WHY CONTROL HOLE DEVIATION?

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Drilling practices have changed considerably through the years. When rotary drilling first started, drill collars (as we know them today) were unheard of. Bits were not designed for heavy loads and only the weight of the drill pipe with a crossover sub (called a collar) between the drill pipe and bit, supplied the drilling weight.

The search for more hydrocarbons required penetration of deeper and harder formations and brought about the development of improved rotary bits with the need for additional weight to make the bit drill.

In an effort to put more weight on the bit, additional drill pipe weight was slacked off putting more drill pipe in compression. This resulted in an increased number of drill pipe failures. It was discovered that when drill pipe is run in compression for bit weight, it buckles and is subject to severe bending fatigue resulting in these failures. This is due to the stress reversals in the thin wall of the drill pipe created by rotating the pipe in compression while it is bent. Using this theory another person developed the idea of using heavy thick-walled pipe between the bit and drill pipe to furnish the necessary weight for the bit. These joints of heavy thick-walled pipe were called drill collars, named after the crossover sub that had been used in the same position in the string.

Only a few collars were used initially, but the quantity increased rapidly with improved bit design and deeper drilling. Very few problems were encountered when only six to nine drill collars were used; but connection failures increased rapidly with the running of additional collars, because the drill collars buckled under the additional drill collar weight. Drill collars differ from drill pipe in that the highest points of stress are in the connection, due to the tube or body being much stiffer and stronger than the connection. The use of special bottomhole assemblies to centralize the collars and stiffen the connections was unheard of at this time.

Initially, not much thought was given to deviation. It was believed that if the kelly were held straight up and down in starting the hole, it would continue straight. No one realized holes were being drilled crooked until the development of the Seminole Field in Oklahoma in about 1928 and 1929. People started to be suspicious when some wells required considerably more footage of casing to complete than others. Since the wells were assumed to be in the same producing horizon, the geologists were confused. It wasn't until two offset drilling wells actually intersected one another, causing numerous fishing jobs, that people realized that crooked holes were possible. They began to be concerned about the cost of the additional tubing and casing to complete these crooked holes, and deviation from vertical became an important factor in the drilling industry. It was at this time that the acid bottle came into use as a means of measuring the hole inclination from vertical. A bottle of hydrofluoric acid was lowered into the well on a line and allowed to sit long enough for the acid to etch the inside of the bottle. This wasn't very accurate, but the approximate deviation from vertical could be determined.

It did not take long to develop better deviation-recording instruments, and operators began to write specifications requiring that the driller maintain the hole angle within some specified maximum. This was when crooked holes began to be a problem. At first, deviation controls were quite liberal, with 10 to 15 degrees being acceptable as maximum inclination from vertical. However, during this period, the California Courts decided that wells crossing over lease boundary lines onto other properties were trespassing, and lawsuits resulted. Also, about this same time, Dr. Fredrick Lahee (Sun Oil Company) wrote several papers advocating that for geological information obtained from drilling of wells to be valid, deviation from vertical should not exceed 1-2°. Operators overreacted to both situations, and by the early 1930's, 1-3° was the maximum permissible hole deviation from top to bottom. Later, during the 1940's, some areas relaxed their deviation restrictions to 3-5°. This came about because deeper and harder formations were being drilled which required more weight to make the bit drill and, therefore, it was almost impossible to stay within a 1-3° contract. However, these operators ignored the rate of hole angle change, and did not eliminate the crooked hole problems caused by severe dog-legs.

During the 1950's, both operators and drilling contractors became quite concerned about the additional amount of money it cost to stay within a 3-5° contract. In the drilling of most wells a reduction of bit weight was necessary to stay within the maximum permissible deviation. This resulted in slower penetration rates and a higher drilling cost because of the additional drilling time required to reach total depth. The realization of this added expense started people thinking about the problem and they began to wonder about what mechanics were involved that would force the bit away from vertical.

WHAT CAUSES CROOKED HOLES?

While no one knows the exact cause of holes going crooked, some logical theories have been conceived.

Henry Woods (Hughes Tool Company) and Arthur Lubinski (Pan American Petroleum Corporation, now AMOCO) stated in one of their earlier papers in 1954, that the size of the bottomhole drill collars would be the limiting factor for lateral movement and the minimum effective hole diameter (MEHD) could be calculated by the following equation:

$$\text{MEHD} = \frac{\text{Bit Size} + \text{Drill Collar OD}}{2}$$

This was followed by a theory expressed by Robert S. Hoch (Phillips Petroleum Company) that, while drilling with an unstabilized bit, an abrupt change in hole angle can occur if hard ledges are encountered. See Fig. 1. He pointed out that a dog-leg of this nature would cause an undersized hole, making it difficult or maybe impossible to run casing. Hoch stated, "To minimize the possibility of sticking casing strings in holes drilled with unstabilized or single stabilized drill collars, it is suggested that the minimum permissible bottom hole drill collar outside diameter always be larger than twice the casing coupling outside diameter to be run minus the bit size."

Minimum permissible drill collar, OD =
2 (casing coupling OD - bit OD)

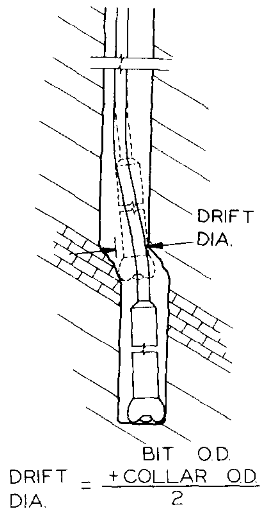

FIG. 1—ABRUPT DOG-LEG-UNDERSIZED HOLE RESULTING FROM A HARD LEDGE

About this same time, Herb Treichler (H.E.T. Drilling Company) theorized that the lateral bit movement of an unstabilized bit in nondipping formations tends to cut a spiraled hole. See Fig. 2. He said that spiraling would be more severe in soft formations where penetration rate is greater and this would produce an undersized hole.

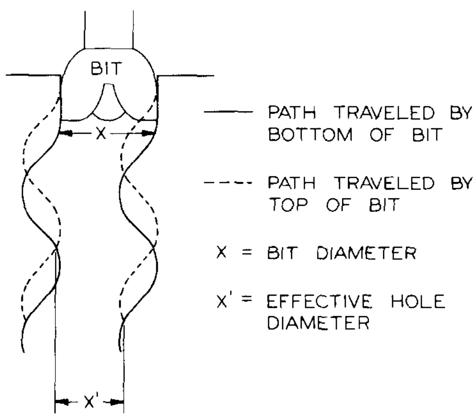

FIG. 2—UNDERSIZED SPIRALED HOLE IN SOFT FORMATION (FAST PENETRATION RATE)

The whipstock theory was presented in 1963 by H.M. Rollins, (Drilco). He said that the formations drilled through in searching for oil and gas are sedimentary formations and are laminar in structure. If these formations are dipping, as the bit drills through each of the laminations, it may reach some load at which that lamination can no longer support the load so it will fracture down to the next lamination. Most such formations tend to fracture perpendicular to the bedding planes, leaving on the uphill side of the hole a small wedge of material which is easily drilled away because it is broken up or is no longer attached to the rock. Conversely, on the downhill side of the hole, a small wedge of material is left attached to the lamination. This wedge forms a small "whipstock" which tends to force the rock bit laterally up-dip or uphill. See Fig. 3. In the middle 50's, Henry Woods was able to simulate this very thing in a laboratory. He mounted sheets of plate glass in a block of cement and drilled through the artificial rock. He filled the drilled hole with plaster of Paris and then carefully chipped away the cement and glass leaving a post representing the bore hole. It was quite obvious that little whipstocks were formed and the bit was deflected up-dip.

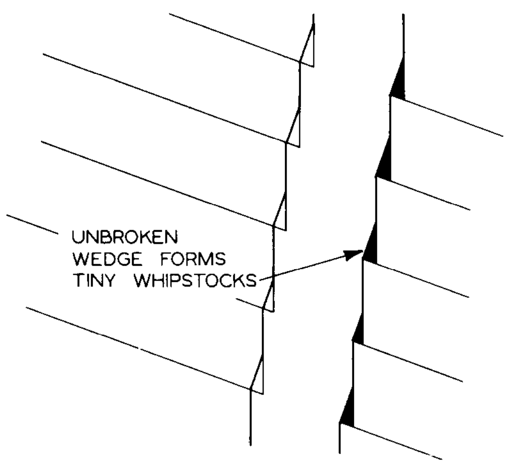

FIG. 3—BIT WILL DRILL UP DIP WHEN FORMATIONS DIP LESS THAN 45 DEGREES

It is also believed that ledges, offsets, and dog-legs are formed when the bit drills hard and soft laminar formations one after the other and the soft sections wash out. The drill collars being smaller in diameter than the bit will allow the bit to move laterally within the washed-out soft formations before drilling the hard sections. After drilling several of these hard sections, the holes in these hard sections do not line up. See Fig. 4.

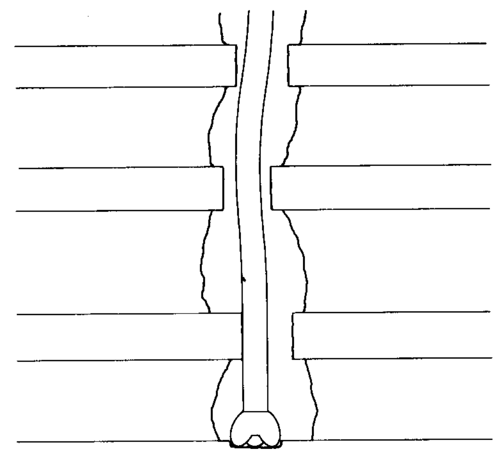

FIG. 4—OFFSET LEDGES

WHY RESTRICT TOTAL HOLE ANGLE?

Total hole angle should be restricted: (1) in order to stay on a particular lease and not drift over into adjacent property, (2) to insure drilling into a specific pay zone like a stratigraphic trap, a lensing sand, a fault block, etc., or (3) to drill a near-vertical hole to meet legal requirements from regulatory agencies, field rules, etc.

WHY RESTRICT RATE OF HOLE ANGLE CHANGE?

Lubinski pointed out in his work (in the early 1960's), that the rate of hole angle change should be the main concern, not necessarily the maximum hole angle; and he expressed this rate of hole angle change in degrees per 100 feet. In 1961 an API study group published a tabular method of determining maximum permissible dog-legs that would be acceptable in rotary drilling and completions. Therefore, the main objective is to drill a "useful" hole with a full-gauge, smooth bore, free from dog-legs, key seats, off-sets, spirals, and ledges.

A key seat is formed after part of the drill pipe string has passed through the dog-leg. Since the drill pipe is in tension, it is trying to straighten itself while going around the dog-leg. This creates a lateral force that causes the drill pipe to cut into the center of the bow as it is rotated. See Fig. 5. This force is proportional to the amount of weight hanging below the dog-leg. A key seat will be formed only if the formation is soft enough and the lateral force great enough to allow penetration of the drill pipe. When severe dog-legs and key seats are formed many problems can develop.

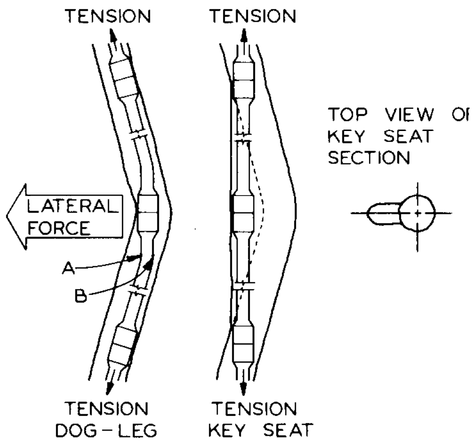

FIG. 5

PROBLEMS ASSOCIATED WITH DOG-LEGS AND KEY SEATS

Stuck Pipe

When the drill string is motionless and lying against the wall of the borehole an impervious seal of filter cake can form between the wall and the drill string, allowing a differential pressure to develop across the pipe. This differential pressure is caused by the hydrostatic pressure of the drilling fluid being greater than the formation pressure at that depth. When this happens, the drill string is "wall-stuck".

Sticking can also occur by sloughing or heaving of the hole and by pulling the large OD drill collars into a key seat while pulling the drill string out of the hole.

Drill Pipe Fatigue

Lubinski presented guidelines (1961) for the rate of change of hole angles. He said that if a program is designed in such a way that drill pipe damage is avoided while drilling the hole, then the hole will be acceptable for conventional designs of casing, tubing, and sucker rod strings as far as dog-leg severity is concerned. A classical example of the severe dog-leg condition which produces fatigue failures in drill pipe can be seen in Fig. 5. The stress at point B is greater than the stress at point A; but as the pipe is rotated, point A moves from the inside of the bend to the outside and back to the inside again so that every fiber on the pipe goes from minimum tension to maximum tension and back to minimum tension again. Cyclic stress reversals of this nature cause fatigue failures in drill pipe, usually within the first two feet of the body adjacent to the tool joint because of the abrupt change of section.

Lubinski suggested that to avoid rapid fatigue failure of pipe, the rate of change of the hole angle must be controlled. Suggested limits can be seen in Fig. 6. This graph is a plot of the tension in the pipe versus change in hole angle in degrees per 100 feet. This curve is designed for 4-1/2 in. 16.60 lb/ft Grade "E" drill pipe, and represents stress endurance limits of the drill pipe under various tensile loads and in various rates of change in hole angle. If conditions fall to the left of this curve, fatigue damage to the drill pipe will be avoided, but to the right, fatigue damage will build up rapidly and failure of the pipe is likely. The curve is based on 2000 lb lateral thrust, which is considered to be the upper stress limit of the drill-pipe body. It can be seen from this plot that if a dog-leg is high in the hole with high tension in the pipe, only a small change in angle can be tolerated. Conversely, if the dog-leg is close to total depth, tension in the pipe will be low and a larger change in angle can be tolerated.

If the stress endurance limit of the drill pipe is exceeded, because of rotation through a dog-leg, an expensive fishing job or a junked hole could develop.

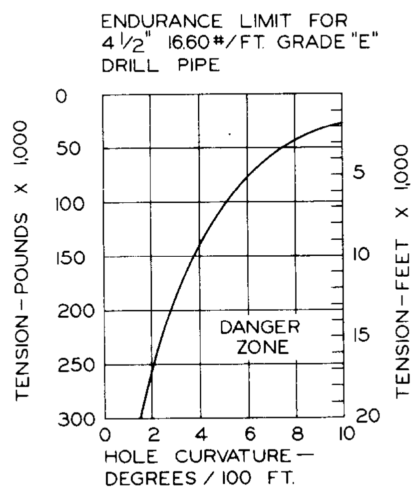

FIG. 6—FATIGUE CURVE

Logging

Logging tools and wire lines can become stuck in key seats. The wall of the hole can also be damaged, causing hole problems.

Running Casing

Running casing through a dog-leg can be a very serious problem. If the casing becomes stuck in the dog-leg, it will not extend through the productive zone. This would make it necessary to drill out the shoe and set a smaller size casing through the productive interval. Even if running the casing to bottom through the dog-leg is successful, the casing could be severely damaged, thereby preventing the running of production equipment.

Cementing

The dog-leg will force the casing over tightly against the wall of the hole, preventing a good cement bond because no cement can circulate between the wall of the hole and the casing at this point.

Casing Wear While Drilling

The lateral force of the drill pipe rotating against the casing in the dog-leg or dragging through it while tripping, can cause a hole to wear through the casing. This could cause drilling problems and/or a possible serious blowout.

Producing Problems

It is useless to drill a well without having a smooth string of casing to produce through. Rod wear and tubing leaks associated with dog-legs can cause expensive repair jobs. It may also be difficult to run packers and tools in and out of the well without getting stuck because of distorted or collapsed casing.

HOW DO WE CONTROL HOLE ANGLE?

Now that we have some ideas as to the possible causes of bit deviation and the problems associated with crooked holes, look at two possible solutions using the pendulum and the packed hole concepts.

Pendulum Theory

In the early 1950's, Woods and Lubinski collaborated in a mathematical examination of the forces on a rock bit when drilling in an inclined hole. In order to make their calculations, they made three basic assumptions:

1. The bit is like a ball-and-socket joint, free to turn, but laterally restrained.
2. The drill collars lie on the low side of the hole and will remain stable on the low side of the hole.
3. The bit will drill in the direction in which it is pushed, not necessarily in the direction in which it is aimed.

Consequently, the forces which act upon the bit can be resolved into:

1. The axial load supplied by the weight of the drill collars
2. The lateral force — the weight of the drill collar between the bit and the first point of contact with the wall of the hole by the drill collar ("Pendulum Force"). "Pendulum Force" is the tendency of the unsupported length of drill collar to swing over against the low side of the hole because of gravity. It is the only force that tends to bring the hole back towards vertical. See Fig. 7.
3. The reaction of the formation to these loads, which may be resolved into two forces, one parallel to the axis of the hole and one perpendicular to the axis of the hole.

This work made it possible to utilize gravity as a means of controlling change in hole angle. The necessary weight for the bit to maintain a certain hole angle can be found in tables especially prepared by Drilco. These tables also show the proper placement of a stabilizer to give the maximum pendulum force and the maximum weight for the bit. The effects of using larger drill collars can also be determined.

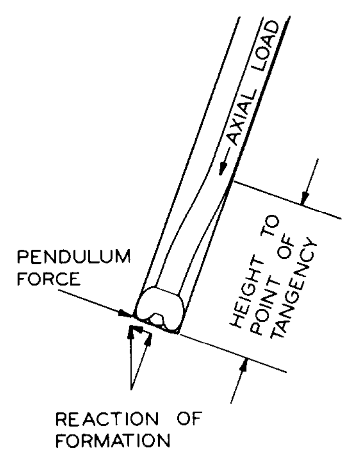

FIG. 7—FORCES ON BIT

Packed Hole Theory

Most people today use a packed hole assembly to overcome crooked hole problems and the pendulum is used only as a corrective measure to reduce angle when the maximum permissible deviation has been reached. The packed hole assembly is sometimes referred to as the "gun barrel" approach because a series of stabilizers is used in the hole already drilled to guide the bit straight ahead. The object should be to select a bottomhole assembly to be run above the bit with the necessary stiffness and wall contact tools to force the bit to drill in the general direction of the hole already drilled. If the proper selection of drill collars and bottomhole tools is made, only gradual changes in hole angle will develop. This should create a useful hole with a full-gauge, smooth bore free from dog-legs, key seats, offsets, spirals and ledges, thereby making it possible to complete and produce the well.

FACTORS TO CONSIDER WHEN DESIGNING A PACKED HOLE ASSEMBLY

Length of Tool Assembly

It is important that wall contact assemblies provide sufficient length of contact to assure alignment with the hole already drilled. Experience confirms that a single stabilizer just above the bit generally acts as a fulcrum or pivot point. This will build angle because the lateral force of the unstabilized collars above will cause the bit to push to one side as weight is applied. Another stabilizing point, for example, at 30 feet above the bit will nullify some of the fulcrum effect. With these two points, this assembly will stabilize the bit and remove some of the hole angle-building tendency, but it would not be considered a good packed hole assembly.

As shown in Fig. 8, two points will contact and follow a curved line, but add one more point and there is no way you can get three points to contact and follow the curve. Therefore, three or more stabilizing points are needed to form a packed hole assembly.

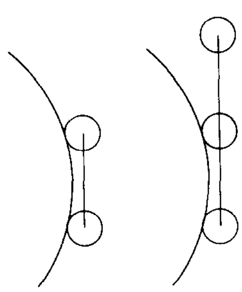

FIG. 8—THREE OR MORE STABILIZING POINTS MAKE A PACKED HOLE ASSEMBLY

Stiffness

Large-diameter drill collars will help provide the ultimate in stiffness, so it is important to select the maximum diameter collars that can be safely run. Drill collars increase in stiffness by the fourth power of the diameter. For example, a 9-1/2 in. diameter drill collar is four times stiffer than a 7-in. diameter drill collar and is two times stiffer than an 8-in. diameter drill collar when all three sizes may be considered appropriate for drilling a 12-1/4 in. hole.

Clearance

There needs to be a minimum clearance between the wall of the hole and the stabilizers. The closer the stabilizer is to the bit, the more exacting the clearance requirements are. If, for example, 1/16-in. undergauge from hole diameter is satisfactory just above the bit, then 60 feet above the bit, 1/8-in. clearance may be close enough. In some areas, wear on contact tools and clearance can be a critical factor for a packed hole assembly.

Wall Support and Length of Contact Tool

Bottom assemblies must adequately contact the wall of the hole to stabilize the bit and centralize the drill collars. The length of contact needed between the tool and the wall of the hole will be determined by the formation. The surface area in contact must be sufficient to prevent the stabilizing tool from digging into the wall of the hole. If this should happen, stabilization would be lost and the hole would drift. If the formation is strong, hard and uniform, a short narrow contact surface, such as a reamer cutter, is adequate and will insure proper stabilization. On the other hand, if the formation is soft and unconsolidated, a long blade stabilizer may be required. Hole enlargement in formations that erode quickly tends to reduce effective alignment of the bottom assembly and special procedures may be required in these formations.

BOTTOMHOLE ASSEMBLIES

We will discuss assemblies for three types of conditions; mild crooked hole, medium crooked hole, and severe crooked hole tendencies.

Mild Crooked Hole Tendencies (See Fig. 9.)

Zone No. 1 is the area directly above the bit. The wall contact tool in this zone must hold gauge for the entire time that each bit is on bottom drilling.

In hard formations this tool would probably be a three-point reamer. Medium hard to soft formations would require some type of long blade stabilizer.

Zone No. 2 is about 30 feet above Zone No. 1 and requires a three-point string reamer in hard rock or a blade stabilizer for medium hard to soft formations.

Zone No. 3 will be 30 feet above Zone No. 2 in a medium size hole (like 8-1/2 in.) or could be 60 feet above Zone No. 2 in a large hole (12-1/4 in. and larger) if large-diameter drill collars are used. In hard formation, this tool would probably be a three-point string reamer or a nonrotating rubber sleeve stabilizer. In medium hard to soft formations it would be a blade-type stabilizer. Any stabilizers run above Zone No. 3 would be used only to prevent the drill collars from buckling or becoming "wall stuck," and in most cases would have very little effect on directing the bit.

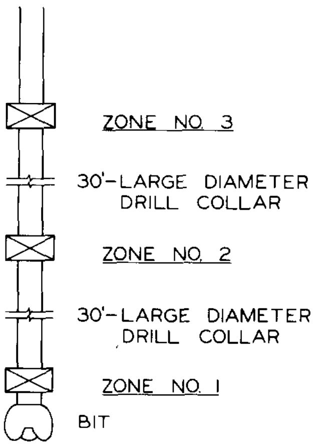

FIG. 9—PACKED ASSEMBLY FOR MILD CROOKED HOLE DRILLING

Medium Crooked Hole Tendencies (See Fig. 10.)

Here again, Zone No. 1 is directly above the bit and stabilizers will be required to keep the hole in gauge in case the bit should start wearing under size. Zone No. 1 can contain one tool or a combination of two or more stabilizing tools. In hard formation it would probably be a six-point reamer. Medium hard formation may require the combined use of a reamer and a blade stabilizer. In soft formations, two or more long blade stabilizers would be appropriate for Zone No. 1.

For medium size and larger holes a 10 to 15 foot long, large-diameter drill collar would be used between Zone No. 1 and Zone No. 2. Small holes less than 7 in. diameter would require the short collar not to be more than 6-8 ft. long. Small-diameter drill collars used in small holes flex more than large-diameter collars and therefore, need to be shorter to maintain stiffness. Zone No. 2, like Zone No. 1, may need one or more stabilizing tools. A string reamer would be used in hard formation. In medium hard formations the combination of a string reamer and a blade stabilizer may be required. One or more long blade stabilizers would be used for Zone No. 2 in soft formations.

For medium size (8-1/2 in.) and large holes, a 30-ft large-diameter drill collar would be used between Zone No. 2 and Zone No. 3. Small holes may require the use of a 10-15 ft large-diameter drill collar between Zone No. 2 and Zone No. 3.

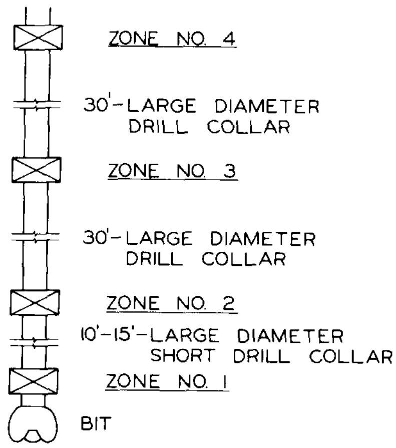

FIG. 10—PACKED ASSEMBLY FOR MEDIUM CROOKED HOLE DRILLING

Zone No. 3, in hard rock drilling, could use a string reamer or a nonrotating rubber sleeve stabilizer. For medium hard formations Zone No. 3 may need a string reamer, a nonrotating rubber sleeve stabilizer or a blade stabilizer. In soft formations, Zone No. 3 would probably require a long blade stabilizer.

A large-diameter 30-ft drill collar would be run between Zone No. 3 and Zone No. 4.

The tools used in Zone No. 4 can be the same type as tools used in Zone No. 3. In large size holes (12-1/4 in. and larger), tools suitable for Zone No. 5 could be used 30-60 ft above Zone No. 4. The same type tools used at Zone No. 3 and Zone No. 4 could be used in Zone No. 5.

Here again, any stabilizers run above Zone No. 4 or No. 5 would be used for the purpose of preventing buckling or wall-sticking of the drill collars, but not for the purpose of packing the hole.

Severe Crooked Hole Tendencies (See Fig. 11)

The same tools used in Zone No. 1 for a medium crooked hole drilling assembly would apply to tools needed for Zone No. 1 for a severe crooked hole drilling assembly. For severe crooked hole conditions a 10-15 ft, large-diameter drill collar would be used between Zone Nos. 1 and 2 and between Zone Nos. 2 and 3. Note: A shorter drill collar may be required in small holes.

Tools used in Zone Nos. 2 and 3 would be the same as tools used in Zone No. 2 for medium crooked hole conditions. A 30-ft large-diameter drill collar would be used between Zones No. 3 and No. 4.

The tools used in Zone No. 4 would be the same as tools used in Zone Nos. 3 and 4 for medium crooked hole conditions. In a large diameter hole tools such as in Zone No. 5 may be required 30-60 ft above Zone No. 4. The same tools would be used that are used in Zone No. 4.

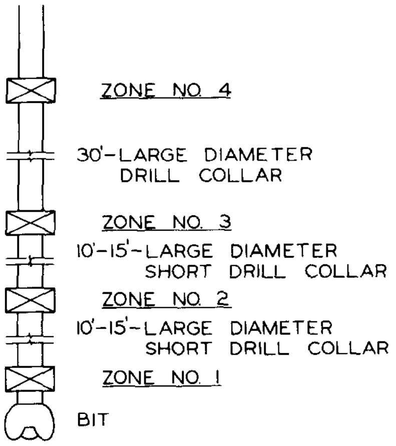

FIG. 11—PACKED ASSEMBLY FOR SEVERE CROOKED HOLE DRILLING

Modern packed hole assemblies, when properly designed and used, will:

- Reduce rate of hole angle change. A smooth-walled hole with gradual angle change is more convenient to work through than one drilled at minimum hole angle with many ledges, offsets, and sharp angle changes.
- Improve bit performance and life by forcing the bit to rotate on a true axis about its design center, thus loading all cones equally.
- Improve hole conditions for drilling, logging, and running casing. Maximum size casing can be run to bottom.
- Allow use of more drilling weight through formations which cause abnormal drift.
- Maintain desired hole angle and course in directional drilling. In these controlled situations, high angles can be drilled with minimum danger of key seating or excessive pipe wear.

PACKED PENDULUM

A packed hole assembly will decrease the rate of hole deviation, but angle may still continue to build. In many cases, the well can be completed without exceeding the maximum permissible deviation, but sometimes it becomes necessary to drop angle. When this situation arises, the "packed pendulum" technique should be used if the packed hole assembly is to be re-run after the hole is brought back within deviation limits. The purpose for this is to prevent sticking of the packed hole assembly. If the packed hole assembly is laid down and then picked up again at a deeper depth, it may be very difficult to work it back to bottom without excessive reaming and/or becoming stuck. The packed pendulum is developed by moving the packed assembly up the hole and swinging the required length of drill collars below to form a pendulum. The lowermost stabilizer or reamer in the packed hole assembly will become the fulcrum for the pendulum. When converting back to a packed hole assembly, only the length of the pendulum in the bottom of the hole will need to be reamed. See Fig. 12.

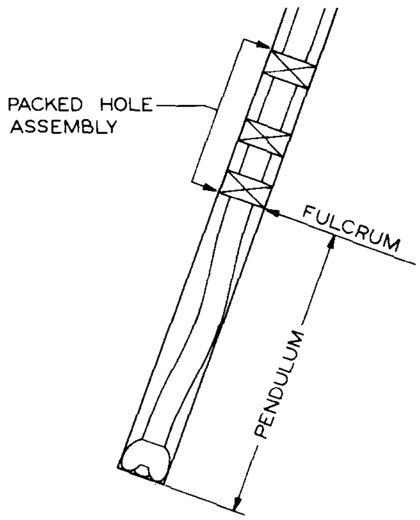

FIG. 12—PACKED PENDULUM

VIBRATION DAMPENING

When rough drilling conditions are encountered, a vibration dampener should be used in the drill string. The dampener will prevent damage to the surface equipment, drill string and the bit. This will increase the performance and the life of the bit and will also reduce drill collar connection failures. When a vibration dampener is used in conjunction with a packed hole assembly, it should be positioned directly above the top stabilizer of the packed hole assembly and not down in the assembly. There is some movement between the mandrel and the housing in a vibration dampener that would reduce the effectiveness of the packed hole assembly.

CONCLUSION

In conclusion, the author would like to point out that this paper was written to acquaint production people with producing problems that can be created by an improperly drilled well, and suggests that more attention be given to the actual drilling operation.

BIBLIOGRAPHY

1. Bachman, W.S.: Drill Collar Practices In Permian Basin, *World Oil,* Jun. 1957.
2. Brantley, J.E.: "History of Oil Well Drilling," 1971, Gulf Pub. Co.
3. Garrett, W.R.: Bits Protected Two Ways By Rubber Element!, *Drlg. Mag.,* 1967.
4. Garrett, W.R.: New Design Widens Application Of Down Hole Shock Absorbers, *Drlg. Mag.,* 1968.
5. Garrett, W.R. and Wilson, G.E.: Proper Field Practices For Drill Collar Strings, Presented At The 49th Ann. Fall Mtg. of SPE of AIME, Houston, Tex., Oct. 6-9, 1974.
6. Hock, R.S.: A Review Of The Crooked-Hole Problem And An Analysis Of Packed Bottom Hole Drill Collar Assemblies, *API Drlg. and Prodn., Prac.,* 1962, p. 27.
7. Lahee, F.H.: Research In Crooked Hole Problems, *Oil & Gas Jour.,* vol. 27, No. 28, Nov. 1928, p. 30.
8. Lahee, F.H.: Crooked Holes, Causes And Effects, Parts I and II, *Oil Wkly.,* Mar. 29, 1929 and Apr. 5, 1929.
9. Lubinski, Arthur: Maximum Permissible Dog-Legs In Rotary Boreholes, *Jour. Petr. Tech.,* Feb. 1961.
10. Moore, S.C.: Current Trends In Controlling Hole Deviation, *Drill Bit,* May 1962; API Spring Mtg. of Eastern Div., presented at Columbus, Ohio, May 16-18, 1962.
11. Pedigo, John R.: Annotated Bibliography Of Published Material Related To Crooked Hole, AAODC Crooked Hole Subcommittee Of The Rotary Drilling Committee, Oct. 1964.
12. Rollins, H.M.: Straight Hole Drilling, Parts I and II, *World Oil,* Mar. and Apr. 1963.
13. Rollins, H.M. and Lubinski, Arthur: Drilling Straight Holes in Crooked Hole Country, Dec. 1968.
14. Rollins, H.M.: How To Drill A Better Hole, Parts I, II, III, & IV, *World Oil,* Jan., Feb., Mar., and Apr. 1970.
15. Treichler, H.E., Jr.: Is A Straight Hole Really Straight?, *Drlg. Mag.,* 1957.
16. Treichler, H.E., Jr.: Penetration Rate Increases With Larger Drill Collars, *World Oil,* Oct. 1959.
17. Wiley, Chad: The Use Of Near-Bit Stabilizer-Sub Assemblies For The Control Of Hole Deviation, *API Drlg. and Prodn. Prac.,* 1965, p. 66.
18. Woods, H.B. and Lubinski, A.: Practical Charts For Solving Problems In Hole Deviation, Spring Mtg. Of Mid-Continent Dist. Of Prodn., Okla. City, Mar. 1954.
19. Woods, H.B. and Lubinski, A.: How To Determine Best Hole And Drill Collar Size, *Oil & Gas Jour.,* vol. 53, No. 19, June 1954, pp. 104, 105, 109.
20. Woods, H.B. and Lubinski, A.: Use Of Stablizers In Controlling Hole Deviation, *Drlg. and Prodn. Prac.,* 1955, *Drlg.,* Apr. 1955.