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Evaluation of the Torsional Strength Characteristics of Two Prototype Roll-Coupled Hitches

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1. Background

Truck/trailer configurations, consisting of a truck connected to a trailer via a pintle hitch, are widely used throughout Canada and the world for hauling a variety of commodities (see Figure 1-1 to the right). These configurations have proven very versatile and manoeuvrable under a wide range of operating conditions.

However, the pintle connection does not provide any roll-coupling between the truck and trailer making these configurations less dynamically stable than tractor/semi-trailer configurations. This has led many jurisdictions to limit the payload these types of configurations can carry on their trailers.

Two types of truck/trailer configurations that are widely used in Canada and have no roll-coupling are truck/pony trailers and truck/full trailers.

Figure 1-1. Truck/Trailer configurations

In previous research (Parker, 2004) Feric, now a division of FPInnovations, determined in computer simulations[1] that adding roll-coupling could significantly improve the dynamic performance of truck/full trailers – to the extent that they could meet or exceed performance standards at full payloads. Feric, in conjunction with Arctic Manufacturing Ltd. of Prince George, BC, designed a prototype hitch to add roll-coupling to the truck/full trailer (see Figure 1-2 below).

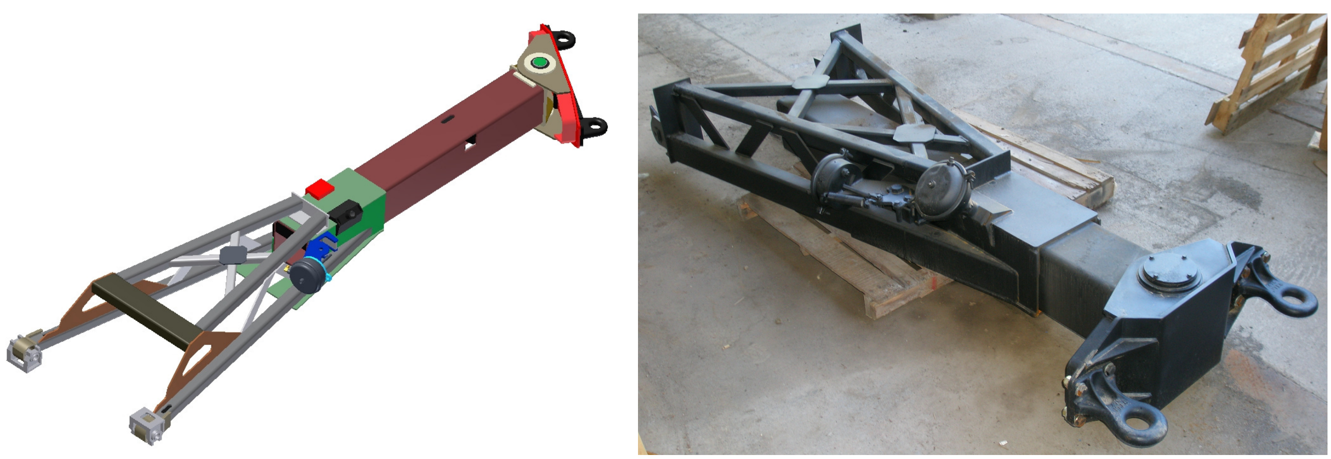

Figure 1-2. Feric prototype full-trailer hitch

[1] Computer simulations were conducted using the University of Michigan Transportation Institute (UMTRI) yaw/roll model.

Larry Wulff (Wolf Trailers Inc.) of Vernon, BC has developed a hitch to address the need for roll-coupling specifically for pony trailers (see Figure 1-3). He approached Feric to evaluate his concept. Using computer simulation, Feric concluded that the addition of roll-coupling would result in improved dynamic performance and stability for the truck/pony trailer at maximum axle weights (Parker, 2008).

A schematic of the final Wolf Trailer prototype hitch is shown in Figure 1-4.

With improved dynamic performance (and the corresponding improvement in overall safety) it was hoped that jurisdictions would increase the weight allowances for these configurations; increasing overall productivity, and decreasing fuel consumption and greenhouse gas emissions (per unit of delivered payload).

Based upon these overriding objectives, Feric (Sinnett, 2008) developed a proposed test plan to evaluate the effectiveness of the Feric hitch. Following the creation of this test plan, Larry Wulff agreed to follow a similar testing methodology for his hitch. Where possible, the testing of the two hitches would be conducted cooperatively; to save both time and cost; to standardize the test procedures; and for better test method repeatability.

Figure 1-3. Early Wolf Trailer prototype pony trailer hitch

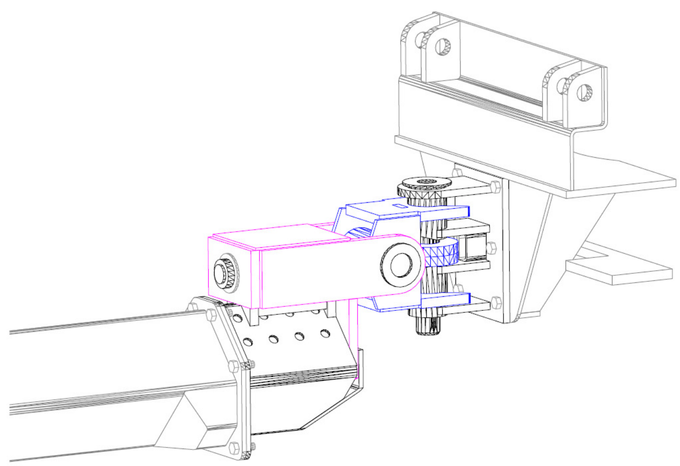

Figure 1-4. Final Wolf Trailer prototype pony trailer hitch

The test plan included the following main steps:

1. Evaluation of hitch torsional stiffness;
2. Evaluation of vehicle performance; and
3. Evaluation of hitch performance in-service.

Phase 1, evaluating the torsional stiffness, has now been completed for both hitches, and is the focus of this document.

2. Torsional Stiffness Test

2.1. Requirements

Feric's test plan proposed torsional strength requirements of a similar nature to those specified for by Transport Canada for C-dollies in Standard 903 (Transport Canada, 1993); increased proportionally to recognize the higher GVW's associated with quad-axle full-trailers as compared to the C-dolly (34 000 kg versus 26 100 kg).

The torsional strength requirements proposed were:

- The ability of sustaining a torque of at least 60 kN•m
- A torsional stiffness of at least 4 kN•m/deg, with respect to the longitudinal direction
- Residual deformation in the hitch (after removal of the torque) of less than 0.5 degrees.

The torsional stiffness test developed was based largely on the existing Test Method 903 (Transport Canada, 1992), created to evaluate the roll stiffness of C-dollies.

While pony trailers do not have the same higher GVW as the full-trailers, the Wolf Trailer hitch was tested to the same requirements as the Feric hitch[2].

2.2. Test Equipment

The torsional stiffness tests were conducted at the FPInnovations – Forintek facility in Vancouver, B.C. The test apparatus (see Figure 2-1) consisted of an H-shaped frame, anchored to the floor, which one end of the hitch was attached to and fixed in place. The

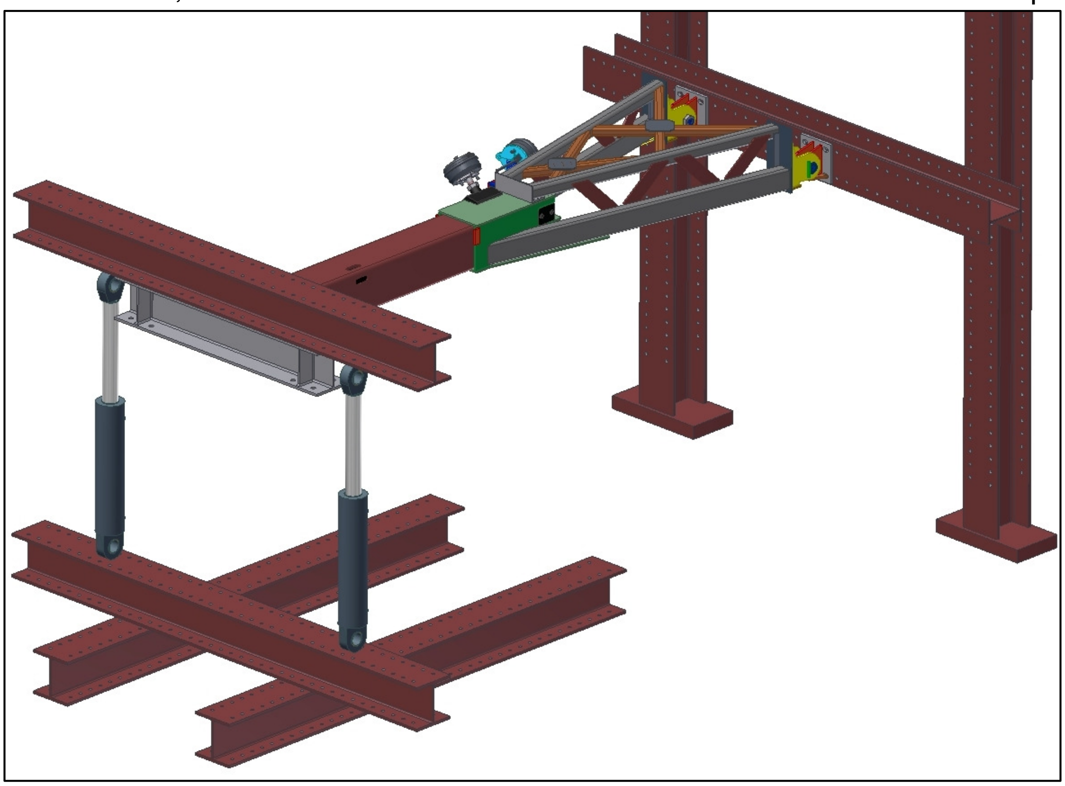

Figure 2-1. Drawing of Forintek Test Apparatus with Feric Hitch

other end of the hitch was attached (through a jig assembly) to two vertically mounted hydraulic cylinders that were attached via a mounting frame to the floor.

The two cylinders were controlled independently through an MTS Flextest computer control system running MultiPurpose Testware (MPT) software (see Figure 2-2). The control system recorded both cylinder displacement and cylinder force (and could control the cylinders using either measure) throughout the test. Controlling the cylinders via displacement ensured that, as one cylinder extended and the other cylinder retracted, the center of twist[3] would remain fixed in space through the entire loading cycle; allowing the hitch to experience pure torsion along its longitudinal axis for the entire test.

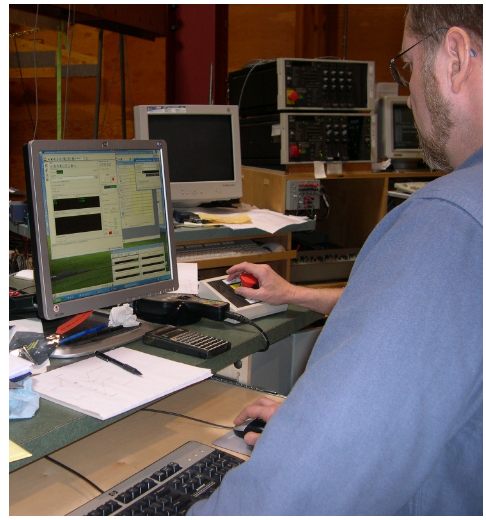

Figure 2-2. Computer control system used for testing

The control system also received data from ten sensors attached to the hitch. These included:

- Cable actuated position sensors, or string-pots (x8). Located (in pairs) at four locations along the length of the hitch. The displacement differential between the two sensors was used to determine the angle of twist at each location.
- Inclinometers (x2)

The locations of the sensors installed on both hitches are shown in Appendix .

2.3. Test Procedure

The test procedure developed (using the computer control system software) consisted of the following steps:

1. Move cylinder 1 to its zero position; defined as the height at which the hitch is level – longitudinally and laterally.
2. Move cylinder 2 to equalize loads between it and cylinder 1. This is the zero torque starting position for the test.
3. Data collection by the control system begins at this point.
4. Gradually apply a torque to the hitch about its longitudinal axis until 60 kN•m is reached; by extending cylinder 1 at a rate of 1 in / 12 seconds and simultaneously retracting cylinder 2 at the same rate until either of the following limits is reached.
    a. A maximum cylinder load of -8000 Lb in cylinder 1 (compression) or +8000 Lb in cylinder 2 (tension) is reached. This load allows the hitch to experience at least the 60 kN•m required. It includes some additional load to account for:
        i. a decrease of the moment arm as the twist angle increases, and

[2] While the Wolf Trailer hitch was specifically designed for pony trailers, it could be in the future adapted to be used on full-trailers. Thus, testing it to the higher requirements seemed appropriate.

[3] The cylinder's center of twist equates to a point equidistant between the top pinned connections of the two cylinders. This point is aligned with the longitudinal axis of the hitch to ensure a purely torsional loading.

ii. some (unknown) level of torque that may be required to take up any slack in the hitch.

b. A maximum of 10 inches of cylinder offset; corresponding to a twist angle of just over 15 degrees[4].

5. Gradually apply a torque to the hitch about its longitudinal axis until 60 kN•m (in the opposite direction) is reached; by retracting cylinder 1 and simultaneously extending cylinder 2 at the same rate as above until either of the following limits is reached.
   a. A maximum cylinder load of +8000 Lb in cylinder 1 (tension) or -8000 Lb in cylinder 2 (compression) is reached.
   b. A maximum of 10 inches of cylinder offset (opposite to that for the initial twist).
6. Gradually remove the torque from the hitch. This is again done at the same rate as above. In order to ensure enough data is collected to identify the zero point, the cylinders are twisted back through to zero to -4000 Lb (cylinder 1) and +4000 Lb (cylinder 2), or 5 inches in the opposite direction.
7. Data collection by the control system ends at this point.
8. Both cylinders are returned to their zero position.

2.4. Analysis Procedure

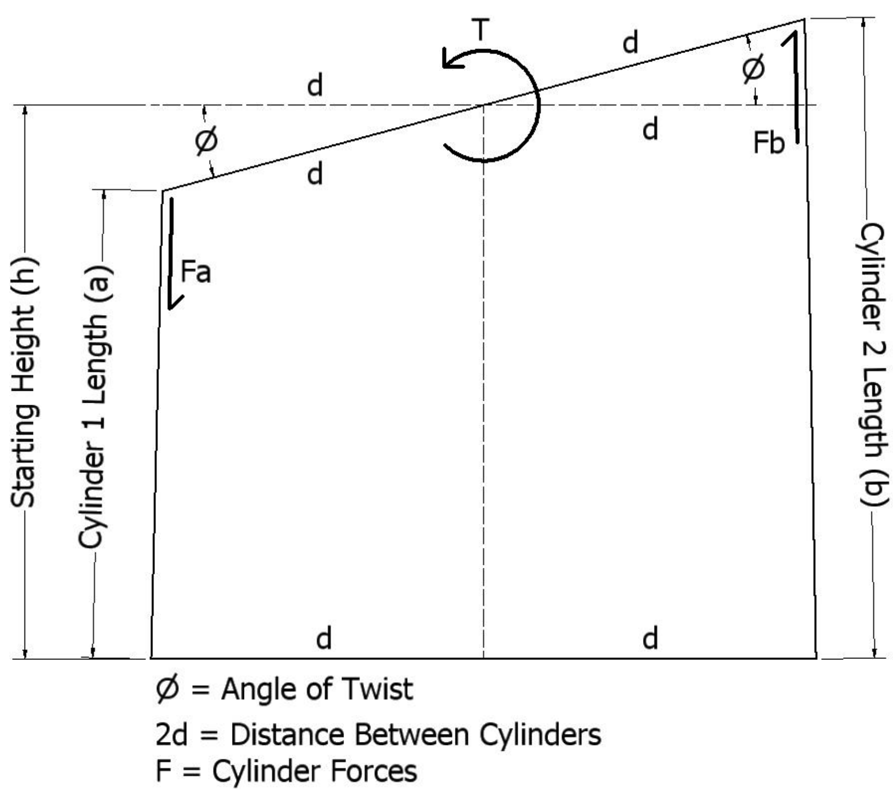

Figure 2-3. Cylinder Geometry

Calculation of Torque

Initially at zero loading, the hitch is level (see Figure 2-3) and there is zero angle of twist. The calculation of torque (T) in such a situation is simply:

$T = F \times 2d$ where T = torque

However, as the angle of twist begins to increase (i.e. – the cylinders begin to extend and retract) the load geometry gets more complex. With an increase in the twist angle, there is a corresponding decrease in the moment arm and a corresponding decrease in torque. For the low twist angles the hitch will experience, the decrease is not large; however it can be compensated for with the following equation:

$T = F \times 2d \times \cos\phi$ where: Ø = angle of twist (at cylinders)

Calculation of Cylinder Twist Angle

The angle of twist (Ø) at the cylinders is calculated using the following equation:

$$\phi = 90° - \arctan(\frac{d}{h}) - \arccos(\frac{2d^2 + h^2 - a^2}{2d\sqrt{d^2 + h^2}})$$

Calculation of Hitch Twist Angle

The overall hitch twist angle (Θ_{hitch}) was determined using the four positional sensors (P1, P2, P3, and P4) identified in Appendix .

The angle at the front of the hitch was calculated with sensors P1 & P2 using the formula:

$$\Theta_{front} = \frac{\delta_{P1} - \delta_{P2}}{D_{1-2}}$$

where:

Θ_{front} = angle at front of hitch

δ_{P1} = sensor P1 change in length

δ_{P2} = sensor P2 change in length

D_{1-2} = distance between P1 & P2

A similar formula was used to determine the angle at the back of the hitch[5]:

$$\Theta_{back} = \frac{\delta_{P7} - \delta_{P8}}{D_{7-8}}$$

Finally, the overall hitch twist angle was found by:

$$\Theta_{hitch} = \Theta_{front} - \Theta_{back}$$

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[4] Once the twist reaches 15 degrees, if the torque has not already reached 60 kN•m, then the torsional stiffness requirement of 4 kN•m/deg will not be reached and the hitch will have failed.

[5] While the back of the hitch was connected to the Forintek test frame, this frame was not perfectly rigid and did deflect somewhat under load. The deflection of the frame needed to be taken into account when determining the twist of the hitch.

3. Results

3.1. Summary

In all of the tests, the hitches responded in a very consistent manner (all of the tests for a given hitch exhibited similar loading curves). For all tests, the hitches were twisted (in both directions) to a torque that exceeded the 60 kN•m required.

There was significant hysteresis exhibited during the tests. The exact mechanism of this energy loss is unknown, however friction losses between parts in the hitch assembly is one probable factor.

The hysteresis meant that the hitch followed different path while loading and unloading. Thus, when the control system indicated that the cylinders had returned to equal loading conditions (zero torque), the hitch would always be at a different angle from where it started. This was not indicative of any residual deformation in the hitch, but it did make any direct measurements of residual deformation difficult. This is discussed further in section 4.1.

After the first test, it became apparent that even at low levels of torque, significant stiffness was encountered. There was no area in the loading curve in which true slack[6] occurred. The stiffness encountered in this low range (between 3 and 4 kN•m/deg) was a great deal less than the rest of the loading/unloading curve. However, as 4 kN•m/deg overall is considered adequate hitch stiffness, this stiffness is clearly significant and cannot be written off as true slack (although it being much lower does indicate that slack is being taken up in this phase).

The lack of any true slack phase together with the hysteresis in the tests also made it impossible to identify a zero point in the data. This made it difficult to determine exactly where the twisting in one direction ended and twisting in the other direction began; making the determination of overall stiffness in one direction problematic.

The overall stiffness of the hitch was determined by using the overall change in torque and the overall change in angle (direction 1 maximum less direction 2 minimum). This methodology, using the whole test in both directions to determine an overall stiffness was similar to that used by the NRC (Preston-Thomas, 1994) to determine tractor and jeep frame torsional stiffness.

Both hitches exhibited a low stiffness range as well as maximum twist angles that appeared to be somewhat offset from zero. Such an offset indicates that, although the hitches started the tests level (at the front and back) there may have been some internal twist slightly biasing the hitch in one direction. This bias would have had no effect on determination of the overall hitch stiffness.

[6] Slack, as defined as angular motion (twist) with little or no torque.

3.2. Feric Hitch

The test procedure was conducted five times for the Feric hitch. The results of these tests are shown in Appendix A and summarized in Table 3-1.

Table 3-1. Feric Hitch Stiffness Test Results

		Test 1	2	3	4	5	Avg
Direction 1							
Maximum Torque	kN-m	-64.3	-64.7	-64.3	-64.3	-64.3	-64.4
Maximum Angle	deg	-4.1	-4.2	-3.9	-4.0	-3.9	-4.0
Stiffness							
Loading	kN-m/deg	20.2	20.7	20.6	20.6	20.8	20.6
Unloading	kN-m/deg	23.6	23.6	23.4	23.2	23.6	23.5
Direction 2							
Maximum Torque	kN-m	65.0	64.6	64.9	64.8	64.9	64.8
Maximum Angle	deg	5.0	4.8	5.1	5.0	5.1	5.0
Stiffness							
Loading	kN-m/deg	19.0	19.5	20.1	19.9	20.1	19.7
Unloading	kN-m/deg	23.3	22.4	22.5	22.7	22.7	22.7
Stiffness							
Low Range	kN-m/deg	4.2	4.0	4.0	3.7	3.7	3.9
Overall	kN-m/deg	14.4	14.4	14.4	14.3	14.4	14.4

In all five tests, the hitch was twisted (in both directions) to a torque that exceeded the 60 kN•m required; averaging 64.6 kN•m.

There was significant hysteresis exhibited during the tests. The stiffness during loading, in both directions, was 12% lower than the stiffness while unloading. One cause may have been the friction (mentioned earlier). Another possible reason may have been the air pressurized clamp locking the extension tube in the assembly (discussed in more detail in section 4.2).

The stiffness encountered in the low range (averaging 3.9 kN•m/deg) was roughly five times less than the rest of the loading/unloading curve. This range extended for roughly 2.5 degrees (roughly -0.75 degrees to +1.75 degrees). This 0.5 degree offset from zero of the low stiffness range corresponded to a similar 0.5 degree offset of the maximum twist angle (averaging -4.0 in direction 1; 5.0 in direction 2).

The overall stiffness of the hitch was determined to be 14.4 4 kN•m/deg, or 3.6 times the stiffness required.

3.3. Wolf Trailer Hitch

The test procedure was conducted seven times for the Wolf Trailer hitch.

The first test revealed a large amount of slack part way through loading. Examination of the hitch found that the bolts fastening the hitch to the jig were not tight and that there was slipping occurring. All of these bolts were tightened with an impact gun and the testing was restarted.

After the next series of three tests further slipping was identified between two bolted sections of the hitch (as indicated by the two offset marker lines shown Figure 3-1). Again, these bolts were re-tightened with an impact gun and the testing was restarted.

A final set of three tests was conducted, and the results of these three tests are shown in Appendix B and summarized in Table 3-2. The four tests with slipping because of loose bolts were not included in the results.

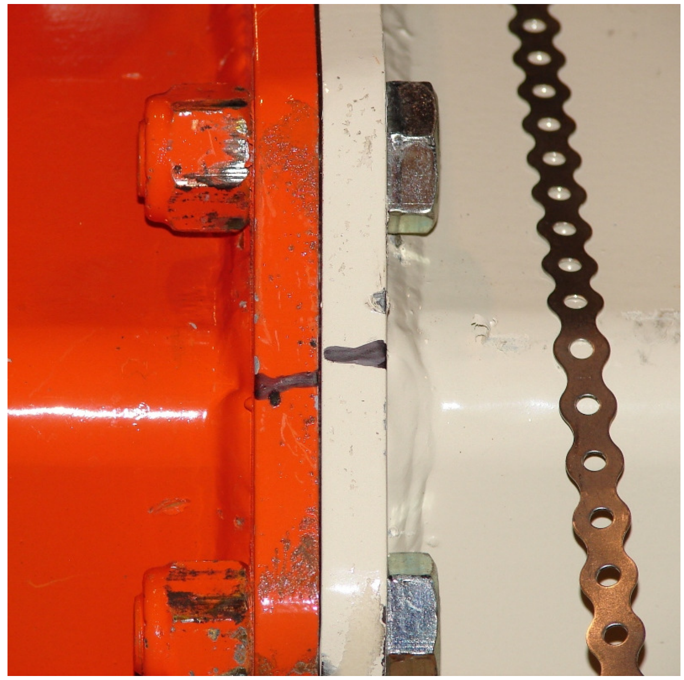

Figure 3-1. Slipping between two bolted sections of Wolf Trailer hitch.

Table 3-2. Wolf Trailer Hitch Stiffness Test Results

	Test	5	6	7	Avg
Direction 1					
Maximum Torque	kN-m	-63.5	-63.5	-63.4	-63.5
Maximum Angle	deg	-4.3	-4.3	-4.3	-4.3
Stiffness					
Loading	kN-m/deg	19.6	19.9	19.9	19.8
Unloading	kN-m/deg	20.2	20.3	20.2	20.2
Direction 2					
Maximum Torque	kN-m	64.3	64.2	64.1	64.2
Maximum Angle	deg	5.1	5.1	5.1	5.1
Stiffness					
Loading	kN-m/deg	19.2	19.1	18.8	19.1
Unloading	kN-m/deg	20.7	20.8	20.7	20.8
Stiffness					
Low Range	kN-m/deg	2.9	2.9	2.9	2.9
Overall	kN-m/deg	13.6	13.6	13.5	13.6

In all five tests, the hitch was twisted (in both directions) to a torque that exceeded the 60 kN•m required; averaging 63.9 kN•m.

The hysteresis exhibited by the Wolf Trailer hitch was much less than that shown for the Feric hitch. This may be due to the lack of a sliding tube-in-tube in the assembly as well as its associated air powered clamp. In direction 1, the stiffness during loading was 2% lower than the stiffness while unloading. In direction 2 this difference was 8%. It is unknown why there was such a difference in energy loss between the two directions.

The stiffness encountered in the low range (averaging 2.9 kN•m/deg) was roughly seven times less than the rest of the loading/unloading curve, however still significant. This range extended for roughly 2.4 degrees (roughly -0.8 degrees to +1.6 degrees). This 0.4 degree offset from zero of the low stiffness range corresponded to a similar 0.4 degree offset of the maximum twist angle (averaging -4.3 in direction 1; 5.1 in direction 2).

The overall stiffness of the hitch was determined to be 13.6 kN•m/deg, or 3.4 times the stiffness required.

4. Discussion

4.1. Residual Deformation

The energy loss (hysteresis) during the tests made direct measurement of potential residual deformation problematic. While it may be possible to reduce the amount of hysteresis, at least on the Feric hitch (see section 4.2 below), significant hysteresis would still remain, masking any deformation that may have occurred[7]. The hysteresis ensured that the zero load point while unloading would always be quite different from that when loading.

In the previous torsional stiffness testing conducted by the NRC (Preston-Thomas, 1994) no attempt was made to identify residual deformation after loading the specimen in one direction – each torsional test consisted a twist in one direction, followed directly by a twist in the opposite direction; in the same manner as the testing was conducted here. However, the C-dolly TM 903 does specify the need to identify any residual deformation in the frame, and limit it to less than 0.5 degrees. As the proposed requirements for the roll-coupled hitches were developed from the C-dolly standard, meeting the 0.5 degrees maximum residual deformation was set as one of the objectives of this testing.

Without any direct measurement to the residual deformation, this objective cannot be confirmed as being met. It is possible, however, to use the test results to indirectly analyze whether any deformation occurred.

Plastic (or residual) deformation results in changes in material properties (Beer & Johnston, 1981). In steel, enough plastic deformation can result in work hardening of the material. Work hardening has the effect of increasing the yield strength of the material in the direction of applied stress and reducing the yield strength of the material by the same amount in the direction opposite to the applied stress. This would change the behaviour the material when twisted one direction as compared to the other direction. However, the results of all of our tests show that both hitches performed similarly in both directions of twist (in terms of stiffness, total torque levels, and the general shape of the loading/unloading graphs). This would seem to indicate that plastic deformation, if present, was not of a sufficient level or duration to cause any change in the material properties of the hitches.

[7] The Wolf Trailer hitch experienced much less hysteresis that the Feric hitch, yet was still unable to stay within 0.5 degrees when returned to the original load conditions.

Another method by which any plastic deformation may be identified involves the comparison of all of the tests for each hitch. If any plastic deformation does occur, the torque curves should move from test to test (by an angle equal to the deformation). To examine this, two points were identified on each test: at 60 kN and at -60 kN. Using the twist angles for these two torque values[8], corresponding twist angles at zero torque were calculated. This was done separately for both the loading and unloading curves, both of which pass through these torque values with slightly different twist angles – due to hysteresis. The methodology is shown in Figure 4-1 and the results are shown in Table 4-1.

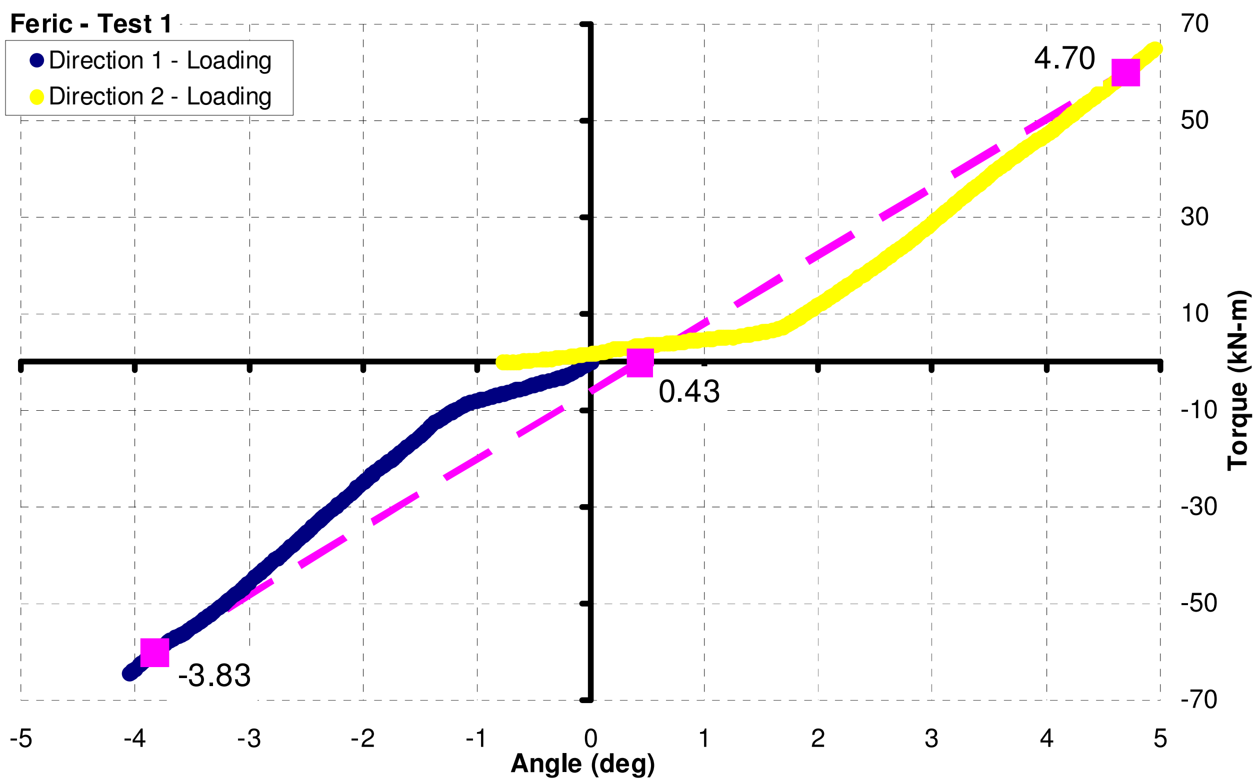

Figure 4-1. Sample X-axis intercept graph

Table 4-1. X-axis Intercept Results

Feric Tests		1	2	3	4	5	Avg
X-axis Intercept							
Loading	deg	0.43	0.31	0.54	0.52	0.54	0.47
Unloading	deg	0.45	0.31	0.54	0.53	0.54	0.47
Average	deg	0.44	0.31	0.54	0.52	0.54	0.47

Wolf Trailer Tests		5	6	7	Avg
X-axis Intercept					
Loading	deg	0.38	0.39	0.37	0.38
Unloading	deg	0.38	0.39	0.37	0.38
Average	deg	0.38	0.39	0.37	0.38

[8] None of the tests had data points exactly at either 60 kN or -60 kN. Values at these points were interpolated from the data points immediately before and after these values.

For the Feric hitch, the X-axis intercept varies by no more than 0.23 degrees, with the final three tests consistently at an X-axis intercept in the range of 0.52 to 0.54 degrees. While the slightly greater variability in tests 1 and 2 may be due to deformations, it is more probable that this is due to the hitch reaching an equilibrium state with the air-operated clamp (discussed further in section 4.2). Regardless, the 0.23 degree variability is less than the 0.5 degrees residual deformation requirement.

For the Wolf Trailer hitch, the X-axis intercept varies from 0.37 to 0.39 degrees. This would seem to indicate plastic deformations were not occurring in this hitch.

One final method by which plastic deformations can be identified in ductile materials, is as a decrease in the slope of the torque-angle of twist graph as the stress approaches the yield point. For all of our tests, the slope of the torque-angle of twist graphs was the same at our maximum torque as it was throughout loading. In the Feric hitch, one exception to this occurred in the (roughly) 40-50 kN•m range of all five tests. A slight flattening of the loading curve through this range did occur. However, in all cases, the curve again returned to its previous slope after this range. This is not behaviour that can be typically associated with plastic deformation, and thus cannot be indicative of such. The exact nature of this behaviour is discussed in section 4.2.

4.2. Air-operated Clamp

A closer analysis of the hysteresis in the Feric hitch shows that the bulk of the hysteresis seems to occur near 55 kN•m, where a slight flattening of the loading curve (or decrease in stiffness) is observed (see Figure 4-2). This occurred in all tests; and in both directions of

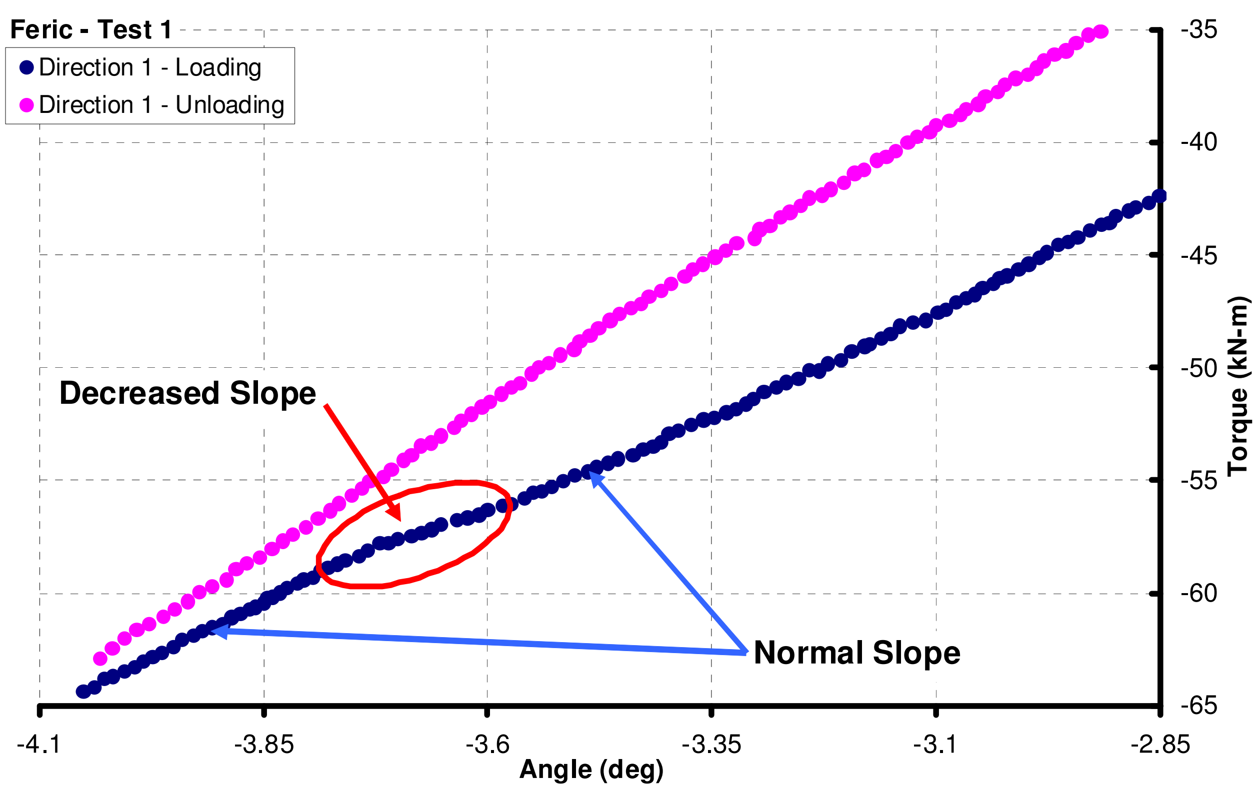

Figure 4-2. Close-up view of change in slope on Torque-Twist graph

twist.

This brief decrease in slope may indicate a limit of the air pressurized clamps' ability to hold the extension tube, which is then sliding slightly in the assembly. That the curve quickly returns to its higher stiffness indicates the movement is momentary and the tube is again held firmly in the assembly.

It is possible that increasing the pressure in the locking clamp may provide increased resistance and eliminate this energy loss – reducing the overall hysteresis. This would increase the stiffness while loading and also (slightly) increase the overall stiffness. However, during testing the air clamp was pressurized to 110psi. A truck air system typically will not be pressurized much higher than this, making this option not viable. Another option would be to replace the air clamp with a mechanical one.

However, the hitch performs more than adequately in its present form and such a change need not be considered a requirement for future operation.

4.3. Fasteners

On two separate occasions fasteners on the Wolf Trailer hitch were not tightened properly; resulting in the invalidations of four tests[9]. It will be critical for any future production units to ensure all fasteners are tightened to their approved torque. As these hitches are used in high vibration environments, the use of a lock nut to prevent future loosening of these bolts may be appropriate. Additionally, any maintenance manual created for the hitch should indicate regular checks of all fasteners.

[9] Preliminary calculations on the data for these four tests indicate that, even with the incurred slippage, the hitch would have had a torsional stiffness well in excess of what was required. However, the results would not have been truly indicative of the torsional stiffness of the hitch.

5. Conclusions

From the results of this testing, it is possible to make the following conclusions:

- Both the Feric hitch and the Wolf Trailer hitch exhibited the ability to sustain a torque of at least 60 kN•m. All tests conducted were to over 64 kN•m. The maximum applied torque resulted in roughly 5 degrees of twist, much less than the 15 degrees allowable.
- Both hitches exhibited a torsional stiffness of at least 4 kN•m/deg, with respect to the longitudinal direction. In the case of the Feric hitch, its average torsional stiffness was 3.6 times this number; while the Wolf Trailer hitch was 3.4 times this number. These results could be used to indicate that both hitches are over-designed, and that design refinements could reduce these factors somewhat – saving weight. However, this is not recommended to any great extent. Truck/Trailer hitches can operate in extreme environments; where a great deal of vibration and atypical loading conditions can occur. Components designed to operate in such conditions require higher than standard factors of safety. Typical components designed for lower risk situations (such as strictly highway operation) can have safety factors in the range of 2; in riskier situations, safety factors in the range of 3 to 3.5 are more appropriate.
- Residual deformations were not directly measured in either hitch and as such no firm conclusions can be made about their existence or degree. However, from indirect analysis of the results, no signs of residual deformation were found in any of the tests.

6. Next Steps

Both hitches will continue to undergo further testing and evaluation prior to looking for full-scale approval of this concept and the desired increase in GVW. The following three steps are proposed:

6.1. Truck frame strength evaluation

At the recommendation of the BC Ministry of Transportation, the next phase of testing will involve the two trucks to which these hitches will be attached. These trucks will be subjected to the same torsional loading that the hitches were; and their strength will be evaluated.

Following this, the hitches will be put on trailers and attached to the two trucks for further testing.

6.2. Stability testing

The next test will be to examine configuration stability, via tilt table testing. Stability will be ascertained using the Static Rollover Threshold (SRT)[10] performance measure. Tests will be conducted in a fashion similar to SAE Recommended Practice J2180.

Vehicle performance shall be determined for a tandem or tridem drive truck / trailer for the following conditions:

[10] The SRT is defined as the maximum lateral acceleration (in g's) which a vehicle can sustain without rolling over. It is deemed acceptable if the SRT is greater than 0.35 g's.

- Trailer loaded to existing weight restrictions with standard non-roll coupled drawbar,
- Trailer loaded to increased weight allowances with standard non-roll coupled drawbar,
- Trailer loaded to existing weight restrictions with roll-coupling device, and
- Trailer loaded to increased weight allowances with roll-coupling device.

The truck shall be loaded to maximum axle group weights on the steering axle and the drive group. Configuration dimensions, axle loads, and component specifications (tires, suspensions, and axles) will be recorded prior to each test.

The configuration will be restrained to prevent complete rollover, thereby ensuring safety is maintained and damage to the configuration is prevented. The tilt table will be raised up to the point where full wheel lift-off has occurred on the high side of the tilt table for all axles except the steering axle. The rotation angle of the tilt table, trailer frame, truck frame and drawbar will be measured. In addition, individual wheel loads will also be recorded to measure the load transfer progression of the configuration.

6.3. In-field evaluation

Further evaluation of the configurations will be conducted during long-term field trials. The trailer will operate at the increased weight limits for the duration of the trial. The in-service evaluation shall occur over a number of months. It will include a number of ride-along trips. These trips will allow observation of the configuration in operation and operator feedback. Information gathered during this trial period shall include:

- Operational issues – One area of potential concern is the ease by which a trailer with this type of hitch can be hooked to the truck, especially on uneven terrain where the truck and trailer may not be level. In such a case, how hard is it for the operator to secure both hitches?
- Hitch durability – On each trip, the hitch shall be fully examined for any signs of cracking or wear. Other areas of the vehicle (e.g. -the truck hitch plate and potentially affected areas of the trailer or dolly) shall also be examined.
- Any other maintenance issues that may arise.
- Vehicle payloads during this period shall also be recorded; for comparison to historical payloads (prior to installation of the hitch) for the vehicle, or ideally to vehicles of similar configuration (without the roll-coupled hitch) that the operator may have operating concurrently.

7. References

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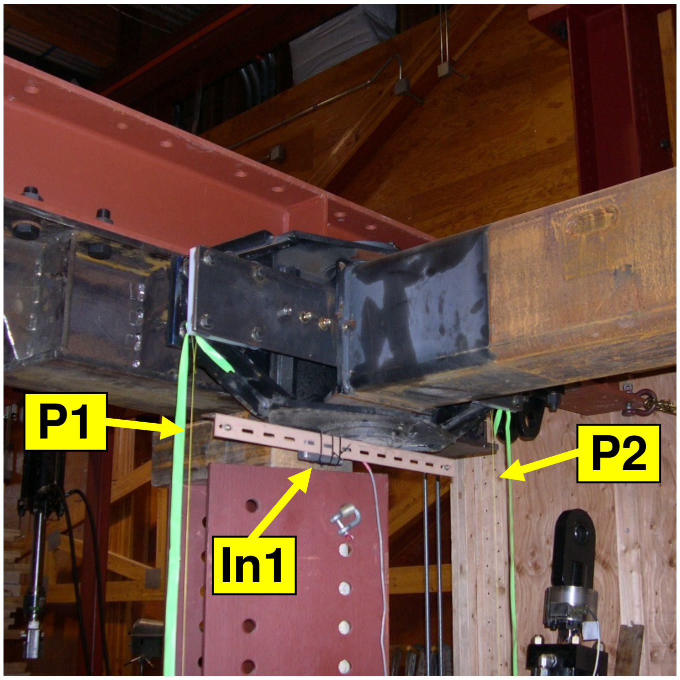
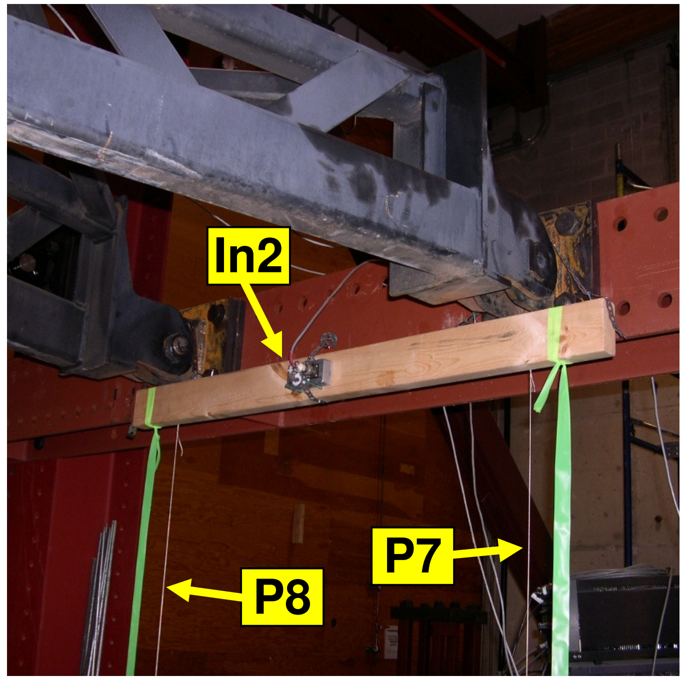
Appendix A. Sensor Locations

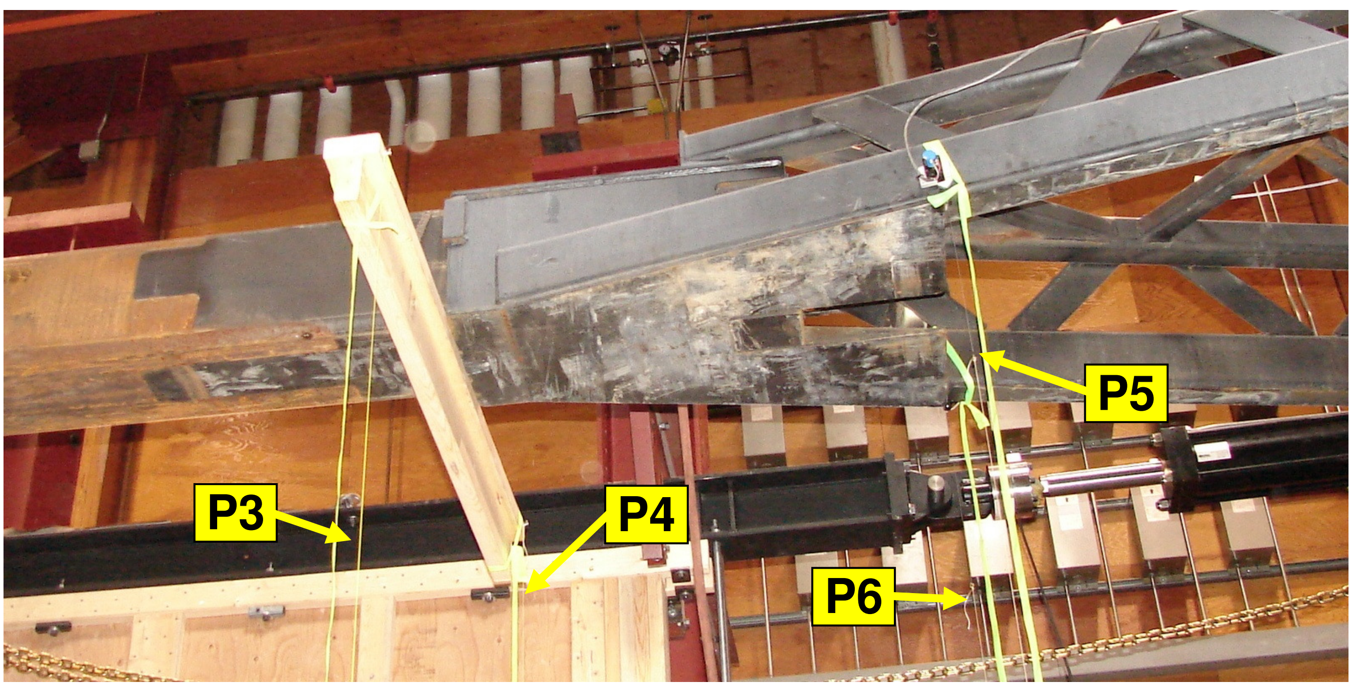
A.1. Feric Hitch



Appendix Figure A-1. Feric Hitch front sensor locations (see A.3 for naming convention)

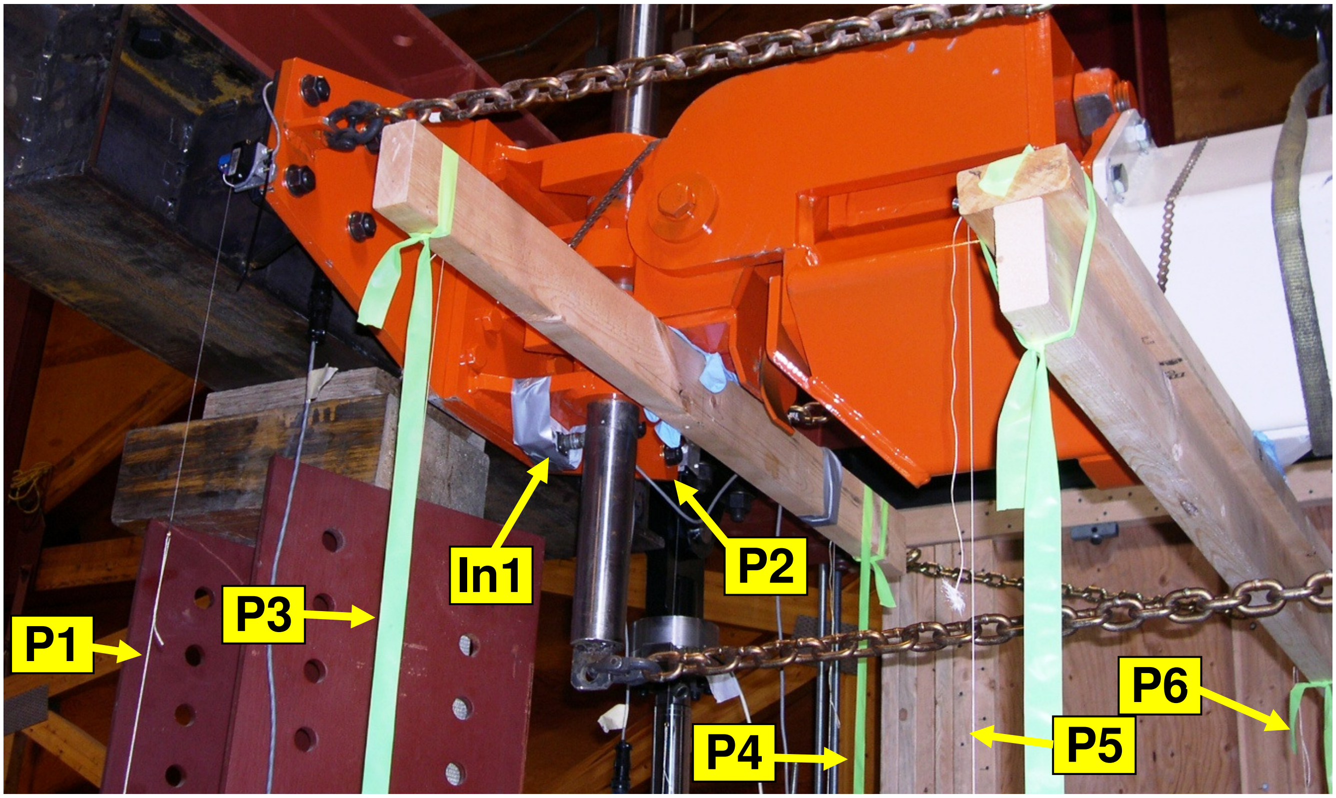


Appendix Figure A-2. Feric Hitch rear sensor locations

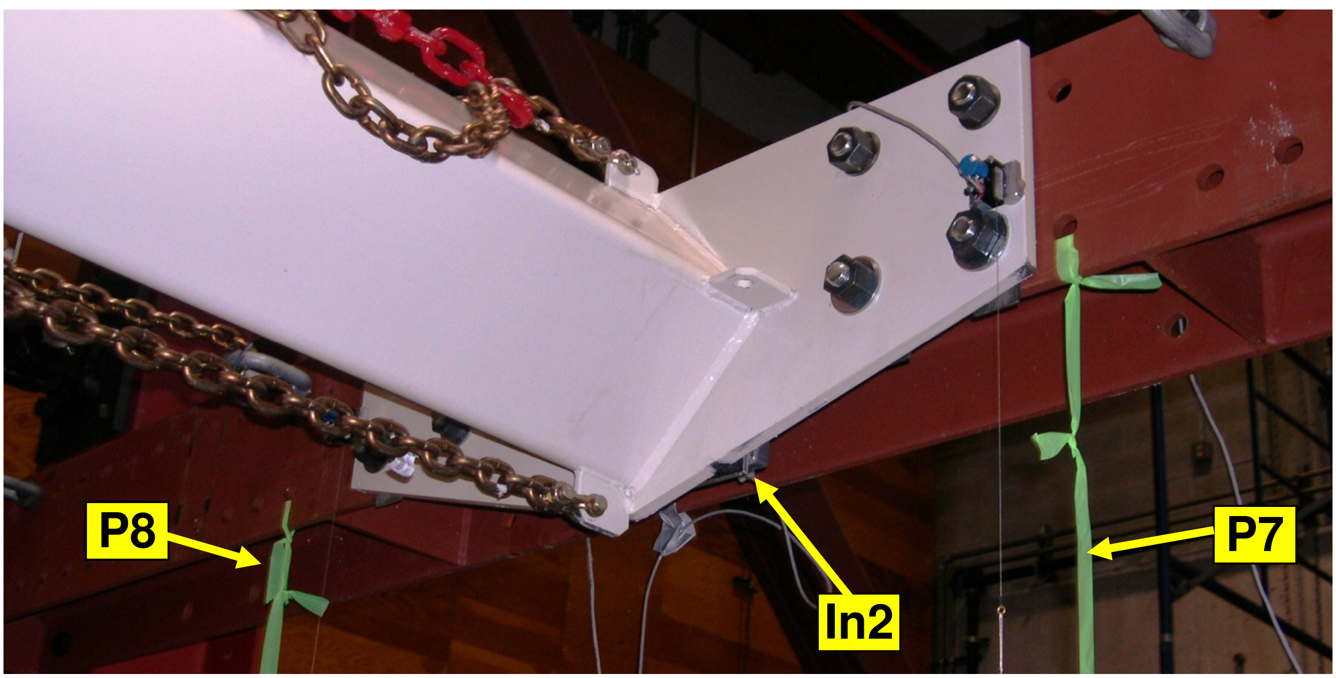


Appendix Figure A-3. Feric Hitch middle sensor locations

A.2. Wolf Trailer Hitch



Appendix Figure A-5. Wolf Trailer Hitch front sensor locations



Appendix Figure A-4. Wolf Trailer Hitch rear sensor locations

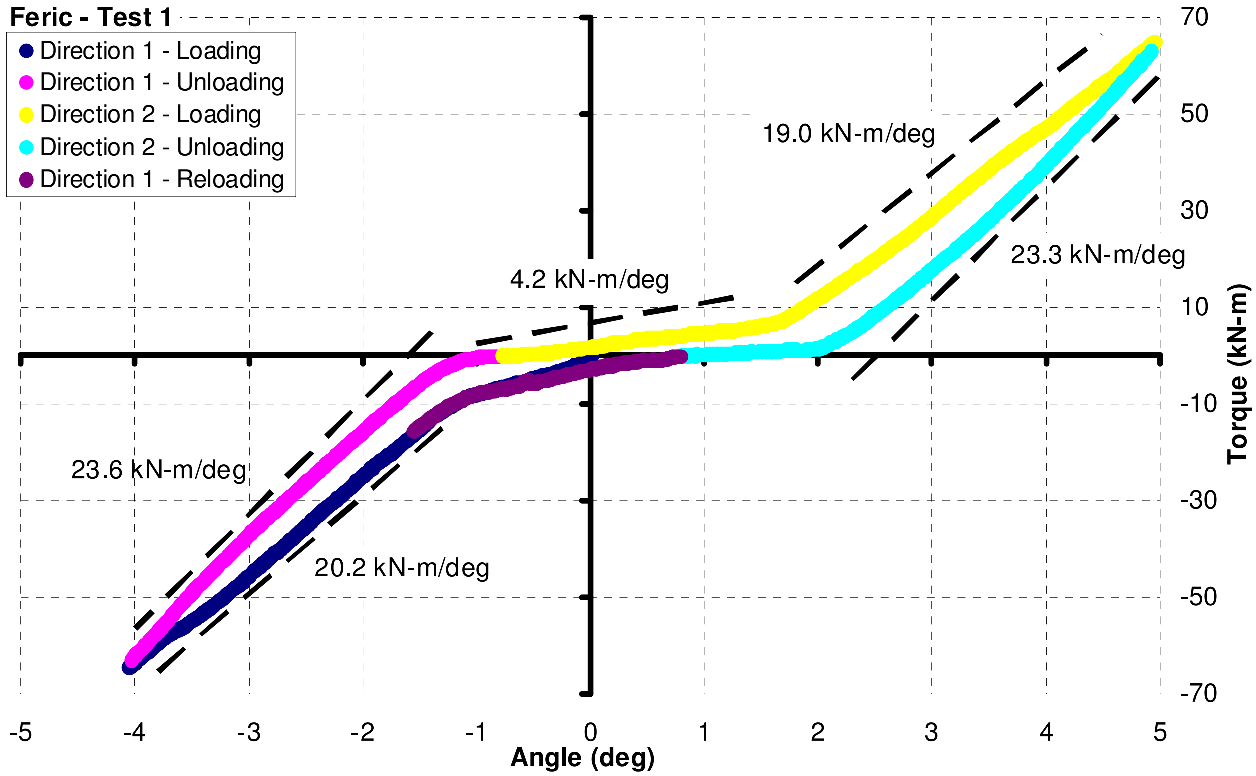
A.3. Sensor Information

P1 through P8 refers to the eight positional sensors. P1 & P2 were used to determine the angle at the front of the hitch. P7 & P8 were used to determine the angle at the back of the hitch. The difference between these two angles represented the overall twist angle of the hitch (used to determine torsional stiffness). The four middle sensors (P3 through P6) were installed as additional information that could be used to indicate in which section of the hitch the majority of twist was occurring.

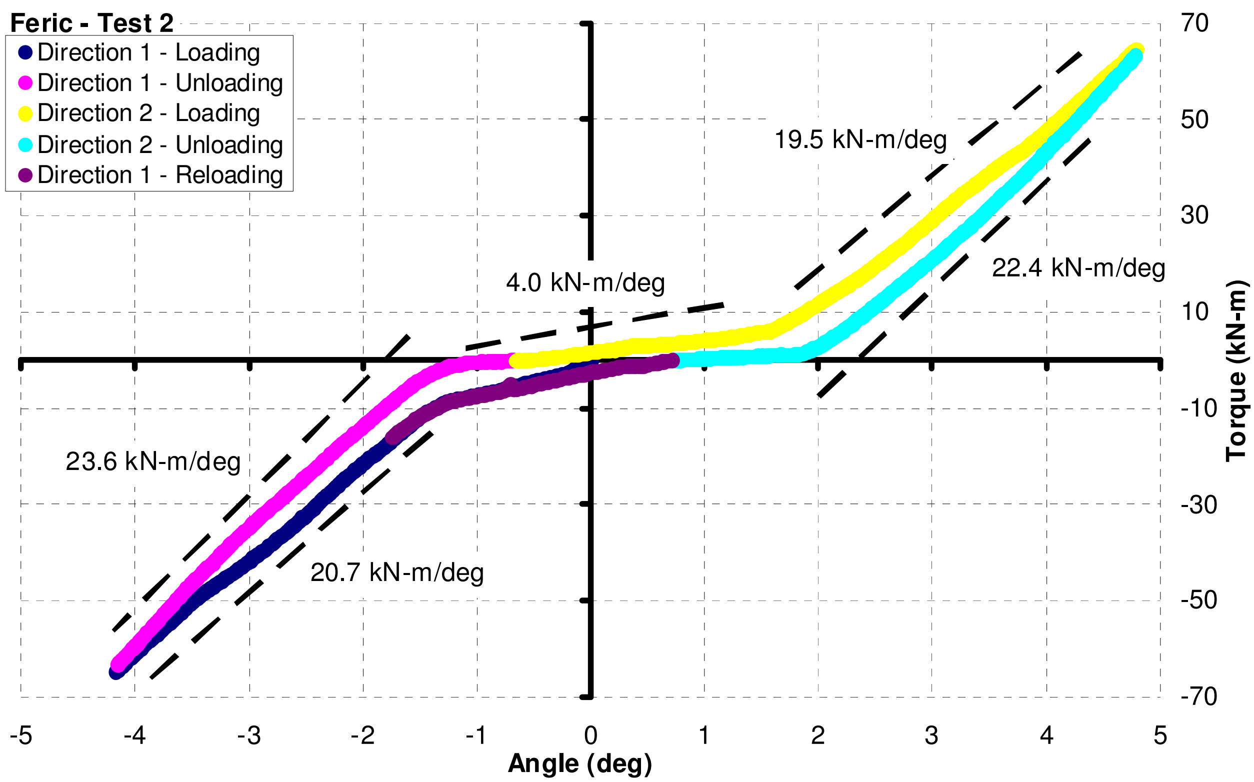
For the Feric hitch, sensors P3 & P4 were mounted off of the hitch itself on the ends of a 2x4. At this location, the hitch was quite narrow and any twist of the hitch would barely have registered on the sensor. This was done to amplify any change of length in the sensor, increasing its resolution. For the Wolf Trailer hitch, sensors P3 through P6 were similarly extended outwards.

In1 and In2 refer to the two inclinometers. They provided secondary confirmation data to compare to the front (P1-P2) and back (P7-P8) positional sensors

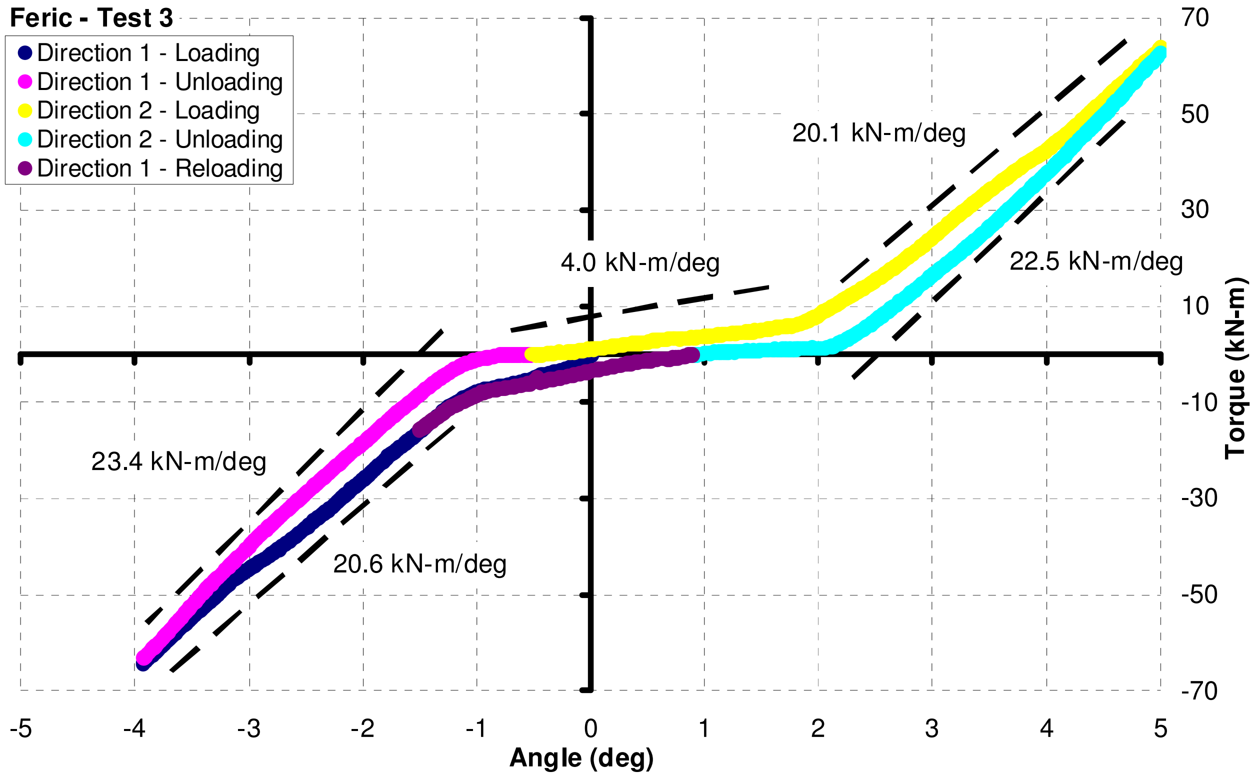
Appendix B. Stiffness Test Results – Feric Hitch



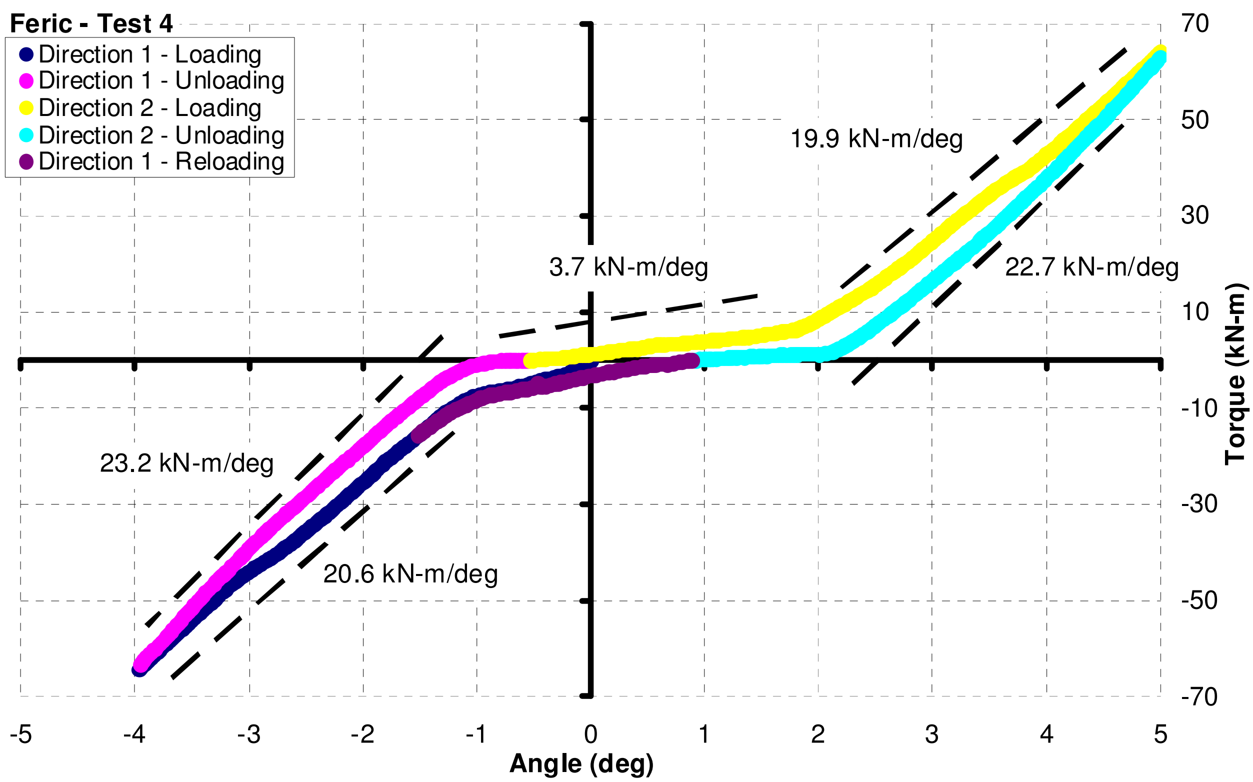
Appendix Figure B-1. Feric Hitch Stiffness Test 1



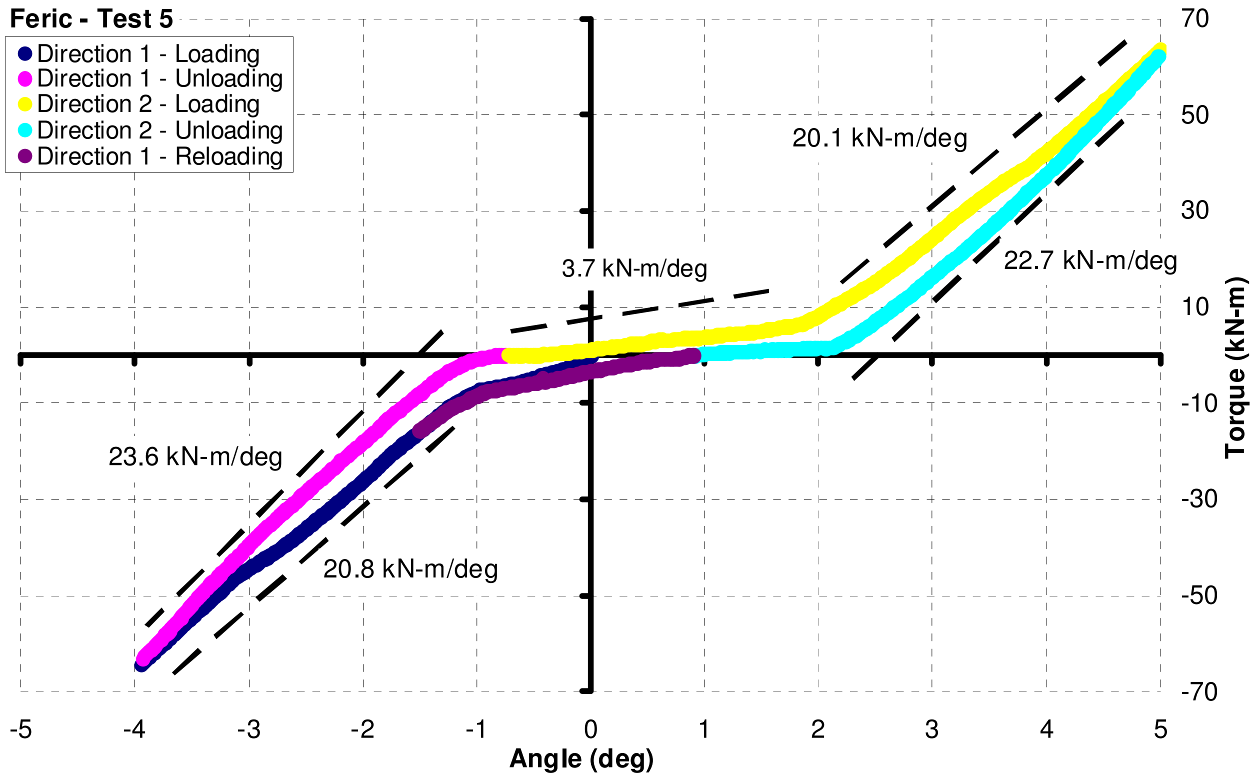
Appendix Figure B-2. Feric Hitch Stiffness Test 2



Appendix Figure B-3. Feric Hitch Stiffness Test 3

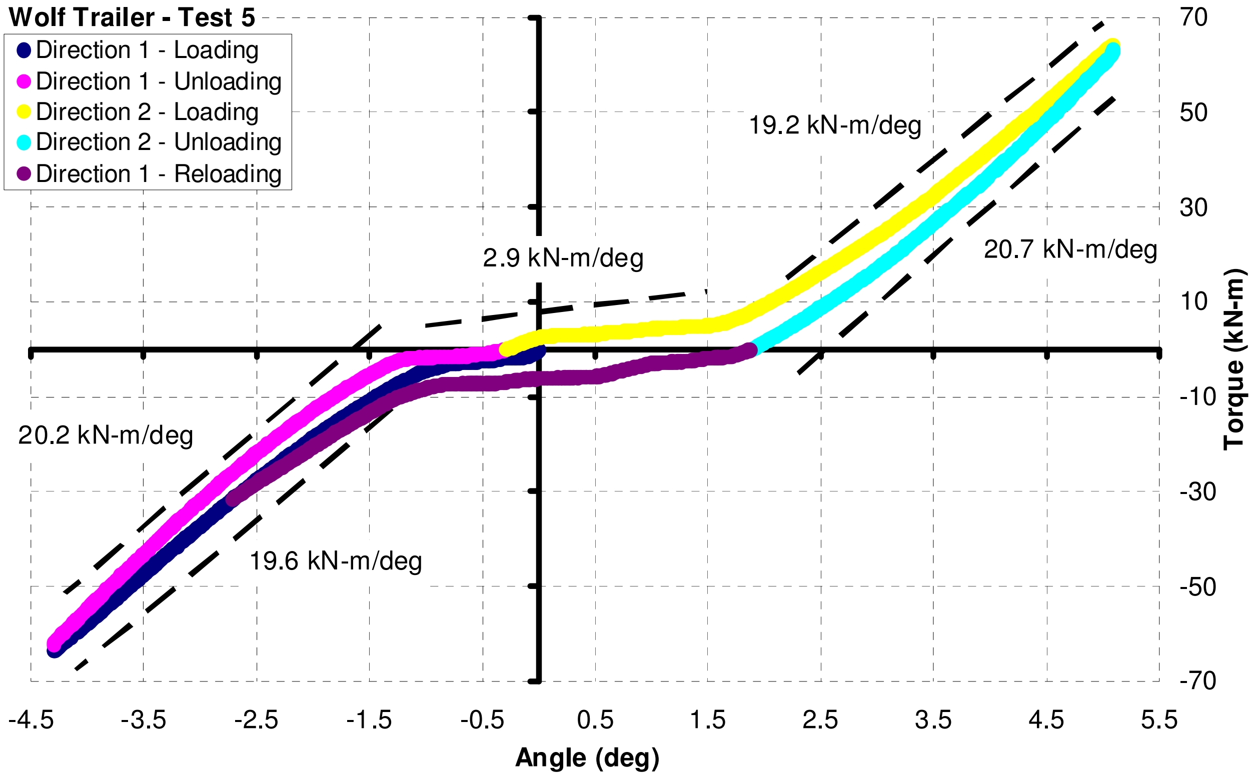


Appendix Figure B-4. Feric Hitch Stiffness Test 4

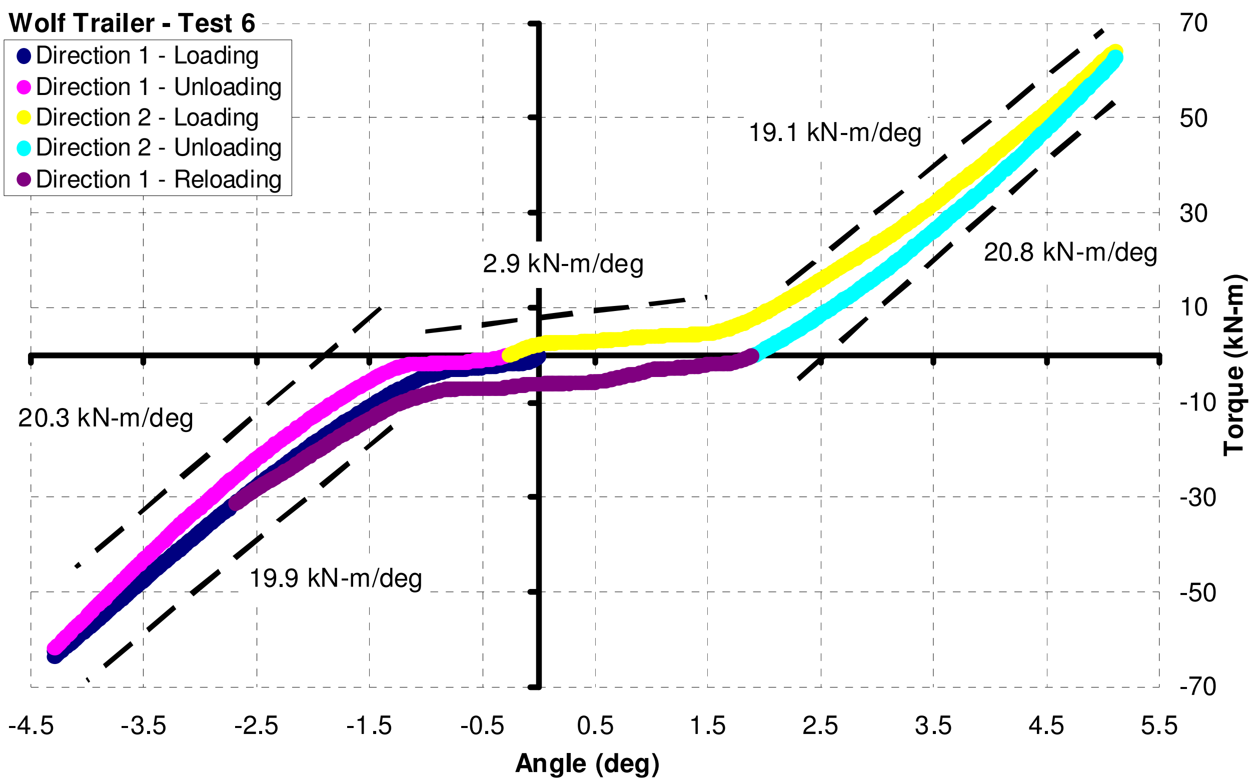


Appendix Figure B-5. Feric Hitch Stiffness Test 5

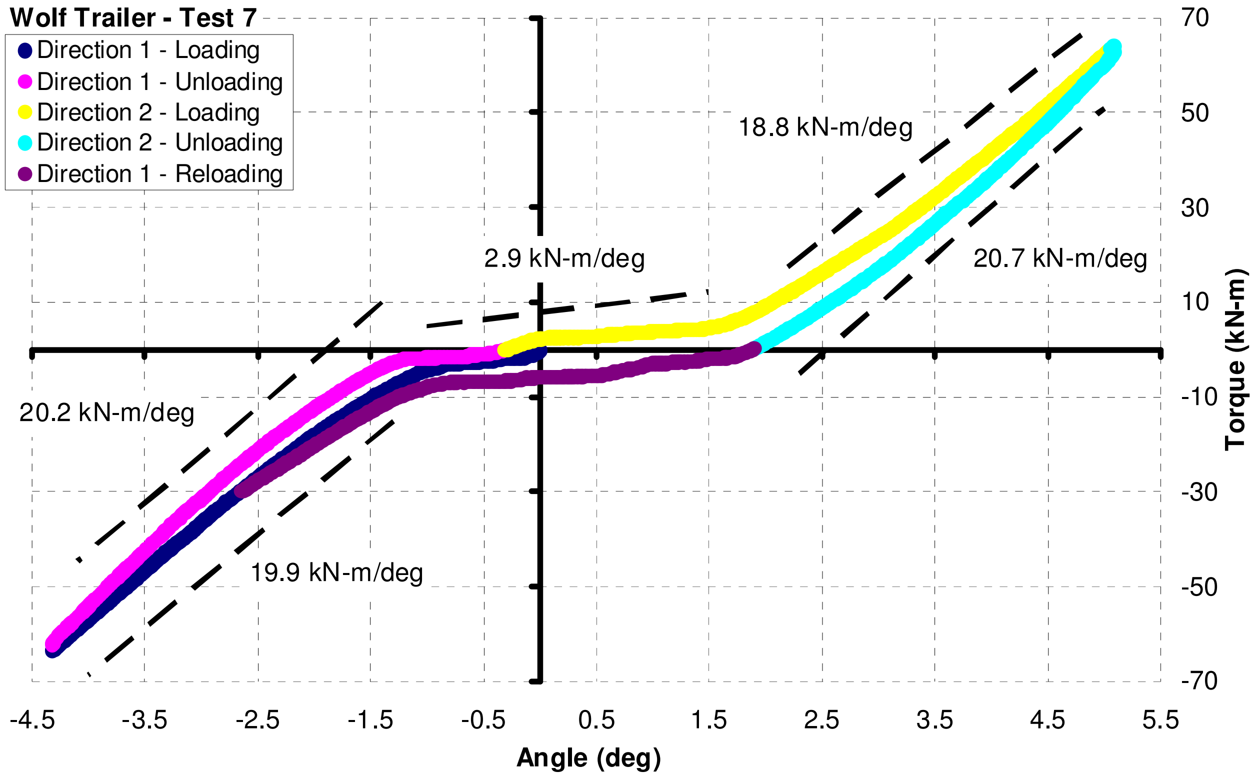
Appendix C. Stiffness Test Results – Wolf Trailer Hitch



Appendix Figure C-1. Wolf Trailer Stiffness Test 5



Appendix Figure C-2. Wolf Trailer Stiffness Test 6



Appendix Figure C-3. Wolf Trailer Stiffness Test 7