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3,205,954

METHOD FOR DRILLING A BOREHOLE

Filed June 5, 1963

FIG. 1

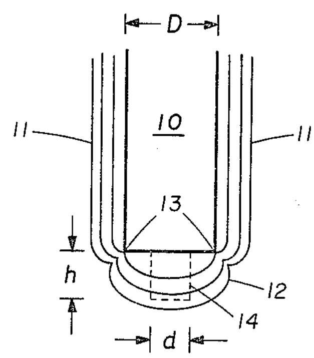


FIG. 3

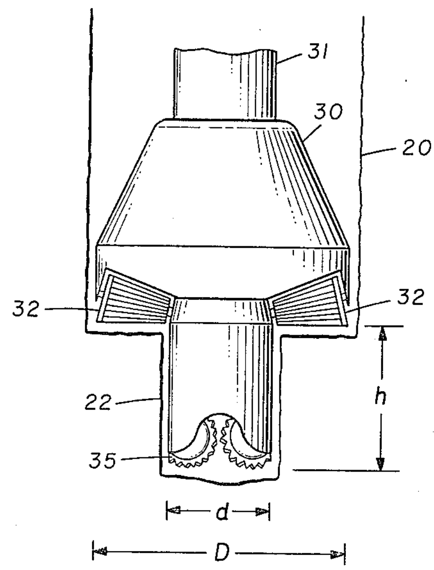


FIG. 4

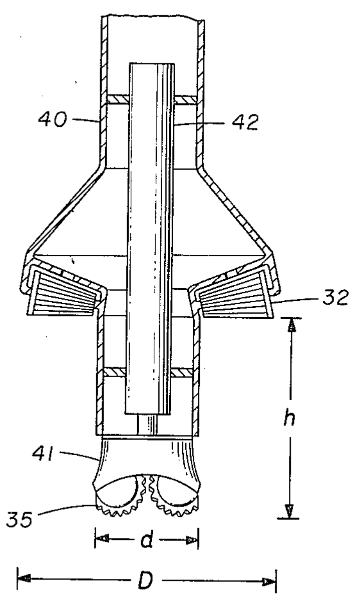
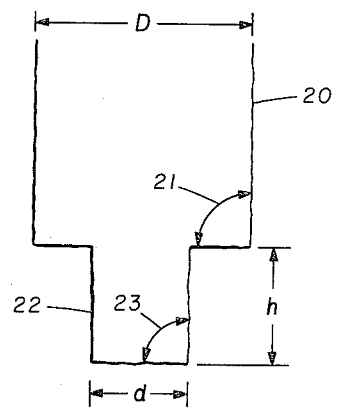


FIG. 2



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METHOD FOR DRILLING A BOREHOLE

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This invention relates to the drilling of a borehole in an earth formation. More specifically, this invention relates to an improved method and apparatus for drilling a borehole.

Of particular interest in drilling technology are the various stresses that surround the bottom of a borehole. These stresses are due to the formation pore pressure, the fluid pressure inside the borehole, and the overburden or geostatic pressure at the particular hole depth. The extremely complex nature of the earth's crust makes theoretical or experimental analysis of the stresses around the borehole exceedingly difficult. An investigation of these stresses was made experimentally by "frozen-stress," three-dimensional, photoelastic techniques using a translucent plastic model. Among the findings of such studies is the fact that the stress concentration around a borehole is a function of borehole geometry. An examination of the stress fields surrounding the bottom of the borehole revealed two locations of stress concentrations, namely, the outside edges and the bottom center of the borehole. It was, therefore, postulated that a more efficient drilling procedure and apparatus would be evolved from a consideration of these stress concentration locations. It was also found that the effective range of the stress gradient around the bottom of the borehole is less than one hole diameter.

It is an object of the prescent invention to provide a method for drilling boreholes in earth formations more efficiently. It is another object of the present invention to provide a method for more effectively drilling a borehole by taking advantage of the stress concentrations in the bottom of a borehole. It is a further object of the present invention to provide a method for drilling boreholes wherein stress concentrations are developed which will permit more effective drilling. It is a still further object of the invention to provide a method for drilling boreholes wherein a borehole geometry is developed which provides stress concentrations favorable to more efficient drilling.

In accordance with one aspect of the invention, there is provided a method of drilling a borehole in an earth formation wherein a first hole is drilled and then a second hole is drilled through the bottom center of the first hole into a zone of stress concentration. A defined relationship is maintained between the diameters of the two holes and the distance between the bottoms of the holes as they are advanced through the formation.

In the drawings:

FIGURE 1 is a diagrammatic representation of a borehole showing the stress field around the borehole.

FIGURE 2 is a view in cross section of the bottom of a borehole drilled in accordance with the invention.

FIGURE 3 is a view in elevation of one form of drilling apparatus constructed in accordance with the invention.

FIGURE 4 is a view partially in section and partially in elevation illustrating another form of drilling apparatus constructed in accordance with the invention.

Referring to FIGURE 1, area **10** represents a longitudinal cross section through the center line of a borehole. Lines **11** represent the stress field in the formation along the wall of the borehole, while lines **12** represent the stress field in the region of the bottom of the borehole. At the base of the wall of the borehole where the wall meets the bottom there is a high concentration of stress as represented by the increased stress line density in the areas **13** of FIGURE 1. Shown below the bottom center of the borehole in FIGURE 1 is a zone **14** which includes a stress field which is particularly favorable to formation rock removal with the expenditure of less than the normal amount of energy. The stress field illustrated in zone **14** below the bottom center of the borehole within the formation is induced by the action of the drilling of borehole **10**. The most favorable stress field for drilling within zone **14** is found when the diameter (d) of zone **14** is less than the distance between the bottom of the zone and the bottom of the borehole, as represented by h in FIGURE 1, and the height of zone **14** (h) is less than the diameter of borehole **10** (D). Preferably, the diameter of zone **14** and the diameter of the borehole **10** are related as follows:

$$0.2D < d < 0.6D$$

The favorable environment for more effective borehole drilling described above and exemplified in FIGURE 1 is taken advantage of by the method of the invention. The method of the invention is carried out by drilling a borehole having the configuration or geometry illustrated in FIGURE 2. In carrying out the method of the invention, a borehale **20** is first drilled into the formation a short distance to effect the establishment of a favorable stress field in advance of or below the bottom of the center of the borehole as explained in connection with FIGURE 1. In the drilling of borehole **20**, it is preferred that the angle **21** between the bottom of the borehole and the wall of the borehole be no greater than 90°, as it has been found that the magnitude of the stresses within the formation around the line of intersection of the bottom and wall of a borehole is inversely proportional to the angle made by the bottom of the borehole with the wall of the borehole. As previously explained, with the drilling of a borehole into a formation, such as borehole **20**, there is induced in advance of the bottom of the borehole a zone of high stress concentration, such as zone **14** in FIGURE 1, which has a height no greater than the distance h, as illustrated in FIGURES 1 and 2. Therefore, the formation material below the bottom center of borehole **20** is readily removed by the second step of the invention which comprises the drilling out of the bottom center of the borehole, as represented by hole **22** in FIGURE 2, to a depth no greater than the distance h in order to take advantage of the favorable stress conditions in this zone and thus effect ready removal of the material within the zone. In order to remain within the zone of high stress, the diameter d of hole **22** is less than the distance h. The angle between the bottom of hole **22** and its wall, angle **23**, also is preferably no greater than 90° in order to induce the highest stresses in the zone around the line of intersection of the bottom of the hole and its side wall. When hole **22** has been advanced to a distance no greater than h, the hole **20** is again drilled until its depth has been extended to a point coincident with the bottom of hole **22** which again advances the zone of high stress concentration in the formation for a distance h below the bottom of hole **20**. Hole **22** is then again advanced for a distance h into the formation below the bottom of hole **20**. These steps are alternatively repeated until the borehole has been advanced to the desired distance into the formation. Obviously, with each incremental advance of the outer or larger hole, there is created in advance of the bottom of the hole the favorable high stress concentration zone into which the smaller inner hole is then drilled. The borehole may be readily advanced as described by the alternate use of large and small drill bits on the drill string to effect the drilling of the two different size holes necessary in carrying out the invention.

As the outer or larger borehole, for example, borehole **20** in FIGURE 2, is advanced, there is simultaneously a constant advance of the zone of high stress concentration for the distance h ahead of or below the bottom of the larger or outer borehole. It has, therefore, been determined that the smaller or inner borehole **22** may be drilled simultaneously with the drilling of the larger outer borehole **20**. In this manner, there will be a constant advancing of the smaller inner borehole into the zone of high stress concentration as that zone is advanced with the drilling of the outer larger borehole **20**. Obviously, this latter process of the simultaneous drilling of the inner and outer boreholes is to be preferred over the above-described method of drilling the holes separately, which may require a large number of bit changes and removals of the drill string from the borehole.

In its preferred form, therefore, the method of the invention is carried out by drilling a first borehole and simultaneously drilling a second borehole which is substantially concentric with the first borehole and encompassed by the first borehole. The second borehole is maintained in advance of or below the first borehole for a distance h which is less than the diameter D of the first borehole. Also, the diameter d of the second borehole is less than the distance of advance h between the bottom of the second borehole and the bottom of the first borehole.

Apparatus, in accordance with the invention, which may be utilized to carry out the preferred form of the method of the invention is illustrated in FIGURES 3 and 4. The apparatus of FIGURE 3 in its simplest terms comprises a two-stage drill bit which is properly proportioned to provide the desired borehole geometry in accordance with the invention. The apparatus of FIGURE 3 includes a bit body, or housing, **30** which is threadedly connected to the lower end of drill string **31**. Secured to body **30** are a plurality of upper, outer cutting elements or cones **32** which function to drill the larger outer portion of the borehole **20**. The effective cutting surfaces of cones **32** are preferably aligned in a plane normal to the longitudinal axis of bit body **30** so that the angle of the bottom of hole **20** with the side wall of the hole will be substantially 90°, as discussed above in connection with FIGURE 2. Cones **32** are arranged around the bit body in a circular fashion such that they will cut a hole having a diameter D. Positioned on the lower end of bit body **30** is a second set of inner or lower cones **35** which serve to cut the inner borehole **22** which, as previously explained, extends into the zone of high stress concentration effected by the drilling of the larger outer borehole. The cutting surfaces of the lower cones, as they form the bottom of hole **22**, are, like cones **32**, positioned so that the bottom of the borehole will lie in a plane substantially normal to the longitudinal axis of the drill bit in order that the angle between the bottom of the hole and the wall of the hole will be substantially 90°. Cones **32** and **35** are of conventional design as may be found in presently commercially available roller-cone type drill bits. The bit body **30** may be provided internally with fluid flow passages which will conduct drilling fluid to the areas around the cones **32** and **35** to

flush the cuttings from the borehole. Such passages are conventional in design and, thus, are not illustrated in FIGURE 3. Cones **35** are arranged around a circle such as to cut a hole **22** having a diameter d, and the cones are placed on the bit body **30** a distance below cones **32** such that the bottom of hole **22** will be cut a distance h in advance of the bottom of hole **20**. The relationship between the circle over which cones **35** are spread, d, and that over which cones **32** are spread, D, together with the distance h between the cutting surfaces of cones **35** and cones **32**, is set out in the following expression:

$$d<h<D$$

FIGURE 4 illustrates another form of drilling apparatus which may be utilized in carrying out the preferred form of the invention. The drilling apparatus illustrated in FIGURE 4 is provided with a tool body or casing **40**, to the lower end of which is rotatably secured a drill bit **41** which includes a plurality of cutting elements **35**. Bit **41** is connected to a prime mover **42** which is supported within the tool housing. Prime mover **42** may be a fluid turbine actuated by drilling fluid flowing through the tool housing or it may be an electric motor. In lieu of prime mover **42**, bit **41** may be actuated by a shaft extending from the surface through the drill string and tool housing. Tool housing **40** is secured to the lower end of a drill string, not shown, in the same manner as the bit illustrated in FIGURE 3. Secured to tool housing **40** are a plurality of cutting elements **32** which perform the same function as cutting elements **32** on the tool illustrated in FIGURE 3. In the tool of FIGURE 4, the effective cutting diameter of cutting elements **32** is represented by D, while the effective cutting diameter of cutting elements **35** is represented by d as explained with reference to FIGURE 3. The planes in which cutting is accomplished by elements **35** and elements **32** are spaced apart vertically the distance represented by h.

The relationship of the effective cutting diameters of lower cutting elements **35** and upper cutting elements **32**, in the apparatus of both FIGURES 3 and 4, is preferably in accordance with the following expression:

$$0.2D<d<0.6D$$

In this preferred form of apparatus of both FIGURES 3 and 4, h is greater than 0.6D and less than D.

Each of the drilling tools illustrated in FIGURES 3 and 4 is used with a conventional type rotary drilling rig to drill a borehole in accordance with the method of the invention. The tools of the invention are rotated by the drill string with cutting elements **32** drilling the first or outside large borehole, while cutting elements **35** drill the smaller inside advancing borehole within the zone of stress concentration created in the formation by cutting elements **32**. As the borehole is advanced, this zone of stress concentration is constantly advanced by virtue of the action of the cutting elements **32**, while within this zone of stress concentration the cutting elements **35** are constantly drilling the smaller advancing hole **22**, as illustrated in FIGURES 2 and 3. By virtue of the simultaneous forming of the concentric boreholes **20** and **22**, a final borehole of diameter D is formed with the expenditure of less total energy than is normally required by conventional, presently employed procedures and apparatus.

Having thus described the method and apparatus of the present invention, it is to be understood that such are limited only within the scope of the appended claims.

What is claimed is:

1. In a method of drilling a borehole in an earth formation, the steps which comprise:

(a) drilling a first hole into said formation to induce a zone of stress concentration in advance of the bottom center of said hole;

(b) drilling a second hole through the bottom center of said first hole into said zone of stress concentration, said first and second holes being related in accordance with the expression

$$d<h<D$$

where

d is the diameter of said second hole,

h is the distance said second hole is drilled into the bottom center of said first hole, and

D is the diameter of said first hole; and

(c) alternately repeating steps (a) and (b) until said formation has been penetrated the desired distance.

2. The method of claim **1** wherein $0.2D<d<0.6D$.

3. The method of claim **2** wherein the angle between the bottom and the wall of said first hole and the angle between the bottom and the wall of said second hole are no greater than 90°.

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