Theories and Development in Rotary Drilling

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Discussion on this subject covers a vast range of applications of rotary drilling right from the empire drilling by manual power or animal power to modern oil-well drilling techniques. These basic principles, which we see are almost the same in every case, were tried as for back as 1866. As the time passed along, many problems were met and solved. Today we know more about the variables of the rotary drilling and the adjustment of these variables for more economical use than the driller of the past. In present time increasing depth of wells and need for more economy has presented more problems to be answered. We must have more automatic operation of the components of rotary rig, keeping in mind the increasing weight and size of equipment needed for increasing depth. This problem must be solved to maintain the drilling efficiency. Other problems in deep drilling are of pressure, temperature, and well conditions. The main problem on which some analytical studies and efforts have been made in the last ten years by Arthur Lubinski and Henry Wood is the control of crooked holes. Although not completely yet we began to have some idea of the bottom hole forces with which we must contend. From their work we get some understanding how to use and implement the only handy tool at our command to cope with the forces that make the hole go crooked. As a result of these studies new efforts to develop tools and techniques for controlling deviations are being made, and we can soon expect additional developments in this field. First is a continuous reading hole deviation indicator. This device will permit the use of bit weights, once considered foolishly reckless, to forge boldly ahead. Secondly, efforts are being made for tools which push the bit from its intended courses. We hope to get the progress report on rationalization of deviation limits. This work will help to provide a tool for assisting in the writing of the specifications for a hole to assure its acceptability for its intended purpose.

A few holes drilled below 20,000 feet resulted in demands for high strength drillpipes. These pipes have had a severe test in the last three years, and as a result a lot has been learned about the manufacturing, installation of tool joints, service, and handling of this pipe to obtain high strength. The pipe is harder and less ductile, so it resists crack initiation but has poor resistance to the propagation of a crack when it has formed. With the strength of pipe the design factor should be increased to compensate for the ductility decrease, drop in impact strength, and increased notch sensitivity. Maximum and minimum yield should be held to 20,000 to 25,000 psi., the reduction in the slip area of outside diameter should not be more than 1/8 inch and drill pipe in excess of 0.025 inch deep notch should not be used. Rockwell hardness should be less than 30. Corrosion of this pipe has the same adverse effect as slip marks.

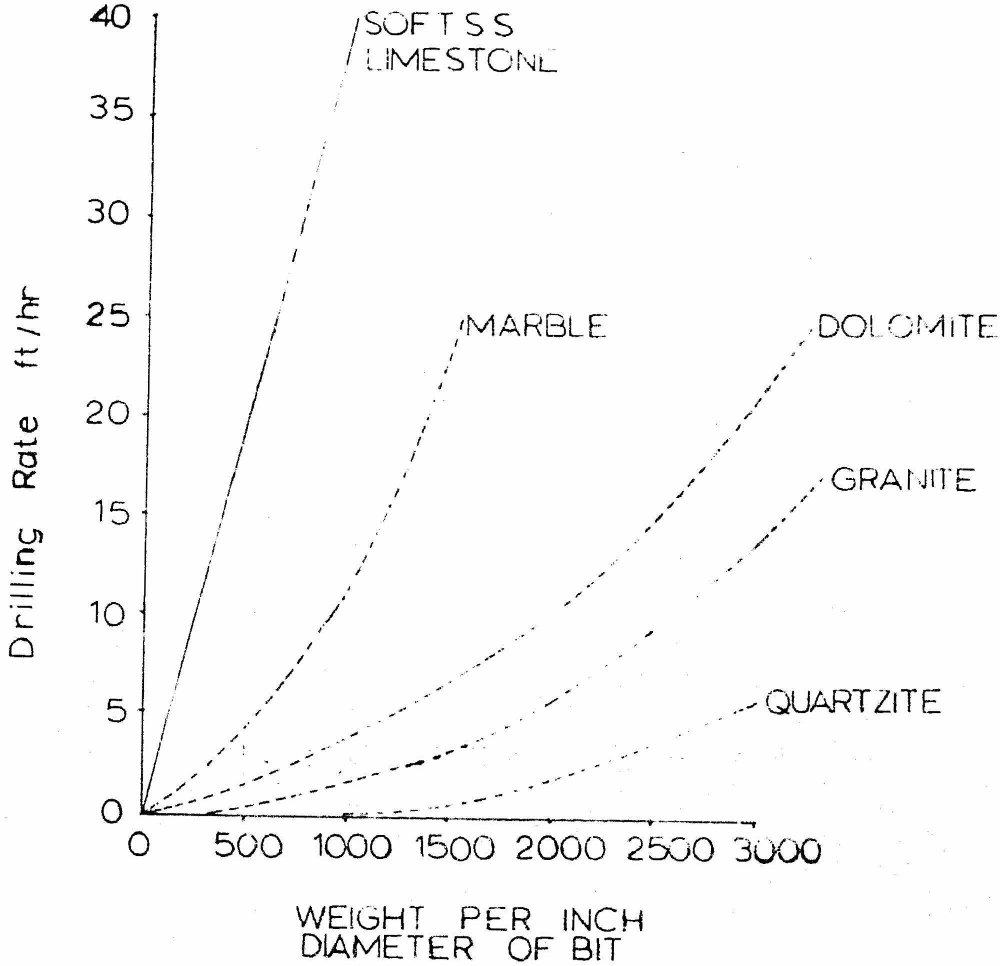
This was all about the development on the construction side of the pipe. Coming to the rotary drilling theory, now, the trend in the drilling is to develop scientifically a weight-speed program to get the maximum efficiency from each bit. The end result may not be faster rate, but it will be the most economical. This, of course, involves calculating all known formation factors to provide a weight-speed program for the entire bit run. The basic factor affecting the drilling is the formation drilled. To meet the requirements imposed, the factors under the control of the operator are the speed of rotation, weight on the bit, and the volume and the characteristics of the mud used. One more way is, of course, the design of the proper type of drilling bit.

Taking first the type of the formation being drilled, in the case of very hard formations the studies of the characteristics of rock are very important to improve the penetration rate and the life of bits, while deep drilling in the formations like dolomite or chert and its application has improved the per-bit footage in this type of drilling. When we speak of the 'rock hardness', we take two meanings of this term. One is the resistance to penetration, which is a function of the crushing strength of the rock, and the second is the resistance to wear, that is, the abrasive hardness. It is the combination of the two that makes the problem. By combining the results of these two hardness tests with the critical thrust for rock, we can determine the limiting conditions for rotary drilling. Along with the two factors stated, i.e. toughness and hardness (abrasive) of the rock, two more factors, namely compressive strength and size and shape of component minerals, are also considered. There is no direct relation between toughness, abrasive properties, and hardness. In very hard rocks high thrust applied may be responsible for the flaking, chipping, and edge-grinding. But in case of highly abrasive rocks we can hardly afford to lose the bit before it has proved its worth. In short we can conclude that the rotary drilling cannot be recommended for rocks which have the following combination :

1. Critical thrust in excess of 200 lbs. (for 1 11/16 inch bits)
2. Shore numbers differing by less than 30.
3. Abrasion factors in excess of 50.

Coming to the point of thrust or weight on bit, experiments in the laboratories give us the relation between the rate of penetration and thrust applied. These recommendations cannot be specified due to inability of duplicating the field conditions in the laboratory. However, they give us safe and satisfactory results.

Below a certain thrust the bit usually works at low frequency. This can be termed as 'critical thrust'. In very hard rocks the bit would grind rather than cut. This phase is termed as 'grinding phase' and must be avoided, as it results in rapid wear of the bit. In less abrasive rocks the rate of penetration is very low below the



critical thrust. Increased thrust means increased drilling rate, but if the applied thrust is too high the rate of removal of debris has to be increased; otherwise the bit may come to stall and choking may result. This phase is refered to as 'choking phase'. This limit can be increased by using streamlined connections between the rod and bit.

The graph shows the drilling rate against the weight on rock bit for different formations at 60 rpm. This is the result of tests by a full size sharp bit and assuming uniformity of the formation. For these tests drillability was defined as the ratio of the rate of penetration in feet per hour to the weight in pounds imposed on the bit. RPM is kept constant to show the relation between the crushing strength of the rock and drillability.

Taking rotation speed of the bit as the next variable, we see that to maintain good drilling efficiency under present conditions, studies in improving the rate of penteration are quite important. But as already said, in the laboratory all the variables are under control, whereas this factor involves the ability and personal judgment of the driller in the field. Despite these limitations results have proved very helpful in practice. To produce the rotation we essentially require torque, and the machine producing the torque must be capable of giving necessary high power to give the bit proper speed of rotation when under high thrust in drilling hard rocks. Hardest rock that can be drilled by rotary drilling needs a machine of at least 5 h. p. Very high power torque machines have one disadvantage, however, that if the choking phase occurs because the rate of removal of the debris is low, torque is built up at the end, and it may result in damage of the bit edges or cutting wings. High rotational speeds give high penetration rates, thus increasing drilling efficiency.

If the rotational speed drilling rate ratio is kept high, we can reduce the possibility of choking. But high rotary speed in harder rocks reduces the rate of penetration per revolution, which results in rapid and severe wear. The bit shears off the cutting edges, and when cutting edges contact the rock, impact occurs which further aggravates the damage problems. Diamond drilling for cores requires special technique as to proper speed of rotation etc. Experiments of rotary drilling with solid diamond bits which cut a full hole has so far been unsuccessful. The reason for this is that penetration by the diamond bit is based on grinding action and requires the correct speed of rotation. With normal speed the diamonds on the outer periphery may be moving with correct speed but the diamonds at the center are almost stationary. So when the outer diamonds cut the formation they leave a continuously increasing load on the center of the bit. This destroys the center of the bit. To keep the

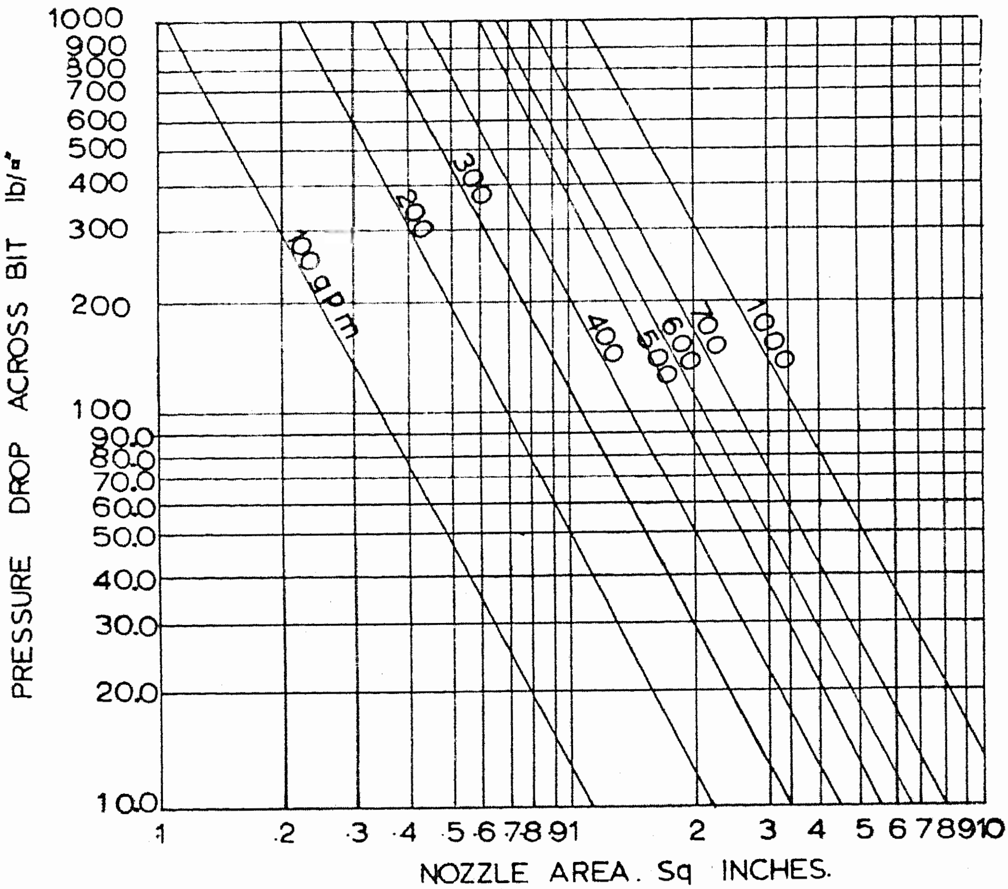
rotational speed at the proper cutting condition, thrust has to be controlled very closely. At depth speed falls off. In the upper part of the hole under favorable conditions it may reach to 300-400 rpm, but at depth it may fall to 125-150 rpm. In California, for example, drilling speed may reach to 160 feet per hour at the surface, while in very deep holes it may be only 3-4 feet per hour.

The torque developed by a certain type of engine depends upon the characteristics of the engine which is further responsible for the design of the engine; quite a different subject than my report. But it is neccessary to mention that torque developed by a steam engine increases as the speed drops, reaching its maximum at the point of installation. The I. C. engine develops its maximum torque at or near its maximum speed, decreasing with the decrease of speed. Moreover the steam engine has a wider range of speed than the I. C. engine. So it is ideally suited for rotary drilling, but the economy of the operation, portability, etc., are the advantages of I. C. engine, which compensate for unfavorable characteristics of the engine.

Now, talking about the bit itself, we see that bits are designed in groups for service in hard formations such as chert, dolomite, and quartzite, medium hard formations like limestone and hard shale, and softer formations such as shale, gypsum, and chalk. For bit head, generally heat-treated steel alloy is used, while blades are drop forged from chromium-nickel steel, hardened by stellite or tungsten carbide. Roller bits are used for hard formations, while fish-tail or drag bits are customary for softer strata. We can further make two distinctions for the type of bit, as eccentric and concentric bits. The former type is used in soft drilling, while the latter is used for harder rocks. If the eccentric bit is used in the harder formation where the rate of penetration is low, unbalanced forces may result in bit wobble. This may damage the tungsten carbide and cause fracture in the legs of the bit. For harder rock the concentric type is recommended, avoiding, of course, small angles at the tips. The angle to be considered most important is the leg rake angle, the angle between the bit axis and the the cutting leg. Drilling rate is increased with the increase in rake angle. Positive rake angles are used for soft rocks while neutral and negative values are used in medium and hard rocks, respectively. With constant thrust and for the same formation results show that wear is very serious in case of positive rake angles and almost negligible for negative rakes. It is, therefore, not advisible to use high rake angles to get higher penetration rate. The other angle to be considered is the clearance angle, which is responsible for the depth of cut per revolution. But in hard rocks high clearance angle may blunt the bit very soon.

A drilling bit may be considered from two points of view, firstly as a hole-cutting tool, and secondly as an element of the circulating system of the rig, affecting its performance and also being affected by the properties of the circulating medium. This last view pertains to the pressure drop across the bit, and the effect on its life and performances left by the mud stream.

The question which needs proper consideration in the design of the bit is the opening of the water course. The graph shows the pressure drop across the bit for different nozzle areas and for different volumes of circulation.



This shows that unless the size of the nozzle is given the consideration for large circulation of mud, as is the order of the day, pressure drop becomes excessive. The destructive cutting action should also be avoided which results by the high speed mud stream on blades

or cutters of the bit. This is due to too small water course opening especially when large volume is required for circulation in drilling upper portion of the well and where mud may contain considerable amount of sand. This question, in general, has been settled in accordance with long experience in the volume of mud and its composition. To diminish the abrasive action of the mud stream the water courses are hardened or the bits are provided with replaceable nozzles.

Some recent developments have been made in small hole drilling. Hollow bit and pilot bit have been introduced in the same connection. Hollow bit is a core type drilling bit, with the exception that no core is allowed to be made. This type is very helpful to avoid the clogging phase and to increase the rate of drilling in hard rocks. This bit will be especially good for drilling long holes for purposes like drainage, etc. The other type of bit is the pilot bit, which has the advantage of pre injecting the strata with some chemicals ahead of the main cutters thus softening the rock. This gives good results with high thrusts. It is almost like the bits being used as reamers, but it will be the first time that it is used for small diameter hole drilling.

In practice the drilling rate is inversely proportional to the square of the diameter of bit, the thrust and rotational speed conditions constant. This can be applied to both small and large hole diameters.

Another fact that plays an important part in the theory of rotary drilling is, as said before, the circulation system. The modern trend of deep hole drilling and using large diameter drill pipes requires special type of mud and proper rate of circulation. The advantage of high drill-pipe to drill-hole ratio has been known for a long time, but it had never been a problem because holes drilled were not so deep. It is evident that there are always pressure losses of the drilling fluid with the depth of the hole. To calculate the formula for the drop of pressure, density and viscosity of the mud must be specified. Other factors to be known for this purpose are friction factor and velocity of flow. So the calculations are valid only for the assumed set of conditions. Velocity of flow depends on rate of circulation and size of annulus. Moreover these equations will give only approximate values, as we have to assume average annular velocity and pressure losses in transition zone from viscous to turbulent flow. Still we will be very close to getting useful calculations. Take as an example that the well drilled is 8,000 feet deep and circulation rate is 400 gpm. Pressure losses taken from the chart are something like this: drill pipe 560 pounds, tool joints 56 pounds, and annulus about 40 pounds. Besides these there are losses occurring in surface lines, stand pipes, house, and kelly, etc., which are about 100 pounds in this case. Taking 50 pounds loss in the bit and considering total back pressure of the system on pump as 850 pounds, we see that 70 percent of this is represented by the losses in drill pipe. Power required for a certain rate of flow to be pumped is proportional to pressure. In this particular example the power needed is 188 h.p.; taking efficiency of pump as 85 percent, total power required is 222 h.p. To get the power requirements, charts are provided for given conditions and two variables: 1) for given depth and changing rate of circulation and 2) for given rate of circulation and changing depth. Ratio of losses of pressure before the mud leaves the bit to the losses after it has left the bit accounts for the efficiency of the system, which in the case stated is only about 11 percent. For the same conditions of the holes but changing to larger diameters of the drill pipe, we get more losses in drill pipes, tool joints, and annulus. Ability to supply to the bit proper volume of the mud without excessive pressure increases the rate of penetration.

The ratio of the time spent by the rig in performing operations like drilling, reaming, or coring, that is, when the bit is actually at the bottom, to the overall time of the rig on the well is the measure of drilling efficiency. The drilling cost per bit is calculated from the footage secured by the bit and the cost of bit along with the time during which the bit is in use.

The time will never come when we shall not see some type of improvement, but we have to satisfy ourselves with as little as 1 to 2 percent increase in the rate of penetration rather than to look for the higher percentage.