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Breakaway (HaloValve) Disconnect/Shut-off for Meter Risers – Phase 3

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Executive Summary

According to U.S. Department of Transportation Data on Serious Pipeline Incidents (2005-2016), the two primary factors that contributed to U.S. gas distribution incidents is "excavation damage" and "other outside force damage (e.g. vehicular impact)". Distribution Integrity Management (DIM) programs require utilities to identify the threats that may affect the safety and performance of the distribution facilities and take action to minimize these threats. One of the most common threats to aboveground piping is vehicular and other outside force damage to meter sets.

The breakaway fitting is designed to do just that, minimize the threat of incident if the meter set or other aboveground distribution piping is impacted by an outside force. Common outside force impacts include vehicular and other motorized equipment impacts and also falling snow and ice from building roofs.

Excess Flow Valves (EFVs) are designed to shut off an excess flow of natural gas created when the natural gas service line is either ruptured or severed; the EFV focuses on excavation damage and not vehicular or other outside force damage to the meter set or other aboveground piping.

The deployment of breakaway fittings on meter sets and other aboveground piping can be complementary or an alternative to the use of an EFV. The breakaway fitting will reduce the risk of a major gas leak, fire, property damage, and injury caused by vehicle damage and other outside forces.

NEXT STEPS:

OPW, HaloValve fitting manufacturer (breakaway fitting) along with GTI's assistance, is moving forward with the commercialization of the breakaway fitting. OPW and GTI are looking for utilities to pilot the commercialization and building of sales channels to initiate the commercialization and eventual large-scale availability of the breakaway fitting.

GTI will work with each utility, your preferred component distributor and OPW to facilitate this initial pilot installation effort. This effort is a critical piece to move the breakaway fitting into our industry. Your participation would be greatly appreciated.

TESTING SUMMARY:

From performing the impact testing on the various meter sets with the breakaways installed, approximately 50% of the tests had a successful breakaway, which broke and had the seal shut off the flow of gas. Additional testing suggests that using a Sch 80 riser could increase the success rate of the breakaway fitting to approximately 82%. In addition, the breakaway (with a Sch 40 riser) was 100% successful during the simulated falling snow / ice testing.

In analyzing the differences between the success rates of the breakaway fitting based on the various impact directions, it was found that the direction at which the suspended weight impacted the meter set and the direction which the regulator was pointing had an effect on the success rates of the breakaway fitting. It was found that having the regulator aimed to the left of the riser, away from the meter, aided the success rate of the breakaway fitting when the meter was impacted by the suspended weight. This finding is verified by the behavior of the meter set when the impact testing videos were analyzed as the regulator helped focus the force of the impact to the breakaway when impacted from the regulator side, and allowed the meter set to bend further when impacted head on.

The results suggest that by aiming the regulator to the left of the riser, away from the meter, and by switching the riser to a Sch 80 thickness, the success rate of the breakaway fitting could increase up to 90%. Further testing would be needed to validate this assumption. There will never be a 100% success rate of the breakaway fitting, but as is the case with Excess Flow Valves, the goal of these breakaway fittings is to add a layer of safety and reduce the risk of incident.

Introduction

Meter Set Assemblies (MSA) and other above ground gas facilities are too often damaged by various outside forces, namely vehicular damage. Vehicular impacts with meter sets and other aboveground gas piping systems are not rare occurrences. These incidents unfortunately occur on a regular basis. The breakaway fitting will reduce the risk of gas leaks, fire, explosion, property damage and possible injury caused by outside forces impacting and damaging the MSA. This new product development will result in increased safety for home-owners and will enhance the overall safety for the delivery of natural gas.

There is a need for a low-cost option to protect aboveground MSA's against "outside forces" such as vehicle damage. A device/fitting is needed to mitigate risk when meter sets and other aboveground gas facilities are situated in driveways, parking lot areas, and other high traffic areas. Falling snow and ice can also cause meter set incidents. This technology will help to prevent property damage caused by MSA failure, and mitigate the risk of harm to residents and gas and emergency personnel.

Recent Distribution Integrity Management (DIM) regulations require utilities to identify the threats that may affect the safety and performance of distribution facilities. Although vehicular damage is not explicitly listed as a threat, damage to aboveground facilities, such as exposed piping and meter assemblies, associated with outside force damage and its mitigation is required by various Federal regulations.

Many industries utilize breakaway disconnects. For example, vehicle fueling stations utilize them on their fuel pumps. If a car accidently drives away with the fuel nozzle still in the gas tank, the breakaway disconnect shuts of the fuel line and eliminates the leak and possible fire hazard. Portable gas grills utilize similar disconnects, which are designed to be pulled apart manually. The liquid and compressed fuels industries also utilize them in filling and recharging cylinders, tanks, and vehicles.

The scope of this phase of work is to jointly develop a breakaway fitting for the natural gas industry. This new fitting will be developed at OPW in Lebanon, Ohio. OPW will manufacture several prototypes for laboratory testing. Prior phases of work focused on concept development. This phase builds on the earlier phases by making the necessary enhancements to the breakaway fitting prior to commercialization.

Some of the enhancements investigated include:

- Variable lengths to accommodate LDC's needs
- Increased flow through the breakaway
- Cast and hex-stock manufactured fittings

In addition to the enhancements, more thorough testing was conducted to provide the OTD sponsors and the rest of the industry with a better understanding of its ability to reduce the risk related to meters being impacted by vehicles and/or falling snow and ice from the roofs of buildings.

New Breakaway Design from OPW

Following the progress made on the previous phase of the project regarding the breakaway fitting and the feedback given by the project sponsors, GTI continued to work with OPW on developing the next generation of breakaway fittings. The new design (shown below in **Figure 1**) allows for increased flow and more options for length and end configurations. The configurations for this new design are 4" through 6" lengths with any combination of male and female ¾" NPT threads on the ends of the fitting. The list of possible configurations and their accompanying drawings are listed in ***Appendix A: Detailed OPW Breakaway Drawings.***

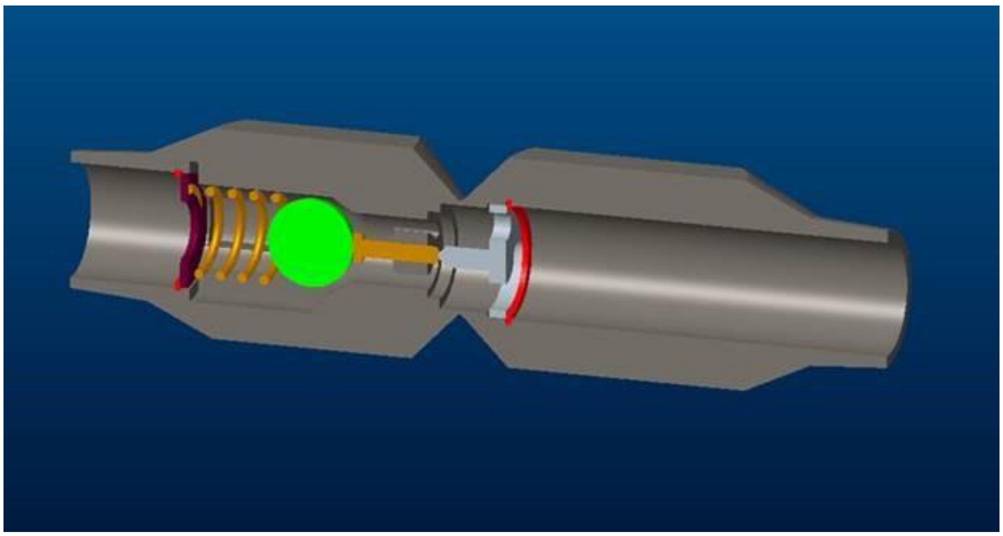

Figure 1: Next Generation OPW Breakaway Fitting Design

OPW sent GTI multiple breakaway fittings that were 6" in length and had male ¾" NPT threads on both ends (seen below in **Figure 2**).

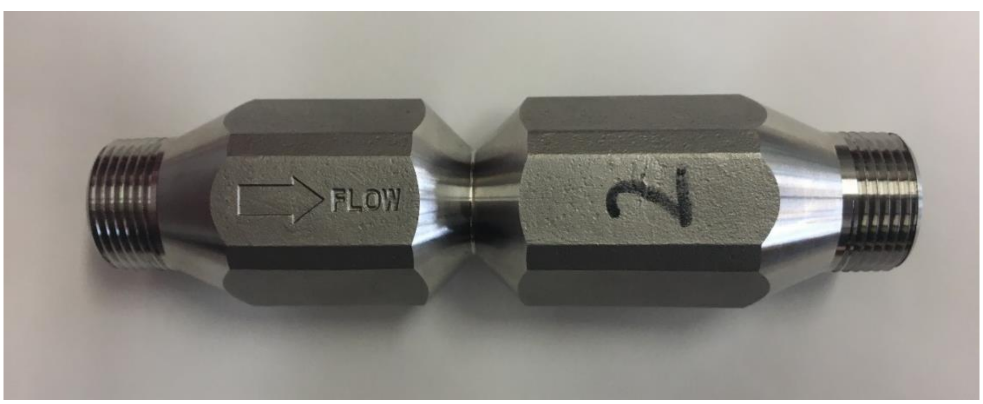

Figure 2: 6" Long Next Generation OPW Breakaway Fitting Design with 3/4" NPT Male Threads on Both Ends

GTI then performed flow testing on the newly designed breakaway fitting and found that the new design not only incorporates external enhancements and various configurations, but also increases the gas flow through the fitting and reduces the pressure drop. Results are shown below in **Figure 3** & **Figure 4**.

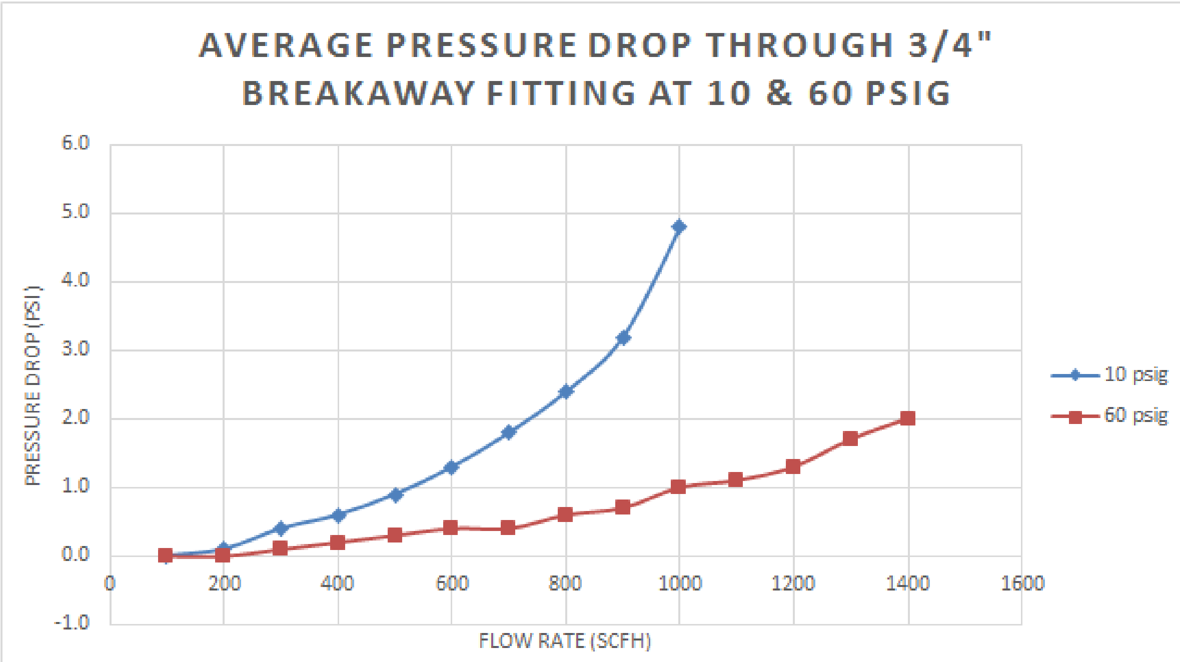

Figure 3: Flow Testing Results through Breakaway Fitting Shown in Figure 2 at 10 & 60 psig

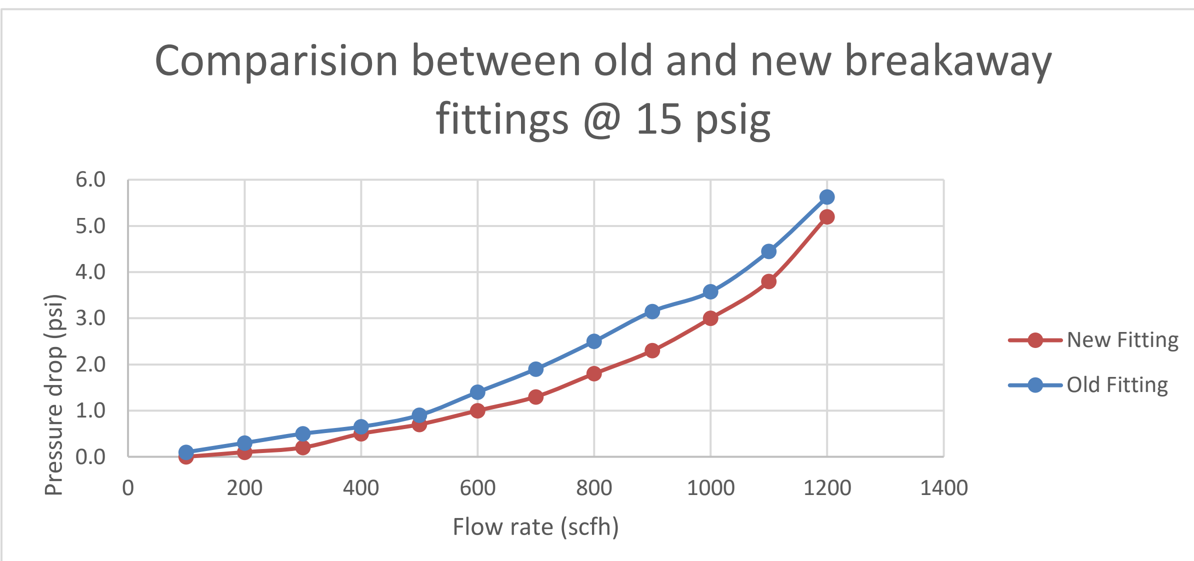

Figure 4: Comparison of Flow Testing Results Between Old and New Generation Breakaway Fittings at 15 psig

Experimental Design

A testing matrix was created to determine the performance of the breakaway fittings on various meter set designs and configurations based on impacts from different directions. The test matrix was designed to simulate 3 types of impact:

- parallel to the wall – impacting the regulator side first
- parallel to the wall – impacting the meter and house line side first
- perpendicular to the wall – head-on

GTI requested meter sets from the project sponsors for the testing. Nine utilities provided meter sets which included 12 different designs/configurations. Based on the number and types of meter sets received, the following matrix (**Table 1**) was created.

Table 1. Design Matrix

Company	Meter Size	House Line Size	Connector Type	Pre-Fab	Regulator Orientation	Ram Orientation	Breakaway	Tested?
Utility 1	20 Lite	1"	No Connector	Hook	Left of Riser (Away from Meter)	Parallel (Regulator Side First)	No	Yes
Utility 1	20 Lite	1"	No Connector	Hook	Left of Riser (Away from Meter)	Parallel (Regulator Side First)	Yes	Yes
Utility 1	20 Lite	1"	No Connector	Hook	Left of Riser (Away from Meter)	Parallel (House Line Side First)	No	Yes
Utility 1	20 Lite	1"	No Connector	Hook	Left of Riser (Away from Meter)	Parallel (House Line Side First)	Yes	Yes
Utility 1	20 Lite	1"	No Connector	Hook	Left of Riser (Away from Meter)	Perpindicular (Head-On)	No	Yes
Utility 1	20 Lite	1"	No Connector	Hook	Left of Riser (Away from Meter)	Perpindicular (Head-On)	Yes	Yes
Utility 1	20 Lite	1"	No Connector	Hook	Left of Riser (Away from Meter)	Not Needed	Extra	Extra
Utility 1	20 Lite	1"	No Connector	Hook	Left of Riser (Away from Meter)	Not Needed	Extra	Extra
Utility 1	20 Lite	1"	No Connector	Hook	Left of Riser (Away from Meter)	Not Needed	Extra	Extra
Utility 2	20 Lite	1"	No Connector	None	Above Riser (Facing away from Meter)	Parallel (Regulator Side First)	No	Yes
Utility 2	20 Lite	1"	No Connector	None	Above Riser (Facing away from Meter)	Parallel (Regulator Side First)	Yes	Yes
Utility 2	20 Lite	1"	No Connector	None	Above Riser (Facing away from Meter)	Parallel (Regulator Side First)	Yes	Yes
Utility 2	20 Lite	1"	No Connector	None	Above Riser (Facing away from Meter)	Parallel (House Line Side First)	No	Yes
Utility 2	20 Lite	1"	No Connector	None	Above Riser (Facing away from Meter)	Parallel (House Line Side First)	Yes	Yes
Utility 2	20 Lite	1"	No Connector	None	Above Riser (Facing away from Meter)	Perpindicular (Head-On)	No	Yes
Utility 2	20 Lite	1"	No Connector	None	Above Riser (Facing away from Meter)	Perpindicular (Head-On)	Yes	Yes
Utility 3	20 Lite	1"	Thin Solid	Hook	Behind Riser (Towards House)	Parallel (Regulator Side First)	No	Yes
Utility 3	20 Lite	1"	Thin Solid	Hook	Behind Riser (Towards House)	Parallel (Regulator Side First)	Yes	Yes
Utility 3	20 Lite	1"	Thin Solid	Hook	Behind Riser (Towards House)	Parallel (Regulator Side First)	Yes	Yes
Utility 3	20 Lite	1"	Thin Solid	Hook	Behind Riser (Towards House)	Parallel (Regulator Side First)	Yes	Yes
Utility 3	20 Lite	1"	Thin Solid	Hook	Behind Riser (Towards House)	Parallel (House Line Side First)	No	Yes
Utility 3	20 Lite	1"	Thin Solid	Hook	Behind Riser (Towards House)	Parallel (House Line Side First)	Yes	Yes
Utility 3	20 Lite	1"	Thin Solid	Hook	Behind Riser (Towards House)	Parallel (House Line Side First)	Yes	Yes
Utility 3	20 Lite	1"	Thin Solid	Hook	Behind Riser (Towards House)	Perpindicular (Head-On)	Yes	Yes
Utility 4	10 Lite	3/4"	Hollow	Hook	Behind Riser (Towards House)	Parallel (Regulator Side First)	Yes	Yes
Utility 4	10 Lite	3/4"	Hollow	Hook	Behind Riser (Towards House)	Parallel (Regulator Side First)	Yes	Yes
Utility 4	10 Lite	3/4"	Hollow	Hook	Behind Riser (Towards House)	Parallel (House Line Side First)	Yes	Yes
Utility 4	10 Lite	3/4"	Hollow	Hook	Behind Riser (Towards House)	Perpindicular (Head-On)	Yes	Yes
Utility 5	1A Sprague	3/4"	No Connector	Hook	Left of Riser (Away from Meter)	Parallel (Regulator Side First)	No	Yes
Utility 5	1A Sprague	3/4"	No Connector	Hook	Left of Riser (Away from Meter)	Extra	Extra	Extra
Utility 5	1A Sprague	3/4"	No Connector	Hook	Left of Riser (Away from Meter)	Parallel (Regulator Side First)	Yes	Yes
Utility 5	1A Sprague	3/4"	No Connector	Hook	Left of Riser (Away from Meter)	Parallel (House Line Side First)	No	Yes
Utility 5	1A Sprague	3/4"	No Connector	Hook	Left of Riser (Away from Meter)	Parallel (House Line Side First)	Yes	Yes
Utility 5	1A Sprague	3/4"	No Connector	Hook	Left of Riser (Away from Meter)	Perpindicular (Head-On)	No	Yes
Utility 5	1A Sprague	3/4"	No Connector	Hook	Left of Riser (Away from Meter)	Perpindicular (Head-On)	Yes	Yes
Utility 5	1A Sprague	3/4"	No Connector	Hook	Left of Riser (Away from Meter)	Extra	Extra	Extra
Utility 5	1A Sprague	3/4"	No Connector	Hook	Left of Riser (Away from Meter)	Extra	Extra	Extra
Utility 5	1A Sprague	3/4"	No Connector	Hook	Left of Riser (Away from Meter)	Extra	Extra	Extra
Utility 6	20 Lite	1"	I-Beam	None	Left of Riser (Away from Meter)	Parallel (Regulator Side First)	Yes	Yes
Utility 6	20 Lite	1"	I-Beam	None	Left of Riser (Away from Meter)	Parallel (Regulator Side First)	Yes	Yes
Utility 6	20 Lite	1"	I-Beam	None	Left of Riser (Away from Meter)	Parallel (House Line Side First)	Yes	Yes
Utility 6	20 Lite	1"	I-Beam	None	Left of Riser (Away from Meter)	Perpindicular (Head-On)	Yes	Yes
Utility 6	30 Lite	1-1/4"	I-Beam	None	Left of Riser (Away from Meter)	Parallel (Regulator Side First)	Yes	Yes
Utility 6	30 Lite	1-1/4"	I-Beam	None	Left of Riser (Away from Meter)	Parallel (Regulator Side First)	Yes	Yes
Utility 6	30 Lite	1-1/4"	I-Beam	None	Left of Riser (Away from Meter)	Parallel (House Line Side First)	Yes	Yes
Utility 6	30 Lite	1-1/4"	I-Beam	None	Left of Riser (Away from Meter)	Perpindicular (Head-On)	Yes	Yes
Utility 7	30 Lite	1"	Thin Solid	Hook	Left of Riser (Away from Meter)	Parallel (Regulator Side First)	No	Yes
Utility 7	30 Lite	1"	Thin Solid	Hook	Left of Riser (Away from Meter)	Parallel (Regulator Side First)	Yes	Yes
Utility 7	30 Lite	1"	Thin Solid	Hook	Left of Riser (Away from Meter)	Parallel (House Line Side First)	No	Yes
Utility 7	30 Lite	1"	Thin Solid	Hook	Left of Riser (Away from Meter)	Parallel (House Line Side First)	Yes	Yes
Utility 7	30 Lite	1"	No Connector	Hook	Left of Riser (Away from Meter)	Parallel (House Line Side First)	Yes	Yes
Utility 7	30 Lite	1"	No Connector	Hook	Left of Riser (Away from Meter)	Perpindicular (Head-On)	No	Yes
Utility 7	30 Lite	1"	No Connector	Hook	Left of Riser (Away from Meter)	Perpindicular (Head-On)	Yes	Yes
Utility 7	30 Lite	1"	No Connector	Hook	Left of Riser (Away from Meter)	Not Needed	Extra	Extra
Utility 8	1A Sprague	3/4"	No Connector	None	Left of Riser (Away from Meter)	Parallel (Regulator Side First)	No	Yes
Utility 8	1A Sprague	3/4"	No Connector	None	Left of Riser (Away from Meter)	Parallel (Regulator Side First)	Yes	Yes
Utility 8	1A Sprague	3/4"	No Connector	None	Behind Riser (Towards House)	Parallel (Regulator Side First)	Yes	Yes
Utility 8	1A Sprague	3/4"	No Connector	None	Left of Riser (Away from Meter)	Parallel (House Line Side First)	No	Yes
Utility 8	1A Sprague	3/4"	No Connector	None	Left of Riser (Away from Meter)	Parallel (House Line Side First)	Yes	Yes
Utility 8	1A Sprague	3/4"	No Connector	None	Left of Riser (Away from Meter)	Perpindicular (Head-On)	No	Yes
Utility 8	1A Sprague	3/4"	No Connector	None	Left of Riser (Away from Meter)	Perpindicular (Head-On)	Yes	Yes
Utility 8	1A Sprague	3/4"	No Connector	None	Behind Riser (Towards House)	Perpindicular (Head-On)	Yes	Yes
Utility 9	10 Lite	1"	Solid	Hook	In Front of Riser (Away from House)	Parallel (Regulator Side First)	Yes	Yes
Utility 9	10 Lite	1"	Solid	Hook	In Front of Riser (Away from House)	Parallel (Regulator Side First)	Yes	Yes
Utility 9	10 Lite	1"	I-Beam	None	In Front of Riser (Away from House)	Parallel (Regulator Side First)	Yes	Yes
Utility 9	10 Lite	1"	Solid	Hook	In Front of Riser (Away from House)	Parallel (House Line Side First)	Yes	Yes
Utility 9	10 Lite	1"	I-Beam	None	In Front of Riser (Away from House)	Parallel (House Line Side First)	Yes	Yes
Utility 9	10 Lite	1"	Solid	Hook	In Front of Riser (Away from House)	Perpindicular (Head-On)	Yes	Yes
Utility 9	10 Lite	1"	I-Beam	None	In Front of Riser (Away from House)	Perpindicular (Head-On)	Yes	Yes

Impact Testing Setup

In order to analyze the effectiveness of the breakaway fittings in real world scenarios, impact testing was performed with the breakaways installed on the various company meter sets on the impact testing rig shown in **Figure 5** below.

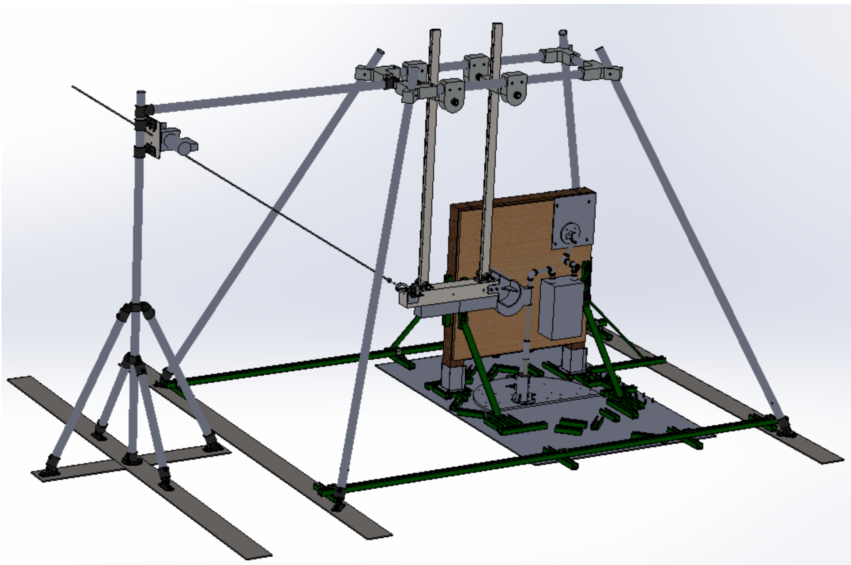

Figure 5: Impact Testing Rig

The impact testing rig consists of a suspended weight with a head that simulates a vehicle bumper, which can be pulled back to various heights via a winch and released by a solenoid. The suspended weight then swings forward and hits a meter set that is held in place in two locations (riser secured to the ground and the fuel line piping entering the building wall). The vertical riser is held by a clamp and polyurethane base that simulates hard soil ground conditions, while the house line is clamped to a simulated wood framed wall that is fixed to a base. The wall can be set up such that the suspended weight can impact the meter set from 5 different directions, but for our testing purposes the three impact directions used were parallel to the wall hitting the vertical riser and regulator first, parallel to the wall hitting the house line and meter first, and perpendicular to the wall in a head on collision. Further description of the full design of the impact testing rig, with pictures, can be found in ***Appendix B: Impact Testing Rig***.

Because the testing rig utilizes a clamp and simulated ground to secure the vertical riser, the ground level used in calculations and assembly of the meter set is changed from the actual ground to the top of the polyurethane (shown below in **Figure 6** as the blue line). This new ground level is also shown in a 3D aspect below in **Figure 7**.

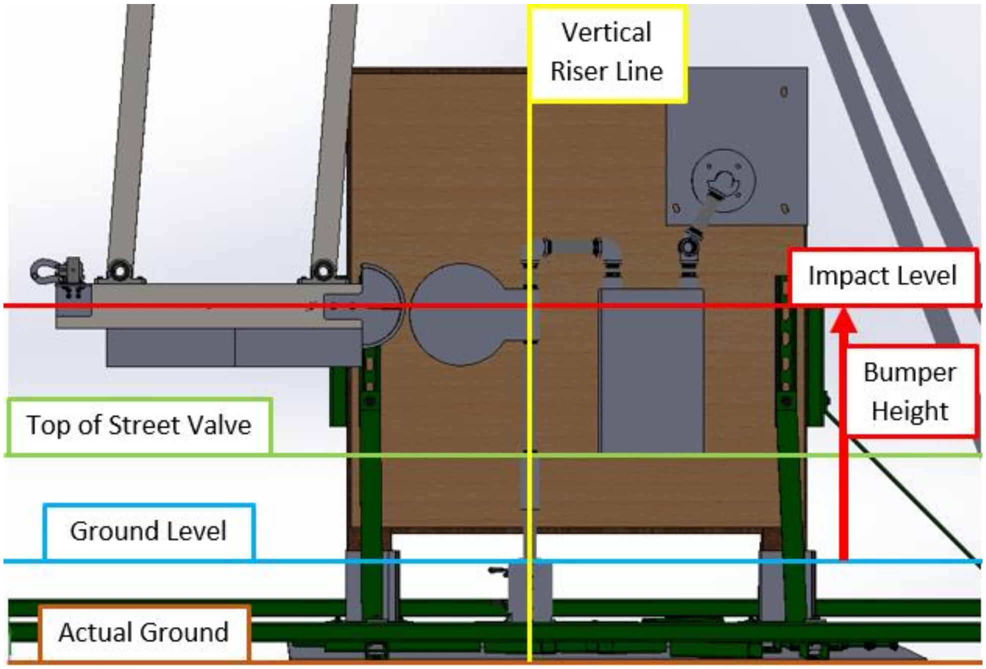

Figure 6: 2D Diagram of Height References from New Ground Level

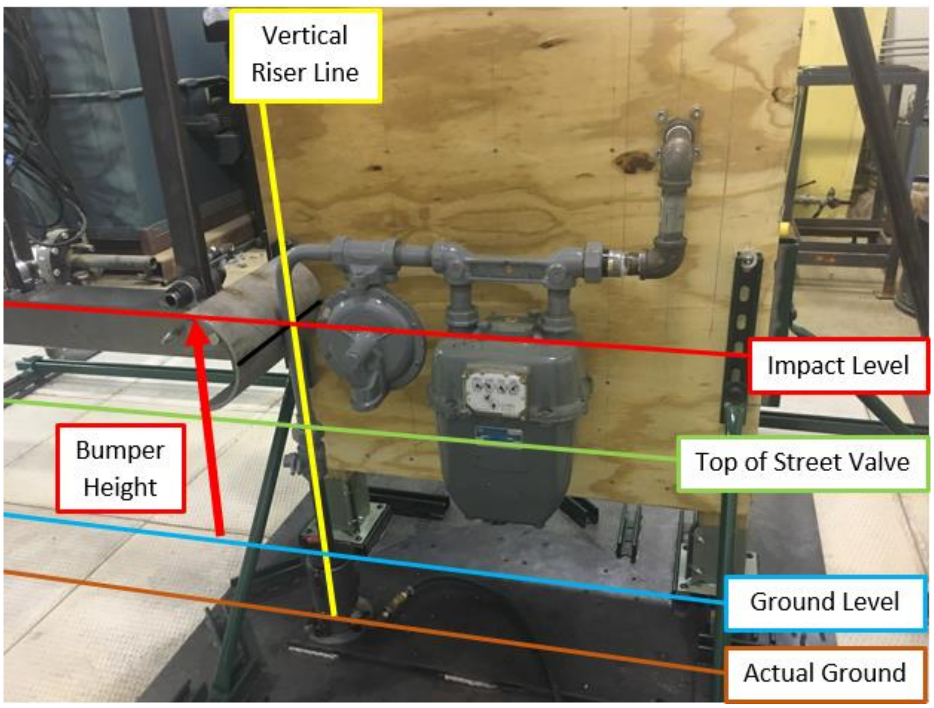

Figure 7: 3D Diagram of Height References from New Ground Level

It is crucial to know where this new ground level is, because in order to conduct proper simulated vehicular impact tests we need to have the bumper impact the meter set at the proper height above the ground. The standard for bumpers is in the Code of Federal Regulations: Title 49 – Transportation, Part 581, which can be read in full in **Appendix C: US CFR: Title 49 – Transportation, Part 581 Bumper Standard**. The test for impacting a bumper is tested between 16 to 20 inches above the ground for any passenger cars. However, during the determination of the potential energy required to break the meter sets, which can be found in **Appendix D: Determination of Potential Energy Required for Meter Set Failure**, it was determined that the bumper height should actually be set higher at 22.75in above the ground level. Since the bumper standard does not list out any requirements for Mini-Vans and SUV's, which are known to be higher, this allows the team to accommodate both types of vehicles in the testing.

From the results found in **Appendix D: Determination of Potential Energy Required for Meter Set Failure**, it was determined that the potential energy created by raising the suspended weight should be between 445 J to 450 J. This means that for the bumper height of 22.75", when using the narrow simulated bumper head (13 lbs) on parallel impacts the Ram Release Height (shown below in **Figure 8**) should be between 55-3/8" and 55-5/8" and when using the wide simulated bumper head (19 lbs) on perpendicular impacts the Ram Release Height should be between 54-1/2" and 54-3/4".

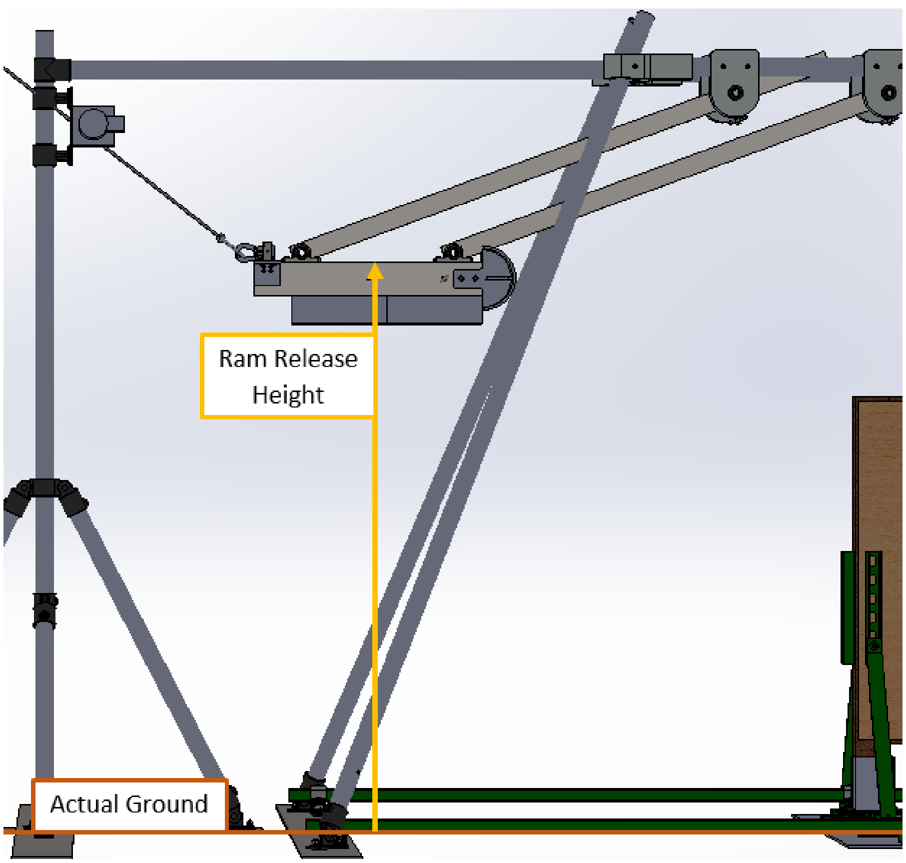

Figure 8: Diagram Showing Measurement of Ram Release Height

Analysis of Impact Testing Results

When testing the meter sets provided by the various utility companies, shown in **Appendix E: Company Meter Sets**, all of the meter sets were attached to a street valve that was connected to a 3/4" NPT Schedule 40 Nipple with the top of the street valve (shown by the green line in **Figure 6 & Figure 7**) set at 11.25" above the ground level, unless otherwise noted. When connecting the house line to the meter set the shortest path was created with Schedule 40 nipples and elbows of the proper pipe size based on the corresponding meter set outlet size. The potential energy of the suspended weight when released from the ram release height for each test was between 445 J and 450 J. Compressed air was run into the vertical riser and through the meter set at 60 psi.

Results from all impact testing done with and without breakaways can be found in **Appendix F: All Impact Testing Results**.

The summary of the failure locations for the tests using breakaways can be found below in **Table 2**. When a location is listed as "Street Valve" it means that the threads into or out of the street valve failed. If the location is listed as "Elsewhere" it means that the street valve remained intact, the breakaway remained intact, and the failure in the line was at some other location.

Table 2: Summary of Failure Locations from Impact Testing on Meter Sets with Breakaways

Company	Meter Size	Pre-Fab	House Line Size	Regulator Direction	Parallel (Hit Regulator First)	Parallel (Hit Meter First)	Perpendicular (Head-On)
Utility 1	20 Lite	Hook	1in	Left of Riser (Away from Meter)	Breakaway Successful	Breakaway Successful	Breakaway Successful
Utility 2	20 Lite	Elbow	1in	Above Riser (Facing away from Meter)	Street Valve	Breakaway Successful	Street Valve
					Street Valve	Not tested	Not tested
Utility 3	20 Lite	Hook	1in	Behind Riser (Towards Wall)	Street Valve	Elsewhere	Breakaway Crack
					Breakaway Successful	Breakaway Successful	Not tested
					Breakaway Successful	Not tested	Not tested
Utility 4	10 Lite	Hook	3/4in	Behind Riser (Towards Wall)	Street Valve	Breakaway Successful	Breakaway Successful
					Street Valve	Not tested	Not tested
Utility 5	1A Sprague	Short Hook	3/4in	Left of Riser (Away from Meter)	Street Valve	Street Valve	Street Valve
Utility 6	20 Lite	Pre-Fab Elbow	1in		Breakaway Successful	Meter Set Intact	Street Valve

				Left of Riser (Away from Meter)	Breakaway Successful	Not tested	Not tested
Utility 6	30 Lite	Elbow	1 1/4in	Left of Riser (Away from Meter)	Breakaway Successful	Breakaway Crack	Breakaway Successful
					Breakaway Crack	Not tested	Not tested
Utility 7	30 Lite	Hook	1in	Left of Riser (Away from Meter)	Breakaway Successful	Breakaway Crack	Breakaway Successful
					Not tested	Breakaway Successful	Not tested
Utility 8	1A Sprague	Elbow	3/4in	Left of Riser (Away from Meter)	Breakaway Successful	Elsewhere	Street Valve
Utility 8	1A Sprague	Elbow	3/4in	Behind Riser (Towards Wall)	Street Valve	Not tested	Meter Set Intact
Utility 8 (8.25” Street Valve Height)	1A Sprague	Elbow	3/4in	Left of Riser (Away from Meter)	Street Valve	Breakaway Successful	Breakaway Successful
					Breakaway Successful	Not tested	Not tested
					Street Valve	Not tested	Not tested
Utility 8 (8.25” Street Valve Height)	1A Sprague	Elbow	3/4in	Behind Riser (Towards Wall)	Street Valve (Sch 40 Riser)	Not tested	Not tested
					Breakaway Successful (Sch 80 Riser)	Not tested	Not tested

Utility 9	10 Lite	Hook	1in	In Front of Riser (Away from Wall)	Street Valve	Breakaway Successful	Elsewhere
					Street Valve	Not tested	Not tested
Utility 9	10 Lite	Elbow	1in	In Front of Riser (Away from Wall)	Street Valve	Breakaway Successful	Street Valve

All the analysis from the impact testing can be found in Appendix G: Impact Testing Analysis Tables.

During testing, it was noted that the impact direction had a significant effect on the success rate of the breakaway fitting. The success rate of the breakaways from each test, grouped by impact direction can be found below in **Figure 9.** Other failures are the combined failures from cracks in the breakaway, failures not at the street valve, and when the meter set remained intact.

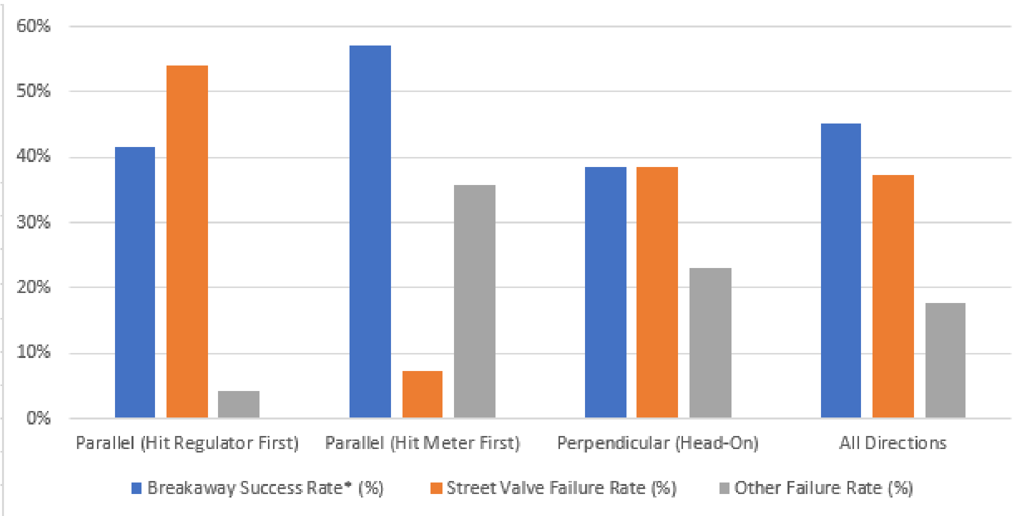

Figure 9: Breakaway Success Rate Based on Impact Direction

Regulator Direction Affecting Breakaway Success Rate

When analyzing the tests where the impact was parallel to the wall and hit the regulator first, there is a difference between when the regulator was aimed to the left of the riser (away from the meter) than when the regulator was aimed behind the riser (towards the wall), in front of the riser (away from the wall) or above the riser. These values are shown in in **Figure 10**.

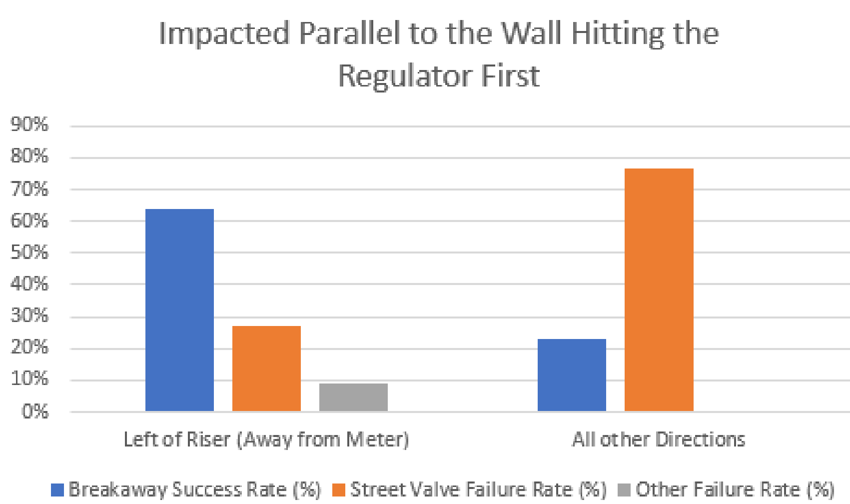

Figure 10: Effects of Regulator Direction on Impact Results when Impacted Parallel to the Wall Hitting the Regulator First

As shown in **Figure 10**, when the regulator was pointed left of the riser (away from the meter) it had a 64% success rate compared to a 23% success rate for all other regulator directions. This makes sense because when the regulator is pointed to the left of the riser and the suspended weight comes parallel to the wall and hits the regulator first, the suspended weight hits the regulator before it hits the vertical part of the pre-fab. When the suspended weight hits the regulator first instead of the vertical portion of the pre-fab, the regulator is knocked down, causing the pre-fab to pivot upward. When the pre-fab pivots upward it pulls the top portion of the breakaway away from the bottom portion of the breakaway (shown below in **Figure 11 & Figure 12**), causing the break to occur at the breakaway, resulting in a successful breakaway.

Figure 11: Impact Test on Utility 1 Meter Set with Breakaway and Regulator Left of Riser (Away from Meter) – Impacted Parallel to Wall from Regulator Side – Before Impact

Figure 12: Impact Test on Utility 1 Meter Set with Breakaway and Regulator Left of Riser (Away from Meter) – Impacted Parallel to Wall from Regulator Side – After Impact

However, when the suspended weight hits the vertical portion of the pre-fab first, the entire impact goes into the contact point, causing the pre-fab to bend inward. When the pre-fab bends inward, it does so throughout the entire system instead of causing a sharp break when the pre-fab pivots. As shown below in **Figure 13 & Figure 14**, this causes the breakaway fitting to remain inline and intact and instead bends the street valve and riser from vertical. This causes the break to occur at the threads below the street valve, resulting in an unsuccessful breakaway.

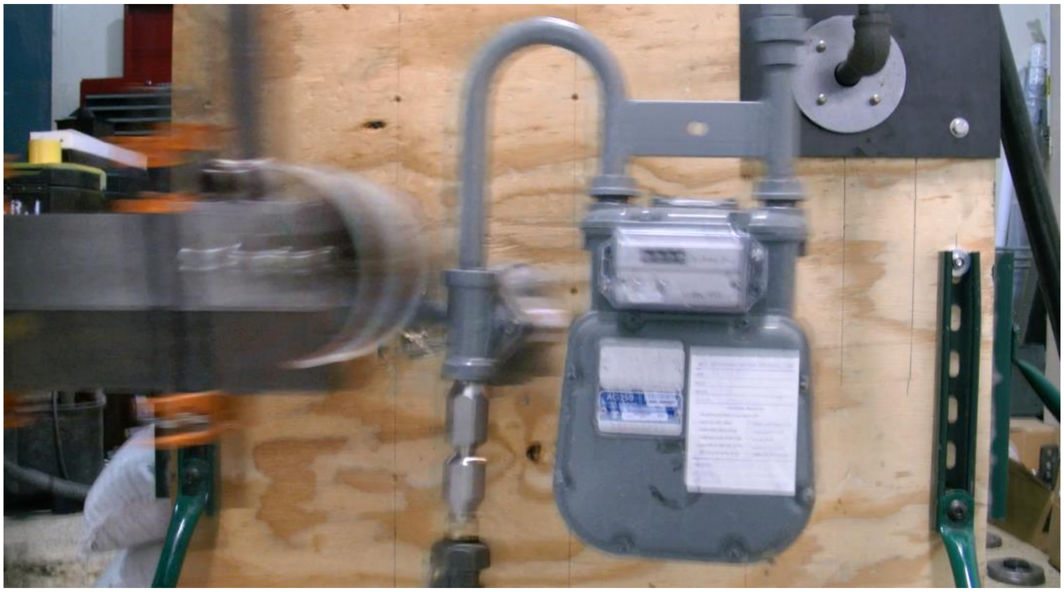

Figure 13: Impact Test on Utility 4 Meter Set with Breakaway and Regulator Behind Riser (Towards Wall) – Impacted Parallel to Wall from Regulator Side – Before Impact

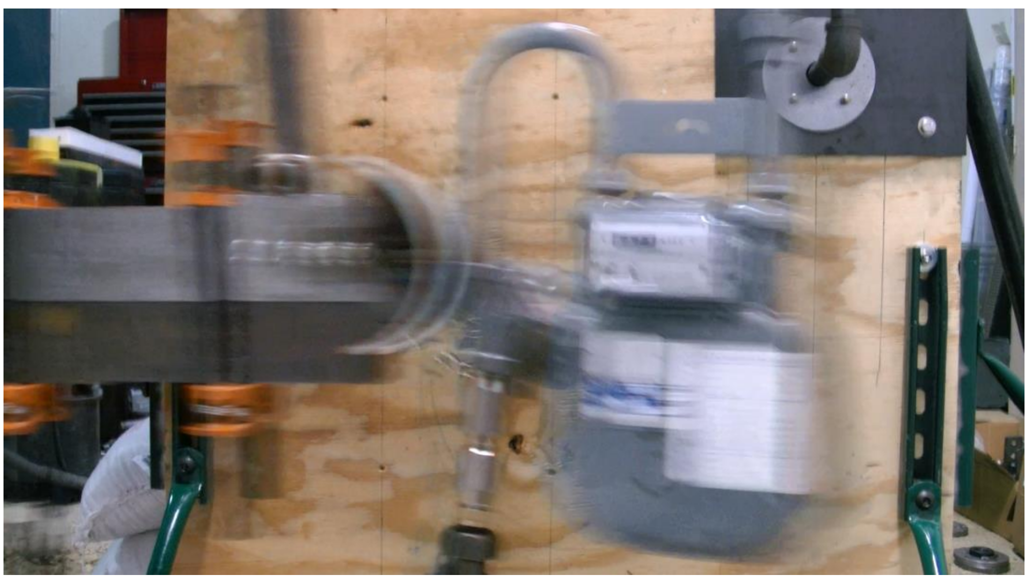

Figure 14: Impact Test on Utility 4 Meter Set with Breakaway and Regulator Behind Riser (Towards Wall) – Impacted Parallel to Wall from Regulator Side – After Impact

The difference in the location of the transference of force from the suspended weight during the impact can be shown below in **Figure 15**. In the left image the pre-fab remains straight and breaks at the center of the breakaway (where red meets green) however in the right image the pre-fab bends above the regulator, leaving the entire breakaway (green) straight. The street valve and riser (orange) remain straight in the left image whereas it bends severely in the right image.

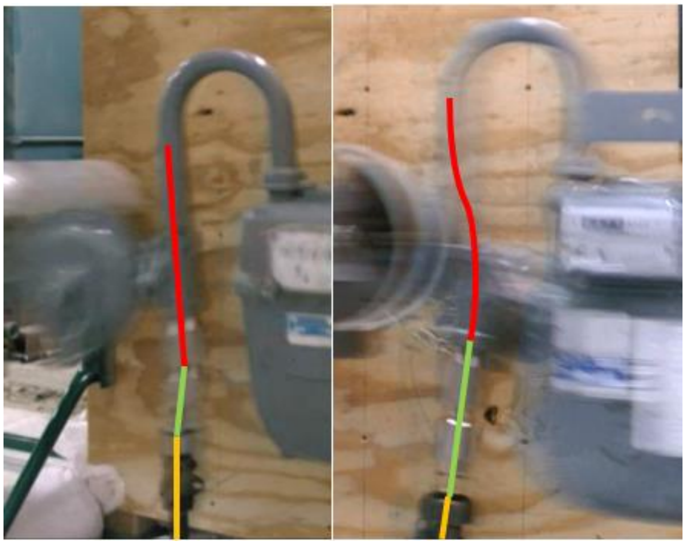

Figure 15: Difference of Bend Point from Impact Parallel to Wall on Regulator Side Between Regulator Aimed to the Left for Utility 1 (left) and Regulator Aimed At the Wall for Utility 4 (right)

With these results regarding the regulator position, it can be assumed that in order to achieve a higher success rate of the breakaway fittings when being impacted from the direction parallel to the wall hitting the regulator line first, the regulator should be aimed to the left of the riser, facing away from the meter. In order to determine if having the regulator aimed to the left of the riser is better for the success rate of the breakaway fitting for multiple impact directions, the success rates were calculated and shown in **Figure 16**.

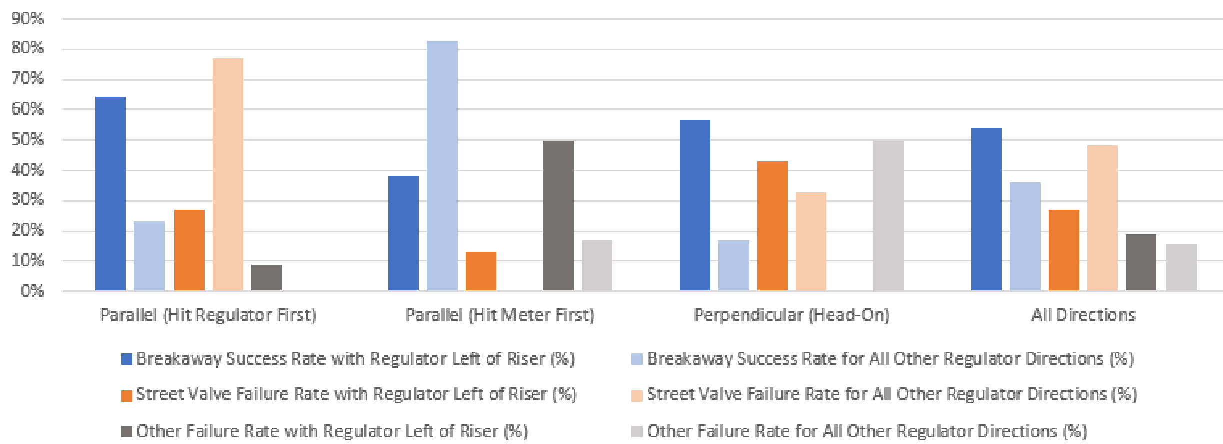

Figure 16: Effect of Direction that Regulator is Facing on Impact Results Based on Impact Direction

As shown in **Figure 16**, having the regulator to the left of the riser also increases the breakaway fitting success rate for head on collisions. This makes sense given that if the regulator was pointed towards the house wall it would stop the riser from pivoting, causing there to be no break at the breakaway, as shown to the right in **Figure 17**.

Figure 17: Head On Impact of Utility 8 Meter Set with Breakaway and Regulator Aimed at Wall

However, when the impact is parallel to the wall coming from the meter side there is a significant difference between the breakaway success rates of having the regulator aimed to the left of the riser (38%) and all other regulator orientations (83%). This result does not make sense when analyzing the design of the meter set. There should be no effect of the regulator orientation when the suspended weight is impacting the meter set from the opposite side of the regulator. It is assumed that there is another factor that was compounded during testing which is affecting this disparity in success rates.

Effect of Connector Bar on Breakaway Success Rate

Other meter set design factors were analyzed in Table 13 in Appendix G: Impact Testing Analysis Tables. The effect of the connector bar connecting the inlet and outlet of the meter was analyzed to see its effects on the success rate of the breakaway fitting. The connector bar is shown in Figure 18 whereas a meter without a connector bar is shown in Figure 19.

Figure 18: Utility 3 Meter Set (with Connector Bar)

Figure 19: Utility 7 Meter Set (Without Connector Bar)

Figure 20 shows the difference between the success rates of the breakaway when the meter set does or does not have a connector bar.

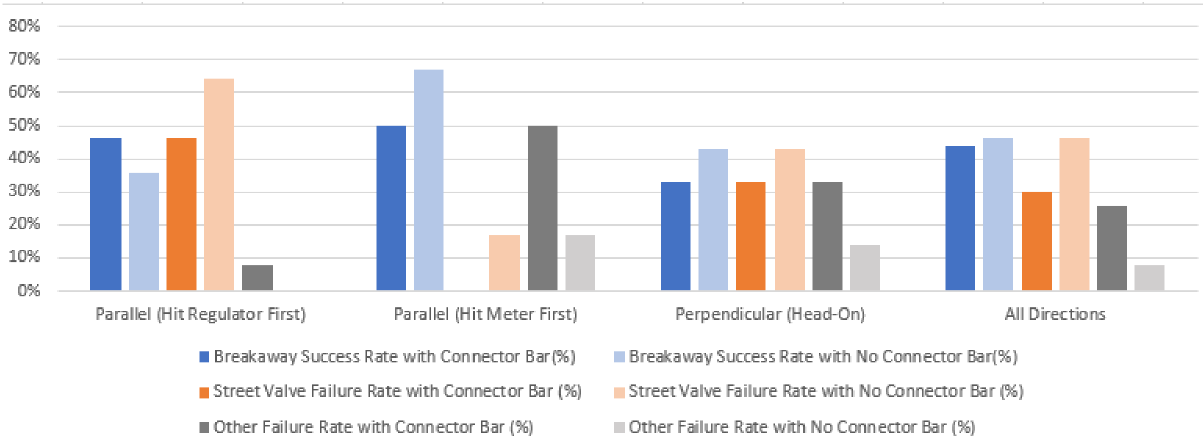

Figure 20: Effect of Presence of Connector Bar on Impact Results Based on Impact Direction

When looking at the effect of the connector bar on impacts from all directions, there is very little difference between the overall breakaway success rates with and without a connector bar. However, when analyzing the success rates from the different impact directions the connector bar had different breakaway success rates depending on the presence of the connector bar. For the impact direction parallel to the wall hitting the regulator first, having a connector bar resulted in a higher breakaway success rate. While in both the impact direction parallel to the wall hitting the meter first and perpendicular to the wall in a head-on impact, having a connector bar resulted in a lower breakaway success rate. Unlike with the regulator direction, there is nothing to be gained from the design of the connector bar to explain this difference. Therefore, due to having a low sample size and conflicting data, further research should be done regarding the effect of this meter set configuration factor.

Effect of Pre-Fab Configuration on Breakaway Success Rate

The effect of the pre-fab configuration between the regulator and the meter inlet was also analyzed to see if it had any effect on the success rate of the breakaway fitting. A meter set with a hook, elbow, short hook and pre-fab elbow are shown below in **Figure 21, Figure 22, Figure 23,** and **Figure 24** respectively.

Figure 21: Utility 7 Meter Set (with Hook Pre-Fab Configuration)

Figure 22: Utility 8 Meter Set (with Elbow Pre-Fab Configuration)

Figure 23: Utility 5 with Short Hook Pre-Fab Configuration

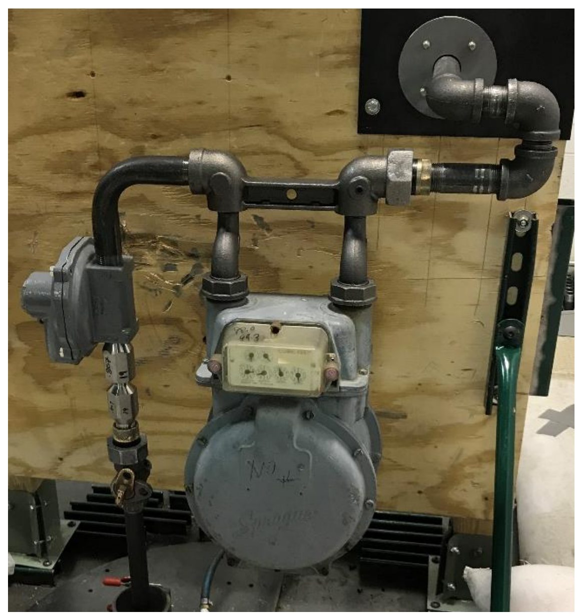

Figure 24: Utility 6 20 Lite Meter Set with Pre-Fab Elbow as Pre-Fab Configuration

Figure 25 shows the difference between the success rates of the breakaway depending on the pre-fab configuration

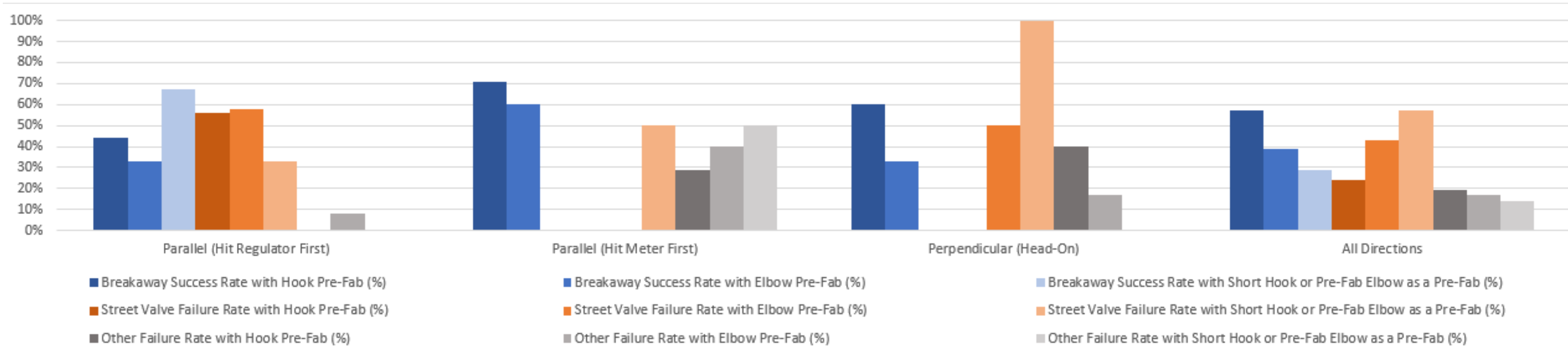

Figure 25: Effect of Hook Pre-Fab Configuration on Impact Results Based on Impact Direction

The Short Hook & Pre-Fab Elbow configurations had the lowest success rate of all 3 configurations when impacted from all directions. While the Short Hook & Pre-Fab Elbow configuration had the highest success rate when impacted in the direction parallel to the wall while hitting the regulator first, this is due to the fact that only 3 tests were performed with this configuration from this direction, resulting in a skew in the percentages. There were no successful Short Hook or Pre-Fab Elbow tests from the other two directions.

The Hook configuration performed slightly better than the Elbow configuration when impacted in both parallel directions, where the hook configuration performed the best when impacted perpendicularly to the wall in a head-on collision. These results showed that the hook configuration performed the best out of all possible pre-fab configurations from all impact directions.

Analyzing Failures at Street Valve

As shown in **Figure 9 on Page 22**, many of the breakaway failures occurred at the street valve (19 tests out of 51, 37%). This is especially prevalent when the impact direction was where the impact was parallel to the wall and hit the regulator first, where 13 out of 24 tests, 54%, had street valve failures. When looking at the impact of the regulator direction on the success of the breakaway failure in **Figure 10 on Page 22**, it was found that most of these street valve failures occurred when the regulator was not oriented to the left of the riser (10 out of 13 tests, 77%, had street valve failures). It was hypothesized that by increasing the wall thickness of the riser from Sch 40 to Sch 80, the street valve failures would have instead been successful breakaway results.

In order to test this hypothesis, one test which experienced a street valve failure was repeated with a schedule 80 riser to see if a thicker riser would move the break point from the street valve to the breakaway. The Utility 8 meter set with the regulator facing towards the wall and the street valve height of 8.25" was tested by the suspended weight impacting the meter set at a bumper height of 19.75in on both Sch 40 and Sch 80 risers. As shown below in **Figure 26 & Figure 27**, the Sch 40 riser began to bend and then because the riser (at the threads) was too thin and the threads going into the street valve broke and the failure occurred at the street valve.

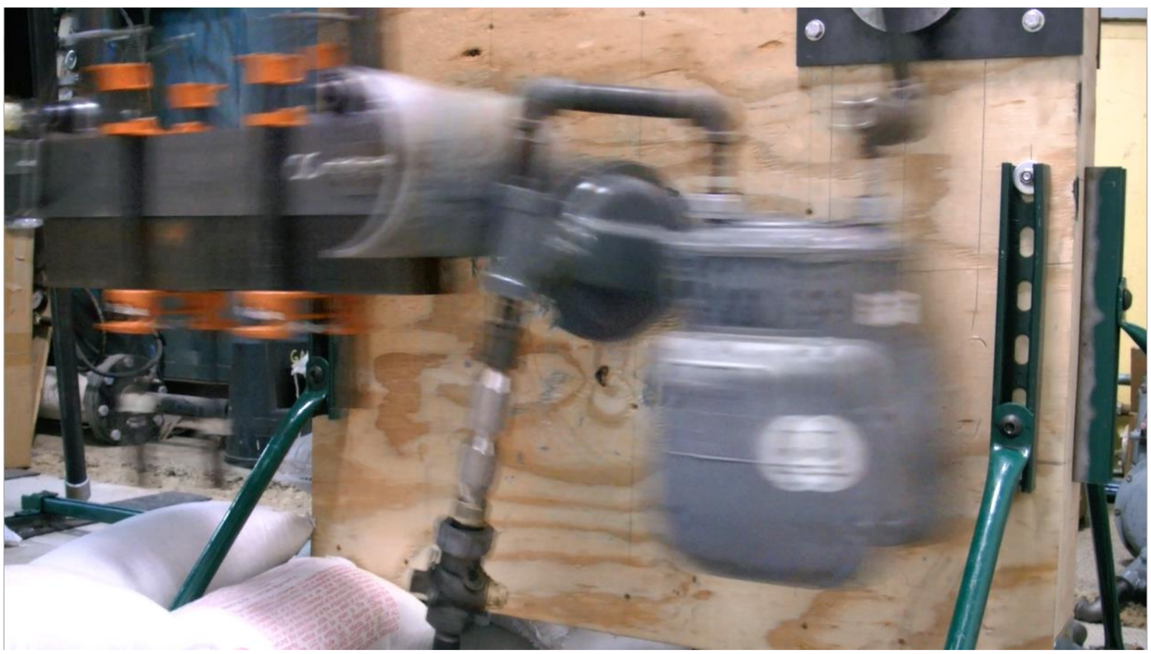

Figure 26: Utility 8 Retest – Sch 40 Riser – Impact Parallel to Wall from Regulator side – Slight Riser Bend Before Break

Figure 27: Utility 8 Retest – Sch 40 Riser – Impact Parallel to Wall from Regulator side – Street Valve Failure (Threads Into Street Valve Broke)

When the test was redone with the Sch 80 riser, as shown below in **Figure 28 & Figure 29**, the riser once again began to bend but because the riser was thicker the threads remained intact, no failure occurred at the street valve, and instead the breakaway successfully broke.

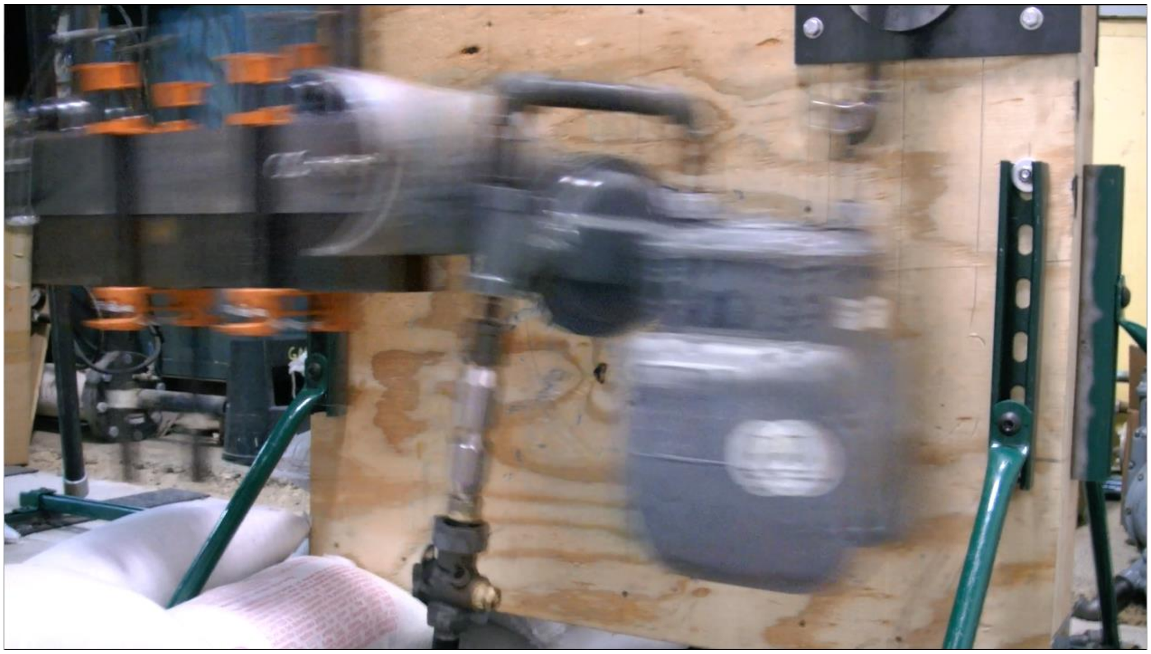

Figure 28: Utility 8 Retest – Sch 80 Riser – Impact Parallel to Wall from Regulator side – Slight Riser Bend Before Break

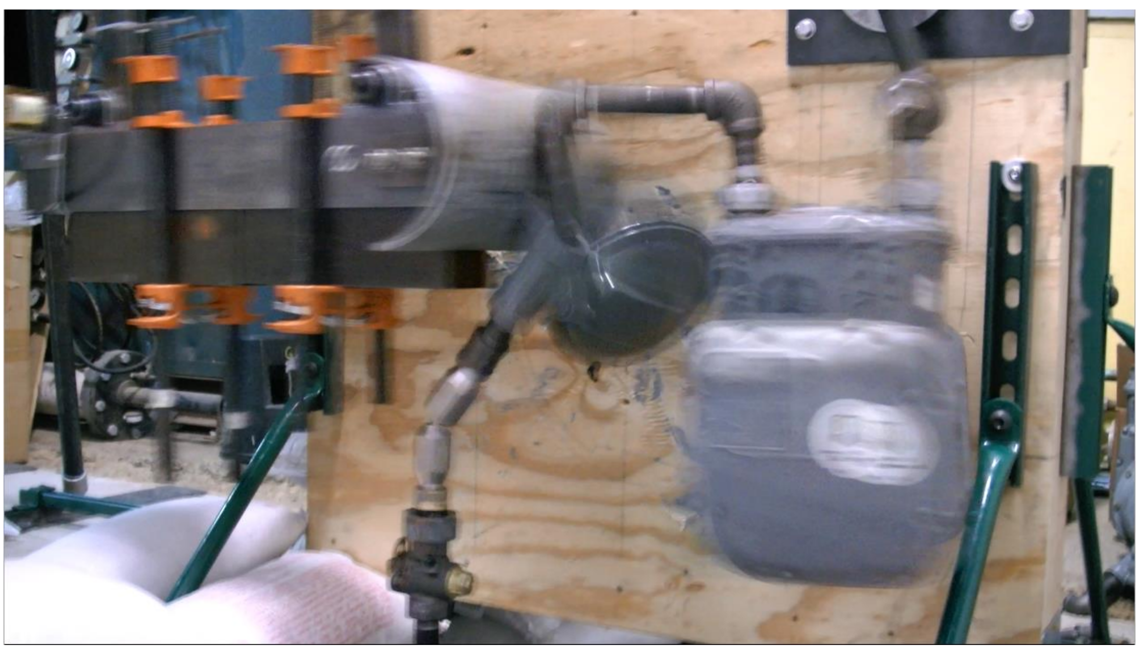

Figure 29: Utility 8 Retest – Sch 80 Riser – Impact Parallel to Wall from Regulator side – Riser Springs Back When Breakaway Breaks

This test using the Sch 80 riser demonstrates that switching from a Sch 40 to a Sch 80 can result in a successful break. The results suggest that to achieve a higher success rate of the breakaways, the most significant change that can be made to the meter set is to change out the Sch 40 risers with Sch 80 risers. If this change had been made to all of the tests, as many as 42 tests out of a possible 51 (82.35%) could have been successful. However, further testing should be done to validate this success rate.

Drop Testing

Besides vehicular impact of meter sets, another risk to meter sets is falling snow and ice. This is especially true in mountainous areas. Therefore, the team also tested the Breakaway Fitting by simulating snow falling off of a roof onto a meter set. For this simulation the team conducted the testing outside on a meter set which had the riser connected to a reinforced elbow which was fixed to a metal plate sitting on the ground, and the house line ran through a wood framed wall connected to the metal plate. The metal plate was bolted to the ground. Pressurized air at 60 psi was fed to the vertical riser and through the meter set. This testing setup can be seen on the next page in **Figure 30**.

Figure 30: Drop Testing Setup of Utility 1 Meter Set with Breakaway

In order to simulate falling snow / ice from a roof, a sandbag was raised to a height of 16ft above the meter set using a forklift (shown below in **Figure 31 & Figure 32**). The sandbag was pulled from the forklift and fell onto the top of the meter, see the path in **Figure 31 & Figure 32**.

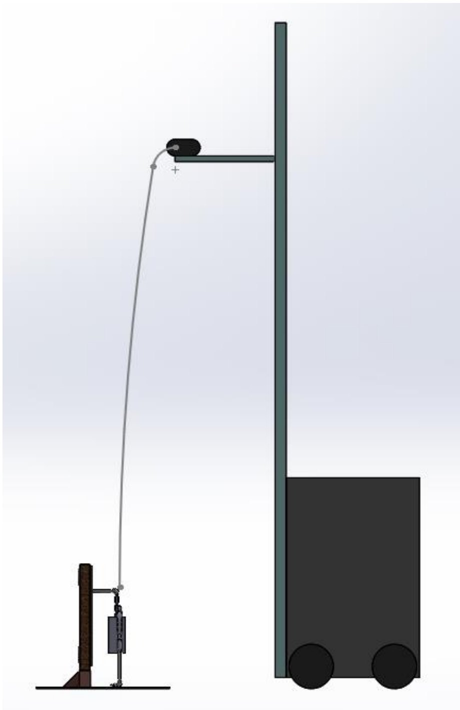

Figure 31: Side View of Path of Sandbag From Drop Test Setup

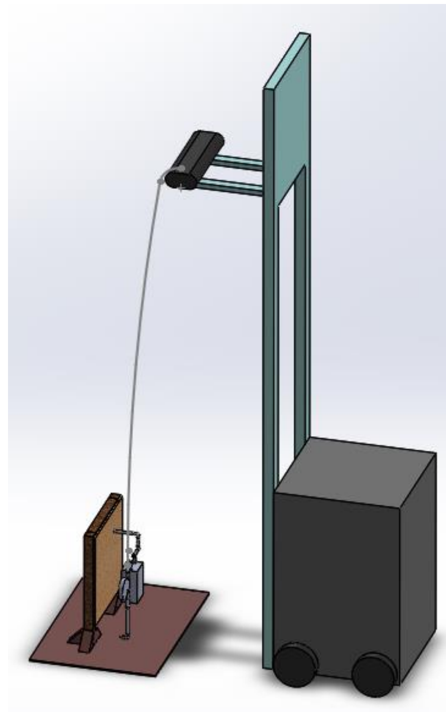

Figure 32: Angled View of Path of Sandbag From Drop Test Setup

During trial runs without a breakaway, it was found that in order to damage the meter set a 70 lb sandbag had to be used which was reinforced with duct tape in order to prevent the sand from leaking immediately on impact. The falling sandbag, just prior to impacting the meter set, can be seen below in **Figure 33**.

Figure 33: Falling 70 lb Sandbag Reinforced by Duct Tape – About to Impact Utility 1 Meter Set with Breakaway

After conducting several tests on meters without a breakaway, testing was conducted on 3 different meter sets with a breakaway fitting installed on the vertical piping just above the service valve. Twice on an Utility 1 meter set and once on a Questar meter set. All 3 tests were performed at freezing temperatures (between 28°F and 31°F). In all 3 cases, the breakaway broke successfully under the impact of the dropped sand bag. On the Utility 7 meter set breakaway test, the sand bag hit the top of the wall first and then impacted the meter set. Even though this occurred, the breakaway still worked successfully. Photos of these Drop Tests are in **Appendix H: Drop Test Pictures**.

Conclusions

According to U.S. Department of Transportation Data on Serious Pipeline Incidents (2005-2016), the two primary factors that contributed to U.S. gas distribution incidents is “excavation damage” and “other outside force damage (e.g. vehicular impact)”. Distribution Integrity Management (DIM) programs require utilities to identify the threats that may affect the safety and performance of the distribution facilities and take action to minimize these threats. One of the most common threats to aboveground piping is vehicular and other outside force damage to meter sets.

The breakaway fitting is designed to do just that, minimize the threat of incident if the meter set or other aboveground distribution piping is impacted by an outside force. Common outside force impacts include vehicular and other motorized equipment impacts and also falling snow and ice from building roofs.

Excess Flow Valves (EFVs) are designed to shut off an excess flow of natural gas created when the natural gas service line is either ruptured or severed; the EFV focuses on excavation damage and not vehicular or other outside force damage to the meter set or other aboveground piping.

The deployment of breakaway fittings on meter sets and other aboveground piping can be complementary or an alternative to the use of an EFV. The breakaway fitting is designed to reduce the risk of a major gas leak, fire, property damage, and injury caused by vehicle damage and other outside forces.

From performing the impact testing on the various meter sets with the breakaways installed, approximately 50% of the tests had a successful breakaway, which broke and had the seal shut off the flow of gas. Additional testing suggests that using a Sch 80 riser could increase the success rate of the breakaway fitting to approximately 82%. In addition, the breakaway (with a Sch 40 riser) was 100% successful during the simulated falling snow / ice testing.

In analyzing the differences between the success rates of the breakaway fitting based on the various impact directions, it was found that the direction at which the suspended weight impacted the meter set and the direction which the regulator was pointing had an effect on the success rates of the breakaway fitting. It was found that having the regulator aimed to the left of the riser, away from the meter, aided the success rate of the breakaway fitting when the meter was impacted by the suspended weight. This finding is verified by the behavior of the meter set when the impact testing videos were analyzed as the regulator helped focus the force of the impact to the breakaway when impacted from the regulator side, and allowed the meter set to bend further when impacted head on.

The results suggest that by aiming the regulator to the left of the riser, away from the meter, and by switching the riser to a Sch 80 thickness, that the success rate of the breakaway fitting could increase up to 90%. Further testing would be needed to validate this assumption. There will never be a 100% success rate of the breakaway fitting, but as is the case with Excess Flow Valves, the goal of these breakaway fittings is to add a layer of safety and reduce the risk of incident.

Future Work and Recommendations

OPW (breakaway fitting manufacturer) along with GTI's assistance, is moving forward with the commercialization of the breakaway fitting. OPW and GTI are looking for utilities to pilot the commercialization and building of sales channels to initiate the commercialization and eventual large scale availability of the breakaway fitting.

GTI will work with each utility, your preferred component distributor and OPW to facilitate this initial pilot installation effort. This effort is a critical piece to move the breakaway fitting into our industry. Your participation would be greatly appreciated.

Appendix A: Detailed OPW Breakaway Drawings

This appendix shows the detailed breakaway drawings for the various breakaway configurations. Those configurations are listed below.

- 6” Long Breakaway with ¾” NPT Female Inlet – ¾” NPT Female Outlet (Figure 34)
- 6” Long Breakaway with ¾” NPT Male Inlet – ¾” NPT Male Outlet (Figure 35)
- 6” Long Breakaway with ¾” NPT Female Inlet – ¾” NPT Male Outlet (Figure 36)
- 6” Long Breakaway with ¾” NPT Male Inlet – ¾” NPT Female Outlet (Figure 37)
- 4” Long Breakaway with ¾” NPT Female Inlet – ¾” NPT Female Outlet (Figure 38)
- 4” Long Breakaway with ¾” NPT Male Inlet – ¾” NPT Male Outlet (Figure 39)
- 4” Long Breakaway with ¾” NPT Male Inlet – ¾” NPT Female Outlet (Figure 40)
- 4” Long Breakaway with ¾” NPT Female Inlet – ¾” NPT Male Outlet (**Figure 41**)

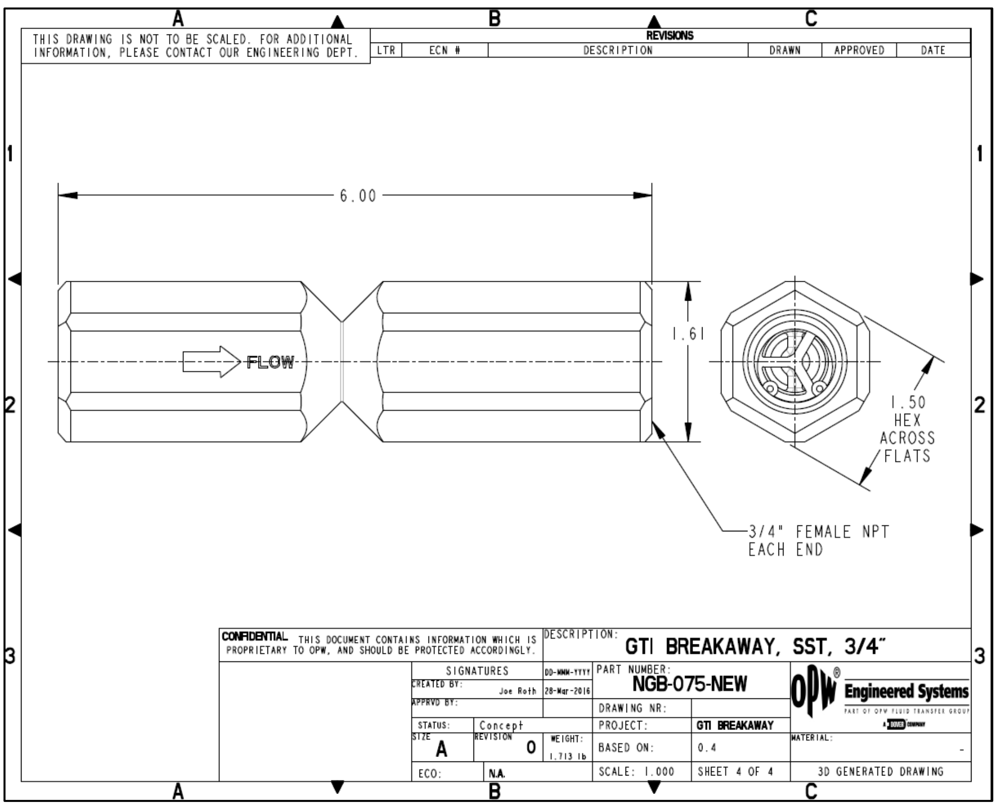

Figure 34: 6” Long Breakaway with ¾” NPT Female Inlet – ¾” NPT Female Outlet

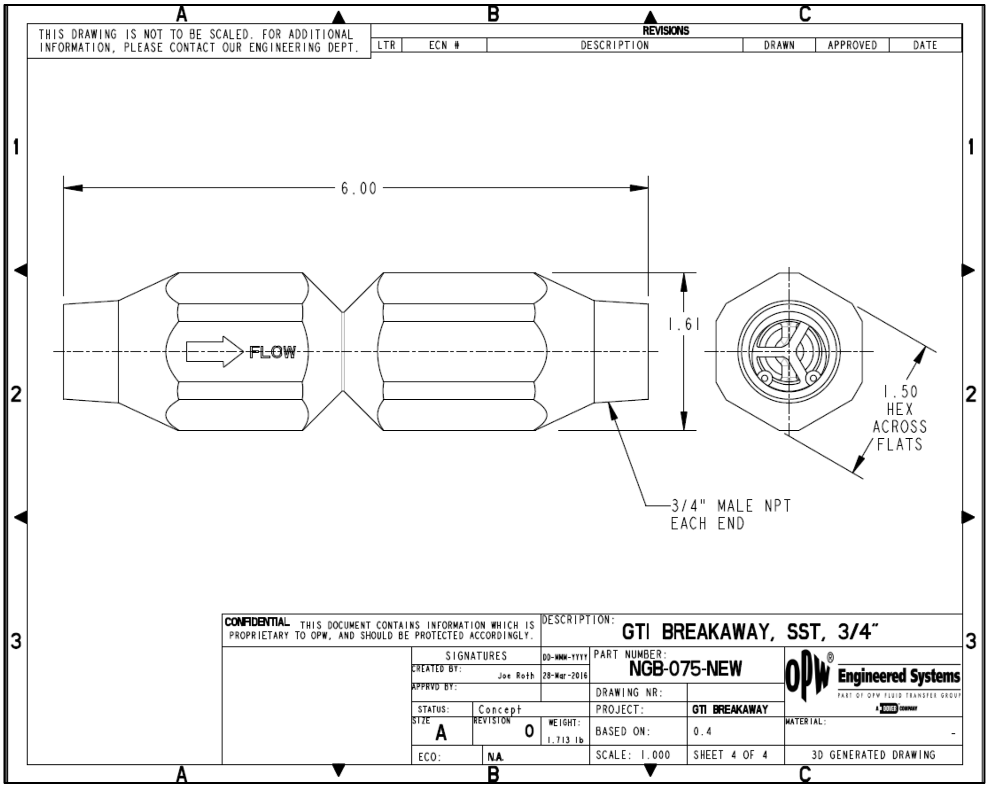

Figure 35: 6" Long Breakaway with ¾" NPT Male Inlet – ¾" NPT Male Outlet

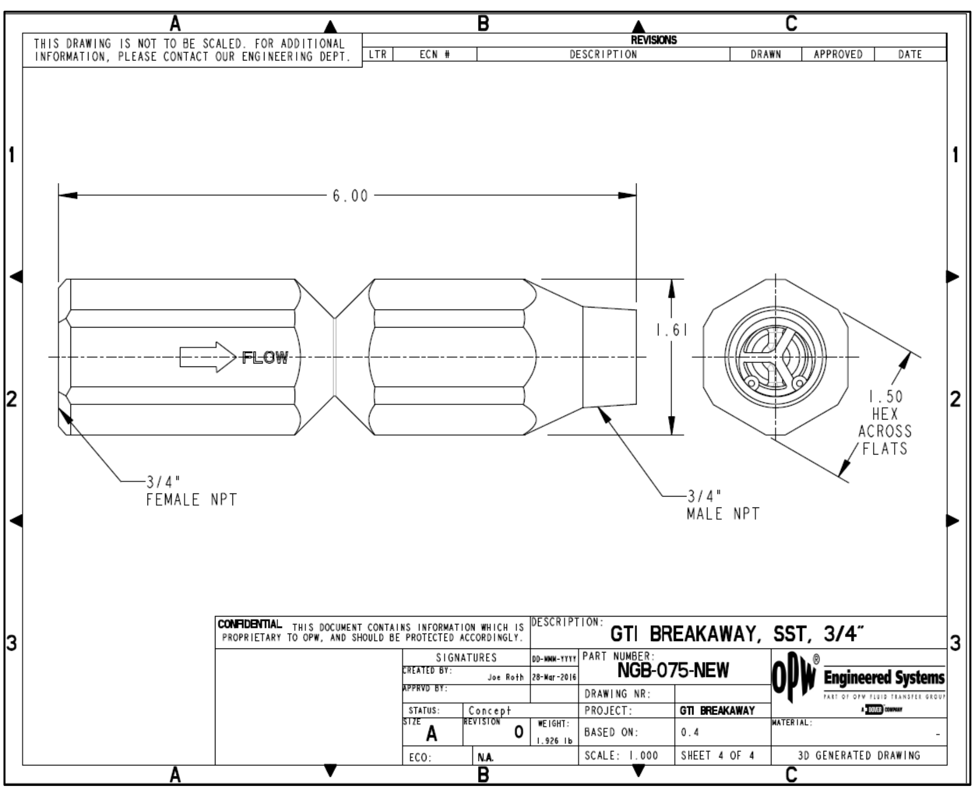

Figure 36: 6" Long Breakaway with ¾" NPT Female Inlet – ¾" NPT Male Outlet

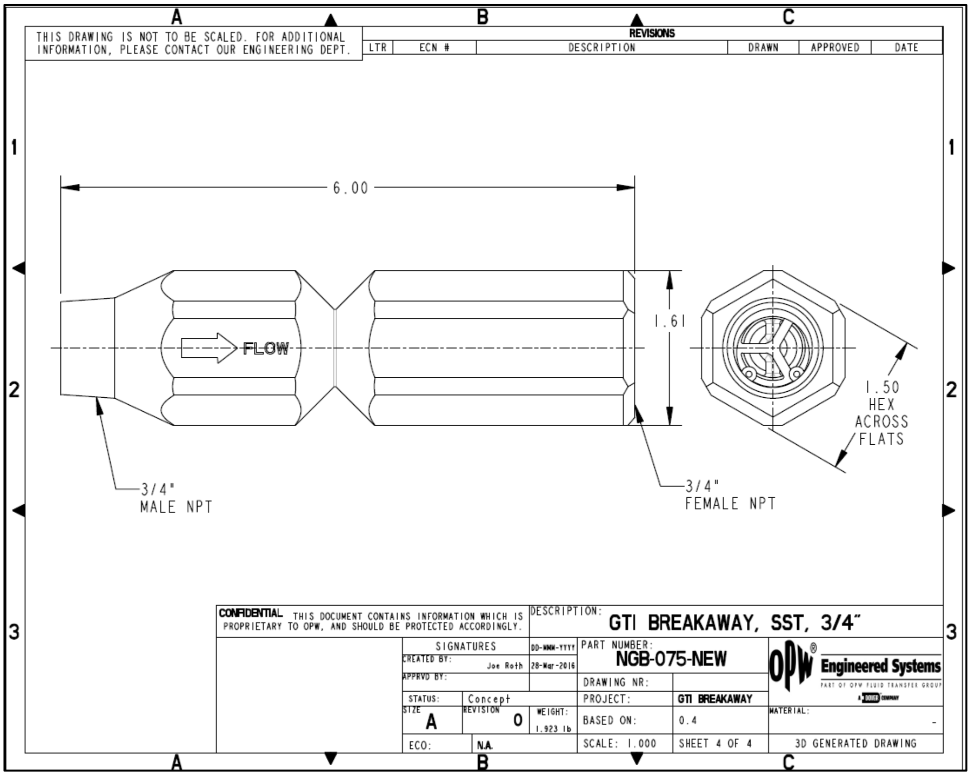

Figure 37: 6" Long Breakaway with ¾" NPT Male Inlet – ¾" NPT Female Outlet

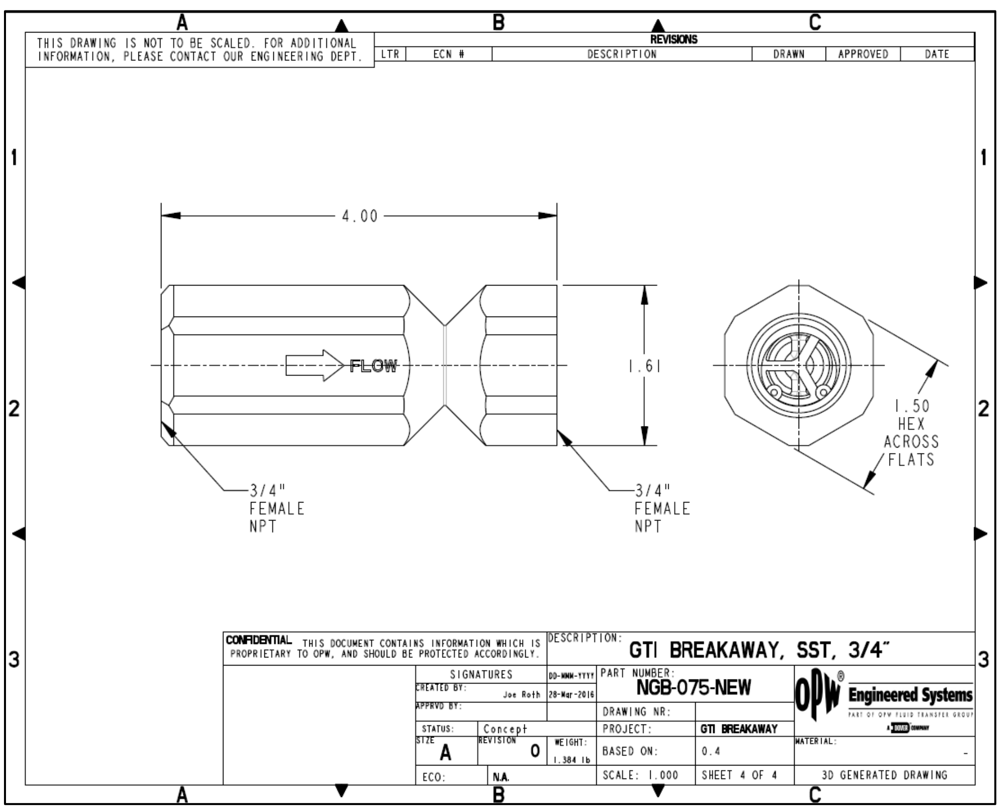

Figure 38: 4" Long Breakaway with ¾" NPT Female Inlet – ¾" NPT Female Outlet

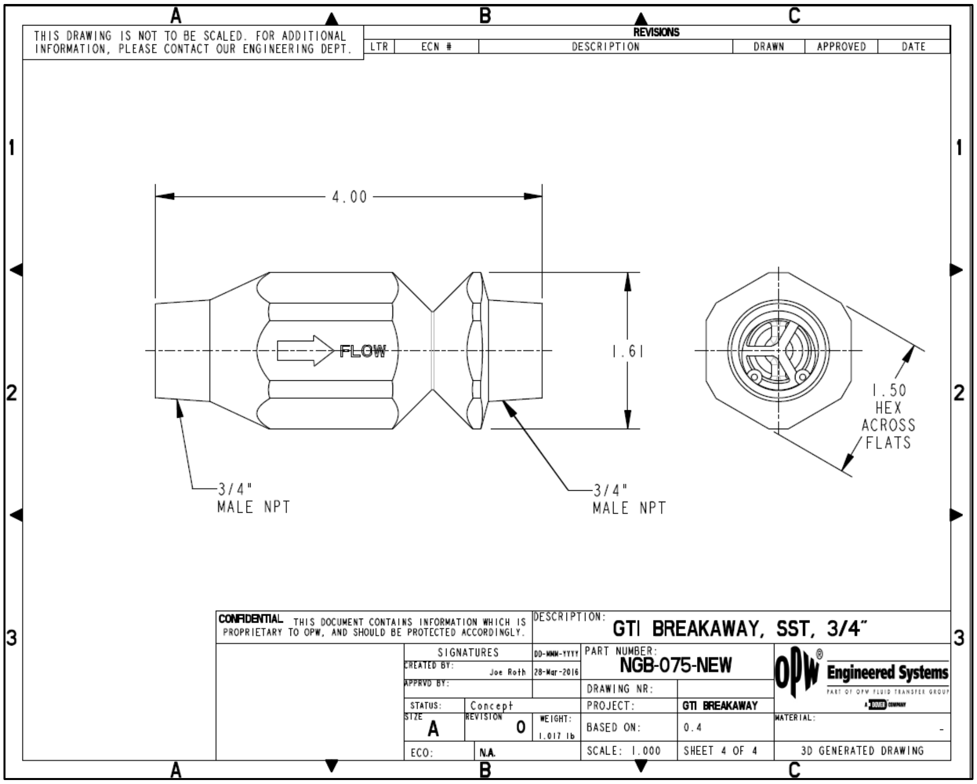

Figure 39: 4" Long Breakaway with ¾" NPT Male Inlet – ¾" NPT Male Outlet

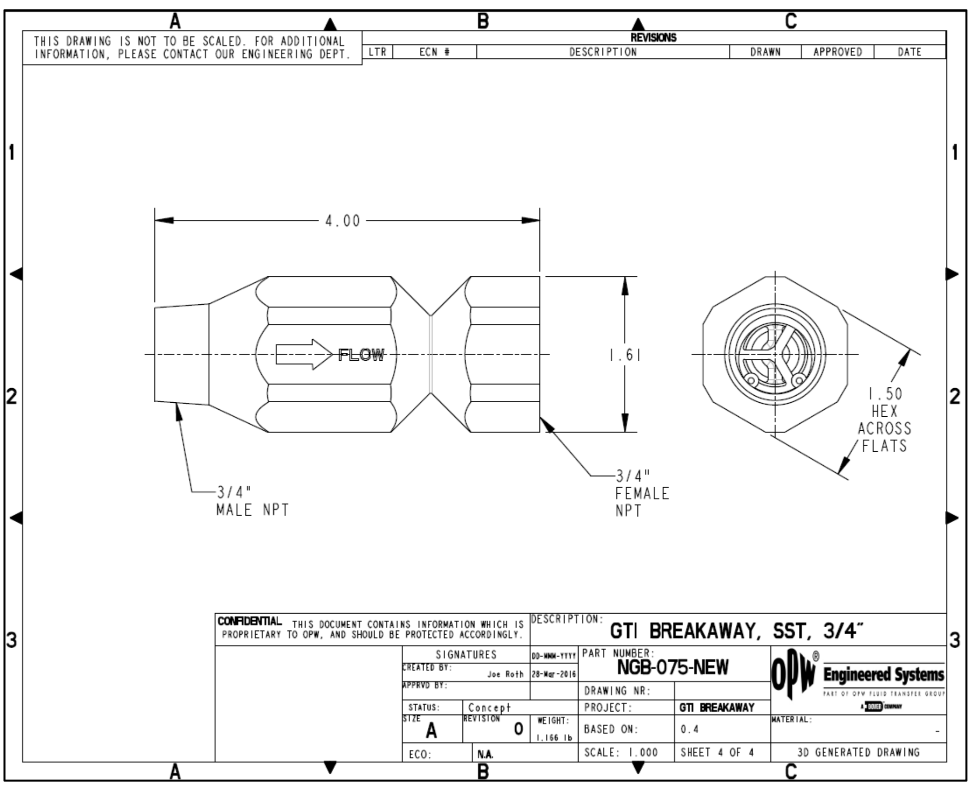

Figure 40: 4" Long Breakaway with ¾" NPT Male Inlet – ¾" NPT Female Outlet

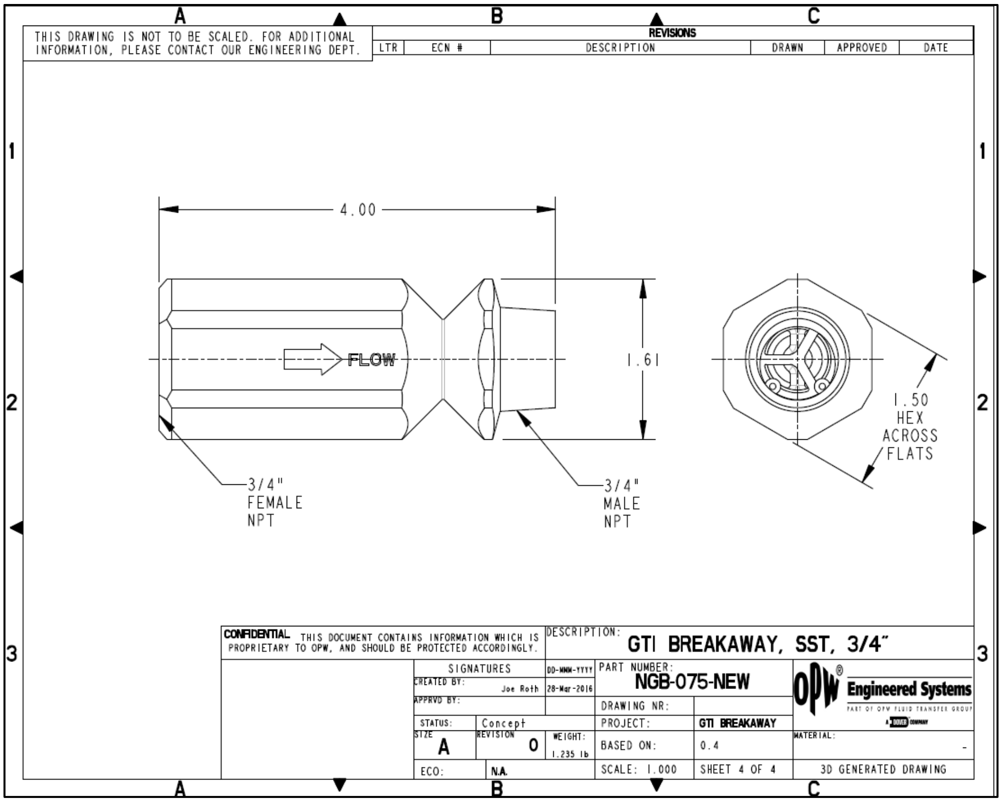

Figure 41: 4” Long Breakaway with ¾” NPT Female Inlet – ¾” NPT Male Outlet

Appendix B: Impact Testing Rig

This appendix describes the design of the rig built for the impact testing to simulate a car impacting a meter set attached to a house.

The entire rig consists of a frame that supports a suspended weight that is pulled back by a winch, also attached to the same frame. Inside the frame lies a base that can support a meter set which is fixed to the ground and is fixed to a wooden wall, which is also supported by the base. The overall rig can be seen below in Figure 42.

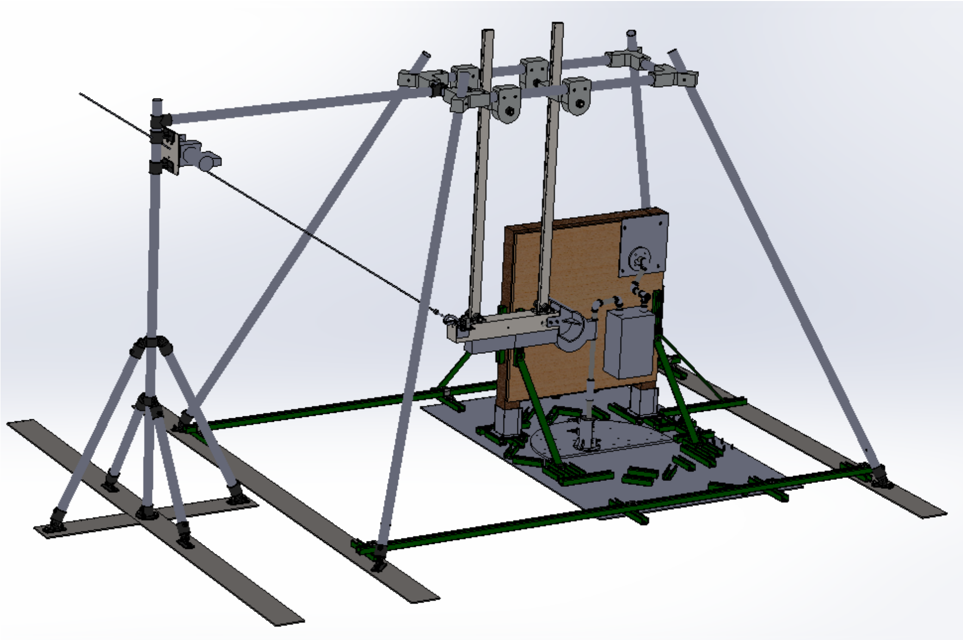

Figure 42: Impact Testing Rig

The overall rig is made up of 1.5" IPS Schedule 40 Steel Pipe with generic rail fittings to anchor the frame to custom base plates, and with custom aluminum joints to angle the legs away from the center of the rig to provide greater stability.

Suspended Weight

The suspended weight used for the impact testing is a 3.5" x 3.5" x 24" steel bar weighing 86 pounds. It is suspended from the frame by two 1" x 2" steel beams (a.k.a pivot arms) which are connected to the suspended weight by a rod that pivots through sleeve bushings on the weight and a sleeve bushing at the bottom of the steel beam (shown in **Figure 43**).

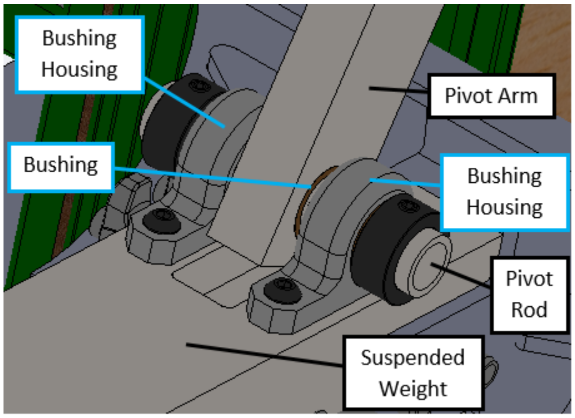

Figure 43: Connection Between Pivot Arm and Suspended Weight

The top of the pivot arm is attached to the overall frame via a custom pivot block that is held and allowed to pivot between two custom sleeve bushings housings that are fixed to the horizontal pipes of the frame (shown to the right in Figure 44). The pivot arm is held in place in the pivot block by a quick disconnect pin to allow the suspended weight to change its height in relationship to the ground. This allows for testing of different bumper heights to be possible (shown below in Figure 45). The custom bushing housings are allowed to move up and down the horizontal pipes of the frame. This movement allows the tester to have the suspended weight impact the meter set when the pivot arm is vertical. The custom bushing housings are locked in place on the horizontal pipes using set screws (shown below in **Figure 46).**

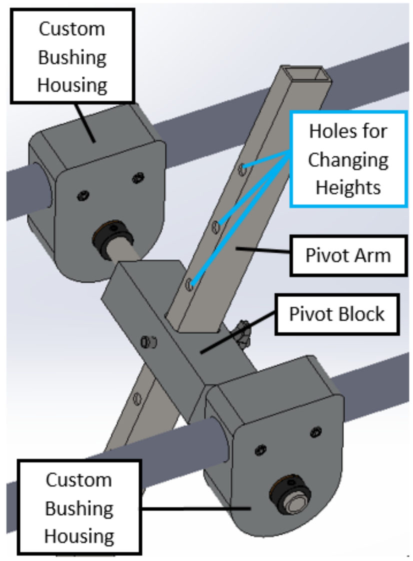

Figure 44: Connection Between Pivot Arm and Overall Frame

Figure 45: Movement of Custom Bushing Housings Along Horizontal Pipes of Frame

Figure 46: Adjustment of Height of Suspended Weight

Attached to the front of the suspended weight is half of a 6” IPS Steel Pipe (6.625” nominal diameter) that is meant to simulate a car bumper. When the testing permits it the wider bumper head (18” long – 19 lb) was used. However, there were testing configurations where the wider bumper head couldn’t fit inside of the wall and therefore the narrow bumper head (12” long – 13 lb) was used instead. Both bumper heads can be seen below in **Figure 47**.

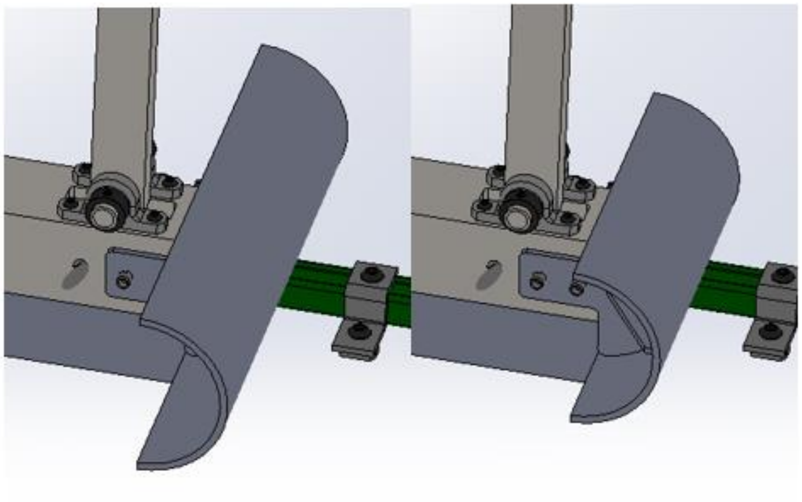

Figure 47: Bumper Heads Attached to Front of Suspended Weight (Left = Wide, Right = Narrow)

In order to create the potential energy which is used to impact the meter set, an electric winch capable is attached to a separate support rig which is connected to the rest of the frame by a single 1.5” IPS Steel Pipe. The winch was placed far enough back to be able to displace the suspended weight as much as possible vertically for every height. The winch pulling up on the suspended weight can be seen below in Figure 48.

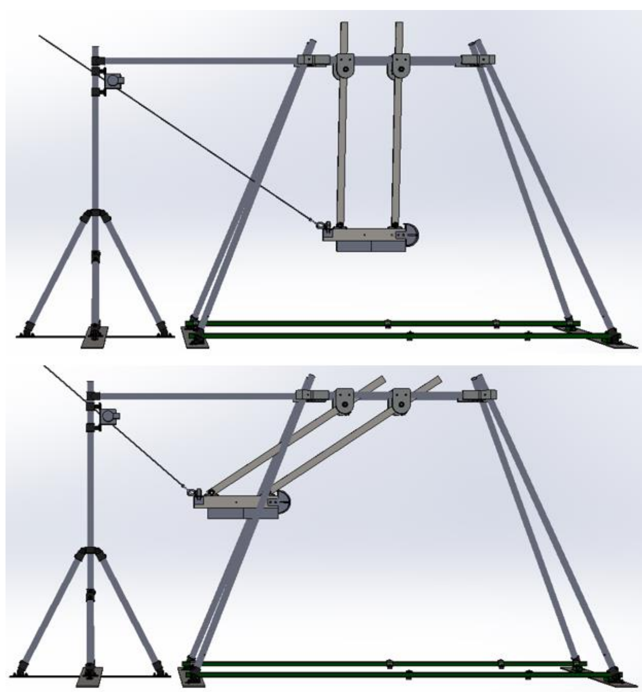

Figure 48: Winch Pulling Suspended Weight Up and Away from Meter Set

When the winch is pulling up on the suspended weight, the winch strap is pulling back on a pelican hook, locked in place by a pivot latch which is controlled by a solenoid (shown to the right in Figure 49). To release the suspended weight from its raised position a solenoid is activated, which pulls back a pivot latch, releasing a pelican hook. Once the pelican hook is released, the suspended weight falls, having the pelican hook sliding through the ring attached to the end of the winch strap, allowing the suspended weight to fall (shown below in **Figure 50**).

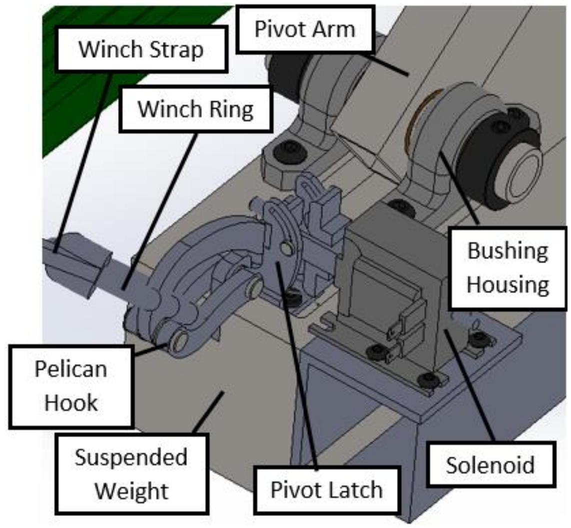

Figure 49: Solenoid and Pelican Hook Assembly on Back of Suspended Weight

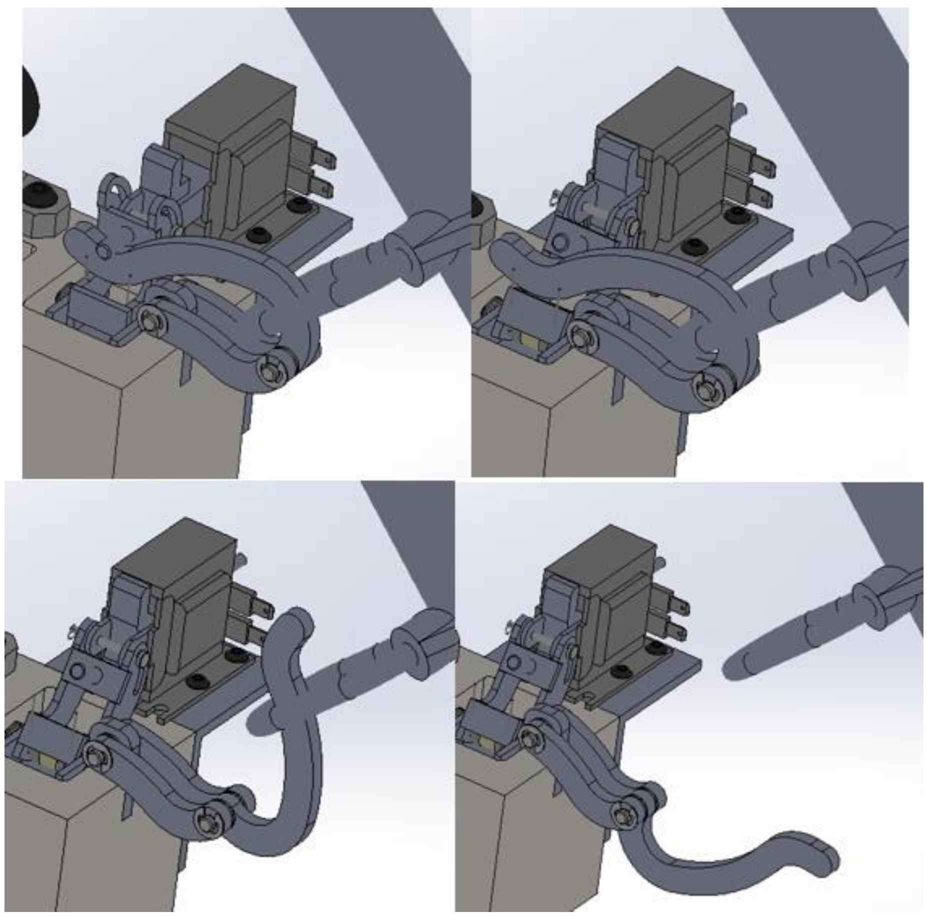

Figure 50: Step by Step of Pelican Hook Release from Winch Ring (Top Left: Pelican Hook Held in Place by Pivot Latch, Top Right: Solenoid Pulls Back Pivot Latch Releasing Pelican Hook, Bottom Left: Pelican Hook Begins to Bend as Suspended Weight Falls, Bottom Right: Pelican Hook Fully Releases from Winch Ring)

Meter Set Assembly

In order to accurately test the meter set, the meter set had to be fixed to a simulated wall to simulate how the meter set is held in place. Because testing had to be done from different directions, the impact rig had to have a method of adjusting the simulated wall. A base was made consisting of metal plate which unistrut was welded to, shown below in **Figure 51**. The metal plate was held in place by brackets on the sides that secured the plate in place to longer unistruts which ran between the base plates of the overall frame of the impact rig.

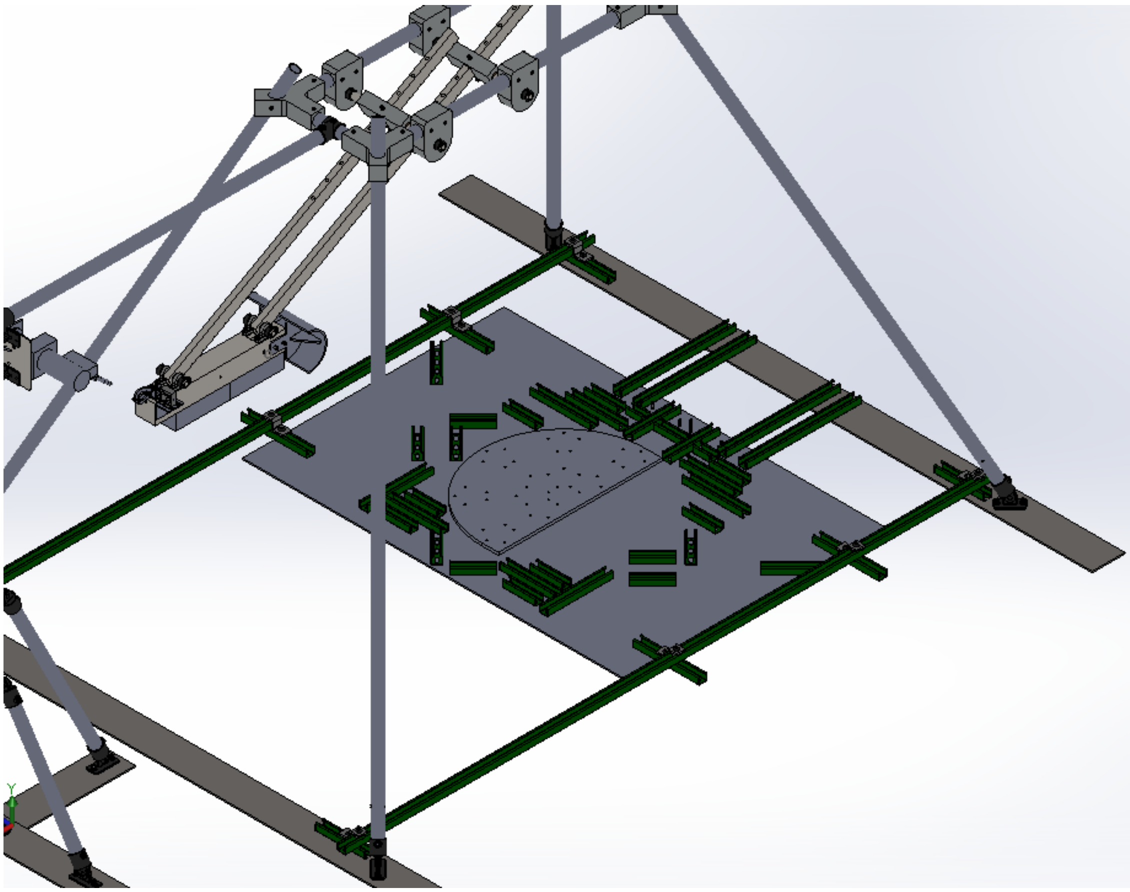

Figure 51: Unistrut Base Plate Underneath the Frame of the Overall Impact Rig

The unistrut was welded in a pattern that allowed for a wall to be set up such that the suspended weight could hit the meter set from a direction perpendicular to the wall (Figure 52), parallel to the wall from the Vertical Riser & Regulator side (Figure 53), parallel to the wall from the House Line & Meter Side (Figure 54), and at 45 degree angles to the wall from the Vertical Riser & Regulator Side (Figure 55) and House Line & Meter Side (**Figure 56**). Each of the wall configurations was supported by at least 4 braces (for the perpendicular wall) and 5 braces for the other configurations (seen in the images on the next pages).

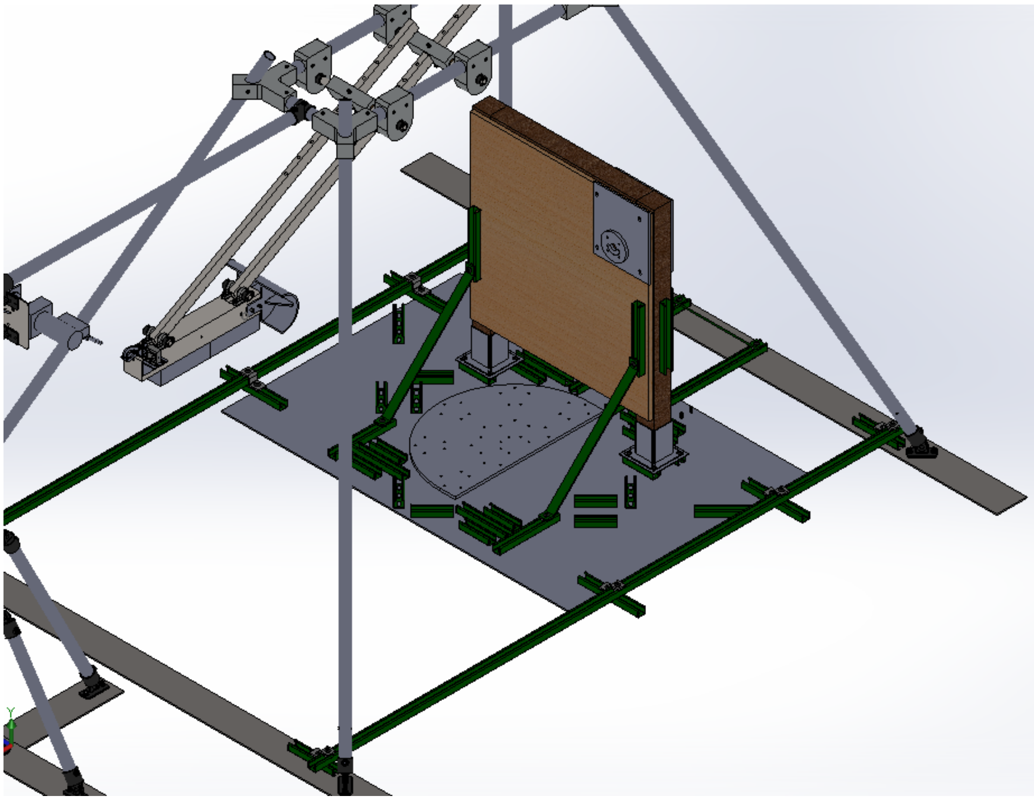

Figure 52: Wall Setup for Head On (Perpendicular) Impacts

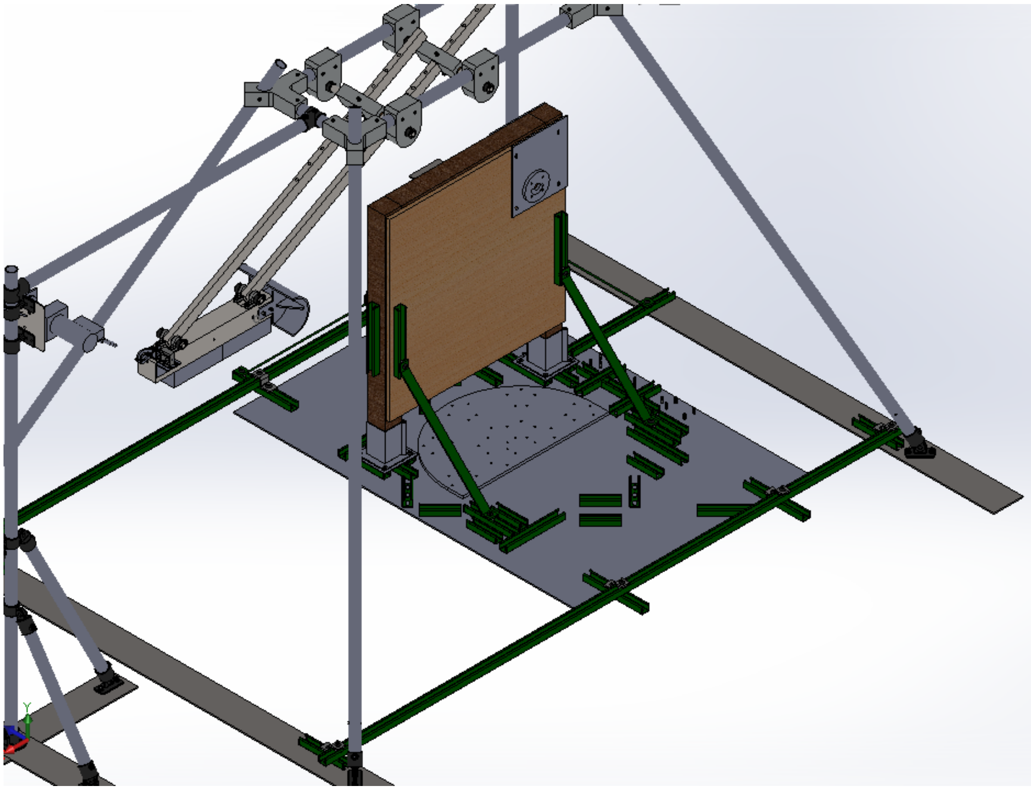

Figure 53: Wall Setup for Parallel Impacts Hitting the Vertical Riser & Regulator First

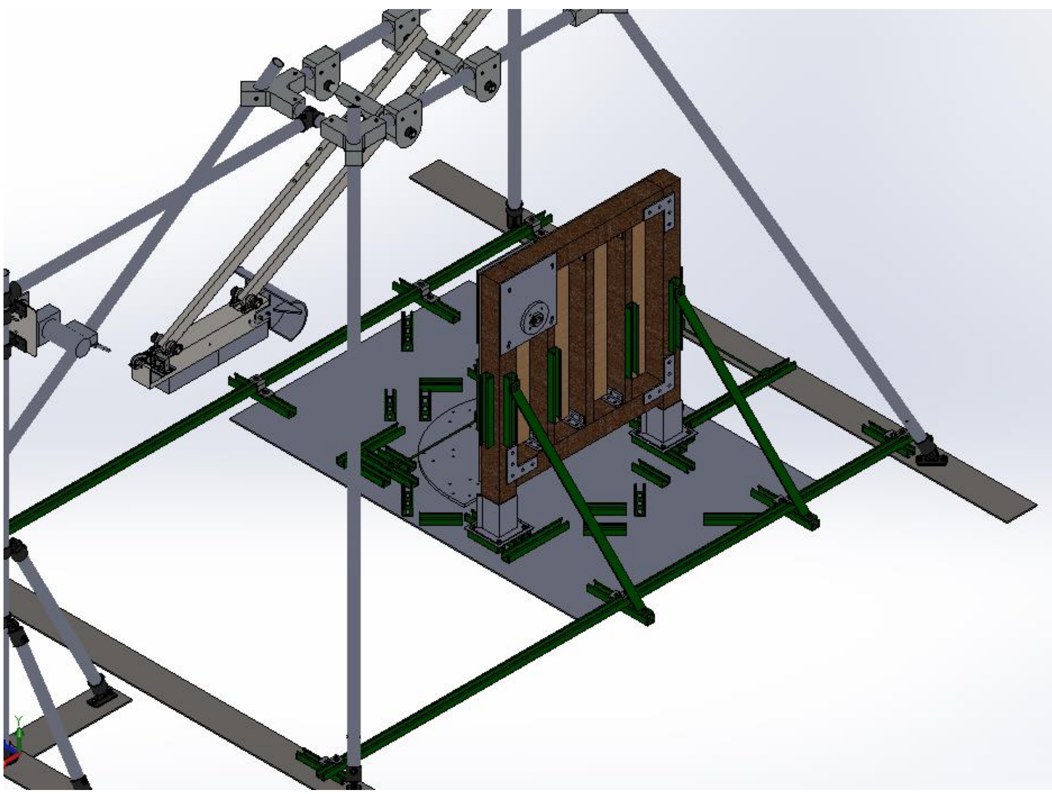

Figure 54: Wall Setup for Parallel Impacts Hitting the House Line & Meter First

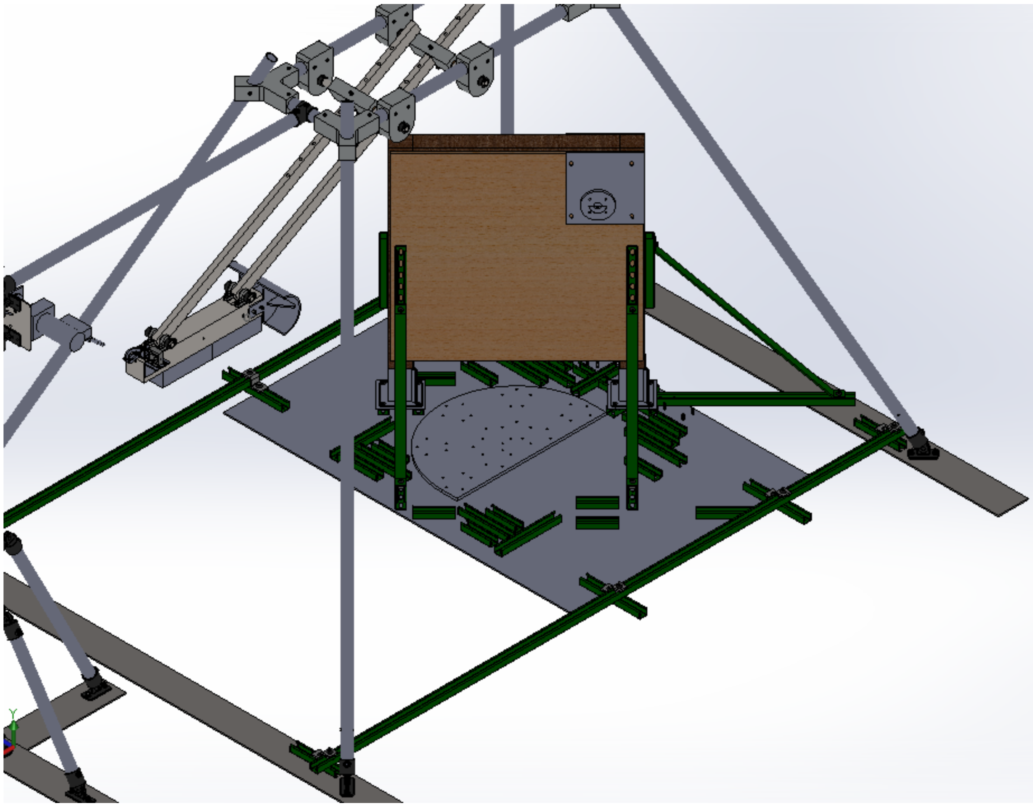

Figure 55: Wall Setup for 45 Degree Impacts Hitting the Vertical Riser & Regulator First

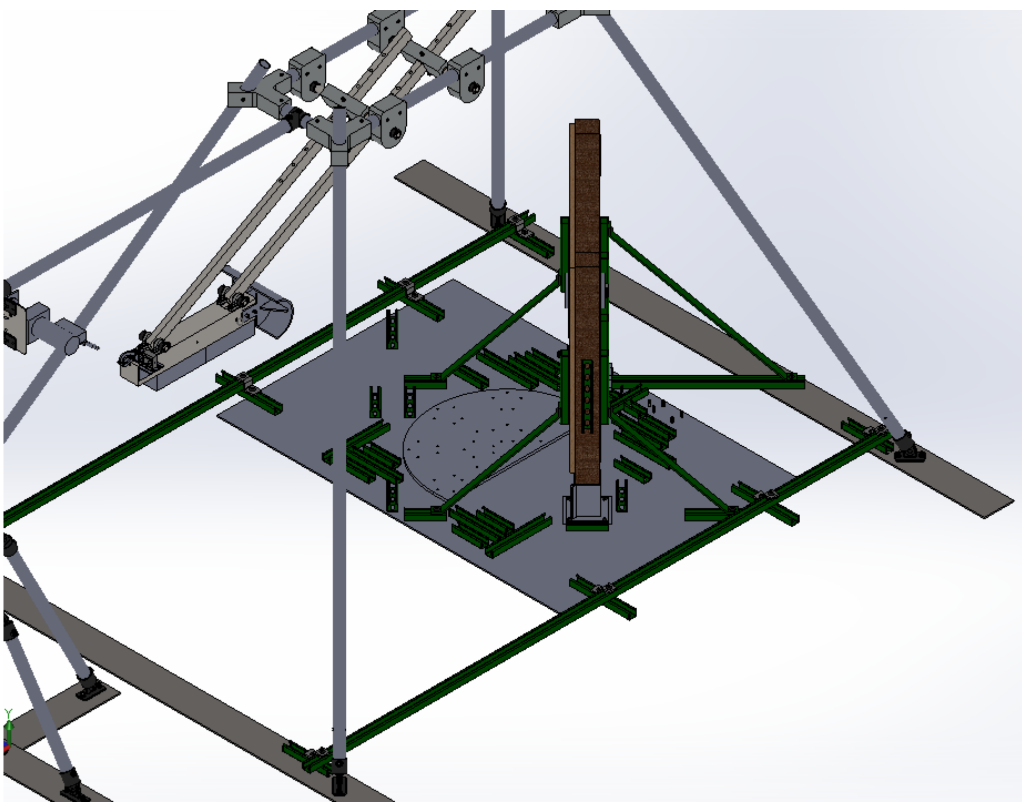

Figure 56: Wall Setup for 45 Degree Impacts Hitting the House Line & Meter First

On the simulated wall there is a hole for the house line to pass through. On the front side there is an open hole that is slightly larger than the house line (shown in Figure 57 **&** Figure 58) and on the back side there is a clamp to fix the house line in place (shown in **Figure 59 & Figure 60**). There are different sized holes to accommodate 3/4” NPT, 1” NPT, and 1-1/4” NPT House Lines which can be screwed in place onto the metal plate when the meter set requires that size house line.

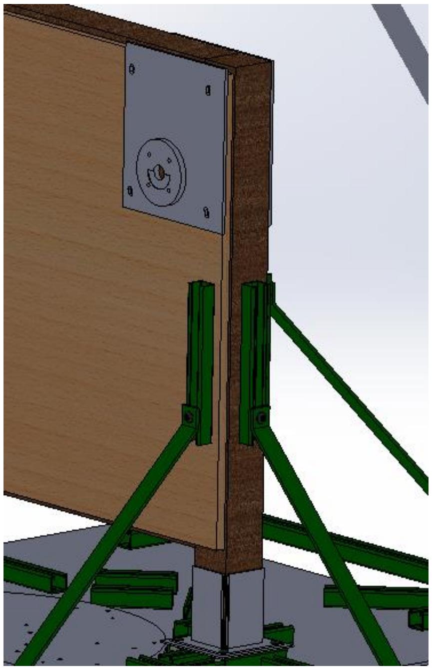

Figure 57: Hole for House Line on Front Side of Simulated Wall (No Meter Set)

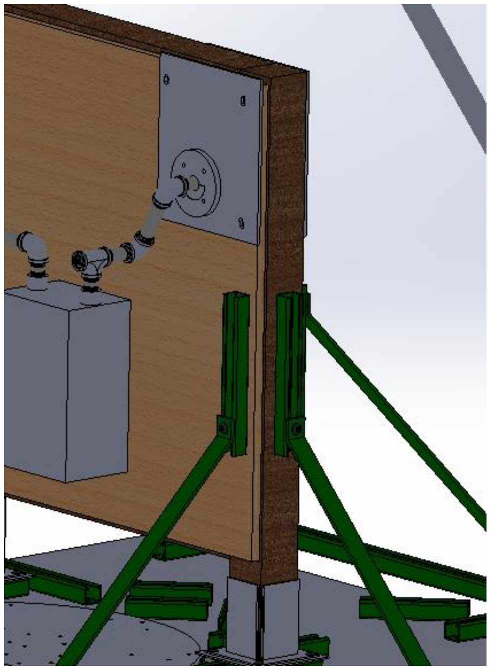

Figure 58: Hole for House Line on Front Side of Simulated Wall (With Meter Set)

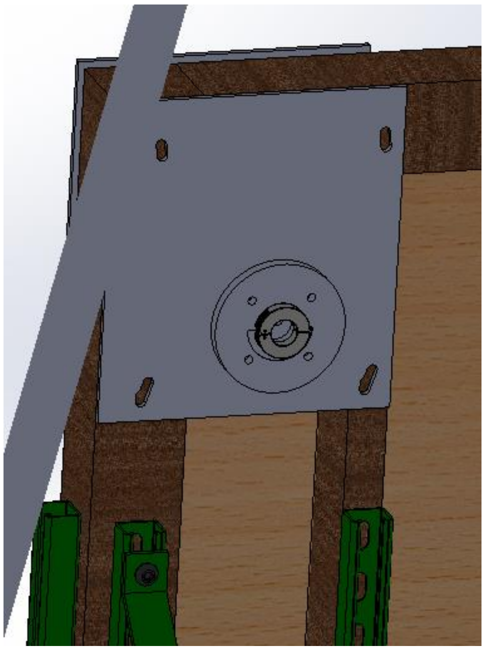

Figure 59: Hole and Clamp for House Line on Back Side of Simulated Wall (No House Line)

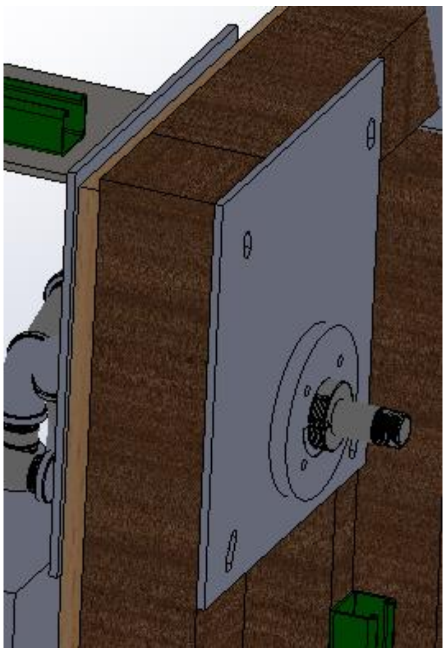

Figure 60: Hole and Clamp for House Line on Back Side of Simulated Wall (With House Line)

In order to utilize the breakaway fitting air had to be fed into the vertical riser, therefore the riser couldn't be fixed straight to the base. In order to fix the vertical riser to the base and simulate ground surrounding the riser a clamp was utilized compressing a polyurethane around the riser to fix it in place (shown in **Figure 61**). The polyurethane consisted of a 6" long cylinder with a slit on one side to be able to slide the riser in and compress when the clamp is closed. The polyurethane could be any durometer in order to simulate different ground densities.

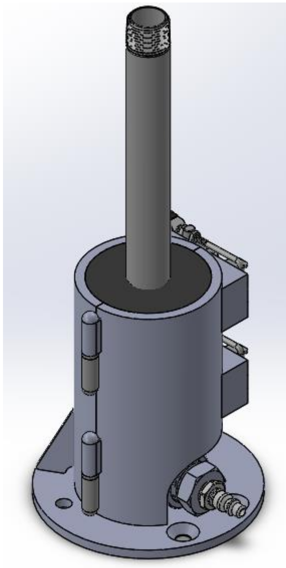

Figure 61: Vertical Riser Clamp and Ground Simulation

In order to be able to have the clamp fixed to the base for all of the different wall orientations a base plate with threaded holes was welded to the unistrut base plate (shown in **Figure 62**).

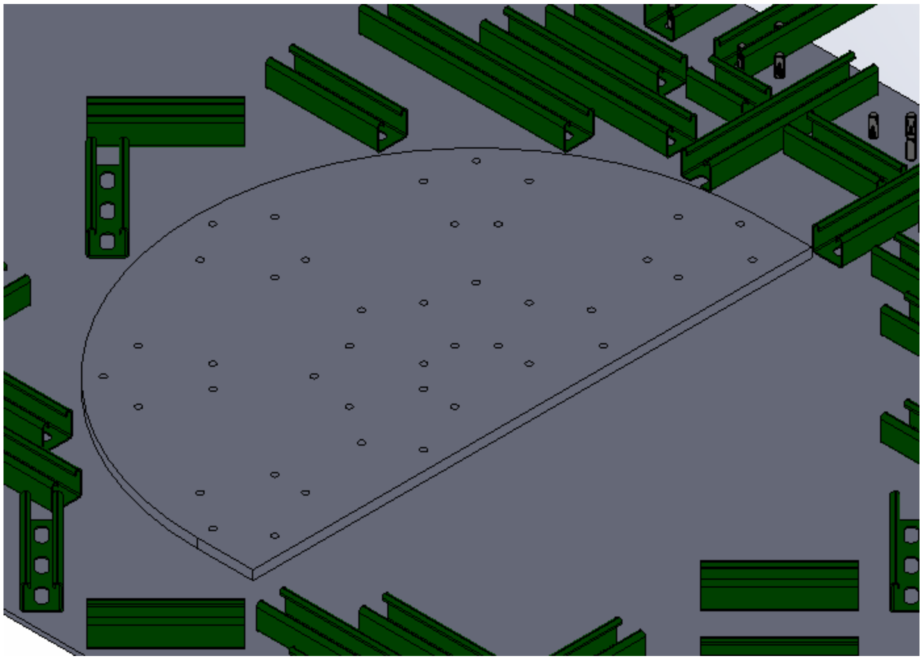

Figure 62: Vertical Riser Clamp Base Plate with Threaded Holes, Welded to Unistrut Base Plate

For each wall orientation the clamp could be screwed in place at 4in from the center of the wall or 12in from the center of the wall. This allowed for meter sets with the regulator on the vertical to be set up at the 4in vertical riser clamp location, whereas meter sets with the regulator on the horizontal could be set up at the 12in vertical riser clamp location since it was wider. Multiple configurations of the vertical riser clamp are shown in **Figure 63** through **Figure 66** on the next pages.

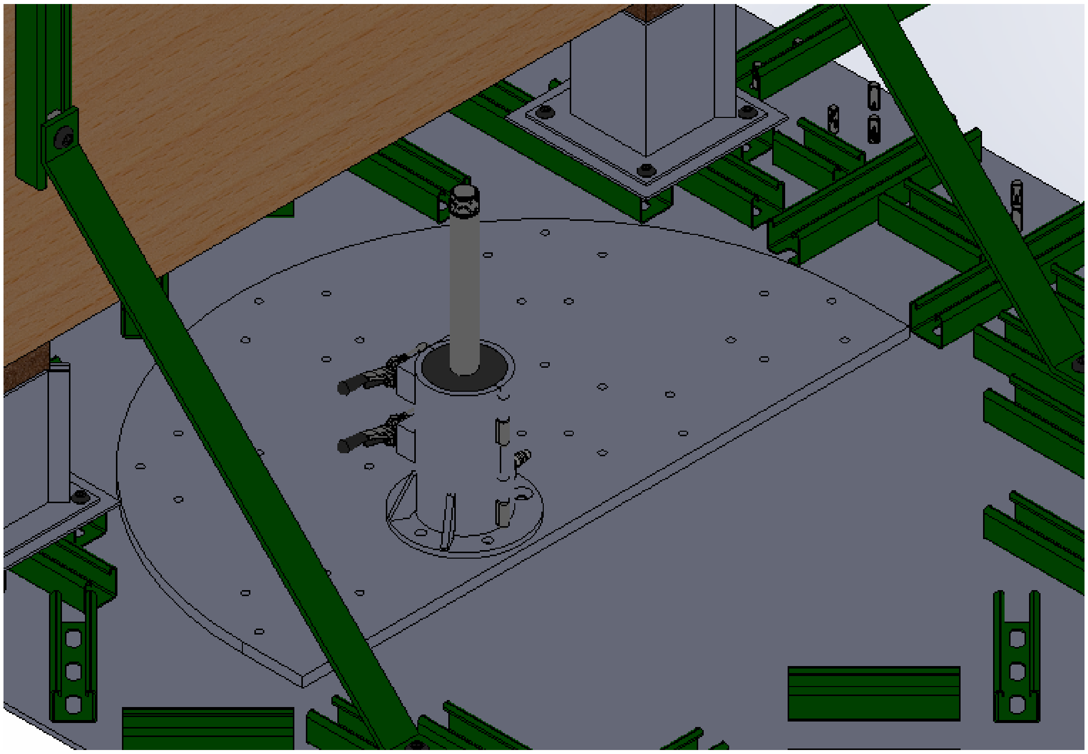

Figure 63: Vertical Riser Clamp on Parallel Impact from the Vertical Riser Side Wall Orientation at 4in Position

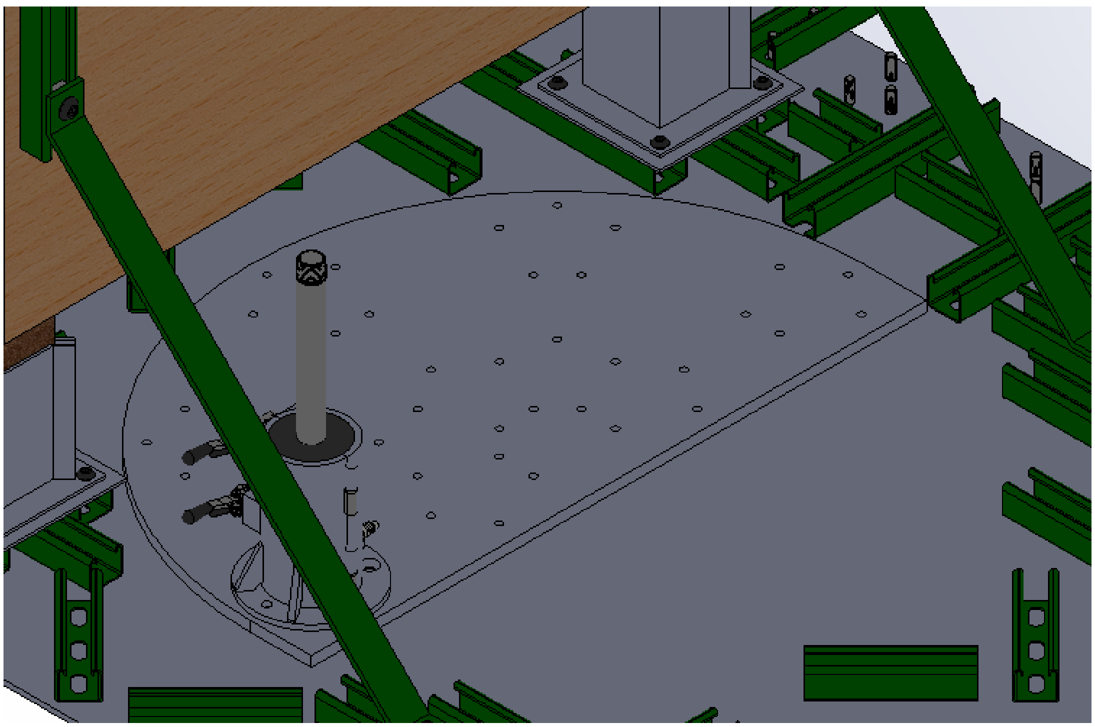

Figure 64: Vertical Riser Clamp on Parallel Impact from the Vertical Riser Side Wall Orientation at 12in Position

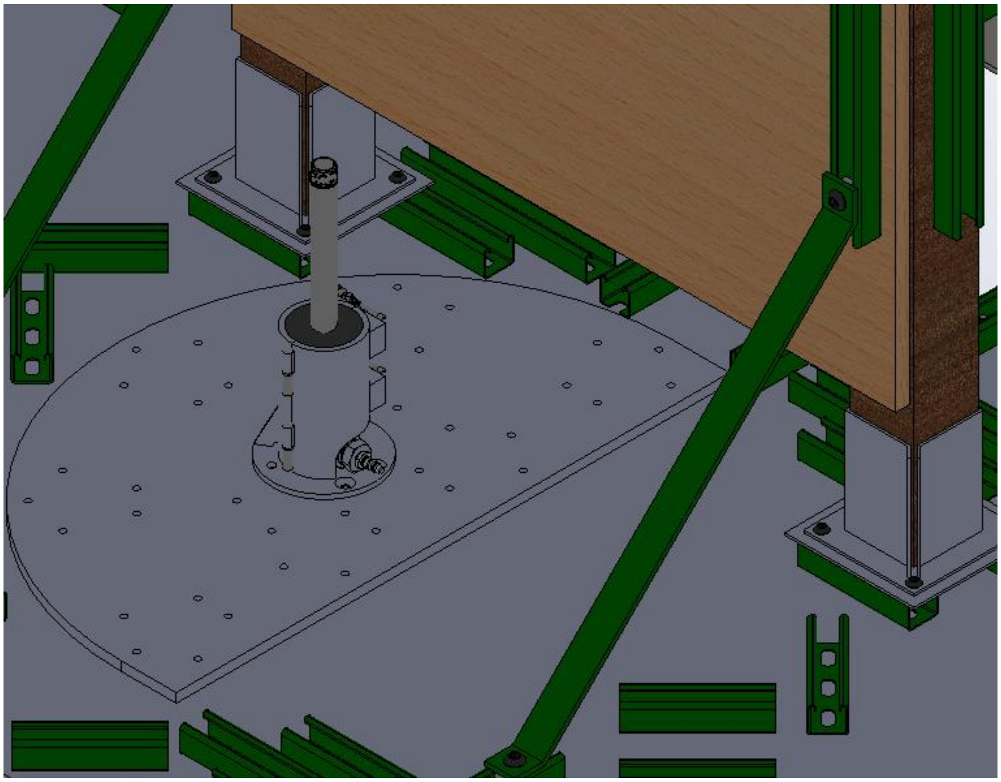

Figure 65: Vertical Riser Clamp on Head On Impact (Perpendicular) Wall Orientation at 4in Position

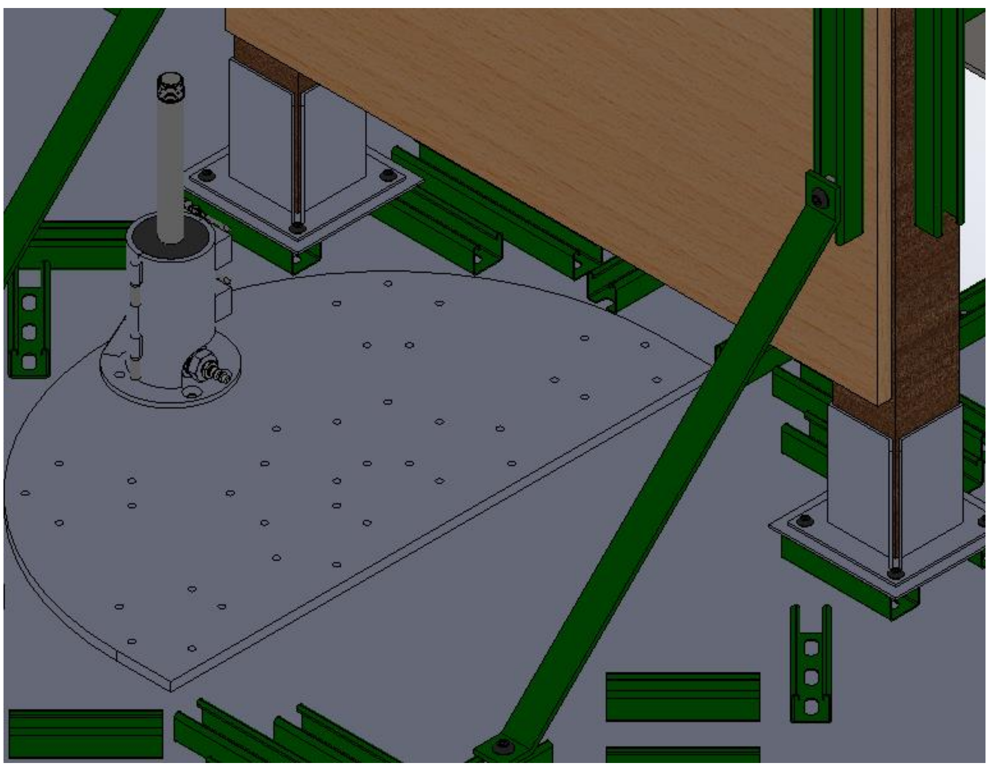

Figure 66: Vertical Riser Clamp on Head On Impact (Perpendicular) Wall Orientation at 12in Position

Appendix C: US CFR: Title 49 – Transportation, Part 581 Bumper Standard

This appendix shows the US Code of Federal Regulations: Title 49 – Transportation, Part 581 Bumper Standard.

(City) __________ (State) ___ (ZIP Code) ________.

PART B. POWER OF ATTORNEY TO REVIEW TITLE DOCUMENTS AND ACKNOWLEDGE DISCLOSURE.

(Part B is invalid unless Part A has been completed.)

I, ____________________ (transferee's name, Print) appoint ____________________ (transferor's name, Print) as my attorney-in-fact, to sign the mileage disclosure, on the title for the vehicle described above, only if the disclosure is exactly as the disclosure completed below.

____
(Transferee's Signature)

____
(Printed Name)

Transferee's Name ____________________

Transferee's Address (Street) ____________________

(City) __________ (State) ___ (ZIP Code) ________.

Federal law (and State Law, if applicable) requires that you state the mileage upon transfer of ownership. Providing a false statement may result in fines and/or imprisonment.

I, ________________ (transferor's name, Print) state that the odometer now reads __________ (no tenths) miles and to the best of my knowledge that it reflects the actual mileage unless one of the following statements is checked.

___ (1) I hereby certify that to the best of my knowledge the odometer reading reflect the mileage in excess of its mechanical limits.

___ (2) I hereby certify that the odometer reading is NOT the actual mileage. WARNING—ODOMETER DISCREPANCY.

____
(Transferor's Signature)

____
(Printed Name)

Transferor's Address (Street) ____________________

(City) __________ (State) ___ (ZIP Code) ________.

Date of Statement ____________

PART C. CERTIFICATION

(To Be Completed When parts A and B Have Been Used)

I, ____________, (person exercising above powers of attorney, Print), hereby certify that the mileage I have disclosed on the title document is consistent with that provided to me in the above power of attorney. Further, upon examination of the title and any reassignment documents for the vehicle described above, the mileage diclosure I have made on the title pursuant to the power of attorney is greater than that previously stated on the title and reassignment documents. This certification is not intended to create, nor does it create any new or additional liability under Federal or State law.

____
(Signature)

____
(Printed Name)

____
Address (Street)

(City) ____________ (State) ___ (ZIP Code) ________

Date ____________

[54 FR 9816, Mar. 8, 1989, as amended at 54 FR 35889, Aug. 30, 1989]

PART 581—BUMPER STANDARD

Sec.

AUTHORITY: 49 U.S.C. 32502; 322, 30111, 30115, 30117 and 30166; delegation of authority at 49 CFR 1.50.

SOURCE: 42 FR 24059, May 12, 1977, unless otherwise noted.

§581.1 Scope.

This standard establishes requirements for the impact resistance of vehicles in low speed front and rear collisions.

§581.2 Purpose.

The purpose of this standard is to reduce physical damage to the front and rear ends of a passenger motor vehicle from low speed collisions.

§581.3 Application.

This standard applies to passenger motor vehicles other than multipurpose passenger vehicles and low-speed vehicles as defined in 49 CFR part 571.3(b).

[63 FR 33217, June 17, 1998]

§581.4 Definitions.

All terms defined in 49 U.S.C. 32101 are used as defined therein.

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Bumper face bar means any component of the bumper system that contacts the impact ridge of the pendulum test device.

[42 FR 24059, May 12, 1977, as amended at 64 FR 2862, Jan. 19, 1999]

§ 581.5 Requirements.

(a) Each vehicle shall meet the damage criteria of §§ 581.5(c)(1) through 581.5(c)(9) when impacted by a pendulum-type test device in accordance with the procedures of § 581.7(b), under the conditions of § 581.6, at an impact speed of 1.5 m.p.h., and when impacted by a pendulum-type test device in accordance with the procedures of § 581.7(a) at 2.5 m.p.h., followed by an impact into a fixed collision barrier that is perpendicular to the line of travel of the vehicle, while traveling longitudinally forward, then longitudinally rearward, under the conditions of § 581.6, at 2.5 m.p.h.

(b) [Reserved]

(c) *Protective criteria.* (1) Each lamp or reflective device except license plate lamps shall be free of cracks and shall comply with applicable visibility requirements of S5.3.1.1 of Standard No. 108 (§ 571.108 of this chapter). The aim of each headlamp installed on the vehicle shall be adjustable to within the beam aim inspection limits specified in Table 1 of SAE Recommended Practice J599 AUG97, measured with the aiming method appropriate for that headlamp.

(2) The vehicle's hood, trunk, and doors shall operate in the normal manner.

(3) The vehicle's fuel and cooling systems shall have no leaks or constricted fluid passages and all sealing devices and caps shall operate in the normal manner.

(4) The vehicle's exhaust system shall have no leaks or constrictions.

(5) The vehicle's propulsion, suspension, steering, and braking systems shall remain in adjustment and shall operate in the normal manner.

(6) A pressure vessel used to absorb impact energy in an exterior protection system by the accumulation of gas pressure or hydraulic pressure shall not suffer loss of gas or fluid accompanied by separation of fragments from the vessel.

(7) The vehicle shall not touch the test device, except on the impact ridge shown in Figures 1 and 2, with a force that exceeds 2000 pounds on the combined surfaces of Planes A and B of the test device.

(8) The exterior surfaces shall have no separations of surface materials, paint, polymeric coatings, or other covering materials from the surface to which they are bonded, and no permanent deviations from their original contours 30 minutes after completion of each pendulum and barrier impact, except where such damage occurs to the bumper face bar and the components and associated fasteners that directly attach the bumper face bar to the chassis frame.

(9) Except as provided in § 581.5(c)(8), there shall be no breakage or release of fasteners or joints.

[42 FR 24059, May 12, 1977, as amended at 42 FR 38909, Aug. 1, 1977; 43 FR 40231, Sept. 11, 1978; 47 FR 21837, May 20, 1982; 64 FR 16360, Apr. 5, 1999; 64 FR 49092, Sept. 10, 1999]

§ 581.6 Conditions.

The vehicle shall meet the requirements of § 581.5 under the following conditions.

(a) *General.* (1) The vehicle is at unloaded vehicle weight.

(2) The front wheels are in the straight ahead position.

(3) Tires are inflated to the vehicle manufacturer's recommended pressure for the specified loading condition.

(4) Brakes are disengaged and the transmission is in neutral.

(5) Trailer hitches, license plate brackets, and headlamp washers are removed from the vehicle. Running lights, fog lamps, and equipment mounted on the bumper face bar are removed from the vehicle if they are optional equipment.

(b) *Pendulum test conditions.* The following conditions apply to the pendulum test procedures of § 581.7 (a) and (b).

(1) The test device consists of a block with one side contoured as specified in Figure 1 and Figure 2 with the impact ridge made of AISI 4130 steel hardened to 34 Rockwell "C." The impact ridge and the surfaces in Planes A and B of the test device are finished with a surface roughness of 32 as specified by

SAE Recommended Practice J449A, June 1963. From the point of release of the device until the onset of rebound, the pendulum suspension system holds Plane A vertical, with the arc described by any point on the impact line lying in a vertical plane (for §581.7(a), longitudinal; for §581.7(b), at an angle of 30° to a vertical longitudinal plane) and having a constant radius of not less than 11 feet.

(2) With Plane A vertical, the impact line shown in Figures 1 and 2 is horizontal at the same height as the test device's center of percussion.

(3) The effective impacting mass of the test device is equal to the mass of the tested vehicle.

(4) When impacted by the test device, the vehicle is at rest on a level rigid concrete surface.

(c) *Barrier test condition*. At the onset of a barrier impact, the vehicle's engine is operating at idling speed in accordance with the manufacturer's specifications. Vehicle systems that are not necessary to the movement of the vehicle are not operating during impact.

(Authority: Sec. 102, Pub. L. 92-513, 86 Stat. 947 (15 U.S.C. 1912); secs. 103, 119, Pub. L. 89-563, 80 Stat. 718 (15 U.S.C. 1392, 1407); delegation of authority at 49 CFR 1.50 and 501.7)

[42 FR 24059, May 12, 1977, as amended at 42 FR 38909, Aug. 1, 1977; 48 FR 43331, Sept. 23, 1983]

§581.7 Test procedures.

(a) *Longitudinal impact test procedures*. (1) Impact the vehicle's front surface and its rear surface two times each with the impact line at any height from 16 to 20 inches, inclusive, in accordance with the following procedure.

(2) For impacts at a height of 20 inches, place the test device shown in Figure 1 so that Plane A is vertical and the impact line is horizontal at the specified height.

(3) For impacts at a height between 20 inches and 16 inches, place the test device shown in Figure 2 so that Plane A is vertical and the impact line is horizontal at a height within the range.

(4) For each impact, position the test device so that the impact line is at least 2 inches apart in vertical direction from its position in any prior impact, unless the midpoint of the impact line with respect to the vehicle is to be more than 12 inches apart laterally from its position in any prior impact.

(5) For each impact, align the vehicle so that it touches, but does not move, the test device, with the vehicle's longitudinal centerline perpendicular to the plane that includes Plane A of the test device and with the test device inboard of the vehicle corner test positions specified in §581.7(b).

(6) Move the test device away from the vehicle, then release it to impact the vehicle.

(7) Perform the impacts at intervals of not less than 30 minutes.

(b) *Corner impact test procedure*. (1) Impact a front corner and a rear corner of the vehicle once each with the impact line at a height of 20 inches and impact the other front corner and the other rear corner once each with the impact line at any height from 16 to 20 inches, inclusive, in accordance with the following procedure.

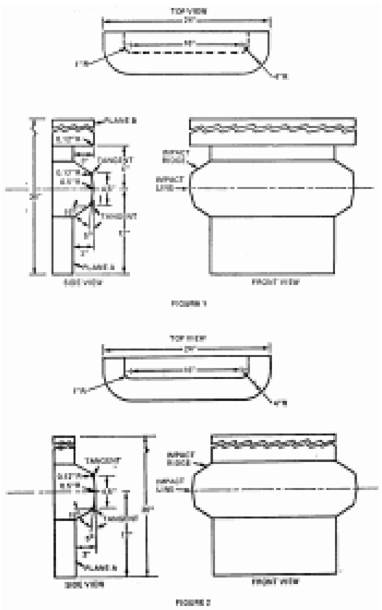
(2) For an impact at a height of 20 inches, place the test device shown in Figure 1 so that Plane A is vertical and the impact line is horizontal at the specified height.

(3) For an impact at a height between 16 inches and 20 inches, place the test device shown in Figure 2 so that Plane A is vertical and the impact line is horizontal at a height within the range.

(4) Align the vehicle so that a vehicle corner touches, but does not move, the lateral center of the test device with Plane A of the test device forming an angle of 60 degrees with a vertical longitudinal plane.

(5) Move the test device away from the vehicle, then release it to impact the vehicle.

(6) Perform the impact at intervals of not less than 30 minutes.



[42 FR 24059, May 12, 1977, as amended at 42 FR 38909, Aug. 1, 1977]

§ 581.8 Exemptions.

A manufacturer of a passenger motor vehicle to which a bumper standard issued under this part applies may apply to the Administrator:

(a) For rulemaking as provided in part 552 of this chapter to exempt a class of passenger motor vehicles from all or any part of a bumper standard issued under this part on the basis that the class of vehicles has been manufactured for a special use and that compliance with the standard would unreasonably interfere with the special use of the class of vehicle; or

(b) To exempt a make or model of passenger motor vehicle on the basis set forth in paragraph (a) of this section or part 555 of this chapter.

(c) An application filed for exemption on the basis of paragraph (a) of this section shall contain the information specified in § 555.5 of this chapter, and set forth data, views, and arguments in support that the vehicle has been manufactured for a special use and that compliance with the bumper standard would interfere unreasonably with the special use of the vehicle.

(d) An application filed for exemption under part 555 of this chapter shall be filed in accordance with the requirements of that part.

(e) The NHTSA shall process exemption applications in accordance with § 555.7 of this chapter. An exemption granted a manufacturer on the basis of paragraph (a) of this section is indefinite in length but expires when the manufacturer ceases production of the exempted vehicle, or when the exempted vehicle as produced has been so modified from its original design that the Administrator decides that it is no longer manufactured for the special use upon which the application for its exemption was based. The Administrator may terminate an exemption in the

Appendix D: Determination of Potential Energy Required for Meter Set Failure

This appendix outlines the results from the initial testing of the rig to determine how much weight was needed and what the release height should be for the various tests.

Estimations Based on Energy Calculations

It was estimated that for this test we would want to simulate a vehicle moving at 5mph and having the impact change its velocity 0.1mph to 4.9mph. In order to figure out how much energy was transferred from this change in velocity, the weight of various sizes of cars were needed. A list of average weights based on standard vehicle sizes was taken from http://cars.lovetoknow.com/List_of_Car_Weights and listed in Table 3 below.

Table 3: Curb Weights of Various Car Types Excluding Passengers and Luggage

Car Type	Weight (lbs)	Weight (kg)
Compact Car	2979	1354
Midsize Car	3497	1590
Large Car	4366	1985
Compact Truck or SUV	3470	1577
Midsize Truck or SUV	4259	1936
Large Truck or SUV	5411	2460

The calculations for the energy lost due to impact is solved by the following equation:

$$\Delta E = KE_o - KE_f = \frac{1}{2}m{v_o}^2 - \frac{1}{2}m{v_f}^2 = \frac{1}{2}m\left({v_o}^2 - {v_f}^2\right)$$

With the assumption that it the initial velocity is 5mph and the final velocity is 4.9mph, the above equation becomes:

$$\Delta E = \frac{1}{2}m((5mph)^2 - (4.9mph)^2) = (0.495mph^2) * mass = \left(\frac{0.099m^2}{s^2}\right) * mass$$

Using the masses from the above table, the loss of energy from a change of velocity from 5mph to 4.9mph due to an impact can be found in **Table 4** below.

Table 4: Loss of Energy of Various Car Types following Change of Velocity from 5mph to 4.9mph

Car Type	Weight (kg)	ΔE (J)
Compact Car	1354	134.046
Midsize Car	1590	157.410

Large Car	1985	196.515
Compact Truck or SUV	1577	156.123
Midsize Truck or SUV	1936	191.664
Large Truck or SUV	2460	243.540

It was decided that we would aim for the energy change of a Large Truck or SUV and therefore decided to aim for 243.540 J to be transferred to the meter from the suspended weight. It was assumed that for the ease of calculations that there was no energy lost in the bushings while the pivot arms were pivoting and that the suspended weight would fully stop once it hits the meter set, therefore the initially potential energy of the suspended weight would equal the energy transferred into the meter set.

In order to calculate the change in potential energy, a diagram was created which is shown below in **Figure 67**. Note: h-ground release and h-ground impact are measured to the top of the suspended weight (body)

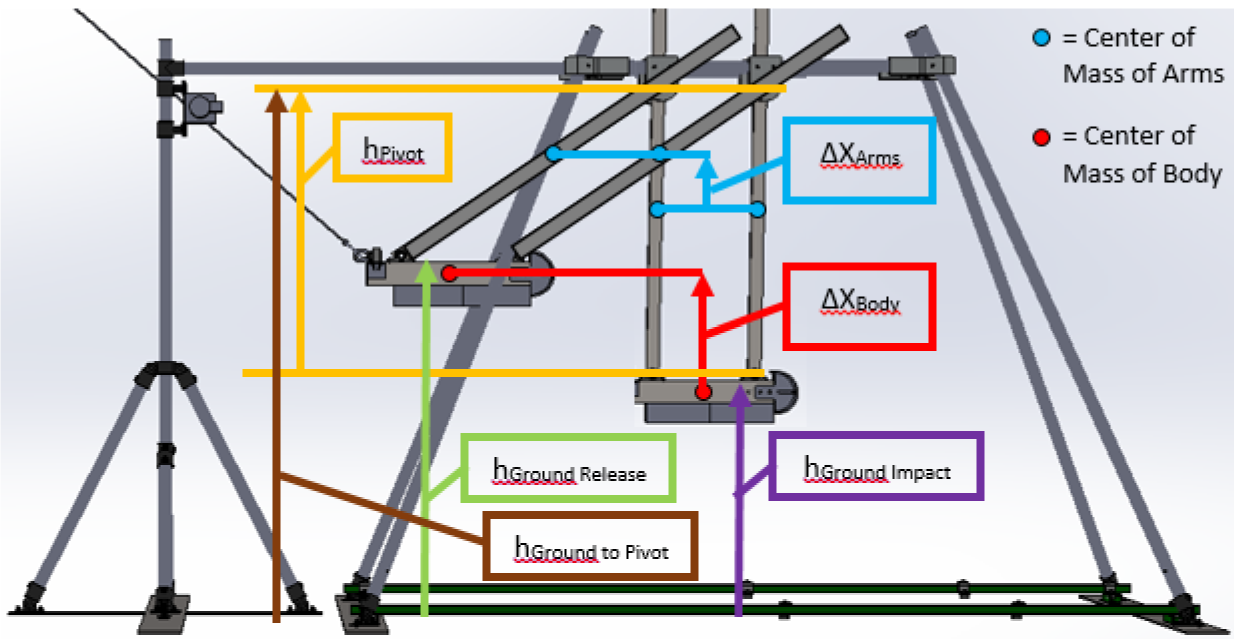


Figure 67: Diagram of Reference Heights for Potential Energy Calculations

In order to achieve a bumper height in between 16in and 20in per US CFR: Title 49 – Transportation, Part 581 Bumper Standard; the pivot arms were secured to the pivot block at the hole 48in from the center of the bushing hole attached to the suspended weight (listed in the above diagram as h-pivot) which places the center of the suspended weight at 19.75in above the "ground level".

Using h-pivot = 48in, h-ground to pivot = 76.8125in and the knowledge that the distance between the pivot point at the bottom of h-pivot and the top of the suspended weight (body) where h-ground impact is measured from is 1.0in, the h-ground impact can be calculated.

$$h_{Ground\ Impact} = h_{Ground\ to\ Pivot} - (h_{Pivot} + 1in) = 76.8125in - (48in + 1in) = 27.8125in$$

Knowing h-ground impact, the change in potential energy can be solved.

$$\Delta E = m_{body} g h_{body_f} - m_{body} g h_{body_o} + m_{arms} g h_{arms_f} - m_{arms} g h_{arms_o}$$

$$\Delta E = m_{body} g (h_{body_f} - h_{body_o}) + m_{arms} g (h_{arms_f} - h_{arms_o})$$

The center of the arms is halfway up the length of the rods from the body, which is therefore 30in above the pivot point. Since the center of the arms pivots about the same axis that the center of the body is on, the displacement of the center of the arms can be calculated by scaling the center of the body. Since the center of the arms is 30in up the 48in height to the pivot, they are 18in away from the pivot point. Therefore, by scale, the displacement of the height of the arms is 18in/48in the displacement of the height of the body, or 3/8.

$$\Delta E = m_{body} g \left(h_{body_f} - h_{body_o}\right) + \frac{m_{arms} g \left(h_{body_f} - h_{body_o}\right)}{2}$$

$$\Delta E = g(m_{body} + \frac{3m_{arms}}{8}) \left(h_{body_f} - h_{body_o}\right)$$

Because the body is composed of the mass of the body as well as the bumper head, the mass must be broken up. And because mass times gravity is weight, we can convert the equation to using the weights of all the objects.

$$\Delta E = (w_{body} + w_{head} + \frac{3w_{arms}}{8}) \left(h_{body_f} - h_{body_o}\right)$$

Because we are measuring the change of the height of the body, as long as we reference the same point on the body we can keep that consistent. So h-body final is h-ground impact and h-body initial is h-ground release. This gets us our base equation for the change in potential energy, labeled as **Eq.1**.

$$\Delta E = (w_{body} + w_{head} + \tfrac{3w_{arms}}{8})(h_{ground\ impact} - h_{ground\ release}) \qquad \textbf{Eq.1}$$

In order to figure out what height to release the suspended mass, the known values for the previous equation must be substituted in.

$$-243.540Nm = \left(86lbs + 13lbs + \frac{3}{8}(16lbs)\right)(27.8125in - h_{ground\ release}) = -2155.511lbs * in$$

$$27.8125in - h_{ground\ release} = \frac{-2155.511lbs * in}{105lbs}$$

$$h_{ground\ release} = 27.8125in + 20.5287in = 48.3412in$$

Trial Runs

The first trial run was attempted on a Nicor Meter Set with the Bumper Height set at 19.75" above Ground Level. The Ram Release Height (shown on the following page in **Figure 68 & Figure 69**) was measured to be 48", corresponding to the estimated energy transfer calculated in the previous section. The impact from the suspended weight was unable to break the meter set.

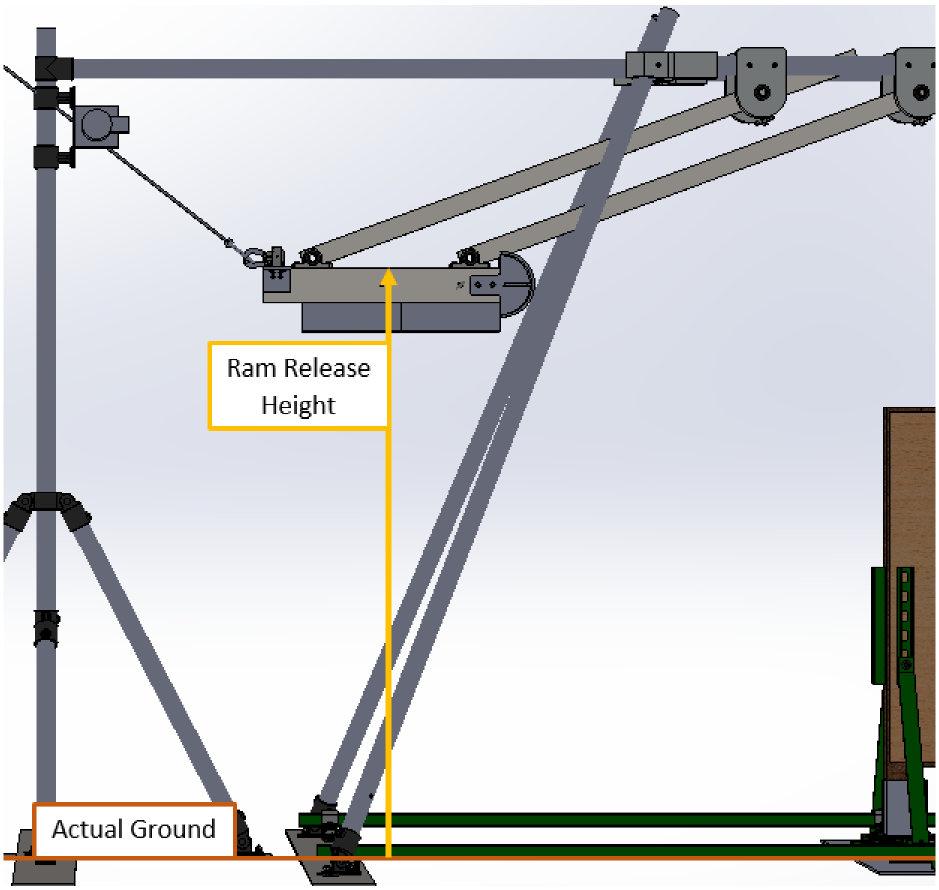


Figure 68: 2D Diagram of Measured Ram Release Height

Figure 69: Tester Taking Measurement of Ram Release Height

For the second trial run, an additional weight (26.84lbs) was secured to the suspended weight which at the 48" Ram Release Height increased the Potential Energy from 2155.511 in*lbs (243.54 J) to 2661.520 in*lbs (300.71 J) (calculated from **Eq.1**). The impact of the increased weight from the 48" Ram Release Height was also unable to break the meter set.

For the third trial run, a second additional weight (29.12lbs) was secured to the suspended weight as well to make the total suspended weight 141.96lbs. Additionally, it was noted that it appeared that the bumper was hitting too low on the meter set, therefore the bumper height was raised 3in to 22.75". This raised the h-ground impact from 27.8125in to 30.8125in. In order to guarantee a break, the Ram Release Height was raised to the maximum value of 58.75". These combined factors increased the Potential Energy from 2661.520 in*lbs (300.71 J) to 4496.82 in*lbs (508.07 J). The impact from the suspended weight with the increased potential energy was successful at breaking the meter set.

For the fourth trial run, the third trial run was desired to be replicated in order to prove success with these conditions. Therefore the 141.96lb suspended weight was released from a Ram Release Height of 58" impacting the Meter Set at a Bumper Height of 22.75" for a potential energy of 4376.1 in*lbs (494.43 J). However, the impact from this test was unable to break the meter set. Instead the impact caused the unistrut base to come off of the floor and the entire Impact Test Rig Frame shifted. Therefore it became evident that we needed to secure the unistrut base to the floor to prevent the energy from shifting the Impact Test Rig instead of transferring completely to the meter set.

For the fifth trial run, fifteen 70-lb sandbags were placed on the Impact Test Rig to prevent it from moving. 10 of the sandbags were placed directly on the unistrut base and the other 5 were placed on the base plates of the Test Rig Frame. The 141.96lb suspended weight was released from a Ram Release Height of 56" impacting the Meter Set at a Bumper Height of 22.75" for a potential energy of 4054.18 in*lbs (458.06 J). Once again the impact from this test was unable to break the meter set.

However, this time the Test Rig Frame did not move but the unistrut base still jolted more than desired. Therefore, more sandbags had to be added.

For the sixth trial run, ten additional 70-lb sandbags were placed on the unistrut base in an attempt to prevent the unistrut base from moving during impact. The 141.96lb suspended weight was released from a Ram Release Height of 54" impacting the Meter Set at a Bumper Height of 22.75" for a potential energy of 3732.26 in*lbs (421.69 J). Once again the impact from this test was unable to break the meter set. However, this time the unistrut base did not move and the pre-fab elbow and riser suffered significant damage during the impact due to bending. Therefore, it was evident that the test was close to the ideal potential energy for creating a break due to impact.

For the seventh trial run, the Ram Release Height was increased to 54.5" resulting in the 141.96lb suspended weight impacting the meter set at a bumper height of 22.75" with a potential energy of 3812.74 in*lbs (430.78 J). The impact from this test did not cause a full break, but there was a leak that was caused at the threads from the outlet of the pre-fab elbow into the regulator. In order to get better results we determined that for the actual tests we would aim to have the potential energy in the suspended weight be between 445 J and 450 J (3938.58 in*lbs and 3982.84 in*lbs respectively).

In order to quantify this energy released from the impact by the suspended weight hitting the meter set, **Table 5** (below) outlines the change in velocity for each car size from a starting velocity of 5mph.

Table 5: Change in Velocity for Various Car Sizes Due to Loss of Energy of 445 J

Car Type	Weight (kg)	Δv (mph)
Compact Car	1354	0.340
Midsize Car	1590	0.288
Large Car	1985	0.230
Compact Truck or SUV	1577	0.291
Midsize Truck or SUV	1936	0.236
Large Truck or SUV	2460	0.184

Appendix E: Company Meter Sets

This appendix shows each of the meter sets sent to us by the meter companies.

The configurations for each meter set are listed in Table 6 below. The pre-fabricated components sent to us for each configuration can be seen in Figure 70 through **Figure 82** shown after the table.

Table 6: Meter Set Configurations

Company	Meter Size	Pre-Fab	Connector Bar?	House Line Size	Regulator Direction
Utility 1	20 Lite	Hook	No	1in	Left of Riser (Away from Meter)
Utility 2	20 Lite	Elbow	No	1in	Above Riser (Facing away from Meter)
Utility 3	20 Lite	Hook	Yes	1in	Behind Riser (Towards Wall)
Utility 4	10 Lite	Hook	Yes	3/4in	Behind Riser (Towards Wall)
Utility 5	1A Sprague	Short Hook	No	3/4in	Left of Riser (Away from Meter)
Utility 6	20 Lite	Pre-Fab Elbow	Yes	1in	Left of Riser (Away from Meter)
Utility 6	30 Lite	Elbow	Yes	1/4in	Left of Riser (Away from Meter)
Utility 7	30 Lite	Hook	Yes & No	1in	Left of Riser (Away from Meter)
Utility 8	1A Sprague	Elbow	No	3/4in	Not Listed
Utility 9	10 Lite	Hook & Elbow	Yes	1in	In Front of Riser (Away from Wall)

Figure 70: Utility 1 Meter Set

Figure 71: Utility 2 Meter Set

Figure 72: Utility 3 Meter Set

Figure 73: Utility 4 Meter Set

Figure 74: Utility 5 Meter Set

Figure 75: Utility 6 Meter Set Components

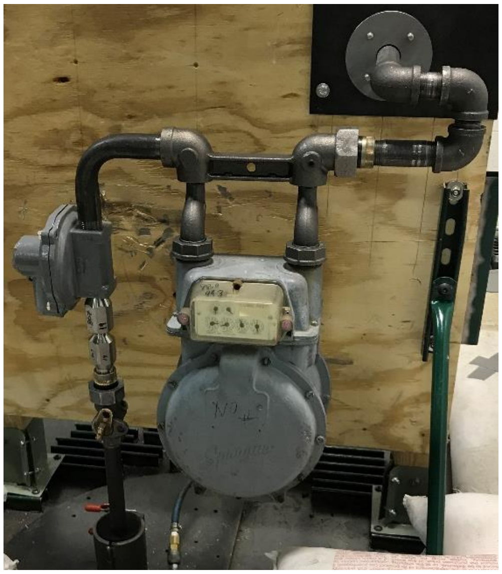


Figure 76: Utility 6 20 Lite Meter Set with Breakaway and Meter

Figure 77: Utility 6 30 Lite Meter Set with Breakaway and Meter

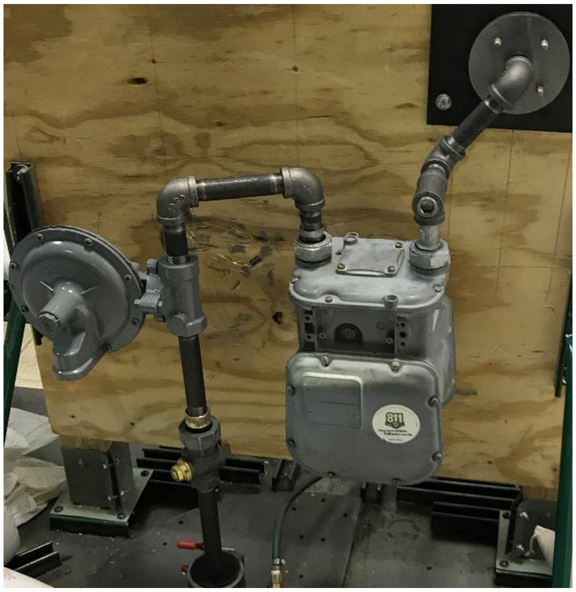


Figure 78: Utility 8 Meter Set

Figure 79: Utility 7 Meter Set #1 (Connector Bar)

Figure 80: Utility 7 Meter Set #2 (No Connector Bar)

Figure 81: Utility 9 Meter Set #1 (Hook Pre-Fab)

Figure 82: Utility 9 Meter Set #2 (Elbow Connections)

Appendix F: All Impact Testing Results

This appendix lists all of the results from the Impact Testing done for this project.

Table 7: Impact Testing Results

Test Name	Ram Orientation	Ram Potential Energy [J]	Breakaway Used?	Breakaway Successful?	Gas Leak?	If so, where?	Riser Bend?	Pre-Fab Elbow Bend?	Wall Line Bend?	Meter Break?
Utility 1	Parallel (Hit Regulator First)	444.9	No	N/A	Yes	Threads into Street Valve & Entry into Meter	Slight	None	Insignificant	Yes
Utility 1	Parallel (Hit Regulator First)	444.9	Yes	Yes	No	N/A	Slight	None	Slight	No
Utility 1	Parallel (Hit Meter First)	444.9	No	N/A	Yes	Threads Into Street Valve & Meter Inlet	None	None	Extreme	Yes
Utility 1	Parallel (Hit Meter First)	444.9	Yes	Yes	No	Meter Inlet & Meter Outlet	None	None	Slight	Yes
Utility 1	Perpendicular (Head-On)	449.8	No	N/A	Yes	Threads into Regulator	Slight	Thread Break	None	Yes
Utility 1	Perpendicular (Head-On)	447.5	Yes	Yes	No	N/A	Significant	Slight	None	Yes
Utility 2	Parallel (Hit Vertical First)	447.2	No	N/A	Yes	Threads into Street Valve & Meter Inlet & Meter Outlet	Extreme	Insignificant	None	Yes
Utility 2	Parallel (Hit Vertical First)	449.4	Yes	No	Yes	Threads into Street Valve & Meter Outlet	Significant	Slight	None	Yes
Utility 2	Parallel (Hit Vertical First)	447.2	Yes	No	Yes	Threads into Street Valve & Meter Outlet	Extreme	Slight	None	Yes
Utility 2	Parallel (Hit Meter First)	449.4	No	N/A	Yes	Threads into Street Valve & Meter Outlet	Insignificant	None	None	Yes
Utility 2	Parallel (Hit Meter First)	449.4	Yes	Yes	No	Meter Outlet	Slight	None	None	Yes

Test Name	Ram Orientation	Ram Potential Energy [J]	Breakaway Used?	Breakaway Successful?	Gas Leak?	If so, where?	Riser Bend?	Pre-Fab Elbow Bend?	Wall Line Bend?	Meter Break?
Utility 2	Perpendicular (Head-On)	445.1	No	N/A	Yes	Threads into Street Valve	Insignificant	None	Thread Break	No
Utility 2	Perpendicular (Head-On)	447.5	Yes	No	Yes	Threads into Street Valve & Threads at Elbow into House	Significant	Slight	Thread Break	No
Utility 3	Parallel (Hit Regulator First)	444.9	No	N/A	Yes	Threads into Street Valve & Threads at Elbow into House	Significant	None	None	No
Utility 3	Parallel (Hit Regulator First)	444.9	Yes	Somewhat	Yes	Threads into Street Valve	Slight	None	Thread Bend	No
Utility 3	Parallel (Hit Regulator First)	447.2	Yes	Yes	No	N/A	Significant	None	None	No
Utility 3	Parallel (Hit Regulator First)	447.2	Yes	Yes	No	Threads at Elbow into House	Extreme	None	Thread Bend	No
Utility 3	Parallel (Hit Meter First)	444.9	No	N/A	Yes	Threads at Elbow into House	None	Slight	Insignificant	No
Utility 3	Parallel (Hit Meter First)	444.9	Yes	No	Yes	Threads at Elbow into House	Slight	Slight	Insignificant	No
Utility 3	Parallel (Hit Meter First)	483.4	Yes	Yes	No	Threads at Elbow into House	Significant	None	Insignificant	No
Utility 3	Perpendicular (Head-On)	447.5	Yes	Somewhat	Yes	Partial Crack in Breakaway (Didn't Seal at Breakaway)	Slight	None	None	Yes
Utility 4	Parallel (Hit Regulator First)	447.2	Yes	No	Yes	Threads into Street Valve & Regulator Outlet	None	None	None	No
Utility 4	Parallel (Hit Regulator First)	447.2	Yes	No	Yes	Threads into Street Valve & Regulator Outlet	None	None	None	No
Utility 4	Parallel (Hit Meter First)	447.2	Yes	Yes	No	N/A	Significant	Extreme	Thread Bend	No
Utility 4	Perpendicular (Head-On)	447.5	Yes	Yes	No	N/A	Significant	None	Thread Bend	No

Test Name	Ram Orientation	Ram Potential Energy [J]	Breakaway Used?	Breakaway Successful?	Gas Leak?	If so, where?	Riser Bend?	Pre-Fab Elbow Bend?	Wall Line Bend?	Meter Break?
Utility 5	Parallel (Hit Regulator First)	449.4	No	N/A	Yes	Threads into Street Valve & Regulator Inlet	None	None	Significant	No
Utility 5	Parallel (Hit Regulator First)	449.4	Yes	Somewhat	Yes	Threads into Street Valve	None	None	Thread Bend	No
Utility 5	Parallel (Hit Meter First)	447.2	No	N/A	No	N/A	Slight	Insignificant	Extreme	No
Utility 5	Parallel (Hit Meter First)	447.2	Yes	No	Yes	Threads into Street Valve & Meter Outlet & Threads out of 1st Elbow After Meter	Extreme	Insignificant	Significant	Yes
Utility 5	Perpendicular (Head-On)	447.5	No	N/A	Yes	Threads into Street Valve & Out of Elbow going into House Line	None	None	Thread Break	No
Utility 5	Perpendicular (Head-On)	447.5	Yes	No	Yes	Threads into Street Valve & Out of Elbow going into House Line	None	None	Thread Break	No
Utility 6	Parallel (Hit Regulator First)	449.4	Yes	Yes	No	N/A	Slight	None	None	No
Utility 6	Parallel (Hit Regulator First)	449.4	Yes	Yes	No	Threads into 1st Elbow After Meter	Extreme	None	Thread Break	No
Utility 6	Parallel (Hit Meter First)	449.4	Yes	No	No	N/A	Significant	None	Extreme	No
Utility 6	Perpendicular (Head-On)	449.8	Yes	No	Yes	Threads into Street Valve & Partial Crack in Breakaway	Insignificant	None	None	No
Utility 6	Parallel (Hit Regulator First)	449.4	Yes	Yes	No	N/A	Slight	None	None	No
Utility 6	Parallel (Hit Regulator First)	449.4	Yes	No	Yes	Partial crack in Breakaway	Significant	None	None	No
Utility 6	Parallel (Hit Meter First)	449.4	Yes	No	Yes	Partial crack (hairline) in Breakaway	Slight	None	Insignificant	No

Test Name	Ram Orientation	Ram Potential Energy [J]	Breakaway Used?	Breakaway Successful?	Gas Leak?	If so, where?	Riser Bend?	Pre-Fab Elbow Bend?	Wall Line Bend?	Meter Break?
Utility 6	Perpendicular (Head-On)	449.8	Yes	Yes	No	N/A	Slight	None	None	No
Utility 7	Parallel (Hit Regulator First)	449.4	No	N/A	Yes	Threads into Regulator	Extreme	Insignificant	None	No
Utility 7	Parallel (Hit Regulator First)	449.4	Yes	Yes	No	N/A	Extreme	None	None	No
Utility 7	Parallel (Hit Meter First)	449.4	No	N/A	Yes	Threads into Street Valve & Regulator & House Line	Insignificant	Insignificant	Thread Break	No
Utility 7	Parallel (Hit Meter First)	449.4	Yes	No	Yes	Partial crack in breakaway	Significant	Insignificant	Significant	No
Utility 7	Parallel (Hit Meter First)	444.9	Yes	Yes	No	Meter Outlet	Extreme	None	None	Yes
Utility 7	Perpendicular (Head-On)	447.5	No	N/A	Yes	Meter Inlet	Slight	None	None	Yes
Utility 7	Perpendicular (Head-On)	449.8	Yes	Yes	No	Meter Inlet	Slight	None	None	Yes
Utility 8	Parallel (Hit Regulator First)	447.2	No	N/A	Yes	Threads into Street Valve	None	Slight	None	No
Utility 8	Parallel (Hit Regulator First)	447.2	Yes	Yes	No	N/A	Extreme	None	None	No
Utility 8 (Regulator Towards Wall)	Parallel (Hit Regulator First)	447.2	Yes	No	Yes	Threads into Street Valve & Threads into 1st Elbow After Regulator	Significant	Elbow Thread Broken	None	No
Utility 8	Parallel (Hit Meter First)	447.2	No	N/A	Yes	Threads into Street Valve & Threads out of 1st Elbow After Meter	Insignificant	Slight	Significant	No
Utility 8	Parallel (Hit Meter First)	447.2	Yes	No	Yes	Threads out of 1st Elbow After Meter	Insignificant	Insignificant	Slight	No

Test Name	Ram Orientation	Ram Potential Energy [J]	Breakaway Used?	Breakaway Successful?	Gas Leak?	If so, where?	Riser Bend?	Pre-Fab Elbow Bend?	Wall Line Bend?	Meter Break?
Utility 8	Perpendicular (Head-On)	447.5	No	N/A	Yes	Threads into Street Valve	Insignificant	None	Thread Bend	No
Utility 8	Perpendicular (Head-On)	447.5	Yes	No	Yes	Threads into Street Valve	None	None	Thread Bend	No
Utility 8 (Regulator Towards Wall)	Perpendicular (Head-On)	447.5	Yes	No	No	N/A	Slight	None	Thread Bend	No
Utility 8	Perpendicular (Head-On)	447.5	Yes	Yes	No	N/A	None	None	Thread Bend	No
Utility 8	Parallel (Hit Meter First)	449.4	Yes	Yes	No	Threads into House Line	None	None	Thread Break	No
Utility 8 (Regulator Towards Wall)	Parallel (Hit Regulator First)	449.4	Yes	No	Yes	Threads into Street Valve & Threads Out of Regulator	Significant	None	Slight	No
Utility 8 (Regulator Towards Wall & Sch 80 Riser)	Parallel (Hit Regulator First)	449.4	Yes	Yes	No	Threads Out of Regulator	Insignificant	None	Slight	No
Utility 8	Parallel (Hit Regulator First)	449.4	Yes	No	Yes	Threads into Street Valve & Meter Inlet Connection	None	None	Thread Bend	No
Utility 8	Parallel (Hit Regulator First)	449.4	Yes	Yes	No	N/A	Slight	None	None	No
Utility 8	Parallel (Hit Regulator First)	449.4	Yes	No	Yes	Threads into Street Valve & Meter Inlet Connection	None	None	None	No
Utility 9	Parallel (Hit Regulator First)	447.2	Yes	Somewhat	Yes	Threads into Street Valve & Threads at Elbow into House	Significant	None	Thread Break	No
Utility 9	Parallel (Hit Regulator First)	438.1	Yes	Somewhat	Yes	Threads into Street Valve & Threads at Elbow into House	Significant	None	Thread Break	No

Test Name	Ram Orientation	Ram Potential Energy [J]	Breakaway Used?	Breakaway Successful?	Gas Leak?	If so, where?	Riser Bend?	Pre-Fab Elbow Bend?	Wall Line Bend?	Meter Break?
Utility 9	Parallel (Hit Regulator First)	447.2	Yes	No	Yes	Threads into Street Valve	Significant	Elbow Twist	None	No
Utility 9	Parallel (Hit Meter First)	447.2	Yes	Yes	No	Threads at Elbow into House	Significant	None	Thread Break	No
Utility 9	Parallel (Hit Meter First)	449.4	Yes	Yes	No	Threads at Elbow into House	Insignificant	None	Thread Break & Significant Bend	No
Utility 9	Perpindicular (Head-On)	449.8	Yes	No	Yes	Failure in physical union below breakaway (not in threads)	Significant	Significant	None	No
Utility 9	Perpindicular (Head-On)	447.5	Yes	No	Yes	Threads into Street Valve	Significant	Elbow Twist	None	No

Explanations for the unclear answers are as follows:

- Utility 1: Gas Leak would have occurred due to failure in meter set, but Breakaway Fitting was successful
- Utility 2: Breakaway Fitting remained intact. Entire vertical broke at threads into Street Valve, causing gas leak.
- Utility 2: Same issue as Utility 2, however riser bent further but Breakaway Fitting still intact
- Utility 2: Gas Leak would have occurred due to failure in meter set, but Breakaway Fitting was successful
- Utility 2: Same issue as Utility 2 and Utility 2 (intact Breakaway Fitting)
- Utility 3: Breakaway Fitting broke as expected, but threads from riser going into street valve broke, causing a gas leak before the Breakaway Fitting
- Utility 3: Gas Leak would have occurred due to failure in meter set, but Breakaway Fitting was successful
- Utility 3: Breakaway Fitting did not break
- Utility 3: Gas Leak would have occurred due to failure in meter set, but Breakaway Fitting was successful
- Utility 3: Breakaway Fitting only partially broke, but not enough to cause the seal to engage, causing a leak at the Breakaway Fitting
- Utility 4: Breakaway Fitting remained intact. The threads into the Street Valve broke, causing a gas leak. Secondary break occurred in the threads coming out of the Regulator.
- Utility 4: Same issue as Utility 4.
- Utility 5: Breakaway Fitting broke in half, however the threads into the Street Valve broke, causing a gas leak below the severed Breakaway Fitting.
- Utility 5: Breakaway Fitting remained intact. The threads into the Street Valve broke, causing a gas leak. Secondary break occurred at the outlet of the Meter as well as the threads out of the 1st Elbow after the Meter.
- Utility 5: Breakaway Fitting remained intact. The threads into the Street Valve broke, causing a gas leak. Secondary break occurred at the outlet of the Meter.
- Utility 6: Gas Leak would have occurred due to failure in threads at elbows after meter set, but Breakaway Fitting was successful
- Utility 6: Breakaway Fitting remained intact. There was no other part of the piping that broke, so there was no gas leak.
- Utility 6:There was a slight crack in the Breakaway Fitting where a leak occurred. However, the threads into the Street Valve also broke, causing a larger leak there.

- Utility 6: There was a crack in the Breakaway Fitting where a leak occurred. However, the crack wasn't large enough for the pin in the Breakaway Fitting to disengage with the spring, so the valve was never engaged.
- Utility 6: There was a hairline crack in the Breakaway Fitting where a leak occurred.
- Utility 7: Breakaway Fitting had slight crack, not a full breakaway. Once disassembled, could see that the pin was not holding down the spring, so the Breakaway Fitting should have worked. However, there was still gas leaking at the Breakaway Fitting.
- Utility 7: Gas Leak would have occurred due to failure in meter set, but Breakaway Fitting was successful
- Utility 7: Gas Leak would have occurred due to failure in meter set, but Breakaway Fitting was successful
- Utility 8: Breakaway Fitting remained intact. The threads into the Street Valve broke, causing a gas leak. Secondary break occurred at the threads into the 1st Elbow after the Regulator.
- Utility 8: Breakaway Fitting remained intact. The threads coming out of the 1st Elbow after the Meter broke, causing a gas leak.
- Utility 8: Breakaway Fitting remained intact. The threads into the Street Valve broke, causing a gas leak.
- Utility 8: Breakaway Fitting remained intact. There was no other part of the piping that broke, so there was no gas leak.
- Utility 8: Breakaway Fitting remained intact. The threads into the Street Valve broke, causing a gas leak. Secondary break occurred at the threads into the 1st Elbow after the Regulator.
- Utility 8: Breakaway Fitting remained intact. The threads into the Street Valve broke, causing a gas leak. Secondary break occurred at the connection at the Inlet of the Meter.
- Utility 8: Breakaway Fitting remained intact. The threads into the Street Valve broke, causing a gas leak. Secondary break occurred at the connection at the Inlet of the Meter.
- Utility 9: Breakaway Fitting broke in half, however the threads into the Street Valve broke, causing a gas leak below the severed Breakaway Fitting.
- Utility 9: Same issue as Utility 9.
- Utility 9: Breakaway Fitting remained intact. The threads into the Street Valve broke, causing a gas leak.
- Utility 9: Gas Leak would have occurred due to failure in threads at elbows after meter set, but Breakaway Fitting was successful
- Utility 9: Same result as Utility 9.
- Utility 9: Breakaway Fitting remained intact. Leak occurred in the body of the union at the top of the Street Valve.

- Utility 9: Same issue as Utility 9.

Appendix G: Impact Testing Analysis Tables

This appendix provides the analysis of the results of the impact testing.

Table 8: Breakaway Success Rate Based on Impact Direction

Impact Direction	Total Tests	Breakaway Successful	Street Valve Failure	Other Failure	Breakaway Success Rate (%)	Street Valve Failure Rate (%)	Other Failure Rate (%)
Parallel (Hit Regulator First)	24	10	13	1	42%	54%	4%
Parallel (Hit Meter First)	14	8	1	5	57%	7%	36%
Perpendicular (Head-On)	13	5	5	3	38%	38%	23%
All Directions	51	23	19	9	45%	37%	18%

Table 9: Analysis of Impact Results when Impacted Parallel to the Wall Hitting the Regulator First

Impact Direction	Regulator Direction	Total Tests	Breakaway Successful	Street Valve Failure	Other Failure	Breakaway Success Rate (%)	Street Valve Failure Rate (%)	Other Failure Rate (%)
Parallel (Hit Regulator First)	Left of Riser (Away from Meter)	11	7	3	1	64%	27%	9%
Parallel (Hit Regulator First)	All other Directions	13	3	10	0	23%	77%	0%

Table 10: Analysis of Impact Results Dependent on Impact Direction and Regulator Direction

Impact Direction	Regulator Direction	Total Tests	Breakaway Successful	Street Valve Failure	Other Failure	Breakaway Success Rate (%)	Street Valve Failure Rate (%)	Other Failure Rate (%)
Left of Riser (Away from Meter)	Parallel (Hit Regulator First)	11	7	3	1	64%	27%	9%
All other Directions	Parallel (Hit Regulator First)	13	3	10	0	23%	77%	0%
Left of Riser (Away from Meter)	Parallel (Hit Meter First)	8	3	1	4	38%	13%	50%
All other Directions	Parallel (Hit Meter First)	6	5	0	1	83%	0%	17%
Left of Riser (Away from Meter)	Perpendicular (Head-On)	7	4	3	0	57%	43%	0%
All other Directions	Perpendicular (Head-On)	6	1	2	3	17%	33%	50%
Left of Riser (Away from Meter)	All Directions	26	14	7	5	54%	27%	19%
All other Directions	All Directions	25	9	12	4	36%	48%	16%

Table 11: Effect of Connector Bar on Breakaway Success Rate Based on Impact Direction

Impact Direction	Connector Bar?	Total Tests	Breakaway Successful	Street Valve Failure	Other Failure	Breakaway Success Rate (%)	Street Valve Failure Rate (%)	Other Failure Rate (%)
Parallel (Hit Regulator First)	No	11	4	7	0	36%	64%	0%
Parallel (Hit Regulator First)	Yes	13	6	6	1	46%	46%	8%
Parallel (Hit Meter First)	No	6	4	1	1	67%	17%	17%
Parallel (Hit Meter First)	Yes	8	4	0	4	50%	0%	50%
Perpendicular (Head-On)	No	7	3	3	1	43%	43%	14%
Perpendicular (Head-On)	Yes	6	2	2	2	33%	33%	33%
All Directions	No	24	11	11	2	46%	46%	8%
All Directions	Yes	27	12	8	7	44%	30%	26%

Table 12: Effect of Pre-Fab Configuration on Breakaway Success Rate Based on Impact Direction

Impact Direction	Pre-Fab Configuration	Total Tests	Breakaway Successful	Street Valve Failure	Other Failure	Breakaway Success Rate (%)	Street Valve Failure Rate (%)	Other Failure Rate (%)
Parallel (Hit Regulator First)	Hook	9	4	5	0	44%	56%	0%
Parallel (Hit Regulator First)	Elbow	12	4	7	1	33%	58%	8%
Parallel (Hit Regulator First)	Short Hook/Pre-Fab Elbow	3	2	1	0	67%	33%	0%
Parallel (Hit Meter First)	Hook	7	5	0	2	71%	0%	29%
Parallel (Hit Meter First)	Elbow	5	3	0	2	60%	0%	40%
Parallel (Hit Meter First)	Short Hook/Pre-Fab Elbow	2	0	1	1	0%	50%	50%
Perpendicular (Head-On)	Hook	5	3	0	2	60%	0%	40%
Perpendicular (Head-On)	Elbow	6	2	3	1	33%	50%	17%
Perpendicular (Head-On)	Short Hook/Pre-Fab Elbow	2	0	2	0	0%	100%	0%
All Directions	Hook	21	12	5	4	57%	24%	19%
All Directions	Elbow	23	9	10	4	39%	43%	17%

All Directions	Short Hook/Pre-Fab Elbow	7	2	4	1	29%	57%	14%

Table 13: Breakaway Success Rates Based on Grouping of Test Configurations

Grouping	Grouping Configuration	Total Tests	Breakaway Success Rate (%)	Street Valve Failure Rate (%)	Other Failure Rate (%) (Elsewhere, Breakaway Cracked, Meterset Intact)
Pre-Fab Configuration	Hook	21	57%	24%	19%
Pre-Fab Configuration	Short Hook/Pre-Fab Elbow	7	29%	57%	14%
Pre-Fab Configuration	Elbow	23	39%	43%	17%
Meter Size	10 Lite	11	36%	55%	9%
Meter Size	1A Sprague	15	33%	53%	13%
Meter Size	20 Lite	17	53%	29%	18%
Meter Size	30 Lite	8	63%	0%	38%
Regulator Direction	Left of Riser (Away from Meter)	26	54%	27%	19%
Regulator Direction	Behind Riser (Towards Wall)	14	43%	36%	21%
Regulator Direction	In Front of Riser (Away from Wall)	7	29%	57%	14%
Regulator Direction	Above Riser (Facing away from Meter)	4	25%	75%	0%
Impact Direction	Parallel (Hit Regulator First)	24	42%	54%	4%
Impact Direction	Parallel (Hit Meter First)	14	57%	7%	36%

Impact Direction	Perpendicular (Head-On)	13	38%	38%	23%
Connector Bar	No Connector	24	46%	46%	8%
Connector Bar	Thin Solid	12	42%	25%	33%
Connector Bar	Hollow	4	50%	50%	0%
Connector Bar	I-Beam	11	45%	27%	27%

Appendix H: Drop Test Pictures

This appendix provides the pictures of the Drop Testing done for this project.

Figure 83: Utility 1 Meter Set with Breakaway After First Drop Test

Figure 84: Close Up of Breakaway from Utility 1 Meter Set After First Drop Test

Figure 85: Bottom Half of Breakaway from Utility 1 Meter Set After First Drop Test – Sand Visible at Seal

Figure 86: Utility 1 Meter Set with Breakaway After Second Drop Test

Figure 87: Questar Meter Set with Breakaway After Drop Test

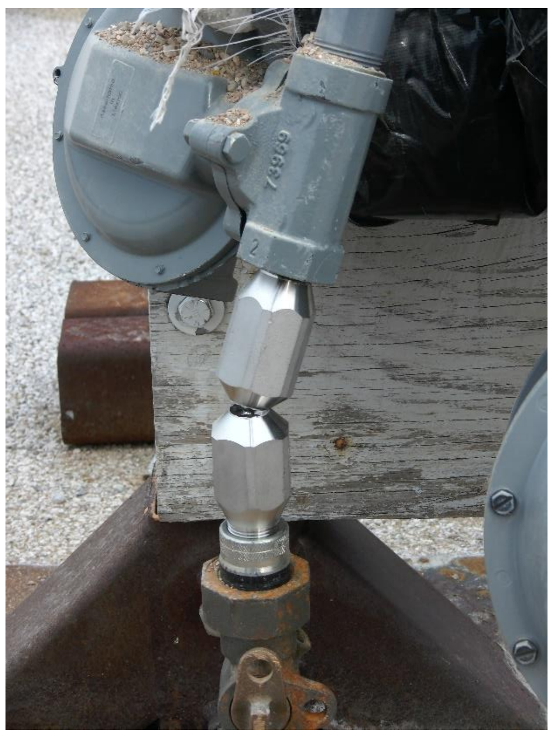


Figure 88: Close-Up of Breakaway from Questar Meter Set after Drop Test

END OF REPORT