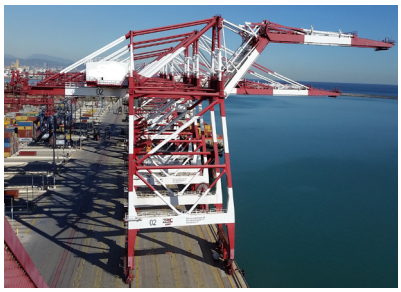
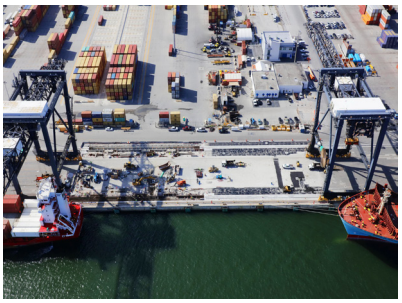
NEW APPROACH TO THE PIPE-TO-GUSSET PLATE CONNECTION





Original: April 4, 2016
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NEW APPROACH TO THE PIPE-TO-GUSSET PLATE CONNECTION

Prepared by Liftech Consultants Inc.
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Quality Assurance Review
for Liftech Consultants Inc.

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CONTENTS

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 a concept for the removable seal plate.

BACKGROUND

The pipe-to-gusset plate connection, “end connection,” is one of the most common ways to connect a pipe member to the crane structure. Figure 1 shows two end connections—without and with 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 primarily influenced by the fluctuating stress range, number of cycles of applied stress, weld detail fatigue classification, and fabrication quality. Fatigue classes mentioned are from BS 7608:2014. Detail classification is based on testing and statistics.

Detail classes D through G are for different weld geometries and member nominal stresses. Class W is for the throat of a weld and weld stresses.

A Class G detail is the least reliable and is prohibited by Liftech crane specifications on fracture critical members (FCMs), 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, and then F, E, and D.

For a given loading history, the classes have different reliabilities, e.g., a Class F2 detail has 1.7 times more expected life than a Class G detail. Refer to http://www.liftech.net/wp-content/uploads/2020/06/Fatigue-Detail-Guidelines_v2_2014-1.pdf.

Fatigue cracks grow over time until they reach a fracture critical length at which the energy from the loading and crack deformation exceeds that which the material can absorb, and fracture occurs.

In 2015, fatigue cracking at a pipe-to-gusset plate connection lead to fracture and catastrophic collapse of the upper works of a container crane in Germany. In many other cranes, cracking was detected and repaired before cracks reached a fracture critical length. See Figure 2 for some examples of cracking. A lot of those were close calls. In some cases, the material was much better (tougher) than specified, which probably prevented fracture and a collapse.

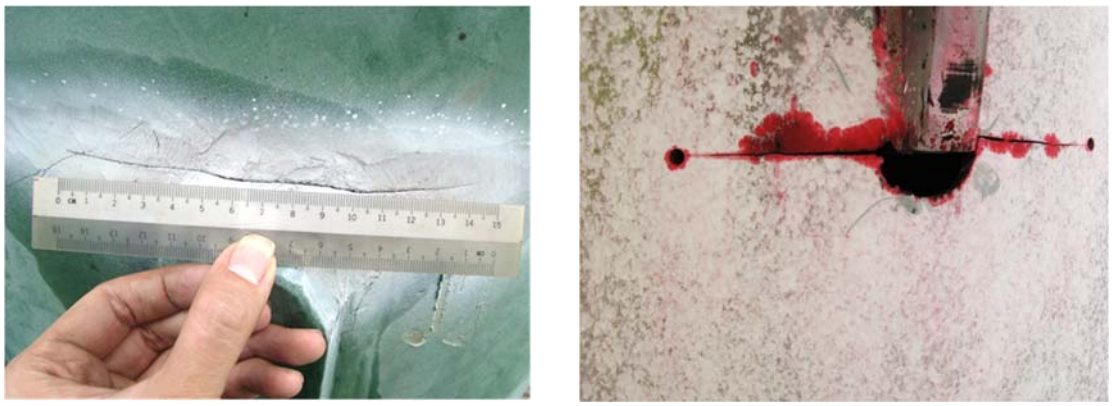


Figure 2: Fatigue cracks nearing fracture critical length, initiating at end of seal plate (left) and at poor fabrication cut of relief hole (right)

COMMON PIPE-TO-GUSSET PLATE CONNECTION DETAILS

Below is a discussion of the 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 with fillet

reinforcing is installed at the end of the slot. Sometimes a reinforcing plate is installed on top of the pipe at the slot for reinforcement. See Figure 3.

Figure 3: End connections with no stress relief hole, square cut without reinforcing plate (left) and with seal plate and fatigue cracks (right)

If the end connection is square, it is important to entirely fill the end connection with weld material, i.e., CJP weld. If not filled, cracks are more likely to grow from the unfused material, particularly 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 will be significantly less than fatigue Class W. Using a round end of the gusset plate is an improvement, as it eliminates the square corner and reduces the stress concentration.

If the weld at the end connection is not a CJP, this is a severe fatigue class, Class W in tension, and is unacceptable at FCMs. The upper diagonals and backstays are common FCMs that have this type of end connection.

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 also typically requires frequent periodic UT and MT examination during the life of the crane to maintain acceptable reliability.

Some designers add a reinforcing plate with the intention of reducing the axial stress at the end connection. However, the seal plate can introduce additional Class W and Class G details outside of the reinforcing plate region, where the stresses may be larger. It also introduces additional Class F2 or Class W details at the end connection. The series reliability, the product of individual reliabilities, of a series of details within an FCM load path can be significantly reduced.

In addition to possibly reducing reliability, the reinforcing plate obstructs nondestructive testing (NDT) inspection of the end connection. Fatigue cracks can be growing undetected below the reinforcing plate.

None of the variants (unreinforced or reinforced) 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.

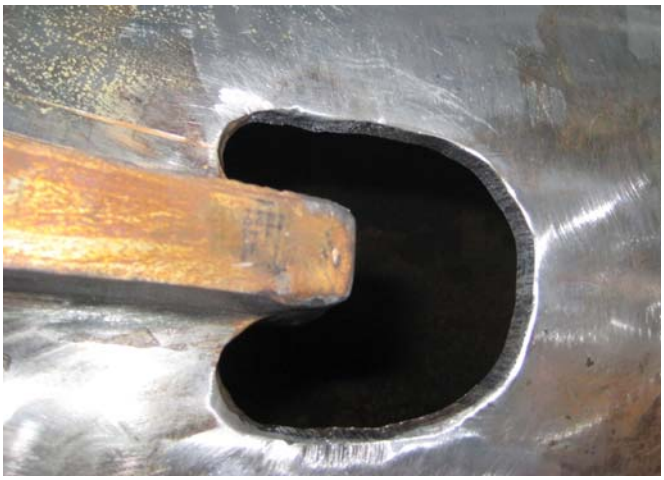


Figure 4: Stress relief hole at the end connection before grinding

Welded Seal Plate

A seal plate is used to seal the pipe. In some non-Liftech designs, a large, thick cover plate or 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 Class G details in the pipe, outside of the seal plate region, where the stresses may be larger.

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.

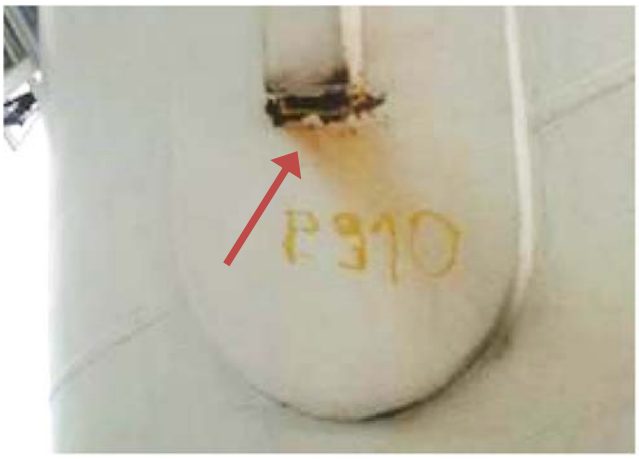


Figure 6: Cracking at the weld of the seal plate

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 seal plate as described above. The thin and small plate allows it to more easily flex and limit stresses. 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.

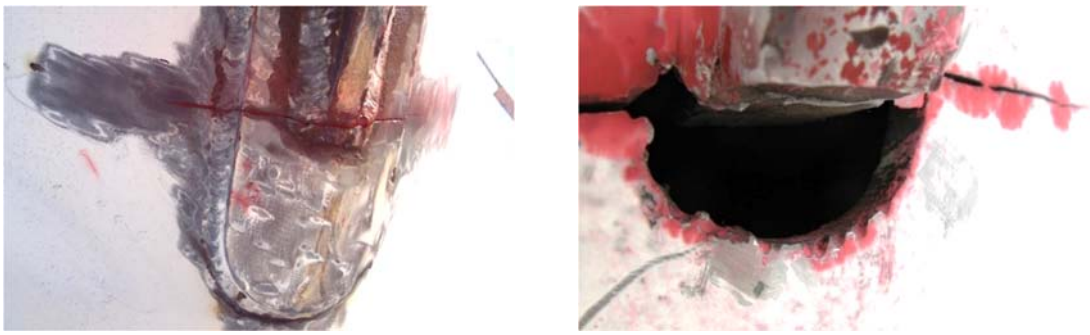
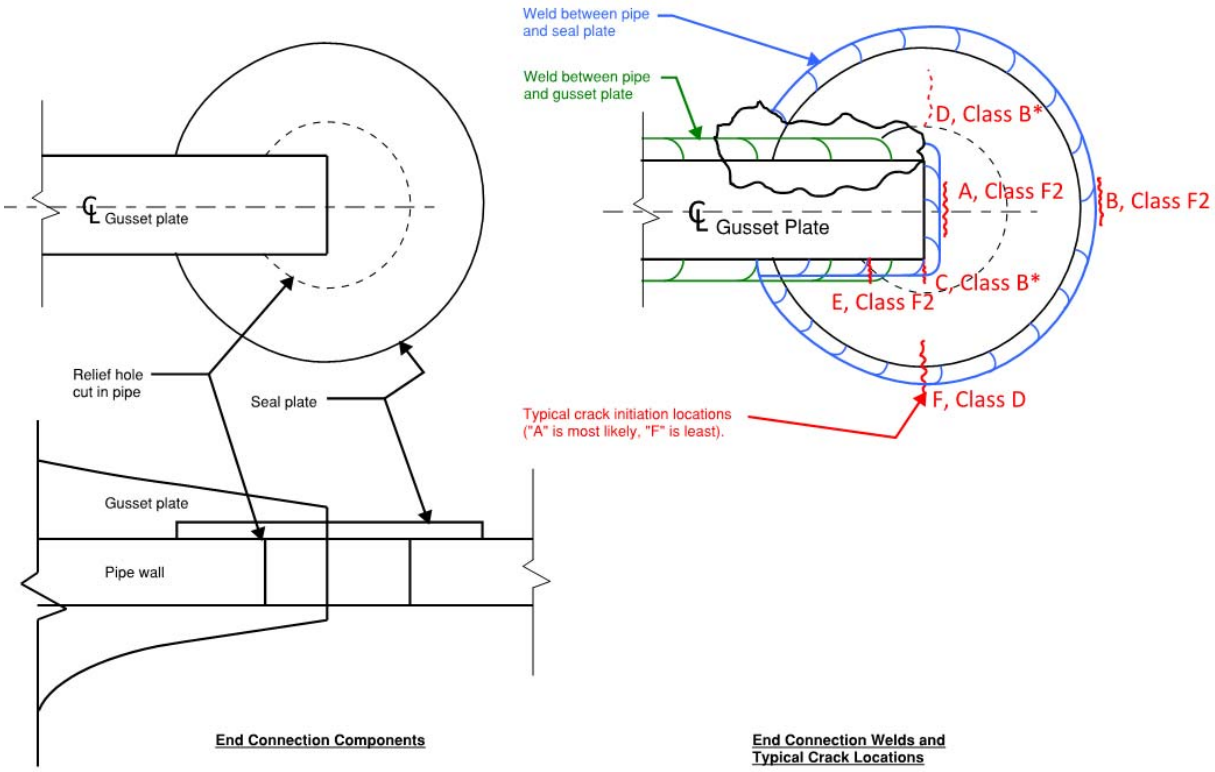


Figure 7: Cracking propagated from notches in pipe

After the seal plate is installed, the condition of the stress relief hole is no longer visible. Sometimes, a fabrication auditor puts a hold point in construction to inspect the hole smoothness 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.



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 less reliable details 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 are eliminated. The seal plate will 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 achieve this, Liftech developed a concept for the removable seal plate using a rubber gasket and caulking. With using an unwelded 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 seal plate, 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 concept described below. 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.

This concept has not yet been tested. We hope to develop and test this detail with the help of a fabricator.

Concept – Removable Seal Plate

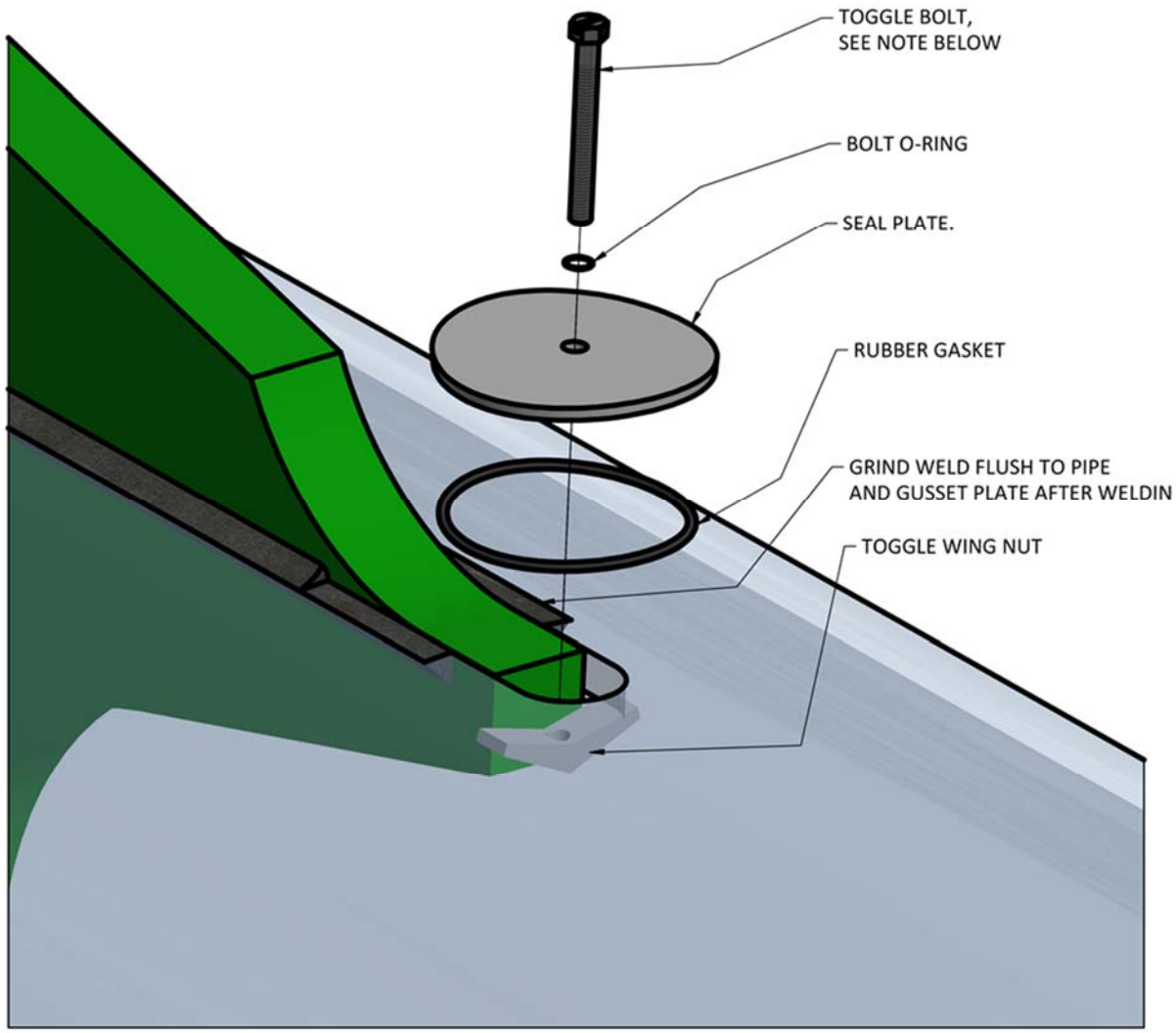


Figure 9: Removable seal plate

See Appendix, page A1 for more details. This concept uses the clamping force of a bolt to compress a rubber gasket against the seal plate and the pipe or gusset plate. This concept is similar to the gasket in a jar lid. The gusset plate is shaped such that there is a "flat" area around the hole, so that the gasket will seal reliably.

After sealing with the rubber gasket, the perimeter of the plate is caulked for further durability and seal reliability.

The slot end is semi-circular to limit stress concentrations. Liftech performed finite element analysis (FEA) and confirmed that the stresses at the hole and at the weld are like those of the standard Liftech design with the relief hole that has a diameter twice of the slot thickness. See Appendix, pages A2 and A3.

SUMMARY

A removable seal plate with the stress relief hole end connection provides the most reliable end connection, avoiding welds that reduce reliability and facilitate periodic inspection. We believe that much of the cracking found, including the recent catastrophic boom collapse in Europe, may have been prevented had a removable seal plate been used and removed for inspection. The concept needs to be designed and tested for seal durability. Other designs for removable seal plates have been developed, notably by ZPMC. Manufacturers are encouraged to adapt this approach in their end connection designs, further improve the design of the end connection and removable seal plate, and test the sealing performance of the proposed removable seal plate.

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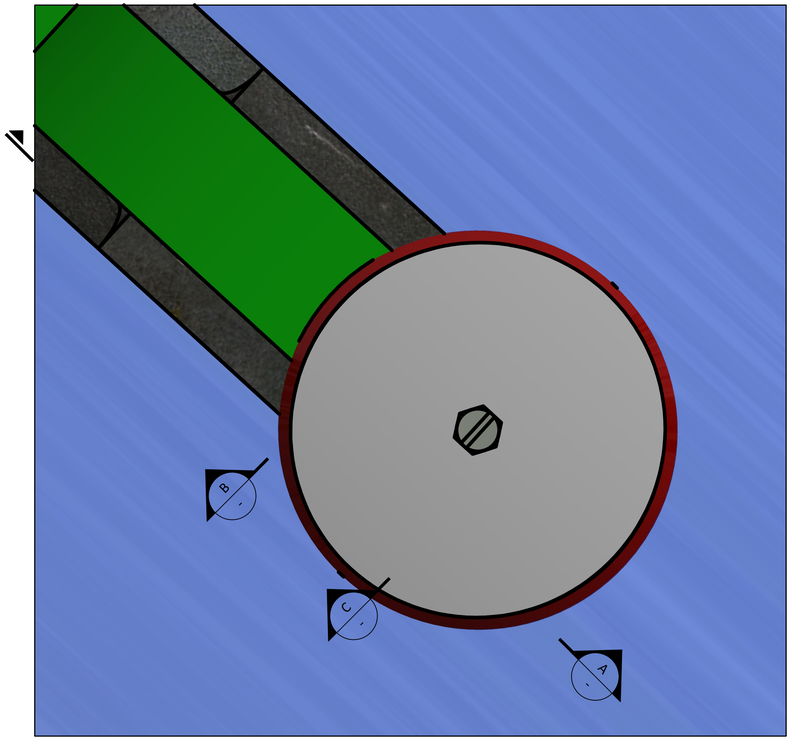
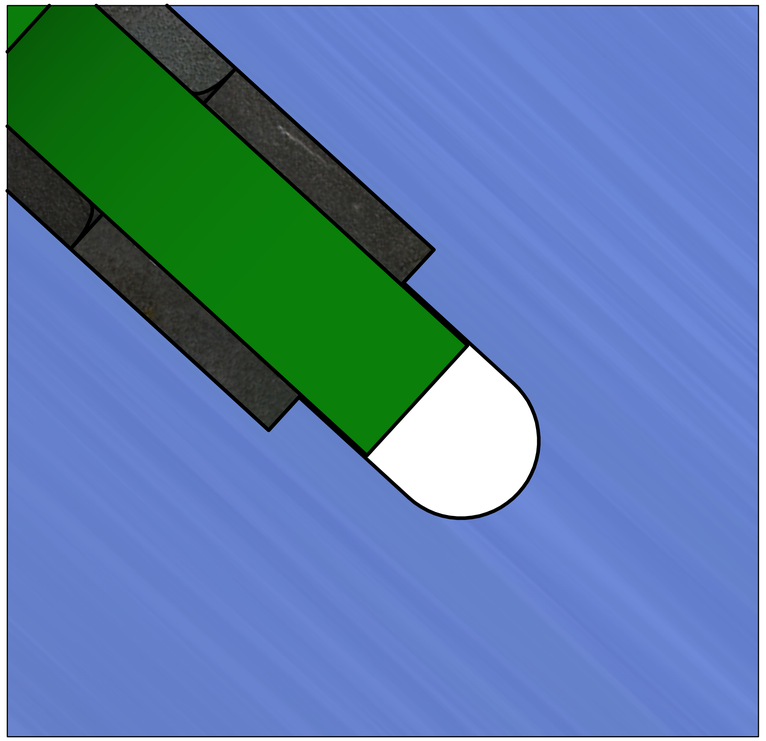
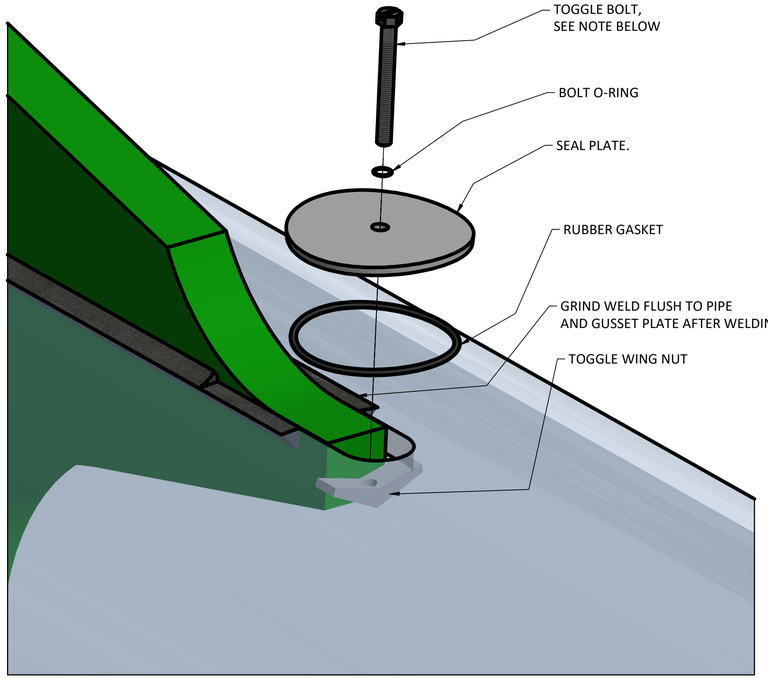
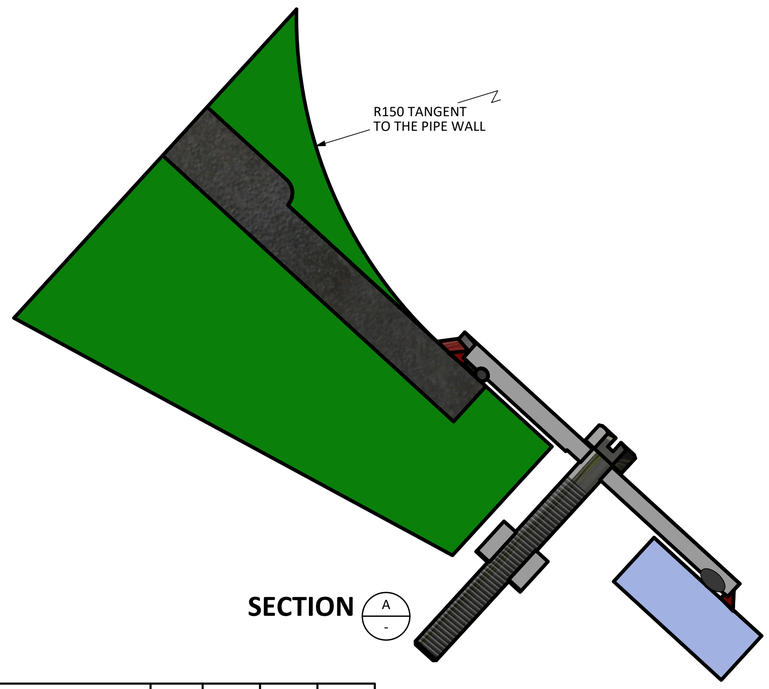


SEAL PLATE - PLAN

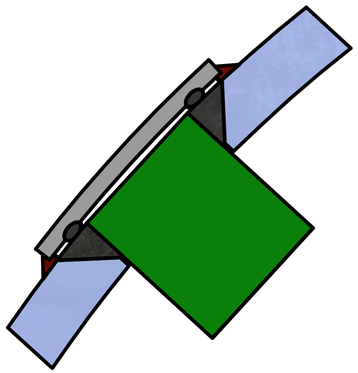


HOLE IN PIPE - PLAN





SECTION A



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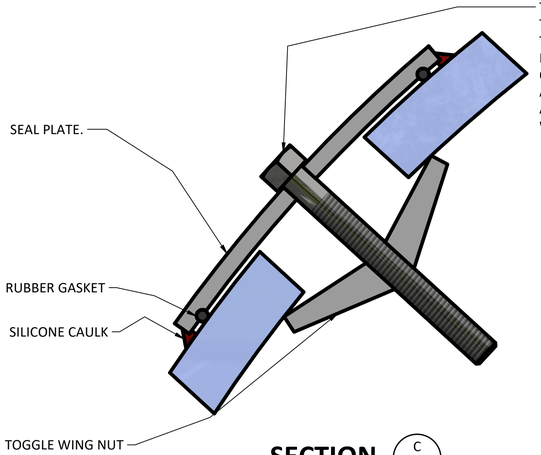

SECTION C

OVER-CENTER LOCKING DEVICE ON JAR

BICYCLE AXLE

NOTES:

1. SEAL PLATE CAN BE EITHER METAL OR PLASTIC.
2. SILICONE CAULK IS NOT FOR AIRTIGHTNESS, BUT TO PROTECT THE RUBBER GASKET FROM THE ELEMENTS.
3. WE EXPECT THAT THE SEAL PLATE WILL BE REMOVED EVERY 6 YEARS FOR INSPECTION OF THE HOLE. AT THAT TIME, THE RUBBER GASKET SHOULD BE REPLACED.
4. PRESSURE TEST EVERY TIME AFTER REINSTALLING THE SEAL PLATE.

No.	Revision	Date	By	Checked	Approved

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10/12/2020

PRELIMINARY
NOT FOR CONSTRUCTION

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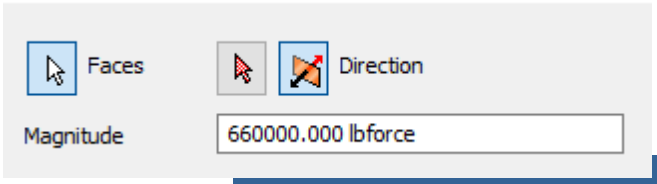
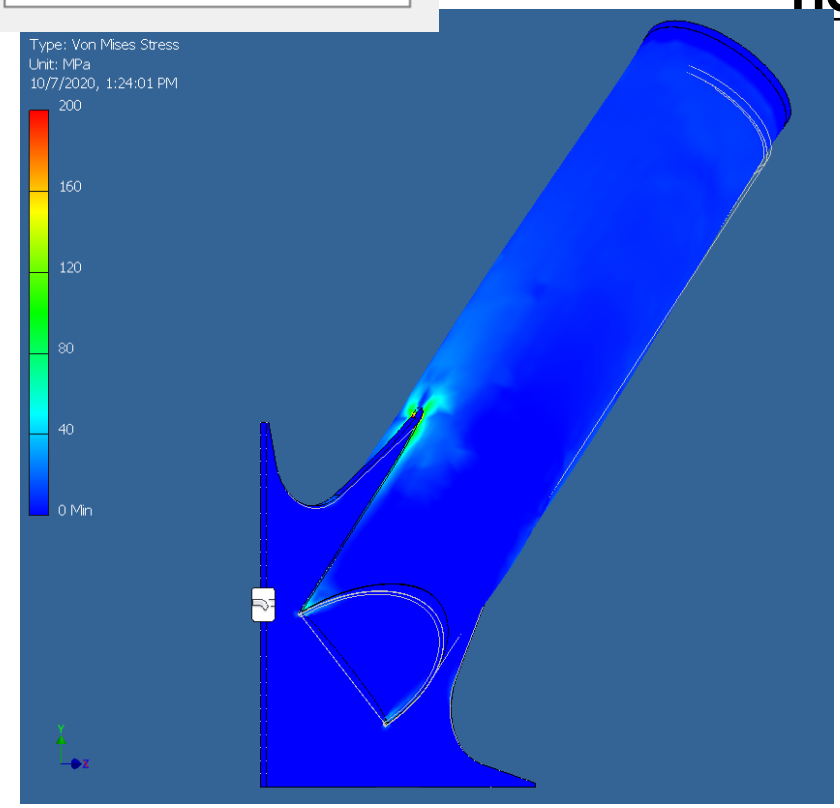
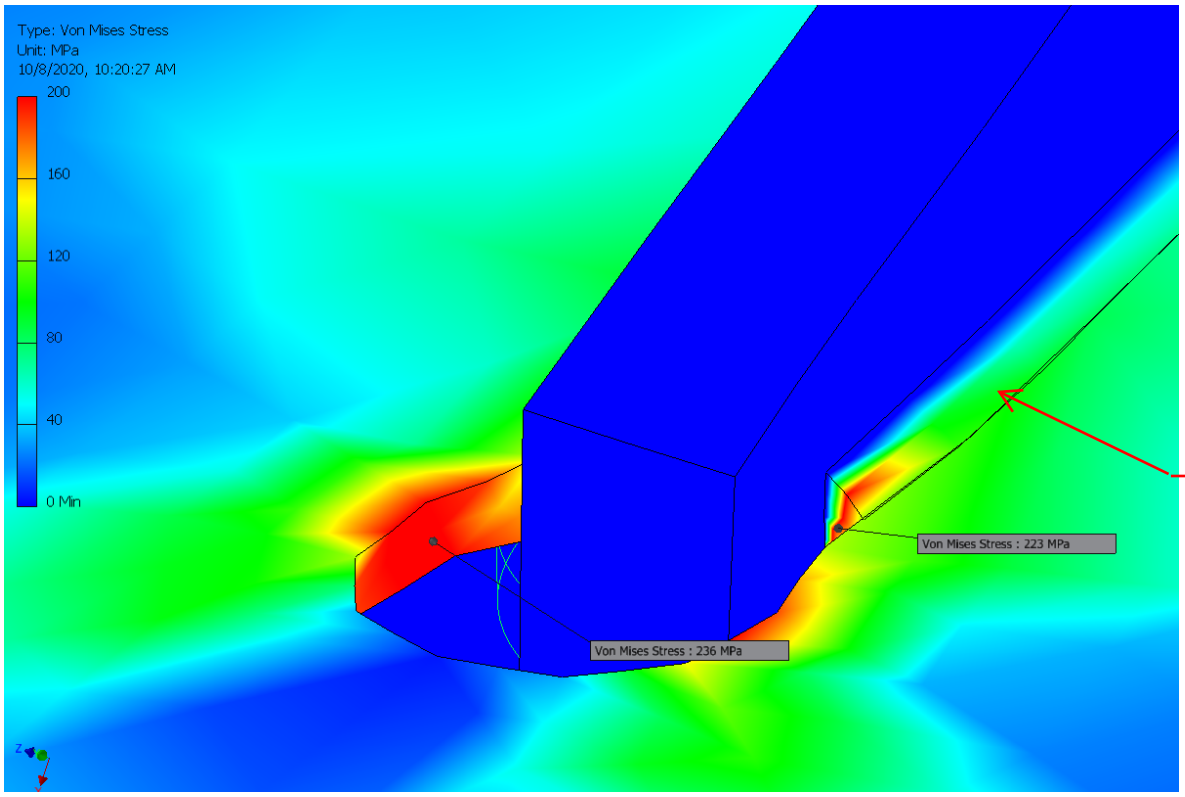
REMOVABLE SEAL PLATE CONCEPT

Project No.			
By AH	Checked KL	Sheet No.	A1
Approved KL		of	A3
Date 10/12/2020		Revision	

FINITE ELEMENT ANALYSIS: EXISTING DESIGN HOLE GEOMETRY







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FINITE ELEMENT ANALYSIS:
NEW DESIGN
HOLE GEOMETRY