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DYNAMIC STRESS ANALYSIS OF STEAM PIPING SYSTEMS

INTRODUCTION

This work addresses the dynamic stress analysis of a 600MW boiler steam piping system. It was done in the context of the rebuild of a power generating unit that had been damaged due to an over-pressurisation incident. Given the high cost of replacing the steam piping systems, it is very important to ensure that it is adequately designed for sustainable operation and maintenance. The main concern with regard to the dynamic stress analysis was the effect of dynamic events on the integrity of the piping system and to determine what supporting mechanisms would be required to ensure code compliance.

DESCRIPTION OF THE PLANT

The piping systems under consideration are for a fossil fuel power generating unit that was constructed between 1978 and 1984. It burns pulverized coal and it is rated at 600MW.

Figure 1 shows an isometric view of the mainsteam, cold reheat and HP bypass piping systems. A feed water system supplies chemically treated water via pumps, feed water heaters and piping to the economisers and then into the evaporator as a steam/water mixture. The steam/water mixture is separated and saturated steam flows to four banks of superheaters. Spray water attemperators are arranged between superheater stages to ensure that steam is supplied to the HP turbine at the correct temperature, pressure and steam condition.

Superheated steam then flows to the HP turbine via the mainsteam piping. An HP bypass system circumvents the HP turbine stage leading to the cold reheat piping system, in turn leading to the boiler's reheater system under upset conditions. Spray water attemperators are arranged between reheater stages to ensure that steam is supplied to the IP and LP turbine stages at the correct steam condition.

Steam then leaves the boiler reheater via the hot reheat piping system. An IP and LP bypass system, which also circumvents the IP and LP turbine stages leading to the condenser, under upset conditions is also present.

Spherical headers present in the piping system were analysed using finite element analysis (as part of a separate analysis) from which the results were incorporated into the piping stress model.

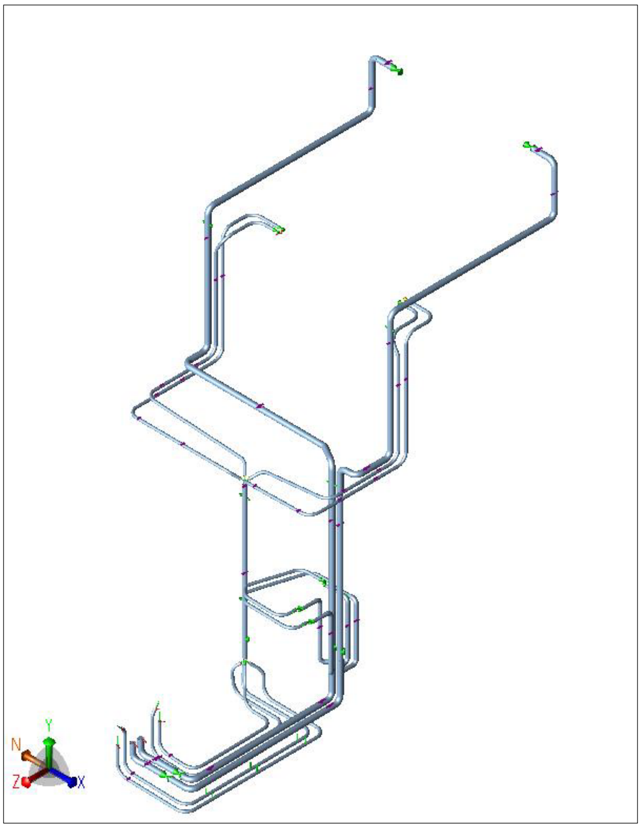

FIGURE 1: ISOMETRIC VIEW OF THE MAINSTEAM, COLD REHEAT AND HP BYPASS PIPING SYSTEMS

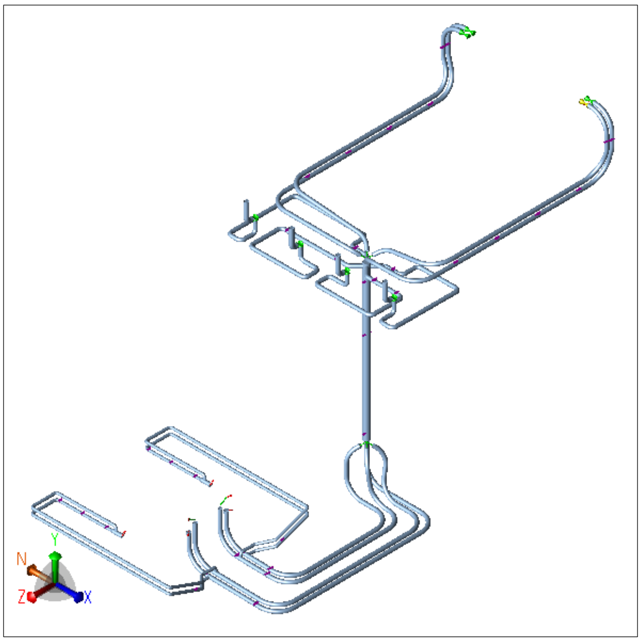

FIGURE 2: ISOMETRIC VIEW OF THE HOT REHEAT AND IP/LP BYPASS PIPING SYSTEMS

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LOADING ON THE PIPING SYSTEMS

In view of a dynamic analysis, it is important to understand the loads experienced and how these cause stresses. The loads on the piping systems are as follows:

- Pressure.
- Temperature.
- Thermal expansion stresses.
- Weight loads (self-weight and equipment).
- Safety valve thrust loads.
- Dynamic/transients events

ANALYSIS METHOD

Throughout this work, methods stipulated in EN 13480-3 were adhered to, to calculate and evaluate stresses, thermal displacements and reaction forces. The analysis involved evaluating the effect of the pressure rise on the piping systems as a result of loading due to dynamic events.

All piping systems were modelled using a real-time thermo-fluid hydraulic network solver called Flownex. Boundary conditions along with characteristic equipment data served as geometry input into the Flownex model. From a process engineering perspective both static and dynamic analyses were completed.

Pressure rises due to a turbine trip (ESV sudden closure), HP bypass opening, IP/LP bypasses opening and safety valves relieving were simulated, the results of which shown below in Figures 3 to 5.

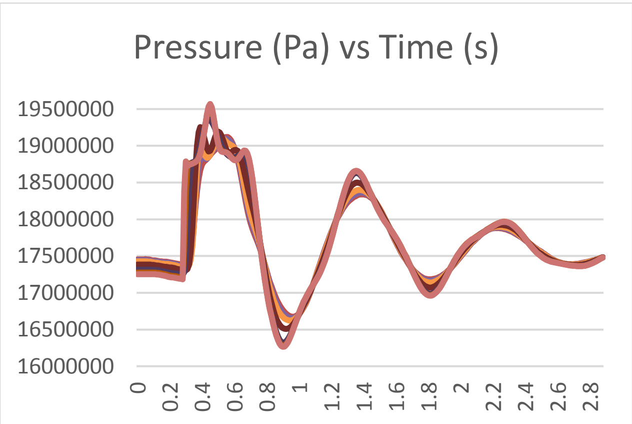

FIGURE 3: PRESSURE PROFILE IN TURBINE LEG PIPING DUE TO RAPID TURBINE ESV CLOSURE

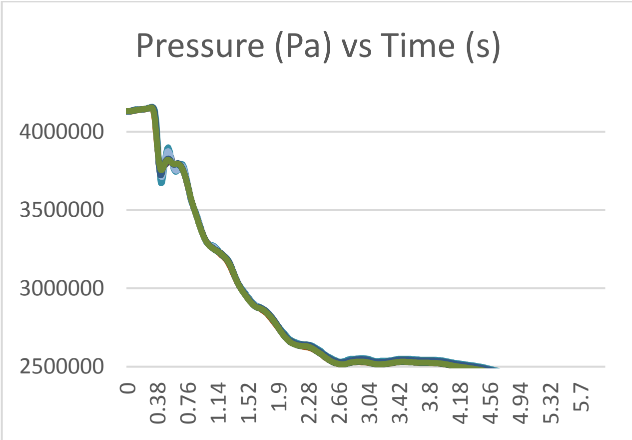

FIGURE 4: PRESSURE PROFILE DUE TO HP BYPASS VALVES OPENING

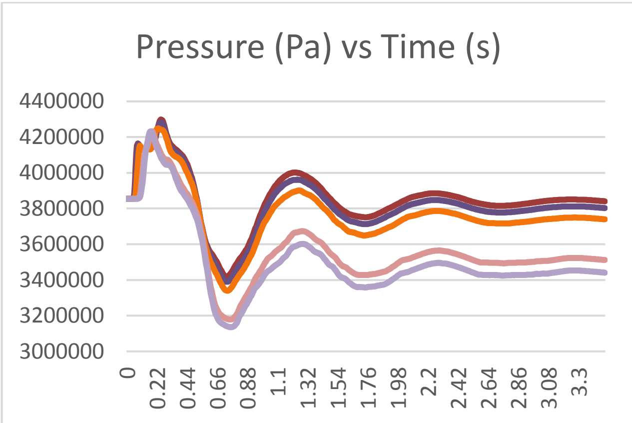

FIGURE 5: PRESSURE PROFILE DUE TO IP/LP BYPASS VALVES OPENING

The above pressure rises were then converted to forces based on the internal pipe cross sectional area which were then applied to the piping system. Unbalanced loads due to pressure waves experienced between elbow pairs in relation to the time it takes for the pressure waves to subside were evaluated. Worst case scenarios whereby unbalanced pressure waves are in effect for the maximum amount of time between elbow pairs leading to the highest stresses as a result of excessive displacement were further evaluated.

The results of the piping stress models were then analysed and changes made to the supporting characteristics to accommodate the forces due to dynamic events, such that the calculated stresses from the piping stress model are below the allowable stresses for the specific materials of construction as defined in EN 13480.

Figures 6 to 17 below show overstress in different areas of the piping systems in comparison to the material allowable stresses stipulated in EN 13480.

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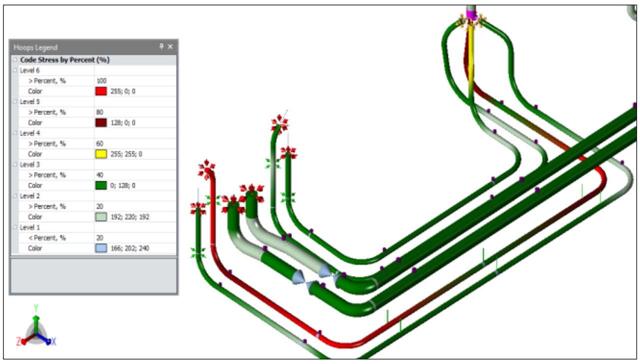

FIGURE 6: OVERSTRESS IN TURBINE LEG RA 21

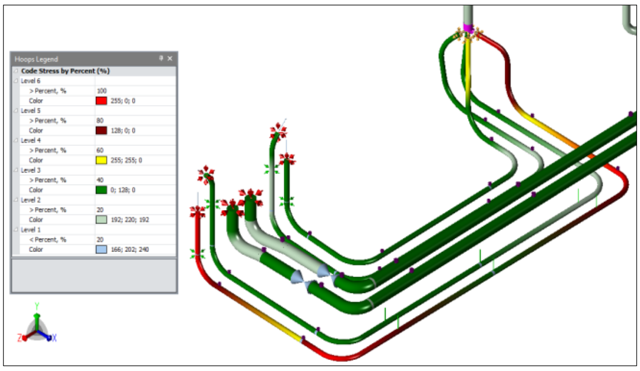

FIGURE 7: OVERSTRESS IN TURBINE LEG RA 22

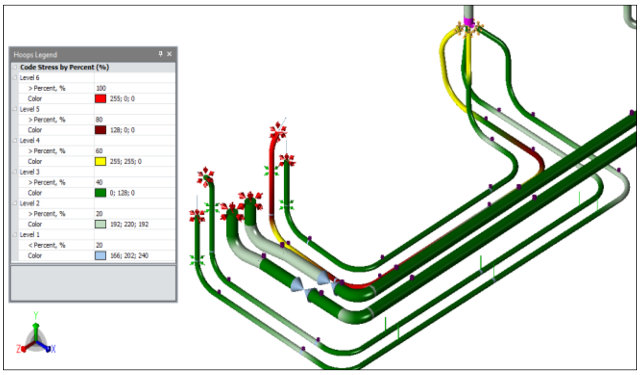

FIGURE 8: OVERSTRESS IN TURBINE LEG RA 23

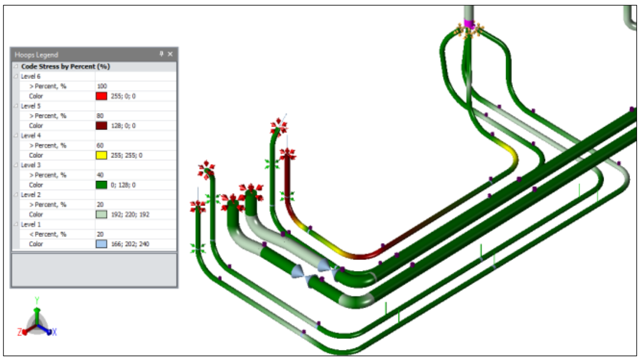

FIGURE 9: OVERSTRESS IN TURBINE LEG RA 24

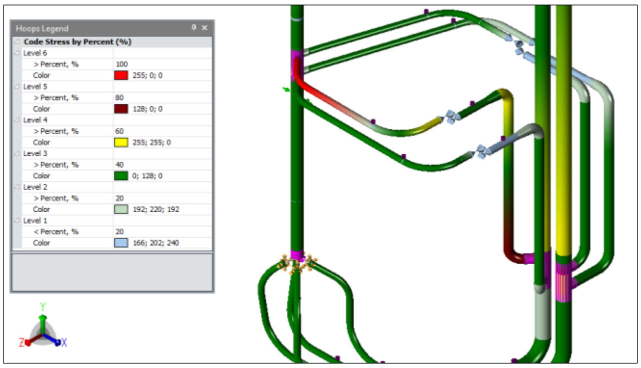

FIGURE 10: OVERSTRESS IN HP BYPASS LEG RA 31

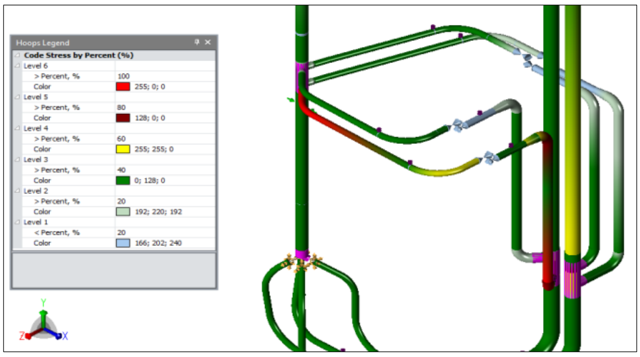

FIGURE 11: OVERSTRESS IN HP BYPASS LEG RA 32

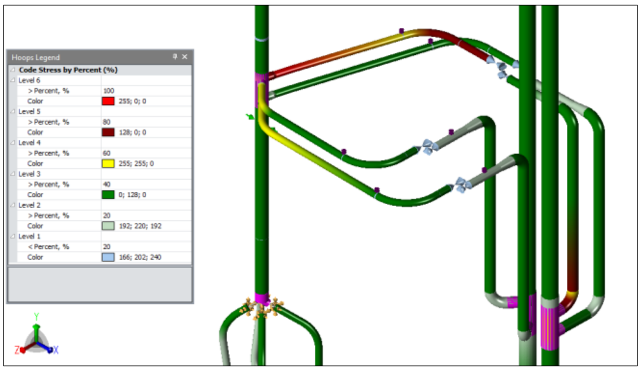

FIGURE 12: OVERSTRESS IN HP BYPASS LEG RA 33

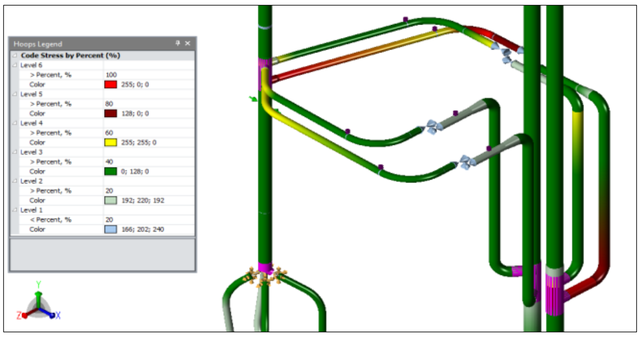

FIGURE 13: OVERSTRESS IN HP BYPASS LEG RA 34

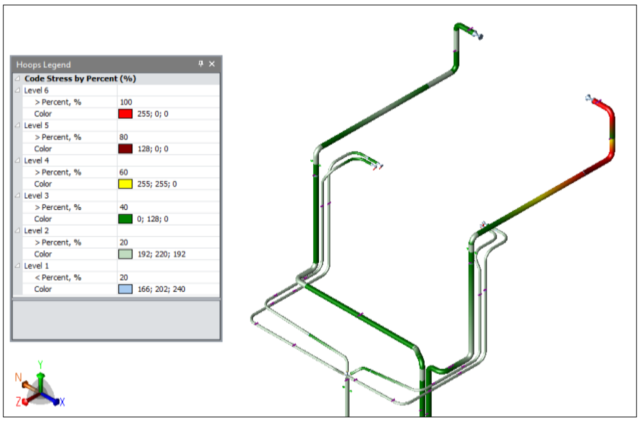

FIGURE 14: OVERSTRESS IN COLD REHEAT LEG RC 11

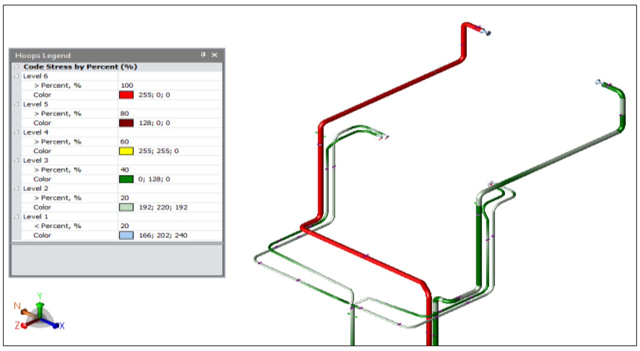

FIGURE 15: OVERSTRESS IN COLD REHEAT LEG RC 12

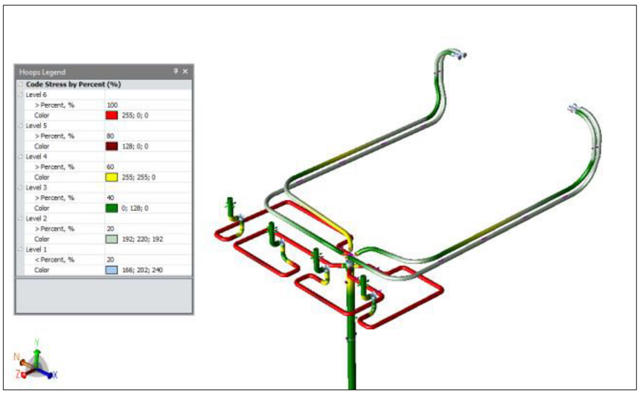

FIGURE 16: OVERSTRESS IN SAFETY VALVE ESCAPE PIPING

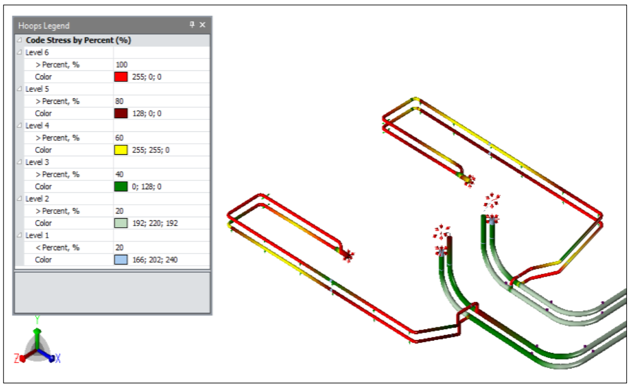

FIGURE 17: OVERSTRESS IN IP/LP BYPASS LEGS

To reduce the uncontrolled displacements and stresses dynamic restraints were implemeted at carefully considered locations. A typical dynamic restraint is shown below in Figure 18.

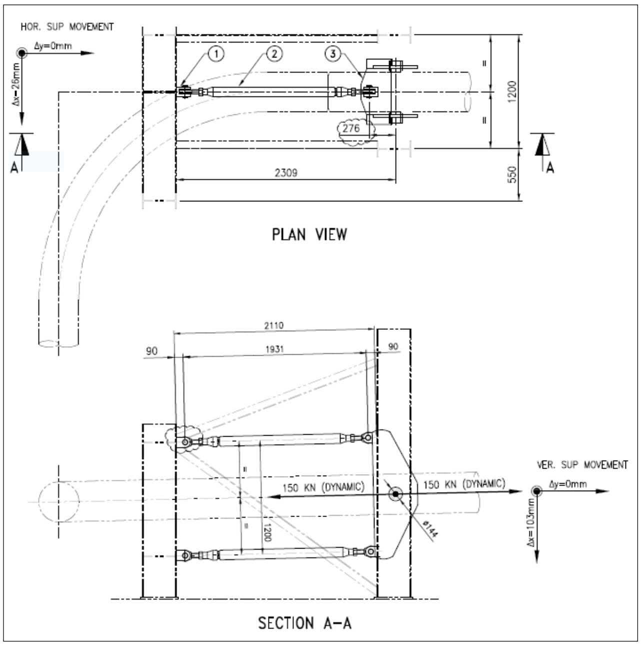

FIGURE 18: TYPICAL DYNAMIC RESTRAINT

The use of dynamic restraints were sufficient to reduce the calculated stressed within the allowables as defined in EN 13480 thus making the system code compliant as shown below in Figures 19 and 20.

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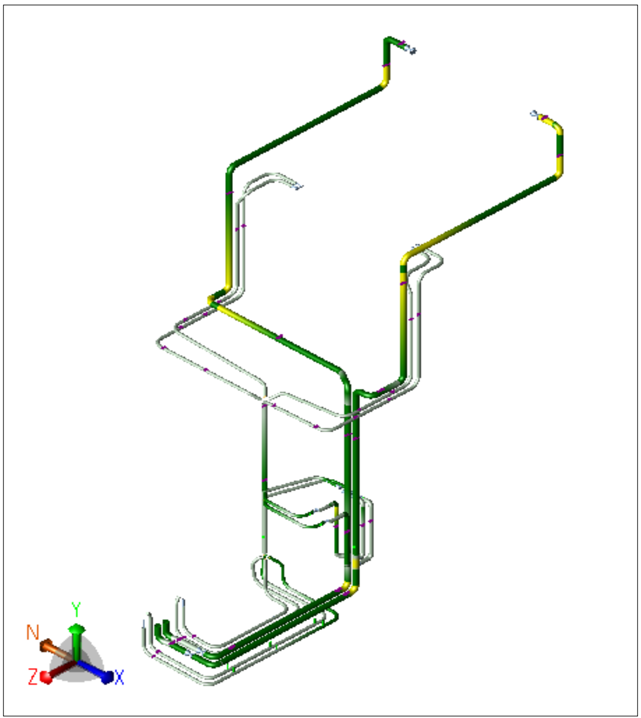

FIGURE 19: MAINSTEAM, COLD REHEAT AND HP BYPASS PIPING SYSTEMS WITHIN ALLOWABLE STRESS

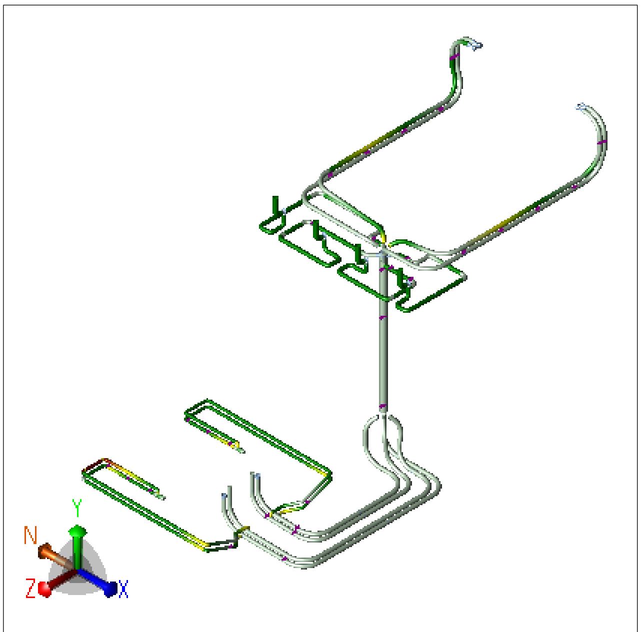

FIGURE 20: HOT REHEAT AND IP/LP BYPASS PIPING SYSTEMS WITHIN ALLOWABLE STRESS

CONCLUSIONS

The main steam, cold reheat, hot reheat, HP and IP/LP bypasses were simulated in real-time using Flownex. The outputs were used to calculate impact forces. Impact forces were calculated and applied to the piping stress models. Calculated stresses were then compared to allowable stresses as defined in EN 13480. Where the calculated stresses were found to be above the allowable stresses, additional supports were selected and added to the piping stress model. The piping stress models were re-evaluated in this manner until calculated stresses were found to be within the allowable stresses.
