Modeling Victaulic Couplings in Piping System Stress Analysis Programs

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Modeling and Analysis of Piping System Designs
With Victaulic Rigid or Flexible Couplings

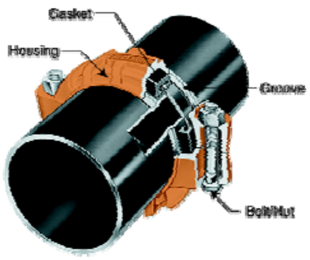
INTRODUCTION

Victaulic grooved mechanical couplings have been used to join pipe since 1925 on diverse piping systems in a variety markets including; power generation, oilfield/refinery, chemical, mining, alternative fuels, clean water, general industrial, PHA and fire protection. The use of Victaulic couplings does not create a need for stress analysis modeling; however, the couplings can be modeled into systems when there is a design requirement. Various customers and consulting engineering firms have requested information regarding how to model Victaulic couplings in stress analysis software or information regarding product performance data so that they can analyze Victaulic systems as they do with welded systems. This document presents methodology on how to incorporate the characteristics of Victaulic grooved mechanical couplings into stress analysis programs.

Victaulic contracted the services of the Worley Parsons Group, a global consulting engineering firm, to verify the proposed approach for modeling Victaulic rigid couplings in piping systems was consistent with industry standards for stress analysis software,. This study verified the suitability of CAESAR II stress analysis software for modeling and analysis of Victaulic rigid couplings. Included herein is a recommended modeling technique and stress analysis models for various piping configurations. The examples in this document range in pipe sizes from 2" (50mm) through 24" (600mm) with a temperature differential (ΔT) of 150°F (83.3°C) from ambient, but the methodology is consistent for other conditions as well. The stress analysis results from these piping configurations utilizing Victaulic couplings were then compared to the stress analysis results from these configurations utilizing standard butt welded construction. It was concluded that with minor input changes, the stress analysis program is a useful tool in analyzing Victaulic systems, producing results in a format similar to piping systems with a welded system construction.

VICTAULIC RIGID and FLEXIBLE COUPLINGS

Understanding the design features of Victaulic rigid and flexible couplings is the first step. Victaulic grooved couplings provide a permanent pipe connection which can withstand full pressure thrust loads at their maximum rated working pressure. Victaulic rigid couplings positively clamp the pipe to create a rigid joint, so axial movement and deflection are eliminated. They are particularly useful on risers, mechanical rooms, horizontal runs with numerous branches and other areas where flexibility is not required. Proper rigid coupling installation provides system behavior characteristics similar to those of other rigid systems, in that all piping remains strictly aligned and is not subject to axial or angular movement during operation. For this reason, systems installed with Victaulic rigid couplings utilize support techniques identical to those used in welded systems. Victaulic rigid couplings are designed to provide rigidity for hanger spacing requirements in accordance with ASME B31.1 Power Piping Code, ASME B31.3 Process Piping Code, ASME B31.9 Building Services Piping Code and NFPA 13 Sprinkler Systems Code.

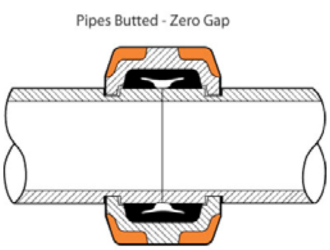


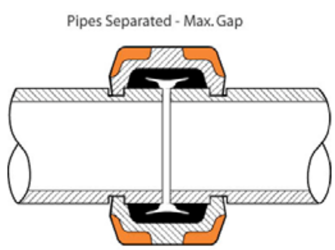
Grooved Coupling

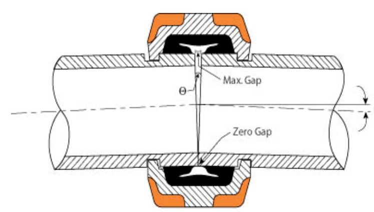

Style 07 Rigid


Style W07 Rigid

Victaulic flexible couplings permit controlled pipe movement within the couplings while they maintain a positive seal and self-restrained joint. This is achieved because the coupling key section engages but "floats" in the groove. The design allows for expansion, contraction and deflection generated by thermal changes, building or ground settlement, and seismic activity. Pipe movement accommodation with Victaulic flexible couplings will minimize the stresses that can be generated by this movement. Victaulic flexible couplings also have superior vibration attenuation characteristics.







Experience has shown that most designers utilize all rigid couplings except where the design features of flexible couplings can be incorporated to achieve optimal design advantage in areas such as those mentioned above. When both flexible and rigid couplings are utilized, the system designer can optimize hanger spacing, eliminate expansion loops and flex connectors and incorporate rigidity and flexibility where desired. A variety of benefits are provided to the system designer, installer and owner, which results in the most reliable system for most applications and makes Victaulic's grooved method the best choice for joining pipe.

VICTAULIC ALLOWABLE COUPLING JOINT LOADS – PRODUCT DESIGN GUIDELINES

Pipe stress analysis software is typically designed to analyze welded piping systems in accordance with standard industrial piping codes. The design capabilities of grooved mechanical couplings are not presently included in these software programs. Victaulic has developed Product Design Guidelines (PDG) to provide some of the critical input data changes for these programs and the allowable coupling loads for rigid couplings to compare with the output load data from these stress analysis programs. Contact Victaulic to request the PDG for the size/style of Victaulic coupling used in your system analysis.

VICTAULIC RIGID COUPLING SYSTEM ANALYSIS

For Systems installed with Victaulic rigid couplings, the allowable coupling loads document (Victaulic PDG) provides the allowable coupling joint loads. There are a few differences in the input parameters for these rigid couplings versus welded joints discussed in this document such as torsional stiffness, stress intensification factor and flexibility factor. Rigid couplings have limited torsional stiffness that is difficult to numerically define or describe as it is dependent upon a multitude of factors, primarily the friction between the coupling and the pipe groove. For system stress analysis, Victaulic suggests a stress intensification factor (SIF) of 2.3 as this is used for threaded joints and simulates a worst case condition, and a flexibility factor of K=1 which is actually the program default setting for welded joints. Victaulic also suggests that the torsional resistance be set identical to welded systems for single plane systems where there are no torsional loads imparted on the pipe joints. On multi-planar systems, where a torsional load may cause rotation within a coupling, the rotational "Gap" on the pipe axis (RX) be set at 1 (1 degree), see the example under the modeling section of this paper. Fitting and valve connections shall be treated as standard wall pipe, provided of course that the piping they are being joined with is standard wall. After changing these input criteria the stress analysis software would be run and the loads calculated by the software would then be compared to the allowable coupling loads tabulated in the Victaulic PDG document previously referenced. If the calculated loads are equal to or less than the allowable loads published, then the use of the couplings in the system as designed is acceptable. If the calculated stresses exceed these published loads, then the piping layout or support method would need to be modified and the program re-run or Victaulic flexible couplings could be incorporated to accommodate the piping movement in these high stress areas.

VICTAULIC FLEXIBLE COUPLING SYSTEM ANALYSIS

For systems installed with flexible couplings or where flexible couplings are incorporated into a system installed with rigid couplings to reduce the calculated loads, the analysis for the piping section installed with the flexible couplings becomes geometry based. Victaulic flexible couplings allow for a controlled amount of linear and angular movement. The system design/layout must be such that these movement values are not exceeded. The flexible couplings allow this free range of movement so metal to metal "lock up" in the joint does not exist. Therefore, the forces induced into the system are minimal when compared to the forces required to elastically deform pipe installed with rigid grooved couplings or welded connections.

Victaulic flexible couplings have mechanical strength that far surpasses other flexible devices such as rubber bellows, braided flex connectors or unrestrained mechanical joints. They create self restrained joints capable of restraining the pipes without anchors or thrust blocks as the full rated pipe joint working pressure. For example, Style 77 flexible couplings have working pressures greater than Style 07 rigid couplings and the Style W77 flexible couplings have the same working pressures as the Style W07 rigid couplings. Therefore, these flexible couplings will handle the same allowable loads as these rigid couplings. However, as stated above, the goal is not to exceed the flexible coupling's movement capabilities so the analysis remains as geometry based. An example of the geometry based analysis may be found in Appendix A.

MODELING VICTAULIC COUPLINGS IN CAESAR II

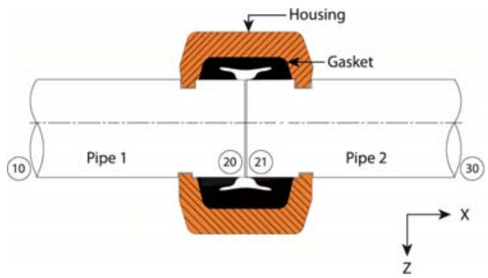
The objective of the study was to provide a method for using CAESAR II modeling techniques for Victaulic rigid couplings comparable to the method for butt welded construction. Although CAESAR II does not have a specific modeling function for Victaulic couplings, it does contain a modeling feature – the restraint CNODE –which can be used for this purpose. The resulting output load values are compared to the Victaulic published maximum rigid coupling allowable loads as found in Victaulic PDG's.

It should be noted that this modeling technique is also applicable to Victaulic flexible couplings as the axial gap and angular offset characteristics of the flexible coupling can be modeled and analyzed. However, piping systems are installed mainly with rigid couplings, with flexible couplings only being utilized where the allowable load capability of the rigid couplings has been exceeded or for other design benefits such as vibration attenuation at equipment connections, accommodation of piping misalignment, building settlement, equipment nozzle movements and seismic movement.

In order to define the Victaulic rigid coupling as a restraint in CAESAR II, the restraint NODE/CNODE (node/connecting node) model input fields are used. The NODE/CNODE model ties a fixed or restrained node at one pipe end to the next pipe end with associated degrees of freedom as inputted. This itemizes the loads on the rigid coupling as well as allows the user to easily filter a restraint report to review only the loads at the rigid coupling locations for the defined load cases.

The below coupling diagram and CAESAR II NODE/CNODE input tables are shown to illustrate the input criteria. Victaulic rigid couplings in single plane system configurations should be modeled in CAESAR II as a restraint with all six degrees of freedom (X, Y, Z, RX, RY and RZ) defined as rigid. All inputs [the "Gap", stiffness (Stif) and coefficient of friction (Mu)], should be left blank which allows the default program setting of a rigid connection to be applied. (Table 1) Alternatively, the coupling locations can be modeled as fixed points. (Table 2) In multi-planar system, five of the six degrees of freedom (X, Y, Z, RX, RY and RZ) should be defined as rigid, with the rotational degree of freedom about the pipe axis as not rigid. The rotational resistance around the pipe axis (Rx in the below diagram) should have the “Gap” set at 1 (or higher) as this signifies a +/-1 degree of free rotation. The “Stif” and the “Mu” should remain empty, applying their default settings when recognizing the rotational (Gap) freedom of axial rotation. (Table 3)

In effect this is a simple pipe end to pipe end (or fitting or valve) restraint model with no attachment to external supporting structures. With all six degrees of freedom defined, CAESAR II calculates the restraint loads the same as it calculates the typical node point forces and moments in a welded or flanged piping system.



(Table 1)

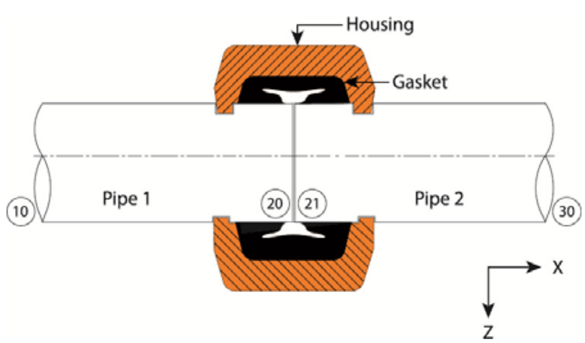
From:	10	Node:	20	CNode:	21
To:	20	Type:	X	Gap:	
Dx:	"X1"	Stif:		Mu:	
		Node:	20	CNode:	21
		Type:	Y	Gap:	
		Stif:		Mu:	
		Node:	20	CNode:	21
		Type:	Z	Gap:	
		Stif:		Mu:	
		Node:	20	CNode:	21
		Type:	RX	Gap:	
		Stif:		Mu:	
From:	21	Node:	20	CNode:	21
To:	30	Type:	RY	Gap:	
Dx:	"X2"	Stif:		Mu:	
		Node:	20	CNode:	21
		Type:	RZ	Gap:	
		Stif:		Mu:	

In modeling and analysis of a single plane piping system, the rigid coupling was modeled simply as a single node point with the Victaulic specified SIF of 2.3 applied. The calculated output loads (FX, FY, FZ, MX, MY, MZ) for a node point are identical to the output loads of the CNODE restraint with all six degrees of freedom set to rigid. The only changes in output were the stress values due to the addition of the SIF factor of 2.3 included at the rigid coupling location. Alternatively, the coupling location can be modeled as an anchor, as its rigid characteristics make it an identical model. To do this, one would enter "ANC" in the input table as shown below.

(Table 2)

From:	10		Node:	20	CNode:	21
To:	20		Type:	ANC	Gap:	
Dx:	"X1"		Stif:		Mu:	
From:	21					
To:	30					
Dx:	"X2"					

For modeling and analysis of multi-plane piping layouts, the rigid coupling was modeled simply as a single node point with the Victaulic specified SIF of 2.3 applied. The calculated output loads (FX, FY, FZ, MX, MY, MZ) for a node point are identical to the output loads of the CNODE restraint with five of the six degrees of freedom set to rigid, with the exception being setting the axial torsional degree of freedom as not rigid, which reduces the resulting bending moments at the coupling locations. In effect, the pipe ends within the coupling were modeled as free to rotate about the pipe axis because these couplings have limited torsional stiffness as discussed previously. In the below example, "X" is the axis of the pipe, therefore the gap at RX is set to 1.



(Table 3)

From:	10	Node:	20	CNode:	21
To:	20	Type:	X	Gap:	
Dx:	"X1"	Stif:		Mu:	
		Node:	20	Cnode:	21
		Type:	Y	Gap:	
		Stif:		Mu:	
		Node:	20	Cnode:	21
		Type:	Z	Gap:	
		Stif:		Mu:	
		Node:	20	Cnode:	21
		Type:	RX	Gap:	1
		Stif:		Mu:	
From:	21	Node:	20	Cnode:	21
To:	30	Type:	RY	Gap:	
Dx:	"X2"	Stif:		Mu:	
		Node:	20	Cnode:	21
		Type:	RZ	Gap:	
		Stif:		Mu:	

When modeling with the NODE/CNODE restraint definition, the loads across the rigid coupling are listed in the output of the Restraint Summary report. In this report, all restraint loads for the six degrees of freedom are listed for each rigid coupling location modeled. The forces and moments at each coupling location must then be manually compared to the maximum allowable rigid coupling loads.

SUGGESTED MODELING TECHNIQUES

1. First model the piping system with supports as a conventional welded system with additional node points and restraints with CNodes added at the proposed Victaulic rigid coupling locations.

2. Apply a Stress Intensification Factor (SIF) of 2.3 to the node at the rigid coupling locations.

3a. For single plane systems, leave all inputs on the NODE/CNODE analysis table at their default values. (leave boxes in input table blank). Or, set the node as an anchor (ANC) and complete the analysis.

3b. For multi-plane systems, set the axial rotational resistance as not rigid by setting the “Gap” value at one (1). All the remaining inputs on the NODE/CNODE analysis table should be left at their default values. (leave boxes in input table blank)

4. Run the static analysis in CAESAR II and review the loads and stresses at the proposed rigid coupling locations.

5. Look for areas within the model with:

   - Rigid coupling location stresses in excess of 80% of code allowable.

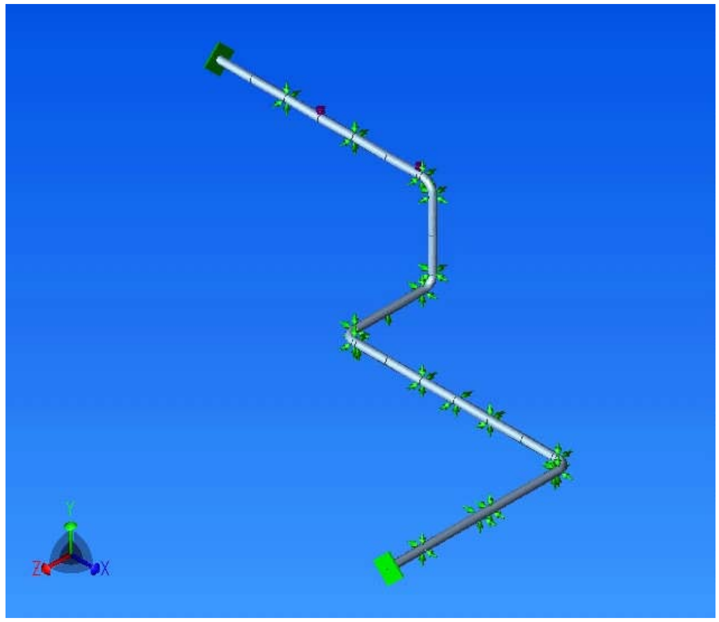
   - Rigid coupling location axial end loads approaching or exceeding Victaulic rigid coupling allowable load values.

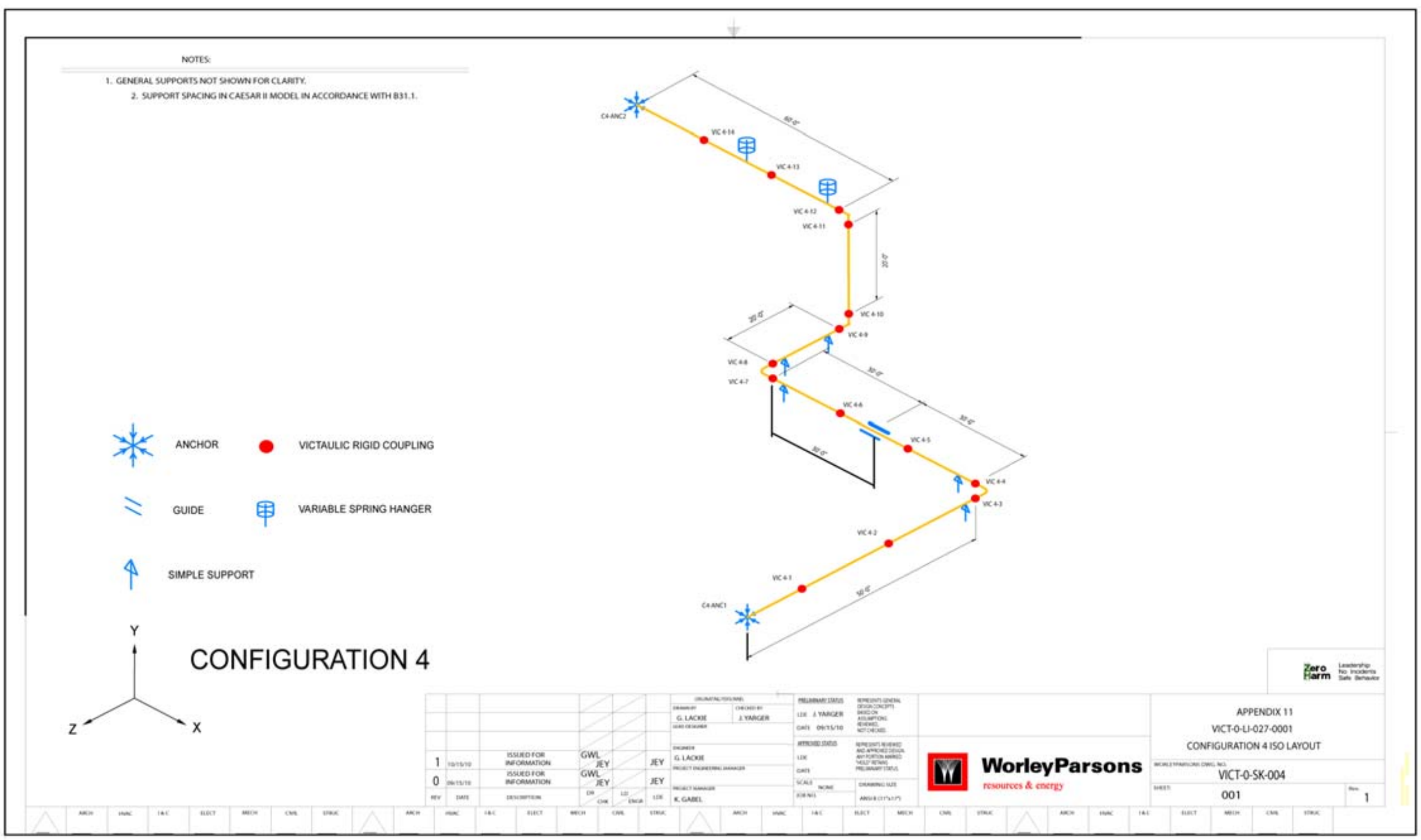
   - Rigid coupling location bending moments approaching or exceeding Victaulic rigid coupling allowable bending moment values.

6. This approach serves to identify areas within the model which may warrant support type and location revisions, pipe routing modifications to reduce loads and stresses to acceptable levels or the incorporation of Victaulic flexible couplings.

RESULTS

Following is a summary of the results for two typical piping runs under the design conditions set forth in the second paragraph of this papers introduction. The first (Configuration 4) was a three dimensional piping configuration having a Z bend with a riser. The following table for “Configuration 4” is a combination of Victaulic provided couplings capabilities and CAESAR II generated data. As shown, the first four columns illustrate the rigid coupling's maximum rated working pressures and the maximum allowable end loads, shear loads and bending moments. The remaining columns illustrate the CAESAR II output results, which are the maximum loads generated at any node, (a worst case analysis). A comparison of these results shows that the rigid coupling allowable loads were not exceeded in all sizes.

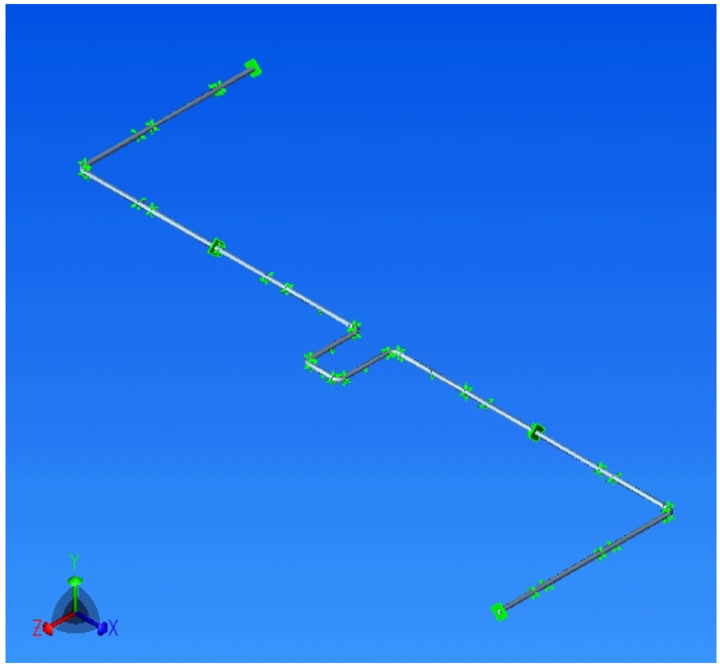

Y
Z
X


NOTES:
1. GENERAL SUPPORTS NOT SHOWN FOR CLARITY.
2. SUPPORT SPACING IN CAESAR II MODEL IN ACCORDANCE WITH B31.1.
C4 ANC2
VIC 4-14
VIC 4-13
VIC 4-12
VIC 4-11
VIC 4-10
VIC 4-9
VIC 4-8
VIC 4-7
VIC 4-6
VIC 4-5
VIC 4-4
VIC 4-3
VIC 4-2
VIC 4-1
C4 ANC1
ANCHOR
VICTAULIC RIGID COUPLING
GUIDE
VARIABLE SPRING HANGER
SIMPLE SUPPORT
CONFIGURATION 4
Y
Z
X
Zero Harm
Leadership
No Incidents
Safe Behavior
1
ISSUED FOR INFORMATION
GWL
JEY
JEY
0
ISSUED FOR INFORMATION
GWL
JEY
JEY
G. LACKIE
J. YARGER
G. LACKIE
K. GABEL
WorleyParsons
resources & energy
APPENDIX 11
VICT-0-LI-027-0001
CONFIGURATION 4 ISO LAYOUT
VICT-0-SK-004
001
1

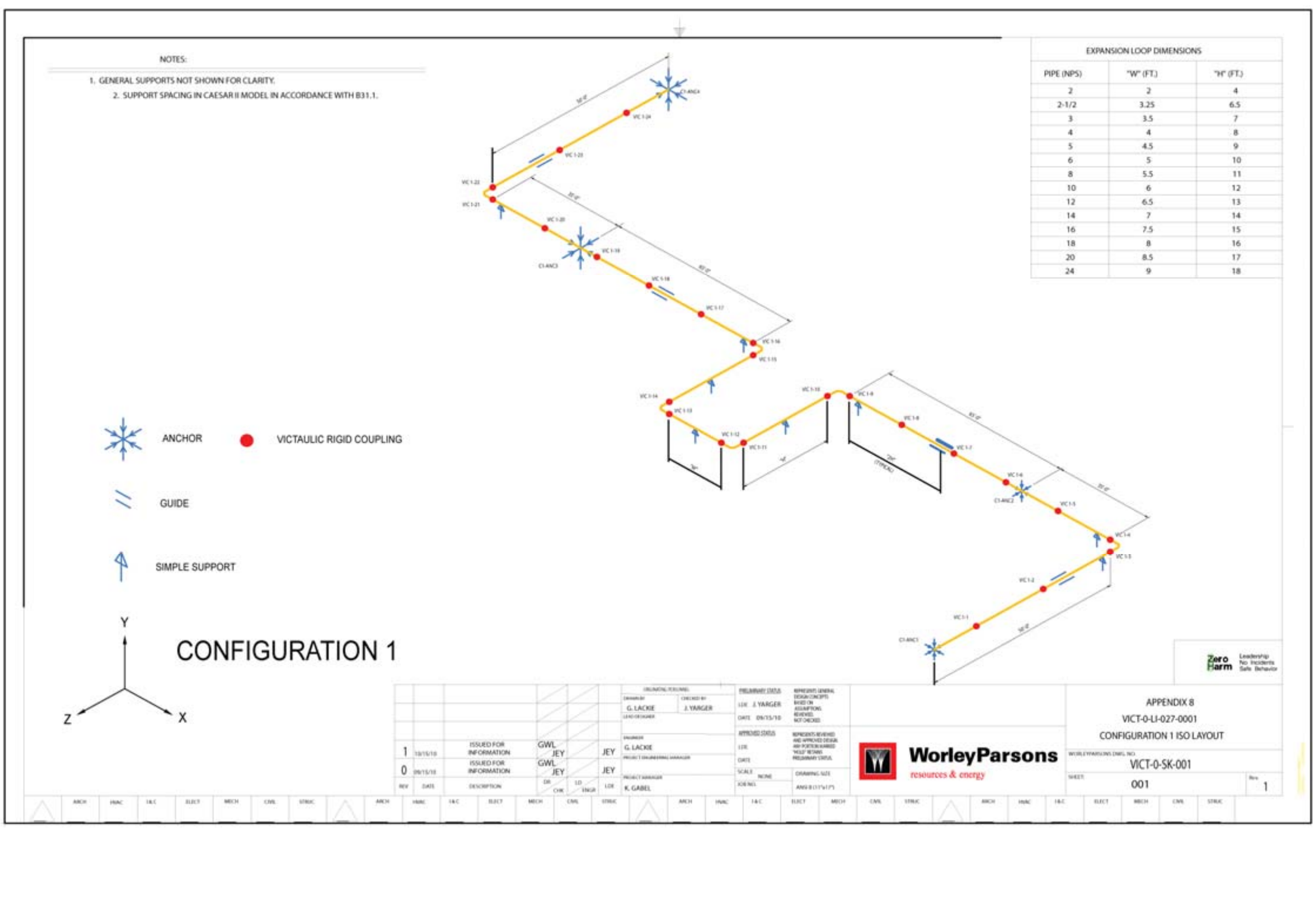
CONFIGURATION 4 - Typical Z bend with riser (3 Dimensional Offset)

	Victaulic - Standard Weight Pipe Allowable Coupling Joint Loads				Caesar II Output Results										
NPS (in)	Max. Working Pressure (psig)	Max. Allowable End Load (lbs)	Max. Allowable Shear Load (lbs)	Max. Allowable Bending Moment (ft-lbs)	Max. Code Stress Ratio (%)	Max. Axial Force (lb)	Max. Shear Force (lb)	Max. Bending Moment (ft-lb)	Max. Torsion Moment (ft-lb)	Max. FX (lb)	Max. FY (lb)	Max. FZ (lb)	Max. MX (ft-lb)	Max. MY (ft-lbs)	Max. MZ (ft-lb)
2	750	+/- 3320	400	700	25.0	66.0	69.0	34.2	0.0	1.0	69.0	1.0	23.4	-19.2	34.2
2 1/2	750	+/- 4875	600	800	22.7	110.0	115.0	73.1	0.0	2.0	115.0	2.0	-37.2	-43.5	73.1
3	750	+/- 7215	800	900	24.2	153.0	162.0	121.2	0.0	3.0	162.0	4.0	-74.4	-75.8	121.2
4	750	+/- 11925	1000	1500	28.2	304.0	319.0	149.7	0.0	8.0	319.0	9.0	-61.1	-178.6	308.6
5	750	+/- 18225	1300	2300	31.0	464.0	493.0	598.2	0.0	16.0	493.0	17.0	244.8	-345.7	598.2
6	700	+/- 24130	1600	3100	31.5	-629.0	672.0	773.4	0.0	20.0	-672.0	24.0	-564.1	-435.1	771.6
8	600	+/- 35000	2000	5000	30.2	-626.0	717.0	1749.4	0.0	62.0	-715.0	69.0	674.4	-1352.6	1748.8
10	500	+/- 45400	2800	6700	29.1	982.0	1141.0	3743.7	0.0	124.0	1141.0	144.0	-1347.2	-2779.1	3743.6
12	400	+/- 51000	3600	10200	27.7	1422.0	1671.0	5757.0	0.0	183.0	1671.0	214.0	-1527.0	-4189.3	5756.9
14	350	+55800, -18200	5000	11600	28.3	1657.0	2075.0	7441.3	0.0	211.0	2075.0	252.0	-3050.6	-4926.5	7441.2
16	350	+72885, -20650	6000	19400	32.1	2208.0	2677.0	10030.2	0.0	277.0	2677.0	333.0	-6861.4	-6591.2	10029.9
18	350	+92245, -23100	7000	23100	34.8	2773.0	3409.0	13036.5	0.0	341.0	3409.0	415.0	-8406.4	-8282.8	13036.1
20	350	+113880, -25550	8000	33600	38.7	3598.0	4436.0	17004.8	0.0	416.0	4436.0	506.0	5133.6	-10268.1	17004.2
24	350	+163990, -30800	10000	51100	46.3	4917.0	6276.0	26031.7	0.0	575.0	6276.0	701.0	-7683.9	-14688.6	26030.3

The second piping configuration (Configuration 1) was a two dimensional, single plain Z bend with an expansion loop. As can be seen in the table for "Configuration 1", the first four columns illustrate the rigid coupling's maximum rated working pressures and the maximum allowable end loads, shear loads and bending moments. The remaining columns illustrate the CAESAR II output results. A comparison of these results shows that the rigid coupling allowable loads were not exceeded in all sizes with the exception of the bending loads for sizes 8", 10" and 12". The specific location of the overstressed joints would be found in the detailed nodal stress analysis output provided by CAESAR II (not shown in this report). The overstressed bending loads have been highlighted in red on the "Configuration 1" table.



Y
Z
X



NOTES:
1. GENERAL SUPPORTS NOT SHOWN FOR CLARITY.
2. SUPPORT SPACING IN CAESAR II MODEL IN ACCORDANCE WITH B31.1.
EXPANSION LOOP DIMENSIONS
PIPE (NPS) | "W" (FT.) | "H" (FT.)
2 | 2 | 4
2-1/2 | 3.25 | 6.5
3 | 3.5 | 7
4 | 4 | 8
5 | 4.5 | 9
6 | 5 | 10
8 | 5.5 | 11
10 | 6 | 12
12 | 6.5 | 13
14 | 7 | 14
16 | 7.5 | 15
18 | 8 | 16
20 | 8.5 | 17
24 | 9 | 18
ANCHOR
VICTAULIC RIGID COUPLING
GUIDE
SIMPLE SUPPORT
CONFIGURATION 1
Y
Z
X
Zero Harm
Leadership
No Incidents
Safe Behavior
ISSUED FOR INFORMATION
GWL
JEY
G. LACKIE
J. YARGER
K. GABEL
WorleyParsons
resources & energy
APPENDIX 8
VICT-0-LI-027-0001
CONFIGURATION 1 ISO LAYOUT
VICT-0-SK-001
001
1

CONFIGURATION 1 - Typical single plane Z bend with an expansion loop

	Victaulic - Standard Weight Pipe Allowable Coupling Joint Loads				Caesar II Output Results										
NPS (in)	Max. Working Pressure (psig)	Max. Allowable End Load (lbs)	Max. Allowable Shear Load (lbs)	Max. Allowable Bending Moment (ft-lbs)	Max. Code Stress Ratio (%)	Max. Axial Force (lb)	Max. Shear Force (lb)	Max. Bending Moment (ft-lb)	Max. Torsion Moment (ft-lb)	Max. FX (lb)	Max. FY (lb)	Max. FZ (lb)	Max. MX (ft-lb)	Max. MY (ft-lbs)	Max. MZ (ft-lb)
2	750	+/- 3320	400	700	34.4	-53.0	53.0	281.3	0.0	53.0	-20.0	11.0	-18.0	-281.3	-40.5
2 1/2	750	+/- 4875	600	800	34.4	-92.0	92.0	538.1	0.0	92.0	-25.0	21.0	14.5	-538.1	-77.8
3	750	+/- 7215	800	900	33.1	-131.0	132.0	829.6	0.0	131.0	-56.0	32.0	52.0	-829.6	119.6
4	750	+/- 11925	1000	1500	29.9	-192.0	194.0	1379.3	0.0	192.0	-74.0	52.0	62.6	-1379.0	64.2
5	750	+/- 18225	1300	2300	27.8	-263.0	267.0	2089.9	0.0	263.0	-144.0	96.0	163.5	-2089.1	224.5
6	700	+/- 24130	1600	3100	29.6	-391.0	396.0	3084.2	0.0	391.0	-241.0	145.0	348.7	-3082.6	593.7
8	600	+/- 35000	2000	5000	27.9	-531.0	534.0	5103.5	0.0	531.0	434.0	162.0	315.1	-5103.2	935.2
10	500	+/- 45400	2800	6700	29.3	-784.0	797.0	8175.1	0.0	784.0	-790.0	296.0	-2445.5	-8173.7	467.1
12	400	+/- 51000	3600	10200	26.1	-934.0	1011.0	10363.4	0.0	934.0	977.0	474.0	-2405.7	-10356.4	-2418.2
14	350	+55800, -18200	5000	11600	28.5	-910.0	1206.0	11003.7	0.0	910.0	-1177.0	606.0	-2403.4	-10950.7	-3369.4
16	350	+72885, -20650	6000	19400	32.2	-1164.0	1576.0	13941.5	0.0	1164.0	1530.0	838.0	-2500.7	-13854.5	-4809.8
18	350	+92245, -23100	7000	23100	36.7	-1532.0	2034.0	14064.4	0.0	1532.0	2027.0	1117.0	-3015.3	-13987.0	-7616.8
20	350	+113880, -25550	8000	33600	37.2	-1362.0	2831.0	17060.3	0.0	1329.0	-2500.0	1362.0	5142.3	-16027.9	-9521.0
24	350	+163990, -30800	10000	51100	49.2	-2562.0	4506.0	33288.5	0.0	2227.0	-4497.0	2562.0	-10178.5	-32878.4	15387.9

Note: The bending moments over allowable are all located on fittings in the short leg of the expansion loop.

As previously mentioned, when calculated loads exceed acceptable limits, the piping layout or support method needs to be modified. The program is then rerun with the new installation criteria. This "iterative" corrective action is consistent regardless of the type of pipe joint. Victaulic also offers the system designer an alternative of installing flexible couplings at select locations to accommodate piping movement in these high stress areas where acceptable loads are exceeded. Since modifying the piping layout or support method is common practice for welded systems, this document will only provide an example of the additional design option that Victaulic provides (how to incorporate flexible couplings in the areas where the rigid coupling allowable loads have been exceeded). A geometric analysis is shown in Appendix A to resolve the excess allowable loads calculated in Configuration 1 at the location of two rigid couplings on the short leg of the expansion loop. (As a general rule, Victaulic recommends the use of Flexible Couplings on expansion loops to reduce overall pipe stress in the loop and to decrease the loop size by 1/2 to 1/3 the weld loop size. In line expansion joints are also available. Please refer to Victaulic publication 26.02 Calculating and Accommodating Pipe Line Thermal Growth.)

CONCLUSION

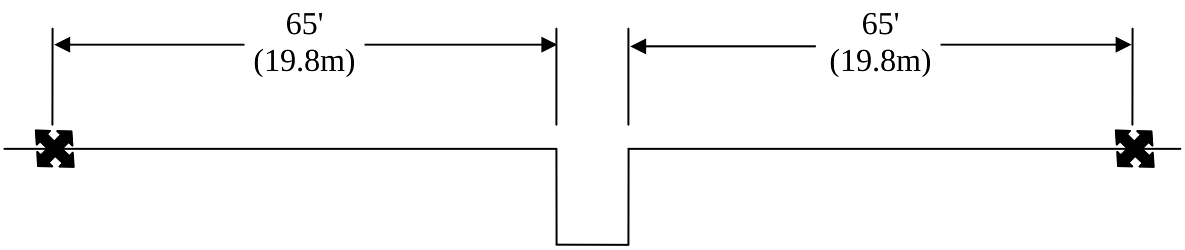
The methodology presented herein demonstrates how Victaulic couplings can be modeled into piping systems using existing stress analysis programs. With only minor input changes, the programs analyze Victaulic systems producing results comparable to welded piping systems.

Victaulic technical expertise is available, please feel free to contact for Victaulic for further information in applying the above methodology should questions arise.

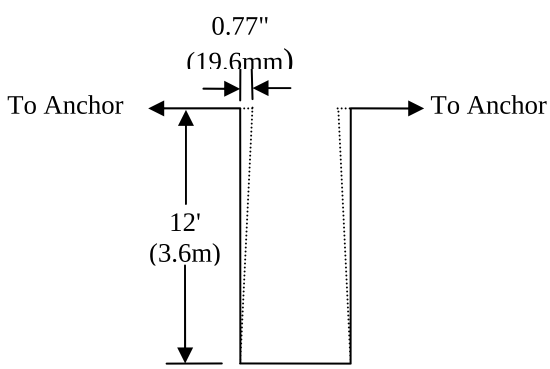
APPENDIX A

GEOMETRIC ANALYSIS USING VICTAUILC FLEXIBLE COUPLINGS

The "Configuration 1" example illustrates shows the length of pipe from the expansion loop to the anchor points on both sides to be 65' (19.8m). As the temperature increases by 150°F (83.3°C) each 65' (19.8m) section will experience an increase in length of .77" (19.6mm).



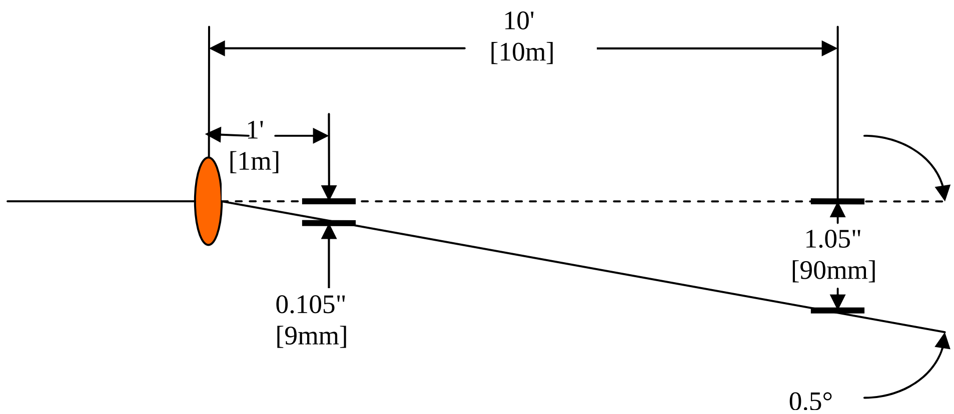
As shown on the drawing, the perpendicular legs of the expansion loop (designed for welded piping) are 12' (3.6m) long. The perpendicular leg lengths were developed using the most common method for sizing welded expansion loops, as found in the ASHRAE Systems and Equipment Handbook.



Weld Construction

The analysis using the same loop and Victaulic rigid couplings revealed an overstressed condition that can be resolved by increasing the lengths of the perpendicular legs or more easily, with the addition of a few strategically located Victaulic Flexible Couplings. 10" pipe size will be used as an example and incorporate the flexible couplings, as is the size that exceeded the rigid coupling allowable loads by the greatest amount and will, therefore, best demonstrate the advantage of the flexible coupling's deflection capability.

The design angle of deflection for Victaulic 10" Style 77 flexible couplings is .5 degrees when installed on roll grooved pipe.[1] This deflection can also be expressed in terms of deflection from centerline per unit length of pipe and this value for the 10" Style 77 flexible coupling is .105"/ft (9mm/m). The below diagram provides an illustration of the centerline offset over 1ft, 10ft, 1m and 10m of pipe due to this deflection, (the imperial and metric dimensions are not direct conversions).



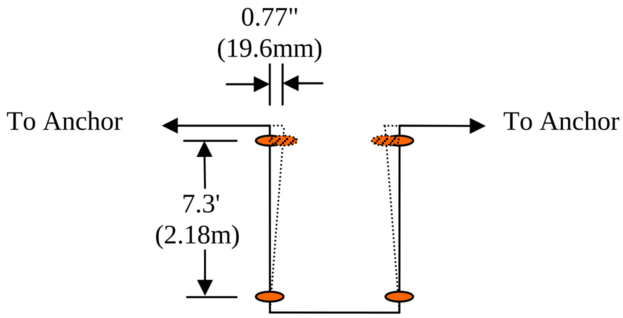
Replacing the two rigid couplings on each 12ft (3.6m) long perpendicular leg of the expansion loop with flexible couplings will allow each leg to accommodate 1.26" (32mm).

.105"/' x 12' = 1.26"
(9mm/m x 3.6m = 32.4mm)

As required by the system design parameters, each leg only needs to accommodate .77" (19.6mm). This gives the designer the option of just replacing the rigid couplings with flexible couplings or to take advantage of the full deflection capability of the two flexible couplings on each leg and reduce the leg lengths to 7.3' (2.19m).

.77" ÷ .105"/' = 7.3'
(19.6mm ÷ 9mm/m = 2.18m)

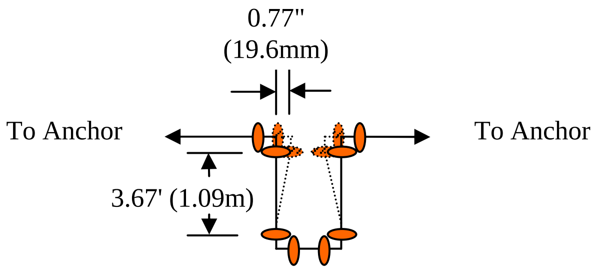
[1] The design angle of deflection for Victaulic Flexible couplings is derived by multiplying Victaulic's published maximum values by an installation safety factor. Victaulic recommends the maximum values be reduced by 50% for ¾" – 3 ½" flexible couplings and by 25% for 4" and larger flexible couplings for designing purposes.



Two Flexible Couplings

To demonstrate the full capability of incorporating flexible couplings into system changes in direction, a third (and preferred) option would be to replace the eight rigid couplings on the four elbows of the expansion loop with flexible couplings. Doubling the number of flexible couplings doubles the offset angle, resulting in the perpendicular leg lengths to be reduced to only 3.67' (1.09m), a tremendous material and space savings.

$$.77'' \div 2(.105''/') = 3.67'$$
$$(19.6\text{mm} \div 2(9\text{mm/m}) = 1.09\text{m})$$



All Flexible Couplings

As can be seen, the use of flexible couplings at system changes in direction can reduce the system footprint which may be very beneficial in areas with spacial constraints or when there are multiple parallel pipelines.

APPENDIX B

Deflected Joints

A normal force applied at a distance from the pipe joint creates a moment that causes pipe deflection to occur at a Victaulic flexible coupling. Similarly, when two pipes are assembled deflected with Victaulic Flexible Couplings, upon pressurization forces are created (see diagram below), which act to straighten the joint. This force applied at the same location, (or moment), is in an equal and opposite direction that would be required to deflect a straight joint.

In situations where one pipe is restrained, the moment to cause deflection or to maintain a deflected joint may be approximated by the formula below. This moment was derived from balancing forces and moments in a free body diagram and does not take in to account any deflection of the "restrained" pipe between the restraint and the Victaulic coupling or the effects of friction.

$$M = \pi p D^3/8$$

Where: M = Moment
p = Internal Pressure
D = Outside Diameter

At a given distance on the "unrestrained" pipe from the coupling, the force required to deflect or to maintain deflection of a joint is approximated by the formula below.

$$F = M/L = \pi p D^3/8L$$

Where: F = Deflecting or Restraining Force
p = Internal Pressure
D = Outside Diameter
L = Length from Centerline of Groove to Force (F)

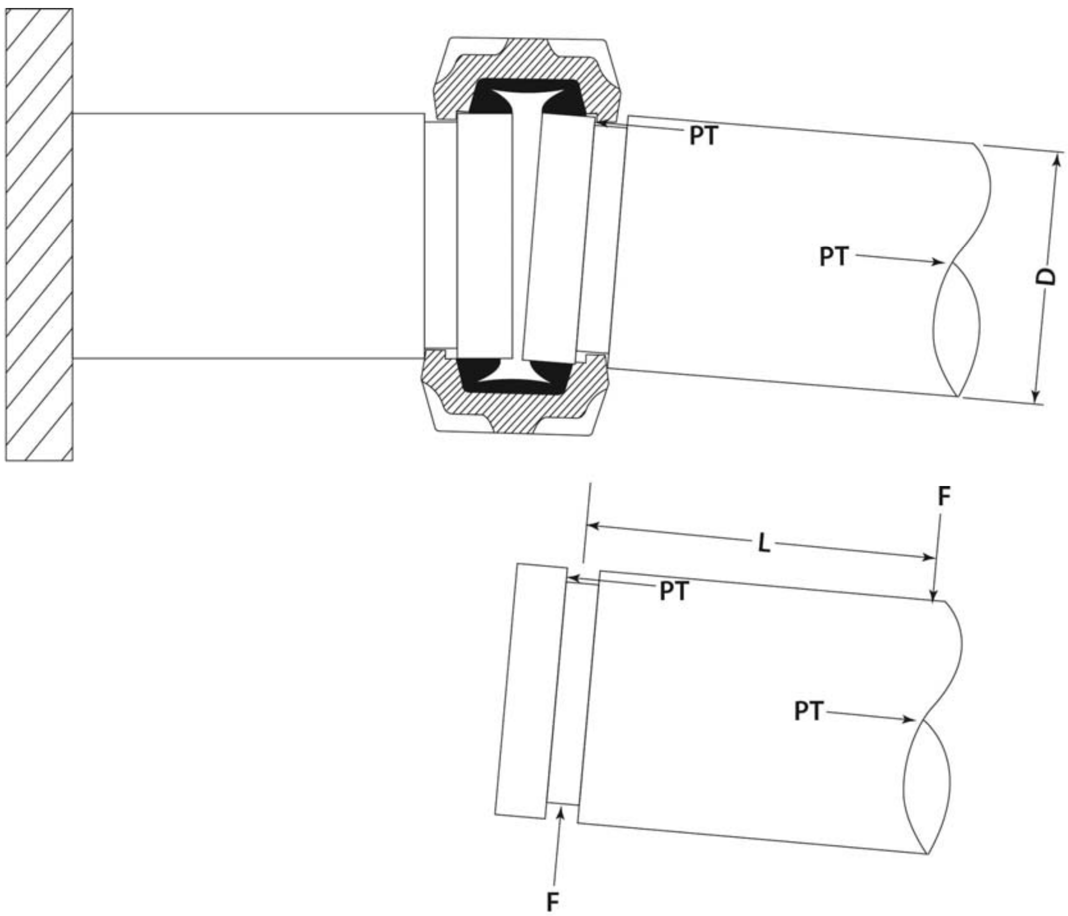


Illustration is exaggerated for clarity