NEW APPROACH TO THE PIPE TO GUSSET PLATE CONNECTION

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EXECUTIVE SUMMARY

Pipe to gusset plate connections have frequently experienced fatigue cracking on ship-to-shore cranes. The cracking at fracture critical pipes has led to several catastrophic failures. There are several common design approaches to this connection, but all are susceptible to fatigue failure. Some approaches include details that are difficult to inspect, and especially unless cracks are quite large. Some common types of connections and issues leading to fatigue cracking are discussed.

This white paper introduces a new approach that significantly increases reliability by using high class fatigue details and facilitating periodic inspection. Access to the connection for inspection and repair is improved. The key element to this new approach is a removable and resealable seal plate, attached without welding. This paper introduces two concepts for the removable seal plate.

BACKGROUND

The pipe to gusset plate connection, “end connection,” is one of the most common ways to join a pipe member to the crane structure. Figure 1 shows two end connections—with and without a seal plate at the end of the gusset plate.

Figure 1: Pipe to gusset plate connection, without seal plate (left) and with seal plate (right)
Fatigue

Fatigue cracking is influenced by the fluctuating stress range, number of cycles of applied stress, weld fatigue classification, and fabrication quality, among others. All fatigue classes mentioned are from BS 7608:2014. Weld classification is based on statistics.

Classes D through G are for different weld geometries and processes, with the weld terminating at the base steel. Class W is for welds within the weld throat. A Class G weld is statistically the most severe, and is prohibited by Liftech crane specifications on fracture critical members (FCMs), which are tension members or tension components of members whose failure would be expected to result in collapse of the crane, part of the crane, collapse or dropping of the trolley or operator’s cab, or dropping the load. Class F2 is the next most severe, then F, E, and D. For the same reliability, a Class F2 detail has 1.7 times more expected life than a Class G detail. Similarly, Class F has 1.5 times that of Class F2, Class E has 1.7 times that of Class F, and Class D has 1.5 times the life of a Class E detail. Class W is also a severe weld class.

In 2015, fatigue cracking at the end connection probably lead to catastrophic collapse of the upper works of a container crane in Germany. In many other cranes, cracking was detected and repaired before the crack reached a fracture critical length. A lot of these were close calls. See Figure 2 for some examples of cracking.

Figure 2: Fatigue cracks nearing fracture critical length, initiating at end of seal plate (left) and at poor fabrication cut of relief hole (right)

EXAMPLES OF COMMON DETAILS

Below is a discussion of two common details. One type has no stress relief hole at the end connection. The other has a stress relief hole at the end connection

No Stress Relief Hole at the End Connection

The end of the slot on the pipe is cut to fit the end of the gusset plate. The end of the gusset plate could be square or rounded. Typically, a partial or complete joint penetration (CJP) weld is installed at the end of the slot. Sometimes a seal plate is installed on top of the pipe at the slot for reinforcement. See Figure 3.
If the end connection is square, it is important to entirely fill the end connection with a groove weld. If not, cracks can propagate from the square corner into the pipe, as the corner is an area of high stress concentration. If the end is not filled, the fatigue life would be significantly less than fatigue Class W. Using a round end of the gusset plate is an improvement, as it eliminates the square corner.

If the groove weld at the end connection is a partial penetration weld, this is a severe fatigue class, Class W in tension. This is unacceptable, especially at FCMs. The upper diagonals and backstays are common FCMs that have end connections.

If the weld at the end connection is CJP, the fatigue class is F2, which is better, but is still a severe fatigue class that typically requires frequent periodic UT and MT examination during the life of the crane to maintain adequate reliability.

Some designers use a seal plate with the intention of reducing the axial stress at the end connection. However, the seal plate can introduce additional Class W and G details in the pipe outside of the seal plate region, where the stresses are larger. It also introduces additional Class F2 or Class W details at the end connection. The series reliability is significantly reduced.

Also, the seal plate obstructs NDT inspection of the end connection. This is problematic as UT and MT examination are required to maintain adequate reliability, as explained above.

Note that none of the variants of this type of end connection are without serious risks. Liftech stopped using this type of end connection in the 1970s.

**Stress Relief Hole at the End Connection**

Another common way to terminate the gusset plate at the end connection is to use a circular stress relief hole.
The Liftech standard hole is a drilled circular hole with a diameter of two times the gusset plate thickness. Some designs use elongated holes to further reduce the stress concentration or improve the gusset plate to pipe weld termination. See Figure 4.

Figure 4: Stress relief hole at the end connection before grinding

**Welded Seal Plate**

A seal plate is used to seal the pipe. In some non-Liftech designs, a large, thick seal plate is installed on top of the pipe at the slot for reinforcement. See Figure 5.

Figure 5: Large seal plate

The intent is to reduce the axial stress at the end connection; however, the seal plate introduces additional Class W and G details in the pipe, outside of the seal plate region, where the stresses are higher.
The seal plate also introduces additional fatigue Class F2 or Class W details at the end connection. Cracking has been found on the seal plate welds, as shown in Figure 6.

![Figure 6: Cracking at the weld of the seal plate](image)

The reliability can be significantly reduced with the wide seal plate, if it is not properly designed and fabricated. Also, any cracks propagating from the details underneath the large seal plate may become dangerously large before they are visible. Reliable NDT inspection is difficult to achieve without removing the seal plate. The bigger the seal plate, the more difficult it is for inspection and for crack repair.

Liftech’s standard seal plate is as thin and small as practical to minimize the problems with the large seal plate described above. The thin and small plate allows it to flex and not take stresses. Thus, it is not a traditional Class G seal plate, as discussed above. However, the weld of the small seal plate is near the stress relief hole and subjected to higher stresses. Also, calculations have shown that the stress relief hole and the gusset plate to pipe weld is likely to require inspection during the life of the structure to maintain acceptable reliability. NDT inspection without removing the seal plate is possible, but not easy.

Some of the cracks that have been observed in this type of end connection are from holes that have inadequate smoothness. Some holes were flame cut and appear to have no grinding. The cracks propagated from the notches left in the pipe. See Figure 7.

![Figure 7: Cracking propagated from notches in pipe](image)
After the seal plate is installed, the condition of the stress relief hole is no longer visible. Sometimes, a third party fabrication auditor puts a hold point to inspect the smoothness of the hole prior to installation of the seal plate while others do not. Therefore, inspection in the factory is not always reliable.

Another downside of the seal plate is that additional weld details are added. See Figure 8 for components and typical crack locations for an end connection with a relief hole and seal plate.

![End Connection Components](image1)

Key to crack initiation locations (“A” is most likely, “F” is least likely)

- A: Weld toe at gusset to seal plate fillet weld
- B: Weld toe at seal plate to pipe fillet weld
- C: Corner of cutout in seal plate, cracking due to poor radius
- D: Relief hole in pipe, cracking due to poor radius and/or stress concentration due to hole
- E: End of weld between gusset and pipe
- F: Fillet weld between seal plate and pipe

**Figure 8:** End connection with seal plate, showing typical crack initiation locations

Series reliability is two or more connections, e.g., welds, in series as links of a chain. The combined reliability of the series is the product of the reliability of each link. Therefore, more added welds result in a reduced overall connection reliability, especially when poor weld Class welds are added.
NEW IDEA: REMOVABLE SEAL PLATE

If the seal plate described above is not welded to the pipe and gusset plate end connection and can be easily removed and reinstalled, most of the problems described above can be eliminated. The severe fatigue details of the seal plate would be eliminated. The seal plate would not participate in taking the pipe stresses, and there would be no added welds that could cause crack propagation into the pipe. The details underneath the seal plate could be inspected conveniently at any time, in the factory or at the port. The weld between the pipe and the gusset plate would also be improved.

To this end, Liftech developed two concepts for the removable seal plate—one using a rubber O-ring and another using silicone caulk. With using a removable seal plate, the biggest concern is water intrusion and the durability of the seal. The typical pipe member is pressure tested after installation to confirm air and water tightness. The plate seal member, while removable, must be able to pass the pressure testing and must be durable to reliably seal the pipe until the next inspection interval. This is the objective of the two concepts described below. For extra safety, a drain hole with a sealing bolt should be installed in the bottom of the pipe, preferably near the center of the pipe end plate, to allow drainage in the event of a breached seal. A pressure testing nipple will still be required to periodically test the seal. We also suggest that the structural maintenance manual incorporate maintenance of the seal plate. The inspection program should require that the inspector remove the seal plate for VT and MT examination of the relief hole below and around the ends of the longitudinal weld between the pipe and gusset plate.

These concepts have not yet been tested. We hope to develop and test these details with the help of a fabricator.

Concept 1 – Rubber O-Ring Seal Plate

See Appendix, page A1. This concept uses clamping force from bolts to compress a rubber O-ring against the seal plate and the pipe or gusset plate. This concept is similar to the gasket in a jar lid. The seal plate has two pieces of machined metal. The larger metal piece compresses the O-ring onto the pipe. The smaller metal piece fits on top of the larger piece and compresses the O-ring onto the larger metal piece and the gusset plate. The end of the gusset plate is rounded to prevent the sharp edge from cutting and damaging the O-ring.

Silicone caulk can be applied between the larger and smaller metal pieces for extra seal protection.

The rubber O-ring will degrade over time and require replacement.

Concept 2 – Silicone Caulk Seal Plate

See Appendix, page A3. This concept uses silicone caulk to seal the seal plate. The seal plate is first mechanically clamped to the pipe using a self-sealing bolt. Then caulk is installed to provide the seal. The seal plate can be metal or plastic, such as Plexiglas. Some tests will be required to determine if thermal expansion is problematic if materials with thermal expansion different than steel are used for the seal plate. Durability of the caulk is a concern. Only exterior grade 100% silicone caulk should be used. Also, the caulk surfaces are all grooved to shelter the caulk from exposure. The caulk lines are curved to prevent corners and potential leakage at the corners.

This concept does not require machined plates and may be easier to implement than Concept 1. It is also more suitable for a retrofit of an existing crane. The concept is slightly more difficult to install than Concept 1. Pressure testing would have to be performed after the caulk is cured, which may be days later.
SUMMARY

A removable seal plate with the stress relief hole end connection provides the most reliable end connection, which facilitates periodic inspection. We believe that much of the cracking found and the recent catastrophic boom collapse in Europe may have been prevented had a removable seal plate been used and removed for inspection. Both concepts need to be designed and tested for seal durability. Other better designs for removable seal plates may be developed. Readers of this paper are encouraged to adapt this approach in their end connection designs and further improve the design of the end connection and removable seal plate.