Nozzle Loads, Piping Stresses, and the Effect of Piping on Equipment

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CA

Topics Covered

- Introduction
- Nozzle Loads – What are they?
- API 610 vs. ANSI Allowable Forces and Moments
- Nozzle Load Issues for Different Pump Types
- Information Stress Engineering Needs
- Special Cases

Please feel free to ask questions!

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Introduction

- As Mechanical Equipment Engineers, we need to understand how our equipment interacts with the other aspects of the plant, especially piping.
- All API equipment codes have formulas or tables for “Allowable Nozzle Loads” – but what do they really mean?
- Lets go back to our university statics course for a moment…

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What are Nozzle Loads?

- Nozzle loads are the net forces and moments exerted on equipment nozzles from the weight and thermal expansion of connected piping and equipment.
- The loads exerted on equipment are directly related to how the equipment and piping are supported.
- Increased nozzle loads are a cause of misalignment and increased wear and vibration rates in pumps.

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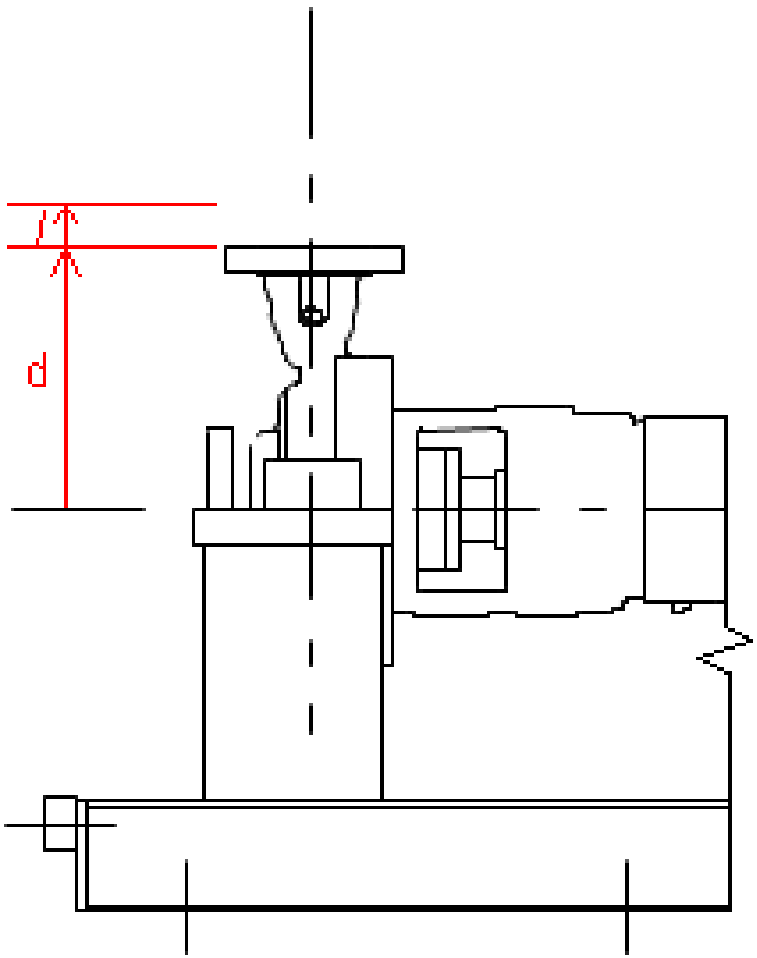
What are Equipment Nozzle Loads? Continued…



- Thermal Growth
  - *l* = growth
  - *d* = centreline to nozzle flange distance
  - α = thermal growth factor
  - (for Carbon Steel @ 100°C α = 1.1in/100ft)
- On an OH2 pump, the discharge nozzle will grow with temperature, exerting a force on the piping above.

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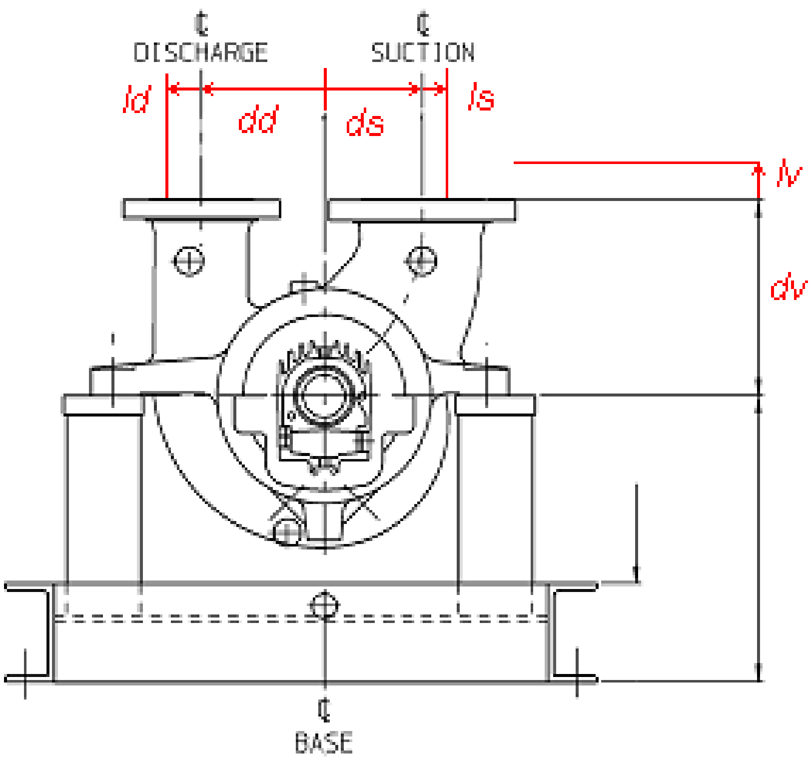
What are Equipment Nozzle Loads? Continued…



- Between bearing pumps are more complicated because the nozzles thermally grow up from the centreline, as well as horizontally away from the centreline.

d_v = centreline to top of nozzle
l_v = vertical nozzle growth
d_s = centreline to centre of suction nozzle
l_s = suction nozzle horizontal growth
d_d = centreline to centre of discharge nozzle
l_d = discharge nozzle horizontal growth

- Assuming point of zero expansion is the centreline of the shaft

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The Piping Effect

- Piping adds another dimension
- The layout and support of the piping will affect the forces and moments exerted on the equipment.
- The net force on the discharge nozzle of a pump is the force of the piping weight and thermal expansion load minus the force of the nozzle's thermal growth.
- "For horizontal pumps, two effects of nozzle loads are considered: Distortion of the pump casing and misalignment of the pump and driver shafts."
  API 610 10th Ed. 5.5.1

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Factors that Affect Nozzle Loads

- Temperature
  - Affects expansion of piping/equipment
- Pressure
  - Affects pipe stiffness (more pressure = thicker pipe)
- Client piping layout requirements
  - Valves at grade or overhead
  - Maintenance access
- Steel / Support locations available
- Baseplate design

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Stress Engineering Tools

- Stress engineers use specialized FEA software packages to do calculations (AutoPIPE®, CAESAR II)
- Allows engineer to build a 3D model of the piping system, add supports, temperature and pressure information, and see how the piping reacts
- Shows movement of the pipe, stresses on the pipe, and loads on supports and equipment flanges
- AutoPIPE® Break…
  - 6x4 OH2 Pump
  - Flow = 909gpm, Head = 426ft, HP = 150hp

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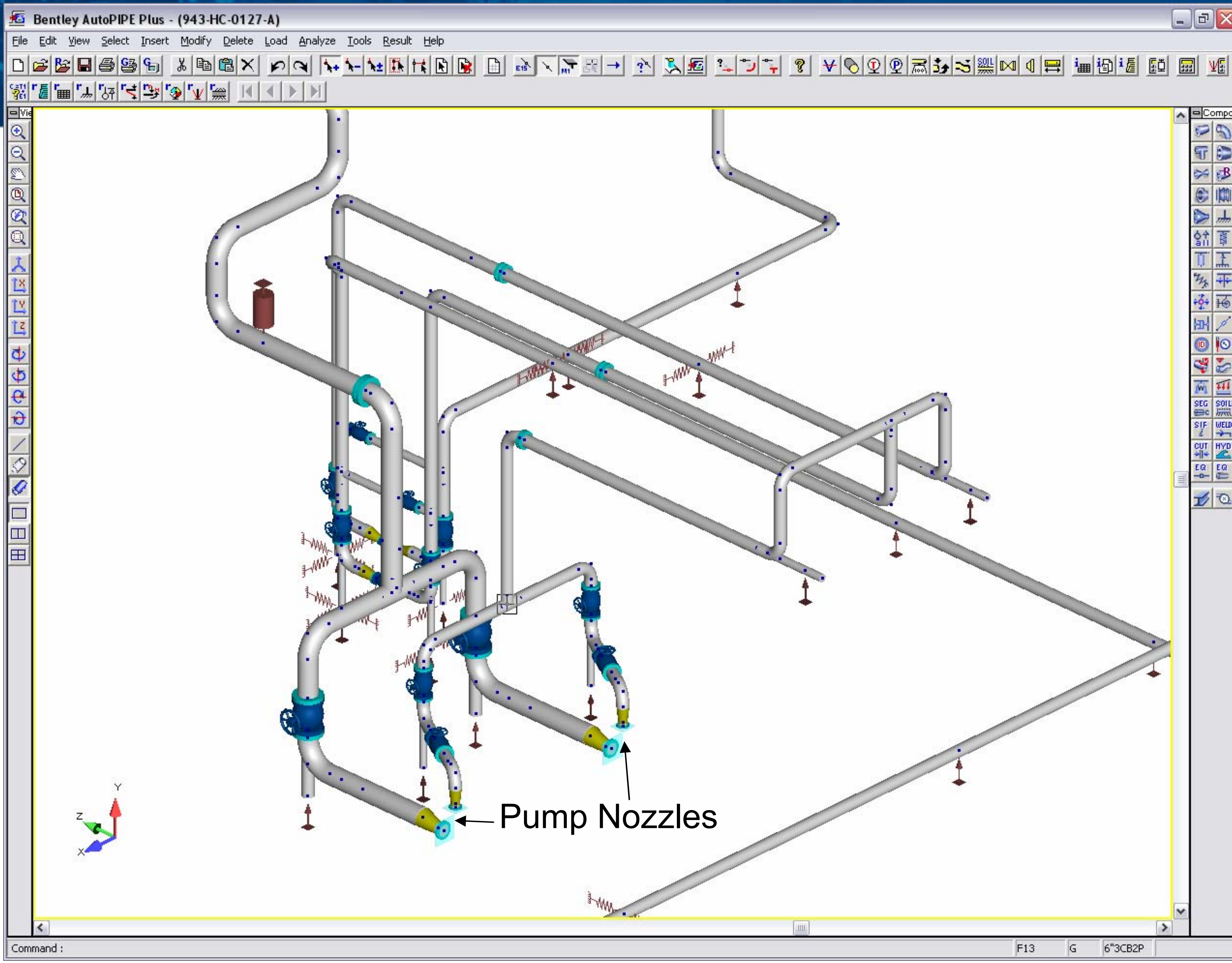
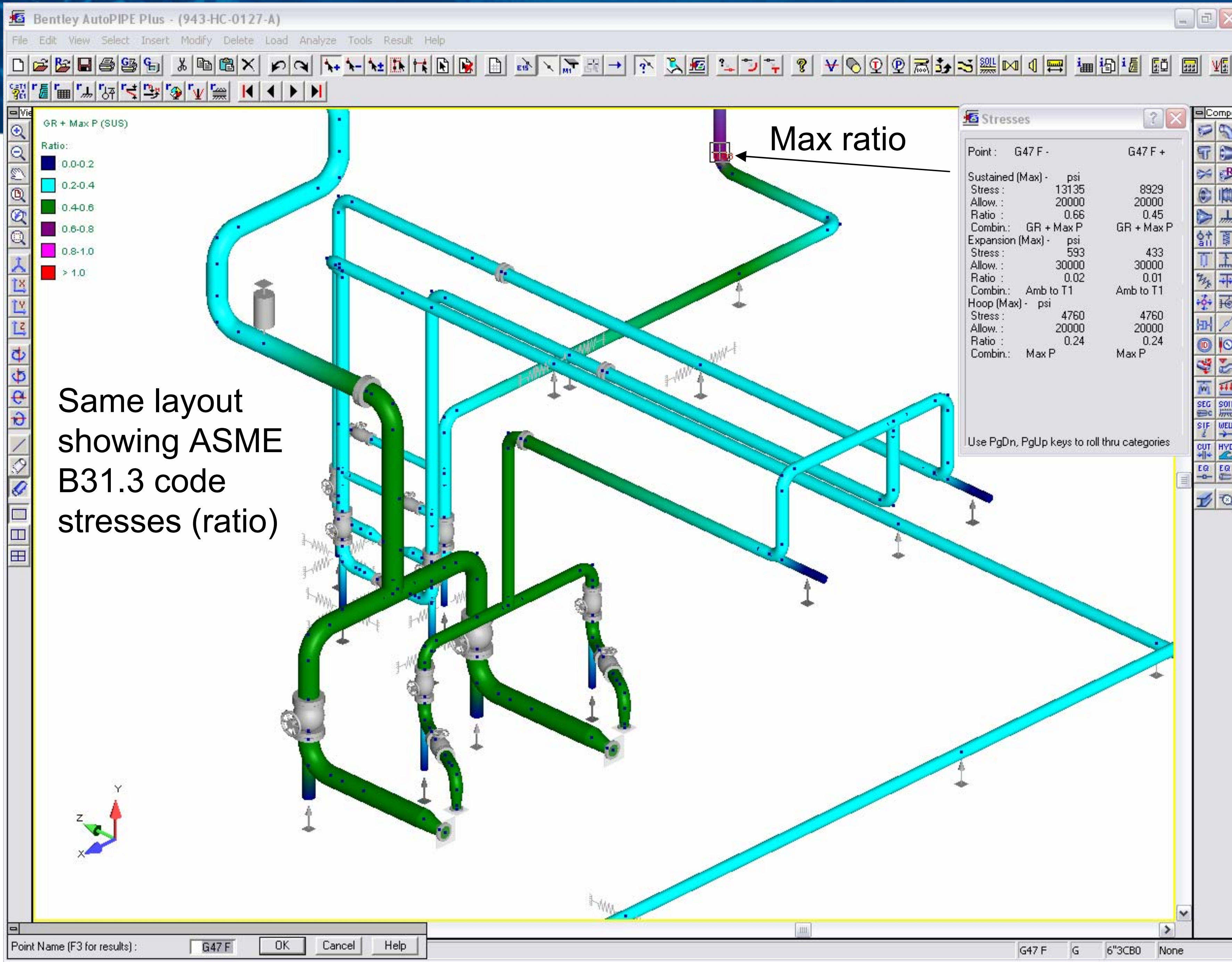
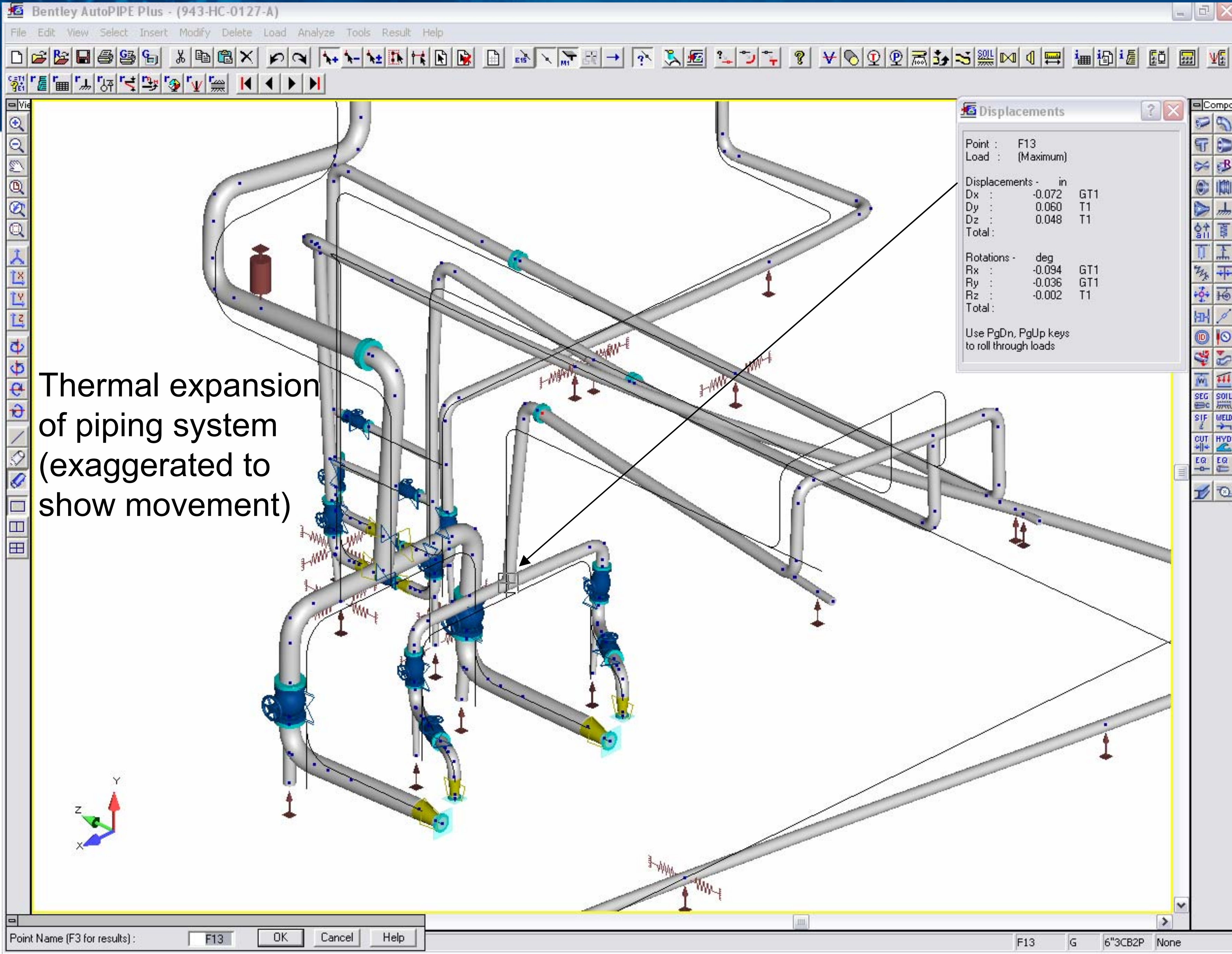


Bentley AutoPIPE Plus - (943-HC-0127-A)
File Edit View Select Insert Modify Delete Load Analyze Tools Result Help
Pump Nozzles
Command :
F13
G
6"3CB2P

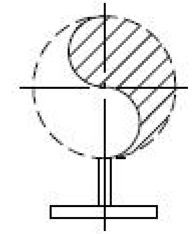
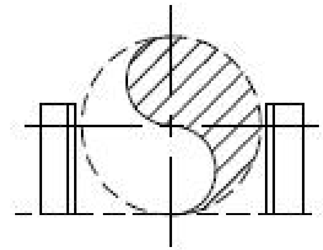
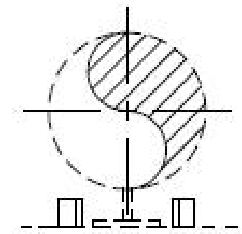
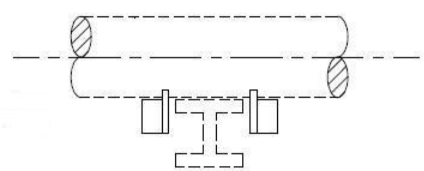
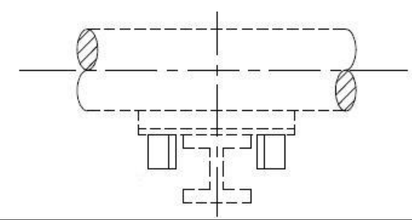

Bentley AutoPIPE Plus - (943-HC-0127-A)
File Edit View Select Insert Modify Delete Load Analyze Tools Result Help
GR + Max P (SUS)
Ratio:
0.0-0.2
0.2-0.4
0.4-0.6
0.6-0.8
0.8-1.0
> 1.0
Max ratio
Same layout showing ASME B31.3 code stresses (ratio)
Stresses
Point : G47 F - G47 F +
Sustained (Max) - psi
Stress : 13135 8929
Allow. : 20000 20000
Ratio : 0.66 0.45
Combin.: GR + Max P GR + Max P
Expansion (Max) - psi
Stress : 593 433
Allow. : 30000 30000
Ratio : 0.02 0.01
Combin.: Amb to T1 Amb to T1
Hoop (Max) - psi
Stress : 4760 4760
Allow. : 20000 20000
Ratio : 0.24 0.24
Combin.: Max P Max P
Use PgDn, PgUp keys to roll thru categories
Point Name (F3 for results) :
G47 F
OK
Cancel
Help
G47 F
G
6"3CB0
None

Thermal expansion of piping system (exaggerated to show movement)



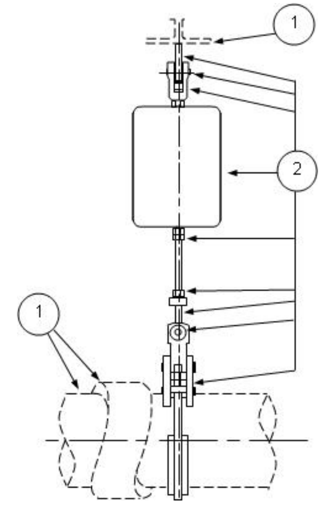
Piping Support Types

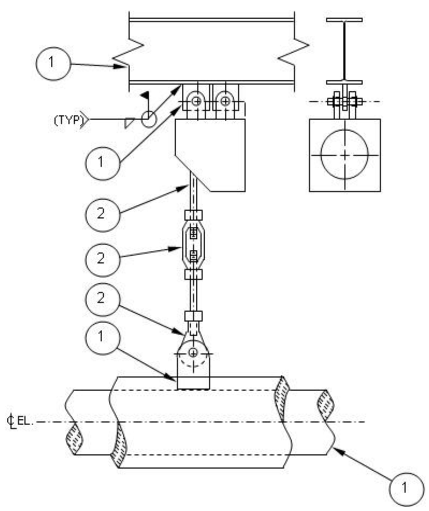
- Vertical Support – keeps the pipe from falling down
  - Eg. Support steel, shoe, base support, spring
- Horizontal Guide – holds the pipe parallel to its axis
- Directional Anchor (DA) – holds the pipe perpendicular to its axis; thermal growth will occur in both directions along the pipe axis
- Full Anchor – combination of a guide and directional anchor; pipe will not move in any direction

Typical pipe support details	Shoe 
Guide - no shoe 	Guide - w/ shoe 
Directional Anchor - no shoe 	Directional Anchor - w/ shoe 

Special Piping Supports

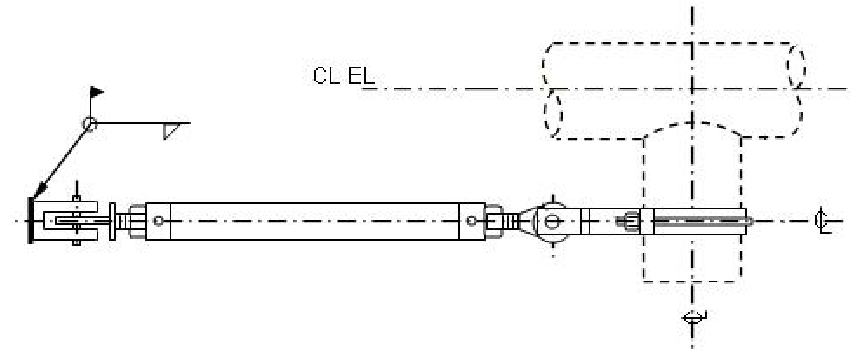
- Variable Spring
  - Takes the weight load (GR) to reduce load in vertical direction
  - Does not impose a reaction load because spring moves up or down
  - As pipe moves, spring reacts
- Constant Spring
  - Similar to variable spring
  - Used for vertical movements > 3”
  - Reduces variability

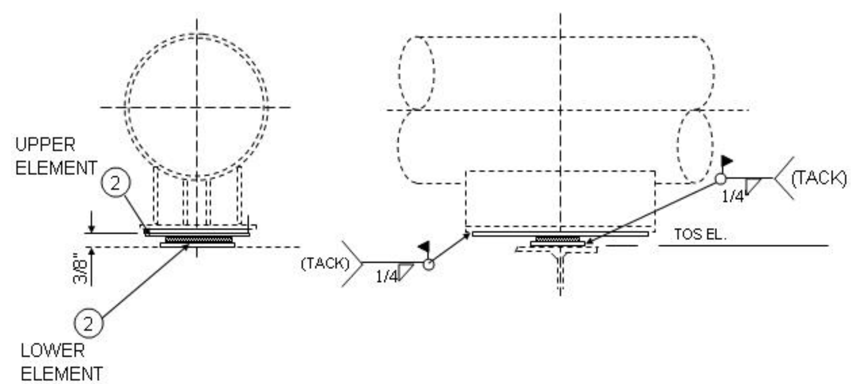




Special Piping Supports continued…

- Strut
  - Used for restraint of piping systems near critical equipment
  - Adjustable; zero gap, zero friction
  - Better than Guides and DAs at restraining thermal/friction loads
  - Not dependant on steel location; can adjust location inches at a time
- Teflon Slide Plate (TSP)
  - Reduces friction so support can slide easily
  - Usually placed under a shoe or base support
  - Allows expansion of pipe & equipment to reach steady state without overcoming a large friction force





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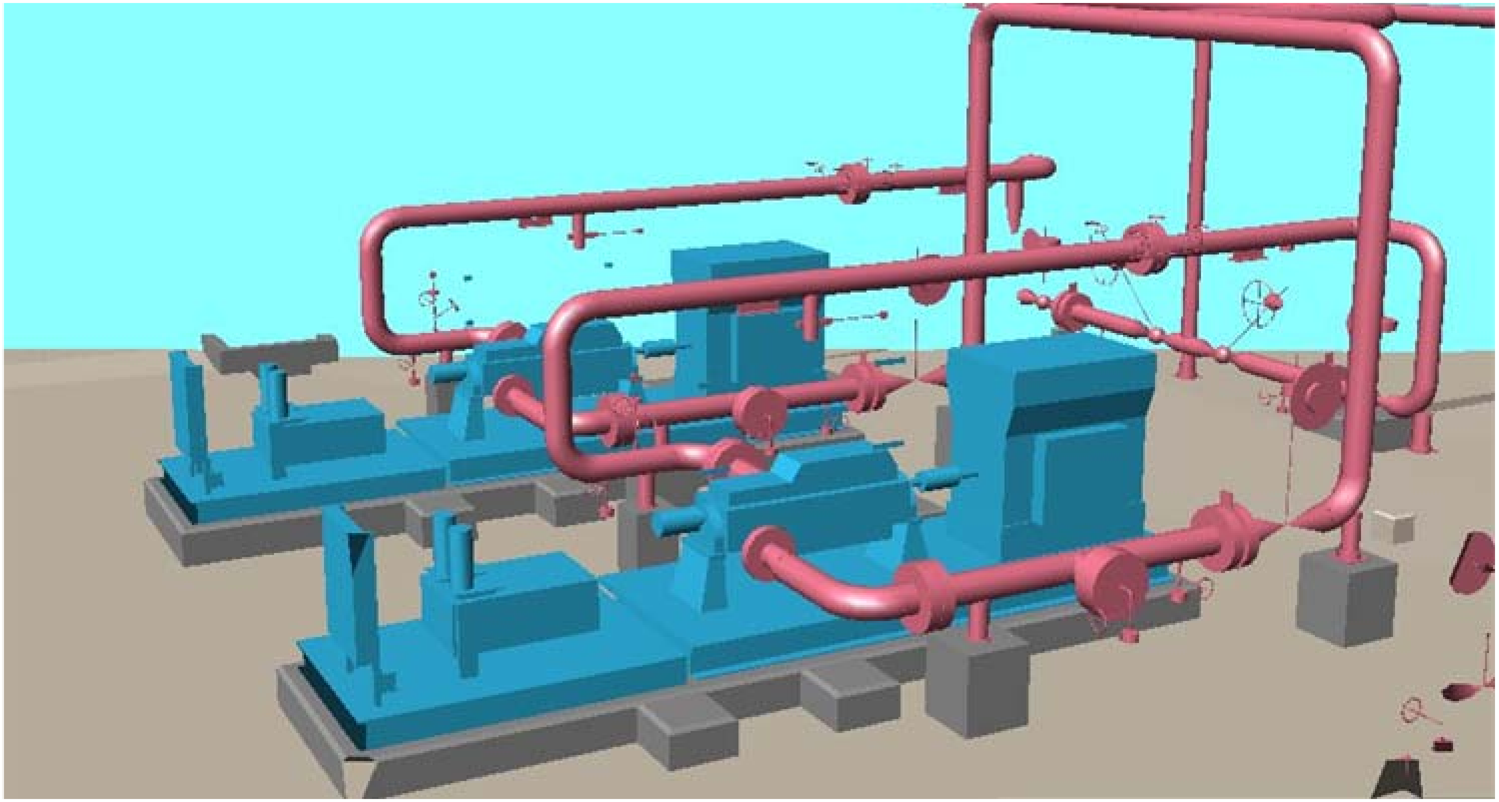
Typical Piping Layout

- Try to negate forces and moments by supporting the pipe at the same level as the pump. (Equal thermal growth)



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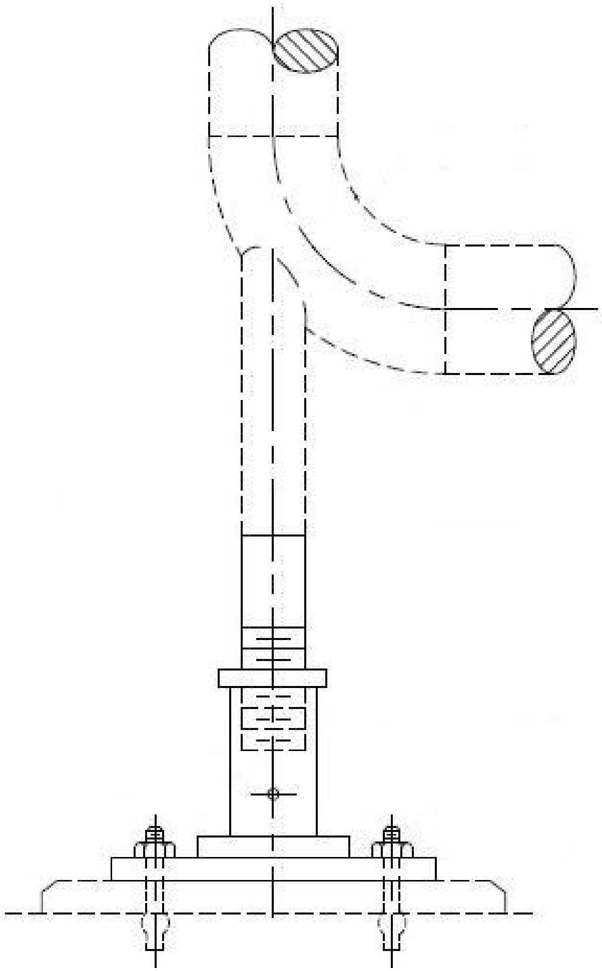
Typical Piping Layout continued…

- First piping support before or after a nozzle is always an adjustable base support or a spring
  - Allows for proper alignment at site, as site conditions never match the elevations in model.
  - Example shown is mounted on an elbow, but these types of supports are used on straight runs of pipe as well.



Typical Adjustable Base Support

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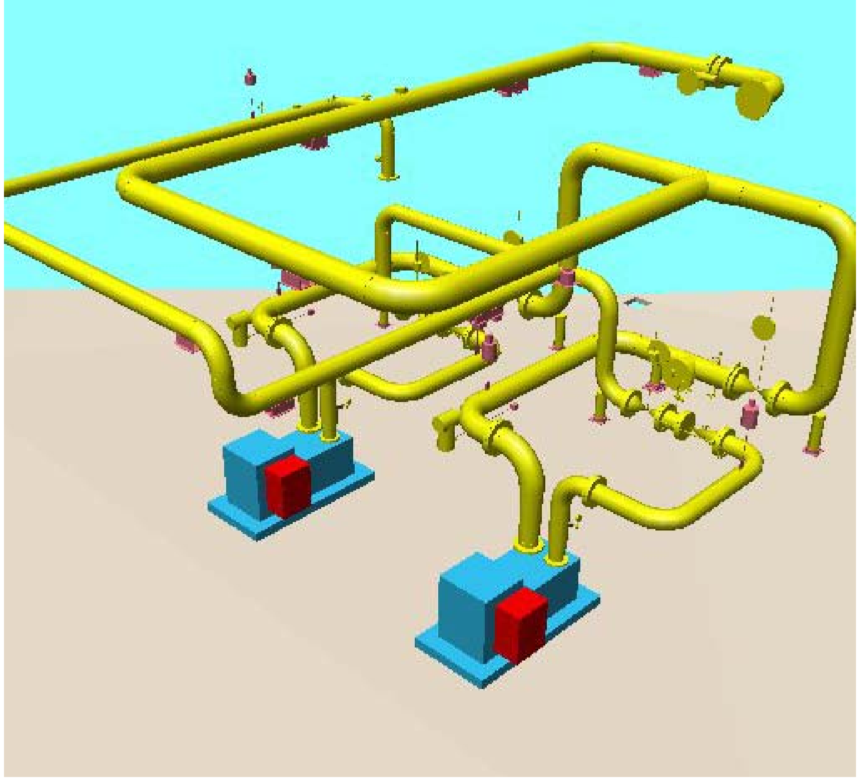
Typical Piping Layout and Support – 2x100% Pumps

- Typical pump arrangements have one pump spared (i.e. not running)
- Thermal effect can be significant
- Piping layout is typically symmetrical for esthetics, and for equal flow if both pumps run together
- Minimize effect of downstream piping
- AutoPIPE® Break…
  - 14x10 BB2 Pumps
  - Flow = 4031gpm, Head = 241ft, HP = 300hp



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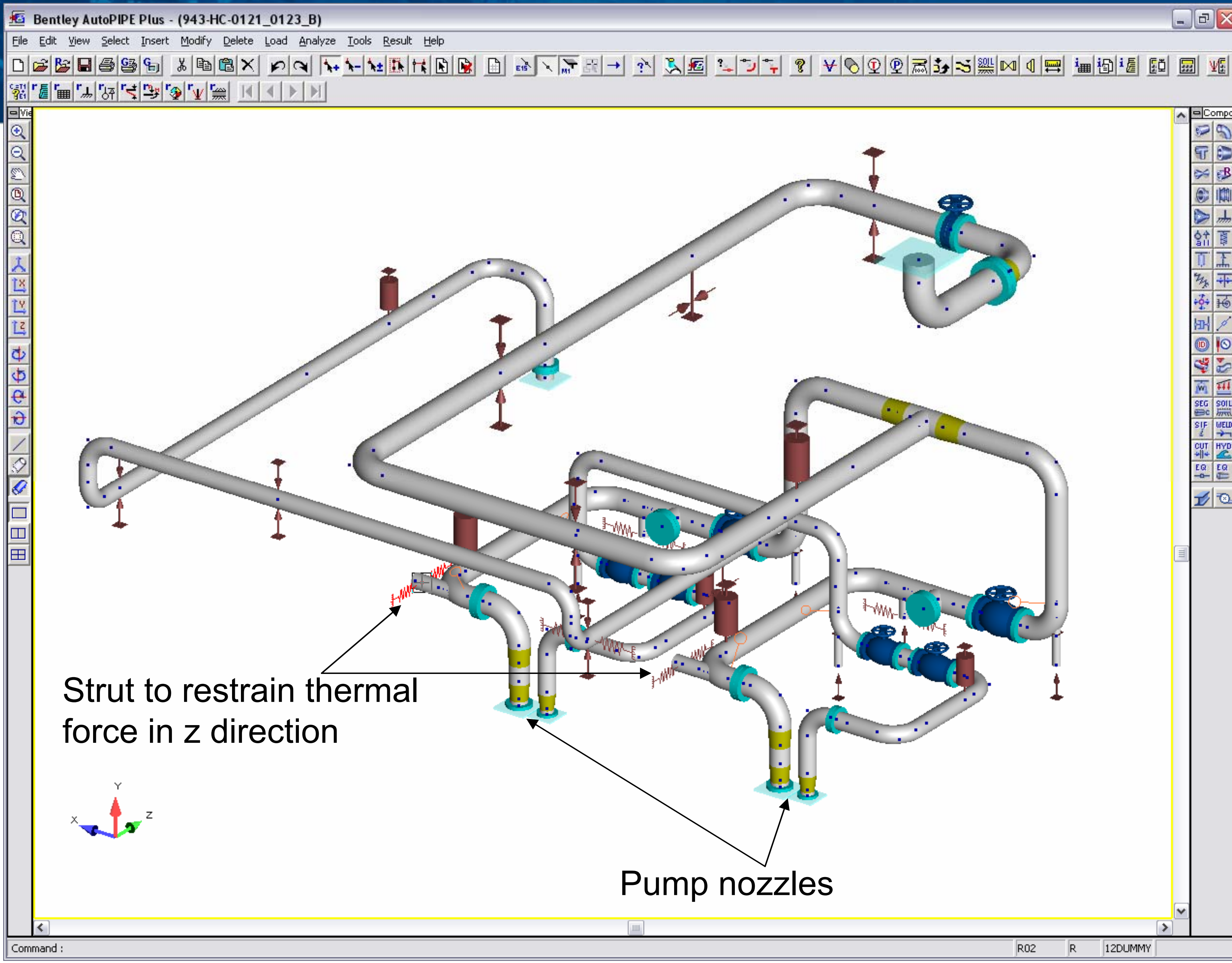
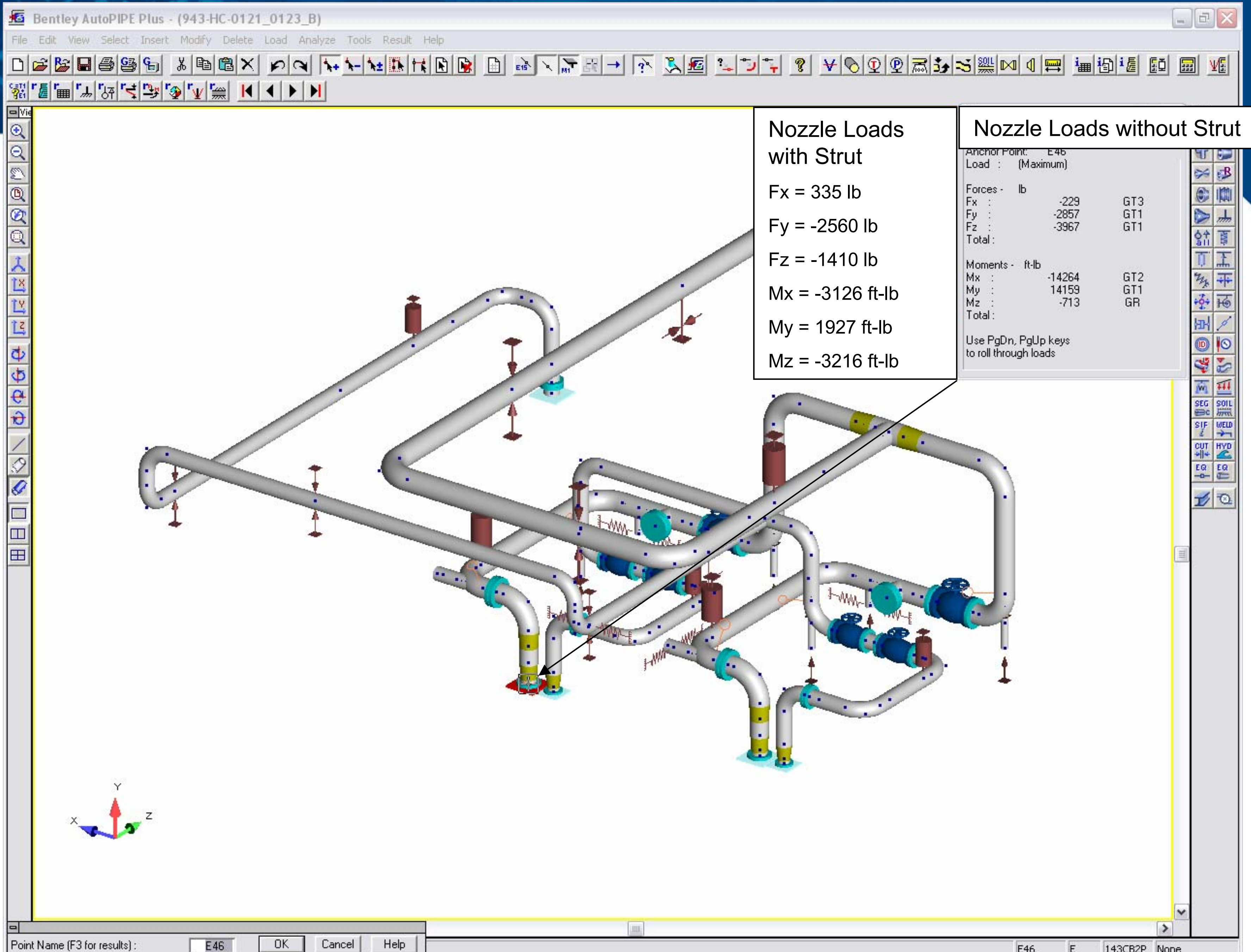
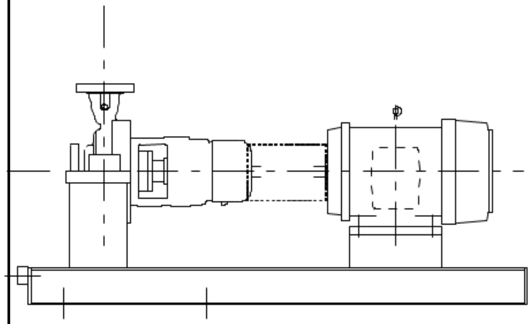
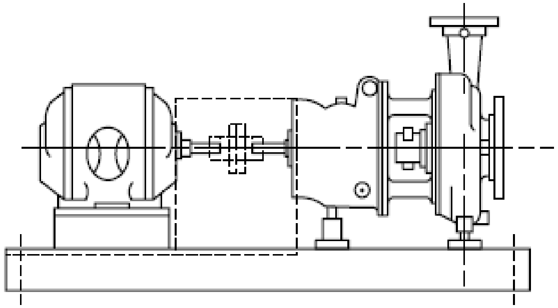

Bentley AutoPIPE Plus - (943-HC-0121_0123_B)
File Edit View Select Insert Modify Delete Load Analyze Tools Result Help
Strut to restrain thermal force in z direction
Pump nozzles
Y
X
Z
Command :
R02
R
12DUMMY


Bentley AutoPIPE Plus - (943-HC-0121_0123_B)
File Edit View Select Insert Modify Delete Load Analyze Tools Result Help
Nozzle Loads with Strut
Fx = 335 lb
Fy = -2560 lb
Fz = -1410 lb
Mx = -3126 ft-lb
My = 1927 ft-lb
Mz = -3216 ft-lb
Nozzle Loads without Strut
Anchor Point: E46
Load : (Maximum)
Forces - lb
Fx : -229 GT3
Fy : -2857 GT1
Fz : -3967 GT1
Total :
Moments - ft-lb
Mx : -14264 GT2
My : 14159 GT1
Mz : -713 GR
Total :
Use PgDn, PgUp keys to roll through loads
Y
X
Z
Point Name (F3 for results) :
E46
OK
Cancel
Help
E46
E
143CB2P
None

API vs ANSI Pump Design

	API 610	ANSI B73.1
		
Mounting	Centreline	Foot
Casing Thickness Basis	Max discharge pressure	ASME B16.5 Class 150 flange P/T rating
Max Temperature	By Manufacturer	260°C
Flanges	Class 300	Class 150

API vs. ANSI Nozzle Loads

- All equipment codes have equations for nozzle loads
  - API 610 – Table 4 and Annex F
  - ANSI/HI 9.6.2
- API 610 allows us three options
  1. Individual Loads up to 1x Table 4 – OK
  2. Individual Loads up to 2x Table 4 – Apply Annex F
     - if all conditions of Annex F are met – OK
  3. Any individual load >2x Table 4 – Pump vendor must be informed to do a detailed analysis, or piping will have to change to reduce loads.

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API vs. ANSI Nozzle Loads continued…

- Annex F allows us to normalize the forces and moments to take credit for low loads in a particular direction.
- Per API 610 5.5.5, "…use of Annex F methods can result in up to 50% greater misalignment than would occur using the loads of Table 4."
- This risk is why the purchaser must agree to the use of Annex F.

API vs. ANSI Nozzle Loads continued…

Allowable Loads	API 610 Table 4		HI 9.6.2.1.1 Allowable Individual Nozzle Loads (ANSI Horizontal A80 6x4x13)	
	6” End Nozzle	4” Top Nozzle	6” End Nozzle	4” Top Nozzle
F_x (lb)	700	320	2700	1400
F_y (lb)	560	260	1350	1350
F_z (lb)	460	400	1500	3250
F_r (lb)	1010	570		
M_x (ft lb)	1700	980	1300	1200
M_y (ft lb)	870	500	1300	1500
M_z (ft lb)	1300	740	1100	690
M_r (ft lb)	2310	1330		

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API vs. ANSI Nozzle Loads continued…

- ANSI nozzle loads don't look too bad when you look at the table on the previous slide
- Deceiving, because there are multiple tables, and a set of equations to meet, along with each table
- Depending on material, temperature and baseplate mounting, derating factors are applied to one or more of the tables, reducing the allowable loads.
- Recalling the first AutoPIPE® model…
  - 6x4 Horizontal Pump
  - Flow = 909gpm, Head = 426ft, HP = 150hp
- API 610 Fluor Nozzle Load Spreadsheet…
- ANSI Fluor Nozzle Load Spreadsheet…

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API vs. ANSI Nozzle Loads continued…

- ANSI pumps are not built as robustly as API pumps and therefore have much lower allowable loads
  - At low temperatures (<100°C), allowable nozzle loads can be met
    - ANSI pumps typically used for chemical or water services
  - REMEMBER TO CONSIDER MORE THAN INDIVIDUAL NOZZLE LOADS
- The Tradeoff
  - At higher temperatures, we have savings on the cost of the pump, but piping costs increase because of complex layouts and supports required to decrease the nozzle loads.
  - The economics of both the pump and piping (whole system) must be considered when choosing the pump.

Nozzle Load Issues for Different Pump Types

- Horizontal Overhung (OH2)
  - Stress engineers calculate the thermal growth of each nozzle and insert that into the assumed anchor of the AutoPIPE calculation.
- Vertical In-Line (OH3)
  - Stress engineering needs to know if these pumps are floating on the foundation.
  - If they are floating, the pump will move with the pipe expansion at startup to a steady state position.

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Nozzle Load Issues for Different Pump Types continued…

- Between Bearing (BB1, BB2, BB3, BB5)
  - Since these pumps are typically a top-top or side-side arrangement, the thermal growth of the nozzles is generally more significant.
    - Mechanical/Vendor needs to provide these values as piping can't always tell where the point of zero expansion is
  - This is especially true of a high-temperature (>200°C) barrel pump (BB5).

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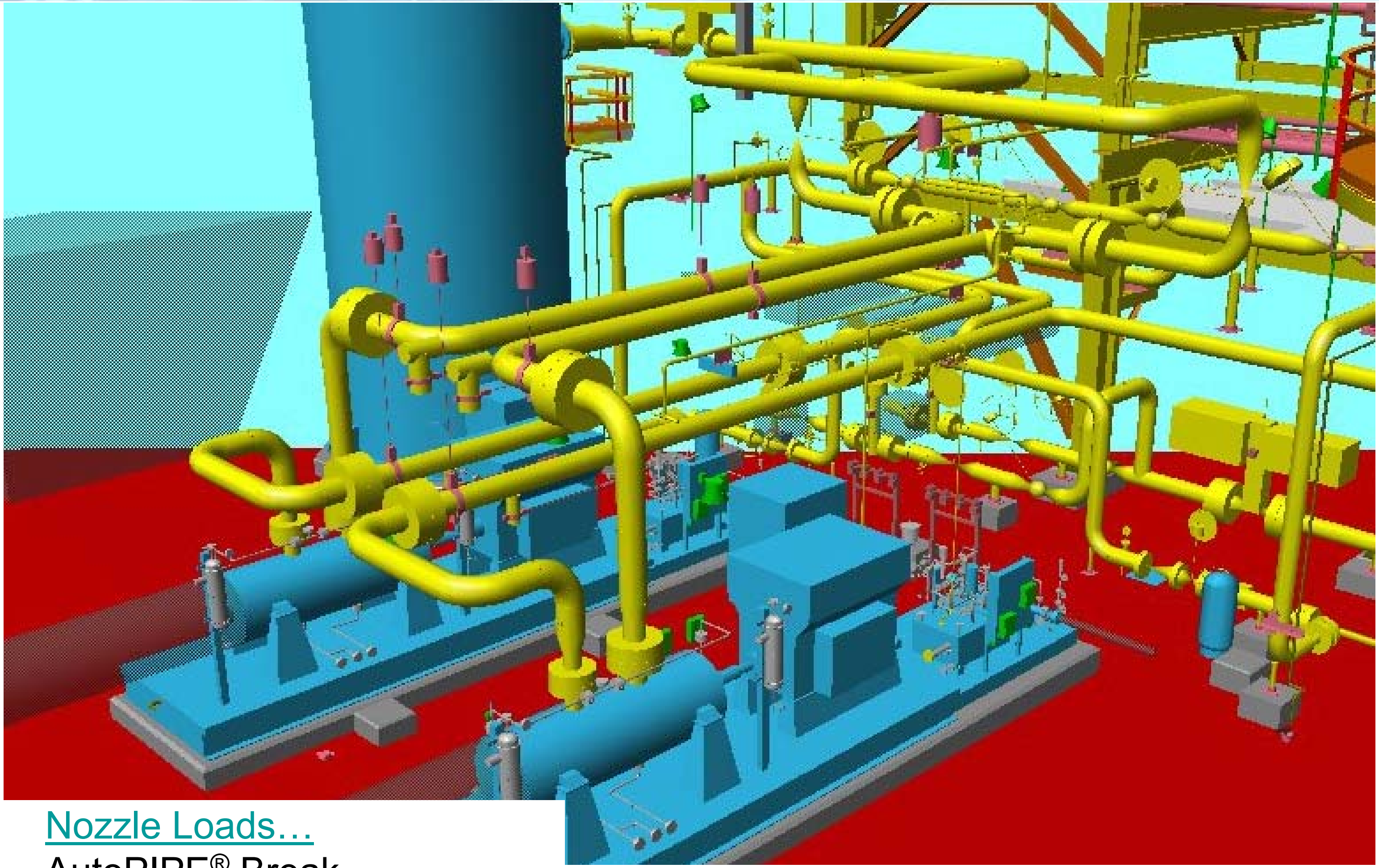
High Temperature Barrel Pump



- Nozzle Loads…
- AutoPIPE® Break…
  - 10x8 BB5 Pump
  - Flow = 1737gpm, Head = 6449, HP = 4500hp

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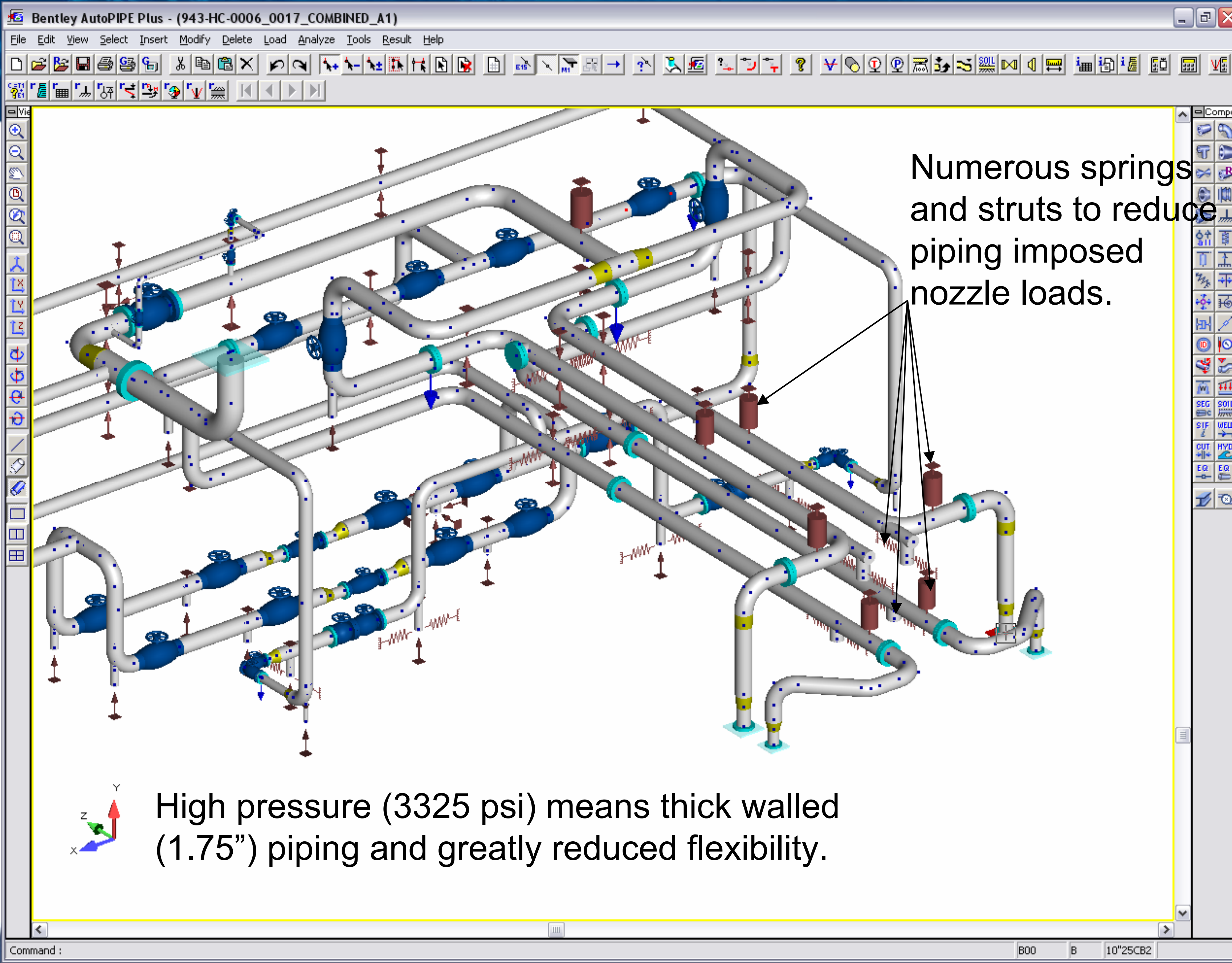
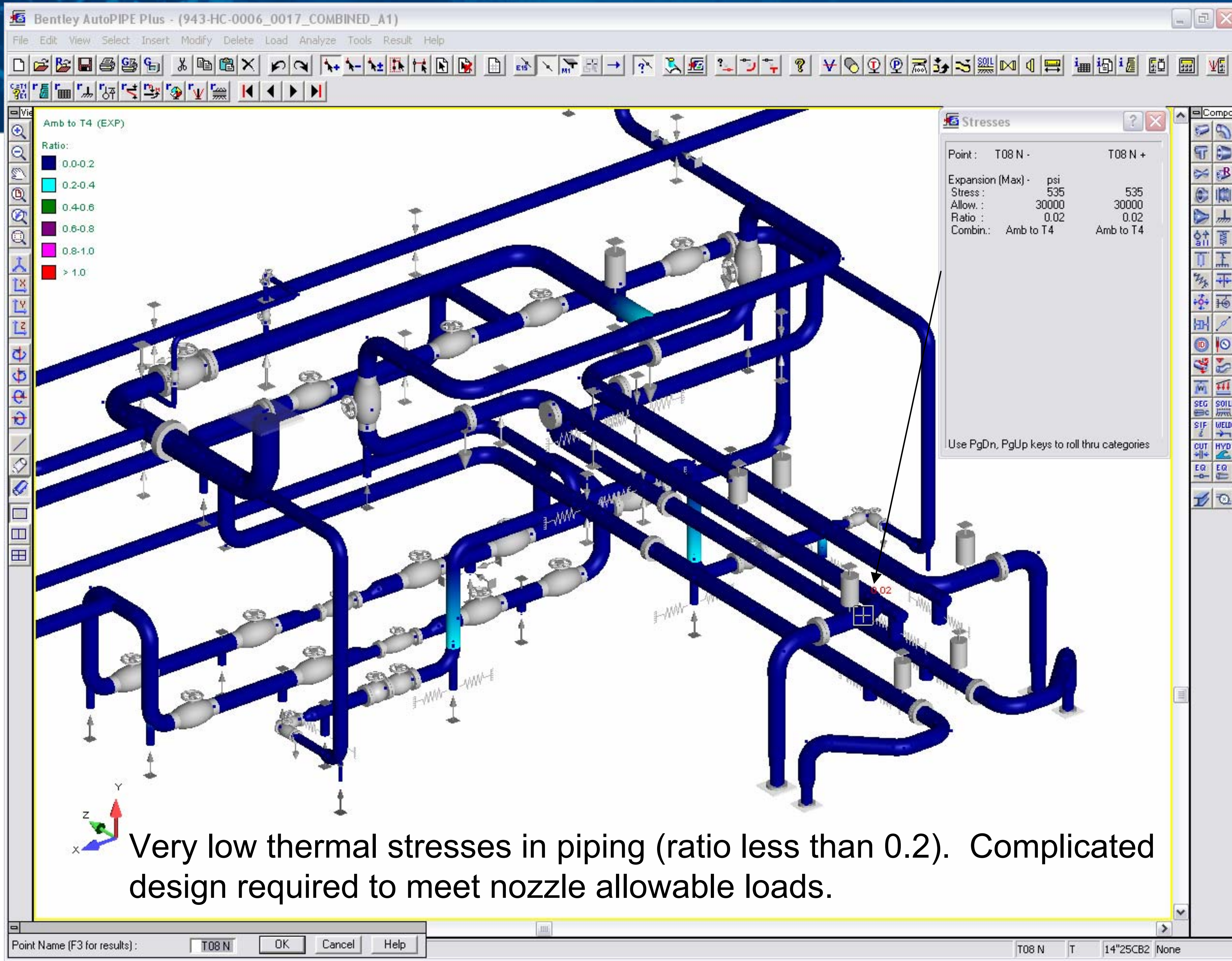

Bentley AutoPIPE Plus - (943-HC-0006_0017_COMBINED_A1)
File Edit View Select Insert Modify Delete Load Analyze Tools Result Help
Numerous springs and struts to reduce piping imposed nozzle loads.
High pressure (3325 psi) means thick walled (1.75”) piping and greatly reduced flexibility.
Command :
B00
B
10"25CB2



Very low thermal stresses in piping (ratio less than 0.2). Complicated design required to meet nozzle allowable loads.

Why is piping always bugging me?

- Piping needs the following information to do their work:
  - Pump type (API/ANSI)
  - GA Drawing of pump showing support location, nozzle distance from centreline, **vendor allowable loads**
  - Temperature info (usually from line list and P&ID)
  - Material of the pump (usually on the GA and datasheet)
  - ANSI flange size (150#, 300#, etc - usually on the GA or detailed drawings)
  - Nozzle movements from equipment zero point (point of zero thermal growth)
    - especially important for high temperature equipment
- This information is used for both the 3D model and the AutoPIPE® model.

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Why is piping always bugging me? Continued…

- Similar information is required for other types of equipment
- Complicated equipment like centrifugal compressors, heaters and reactors require more information from vendors like growth calculations, skin temperatures and layout of piping within the equipment
- Reciprocating compressors often require acoustic analysis to see how the vibrations of the equipment affect the piping
  - See API 618 (Section 7.9.4.2 and Annex N)
  - Analysis usually done by a third-party, and includes all piping and equipment
  - Also helps determine the need for pulsation suppression devices

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Why is piping always bugging me? Continued…

- Something to keep in mind:
  - **Mechanical data supports piping design**
  - Timely receipt of mechanical data is necessary to keep projects moving

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How can Nozzle Loads be Reduced?

- Increase piping flexibility (add loops)
- Add springs, struts and slide plates
- Add hot by-pass (very common)
- Can mount pumps on slide plates or springs
- In extreme cases, add expansion joints
  - Must be a low pressure system
  - Not recommended; expansion joint is usually the weakest point in the system

Examples of Special Cases

- Heavy Flanges (ANSI 1500#)
  - See Barrel Pump Example
- High Temperature Pumps
  - See Barrel Pump Example
- Sea Water Pumps (HDPE piping)
  - Expansion joints
- Reciprocating Compressors
  - Cast cylinder heads; very low allowable loads
  - Hold down supports, snubbers
- Steam Turbines
- Screw Pump Example…
  - 10x8 Screw Pump
  - Flow = 198.95 m^3/h, ΔP = 2255 kPa, HP = 300hp

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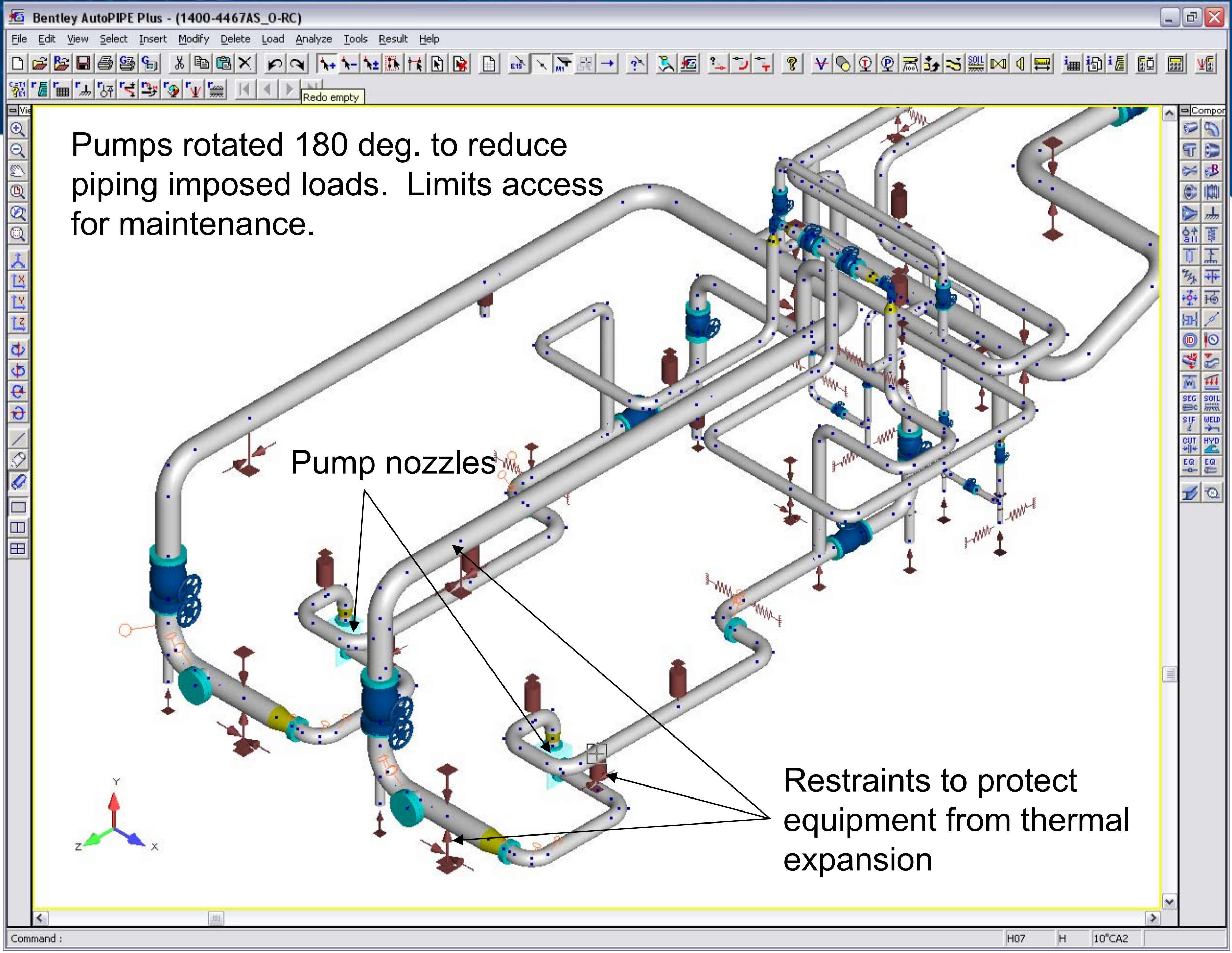
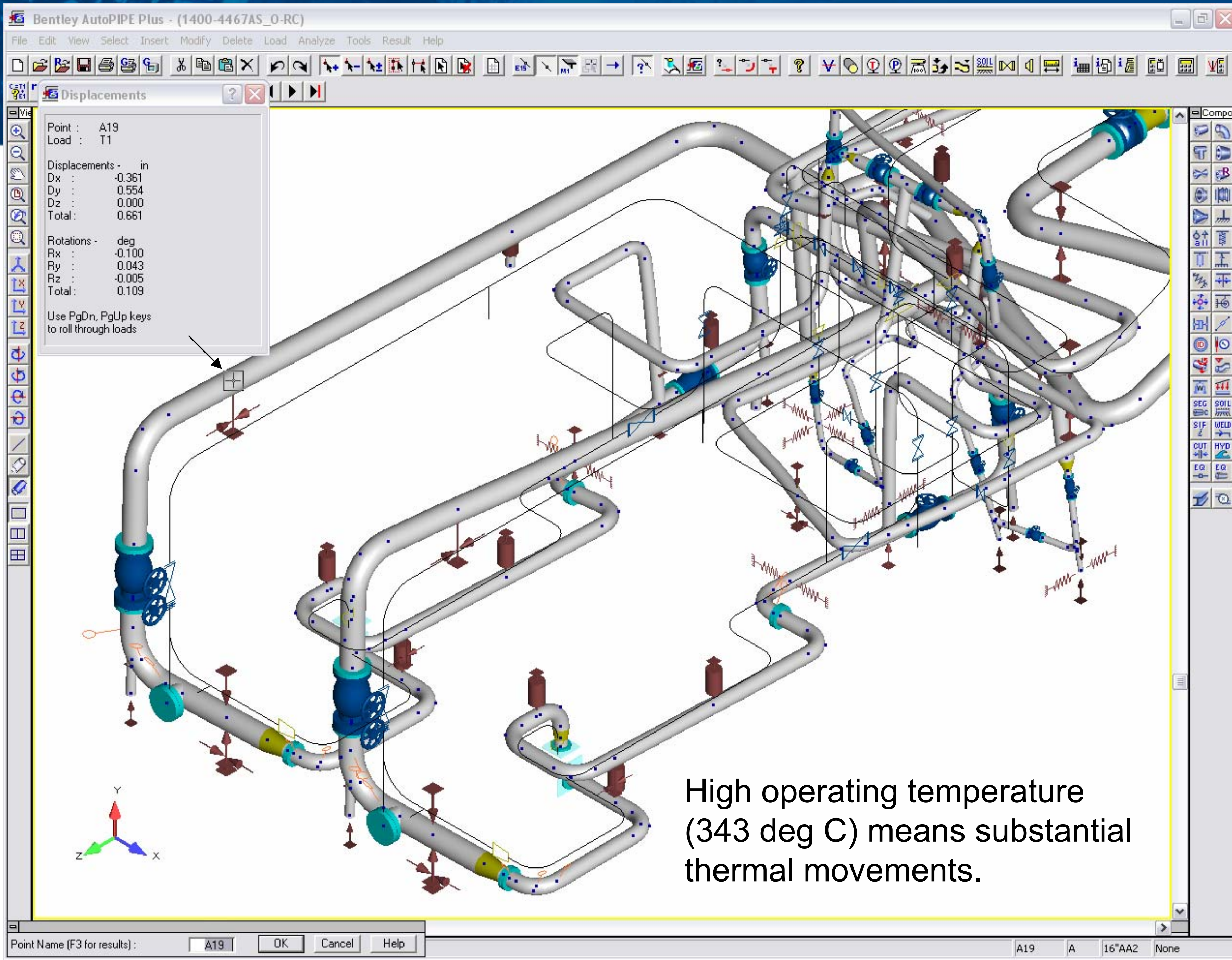

Bentley AutoPIPE Plus - (1400-4467AS_0-RC)
File Edit View Select Insert Modify Delete Load Analyze Tools Result Help
Redo empty
Pumps rotated 180 deg. to reduce piping imposed loads. Limits access for maintenance.
Pump nozzles
Restraints to protect equipment from thermal expansion
Command :
H07
H
10"CA2



High operating temperature (343 deg C) means substantial thermal movements.

References

- Pumps
  - API 610 10th Ed., Section 5.5 and Annex F
  - ANSI/HI 9.6.2 – Centrifugal and Vertical Pumps for Allowable Nozzle Loads
  - PIP RESP002 – Design Of ASME B73.1 And General Purpose Pump Baseplates
- Compressors
  - API 617 7th Ed., Section 2.3.4 and Annex 2.E
  - API 618 5th Ed., Section 7.9.4.2 and Annex N
  - API 619 4th Ed., Section 5.4 and Annex C
- Piping
  - ASME B31.3 – 2008, Chapter II Part 5 – Flexibility and Support

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Thank you!

Any questions?

Feel free to contact us:

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