QUICK RELEASE PERFORMANCE ANALYSIS
REPORT 1

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I. SUMMARY

This report summarizes a year's effort in exploring the performance of bicycle quick releases (QR's) relative to the International Standards Organization's 4210 standard. This work was spawned by questions raised by John Barnett and C. Calvin Jones of the Barnett Bicycle Institute after their reading of an article by Fred De Long (De Long, A. F., 1991. New Quick Release Standards. Cycling Science, March: 23-26).

Reported herein are:

1. A brief review of De Long's article;
2. A description of the experimental methods and equipment developed during the course of this research;
3. Experimental measurements for closing, opening and angle of engagement;
4. Experimental measurements for clamping force;
5. Experimental measurements for pull-out or retention force;
6. Experimental measurements analyzing the effect of fork material;
7. Experimental measurements studying the effect of fork alignment; and,
8. Development of a preliminary guideline for proper quick release engagement.

It must be understood that the guideline developed herein is based on preliminary analysis of data. Additional data and refined analysis are required before a final guideline can be established.

The principal conclusions drawn herein are:

1. The experimental methods developed at KTL are repeatable and suitable for study of quick release performance.
2. The ISO standard for retention is easily met by all quick releases studied.
3. An engagement angle of 90^o appears to be a suitable guideline. It insures that the quick releases are properly engaged without over-stressing the skewer *based on our sample set and aligned forks*.
4. De Long's recommended criteria of 12 lb_f opening force applied 55 mm from the lever pivot appears to be insufficient to insure that the ISO standard is met.
5. The angle of engagement is affected by fork alignment such that engaging a quick

release at 90^o on severely misaligned forks will result in a lower retention force than the ISO standard for some releases although well above the 1989 standard.

6. Additional data, a larger sample set and refined analysis are required prior to establishing a firm guideline.

We wish to acknowledge the support of Barnett Bicycle Institute, Bicycle Art (Indianapolis, Indiana), Campagnolo, Cycle Works (Lawrence, Kansas), Mavic and Sachs. Funds from Occidental Petroleum Foundation were used for supplies and test equipment: we gratefully acknowledge their support.

II. PROJECT SCOPE

The purpose of this work is to develop a guideline for the proper adjustment of quick release retention systems. The guideline will only be useful if it is easily implemented by shop mechanics, if it can be taught to consumers and if it is traceable to appropriate international standards. The guideline is to be based on fundamental experimental measurements with emphasis on quick releases and forks found on bicycles intended for general public use.

The purpose of this report is to describe the experimental procedures and equipment developed to date, to present summaries of the initial measurements of closing, opening, clamping and pull-out force and to develop a preliminary guideline.

This guideline is not final and should not be used as a shop standard until additional data are acquired with a more comprehensive analysis of all of the data.

III. INTRODUCTION

Quick Release (QR) retention systems were once placed only on upper-end, competitive bicycles. However, in recent years, QR's have become more and more common in entry-level bicycles. Use of QR's for front wheel retention eases removal; however, many entry-level riders are not familiar with proper QR adjustment. Shops frequently do not train consumers in proper adjustment. Therefore, consumers who do not know how to properly adjust a quick release are purchasing sophisticated retention systems.

The ease of QR disengagement and front wheel removal potentially leads to improper adjustment and catastrophic disengagement of the wheel and injury to the rider. The increased frequency of injuries due to front wheel disengagement has led to increased litigation with subsequent financial damage to the industry.

In response, manufacturers have added secondary devices designed to provide a second layer of protection to QR retention. These devices frequently require loosening the QR adjusting nut for wheel removal. The addition of these devices may actually increase the potential for improper installation. Even if the bicycle leaves the shop with the QR properly adjusted, removal of the front wheel by the consumer will result in a change in the QR adjustment with the potential for catastrophic disengagement.

The fundamental fact is, *QR's have been effective in attaching front and rear wheels to bicycles under extreme operating conditions*. Therefore, the failure of front wheel retention must generally be due to improper installation.

The International Standards Organization (ISO) has published standards for front wheel retention. The purpose of ISO 4210, *Cycles - Safety Requirements of Bicycles*, (Third Edition, 1989-10-01) is "to ensure that bicycles manufactured in compliance with it will be as safe as is practically possible".

In Section 2.6.4, it is stated that: "Wheels shall be secured to the bicycle frame with a positive locking device and shall be tightened to the manufacturer's specification."

In Section 2.6.4.1, under Front Wheel Retention, it states that: "There shall be no relative motion between the axle and the front fork when a force of 500 N is applied symmetrically to the axle for a period of 30 s in the direction of removal of the wheel." A retention force of 500 N is equivalent to a force of 112 lb_f. De Long (De Long, A. F., 1991. New Quick Release Standards. Cycling Science, March: 23-26) states that the standard was revised upward to a retention force of 2300 N (517 lb). However, at the time of this writing, the ISO publication has not been changed.

The shop or the consumer can not easily measure wheel retention forces described above. The mechanic and consumer do not know *a priori* whether a QR is properly adjusted. Consequently, an installation guideline that can be used by shops and taught to consumers is required to minimize the potential for injury.

The purpose of this research is to develop this guideline. It is to be firmly based on the ISO 4210 standard and on experimental measurements. The guideline should be applicable to all commonly-available QR's intended for general consumer use.

IV. ANALYSIS OF DE LONG'S ARTICLE

De Long (De Long, A. F., 1991. New Quick Release Standards. Cycling Science, March: 23-26) writes that lawsuits have threatened the integrity of the QR system. De Long states that in an effort to minimize litigation manufacturers have concentrated on testing, design changes (aforementioned secondary devices), international standards and instruction/education. He presents a six point guideline for proper installation of wheels attached with QR's.

Focusing on the front wheel, De Long's steps are:

1. The front wheel axle is to be placed in the drop-outs such that it seats against the top of the drop-out. The adjusting nut on the QR is to be turned such that "some resistance" is felt when the lever is "a bit" beyond parallel with the axle. The QR is not to be over-tightened more than 45 pounds applied at 55 mm from the lever pivot to avoid over-stressing the QR skewer.

2. A QR that is properly adjusted should emboss the drop-outs. The maximum force should be 44.8 pounds (2300 N - his value, the conversion is not correct) applied at 55 mm from the lever pivot.

3. Once locked, the clamping should be checked by opening the QR. The release force applied at 55 mm from the pivot should be greater than or equal to 12 pounds. If the force to open is less, the adjusting nut should be tightened and the procedure repeated.

4. As a double-check, the bicycle should be lifted and the wheel given a sharp downward blow. It should not loosen.

5. Despite the presence of secondary devices, QR's should be adjusted as above. The manufacturer's recommendations are to be followed in installing and adjusting the secondary devices.

6. If the bicycle is loaned, instructions are to be given to the borrower.

These instructions are well intentioned but do not take into account fork alignment, fork material, lever length, QR condition or QR lubrication. The QR length is significant since some are less than 55 mm long. All of these affect the force measurements and consequently, proper wheel retention. Further, consider the figures given in the text. De Long's principal recommendation is that the QR opening force is to be greater than 12 lb_f applied at 55 mm from the pivot. De Long does not plot opening force v. wheel retention for direct comparison. Using his Figure 2, this minimum opening force corresponds to a range of closing forces between 24 and 42 lb_f. Using his Figure 1, this range in closing forces corresponds to wheel retention force between of 400 to 1000 lb_f at the low end and 1700 lb_f at the high end. It is probable that the minimum in opening force corresponds to a minimum in closing force since this is a function of the cam design. However, if this is not the case, the minimum opening force criterion does not result in sufficient wheel retention. The argument for using 12 lb opening force is not compelling. Compounding the problem is that preliminary measurements taken by C. Calvin Jones of the Barnett Bicycle Institute and analyzed by one of us (CSH letter to C. Calvin Jones, 3/12/92) indicate that some QR's fall outside De Long's minimum and maximum ranges reported in his Figure 2.

De Long's maximum unclamping load of 16 lb_f results in excessive closing forces that, according to De Long, may be sufficient to over-stress the skewer.

Most importantly, however, *is that the 12 lb_f opening force criterion is difficult to implement*. De Long recommends that mechanics and consumers essentially calibrate their hands using a grocery store scale. It is unlikely that most are sensitive enough and have enough muscle memory to retain this calibration for long. Second, with a maximum recommended value of 16 lb_f, there is little range above 12 lb_f before the skewer is over-stressed. Finally, the 12 lb_f criterion adds a hurdle to proper engagement of the QR.

Therefore, we believe that it is imperative to develop and adopt an easily implemented procedure, traceable to the ISO standard, for QR engagement.

V. EXPERIMENTAL PROCEDURES

The goal of the research, then, is to develop an easily implemented guideline, usable by shops and consumers alike, traceable to the ISO 4210 standard, accounting for fork materials and alignment, which will insure that front QR's are properly engaged. The development of this guideline must be evolutionary. First, a small (46 total) number of QR's which are widely available will be used to develop and test the experimental methods. Second, the experimental methods will be refined to better approximate the ISO standard with data acquisition modified to reflect the experimental errors in the preliminary measurements. Third, exotica more often found on competitive bicycles from after market suppliers will be tested.

We believe that there are five principal measurements that will describe quick release performance.

First, there is the closing force applied to the lever that engages the cam and clamps the QR against the fork drop-outs. This is one of the forces measured and reported by De Long. His measurement was at the point 55 mm from the pivot.

Second, there is the opening force applied to the lever. This disengages the cam and unclamps the QR from the drop-outs. This, too, was measured and reported by De Long. His principal criterion was that a QR is properly engaged when an opening force greater than or equal to 12 lb_f is applied to the lever 55 mm from the pivot centerline.

Third, there is the actual clamping force applied to the drop-outs. It is this clamping force which embosses the drop-outs and retains the axle in the forks.

Fourth is the retention (or, pull-out) force. This is the force required to pull the front wheel from the drop-outs. The minimum retention force applied for 30 seconds is ISO standard of 112 lb_f (500 N). De Long stated that this has been increased to a minimum of 517 lb_f (2300 N) applied for 30 seconds.

None of these forces are easily measured by a shop mechanic or consumer. While special sockets (proposed by C. Calvin Jones of Barnett Bicycle Institute and modified by us) along with a torque wrench could be used to measure the first two, special instruments are required for the latter two. Still, most consumers will neither have nor use a torque wrench. This leads to the fifth and most promising measurement.

The fifth measurement is the angle of engagement. This is the angle of the lever measured perpendicular to the plane of the wheel when the first resistance is felt as the QR is closed. Note that De Long refers to this as an aside in his first step of his recommended procedure. BBI recommends an angle of engagement of 90^o.

Following is a description of the experimental methods used to measure each of the five.

A. Closing and Opening Force Procedure

For the purposes of these measurements, the closing torque is the value indicated on the torque wrench when the lever arm of the QR ceases to move in the closing direction. The opening torque is the value indicated by the torque wrench when the lever arm of the closed QR first moves towards opening.

A variety of forks and QR's were tested during this initial phase of the program. The fork was placed in a fork vice. Unless otherwise noted, they were then aligned using Park fork alignment tools. A front hub assembly was then placed in the forks. Figure V.A.1 presents a sketch of a QR with a definition of terms used in this report. Figure V.A.2 presents a figure of the apparatus. A slot was cut in a 1/4" drive socket so that it could slip over the lever arm of the QR. This is shown in Figure V.A.3. The socket was positioned with the center of the torque wrench drive 2" (51 mm) from the QR pivot.

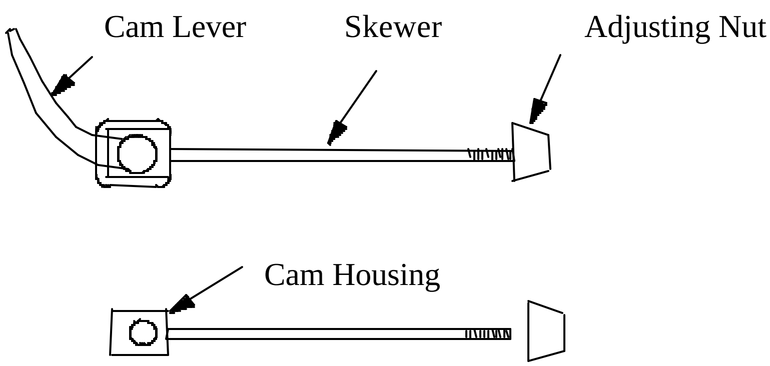


Figure V.A.1: Schematic of Typical Quick Release

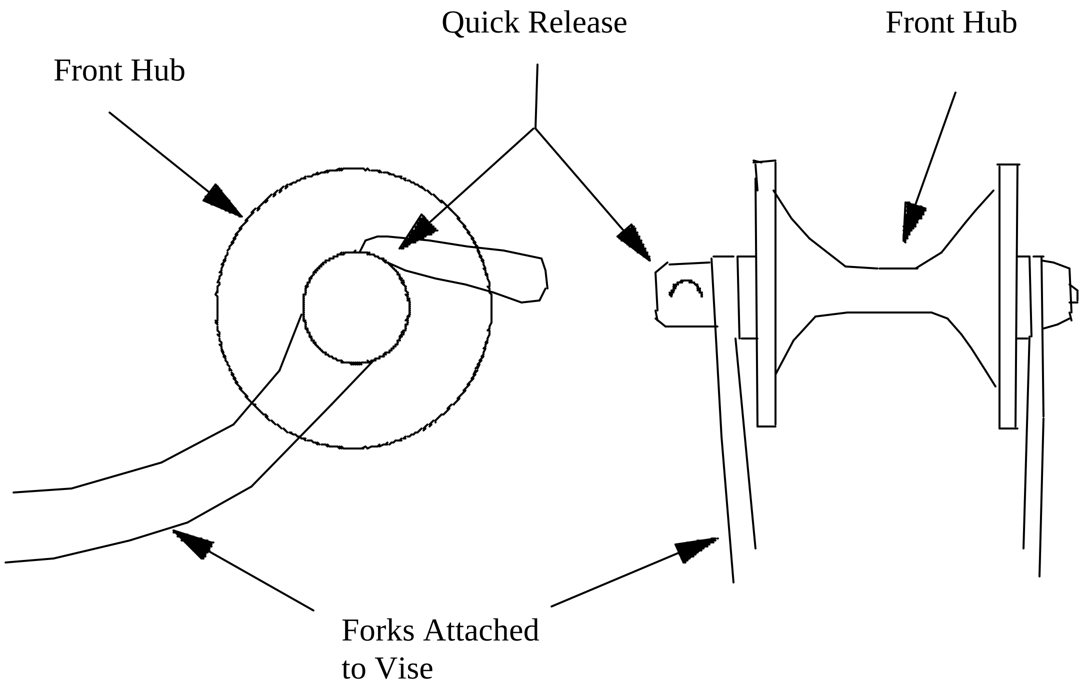


Figure V.A.2: Schematic of Closing/Opening Apparatus

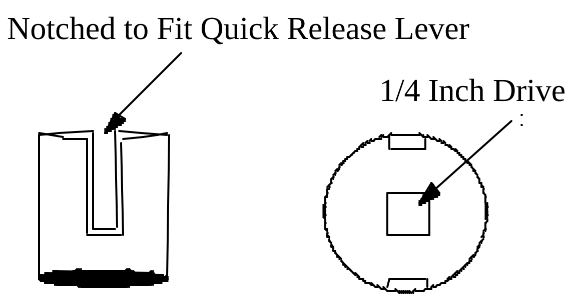


Figure V.A.3: Schematic of Modified Socket

The explicit procedure used is:

1. Select forks to be tested, place them in the fork vise with drop-outs facing up, tighten the forks in place and adjust the alignment as required.

2. Place the hub in the drop-outs and insure that the axle is properly seated.

3. Select a QR to be tested, oil the cam housing of the QR, insure that it is functioning properly (closes and opens smoothly).

4. Remove the adjusting nut and one spring from the QR, insert the skewer through the axle, and replace the spring and the adjusting nut.

5. Before placing any tension on the release, open and close the release to note the exact position of the completely closed QR.

6. Place the modified socket on the lever, spacing it two inches from the center of the lever pivot to the center of the socket. Mark that position on the QR lever. (It should be noted that De Long's 55 mm (2.2") could not be used on all QR's so we opted for 2".) At this point, the experimental measurements can begin.

7. Tighten the adjusting nut to the first position. We typically would start with the adjusting nut loose such that the QR engagement would be less than ISO standards.

8. Carefully connect the torque wrench to the socket so that the wrench handle is perpendicular to the release lever. The QR lever is in the open position.

9. Using the torque wrench, the QR is slowly closed. As noted below, when 7.5 - 10 in-lb_f indicated, the angle of the lever relative to the plane of the wheel is measured using a protractor.

10. Continue closing the release insuring that the wrench is being pulled parallel to the beam. This is required to insure that a repeatable, accurate reading is made. Note the torque applied to close the lever by reading the torque wrench when the QR reaches the closed position. Care is required because the torque reading will continue to increase after the QR is closed. The closing torque is that torque reading precisely when the QR is closed.

11. Without removing the wrench and socket from the lever, begin opening the lever. The opening torque is the peak value as lever opens.

12. Repeat the procedure at the same adjusting nut position four more times. This is done to insure that the measurements are repeatable. It also gives an indication of

the repeatability between different investigators.

13. With the lever open, tighten the adjusting nut to the next position. Leave the wrench in place; if the wrench slips off make sure it is placed back on the lever at the same location as indicated by the mark.

14. Repeat the procedure for new settings until at least five sets of data are recorded, covering the desired range of adjusting nut positions.

15. Data analysis consists of plotting on x,y coordinates and a least squares line is fitted with x being closing torque and y being opening torque. Deviations between the data and lines as well as deviations among investigators are used to determine whether the data are of sufficient accuracy and precision for further analysis.

B. Clamping Force Procedure

Clamping and Pull-out force measurements were made using Instron Model 1125 equipment. For both sets of measurements, we built fixtures to meet our needs. Figure V.B.1 presents a schematic of the fixture for the clamping force measurements.

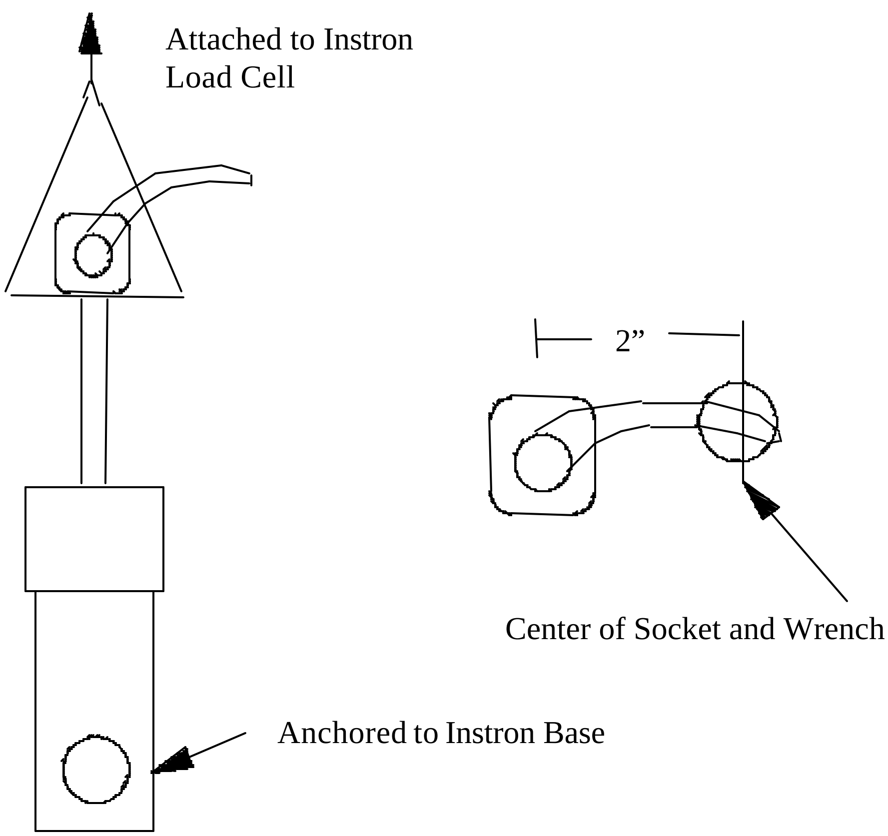


Figure V.B.1: Schematic of Clamping Fixture for Instron

1. Lubricate the QR as needed.

2. Place the threaded end of the skewer through the hole in the center of the clamping apparatus (See Figure V.B.1).

3. Calibrate the Instron using weights as described in the operations manual.

4. Secure the skewer by threading it into the Instron anchor. Then secure the anchor to the base.

5. Attach the fixture to the load cell vise.

6. Slowly raise the Instron cross-head to simulate the desired adjusting nut position.

7. Measure the closing torque required to completely close the quick release lever using the procedure described in Section V.A.

8. The Instron measures the clamping force behavior as the QR lever is closed.

9. Steps 6 and 7 are repeated at least 2 more times before altering the Instron Cross-head position. Again, the purpose is to insure that the results are repeatable.

10. Repeat steps 1-8 for each release that requires testing.

11. The closing/clamping data were plotted and described with a least squares line. Only one of us (Mills) performed clamping measurements. Consequently, there was no comparison among investigators.

It must be noted that we did not conduct an exhaustive set of measurements. The purpose of this preliminary effort was to demonstrate that the experimental procedure was sound and repeatable. A detailed analysis of data are underway to determine which experiments will be necessary in developing and understanding the QR performance. Should clamping data become one of those important sets, additional data will be acquired.

C. Pull-out Force (Retention Force) Procedure

The fixture used for the pull-out measurements is shown in Figure V.C.1. The procedure is as follows:

1. Calibrate the Instron to specifications.

2. Secure upper fixture to load cell.

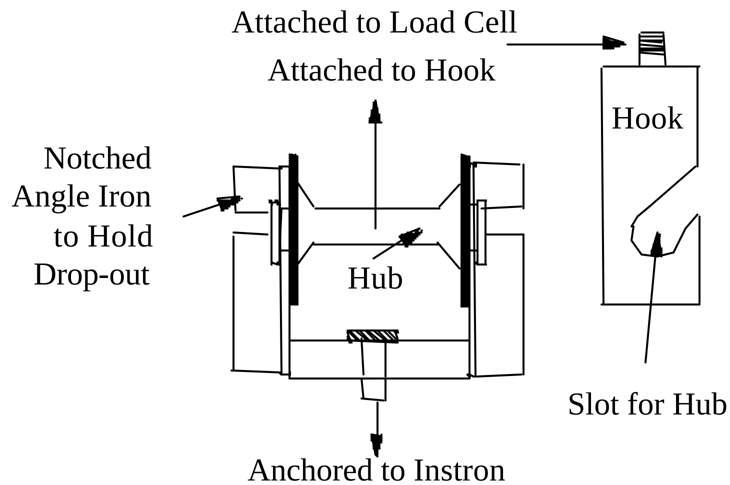


Figure V.C.1: Schematic of Pull-out Fixture for Instron

3. Zero Instron to account for fixture weight.

4. Secure bottom fixture to Instron base.

5. Place the axle into the dropouts of the bottom fixture

6. Select a release and place it through the axle.

7. Measure the closing torque using the procedure in Section V.A.

8. Increase the load exerted on the axle by raising the cross-head of the Instron. Raising the cross-head can be done either manually or automatically. Both methods give repeatable results although time delays at incremental loads can be pre-set in the automatic mode. Continue increasing the load until the force peaks at its maximum value. This peak force is the pull-out force for the purposes of these preliminary measurements.

9. Lower the Instron cross-head to relax the force on the hub assembly.

10. Inspect the faces of the drop-outs. At high loadings, the drop outs will scar as the QR moves across the face. Replace the drop-outs if the damage is extreme.

10. Repeat the pull-out at this setting to insure that the results are repeatable.

11. Change the position of the adjusting nut and repeat the pull-out measurements.

This procedure was developed to test the suitability of the Instron for pull-out measurements. There is a significant deficiency in the procedure, however, relative to the ISO standard. That is, we did not hold the pull-out force for 30 seconds at each adjusting nut position. It is likely, therefore, that the pull-out forces reported in this set of measurements are slightly above those which would result from holding tension for 30 seconds at each setting. However, we raised the cross-head very slowly which approximates holding for 30 seconds and the results should not differ markedly from true values.

D. Angle of Engagement Procedure

These measurements are made at the same time that the opening and closing force measurements are made. The closing procedure reported in Section V.A. is followed. At the point where the torque wrench registers 7 to 10 in-lb_f, the angle of the lever relative to the plane of the wheel is measured using a protractor. This angle is the angle of engagement. As points of clarification, if the resistance is felt at 90^o, then the lever is parallel to the axle. If no resistance is felt with the QR closed, the angle of engagement is nominally 0^o.

E. Quick Release Sample Set

The following is a list of the QR's used throughout this experimental program. Barnett Bicycle Institute, Campagnolo, Cycle Works (Lawrence, Kansas), Mavic and Sachs supplied samples for our study as noted. In addition, commonly available QR's including some from Mavic were purchased from United Bicycle Parts in Ashland, Oregon.

All of the quick releases were cleaned and lubricated prior to being subjected to the experiments. These releases were subjected to over 100 openings and closings with some settings at extreme loads. Some began to show wear as evidenced by rough movement and metal shavings. Four ultimately failed due to extreme loads.

Table V.E.1
Quick Release Sample Set

QR Description	Quantity
ACS	2
American Classic	2
Campagnolo (* BBI)	1
Campagnolo (* BBI)	1
Campagnolo Athena (* Campagnolo)	2
Campagnolo Record (* Campagnolo)	2
JoyTech	2
Mavic 500 Steel (* Mavic)	6
Mavic 500 Alloy	2
Mavic 500 Steel	2
M. M. Atom	1
Omega	1
Sachs OE NS Skewers (* Sachs)	2
Sachs ST 5 mm Skewers (* Sachs)	2
Sansin	2
Shimano Ultegra	2
Shimano Deore	2
Shimano Standard	2
Shimano Exage/105	2
Shimano Exage Mountain	2
Suntour	2
Suzie	2
Unknown Manufacturer	2
Total in Sample Set	**46**

(*) Donated to KTL with Donor Company in Parenthesis

VI. CLOSING, OPENING AND ANGLE OF ENGAGEMENT RESULTS

Two of us (Mills and Klocek) were the principal experimentalists. Mills began the program during the summer of '92 and completed his work 5/93. Klocek performed all of his work during Spring '93. Mills' responsibility was to develop the experimental procedures for closing, opening, angle of engagement, clamping and pull-out. Klocek was to prove that he was consistent with Mills and, then, study the effect of fork drop-out material and alignment on all measurements. Klocek's scope was modified to improve the angle of engagement procedure to reduce scatter. Pull-out measurements with different materials and alignment were not done because Mills had not developed and tested the procedure until late Spring '93.

An immense number of data were acquired during the course of this investigation. These data are found in two final reports written by Mills and Klocek, individually. The data are not reported in total herein. Instead representative figures and summaries are given. The final reports with disk support will be provided upon request.

This section presents data and interpretations of closing and opening torques and angle of engagements. It is divided into two sections. Section VI.A presents the closing and opening torque information as measured by both Mills and Klocek. A global graph presenting all data is given in the end. Section VI.B presents the angle of engagement data for a subset of the releases given in Table V.E.1.

A. Closing and Opening Torque Measurements

Representative plots of opening v. closing torques are given in Figures VI.A.1 through VI.A.10. These data were acquired by Mills. Figure VI.A.1 shows the data and interpreted lines for both Shimano Ultegra QR's. This graph is representative of that obtained for all duplicate QR samples. Note first that the scatter among groups of points is very small. Note further that data for the two Ultegra releases are equivalent. This indicates first that the experimental method is repeatable. Second, it indicates that, at least for the samples used in this study, there is consistency among QR samples.

Figures VI.A.2 - VI.A.10 give data for representative releases from most of the manufacturers in the QR sample set. Note that all releases follow a linear trend. However, the slopes of the relationships are different from one release to the next.

Figure VI.A.11 gives a summary of all of Mills' measurements made for this study. There is a wide range of performance on opening torques at a given closing torque. For example, consider a closing torque of 40 in-lb_f. The minimum opening torque is 12 in-lb_f and the maximum value is 35 in-lb_f. This performance is QR specific and not representative of data scatter. For example, the JoyTech and Suntour QR's are at the lower end of the scale while the Shimano's are at the upper end. Therefore, any guideline must ultimately be tested against specific QR's to insure that each, when subjected to the guideline, has wheel retention exceeding

Figure VI.A.1: Opening v. Closing
Shimano Ultegra Repeatability

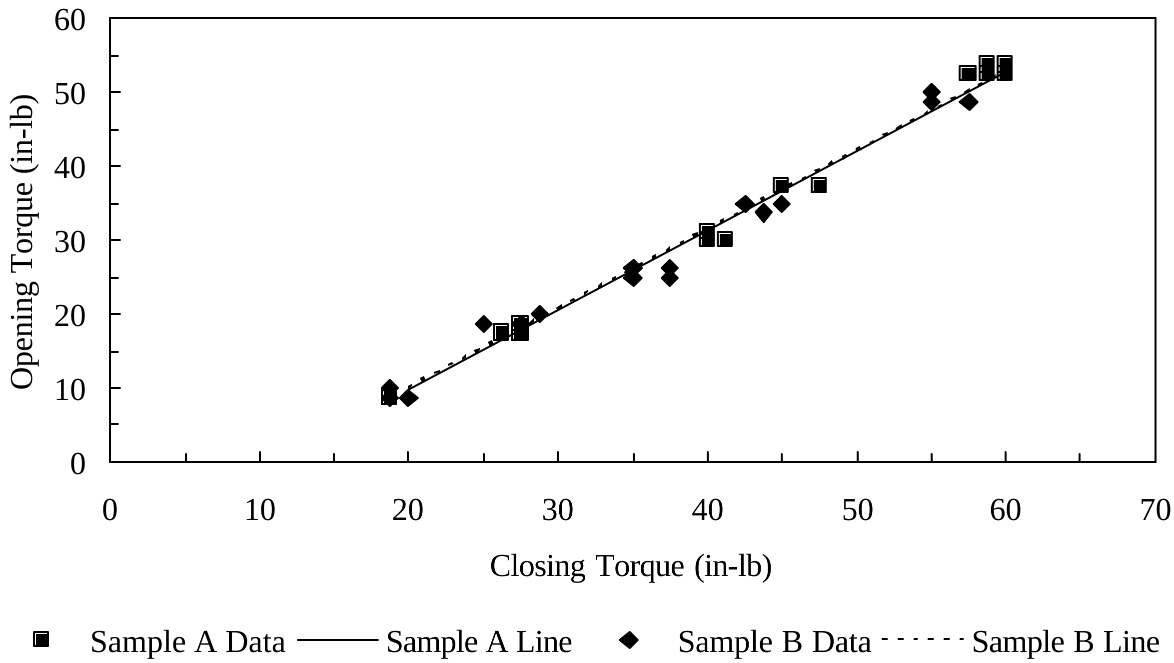


Figure VI.A.2: Opening v. Closing
Campagnolo Athena QR (Sample A)

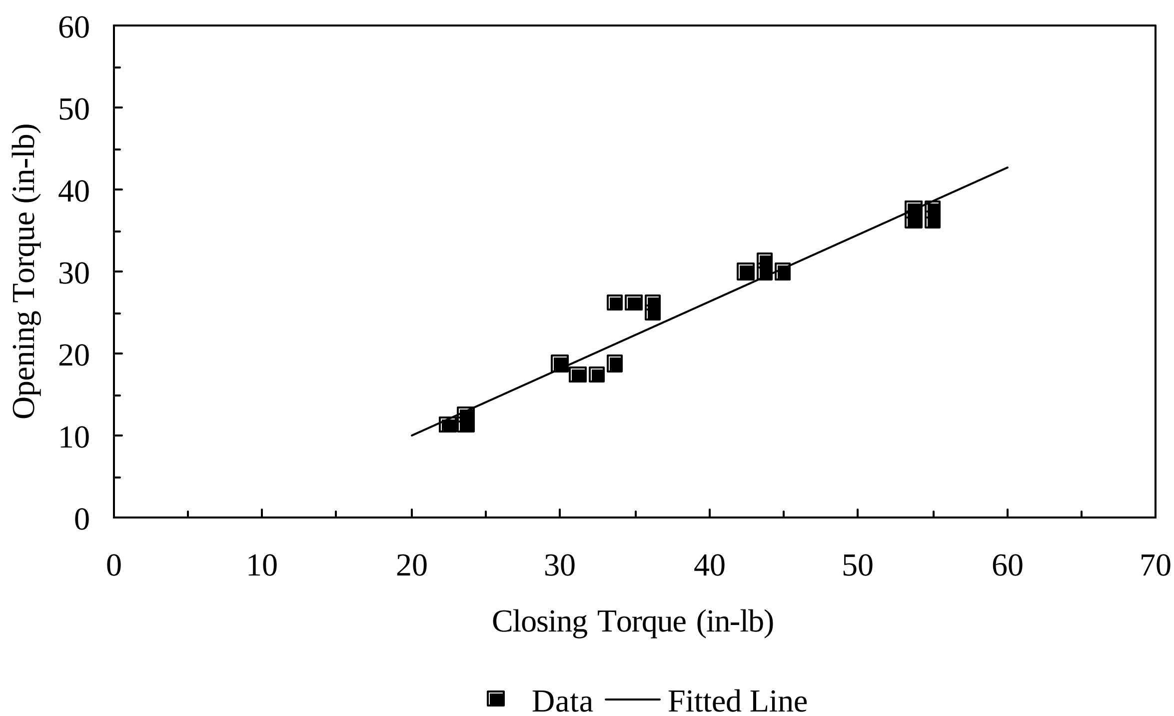


Figure VI.A.3: Opening v. Closing
JoyTech QR (Sample A)

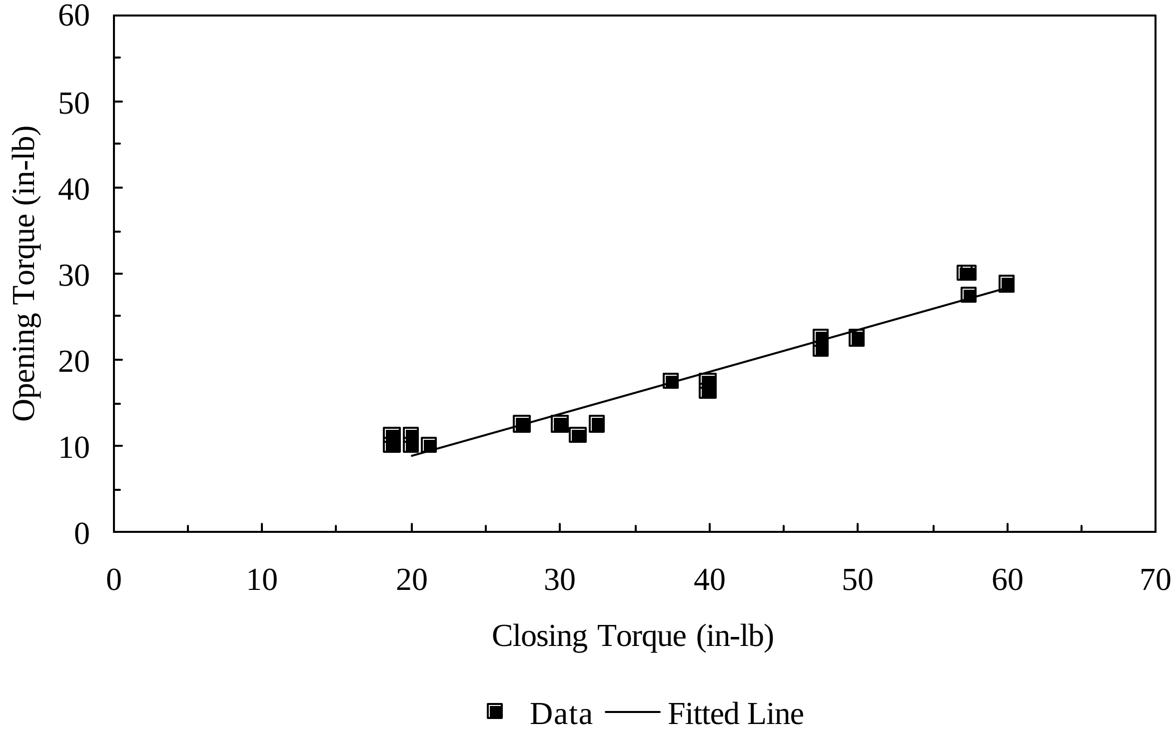


Figure VI.A.4: Opening v. Closing
Suzie QR (Sample A)

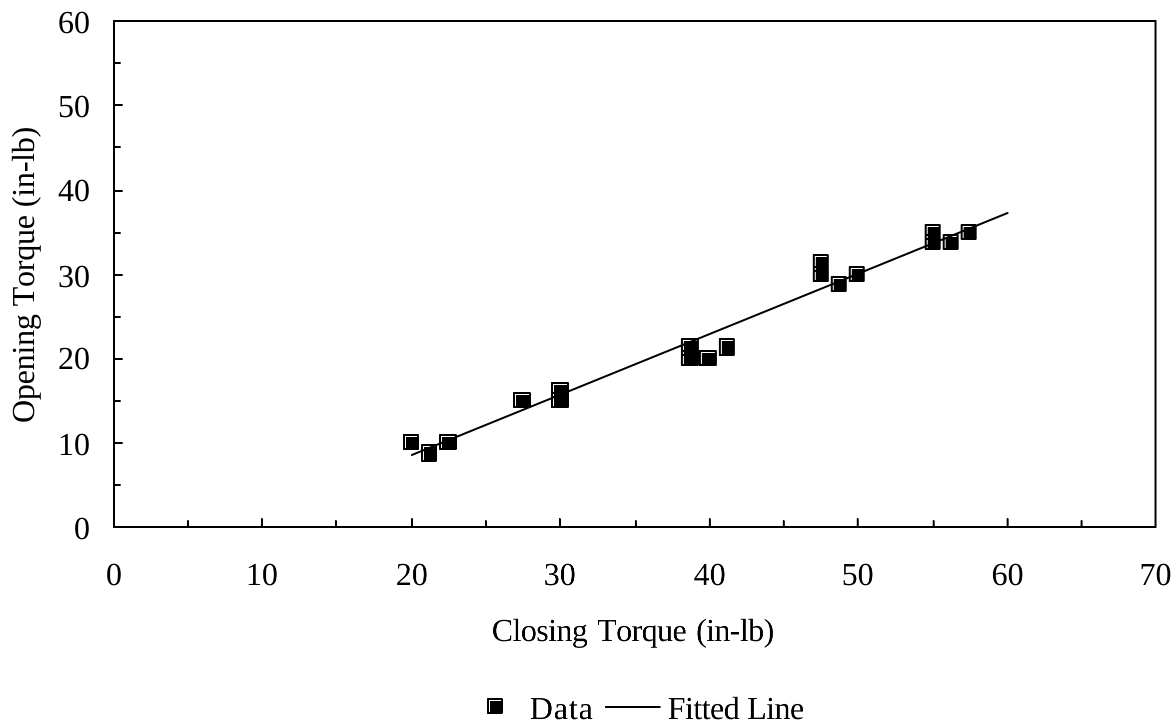


Figure VI.A.5: Opening v. Closing
Mavic Steel QR (Sample A - from UBP)

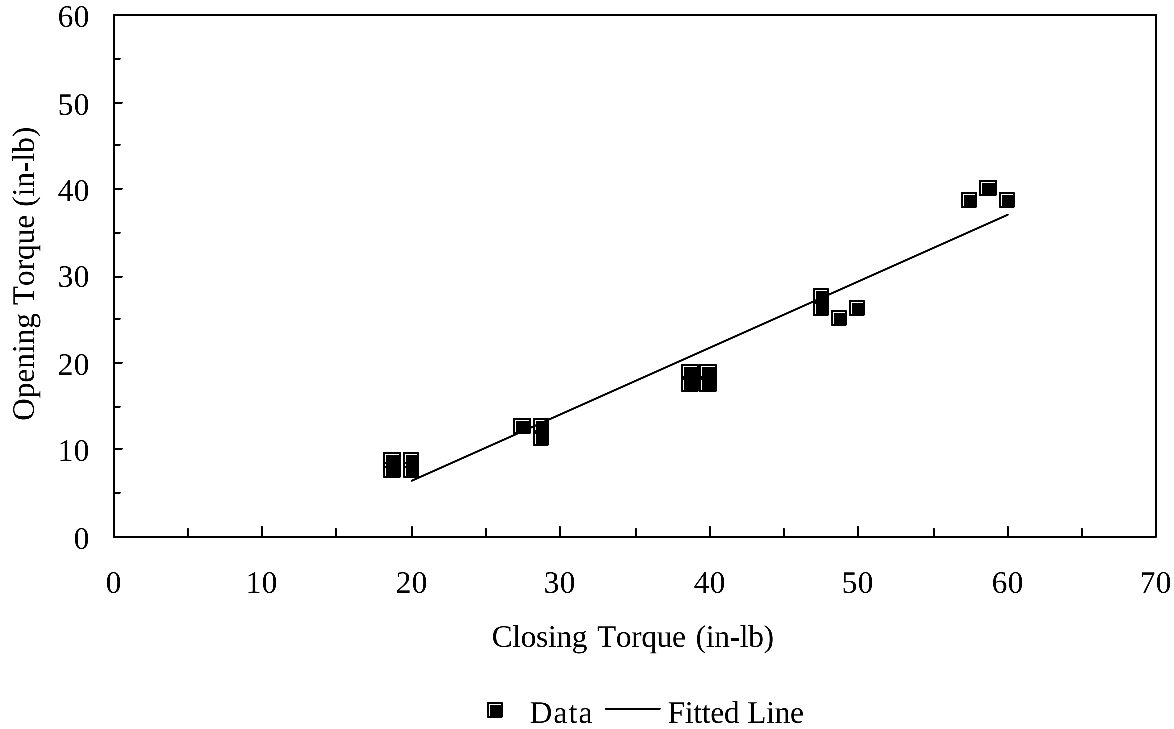


Figure VI.A.6: Opening v. Closing
Sachs Standard QR (Sample A)

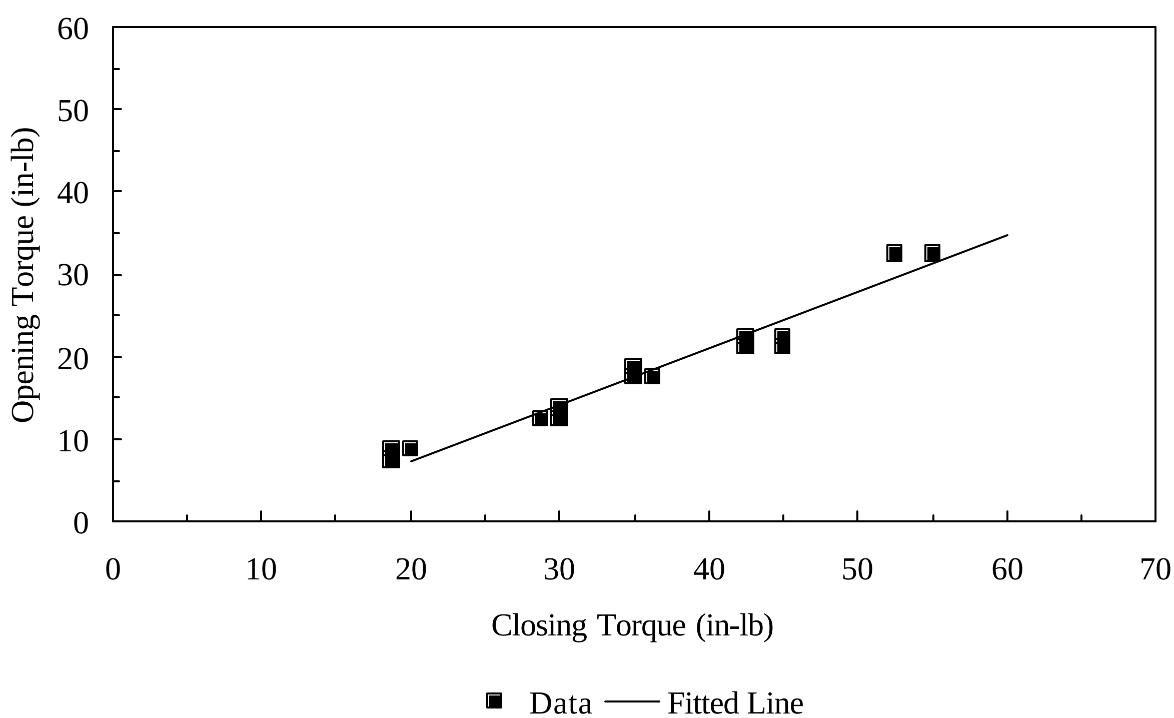


Figure VI.A.7: Opening v. Closing
Sansin QR (Sample A)

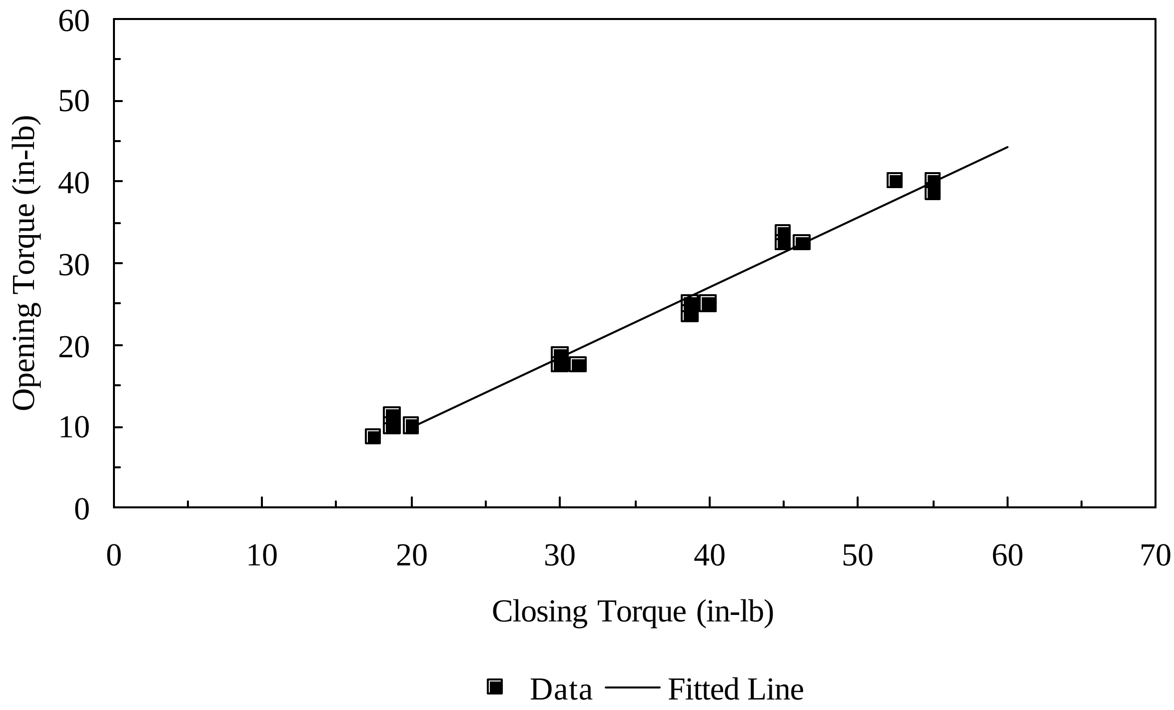


Figure VI.A.8: Closing v. Opening
Shimano Deore QR (Sample A)

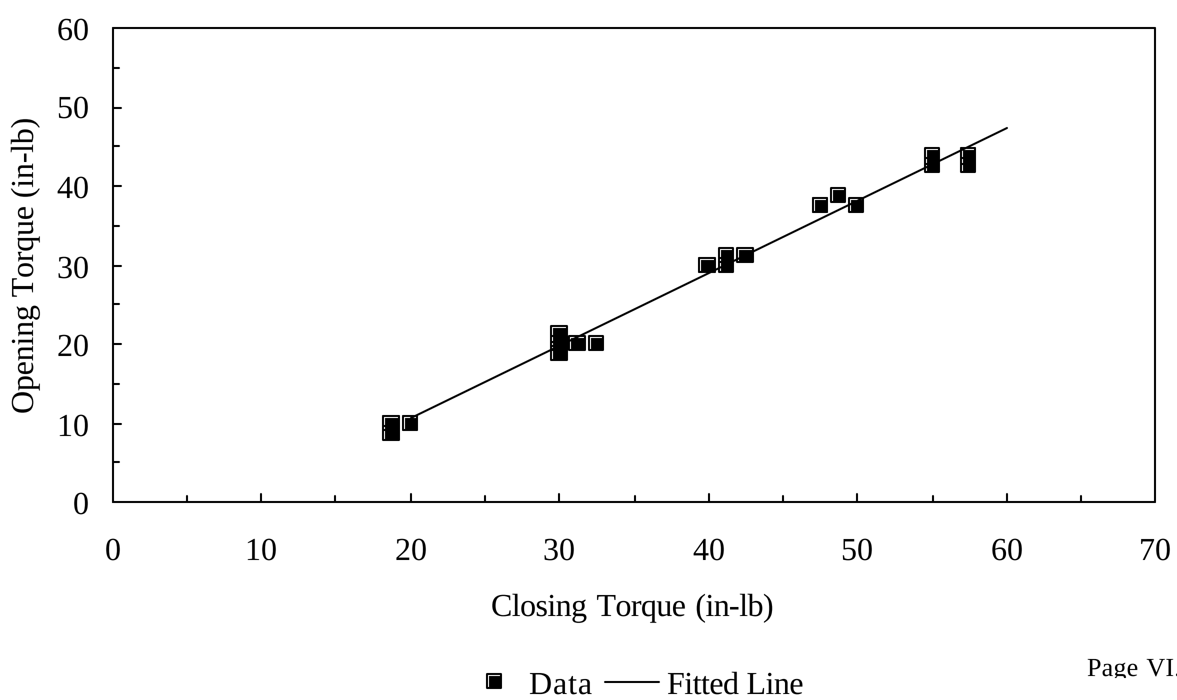


Figure VI.A.9: Opening v. Closing
Shimano Exage Mountain QR (Sample A)

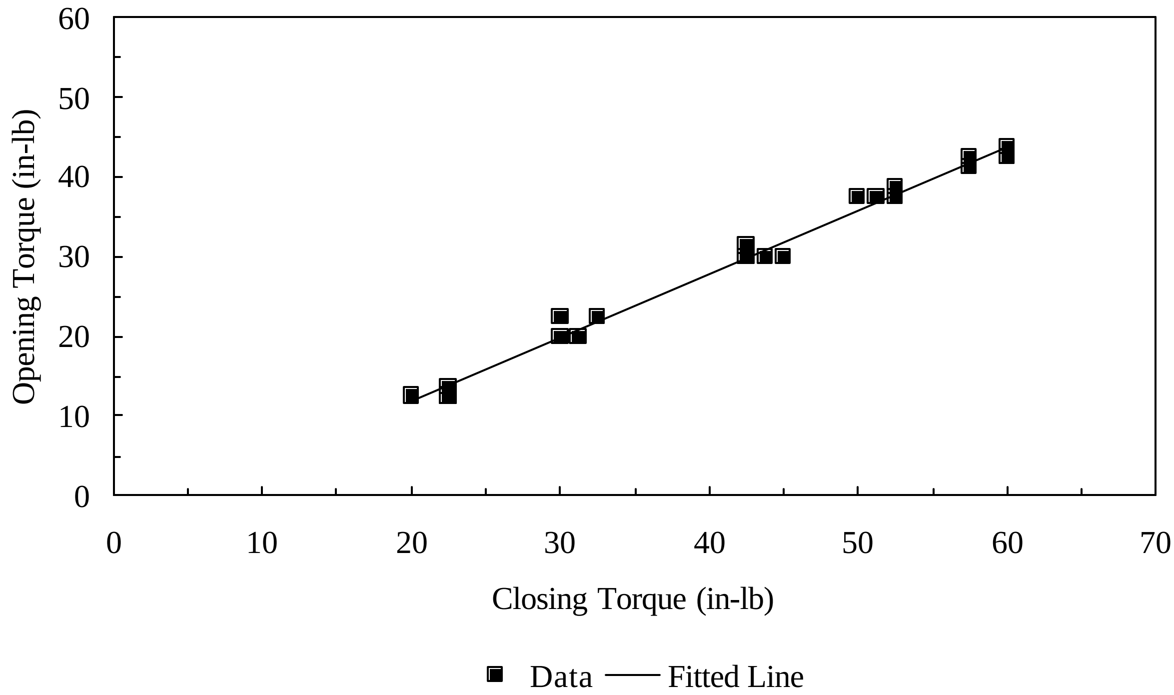


Figure VI.A.10: Opening v. Closing
Suntour QR (Sample B)

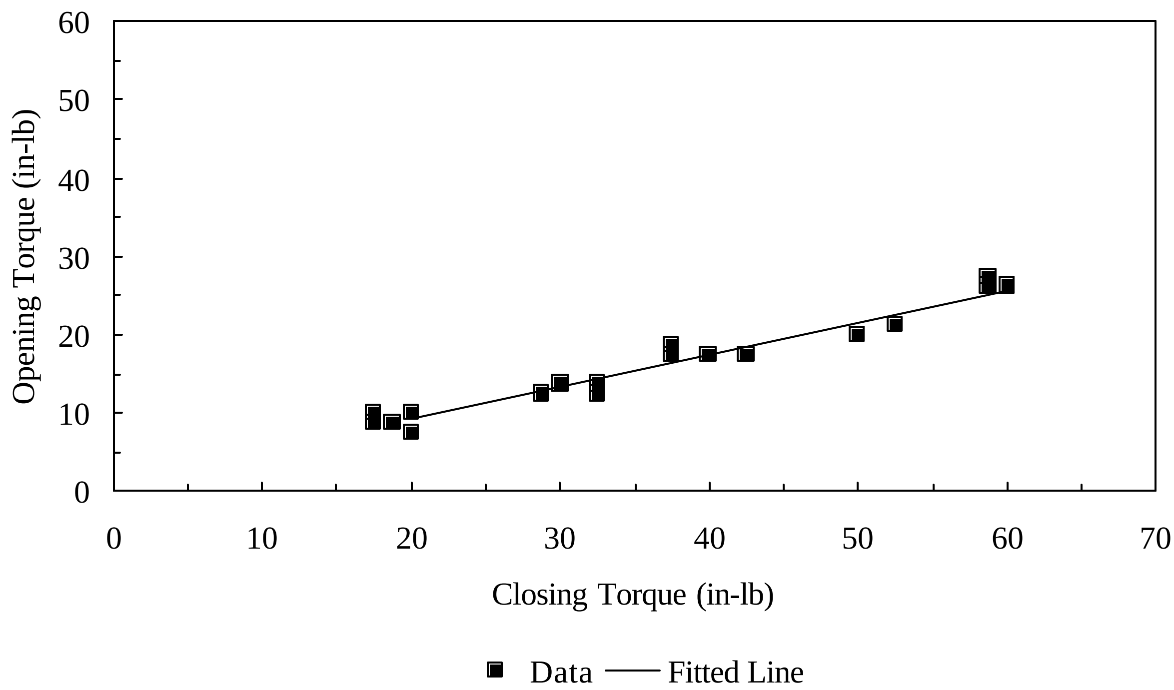
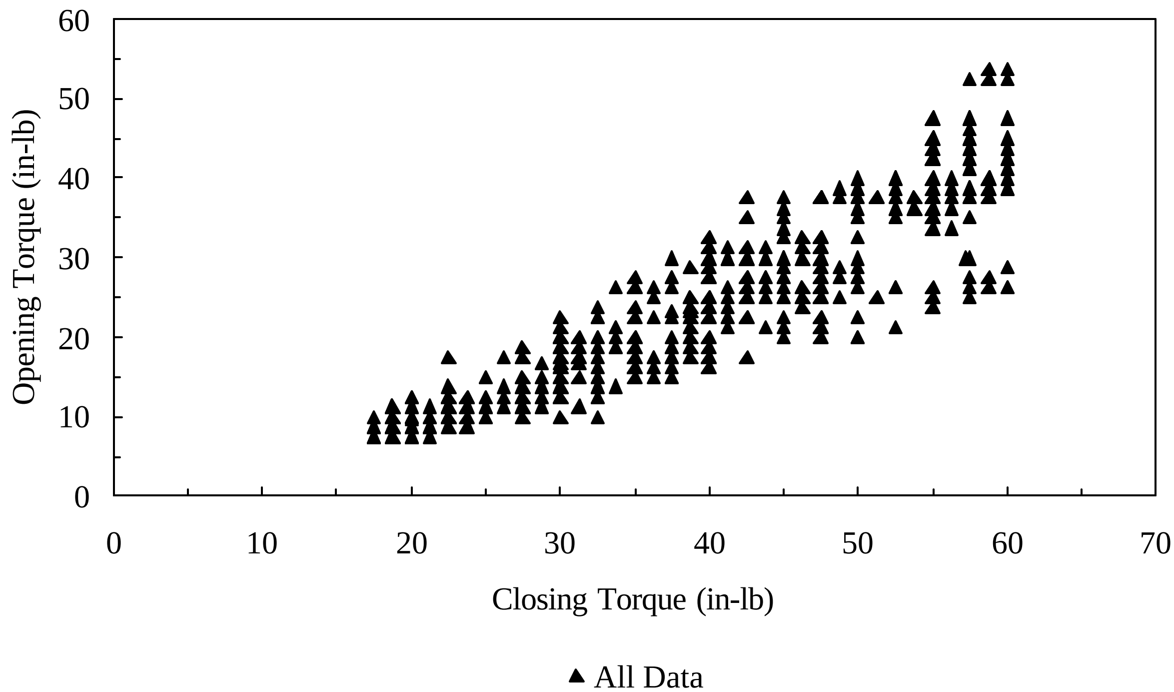


Figure VI.A.11: Opening v. Closing
Data for all Sample QR's



the ISO standard.

Consider De Long's recommendation of opening force of 12 lb_f applied 55 mm from the lever pivot. This corresponds to an opening torque of 26 in-lb_f. At this torque, the closing torque varies between a minimum of 28 and a maximum of 60 in-lb_f. This implies that a general guideline for all QR's is not possible based on opening force (or, torque) due to the wide range in corresponding closing torque.

B. Angle of Engagement Measurements

The initial angle of engagement measurements showed significant scatter. Consequently, the method needed refinement. One of us (Klocek) developed a repeatable method that he tested with a subset of the QR's. Since the extensive opening and closing torque data of Mills was to be used to develop the guideline, it was critical that both experimentalists were consistent in their opening and closing torque measurements.

Figures VI.B.1 - VI.B.4 are representative of all of the comparisons made between the opening and closing data of Mills and Klocek. Figures VI.B.1 and VI.B.2 present comparisons of the Campagnolo Athena (Sample A) and Sachs Standard QR (Sample A), respectively. The actual measurements are essentially equivalent. Figures VI.B.3 and VI.B.4 are a more sensitive

Figure VI.B.1: Opening v. Closing
Campagnolo Athena (Mills v. Klocek)

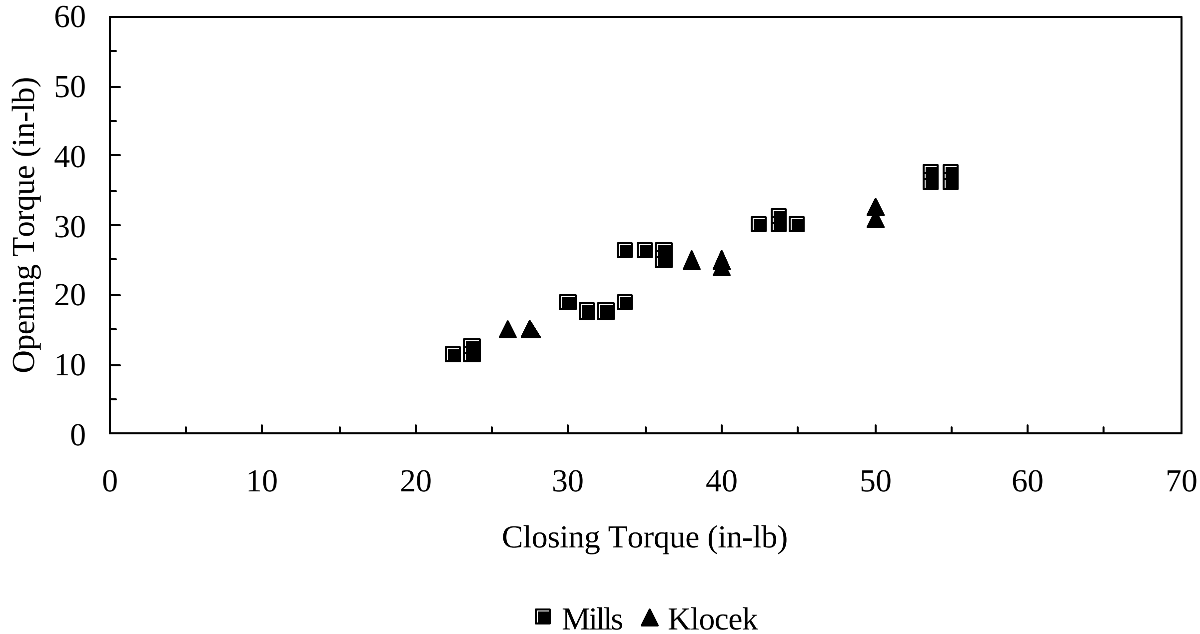


Figure VI.B.2: Opening v. Closing
Sachs Standard QR (Mills v. Klocek)

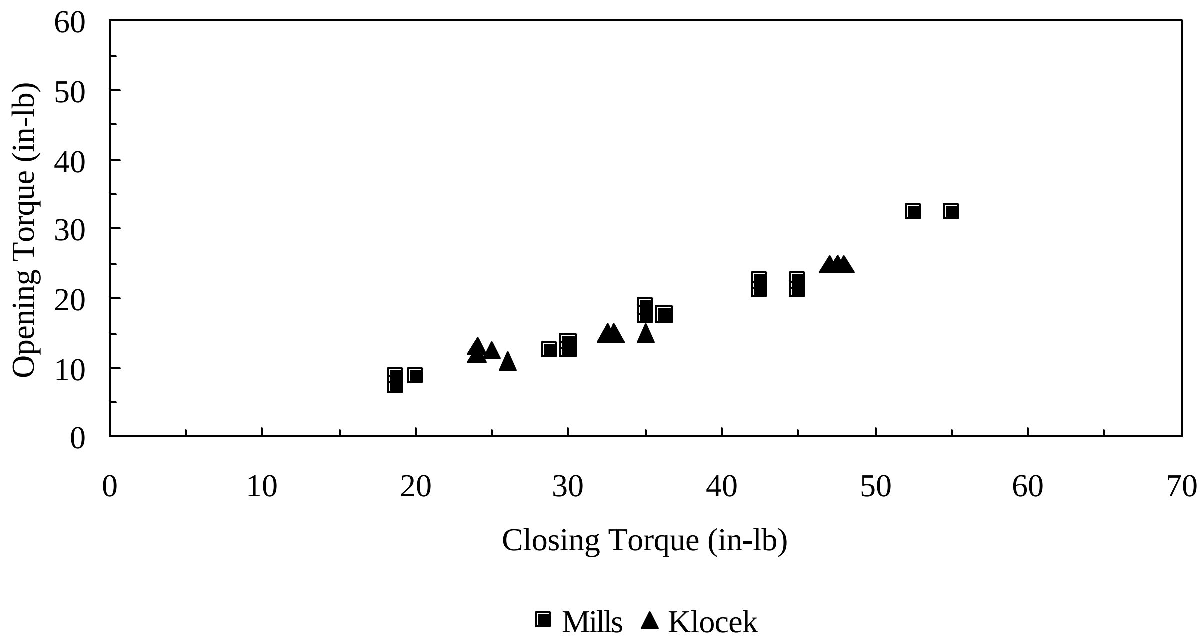


Figure VI.B.3: Open Deviation Analysis
Campagnolo Athena (Mills v. Klocek)

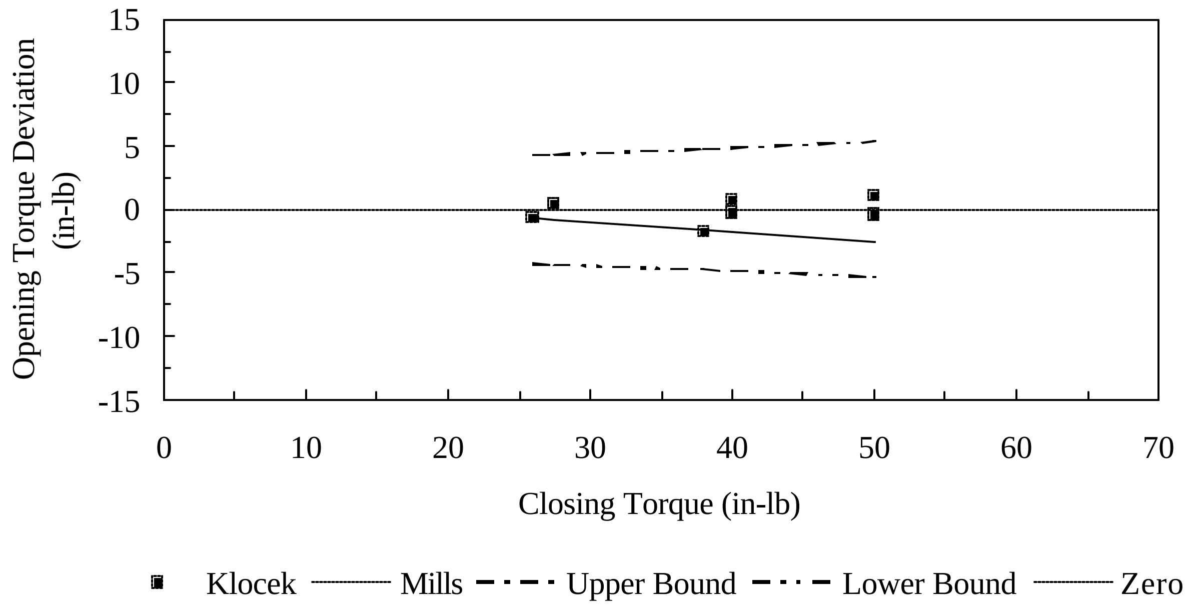
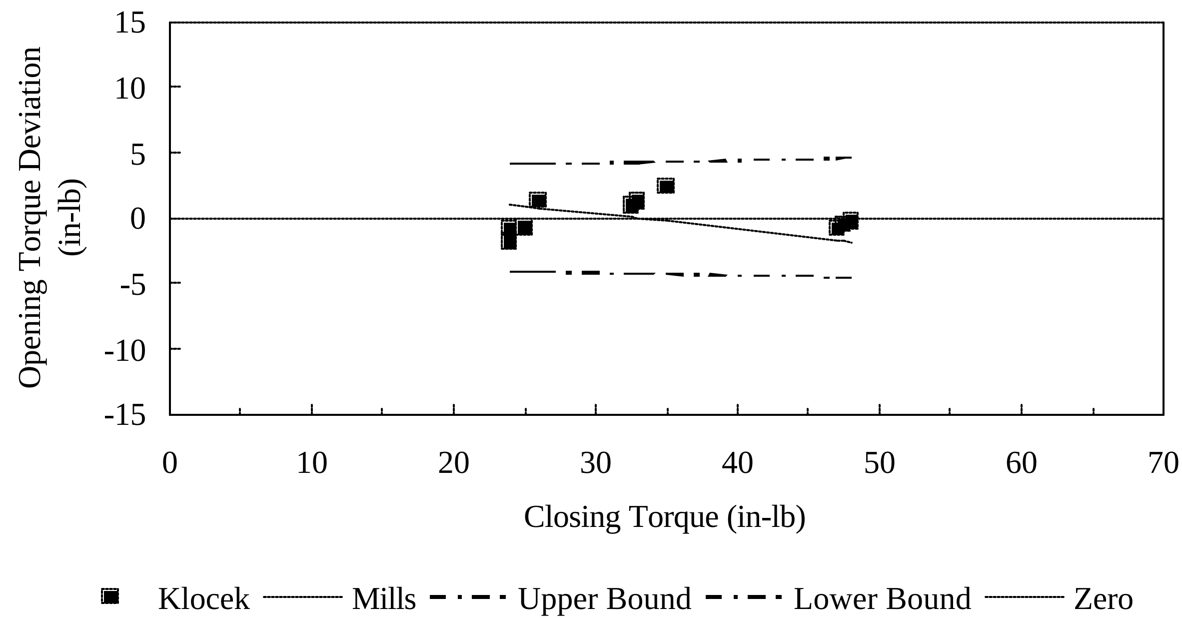


Figure VI.B.4: Open Deviation Analysis
Sachs Standard QR (Mills v. Klocek)



comparison of the same information. On these graphs, Klocek's data are plotted as a deviation from his best fit line. The equivalent best-fit line for Mills' data is also plotted as a deviation from Klocek's line. In addition, error bars are superimposed where they represent a statistical combination of the error in socket placement and error in torque wrench calibration. Klocek's and Mills' data and interpreted lines are in agreement if they fall within the region bounded by the error bars. This is the case for these two QR's and for the others compared. Therefore, the experimental procedure is repeatable among different researchers.

Once consistency was established, Klocek measured the angle of engagement for his sample set QR's. All of the data are plotted in Section X for various fork materials. Representative plots for the Campagnolo Athena and Shimano Exage Mountain QR's are given in Figures VI.B.5 and VI.B.6. Figure VI.B.7 presents all of the mild steel drop-out data. Variability is due to the QR and not due to the experimental method.

Figure VI.B.5: Closing v. Angle
Campagnolo Athena (Mild Steel Drop-out)

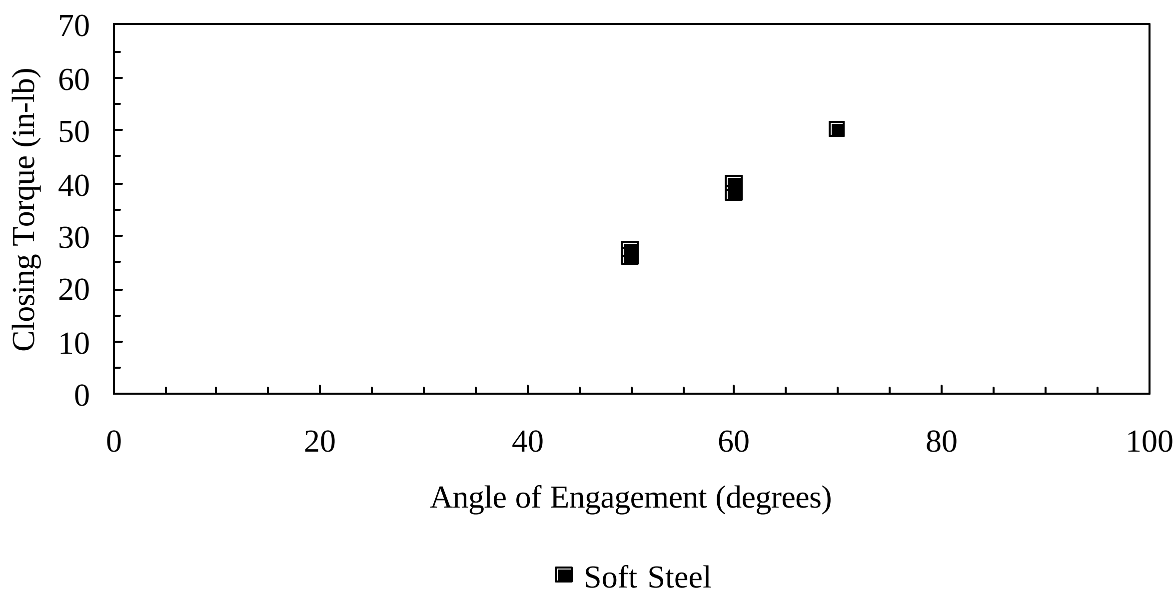


Figure VI.B.6: Closing v. Angle
Shimano Exage Mtn (Mild Steel Dropout)

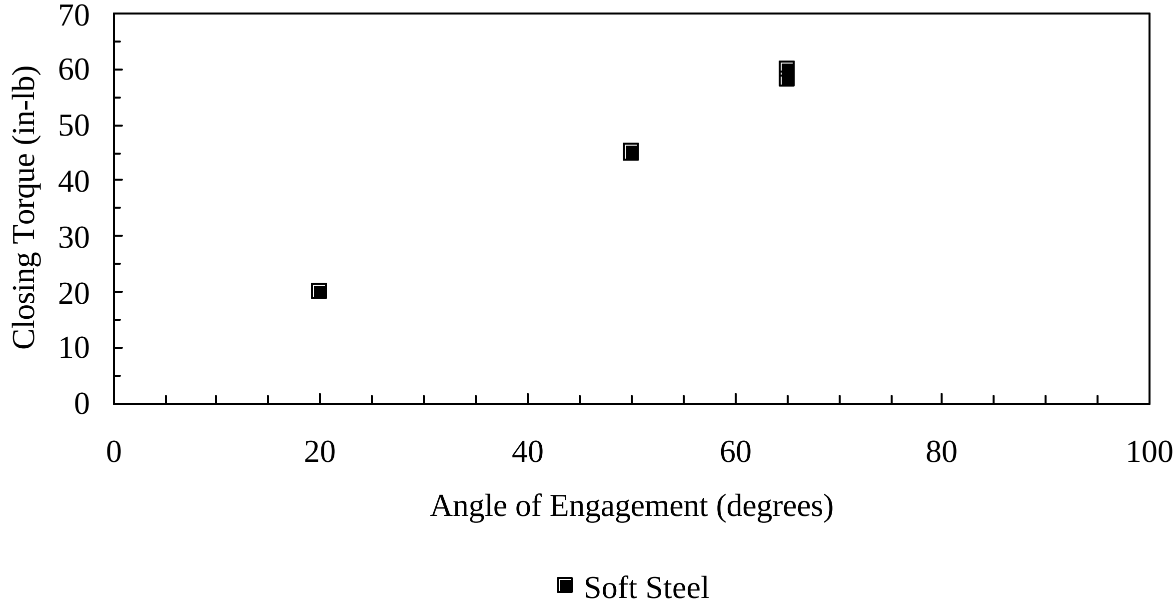
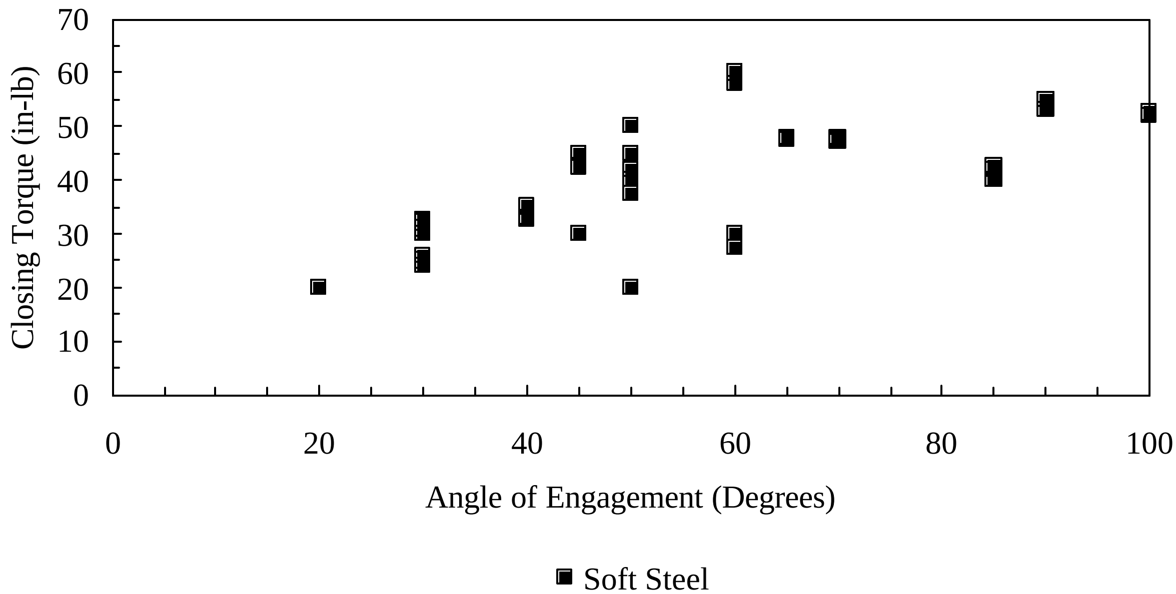


Figure VI.B.7: Closing v. Angle
Klocek Sample Set (Mild Steel Dropout)



VII. CLAMPING FORCE RESULTS

All of the QR's listed in Table V.E.1 were used in this experimental program. Nine measurements of clamping force v. closing torque for each release were made. The purpose of this work was to prove that the experimental procedure was repeatable.

Figure VII.1 presents data for one of the Shimano Exage Mountain QR's. There is a large time gap between the two sets of data. Note that the measurements are essentially repeatable.

Figure VII.2 presents the interpreted data for all of the Mavic steel releases. With the exception of one release, the performance is the same. Note that these Mavic releases were no longer smooth in operation indicating wear. Ultimately, two of them failed during this set of measurements.

Figure VII.3 presents data for all of the measurements made. The outliers (those circled are for both Shimano 105/Exage releases and one of the Shimano standards. These releases were rough to operate at the end of the experimental measurements. The outlier performance may be indicative of the wear. The general trend indicates that the mechanical advantage of the releases are similar.

Additional analysis is required to group the releases according to position on the graph. This will be done if clamping force becomes a significant correlating variable in developing the guideline.

Figure VII.1: Clamping v. Closing
Shimano Exage Mountain QR (Repeat)

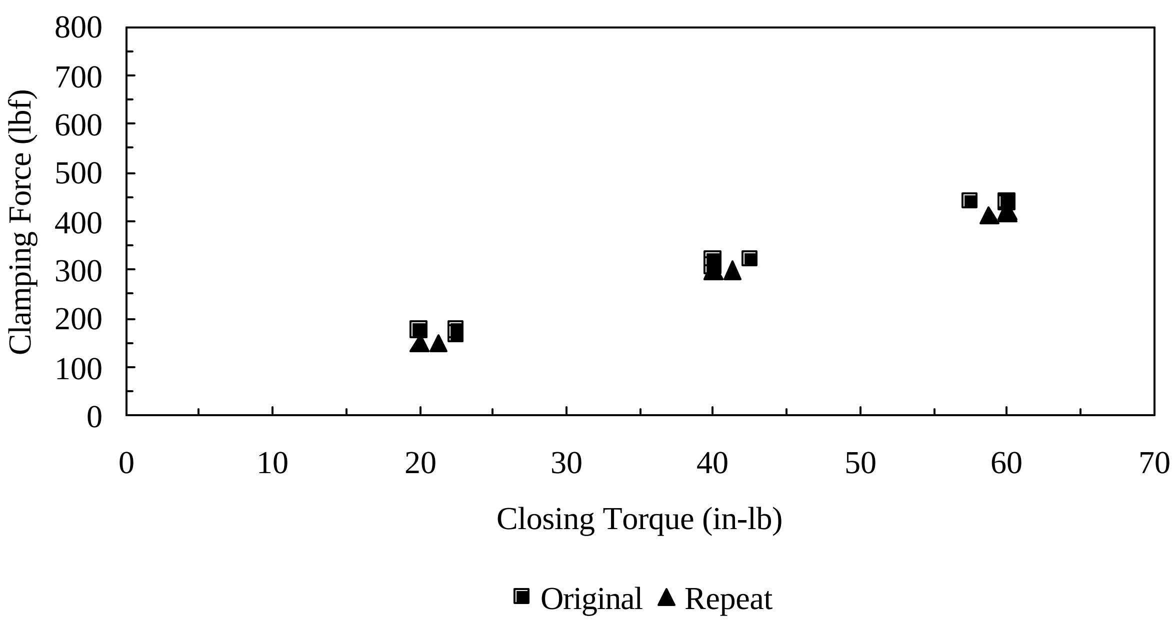


Figure VII.2: Clamping v. Closing
Mavic Steel QR's (Interpretted)

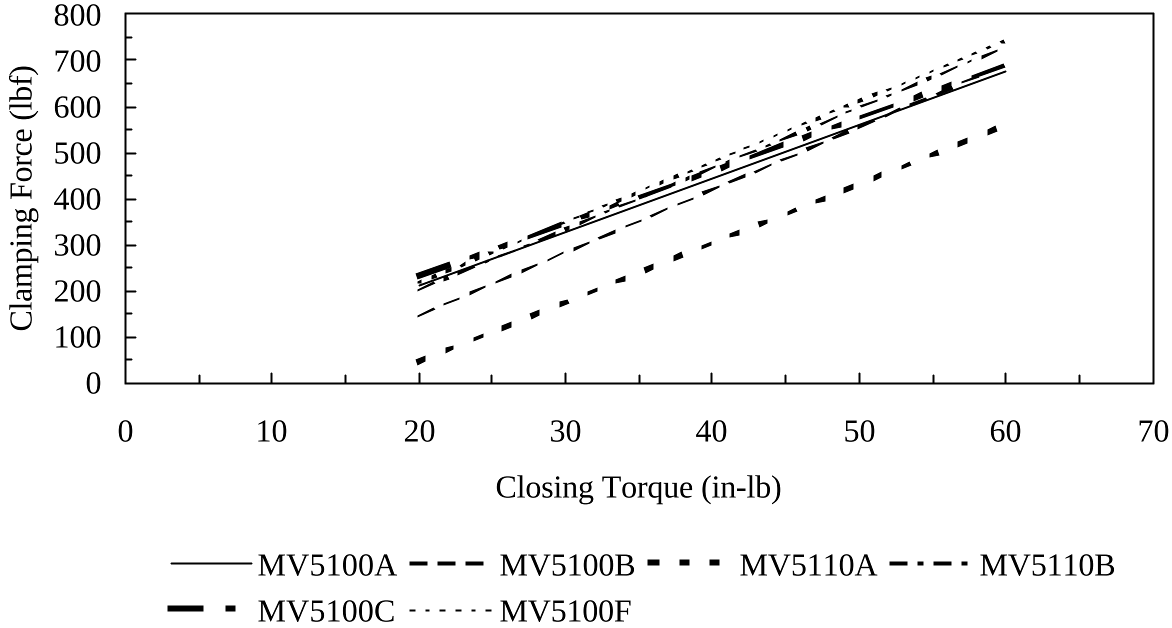
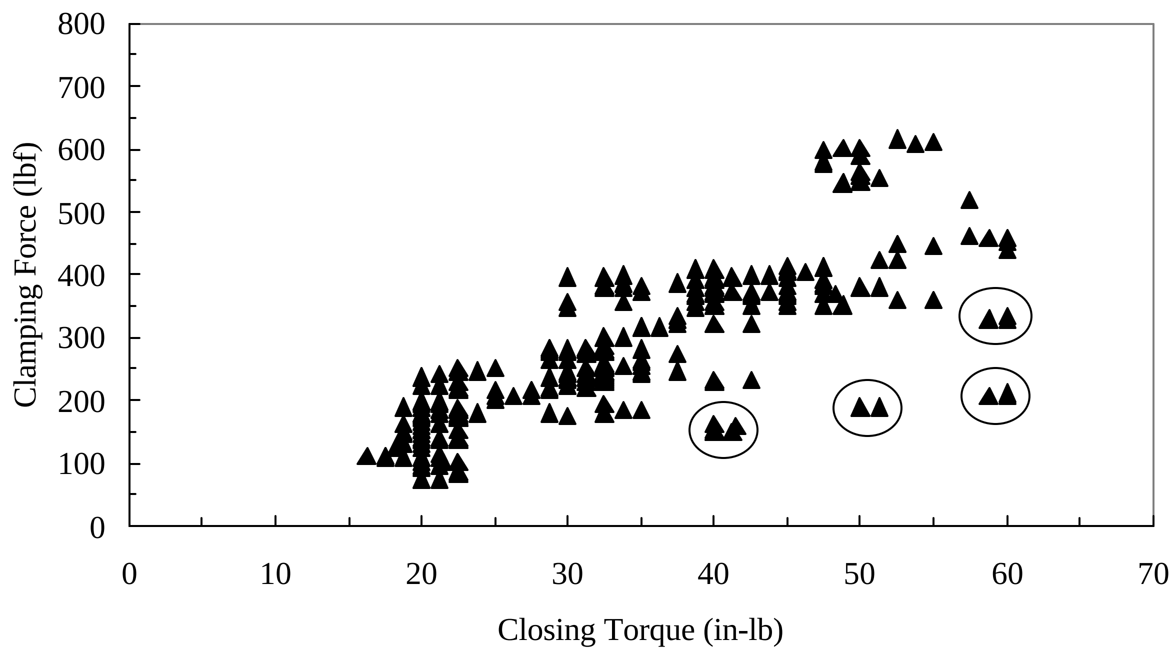


Figure VII.3: Clamping v. Closing
Data for All Quick Releases



VIII. PULL-OUT FORCE RESULTS

The experimental procedure used to acquire the following data is described in Section V. Before discussing the data in detail, it is important to recognize that two principal refinements are required in the procedure.

First, with some of the data given below, the cross-head of the Instron was raised manually. While we tried to keep the velocity constant, this was not always possible. Therefore, the slope of the load with time was not uniform. We solved this problem by placing the Instron in automatic. This caused the slope of the load to be uniform. However, we had insufficient time to determine whether slope had any affect on the pull-out force. As will be seen, some of the data have significant scatter, which might be attributable to the rate of load increase.

Second, the ISO standard requires no slippage at 112 (or, 517) lb_f to meet the pull-out criterion. We did not program the Instron to hold forces for 30 s before increasing to the next level. Instead, we steadily (and, slowly) increased the force until the QR slipped in the drop-outs. It should be noted that the Instron is extremely sensitive. Small slips, which could result in a reduction of force from 600 to 550 lb_f, are not visible. ISO slippage and that measured by the Instron are probably different. This difference will have to be explored in future studies. For our purposes, we defined the load as the maximum force at which the QR could hold the hub in the drop-outs. Any forces greater than this resulted in the hub slipping in the fixture.

The first step is to prove repeatability. Damage to the drop-outs and QR are possible when the fixture is subjected to extreme loads. Consequently, pull-out forces using the Shimano Deore QR were measured at the beginning of the program and at the end of this phase. The results are given in Figure VIII.1. The scatter probably reflects the need to improve the procedure. However, it is clear that the two sets of data follow the same trend.

Performance of ten releases was measured during this phase. The data are plotted in Figures VIII.2 and VIII.3. The Shimano Deore QR data are shown on both figures for reference. Note that the trends for each type of QR are different. This is probably due to the area and type of contact between the QR and drop-outs. For example, some QR's have a knife-edge contact. Some have a serrated contact. Others are smooth-faced with large contact area. It is likely that the performance is different.

Figure VIII.4 presents all of the data on the same graph to give a clear view of the range of the performance. It is the trends of this graph along with those presented in Section VI which form the basis of the preliminary guideline given below.

Figure VIII.1: Pull-out v. Close
Shimano Deore QR (Repeatability)

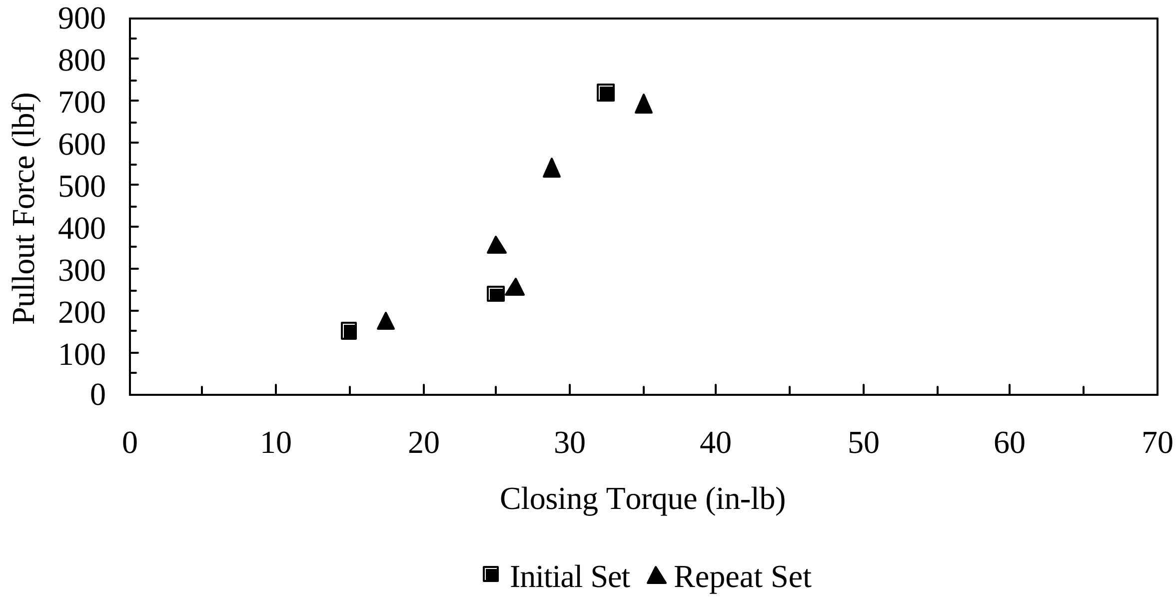


Figure VIII.2: Pull-out v. Close
Data for Set 1

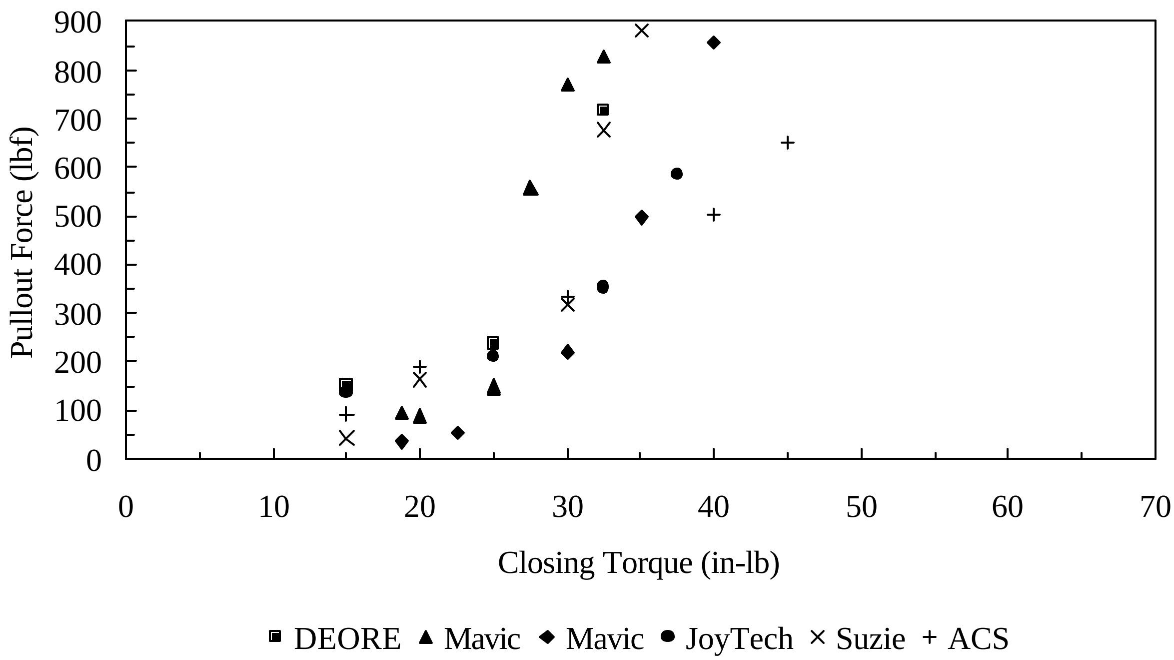


Figure VIII.3: Pull-out v. Close
Data for Set 2

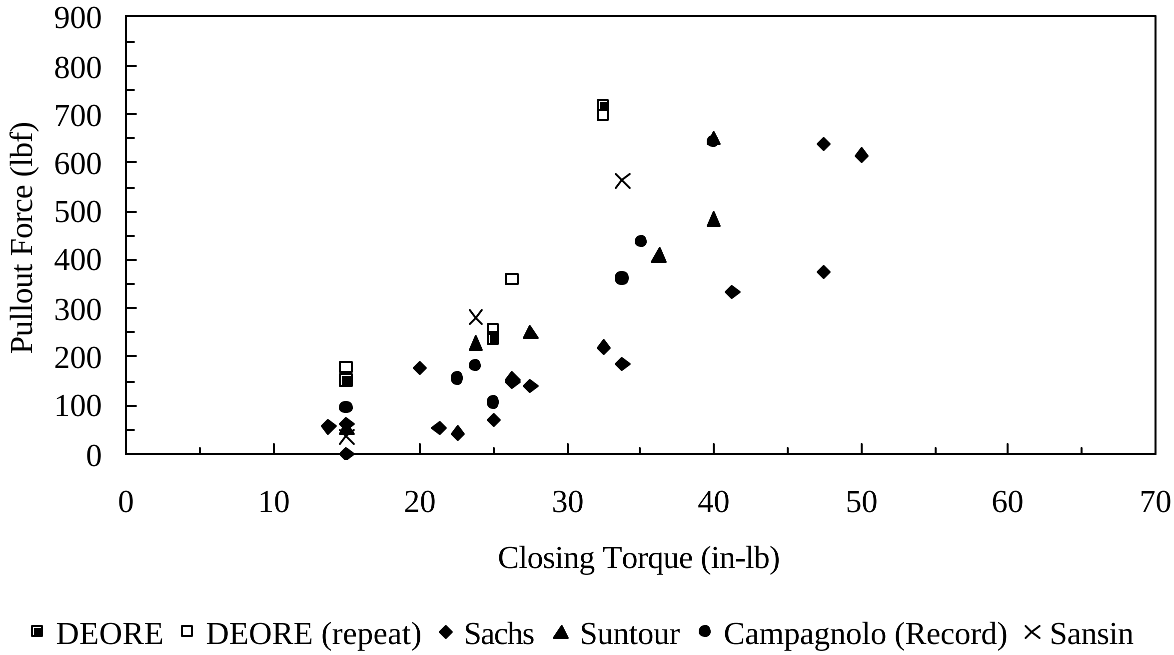
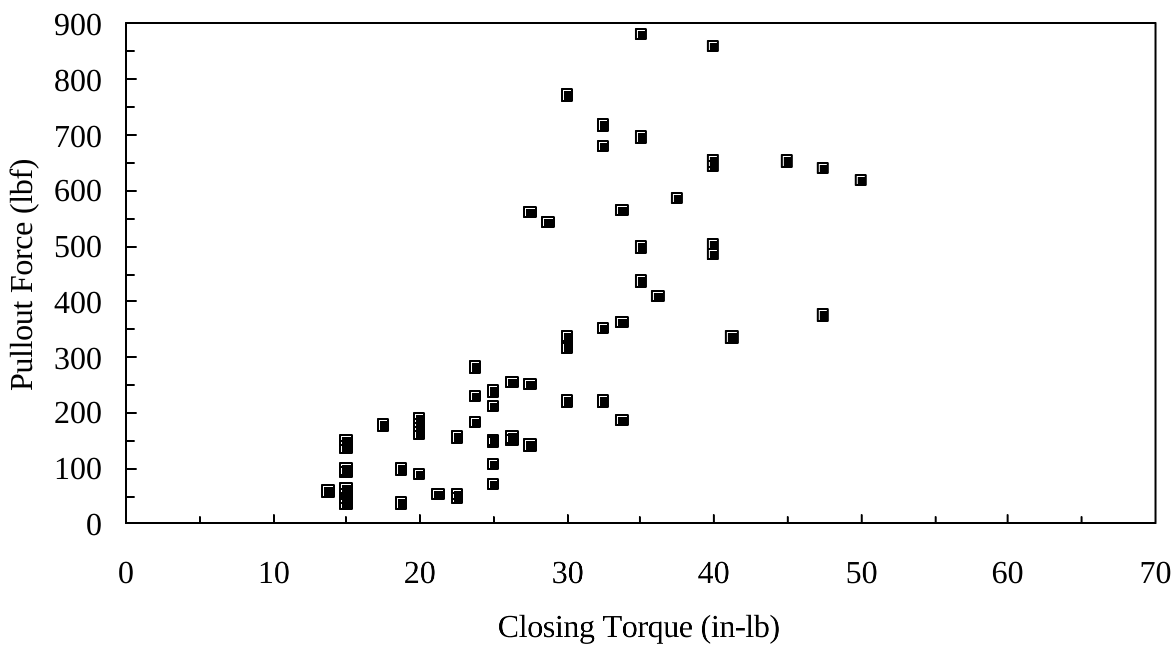


Figure VIII.4: Pull-out v. Close
All Preliminary Data



IX. PRELIMINARY RECOMMENDATIONS

At this point, the suitability of a general guideline can be examined. The previous three sections include information on opening and closing torques, closing torque and angle of engagement, closing torque and clamping force and closing torque and pull-out (retention) force. Figures VIII.4, VI.B.7 and VI.A.11 have been re-plotted as Figures IX.1, IX.2 and IX.3, respectively. Consider the following analysis.

De Long states that the desired minimum retention (pull-out) force is 517 lb_f (2300 N). This standard is superimposed on Figure IX.1 which plots closing torque v. pull-out force. The figure gives an expected range for closing torques for any given pull-out force. This range is not based on rigorous statistical interpretation. That study is underway. Given this range, the figure indicates that the minimum closing torque required to insure that this pull-out force is met is between 24 and 46 in-lb_f. Given the socket placement at 2" (51 mm), this corresponds to closing forces of 12 to 23 lb_f. This is well-below the maximum torque of 100 in-lb_f set by De Long.

Now turn to Figure IX.2. In this figure, closing torque is plotted against angle of engagement. As with the previous figure, an estimated region is shown. Table IX.1 provides an interpretation of the range of engagement angles corresponding to the range of closing torques discussed above.

Table IX.1
Estimated Angles of Engagement

Closing Torque (in-lb_f) Required for 517 lbf Pull-out	Minimum Corresponding Engagement Angle	Maximum Corresponding Engagement Angle
24 (Minimum)	24^o	54^o
46 (Maximum)	45^o	100^o

At first blush, this indicates that if the angle of engagement for all QR's is set at 100^o, then it would insure that the pull-out force is in excess of the ISO standard. Given the uncertainty in the data, Barnett's angle of engagement of 90^o is probably conservative. Further, De Long's recommendation in his step one of feeling resistance just passed 90^o is also probably conservative. It is important to recognize, however, the range in values indicated by this sample set of QR's. The proper angle of engagement is between 24^o and 100^o. Further, suppose that a shop mechanic engages the QR at 100^o when 24^o is proper. Extrapolating the Maximum Range line of Figure IX.2 to 100^o corresponds to a closing torque of 102 in-lb_f, which is approximately

Figure IX.1: Closing v. Pull-out
All Preliminary Data

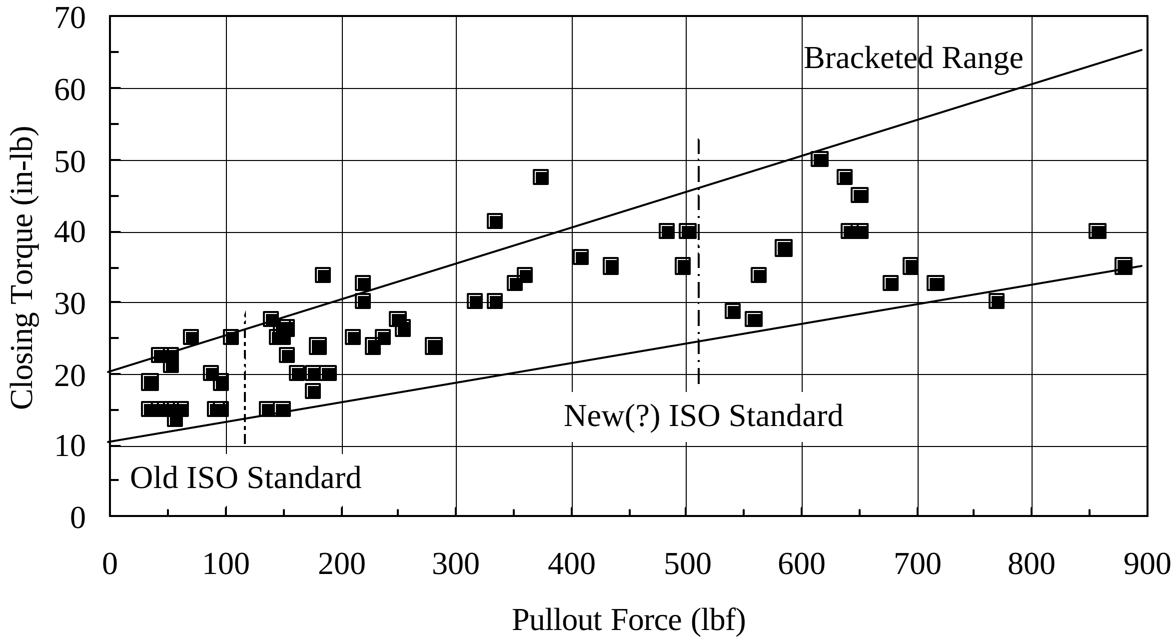


Figure IX.2: Closing v. Angle
Data with Mild Steel Drop-outs

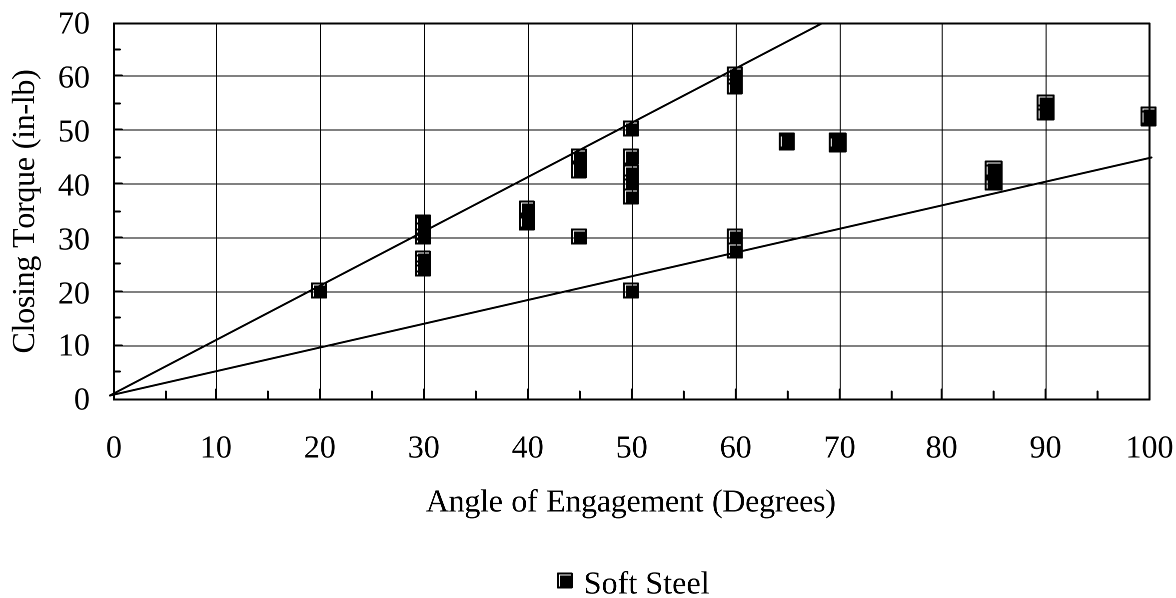
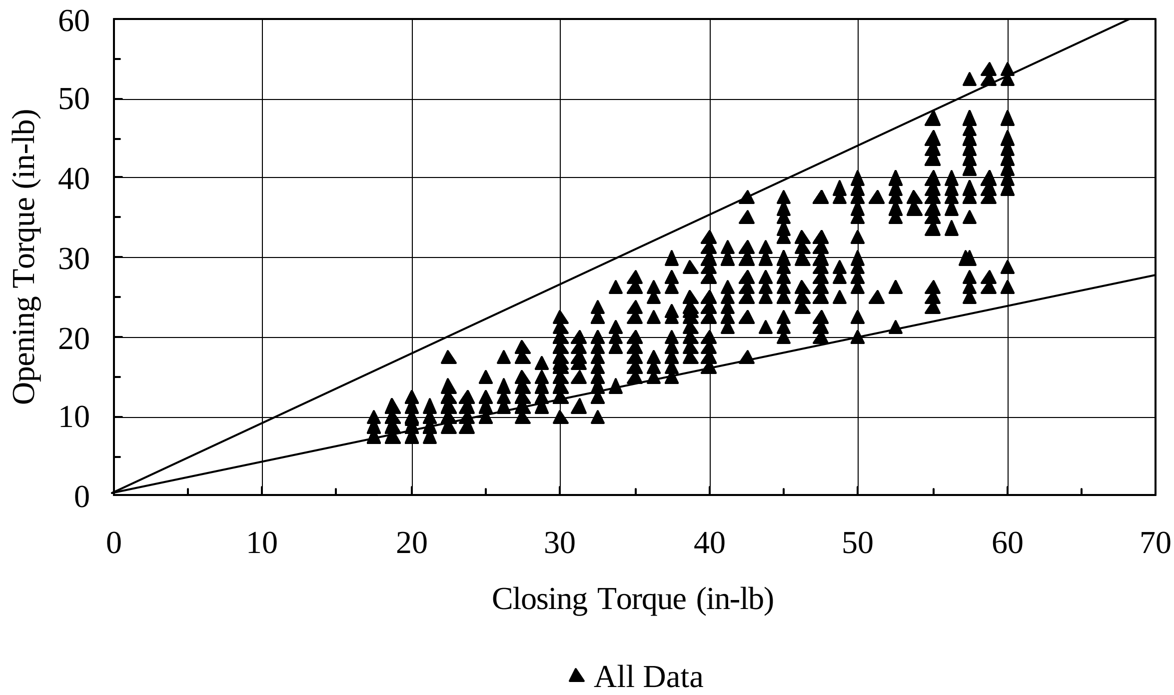


Figure IX.3: Relation of Open & Close Data for all Sample QR's (Mills' Data)



the maximum recommended by De Long and, consequently, the skewer is not over-stressed. Given the conservative nature of the ranges shown in the figures, an engagement angle of 90^o is reasonable.

Now compare this range of closing torques to the corresponding opening torques given in Figure IX.3. De Long recommends using opening force of 12 lb_f (26 in-lb_f torque) as his check for proper engagement. Table IX.2 presents the range of corresponding opening torques to the closing torque range required in Figure IX.1.

Table IX.2
Estimated Opening Torques and Forces

Closing Torque (in-lb_f) Required for 517 lbf Pull-out	Minimum Corresponding		Maximum Corresponding	
	Torque	Force	Torque	Force
24 (Minimum)	8 in-lb_f	4 lb_f	22 in-lb_f	11 lb_f
46 (Maximum)	18 in-lb_f	9 lb_f	40 in-lb_f	20 lb_f

This interpretation indicates that De Long's recommended force of 12 lb_f (26 in-lb_f of torque) may not be sufficient to insure that the ISO standard is met. A guideline based on Opening Torque may be useful, albeit at a value above 26 in-lb_f. As will be seen in Section XI, opening and closing torques are not affected by fork alignment while angle of engagement is.

Therefore, for these preliminary purposes, we recommend that the angle of engagement be used as a measure of proper QR engagement. Specifically, at this time, with aligned forks, we recommend an angle of engagement of 90^o be taught to shop mechanics and consumers.

X. EFFECT OF FORK MATERIAL

A subset of the QR's listed in Table V.E.1 were tested on different forks with different alignments. The subset is listed in Table X.1.

Table X.1
QR's Used in Material and Alignment Experiments

Campagnolo Athena
Campagnolo Record
Mavic Alloy
Sachs Standard
Shimano Exage Mountain
Sansin
Suntour

The fork drop-outs were aligned for all these measurements reported in this section. When sets of experiments were performed over a long duration of time, initial measurements were repeated to insure that procedures had not changed.

Figures X.1 and X.2 are representative plots of opening v. closing and closing v. angle of engagement for the Shimano Exage Mountain QR. These plots show the actual data measured. Best fit lines of the same information are shown in Figures X.3 and X.4. Similar plots were developed for all other QR's listed in Table X.1. Figures X.5 - X.10 present the actual data for closing v. angle of engagement for the other six releases. All of the data are combined in Figure X.11. The individual plots show that closing torque v. angle of engagement is not affected by the fork material. However, Figure X.11 shows that there is variability among the individual releases.

Analysis of the figures indicates that performance in terms of opening, closing and angle of engagement are unaffected by the fork material. Therefore, an angle of engagement of 90^o *is still suitable independent of fork material.*

Figure X.1: Opening v. Closing Torques
Shimano Exage Mountain QR

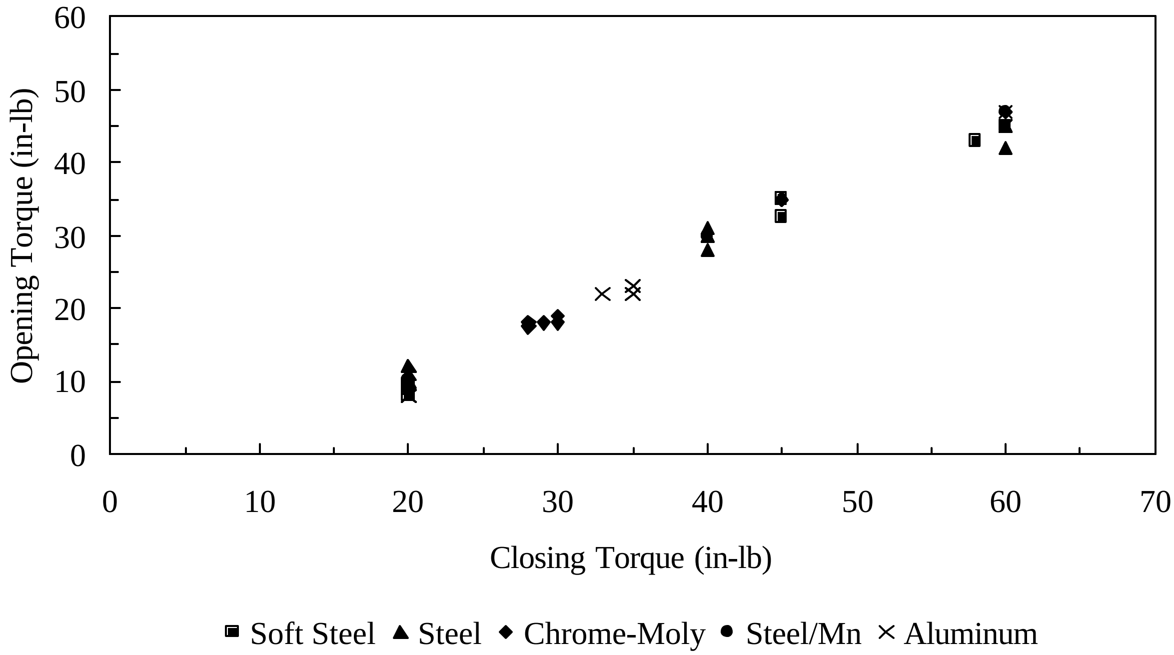


Figure X.2: Angle v. Closing Torque
Shimano Exage Mountain QR

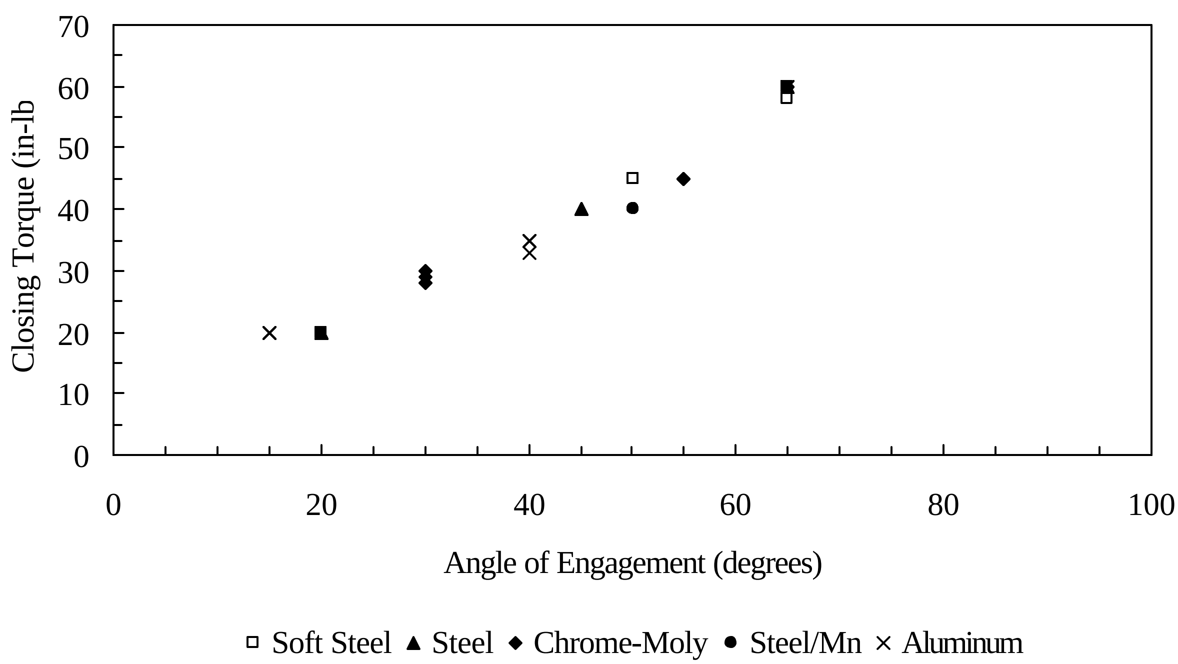


Figure X.3: Interpretted Open v. Close
Shimano Exage Mountain QR

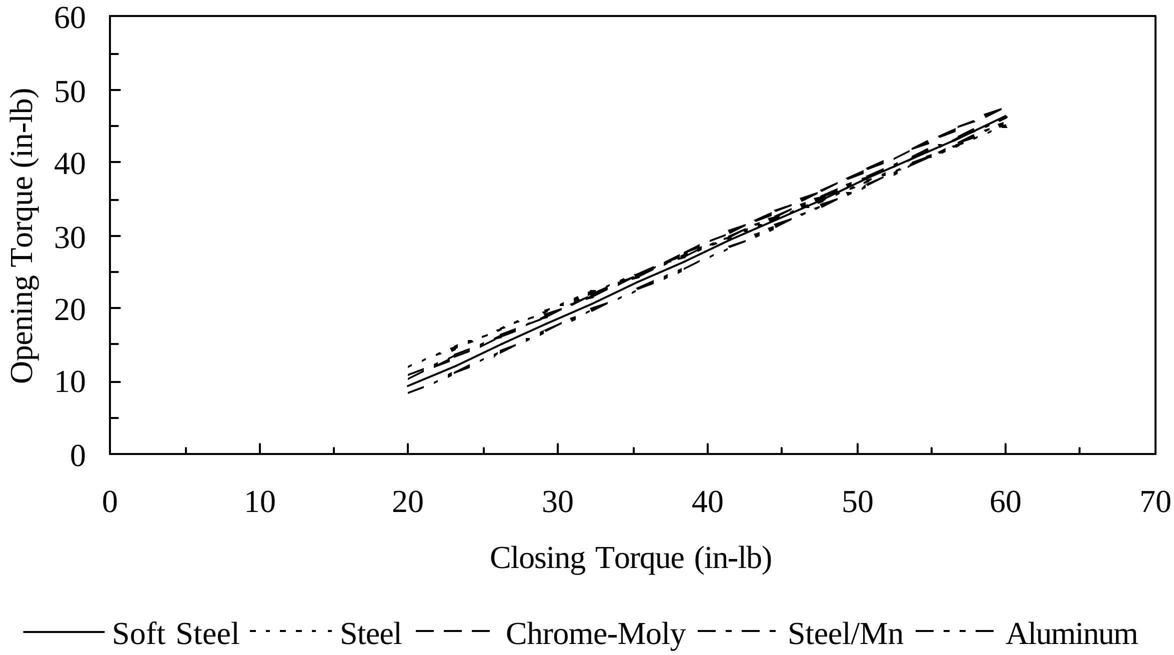


Figure X.4: Interpretted Close v. Angle
Shimano Exage Mountain QR

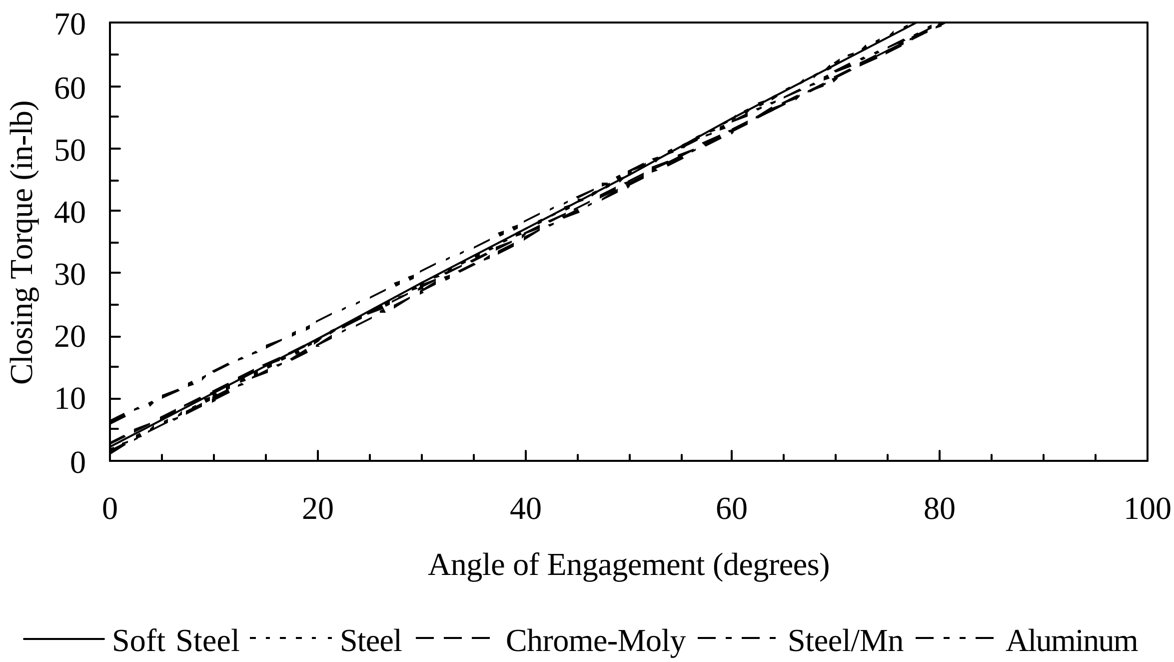


Figure X.5: Closing v. Angle
Campagnolo Athena QR

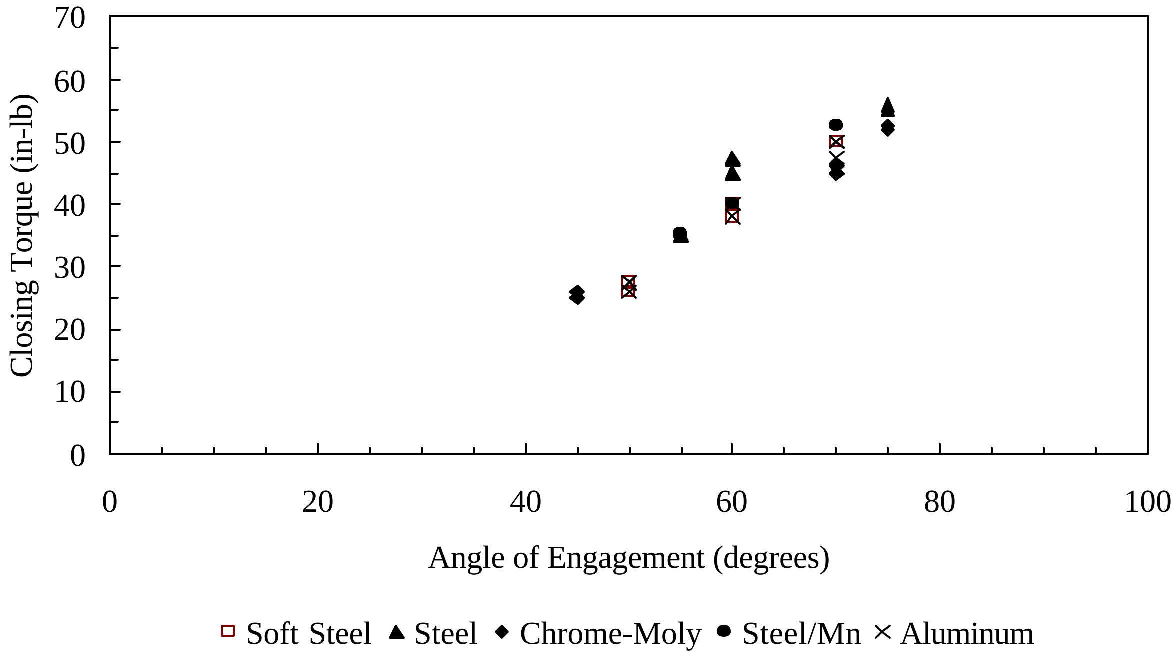


Figure X.6: Close v. Angle
Campagnolo Record QR

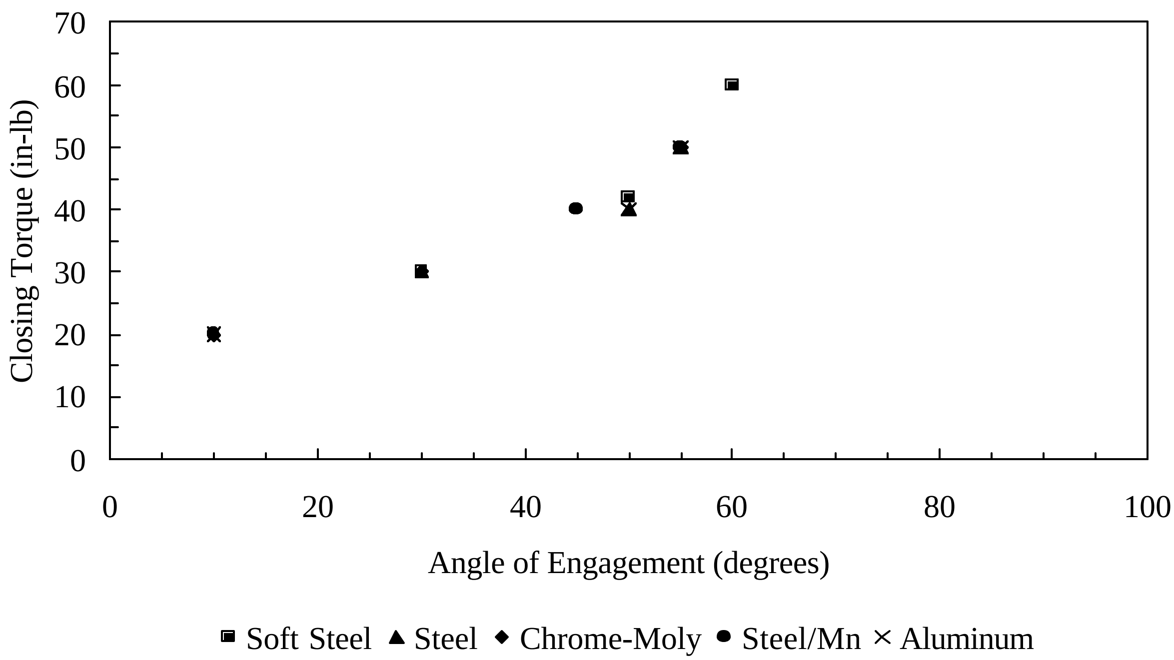


Figure X.7: Close v. Angle
Mavic Alloy QR

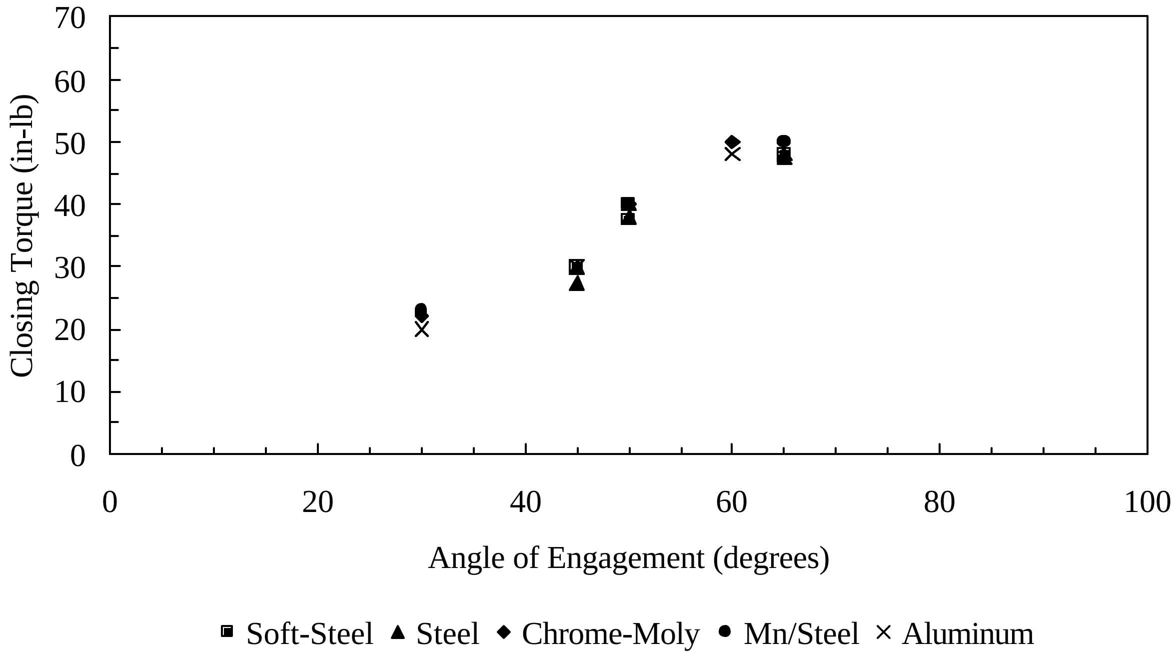


Figure X.8: Close v. Angle
Sachs Standard QR

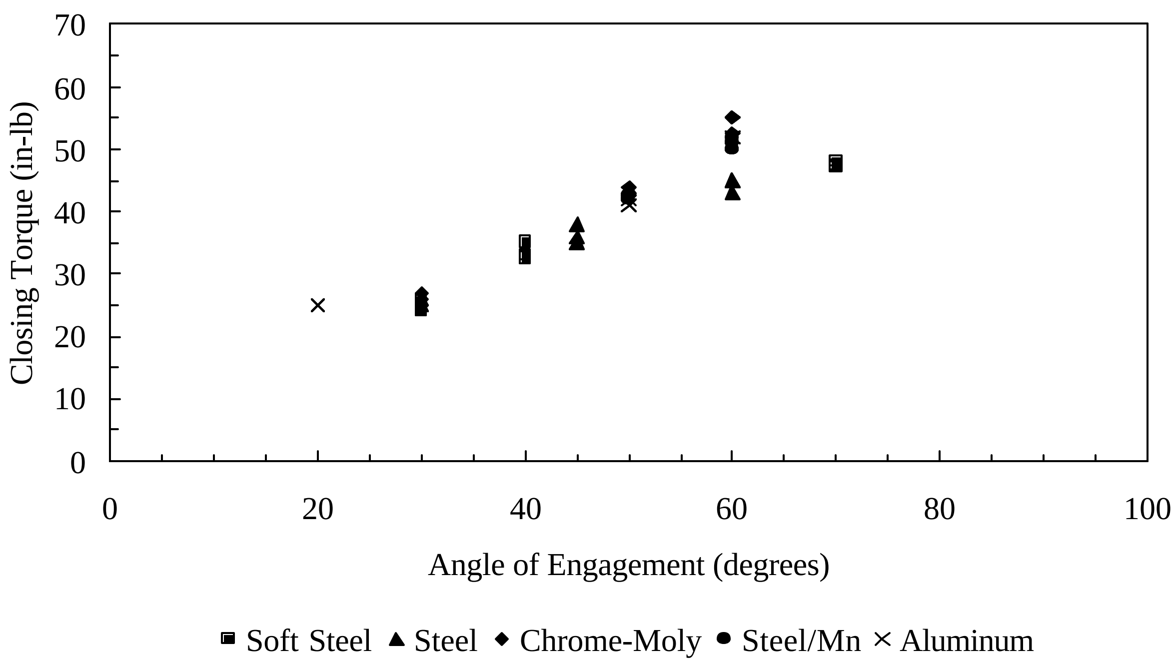


Figure X.9: Close v. Angle
Sansin QR

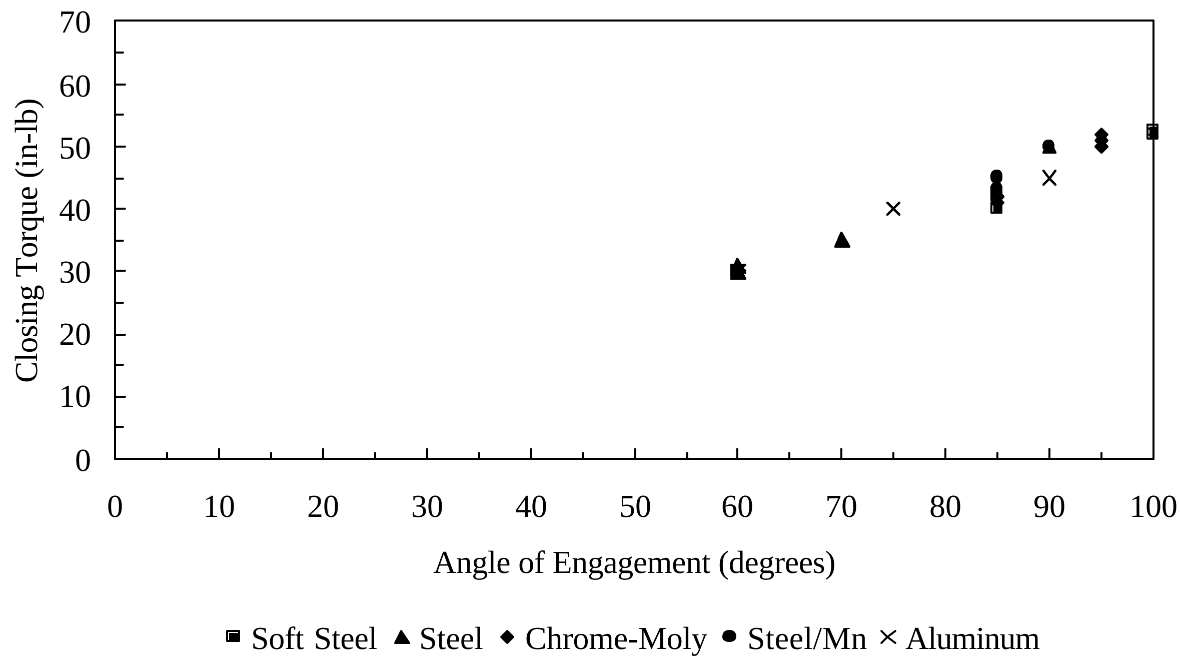


Figure X.10: Close v. Angle
Suntour QR

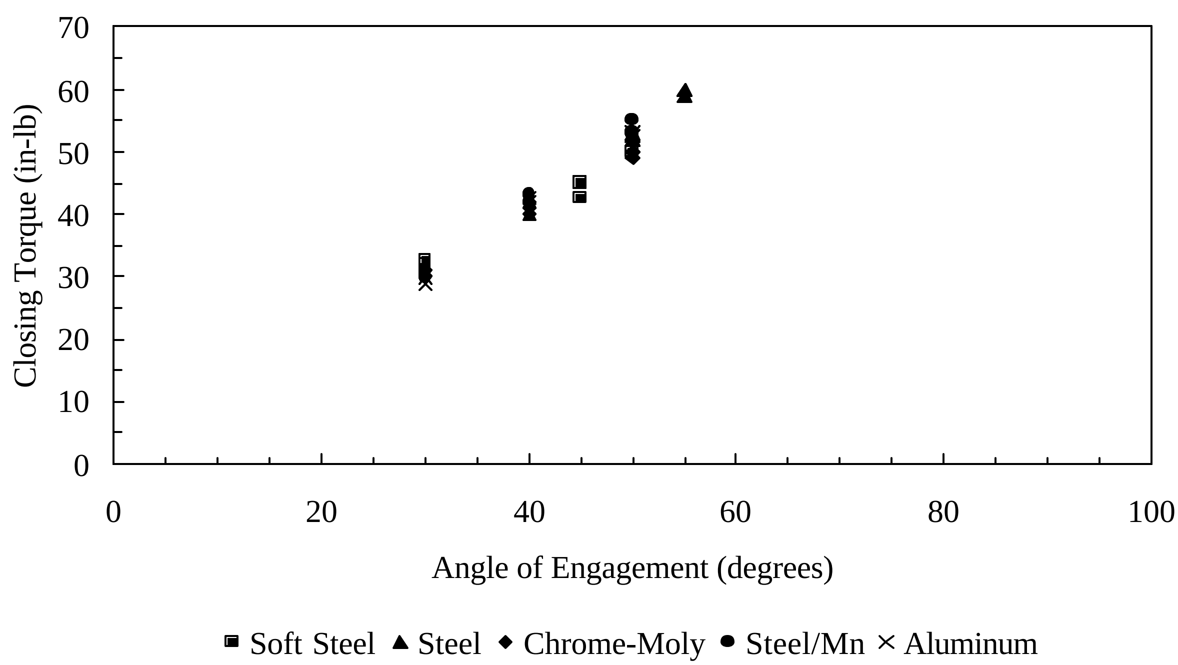
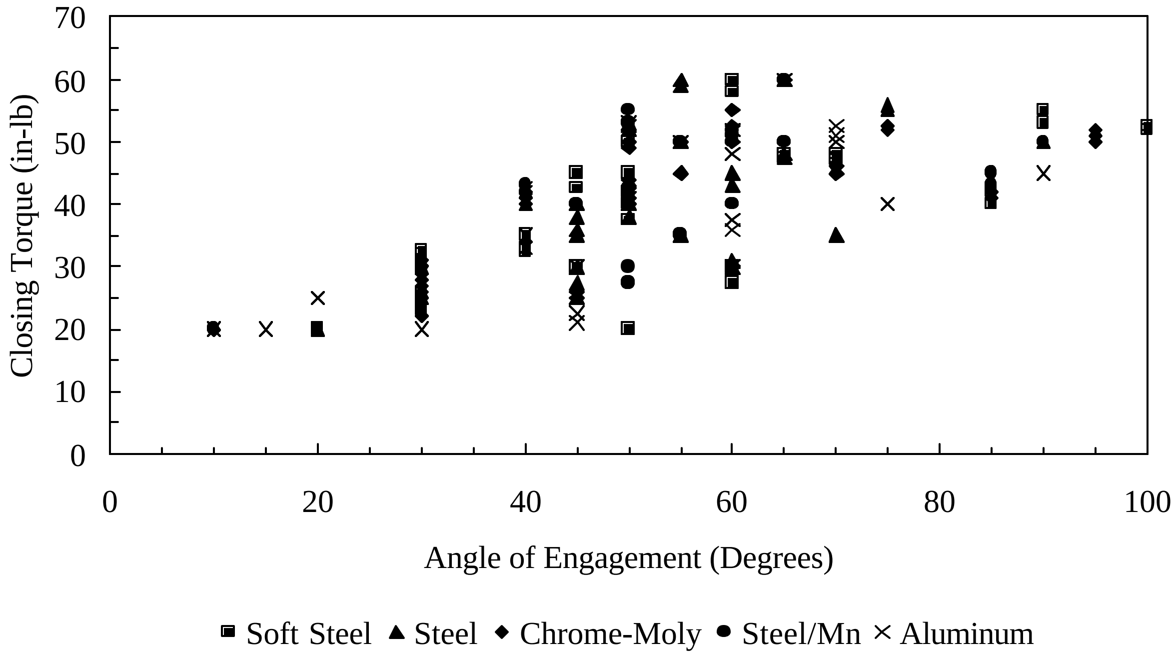


Figure X.11: Close v. Angle
Data for All Seven QR's in Table X.1



XI. EFFECT OF FORK ALIGNMENT

One of the comments regarding De Long's paper is that fork drop-out alignment is not discussed. It is likely that the alignment has an effect on the retention force. More importantly, any guideline that may be developed might be affected by the alignment. For example, if the guideline is related to the angle of engagement, it is possible that, for misaligned drop-outs, the apparent angle of engagement is greater than the actual value. This would result in wheel retention that is less than that anticipated from the guideline. Consequently, we developed a procedure for determining the effect of the misalignment on closing torque, opening torque and angle of engagement. Ultimately, the study of misalignment will be expanded to include pull-out force.

This section reports the preliminary measurements regarding misalignment. The QR's used are those reported in Table X.1. Fork alignment was measured as the gap between edges of Park Alignment tools when diametrically opposed edges touched. The dropouts were symmetrically misaligned. Measurements were made with the misalignment pointing to all four quadrants. In an effort to exaggerate the effect, the initial misalignment was set at 0.21" (5 mm). Subsequent measurements had the misalignment set at 0.1" (2.5 mm). The chrome-moly and aluminum drop-out forks were used for these measurements. The chrome-moly fork was studied at the larger misalignment setting. The aluminum fork was studied at both settings. The behavior of all seven QR's was similar. Consequently, only the Exage Mountain QR will be discussed in detail.

For the purposes of the following graphs, "+" indicates a flare downward, "-" indicates a flare upward, "++" indicates a flare forward and "--" indicates a flare backward. All directions are referenced to the bicycle's typical direction of travel.

First, consider the set of data with the forks misaligned at 0.21" (5 mm). Figure XI.1 shows all data for opening v. closing torques for the Exage Mountain QR with the chrome-moly fork. Note that there is no significant difference in the trends with direction of flare compared to the aligned data. This is perhaps better seen in Figure XI.2, which gives the best fit lines for the soft steel (aligned), chrome-moly (aligned) and chrome-moly (misaligned) measurements. Effectively, this indicates that the force to clamp the QR is greater than that required to align the drop-outs (and/or bend the axle) when the forks are misaligned.

Now consider, Figure XI.3. This is a plot of the same data presented as closing torque v. angle of engagement. It is clear that there is substantial offset to the right due to the misalignment. This is intuitively clear. With the dropouts flared, the QR contacts the drop-outs at an earlier effective angle because the flare effectively increases the thickness of the drop-out. *The significance of these results is that any guideline based on the angle of engagement must require that the forks be reasonably aligned.* Note that in this figure the relative position of the flare does not impact the data.

Now consider a reduced flare along with those reported above. Figure XI.4 presents

Figure XI.1: Opening v. Closing Torque
Shimano Exage Mountain QR (Mis-aligned)

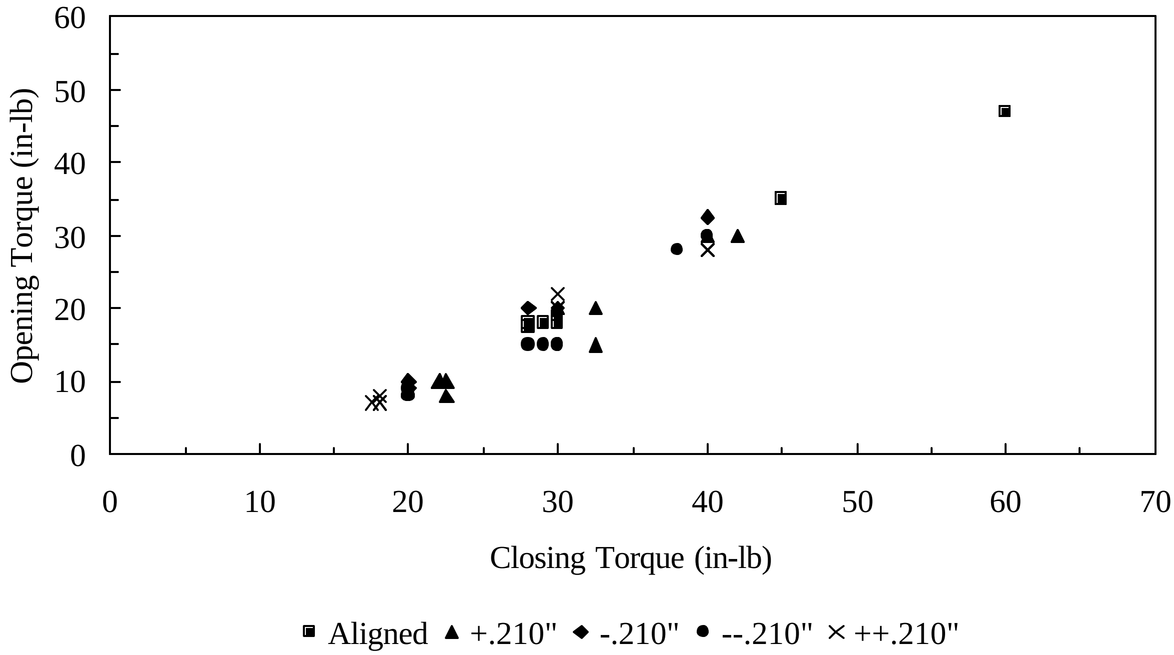


Figure XI.2: Interpretted Open v. Close
Shimano Exage Mountain QR (Mis-aligned)

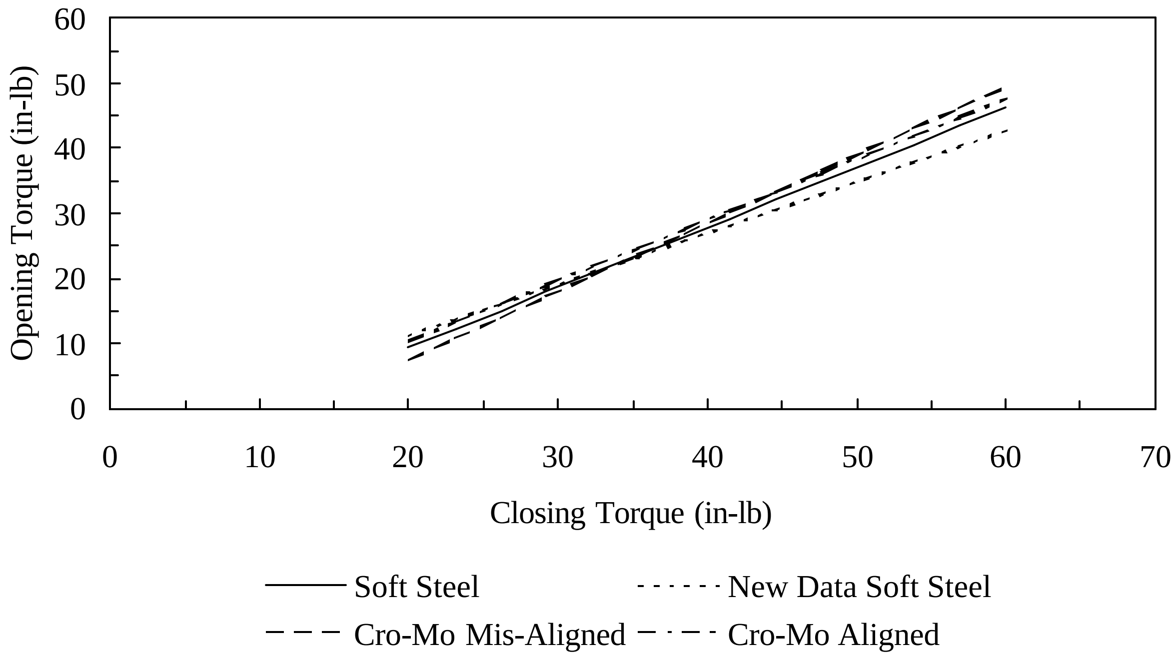


Figure XI.3: Close v. Angle
Shimano Exage Mountain QR (Mis-aligned)

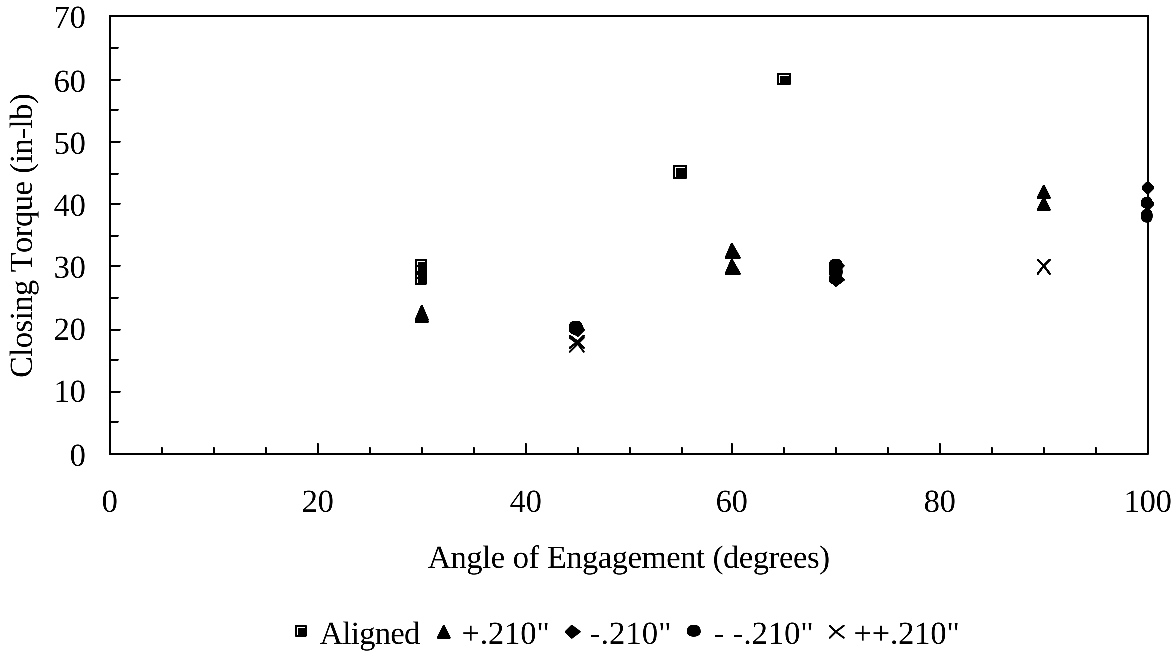
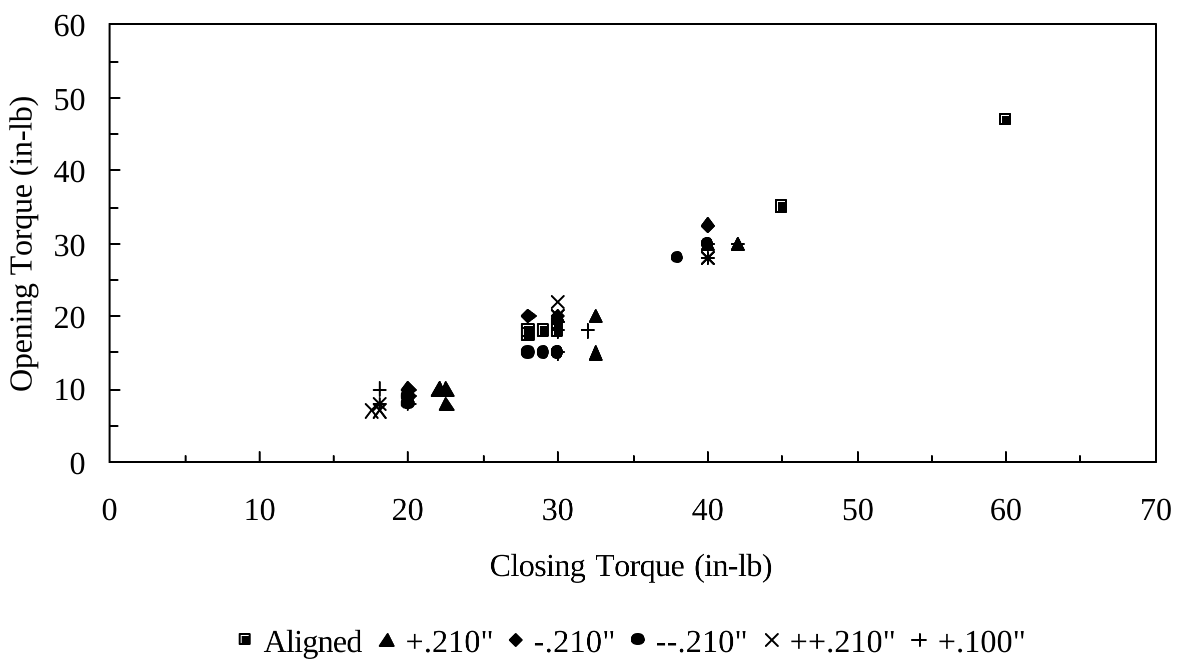


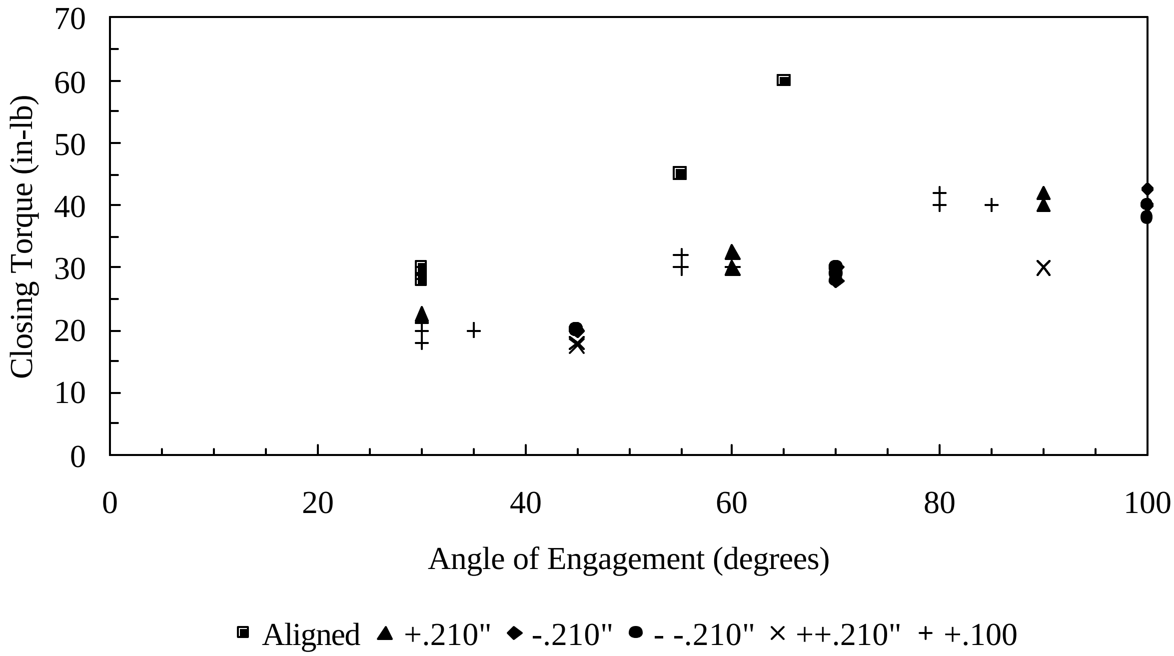
Figure XI.4: Opening v. Closing Torque
Shimano Exage Mountain QR (Mis-aligned)



opening v. closing torques. Figure XI.5 presents closing torque v. angle of engagement. For these plots, both fork materials are lumped for the 0.1" (2.5 mm) flare. Note as before that there is no difference between the aligned and misaligned data for the opening v. closing information. However, again, there is offset among the aligned and misaligned closing v. angle data with the offset less for the 0.1" (2.5 mm) data.

The principal conclusion is that the angle of engagement is not a direct measure of the closing torque, and, therefore, the retention force. The fork alignment contributes to the relationship. Any guideline will have to take fork alignment into account or provide sufficient safety factor to account for reasonable misalignments.

Figure XI.5: Close v. Angle
Shimano Exage Mountain QR (Mis-aligned)



XII. CONCLUSIONS

The data presented herein show that repeatable methods have been developed for measuring closing and opening torques, clamping force, pull-out force and angle of engagement. Preliminary analysis indicates that an angle of engagement of 90^o is suitable to insure that the QR is properly engaged as long as the fork drop-outs are aligned. If the forks are badly misaligned, using 90^o engagement may result in a retention force less than the new ISO standard. Nevertheless, even with the extreme misalignments studied herein and interpreting the data in the worst light, 90^o engagement is well-above the old ISO standard of 112 lb_f.

Refinements are required for the pull-out experimental method. Once the procedure is refined, additional data with an expanded QR set and a variety of drop-out materials are required. This will lead to a firmer recommendation for proper angle of engagement.

The data analysis procedures should be modified to include the clear differences among manufacturers. Instead of analyzing the data globally as was done here, each manufacturer's QR's should be analyzed separate from other manufacturers'. Then the angle of engagement, or some other, guideline could be checked against each.

XIII. ACKNOWLEDGEMENTS

We wish to acknowledge the generous support of Barnett Bicycle Institute, Bicycle Art (Indianapolis, Indiana), Campagnolo, Cycle Works (Lawrence, Kansas), Mavic and Sachs who have contributed equipment and insight during the course of this research. Without their generous contributions of quick release and fork samples, this work would not have been possible. Supplies and test equipment were purchased with funds from Occidental Petroleum Foundation whose support of these activities and others is gratefully acknowledged.