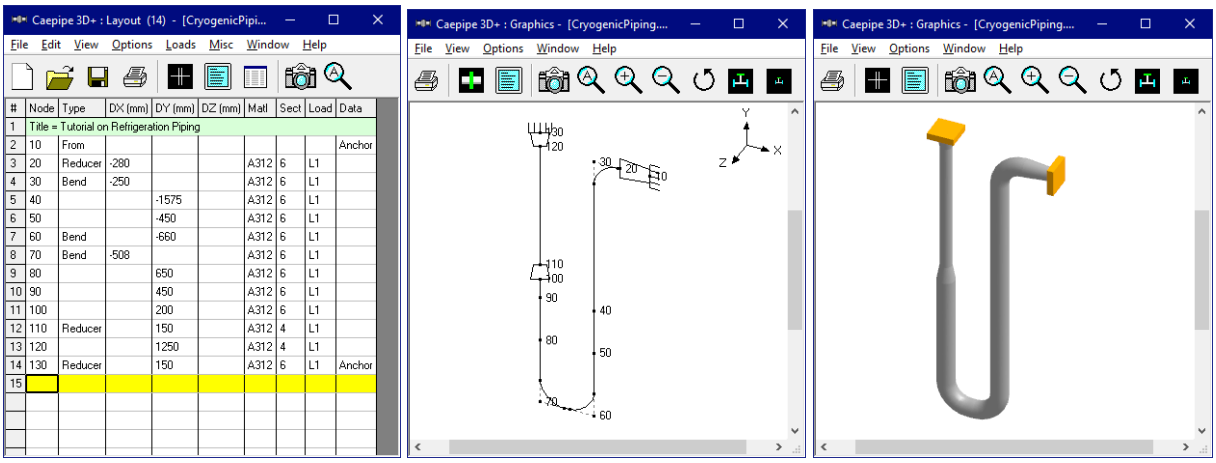
Tutorial on Cryogenic Piping using CAEPIPE

Steps to perform Analysis of Cryogenic Piping with ASME B31.5 Code using CAEPIPE:

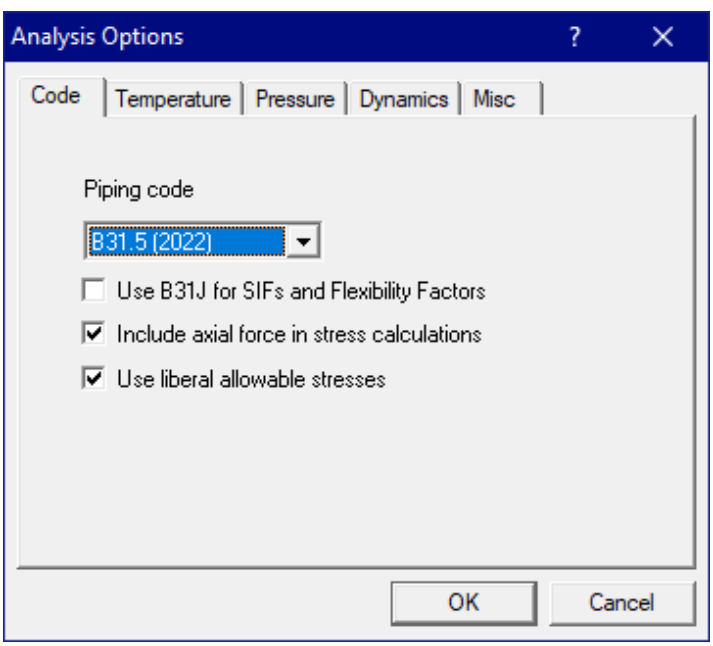
The snap shot below shows the sample layout of a cryogenic piping system. The system experiences an Operating Temperature during its operation as -130 deg. C with its Design Temperature as -195 deg. C. The installation temperature is 20 deg. C. For this cryogenic piping, the analysis code is selected as ASME B31.5 as this code is used for Refrigeration Piping analysis that includes sub-zero temperatures.



#	Node	Type	DX (mm)	DY (mm)	DZ (mm)	Matl	Sect	Load	Data
1	Title = Tutorial on Refrigeration Piping								
2	10	From							Anchor
3	20	Reducer	-280			A312	6	L1	
4	30	Bend	-250			A312	6	L1	
5	40			-1575		A312	6	L1	
6	50			-450		A312	6	L1	
7	60	Bend		-660		A312	6	L1	
8	70	Bend	-508			A312	6	L1	
9	80			650		A312	6	L1	
10	90			450		A312	6	L1	
11	100			200		A312	6	L1	
12	110	Reducer		150		A312	4	L1	
13	120			1250		A312	4	L1	
14	130	Reducer		150		A312	6	L1	Anchor
15									

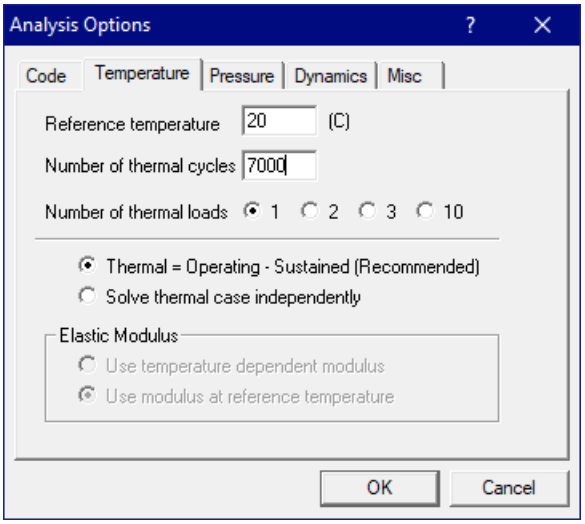
Step 1:

Select the Analysis code as ASME B31.5 (2022) through Layout Window > Options > Analysis as shown below.



Step 2:

As the piping layout involves one (1) operating temperature, “Number of Thermal Loads” needs to be set as “1”. This can be done through Layout Window > Analysis > Temperature as shown below. In addition, the installation temperature (same as “Reference temperature”) can be input as shown below.

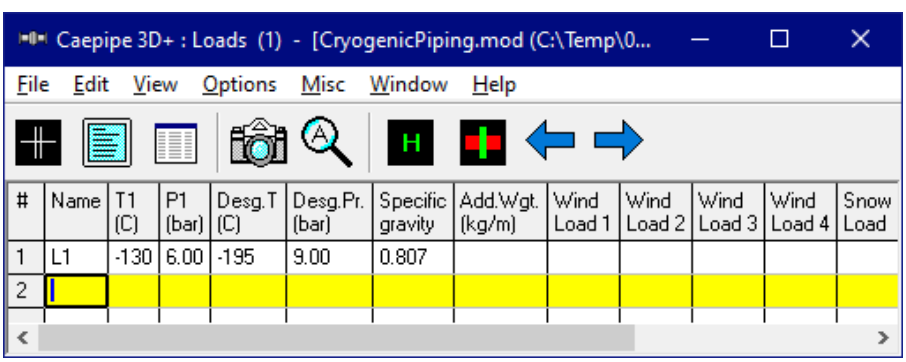


Note:

As per para. 519.4.5(a) of ASME B31.5 (2022), bending and torsional stresses shall be computed using the as-installed modulus of elasticity, i.e., E_c at installation temperature (same as “Reference temperature”). Hence, "Use modulus at reference temperature" is set as "default" and is disabled for user to modify.

Step 3:

Enter the Operating Temperature (T1), Operating Pressure (P1), Design Temperature (Desg. T) and Design Pressure (Desg. Pr) of the piping layout through “Layout Window > Misc > Loads” as shown below. Specific Gravity of the Liquid Nitrogen with respect to water is entered as 0.807 to include the content weight in the analysis. From the link https://demaco-cryogenics.com/blog/liquid-nitrogen-density-and-weight/, the density of the Liquid Nitrogen is taken as 807 kg/m3 at -196 deg. C.



Note:

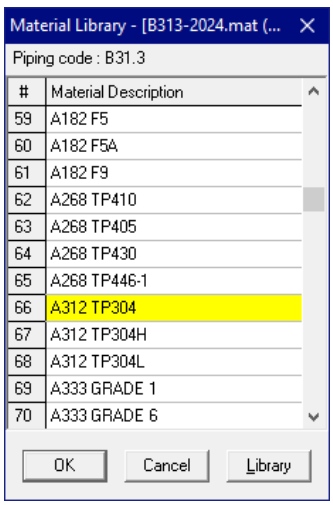
Design Temperature entered will be used to determine the allowable stress for material, which is in turn used to compute the Allowable Pressure as per the piping code selected (B31.5 in this case).

The Allowable Pressure so computed as per the piping code selected is then compared against the Design Pressure entered above and reported in the Code Compliance results.

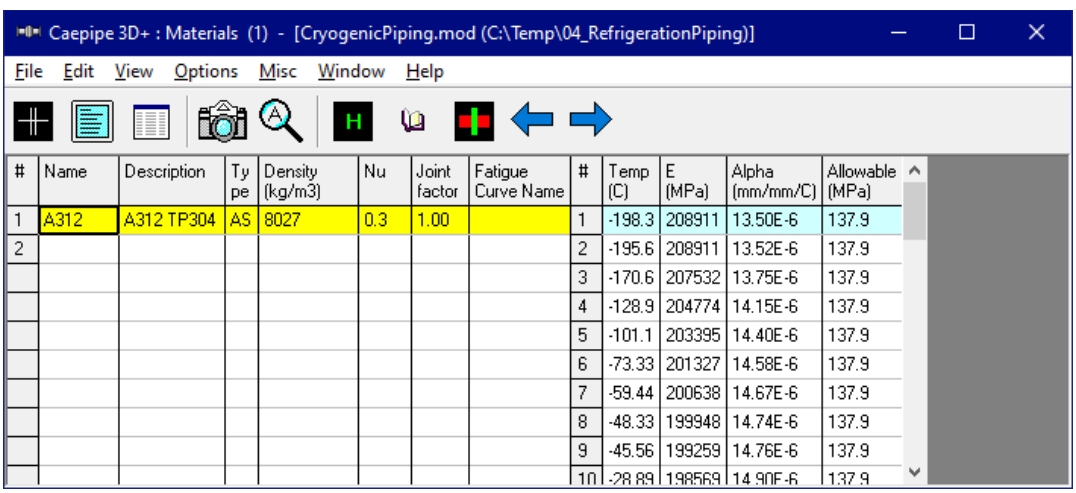
In addition, when Design (W+PD+TD) load case is selected for Analysis, CAEPIPE will compute and show results for Displacements, Element Forces & Moments, Support Loads and Support Load Summary. This Design load case is NOT included in Stress Calculations, Rotating Equipment Qualifications and Flange Equivalent Pressure Calculations, as many of the piping and equipment codes do not require the qualification to be carried out at Design condition.

Step 4:

Material properties corresponding to the cryogenic temperature considered for this analysis are not available in ASME B31.5 (2022) code. On the other hand, ASME B31.3 (2024) code includes several materials for sub-zero temperatures. For example, for this analysis, we have chosen a material with name ASTM A312 TP304 that contains mechanical properties corresponding to the sub-zero temperatures up to -198 deg. C from the ASME B31.3 (2024) Material library. This material library supplied with CAEPIPE software is available in the CAEPIPE installation folder\Material_Library. The material from this library can be selected through “Layout Window > Misc > Materials > File > Library…> Library > Material_Library > B313-2024.mat”.



From the dialog box shown, select the Material as A312 TP304 and press the button “OK”.

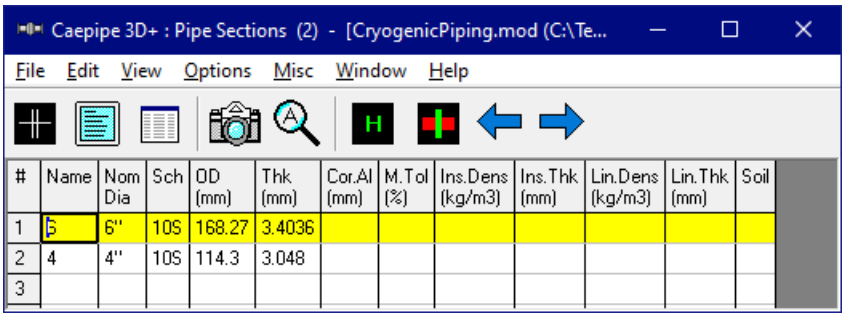


#	Name	Description	Type	Density (kg/m3)	Nu	Joint factor	Fatigue Curve Name
1	A312	A312 TP304	AS	8027	0.3	1.00	
2							

#	Temp (C)	E (MPa)	Alpha (mm/mm/C)	Allowable (MPa)
1	-198.3	208911	13.50E-6	137.9
2	-195.6	208911	13.52E-6	137.9
3	-170.6	207532	13.75E-6	137.9
4	-128.9	204774	14.15E-6	137.9
5	-101.1	203395	14.40E-6	137.9
6	-73.33	201327	14.58E-6	137.9
7	-59.44	200638	14.67E-6	137.9
8	-48.33	199948	14.74E-6	137.9
9	-45.56	199259	14.76E-6	137.9
10	-28.89	198569	14.90E-6	137.9

Step 5:

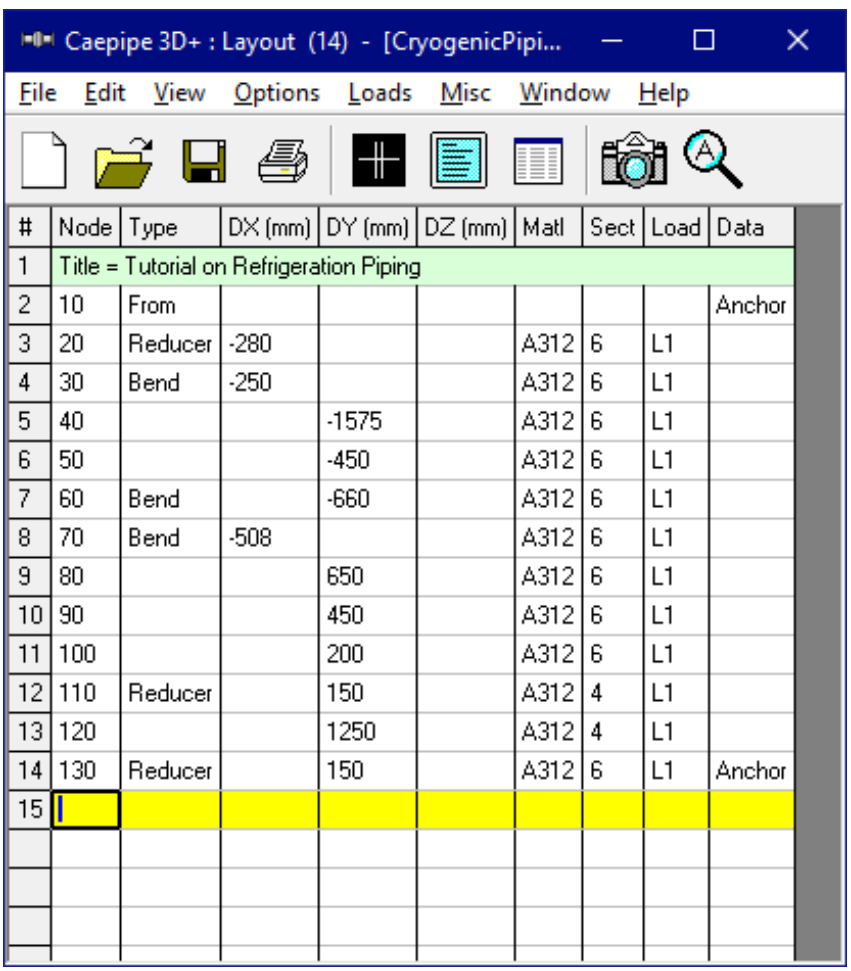
Define the section properties through “Layout Window > Misc > Sections”.



#	Name	Nom Dia	Sch	OD (mm)	Thk (mm)	Cor.Al (mm)	M.Tol (%)	Ins.Dens (kg/m3)	Ins.Thk (mm)	Lin.Dens (kg/m3)	Lin.Thk (mm)	Soil
1	6	6"	10S	168.27	3.4036							
2	4	4"	10S	114.3	3.048							
3												

Step 6:

Generate the piping layout as shown below.



#	Node	Type	DX (mm)	DY (mm)	DZ (mm)	Matl	Sect	Load	Data
1	Title = Tutorial on Refrigeration Piping								
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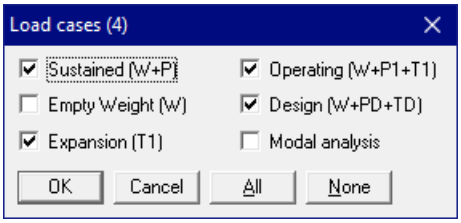
4	30	Bend	-250			A312	6	L1	
5	40			-1575		A312	6	L1	
6	50			-450		A312	6	L1	
7	60	Bend		-660		A312	6	L1	
8	70	Bend	-508			A312	6	L1	
9	80			650		A312	6	L1	
10	90			450		A312	6	L1	
11	100			200		A312	6	L1	
12	110	Reducer		150		A312	4	L1	
13	120			1250		A312	4	L1	
14	130	Reducer		150		A312	6	L1	Anchor
15									

Step 7:

After creating the stress model, turn ON load cases through “Layout Window > Loads > Load cases as follows: Expansion (T1) {which is the same as the range (T1 – Tref)}.

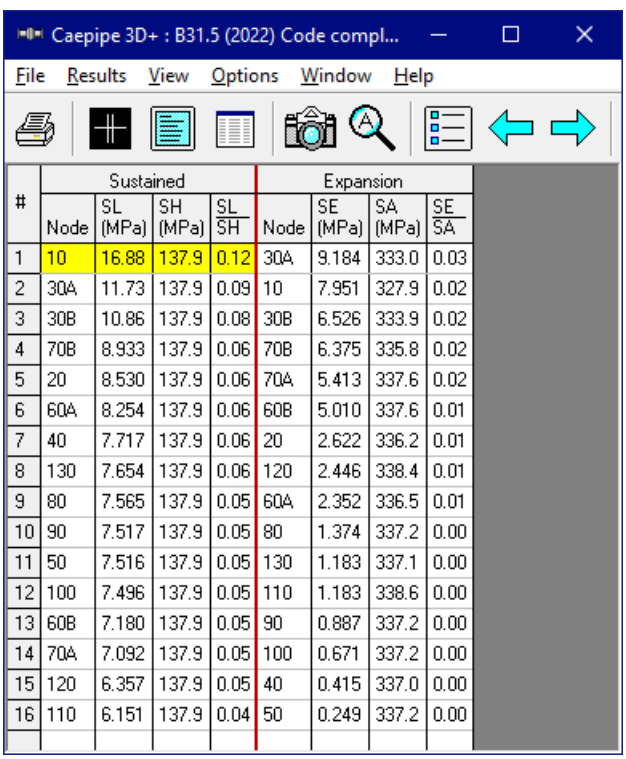


Step 8:

Save the model and perform analysis through Layout window > File > Analyze.

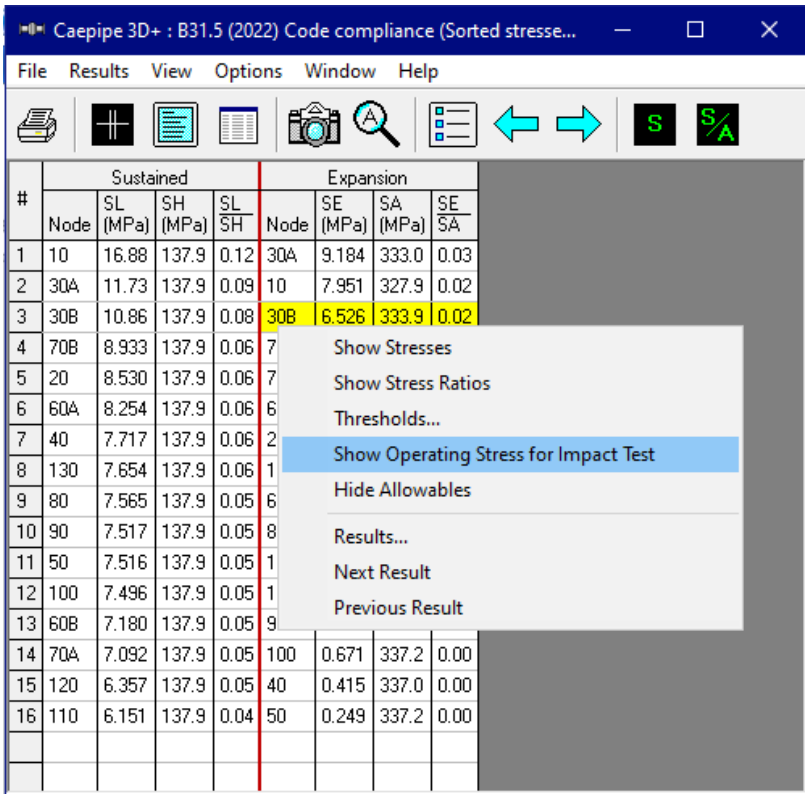
In order to understand the loads and load combinations used for analysis, review the CAEPIPE results file for Sorted Stress, Code Compliance, Displacements, Support Loads (loads acting on the supports by the piping for each load case), Element Forces & Moments (local/global forces and moments on each element for each load case) and Support Load Summary (listing support loads at a particular support for all relevant load cases and load combinations).

As stated above, Sorted Stresses in CAEPIPE lists the maximum of Expansion stresses for all thermal range cases at each node (only T1 – Tref in this case). On the other hand, for Sustained case, it always uses the maximum pressure among the input pressures (only P1 in this case) while computing Sustained Stress at each node.

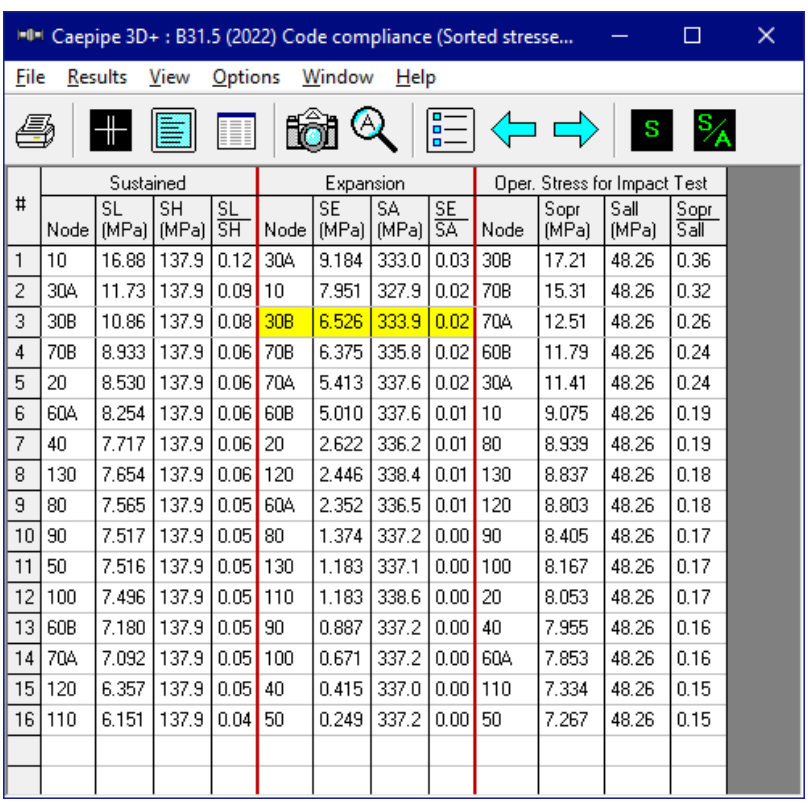


#	Sustained				Expansion			
	Node	SL (MPa)	SH (MPa)	SL/SH	Node	SE (MPa)	SA (MPa)	SE/SA
1	10	16.88	137.9	0.12	30A	9.184	333.0	0.03
2	30A	11.73	137.9	0.09	10	7.951	327.9	0.02
3	30B	10.86	137.9	0.08	30B	6.526	333.9	0.02
4	70B	8.933	137.9	0.06	70B	6.375	335.8	0.02
5	20	8.530	137.9	0.06	70A	5.413	337.6	0.02
6	60A	8.254	137.9	0.06	60B	5.010	337.6	0.01
7	40	7.717	137.9	0.06	20	2.622	336.2	0.01
8	130	7.654	137.9	0.06	120	2.446	338.4	0.01
9	80	7.565	137.9	0.05	60A	2.352	336.5	0.01
10	90	7.517	137.9	0.05	80	1.374	337.2	0.00
11	50	7.516	137.9	0.05	130	1.183	337.1	0.00
12	100	7.496	137.9	0.05	110	1.183	338.6	0.00
13	60B	7.180	137.9	0.05	90	0.887	337.2	0.00
14	70A	7.092	137.9	0.05	100	0.671	337.2	0.00
15	120	6.357	137.9	0.05	40	0.415	337.0	0.00
16	110	6.151	137.9	0.04	50	0.249	337.2	0.00

Operating Stress for Impact Test can be seen by selecting the option “Show Operating Stress for Impact Test” through Mouse Right click.



#	Sustained				Expansion			
	Node	SL (MPa)	SH (MPa)	SL/SH	Node	SE (MPa)	SA (MPa)	SE/SA
1	10	16.88	137.9	0.12	30A	9.184	333.0	0.03
2	30A	11.73	137.9	0.09	10	7.951	327.9	0.02
3	30B	10.86	137.9	0.08	30B	6.526	333.9	0.02
4	70B	8.933	137.9	0.06	7			
5	20	8.530	137.9	0.06	7			
6	60A	8.254	137.9	0.06	6			
7	40	7.717	137.9	0.06	2			
8	130	7.654	137.9	0.06	1			
9	80	7.565	137.9	0.05	6			
10	90	7.517	137.9	0.05	8			
11	50	7.516	137.9	0.05	1			
12	100	7.496	137.9	0.05	1			
13	60B	7.180	137.9	0.05	9			
14	70A	7.092	137.9	0.05	100	0.671	337.2	0.00
15	120	6.357	137.9	0.05	40	0.415	337.0	0.00
16	110	6.151	137.9	0.04	50	0.249	337.2	0.00



#	Sustained				Expansion				Oper. Stress for Impact Test			
	Node	SL (MPa)	SH (MPa)	SL/SH	Node	SE (MPa)	SA (MPa)	SE/SA	Node	Sopr (MPa)	Sall (MPa)	Sopr/Sall
1	10	16.88	137.9	0.12	30A	9.184	333.0	0.03	30B	17.21	48.26	0.36
2	30A	11.73	137.9	0.09	10	7.951	327.9	0.02	70B	15.31	48.26	0.32
3	30B	10.86	137.9	0.08	30B	6.526	333.9	0.02	70A	12.51	48.26	0.26
4	70B	8.933	137.9	0.06	70B	6.375	335.8	0.02	60B	11.79	48.26	0.24
5	20	8.530	137.9	0.06	70A	5.413	337.6	0.02	30A	11.41	48.26	0.24
6	60A	8.254	137.9	0.06	60B	5.010	337.6	0.01	10	9.075	48.26	0.19
7	40	7.717	137.9	0.06	20	2.622	336.2	0.01	80	8.939	48.26	0.19
8	130	7.654	137.9	0.06	120	2.446	338.4	0.01	130	8.837	48.26	0.18
9	80	7.565	137.9	0.05	60A	2.352	336.5	0.01	120	8.803	48.26	0.18
10	90	7.517	137.9	0.05	80	1.374	337.2	0.00	90	8.405	48.26	0.17
11	50	7.516	137.9	0.05	130	1.183	337.1	0.00	100	8.167	48.26	0.17
12	100	7.496	137.9	0.05	110	1.183	338.6	0.00	20	8.053	48.26	0.17
13	60B	7.180	137.9	0.05	90	0.887	337.2	0.00	40	7.955	48.26	0.16
14	70A	7.092	137.9	0.05	100	0.671	337.2	0.00	60A	7.853	48.26	0.16
15	120	6.357	137.9	0.05	40	0.415	337.0	0.00	110	7.334	48.26	0.15
16	110	6.151	137.9	0.04	50	0.249	337.2	0.00	50	7.267	48.26	0.15

Similarly, Code Compliance report lists the Stresses element-wise following the same procedure as done for Sorted Stresses.

Caepipe 3D+ : B31.5 (2022) Code Compliance - [CryogenicP...

File Results View Options Window Help

#	Node	Press. Allow. (bar)	Sustained SL (MPa)	Sustained SH (MPa)	Sustained SL/SH	Expansion SE (MPa)	Expansion SA (MPa)	Expansion SE/SA
1	10	9.00	16.88	137.9	0.12	7.951	327.9	0.02
	20		8.530	137.9	0.06	2.622	336.2	0.01
2	20	9.00	8.530	137.9	0.06	2.622	336.2	0.01
	30A	56.7	8.297	137.9	0.06	2.575	336.4	0.01
3	30A	9.00	11.73	137.9	0.09	9.184	333.0	0.03
	30B	56.7	10.86	137.9	0.08	6.526	333.9	0.02
4	30B	9.00	8.319	137.9	0.06	1.871	336.4	0.01
	40	56.7	7.717	137.9	0.06	0.415	337.0	0.00
5	40	9.00	7.717	137.9	0.06	0.415	337.0	0.00
	50	56.7	7.516	137.9	0.05	0.249	337.2	0.00
6	50	9.00	7.516	137.9	0.05	0.249	337.2	0.00
	60A	56.7	7.323	137.9	0.05	0.715	337.4	0.00
7	60A	9.00	8.254	137.9	0.06	2.352	336.5	0.01
	60B	56.7	7.180	137.9	0.05	5.010	337.6	0.01
8	60B	9.00	7.036	137.9	0.05	1.419	337.7	0.00
	70A	56.7	7.011	137.9	0.05	1.530	337.7	0.00
9	70A	9.00	7.092	137.9	0.05	5.413	337.6	0.02
	70B	56.7	8.933	137.9	0.06	6.375	335.8	0.02
10	70B	9.00	7.610	137.9	0.06	1.829	337.1	0.01
	80	56.7	7.565	137.9	0.05	1.374	337.2	0.00
11	80	9.00	7.565	137.9	0.05	1.374	337.2	0.00

From the Displacement results for Expansion (T1), it is observed that the Displacements are +ve in Global Y direction confirming that the piping is shrinking due to temperature decrease under cryogenic conditions.

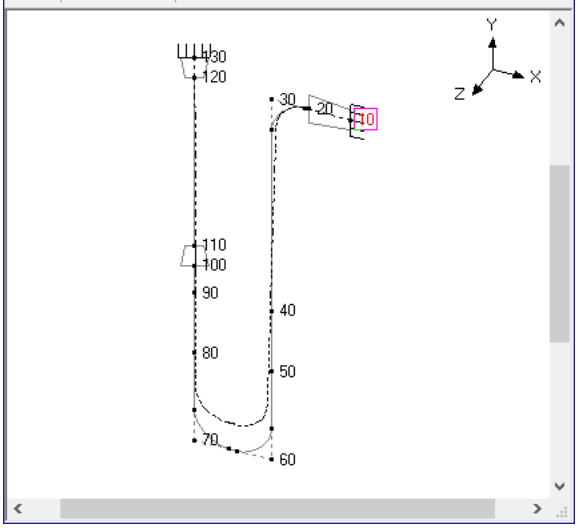
Caepipe 3D+ : Displacements: Expansion (T1) - [CryogenicPi...

File Results View Options Window Help

#	Node	Displacements (global) X (mm)	Y (mm)	Z (mm)	XX (deg)	YY (deg)	ZZ (deg)
1	10	0.000	0.000	0.000	0.0000	0.0000	0.0000
2	20	0.590	0.014	0.000	0.0000	0.0000	-0.0051
3	30A	0.635	0.016	0.000	0.0000	0.0000	-0.0053
4	30B	1.001	0.580	0.000	0.0000	0.0000	-0.0420
5	40	-0.058	3.416	0.000	0.0000	0.0000	-0.0469
6	50	-0.428	4.363	0.000	0.0000	0.0000	-0.0470
7	60A	-0.781	5.272	0.000	0.0000	0.0000	-0.0464
8	60B	-0.463	5.905	0.000	0.0000	0.0000	-0.0297
9	70A	-0.356	5.931	0.000	0.0000	0.0000	-0.0295
10	70B	0.173	5.523	0.000	0.0000	0.0000	0.0002
11	80	0.162	4.636	0.000	0.0000	0.0000	0.0024
12	90	0.136	3.689	0.000	0.0000	0.0000	0.0041
13	100	0.121	3.268	0.000	0.0000	0.0000	0.0045
14	110	0.108	2.952	0.000	0.0000	0.0000	0.0050
15	120	0.000	0.316	0.000	0.0000	0.0000	0.0010
16	130	0.000	0.000	0.000	0.0000	0.0000	0.0000

Caepipe 3D+ : Deflected shape: Expansion (T1) ...

File View Options Window Help



Element Forces & Moments (local and global forces and moments) on each element for Operating load case are shown below.

Caepipe 3D+ : Pipe forces in local coordinates: Operating (W+P1+T1) - [CryogenicPiping.res (C:\Te...

File Results View Options Window Help

#	Node	Axial (N)	y Shear (N)	z Shear (N)	Torsion(Nm) Moment	Torsion(Nm) SIF	Inplane(Nm) Moment	Inplane(Nm) SIF	Outplane(Nm) Moment	Outplane(Nm) SIF	Flex. Factors FFi	Flex. Factors FFo	Flex. Factors FFt	Sopr (MPa)
1	10	97	-685	0	0		-110	1.00	0	1.00				9.075
	20	97	-623	0	0		73	1.00	0	1.00				8.053
2	20	97	-623	0	0		73		0					8.053
	30A	97	-616	0	0		87		0					8.239
3	30A	97	616	0	0	1.00	-87	3.61	0	3.01	13.80	13.80		11.41
	30B	508	-97	0	0	1.00	-196	3.61	0	3.01	13.80	13.80		17.21
4	30B	508	97	0	0		196		0					10.01
	40	103	97	0	0		66		0					7.955
5	40	103	97	0	0		66		0					7.955
	50	-32	97	0	0		22		0					7.267
6	50	-32	97	0	0		22		0					7.267
	60A	-162	97	0	0		-19		0					7.147
7	60A	-162	97	0	0	1.00	-19	3.61	0	3.01	13.80	13.80		7.853
	60B	97	270	0	0	1.00	-94	3.61	0	3.01	13.80	13.80		11.79
8	60B	97	270	0	0		-94		0					8.344
	70A	97	285	0	0		-108		0					8.542
9	70A	97	285	0	0	1.00	-108	3.61	0	3.01	13.80	13.80		12.51
	70B	393	-97	0	0	1.00	-160	3.61	0	3.01	13.80	13.80		15.31
10	70B	393	97	0	0		160		0					9.439
	80	520	97	0	0		119		0					8.939
11	80	520	97	0	0		119		0					8.939
	90	655	97	0	0		76		0					8.405

Caepipe 3D+ : Pipe forces in global coordinates: Operating (W+P1+T1) - [CryogenicPiping.res (C:\T...

File Results View Options Window Help

#	Node	FX (N)	FY (N)	FZ (N)	MX (Nm)	MY (Nm)	MZ (Nm)
1	10	97	685	0	0	0	-110
	20	-97	-623	0	0	0	-73
2	20	97	623	0	0	0	73
	30A	-97	-616	0	0	0	-87
3	30A	97	616	0	0	0	87
	30B	-97	-508	0	0	0	-196
4	30B	97	508	0	0	0	196
	40	-97	-103	0	0	0	-66
5	40	97	103	0	0	0	66
	50	-97	32	0	0	0	-22
6	50	97	-32	0	0	0	22
	60A	-97	162	0	0	0	19
7	60A	97	-162	0	0	0	-19
	60B	-97	270	0	0	0	94
8	60B	97	-270	0	0	0	-94
	70A	-97	285	0	0	0	108
9	70A	97	-285	0	0	0	-108
	70B	-97	393	0	0	0	160
10	70B	97	-393	0	0	0	-160
	80	-97	520	0	0	0	119
11	80	97	-520	0	0	0	-119
	90	-97	655	0	0	0	76

Support Loads on all supports by the piping for Operating Load case 1 are shown below.

Caepipe 3D+ : Loads on Anchors in Global Coordinates: Operating (W...

File Results View Options Window Help

#	Node	Tag	FX (N)	FY (N)	FZ (N)	MX (Nm)	MY (Nm)	MZ (Nm)
1	10		-97	-685	0	0	0	110
2	130		97	-978	0	0	0	94

Support Load Summary [listing loads on a particular support (at Anchor Node 10) by the piping] for all <u>relevant</u> load cases is shown below.

Caepipe 3D+ : Support load summary for anchor at node 10 - [CryogenicPiping.res (C:\Temp\04...

File Results View Options Window Help

Load combination	FX (N)	FY (N)	FZ (N)	MX (Nm)	MY (Nm)	MZ (Nm)	FR (N)	MR (Nm)	Displacements (global)		
									X (mm)	Y (mm)	Z (mm)
Sustained	-20	-841	0	0	0	337	841	337	0.000	0.000	0.000
Operating1	-97	-685	0	0	0	110	692	110	0.000	0.000	0.000
Design	-127	-623	0	0	0	20	636	20	0.000	0.000	0.000
Maximum	-20	-623	0	0	0	337	841	337	0.000	0.000	0.000
Minimum	-127	-841	0	0	0	20	636	20	0.000	0.000	0.000
Allowables	0	0	0	0	0	0	0	0	0.000	0.000	0.000