ROD GUIDE THEORY, SPACING METHODOLOGY, AND FIELD APPLICATION

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Abstract

A major maintenance expense for rod pumped wells is sucker rod induced wear on the tubing string. In most cases this wear is due to 1) deviated wellbores, 2) rod buckling on the downstroke and/or, 3) tubing buckling on the upstroke due to unanchored tubing. In order to address these problems operators frequently rely on rules of thumb gained after years of trial and error experience.

This paper describes a systematic approach for predicting when rod/tubing wear is significant and offers recommendations to help reduce its detrimental effects. The deviated wellbore calculations are performed using a rod by rod force balance that considers deviation survey data. The rod buckling portion is based on static load tests of three rod sizes equipped with up to four guides per rod. The test results are compared to Euler's column buckling equations for different l/r (length/radius of gyration) ratios in an effort to determine a predictive equation. Tubing effects are considered using the methods proposed by Lubinski.

Field verification tests were performed since 1991 for several rod strings equipped with rod guides in different producing environments. Also, a computer design program was developed and used to deliver this technology to the field.

Introduction

In beam pumping wells the most expensive routine well servicing cost is the repair of tubing leaks. Many of the tubing leaks are "split" type due to sucker rod on tubing wear. Rod/tubing wear is becoming more serious as our fields mature and the water/oil ratios increase, which decreases the lubricity of the produced fluids and in turn allows greater rod/tubing wear.

The purpose of this paper is to present a systematic approach for predicting rod/tubing wear and offer recommendations to reduce its effects. Also, a computer program was developed that helped to transfer the technology to the field and combine the rod guide spacing calculations with other typical calculations used in sucker rod pumping system design. These additional calculations include the API-RP 11L design[1] method along with guidelines for rod guide material and geometry selection.

Background

In 1990 the Homer Nacatoch Sand Unit in NW Louisiana was composed of 64 sucker rod pumped wells with pump depths from 1000 ft to 1400 ft, daily production rates of up to 1800 BFPD/well, 98% water cut, and 35° - 37° API oil with water chlorides of approximately 3000 to 5000 ppm. In an effort to reduce well servicing costs, 1988-1989 records of the 21 highest failure rate wells were analyzed to determine if there was a pattern to the well failures. The results in Table 1 indicated that approximately 72% of the tubing failures and 37% of the rod parts occurred in the bottom one-half of the tubing string.[2] Since the majority of the tubing failures and a significant portion of the rod failures were in the bottom of the string, efforts were concentrated on determining what caused the failures in this area.

Visual inspections of the failures showed that the rods exhibited moderate to severe wear with some stress cracks. The majority of the tubing leaks were split type with a few instances of corrosion and thread leaks. The rod wear and split-type leaks indicated that rod/tubing wear was the major reason for the failures.

The next step was to determine what could cause the rods to contact the tubing and what could be done to reduce this wear. Possible causes of rod/tubing wear are:

- "Crooked" or deviated wellbores
- Tubing buckling
- Sucker rod buckling

Methods to reduce rod/tubing wear include:

- Installing rod guides in the crooked/deviated portion of the wellbore where coulomb friction is high. Also, rod guides are typically installed in areas where tubing buckling and/or rod buckling occurs. In these cases the rod guides are sacrificed rather than the rods or tubing.

- Similarly, installing plastic-lined tubing in the deviated portion of the wellbore and in areas where tubing buckling or rod buckling occurs can reduce the failure frequency due to rod/tubing wear. However, plastic-lined tubing is usually more expensive than rod guides and may reduce the size of insert pumps that can be run in a given tubing size. Also, since tubing must be pulled the job is more costly to install than just running rods with guides.

- Straightening the wellbore is an option to overcome the problems associated with producing deviated wells. However, the rig work required to straightening the wellbore is usually cost prohibitive and not practical. Also, this straightening job does not address problems associated with rod and tubing buckling that can even occur in vertical wells.

- Installing a tension type tubing anchor is a good solution to tubing buckling, but in many wells if the pump is set below the producing interval the anchor could get stuck due to produced solids.

- Running tail pipe below the pump is also an option to help keep the tubing in tension. Nevertheless, in many wells there's insufficient "rat hole" to allow enough tail pipe to be set below the pump to overcome the tubing buckling forces.

- Decreasing the load required to move the pump plunger on the downstroke can reduce rod buckling. This can be accomplished by increasing the barrel/plunger fit and/or changing the TV design.

- Installing sinker or weight bars can help keep the sucker rods in tension. However, the trade-off is that the added weight increases the lift energy costs and could overload the pumping unit.

- Reducing the pumping speed and/or stroke length to eliminate severe fluid pound can reduce rod buckling. This requires special attention to the system design so that full pump fillage is achieved with maximum fluid inflow.

Rod guides are a common denominator in reducing split-type tubing failures due to the above well conditions and could possibly be the most cost-effective method of controlling these failures. However, rod guides are not widely used to prevent rod/tubing wear at present, in part due to the past limitations of the guide materials, misapplications, and the lack of a standard design method that's used across the industry.

To effectively design a rod string equipped with rod guides and minimize rod/tubing wear, there needs to be some systematic method of determining the rod guide spacing and number of guides on each rod for a wide variety of wellbore conditions. This systematic method must be applicable even in cases where failure history data are lacking.

Design calculations exist in the industry that account for deviated wellbores[3] and tubing buckling.[4] Also, the manufacturers often consider the wear properties of the guide material along with guide geometry and volume of material that can be eroded. In addition, calculation methods are available that identify the rod string neutral point and offer recommendations for sinker bar design.[5] However, to date no calculations are available to recommend guide spacing to reduce the effects of rod buckling.

Current Trial and Error Practices

Current methods of determining rod guide spacing involve searching databases which have been compiled based on field inspection of rod/tubing wear and rod guide wear. For wells that are not currently equipped with rod guides, a database is searched for a previously equipped well operating under similar conditions of fluid production and gravity for both oil and water, well depth, stroke length, SPM, pump size, tubing size, rod size, etc.

The subject well is then equipped with the number of rod guides that has performed adequately in a well operating under similar conditions. If the failure frequency or rod guide wear is greater than predicted, then more guides are added the next time a failure occurs. This method is quite labor intensive and requires continuously updating the database. Furthermore, this trial and error approach could lead to recommending more guides than are necessary to insure success. Over time this approach could take several iterations and become costly because rod guides:

- cost money
- can increase the friction load (Note: The rod guides referred to in this paper are molded on plastic rod guides and not wheeled guides.)
- can increase the power requirements of the system due to increased friction
- can limit the SPM if the rods "float"
- can cause erosion of rods and tubing due to turbulence
- can wipe off corrosion inhibitors due to mechanical rubbing and turbulence

Overall a database is an excellent tool for analyzing well failure history data. However, databases in general are limited by the amount of information that populates the database and extrapolation can be questionable. To supplement the statistical results from a database analysis, it's always useful to understand the physics that governs the behavior of the system.

Determining Rod Guide Spacing Due to Rod Buckling

Sucker rod buckling in beam pumping conditions will be defined as "the compressive stress required to buckle a sucker rod sufficient for the rod and/or rod coupling to contact the ID of the tubing."

A common type of buckling is the buckling of columns. Euler developed a general equation[6] for column buckling which can predict the compressive load required to buckle a column.

Euler's General Equation

$$P = C(\pi^2 EI/L^2)$$

Where:

P = Compressive load required to buckle a column
C = A constant depending on column "end" conditions
E = Modulus of elasticity of the column material
I = Moment of inertia of the column
L = Length of column

Euler's Equation Applied to Sucker Rods

$$S = (KD/L)^2$$

Where:

S = Compressive stress in psi required to buckle the rod
L = Effective rod length in inches

K = Constant dependent on the column end conditions, modulus of elasticity of the rod material, $E = 30 \times 10^6$ psi for steel, and the moment of inertia of the rod

K = 2151 for "Free - Fixed" end conditions
K = 4302 for "Free - Free" end conditions
K = 8604 for "Fixed - Fixed" end conditions
D = Rod diameter in inches

When a sucker rod is equipped with rod guides all of the variables can be determined except the "end" conditions.

Experimental Tests

A two rod length section of 3/4", 7/8", and 1" grade "D" rods was tested in a vertical section of 2-7/8" tubing to determine:

- if Euler's equations could be applied to sucker rods
- what end conditions are applicable
- the effect of rod guide spacing along the rod

The number of plastic rod guides for each sucker rod varied from one to four using two spacing configurations:

- symmetrically along the rod (Figure 4)
- asymmetrically along the rod with the first guide 16" from one end (Figure 5)

A load was applied to the top of the rods using a 1.25 inch diameter hydraulic cylinder equipped with a pressure gauge. This load plus the weight of the rods was then divided by the cross section of the sucker rod to determine the maximum compressive stress on the rod. Rod/tubing contact due to rod buckling, was determined using an ohmmeter connected between the rods and tubing as illustrated in Figures 4 and 5.

Static Test Results

The test results in Table 2 were compared to Euler's equations for three different types of end conditions. The results are shown graphically in Figures 1, 2, and 3. With two exceptions, the tests indicated that the asymmetrical guide configuration allowed higher compressive stresses before rod buckling occurred than did the symmetrical configuration.

As can be seen in Figures 1 - 3, the test results for the rods closely approximated Euler's values for the Free-Free end conditions. Also, the asymmetrical guide placement provided the better fit of Euler's values for Free-Free end conditions than did the symmetrical guide placement. This implies that the compressive stresses required to buckle sucker rods can be closely predicted using Euler's equation for Free-Free end conditions.

These tests point out that the rod immediately above the pump is more susceptible to buckling than the other rods in the string due to its end condition being Fixed-Free, which can withstand the least amount of compressive stress before buckling. The unknown in applying these equations to beam pumping conditions is whether or not sucker rods in a dynamic pumping system react similar to the rods in this static test setup. However, it is the only method at present that is capable of predicting rod buckling. Further field tests and failure investigation will determine how accurate this method is under dynamic conditions.

Field Tests

Shallow Vertical Well Applications

In 1991 twelve wells in the Homer Field, with the highest tubing leak frequency in 1990, were selected for testing the cost-effectiveness of using rod guides to reduce split type tubing leaks due to rod/tubing wear. Rod guide spacing was based on the static sucker rod tests performed in 1990, and the number of rods with guides was based on the rod string and tubing string neutral points. The rod string neutral point was determined from analysis of dynamometer cards. Rod guide material, Ryton, was selected on the basis of recommendations from rod guide manufacturers.

Well servicing costs in 1990 for the twelve test wells was $13.75 per day. After rod guide installation in 1991, the well servicing costs were $7.01 per day. Rod guide costs for the test wells averaged $667 per well. Rod guide payout based on guide costs alone was 99 days.

One well, 24-A-37 (11 BOPD, 1120 BWPD, 37° API oil), was equipped with a full string of rods equipped with guides molded of three different types of rod guide material which were placed in random order along the rods. Measurements of the guides after 102 days of service showed that Amodel with 30% fiberglass lost 0.27 inches in diameter (12%), Ryton lost 0.36 inches (16%), and Amodel with Kevlar lost 0.48 inches (21%).

Tests on these twelve wells confirm that Ryton is not as cost-effective as 33% fiberglass reinforced nylon which had been in well 19-3-28 (10 BOPD, 1030 BWPD, 37° API oil) for over 20 months and experienced only 18% loss in diameter. However, nylon is not recommended for use in water with moderate to high chlorides.

Based on the initial field trials, the ALC (Artificial Lift Consultant) program (Figure 6) was written to design rod guided strings in both "vertical" and directionally drilled wells.

Deviated Well Applications

In the Bakersfield area[7] the ALC program has been used to design rod strings with guides in deviated wells. Well 58X Sec. 8Z (TD 8060 ft, 92 BOPD, 165 BWPD, 250 Mcf/D) experienced seven non-pump related failures in twenty-eight months prior to installing rod guides. Well servicing costs alone were $56,000. In the twenty-nine months since the rod guides were installed, there have been no rod or tubing failures.

Well 87X Sec. 8Z (TD 8366 ft, 17 BOPD, 43 BWPD, 110 Mcf/D) experienced 15 failures between January 1991 and August 1995. Rod guides were installed in August and a scale program was initiated in December 1995. Two additional rod failures occurred between November 1995 and May 1996.

Between January 1991 and May 1996 the worn tubing, rod, and couplings replacement costs averaged $4300 per year. Additional rod guides using PPS material and a POC were installed in May 1996. Between May 1996 and December 1997 there has been one pump failure and only two joints of tubing have been replaced. Prior to running guides the average well servicing cost alone was approximately $25,000 per year. After running the initial guides and initiating a scale treatment the cost has been reduced to $12,500 per year. Since the rod guided portion was redesigned and a POC installed, the well servicing costs have averaged $5,000 per year and equipment replacement costs have been less than $100 per year.

Computer Applications

Application Development

To transfer the rod guide spacing technology to a wide range of users, and to verify the predictions for a wide range of conditions, a computer application was developed. This application was built entirely using a common spreadsheet program that could be programmed using macros written in BASIC. By choosing this environment, the time spent building a user interface was minimized. In addition, since most of the users were already proficient with using this spreadsheet environment, the learning curve was low. Also, since the development environment was a standard spreadsheet, the end users had the flexibility of customizing the graphics and adding specific calculations that used any piece of data in the application.

User help documentation could be typed in directly on the worksheet or imbedded in notes attached to individual cells. Since the typical spreadsheet gives you a lot of room to work with it was even possible to add some lengthy help messages and likewise the individual users could edit or add in their own help messages. Output summary reports can be generated and stored as ASCII text files. Similarly, deviation survey data stored in ASCII can be read directly into the application.

So far the maintenance costs for this type of application have been very low and have experienced no compatibility problems when either the spreadsheet or operating system were upgraded. Also, giving the end users the ability customize the application has not lead to a wild proliferation of different unmaintainable versions. In fact, most of the changes made by end users were small and could easily be copied and pasted into future versions for general release.

Application Capabilities

The capabilities built into the application were more comprehensive than just the spacing of rod guides due to rod buckling. To increase the utility of this application, it was also necessary to perform some basic sucker rod design calculations, as well as, consider the characteristics of the rod guide material and geometry. These additional capabilities include the following:

- API-RP11L design sensitivity analysis to help you select the optimum equipment configuration that will help maximize production and minimize energy usage and equipment loading. After all, if you can design a system that will operate with a full pump and deliver maximum production, you will reduce the chances that your system will pound fluid. While the API-RP11L does not account for added friction due to rod guides, it can be extremely useful to make quick ballpark estimates and sensitivity studies. Later, more rigorous design programs can be used if you need to fine tune the result.

- Rod guide spacing requirement due to wellbore deviations. This calculation performs a rod by rod force balance calculation based on a maximum polished load that can either be estimated from a design program or obtained from measured field data. A wellbore deviation survey is required for this type of calculation.

- Rod guide spacing due to tubing buckling is calculated by using the method suggested by Lubinski.[3] This calculation is performed in wells where the tubing is unanchored or in cases where some of the tubing is below the anchor.

- Rod guide spacing due to rod buckling is calculated using the method proposed in this paper.

- Final rod guide recommendations combine requirements due to wellbore deviations along with tubing and rod buckling.

- Rod guide geometry and materials selection worksheet are also included that contains many of the important physical properties of the rod guides. This worksheet shows you a list of all possible rod guides that can be used for a given well. Also, reasons for not recommending a particular guide are given. Additional information is given about book value costs along with relative wear, abrasiveness, and load tolerance. By providing this information the users can make a decision to see if the increased wear characteristic of the guide justifies the use of a higher cost material.

References

1. "Design Calculations for Sucker Rod Pumping Systems," API Bulletin 11L, third edition, Washington, DC (1977).

2. Shellenberger, F.A. and Long J.D.: "Rod and Tubing Failures in the Homer Nacatoch Sand Unit," unpublished paper (1990).

3. Gibbs, S.G.: "Design and Diagnosis of Deviated Rod-Pumped Wells," *JPT* (July 1992).

4. Lubinski, A. and Blenkarn, K.A.: "Buckling of Tubing in Pumping Wells, Its Effects and Means for Controlling It," *Trans.* AIME, 210, 73-88 (1957).

5. Lea, J.F. and Patillo, P.D.: "Interpretation of Calculated Forces on Sucker Rods," Production Operations Symposium of SPE, Oklahoma City (March 21 - 23, 1993).

6. Timoshenko, S.: "Elements of Strengths of Materials," third edition, D. Van Nostrand Co. Princeton, NJ, pgs. 288-297.

7. Curtis, D.: "Field Results of Rod Guide String Design Using the Artificial Lift Consultant Program," Presented at Chevron Artificial Lift Forum, Sept. 23, 1997, Sheraton Crown, Houston, TX.

Table 1
HO-NAC-SU

1988-1989 Well Failures

	1988 - 1989				1988 -1989			
	No. of Tbg. Leaks per Tbg. String Quarter				No. of Rod Parts per Rod String Quarter			
WELL	Top 1/4	1/4 - 1/2	1/2 -3/4	Btm 1/4	Top 1/4	1/4 - 1/2	1/2 - 3/4	Btm 1/4
19-3-28	0	1	4	4	9	3	4	2
20-3-29	0	3	6	5	1	4	2	4
17-1-16	0	2	3	3	11	3	0	3
19-1-21	0	0	2	5	3	2	4	2
19-1-24	2	0	4	1	5	3	0	3
19-1-25	1	5	1	6	2	0	2	1
19-2-23	2	4	5	6	2	0	0	1
24-A-37	2	3	4	3	1	1	1	2
18-8-1	0	0	5	4	5	0	0	0
20-2-31	0	1	1	2	3	2	5	0
17-1-4	0	2	3	2	2	1	2	2
19-3-7	1	0	0	0	9	2	0	1
19-5-2	2	1	1	1	7	0	0	1
20-3-18	0	1	0	0	4	2	4	1
24-A-3	1	0	0	8	2	0	0	0
17-2-2	0	0	2	1	3	3	2	3
24-A-11	1	3	3	4	0	0	0	0
17-2-4	0	0	0	1	2	1	4	2
24-A-42	0	1	2	1	2	3	0	0
17-1-9	0	0	0	0	3	0	4	3
18-7-2	0	1	0	2	3	4	1	1
TOTAL	12	28	46	59	79	34	35	32
%	8	19	32	41	44	19	19	18
%	28		72		63		37	

Table 2
Euler's Long Column Equation Values and Static Test Compressive Stresses Required to Achieve Contact Between Sucker Rod Body and/or Rod Coupling in 2-7/8" Tubing

				Euler's Values			Test Values	
D	N	L	L/r	Fixed-Free	Free-Free	Fixed-Fixed	Symmetrical	Asymmetrical
0.75	4	75	400	463	1851	7403	2053	1920
0.75	3	100	533	260	1041	4164	976	1156
0.75	2	150	800	116	463	1851	352	506
0.75	1	300	1600	29	116	463	185	196
0.875	4	75	343	630	2519	10076	2156	2461
0.875	3	100	457	354	1417	5668	889	1527
0.875	2	150	686	157	630	2519	343	823
0.875	1	300	1371	39	157	630	180	295
1	4	75	300	823	3290	13161		3122
1	3	100	400	463	1851	7403	1731	1673
1	2	150	600	206	823	3290	183	860
1	1	300	1200	51	206	823		299

Where D = rod diameter in inches, N = number of guides per rod, L = effective column length or distance between guides, inches and L/r = effective column length or distance between guides divided by the rod's radius of gyration, for round sections = D/4

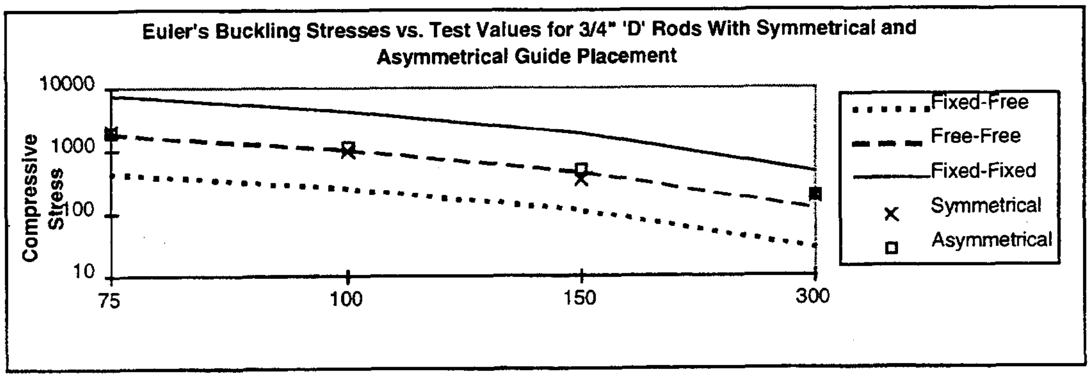

Figure 1 - L, Distance Between Guides, in.

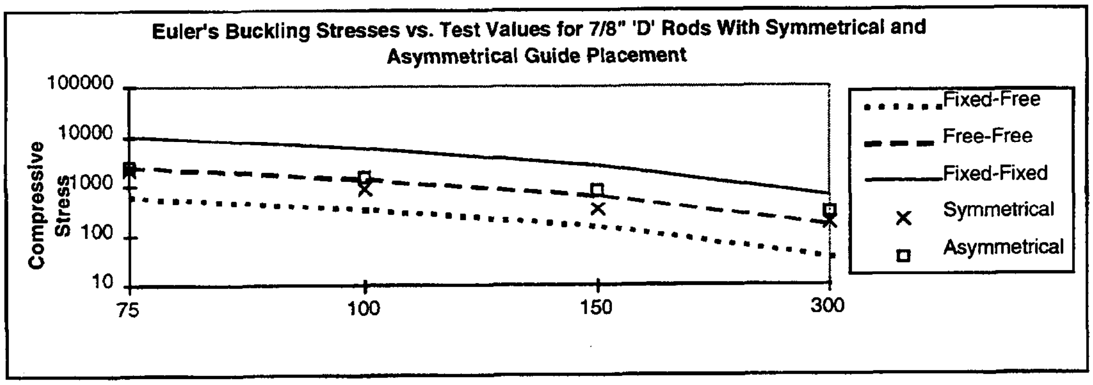

Figure 2 - L, Distance Between Guides, in.

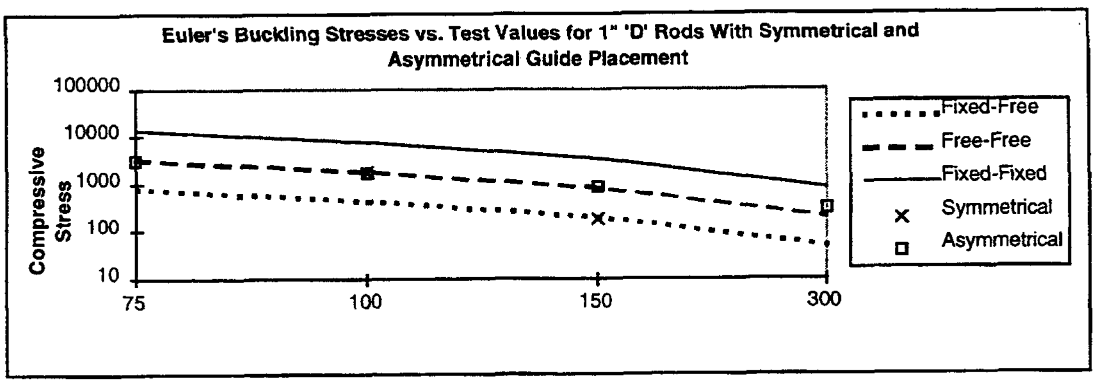

Figure 3 - L, Distance Between Guides, in.

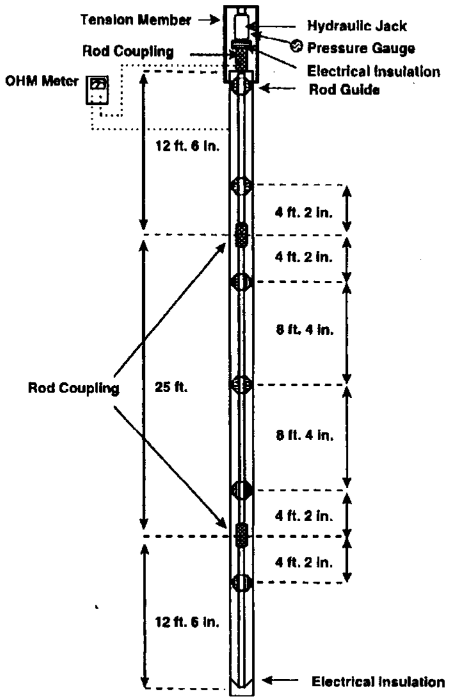

Figure 4 - Test Apparatus for Sucker Rod Buckling, Three Rod Guides per Rod Symmetrical Configuration.

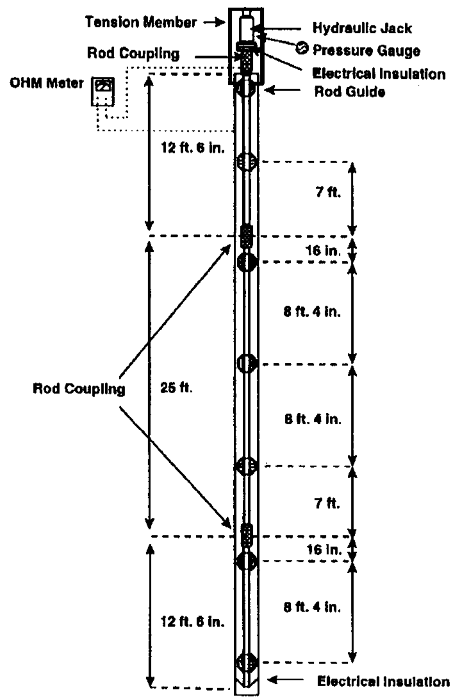

Figure 5 - Test Apparatus for Sucker Rod Buckling, Three Rod Guides per Rod Asymmetrical Configuration.

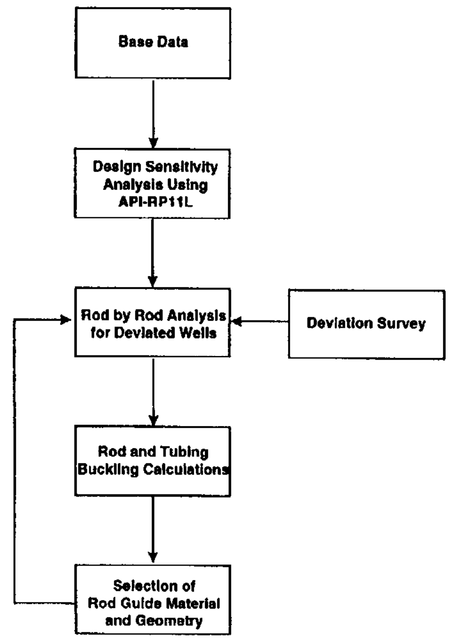

Figure 6 - Flow Chart for ALC (Artificial Lift Consulting) Program.