

## FE-107 Experimental Validation

Has your finite element analysis (FEA) software been validated against real-world pressure vessel problems? FE-107 and other PRG software are continuously validated against actual problems faced by practicing engineers. Follow this link for to learn more about an experimental validation of the FE-107 solutions and see how WRC 107 fails to predict accurate stresses in a real world application.

### *Real-world validation of PVP Designs*

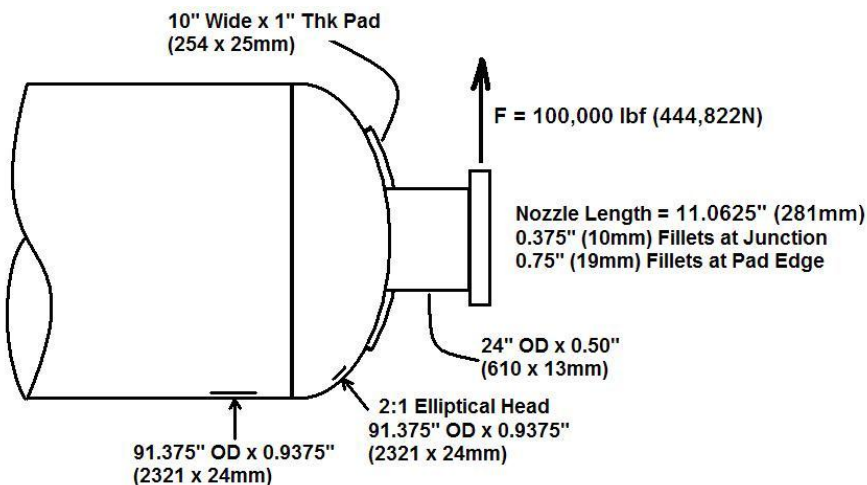
Validation comes in two forms: numerical validations and real-world validations. All FEA programs are numerically validated...few are validated against problems you face everyday in the pressure vessel and piping industry.

An external load was applied to the nozzle located in an elliptical head as shown below. Strain gauges were placed on the head adjacent to the pad and in the nozzle neck to validate the finite element solution.



*Details of the Experiment*

The horizontal vessel was lifted from the bolted cover, resulting in a load of 20,000 lbf. Details of the pressure vessel and nozzle are given below.

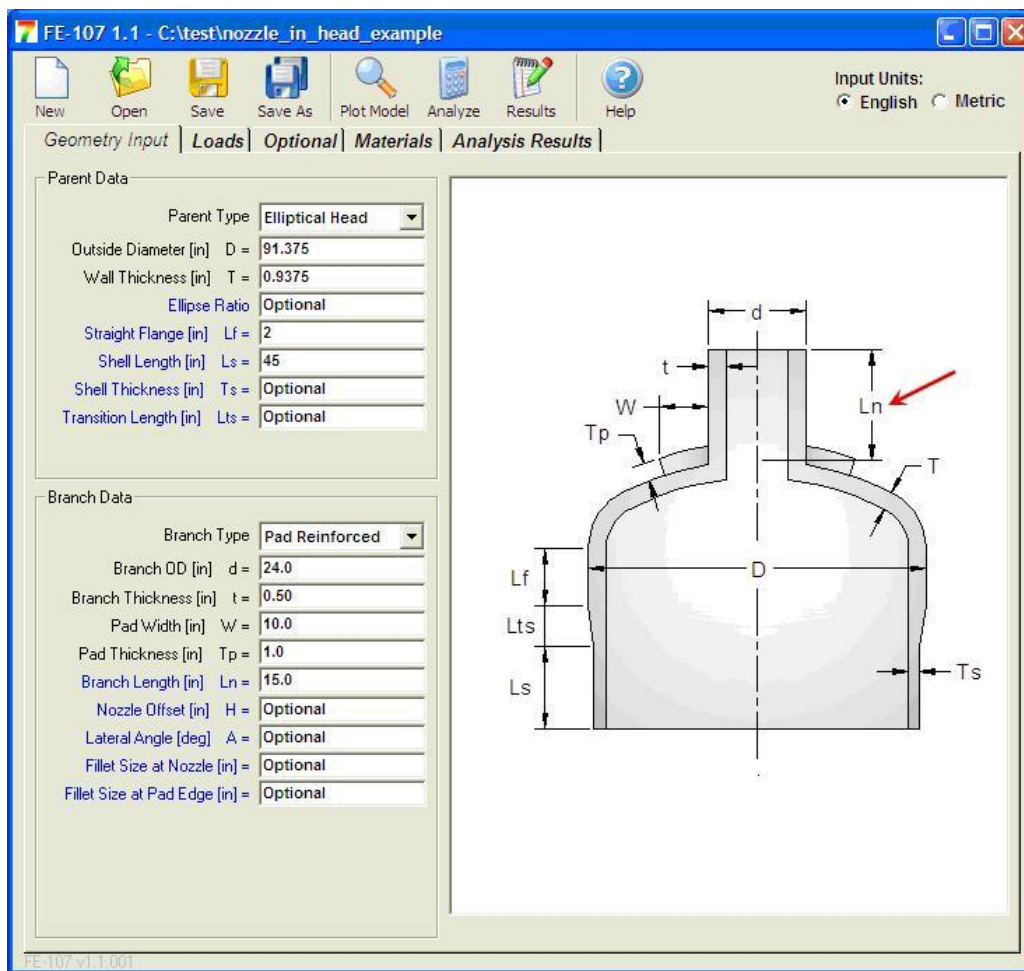


The next step is to input the model in the FE-107 input screens.

### FE-107 Input

FE-107's input is specifically designed to make the design and analysis of typical pressure vessel and piping (PVP) geometries with nozzle very easy. Unlike general FEA programs that require the user to create models from scratch, FE-107 creates the model for you using input that is familiar to all PVP engineers.

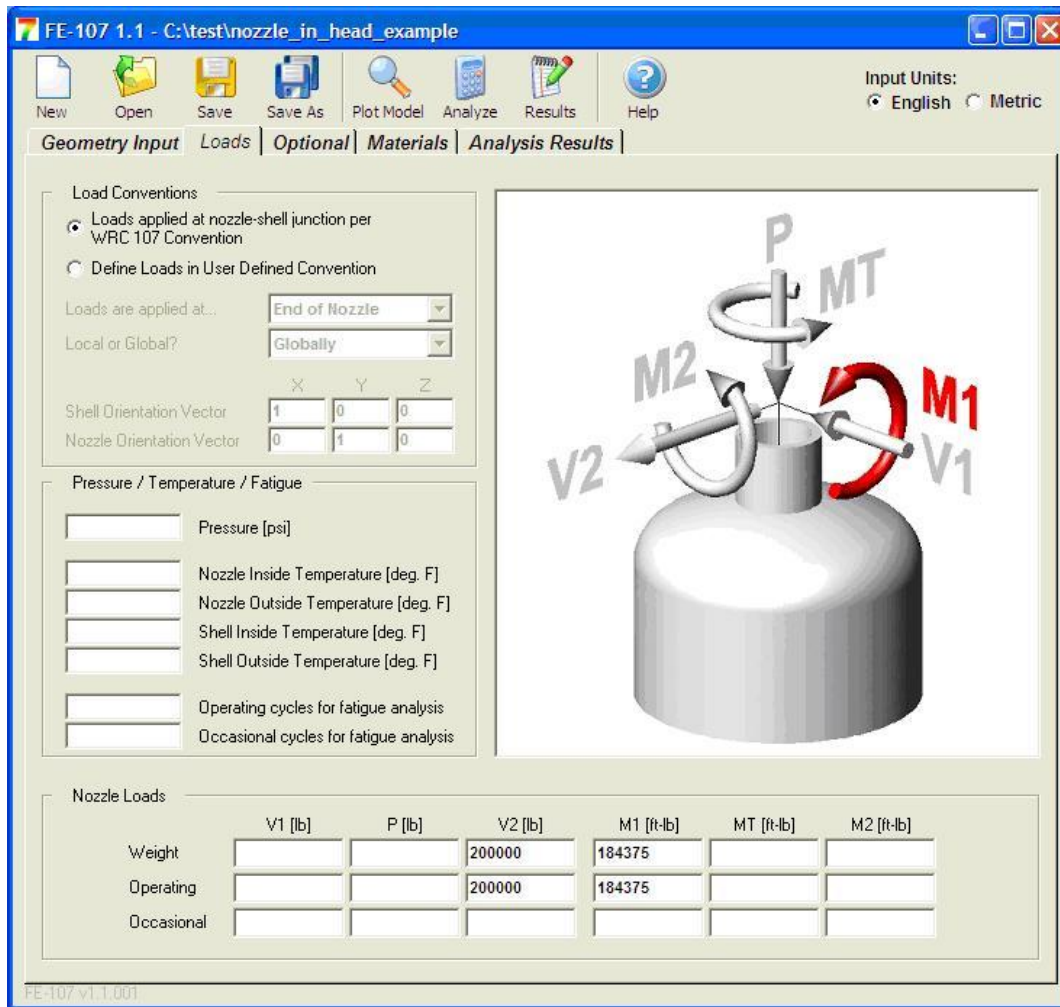
In this case, the geometry can be defined using just 11 input fields as shown below. The required input accompanied by a drawing for each type of model available in FE-107. This makes it very easy to understand the input.



Next, the orientation and loads are defined. FE-107 can accommodate any orientation of the head and nozzle.

Some other features:

1. Loads can be specified using WRC conventions or in a user defined convention.
2. Loads can be defined at the centerline, nozzle-shell junction, or end of the nozzle.
3. Input for weight, operating, and occasional loads.
4. Specify the number of fatigue cycles for an automatic fatigue analysis of external loads and pressure.



### Run the Analysis

To start the analysis, the user clicks the "Run" icon located on the FE-107 toolbar. FE-107 will automatically construct the model, apply the loads, and boundary conditions based on the user's input. You don't need to be an FEA expert to use FE-107.

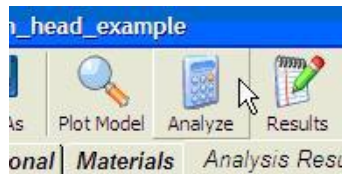
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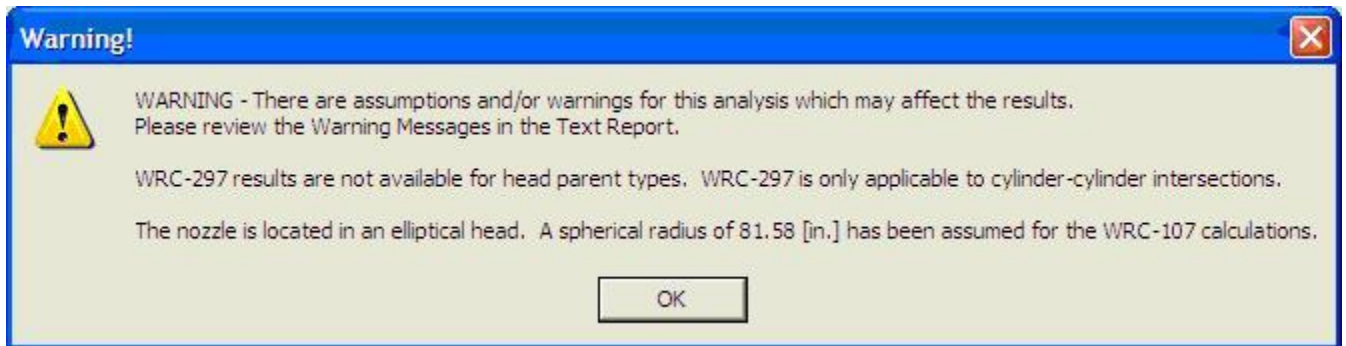
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**Experimental Validation shows that FE-107 Provides More Accurate Results than WRC-107**



During the analysis, FE-107 will give the user useful information and provide alerts when assumptions must be made. In this case, neither WRC-107 nor WRC-297 methods are ideally suited for the analysis since the nozzle is located in an elliptical head.



## Analysis Results – WRC 107 FAILS

The following are the comparative results between the experimental stresses, FE-107's FEA solution, and the WRC-107 & WRC-297 comparisons.

As shown below, FE-107 predicts conservative and accurate stresses in all cases.

WRC-107 fails the validation by significantly over predicting the stresses in the pad and not providing any stress calculation for the highest stresses which occur in the nozzle neck. This clearly shows why the WRC methods are not adequate for PVP designs.

Can you afford to miss the highest stress by a factor of 4.0 using outdated analysis methods?

Location	Strain Gage Results	FEA Results	WRC-107	WRC-297
Shell near pad weld	7000 psi (48 MPa)	6350 psi (44 MPa)	32140 psi (109 MPa)	Not applicable
Pad near nozzle weld	23440 psi (162 MPa)	20240 psi (140 MPa)	31882 psi (109 MPa)	Not applicable
Nozzle neck near nozzle weld	51500 psi (355 MPa)	64750 psi (446 MPa)	Not available	Not applicable

## FE-107 Output

The FE-107 results are presented in an easy to use interface and include ASME Code compliance reporting.

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Some features of the FE-107 output:

1. Finite element results are given in three easy to use formats (spreadsheets, printable reports, 3D interactive graphics)
2. Automatic ASME stress classification – no other FEA software offers this for shell elements.
3. Automatic ASME Code compliance reports
4. Comparisons against WRC-107 and WRC-297 methods

	Location	ASME Category	Stress	Allowable Stress	% Allowed	3D Plot
1	Elliptical Head	PI+Pb < 1.5(k)Smh [Pb=0]	7,174.08	30,000.0	24	Plot...
2	Nozzle 1 Next to Shell	PI+Pb < 1.5(k)Smh [Pb=0]	29,332.31	30,000.0	98	Plot...
3	Nozzle 1	PI+Pb < 1.5(k)Smh [Pb=0]	22,022.19	30,000.0	73	Plot...
4	Shell Next to Nozzle 1 Pad	PI+Pb < 1.5(k)Smh [Pb=0]	7,157.34	30,000.0	24	Plot...
5	Shell In Nozzle 1 Vicinity	PI+Pb < 1.5(k)Smh [Pb=0]	7,174.08	30,000.0	24	Plot...
6	Pad Next to Nozzle 1	PI+Pb < 1.5(k)Smh [Pb=0]	8,250.87	30,000.0	28	Plot...
7	Nozzle 1 Pad Weld Area	PI+Pb < 1.5(k)Smh [Pb=0]	3,552.29	30,000.0	12	Plot...
8	Parent Base SCR	PI+Pb < 1.5(k)Smh [Pb=0]	3,031.47	30,000.0	10	Plot...
9						
10	Elliptical Head	PI+Pb+Q < 3(k)Smavg	9,807.38	60,000.0	16	Plot...
11	Nozzle 1 Next to Shell	PI+Pb+Q < 3(k)Smavg	80,340.73	60,000.0	134	Plot...
12	Nozzle 1	PI+Pb+Q < 3(k)Smavg	24,120.99	60,000.0	40	Plot...
13	Shell Next to Nozzle 1 Pad	PI+Pb+Q < 3(k)Smavg	9,849.95	60,000.0	16	Plot...
14	Shell In Nozzle 1 Vicinity	PI+Pb+Q < 3(k)Smavg	9,978.12	60,000.0	17	Plot...
15	Pad Next to Nozzle 1	PI+Pb+Q < 3(k)Smavg	21,121.74	60,000.0	35	Plot...
16	Nozzle 1 Pad Weld Area	PI+Pb+Q < 3(k)Smavg	9,569.39	60,000.0	16	Plot...
17	Parent Base SCR	PI+Pb+Q < 3(k)Smavg	3,182.25	60,000.0	5	Plot...
18						
19						
20						
21						
22						

More FE-107 Output Screens

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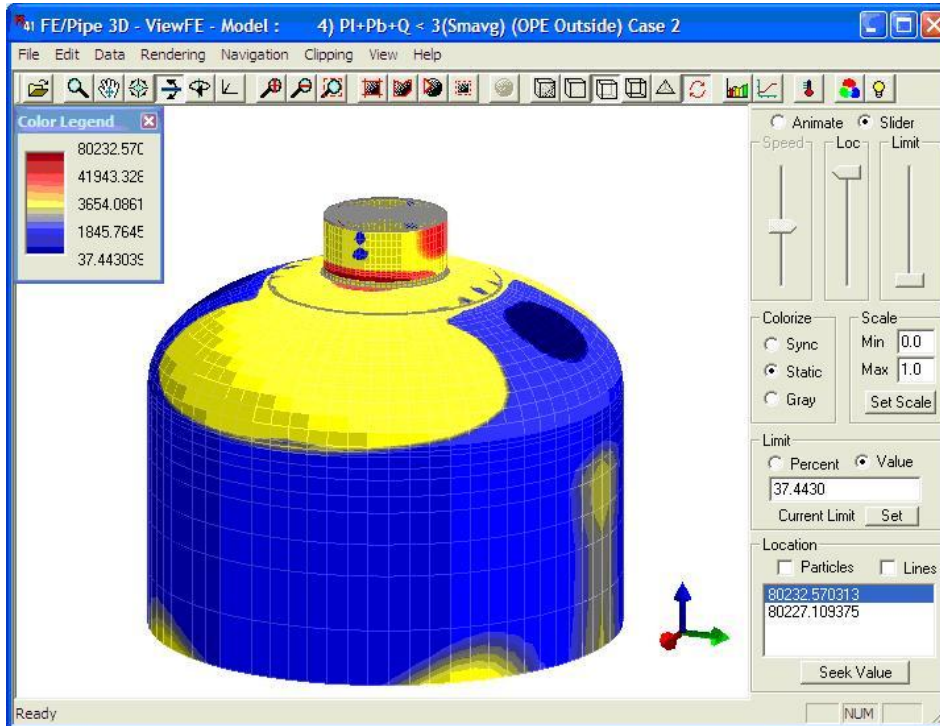
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Phone: 281.920.9775

Website: www.paulin.com

**Experimental Validation shows that FE-107 Provides More Accurate Results than WRC-107**

Interactive 3-D graphical results for evaluating results.



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**Experimental Validation shows that FE-107 Provides More Accurate Results than WRC-107**

A text report is provided for documentation and distribution to clients and inspectors. The report includes drawings, dimensions, tabulated stresses, and graphical results

The screenshot displays the FE-107 software interface. The title bar reads "FE-107 1.1 - C:\test\nozzle\_in\_head\_example". The menu bar includes "New", "Open", "Save", "Save As", "Plot Model", "Analyze", "Results", and "Help". The "Input Units" are set to "English". The main menu is "Geometry Input | Loads | Optional | Materials | Analysis Results". Below the menu, there are icons for "Tables", "Text Report", "Print Report", and "Save Report".

The text report content is as follows:

```
Dimensions for Elliptical Head
Outside Diameter      D = 91.375 [in.]
Wall Thickness        T = 0.9375 [in.]
Straight Flange Length Lf = 2 [in.]
Attached Shell Length Ls = 45 [in.]

Dimensions for Pad Reinforced Branch
Branch Diameter       d = 24.0 [in.]
Branch Wall Thickness t = 0.50 [in.]
Reinforcing Pad Width W = 10.0 [in.]
Reinforcing Pad Thickness Tp = 1.0 [in.]
Fillet Weld Size at Intersection = 0.375 [in.]
Fillet Weld Size at Edge of Pad = 0.75 [in.]
```

The technical drawing below the text report shows a cross-section of a nozzle-in-head assembly. The main body has an outside diameter  $D$  and a wall thickness  $T$ . The straight flange length is  $L_f$  and the attached shell length is  $L_s$ . The nozzle has a branch diameter  $d$  and a wall thickness  $t$ . The reinforcing pad has a width  $W$  and a thickness  $T_p$ . The fillet weld size at the intersection is  $0.375$  and at the edge of the pad is  $0.75$ . The nozzle length is  $L_n$  and the shell thickness is  $T_s$ .

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**Experimental Validation shows that FE-107 Provides More Accurate Results than WRC-107**

A text report is provided for documentation and distribution to clients and inspectors. The report includes drawings, dimensions, tabulated stresses, and graphical results (contd.)

**FE-107 1.1 - C:\test\nozzle\_in\_head\_example**

Input Units:  English  Metric

Geometry Input | Loads | Optional | Materials | Analysis Results

Tables | Text Report | Print Report | Save Report

FINITE ELEMENT STRESS RESULTS

The following table contains the finite element stress solutions for the analyzed geometry. The analysis is in accordance with ASME Section VIII-2 requirements. Primary local membrane, secondary, and peak stress categories are included. In addition, fatigue calculations are provided based on the specified number of cycles.

Location	ASME Category	Stress	Allowable Stress	% Allowed	Plot #
Elliptical Head	PI+Pb < 1.5(k)Smh [Pb=0]	7,147.46	30,000.0	24	2
Nozzle 1 Next to Shell	PI+Pb < 1.5(k)Smh [Pb=0]	28,903.17	30,000.0	96	3
Nozzle 1	PI+Pb < 1.5(k)Smh [Pb=0]	22,022.98	30,000.0	73	4
Shell Next to Nozzle 1 Pad	PI+Pb < 1.5(k)Smh [Pb=0]	7,161.62	30,000.0	24	5
Shell in Nozzle 1 Vicinity	PI+Pb < 1.5(k)Smh [Pb=0]	7,179.68	30,000.0	24	6
Pad Next to Nozzle 1	PI+Pb < 1.5(k)Smh [Pb=0]	8,125.05	30,000.0	27	7
Nozzle 1 Pad Weld Area	PI+Pb < 1.5(k)Smh [Pb=0]	3,464.96	30,000.0	12	8
Parent Base SCR	PI+Pb < 1.5(k)Smh [Pb=0]	3,031.63	30,000.0	10	9
Elliptical Head	PI+Pb+Q < 3(k)Smavg	9,984.73	60,000.0	17	10
Nozzle 1 Next to Shell	PI+Pb+Q < 3(k)Smavg	80,232.57	60,000.0	134	11
Nozzle 1	PI+Pb+Q < 3(k)Smavg	24,025.28	60,000.0	40	12
Shell Next to Nozzle 1 Pad	PI+Pb+Q < 3(k)Smavg	9,958.16	60,000.0	17	13
Shell in Nozzle 1 Vicinity	PI+Pb+Q < 3(k)Smavg	10,127.43	60,000.0	17	14
Pad Next to Nozzle 1	PI+Pb+Q < 3(k)Smavg	21,648.09	60,000.0	36	15
Nozzle 1 Pad Weld Area	PI+Pb+Q < 3(k)Smavg	9,155.61	60,000.0	15	16
Parent Base SCR	PI+Pb+Q < 3(k)Smavg	3,178.54	60,000.0	5	17

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**Experimental Validation shows that FE-107 Provides More Accurate Results than WRC-107**

FE-107 also provides allowable loads and flexibility results for the nozzle. Flexibilities can be used by piping engineers for more accurate piping analysis.

FE-107 1.1 - C:\test\nozzle\_in\_head\_example

Input Units:  English  Metric

Geometry Input | Loads | Optional | Materials | Analysis Results

Tables | Text Report | Print Table

FEA Stress | Allowables | Flexibilities | FEA vs. WRC | WRC 107 | WRC 297

The following are the allowable loads which can be applied to the geometry.

	Maximum Individual Occurring	Conservative Simultaneous Occurring	Realistic Simultaneous Occurring
<b>SECONDARY ALLOWABLES</b>			
Axial Force [lb]	312841.60	104280.50	156420.80
In-Plane Moment [ft-lb]	2305534.00	543419.70	1152767.00
Out-of-Plane Moment [ft-lb]	2280437.00	537504.10	1140218.00
Torsional Moment [ft-lb]	6376340.00	2125447.00	3188170.00
Pressure [psi]	0.00	0.00	0.00
<b>PRIMARY ALLOWABLES</b>			
Axial Force [lb]	175784.60	58594.87	87892.30
In-Plane Moment [ft-lb]	1156845.00	272670.90	578422.40
Out-of-Plane Moment [ft-lb]	1155304.00	272307.90	577652.20
Torsional Moment [ft-lb]	8594649.00	2864883.00	4297324.00
Pressure [psi]	0.00	0.00	0.00

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**Experimental Validation shows that FE-107 Provides More Accurate Results than WRC-107**

FE-107 also provides allowable loads and flexibility results for the nozzle. Flexibilities can be used by piping engineers for more accurate piping analysis. (contd.)

The screenshot shows the FE-107 software interface. The title bar reads "FE-107 1.1 - C:\test\nozzle\_in\_head\_example". The menu bar includes "New", "Open", "Save", "Save As", "Plot Model", "Analyze", "Results", and "Help". The "Input Units" are set to "English". The main menu is "Geometry Input | Loads | Optional | Materials | Analysis Results". The "Analysis Results" menu is expanded, showing "Tables", "Text Report", and "Print Table". The "Flexibilities" tab is selected, displaying the following results:

FEA Stress	Allowables	Flexibilities	FEA vs. WRC	WRC 107	WRC 297
The following are the nozzle flexibility results generated by the Finite Element Method. These values can be used in a piping beam analysis for a more accurate model of the actual nozzle intersection stiffnesses.					
Axial Stiffness [lb/in.]		4.47E+06			
In-Plane Bending Stiffness [in.lb./deg]		1.18E+07			
Out-of-Plane Bending Stiffness [in.lb./deg]		1.18E+07			
Torsional Stiffness [in.lb./deg]		1.79E+08			

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**Experimental Validation shows that FE-107 Provides More Accurate Results than WRC-107**

Automatic comparisons between FE-107, WRC-107, and WRC-297 are given to show when the WRC methods are not appropriate.

The screenshot shows the FE-107 software interface with the 'FEA vs. WRC' tab selected. It displays a comparison table of maximum ASME Code stresses for different locations and stress categories. The table compares FEA results (in psi) with WRC-107 and WRC-297 results (in psi) against allowable stress values. A specific value of 80233 psi for FEA at the Nozzle location under Max PL+Pb+Q is highlighted in yellow.

A comparison between the maximum ASME Code stresses according to FEA, WRC-107, and WRC-297 are given in the following table. WRC-107 and WRC-297 results may be subject to error depending on the geometric parameters used in the analysis. More meaningful comparisons are made using the stress indices (see below).

Location	Stress Category	FEA [psi]	WRC 107 [psi]	WRC 297 [psi]	Allowable [psi]
Nozzle	Max PL	28903	N.A.		30000
Nozzle	Max PL+Pb+Q	80233	N.A.		60000
Nozzle	Max PL+Pb+Q+F		N.A.		Varies
Shell or pad	Max PL	8125	21736		30000
Shell or pad	Max PL+Pb+Q	21648	32140		60000
Shell or pad	Max PL+Pb+Q+F				Varies

The following are stress indices for FEA, WRC-107, and WRC-297. The stress indices are the calculated stress divided by the nominal stress. These indices provide a more realistic comparison between FEA and WRC results since each load component may be evaluated independent of other load components. As a result, issues such as off-axis loading, stress combinations, load combinations, etc. do not introduce complexity and assumptions.

Source	Case	Pressure	Axial	In-Plane	Out-of Plane	Torsion
FEA	Peak	0.00	8.70	7.61	7.62	1.02
WRC 107	Peak		5.06	3.05	3.05	0.48
WRC 297	Peak					
FEA	Secondary	0.00	8.70	7.61	7.62	1.02
WRC 107	Secondary		5.06	3.05	3.05	0.48
WRC 297	Secondary					
FEA	Primary	0.00	2.54	2.75	2.70	1.00