Allowable Skid Edge Loads; Deficiencies and Recommended Changes to Design Practices

This application note highlights a common engineering problem where the piping system is in transition between the equipment, such as a compressor or pump package, and the plant piping system. It discusses the commonly referred to specification of allowable skid edge loads and provides practical design practices to ensure the pipe design is acceptable. A case study is presented to illustrate the issues.

The Problem

Piping flexibility studies (thermal analyses) are commonly done on piping systems to ensure the stress, force and deflection due to loads from pressure, temperature, and weight are within safe limits. The design of a particular facility is often a shared responsibility of several different companies. For example, the compressor packager designs the piping and vessels within their package limit (also referred to as skid edge) and the EPC company designs the interconnecting piping from the compressor package limit to the rest of the facility.

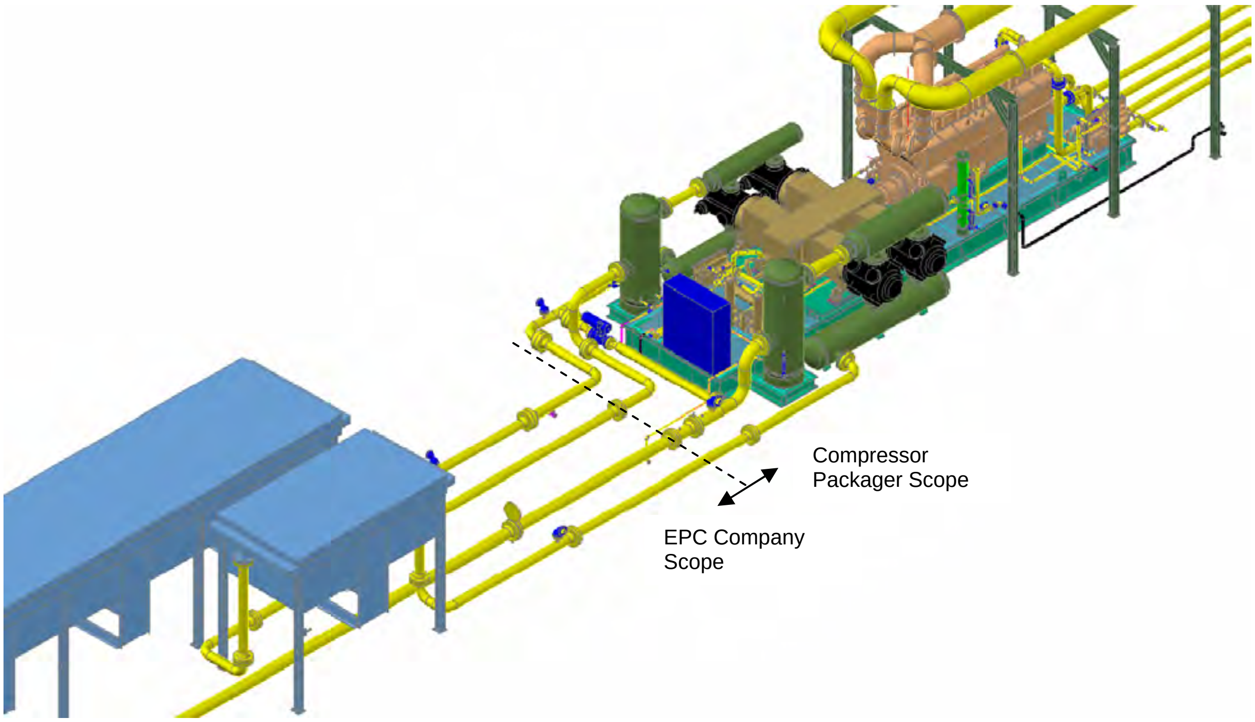

Figure 1: Typical Reciprocating Compressor Installation

The problem in situations where there is shared responsibility in the overall system design is: how do the different parties conduct their individual studies to qualify their design. The EPC company does not want to take responsibility for design of the compressor packager's piping and vessels. Similarly, the compressor packager does not want to be responsible for design of the EPC company's piping and supports.

Common Design Practice

The typical design practice in cases of shared responsibility for a system's flexibility design is to define a specification indicating that the point where responsibility changes between two parties, i.e., the skid edge:

1. is to be an anchor point, and
2. the allowable forces and moments at the skid edge connection are to be supplied by the equipment vendor (compressor packager in this example).

These two specifications allow for the two parties to conduct their respective flexibility studies; however, there are several drawbacks or limitations to this approach.

<u>Anchor Specification</u>

The specification of an anchor point in the piping system (and in the engineer's computer model) is one method to minimize the interaction between the piping system from two different suppliers. However, there are several cases were an anchor is not practical or possible. For example, an elevated piping support at skid edge cannot be an anchor. The support will be flexible to forces in the horizontal plane, perhaps even more flexible than the pipe itself.

In some cases a skid edge support can be said to be effectively anchored if the other pipe restraints in the system are very flexible. Pipe stress engineers typically assume a flat bar clamp or a combination of a line stop and guide to be an anchor. This approach may work for systems where there are only static loads, or the dynamic loads are considered negligible, for example instrument air lines, purge lines, or drain lines. In this case, pipe rests and guides are typically sufficient for pipe restraints.

This approach does not work in cases where there are significant dynamic forces acting on the piping, such as in a reciprocating compressor or reciprocating pump installation. Pipe restraints and pipe supports must be designed with sufficient stiffness to minimize vibration from the dynamic loads. Pipe rests and guides are generally unacceptable for restraining pipe with dynamic loads, so pipe clamps are required to ensure the pipe dynamic response is controlled. Designing a pipe anchor requires a large and robust pipe restraint, as well as an equally massive pipe support structure when the rest of the piping system has stiff pipe restraints, such as flat bar clamps. Designing, constructing, and installing an anchor in these applications is costly and impractical.

One final point is that even if an anchor point is possible and practical to install at the skid edge location, there can be a very negative impact on the equipment vendor's piping. Consider the case of a typical reciprocating compressor package as shown in Figure 1. The piping from the compressor discharge is at a very hot temperature. Very high stresses can be generated in even a short amount of piping if an anchor is assumed at the skid edge. Reducing the stress to acceptable levels requires making significant changes to the piping layout.

<u>Allowable Skid Edge Loads</u>

Piping stress engineers are familiar with the concept of allowable nozzle loads for equipment such as heat exchangers, pumps, and vessels. The allowable nozzle loads are based on the stress induced in the pressure containing device, or minimizing deflection of equipment casings (to avoid damage to the moving parts inside the equipment).

Many companies have developed their own set of allowable nozzle loads based on many factors, one including a healthy design margin to ensure these design loads are acceptable. Table 1 is an example. The loads are not meant to be the maximum absolute allowable, but are instead a design guideline for the pipe stress engineer. If the allowable loads are exceeded with the pipe design, then changes are made to the pipe layout. Alternatively, if pipe layout changes are undesirable, a stress specialist is retained to do a more detailed analysis of the nozzle.

Table 1: Typical Allowable Nozzle Loads

NPS Nozzle Size (inch)	Flange Rating	Pr (N)	Vc, Vl (N)	Fr (N)	Mt (Nm)	Mc, Ml (Nm)	Mr (Nm)
6”	150	3780	4630	7560	4075	2880	5765
	300	4600	5630	9200	4860	3440	6880
	600	5695	6975	11390	5865	4145	8295
	900	7250	8880	14505	7185	5080	10160
	1500	10595	12975	21185	9605	6795	13585
	2500	10595	13150	21475	9700	6860	13720

Nomenclature

- Pr is the radial loading on the nozzle
- Vc is the circumferential shear force on the nozzle
- Vl is the longitudinal shear force on the nozzle
- Mt is the torsion moment on the nozzle
- Mc is the circumferential moment on the nozzle
- Ml is the longitudinal moment on the nozzle
- Fr, Mr are the resultant force and resultant moment

Applying the allowable nozzle loads as shown in Table 1 is a reasonable approach for nozzle connections on vessel connections and, to some degree, other equipment such as heat exchangers. However, these allowable nozzle loads should not be used as design values for all skid edge connections. The skid edge connection in a majority of cases is not a nozzle on a vessel on a piece of equipment. In most instances there is a pipe spool, or spools, between the skid edge connection and the vessel or equipment,

Pipe spools may have several bends with supports, which have a significant impact on the loads on the equipment. Determining a simple chart of allowable skid edge nozzle loads for specific pipe sizes and flange ratings, as shown in Table 1, is not a practical approach given the variability in the piping design from skid edge to the vessel, or to equipment mounted on the skid.

Recommended Practice

Recommended Design Practice

The piping system will respond as an overall or comprehensive system, irrespective of the limit of responsibility for the system design. The piping on the compressor packager’s skid will push and pull and twist on the piping that is within the EPC’s scope of supply. The pipe support design for the EPC’s piping will affect the way the compressor packager’s piping deforms. A simulation of the ***complete*** piping system will determine the interaction between the system components and determine the best design for the overall system.

Therefore, the recommended design practice is to

1. create a model that considers the complete system,
2. terminate the model at a known boundary condition, and
3. include the flexibility of pipe supports.

There will be some overlap in the modeling effort by the EPC and the compressor packager to model the effect of the complete system. However, this does not mean that the compressor packager must model the complete EPC piping and the EPC company must model the complete compressor packager piping. Typically, only a small portion of the piping system beyond the company’s responsibility needs to be modeled to achieve an accurate representation of the overall system response.

The example of a reciprocating compressor or pump package design has been used throughout this discussion. This is because there are competing design requirements for the pipe stress designer and vibration control designer. The pipe stress designer wants to make the system more flexible and include assumptions in the computer simulation that make the design more conservative as per good engineering practice. These assumptions and design goals are contrary to the vibration control designer, since the goal is to make the pipe layout and support stiff. If the piping design is conducted without considering both of these design goals, the design process may involve many design iterations. It is recommended that the same party that conducts the pipe design for vibration control also conducts the piping flexibility study. This approach is also recommended in API 618, 5th Edition.

Why Hasn't my Piping System Failed?

Beta recognizes that the commonly used design practices for piping systems has worked in many different applications for many years and is still used every day by many pipe stress designers. So why haven't there been many piping failures because of the faults in this design approach?

First, the allowable nozzle loads include a large factor of safety to ensure the design is acceptable. If these loads are applied to the skid edge loads, the piping system will be designed very conservatively.

Also, the analysis is typically done for a worst case load condition and assumes the loads will be cycled a specific number of times over the life of the equipment. A typical pipe stress analysis will assume 7,300 start-up/shut-down cycles over a 20 year life. This assumes 1 cycle per day, every day for 20 years. Most systems do not experience this extreme in system operation or system cycling.

Impact of the Recommended Design Practice for Piping System Design

The common practice of dividing the piping system design is a conservative approach for most cases. This conservative design approach generally means that additional pipe supports are added, resulting in additional fabrication costs and longer construction schedules. These additional costs are avoided when the recommended design practice of analyzing the complete piping system is followed.

The other benefit of the complete piping system analysis, as compared to the divided piping system analysis approach, is that the complete piping system analysis does not rely on the assumption of an anchor at the skid edge. As mentioned earlier, implementing a skid edge anchor is often impractical to implement for elevated piping. Support structures for elevated piping can often be quite flexible. The flexibility analysis conducted by the equipment supplier and the EPC company will not be accurate and will not represent the actual system response if the skid edge support is not an effective anchor. The end result may be areas with stress over design guidelines or excessive loads on equipment that can lead to failures.

The following case study shows the impact of two approaches for conducting piping flexibility analyses.

Case Study

This case study shows the differences between simulating the piping system from the common practice of an anchor at skid edge and the recommended approach of using a comprehensive system model.

The analysis includes simulation of a multi-phase pump system piping, as shown in Figure 2. The media being pumped is water with entrained gas at a relatively high temperature ranging from 284°F to 455°F (140°C to 235 °C) and 435 psi (3,000 kPa). The water is pumped from wells through a large air cooler heat exchanger before returning to the process for reinjection to the well.

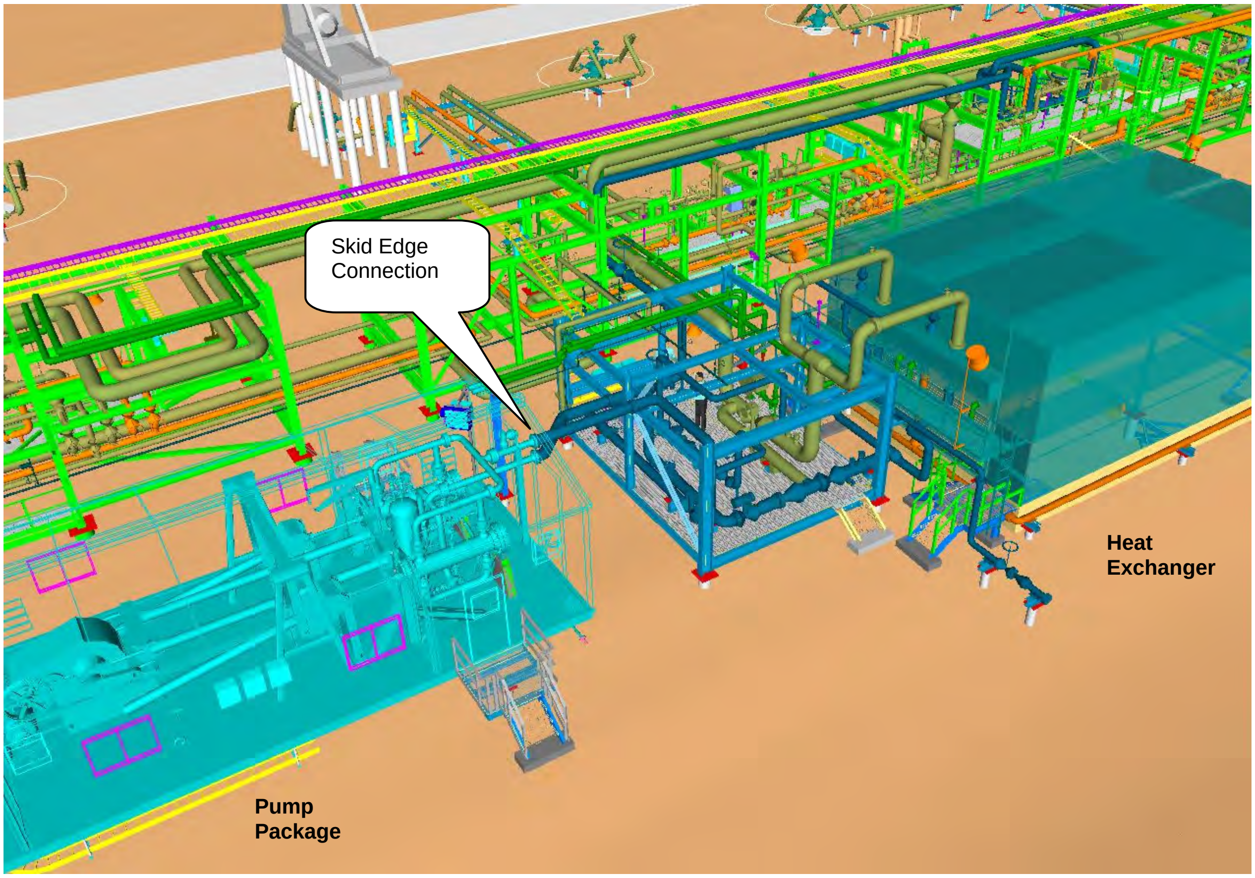

Figure 2: Equipment Arrangement

The EPC company conducted a flexibility analysis of the yard piping including the piping from the wellhead and heat exchangers, up to the pump skid edge connection. Their analysis assumed the skid edge connection would be an anchor, in this case, a combination guide and line stop.

The pump manufacturer is responsible for the piping on the pump skid up to the skid edge connection. An image of the pump package is shown in Figure 3. The support at the skid edge connection was an elevated support fabricated from 2, 6”x6” (150mmx150mm) structural tubes approximately 92” (2.3m) long. The pipe support included a guide but not the line stop. The piping spools and pipe support had been fabricated and the package was scheduled to ship when the missing line stop, required by the EPC company analysis, was noticed.

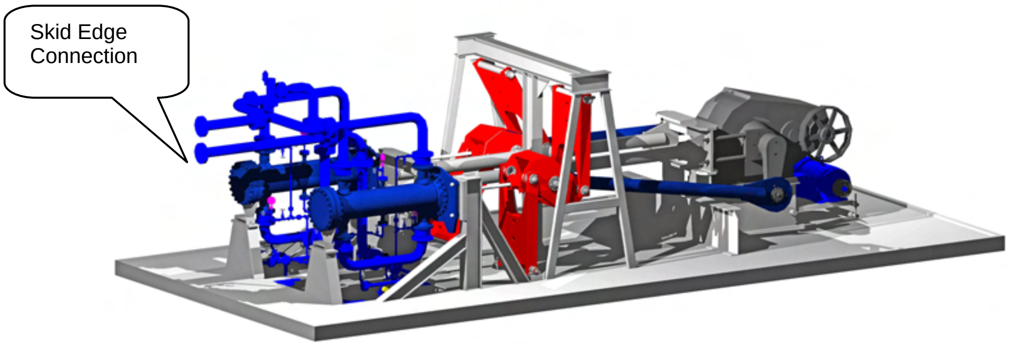

Figure 3: Pump Package

A piping flexibility analysis was conducted on the suction and discharge piping within the pump packager's responsibility. Figure 4 is a plot of the pump piping.

The EPC company supplied calculated displacements at the skid edge connection from their model, assuming a line stop was not installed at the skid edge. These displacements were applied to the pump piping model in addition to the loads from pressure, temperature, and weight. The results show that the stress in the pump piping could be more than 2.5 times the allowable stress, Figure 5.

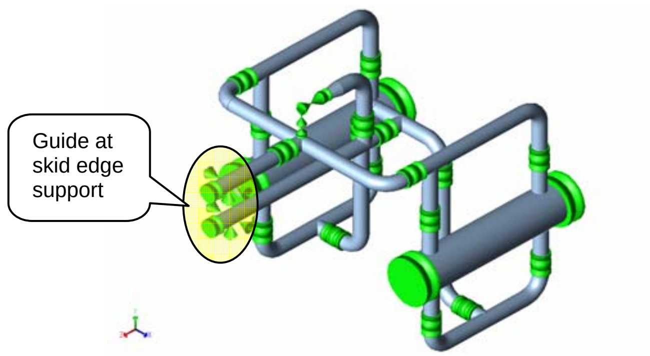

Figure 4: Pump Package Piping

The simulation was then rerun with a guide and line stop at the skid edge support as per the EPC company's model. The forces and moments calculated by the EPC company were applied at the skid edge connection of the pump pipe model. The results from the analysis showed that the maximum stress in the pump piping was 62% of the design guideline. The design was acceptable with the guide and line stop.

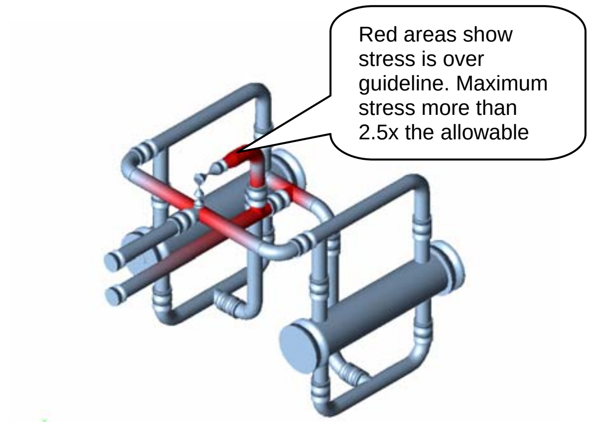

Figure 5: Pump Package Piping Showing Over-stress Areas

Normally, the analysis would not have proceeded past this point since the EPC company was satisfied that their system design was OK and the pump packager piping was also OK. However, the pump package construction had already been completed and the package was scheduled to be shipped within a few days. Adding the line stop would have required modifications to the piping system – an additional cost to the pump packager. A bigger factor than the cost for the piping modification was the delay in shipping that would be caused while modifications were made. The shipping delay has an impact on the overall project schedule.

During review of the pump piping system flexibility analysis, it was demonstrated that the elevated design of the skid edge pipe support design would not provide enough stiffness to be an effective line stop. Figure 6 shows the pipe support. The height of the support results in the support being very flexible in the horizontal direction, perhaps even more flexible than the piping. This support will not provide a rigid line stop as was simulated by the piping flexibility models. A different analysis approach was proposed to evaluate the requirement for the pipe support at the skid edge.

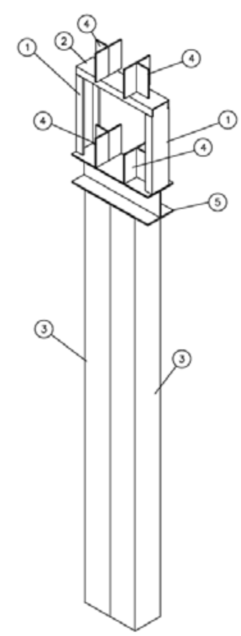

Figure 6: Skid Edge Support

A more accurate method of determining the response of the system and the support requirements is to create a combined model with the yard and cooler piping to determine the overall system response. Figure 7 is a plot showing the combined system model including the elevated support at the pump skid edge. Figure 8 is a zoomed-in view of the same model showing the pump skid with the support at skid edge.

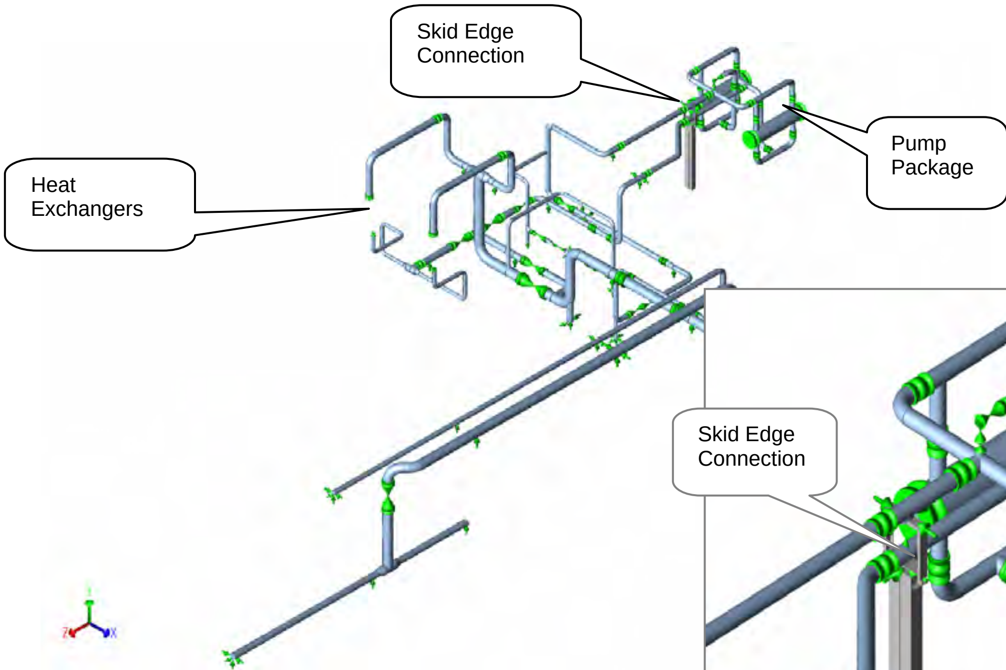

Figure 7: Complete Pump Piping System Model

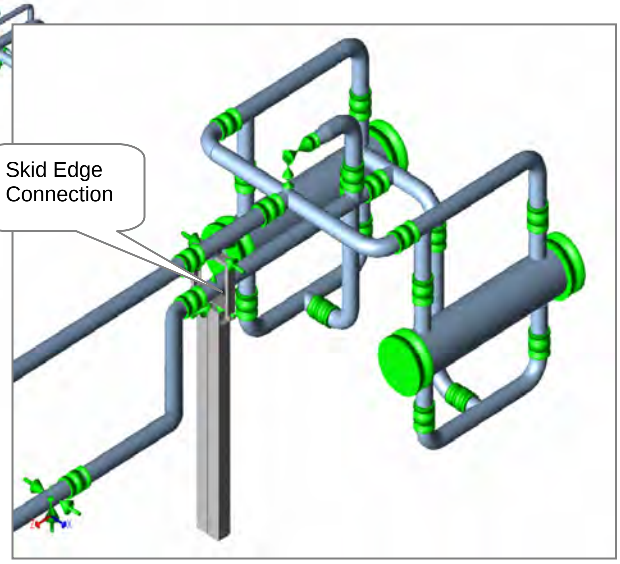

Figure 8: Pump Package Piping with Skid Edge Support and System Piping

The simulation was rerun for the overall system model to determine if the system design was acceptable with the guide pipe support at the pump skid edge. The analysis determined that the maximum stress was 53% of the design limit, therefore the proposed design was acceptable.

The location of the maximum stress occurred at a dummy leg support for the yard piping, as shown in Figure 9. The maximum stress in the pump package piping was 45% of guideline when all the piping was added, compared to 62% of guideline when the line stop was assumed at the skid edge.

The analysis shows that when the complete system model is simulated, the stress in the pump piping is actually lower than the simplified model. The pump piping and pump support did not need to be modified and the unit could be shipped on schedule.

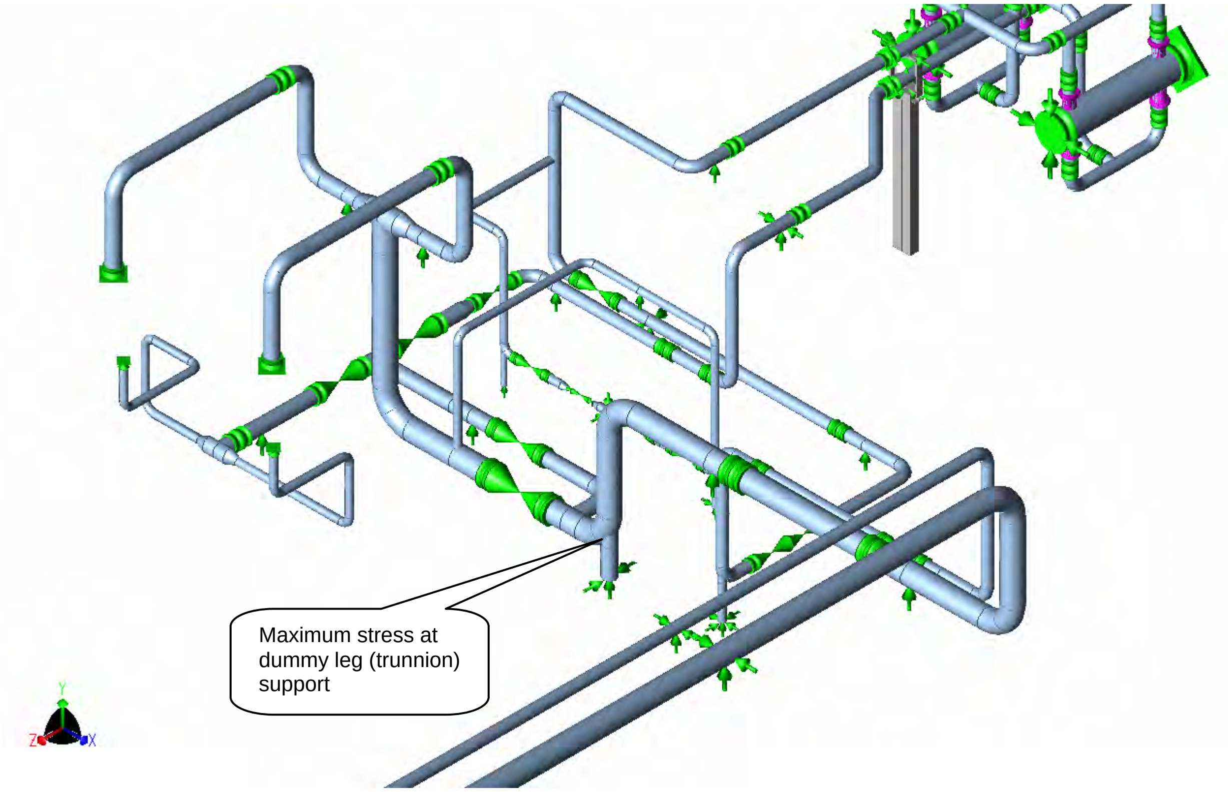

Figure 9: Complete System Model

Summary

An overall system flexibility analysis is recommended, rather than conducting separate flexibility studies by splitting the piping system at the point where responsibility changes between parties. This is especially important when dynamic forces are acting on the piping, or for flexible pipe supports.

The system model does not need to be a comprehensive model of the complete piping system. The equipment supplier shall generate a detail model of their piping and a simplified model of the EPC company's piping to evaluate the interaction between the piping system. The equipment supplier does not need to model the complete pipe system designed by the EPC company. Instead, only a portion of the EPC company piping that will impact the response of the equipment supplier piping needs to be included. Knowing how to simplify the model of the EPC company piping takes the understanding of an experienced pipe stress analyst.

Similarly, the EPC company shall generate a detail model of their piping and a simplified model of the equipment supplier's piping to evaluate the interaction of the overall piping system.

The specification for an anchor at the point or changing responsibility and defining allowable skid edge nozzle loads is not an accurate method of assessing the piping system. This approach will, in most cases, result in an overly conservative (expensive) design.

Careful consideration of static and dynamic (vibration) support requirements are necessary to minimize design iterations. A company with expertise in both these fields is recommended.

For further information, please visit our web site or email info@BetaMachinery.com.