```
FETee 1.1 - Tee Modeler
Paulin Research Group



Notes
-----
Results shown below, under stresses are:
- Front Pipe (+side attached run pipe)
- Back  Pipe (-side attached run pipe)
- Top   Pipe (Branch attached pipe)
- Tee Body   (branch and run fitting lengths outside crotch area)
- Transition to front pipe (Transition from weld to +side run pipe)
- Transition to back  pipe (Transition from weld to -side run pipe)
- Transition to top   pipe (Transition from weld to branch pipe)
- Tee Crotch Area


Type Of Model         : Welding Tee (Shell)
Units                 : Metric
Stress Calculation    : AVERAGED


Vectors
-------
Run    Vector         :      1.000,     0.000,     0.000
Branch Vector         :      0.000,     1.000,     0.000

Gravity               :      0.000,    -1.000,     0.000


Model Geometry
--------------
Tee OD at Run         :    924.878 mm.
Tee OD at Branch      :    620.078 mm.

Tee Thk at Run        :     14.764 mm.
Tee Thk at Branch     :     14.764 mm.

Tee Crotch Radius     :     97.536 mm.

Run Fitting Length    :   1346.200 mm.
Br. Fitting Length    :    637.791 mm.

-side Att. Pipe (User):   4195.070 mm.
+side Att. Pipe (User):   4195.070 mm.
Branch Att.Pipe (User):   1722.700 mm.


Optional Entries (Options Screen)
---------------------------------
(User) - User defined values.
(Comp) - Default values used, computer generated.
Opt. -side  OD (User) :    914.400 mm.
Opt. +side  OD (User) :    914.400 mm.
Opt. Branch OD (User) :    609.600 mm.

Opt. -side  Thk (User):      9.525 mm.
Opt. +side  Thk (User):      9.525 mm.
Opt. Branch Thk (User):      9.525 mm.


Weld Details and SCF


--------------------
-side Weld Len. (User):      0.000 mm.
+side Weld Len. (User):      0.000 mm.
Branch Weld Len.(User):      0.000 mm.
Crotch Area SCF (User):      1.000


Crotch Thickness Profile
------------------------
The values below may be computer generated or defined
by the user.
(User) - User defined values.
(Comp) - Default values used, computer generated.

Center Long. (User):     16.240 mm.
Center 45deg (User):     16.240 mm.
Center Circ. (User):     16.240 mm.

Run Long.    (User):     14.764 mm.
Run 45deg    (User):     15.133 mm.
Run Circ.    (User):     15.502 mm.

Branch Long. (User):     16.240 mm.
Branch 45deg (User):     16.240 mm.
Branch Circ. (User):     16.240 mm.


Loads
-----
Loads Applied at      : End of Branch
Loads Defined as      : GLOBAL

Forces in (  N  ) and Moments in ( mm. N  )
                FX         FY         FZ         MX        MY         MZ
Weight    :     0.000      0.000      0.000      0.000     0.000      0.00
Operating :     0.000      0.000      0.000      0.000     0.000      0.00
Occasional:     0.000      0.000      0.000      0.000     0.000      0.00
Thermal   :     0.000      0.000      0.000      0.000     0.000      0.00

Pressure              :      1.078 MPa


Material Properties
-------------------
-side  - negative outplane side, this is defined as the negative
         section of the run.
+side  - Positive outplane side, positive section of the run.
Branch - The attached branch on the tee.

Tee Cold Allowable    :    138.000 MPa
```

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General

```
      1       <———— Number of Operating  Load Cycles
      1       <———— Number of Occasional Load Cycles

     RUN      <———— Compute Intersections Sif's and Stiffnesses
                    (YES/NO/RUN) If RUN then compute Sif's and
                    Stiffnesses for loads thru the run pipe.

     1.000,     0.000,     0.000   <—— Header Orientation (Local "Z")
   0.000,     1.000,     0.000     <—— Nozzle Orientation (Local "Y")
                  (Nozzle and Header Directions Should Be Orthogonal)

                    PIPE LENGTHS FOR LOAD REDUCTION ESTIMATE
   0.000      <———— Inplane attached pipe length  (mm.)
   0.000      <———— Outplane attached pipe length (mm.)
    0.000     <———— Axial attached pipe length (mm.)

         NO   <———— Save Stiffness Matrix
         NO   <———— Reuse Saved Stiffness Matrix (Only Loads Changed)

  21.100      <———— Ambient Temperature

    YES       <———— Add Branch Pressure Thrust
```

NO 0.000, -1.000, 0.000	Include Weight Loads (Y/N) Direction of Gravity (vx,vy,vz)
YES YES	Include Pressure Loads (Y/N) Include Thermal Loads (Y/N)
NO OCC	Include Wind Loads (Y/N) Include Wind in Which Load Cases ? (WGT, OPE, OCC, THE)
	Wind Direction (wx,wy,wz) Elev.(mm.), Pressure (N /sq.mm.) Elev.(mm.), Pressure (N /sq.mm.)

Enter Insulation/Refractory Data Below: (mm.) and (N per cu.mm.)

Insulation Thick. ——>	Insul. Density ——>
Refractory Thick. ——>	Refrt. Density ——>

Tee Geometry

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——————————————————— Tee Geometry ———————————————————————————————————————

924.878 <———— OD Fitting at Run Pipe Connection (mm.)
620.078 <———— OD Fitting at Branch Pipe Connection (mm.)

97.536 <———— Crotch Radius in Longitudinal Plane (mm.)

1346.200 <———— Fitting Length along run (weld-to-weld) (mm.)
637.791 <———— Fitting Height, Centerline to branch weld (mm.)

14.764 <———— Nominal Fitting Thickness in Run
14.764 <———— Nominal Fitting Thickness in Branch

——————————————————— Optional Tee Profile Thicknesses ———————————————————————

16.240 <———— Center of Crotch, Longitudinal Plane (mm.)
16.240 <———— Center of Crotch, @45° (mm.)
16.240 <———— Center of Crotch, Circumferential Plane (mm.)

14.764 <———— Base of Crotch, Longitudinal Plane (mm.)
15.133 <———— Base of Crotch, @45° (mm.)
15.502 <———— Base of Crotch, Circumferential Plane (mm.)

16.240 <———— Top of Crotch, Longitudinal Plane (mm.)
16.240 <———— Top of Crotch, @45° (mm.)
16.240 <———— Top of Crotch, Circumferential Plane (mm.)

<———— Circumferential Plane, Bottom of fitting (mm.)

Attached Pipe Dimensions

——————————————————— Attached Pipe Dimensions ———————————————————————————————

4195.070 <———— Left End Pipe Length (mm.)
4195.070 <———— Right End Pipe Length (mm.)
1722.700 <———— Top(Branch) Pipe Length (mm.)

914.400 <———— Left Pipe OD (If different from tee) (mm.)
914.400 <———— Right Pipe OD (If different from tee) (mm.)
609.600 <———— Top Pipe OD (If different from tee) (mm.)

9.525 <———— Left Pipe Thickness (If different from tee) (mm.)
9.525 <———— Right Pipe Thickness (If different from tee) (mm.)
9.525 <———— Top Pipe Thickness (If different from tee) (mm.)

0.000 <———— Left Pipe Weld Length (mm.)
0.000 <———— Right Pipe Weld Length (mm.)
0.000 <———— Top Pipe Weld Length (mm.)

<———— Loading Ring Axial Length (mm.)

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Material Properties

```
 TEE Material Properties:
 ____________________________________________________________________________
      1.078   <───── Pressure ( N /sq.mm.)

    21.100    <───── Inside Temperature (deg)
   21.100     <───── Outside Temperature (deg)

  1           <───── Tee Material for Fatigue Calculations (1-6)

  138.000     <───── Tee Cold Allowable Stress (MPa)
  138.000     <───── Tee Hot  Allowable Stress (MPa)

              <───── Tee Tensile Strength (@Ambient) (MPa)
              <───── Tee Yield Strength (@Ambient) (MPa)
              <───── Tee Yield Strength (@Temperature) (MPa)

   199950.000 <───── Tee Elastic Modulus (@Ambient) (MPa)
   0.300      <───── Tee Poissons Ratio
    0.117E-04 <───── Tee Expansion Coefficient (mm./mm./deg)
    0.000     <───── Density of Tee Pipe    ( N /cu.mm.)
 ____________________________________________________________________________
      "Only enter attached pipe properties below, if they are
           different than those  entered for the tee."

 LEFT End Pipe Material Properties:
 ____________________________________________________________________________
    1         <───── Left Pipe Material for Fatigue Calculations (1-6)

    138.000   <───── Left Pipe Cold Allowable Stress (MPa)
    138.000   <───── Left Pipe Hot  Allowable Stress (MPa)

              <───── Left Pipe Tensile Strength (@Ambient) (MPa)
              <───── Left Pipe Yield Strength (@Ambient) (MPa)
              <───── Left Pipe Yield Strength (@Temperature) (MPa)

   199950.000 <───── Left Pipe Elastic Modulus (@Ambient) (MPa)
     0.300    <───── Left Pipe Poissons Ratio
    0.117E-04 <───── Left Pipe Expansion Coefficient (mm./mm./deg)

 RIGHT End Pipe Material Properties:
 ____________________________________________________________________________
    1         <───── Right Pipe Material for Fatigue Calculations (1-6)

    138.000   <───── Right Pipe Cold Allowable Stress (MPa)
    138.000   <───── Right Pipe Hot  Allowable Stress (MPa)

              <───── Right Pipe Tensile Strength (@Ambient) (MPa)
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```
            <———— Right Pipe Yield Strength (@Ambient) (MPa)
            <———— Right Pipe Yield Strength (@Temperature) (MPa)

  199950.000 <———— Right Pipe Elastic Modulus (@Ambient) (MPa)
    0.300    <———— Right Pipe Poissons Ratio
   0.117E-04 <———— Right Pipe Expansion Coefficient (mm./mm./deg)
```

BRANCH Pipe Material Properties:

```
   1         <———— Branch Pipe Material for Fatigue Calculations

  138.000    <———— Branch Pipe Cold Allowable Stress (MPa)
  138.000    <———— Branch Pipe Hot  Allowable Stress (MPa)

             <———— Branch Pipe Tensile Strength (@Ambient) (MPa)
             <———— Branch Pipe Yield Strength (@Ambient) (MPa)
             <———— Branch Pipe Yield Strength (@Temperature) (MPa)

  199950.000 <———— Branch Pipe Elastic Modulus (@Ambient) (MPa)
   0.300     <———— Branch Pipe Poissons Ratio
   0.117E-04 <———— Branch Pipe Expansion Coefficient (mm./mm./deg)
```

Loads

```
     3       <———— Loads Entered below act:
                   1 - At the branch/header centerline intersection
                   2 - At the surface of the header/vessel
                   3 - At the end of the branch

   GLOBAL    <———— Loads Entered in (L)ocal or (G)lobal coordinates
```

FORCE Axial N	FORCE Inplane N	FORCE Outplane N	MOMENT Torsion mm. N	MOMENT In-plane mm. N	MOMENT Outplane mm. N	
.0000E+00,	.0000E+00,	.0000E+00,	.0000E+00,	.0000E+00,	.0000E+00	WEIGHT
.0000E+00,	.0000E+00,	.0000E+00,	.0000E+00,	.0000E+00,	.0000E+00	OPERATING
.0000E+00,	.0000E+00,	.0000E+00,	.0000E+00,	.0000E+00,	.0000E+00	OCCASIONAL
.0000E+00,	.0000E+00,	.0000E+00,	.0000E+00,	.0000E+00,	.0000E+00	THERMAL

Node ID's

```
             <———— Node Number for  Branch   End
```

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              <———— Node Number for +Z Header End

              <———— Node Number for -Z Header End

====================================================================
                   Optional
====================================================================

     1        <———— Crotch Area Stress Concentration

     YES      <———— Free +Outplane End of Header/Vessel (Open End)
     NO       <———— Free -Outplane End of Header/Vessel (Open End)

    NO        <———— Remove Bottom Half of Model

     0.000    <———— Length of Branch to Remove for Join    (mm.)
   0.000      <———— Length of +Outplane to Remove for Join (mm.)
   0.000      <———— Length of -Outplane to Remove for Join (mm.)

     PRIMARY  <———— Analyze Occasional Loads as (P)rimary or (F)atigue
  C           <———— Nominal Stress computed at (S)urface or (C)enterline
    AVERAGED  <———— Nodal Stress Calculation: AVERAGED/NOTAVERAGED/
                                          GAUSSAVERAGE/GAUSSNOTAVERAGE
    10000.000 <———— Relative Stiffness (to branch) of Loading Ring

                    MESH CONTROL PARAMETERS
              <———— Density Index for Nodes at Intersection
                   ( > 0 for more elements at the intersection)

  1.00000     <———— Global Mesh Multiplier Override

    0.00000   <———— Merge Nodes Override
    0.000     <———— Intersection Tolerance Override
          YES <———— Adjust Determinant of Jacobian for Poorly Shaped
                    Elements.  (Should be used with caution. Stiffnesses
                    of poorly shaped elements computed approximately.)

              <———— Branch mesh area sweep factor (>0.8)

    32        <———— Number of nodes around branch circumference, <OR>
              <———— Number of nodes around header
   7          <———— Number of nodes radially in crotch
     5        <———— Number of nodes radially in header adjacent to crotch
     5        <———— Number of nodes radially in tee above crotch area
              <———— Number of nodes in bottom surfaces
              <———— Number of nodes circumferentially around branch per
                    surface.  (Note 6 total surfaces around branch.)
              <———— Number of nodes along +Outplane attached pipe
              <———— Number of nodes along -Outplane attached pipe
              <———— Number of nodes along  branch   attached pipe

   1          <———— Adjust Attached Pipe Midsurface
```

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Database Operations

0 <──── Database "Read/Write" Option
0 - No Database Operation
1 - Write Out Database for this Job for later "Reading"
2 - Read In Database(s) to "Include" with this Job

Enter the node numbers in this model that will be connected to nodes in another database. The node number may correspond to any element end. This list is used with database options 1 or 2.

Enter the names of the jobs whose databases are to be read into and "INCLUDED" with this job. (These jobs must already have had their databases written to the hard disk.) These names are only used with database option 2.

JOBNAMES	(Optional See ?-Help) Coordinate Shift (X,Y,Z) (mm.)
	, ,

```
Load Case Report                                      26: 2:10 20 Aug 2016

Inner and outer element temperatures are the same
throughout the model.  No thermal ratcheting
calculations will be performed.

THE   7  LOAD CASES ANALYZED ARE:

  1   SUSTAINED      (Pr Only)

      Sustained case run to satisfy local primary
      membrane and bending stress limits.

      /-------- Loads in Case   1
        Pressure Case    1

  2   OPERATING      (Fatigue Calc Performed)

      Case run to compute the operating stresses used in
      secondary, peak and range calculations as needed.

      /-------- Loads in Case   2
        Pressure Case    1

  3   Program Generated -- Force Only

      Case run to compute sif's and flexibilities.
      /-------- Loads in Case   3
        Loads from (Axial)

  4   Program Generated -- Force Only

      Case run to compute sif's and flexibilities.
      /-------- Loads in Case   4
        Loads from (Inplane)

  5   Program Generated -- Force Only

      Case run to compute sif's and flexibilities.
      /-------- Loads in Case   5
        Loads from (Outplane)

  6   Program Generated -- Force Only

      Case run to compute sif's and flexibilities.
      /-------- Loads in Case   6
        Loads from (Torsion)

  7   Program Generated -- Force Only

      Case run to compute sif's and flexibilities.
      /-------- Loads in Case   7
        Pressure Case    1
```

Solution Data

Maximum Solution Row Size = 936
Number of Nodes = 2694
Number of Elements = 890
Number of Solution Cases = 7

Summation of Loads per Case

Case #	FX	FY	FZ
1	701190.	-5345.	0.
2	701190.	-5345.	0.
3	307403008.	0.	0.
4	0.	0.	0.
5	0.	0.	0.
6	0.	0.	0.
7	701190.	-5345.	0.

Beam Detailed Results

Notes:

For pipe, there are five stress values printed for
each end node on an 18dof element: Saa, Sab, Sac, Scc, and SI.
where

- Saa = Axial stress
- Sab = Shear stress normal to the pipe skin
- Sac = Shear stress along circumferential direction
- Scc = Hoop stress
- SI = Stress intensity

If an element is lined with refractory layers, four stress
values are printed for each layer of refractory at each
element end node.
where

- MxPr = Maximum principal stress
- MnPr = Minimum principal stress
- SI = Stress intensity
- Se = von Mises stress

LOAD CASE 1 --> (Pr Only)

LOAD CASE 2 -->

LOAD CASE 3 -->

LOAD CASE 4 -->

LOAD CASE 5 -->

LOAD CASE 6 -->

LOAD CASE 7 -->

ASME Code Stress Output Plots 26: 2:10 20 Aug 2016

1) Pl < (1.5)(S) (SUS,Membrane) Case 1

2) Qb < SPS (SUS,Bending) Case 1

3) S1+S2+S3 < 4S (SUS,S1+S2+S3) Case 1

4) Pl+Pb+Q < SPS (OPE,Inside) Case 2

5) Pl+Pb+Q < SPS (OPE,Outside) Case 2

6) Pl+Pb+Q+F < Sa (EXP,Inside) Case 2

7) Pl+Pb+Q+F < Sa (EXP,Outside) Case 2

8) Membrane < User (OPE,Membrane) Case 2

9) Bending < User (OPE,Bending) Case 2

10) Pl+Pb+Q+F < Sa (SIF,Outside) Case 3

11) Pl+Pb+Q+F < Sa (SIF,Outside) Case 4

12) Pl+Pb+Q+F < Sa (SIF,Outside) Case 5

13) Pl+Pb+Q+F < Sa (SIF,Outside) Case 6

14) Pl+Pb+Q+F < Sa (SIF,Outside) Case 7

Region Data 26: 2:10 20 Aug 2016

Tee Crotch Area

```
  Cold Allowable ...........      138.  MPa
  Cold Elasic Modulus ......   199950.  MPa
  Hot Allowable @  21 deg ..      138.  MPa
  Case   1
  Pressure Stress (Pd/2t) ..       52.  MPa
  Case   2
  Pressure Stress (Pd/2t) ..       52.  MPa
  Case   3
  Nominal Stress   (M/Z) ...    11353.  MPa
  Case   4
  Nominal Stress   (M/Z) ...       51.  MPa
  Case   5
  Nominal Stress   (M/Z) ...       51.  MPa
  Case   6
  Nominal Stress   (M/Z) ...       51.  MPa
  Case   7
  Nominal Stress   (M/Z) ...       52.  MPa
  Smallest Thickness .......    9.525   mm.
  Stress Concentration .....    1.000
```

Tee Body

```
  Cold Allowable ...........      138.  MPa
  Cold Elasic Modulus ......   199950.  MPa
  Hot Allowable @  21 deg ..      138.  MPa
  Case   1
  Pressure Stress (Pd/2t) ..       52.  MPa
  Case   2
  Pressure Stress (Pd/2t) ..       52.  MPa
  Case   3
  Nominal Stress   (M/Z) ...    11353.  MPa
  Case   4
  Nominal Stress   (M/Z) ...       51.  MPa
  Case   5
  Nominal Stress   (M/Z) ...       51.  MPa
  Case   6
  Nominal Stress   (M/Z) ...       51.  MPa
  Case   7
  Nominal Stress   (M/Z) ...       52.  MPa
  Smallest Thickness .......    9.525   mm.
  Stress Concentration .....    1.000
```

Stress Results - Notes

- Results in this analysis were generated using the finite element solution method.

- Using 07-12 ASME Section VIII Division 2

- Use Polished Bar fatigue curve.

- Ratio between Operating and Design Pressure = 1.000000
  Assume pressure increases all other stresses.

- Assume free end displacements of attached pipe are secondary loads within limits of nozzle reinforcement.

- User OVERRIDE - USE Stress Intensity (TRESCA) for ASME Calculation.
  Tresca may be 10% higher than equivalent stress.

- S1+S2+S3 evaluation omitted from operating stress.
  Include S1+S2+S3 evaluation in primary case evaluation.
  Assume bending stress not local primary for S1+S2+S3.

- Use local tensor values for averaged and not averaged stresses.

- Use shell midsurface diameter for nozzle pressure thrust load - may not be conservative.

B31 Expansion Stresses 26: 2:10 20 Aug 2016

Expansion Stress MPa	B31 Allowable MPa	ASME Allowable MPa	Markl Allowable MPa	Regions / Notes
65.	345.	12236.	1689.	Tee Crotch Area Load Case 2, Inner, Plot 6
45.	345.	12236.	1689.	Tee Body Load Case 2, Outer, Plot 7

ASME Overstressed Areas 26: 2:10 20 Aug 2016

*** NO OVERSTRESSED NODES IN THIS MODEL ***

Highest Primary Stress Ratios 26: 2:10 20 Aug 2016

Tee Crotch Area

Pl	(1.5)(S)	Primary Membrane Load Case 1
101	207	Plot Reference:
MPa	MPa	1) Pl < (1.5)(S) (SUS,Membrane) Case 1

48%

Tee Body

Pl	(1.5)(S)	Primary Membrane Load Case 1
77	207	Plot Reference:
MPa	MPa	1) Pl < (1.5)(S) (SUS,Membrane) Case 1

37%

Highest Secondary Stress Ratios 26: 2:10 20 Aug 2016

Tee Crotch Area

Pl+Pb+Q	SPS	Primary+Secondary (Inner) Load Case 2
131	414	Plot Reference:
MPa	MPa	4) Pl+Pb+Q < SPS (OPE,Inside) Case 2

31%

Tee Body

Pl+Pb+Q	SPS	Primary+Secondary (Outer) Load Case 2
90	414	Plot Reference:
MPa	MPa	5) Pl+Pb+Q < SPS (OPE,Outside) Case 2

21%

```
Highest Fatigue Stress Ratios                          26: 2:10 20 Aug 2016


Tee Crotch Area

Pl+Pb+Q+F     Damage Ratio    Primary+Secondary+Peak (Inner) Load Case 2
       65      0.000 Life     Stress Concentration Factor = 1.000
      MPa      0.005 Stress   Strain Concentration Factor = 1.000
                              Cycles Allowed for this Stress = 1.2059E8
Allowable                     "B31" Fatigue Stress Allowable = 345.0
 12,236.4                     Markl Fatigue Stress Allowable = 1689.2
      MPa                     WRC 474 Mean Cycles to Failure = 1,752,182.
                              WRC 474 99% Probability Cycles = 407,048.
       0%                     WRC 474 95% Probability Cycles = 565,135.
                              BS5500 Allowed Cycles(Curve F) = 323,713.
                              Membrane-to-Bending Ratio = 2.961
                              Bending-to-PL+PB+Q Ratio = 0.252
                              Plot Reference:
                              6) Pl+Pb+Q+F < Sa (EXP,Inside) Case 2


Tee Body

Pl+Pb+Q+F     Damage Ratio    Primary+Secondary+Peak (Outer) Load Case 2
       45      0.000 Life     Stress Concentration Factor = 1.000
      MPa      0.004 Stress   Strain Concentration Factor = 1.000
                              Cycles Allowed for this Stress = 1.0000E11
Allowable                     "B31" Fatigue Stress Allowable = 345.0
 12,236.4                     Markl Fatigue Stress Allowable = 1689.2
      MPa                     WRC 474 Mean Cycles to Failure = 6,344,108.
                              WRC 474 99% Probability Cycles = 1,473,794.
       0%                     WRC 474 95% Probability Cycles = 2,046,177.
                              BS5500 Allowed Cycles(Curve F) = 997,310.
                              Membrane-to-Bending Ratio = 0.728
                              Bending-to-PL+PB+Q Ratio = 0.579
                              Plot Reference:
                              7) Pl+Pb+Q+F < Sa (EXP,Outside) Case 2
```

```
 Highest Stress Ratios Per Region                      26: 2:10 20 Aug 2016


 Tee Crotch Area

       Pl       (1.5)(S)     Primary Membrane Load Case 1
      101            207     Plot Reference:
      MPa            MPa     1) Pl < (1.5)(S) (SUS,Membrane) Case 1

            48%

       Qb            SPS     Primary Bending Load Case 1
       75            414     Plot Reference:
      MPa            MPa     2) Qb < SPS (SUS,Bending) Case 1

            18%

 S1+S2+S3             4S     Part 5 (5.3.2) Load Case 1
      124            552     Plot Reference:
      MPa            MPa     3) S1+S2+S3 < 4S (SUS,S1+S2+S3) Case 1

            22%

  Pl+Pb+Q            SPS     Primary+Secondary (Inner) Load Case 2
      131            414     Plot Reference:
      MPa            MPa     4) Pl+Pb+Q < SPS (OPE,Inside) Case 2

            31%

  Pl+Pb+Q            SPS     Primary+Secondary (Outer) Load Case 2
      103            414     Plot Reference:
      MPa            MPa     5) Pl+Pb+Q < SPS (OPE,Outside) Case 2

            24%

Pl+Pb+Q+F    Damage Ratio    Primary+Secondary+Peak (Inner) Load Case 2
       65     0.000 Life     Stress Concentration Factor = 1.000
      MPa     0.005 Stress   Strain Concentration Factor = 1.000
                             Cycles Allowed for this Stress = 1.2059E8
Allowable                    "B31" Fatigue Stress Allowable = 345.0
 12,236.4                    Markl Fatigue Stress Allowable = 1689.2
      MPa                    WRC 474 Mean Cycles to Failure = 1,752,182.
                             WRC 474 99% Probability Cycles = 407,048.
       0%                    WRC 474 95% Probability Cycles = 565,135.
                             BS5500 Allowed Cycles(Curve F) = 323,713.
                             Membrane-to-Bending Ratio = 2.961
                             Bending-to-PL+PB+Q Ratio = 0.252
                             Plot Reference:
                             6) Pl+Pb+Q+F < Sa (EXP,Inside) Case 2

Pl+Pb+Q+F    Damage Ratio    Primary+Secondary+Peak (Outer) Load Case 2
       51     0.000 Life     Stress Concentration Factor = 1.000
      MPa     0.004 Stress   Strain Concentration Factor = 1.000
                             Cycles Allowed for this Stress = 1.5675E10
Allowable                    "B31" Fatigue Stress Allowable = 345.0
 12,236.4                    Markl Fatigue Stress Allowable = 1689.2
      MPa                    WRC 474 Mean Cycles to Failure = 3,702,754.
                             WRC 474 99% Probability Cycles = 860,183.
```

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 Highest Stress Ratios Per Region                      26: 2:10 20 Aug 2016

        0%                    WRC 474 95% Probability Cycles = 1,194,256.
                              BS5500 Allowed Cycles(Curve F) = 664,460.
                              Membrane-to-Bending Ratio = 15.705
                              Bending-to-PL+PB+Q Ratio = 0.060
                              Plot Reference:
                              7) Pl+Pb+Q+F < Sa (EXP,Outside) Case 2

  Membrane            User    Component Evaluation Load Case 2
       101             414    Plot Reference:
       MPa             MPa    8) Membrane < User (OPE,Membrane) Case 2

             24%

   Bending            User    Component Evaluation Load Case 2
        75             414    Plot Reference:
       MPa             MPa    9) Bending < User (OPE,Bending) Case 2

             18%


 Tee Body

        Pl       (1.5)(S)     Primary Membrane Load Case 1
        77             207    Plot Reference:
       MPa             MPa    1) Pl < (1.5)(S) (SUS,Membrane) Case 1

             37%

        Qb             SPS    Primary Bending Load Case 1
        72             414    Plot Reference:
       MPa             MPa    2) Qb < SPS (SUS,Bending) Case 1

             17%

  S1+S2+S3              4S    Part 5 (5.3.2) Load Case 1
       105             552    Plot Reference:
       MPa             MPa    3) S1+S2+S3 < 4S (SUS,S1+S2+S3) Case 1

             19%

   Pl+Pb+Q             SPS    Primary+Secondary (Inner) Load Case 2
        83             414    Plot Reference:
       MPa             MPa    4) Pl+Pb+Q < SPS (OPE,Inside) Case 2

             19%

   Pl+Pb+Q             SPS    Primary+Secondary (Outer) Load Case 2
        90             414    Plot Reference:
       MPa             MPa    5) Pl+Pb+Q < SPS (OPE,Outside) Case 2

             21%

 Pl+Pb+Q+F    Damage Ratio    Primary+Secondary+Peak (Inner) Load Case 2
        41     0.000 Life     Stress Concentration Factor = 1.000
       MPa     0.003 Stress   Strain Concentration Factor = 1.000
                              Cycles Allowed for this Stress = 1.0000E11
```

```
Highest Stress Ratios Per Region                      26: 2:10 20 Aug 2016

Allowable                    "B31" Fatigue Stress Allowable = 345.0
 12,236.4                    Markl Fatigue Stress Allowable = 1689.2
      MPa                    WRC 474 Mean Cycles to Failure = 7,419,715.
                             WRC 474 99% Probability Cycles = 1,723,667.
       0%                    WRC 474 95% Probability Cycles = 2,393,095.
                             BS5500 Allowed Cycles(Curve F) = 1,275,575.
                             Membrane-to-Bending Ratio = 3.052
                             Bending-to-PL+PB+Q Ratio = 0.247
                             Plot Reference:
                             6) Pl+Pb+Q+F < Sa (EXP,Inside) Case 2

Pl+Pb+Q+F   Damage Ratio     Primary+Secondary+Peak (Outer) Load Case 2
       45    0.000 Life      Stress Concentration Factor = 1.000
      MPa    0.004 Stress    Strain Concentration Factor = 1.000
                             Cycles Allowed for this Stress = 1.0000E11
Allowable                    "B31" Fatigue Stress Allowable = 345.0
 12,236.4                    Markl Fatigue Stress Allowable = 1689.2
      MPa                    WRC 474 Mean Cycles to Failure = 6,344,108.
                             WRC 474 99% Probability Cycles = 1,473,794.
       0%                    WRC 474 95% Probability Cycles = 2,046,177.
                             BS5500 Allowed Cycles(Curve F) = 997,310.
                             Membrane-to-Bending Ratio = 0.728
                             Bending-to-PL+PB+Q Ratio = 0.579
                             Plot Reference:
                             7) Pl+Pb+Q+F < Sa (EXP,Outside) Case 2

 Membrane          User      Component Evaluation Load Case 2
       77           414      Plot Reference:
      MPa           MPa      8) Membrane < User (OPE,Membrane) Case 2

            18%

  Bending          User      Component Evaluation Load Case 2
       72           414      Plot Reference:
      MPa           MPa      9) Bending < User (OPE,Bending) Case 2

            17%
```

Highest Stresses Per Load Case 1 26: 2:10 20 Aug 2016

Tee Crotch Area

```
      Pl       (1.5)(S)     Primary Membrane Load Case 1
     101            207     Plot Reference:
     MPa            MPa     1) Pl < (1.5)(S) (SUS,Membrane) Case 1

           48%
```

Tee Crotch Area

```
      Qb            SPS     Primary Bending Load Case 1
      75            414     Plot Reference:
     MPa            MPa     2) Qb < SPS (SUS,Bending) Case 1

           18%
```

Tee Crotch Area

```
S1+S2+S3             4S     Part 5 (5.3.2) Load Case 1
     124            552     Plot Reference:
     MPa            MPa     3) S1+S2+S3 < 4S (SUS,S1+S2+S3) Case 1

           22%
```

Tee Body

```
      Pl       (1.5)(S)     Primary Membrane Load Case 1
      77            207     Plot Reference:
     MPa            MPa     1) Pl < (1.5)(S) (SUS,Membrane) Case 1

           37%
```

Tee Body

```
      Qb            SPS     Primary Bending Load Case 1
      72            414     Plot Reference:
     MPa            MPa     2) Qb < SPS (SUS,Bending) Case 1

           17%
```

Tee Body

```
S1+S2+S3             4S     Part 5 (5.3.2) Load Case 1
     105            552     Plot Reference:
     MPa            MPa     3) S1+S2+S3 < 4S (SUS,S1+S2+S3) Case 1

           19%
```

Highest Stresses Per Load Case 2   26: 2:10 20 Aug 2016

Tee Crotch Area

```
  Pl+Pb+Q            SPS     Primary+Secondary (Inner) Load Case 2
      131            414     Plot Reference:
      MPa            MPa     4) Pl+Pb+Q < SPS (OPE,Inside) Case 2

            31%
```

Tee Crotch Area

```
  Pl+Pb+Q            SPS     Primary+Secondary (Outer) Load Case 2
      103            414     Plot Reference:
      MPa            MPa     5) Pl+Pb+Q < SPS (OPE,Outside) Case 2

            24%
```

Tee Crotch Area

```
Pl+Pb+Q+F    Damage Ratio    Primary+Secondary+Peak (Inner) Load Case 2
       65     0.000 Life     Stress Concentration Factor = 1.000
      MPa     0.005 Stress   Strain Concentration Factor = 1.000
                             Cycles Allowed for this Stress = 1.2059E8
Allowable                    "B31" Fatigue Stress Allowable = 345.0
 12,236.4                    Markl Fatigue Stress Allowable = 1689.2
      MPa                    WRC 474 Mean Cycles to Failure = 1,752,182.
                             WRC 474 99% Probability Cycles = 407,048.
       0%                    WRC 474 95% Probability Cycles = 565,135.
                             BS5500 Allowed Cycles(Curve F) = 323,713.
                             Membrane-to-Bending Ratio = 2.961
                             Bending-to-PL+PB+Q Ratio = 0.252
                             Plot Reference:
                             6) Pl+Pb+Q+F < Sa (EXP,Inside) Case 2
```

Tee Crotch Area

```
Pl+Pb+Q+F    Damage Ratio    Primary+Secondary+Peak (Outer) Load Case 2
       51     0.000 Life     Stress Concentration Factor = 1.000
      MPa     0.004 Stress   Strain Concentration Factor = 1.000
                             Cycles Allowed for this Stress = 1.5675E10
Allowable                    "B31" Fatigue Stress Allowable = 345.0
 12,236.4                    Markl Fatigue Stress Allowable = 1689.2
      MPa                    WRC 474 Mean Cycles to Failure = 3,702,754.
                             WRC 474 99% Probability Cycles = 860,183.
       0%                    WRC 474 95% Probability Cycles = 1,194,256.
                             BS5500 Allowed Cycles(Curve F) = 664,460.
                             Membrane-to-Bending Ratio = 15.705
                             Bending-to-PL+PB+Q Ratio = 0.060
                             Plot Reference:
                             7) Pl+Pb+Q+F < Sa (EXP,Outside) Case 2
```

Tee Crotch Area

```
Highest Stresses Per Load Case  2                     26: 2:10 20 Aug 2016


 Membrane           User     Component Evaluation Load Case 2
      101            414     Plot Reference:
      MPa            MPa     8) Membrane < User (OPE,Membrane) Case 2

            24%


Tee Crotch Area

  Bending           User     Component Evaluation Load Case 2
       75            414     Plot Reference:
      MPa            MPa     9) Bending < User (OPE,Bending) Case 2

            18%


Tee Body

  Pl+Pb+Q            SPS     Primary+Secondary (Inner) Load Case 2
       83            414     Plot Reference:
      MPa            MPa     4) Pl+Pb+Q < SPS (OPE,Inside) Case 2

            19%


Tee Body

  Pl+Pb+Q            SPS     Primary+Secondary (Outer) Load Case 2
       90            414     Plot Reference:
      MPa            MPa     5) Pl+Pb+Q < SPS (OPE,Outside) Case 2

            21%


Tee Body

Pl+Pb+Q+F    Damage Ratio    Primary+Secondary+Peak (Inner) Load Case 2
       41     0.000 Life     Stress Concentration Factor = 1.000
      MPa     0.003 Stress   Strain Concentration Factor = 1.000
                             Cycles Allowed for this Stress = 1.0000E11
Allowable                    "B31" Fatigue Stress Allowable = 345.0
 12,236.4                    Markl Fatigue Stress Allowable = 1689.2
      MPa                    WRC 474 Mean Cycles to Failure = 7,419,715.
                             WRC 474 99% Probability Cycles = 1,723,667.
       0%                    WRC 474 95% Probability Cycles = 2,393,095.
                             BS5500 Allowed Cycles(Curve F) = 1,275,575.
                             Membrane-to-Bending Ratio = 3.052
                             Bending-to-PL+PB+Q Ratio = 0.247
                             Plot Reference:
                             6) Pl+Pb+Q+F < Sa (EXP,Inside) Case 2


Tee Body

Pl+Pb+Q+F    Damage Ratio    Primary+Secondary+Peak (Outer) Load Case 2
```

```
Highest Stresses Per Load Case  2                    26: 2:10 20 Aug 2016

      45     0.000 Life     Stress Concentration Factor = 1.000
     MPa     0.004 Stress   Strain Concentration Factor = 1.000
                            Cycles Allowed for this Stress = 1.0000E11
Allowable                   "B31" Fatigue Stress Allowable = 345.0
 12,236.4                   Markl Fatigue Stress Allowable = 1689.2
     MPa                    WRC 474 Mean Cycles to Failure = 6,344,108.
                            WRC 474 99% Probability Cycles = 1,473,794.
      0%                    WRC 474 95% Probability Cycles = 2,046,177.
                            BS5500 Allowed Cycles(Curve F) = 997,310.
                            Membrane-to-Bending Ratio = 0.728
                            Bending-to-PL+PB+Q Ratio = 0.579
                            Plot Reference:
                            7) Pl+Pb+Q+F < Sa (EXP,Outside) Case 2


Tee Body

 Membrane          User     Component Evaluation Load Case 2
      77            414     Plot Reference:
     MPa            MPa     8) Membrane < User (OPE,Membrane) Case 2

           18%


Tee Body

  Bending          User     Component Evaluation Load Case 2
      72            414     Plot Reference:
     MPa            MPa     9) Bending < User (OPE,Bending) Case 2

           17%
```

Stress Intensification Factors 26: 2:10 20 Aug 2016

Branch/Nozzle Sif Summary

	Peak	Primary	Secondary	SSI
Axial :	1.569	1.827	3.138	1.109
Inplane :	1.368	1.533	2.735	1.110
Outplane:	0.444	0.690	0.888	0.830
Torsion :	1.486	2.606	2.973	1.219
Pressure:	1.263	1.955	2.526	1.055

The above stress intensification factors are to be used in a beam-type analysis of the piping system. Inplane, Outplane and Torsional sif's should be used with the matching branch pipe whose diameter and thickness is given below. The axial sif should be used to intensify the axial stress in the branch pipe calculated by F/A. The pressure sif should be used to intensify the nominal pressure stress in the PARENT or HEADER, calculated from PDo/2T. B31 calculations use mean diameters and Section VIII calculations use outside diameters. SSIs are based on peak stress factors and correlated test results.

Pipe OD :	914.400	mm.
Pipe Thk:	9.525	mm.
Z approx:	6125361.500	cu.mm.
Z exact :	6062227.500	cu.mm.

(SSI = SIF^x)	Axial	Inpl	Outpl	Tors	Pres
SIF/SSI Exponents:	1.338	1.364	0.456	2.417	2.871

SIF/SSI exponent based on relationship between primary and peak stress factors from the finite element analysis.

B31.3 Branch Pressure i-factor = 3.849
Header Pressure i-factor = 2.553

The B31.3 pressure i-factors should be used with with F/A, where F is the axial force due to pressure, and A is the area of the pipe wall. This is equivalent to finding the pressure stress from (ip)(PD/4T).

B31.3 (Run)

Peak Stress Sif	0.000	Axial
	3.547	Inplane
	4.396	Outplane
	1.000	Torsional
From Markl	3.444	Inplane
	4.259	Outplane

B31.1 (Run)

Peak Stress Sif	0.000	Axial
	4.396	Inplane
	4.396	Outplane
	4.396	Torsional
From Markl	3.444	Inplane

Stress Intensification Factors 26: 2:10 20 Aug 2016

4.259 Outplane

Allowable Loads 26: 2:10 20 Aug 2016

SECONDARY Load Type (Range):		Maximum Individual Occuring	Conservative Simultaneous Occuring	Realistic Simultaneous Occuring
Axial Force	(N)	2368639.	540269.	810403.
Inplane Moment	(mm. N)	401423712.	64743916.	137342576.
Outplane Moment	(mm. N)	1236251008.	199389632.	422969280.
Torsional Moment	(mm. N)	369410880.	92989696.	139484544.
Pressure	(MPa)	3.41	1.08	1.08

PRIMARY Load Type:		Maximum Individual Occuring	Conservative Simultaneous Occuring	Realistic Simultaneous Occuring
Axial Force	(N)	2034090.	346638.	519957.
Inplane Moment	(mm. N)	358133184.	43155436.	91546504.
Outplane Moment	(mm. N)	795205440.	101837800.	216030592.
Torsional Moment	(mm. N)	210710224.	35908028.	53862040.
Pressure	(MPa)	2.21	1.08	1.08

NOTES:

1) Maximum Individual Occuring Loads are the maximum allowed values of the respective loads if all other load components are zero, i.e. the listed axial force may be applied if the inplane, outplane and torsional moments, and the pressure are zero.

2) The Conservative Allowable Simultaneous loads are the maximum loads that can be applied simultaneously. A conservative stress combination equation is used that typically produces stresses within 50-70% of the allowable stress.

3) The Realistic Allowable Simultaneous loads are the maximum loads that can be applied simultaneously. A more realistic stress combination equation is used based on experience at Paulin Research. Stresses are typically produced within 80-105% of the allowable.

4) Secondary allowable loads are limits for expansion and operating piping loads.

5) Primary allowable loads are limits for weight, primary and sustained type piping loads.

Flexibilities 26: 2:10 20 Aug 2016

The following stiffnesses should be used in a piping, "beam-type" analysis of the intersection. The stiffnesses should be inserted at the surface of the branch/header or nozzle/vessel junction. The general characteristics used for the branch pipe should be:

Outside Diameter = 609.600 mm.
Wall Thickness = 9.525 mm.

Inplane Rotational Stiffness = 33409327104. mm. N /deg
Torsional Rotational Stiffness = 19059507200. mm. N /deg

The following stiffness(es) were not generated because of errors in input or because the finite element model is stiffer than the piping model.

Axial Translational Stiffness
Outplane Rotational Stiffness

Intersection Flexibility Factors for Header/Run

Find axial stiffness: K = 3EI/(kd)^3 N /mm.
Find bending and torsional stiffnesses: K = EI/(kd) mm. N per radian.
The EI product is 0.55419E+15 N mm.^2
The value of (d) to use is: 904.875 mm..
The resulting bending stiffness is in units of force x length per radian.

Inplane Flexibility Factor (k) = 0.320
Torsional Flexibility Factor (k) = 0.561