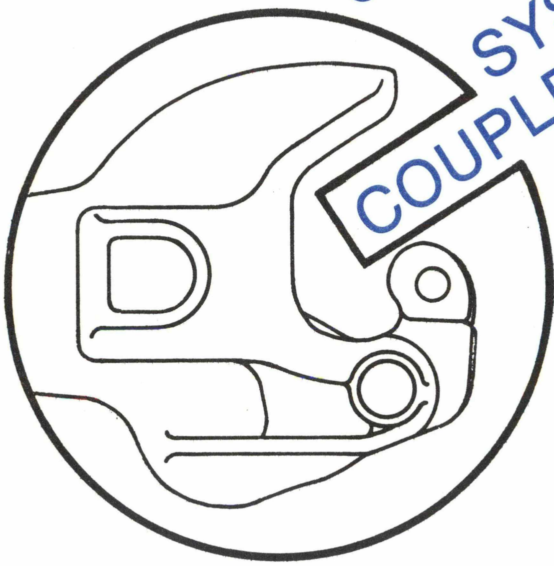
CHARACTERIZATION OF DRAWGEAR SYSTEMS DURING COUPLER ANGLING



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An International Government-Industry
Research Program on Track-Train Dynamics

R-187

CHARACTERIZATION OF DRAWGEAR SYSTEMS DURING COUPLER ANGLING

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ACKNOWLEDGEMENT

This reference manual on the lateral force characteristics of various types of draft gears and couplers under draft and buff loads during angling, was developed as a joint effort of the Association of American Railroads, the Railway Progress Institute, the Federal Railroad Administration, and the Transportation Development Agency of Canada under the auspices of the International Government-Industry Research Program on Track-Train Dynamics.

The work described herein was performed by the National Castings Division of Midland-Ross Corporation under contract to the Track Train Dynamics Program. Details of this contract were worked out between the undersigned and Mr.D.J.Albanese, Director, Technical and International Operations of National Castings.

Mr. Albanese handled the overall administration of this project at their Technical Center; Mr. W.E.Baillie, Manager, New Products, was responsible for the concept of the laboratory simulation and for technical guidance throughout the program, and Mr. R.M.Hanula, Commercial Engineer, assumed responsibility for the project management and analysis of the information obtained.

Data from these tests will be used in several Track Train Dynamics mathematical models, particularly the Lateral Train Stability Model and the Quasi-static Lateral Train Stability Model. We acknowledge the work directed by Dr. Gregory C. Martin of the AAR through which the family of models was developed. In particular, Mr. Raj. Penemetsa Consultant, Dynamic Analysis, should be acknowledged for his work in the development of the Lateral Train Stability Model; Electro-Motive Division, General Motors Corporation is also acknowledged for their contribution of the Quasi-Static Lateral Train Stability Model which they expanded, with assistance from Dr. Martin, from an earlier model they developed for locomotives.

E.F.LIND,
Project Director - Phase I
Track Train Dynamics Program

FOREWORD

This report describes the lateral force characteristics of a variety of coupler and draft gear combinations under various buff and pull train loads. Data from these tests will provide input into several analytical models used to describe train behavior. More specifically, the programs that will use these data are the Quasi-Static Lateral Train Stability and Detailed Lateral Train Stability models.

The types of adverse track train dynamic interactions these models are intended to investigate, are those created by certain combinations of long and short cars, the placement of long, light cars at the head end of trains, the length of tangent between reversing curves, and the amount and rate of change of superelevation within the spiral. The programs are designed to investigate jackknifing tendencies for a variety of car combinations, track geometries, and operating practices.

It is with these models, with input from the data contained in this report, that better insights will be provided for corrective track geometry and operating guidelines.

Report on
National Castings Division, Midland-Ross Corporation
Participation In
AAR-RPI-FRA Track Train Dynamics Program

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STATIC ANGLING TEST AND ANALYSIS

OF

FREIGHT CAR COUPLING SYSTEMS

National Castings Division
Midland-Ross Corporation

Participation in AAR-RPI-FRA
Track Train Dynamics Program

SUMMARY

This testing and analysis was done for the Track Train Dynamics Program.

The tests were conducted between February and October of 1974 at the Technical Center of the National Castings Division of Midland Ross Corporation, Cleveland, Ohio.

The purpose of the tests and analysis was contracted to determine the lateral force characteristics of the drawgear system during coupler angling under various buff and pull train loads. Components involved in the drawgear include coupler, yoke, draft gear and related parts. Characteristics of a coupling system with a simple spherical shank bearing surface under buffing loads were estimated without test.

Specific tests were conducted on both the Standard AAR rigid shank E coupler connection and on the Standard AAR F coupler with alignment shoulder connection. Conventional 24-5/8" pocket draft gears were varied throughout test and include common high capacity (AAR Specification M-901E) friction, rubber friction and rubber types, as well as three common older (AAR Specification M-901) friction gears. Results proved to be basically independent of draft gear type, except as noted later in this report.

Because of differences in results caused by friction, lateral force characteristics under both buff and pull loads were determined by the test for coupler angle increasing and coupler angle decreasing. For rigid shank E coupler connection tests only, initial positioning of the coupler shank was found to appreaciably affect lateral forces and shank positioning was varied to determine maximum and minimum extremes.

In pull, only the rigid shank E coupler connection was tested and only with the Mark 50 draft gear. Under pull, because the F coupler butt with alignment shoulders separates from the front follower and there is no alignment effect, reaction is identical to a simple pinned connection. Accordingly, test results for the locomotive assembly with plunger type alignment control and M-381 draft gear prior to alignment shoulder contact are used to represent pull characteristics for F coupler shank connections, National Report No. 266.

Based on the results of the static angling tests and analysis, curves were developed to illustrate angling characteristics of the various drawgears with no longitudinal force, and with 50, 100, 200, 300 and 400 thousand pounds of longitudinal force in both buff and pull. Because the information described is to be used in a computer program which utilizes moment characteristics to determine lateral forces during simulated train negotiation of curves, longitudinal and lateral forces recorded during the test were used to calculate moments. These moments are located on the car (draft gear pocket) centerline 28-1/2" from the coupling line

for the E coupler rigid shank connection tested, and 29¼" for the F coupler shank connection tested. Curves developed illustrate these moments vs. the lateral displacement at the coupling line translated into degrees of angling of a theoretically fixed and centered coupler shank.

Figures Nos. 6, 7, and 8 indicate formulas and assumptions used for calculations. Figures 9 through 42 illustrate results. Photographs of the fixture setup for both buff and pull are on Figures Nos. 4 and 5.

INTRODUCTION

The Track Train Dynamics Program is a joint government and industry research program involving the Association of American Railroads, the Federal Railroad Administration, the Railway Progress Institute and the Transportation Development Agency. This is a multi-year, national study and implementation project designed to improve freight transportation. The study covers all of the interacting forces that influence the motion of a train as a whole, its individual locomotives, cars and their contents and track structure.

In the Track Train Dynamics Program was the assignment to develop a mathematical model to determine lateral wheel-to-rail forces generated by a train negotiating any track geometry. These wheel-to-rail forces are influenced by the lateral force characteristics of the drawgear system during coupler lateral angling under various buff and pull train loads. National Castings assignment was to determine the lateral force characteristics of the drawgear system. Communication during this testing and analysis was with Mr. E. F. Lind, Project Director of the Track Train Dynamics Program, who was located at the AAR Research Laboratory in Chicago, Illinois. Testing started February of 1974 and was completed in October of 1974.

Prior to the Track Train Dynamics Program assignment, National Castings had cooperated with Electro-Motive Division of General Motors Corporation in establishing analytical methods for determining lateral wheel-to-rail forces used in a computer program for locomotives and cars negotiating various curve conditions. At that time, research tests were conducted by National to obtain lateral force characteristics for the locomotive coupling system, Report No. 266, for an AAR Standard Rigid Shank E coupler arrangement, Report No. 566. Both reports were made available to Track Train Dynamics for their use. With some modification as described in this report, techniques used for determing lateral forces and illustrating data in a proper form for analysis in the Electro-Motive program were utilized in the Track Train Dynamics Program assignment.

PURPOSE OF TEST

Static angling tests were conducted on an AAR Standard rigid shank E coupler connection and on a Standard AAR F coupler with alignment shoulder connection to determine maximum and minimum lateral forces required to increase or decrease the coupler angle under various longitudinal buff and pull loads. Draft gears were varied during buff tests to determine effect.

MATERIAL TESTED

The test assembly consisted of a conventional 24-5/8" pocket draft gear, with follower when applicable, and either

a. AAR former Standard B-E60B-HT* coupler with head end modified per National Drawing No. TE660308, AAR former Standard B-Y40* yoke, AAR Standard E coupler cast striker modified per National Drawing No. 651123-2 and draft key or

b. AAR Standard F70BHT coupler with head end modified per National Drawing No. TE660308-1, AAR former Standard B-Y45 yoke*, AAR Standard F coupler striker with 13^{o} lateral angling capability modified per National Drawing No. TE651123-3 and Y47 pin.

*Coupler B-E60B-HT is functionally equivalent to current E60CHT, yoke B-Y40 is functionally equivalent to current Y45AHT.

Draft gear types used were selected because they are representative of the greatest number and types of draft gears found in service, and representative of the greatest number of gears presently being produced by the three major draft gear manufacturers. The three high capacity (AAR Specification M-901E) draft gears tested include the Cardwell Westinghouse friction type Mark 50, the Miner rubber friction type RF-444, and the National Castings rubber type NC-440 (for E coupler arrangement) and NC-440-1 (for F coupler arrangements). Three common older (AAR Specification M-901) friction draft gears with lower capacities tested include the Cardwell Westinghouse NY-11-F, the Miner A-22-XL and the National Castings M-17-A Rev. 1.

TEST EQUIPMENT

Test equipment included a 1,200,000 lb. universal static test machine and a test fixture which simulated a freight car center sill and draft gear pocket. Details of the test fixture are on National Drawing No. TE651123A.

Instrumentation includes static strain equipment and miscellaneous mechanical and electrical measuring devices described in Appendix A.

TEST PROCEDURE

1. Summary

With modified coupler, draft gear, yoke and related parts assembled into the test fixture, the assembly was set up in the 1,200,000 pound testing machine as shown in Figures 1, 2 and 3. While the static test machine applied load was held constant by moving the cross head up or down, the coupler angle was increased and decreased by varying the coupler displacement at the coupling line with Jack J or Jack K. Coupler angling was stopped only long enough to record data or reverse direction. Jacking forces were recorded at various displacements along with dimension C between fixed and movable test machine loading pivots as indicated on Figures 1, 2 and 3, and angular rotation of test fixture and coupler angles X and Y respectively as indicated on Figures 6 and 7. Draft gear travel, dimensions A and B on Figures 1, 2 and 3, recorded during early testing were later eliminated as unnecessary.

Longitudinal static test machine loads at which lateral forces were determined for a complete test of an arrangement in buff and pull were zero; 50,000; 100,000; 200,000; 300,000; and 400,000 pounds.

For other than screening tests, data was recorded in coupler angling increments of one degree as determined by the actual coupler angle (angle between shank and gear pocket centerlines), which is equal to the sum of measured angles X and Y as illustrated on Figures 6 and 7.

To begin, testing was intended to obtain results only for couplers that were initially centered. In addition, the original test arrangement had no provision for obtaining lateral forces when the jacking force at the coupling line became less than zero as was the case under some conditions with reducing coupler angling, or for allowing coupler angling much beyond 7°. Analysis of early test results along with a supplemental rigid shank test with the Mark 50 draft gear indicated the desireability of modification to the test procedure and fixturing.

2. Initial Positioning of Components for Buff Test - E Coupler Rigid Shank

The rigid shank E connection with horizontal cross key allows the shank to initially locate laterally within an approximate two inch range with normal dimensions (See Figure 1). In service, the position of the coupler and yoke within the arrangement at any one time can vary dependent only upon its past action, influenced by conditions of track and train reaction.

The supplemental rigid shank test with the Mark 50 draft gear confirmed both indications from early test results with centered gears and analysis that initial positioning of parts would significantly effect test results.

To obtain maximum and minimum lateral forces with the rigid shank connection, testing was conducted with coupler shank and yoke initially positioned to both lateral extremes.

3. Recording of Maximum and Minimum Lateral Force

With increasing angling, small angles of the rigid shank coupler are achieved by lateral movement of the forward portion of the coupler shank within the yoke, and lateral movement of the yoke within the striker. When lateral displacement at the forward portion of the shank is used up, additional coupler angling under heavy buff requires lateral movement of the coupler shank butt relative to the front draft gear follower. Under heavy buff, high lateral force is required to move the coupler shank butt laterally relative to the draft gear follower. The procedure used to determine maximum and minimum lateral forces for a coupler arrangement and initial positioning, at a particular coupler angle X was as follows (See Figure 6).

To obtain the maximum lateral force, readings were first recorded as angle X was reached during initial coupler angle increasing. To obtain the minimum lateral force for the same angle X, the angle was increased another $.5^{o}$, (to X + $.5^{o}$), where coupler angling was reversed and readings were again recorded at angle X, but with the coupler angle increasing. To obtain the minimum lateral force for coupler angle increasing, the coupler angle was decreased another $.5^{o}$, (to X - $.5^{o}$), where angling was again reversed and readings at angle X were recorded again for coupler angle increasing. With the coupler angle increasing the second time, lateral movement at the forward portion of the shank was no longer restricted, and the lateral force was reduced from that recorded the first time.

Testing of the rigid shank connection in buff with the Mark 50 draft gear included all readings as described in the previous paragraph and initially at both lateral extremes. Based on these results, readings not required to establish lateral force limits were eliminated in later testing. In addition only screening tests were conducted on the older type friction gears, the A22XL, M17A and NY11F, and on the all rubber NC-440 and NC440-1 draft gears to determine certain limits or to determine that their results would fall within the same limits as the other draft gears tested.

Screening of an F coupler shank application established that initial positioning of the parts (much less variation than for the rigid shank)does not appreciably effect angling characteristics under buff load.

4. Supplemental Jacking Means

To obtain forces when the jacking force at the coupling line became less than zero, an additional jack and load cell, Jack K on Figures 1 and 3, was added. Jacking at location K became necessary in buff only when decreasing the coupler angle.

5. Increasing Fixturing Angling for F Arrangement

For early F coupler testing, the fixture limited coupler angling to approximately 8^{o}. Under small buff loads, coupler angling with the F arrangement can approach 13^{o}. With the minor design changes the fixture angling capabiltiy was increased to allow 13^{o} of lateral angling of the F coupler shank. Later F coupler tests for the NC-440, A22XL and M-17A draft gears were conducted to the maximum capability of the arrangements.

6. Pull Test

a. F Coupler Shanks

Under pull forces the F coupler shank butt separates from the front follower due to draft gear travel. At 50,000 lb pull force or greater, normal draft gear travel is sufficient that alignment shoulders do not make contact with the front follower at any angle. Under these conditions the coupler is identical to a simple pinned connection. Analysis of the F coupler in pull is included under Results of Test.

b. E Coupler Rigid Shank

For the E coupler rigid shank arrangement in pull, draft gear travel separates the coupler shank from the front follower. Lateral force required to angle the coupler due to lateral displacement of the yoke head, although somewhat dependent upon draft gear, is negligible, indicating that for other than very small coupler angles, angling characteristics are independent of draft gear characteristics. Accordingly it was decided the rigid shank pull test would be conducted with the Mark 50, a very common high capacity (AAR Specification M-901E) friction draft gear.

Analysis of the rigid shank connection in pull indicated that initial positioning of the shank and yoke in the arrangement would appreciably effect angling characteristics. It was decided that angling test results would be obtained for three separate initial positions.

To obtain minimum lateral force at greater coupler angles during coupler angle increasing, parts for the rigid shank arrangement were initially positioned to allow maximum displacement at the coupling line without requiring the coupler shank to laterally displace within the yoke. This is noted as position A on Figures 38 through 42 illustrating resulting moments.

To obtain minimum lateral force at lesser coupler angles during coupler angle increasing, parts were initially positioned to allow maximum displacement at the coupling line without requiring the shank to laterally displace or angle within the yoke. This is noted as position B on Figures 38 through 42.

To obtain maximum lateral force J during coupler angle increasing, parts were initially positioned to require both shank displacement and angling within the yoke with minimum displacement at the coupling line. This is noted as position C on Figures 38 through 42.

During pull testing, coupler angles were increased continuously to maximum without reversal, and angles were decreased continuously with readings at one or two points to establish limits.

To avoid fixture damage, such as deformation of the striker or coupler shank bending, jacking force J in pull was limited to 60,000 lb.

RESULTS OF TEST

Moments calculated from test results are illustrated graphically on Figures 9 through 42. Theoretical estimates of the frictional moments in buff for an F coupler shank without alignment shoulders are illustrated graphically on Figure 42.

1. Moments and Coupler Angle Calculations

Calculations for coupler moments and angles are illustrated on Figures 6, 7 and 8. In all cases, a positive lateral force on the coupler is defined as being perpendicular to the car center line, and in the same direction as the coupler displacement. A buffing force is defined as being parallel with the car center line. Positive moments on the angling fixture resulting from the forces on the coupler shank at the head pin are counter clockwise viewing the coupler with displacement left.

Calculations for lateral force L on the coupler shank fixture at the head pin centerline are illustrated on Figure 6 for Jack J, and on Figure 7 for Jack K in buff. Since the applied machine force F was not parallel with the gear pocket centerline (car centerline), the lateral force component was added to the coupler displacement jacking load to obtain the resultant lateral force.

In calculations it is desirable to replace the complex force system involved in the actual draft gear arrangement with a simpler equivalent coupler arrangement. The method described in Appendix B for determining lateral forces at the truck center of a railroad car is an example. Simplification of calculations results from a constant dimension between coupler pivots for varying coupler angles. Figure 8 illustrates calculations used for determining moments from test results for a theoretically fixed 28-½" length E rigid shank and 29-¼" length F coupler in buff or pull.

All moment curves illustrated on Figures 9 through 42 have had moments M and coupler angle Z calculated from test results as described in this section. Individual points are illustrated on Figures 9 through 18 and 26 through 32.

2. E Coupler Rigid Shank Results - Buff

a. Extreme Moments, Coupler Angle Increasing - Buff

Figures 9 through 13 illustrate maximum and minimum moment curves in buff for an angle increasing E rigid shank coupler based on results of all gears tested, as well as extremes for individual RF-444, Mark 50 (at 100, 200 and 300 thousand lbs), NY11F and A22XL (both screened at 100 and 300 thousand lbs) draft gears. Individual points from centered gears which were used in establishing extremes are illustrated on curves. The primary reason for the wide variations in moment extremes prior to the 7° normal maximum rigid shank E coupler angling is friction between shank and follower.

For any angle, the forward portion of the shank may or may not be restricted within the striker, depending upon the lateral position of the shank butt within the yoke. When the forward portion of the shank is restricted, any additional coupler angling requires lateral displacement of the shank butt relative to the follower. Under buff forces, frictional resistance can be considerable, causing high moments. For the same angling without restriction at the forward portion of the shank, moments are significantly lower.

Secondary variations in maximum moments for individual draft gears indicate the erratic behavior of friction during the lateral motion between coupler shank butt and follower.

Minimum moments for coupler angle increasing most probably represent conditions where the resultant load is concentrated on the edge of the rigid shank (cornering) with no lateral restriction at the forward portion of the coupler shank.

b. Extreme Moments, Coupler Angle Decreasing, Buff

Figures 14 through 18 illustrate maximum and minimum moment extremes for an angle decreasing E rigid shank coupler based on results of all gears tested, as well as extremes for the same gears as listed for coupler angle increasing. Individual center gear points used in establishing extremes are illustrated on curves.

Although minimum moments for coupler angle decreasing on Figures 14-18 are slightly lower than minimum moments for coupler angle increasing, Figures 9-13, they tend to agree, indicating again edge loading (or cornering) of the rigid shank butt without lateral restriction at the forward portion of the shank. One negative moment, $-.03 \times 10^6$ in-lb for the RF-444 at 50,000 lb buff on Figure 14 was neglected because it was not consistent with other data and could be in error.

c. Extreme Moments, Coupler Increasing or Decreasing

Figure 19 illustrates extreme moments for rigid shank E couplers in buff with angle increasing and decreasing for all gears tested.

d. Moment Ranges, Coupler Angle Increasing

Figures 20 through 25 indicate the moment ranges for originally centered rigid shank E couplers under buff with various types of draft gears. The range of moments for the three centered M-17A friction gears is much wider than that for the two all rubber NC-440 draft gears, again indicating the erratic effects of friction.

Results of the centered Mark 50 are illustrated separately on Figures 20-25 to represent a very common high capacity (AAR Specification M-901E) friction draft gear.

In general, the tendency for an originally centered rigid shank E coupler arrangement is for moments to remain at a lower level (toward minimum) for smaller angles, and rapidly increase as lateral restriction is encountered at the forward portion of the shank.

e. E Coupler Extremes, No Buff or Pull, Coupler Angle Increasing

Positioning of the rigid shank E coupler with no longitudinal load was found to be independent of initial positioning, because the shank butt can easily displace laterally at small coupler angles. Without load, however, the angling characteristics are dependent upon draft gear performance for greater angles where lateral force at the head must compress the draft gear.

Figure 20 illustrates rigid shank E coupler moment ranges with no longitudinal load. Again the moment range established by the M-17A friction gear is wider than that of the all rubber NC-440 draft gear, indicating the effects of friction. During coupler angle decreasing, moments rapidly fall off to zero and are generally negligible.

3. F Coupler Shank with Alignment Shoulders - Buff

a. F Coupler with Shoulders, Various Gears, Increasing and Decreasing

Figures 26-31 illustrate moment results for the various arrangements of coupler with alignment shoulders, with coupler angle increasing and decreasing. Moment results include: the RF-444, tested for maximum and minimum lateral at all buff forces with the method as described in Section 3 of this report procedure; for the M-17A Mark 50, and the NC-440-1 continuous coupler angle increasing moments to approximately 8° only for all buff forces; and further screening tests on the M-17A, NC-440-1 and A22XL to the maximum lateral displacement of the arrangements.

Maximum moments occur with the pin connection laterally restricted, where lateral displacement must occur between shank butt and follower. Frictional slippage between butt and follower tends to give reduced moments, as can be particularly observed for the M-17A on Figures 29-31. Maximum moment results of the NC-440-1 all rubber gear tend to remain appreciably below the maximums of the other gears tested.

Minimum moments are established by the A22XL and NC-440-1 draft gears, and, similar to the maximum moments, occur with restricted lateral displacement at the pin connection, where further coupler angle reduction requires lateral displacement of the shank butt relative to the follower.

At lower buff forces up to 200,000 lbs, there is a tendency toward constant moments for angles below 4°. Below 4° of coupler angling the F coupler is designed normally for no contact with alignment shoulders, and this may be cause for this constant moment tendency. At greater buff forces, these constant moments are not apparent, suggesting that the coupler has a tendency to lift at the edge of the spherical surface. Indications of heavy indentation on the edges of the spherical surfaces of shank butt and follower after test give evidence of lift.

Analysis of moments for the F coupler with alignment shoulder in buff indicated three distinct ranges. Two ranges are the maximum and minimum, as described in the preceding two paragraphs, both with lateral restriction and dependent upon friction between butt and follower. There is a third range, approximately midway between the maximum and minimum ranges. This range is indicated by results of the NC-440-1 all rubber gear with coupler angle increasing, friction gears with slippage, minimum moments with the RF-444 (at smaller coupler angles) with coupler angle increasing, and the RF-444 with coupler angle decreasing. This center range appears to represent angling of the F coupler without lateral restriction at the pin and is accordingly independent of friction at the shank butt. This center range is similar to the cornering of the rigid shank butt without lateral restriction. With tolerances in fit of pin, pin holes in shank and yoke and yoke within sill, there is free displacement of the F coupler pin connection. Moments remain in this non-frictional range after reversal of coupler angling direction until angling is sufficient for lateral restriction of the shank. Because of the test procedure described in Section 3 under Recording of Maximum and Minimum Lateral Forces, minimum moments both angle increasing and decreasing remained in the non-frictional range for the RF-444 draft gear.

To confirm that coupler increasing moments for the F coupler shank with the NC-440-1 were in the non-frictional range, a supplemental test was run at 200,000 lb buff. With the coupler angle increased continuously, moments were essentially identical to minimum angle increasing moments using the recording method of Section 3.

It is important to note, that for any coupler angle, moments for either one of the three ranges can result from proper location and angling of the F shank with alignment shoulders.

b. Extreme Moments, Coupler Angle Increasing and Decreasing

Figure 32 illustrates extreme maximum moments for arrangements with the F coupler shank with alignment shoulders in buff with the angle increasing for all gears tested.

Figure 32A illustrates extreme minimum moments for arrangements with the F coupler shank with alignment shoulders in buff with the angle decreasing.

c. Moment Ranges, Coupler Angle Increasing.

Figures 33 through 37 indicates the moment ranges for friction gears (including the rubber friction RF-444) vs. the all rubber NC-440-1. Again, as with the rigid shank E coupler, the rubber gear range is smaller than that for the friction gears.

In general, moments increase with increased buff forces and increased coupler angling.

d. Moments at No Buff or Pull

Figure 26 illustrates the F coupler moments with zero longitudinal load. Curve shown is of the NC-440-1, which gave maximum moments for all gears tested.

At no longitudinal load, coupler angling is completely dependent upon gear closure. The only significant moments obtained were from the all rubber NC-440-1. Minimum moments for all gears tested approximate zero but are shown only for the NC-440-1.

4. Rigid Shank E Coupler Results - Pull

Figures 38 through 42 illustrate moments for the three positions described under Section 6 of Procedure of this report. As noted, these results were established only by the Mark 50 high capacity (AAR Specification M-901E) friction draft gear, but are indicative of any arrangement utilizing a conventional 24-5/8" pocket draft gear.

Maximum moments are indicated on Figures 38-42 curves as established from position C, where there is minimum coupler displacement prior to the displacement of the shank butt within the yoke. At higher pull forces beyond 100,000 lb., moments increase almost linearly at a rapid rate.

A minimum curve for coupler angle decreasing is not illustrated on Figures 38-42 because it has not been satisfactorily established. This occurs particularly at the higher pulling forces at 300,000 and 400,000 lb, Figures 41 and 42, where indications are that the coupler angle decreasing curves would continue on to great negative values. Lower pull force curves on Figures 38-40, and results from rigid shank E coupler pull tests on the M-17-A draft gear, National Report No. 566 indicate leveling off of moments to no lower than $-.2 \times 10^6$ in-lb at 200,000 lb pull force.

5. F Coupler Shank - Pull

Theoretical calculations for coupler moments, assuming a swivel shank with a 3-1/2" diameter pin and .2 coefficient of friction were compared with moments for the M-381 locomotive arrangement, (National Report No. 266), prior to alignment shoulder contact. Prior to alignment shoulder contact the M-381 arrangement is a simple swivel shank with 3-1/2" diameter pin. Moments in in-lb x 10^6 were compared as follows:

Pull Load	Report No. 266		Theoretical	
(lb)	Increasing	Decreasing	Increasing	Decreasing
50K	+.07	0 to -.01	+.020	-.020
100K	+.10 to .18	-.02 to -.03	+.035	-.035
200K	+.20 to .28	-.06 to -.07	+.070	-.070
300K	+.30 to .39	-.06 to -.08	+.105	-.105
400K	+.33 to .43	-.15 to -.17	+.140	-.140

Test results (Report No. 266) confirm that moments for a swivel shank coupler are independent of coupler angle and remain essentially constant for a constant pull load.

Comparison of test moments with theoretical moments indicates the effect of the fixture, virtually no fixture effect with coupler angle decreasing. Differences between test and theoretical moments at the various load levels for coupler angle increasing range from .05 x 10^6 in-lb at 50K lb, to .29 x 10^6 in-lb at 400K lb.

Because the theoretical moment results as tabulated do not include fixture effect and do correlate with test results for coupler angle decreasing, it is recommended that these figures be used to represent constant moments for complete angling of the F coupler shank in pull at the various buff loads.

6. F Coupler Shank Without Alignment Shoulders - Buff

Moments for an F coupler shank butt were calculated similar to that of the F coupler shank in pull except the 3-1/2" pin diameter was changes to a 5¼" spherical radius. Resulting moments are illustrated graphically on Figure 43.

F coupler results from buff tests indicate that at smaller coupler angles, moments tend to remain constant for both coupler angle increasing and decreasing; approximately ± .1 x 10^6 in-lb at 50,000 lb (Figure 27), and ± .2 x 10^6 in-lb at 100,000 lb (Figure 28). Since the F shank with alignment shoulders has 4° free lateral angling capability prior to alignment shoulder contact, this somewhat confirms the theoretical no alignment control F shank butt moment characteristics in buff. At greater buff loads, these constant moments are not apparent, suggesting that the coupler is not rotating in the 5¼" spherical seat, but tending to lift similar to the cornering of the rigid shank E coupler arrangement. Heavy indentations on the edges of the spherical surface of both F shank butt and follower tend to confirm lifting. Both smoothing and improving fit between adjacent spherical surfaces resulting from service wear, particularly at lower buff forces, may reduce this lifting tendency.

7. Effects of Fixture

Because frictional forces are determined only by normal forces and the direction of impending motion, moments created by these frictional forces should be essentially independent of the direction of the longitudinal load (buff or pull). These frictional moments caused by the fixture should be dependent only upon the magnitude of the longitudinal load and the direction of coupler angling (increasing or decreasing). If it is desired to remove fixture effect for buff test results, we suggest using the differences between theoretical and actual moments as listed under Section 5, Test Results, for correction factors at the various buff loads.

CONCLUSIONS

1. General

Coupler angling characteristics are dependent upon friction between associated parts of the arrangment. Because differences between static friction and moving friction are appreciable, coupler angling characteristics can vary accordingly. Although coupler angling characteristics for cars moving at extremely low velocities may approach static friction results, it is expected that in service moments dependent upon friction are less than those determined by laboratory test. Forces and moments obtained from service tests must be compared with analytical results using laboratory data for validation.

Rubber draft gears show less variation in moments than do friction draft gears, indicating repeatability under test. Also, maximum moments with coupler angle increasing for an F arrangement with an all rubber draft gear tend to be lower than with friction gears. It is estimated that over the last six year period, friction and rubber friction types represent 95% of the total conventional 24-5/8" draft gears installed on new freight car. Except for the conditions described, coupler angling characteristics appear to be independent of draft gear type both in buff and pull.

Lateral placement of parts within the rigid shank coupler arrangement in the laboratory under buff and pull can vary moment results appreciably. Since the position of parts within the coupling system in service is not predictable, moment extremes should be considered in analysis to determine maximum lateral force on the car.

Under service conditions, velocity and vibration are expected to reduce frictional resistance between arrangement parts and alter moments from laboratory test results. It is expected that in service maximum moments will be reduced over those shown on Figures 19 and 32, and minimum moments for the F shank will be increased from those shown on Figure 32A. Without friction, the limit for the rigid shank arrangement in buff is indicated by minimum moments on Figure 19. For the F coupler arrangement with alignment shoulders in buff, limits without friction are indicated by minimum moment curves for the RF-444 draft gear on Figures 27-31, both coupler angle increasing and decreasing. Moments in buff without friction are directly proportional to the width between alignment shoulders. Width of the E coupler rigid shank (equivalent to width between shoulders) is 5¼" while the width between F coupler shank shoulders is 7½", indicating that without friction, moments for the F coupler arrangement should be greater than for the rigid shank arrangement. Test results confirm this analysis. Moments without friction tend to increase with increased coupler angling and buff forces.

With proper considerations as described, angling characteristics in buff as determined by these tests may be used to analytically predict lateral force limits on a railroad car in service with a rigid E coupler shank or F shank with alignment shoulders.

2. Test Results

a. Buff

Maximum moments during coupler angle increasing under buff indicate angling characteristics are dependent on friction between associate parts within the arrangement. Maximum moments for individual draft gears vary appreciably because they rely on friction. At identical buff force and coupler angle, maximum moments for the rigid E shank are significantly greater and indicate larger variation than maximum moments for the F shank with alignment shoulders. These results confirm analysis that maximum moments are directly proportional to the dimension between shank butt and location of shank lateral restriction within the sill. For the F coupler this dimension is 4½", and for the rigid shank, this dimension is approximately 10½". Once maximum moments have peaked, they tend to remain constant until maximum coupler angling has been reached. The normal rigid shank coupler maximum angling is 7°, while the F coupler normal maximum angling is 13° at zero load, and decreases with increased buff force.

Minimum moments for the rigid shank coupler arrangements appear to be independent of friction, since they are essentially alike with both coupler angle increasing and decreasing. The reason for moments independent of friction is lateral slack within the rigid shank connection. During test, this lateral slack prevented solid contact of the front portion of the coupler shank within the yoke after reversal of coupler angling direction from increasing to decreasing. With proper positioning of the rigid shank butt and yoke butt prior to coupler angle decreasing, lateral contact at the front portion of the coupler shank is possible only for very small coupler angles at approximately one degree. Minimum moments with contact at the forward portion of the coupler shank would be dependent upon friction between shank butt and follower, and would be reduced over minimum moments without shank contact.

Except for the RF-444 draft gear which was tested differently, minimum moments for F coupler arrangements tested were affected by friction. Minimum moments for all gears tested with the F arrangement during coupler angle decreasing are significantly less than minimum moments for coupler angle increasing. Because of less lateral slack with the pinned F connection, (approximately 3/8" total), than for the E rigid shank, (approximately 2" total), with sufficient coupler angle decreasing after reversal of coupler angling direction, there is shank restriction at the pin. With shank restriction, minimum moments are appreciably reduced. With RF-444 testing at each angle, coupler angling was reduced by only one half of a degree during coupler angle decreasing, not sufficient to obtain shank restriction at the pin.

Minimum moment in buff for both arrangements tend to increase with coupler angling.

b. Zero Longitudinal Force

Moments for coupler angling without longitudinal load are dependent on gear closure characteristics. For rigid shank coupler arrangements and coupler angle increasing, wide variations in moments were achieved with friction gears, and a smaller range with the all rubber gear.

Maximum moments for the rigid shank coupler arrangement at zero longitudinal loads with a friction draft gear are significant, and should be considered when evaluating lateral forces on railroad cars. This is particularly true when lightweight cars are involved where small lateral force may lift wheels.

Moments for F coupler arrangements with alignment shoulders and no longitudinal force were significantly smaller than for rigid shank coupler arrangements. Maximum moments with the F coupler arrangement were significant only with the all rubber gear, and only at greater coupler angles (above 12°).

At zero longitudinal load, moments increase with coupler angling, and initial positioning of arrangement parts does not affect coupler angling characteristics.

c. Pull

Analysis of the rigid shank coupler in pull indicates angling results are independent of draft gear type, but dependent on positioning of parts in the arrangement.

By initially positioning parts (position C on Figures 38-42), maximum moments for coupler angle increasing were obtained in pull. After small coupler angling due to yoke displacement, moments increase rapidly with coupler angling to significant magnitudes for all pull forces, and are dependent on friction.

From Figures 38-42, rigid shank coupler minimum moments for coupler angle increasing (indicated by arrows pointing up) are illustrated by position B results prior to 5°, and by position A results beyond 5°.

Because positioning was not varied to obtain minimum moments for the rigid shank coupler in pull with coupler angle decreasing (lines with arrows pointing down), minimums have not been satisfactorily established. It is apparent from the data available, however, that minimum coupler angle decreasing moments reduce rapidly on reversal of coupler angling to values less than zero. Up to 200,000 lb pull, resulting coupler angle decreasing moments indicate leveling off to constant moments, with a minimum moment for coupler angle decreasing of approximately $.2x10^6$ in-lb at 200,000 lb pull.

3. Analytical Estimates

a. F Coupler Shank - Pull

The F coupler shank with or without alignment shoulders acts similar to a simple 3½" diameter pinned connection. Comparison of theoretical estimates using 0.2 for a coefficient of friction with test results for a 3½" diameter pin swivel shank established correlation. Accordingly, frictional moments for various buff loads were estimated and appear in Section 5, under Results of Test.

Moments for the F shank and a given pull load are constant for all coupler angles below maximum. At maximum angling, moments in pull would increase rapidly indicating maximum angling had been reached.

b. F Coupler Shank without Alignment Shoulders - Buff

Moments for the F shank without alignment shoulders were calculated using a coefficient of friction of 0.2, and using the shank butt spherical radius of 5¼". Results are illustrated on Figure 43.

Moments for this analysis at the same buff force are constant for all coupler angles up to maximum (illustrated by points at end of lines). Maximum angling for an F coupler arrangement varies with buff force. Maximum angling in buff for the F coupler arrangement was estimated from buff test results of the F coupler with alignment shoulders and coupler angle increasing. Maximum coupler angling is independent of shank butt aligning shoulders. Indications of maximum angling are rapid increases in moments during coupler angle increasing. Beyond maximum angling, moments would increase sharply until failure of parts.

4. Future Analysis

Conclusions have been presented based on the data obtained during this test. Because of the complexity of the arrangements and the abundance of data, however, continuation of the analysis to extract useful data is most desirable. In addition, the information presented in this report will become much more meaningful with its use in the overall program of analyzing railroad car service performance.

Figure 1

BUFF TEST SET-UP AND LOCATION OF MEASUREMENTS
IN STATIC ANGLING TEST
RIGID SHANK COUPLER ARRANGEMENT

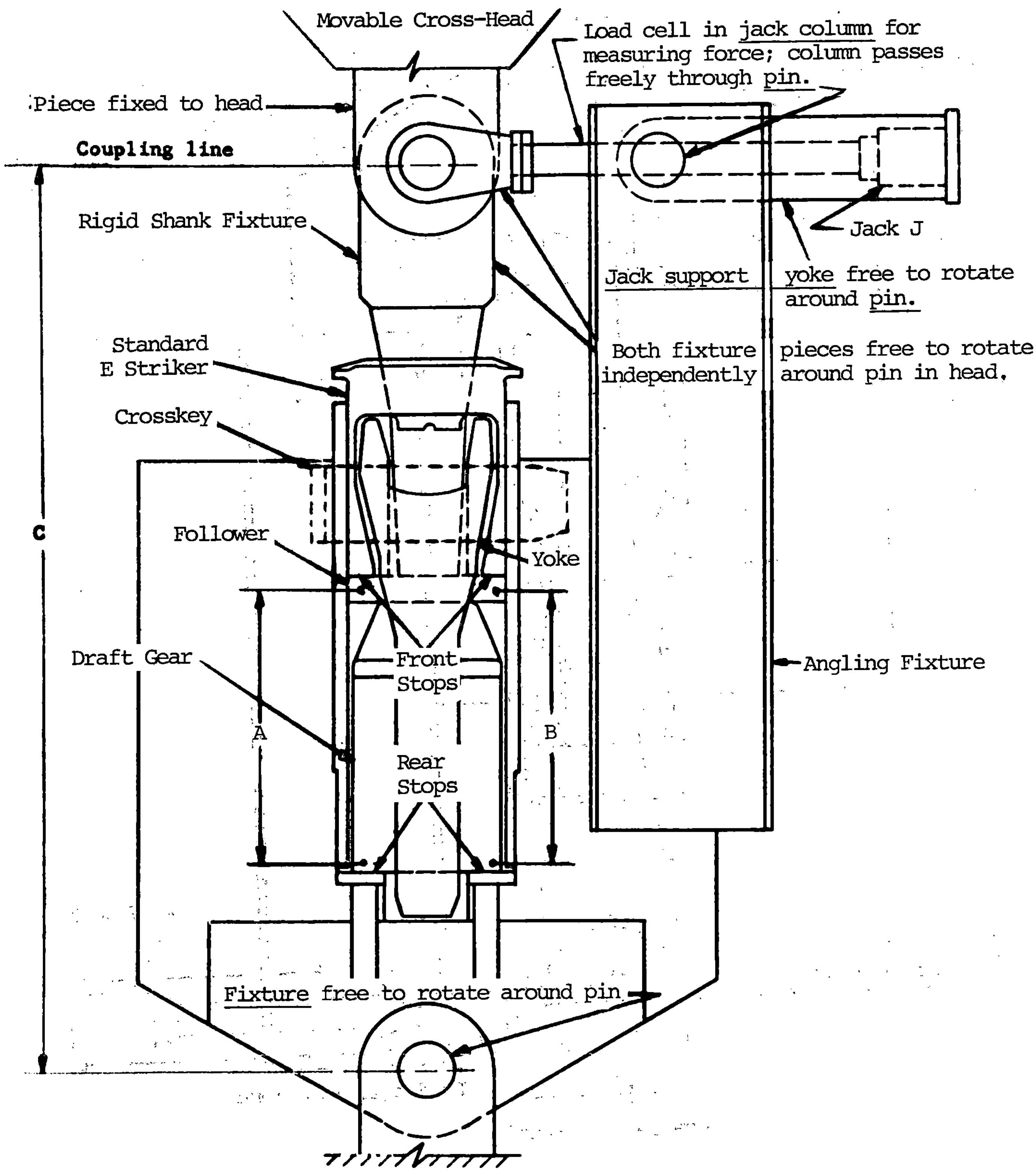


Figure 2

PULL TEST SET-UP AND LOCATION OF MEASUREMENTS
IN STATIC ANGLING TEST
RIGID SHANK COUPLER ARRANGEMENT

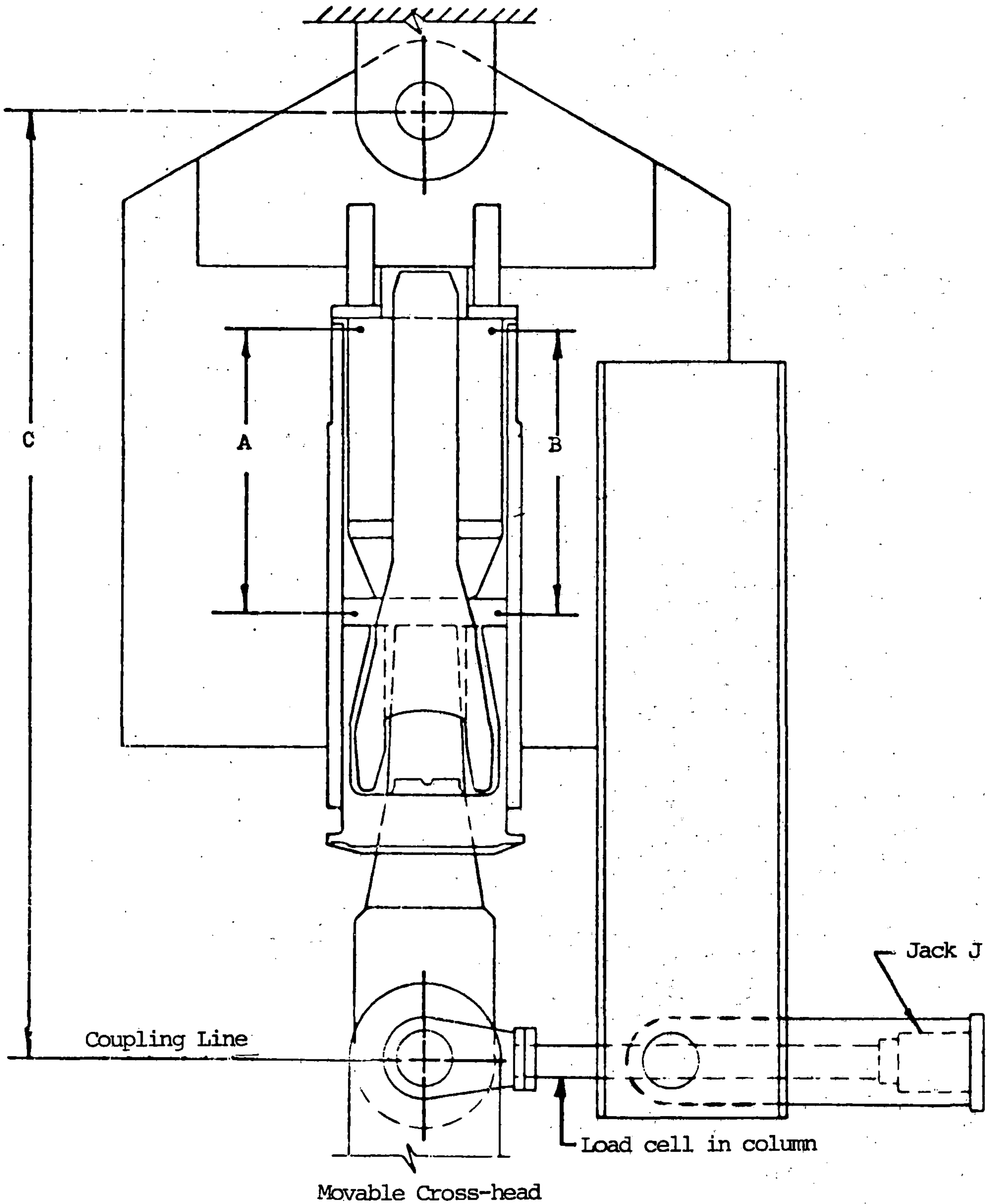
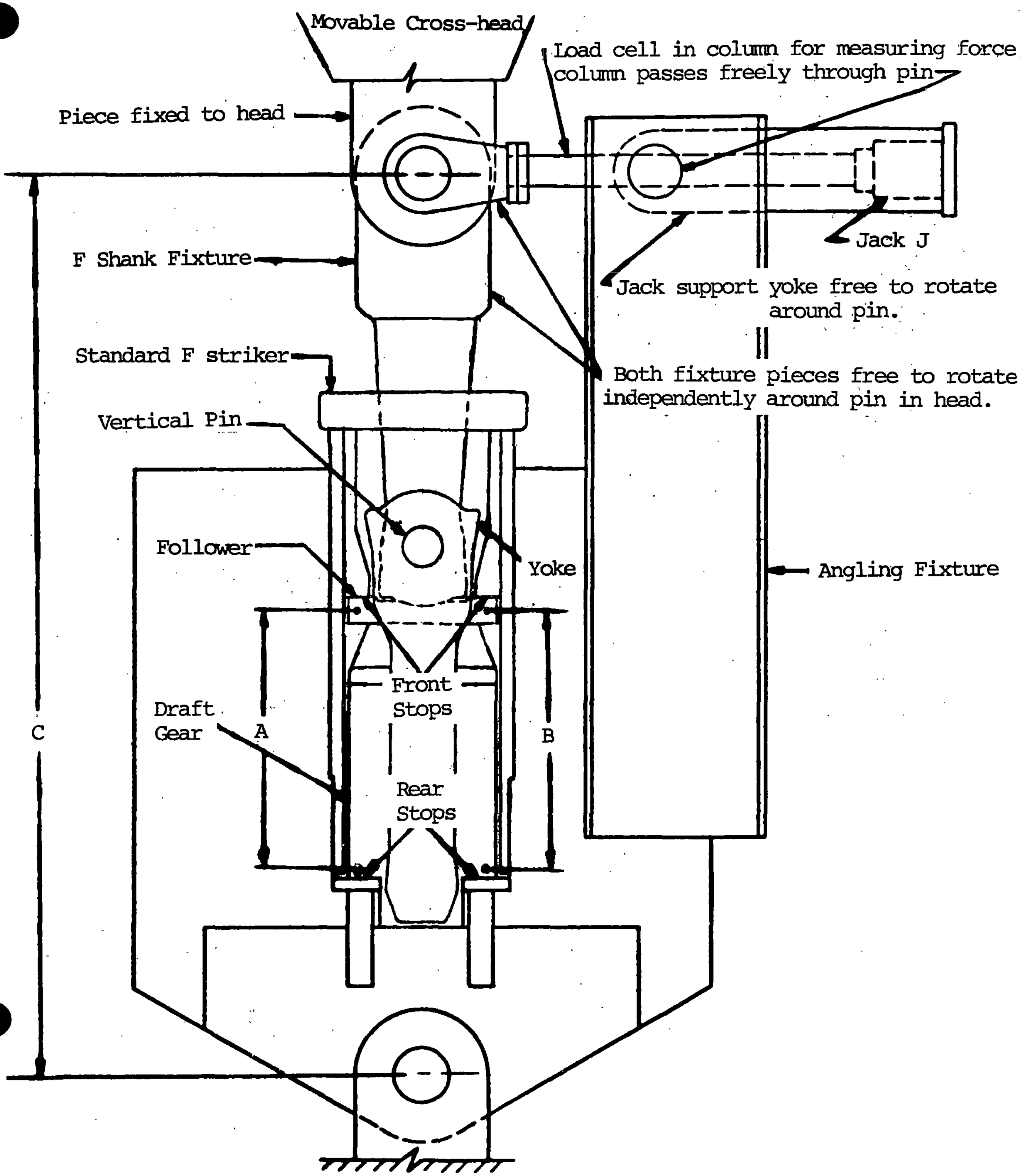


Figure 3

BUFF SET-UP AND LOCATION OF MEASUREMENTS
IN STATIC ANGLING TEST
F COUPLER SHANK WITH ALIGNMENT SHOULDERS



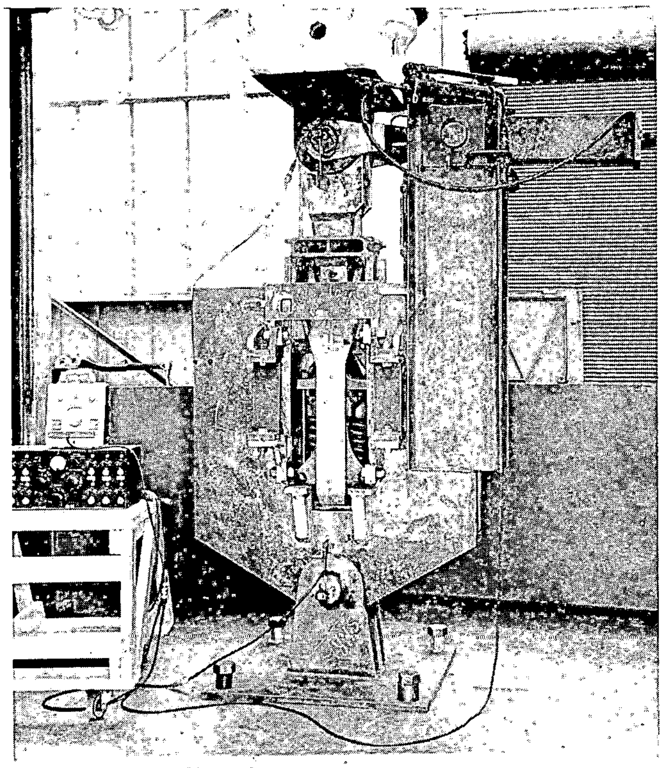


Figure 4

Buff Test Set-up in
1,200,000 Pound
Universal Static
Test Machine

Figure 5

Pull Test Set-up in
1,200,000 Pound
Universal Static
Test Machine

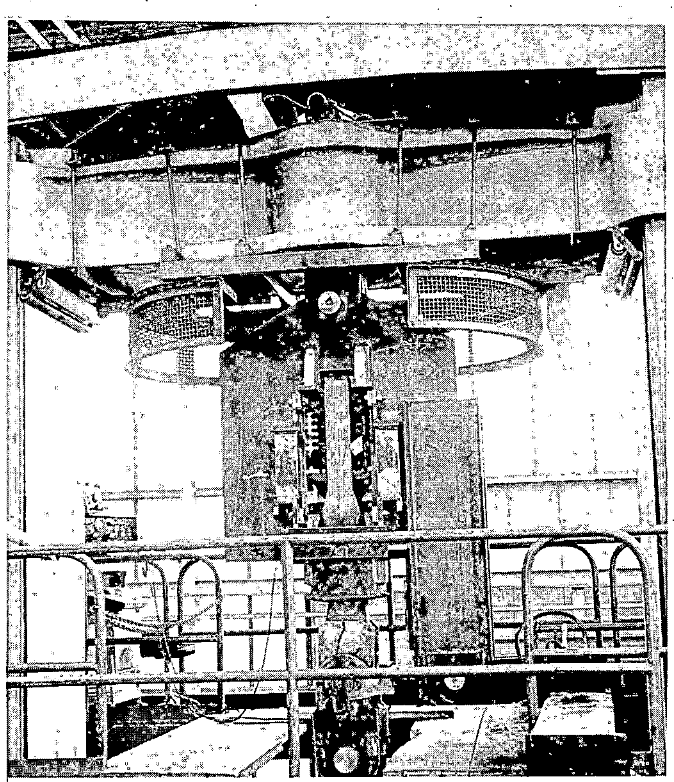
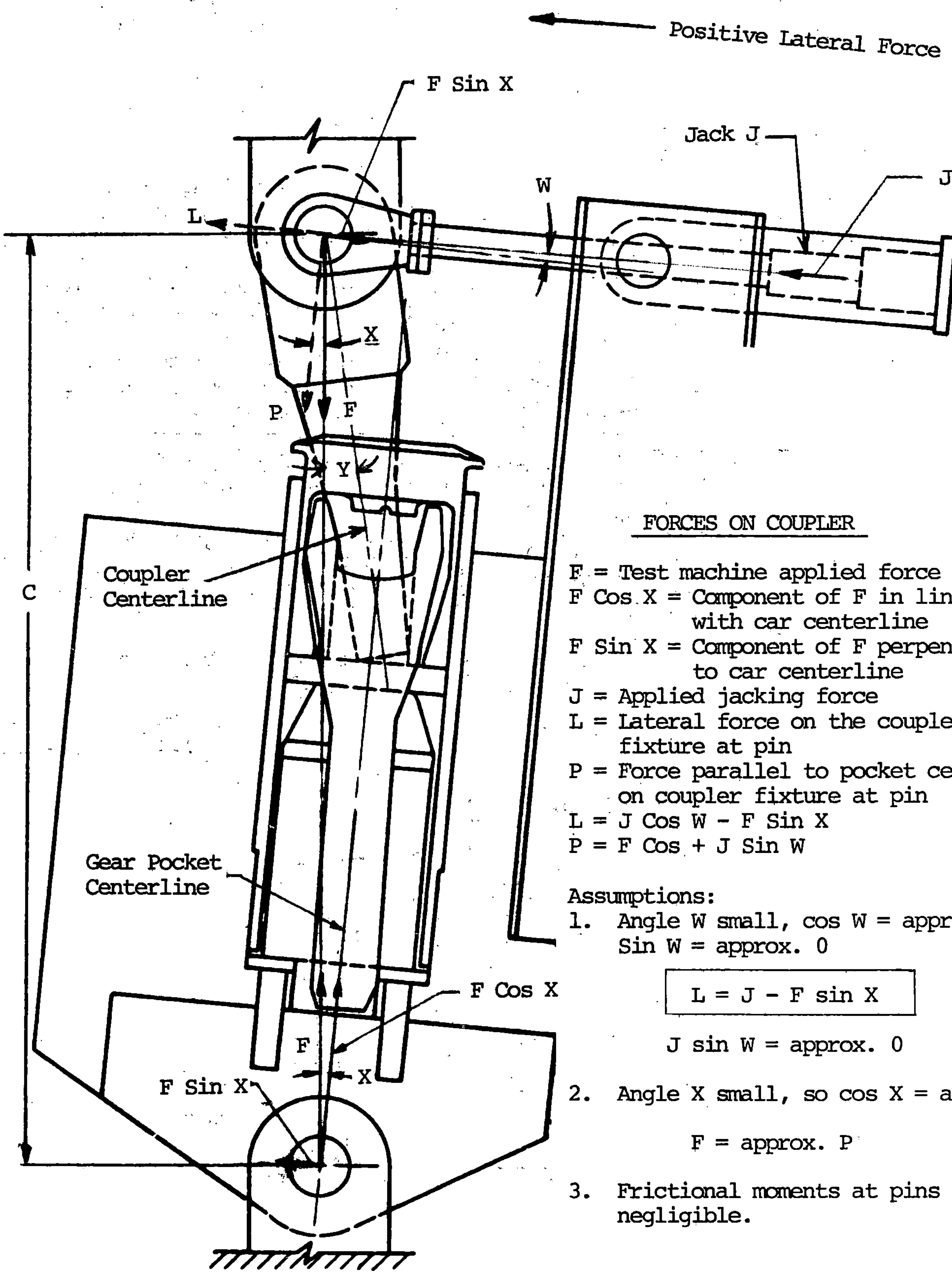


Figure 6

BUFF TEST FORCE DIAGRAM WITH JACK J
STATIC ANGLING TEST



FORCES ON COUPLER

F = Test machine applied force
F Cos X = Component of F in line with car centerline
F Sin X = Component of F perpendicular to car centerline
J = Applied jacking force
L = Lateral force on the coupler fixture at pin
P = Force parallel to pocket centerline on coupler fixture at pin
L = J Cos W - F Sin X
P = F Cos + J Sin W

Assumptions:

1. Angle W small, cos W = approx. 1, Sin W = approx. 0

L = J - F sin X

   J sin W = approx. 0

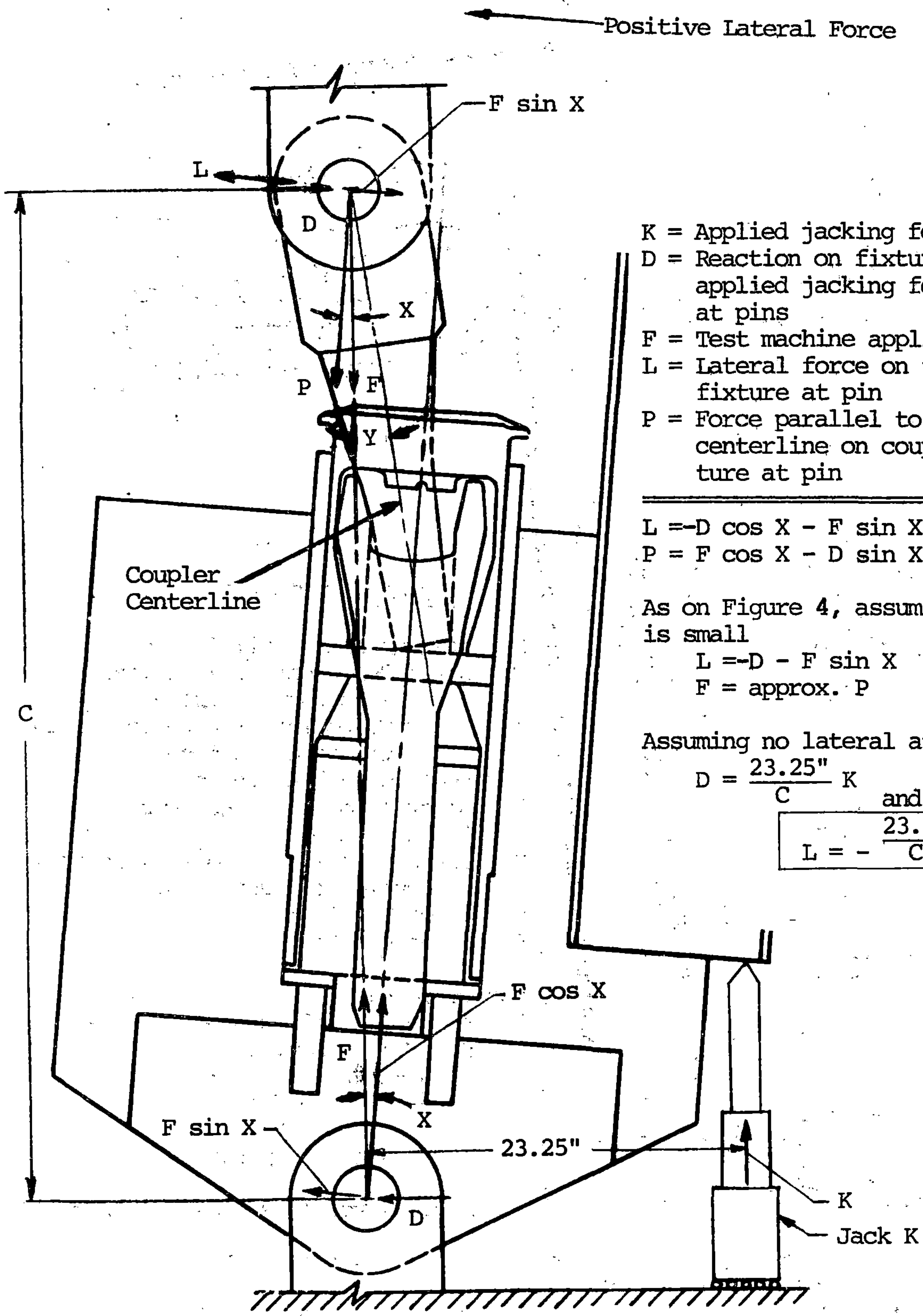
2. Angle X small, so cos X = approx 1,

   F = approx. P

3. Frictional moments at pins are negligible.

Figure 7

BUFF TEST FORCE DIAGRAM WITH JACK K
STATIC ANGLING TEST



K = Applied jacking force
D = Reaction on fixture due to applied jacking force (K) at pins
F = Test machine applied force
L = Lateral force on the coupler fixture at pin
P = Force parallel to pocket centerline on coupler fixture at pin

---

$L = -D \cos X - F \sin X$

$P = F \cos X - D \sin X$

As on Figure 4, assuming angle X is small

$L = -D - F \sin X$

$F = \text{approx. } P$

Assuming no lateral at jack K

$D = \frac{23.25"}{C} K$

and,

$$L = - \frac{23.25"}{C} K - F \sin X$$

Figure 8
MOMENT CALCULATIONS

Rigid Shank

Buff

1. Forces F and L are as described on Figures Nos. 4 and 5.
2. Z = angle of theoretical coupler with its centerline intersecting the gear pocket centerline 28.5" from coupling line with displacement = C sin X.

$$Z = \text{Arc sin } C \sin X/28.5''$$

3. Moments M are taken around a point on the pocket centerline, 28.5" from the coupling line.

$$M = 28.5\,(F \sin Z + L \cos Z)$$

Pull

Reverse direction of force F.

1. From Figure 6,

$$L = J + F \sin X$$

2. Z is the same as item 2 under buff.
3.

$$M = 28.5\,(L \cos Z - F \sin Z)$$

F Coupler Shank

Buff

See Figures 6 and 7 for L

*Moments calculated around point on pocket centerline 29.25" from coupling line.

$$Z = \text{Arc sin } C \sin X/29.25''$$

$$M = 29.25''\,(F \sin Z + L \cos Z)$$

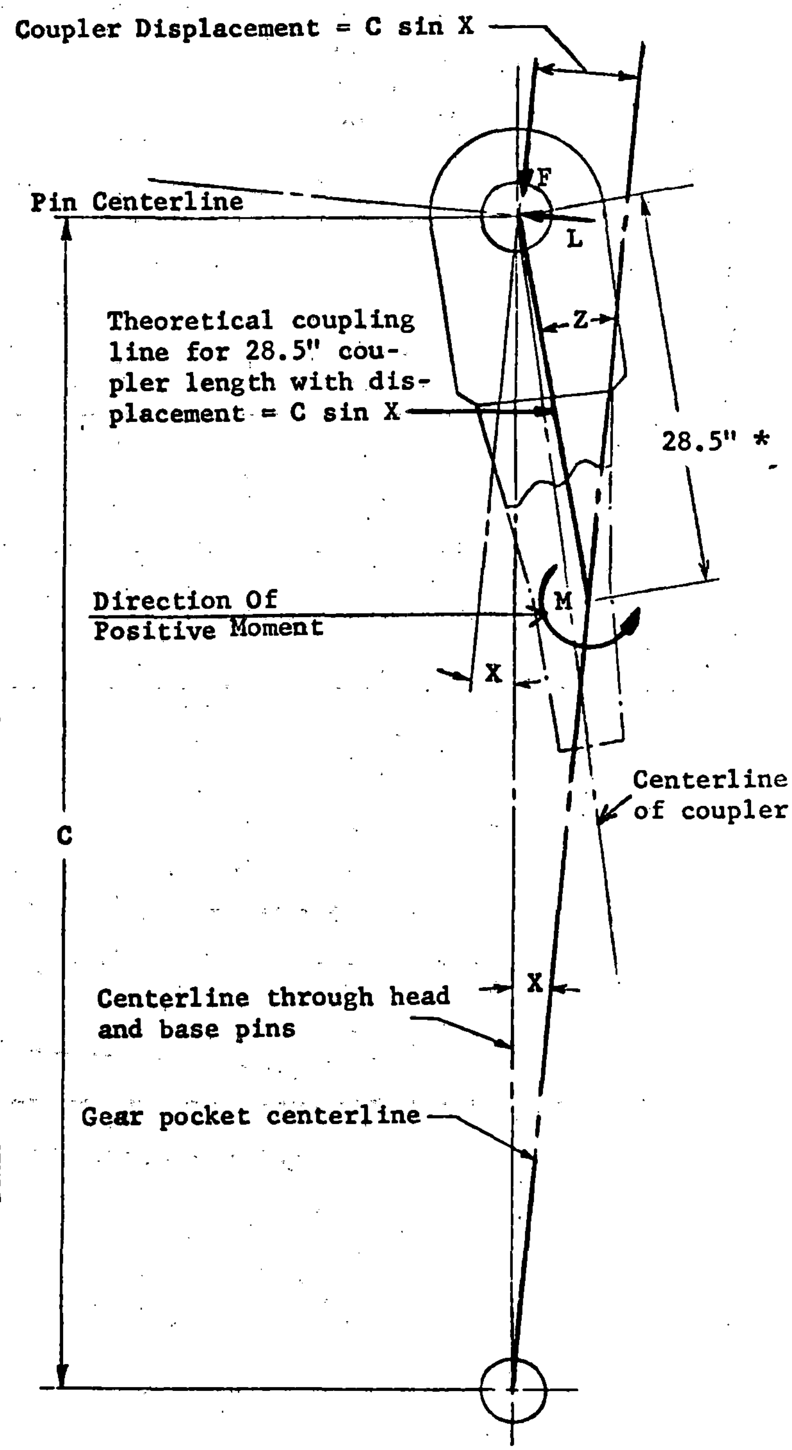


Figure 9

E COUPLER RIGID SHANK
EXTREME MOMENTS
ANGLE INCREASING
50,000 LB. BUFF

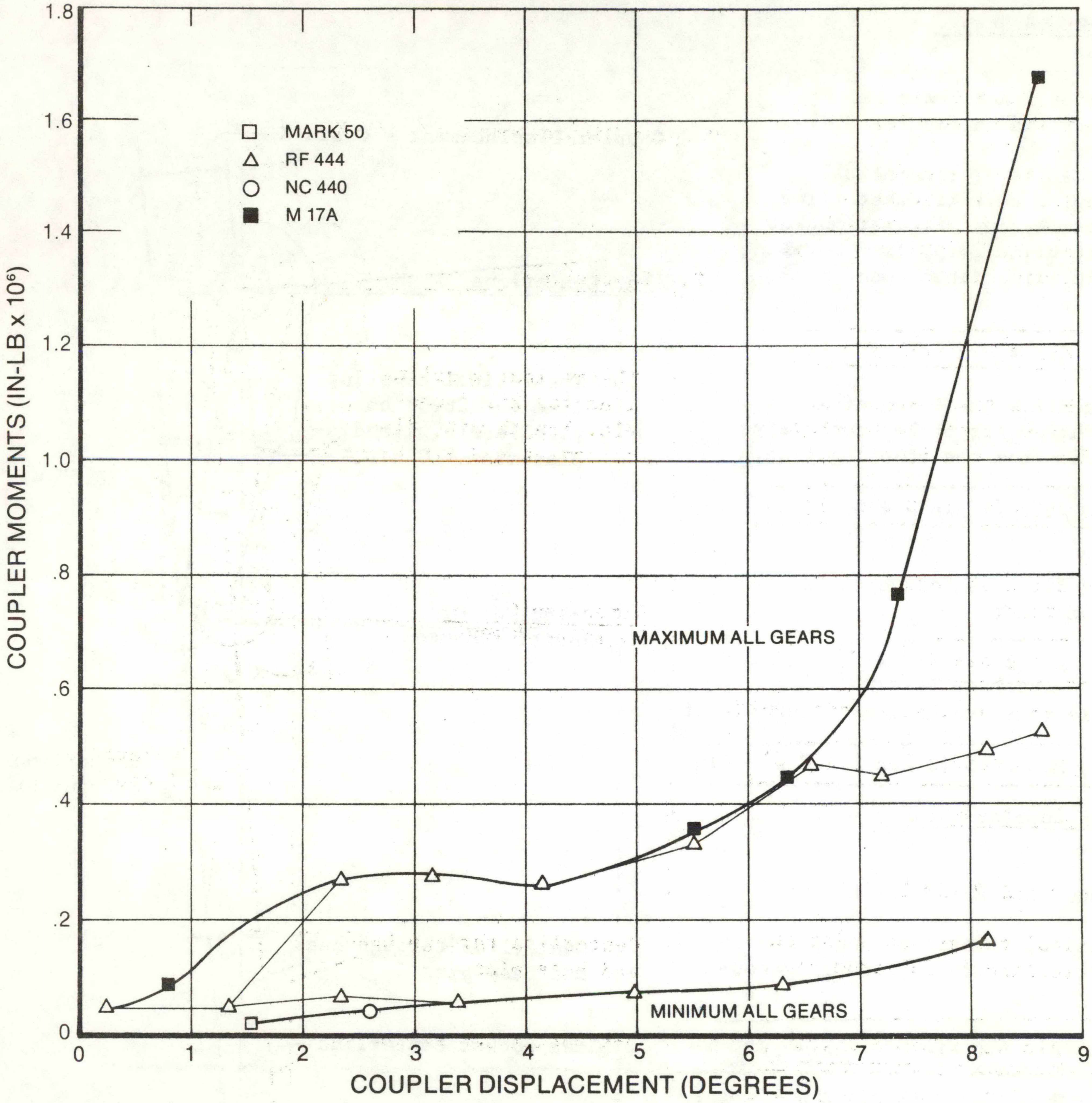


Figure 10

E COUPLER RIGID SHANK
EXTREME MOMENTS
ANGLE INCREASING

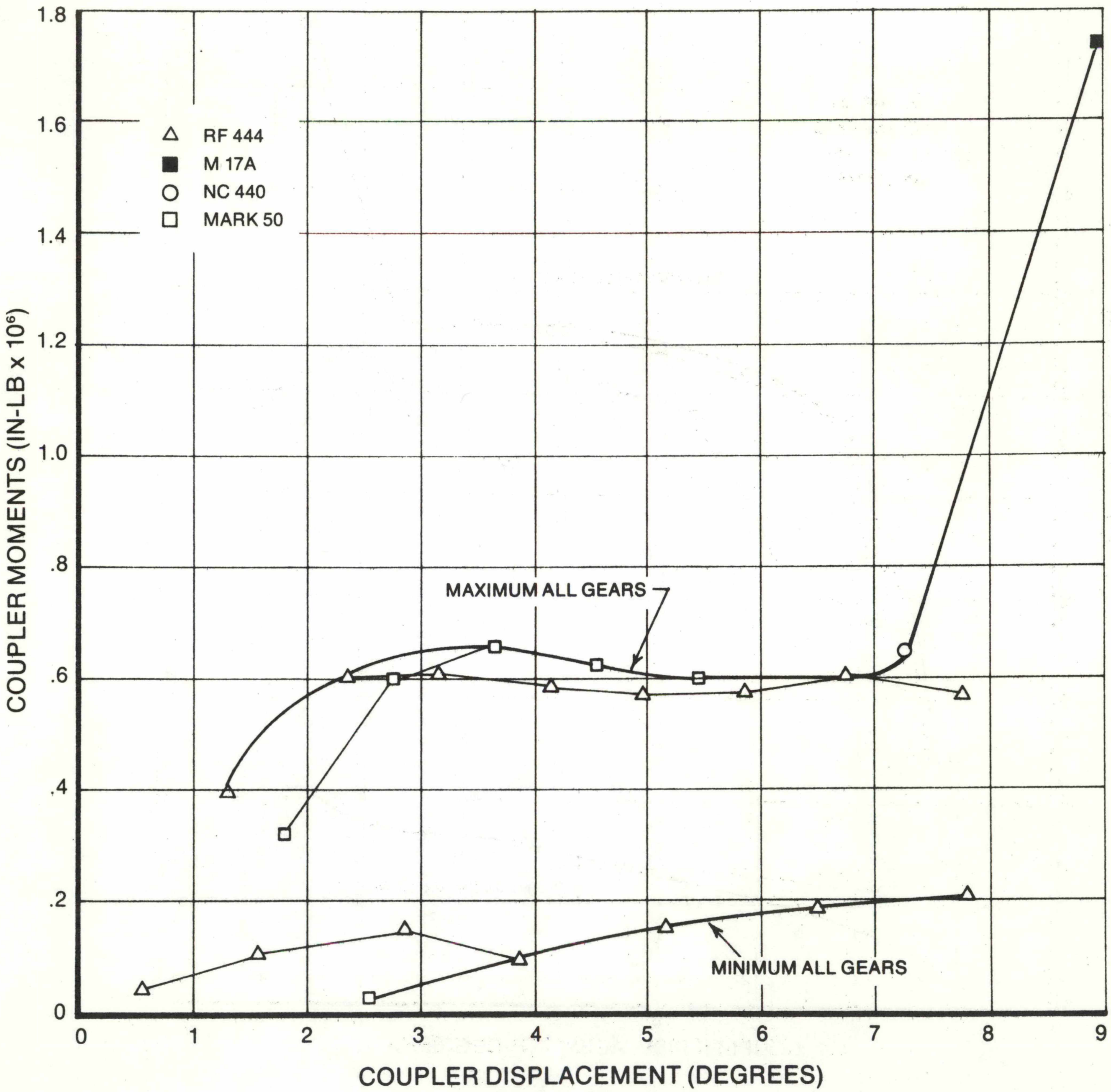


Figure 11

E COUPLER RIGID SHANK
EXTREME MOMENTS
ANGLE INCREASING
200,000 LB. BUFF

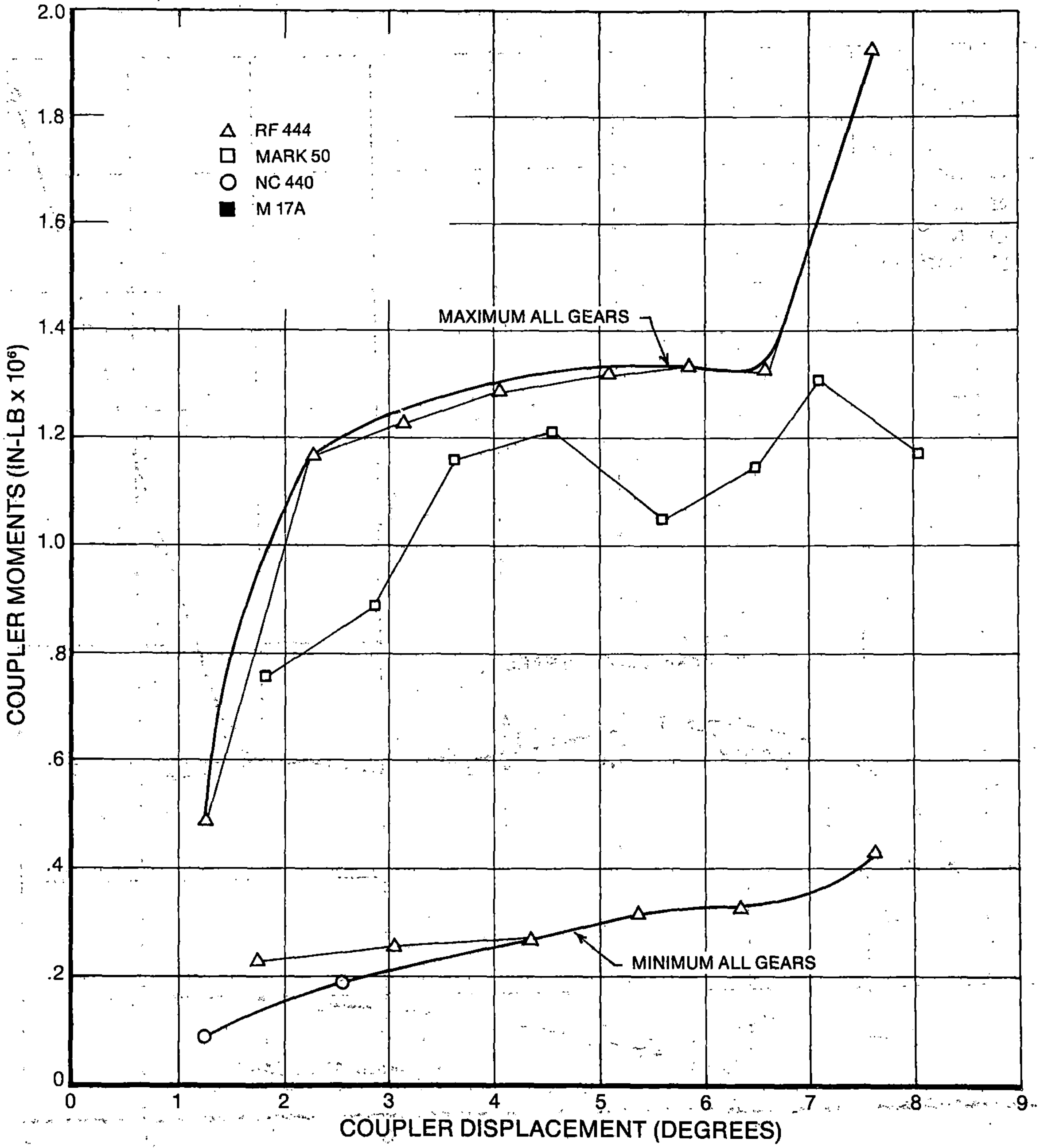
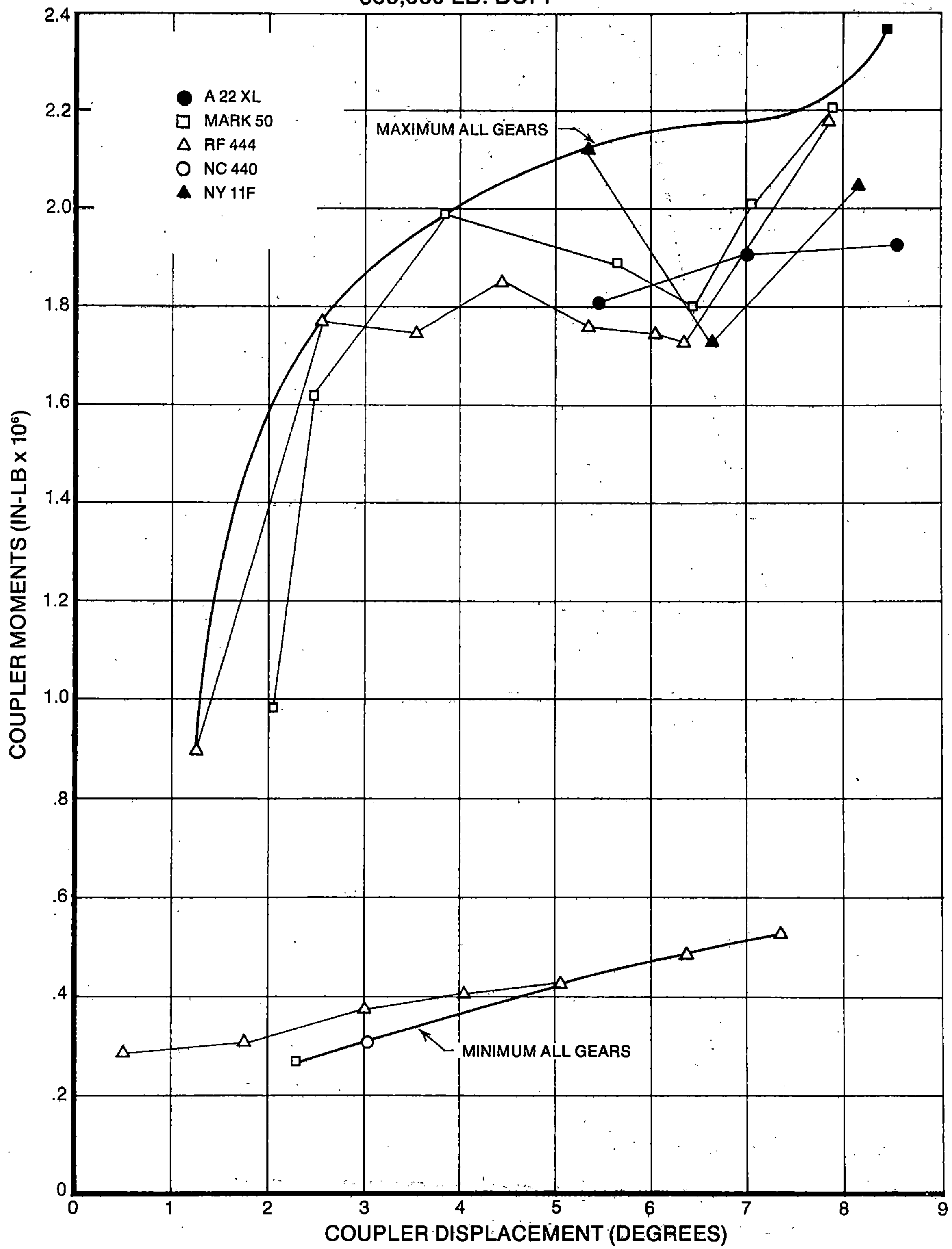


Figure 12

E COUPLER RIGID SHANK
EXTREME MOMENTS
ANGLE INCREASING
300,000 LB. BUFF



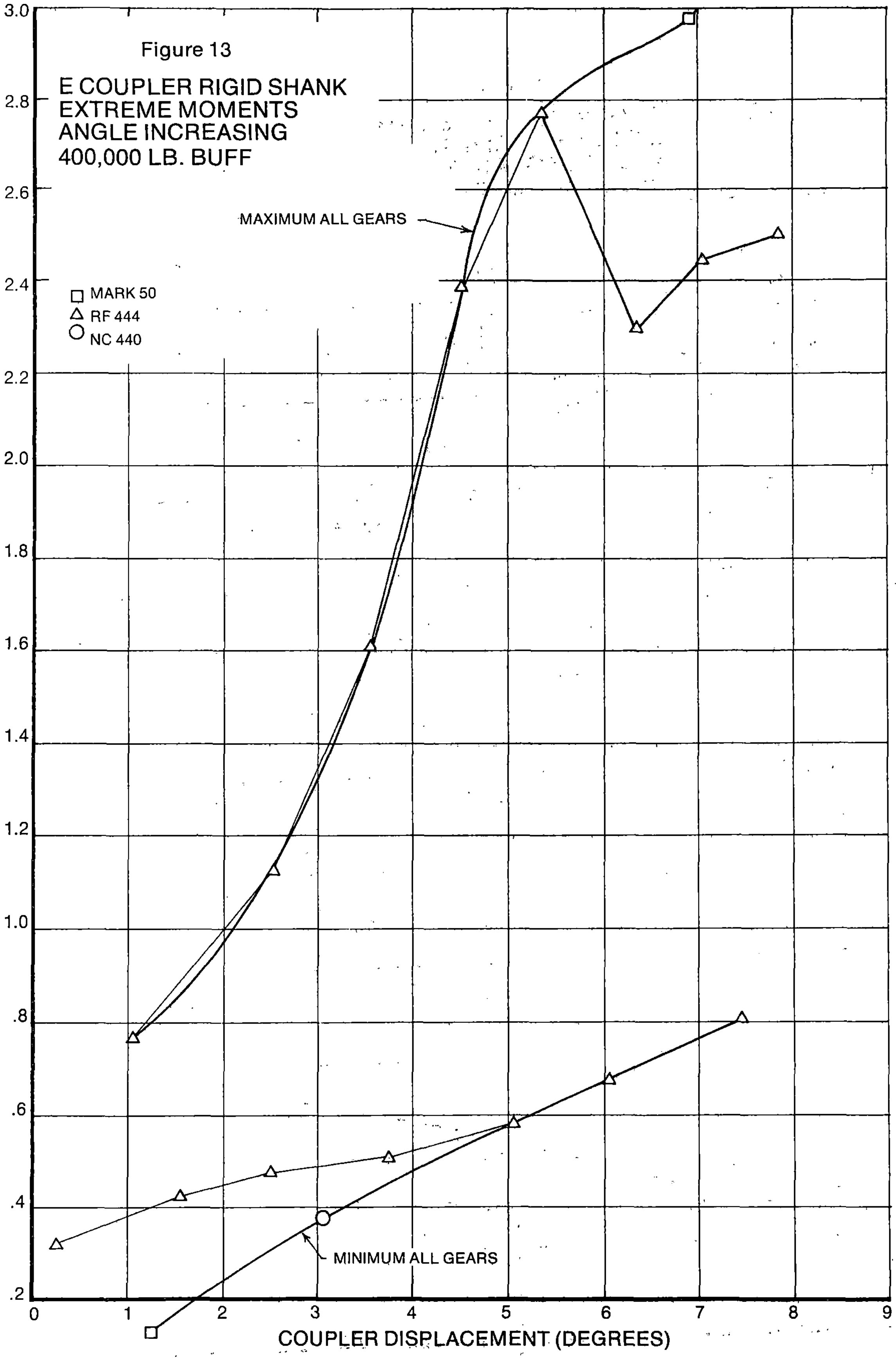


Figure 13
E COUPLER RIGID SHANK
EXTREME MOMENTS
ANGLE INCREASING
400,000 LB. BUFF
MAXIMUM ALL GEARS
MARK 50
RF 444
NC 440
MINIMUM ALL GEARS
COUPLER DISPLACEMENT (DEGREES)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
1
2
3
4
5
6
7
8
9

Figure 14

E RIGID SHANK COUPLER
EXTREME MOMENTS
ANGLE DECREASING

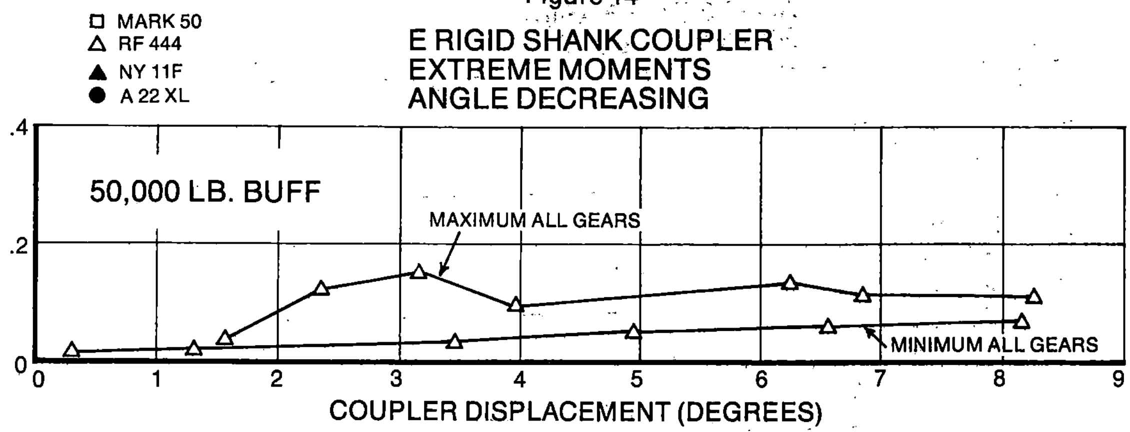


Figure 15

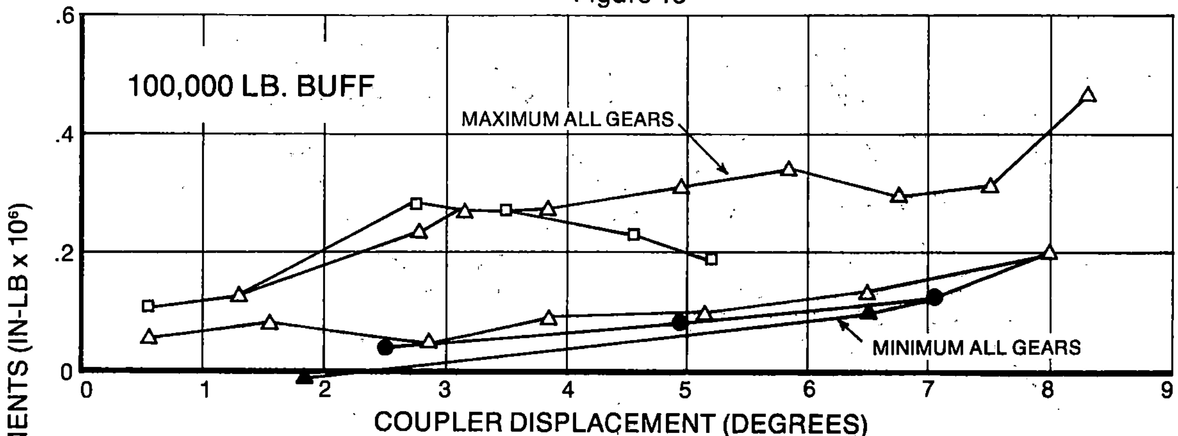


Figure 16

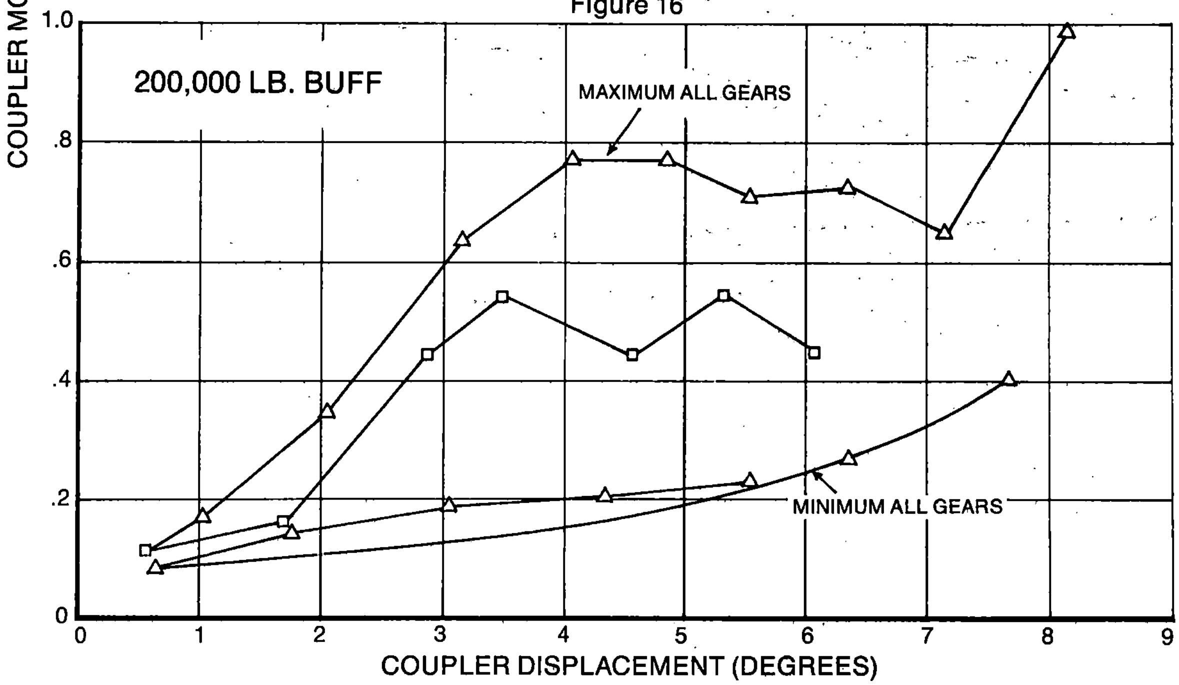


Figure 17

E COUPLER RIGID SHANK
EXTREME MOMENTS
ANGLE INCREASING
300,000 LB. BUFF

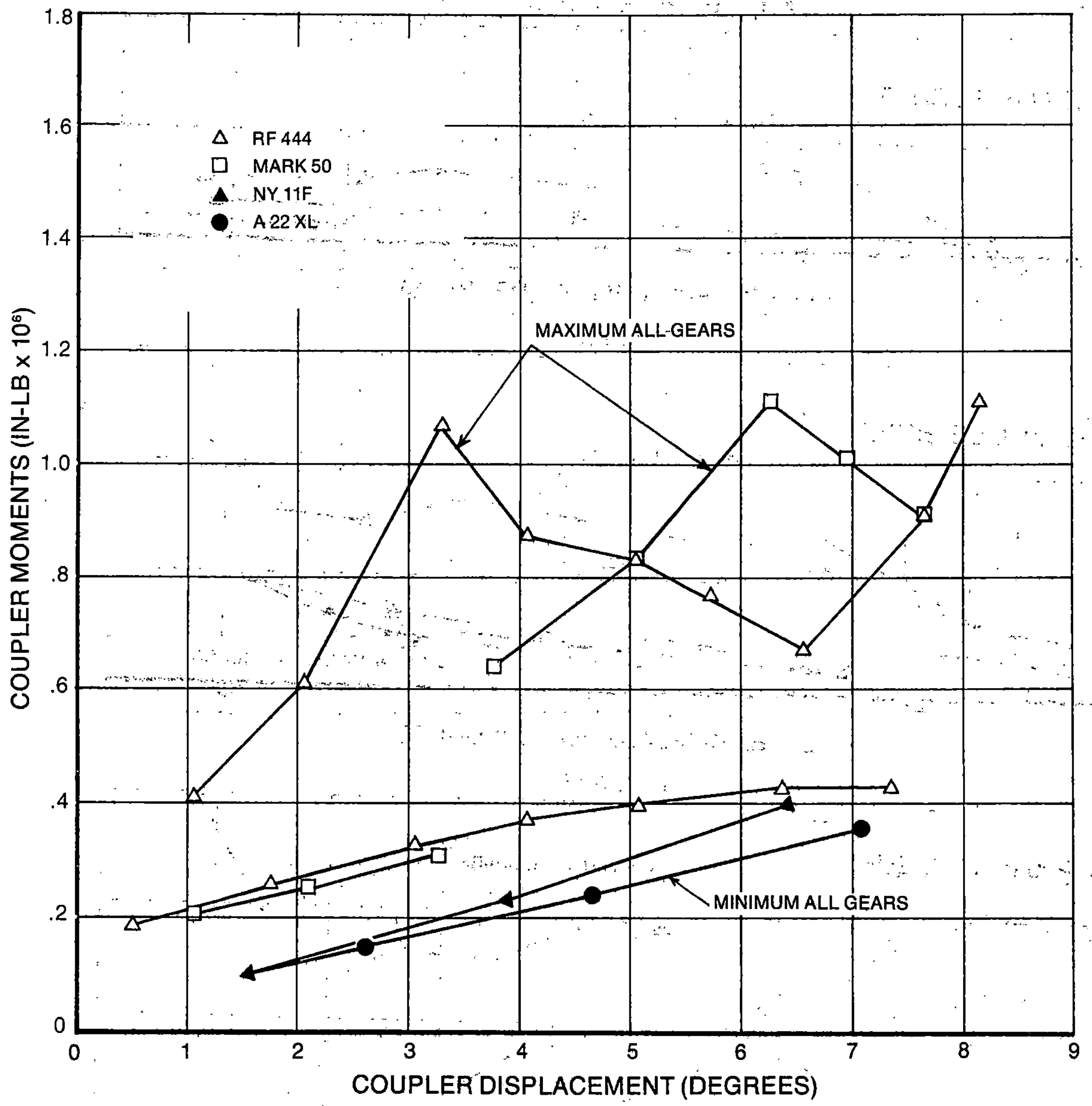
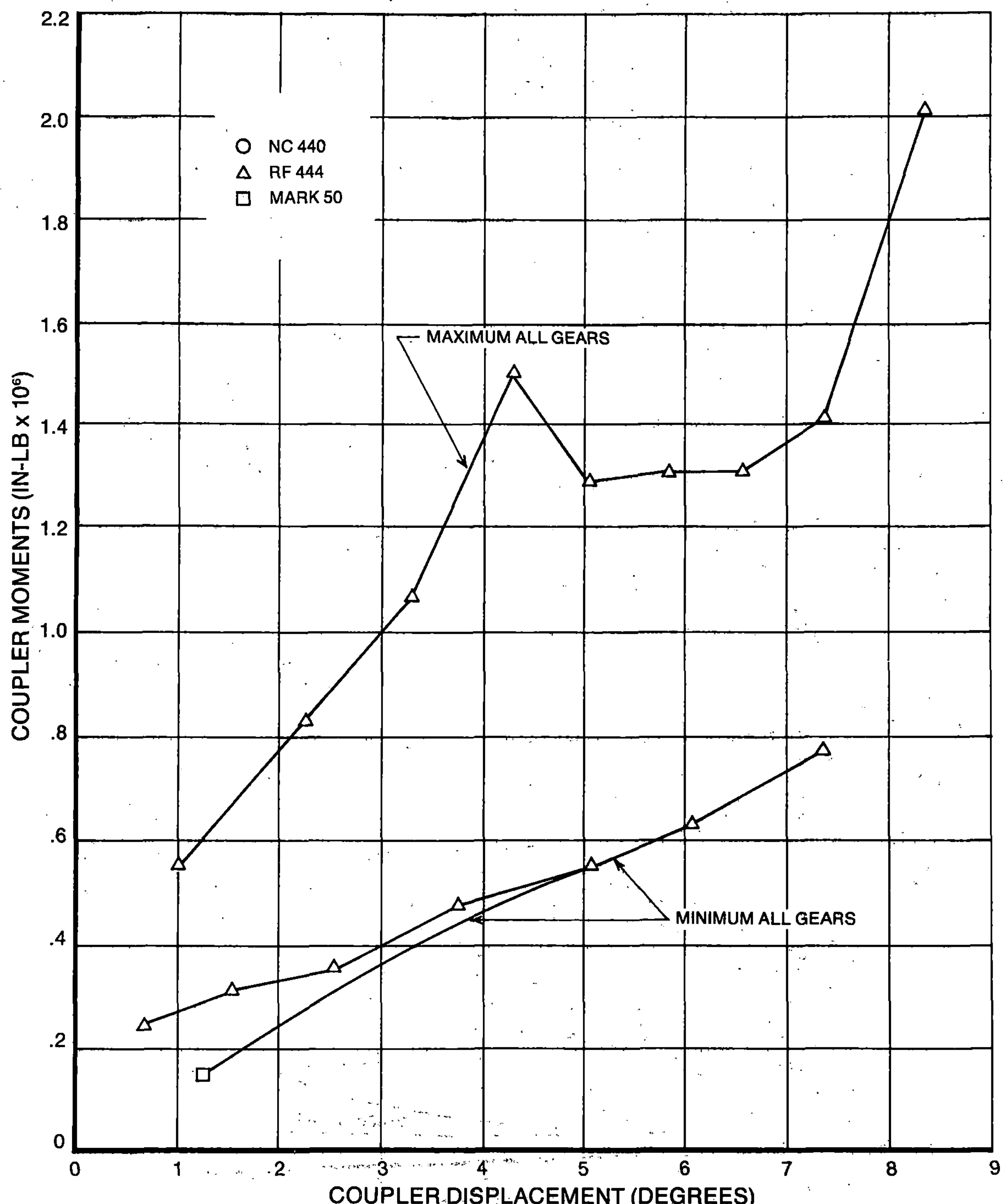


Figure 18

E RIGID SHANK COUPLER
EXTREME MOMENTS
ANGLE DECREASING
400,000 LB. BUFF



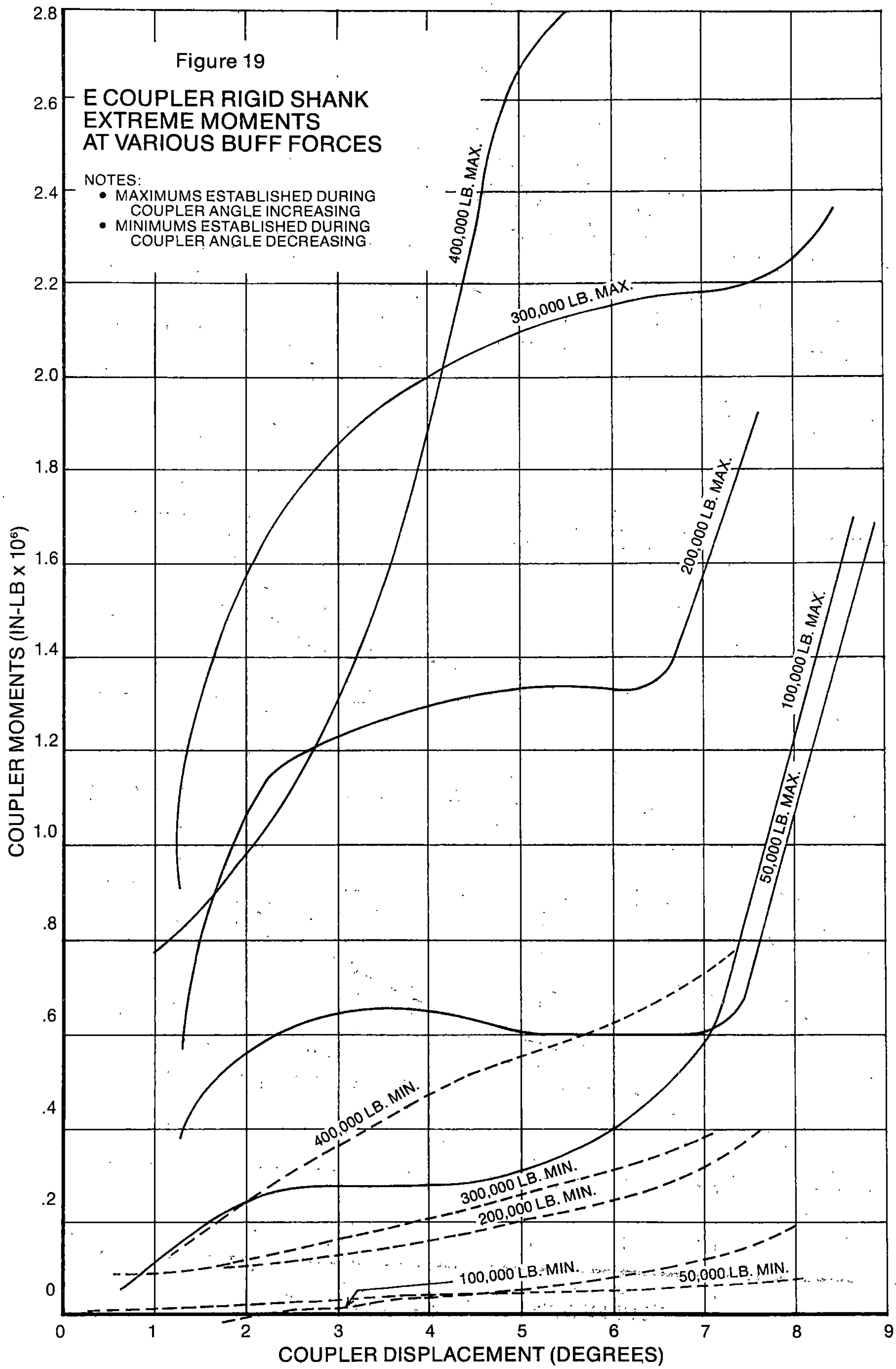


Figure 19
E COUPLER RIGID SHANK
EXTREME MOMENTS
AT VARIOUS BUFF FORCES
NOTES:
• MAXIMUMS ESTABLISHED DURING COUPLER ANGLE INCREASING
• MINIMUMS ESTABLISHED DURING COUPLER ANGLE DECREASING
400,000 LB. MAX.
300,000 LB. MAX.
200,000 LB. MAX.
100,000 LB. MAX.
50,000 LB. MAX.
400,000 LB. MIN.
300,000 LB. MIN.
200,000 LB. MIN.
100,000 LB. MIN.
50,000 LB. MIN.
COUPLER MOMENTS (IN-LB x 10⁶)
COUPLER DISPLACEMENT (DEGREES)
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
0
1
2
3
4
5
6
7
8
9

Figure 20

E COUPLER RIGID SHANK
MOMENT RANGE, CENTER ARRANGEMENT
ANGLE INCREASING
ZERO LB. BUFF OR PULL

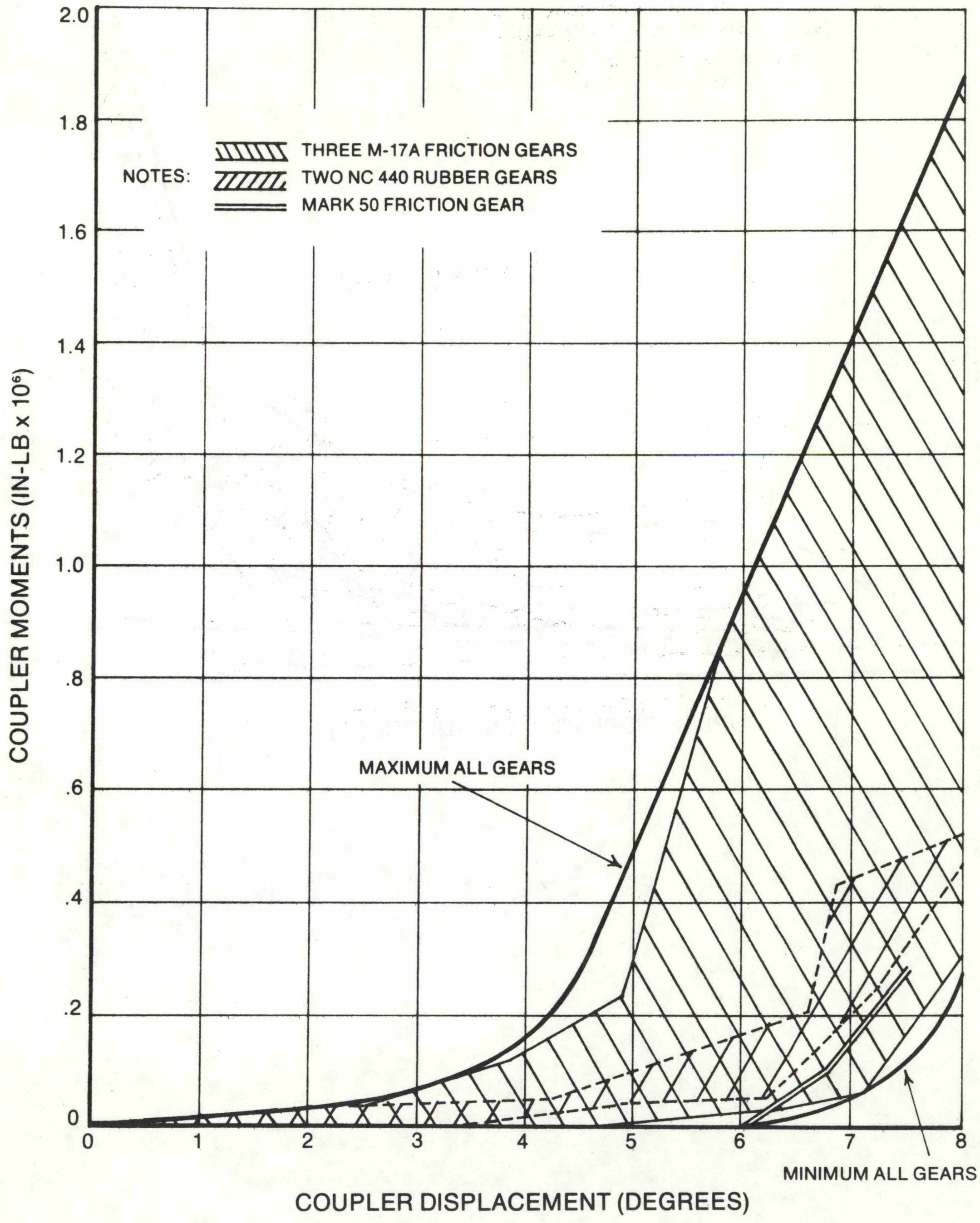


Figure 21

E COUPLER RIGID SHANK
MOMENT RANGE, CENTER ARRANGEMENT
ANGLE INCREASING
50,000 LB. BUFF

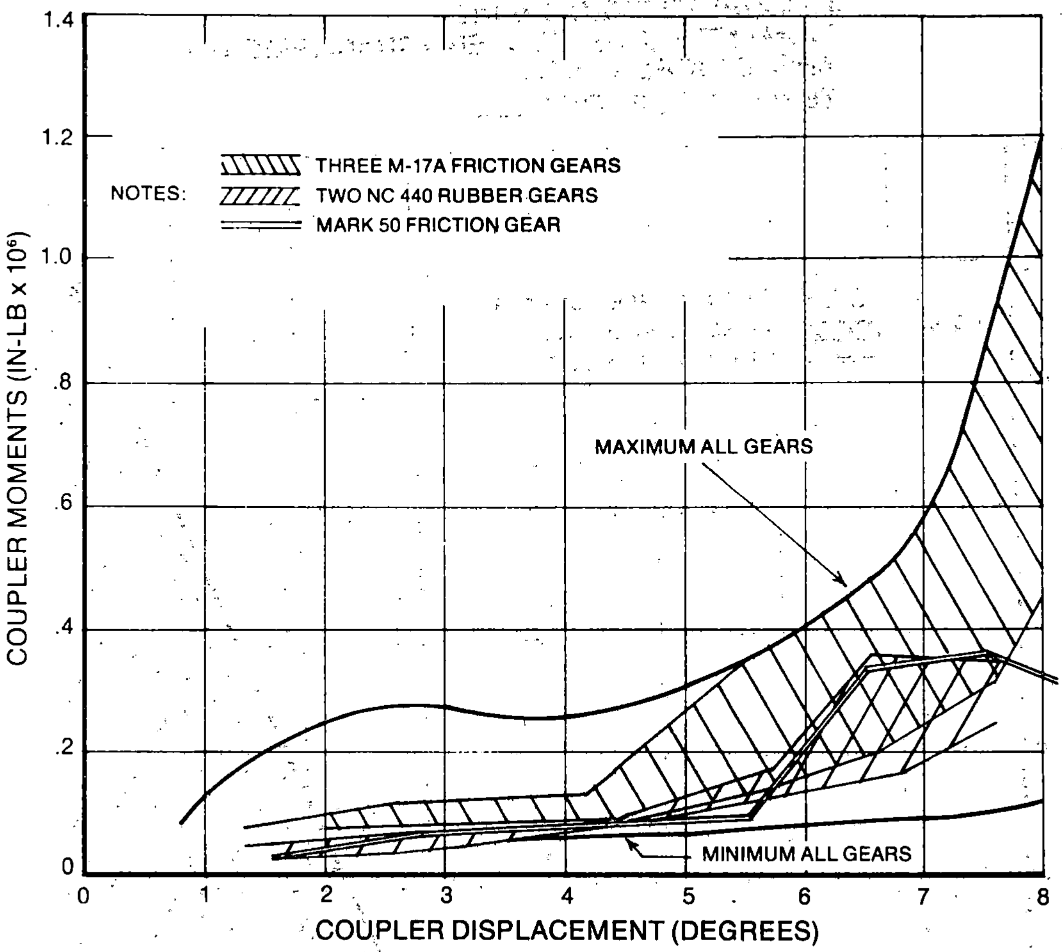


Figure 22

E COUPLER RIGID SHANK MOMENT RANGE, CENTER ARRANGEMENT ANGLE INCREASING 100,000 LB. BUFF

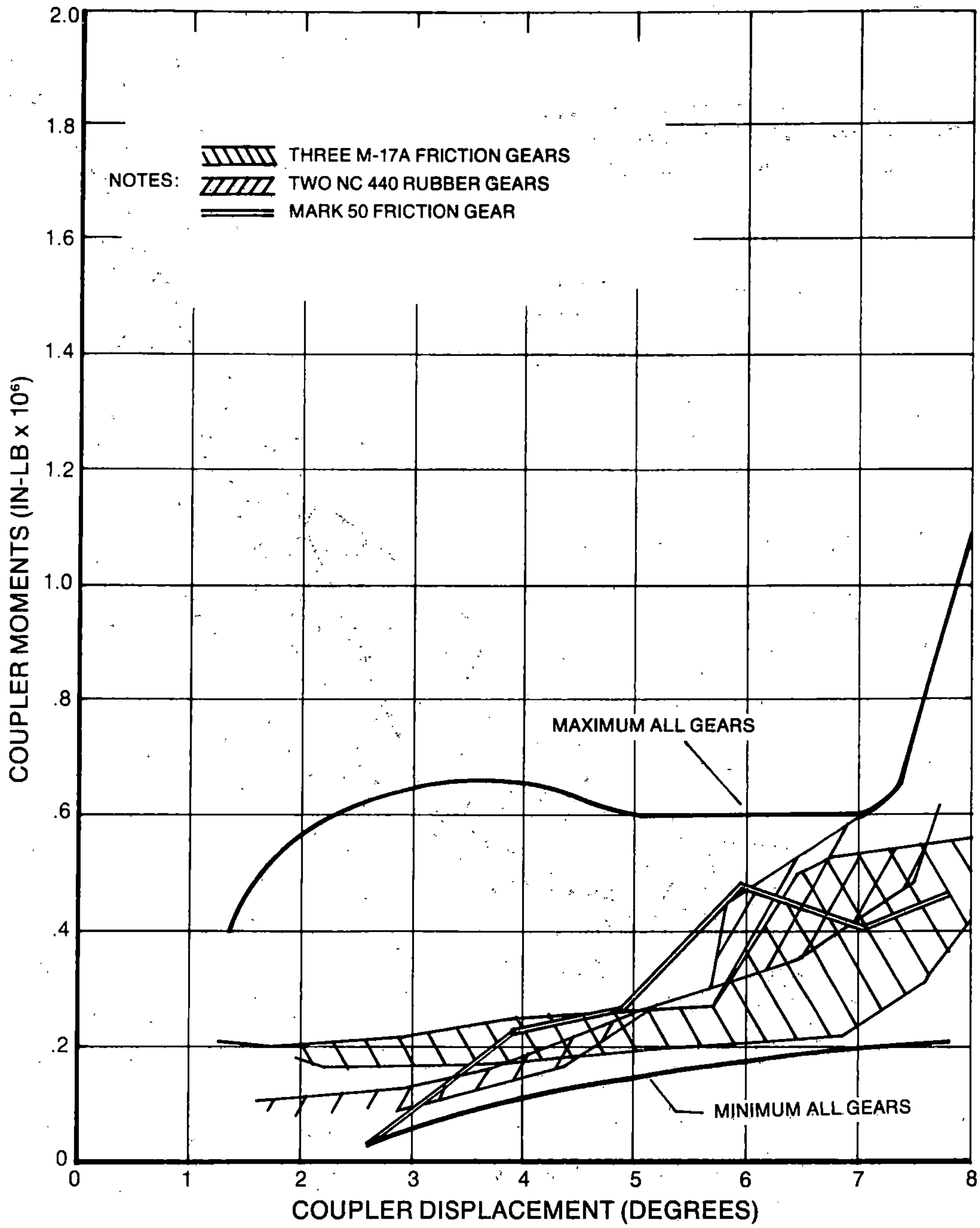


Figure 23

E COUPLER RIGID SHANK
MOMENT RANGE, CENTER ARRANGEMENT
ANGLE INCREASING
200,000 LB. BUFF

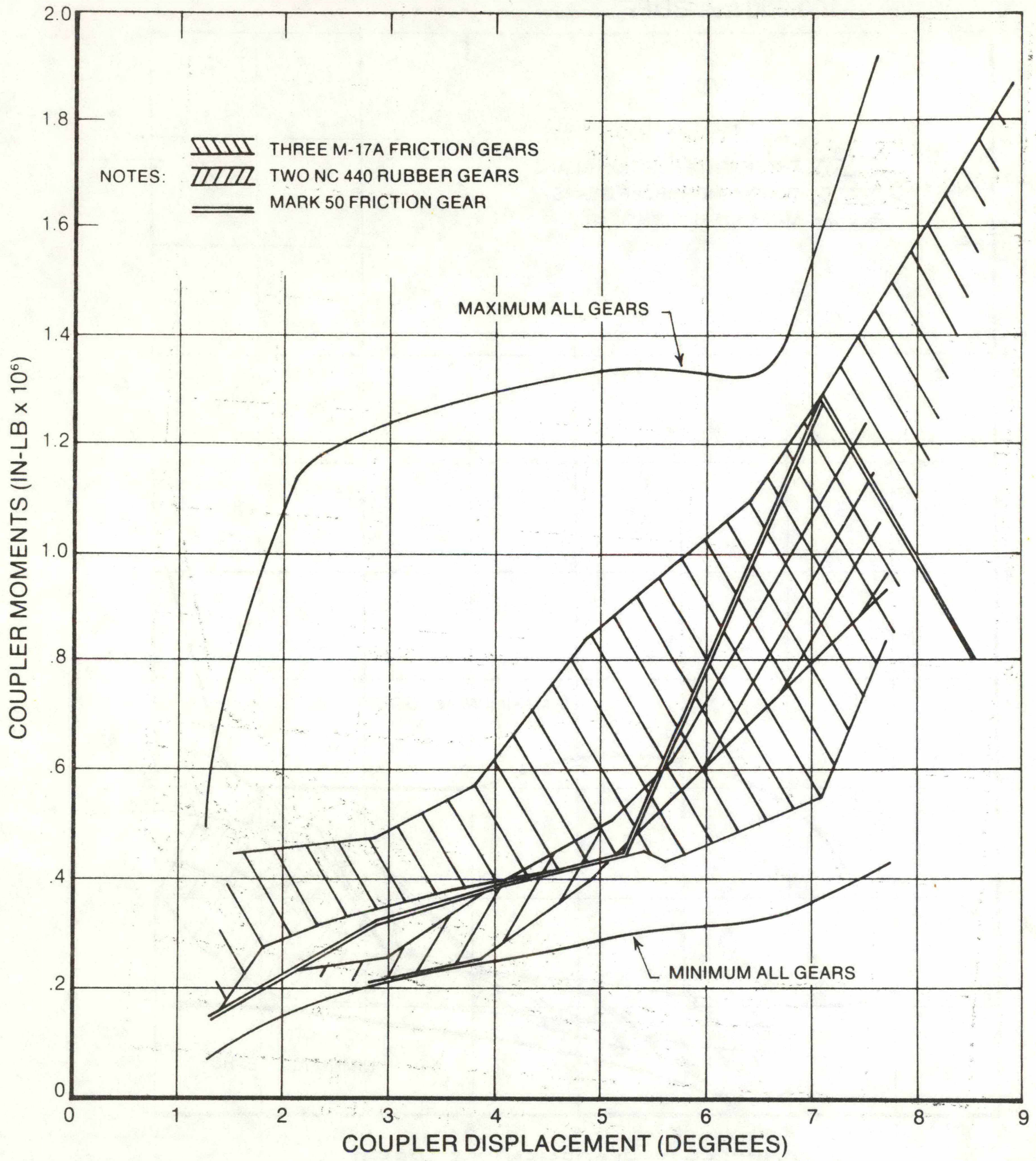
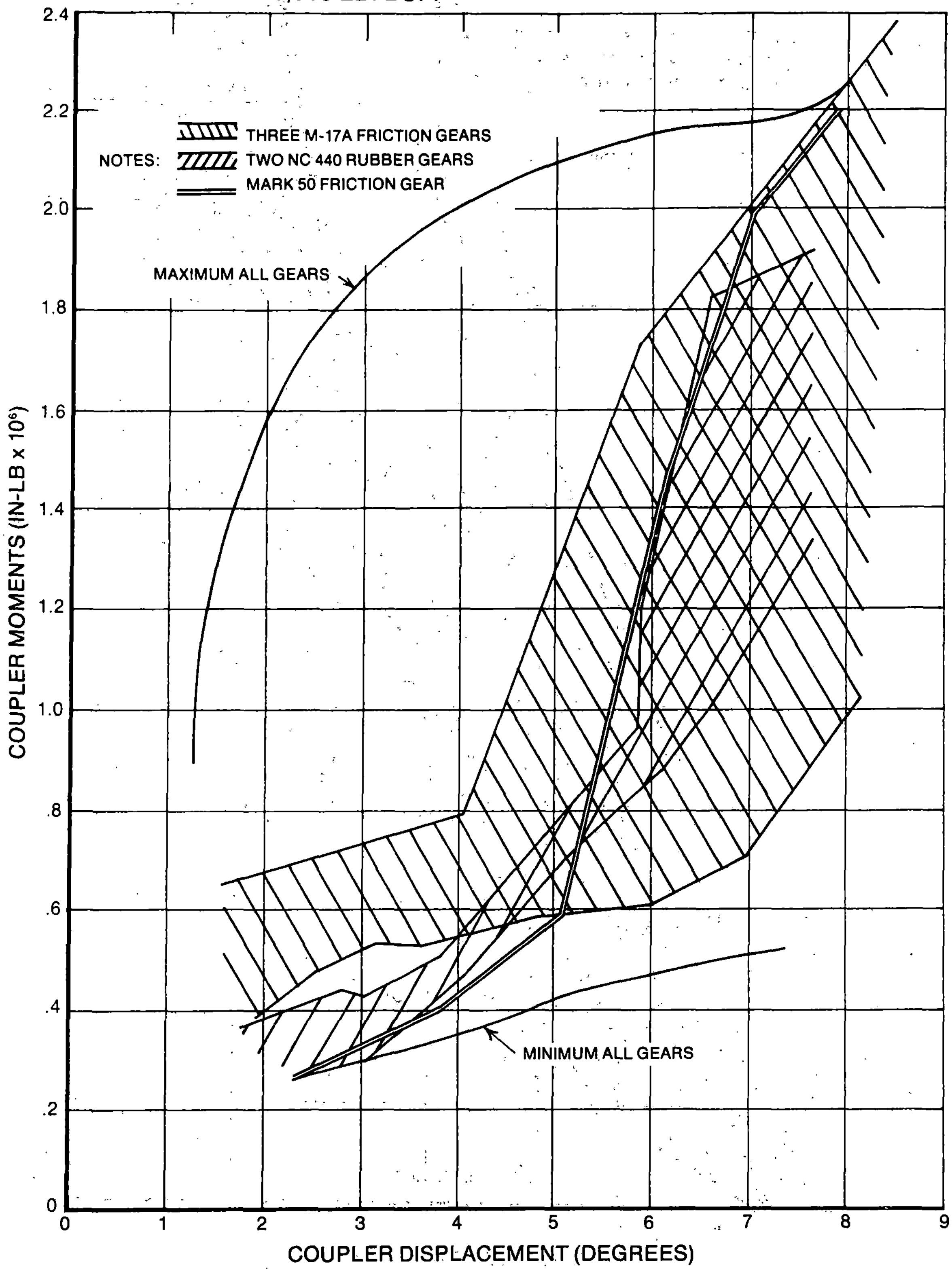


Figure 24

E COUPLER RIGID SHANK
MOMENT RANGE, CENTER ARRANGEMENT
ANGLE INCREASING
300,000 LB. BUFF



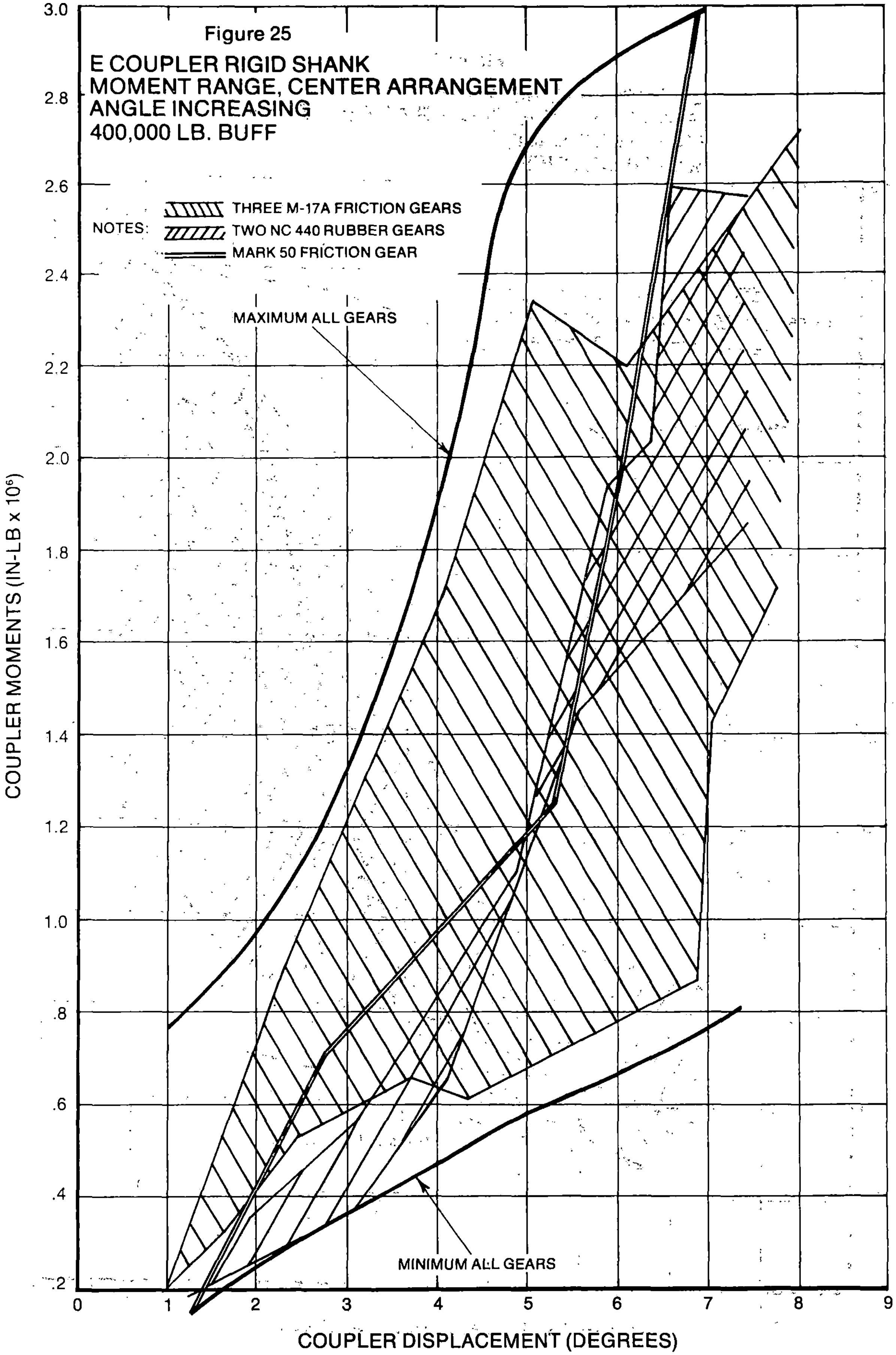


Figure 25
E COUPLER RIGID SHANK
MOMENT RANGE, CENTER ARRANGEMENT
ANGLE INCREASING
400,000 LB. BUFF
NOTES:
THREE M-17A FRICTION GEARS
TWO NC 440 RUBBER GEARS
MARK 50 FRICTION GEAR
MAXIMUM ALL GEARS
MINIMUM ALL GEARS
COUPLER MOMENTS (IN-LB x 10⁶)
COUPLER DISPLACEMENT (DEGREES)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
1
2
3
4
5
6
7
8
9

Figure 26

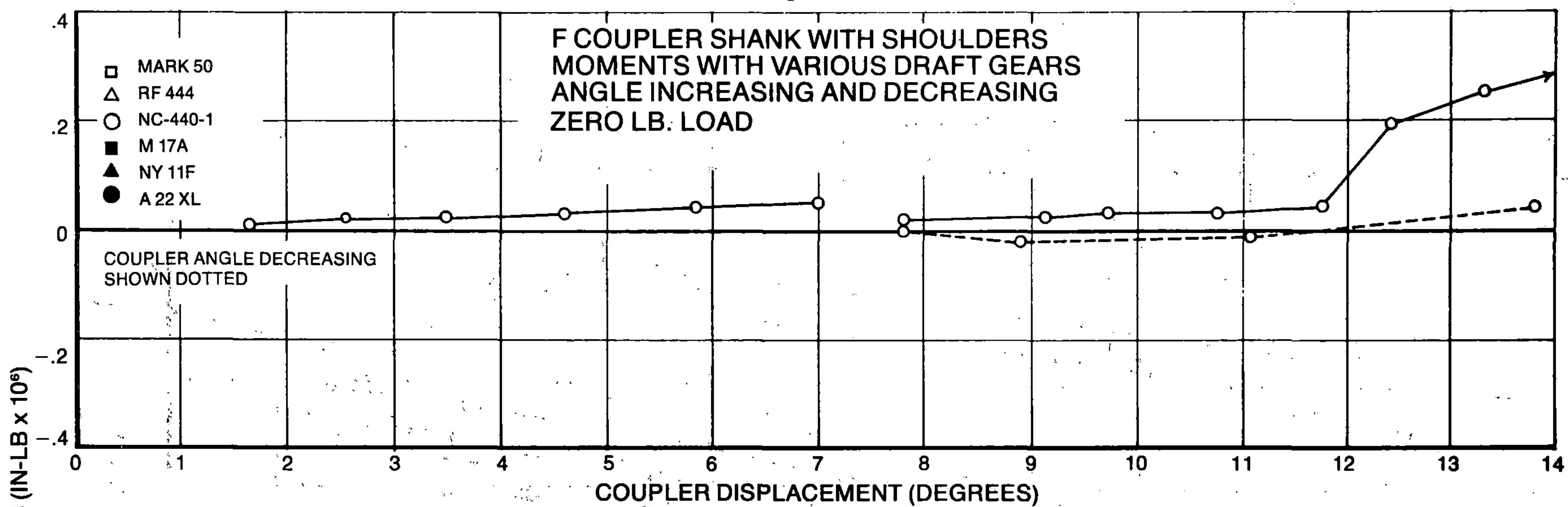


Figure 27

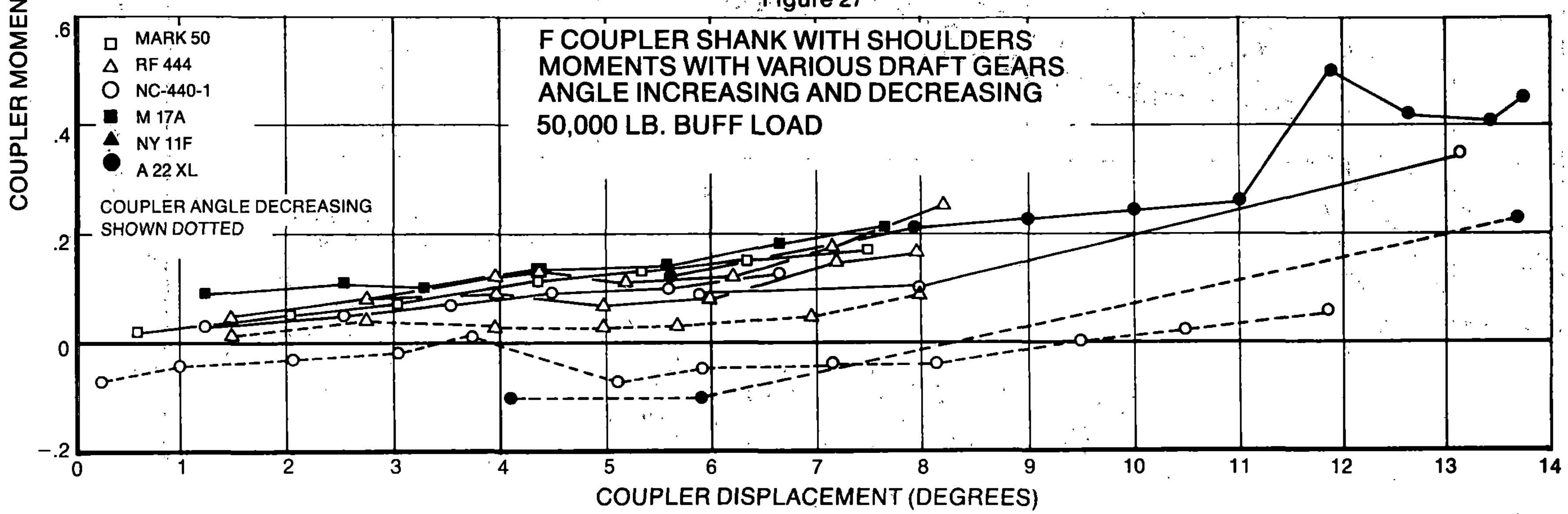
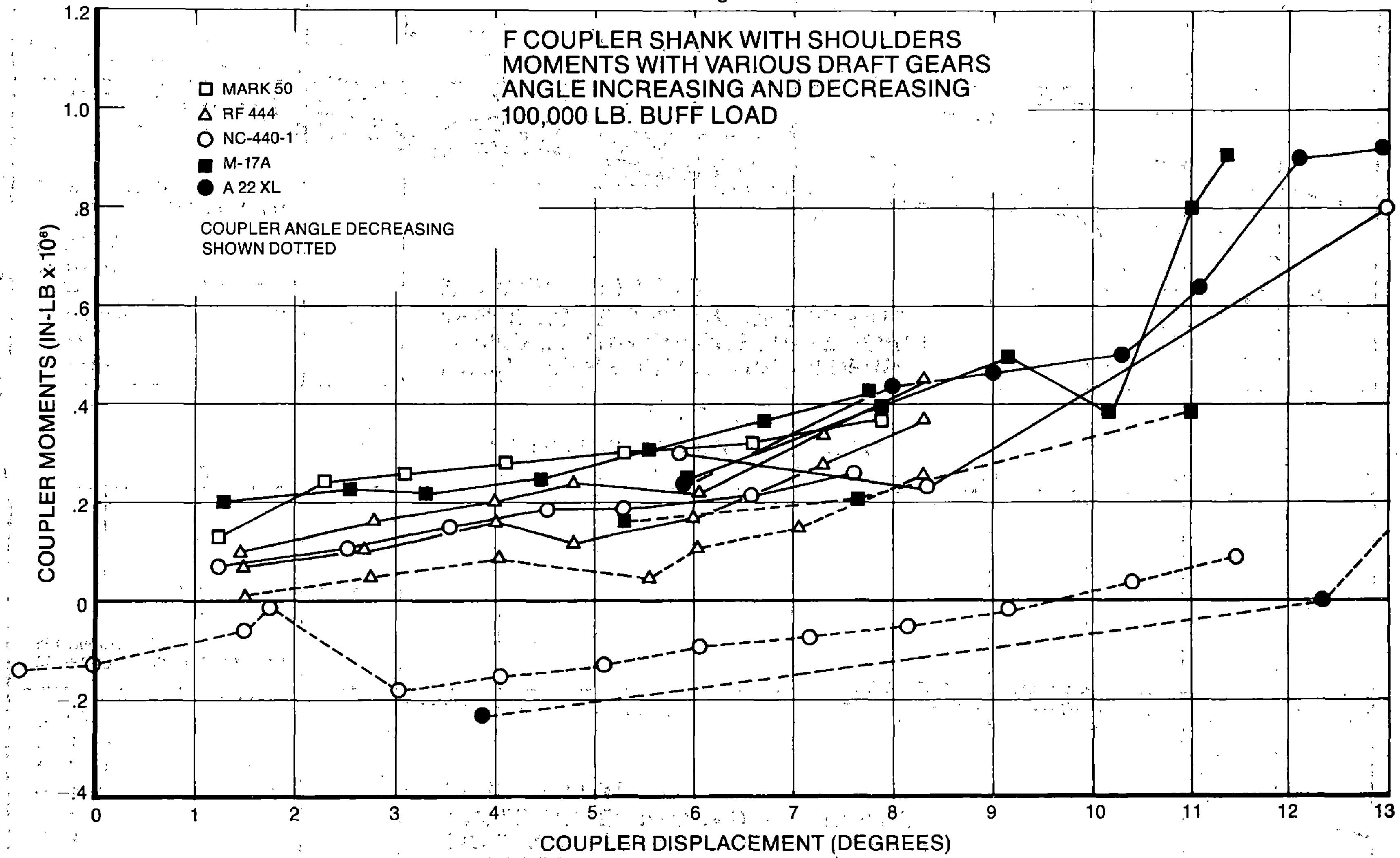
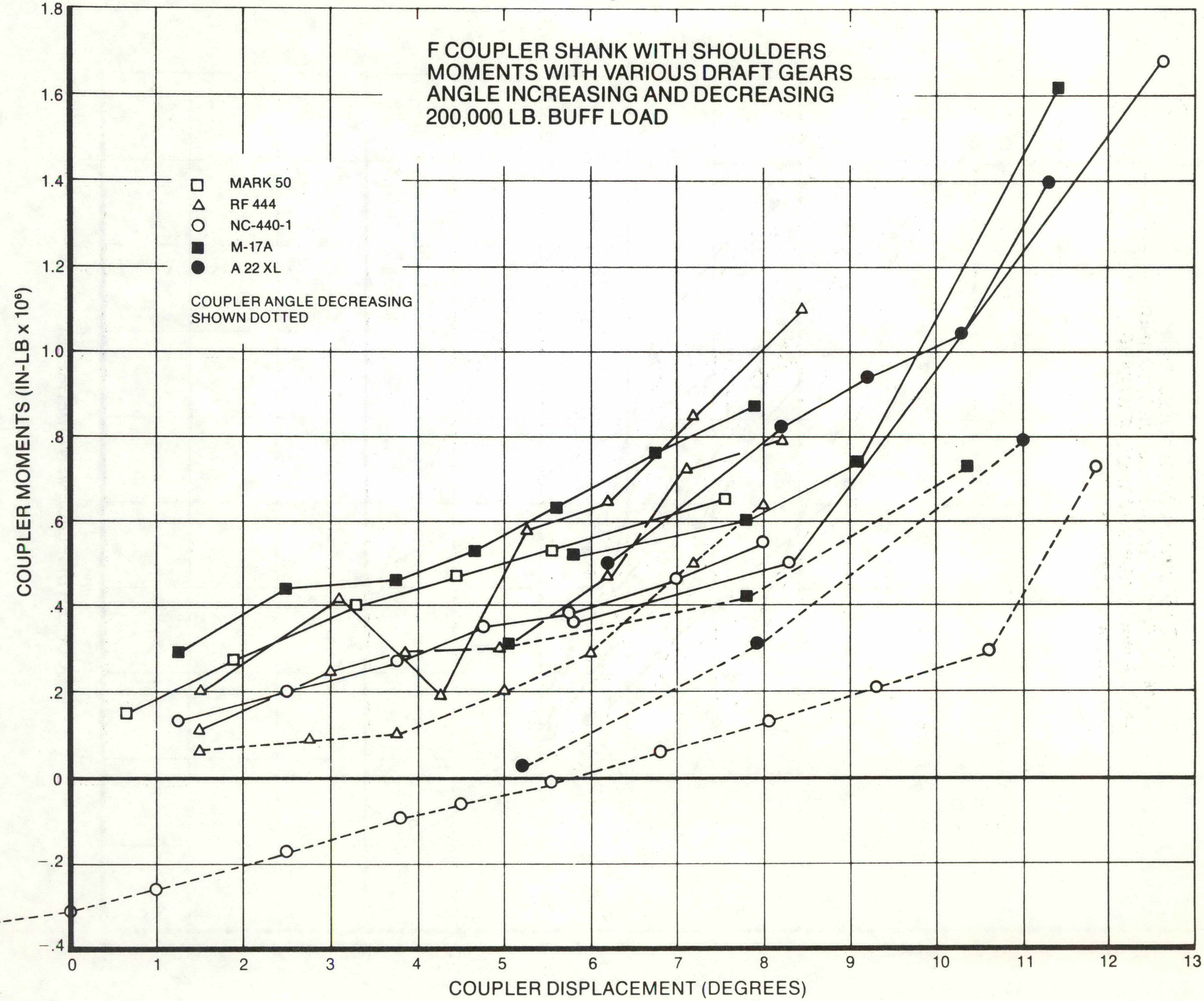


Figure 28



F COUPLER SHANK WITH SHOULDERS
MOMENTS WITH VARIOUS DRAFT GEARS
ANGLE INCREASING AND DECREASING
100,000 LB. BUFF LOAD
MARK 50
RF 444
NC-440-1
M-17A
A 22 XL
COUPLER ANGLE DECREASING
SHOWN DOTTED
COUPLER MOMENTS (IN-LB x 10⁶)
1.2
1.0
.8
.6
.4
.2
0
-.2
-.4
0
1
2
3
4
5
6
7
8
9
10
11
12
13
COUPLER DISPLACEMENT (DEGREES)

Figure 29



F COUPLER SHANK WITH SHOULDERS
MOMENTS WITH VARIOUS DRAFT GEARS
ANGLE INCREASING AND DECREASING
200,000 LB. BUFF LOAD
MARK 50
RF 444
NC-440-1
M-17A
A 22 XL
COUPLER ANGLE DECREASING
SHOWN DOTTED
COUPLER MOMENTS (IN-LB x 10⁶)
COUPLER DISPLACEMENT (DEGREES)
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
-.2
-.4
0
1
2
3
4
5
6
7
8
9
10
11
12
13

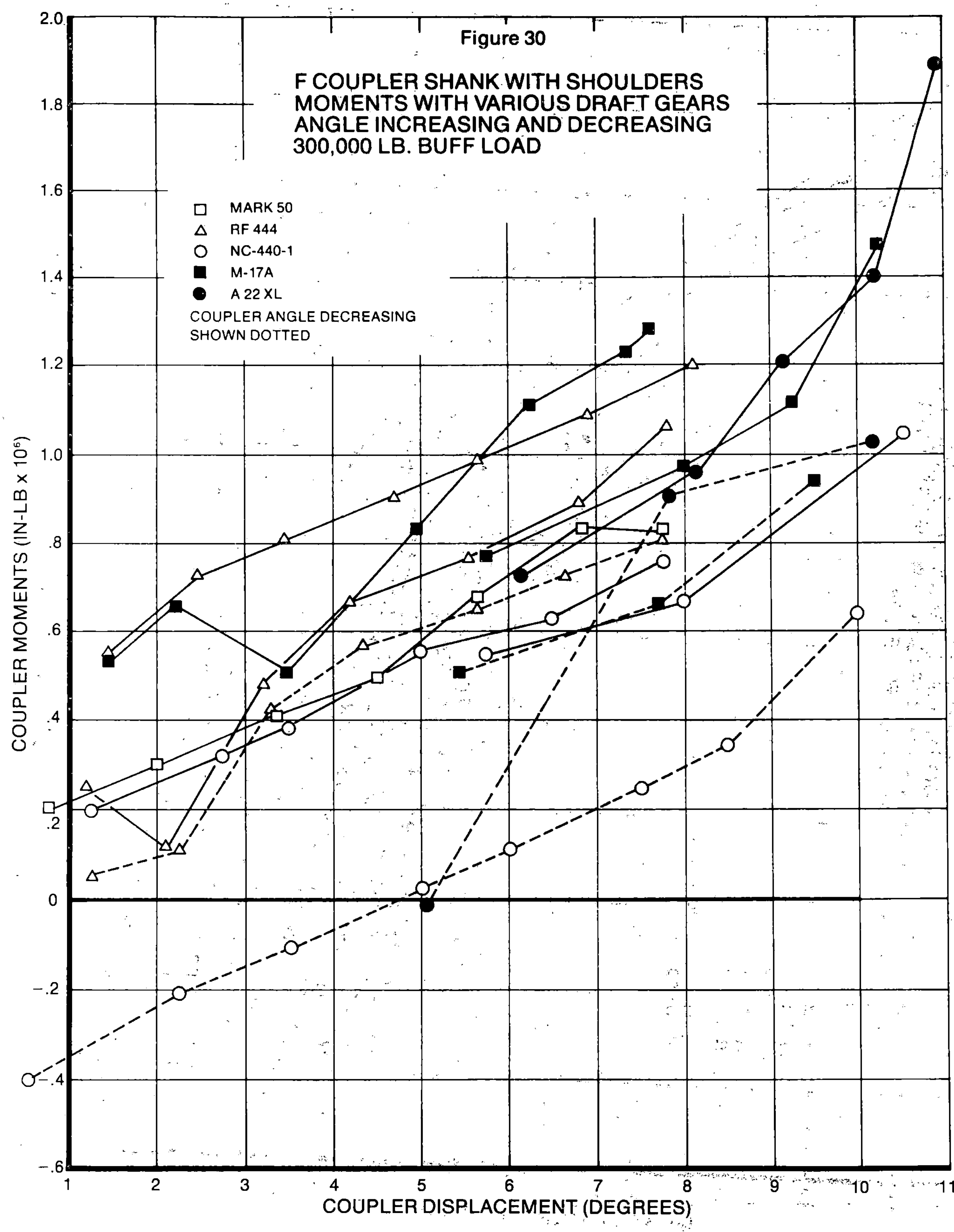


Figure 30
F COUPLER SHANK WITH SHOULDERS
MOMENTS WITH VARIOUS DRAFT GEARS
ANGLE INCREASING AND DECREASING
300,000 LB. BUFF LOAD
MARK 50
RF 444
NC-440-1
M-17A
A 22 XL
COUPLER ANGLE DECREASING
SHOWN DOTTED
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
−.2
−.4
−.6
COUPLER MOMENTS (IN-LB x 10⁶)
1
2
3
4
5
6
7
8
9
10
11
COUPLER DISPLACEMENT (DEGREES)

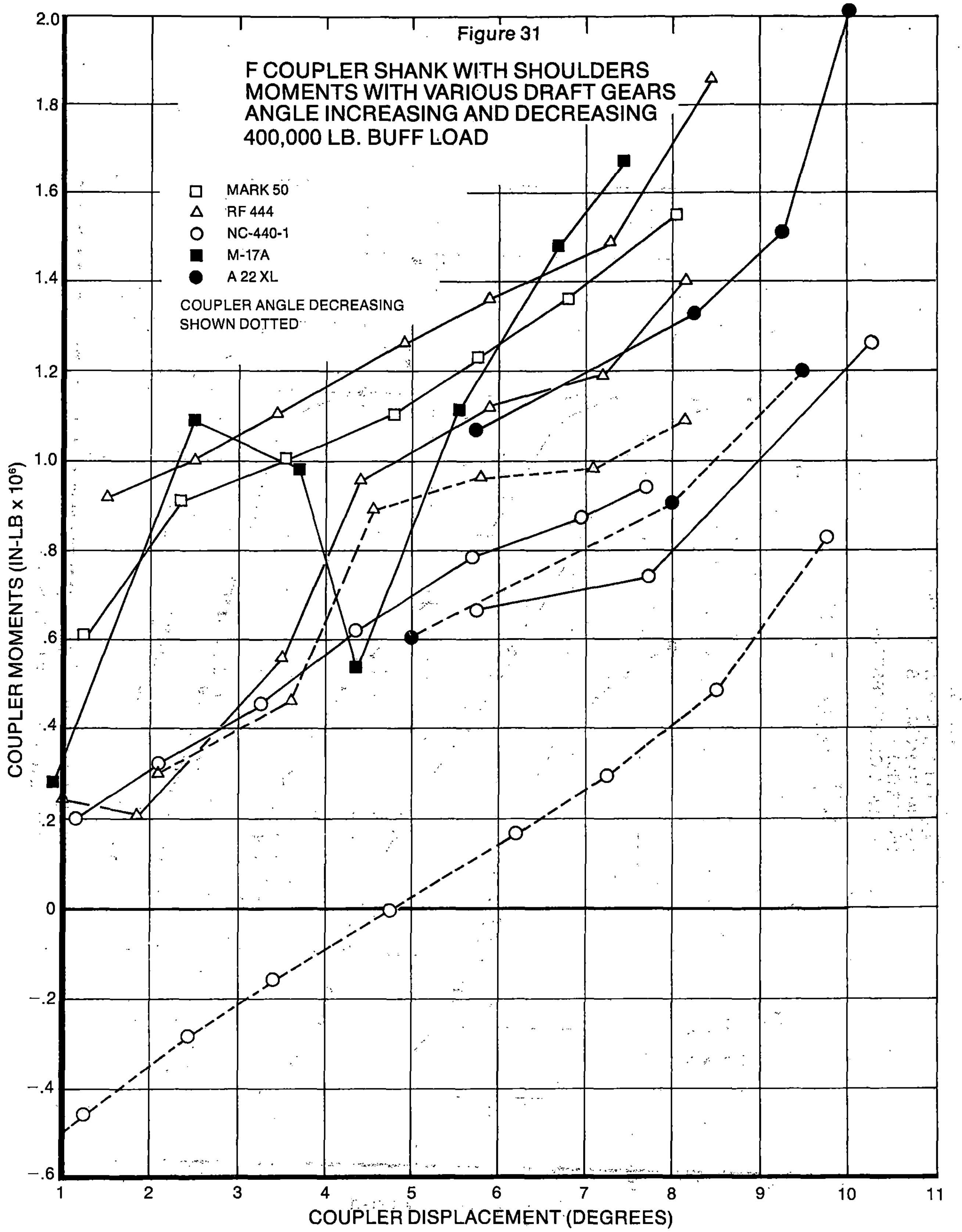


Figure 31
F COUPLER SHANK WITH SHOULDERS
MOMENTS WITH VARIOUS DRAFT GEARS
ANGLE INCREASING AND DECREASING
400,000 LB. BUFF LOAD
MARK 50
RF 444
NC-440-1
M-17A
A 22 XL
COUPLER ANGLE DECREASING
SHOWN DOTTED
COUPLER MOMENTS (IN-LB x 10⁶)
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
−.2
−.4
−.6
1
2
3
4
5
6
7
8
9
10
11
COUPLER DISPLACEMENT (DEGREES)

Figure 32

F COUPLER SHANK WITH SHOULDERS
MAXIMUM MOMENTS
UNDER BUFF
(FOR ALL GEARS TESTED)

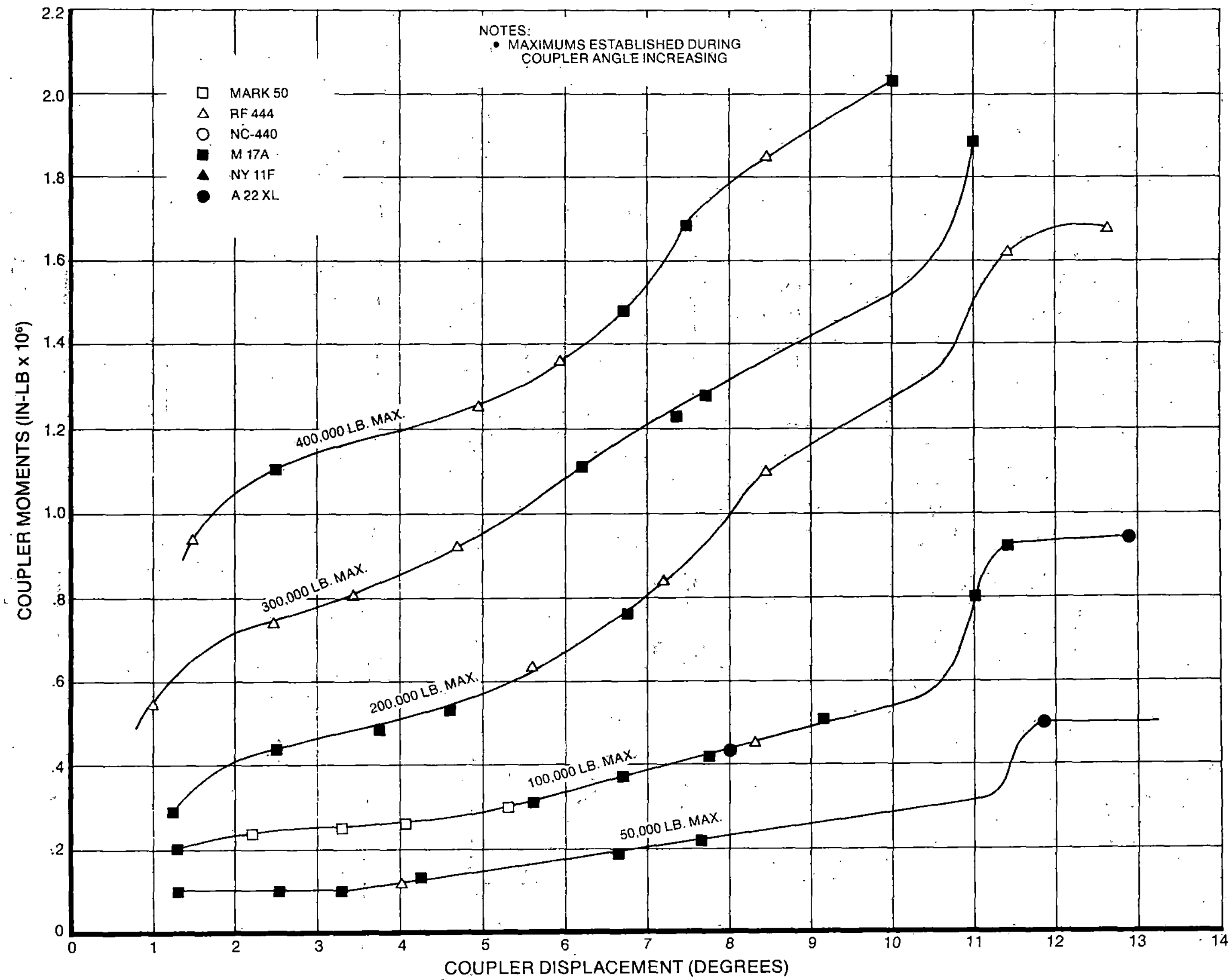


Figure 32A

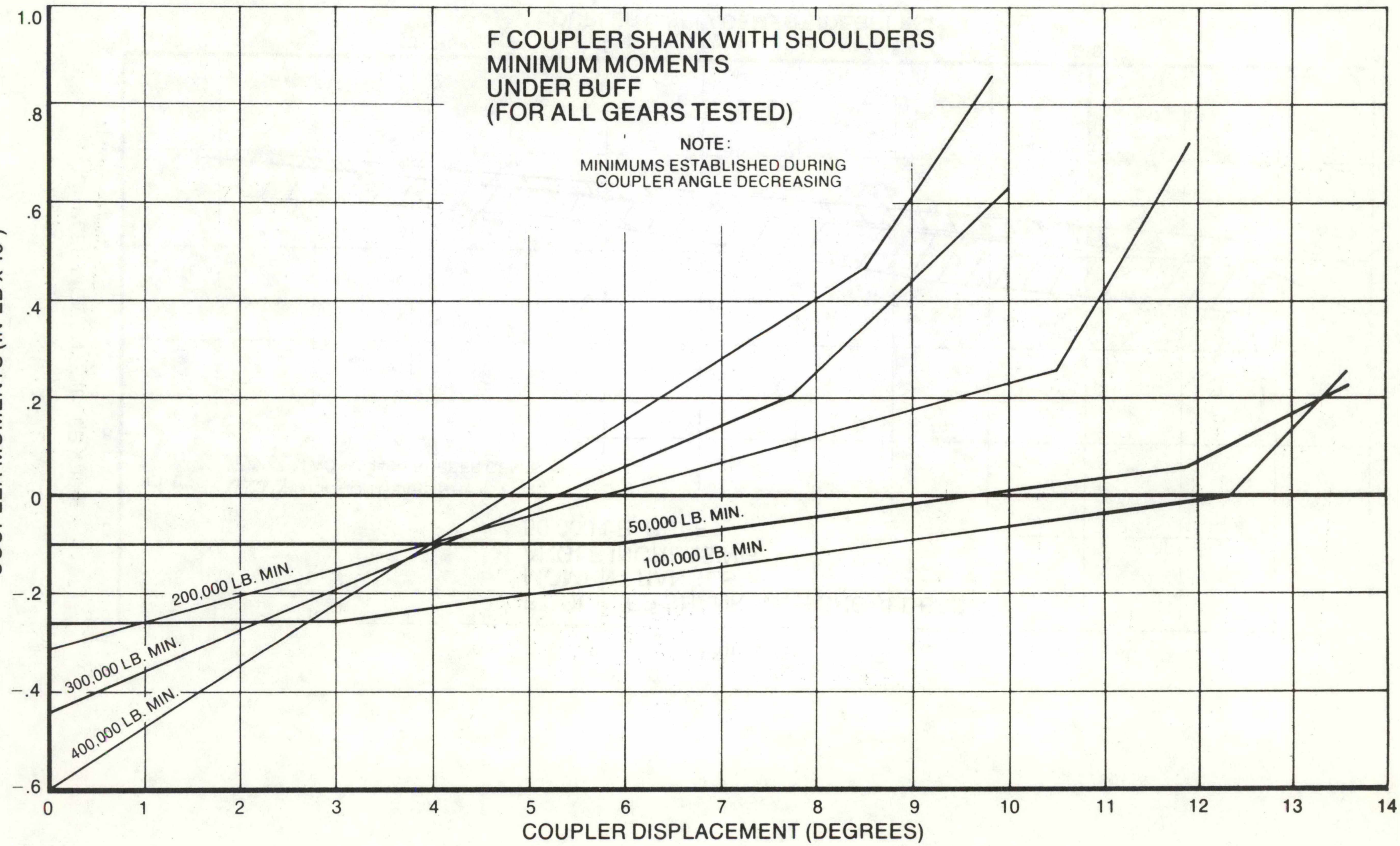
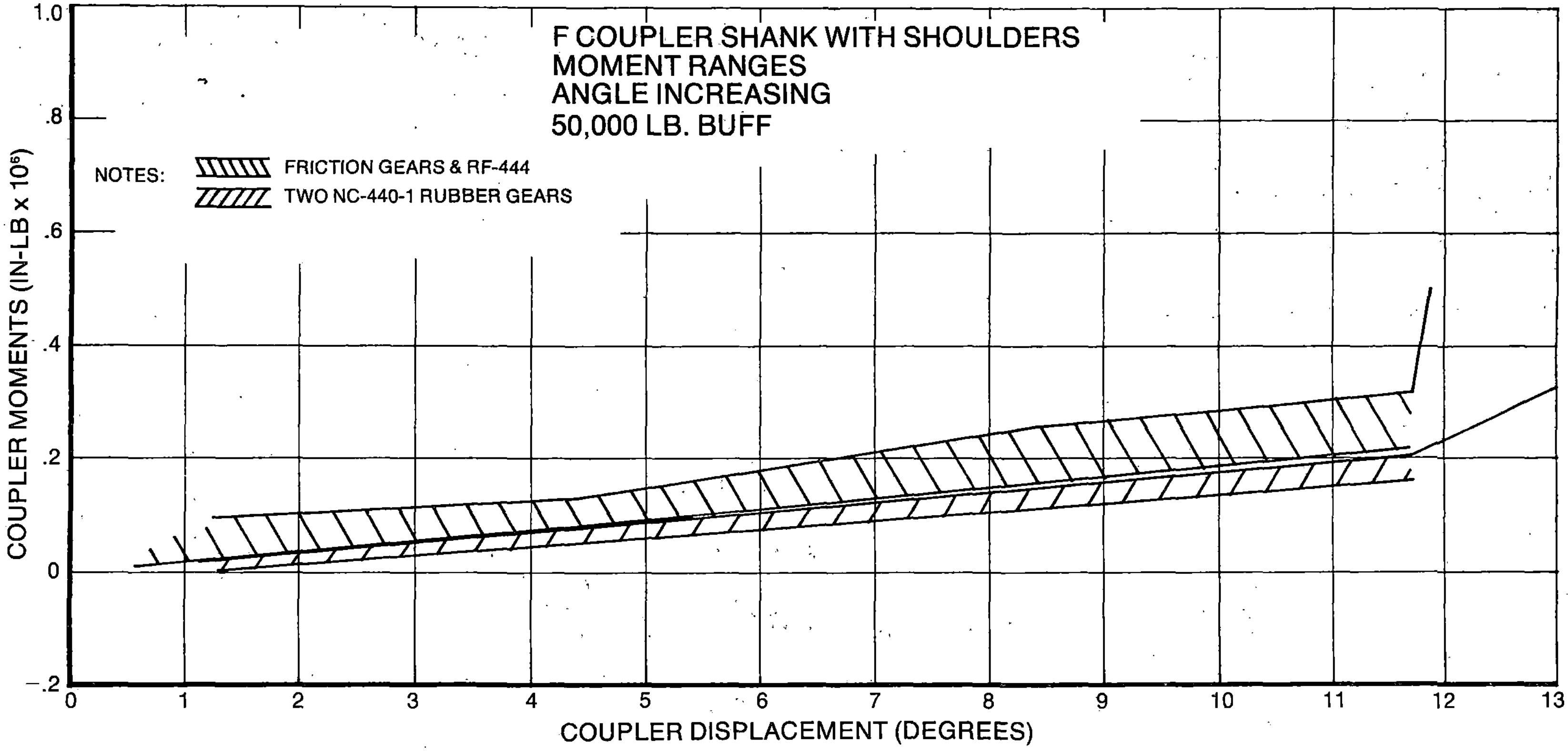

F COUPLER SHANK WITH SHOULDERS
MINIMUM MOMENTS
UNDER BUFF
(FOR ALL GEARS TESTED)
NOTE:
MINIMUMS ESTABLISHED DURING
COUPLER ANGLE DECREASING
50,000 LB. MIN.
100,000 LB. MIN.
200,000 LB. MIN.
300,000 LB. MIN.
400,000 LB. MIN.
COUPLER MOMENTS (IN-LB x 10⁶)
1.0
.8
.6
.4
.2
0
-.2
-.4
-.6
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
COUPLER DISPLACEMENT (DEGREES)

Figure 33



F COUPLER SHANK WITH SHOULDERS
MOMENT RANGES
ANGLE INCREASING
50,000 LB. BUFF
NOTES:
FRICTION GEARS & RF-444
TWO NC-440-1 RUBBER GEARS
COUPLER MOMENTS (IN-LB x 10⁶)
1.0
.8
.6
.4
.2
0
−.2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
COUPLER DISPLACEMENT (DEGREES)

Figure 34

F COUPLER SHANK WITH SHOULDERS
MOMENT RANGER
ANGLE INCREASING
100,000 LB. BUFF

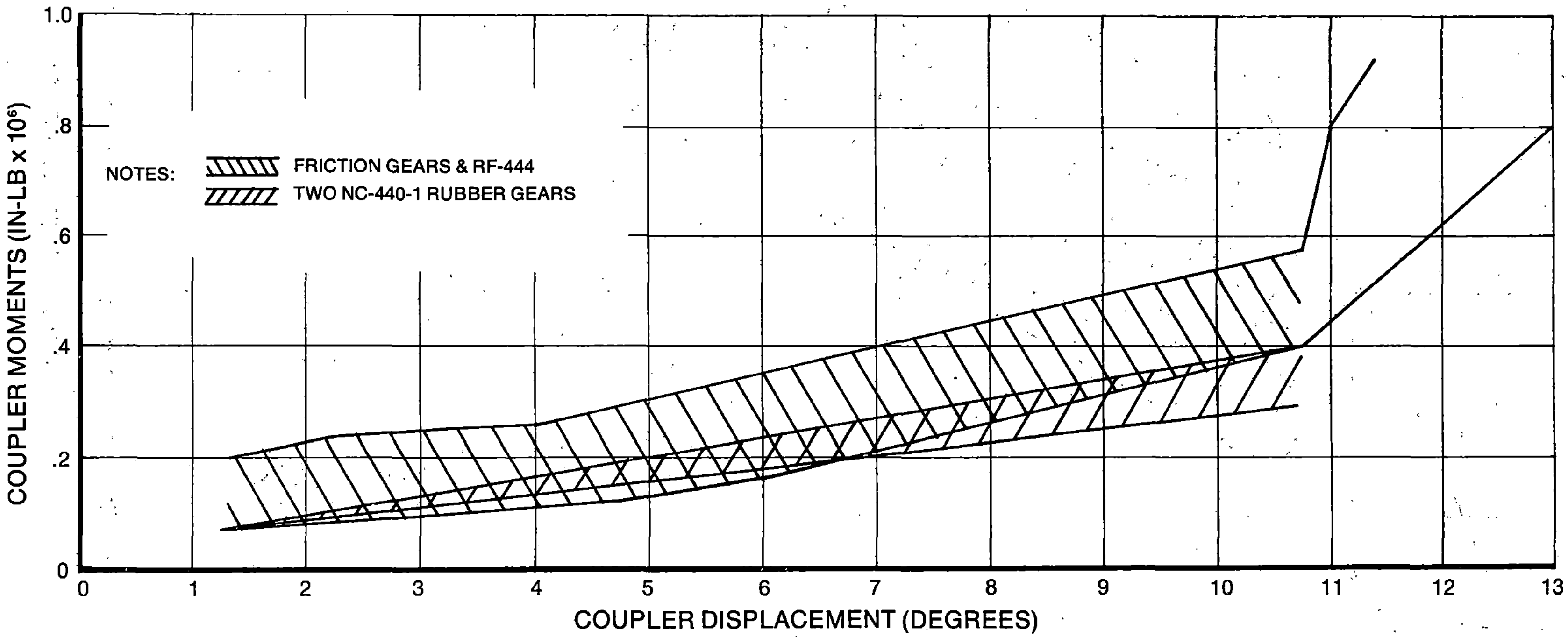
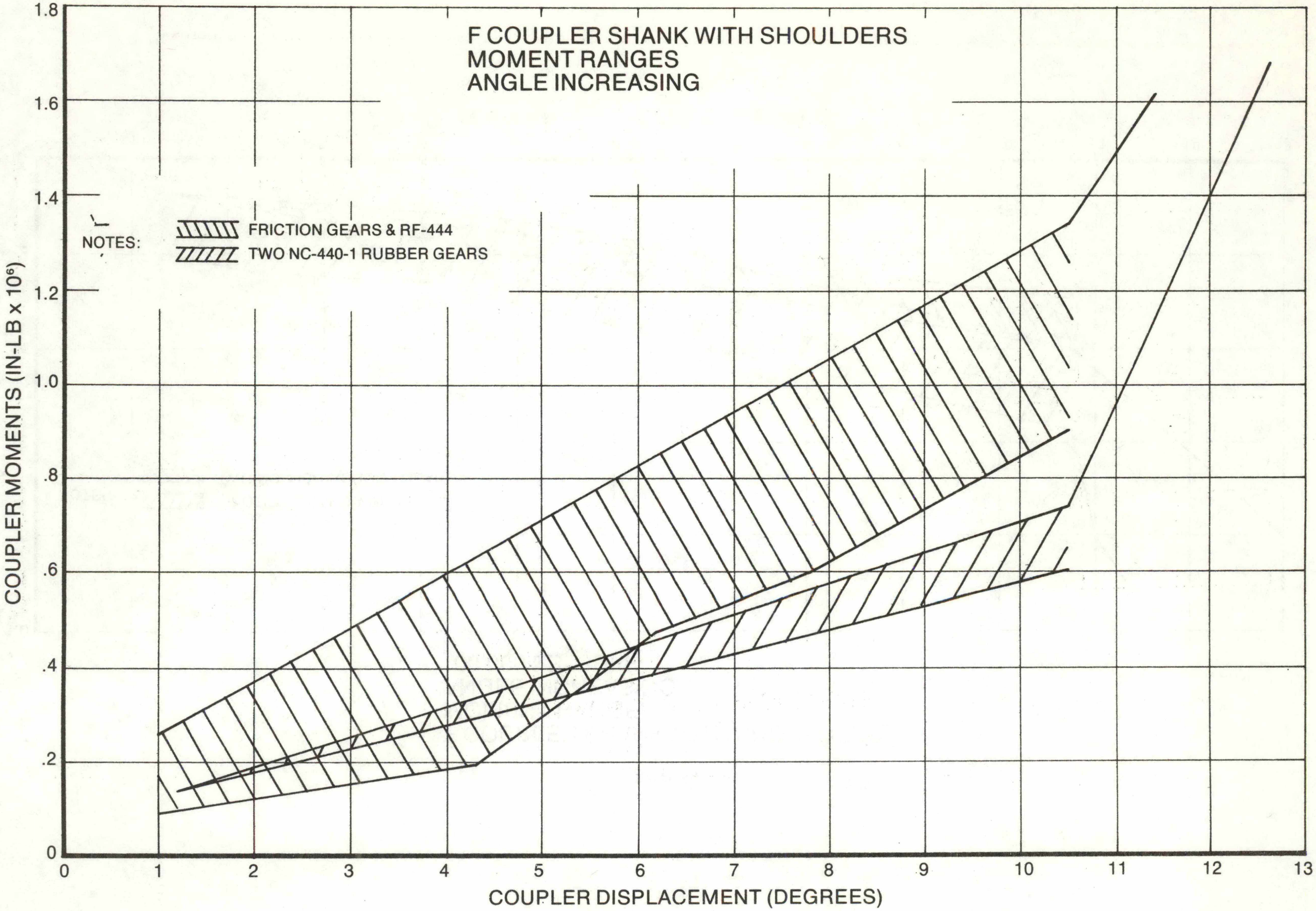


Figure 35



F COUPLER SHANK WITH SHOULDERS
MOMENT RANGES
ANGLE INCREASING
NOTES:
FRICTION GEARS & RF-444
TWO NC-440-1 RUBBER GEARS
COUPLER MOMENTS (IN-LB x 10⁶)
COUPLER DISPLACEMENT (DEGREES)
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
0
1
2
3
4
5
6
7
8
9
10
11
12
13

Figure 36

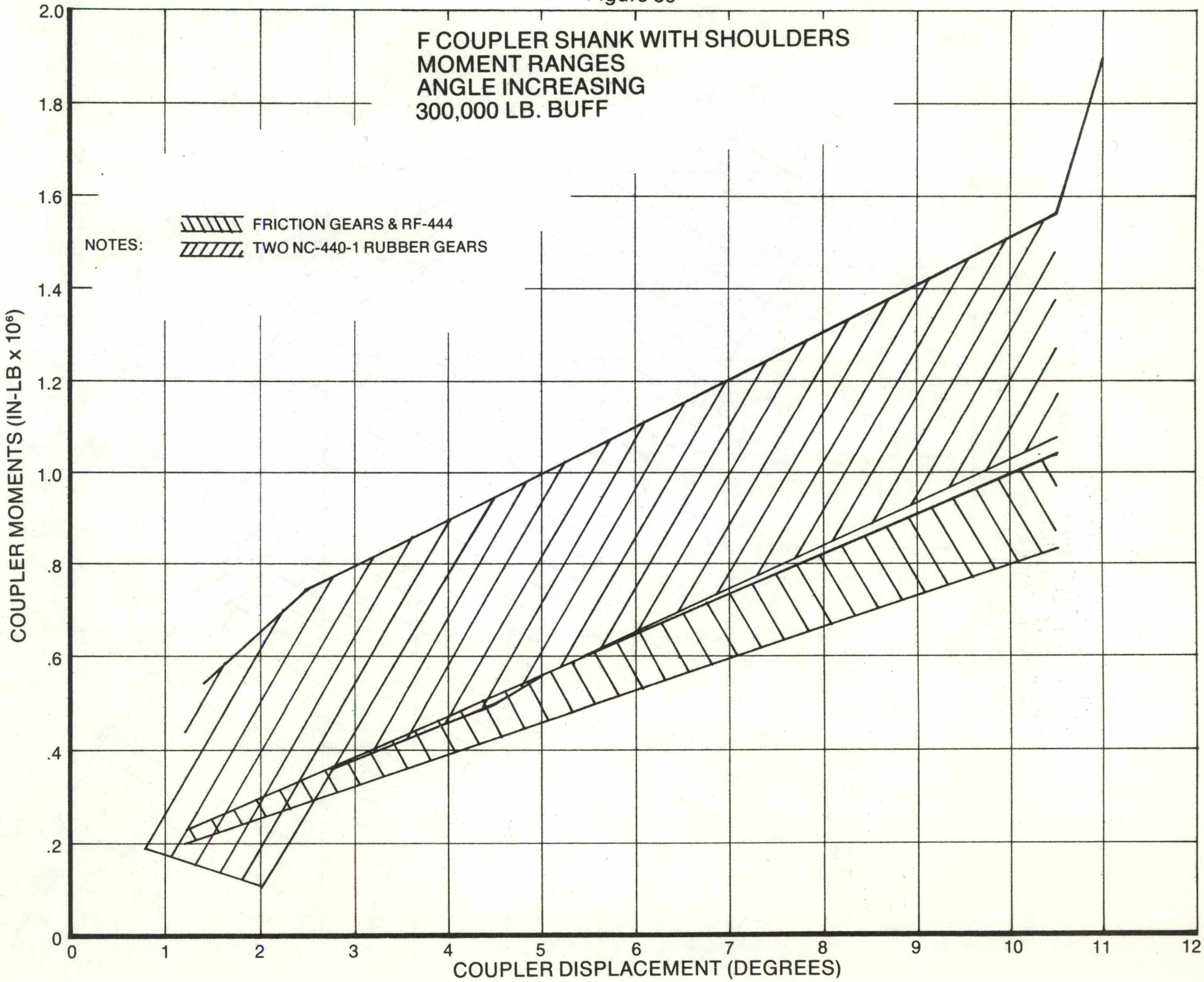

F COUPLER SHANK WITH SHOULDERS
MOMENT RANGES
ANGLE INCREASING
300,000 LB. BUFF
NOTES:
FRICTION GEARS & RF-444
TWO NC-440-1 RUBBER GEARS
COUPLER MOMENTS (IN-LB x 10⁶)
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
0
1
2
3
4
5
6
7
8
9
10
11
12
COUPLER DISPLACEMENT (DEGREES)

Figure 37

F COUPLER SHANK WITH SHOULDERS
MOMENT RANGES
ANGLE INCREASING
400,000 LB. BUFF

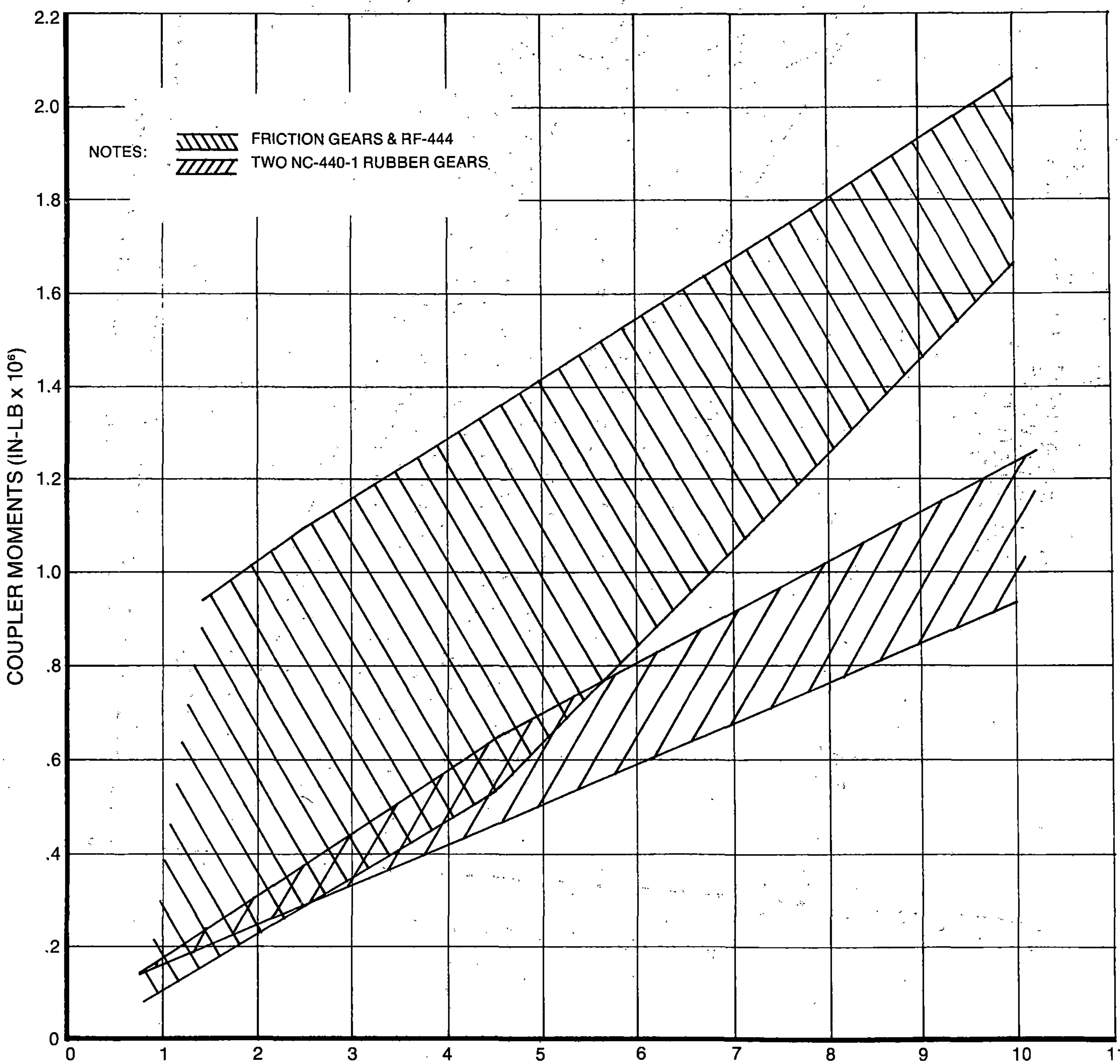


Figure 38

E COUPLER RIGID SHANK
EXTREME MOMENTS
ANGLE INCREASING & DECREASING
50,000 LB. PULL

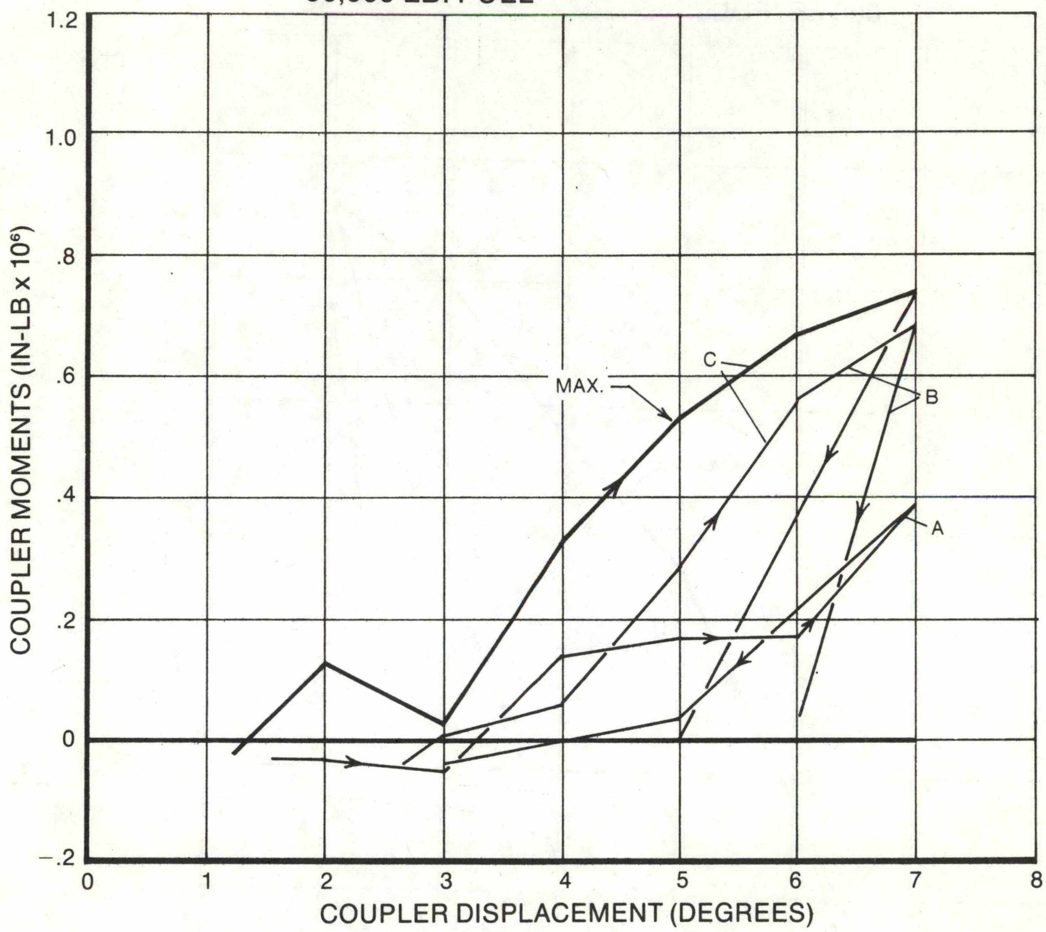


Figure 39

E COUPLER RIGID SHANK
EXTREME MOMENTS
ANGLE INCREASING & DECREASING
100,000 LB. PULL

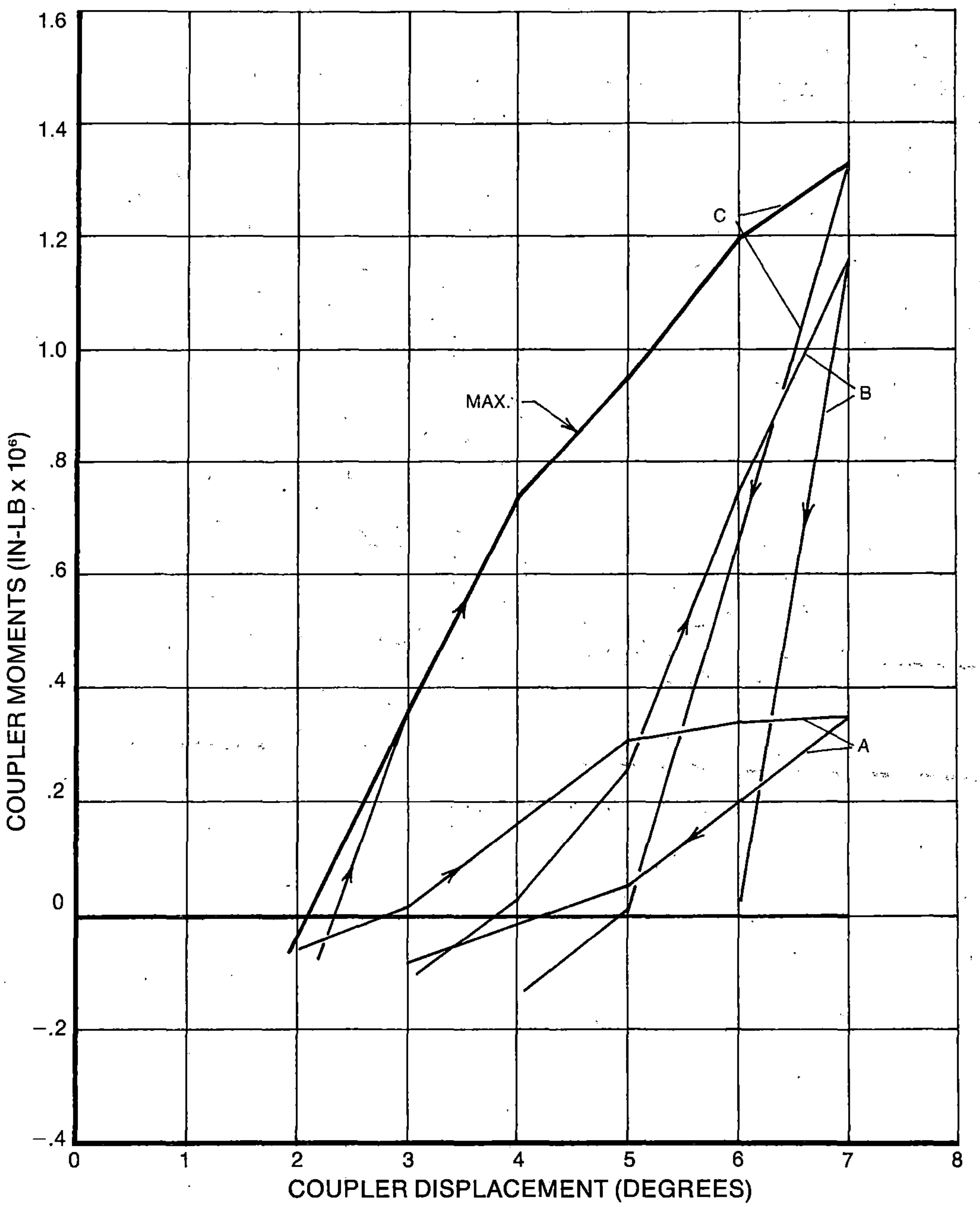


Figure 40

E COUPLER RIGID SHANK
EXTREME MOMENTS
ANGLE INCREASING & DECREASING
200,000 LB. PULL

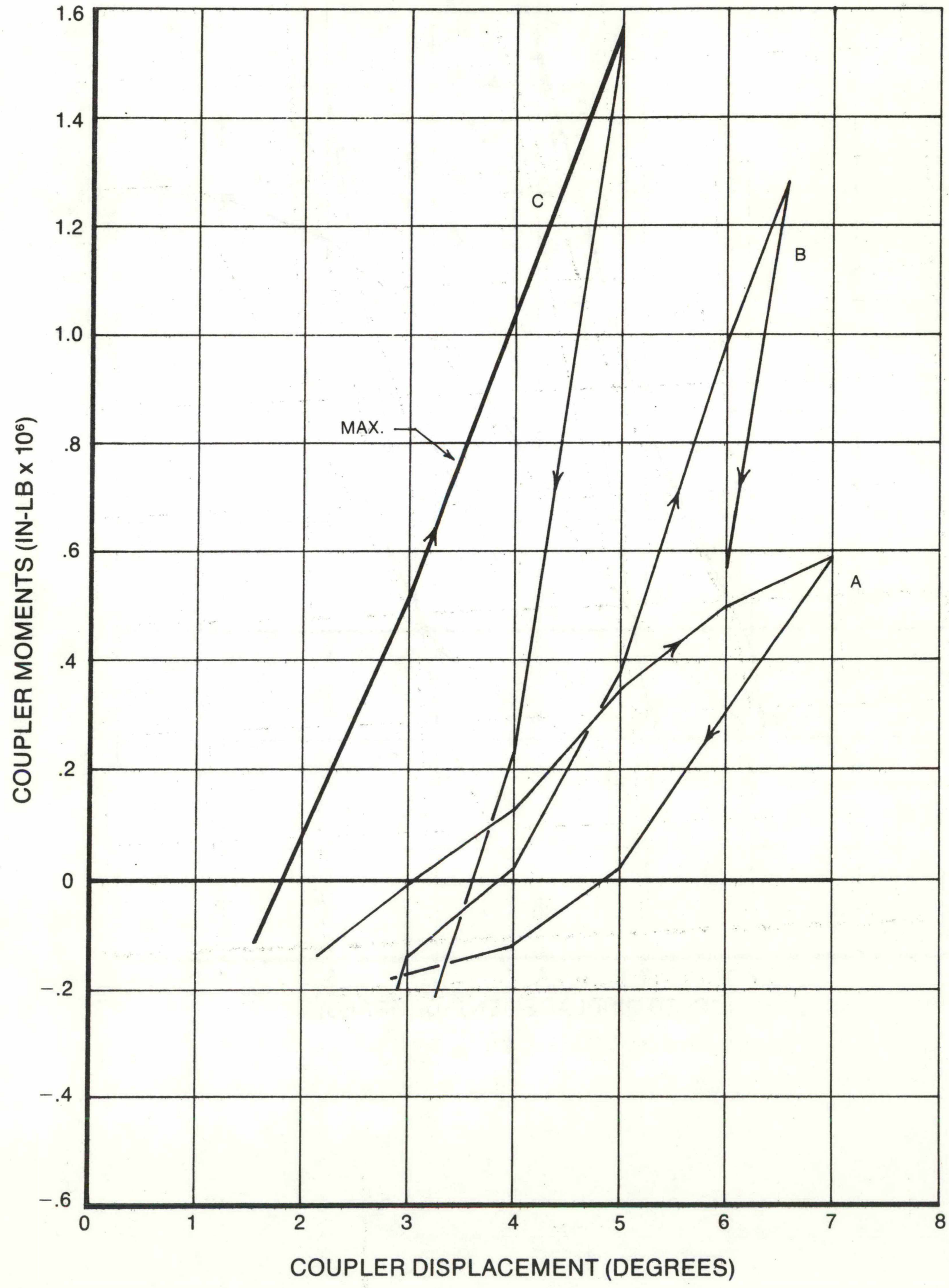


Figure 41

E COUPLER RIGID SHANK
EXTREME MOMENTS
ANGLE INCREASING & DECREASING
300,000 LB. PULL

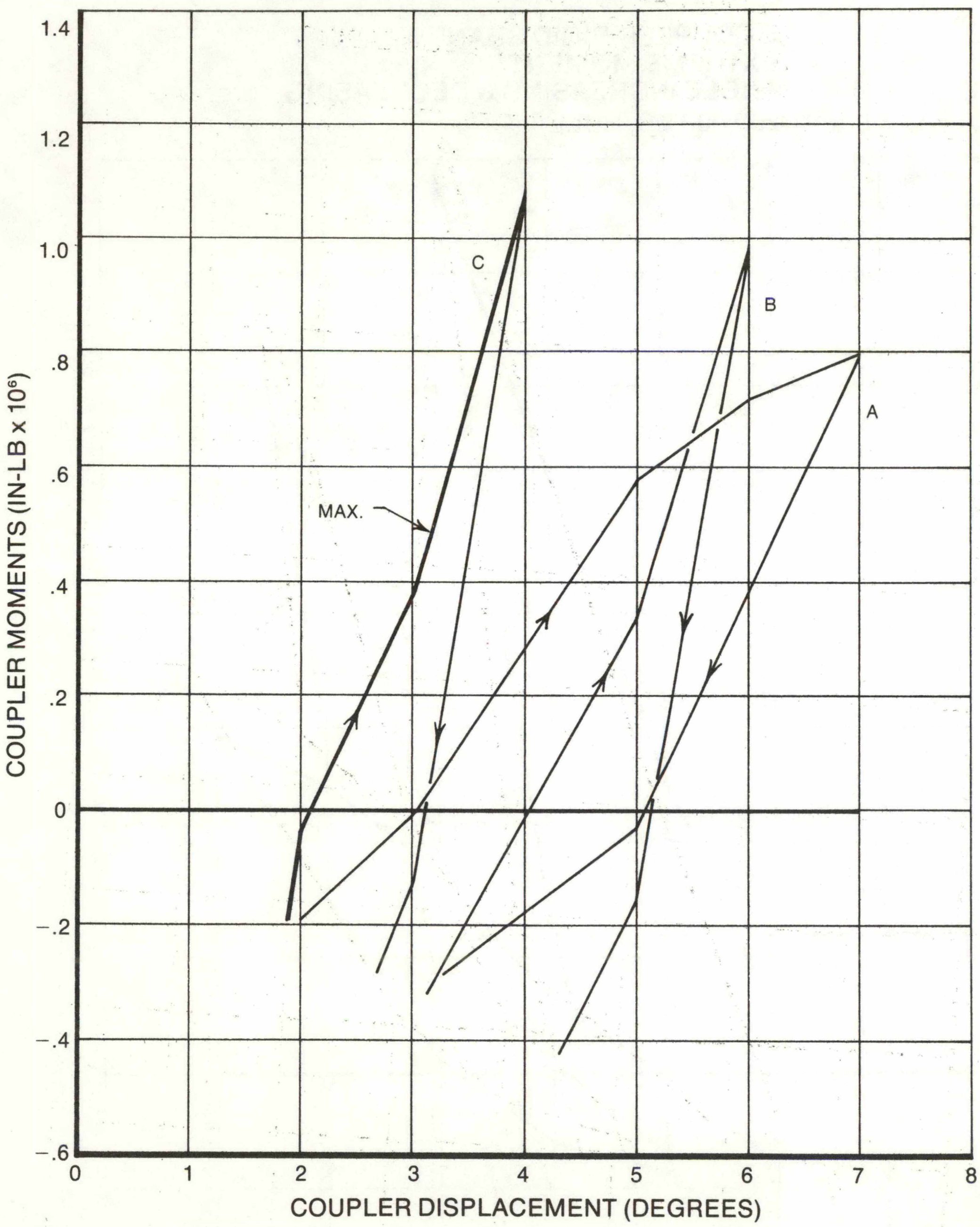


Figure 42

E COUPLER RIGID SHANK
EXTREME MOMENTS
ANGLE INCREASING & DECREASING
400,000 LB. PULL

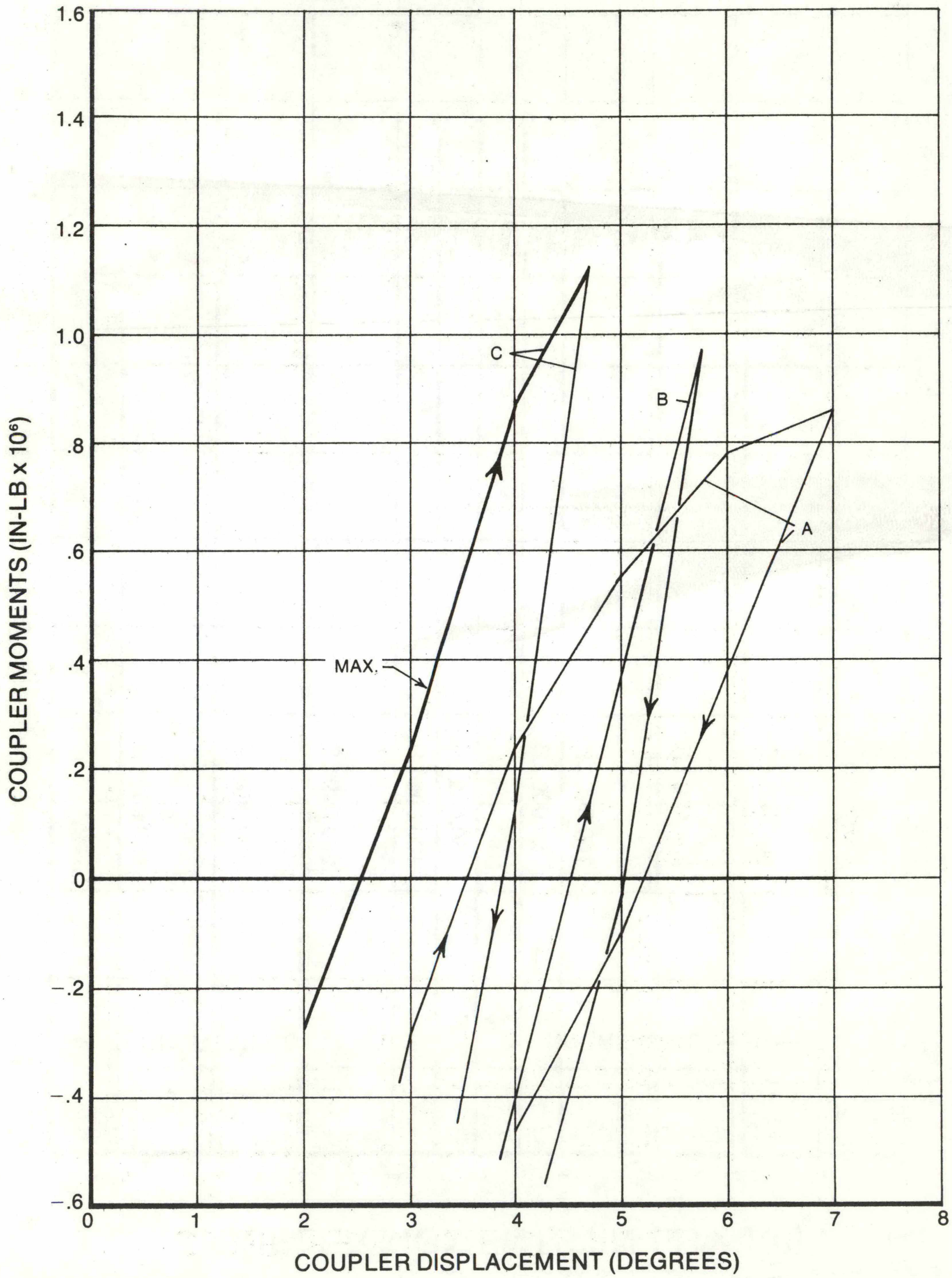
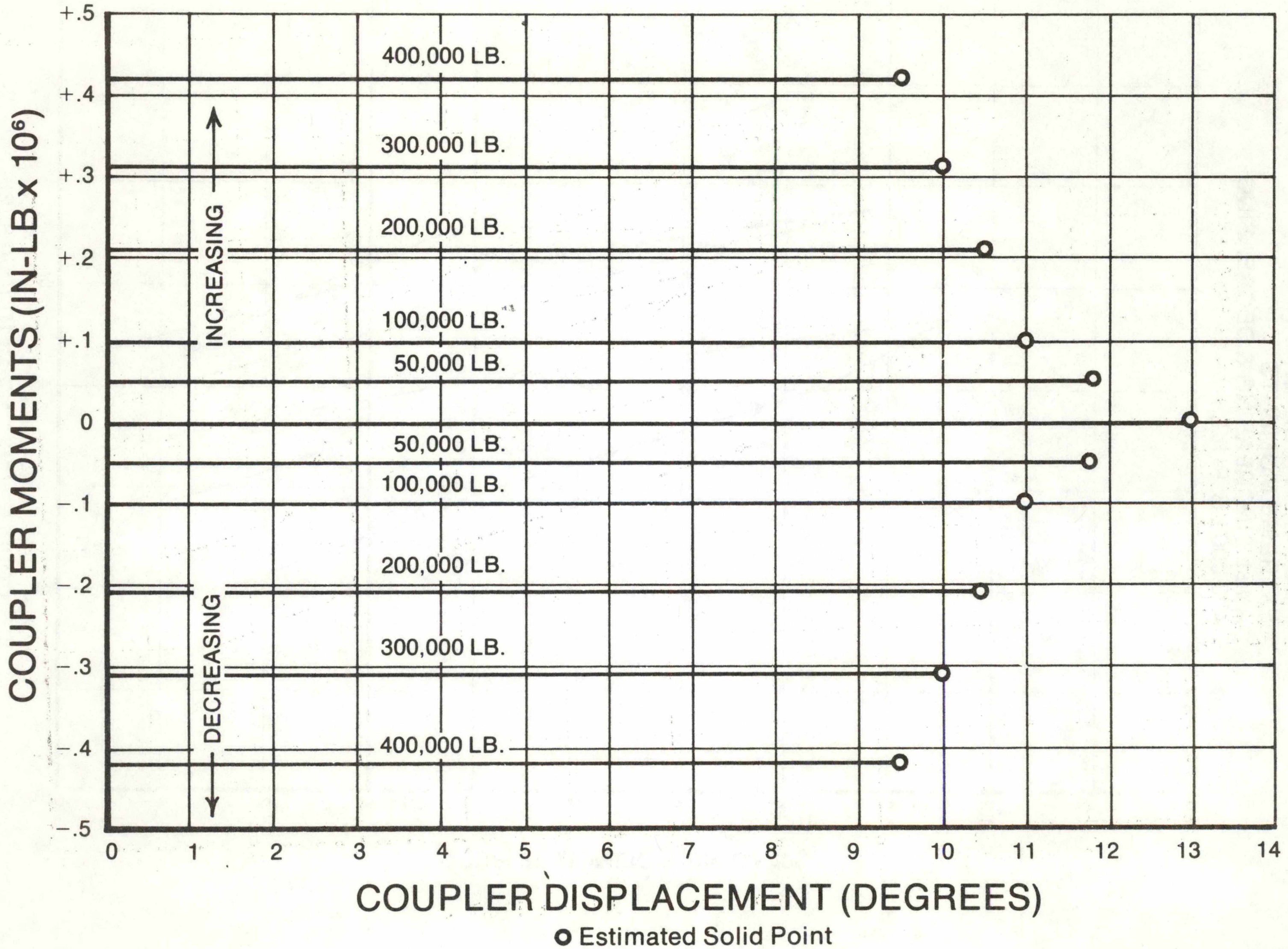


Figure 43

F COUPLER SHANK WITH SHOULDERS THEORETICAL MOMENTS ANGLE INCREASING AND DECREASING BUFF LOADS



APPENDIX A

Test Instrumentation

BUFF TEST

Fixture Angle (X) - The fixture angle with respect to the machine vertical was measured by suspending a pendulum from the fixture and measuring the lateral displacement. The length of the pendulum was adjusted to provide a one inch arc length equal to one degree.

Coupler Shank Angle (Y) - A scale was marked on the coupler shank and a fixed pointer mounted on the shank pivot fixture. The scale was positioned to provide an angle measurement to one degree equal to 0.2 inch of arc length.

Lateral Jacking Force (J) - Strain gages were mounted on the tension and compression surfaces of the bending element of the jacking yoke. The yoke was precalibrated with the strain gage output equated to the applied jacking force.

Vertical Jacking Force (K) - A strain gaged load cell was applied between the floor jack and the test fixture for the purpose of applying a restoring moment to the test fixture.

The forces were read using a signal conditioner, amplifier and displayed on a digital voltmeter. The force to be read was selected through a channel switch.

Since the test was conducted in increments of coupler shank to fixture angle, a method was devised to obtain the sum of the coupler shank angle relative to the vertical and the fixture angle relative to the vertical. This summation corresponds to the desired shank to fixture angle.

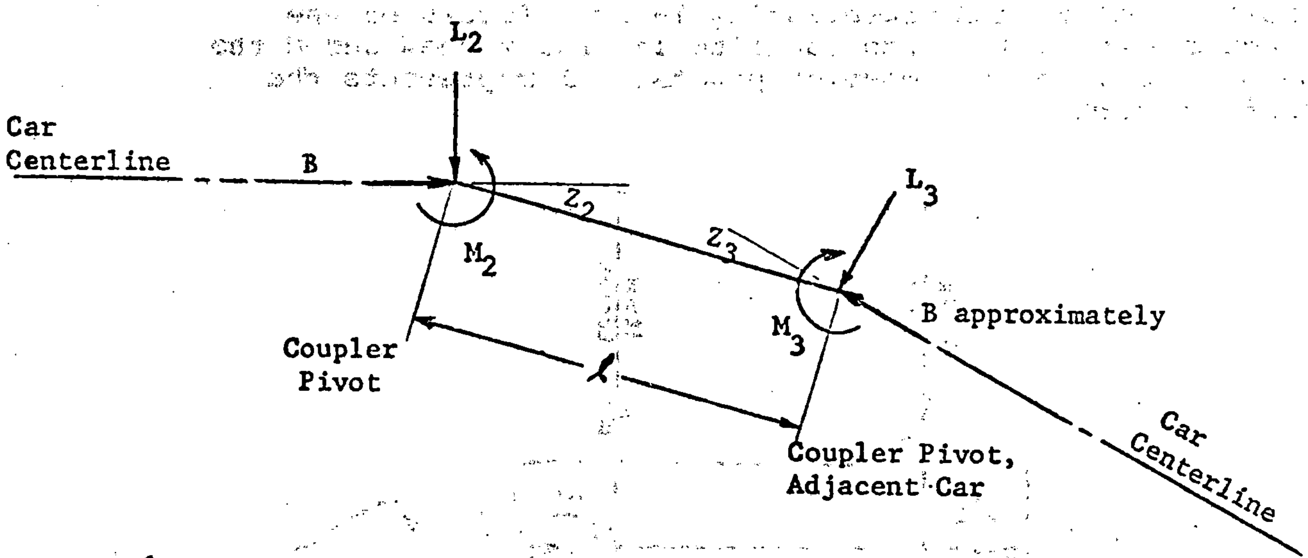
A strain gaged cantilever beam was attached between the test fixture's lower pivot center and the fixture body to read the fixture angle. Another cantilever beam was attached between the top pivot center of the coupler shank and the body of the coupler shank. These two angle measurements were calibrated in degrees and summed electrically and displayed to provide the increments of angular displacement. Since the fixture's pivot center moved slightly during the test due to the mechanical clearances inherent in the design, the angle summation figures were used only as a guide in selecting the increments. The tabulated angles were those obtained from the mechanical methods listed above.

PULL TEST

The addition of an extra fixture link in the pull test made it impractical to use the pendulum for measuring the

Assuming car dimensions and moments are known, these equations contain four unknowns, L_1, L_2, X_1 and X_2.

Consider a free body diagram of the couplers as shown below, with ℓ representing the distance between coupler pivots and Z representing coupler angles.



ℓ = Distance between coupler pivots
Z = Coupler angle

By summing up moments around coupler pivot #3 and letting them equal zero,

$$L_2 = B(\tan Z_2) + \frac{M_3 - M_2}{\ell(\cos Z_2)} \qquad (3)$$

Assuming all the coupler moments and dimensions are known, solve for L_2.

With similar analysis, solve for L_1.

With L_1 and L_2, solve for X_2 in formula No. (1) and determine X_1 with formula No. (2).

Characterization of Drawgear Systems During Coupler Angling, 03-Rail Vehicles and Components