour, the other is elastic. The difference between the elastic and elastic-plastic reaction of the piping system is a factor of two. The reaction moment on the assumption that a solely elastic material model is provoked to reach over normal stress limits for comparing the reaction moment using an elastic plastic material model. Using the limitation of stress, the load is not allowed. The elastic plastic reaction moment stops around the technical fracture strength. The differences result in higher strains using an elastic plastic material model. There are big differences in strain. The strain under solely elastic reaction of the piping system leads to strains which are very small. Figure 16 shows the maximum local strains and the maximum integral strains which are the equivalent strains middled over the cross sectional area along the pipe system using the actual elastic plastic material characteristics. Carrying the same load the elastic plastic reaction of the system leads to local equivalent plastic strains around 1.4%. The averaged plastic strains are even lower. The positions 1, 2 and 3 in Figure 16 are the locations where high strains are calculated. In Figure 17 the values of the coefficient of multiaxiality of the stress state versus the normalized wall thickness at the positions of the highest strains calculated are shown in Figure 16. In all cases the q value is higher than 1 and therefore plastification is not restricted. This means, there will be no risk of cleavage fracture. However due to the reduced triaxiality of the stress state, plastic deformation could occur which results in a stress redistribution and in decreased stresses. Under these conditions a strain limit for equivalent plastic...
Figure 15: Comparison of reaction moments using an elastic and an elastic-plastic material model

Figure 16: Comparison of maximum and integral equivalent plastic strains at the cross sections along the piping system using an elastic-plastic material model
strain of 4% for the level D has been suggested as a conservative value proposal for a strain limit.

2.6 Conclusions

For steels with high deformation possibilities like the austenitic material X-6-CrNiNb18-10 demonstrated with high notch bar impact energy values in [18] and with the stress states in straight piping components under bending moment and internal pressure a strain limit for level D of 4% is proposed. This was verified with the coefficient of multiaxiality q.

The parametric studies performed at straight pipes with FE-calculations on the basis of the material X-6-CrNiNb18-10 can be used to assign elastic plastic strains to analytical calculated stresses on the basis of a linear elastic material behaviour. With the so defined allowable elastic plastic strains the admissible loads can be estimated. It helps to reduce the conservatism in the analysis, without any loss of safety in the piping system.
3 LITERATURE

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