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Technical Specification for Directional Drilling

定向钻探技术规程

（*English Translation*）

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Contents

Foreword

SAC/TC 93 (National Technical Committee on Land and Resources) is in charge of this english translation. In case of any doubt about the contents of english translation, the Chinese original shall be considered authoritative.

This document is drafted in accordance with the rules given in the GB/T 1.1-2009 *Directives for standardization-Part 1: Structure and drafting of standards*.

This document replaces the DZ/T 0054—1993 *Technical Standard for Directional Drilling* in whole. On the basis of inheriting the important technical contents of DZ/T 0054-1993 , this specification supplemented and modified the name, chapter structure, technical contents and annex contents of the standard. In addition to a number of editorial changes, the following technical deviations have been made with respect to the DZ/T 0054—1993:

——The name of the standard is changed to "Technical Specification for Directional Drilling";

——Structural contents such as "Preface", "Table of Contents" and "References" are added;

——Chapters such as "Normative References", "Special Directional Drilling", "Control of Directional Borehole Trajectory ", " Measurement of Direcitonal Borehole and Calculation of Trajectory " are added, and the text arrangement is technically modified;

——Some significant modifications are made in chapters of "Design of Direcitonal Drilling Engineering", "Selection of Directional Drilling Equipment and Apparatus", "Construction Technology of Directional Drilling", and "Prevention and Treatment of Directional Drilling Accidents";

——Some out of date and unsuitable contents of technology are deleted, and new contents related to new equipment, new apparatus and new technology are added;

——The parameter tables of mud pump, continuous whipstock and hydraulic bottom hole drilling tool recommended in "Selection of Directional Drilling Equipment and Apparatus" are deleted, and some record tables for inclination measurement during kick-off drilling, final hole acceptance inspection, and calculation of trajectory coordinates of direction hole axis are supplemented;

——Two annexes related to "Calculation of Directional Tool Face Angle" and "Method for

Calculating the Axis Trajectory of Directional Borehole " are added.

This document was proposed by Ministry of Land and Resources of the People's Republic of China.

This document was prepared by SCA/TC 93(National Technical Committee 93 on Land and Resources of Standardization Administration of China).

The previous edition of DZ/T 0054 is as follows:

——DZ/T 0054-1993.

Technical Specification for Directional Drilling

1 Scope

This document specifies the technical requirements for design, equipment selection, construction technology, trajectory control and measurement, Accidents prevention and treatment, construction management and other technical requirements for directional drilling.

This document is applicable to directional drilling in geological core drilling engineering. The design and construction of directional drilling in engineering exploration, engineering construction, hydrological well drilling, and petroleum and gas well drilling can refer to this document.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document(including any amendments) applies.

GB/T 5005 *Specifications for Drilling Fluid Materials*

GB 9151 *Terms of Drilling Engineering*

AQ 2004 Safety *Regulations for Geological Prospecting Operation*

DZ/T 0227 *Geological Core Drilling Regulations*

3 Terms and Definitions

For the purposes of this document, the following terms and definitions apply. For the convenience of usage, some terms and definitions related to directional drilling in GB 9151 are listed here, and some of them are supplemented and improved.

3.1
directional drilling

Drilling method that makes use of the natural bending law of borehole or uses aritificial deflecting tool to produce a certain bend in the borehole to force the axis of the borehole to extend according to the designed trajectory

3.2
preliminary directional borehole

Directional borehole that is drilled by using conventional techniques and technologies and the natural inclination trend and law of formation

3.3
controlled directional borehole

Directional borehole drilled with deflecting tool and technological measures, and its axis extends along the designed trajectory

3.4
main borehole

Borehole that is firstly designed and constructed

3.5
branch borehole

Borehole that is separated from the main borehole

3.6
horizontal borehole

Borehole that the axis of its final section is nearly horizontal

3.7
intersected borehole

Two or more boreholes that separated by a certain of distance and required to be connected within the target area

3.8
drift angle

Angle between vertical line and the tangent line of a given point on the axis of a borehole

[GB/T 9151-1988, Definition 14.1.4]

3.9
azimuth angle

In horizontal plane, starting clockwise from the due north direction, the angle between due north and the tangent line of a point on the horizontal projection of the borehole axis

[GB/T 9151-1988, Definition14.1.1]

3.10
deflection rate

Total bending angle of a borehole per unit footage produced in kick-off drilling

3.11
target

Designed terminal point of a borehole

3.12
target area

Allowable deviation area centered a target

3.13
tool face angle

Angle between the plane of the bending direction of a deflecting tool and the vertical plane of the borehole axis at the kick-off point

3.14
inverse torque angle

Angle of a shell that housing downhole drilling tool rotates anticlockwise due to the negative torque generated by positive displacement motor (PDM)

3.15
measuring while drilling (MWD)

Technique that is capable of real-time measuring downhole parameters during drilling.

3.16

electro-magnetic measuring while drilling (EMWD)

Technique of MWD that utilizing electromagnetic wave for data transmission

3.17
vertical drilling system (VDS)

Drilling system that is capable of maintaining a vertical borehole by real-time measuring and automatically correction of borehole deflection.

3.18
mud pulse measuring while drilling (MP-MWD)

Technique of MWD that transmitting data via the pressure change of drilling fluid

3.19
target-hitting guidance system

Drilling system that guiding the drill bit into the target by measuring the relative position between drill bit and the target with the help of measuring techniques such as artificial magnetic field

4. Design of Directional Drilling Engineering

4.1 Basic Design Requirements

4.1.1 Each directional drilling engineering should be designed before construction and should not be constructed without being approved.

4.1.2 In case that there are multiple directional boreholes to be drilled in one area, the overall construction design and single hole design should be provided. For directional boreholes with the same structure, the representative single borehole design is enough.

4.2 Design Basis

4.2.1 Geological conditions

4.2.1.1 Geological structure, occurrence of rock stratum or ore bed, morphology of mine, formation pressure, geothermal gradient and characteristics of drilling.

4.2.1.2 Stage of exploration, density of exploration grid and depth of target stratum.

4.2.1.3 If magnetic instruments are to be used, it is also necessary to understand the geomagnetic field parameters in the construction area, such as the intensity of magnetic field, the angle of magnetic inclination and declination, etc.

4.2.2 Metrological Data

Meteorological data of the exploration area includes annual temperature, humidity, barometric pressure and precipitation, etc.

4.2.3 Topographic Conditions

The limitation of ground surface to the location of boreholes.

4.2.4 Historical Construction Data

Inclinometer data of completed boreholes (if any) in the same area.

4.2.5 Requirements for Target-hitting

Requirements for the dimension of target area.

4.2.6 Contract or Agreement

A contract or agreement between the client and the designer that concerning the design of exploration projects.

4.3 Design Contents

4.3.1 Design of Axis Trajectory of Directional Borehole

4.3.1.1 Select the appropriate design and calculation method of directional borehole trajectory. The recommended method for the design and calculation of directional borehole trajectory is shown in Annex A.

4.3.1.2 Determine the type and profile of directional boreholes.

4.3.1.3 Determine the accuracy of target-hitting.

4.3.1.4 Determine the penetration angle at the target.

4.3.1.5 Determine the position of kick-off point or branch point.

4.3.1.6 Determine the curvature and length of curved borehole section.

4.3.1.7 Determine the spatial elements of each borehole section.

On the basis of the determined target area, penetration angle at the target, the position of the deflecting point or branch point, and the curvature of the curved borehole section, the following parameters should also be investigated:

a) The length of each borehole section;

b) Drift and azimuth angles of starting and ending point of each borehole section;

c) Vertical depth and horizontal displacement of starting and ending point of each borehole section.

4.3.1.8 Draw the designed 3D graph or 2D projection chart of borehole trajectory.

4.3.1.9 Check the curvature of the borehole.

4.3.1.10 Determine the borehole structure.

4.3.2 Design of Directional Borehole Drilling Technology

The following contents for the design of directional borehole drilling technology should be included:

a) Selection of equipment, tools, and instruments;

b) Parameter matching calculation among drill rig, mud pumps and directional drilling tools;

c) Design of bottom hole assembly;

d) Design of key technical parameters;

e) Directional drilling method and measurement techniques;

f) Technical measurements for orientation, angle building and angle holding drilling;

g) Tools and techniques for core sampling;

h) preparation of drilling fluid and measurements for borehole protection and leaking plugging;

i) Preparatory plan in case kick-off operation fails.

4.3.3 Design of Construction Organization for Directional Borehole Drilling

The following contents should be included in the design of construction organization of directional borehole drilling:

a) Staff organization and pre-service training;

b) Maintenance, usage and storage of equipment, instruments and materials;

c) Construction period plan;

d) Supply of water and electricity, and logistic support measurements;

e) Contingency plan;

f) Safety and environmental protection measures;

g) Estimated economic benefits.

4.4 Technical Requirements of Design

4.4.1 Fully understand the raw data of directional boreholes.

4.4.2 Ensure the purpose and requirement of the engineering.

4.4.3 Make full use of the natural deflection law of formations to minimize the workload of artificial deflection.

If conditions permit, the primary directional borehole should be used as far as possible to hit the target.

4.4.4 Choose reasonable sequence in trajectory design.

The design sequence of the trajectory of borehole axis should be reasonably selected according to the following requirements.

a) If the position of hole-opening point or branch point is determined, generally the trajectory should be designed from this position to the target; otherwise, the trajectory should be designed from the target to the position of hole-opening point or branch point.

b) For multiple branch boreholes, the main borehole should be designed firstly, then branch holes.

4.4.5 The penetration angle should not be less than 30°. Choose larger angle when conditions permit.

4.4.6 Choose an appropriate borehole curvature, to obtain the minimum borehole depth on the basis of ensuring that coarse diameter drilling tools and casing pipes can passing through smoothly, and the safety of the drill string is guaranteed.

4.4.7 The drift angle of the borehole should be selected reasonably, and the main borehole of deeper directional holes and multi-branch holes should be designed as a straight hole.

4.4.8 Determine the appropriate position of kick-off point and branch point.

Attention should be paid to the following points when determining the position of kick-off point or branch point:

a) The position of kick-off point or branch point should be selected in stable rock layer, avoiding hard, brittle, fractured rock layers, karst caves and sand layers.

b) If the vertical depth of the target is small and horizontal displacement is large, the position of kick-off point or branch point should be selected at the shallow part of the borehole; otherwise, it should be selected at the deep part of the borehole.

c) Kick-off point, branch point and the deflecting section of borehole should not be selected in the ore bed, the roof of the ore bed, the floor of the ore bed or the geological marker layer, avoiding the ore bed and mineralized zone.

4.4.9 The convenience and safety of drilling operation should be considered in the design of the trajectory of borehole axis.

4.4.10 Determine an appropriate borehole structure.

When determining the borehole structure, attention should be paid to:

a) Factors such as properties of formation, measurements for borehole wall stability, drilling method and end hole diameter should be considered comprehensively. The borehole structure should be simplified on the premise of safety drilling operation.

b) In case of complex strata, multiple borehole diameters and casing pipes should be adopted.

4.4.11 Pay attention to social and economic benefits.

5. Selection of Directional Drilling Equipment and Apparatus

5.1 Selection of Conventional Drilling Equipment

5.1.1 Equipment for conventional drilling should be selected based on the stratum conditions of mining area, designed borehole depth, borehole structure, drilling method and the type of deflecting tool, etc.

5.1.2 Hydraulic drill rig with large speed range and drilling parameter instrument should be selected.

5.1.3 Mud pump that is compatible with the deflecting technology should be selected. When drilling with PDM, the mud pump should also meet the requirements of PDM running.

5.2 Selection of Deflecting Tool

5.2.1 Eccentric Wedge

5.2.1.1 The eccentric wedge is suitable for the integral formation with drillability above grade 4.

5.2.1.2 Depending on the drillability of rocks and requirements of kick-off drilling, the vertex angle of eccentric wedge should be in the range of 2° to 5°. If drilling in soft formation, or only a short distance needs to be drilled after deflection by eccentric wedge, a larger vertex angle could be chosen. Otherwise, a smaller vertex angle should be used.

5.2.1.3 Fixed eccentric wedge is suitable for branch hole kick-off drilling, while retrievable eccentric wedge is suitable for kick-off drilling from the original hole bottom.

5.2.1.4 The open type eccentric wedge with fully open top could be used for the same diameter directional drilling, while the close type eccentric wedge with support ring on the upper part can only be used for the situation that the diameter of eccentric wedge is one grade smaller than that of drilling hole in kick-off drilling.

5.2.1.5 When the drift angle of the borehole is greater than 30°, eccentric wedge is not suitable for azimuth correction.

5.2.2 Continuous whipstock

5.2.2.1 Continuous whipstock should be used in integral formation.

5.2.2.2 Continuous whipstock could be driven by drill string or PDM.

5.2.2.3 Continuous whipstock should be fixed firmly in the borehole, otherwise it couldn't be used for kick-off drilling.

5.2.2.4 Continuous whipstock is suitable for the same diameter continuous kick-off drilling, and the intensity of deflection should be restricted in the range of 0.3°/m to 1.8 °/m.

5.2.3 PDM

5.2.3.1 When continuous deflecting is required and the deflecting tool is required to have strong adaptability to the formation, PDM should be selected. PDM can be used not only in medium hard to hard formations, but also in weak and broken rock layers, or formations with drillability as low as grade 3.

5.2.3.2 Appropriate parameters should be selected in kick-off drilling with PDM. It is suitable that the intensity of deflection to be restricted in the range of 0 to 1.2°/m. In special situations, the deflection intensity can be increased to 1.2°/m to 2°/m, but this intensity could not be used for long distance or continuous kick-off drilling.

5.2.3.3 Appropriate stator-rotor ratio of PDM should be selected according to flow rate and pressure of mud pump, weight on bit (WOB) and drilling torque.

5.2.3.4 The rotary speed and torque of PDM should be determined according to the drillability of stratum and the type of drill bit.

5.2.3.5 Suitable deflection parts should be configurated according to the requirement of kick-off drilling, such as fixed bent sub, bent outer tube, double bent outer tube, adjustable bent sub and near-bit eccentric block, etc.

5.2.3.6 PDM should have priority to be chosen as deflecting tool in the construction of directional borehole, such as horizontal borehole, intersected borehole, or high precision vertical borehole.

5.2.3.7 After overhaul, the PDM is not allowed to be further used if it has not undergone factory test, issued a test report and obtained a product quality certificate.

5.3 Selection of Measuring Instruments

5.3.1 Measuring instrument should be selected according to the type of deflecting tool, the requirement of orientation precision and the existence of magnetic field disturbance.

5.3.2 In non-magnetic mining area, magnetic inductive measurement instruments can be selected, such as single shot clinometer, multi shot clinometer, MWD clinometer, etc. In magnetic mining area, measuring instruments that are free from magnetic field disturbance should be selected, such as gyro clinometer, photoelectric clinometer, and strain gauge type clinometer, etc.

5.3.3 When orientating with eccentric wedge or continuous whipstock, generally single shot orientation instrument should be utilized, and the drift angle of borehole should be no less than 3°.

5.3.4 In kick-off drilling with PDM, single shot clinometer, multi shot clinometer, or MWD clinometer can be used.

5.3.5 When high precision vertical boreholes are drilled, vertical drilling system can be used.

5.3.6 When intersected boreholes are drilled, MWD clinometer and target-hitting guidance system should be used.

5.4 Selection of Deflecting Bit

5.4.1 The deflecting bit should be selected according to the rock drillability of the deflecting section and the type of deflecting tool.

5.4.2 For stratum with drillability equal to or lower than grade 6, cone bit, carbide bit, PDC bit or diamond bit should be used. For formations with drillability equal to or larger than grade 7, diamond drill bit is suitable.

5.4.3 When a full face deflecting bit is used in hard rock stratum, the drill bit should be set a central water nozzle to drill small cores to avoid forming a "dead point" in the center of the bit; when using a full face deflecting bit in soft and medium hard rocks, an asymmetric inner cone eccentric water nozzle should be set.

5.4.4 At the bottom of the diamond bit, there should be a concave angle of around 170° and enough passage for water flow.

5.4.5 High grade diamond should be selected for the outer cutting blade of diamond bit. The height of the cutting blade should be short, and the blades should be strengthened; the inner cutting blades of the deflecting bit with central water nozzle should also be strengthened.

5.4.6 When the continuous whipstock is used to make a deflect drilling, the drill bit with sharp cutting blades should be used.

5.5 Selection of Auxiliary Tools for Directional Drilling

5.5.1 Non-magnetic drill pipe

The length of non-magnetic drill pipe should not be less than 5m. The relative magnet conductivity of non-magnetic drill pipe must be less than 1.02, and high tensile strength and good corrosion resistance are also required.

5.5.2 Cable swivel

Cable swivel is a kind of swivel whose center is hollow, allowing a cable to pass through. The cable swivel should be selected by:

a) The diameter of the through hole should be big enough to allow the measuring instrument to pass through smoothly;

b) Ensure the sealing performance between the armored cable and the through hole of the swivel;

c) Its capacity of enduring pressure should match with the working pressure of mud pump;

d) Its hoisting weight should match with the hook load.

5.5.3 Armored cable and winch

Armored cable and winch should be selected by:

a) The number of cores of armored cable should be selected according to the signal transmission mode of measuring instrument;

b) The diameter and length of armored cable should be determined according to the depth of directional borehole. Also, the total length of cable should be reserved;

c) The winch should be selected according to the diameter and length of the armored cable;

d) The winch should be equipped with gearshift, reliable brake, and instrument that is capable of measuring the length of cable precisely.

5.5.4 High pressure hose

When PDM is used for kick-off drilling, the pressure resistance of high-pressure hose should be no less than 20MPa.

5.5.5 pressure stabilizing tank

When PDM is used for kick-off drilling, a pressure stabilizing tank must be installed in the output pipeline of the mud pump, and its safety pressure should not be lower than 20MPa.

5.5.6 Selection of mud purification facilities

Solid control devices should be equipped in mud circulation system, and filter devices should be installed in the suction pipeline and the output pipeline.

5.5.7 Anti-torque device

For directional drilling with PDM, anti-torque device should be installed.

6 Construction Technology of Directional Drilling

6.1 Preparation Prior to Directional Drilling

6.1.1 Before kick-off drilling, the borehole should be cleaned, the residual core should be removed, the cutting chips in the bottom of the hole should be washed away, and the hole depth should be calibrated.

6.1.2 If it is difficult to drill a new borehole in branch kick-off drilling, an artificial bottom of borehole should be constructed.

6.1.3 Before kick-off drilling, all parts of measuring instrument, cable and winch should be checked to ensure them running properly.

6.1.4 Before kick-off drilling, the drill rigs, mud pumps, drill strings, power systems and high-pressure pipeline systems should be inspected and confirmed to be in normal operation. The instruments equipped in the drill rig should be sensitive and reliable.

6.1.5 Appropriate drilling fluid should be prepared to ensure the circulation system works normally.

6.2 Construction of Artificial Borehole Bottom

6.2.1 The construction of artificial borehole bottom is to fill the well section below the branch point with filling materials or appliance, so as to provide a solid foundation for the deflecting operation.

6.2.2 The artificial hole bottom bridging materials can be wood plugs, metal plugs and cement plugs, and cement plugs are recommended.

6.2.3 If the upper and lower borehole walls of the branch point are regular and there is no diameter enlargement phenomenon, wooden plug or metal plug can be used as a bridge in the hole, and the upper part above the plug is filled with cement to form artificial hole bottom.

6.2.4 If the branch point is close to the bottom of the borehole, or if the hole wall is irregular or excessively large, wooden or metal plugs cannot be used to "bridge", then inert material such as sand, gravel or cement could be grouted from borehole bottom to the predetermined position.

6.2.5 High grade Portland cement, super hardening cement and oil well cement can be used as cement plug materials for artificial hole bottom, and the latter two should be used when conditions permit.

6.2.6 In the process of artificial cement hole bottom establishing, the borehole should be cleaned before grouting, and the cement should be poured to 15m — 20m above the branch point. The cement core should be drilled out after curing for 48—72 hours, and whether to start the branch drilling can be determined according to the solidification condition of the cement.

6.3 Check of Deflecting Tool

6.3.1 Check of Eccentric Wedge

6.3.1.1 The supporting clamp should be able to stretch out and draw back freely.

6.3.1.2 The surface of wedge should be smooth.

6.3.1.3 The connection of each component after assembly should be firm and reliable.

6.3.2 Check of continuous whipstock

6.3.2.1 Before use, the continuous whipstock should be assembled and tested in accordance with the requirements of the instruction manual.

6.3.2.2 After assembly, all parts of the continuous whipstock should be rotate flexibly, and the supporting clamp could be stretched out or drew back freely.

6.3.2.3After using for 1-2 times, it should be disassembled for cleaning and inspection, and the worn parts should be replaced.

6.3.3 Check of PDM

6.3.3.1 The drilling tool must be assembled, disassembled and tested in strict accordance with the assembly drawings and operation manual.

6.3.3.2 Before tripping in the drill string, start the PDM at the borehole orifice, check whether the bypass valve can close and open flexibly, and check whether the PDM can work normally under the starting pump pressure and idle pump pressure.

6.4 Lowering of Deflecting Tool

6.4.1 Deflecting tool should be lowered slowly.

6.4.2 Do not run into the hole the drill pipe that is bent, deformed, or has poor thread sealing or other defects. Before connecting the drill pipe to the drill string, check whether there is any blockage in the drill pipe.

6.4.3 When the continuous whipstock is stuck in the process of running into the borehole, it should be lifted out of the hole, and then use the conventional drilling tool to remove the obstacles in the hole. The continuous whipstock should not be used as a borehole sweeping tool.

6.4.4 Before running into the casing, the PDM should be checked for its passing ability in the casing, so as to avoid that the drilling tool cannot run in due to excessive diameter caused by the bent outer tube.

6.4.5 When PDM encounters resistance in the lowering process, the pump can be opened to flush the hole, remove the obstacles or trim the hole wall. When flushing the hole, the WOB should be low, and the lowering speed should be slow. Rotate the drill pipes reversely is forbidden.

6.4.6 When the deflecting tool is lowered around 0.5m above the borehole bottom, the mud pump should be started to flush the borehole. When directional drilling with PDM, it should be confirmed that the PDM runs normally before directional drilling starts.

6.5 Orientation of Deflecting Tool

6.5.1 Determination of tool face angle

6.5.1.1 The face angle of deflecting tool can be calculated by plotting or formula. Please refer to Annex B for the calculation of tool face angle.

6.5.1.2 The assembly errors caused by the assembly of the directional joint and the deflecting tool must be included in the value of tool face angle.

6.5.1.3 After deflecting tool goes into the borehole, it must orient to the designed tool face angle.

6.5.2 Method of Orientation

6.5.2.1 If the drift angle $\theta \leqslant 3°$, the direct orientation method should be used.

6.5.2.2 If the drift angle $\theta > 3°$, both direct and indirect orientation methods can be used.

6.5.2.3 In kick-off drilling with PDM and requiring high accuracy target-hitting, MWD method should be adopted.

6.5.3 Orientation operation

6.5.3.1 The operator must fully understand and master the principle, structure, performance, scope of application, operation method and maintenance technology of the measuring instrument.

6.5.3.2 Before the measuring instrument being put into the borehole, its accuracy of drift angle, azimuth angle and tool face angle should be verified, and the calibration record should be kept.

6.5.3.3 A short section of safety cable, which has a lower tensile strength than normal cable, should be set between the probe tube and the armored cable.

6.5.3.4 The annulus space between the probe tube and the inner wall of non-magnetic drill pipe should be less than 3mm, otherwise, a centralizer should be connected to the probe tube to ensure that the inclined pipe shoe at the lower part of the probe tube could enter the spline smoothly.

6.5.3.5 The lowering of the probe tube in the drill string should be slow and steady to avoid damage to the instrument due to obstruction or excessive impact when entering the spline.

6.5.3.6 In orientating with wireline measuring instrument, the probe tube should be lifted and lowered for several times. If the results are repetitive, it means that the probe tube is at the right position.

6.5.3.7 After orientation, it is unnecessary to take MWD instrument out of probe pipe, but the connection between swivel and cable should be sealed tightly.

6.6 Kick-off Drilling with Eccentric Wedge

6.6.1 When drilling directional holes at the bottom of natural holes or implementing borehole direction rectification, a removable eccentric wedge should be used.

The following construction technology should be followed when using retrievable eccentric wedge:

a) The eccentric wedge is lowered to about 0.5m away from the hole bottom with drill pipes, and then it is oriented; after orientation, the eccentric wedge is lowered to the hole bottom, and the wedge body is clamped with the hole wall by pressure.
b) Drill the Directional borehole with smaller size drill bit along the wedge face, until the drilling distance from the wedge surface is 2.5m to 3.0m.
c) Ream the hole to the final depth of the new hole with a tapered guide bit of the same diameter, and continue drilling after the hole wall is trimmed.

6.6.2 In branch drilling at artificial borehole bottom, it is recommended to use fixed eccentric wedge.

When fixed eccentric wedge is used, the following construction technology should be followed:

a) The eccentric wedge marked with orientational generatrix is lowered to the position about 0.5m above the hole bottom with drill pipes. After orientating, the eccentric wedge is lowered to the artificial hole bottom, and the wedge body is clamped with the hole wall by pressure. Continue exerting pressure until the bolt connecting eccentric wedge and drill pipe is broken, keep the eccentric wedge left at the bottom of the hole.
b) Drill along the wedge surface with a tapered bit until a distance of 0.5m to 1m away from the wedge surface, and then, change to inclined extension drilling tool continue drilling for 3m more.
c) Survey the inclination to confirm whether the new bottom of branch borehole is formed as expected;
d) Trimming the borehole to make sure that conventional drill string could pass the deflecting section smoothly.

6.6.3 When drilling through the wedge surface, it should be performed with low WOB, low rotary speed, low rate of penetration, and the drilling string should be lifted frequently.

6.7 Kick-off Drilling with Continuous Whipstock

6.7.1 In kick-off drilling with continuous whipstock, the drilling parameters should be determined according to the drillability of stratum and the type of drill bit. Generally, the WOB is 25-30 kN, the rotary speed is 100-200 rpm, and the flow rate of pump is 50-80 L/min.

6.7.2 When the continuous whipstock is lowered down to about 0.5m away from the bottom of the hole, the pump flow rate should be increased while the whipstock getting down to the bottom of the hole. After the pump pressure is normal, lift it away from the bottom of the hole for orientation.

6.7.3 WOB should be imposed before drilling start, and it should be higher than that of normal drilling, to ensure that the rotor of continuous whipstock is firmly fixed with borehole wall. Drill 0.2-0.3m deep with slow speed, if there is nothing abnormal, continue drilling with normal parameters.

6.7.4 It is strictly forbidden to lift the drilling tool during kick-off drilling; pay attention to changes in pump pressure.

6.7.5 When adding a drill pipe into the drill string, stop the rotation of drill string firstly, then unload WOB. After a drill pipe is added to the drill string, WOB must be imposed firstly before starting the rotation of drill string. The rotary table should not be started unless enough WOB is imposed.

6.7.6 During kick-off drilling, if the orientation of continuous whipstock is changed due to improper operation, the drilling should be halted immediately, and the drill string should be raised to the surface. Drilling could be continued only after the continuous whipstock is re-orientated to the right direction.

6.7.7 The footage of each run of kick-off drilling with continuous whipstock should be around 1.0-1.5m, depending on the aim of kick-off drilling and the strength of stratum. It should be less than 1.2m when drilling with wireline core assembly.

6.7.8 After kick-off drilling, the coarse drilling tool with a length of 1.0-1.2m should be used to trim and enlarge the borehole, and drill 2-3m more, and then extend core barrel gradually.

6.7.9 After trimming and extension drilling, clinometer should be laid down to confirm the result of kick-off drilling.

6.7.10 For kick-off drilling in the hole bottom made of cement plug, it is recommended to use drill bit with sharp blade, and increase WOB to 30-32kN, decrease rotary speed to less than 100 r/min. The footage of directional drilling should also be extended.

6.8 Kick-off Drilling with PDM

6.8.1 For kick-off drilling with PDM, drilling parameters such as deflecting rate, WOB, rate of penetration, rotary speed of drill bit, the flow rate and pressure of drilling mud should be determined according to the drillability of formations and the type of drill bit.

6.8.2 For kick-off drilling with PDM, the influence of reverse torque angle on the tool face angle should be eliminated in time.

6.8.3 When adding a piece of drill pipe into the drill string, firstly stop the rotary table and mud pump before releasing the chuck, the drill pipe should be stuck to prevent it from reverse rotation and changing the tool face angle.

6.8.4 In a homogeneous and stable formation, kick-off drilling can be completed continuously. When cores are required, kick-off drilling can be carried out in sections or alternately.

6.8.5 When using MWD technology to construct directional holes without coring, it is advisable to lengthen the footage per round trip.

6.8.6 New bit should be used in branch drilling.

6.8.7 In soft formation, branch drilling should be performed by lowering WOB. In hard rock stratum, branch drilling can be carried out after "bridging" with cement plug.

6.8.8 In the process of branch kick-off drilling, the bent outer tube PDM with 1.5° or above should be used, and the rate of penetration should be controlled within the range of 0.5m/h ~ 0.8m/h.

6.8.9 After the bottom of the new hole is formed, it should continue to drill for about 2m, flush the hole for 5-10 minutes, and then trip out the drill string.

6.8.10 After the completion of the kick-off drilling, the borehole must be trimmed, and then stable kick-off drilling can be carried out.

6.8.11 During kick-off drilling, the pressure of mud pump should be monitored closely.

6.9 Requirements of Directional Drilling for flushing fluid

6.9.1 The fluid type should be correctly selected and the performance parameters should be determined according to the characteristics of each layer, the depth of drilling, the requirements of continuous whipstock and PDM. The materials of drilling mud should meet the provisions of GB/T 5005.

6.9.2 In order to maintain the normal operation of continuous whipstock and PDM and prolong their service life, the sand content in the fluid should be controlled within 1%.

6.9.3 High quality mud with good rheological property, good lubricity and strong cuttings-carrying capacity should be used. When flushing with water, lubricant should be added to improve its lubrication performance.

7 Special Directional Drilling

7.1 High Precision Vertical Borehole Drilling

7.1.1 The deviation of high precision vertical borehole should be controlled within three thousandths (3‰), and the vertical hole should be drilled with advanced drilling equipment, instruments and construction technology.

7.1.2 Drilling tools of high stiffness should be selected, and the weighted drill collars should be used in the lower part of drill string.

7.1.3 It is recommended to use percussion drilling tools or the combination of PDM and hydraulic percussive tools.

7.1.4 Drilling parameters should be controlled strictly, such as low WOB and slow rotation.

7.1.5 If the axis of borehole is deviated, it should be corrected by PDM.

7.1.6 Deviation survey should be performed by high precision clinometer with drift angle accuracy of ±0.1° and azimuth angle accuracy of ±1.0°. The interval of survey should not be more than 10m.

7.1.7 If possible, drill the borehole with vertical drilling system, which enables measuring and straightening while drilling.

7.2 Directional Drilling of High Drift Angle and Horizontal Borehole

7.2.1 It is recommended to use downhole power drill tool.

7.2.2 It is recommended to choose power head drill rig.

7.2.3 It is recommended to use MWD instrument. If the borehole is deep, mud pulse or electro-magnetic MWD instrument is recommended.

7.2.4 When the drift angle of the hole is greater than 55°, the probe tube cannot connect with spline by gravity. In this case, it should be driven by mud pump pressure to enter into the locking spline.

7.2.5 When drilling with stable inclination in horizontal section, it is recommended to use single bent housing PDM. If drill string has enough strength, it can be rotated slowly to carry out combined drilling.

7.2.6 High quality drilling mud is recommended to enhance borehole cleaning. By adding lubricant to the drilling mud, its performance of lubricity will be improved, which facilitates to decrease resistance and to prevent stuck.

7.3 Drilling of Intersected Boreholes

7.3.1 Intersected boreholes should be drilled with high accuracy of target-hitting. High precision instruments should be adopted to monitor the trajectory of borehole and guide the drill bit to hit the target.

7.3.2 In order to improve the rate of hitting the target, it is advisable to borehole reaming or water-soluble method to expand the cavity at the target point to create a target area. For soluble minerals, the recommended target area expansion cavity diameter range is 0.5m~6m. In soft formations (such as coal seams), an excessively large enlarged cavity diameter may lead to hole collapse. Depending on the formation conditions, the enlarged cavity diameter should be controlled within the range of 0.5m to 1.0m.

7.3.3 When intersecting at weak formation, continuous and rapid drilling is recommended.

7.3.4 The MWD system with drift angle accuracy of ±0.2° and azimuth angle of ±1.5° should be used. The instrument should be calibrated regularly, and no less than once every half year.

7.3.5 When the diameter of target area is less than 3m, drilling should be performed with target-hitting guidance system to access the target accurately.

7.3.6 The axis trajectory of the target hole should be accurately measured, the displacement of the hole bottom should be calculated, and the correct space coordinate value of the intersecting point should be provided.

7.3.7 In intersected drilling with multi targets, the negative influence of the previous target hole on the subsequent mud circulation should be prevented.

7.3.8 If it fails to hit the target for the first time, a new branch borehole can be drilled, the direction of the new hole should be readjusted and the second time target-hitting operation can be carried out. The distance between the branch point and the target should not be less than 40m, and appropriate drift angle and azimuth angle should be selected.

8 Control of Directional Borehole Trajectory

8.1 Drilling in Straight Borehole Section

8.1.1 It is recommended to drill with anti-deviation BHA.

8.1.2 Monitor the deviation data. When the drift angle or azimuth angle affects trajectory control, the deviation correction measurements should be taken.

8.1.3 Make preparations before kick-off drilling.

8.2 Drilling in Kick-off Borehole Section

8.2.1 It is recommended to use kick-off assembly and non-magnetic drill pipe assembly for kick-off drilling.

8.2.2 The bending angle of kick-off assembly should be determined according to the designed deflecting rate and the deflecting difficulty of the formation.

8.2.3 The drilling parameters such as WOB, rate of penetration and flow rate of mud pump should be determined according to the type of drill bit and drillability of stratum.

8.2.4 The borehole trajectory must be monitored by fixed measuring instrument or MWD.

8.2.5 When the actual deflecting rate does not meet the requirements of trajectory control, the drill string should be lifted to the ground, and the kick-off assembly and its relevant components should be adjusted, inspected or replaced.

8.3 Drilling in Stable Inclined Section and Horizontal Section

8.3.1 Packed hole assembly, weighted drill collars or other BHA should be used to stabilize the inclined drilling.

8.3.2 Hydraulic percussion drilling or the combination of PDM and hydraulic impactor can be used for stable inclined drilling.

8.3.3 Under the condition that the coarse diameter drilling tool can pass through the curved hole section, the lengthened coarse diameter drilling tool should be used.

8.3.4 Diamond bit should be used to ensure small annular clearance.

8.3.5 If possible, the method of drilling with PDM and MWD should be adopted.

8.3.6 When the hole deviation is found to be unqualified, corresponding technical measures should be taken immediately.

8.3.7 When drilling with rib drill bit or drill bit with long outer blade, rib or carbide should be inserted at the surface of reducer for guidance and gauge protection.

8.3.8 When drilling into a new stratum, the WOB and rotary speed should be kept low and a longer core barrel should be used.

9 Measurement of Directional Borehole and Calculation of Trajectory

9.1 The method of directional drilling and the type of measuring instrument should be selected according to the design requirements and the stratum characteristics of the working area.

9.2 The instrument calibration and measuring work should be strictly executed under the instruction of operation manuals or specifications.

9.3 During kick-off drilling, each deviation measurement operation should be recorded in the form shown in Table 1.

Table 1 Deviation measurement record of kick-off drilling

Area Name: ______ Borehole ID: ______ Coordinate: X______ Y______ Z______			Formation: ______ Drillability Grade: ______ Deflecting tool: ______ Bit Type: ______ Bit Size: ______ Model of Inclinometer: ______		
No.	Measured Depth (m)	Drift Angle (°)	Azimuth Angle (°)	Date & Time	Note
1					
2					
3					
……					

Operated by: Recorded by: Checked by:

9.4 The final acceptance measurement of directional hole should be performed from the top to the bottom of the hole. The distance between the last measuring point and the bottom of the hole should not be more than 10m. All the results should be recorded in the form shown in Table 2. The measurement spacing could be 30m ~ 50m in the upper part of the hole section, 5m ~ 10m in the inclined hole section, 15m ~ 20m in the stable inclined hole section and horizontal section.

Table 2 Final Hole Acceptance Measurement Record

Area Name: ______ Borehole ID: ______ Coordinate: X______ Y______ Z______			Formation: ______ Drillability Grade: ______ Deflecting tool: ______ Date of Measurement: ______	
No.	hole	Drift Angle	Azimuth Angle (°)	Note

	depth (m)	(°)						
		1st	2nd	Average	1st	2nd	Average	
1								
2								
3								
……								

Operated by: Recorded by: Checked by:

9.5 The same measuring point should be measured twice. If the difference between two results is too much, an extra measurement should be performed. Abnormal measurement results should be analyzed and corrected.

9.6 Setting top hole coordinate as starting point, the coordinate value of each measuring point on the drilling axis is calculated according to their drift angle, azimuth angle and hole depth of each measuring point (see Annex C for calculation method). Fill in the results in Table 3, and draw the actual axis trajectory of the directional borehole.

9.7 By comparing the actual axis trajectory with designed trajectory, the accuracy of target-hitting in the directional hole can be calculated.

Table 3 Computation Sheet of Directional Borehole Trajectory Coordinate

Area name: ______________ Date: ______________

Borehole ID: ______________ Target Coordinate: X ______________

Coordinate: X ______________ Y ______________

Y ______________ Z ______________

Z ______________

No.	hole depth (m)	Drift Angle (°)	Azimuth Angle (°)	Calculated Coordinates of Directional Borehole Trajectory					
				X		Y		Z	
				△X	ΣX	△Y	ΣY	△Z	ΣZ
1									

2									
3									
……									

Calculated by: Checked by:

10 Prevention and Treatment of Directional Drilling Accidents

10.1 General Requirements

10.1.1 Prevention and treatment of common Accidents in directional drilling is referred to DZ/T 0227.

10.1.2 Operators should strictly abide by the design and operational specifications to avoid any drilling Accidents.

10.1.3 Do not store magnetic measuring instruments, non-magnetic drill pipes and strong magnetic materials together to avoid being magnetized.

10.1.4 Precision instruments such as gyro clinometer should be kept by assigned person. Be cautious during the process of transportation and usage, to avoid failure caused by excessive vibration.

10.2 Prevention and Treatment of Drilling Accidents Related to Eccentric Wedge

10.2.1 Ensure the strength of the connection between eccentric wedge and drill pipe. If the eccentric wedge falls into the hole due to the fracture of the connecting piece, the single pipe impregnated bit can be used to retrieve it.

10.2.2 After the eccentric wedge is laid down to the expected position in the borehole, in addition to the squeezing between the wedging mechanism and the hole wall, it should also be poured with appropriate amount of cement for consolidation.

10.2.3 Round steel or cast eccentric wedge should be used, and inclined guidance drilling tool with universal joint and inclined guidance diamond bit should be used. Low WOB and slow speed drilling technology should be adopted to prevent wedge surface damage.

10.3 Prevention and Treatment of Drilling Accidents Related to Continuous Whipstock

10.3.1 Do not use the continuous whipstocks that exceed the designed service life.

10.3.2 The continuous whipstock should be disassembled for inspection and the worn bearing should be replaced after 1-2 times of kick-off drilling to maintain the single action flexibility of the rotor. In the hole filled with mud of high solid content, the continuous whipstock must be cleaned and checked every time after drilling.

10.3.3 If the roller falls into the hole due to excessive wear, the coring tool or magnetic fisher can be used to retrieve it.

10.3.4 If the rotor shaft is broken and the whipstock falls into the hole, it can be retrieved by a guide male fishing tap. When the treatment is ineffective, cement can be poured into the hole and perform sidetracking.

10.4 Prevention and Treatment of Drilling Accidents Related to PDM

10.4.1 The lower part of the drill string should be new drill pipes. During tripping in or out drill string, the threads of the drill pipe joints should be checked to ensure that the screw threads of the drill pipe joints are tightened.

10.4.2 If drilling tool falls in the borehole, it could be retrieved by fishing tap.

10.4.3 After each run of kick-off drilling, the time for borehole flushing should be prolonged to prevent the drill bit from being stuck by rock chips.

10.4.4 After the completion of kick-off drilling, the PDM should be maintained to keep it clean inside.

10.5 Prevention and Treatment of Drilling Accidents in angle-holding stage

10.5.1 In angle-holding drilling, the lower part of the drill string should use relatively newer drill pipes. The rotary speed and weight on bit should be reduced. The hole wall should be trimmed to prevent drill pipes from breaking.

10.5.2 Avoid excessive deflection in local hole section, so as to prevent the formation of key slot at the sharp bending point and the occurrence of drill pipes sticking accident.

10.5.3 In case of sticking in the key slot, the stuck drilling tool should be extracted without exerting strong pulling forces.

10.5.4 After the key slot is stuck, it could be removed by the long core barrel with drill collars, and then drill with reverse drill bit or reducer with milling cutter. When the drill string is stuck when tripping out, the key slot can be swept upward by the rotating drill string.

11 Quality of Directional Drilling Borehole

11.1 Quality Requirements for Directional Drilling Borehole

11.1.1 The quality requirements for directional drilling borehole include core recovery rate and core sample arrangement, drift angle measurement, simple hydrological observation, error estimation and calibration of measured depth, raw record and borehole sealing. Except for drift angle measurement, other indicators should be implemented according to DZ/T 0227.

11.1.2 The accuracy of target-hitting is a specialized quality index for evaluating the quality of geological effect of directional drilling borehole. If the actual trajectory passes through the target area, the index is qualified, otherwise it is unqualified.

11.1.3 The borehole deviation measurement should be carried out in strict accordance with the construction design. If necessary, the measuring interval should be shortened appropriately.

11.1.4 For the inclined borehole section, coring could be omitted, and it is not taken into account in the calculation of recovery rate of overall borehole. If possible, during kick-off drilling, some short pieces of core samples could be taken as a reference for geologists.

11.2 Measurements to Improve the Quality of Directional Drilling Borehole

11.2.1 The construction must be organized according to the design. All rules and regulations must be strictly implemented.

11.2.2 Implement comprehensive quality management including design, construction inspection, regular reporting, acceptance and summary.

11.2.3 In construction, the data of borehole orientation and inclinometer must be accurate, and the inclination measurement, calculation and correction must be carried out in time.

11.2.4 The construction site should be equipped with complete angle-building and angle-holding drilling tools according to the design.

12 Management of Directional Drilling Construction

12.1 Insist on the principle that design should be done before construction and no construction without design.

12.2 The document of "Technical Design of Directional Borehole Construction" should be compiled by the personnel of construction company, and should not be execute before being approved.

12.3 Construction is not allowed if the materials needed for construction are not ready.

12.4 Before directional drilling, technicians and drill rig operators should be trained. During construction, the job responsibilities of the rig foreman, squad leader, material clerk, recorder, equipment administrator, mud administrator, etc., the shift system, the squad leader meeting system, etc. should be implemented in accordance with the relevant regulations in DZ/T 0227.

12.5 All requirements related to health, safety and environmental protection management (HSE) should be implemented according to AQ 2004 and DZ/T 0227.

12.6 Documentation of the technical data of directional drilling should follow the regulations in DZ/T 0227.

Annex A
(Informative)
Recommended Method for Directional Borehole Design and Calculation

A.1 Design and Calculation of Directional Borehole in Vertical Plane

A.1.1 For the directional borehole in vertical plan, only drift angle changes, while azimuth angle keeps constant. Generally, the curve section bents upwards, that is, the drift angle increases gradually.

A.1.2 Under normal circumstances, dip angle of seam η, vertical depth of target H, drift angle curvature of curved section K_θ and penetration angle of target δ are known, and the vertical plane is perpendicular to the seam strike.

A.1.3 Drift angle of target θ_t(°) is calculated by formula (A.1) and (A.2).

$$\theta_t = \eta + (90 - \delta), \ \theta_t > \eta \tag{A.1}$$

$$\theta_t = \eta - (90 - \delta), \ \theta_t < \eta \tag{A.2}$$

A.1.4 Curve type directional borehole is calculated by formula (A. 3) ~ (A.6) and Fig. A. 1.

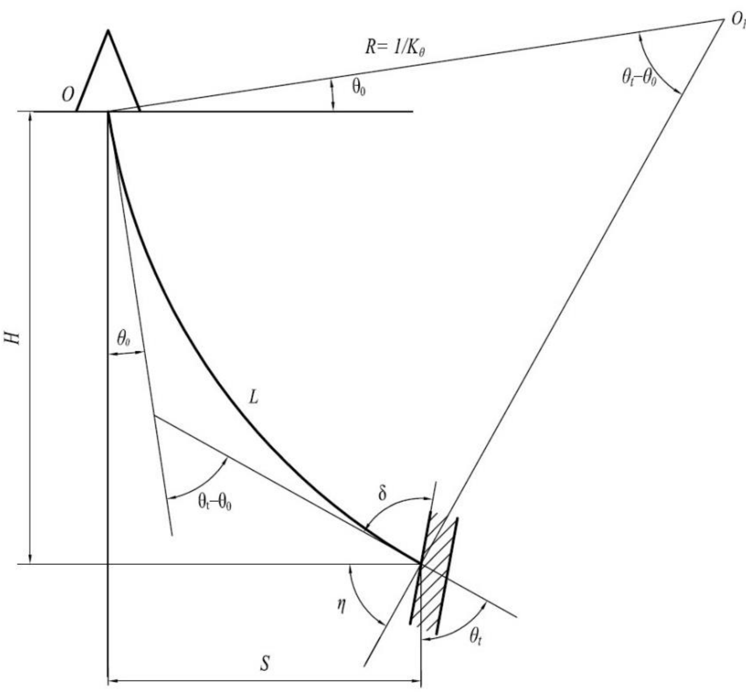

Fig. A. 1

a) Drift angle of opening borehole θ_0(°)

$$\theta_0 = \arcsin(\sin\theta_t - K_\theta H) \tag{A.3}$$

b) Horizontal displace of target S(m)

$$S = \frac{\cos\theta_0 - \cos\theta_t}{K_\theta} \tag{A.4}$$

c) Length of borehole L (m)

$$L = \frac{0.01745(\theta_t - \theta_0)}{K_\theta} \tag{A.5}$$

d) Drift angle of any given point on the axis of the borehole θ_i(°)

$$\theta_i = \theta_0 + 57.3K_\theta L_i \tag{A.6}$$

Where L_i is the length of any given point, m.

A.1.5 Curve-straight line type directional borehole is calculated by formula (A.7) ~ (A.9) and Fig.A.2.

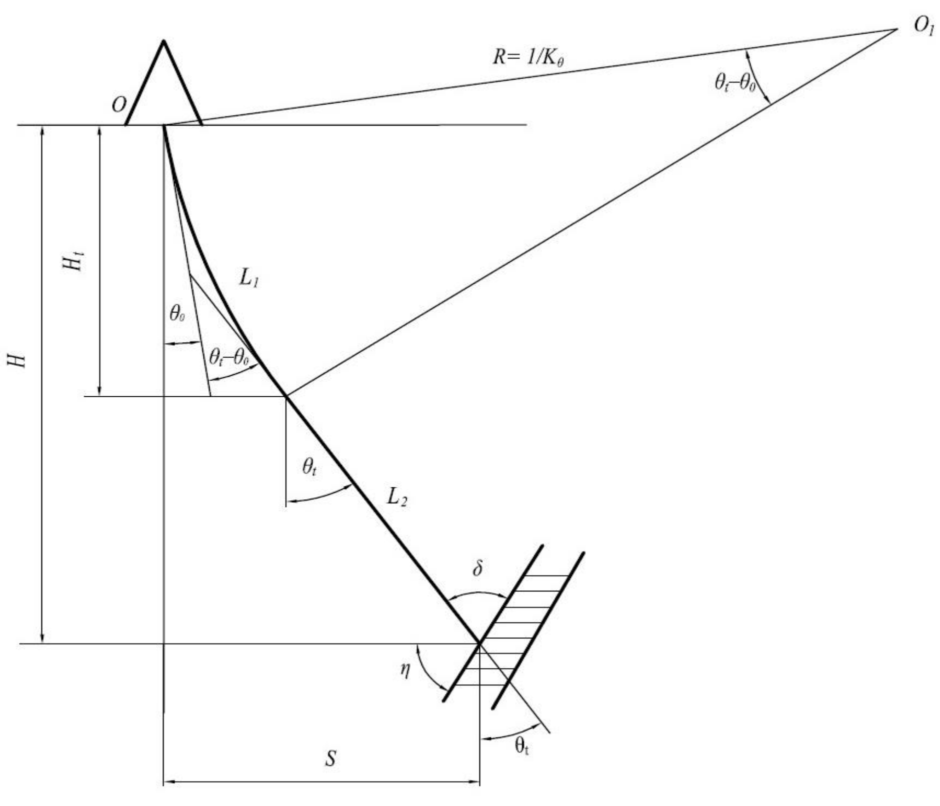

Fig. A. 2

a) Drift angle of opening borehole θ_0(°)

Normally θ_0 =0～5°.

b) Vertical depth at the end of curved hole section H_t(m)

$$H_t = \frac{\sin\theta_t - \sin\theta_0}{K_\theta} \tag{A.7}$$

c) Horizontal displacement of target S(m)

$$S = \frac{\cos\theta_c - \cos\theta_t}{K_\theta} + (H - H_t)\tan\theta_t \tag{A.8}$$

d) Length of borehole L(m)

$$L = L_1 + L_2 = \frac{0.01745(\theta_t - \theta_0)}{K_\theta} + \frac{H - H_t}{\cos\theta_t} \tag{A.9}$$

A.1.6 Straight line-curve type directional borehole is calculated by formula (A.10) ~ (A.13) and Fig. A. 3.

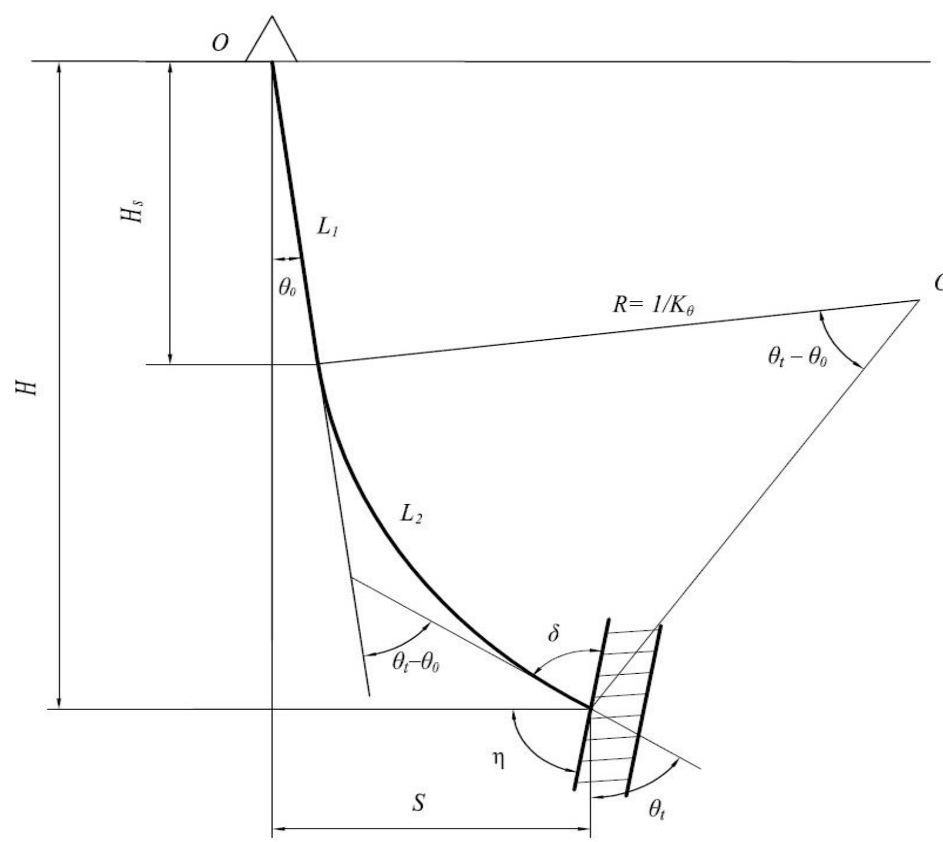

Fig. A.3

a) Drift angle of opening borehole θ_0(°)

Normally θ_0 =0～5°.

b) Vertical depth at the end of straight-line section H_s(m)

$$H_s = H - \frac{\sin\theta_t - \sin\theta_0}{K_\theta} \tag{A.10}$$

c) Horizontal displacement of target S(m)

$$S = H_s \tan\theta_0 + \frac{\cos\theta_0 - \cos\theta_t}{K_\theta} \tag{A.11}$$

d) Length of borehole L(m)

$$L = L_1 + L_2 = \frac{H_s}{\cos\theta_0} + \frac{0.01745(\theta_t - \theta_0)}{K_\theta} \tag{A.12}$$

e) Drift angle of any given point on the curve section θ_r(°)

$$\theta_r = \theta_0 + 57.3\left(L_r - \frac{H_s}{\cos\theta_0}\right)K_\theta \tag{A.13}$$

Where L_r is the length of any given point on the curve section, m.

A.2 Design and Calculation of Branch borehole in Vertical Plane

A.2.1 For branch borehole in vertical plane, only drift angle changes, while azimuth angle keeps constant. Generally, the curve section bent upwards, that is, the drift angle increases gradually.

A.2.2 Under normal circumstances, dip angle of seam η, drift angle of main borehole θ_0, vertical depth of main borehole target H, penetration angle of main borehole target δ_1, vertical depth of branch borehole target H_b, Horizontal displace of branch borehole target S_b, penetration angle of branch borehole target δ_2, drift angle curvature of curved section of branch borehole K_θ are known, and the vertical plane where the branch borehole is located is perpendicular to the direction of the strike of the seam.

A.2.3 Drift angle of target for branch borehole θ_t is calculated by formula (A.14) and (A.15).

$$\theta_t = \eta + (90 - \delta_2), \theta_t > \eta \tag{A.14}$$

$$\theta_t = \eta - (90 - \delta_2), \theta_t < \eta \tag{A.15}$$

A.2.4 Curve type branch borehole is calculated by formula (A.16) ~ (A.18) and Fig.A.4

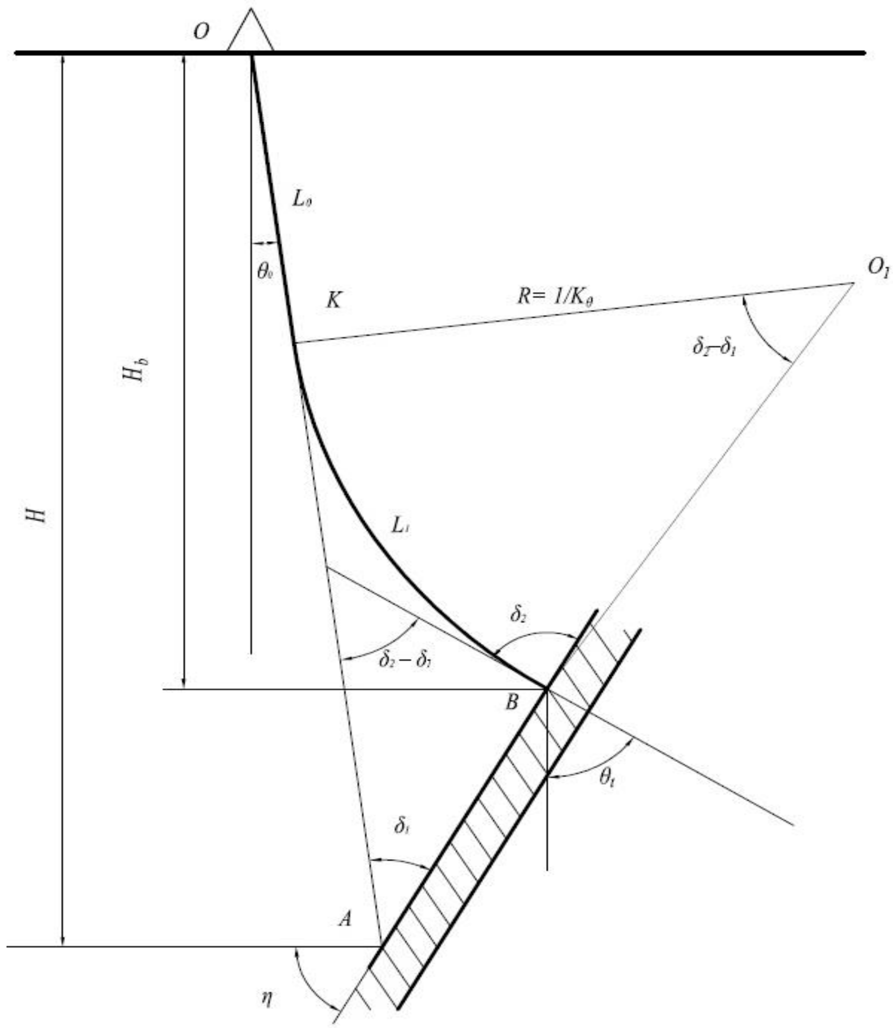

Fig. A.4

a) Length of branch point L_0(m)

$$L_0=\frac{H}{\cos\theta_0}-\frac{\sin(\delta_2-\delta_1)}{K_\theta}-\frac{H-H_b}{\sin\eta}\cos\delta_1 \qquad (A.16)$$

b) Length of branch borehole L_1(m)

$$L_1=\frac{0.01745(\delta_2-\delta_1)}{K_\theta} \qquad (A.17)$$

c) Drift angle of any given point on the axis of branch borehole θ_i(°)

$$\theta_i=\theta_0+57.3K_\theta(L_i-L_0) \qquad (A.18)$$

Where L_i is the length of any given point on the axis of branch borehole, m.

A.2.5 The curve-straight line type branch borehole is calculated by formula (A.19) ~ (A.21) and Fig. A.5.

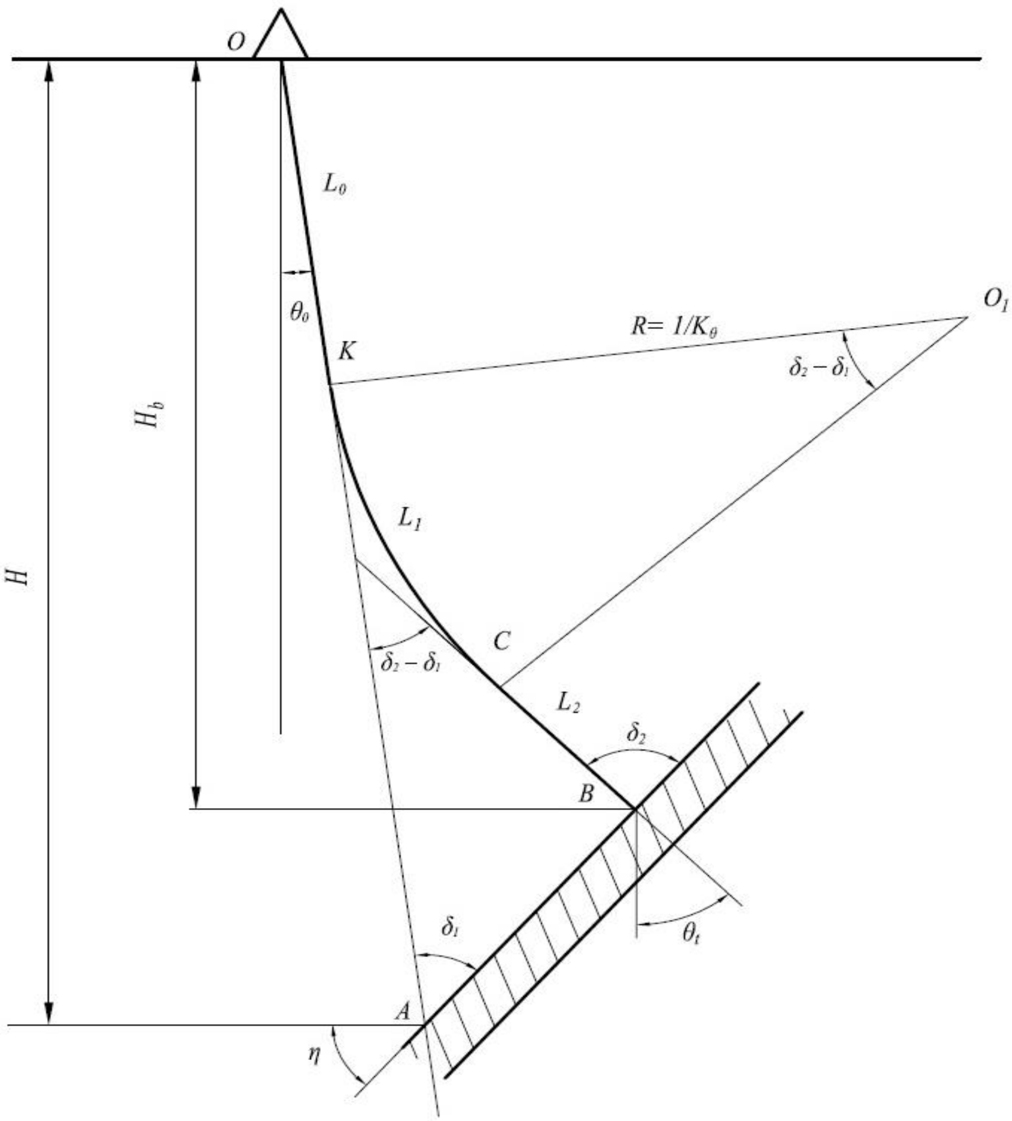

Fig. A.5

a) Length of branch point L_0(m)

$$L_0=\frac{H}{\cos\theta_0}-\frac{\tan\left(\frac{\delta_2-\delta_1}{2}\right)}{K_\theta}-\frac{H-H_b}{\sin\eta\sin(\delta_2-\delta_1)}\sin\delta_2 \tag{A.19}$$

b) Length of branch borehole L(m)

$$L=L_1+L_2=\frac{0.01745(\delta_2-\delta_1)}{K_\theta}+\frac{\frac{H-H_b}{\sin\eta}\sin\delta_1-\frac{2\sin^2\left(\frac{\delta_2-\delta_1}{2}\right)}{K_\theta}}{\sin(\delta_2-\delta_1)} \tag{A.20}$$

c) Drift angle of any given point on the curve section of branch borehole θ_i(°)

$$\theta_i = \theta_0 + 57.3(L_i - L_0)K_\theta \tag{A.21}$$

Where L_i is the length of any given point on the curve section of branch borehole, m.

A.2.6 Straight line-curve type branch directional borehole is calculated by formula (A.22) ~ (A.28) and Fig. A.6.

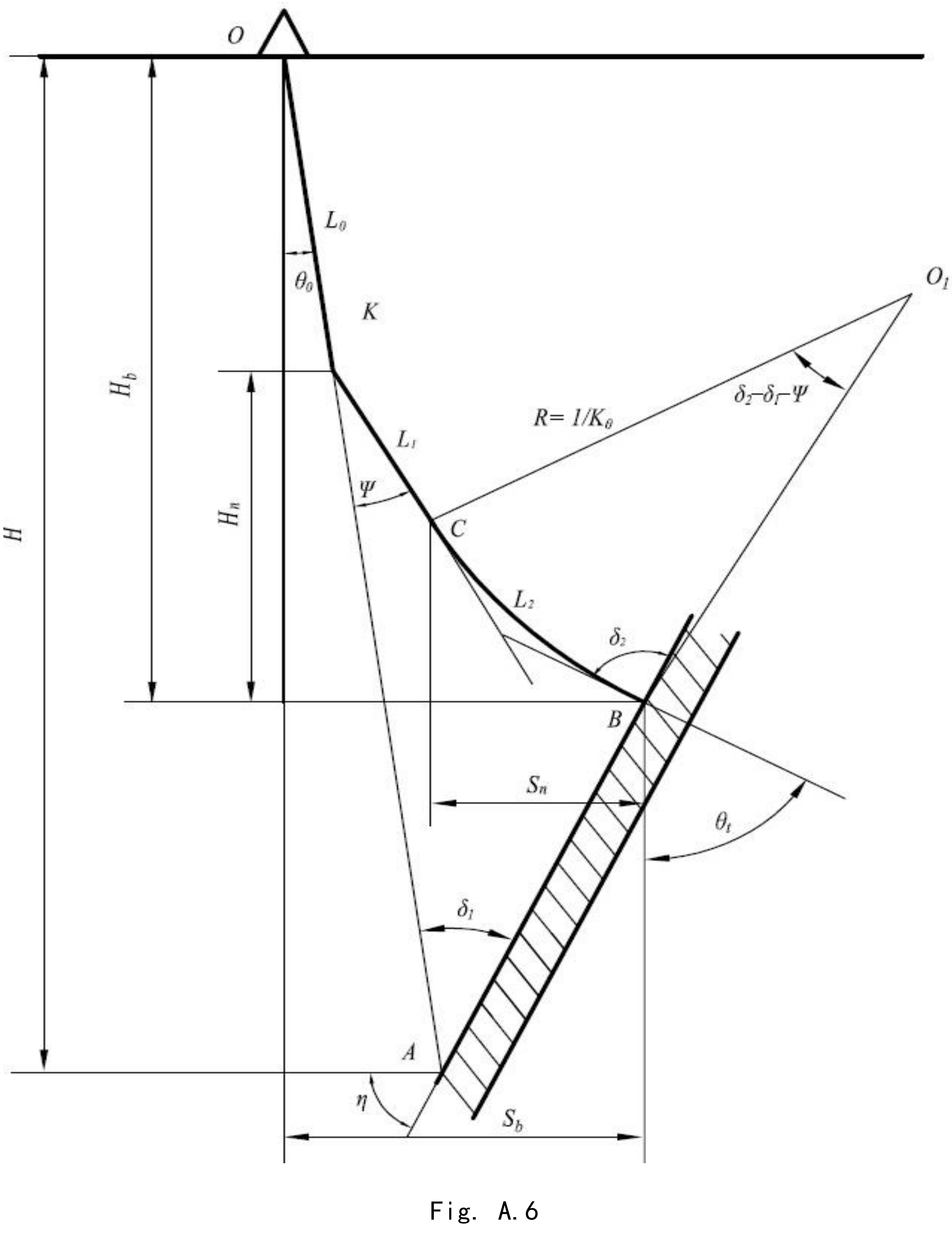

Fig. A.6

a) Total bending angle and length of curve section of branch borehole γ(°), L_2(m)

$$\gamma = \delta_2 - \delta_1 - \Psi \tag{A.22}$$

Where Ψ is the vertex angle of eccentric wedge, (°)

$$L_2 = \frac{0.01745(\delta_2 - \delta_1 - \Psi)}{K_\theta} \tag{A.23}$$

b) Vertical depth H_n(m) and horizontal displacement S_n(m) at the ending point of curve section of branch borehole (point C in Fig.6) relative to the starting point of the section (point B in Fig.6)

$$H_n = 2R\sin\left(\frac{\delta_2 - \delta_1 - \Psi}{2}\right) \tag{A.24}$$

$$S_n = 2R\sin\left(\frac{\delta_2 - \delta_1 - \Psi}{2}\right)\sin\left(\theta_0 + \frac{\delta_2 - \delta_1 + \Psi}{2}\right) \tag{A.25}$$

c) Length of branch point L_0(m) and length of straight section of branch borehole L_1(m)

$$L_0\cos\theta_0 + L_1\cos(\theta_0 + \Psi) = H_b - H_n \tag{A.26}$$

$$L_0\sin\theta_0 + L_1\sin(\theta_0 + \Psi) = S_b - S_n \tag{A.27}$$

L_0(m) and L_1(m) can be solved from the formula (A.26) ~ (A.27).

(d) Drift angle of any given point on the curve section of branch borehole, θ_i(°)

$$\theta_i = \theta_0 + \Psi + 57.3(L_i - L_1 - L_0)K_\theta \tag{A.28}$$

Where L_i is the length of any given point on the curve section of branch borehole, m.

A.3 Supplementary Statement

The curvature of the curve section of the directional hole should ensure the safety of tripping in/out of the drill string and drilling operation, that is, it should be able to pass the coarse diameter drilling tool smoothly, and the drill string should not be broken due to excessive drilling curvature.

Annex B
(Informative)
Calculation of Directional Tool Face Angle

B.1 The First Method

When the increment of azimuth angle, drift angle of new borehole and vertex angle of eccentric wedge, or total bending angle of kick-off section are known, the face angle of directional tool can be solved by formula (B.1)

$$\beta = \arcsin\frac{\sin\theta_2 \sin\Delta\alpha}{\sin\phi} \tag{B.1}$$

B.2 The Second Method

When the increment of azimuth angle, drift angle of both original borehole and new borehole are known, the face angle of directional tool can be solved by formula (B.2)

$$\beta = \arctan\frac{\sin\Delta\alpha}{\cos\theta_1 \cos\Delta\alpha - \sin\theta_1 \cot\theta_2} \tag{B.2}$$

B.3 Relations Among All Parameters

The relationships among total bending angle, drift angle of original borehole, drift angle ofnew borehole and increment of azimuth angle could be expressed as

$$\phi = \arccos(\cos\theta_1 \cos\theta_2 + \sin\theta_1 \sin\theta_2 \cos\Delta\alpha) \tag{B.3}$$

$$\theta_2 = \arccos(cos\,\phi\, cos\,\theta_1 - sin\,\phi\, sin\,\theta_1\, cos\,\beta) \tag{B.4}$$

$$\Delta\alpha = \arctan\frac{\sin\beta}{\sin\theta_1 \cot\phi + \cos\theta_1 \cos\beta} \tag{B.5}$$

Where

β = tool face angle;

ϕ = vertex angle of eccentric wedge. For continuous whipstock and PDM, ϕ refers to the full bending angle of the section of kick-off borehole;

θ_1 = drift angle of original borehole;

θ_2 = drift angle of new borehole;

$\Delta\alpha$ = increment of azimuth angle, refers to the increased value of azimuth angle of new borehole relative to that of original borehole.

Annex C
(Informative)
Method for Calculating the Axis Trajectory of Directional Borehole

C.1 Tangent Line Method (Lower Tangent Line Method)

Only the data of lower measuring point is taken into calculation. This method is based on the hypothesis that the line connecting the upper and lower measuring points has the same drift angle and azimuth angle. The formulas are as follows:

$$\Delta X_{1.2} = \Delta L_{1.2} \sin\theta_2 \cos\alpha_2 \qquad (C.1)$$

$$\Delta Y_{1.2} = \Delta L_{1.2} \sin\theta_2 \sin\alpha_2 \qquad (C.2)$$

$$\Delta Z_{1.2} = \Delta L_{1.2} \cos\theta_2 \qquad (C.3)$$

Where:

$\Delta X_{1.2} =$ increment in north-south direction;

$\Delta Y_{1.2} =$ increment in east-west direction;

$\Delta Z_{1.2} =$ increment of vertical depth;

$\Delta L_{1.2} =$ distance between upper and lower measuring points along borehole axis;

$\theta_2 =$ drift angle of lower measuring point;

$\alpha_2 =$ azimuth angle of lower measuring point.

This calculation method has a large error and can only be applied to approximately vertical boreholes with a drift angle of no more than 3 ° .

C.2 Balanced Tangent Line Method (Trapezoid Method)

This method adopts tangent compensation at the beginning and end of the measuring section. According to the measured drift angle and azimuth angle, the coordinate value of directional borehole axis is determined by the average value of trigonometric function. The formulas are as follows:

$$\Delta X_{1.2} = \frac{\Delta L_{1.2}}{2}(\sin\theta_1 \cos\alpha_1 + \sin\theta_2 \cos\alpha_2) \qquad (C.4)$$

$$\Delta Y_{1.2} = \frac{\Delta L_{1.2}}{2}(\sin\theta_1 \sin\alpha_1 + \sin\theta_2 \sin\alpha_2) \qquad (C.5)$$

$$\Delta Z_{1.2} = \frac{\Delta L_{1.2}}{2}(\cos\theta_1 + \cos\theta_2) \qquad (C.6)$$

Where:

$\Delta X_{1.2}$ = increment in north-south direction;

$\Delta Y_{1.2}$ = increment in east-west direction;
$\Delta Z_{1.2}$ = increment of vertical depth;
θ_1 = drift angle of upper measuring point;
θ_2 = drift angle of lower measuring point;
α_1 = azimuth angle of upper measuring point;
α_2 = azimuth angle of lower measuring point;
$\Delta L_{1.2}$ = distance between the upper and lower measuring points along borehole axis.

C.3 Average Angle Method (Average Angle Full Distance Method)

According this method, the section between two neighboring measuring points is considered as a straight line, and the average drift angle and azimuth angle of upper and lower measuring points are considered as the drift angle and azimuth angle of the whole section. The formulas are as follows:

$$\Delta X_{1.2} = \Delta L_{1.2}\sin\frac{\theta_1+\theta_2}{2}\cos\frac{\alpha_1+\alpha_2}{2} \tag{C.7}$$

$$\Delta Y_{1.2} = \Delta L_{1.2}\sin\frac{\theta_1+\theta_2}{2}\sin\frac{\alpha_1+\alpha_2}{2} \tag{C.8}$$

$$\Delta Z_{1.2} = \Delta L_{1.2}\cos\frac{\theta_1+\theta_2}{2} \tag{C.9}$$

Where:
$\Delta X_{1.2}$ = increment in north-south direction;
$\Delta Y_{1.2}$ = increment in east-west direction;
$\Delta Z_{1.2}$ = increment of vertical depth;
θ_1 = drift angle of upper measuring point;
θ_2 = drift angle of lower measuring point;
α_1 = azimuth angle of upper measuring point;
α_2 = azimuth angle of lower measuring point;
$\Delta L_{1.2}$ = distance between the upper and lower measuring points along borehole axis.
This method is extensively used due to its ease of computation and precision.

C.4 Curvature Radius Method (Changed Angle Cylinder Spiral Method, Cylinder Face Cutting Method)

This method assumes that the measuring section between the two measuring points is a cylindrical spiral with constant spiral angle, and the spiral is tangent to the drilling axis at the upper and lower measuring points at both ends. The formulas are as follows:

$$\Delta X_{1.2} = \frac{\Delta L_{1.2}(\cos\theta_1-\cos\theta_2)(\sin\alpha_2-\sin\alpha_1)}{(\theta_2-\theta_1)(\alpha_2-\alpha_1)} \tag{C.10}$$

$$\Delta Y_{1.2} = \frac{\Delta L_{1.2}(\cos\theta_1 - \cos\theta_2)(\cos\alpha_1 - \cos\alpha_2)}{(\theta_2 - \theta_1)(\alpha_2 - \alpha_1)} \quad (C.11)$$

$$\Delta Z_{1.2} = \frac{\Delta L_{1.2}(\sin\theta_2 - \sin\theta_1)}{\theta_2 - \theta_1} \quad (C.12)$$

Where:

$\Delta X_{1.2}$ = increment in north-south direction;

$\Delta Y_{1.2}$ = increment in east-west direction;

$\Delta Z_{1.2}$ = increment of vertical depth;

θ_1 = drift angle of upper measuring point;

θ_2 = drift angle of lower measuring point;

α_1 = azimuth angle of upper measuring point;

α_2 = azimuth angle of lower measuring point;

$\Delta L_{1.2}$ = distance between the upper and lower measuring points along borehole axis.

C.5 Minimum Curvature Method

The minimum curvature method assumes that the section between the two measuring points is a plane arc, and the circular arc is tangent to the borehole direction line at the upper and lower measuring points at both ends. This method is one of the most accurate methods to calculate the axis trajectory of a directional hole. The formulas are as follows:

$$\Delta X_{1.2} = \frac{\Delta L_{1.2}}{2}(\sin\theta_1\cos\alpha_1 + \sin\theta_2\cos\alpha_2)RF \quad (C.13)$$

$$\Delta Y_{1.2} = \frac{\Delta L_{1.2}}{2}(\sin\theta_1\cos\alpha_1 + \sin\theta_2\sin\alpha_2)RF \quad (C.14)$$

$$\Delta Z_{1.2} = \frac{\Delta L_{1.2}}{2}(\cos\theta_1 + \cos\theta_2)RF \quad (C.15)$$

$$RF = \frac{2}{\gamma}\tan\frac{\gamma}{2} \quad (C.16)$$

Where:

$\Delta X_{1.2}$ = increment in north-south direction;

$\Delta Y_{1.2}$ = increment in east-west direction;

$\Delta Z_{1.2}$ = increment of vertical depth;

θ_1 = drift angle of upper measuring point;

θ_2 = drift angle of lower measuring point;

α_1 = azimuth angle of upper measuring point;

α_2 = azimuth angle of lower measuring point;

$\Delta L_{1.2}$ = distance between the upper and lower measuring points along borehole axis;

RF = correction coefficient;

γ = total bending angle between two measuring points.

RF is a value greater than 1 but very close to 1. In case that total bending angle γ is sufficiently small, RF roughly equals to 1, and then the above calculation formula will completely become the formula of equilibrium tangent, so it is the correction of the formula of equilibrium tangent method.

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