History of WRC 107

Using WRC 107 and NozzlePRO FEA

Presented by: Ray Delaforce
History of WRC 107

Example of membrane stress in a cylinder subject to internal pressure
- ASME Section VIII, Division 1
- ASME Section VIII, Division 2
- PD 5500 (British Code)
- EN 13445 (European Code)
- AD 2000 (Merkblatter) (German Code)
- CODAP (French Code)

They mainly concentrated on primary membrane stresses (more later)
These stresses had to be below the yield stress of the metal
The strain is not to exceed about 0.2%

\[
\sigma - \epsilon
\]

\[\sigma \text{ Yield} \]

Within this region

\[0.2\% \quad \varepsilon\]
History of WRC 107

Stress analysis is really required in a cylinder subject to internal pressure. The code allowable stress is about here, below yield. In the case of nozzles subject to external loads, the stresses can be here. That is beyond the scope of the codes. Strains go beyond 0.2%.
History of WRC 107
Stress analysis is really required
WRC107 was published for this purpose
WRC107 offered a graphical method of doing the stress analysis
Here is a typical graph:
Many of the graphs are difficult to read - more of that later
WRC107 first published in 1965
History of WRC107 principles of stress analysis

Stress analysis is really required

WRC107 was published for this purpose

WRC107 offered a graphical method of doing the stress analysis

Here is a typical graph:

Many of the graphs are difficult to read – more of that later

WRC107 first published in 1965

- Revised 1968
- Revised 1970
- Revised 1972
- Revised 1979

Based upon the theoretical work of Prof. Biljaard of Cornell University

Attachments (nozzles) on cylinders and spheres only can be analysed

There are also geometric limitations

Using WRC 107 is very tedious and time consuming

PV Elite and CodeCalc make this analysis simple and fast
Let us look at some principles of stress analysis.

Suppose we have a bar subjected to tensile stress by this arrangement:

Once the stress passes yield, it continues to stretch until collapse occurs.

So, we could re-label the strain axis as time to collapse.

This shows we must under normal conditions stay below yield.
Let us look at some principles of stress analysis.

Suppose the force were delivered by this arrangement.

If the weight were heavy enough – fracture would occur.

The stress is directly proportional to the load.

\[ \sigma = \frac{\text{force}}{\text{area}} \]  

thus stress is directly related to the load (force).

![Diagram showing stress over time](image)
Let us look at some principles of stress analysis.

Suppose there is a weight directly related to the load (force)

By definition this is a Primary Stress

- The Internal stress is directly related to the external load
- Fracture will occur as the stress increases beyond yield

The stress also exist Everywhere in the bar - membrane stress

- Everywhere designates the stress as a General Stress
- Therefore we have a General Primary Membrane stress
Let us look at some principles of stress analysis.

Suppose weight is NOT related to the stress, but to the movement.

The weight can only descend so far.

The stress is now controlled by movement.

Stress does not reach fracture, because movement is limited.

The weight is NOT related to the stress. Only to the movement.
Let us look at some principles of stress analysis.

Now, consider a Cantilever subject to un-restricted force. The weight is NOT related to the stress. Only the movement is.

This is known as **Secondary Stress**:
- Controlled by movement of another element
- Internal stress **not related** to the force in the other component
- Also called strain related

\[
\sigma
\]

Yield

0,2%  TIME
Let us look at some principles of stress analysis

We again consider the motion of a beam subject to an un-restricted force.

There is an internal bending stress in the beam.

This bending stress can exist everywhere at this location.

This stress has the following characteristics:

- The internal stress is directly related to the load - **Primary**
- It exists Everywhere - **General**

This is a **General Primary Bending stress**.
Let us look at some principles of stress analysis.

We again restrict the motion of the weight.

The bending stress is NOT directly related to the load (weight).

The bending strain is restricted, and does not proceed to fracture.

It is strain controlled, and not load controlled.

We have a **Secondary** bending stress.
Let us look at some principles of stress analysis

Now look at this arrangement so far:

The rod is heated, so it expands

Again the stress is controlled by the strain

This is also a Secondary stress - also called an Expansion stress
Let us look at some principles of stress analysis

Consider what you have been subjected to an external moment

<table>
<thead>
<tr>
<th>Primary stress</th>
<th>Secondary stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directly related to the imposed load: eg ( \sigma = \frac{F}{A} )</td>
<td>Relate to the strain induced in the component - strain controlled</td>
</tr>
<tr>
<td>If the load is great, failure can occur</td>
<td>The strain is restricted so failure does not occur</td>
</tr>
<tr>
<td></td>
<td>Often from expansion of another component - example, thermal expansion</td>
</tr>
</tbody>
</table>

There is one more stress category we have dealt with
Let us look at some principles of stress analysis.
Consider a nozzle in a shell subject to an external moment.
The shell deforms to accommodate the moment like this.
Notice how it pulls the shell to the left, giving rise to a membrane stress.
This stress fades away rapidly from the nozzle to shell junction.

The bending stress is ignored for the moment.
Let us look at some principles of stress analysis

Consider a nozzle in a shell subject to an external moment. The shell deforms to accommodate the moment like this. Notice how it pulls the shell to the left, giving rise to a membrane stress. This stress *fades away* rapidly from the nozzle to shell junction. That stress does *not* exist everywhere, therefore it is *LOCAL*.

This is a *Local Primary Membrane stress*.

*The bending stress is treated as *Secondary stress*.*
Let us look at some principles of stress analysis

Summing what we have learned so far:

ASME Section VIII, Division 2 gives them symbols

These stresses can exist in combination

<table>
<thead>
<tr>
<th>Stress type</th>
<th>Symbol</th>
<th>Allowable stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Primary Membrane</td>
<td>$P_m$</td>
<td>$S$</td>
</tr>
<tr>
<td>Local Primary Membrane</td>
<td>$P_L$</td>
<td>1.5$S$</td>
</tr>
<tr>
<td>Primary Bending</td>
<td>$P_b$</td>
<td>1.5$S$</td>
</tr>
<tr>
<td>Secondary:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Local Membrane</td>
<td>$Q$</td>
<td>3$S$ or 2$S_y$</td>
</tr>
<tr>
<td>- Local Bending</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Let us look at some principles of stress analysis

Summarizing what we have learned so far:

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<td>Primary</td>
<td>$P_m$</td>
<td>$S$</td>
</tr>
<tr>
<td>Primary + Local</td>
<td>$P_m + P_L$</td>
<td>$1.5S$</td>
</tr>
<tr>
<td>Primary + Local</td>
<td>$P_m + P_L + P_B$</td>
<td>$1.5S$</td>
</tr>
<tr>
<td>Primary + Local + Secondary</td>
<td>$P_m + P_L + P_B + Q$</td>
<td>$3S$ of $2S_y$</td>
</tr>
</tbody>
</table>

This is the ‘Hopper’ diagram from ASME Section VIII, Division 2.
Let us look at some principles of stress analysis.

This is the ‘Hopper’ diagram from ASME Section VIII, Division 2.

<table>
<thead>
<tr>
<th>Stress Category</th>
<th>General Membrane</th>
<th>Local Membrane</th>
<th>Bending</th>
<th>Secondary Membrane plus Bending</th>
<th>Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Average primary</td>
<td>Average stress</td>
<td>Component of primary stress proportional to distance from centroid of solid section. Excludes discontinuities and concentrations.</td>
<td>Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at structural discontinuities. Can be caused by mechanical load or by differential thermal expansion. Excludes local stress concentrations.</td>
<td>1. Increment added to primary or secondary stress by a concentration (notch). 2. Certain thermal stresses which may cause fatigue but not distortion of vessel shape.</td>
</tr>
<tr>
<td>(For examples, see Table 5.2)</td>
<td>stress across solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.</td>
<td>stress across any solid section. Considers discontinuities but not concentrations. Produced only by mechanical loads.</td>
<td>Component of primary stress proportional to distance from centroid of solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Symbol: \( P_m \), \( P_L \), \( P_b \), \( Q \), \( F \)
Nozzle removed - here is the hole

Labeling convention

U = upper surface (outside)
L = lower surface (inside)
Type of Loading for Stress Analysis

Sustained load
- Loads that are there for long periods
- Pressure
- Weight (on an attachments)

Occasional
- Loads that are momentary (lasting a short time)
- Wind loading
- Seismic loading
- Because they are short lived - add 20% to allowable stress

Expansion
- Strain controlled
- From thermal expansion of piping
- Always Secondary Stresses

Operating loads
- These are commonly Sustained + Thermal (eg: CAESAR II)
WRC 107 Demonstration (First)

Here are the regions around the nozzle

### Stresses in the Vessel at the Attachment Junction

<table>
<thead>
<tr>
<th>Type of Stress Load</th>
<th>Stress Values at (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Au</td>
</tr>
<tr>
<td>Circ. Memb. MC</td>
<td>0</td>
</tr>
<tr>
<td>Circ. Bend. MC</td>
<td>0</td>
</tr>
<tr>
<td>Circ. Memb. ML</td>
<td>-23</td>
</tr>
<tr>
<td>Circ. Bend. ML</td>
<td>-46</td>
</tr>
</tbody>
</table>

Here are the final stress final stress Categories

<table>
<thead>
<tr>
<th>Type of Stress Int.</th>
<th>Max. S.I. (MPa)</th>
<th>S.I. Allowable</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pm (SUS)</td>
<td>94.38</td>
<td>137.97 S</td>
<td>Passed</td>
</tr>
<tr>
<td>Pm (SUS+OCC)</td>
<td>94.38</td>
<td>165.56 1,2S</td>
<td>Passed</td>
</tr>
<tr>
<td>Pm+Pl (SUS)</td>
<td>93.82</td>
<td>206.95 1,5S</td>
<td>Passed</td>
</tr>
<tr>
<td>Pm+Pl (SUS+OCC)</td>
<td>84.03</td>
<td>248.34 1,8S</td>
<td>Passed</td>
</tr>
<tr>
<td>Pm+Pl+Q (TOTAL)</td>
<td>349.95</td>
<td>413.91 3S</td>
<td>Passed</td>
</tr>
</tbody>
</table>

1,8=1,2 x 1,5
Thrust $F = P\pi d_o^2/4$, this can be added in PV Elite (Demo)
There is a stress concentration at the Nozzle to Shell junction. The stress increases at the junction like this:

\[ S_A \text{ is the average stress, } S_C \text{ is the increases stress} \]

\[ \frac{S_C}{S_A} \text{ is known as the stress concentration factor (scf)} \]

It is usually about 3.

ASME VIII, Division 2 calls the scf by the name of Pressure Index.
It now **FAILS**, we can fix the problem by adding a re-pad (Demo)

<table>
<thead>
<tr>
<th>Type of Stress Int.</th>
<th>Max. S.I.</th>
<th>S.I. Allowable</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_m$ (SUS)</td>
<td>301.89</td>
<td>137.97</td>
<td>Failed</td>
</tr>
<tr>
<td>$P_m$ (SUS+OCC)</td>
<td>301.89</td>
<td>165.56</td>
<td>Failed</td>
</tr>
<tr>
<td>$P_m+P_l$ (SUS)</td>
<td>326.16</td>
<td>206.95</td>
<td>Failed</td>
</tr>
<tr>
<td>$P_m+P_l$ (SUS+OCC)</td>
<td>318.45</td>
<td>248.34</td>
<td>Failed</td>
</tr>
<tr>
<td>$P_m+P_l+Q$ (TOTAL)</td>
<td>348.96</td>
<td>413.91</td>
<td>Passed</td>
</tr>
</tbody>
</table>
We now have two analyses for the WRC107 deficiencies:

### Nozzle junction

<table>
<thead>
<tr>
<th>Type of Stress Int.</th>
<th>Max. S.I. MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pm (SUS)</td>
<td>151.90</td>
</tr>
<tr>
<td>Pm (SUS+OCC)</td>
<td>151.90</td>
</tr>
<tr>
<td>Pm+P1 (SUS)</td>
<td>155.85</td>
</tr>
<tr>
<td>Pm+P1 (SUS+OCC)</td>
<td>155.55</td>
</tr>
<tr>
<td>Pm+P1+Q (TOTAL)</td>
<td>171.23</td>
</tr>
</tbody>
</table>

### Edge of the pad

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<td>94.38</td>
</tr>
<tr>
<td>Pm (SUS+OCC)</td>
<td>94.38</td>
</tr>
<tr>
<td>Pm+P1 (SUS)</td>
<td>111.59</td>
</tr>
<tr>
<td>Pm+P1 (SUS+OCC)</td>
<td>104.08</td>
</tr>
<tr>
<td>Pm+P1+Q (TOTAL)</td>
<td>168.28</td>
</tr>
</tbody>
</table>
It only considers 4 points around the nozzle

The method is only an approximation

We need better tools to get a better answer

The answer if FEA!
Now we set the same nozzle up in CodeCalc (Demo)
What is a direction cosine?

Setting the nozzle-vessel in Global Units

Radial force \( P \) is in the +X direction
Longitudinal force \( V_L \) is in the -Y direction from B to A
Circumferential force \( V_C \) is in the +Z direction from D to C

We need to know the Orientation of the Nozzle and the Vessel

+X and +Y are known as Direction Cosines

We need to understand Direction Cosines
What is a direction cosine?

These angles define the direction of a vector in a system.

The axes can be thought of as the corners of a box.

Label the 3 directions by the letters $x$, $y$, and $z$.

A vector can be represented by an arrow from the origin.

The vector can be represented by $\mathbf{r}$, defines magnitude & direction.

The magnitude (length) is defined as $|\mathbf{r}|$, or simply $r$. 
What is a direction cosine?

Let the direction cosines of the vector represented by $V_x$, $V_y$ and $V_z$ be defined.

Now, put in the distances along the axes of the vector.

The direction cosine of $y$ is defined as $\cos(\varphi_y) = \frac{a_y}{r}$.

Similarly $\cos(\varphi_x) = \frac{a_x}{r}$, and $\cos(\varphi_z) = \frac{a_z}{r}$.
What is a direction cosine?

Let the direction cosines be represented by \( V_x \), \( V_y \) and \( V_z \)

Then \( V_x = \cos(\Phi_x) \), \( V_y = \cos(\Phi_y) \) and \( V_z = \cos(\Phi_z) \)

Now, if \( V_y = 1 \), it follows that \( \Phi_y = 0^\circ \) because \( \cos(0^\circ) = 1 \)

But, if \( V_x = 0 \), and \( V_z = 0 \), then \( \Phi_x = 90^\circ \) and \( \Phi_z = 90^\circ \)

The vector would then point in the direction of \(+y\)
What is a direction cosine?

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Then $V_x = \cos(\Phi_x)$, $V_y = \cos(\Phi_y)$ and $V_z = \cos(\Phi_z)$

If $V_x = 0$, $V_y = 0$ and $V_z = 0$, the vector would point along $x$ axis.
What is a direction cosine?

Let the direction cosines be represented by $V_x$, $V_y$ and $V_z$

$$\phi_x = 90^\circ$$

Then $V_x = \cos(\phi_x)$, $V_y = \cos(\phi_y)$ and $V_z = \cos(\phi_z)$

If $V_x = 0$, $V_y = 0$ and $V_z = 1$, the vector would point along the $z$ axis.
What is a direction cosine?

We just set the **direction cosine to 1** for the particular direction.

Thank you for watching are there any questions?