SAUL Program for On-Line Analysis of Stresses and Fatigue on Structures

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1. **INTRODUCTION**

Monitoring of the stress situation in the piping of a nuclear power reactor is obviously a relevant and important factor in assessing the safety of the plant, in particular from the usage factor point of view. Direct measurements of the stresses by means of strain gages is possible but has obvious disadvantages; a simpler approach has been followed in this case. The data acquisition relays basically on the variables that the supervision system of the station is acquiring for monitoring and control; the data acquired in this way are the basis for the evaluation of the usage factor in the piping. Hence basically the following steps are followed:

a) identification of the critical points in piping
b) data acquisition
c) correlation between acquired data and stress
d) fatigue analysis and computation of the usage factor

2. **IDENTIFICATION OF THE CRITICAL POINTS**

All the piping in a power station are carefully and completely stress analyzed prior to commissioning; the stress report is generally then the main source for the evaluation of the critical points. Different criteria can be followed, as an example all the points where the usage factor is larger than a given amount (say 0.05) or the ten, twenty (or any other number) most stressed points. A careful examination of the stress is useful to identify the variables which are important for an effective stress usage control; they generally are pressure, temperature, position of a given set of values.

As an example a careful examination of the stress report in a nuclear power station produced the following list:
TABLE 2.1

Identification of critical points (ref. ASME 3 NB)

<table>
<thead>
<tr>
<th>Line</th>
<th>Point Criteria</th>
<th>Value</th>
<th>Allowable</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>FW B</td>
<td>Anchor 1</td>
<td>104.1</td>
<td>53.1</td>
<td>Usage factor</td>
</tr>
<tr>
<td></td>
<td>Elbow 190</td>
<td>131.</td>
<td>53.1</td>
<td>.23</td>
</tr>
<tr>
<td>FW A</td>
<td>Branch</td>
<td>109.</td>
<td>53.1</td>
<td>.89</td>
</tr>
<tr>
<td></td>
<td>Tee</td>
<td>122</td>
<td>53.1</td>
<td>.89</td>
</tr>
</tbody>
</table>

It can be seen than in generale the identified points are the ones where analysis has shown the inability to achieve shakedown, and the simplified elastoplastic method was followed.

3. DATA ACQUISITION

The variables to be taken are thermodynamic properties pressure p, temperature T and the position of a set of valves, as resulting from the analysis in paragrath 2. In general they can be taken from the present instrumentation in the reactor, even if some additions can be necessary particularly in the case of old plants. The data acquisition details depend on the type of plant and can be either tapping of the signal from the panels (serial) or direct acquisition from the computerized monitoring system. In any case it can be assumed that a tape can be made available listing the main variables recorded at different times (0.1 sec. acquisition):

\[ V_i (t_j) \] 

The data acquisition does not take into consideration fast variables such as rapid stress variation due to safety discharge in a boiling water or seismic variables. Their influence will be discussed later on.

4. STRESS CORRELATION

Suppose that all the data have been acquired, then the following steps are followed:

a) data processing in order to eliminated all the data corresponding to a stationary situation (Δ processing)

b) reducing the data to a set of ramps (linear changes) of the fluid temperature

c) elimination of the small (negligible) ramps

d) grouping of the ramps in a discrete series, characterized by similar (within = 10%) time gradients and maximum temperatures

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In this way all the data are reduced to a series of similar ramps, each one characterized by its number of events. Standard methods are then used to compute the three main variables temperature:

\[ \Delta T_m, \Delta T_1, \Delta T_2 \quad (\text{ASME 3 variables}) \]

to the main parameter \( F_0 \):

\[ F_0 = a \cdot \frac{\Delta T_f}{t^2} + C \quad (1) \]

- \( T_m \): change in main temperature of the metal
- \( T_1, T_2 \): primary and secondary gradient in the thickness
- \( a \): diffusivity
- \( C \): rate of change of fluid temperature
- \( \Delta T_f \): total change in fluid temperature

Suppose now that the design analysis is reconsidered then the generalized stress \( S_i \) is correlated to the field variables (pressure, temperature) by means of a correlation of the type:

\[ S_i = \sum_j m_j \cdot f_{ij} (a_j) \quad (2) \]

- \( S_i \): \( i \)th component of the stress
- \( m_j \): known multiplier factor
- \( f_{ij} \): known function
- \( a_j \): field variable

Note that once the field variable are acquired then the problem is exactly the same as the one found in the design phase and consequently can be solved in the same way. Basically (2) correlation is stored in the computer using the methods and data in the design phase. As an example the main stress is:

\[ S_n = C_1 \times \frac{P o D_0}{2t} + C_2 \frac{D_0}{2I} + C_3 \frac{E}{E_{a b}} \left[ a_{Ta} - a_{Tb} \right] \quad (3) \]

- \( C_i \): stress concentration factor
- \( D_i, t, I \): diameter, thickness and inertia moment
- \( E_{a b} \): Young modulus
- \( a_{Ta}, a_{Tb} \): dilatation coefficient

Let

\[
\begin{align*}
& m_1 = C_1 \times \frac{D_0}{2t} \\
& m_2 = C_2 \times \frac{D_0}{2I} \\
& m_3 = C_3 E_{a b} a \\
& m_4 = C_4 E_{a b} b
\end{align*}
\]
then let

\[ M_i = \beta_1 \cdot T_i + \beta_2 \cdot D_5 + \beta_3 \]
\[ T_a = \beta_4 \cdot T_i + \beta_5 \cdot T_j \]
\[ T_b = \beta_6 \cdot T_i + \beta_7 \cdot T_j \]

where all the \( m_i, \beta_i \) factors are known and stored in the computer manually, then (3) reduces to:

\[ S_n = m_1 \cdot p + m_2 \cdot T_i + m_3 \cdot T_j \]  
\[(3')\]

5. MECHANICAL TRANSIENTS

Stresses may arise as a consequence of mechanical transients either due to upset conditions (e.g. opening of safety valves) or due to accident conditions (e.g. seismic); the thermodynamic evaluations is not sufficient for and evaluation of the mechanical transient stresses. The code associates the presence of a mechanical transient to an on/off signal (e.g. the opening of a safety relief valve); then the mechanical stresses are added as resulting from the data stored in the computer memory and corresponding to this event. In turn these data are relative to the ones computed during the design phase. Consequently the mechanical transients are evaluated on the basis of the design calculated ones.

6. CONCLUSIONS

The basic characteristics of SAUL code have been described, typical outputs are shown.