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 : 914.400 mm.
Tee OD at Branch : 609.600 mm.

Tee Thk at Run : 9.525 mm.
Tee Thk at Branch : 9.525 mm.

Tee Crotch Radius : 97.536 mm.

Run Fitting Length : 1346.200 mm.
Br. Fitting Length : 631.976 mm.

-side Att. Pipe (Comp): 2743.200 mm.
+side Att. Pipe (Comp): 2743.200 mm.
Branch Att.Pipe (Comp): 1828.800 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): 9.525 mm.
Center 45deg (User): 9.525 mm.
Center Circ. (User): 9.525 mm.

Run Long. (User): 9.525 mm.
Run 45deg (User): 9.525 mm.
Run Circ. (User): 9.525 mm.

Branch Long. (User): 9.525 mm.
Branch 45deg (User): 9.525 mm.
Branch Circ. (User): 9.525 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	Include Weight Loads (Y/N)
0.000, -1.000, 0.000	Direction of Gravity (vx,vy,vz)
YES	Include Pressure Loads (Y/N)
YES	Include Thermal Loads (Y/N)
NO	Include Wind Loads (Y/N)
OCC	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   ———————————————————————————————————————

      914.400 <———— OD Fitting at Run Pipe Connection (mm.)
      609.600 <———— 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.)
      631.976 <———— Fitting Height, Centerline to branch weld (mm.)

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

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

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

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

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

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

Attached Pipe Dimensions

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

   2743.200   <———— Left   End  Pipe Length (mm.)
  2743.200    <———— Right  End  Pipe Length (mm.)
    1828.800  <———— 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.)
```

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 44: 5:10 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	693139.	1.	0.
2	693139.	1.	0.
3	191675392.	0.	0.
4	0.	0.	0.
5	0.	0.	0.
6	0.	0.	0.
7	693139.	1.	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 44: 5:10 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 44: 5:10 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) ...     7079.  MPa
  Case   4
  Nominal Stress   (M/Z) ...       32.  MPa
  Case   5
  Nominal Stress   (M/Z) ...       32.  MPa
  Case   6
  Nominal Stress   (M/Z) ...       32.  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) ...     7079.  MPa
  Case   4
  Nominal Stress   (M/Z) ...       32.  MPa
  Case   5
  Nominal Stress   (M/Z) ...       32.  MPa
  Case   6
  Nominal Stress   (M/Z) ...       32.  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 44: 5:10 20 Aug 2016

Expansion Stress MPa	B31 Allowable MPa	ASME Allowable MPa	Markl Allowable MPa	Regions / Notes
104.	345.	12236.	1689.	Tee Crotch Area Load Case 2, Inner, Plot 6
77.	345.	12236.	1689.	Tee Body Load Case 2, Outer, Plot 7

ASME Overstressed Areas 44: 5:10 20 Aug 2016

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

Highest Primary Stress Ratios 44: 5:10 20 Aug 2016

Tee Crotch Area

Pl	(1.5)(S)	Primary Membrane Load Case 1
168	207	Plot Reference:
MPa	MPa	1) Pl < (1.5)(S) (SUS,Membrane) Case 1

81%

Tee Body

Pl	(1.5)(S)	Primary Membrane Load Case 1
126	207	Plot Reference:
MPa	MPa	1) Pl < (1.5)(S) (SUS,Membrane) Case 1

60%

Highest Secondary Stress Ratios 44: 5:10 20 Aug 2016

Tee Crotch Area

Pl+Pb+Q	SPS	Primary+Secondary (Inner) Load Case 2
208	414	Plot Reference:
MPa	MPa	4) Pl+Pb+Q < SPS (OPE,Inside) Case 2

50%

Tee Body

Pl+Pb+Q	SPS	Primary+Secondary (Outer) Load Case 2
154	414	Plot Reference:
MPa	MPa	5) Pl+Pb+Q < SPS (OPE,Outside) Case 2

37%

```
Highest Fatigue Stress Ratios                        44: 5:10 20 Aug 2016


Tee Crotch Area

Pl+Pb+Q+F    Damage Ratio    Primary+Secondary+Peak (Inner) Load Case 2
      104     0.000 Life     Stress Concentration Factor = 1.000
      MPa     0.008 Stress   Strain Concentration Factor = 1.000
                             Cycles Allowed for this Stress = 260,275.
Allowable                    "B31" Fatigue Stress Allowable = 345.0
 12,236.4                    Markl Fatigue Stress Allowable = 1689.2
      MPa                    WRC 474 Mean Cycles to Failure = 599,503.
                             WRC 474 99% Probability Cycles = 139,270.
       0%                    WRC 474 95% Probability Cycles = 193,359.
                             BS5500 Allowed Cycles(Curve F) = 80,779.
                             Membrane-to-Bending Ratio = 2.743
                             Bending-to-PL+PB+Q Ratio = 0.267
                             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
       77     0.000 Life     Stress Concentration Factor = 1.000
      MPa     0.006 Stress   Strain Concentration Factor = 1.000
                             Cycles Allowed for this Stress = 4,738,299.
Allowable                    "B31" Fatigue Stress Allowable = 345.0
 12,236.4                    Markl Fatigue Stress Allowable = 1689.2
      MPa                    WRC 474 Mean Cycles to Failure = 1,694,395.
                             WRC 474 99% Probability Cycles = 393,623.
       0%                    WRC 474 95% Probability Cycles = 546,496.
                             BS5500 Allowed Cycles(Curve F) = 198,887.
                             Membrane-to-Bending Ratio = 0.606
                             Bending-to-PL+PB+Q Ratio = 0.623
                             Plot Reference:
                             7) Pl+Pb+Q+F < Sa (EXP,Outside) Case 2
```

```
 Highest Stress Ratios Per Region                      44: 5:10 20 Aug 2016


 Tee Crotch Area

        Pl       (1.5)(S)     Primary Membrane Load Case 1
       168            207     Plot Reference:
       MPa            MPa     1) Pl < (1.5)(S) (SUS,Membrane) Case 1

             81%

        Qb            SPS     Primary Bending Load Case 1
       142            414     Plot Reference:
       MPa            MPa     2) Qb < SPS (SUS,Bending) Case 1

             34%

  S1+S2+S3             4S     Part 5 (5.3.2) Load Case 1
       210            552     Plot Reference:
       MPa            MPa     3) S1+S2+S3 < 4S (SUS,S1+S2+S3) Case 1

             37%

   Pl+Pb+Q            SPS     Primary+Secondary (Inner) Load Case 2
       208            414     Plot Reference:
       MPa            MPa     4) Pl+Pb+Q < SPS (OPE,Inside) Case 2

             50%

   Pl+Pb+Q            SPS     Primary+Secondary (Outer) Load Case 2
       189            414     Plot Reference:
       MPa            MPa     5) Pl+Pb+Q < SPS (OPE,Outside) Case 2

             45%

 Pl+Pb+Q+F    Damage Ratio    Primary+Secondary+Peak (Inner) Load Case 2
       104     0.000 Life     Stress Concentration Factor = 1.000
       MPa     0.008 Stress   Strain Concentration Factor = 1.000
                              Cycles Allowed for this Stress = 260,275.
 Allowable                    "B31" Fatigue Stress Allowable = 345.0
  12,236.4                    Markl Fatigue Stress Allowable = 1689.2
       MPa                    WRC 474 Mean Cycles to Failure = 599,503.
                              WRC 474 99% Probability Cycles = 139,270.
        0%                    WRC 474 95% Probability Cycles = 193,359.
                              BS5500 Allowed Cycles(Curve F) = 80,779.
                              Membrane-to-Bending Ratio = 2.743
                              Bending-to-PL+PB+Q Ratio = 0.267
                              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
        94     0.000 Life     Stress Concentration Factor = 1.000
       MPa     0.008 Stress   Strain Concentration Factor = 1.000
                              Cycles Allowed for this Stress = 402,206.
 Allowable                    "B31" Fatigue Stress Allowable = 345.0
  12,236.4                    Markl Fatigue Stress Allowable = 1689.2
       MPa                    WRC 474 Mean Cycles to Failure = 799,285.
                              WRC 474 99% Probability Cycles = 185,681.
```

```
Highest Stress Ratios Per Region                      44: 5:10 20 Aug 2016

       0%                    WRC 474 95% Probability Cycles = 257,795.
                             BS5500 Allowed Cycles(Curve F) = 107,519.
                             Membrane-to-Bending Ratio = 4.984
                             Bending-to-PL+PB+Q Ratio = 0.167
                             Plot Reference:
                             7) Pl+Pb+Q+F < Sa (EXP,Outside) Case 2

 Membrane           User     Component Evaluation Load Case 2
      168            414     Plot Reference:
      MPa            MPa     8) Membrane < User (OPE,Membrane) Case 2

            40%

  Bending           User     Component Evaluation Load Case 2
      142            414     Plot Reference:
      MPa            MPa     9) Bending < User (OPE,Bending) Case 2

            34%


Tee Body

       Pl       (1.5)(S)     Primary Membrane Load Case 1
      126            207     Plot Reference:
      MPa            MPa     1) Pl < (1.5)(S) (SUS,Membrane) Case 1

            60%

       Qb            SPS     Primary Bending Load Case 1
      129            414     Plot Reference:
      MPa            MPa     2) Qb < SPS (SUS,Bending) Case 1

            31%

 S1+S2+S3             4S     Part 5 (5.3.2) Load Case 1
      171            552     Plot Reference:
      MPa            MPa     3) S1+S2+S3 < 4S (SUS,S1+S2+S3) Case 1

            30%

  Pl+Pb+Q            SPS     Primary+Secondary (Inner) Load Case 2
      138            414     Plot Reference:
      MPa            MPa     4) Pl+Pb+Q < SPS (OPE,Inside) Case 2

            33%

  Pl+Pb+Q            SPS     Primary+Secondary (Outer) Load Case 2
      154            414     Plot Reference:
      MPa            MPa     5) Pl+Pb+Q < SPS (OPE,Outside) Case 2

            37%

Pl+Pb+Q+F    Damage Ratio    Primary+Secondary+Peak (Inner) Load Case 2
       69     0.000 Life     Stress Concentration Factor = 1.000
      MPa     0.006 Stress   Strain Concentration Factor = 1.000
                             Cycles Allowed for this Stress = 39,180,460.
```

```
Highest Stress Ratios Per Region                       44: 5:10 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 = 2,140,100.
                             WRC 474 99% Probability Cycles = 497,165.
       0%                    WRC 474 95% Probability Cycles = 690,251.
                             BS5500 Allowed Cycles(Curve F) = 276,818.
                             Membrane-to-Bending Ratio = 4.819
                             Bending-to-PL+PB+Q Ratio = 0.172
                             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
       77     0.000 Life     Stress Concentration Factor = 1.000
      MPa     0.006 Stress   Strain Concentration Factor = 1.000
                             Cycles Allowed for this Stress = 4,738,299.
Allowable                    "B31" Fatigue Stress Allowable = 345.0
 12,236.4                    Markl Fatigue Stress Allowable = 1689.2
      MPa                    WRC 474 Mean Cycles to Failure = 1,694,395.
                             WRC 474 99% Probability Cycles = 393,623.
       0%                    WRC 474 95% Probability Cycles = 546,496.
                             BS5500 Allowed Cycles(Curve F) = 198,887.
                             Membrane-to-Bending Ratio = 0.606
                             Bending-to-PL+PB+Q Ratio = 0.623
                             Plot Reference:
                             7) Pl+Pb+Q+F < Sa (EXP,Outside) Case 2

 Membrane           User     Component Evaluation Load Case 2
      126            414     Plot Reference:
      MPa            MPa     8) Membrane < User (OPE,Membrane) Case 2

           30%

  Bending           User     Component Evaluation Load Case 2
      129            414     Plot Reference:
      MPa            MPa     9) Bending < User (OPE,Bending) Case 2

           31%
```

```
Highest Stresses Per Load Case  1                      44: 5:10 20 Aug 2016


Tee Crotch Area

       Pl       (1.5)(S)     Primary Membrane Load Case 1
      168            207     Plot Reference:
      MPa            MPa     1) Pl < (1.5)(S) (SUS,Membrane) Case 1

            81%


Tee Crotch Area

       Qb            SPS     Primary Bending Load Case 1
      142            414     Plot Reference:
      MPa            MPa     2) Qb < SPS (SUS,Bending) Case 1

            34%


Tee Crotch Area

 S1+S2+S3             4S     Part 5 (5.3.2) Load Case 1
      210            552     Plot Reference:
      MPa            MPa     3) S1+S2+S3 < 4S (SUS,S1+S2+S3) Case 1

            37%


Tee Body

       Pl       (1.5)(S)     Primary Membrane Load Case 1
      126            207     Plot Reference:
      MPa            MPa     1) Pl < (1.5)(S) (SUS,Membrane) Case 1

            60%


Tee Body

       Qb            SPS     Primary Bending Load Case 1
      129            414     Plot Reference:
      MPa            MPa     2) Qb < SPS (SUS,Bending) Case 1

            31%


Tee Body

 S1+S2+S3             4S     Part 5 (5.3.2) Load Case 1
      171            552     Plot Reference:
      MPa            MPa     3) S1+S2+S3 < 4S (SUS,S1+S2+S3) Case 1

            30%
```

```
 Highest Stresses Per Load Case  2                      44: 5:10 20 Aug 2016


 Tee Crotch Area

   Pl+Pb+Q            SPS     Primary+Secondary (Inner) Load Case 2
       208            414     Plot Reference:
       MPa            MPa     4) Pl+Pb+Q < SPS (OPE,Inside) Case 2

             50%


 Tee Crotch Area

   Pl+Pb+Q            SPS     Primary+Secondary (Outer) Load Case 2
       189            414     Plot Reference:
       MPa            MPa     5) Pl+Pb+Q < SPS (OPE,Outside) Case 2

             45%


 Tee Crotch Area

 Pl+Pb+Q+F    Damage Ratio    Primary+Secondary+Peak (Inner) Load Case 2
       104     0.000 Life     Stress Concentration Factor = 1.000
       MPa     0.008 Stress   Strain Concentration Factor = 1.000
                              Cycles Allowed for this Stress = 260,275.
 Allowable                    "B31" Fatigue Stress Allowable = 345.0
  12,236.4                    Markl Fatigue Stress Allowable = 1689.2
       MPa                    WRC 474 Mean Cycles to Failure = 599,503.
                              WRC 474 99% Probability Cycles = 139,270.
        0%                    WRC 474 95% Probability Cycles = 193,359.
                              BS5500 Allowed Cycles(Curve F) = 80,779.
                              Membrane-to-Bending Ratio = 2.743
                              Bending-to-PL+PB+Q Ratio = 0.267
                              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
        94     0.000 Life     Stress Concentration Factor = 1.000
       MPa     0.008 Stress   Strain Concentration Factor = 1.000
                              Cycles Allowed for this Stress = 402,206.
 Allowable                    "B31" Fatigue Stress Allowable = 345.0
  12,236.4                    Markl Fatigue Stress Allowable = 1689.2
       MPa                    WRC 474 Mean Cycles to Failure = 799,285.
                              WRC 474 99% Probability Cycles = 185,681.
        0%                    WRC 474 95% Probability Cycles = 257,795.
                              BS5500 Allowed Cycles(Curve F) = 107,519.
                              Membrane-to-Bending Ratio = 4.984
                              Bending-to-PL+PB+Q Ratio = 0.167
                              Plot Reference:
                              7) Pl+Pb+Q+F < Sa (EXP,Outside) Case 2


 Tee Crotch Area
```

```
 Highest Stresses Per Load Case  2                     44: 5:10 20 Aug 2016


  Membrane           User     Component Evaluation Load Case 2
       168            414     Plot Reference:
       MPa            MPa     8) Membrane < User (OPE,Membrane) Case 2

             40%


 Tee Crotch Area

   Bending           User     Component Evaluation Load Case 2
       142            414     Plot Reference:
       MPa            MPa     9) Bending < User (OPE,Bending) Case 2

             34%


 Tee Body

   Pl+Pb+Q            SPS     Primary+Secondary (Inner) Load Case 2
       138            414     Plot Reference:
       MPa            MPa     4) Pl+Pb+Q < SPS (OPE,Inside) Case 2

             33%


 Tee Body

   Pl+Pb+Q            SPS     Primary+Secondary (Outer) Load Case 2
       154            414     Plot Reference:
       MPa            MPa     5) Pl+Pb+Q < SPS (OPE,Outside) Case 2

             37%


 Tee Body

 Pl+Pb+Q+F    Damage Ratio    Primary+Secondary+Peak (Inner) Load Case 2
        69     0.000 Life     Stress Concentration Factor = 1.000
       MPa     0.006 Stress   Strain Concentration Factor = 1.000
                              Cycles Allowed for this Stress = 39,180,460.
 Allowable                    "B31" Fatigue Stress Allowable = 345.0
  12,236.4                    Markl Fatigue Stress Allowable = 1689.2
       MPa                    WRC 474 Mean Cycles to Failure = 2,140,100.
                              WRC 474 99% Probability Cycles = 497,165.
        0%                    WRC 474 95% Probability Cycles = 690,251.
                              BS5500 Allowed Cycles(Curve F) = 276,818.
                              Membrane-to-Bending Ratio = 4.819
                              Bending-to-PL+PB+Q Ratio = 0.172
                              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 44: 5:10 20 Aug 2016

77	0.000 Life	Stress Concentration Factor = 1.000
MPa	0.006 Stress	Strain Concentration Factor = 1.000
		Cycles Allowed for this Stress = 4,738,299.
Allowable		"B31" Fatigue Stress Allowable = 345.0
12,236.4		Markl Fatigue Stress Allowable = 1689.2
MPa		WRC 474 Mean Cycles to Failure = 1,694,395.
		WRC 474 99% Probability Cycles = 393,623.
0%		WRC 474 95% Probability Cycles = 546,496.
		BS5500 Allowed Cycles(Curve F) = 198,887.
		Membrane-to-Bending Ratio = 0.606
		Bending-to-PL+PB+Q Ratio = 0.623
		Plot Reference:
		7) Pl+Pb+Q+F < Sa (EXP,Outside) Case 2

Tee Body

Membrane	User	Component Evaluation Load Case 2
126	414	Plot Reference:
MPa	MPa	8) Membrane < User (OPE,Membrane) Case 2
30%		

Tee Body

Bending	User	Component Evaluation Load Case 2
129	414	Plot Reference:
MPa	MPa	9) Bending < User (OPE,Bending) Case 2
31%		

Stress Intensification Factors 44: 5:10 20 Aug 2016

Branch/Nozzle Sif Summary

	Peak	Primary	Secondary	SSI
Axial :	2.258	3.116	4.515	1.206
Inplane :	1.915	2.633	3.830	1.242
Outplane:	0.701	1.083	1.402	0.922
Torsion :	2.660	4.806	5.320	1.631
Pressure:	2.006	3.248	4.012	1.174

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:	1.395	1.490	-0.223	1.605	1.692

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

B31.3 Branch Pressure i-factor = 6.114
Header Pressure i-factor = 4.055

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	8.023	Inplane
	10.364	Outplane
B31.1 (Run)		
Peak Stress Sif	0.000	Axial
	4.396	Inplane
	4.396	Outplane
	4.396	Torsional
From Markl	8.023	Inplane

Stress Intensification Factors 44: 5:10 20 Aug 2016

10.364 Outplane

Allowable Loads 44: 5:10 20 Aug 2016

SECONDARY Load Type (Range):		Maximum Individual Occuring	Conservative Simultaneous Occuring	Realistic Simultaneous Occuring
Axial Force	(N)	1646375.	273580.	410370.
Inplane Moment	(mm. N)	286708128.	33688412.	71463912.
Outplane Moment	(mm. N)	783169536.	92022984.	195210224.
Torsional Moment	(mm. N)	206413872.	37154712.	55732068.
Pressure	(MPa)	2.15	1.08	1.08

PRIMARY Load Type:		Maximum Individual Occuring	Conservative Simultaneous Occuring	Realistic Simultaneous Occuring
Axial Force	(N)	1193059.	74771.	112157.
Inplane Moment	(mm. N)	208552256.	9242144.	19605548.
Outplane Moment	(mm. N)	507149152.	22474682.	47676000.
Torsional Moment	(mm. N)	114242344.	7159784.	10739676.
Pressure	(MPa)	1.33	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 44: 5:10 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.

Axial Translational Stiffness   =       7290102.   N /mm.
Inplane Rotational Stiffness    =    7208148480.  mm. N /deg
Torsional Rotational Stiffness  =    4587169792.  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.

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.

Axial Flexibility Factor     (k) =     0.675
Inplane Flexibility Factor   (k) =     1.483
Torsional Flexibility Factor (k) =     2.330
```