# 기술보고

# Thermal stress analysis for high pressure and temperature pipelines in ultra steam turbine (UST) system

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## Abstract

A reliable assessment and analysis of the condition of high pressure and temperature steam pipelines requires defining stress state, which will take into consideration not just the impact of internal pressure and temperature but all applied loads. For that, usage of modeling and numerical methods for calculation and analysis of stress state is essential. The main aim of piping stress analysis is to check the design of piping layout, which will allow simple, efficient and economical piping supports and provide flexibility to the piping system for loads and stresses. The piping stress analysis is carried out using CAESER II software. By using this software we can evaluate stresses, stress ratios, flange condition, support loads, element forces and displacements at each node and points. In this paper, only the maximum and minimum displacement results are tabulated, which is also shown in detail by an example of main steam pipelines of UST Main Engine System [1].

**Keywords:** CEASER II software, High Pressure Steam Pipes, UST, Stress Analysis

## 1. Introduction

Pipe stress generally is a force which acting from internal and external of piping system. This comprises fluid pressure, piping fittings and valves, external forces due to sagging, hogging, or waves and also pipe expansion and contraction due to temperature differences [1].

High pressure steam pipelines are critical components of UST system, which have significant influence on reliability and operability of system as well as operators safety. They are subjected to almost all kinds of stresses and loads, intentional or unintentional. Thus, it is very important to take note of all potential loads that this piping system would encounter during operation as well as during other stages in the life cycle of overall steam plant [1].

## 2. Objectives

Key objectives of pipe stress analysis are [5]:

i. To evaluate reliability and operability of high pressure steam pipe lines in design and actual installation conditions due to internal and external forces
ii. To ensure integrity of equipment nozzle connection able to compensate any acting load towards piping within tolerate value
iii. To determine proper support configuration for high pressure steam pipelines to withstand any applied loads

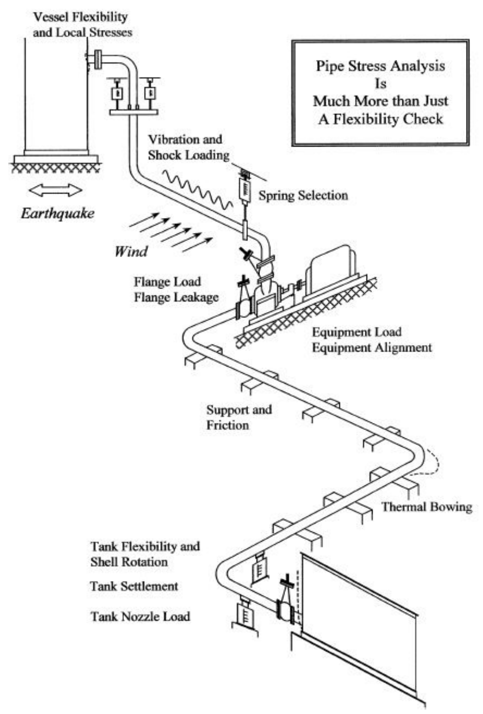



Fig. 1 Pipe Flexibilities in UST System [5]

## 3. Stress Analysis Procedures

The following steps need to be accomplished prior to the analysis and evaluation of pipe stress [5]:

ⅰ. Check relevant and applicable Code i.e. ASME B31.1 or B31.3, Equipment Nozzle Allowable Load, API 610, API 611, API 650 and NEMA SM23

ⅱ. Review owner specification to determine design conditions i.e. temperature conditions, design coefficient, and design tolerances

ⅲ. Ensure piping design is complying and satisfy Code Stress (Direct piping and stability) and considering design quality, cost savings and ease of installation

ⅳ. Determine suitability of piping connection towards equipment, support design and locations, with support strength analysis

ⅴ. Valid analysis software CEASER II™ and AVEVA MARINE™ Modeling Software

## 4. Application of Stress

The study on stress equation which derive from cylindrical stresses equation which comprises of [5]:

ⅰ. Longitudinal Stress (Axial Stress)

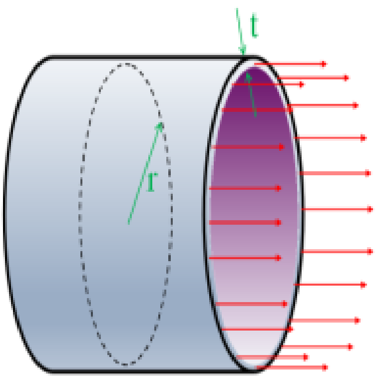



Fig. 2 Longitudinal force acting

Force = Pressure x Cross Sectional Area of Pipe

Force applied = $P\pi r^2$

Area of pipe = $2\pi rt$

Longitudinal Stress (Axial Stress), $\sigma e$

$$= \text{Force} / \text{Area}$$

$$= P\pi r^2 / 2\pi rt$$

$$= Pr / 2t \qquad \text{(Eq. 1)}$$

ⅱ. Hoop Stress (Circumference Stress)

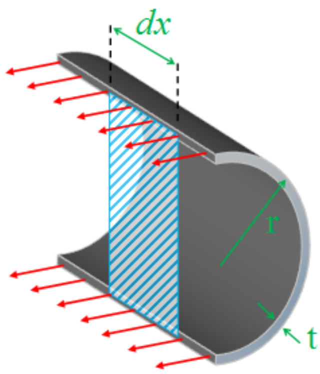



Fig. 3 Hoop force acting

Force = Pressure x Cross Sectional Area of Pipe

Force applied = 2r(P)dx

Area of force acting = 2dx(t)

Hoop Stress (Circumference Stress), $\sigma h$

$$= \text{Force} / \text{Area}$$

$$= 2r(P)dx / 2(t)dx$$

$$= Pr / t \qquad \text{(Eq. 2)}$$

Where,

P : Pressure applied (Kg/cm3)

r : Cylinder radius (cm)

t : Thickness of cylinder (cm)

dx : Pipe length (cm)

Based on Eq. 1 and Eq. 2 above, simple calculation on stress applied in from internal fluid force acting towards pipe thickness can be determined.

## 5. Effect of Excessive Hoop Stress

Excessive hoop stress will cause pipe to burst; as shown in Fig. 4. It is important to determine and indicate correct pipe wall thickness to prevent excessive load acting towards circumference of the pipe.

Fig. 4 Pipe bursting due to excessive internal pressure

## 6. Piping Arrangement of UST System

Piping arrangement of UST system need to be arranged in such a way that the flexibility, operability and safety are complies during design, installation and also actual operation.

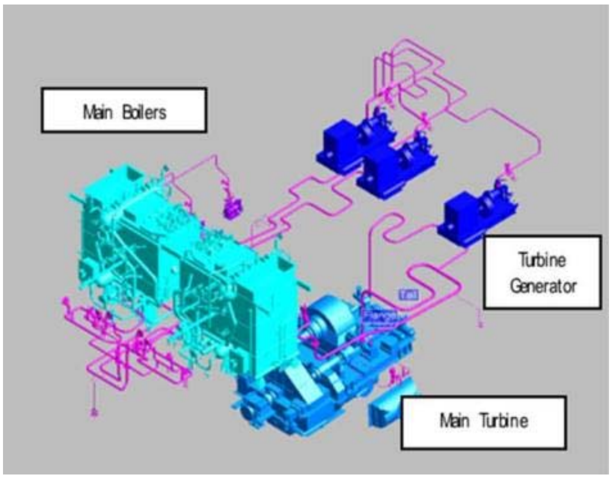



Fig. 5 Superheated pipe layout in UST System (560°C, 102 bar)

Fig. 5 shows superheated pipe arrangement from isometric view. This model generated by AVEVA MARINE ™ Modeling Software which indicate connection between Main Boiler, Main Turbine, and Turbine Generators.

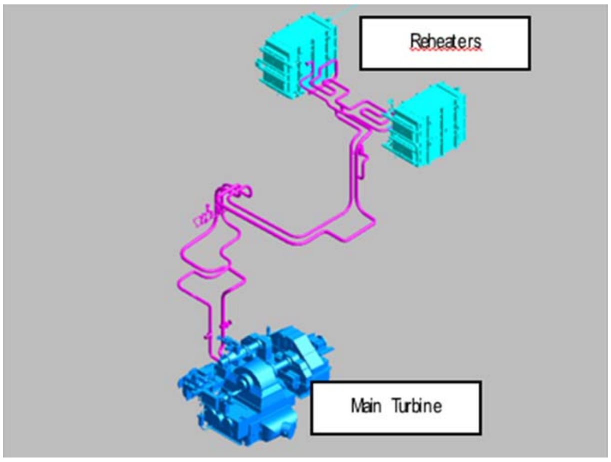



Fig. 6 Reheater pipe layout in UST system (560°C, 30 bar)

Fig. 6 shows connection between reheater pipe between Main Boiler Reheater and Main Turbine from isometric view. Reheater function is to reheat outlet steam from High Pressure turbine and to be transferred to Intermediate Pressure turbine to improve steam consumptions.

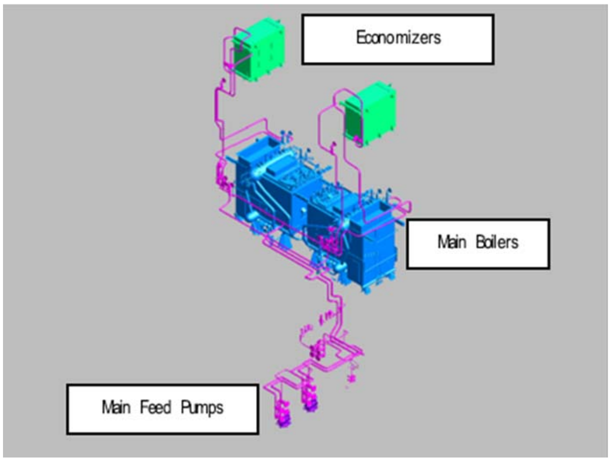



Fig. 7 Feed water pipe layout in UST system (150°C, 150 bar)

Fig. 7 shows connection between feed water piping arrangement from Main Feed Pumps to Economizers before feed into Main Boilers for steam generations.

## 7. Type of Pipe Supports

Pipe support is ancillary structural element which able to sustain and transfer loads to main structure members. This support will withstand and uphold pipe dynamic loads throughout operation. In order to determine suitability and effective supports, pipe stress analysis need to be conducted in order to evaluate the supports. These are among types of pipe supports which applied in UST system [4]:

ⅰ. Rigid Type Support – Support is intended to restrict displacement of piping. Apply at location in which displacement is not desired or needs to be limited i.e. long straight pipelines

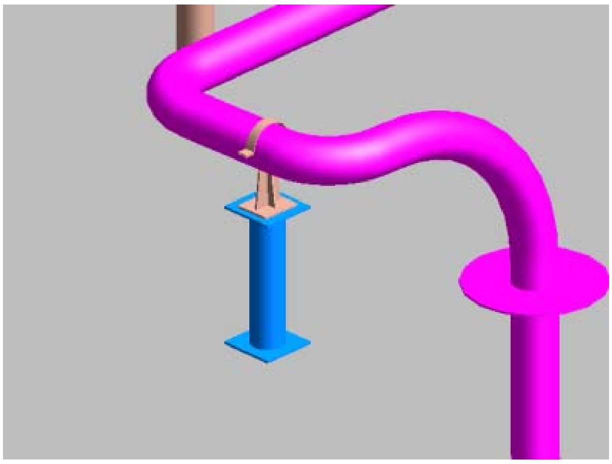


Fig. 8 Rigid Type Support Modeling

ⅱ. Hanger type support - Support consists of coil springs encased in a canister. It supply variable supporting load based on spring formula

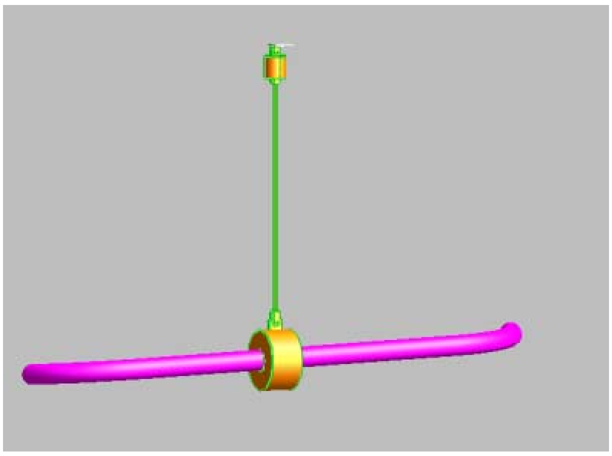


Fig. 9 Hanger Type Support Modeling

ⅲ. Guided type support - Support is a rigid or else flexible restrain which results lateral pipe movement

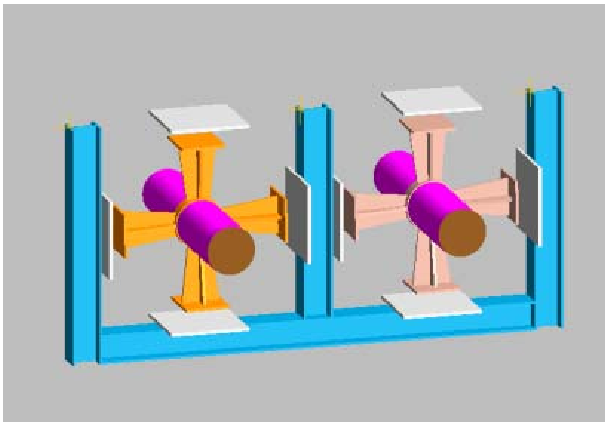


Fig. 10 Guided Type Support Modeling

## 8. Code Requirement

For pipe stress analysis, ASME B31.1 is adopted in this UST system. It covers boiler external piping for power boilers and high temperature and pressure in which steam is generated at a pressure more than 1 bar (15 psig) and temperatures exceeding 120° C (250° F) [3]. According to ASME Code B31.1, loads are classified as the following three types for pipe stress analysis as follows

ⅰ. Sustained loads – Caused by forces that are present throughout normal operation, such as pipe weight and internal pressure

(SI Unit)

$$SL=(PDO/(1000)4tn)+(0.75iMA/Z)<1.0Sh \qquad (Eq.3)\ [3]$$

ⅱ. Occasional loads - It do not occur on a regular basis but do happen during operation

(SI Unit)

$$= (PDO/(1000)4tn)+(0.75iMA/Z)+(0.75iMB/Z)<kSh \qquad (Eq.4)\ [3]$$

ⅲ. Expansion/Displacement load - This loads caused by pipe thermal expansion, displacement from thermal expansion or foundation settlement

(SI Unit)

SE=(1000(iMc)/Z)〈SA (Eq.5) [3]

Where,

I : Stress intensification factor

MA/MB/MC : Resultant moment loading (mm-N)

Sh : Allowable stress at max. temperature

SL : Sum of longitudinal stresses

Z : Section modulus ($mm^3$)

K : 1.15 for occasional loads more than 8 hours

: 1.2 for occasional loads less than 1 hour

Based on this modeling with CEASER II™ software, the acceptable allowable stress at pipe material yield strength is below 80%, which not over from pipe material elastic deformation region. This allowable stress is the basis to determine supports stiffness at pipe node to ensure no excess load along high pressure and temperature pipes.

## 9. Results with CAESER II™ Pipe Stress Analysis

CAESER II™ capable to define excessive load points when it simulates code stress check in relation of load cases i.e. basic load (operating and sustained) cases and combination load cases (expansion). Based on analysis and evaluation, it will indicate acting load values. By applying corrective measurements, it will properly determine suitability and flexibility of pipe support and avoid from catastrophe to occur.

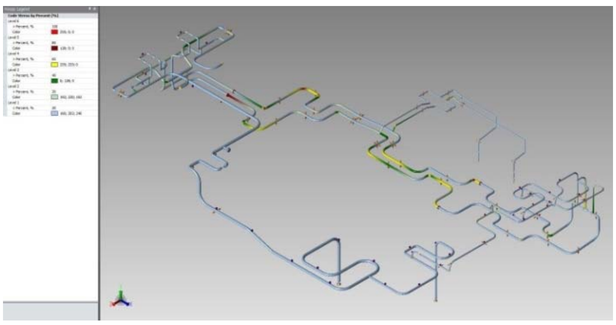


Fig. 11 Result of Code Stress Evaluation

Fig. 11 shows the piping design code stress simulation prepared for UST high pressure and temperature steam pipelines with temperature reach up to 560° C and pressure uphold of 102 bar. Based on color codes, it indicates point of potential high stresses. This stress to be overcome by increase the stiffness factor and correct pipe supports to ensure it will cater for the excessive loads.

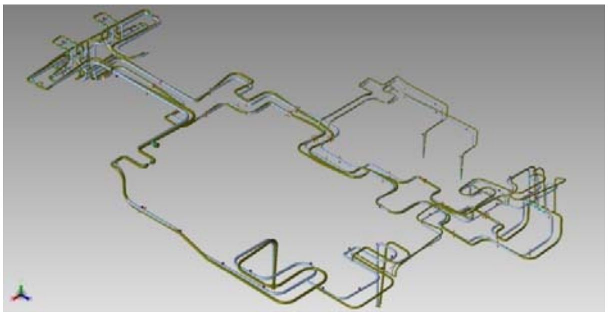
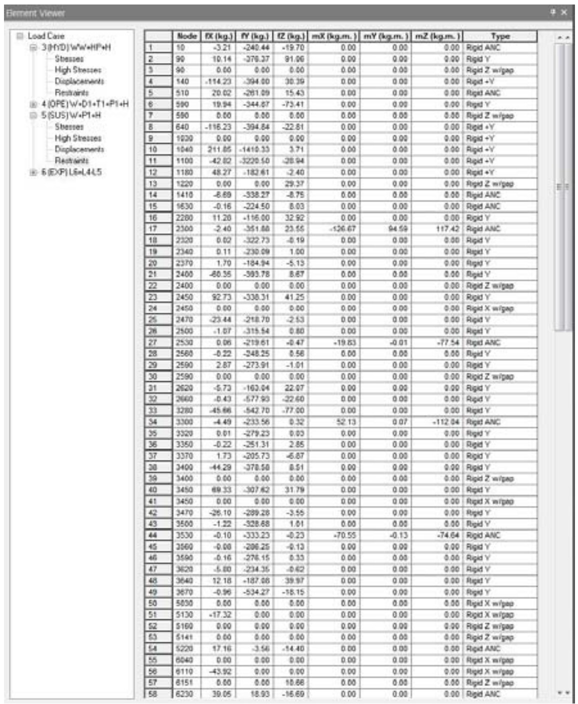


Fig. 12 Result of Piping Deflection

With reference to Fig. 12, it shows simulation of piping under deflection (operation) condition. This condition is simulated in relation of maximum continuous rating of vessel condition means main boiler operates at its maximum steam generation condition, with reheat and main burner functioning.




| | Node | fX (kg.) | fY (kg.) | fZ (kg.) | mX (kg.m.) | mY (kg.m.) | mZ (kg.m.) | Type |
|---|---|---|---|---|---|---|---|---|
| 1 | 10 | -3.21 | -240.44 | -19.70 | 0.00 | 0.00 | 0.00 | Rigid ANC |
| 2 | 90 | 10.14 | -376.37 | 91.06 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 3 | 90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Rigid Z w/gap |
| 4 | 140 | -114.23 | -394.00 | 30.39 | 0.00 | 0.00 | 0.00 | Rigid +Y |
| 5 | 510 | 20.02 | -261.09 | 15.43 | 0.00 | 0.00 | 0.00 | Rigid ANC |
| 6 | 590 | 19.94 | -344.87 | -73.41 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 7 | 590 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Rigid Z w/gap |
| 8 | 640 | -116.23 | -394.84 | -22.81 | 0.00 | 0.00 | 0.00 | Rigid +Y |
| 9 | 1030 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Rigid +Y |
| 10 | 1040 | 211.85 | -1410.33 | 3.71 | 0.00 | 0.00 | 0.00 | Rigid +Y |
| 11 | 1100 | -42.82 | -3220.50 | -28.94 | 0.00 | 0.00 | 0.00 | Rigid +Y |
| 12 | 1180 | 48.27 | -182.61 | -2.40 | 0.00 | 0.00 | 0.00 | Rigid +Y |
| 13 | 1220 | 0.00 | 0.00 | 29.37 | 0.00 | 0.00 | 0.00 | Rigid Z w/gap |
| 14 | 1410 | -6.69 | -338.27 | -8.75 | 0.00 | 0.00 | 0.00 | Rigid ANC |
| 15 | 1630 | -0.16 | -224.50 | 8.03 | 0.00 | 0.00 | 0.00 | Rigid ANC |
| 16 | 2280 | 11.20 | -116.00 | 32.92 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 17 | 2300 | -2.40 | -351.88 | 23.55 | -126.67 | 94.59 | 117.42 | Rigid ANC |
| 18 | 2320 | 0.02 | -322.73 | -0.19 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 19 | 2340 | 0.11 | -230.09 | 1.00 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 20 | 2370 | 1.70 | -184.94 | -5.13 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 21 | 2400 | -60.36 | -393.78 | 8.67 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 22 | 2400 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Rigid Z w/gap |
| 23 | 2450 | 92.73 | -338.31 | 41.25 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 24 | 2450 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Rigid X w/gap |
| 25 | 2470 | -23.44 | -218.70 | -2.53 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 26 | 2500 | -1.07 | -315.54 | 0.80 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 27 | 2530 | 0.06 | -219.61 | -0.47 | -19.83 | -0.01 | -77.54 | Rigid ANC |
| 28 | 2560 | -0.22 | -248.25 | 0.56 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 29 | 2590 | 2.87 | -273.91 | -1.01 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 30 | 2590 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Rigid Z w/gap |
| 31 | 2620 | -5.73 | -163.04 | 22.07 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 32 | 2660 | -0.43 | -577.93 | -22.60 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 33 | 3280 | -45.66 | -542.70 | -77.00 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 34 | 3300 | -4.49 | -233.56 | 0.32 | 52.13 | 0.07 | -112.04 | Rigid ANC |
| 35 | 3320 | 0.01 | -279.23 | 0.03 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 36 | 3350 | -0.22 | -251.31 | 2.85 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 37 | 3370 | 1.73 | -205.73 | -6.87 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 38 | 3400 | -44.29 | -378.58 | 8.51 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 39 | 3400 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Rigid Z w/gap |
| 40 | 3450 | 69.33 | -307.62 | 31.79 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 41 | 3450 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Rigid X w/gap |
| 42 | 3470 | -26.10 | -289.28 | -3.55 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 43 | 3500 | -1.22 | -328.68 | 1.01 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 44 | 3530 | -0.10 | -333.23 | -0.23 | -70.55 | -0.13 | -74.64 | Rigid ANC |
| 45 | 3560 | -0.08 | -286.25 | -0.13 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 46 | 3590 | -0.16 | -276.15 | 0.33 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 47 | 3620 | -5.00 | -234.35 | -0.62 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 48 | 3640 | 12.18 | -187.08 | 39.97 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 49 | 3670 | -0.96 | -534.27 | -18.15 | 0.00 | 0.00 | 0.00 | Rigid Y |
| 50 | 5030 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Rigid X w/gap |
| 51 | 5130 | -17.32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Rigid X w/gap |
| 52 | 5160 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Rigid Z w/gap |
| 53 | 5141 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Rigid Z w/gap |
| 54 | 5220 | 17.16 | -3.56 | -14.40 | 0.00 | 0.00 | 0.00 | Rigid ANC |
| 55 | 6040 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Rigid X w/gap |
| 56 | 6110 | -43.92 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Rigid X w/gap |
| 57 | 6151 | 0.00 | 0.00 | 18.66 | 0.00 | 0.00 | 0.00 | Rigid Z w/gap |
| 58 | 6230 | 39.05 | 18.93 | -16.69 | 0.00 | 0.00 | 0.00 | Rigid ANC |

Fig. 13 Analysis result for force and moment of pipe node

Fig. 13 shows the element viewer of Caesar II™. This function is allowing sequential review of each element's data in graphical view. (Refer Fig. 13 for graphical view). The data display includes the node numbers, the displacements, forces and stresses. From this viewer, designer able to evaluate structural responses and stress of UST piping system and also indication of support or pipe modification at node points if required.

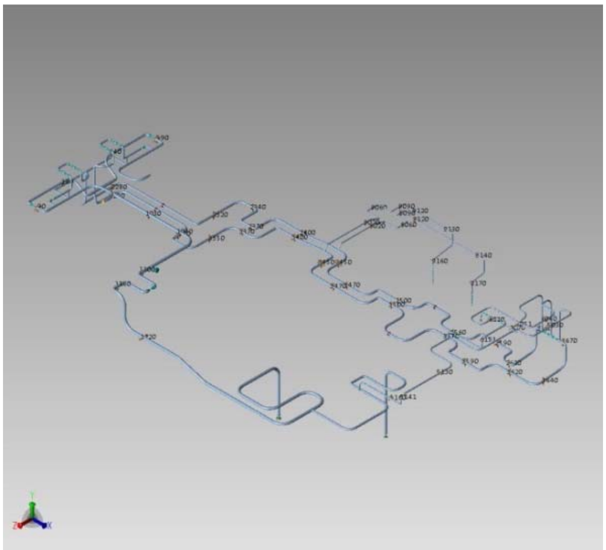


Fig. 14 Graphical view of load element

## 10. Conclusions

Following conclusions are made from the analysis of high thermal and pressure pipe stress of UST system:

i. The designed pipe verified all conditions of loads defined by ASME Code for Pressure Piping, B31, and Power Piping B31.

ii. Based on CAESER II™ modelling, pipe stress which reaches maximum allowable stress will need to be increased with supporting load factor, K (stiffness factor)

iii. Pipe II™ modelling, pipe stress which reaches maximum allowable stress will need to be increased with supporting load factor, K (stiffness factor)

iv. Allowable stress at pipe material yield strength is below 80%, which not over from pipe material elastic deformation region

v. Support loading modelling shows satisfactory loading condition for thermal and pressure pipe for UST system

## References

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