SOCIETY OF PETROLEUM ENGINEERS OF AIME
6200 North Central Expressway
Dallas, Texas 75206

PAPER NUMBER SPE 2656

THIS IS A PREPRINT --- SUBJECT TO CORRECTION

Field Application and Results of Pipe Tripping Nomographs

By

Donald A. Bazer and Harry B. Owens, Jr., Members AIME, Amerada Hess Corp.

This paper was prepared for the 44th Annual Fall Meeting of the Society of Petroleum Engineers of AIME, to be held in Denver, Colo., Sept. 28-Oct. 1, 1969. Permission to copy is restricted to an abstract of not more than 300 words. Illustrations may not be copied. The abstract should contain conspicuous acknowledgment of where and by whom the paper is presented. Publication elsewhere after publication in the JOURNAL OF PETROLEUM TECHNOLOGY or the SOCIETY OF PETROLEUM ENGINEERS JOURNAL is usually granted upon request to the Editor of the appropriate journal provided agreement to give proper credit is made.

Discussion of this paper is invited. Three copies of any discussion should be sent to the Society of Petroleum Engineers office. Such discussion may be presented at the above meeting and, with the paper, may be considered for publication in one of the two SPE magazines.

ABSTRACT

Operational problems associated with tripping drill pipe or running casing become more severe and complicated as drilled holes get deeper and smaller. To reduce the many calculations required, primarily by the men on the rigs, nomographs were developed for solving annular, hole and pipe capacities and displacement volumes. A set of simplified nomographs were also developed, from previously published formulas, which can be used to estimate swab or surge pressures generated when annulus displacement mud flow is laminar. Examples of the use and accuracy of the nomographs are presented. The field results of using these nomographs are mostly in the form of trouble free pipe trips, but some interesting and informative field results are presented.

INTRODUCTION

The swab and surge pressures generated while tripping pipe, become more critical as wells are drilled deeper and holes get smaller. If abnormal formation pore pressures are encountered which approach the formation fracture pressures, the problem becomes even more critical.

References and illustrations at end of paper.

Induced swab or surge pressures while tripping out or into a hole cannot be eliminated but can be reduced to safe values. The most critical conditions exist when the mud hydrostatic pressure is very close to either the formation pore or fracture pressure.

Several methods for predicting swab and surge pressures while tripping pipe have been published.[1,2,3] The mathematical methods, which have been proven to the most accurate by actual test, were found to be too involved and laborious for use by field personnel. The graphical methods found in the literature did not cover all ranges of mud properties and pipe-hole size combinations, and therefore were deemed inadequate for field use. Using the proven mathematical methods developed by J. A. Burkhardt[3], nomographs were developed and are included in this paper. The nomographs have been in use for approximately one and one-half years and have proven to be reliable. Also included are nomographs for displacement volumes of drill pipe and collars, and annular or hole capacities developed as additional aids for the man on the rig to use in conjunction with tripping pipe.

The three factors which control pipe tripping swab or surge pressures in any given pipe-hole size combination are pipe velocity, mud yield point and mud plastic viscosity. The reduction of any one of these factors will reduce the swab or surge pressures.

THEORY

One of the main points of agreement between the previously noted studies and tests of well bore pressure surges due to pipe motion has been that the maximum surge or swab is usually due to viscous drag of the flowing mud. Hence, the maximum surge would be at the time of greatest mud velocity, which would be at the time of greatest pipe velocity. J. A. Burkhardt proved that with the displacement and flow in the laminar state, the pressure surge can be described by the formula:

$$P_s = \beta\, B\, \overline{PV}\, V_p + \overline{YP}/.3\,(D_h - D_e). \quad . \quad . \quad . \quad (1)$$

Where: P_s = Pressure surge, psi/1000 ft of pipe

$\overline{PV}$ = Plastic Viscosity of the mud, cp

$\overline{YP}$ = Yield point of the mud, psi/100 ft^2

V_p = Velocity of the pipe, ft/min

$D_h - D_e$ = Effective annular clearance, in.

β = Laminar flow opening coefficient, empirical

B = Laminar flow geometry coefficient, empirical

Note that the second term of the equation is independent of pipe velocity; therefore, if the pipe is in motion, this component of the surge will be constant. This term of Eq. 1 has been designated as $P_s\overline{yp}$ and is solved in nomograph form on Fig. 2. The value of D_h-D_e is obtained from Fig. 1.

The first term of Eq. 1 has been designated as $P_s\overline{pv}$ and is solved by either Fig. 3, 4, or 5. The velocity of the pipe in ft/min has been converted to the more convenient form of seconds of running time, from slips to slips, corrected for acceleration and deceleration. The value of β and B as presented by Burkhardt, were used for each hole and pipe size shown. Fig. 3 can be used for estimating $P_s\overline{pv}$ when pulling or running drill pipe and drill collars in 90 ft stands, with an open bit. Fig. 4 can be used when liners are being run on drill pipe in 90 ft stands. This chart assumes closed pipe, which is usually the case by the time most fill up devices approach bottom. Fig. 5 is for use when running casing in 41 ft joints. This chart is also for closed pipe.

When the displacement mud flow is in the turbulent state, the pressure surge can be calculated by Burkhardt's turbulent formula:

$$P_s = \alpha\, A\, PV^{.21}\, \rho^{.806}\, V_p^{1.8} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Where: α = Turbulent flow opening coefficient, empirical

A = Turbulent flow geometry coefficient, empirical

ρ = Mud wt., pounds per gallon

The upper limit of accuracy of the charts has been reached when the surge calculated by the turbulent formula is equal to or greater than that calculated by the laminar formula. This upper limit of accuracy has been calculated for Figs. 3, 4, and 5 for each pipe and hole size combination presented for three typical sets of mud properties as follows:

1. 10 ppg mud, 20 cp plastic viscosity, 5 psi/100 ft^2 yield point. The upper limit of accuracy for this mud is indicated by a marker to the left of the annulus line pointing southwest.

2. 14 ppg mud, 28 cp plastic viscosity, 10 psi/100 ft^2 yield point. The upper limit of accuracy for this mud is indicated by a marker to the right of the annulus line pointing northeast.

3. 18 ppg mud, 48 cp plastic viscosity, 10 psi/100 ft^2 yield point. The upper limit of accuracy for this mud is indicated by a "T" crossing the end of the annulus line.

In order to keep the surge pressure low, especially in deep small holes it is necessary to reduce pipe speed to where displacement flow is laminar; therefore, it is felt that the laminar flow charts will apply in most cases.

The fill-up chart, Fig. 6, was constructed by using geometry and hydrostatic calculations. The pump strokes required to fill up are calculated using average pump rod sizes and 90% volumetric efficiency.

The annular capacity nomograph, Fig. 7, is constructed by geometry alone.

TRIPPING PIPE OUT OF HOLE

To determine the safe speed at which pipe can be pulled from a hole, the maximum formation pore pressure in the open hole must be known. In many cases, accurate estimates of formation pore pressures can be established from offset wells. In rank wildcat wells, formation pore pressures can be estimated with fair accuracy from information collected and recorded by one of the modern mud logging units. In either case, a graph of anticipated formation pore and fracture pressures, such as Fig. 8, should be made, and updated while drilling if need be. The hydrostatic pressure of the annulus mud column minus the swab pressure and the pressure loss due to the reduction of the mud column by pipe removal must not be allowed to fall below the maximum pore pressure in the open hole.

The loss in hydrostatic head due to loss of displacement volume can be determined from the fill-up chart, Fig. 6. This chart also gives the number of pump strokes required to fill up for any given number of stands of pipe pulled.

The loss in hydrostatic head due to swab action at any pulling speed can be determined from the swab and surge nomographs.

If the remaining hydrostatic head after pulling the maximum number of stands between fill-up, usually 5 to 10 stands, at a given speed is less than the maximum pore pressure, then the pipe must be pulled more slowly. By this trial and error method, and by working backwards through the charts, a pulling speed schedule such as Fig. 9 can be worked up for each section of the hole. This schedule will give the maximum safe pulling speed for each joint.

TRIPPING INTO HOLE WITH DRILL STRING OR CASING

The limiting factor for maximum pipe speed when tripping into the hole is the lowest formation fracture pressure in the open hole. This will normally be just below the casing shoe, but in some abnormally pressured areas, it has been found to be in zones of pressure regression. The maximum surge pressure which can be tolerated is equal to the difference between formation fracture pressure and the hydrostatic mud pressure minus a safety factor based on experience in the area. A pipe running speed schedule, Fig. 10, can be constructed and in many cases will be found to be very close to the pulling speed schedule.

FIELD RESULTS

The measured surge pressure data, published by L. E. Wilson,[4] was solved using the nomographs with excellent results. In his test, 11,000 ft of 4-1/2 in. drill pipe and 450 ft of 6 in. drill collars were lowered inside of 9-5/8 in. casing at 225 ft per minute. The plastic viscosity of the mud was 50 cp and the yield point 26 psi/100 ft^2. The actual measured surge pressure was 443 psi while the surge pressure from the nomographs was found to be 448 psi. The velocity of 225 ft per minute was converted to 43 sec per stand, slips to slips.

Recently in South Louisiana, while running a string of 9-5/8 in. casing, returns were lost when the pipe was at a depth of 6,700 ft with the running speed reported at 30 sec per 41 ft joint. The hole size was 12-1/4 in. The mud properties were, weight 12.8 ppg, yield point 8 psi/100 ft^2 and plastic viscosity 30 cp. A string of 13-3/8 in. 68 lb casing had been set at 4,144 ft and the formation just below the casing was tested with pressure equivalent to a 13.5 ppg mud gradient. From the nomographs, the surge pressure was found to be equivalent to a mud gradient of 0.87 ppg. This surge plus the 12.8 ppg mud gradient exceeded the surface pipe shoe test by 0.17 ppg. In addition, it appeared from the charts that the annular mud flow was turbulent. Calculations were run, and the flow was indeed turbulent, thus the actual surge was higher than that estimated above. The running speed of the pipe was slowed to 60 sec per joint putting the mud in laminar flow and full returns were regained. The casing was lowered to bottom with no further difficulties.

On the same well after subsequent drilling, the drill string pulling speed off bottom was 90 sec per stand. The average mud properties at the time were, weight 17.8 ppg, yield point 10 psi/100 ft^2 and plastic viscosity 48 cp. The bottom-hole pressure was estimated to be 15,300 psi or equivalent to a 17.4 ppg mud gradient. The swab pressure, as estimated from the nomographs, was 436 psi which is equivalent to a 0.48 ppg mud gradient. It is obvious that a balanced or slightly under balanced condition existed. This was confirmed by the considerable volume of so-called trip gas and gas-cut mud when bottoms were circulated up after each trip. After quite a lengthy battle with some contaminated oil-base mud which was replaced by water-base mud, a trip out was started at the same speed as previously used, 90 sec per stand. The only difference in the mud properties was that the yield point had increased from 10 to 14 psi/100 ft^2. After pulling six stands, the hole started swabbing.

The swab pressure with the increased yield point, from the nomographs, was found to be 500 psi which is equivalent to a mud gradient of 0.54 ppg. The well should have swabbed in. The pipe was tripped back to bottom and the mud circulated out and conditioned for five hours. Hindsight tells us that if the pulling speed had been calculated and decreased off bottom to 105 seconds per stand, the pipe could have been tripped out safely.

The above mentioned three examples are the only results where actual problems have been solved with the nomographs, and reliably checked. The nomographs have been used extensively in many other applications for determining drill pipe and casing string tripping speed with apparent excellent results, since no problems were encountered in these instances.

CONCLUSIONS

1. The nomographs, constructed from a proven laminar flow formula, are reliable for predicting swab and surge pressures while tripping for a wide range of mud conditions and pipe-hole size combinations.

2. The nomographs are simple and convenient enough to be used by both technical and non-technical personnel.

3. Use of the nomographs has helped to familiarize the engineers, drilling personnel and tool pushers with the relationship between surge and swab pressures, pipe-hole sizes, pipe speed, and mud properties.

4. Most kicks, cut mud, and lost circulation can be eliminated while tripping pipe if trip speeds are calculated.

REFERENCES

1. Goins, W. C., Jr., Weicher, J. P., Burba, J. L., Jr., Dawson, D. D., Jr., and Teplitz, A. J.: "Down The Hole Pressure Surges and Their Effect on Loss of Circulation", API Drilling and Production Practice (1951) P. 125.

2. Clark, E. H., Jr.: "Bottom-Hole Pressure Surges While Running Pipe", ASME No. 54-Pet.-22 presented at the Petroleum Mechanical Engineering Conference, Los Angeles (September, 1954).

3. Burkhardt, J. A.: "Wellbore Pressure Surges Produced by Pipe Movement", AIME Transactions, 222, (1961) P. 595.

4. Wilson, L. E.: "Results of a Field Test on Circulating and Surge Pressures", World Oil (September, 1962).

APPENDIX: USE OF THE CHARTS

Example Problem One

Determine the maximum safe pulling speed off bottom in a 17,000 ft well with an equivalent pore pressure of 17 ppg. The mud weight in the hole is 17.5 ppg, the plastic viscosity is 40 cp and the yield point is 10 psi/100 ft^2 9-5/8 in. casing is set to 13,000 ft with an 8-1/2 in. hole to total depth. There are 500 ft of 6 in. drill collars below 4-1/2 in., 16.60 lb drill pipe. The hole is to be filled every 10 stands.

First enter the fill-up chart, Fig. 6, at 10 stands. Go vertically upwards to the 4-1/2 in., 16.60 lb drill pipe line. Go horizontally to the right to the pivot line, thence down vertically to the 9-5/8 in. casing line. From this point go horizontally to the right and read the annulus mud drop of 80 ft. Continue to the right to the 17.5 ppg mud weight line thence downward to read a 72 psi loss in hydrostatic head.

Continuing to the right at the pivot line would have shown the fill-up displacement to be 250 gallons. Starting at the 250 gal point on the proper pump stroke length line, in this case use 18 in., go horizontally to the right to the 5-1/2 in. pump liner size, thence downward vertically to read 42 strokes to fill the hole.

Enter Fig. 1 at the 8-1/2 in. hole size on the abscissa and find D_h-D_e for 4-1/2 in. drill pipe to be 3.3 in. and for 6 in. collars to be 2.2 in. For all practical purposes we can assume an 8-1/2 in. hole to the surface, as that will be very close to the ID of the 9-5/8 in. casing, and any error will be in the nature of a safety factor.

Next enter Fig. 2 with the two above values of D_h-D_e and find the $P_s$yp for the drill pipe to be 10 psi/1000 ft, and for the collars 15 psi/1000. With 16,500 ft of drill pipe in the hole and 500 ft of collars, the total surge independent of pipe velocity is:

10 x 16.5 + 15 x .5 = 165 + 7.5 = 172.5 psi

The estimated BHP is:
17 x .052 x 17000 = 15,028 psi

The estimated available hydrostatic pressure is:
17.5 x .052 x 17000 - 173 - 72 = 15470 - 173 - 73 = 15,225 psi

The maximum allowable surge from pipe velocity is:
15,225 - 15,028 = 197 psi

Estimate 185 psi from 16,500 ft of 4-1/2 in. drill pipe, or 11.2 psi/1000 ft. Enter Fig. 3 with 11.2 psi/1000 ft, go down vertically to 4-1/2 in. drill pipe x 9-5/8 in. casing annulus line, thence horizontally to the left to the 40 cp PV line, then vertically downward to read 40 sec/stand. Re-enter the chart, Fig.3, at 40 sec/stand, go up to 40 cp PV line, over to the 6 in. drill collar x 8-1/2 in. hole annulus line, and thence upward to read 26.6 psi/1000 ft. For 500 ft of collars, this would be 13 psi. Since 12 psi was estimated for the collars, theoretically, the hydrostatic head of the mud would be 1 psi light while pulling up at 40 sec/stand. Allowing a small safety factor, 45 sec/stand would be a good speed with which to start off bottom.

Example Problem Two

Find the volume of cement required to fill the annulus between 850 ft of 8 in. casing in a 14-1/2 in. hole.

On the annular and hole capacity nomograph, Fig. 7, line up 14-1/2 in. on column A with 8 in. on column B to find point C, which is the volume/linear ft of annulus. Then line up point C with 850 ft at point D. Read the answer of 121 bbl or 680 cu ft on column D. Had the hole been 8500 ft deep then the volume would be multiplied by 10, giving 1210 bbl or 6800 cu ft.

To find the volume in an open hole or pipe capacity, point A will be the ID in question, and point B will be at zero.

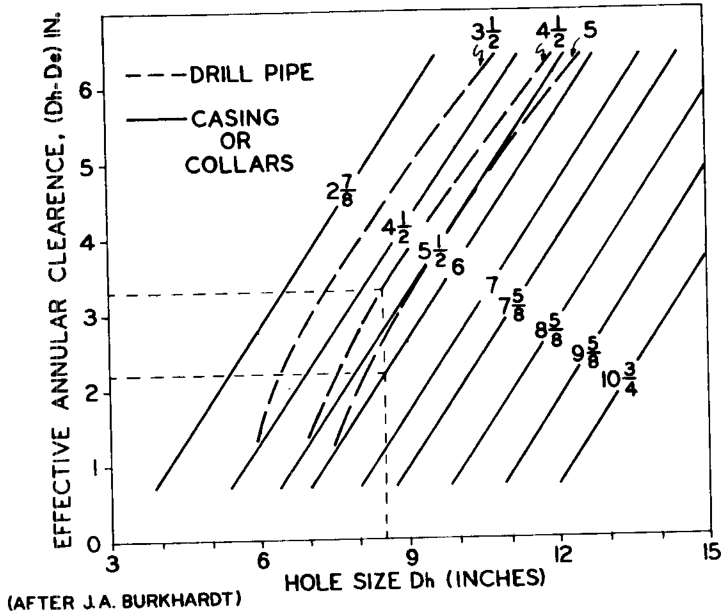

Fig. 1 - Effective annular clearance.

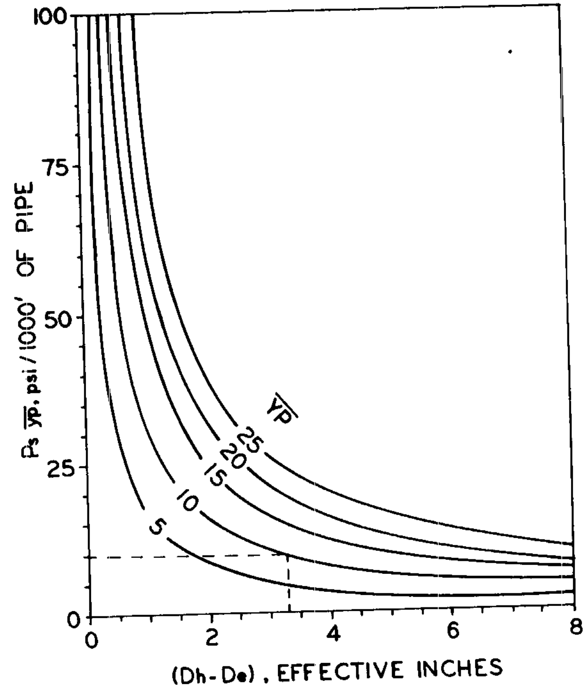

Fig. 2 - Surge independent of pipe velocity.

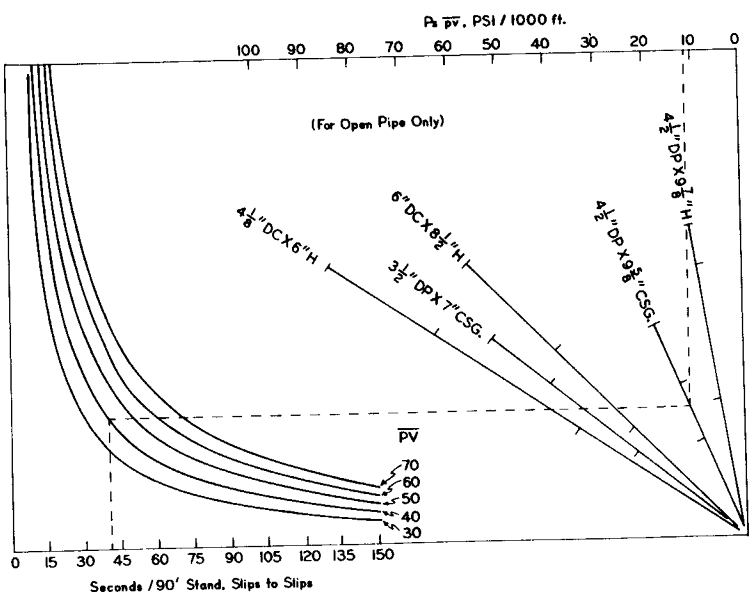

Fig. 3 - Running speed for drill pipe and collars.

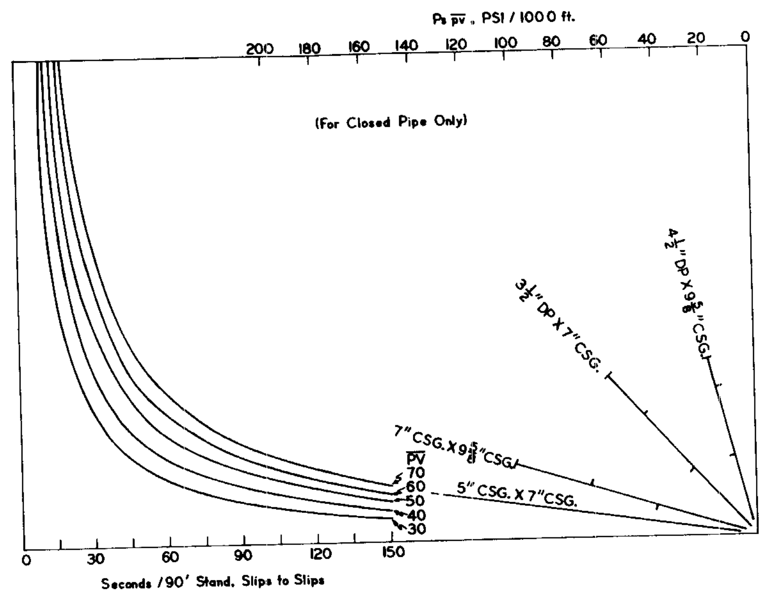

Fig. 4 - Running speed for liners.

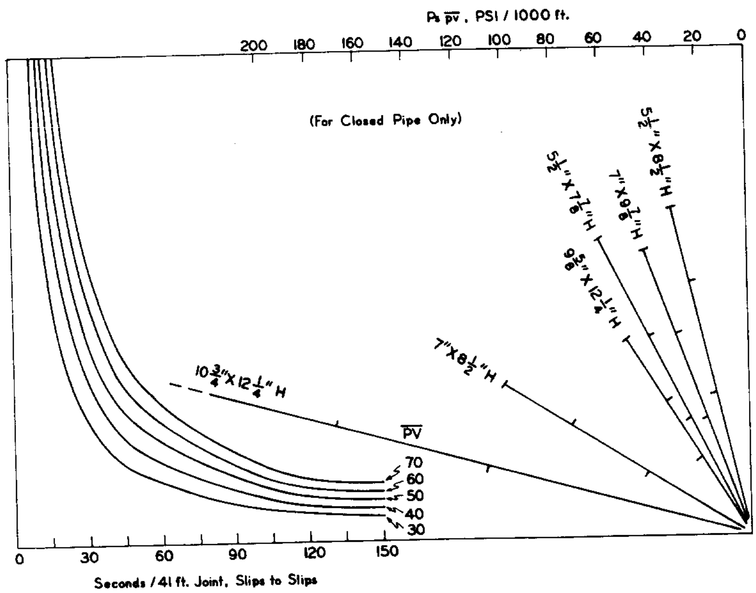

Fig. 5 - Running speed for casing.

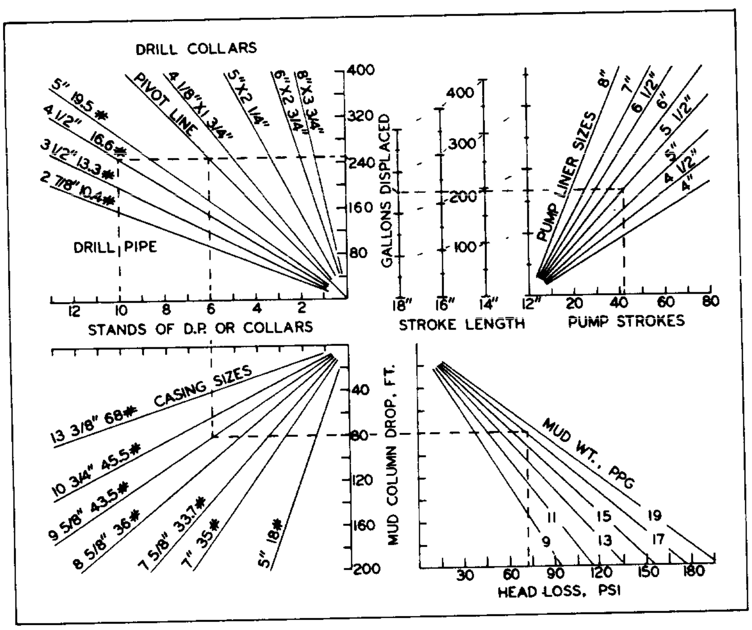

Fig. 6 - Fillup and head loss chart.

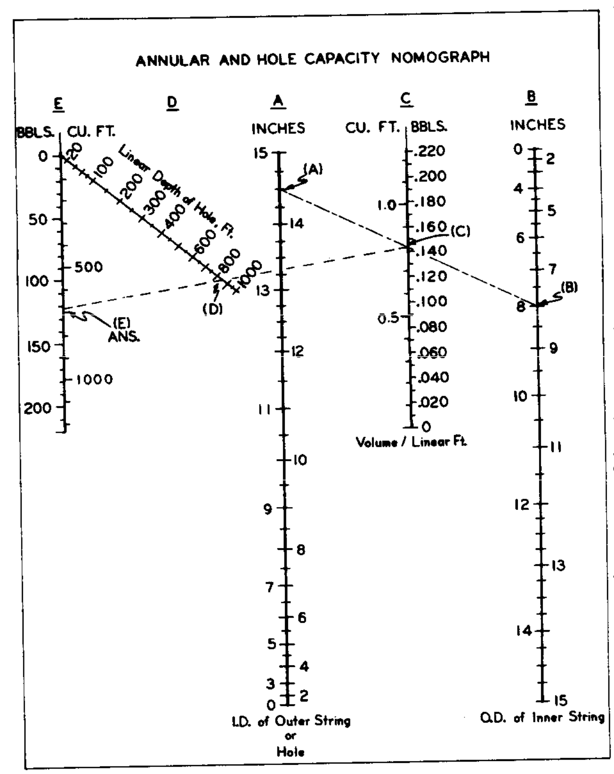

Fig. 7 - Annular and hole capacity.

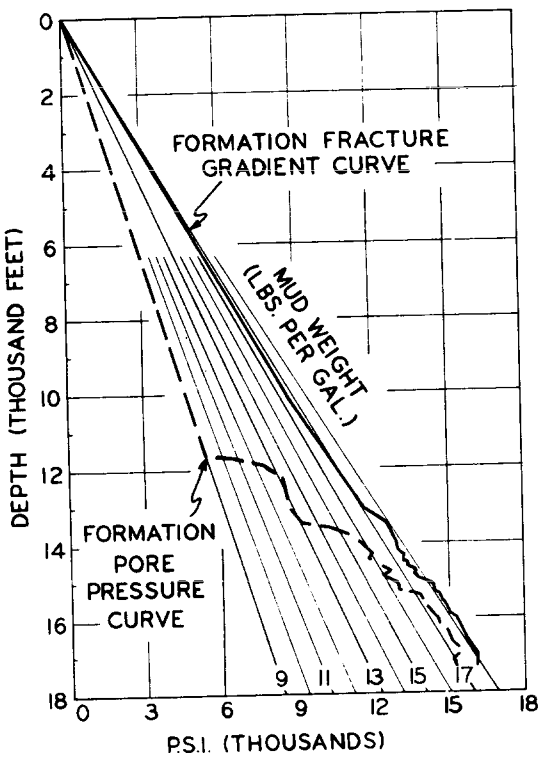

Fig. 8 - Typical pore and fracture pressure curve.

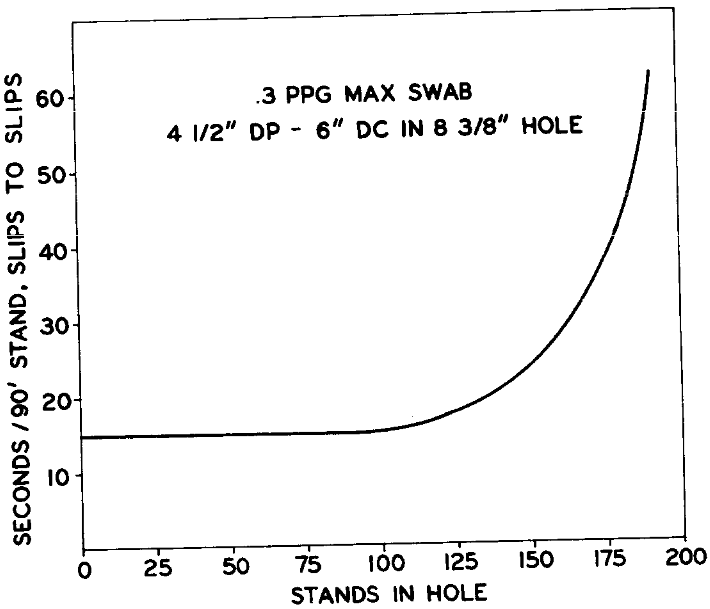

Fig. 9 - Drill pipe pulling speed schedule.

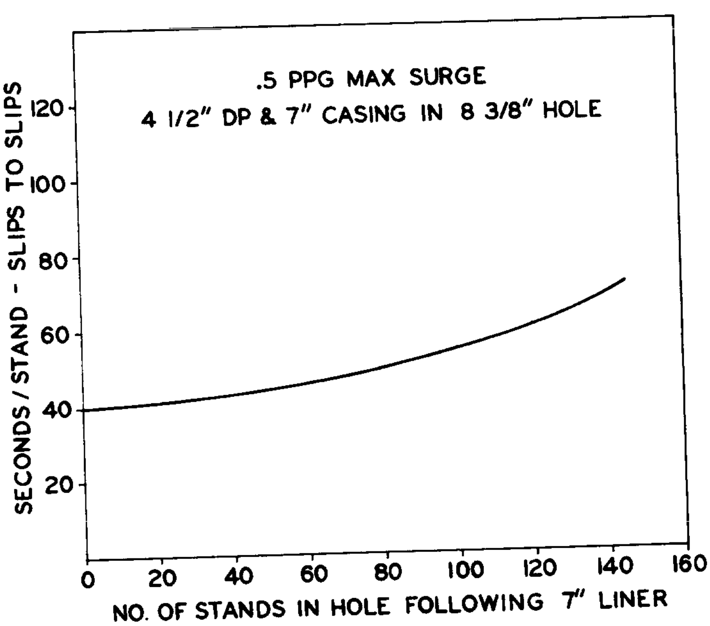

Fig. 10 - Liner running speed schedule.