Underreamers, Bi-Center Reamers, and Mud Motors

OCEAN DRILLING PROGRAM
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Scientific Application

The Ocean Drilling Program (ODP) installs reentry cones and casing in sediments and basement, typically by coring the hole and then enlarging (i.e., underreaming) it to run casing. Underreamers (Fig. 1) and bi-center reamers (Fig. 2) are used during casing installations to drill an enlarged hole (usually below a casing shoe) to provide clearance to run additional casing strings and provide annular clearance for adequate cement thickness (Table 1). Both tools drill a larger hole than the casing "pass-through diameter" (the maximum diameter of tools that will pass through the casing) by expanding hydraulically (underreamer) or rotating eccentrically (bi-center reamer) once they are through the casing. Underreamers were designed for use in softer sediments. Because of the hydraulically expanding arms, underreamers are not as robust as bi-center reamers. Bi-center reamers are newer than underreamers and are designed to drill in firm sediments and basement rocks. They have fixed eccentric wobble shell cutters (Fig. 2) and, thus, cannot drill as large a hole as an underreamer for any given pass-through diameter.

The engineer determines which tool to use depending on the formation type and the casing sizes. Both tools can be used (1) to enlarge an existing hole, (2) as a precautionary tool to reopen an enlarged hole if it has closed, and (3) to drill a new hole. More rarely, these tools can be used to "drill-in casing." The term drill-in casing refers to running a mud motor (see Section III) inside the casing to rotate one of these tools as a precaution to ensure the hole is open ahead of the casing (Fig. 3) or (rarely) to drill and run casing simultaneously (Fig. 4).

I. Underreamers

Tool Operation

The underreamer (Fig. 1) is run using 6 to 12 drill collars in the bottom-hole assembly (BHA) below the drill pipe to add weight. A pilot bit drills ahead of the roller cone cutters to center the rotation of the underreamer body to force the roller cones to cut a concentric hole. Fluid pressure inside the drill string is used to hydraulically extend the two underreamer arms, which have roller-cone cutters. The underreamer arms are pre-adjusted to the required hole diameter

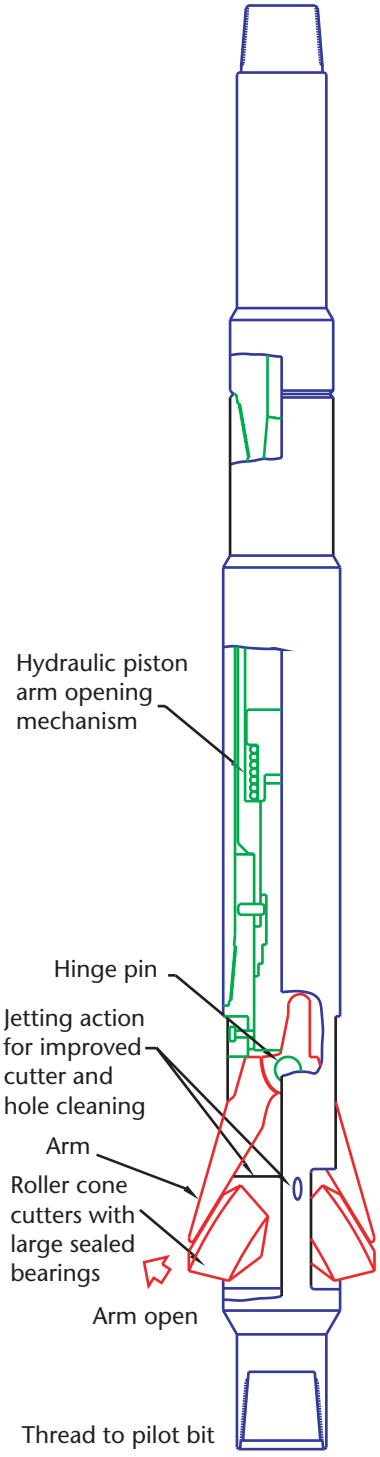

Figure 1. Schematic of the underreamer tool. Mill-tooth roller cone cutters are used with softer sediments. Tungsten carbide roller cone cutters are used with firmer sediments and hard rock.

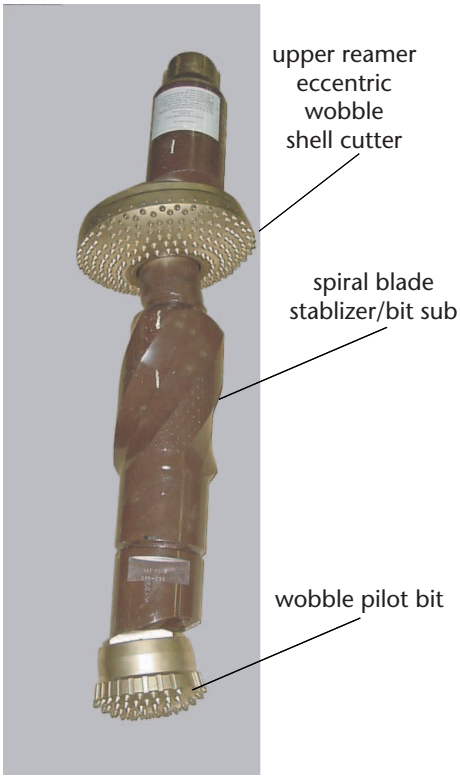

Figure 2. Photo of bi-center reamer.

before drilling. The pilot bit and underreamer nozzles must be sized correctly to ensure adequate hole cleaning and provide enough backpressure to open the underreamer arms at the same time.

Design Features

1) Formation Compatibility

Underreamers are compatible with sediments ranging from soft silts/sands and sticky clays to moderately firm sediments. Medium- and hard-formation bit cones are available. Limited (~20 m) basement (e.g., basalt) penetrations are also possible.

Benefit: One underreamer tool can drill a wide range of sediments without a trip to change bits.

2) Hole Size/Operating Parameters

Underreamers have adjustable arms that open hydraulically. Table 2 shows the model, underreamer body size, outer diameter (OD) of the casing the underreamer can pass through, the size of the hole that can be drilled when the arms open, and typical operating parameters (weight on bit [WOB] and revolutions per minute [rpm]).

Benefit: The underreamer arms can be adjusted to cut different hole diameters, reducing the need for a separate tool for each casing size. Operating parameters can be adjusted to optimize performance in different formations based on rate of penetration, hole conditions, swelling formations, etc.

Underreamer Specifications

Roller cone cutters include mill tooth cutters for soft sediments and tungsten carbide tooth cutters for firm sediments, chert, and limited (~20 m) basement penetration.

The pressure drop through the underreamer is 250–500 psi (at 1000 gpm maximum). An underreamer will typically require a flow rate of 30–500 gpm/in. hole diamter for proper hole cleaning.

A Drilex D950SSHF (slow speed, high-flow rate) mud motor is used with the underreammer when a mud motor is used to run casing.

Underreamer Typical Operating Range

Formation: Soft to moderately firm sediments

Depth Range: No limit

Rate of Penetration: Depends on rock properties, but ~30 to 3 m/hr

Limitations

Should not be used to drill very firm sediments, chert, or deep into volcanic basement rock due to potential damage to the arms.

Holes in granular sediments (such as sand, fractured rock, or rubble) usually will not stay open.

To underream a reasonably straight and concentric hole, the pilot bit should be the same size

Table 1. Comparison of underreamer and bi-center reamer casing and drill bit specifications.

Casing OD (in.)	Casing weight (lb/ft)	Casing drift ID (in.)	Buttress coupling OD (in.)	Drill bit option (in.)	DDI bi-center drill-in casing model number	HOC underreamer (in.)	
						DTU 95	DTU 1175
20	94	18.936	21	Jet-in	B#182x215	-----	22
16	75	14.936	17	18.5	B#145x185	-----	20
13.375	54.5	12.459	14.375	14¾	B#122x146	14¾	-----
10.75	40.5	9.894	11.75	12¼	-----	14¾	-----

Notes: OD = outer diameter; ID = inner diameter; DDI = Downhole Design, Inc.; HOC = Hole Opener Corporation; DTU is part of the model number.

or larger than the predrilled pilot hole.

II. Bi-Center Reamers

Tool Operation

Bi-center reamers (Figs. 2, 5; Table 3) are also run on a BHA composed of 6 to 12 drill collars below the drill pipe. A pilot bit below the bi-center reamer must center the tool body in a hole so the upper reamer shell can rotate eccentrically to enlarge the hole. The pilot bit and bi-center reamer nozzles must be sized correctly to ensure adequate hole cleaning.

Design Features and Benefits

1) Formation Compatibility

Bi-center reamers are compatible with moderately firm sediments and volcanic basement.

Benefit: A bi-center reamer can drill or underream a wide range of firm sediments to basement without a trip to change bits.

2) Durability

The bi-center reamers are a fixed outer diameter (i.e., not hydraulically opened).

Benefit: No tool closure is required to pull the tool back through casing, and the design is more robust.

3) Hole Size

Bi-center reamers use IADC Class 5 conical tungsten carbide cutters.

Benefit: Bi-center reamers can drill firm sediments and basement rocks that might damage a hydraulic-arm type underreamer.

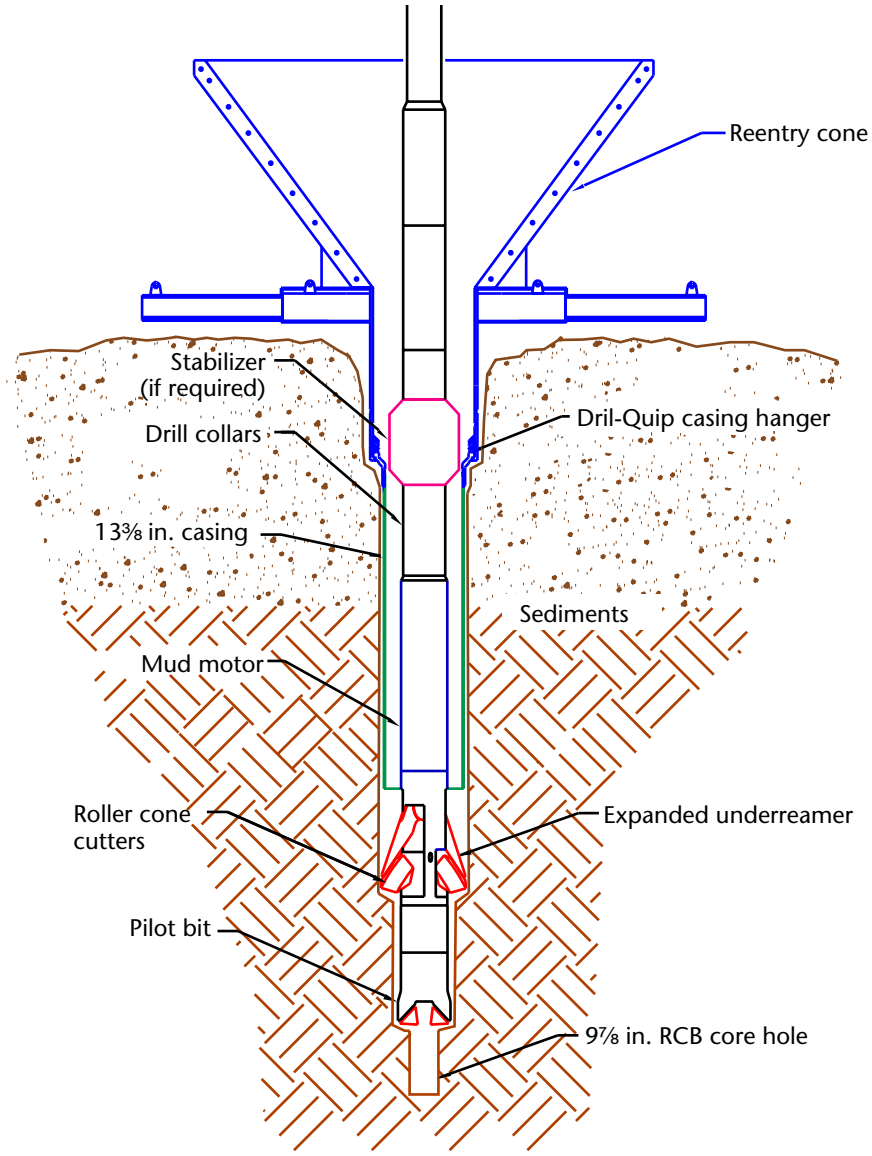

Figure 3. Underreaming (enlarging) 9⅞ in. core hole with an expanded underreamer below conductor casing before running next casing. If a bi-center reamer was used, it would be in the same position below the mud motor as the underreamer.

4) Stabilizer and Wobble Bit

A 9⅞ in. OD integral blade stabilizer and a 9⅞ in. OD single-cone wobble bit are available.

Benefit: The stabilizer absorbs the side loading forces as a result of eccentric "wobble" of the bi-center reamer shell and reduces damage sustained by the drill or wobble bits. Wobble bits have a larger bearing than tricone bits and are more robust.

Bi-Center Reamer Specifications

9⅞ in. OD integral blade stabilizer

9⅞ in. OD single-cone wobble pilot bit

Weight on Bit: 3K to 6K lbf/in. of bit diameter

Circulation Rate: 30 to 50 gpm/in. of hole diameter

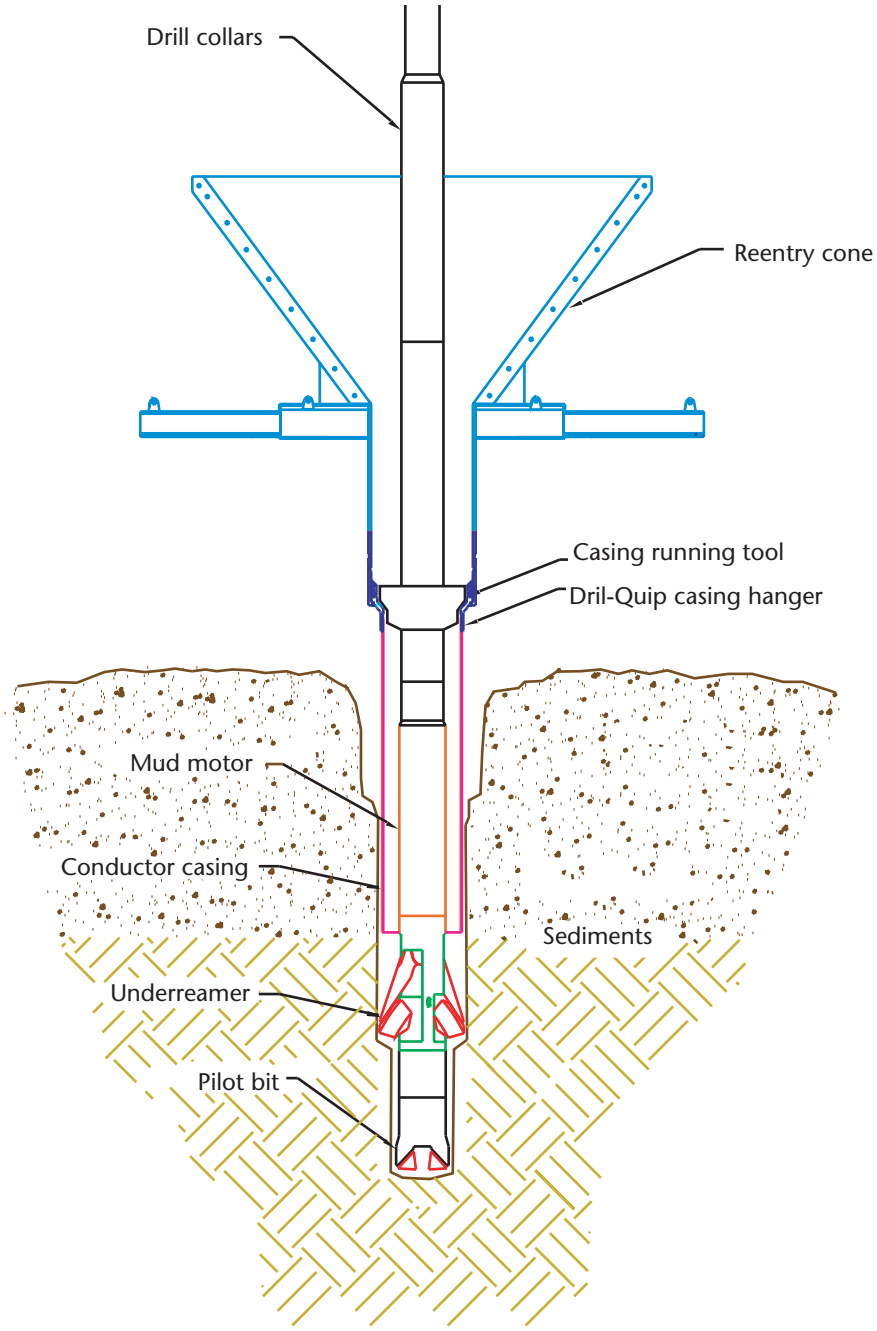

Figure 4. Underreaming ahead of conductor casing in unstable sediment cover to set reentry cone.

Table 2. HOC and underreamer models and specifications.

HOC model	UR body size (in.)	OD casing (in.)	Hole size drilled (in.)	WOB (klb)	Rev/min (rpm)
DTU 1175	11¾	20, 16, 13⅜	11¾ to 22	0-20	70-110
DTU 950	9½	10¾	9½ to 14¾	0-15	70-110

Note: UR = underreamer.

Bi-Center Reamer Typical Operating Ranges

Formation: Firm to moderately firm sediments to hard volcanic basement rock

Depth Range: No limit

Rate of Penetration: Depends on rock properties, but ~30 to 10 m/hr in sediments and ~6 to 2 m/hr in basement

Limitations

Bi-center reamers are not effective for re-reaming an existing large or ruggose hole because the pilot bit must be constrained in (i.e., centered in) the hole to center the tool body and force the eccentric upper reamer shell to drill.

No tool is effective in opening a hole in unstable or granular sediments (such as sand, fractured rock, or rubble).

III. Mud Motors

Tool Operation

Because casing cannot be rotated from the surface, a mud motor (Fig. 6) is used inside casing to rotate underreamers, bi-center reamers, or bits, using pressure from circulating fluid pumped down the drill pipe. The mud motor nozzles must be sized correctly to ensure adequate hole cleaning for the pilot bit and underreamer or bi-center reamer nozzles. ODP uses a Drilex D950SSHF mud motor (special low rotating speed but with high flow rate and high torque), which runs at ~500 psi pressure drop on bottom when fully loaded. The mud motor assists the casing string past bridges and tight spots in a predrilled hole. A mud motor can also drill-in casing without a predrilled hole over short intervals

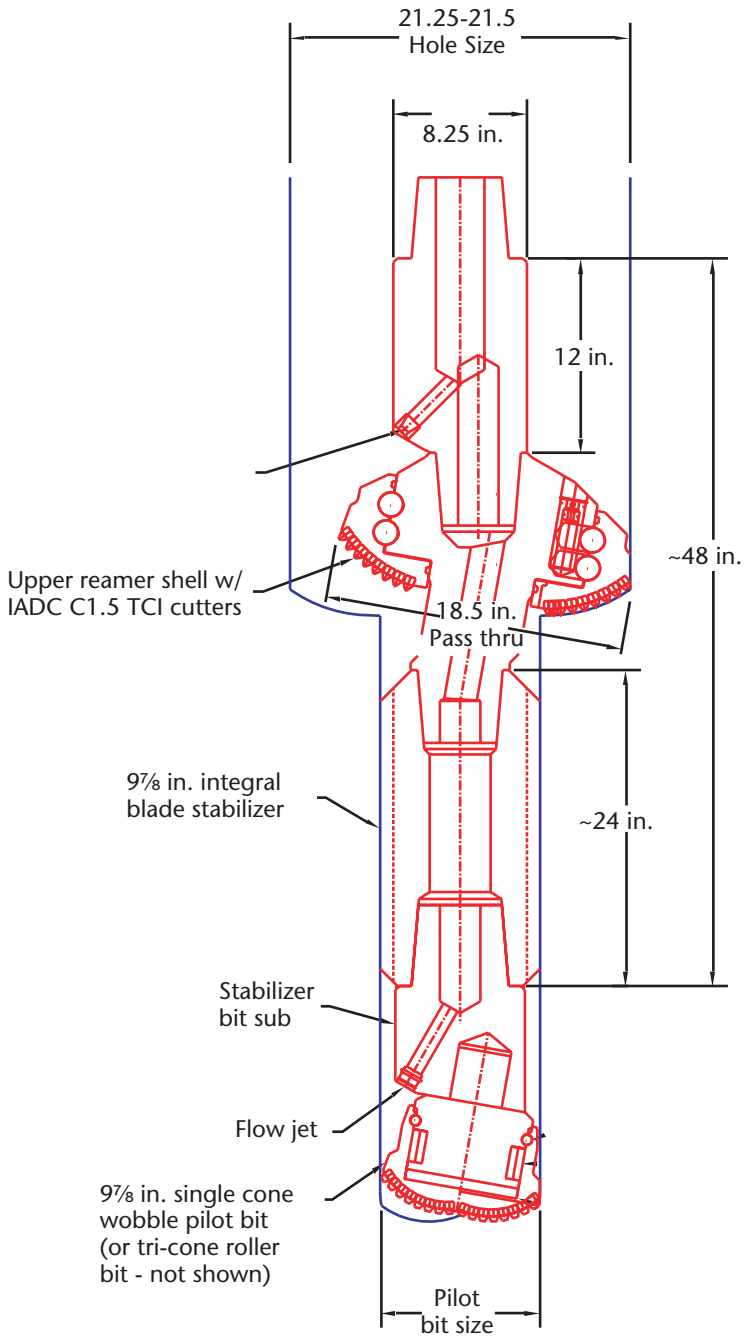

Figure 5. Schematic of a bi-center reamer by Downhole Design Inc. (DDI).

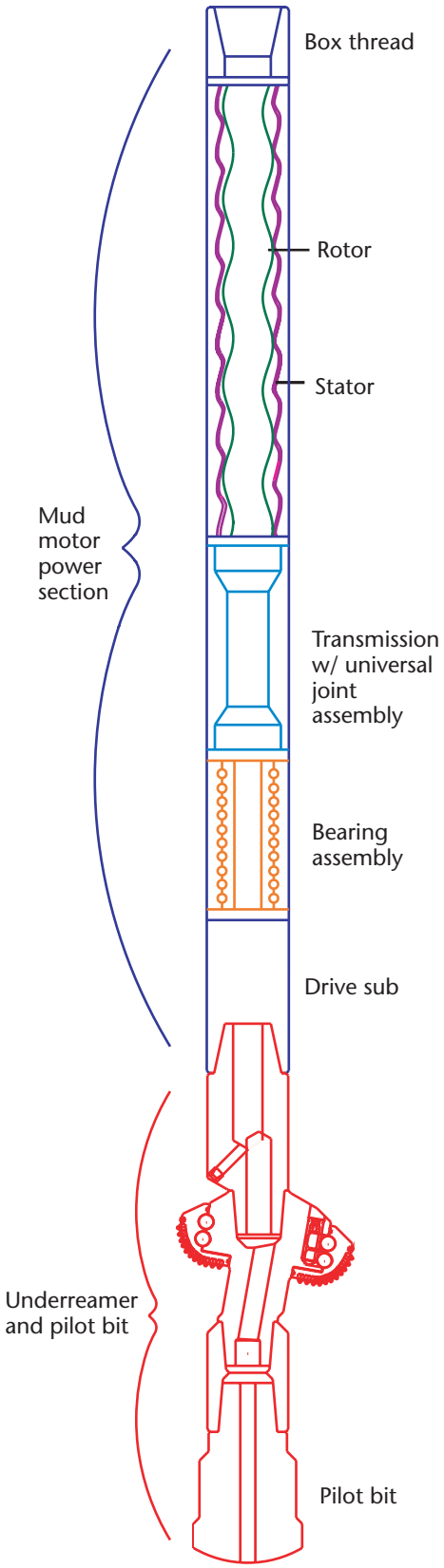

Figure 6. Schematic diagram of the mud motor with a bi-center reamer and pilot bit. The mud motor could also be used with an underreamer and pilot bit or with only a bit.

Table 3. DDI bi-center reamer models and specifications.

DDI bi-center model	Pass-through size (in.)	Hole size (in.)	WOB max. (lb)	Rev/min (rpm)	Est. rot. hours (hr)	Est. ROP (ft/hr)
B#182x215	18.25	21.5	100K	50-60	60-80	20-2
B#145x185	14.5	18.5	70K	60-70	60-80	30-2
B#122x146	12.25	14.625	40K	60-70	60-80	25-2

Notes: Est. = estimated; rot. = rotating; ROP = rate of penetration.

(i.e., less than ~150 m in unstable sediments such as sand or swelling clay).

Design Features

1) Compatibility

The mud motor is compatible with underreamers, bi-center reamers, and tricone drill bits when they are run with the appropriate nozzles and hydraulics.

Benefit: One mud motor can be used to drill sediments and basement with a wide range of different tools.

2) Durability

The Drilex D950SSHF mud motor has high stall torque and relatively low rpm.

Benefit: Large drilling tools, such as underreamers and bi-center reamers, require low rpm and high torque to drill in hard and fractured rock.

3) Pass-Through Hole Size

The Drilex D950SSHF mud motor has a 9.47-in. OD.

Benefit: Can be run inside 10¾ in. casing (9.950-in. nominal/ 9.794-in. drift ID). It is the largest motor available that will pass through the 10¾ in. (smallest) casing size used by ODP.

Mud Motor Specifications

The mud motor has a 9.47-in. OD.

Pressure drop is 200–300 psi no load and 500 psi on bottom when fully loaded.

Motor displacement is 6.11 gal/ rpm with a rotor speed of 90–164 rpm off-bottom and 72–131 rpm on-bottom at a flow rate of 550–1000 gpm. On-bottom torque is 7600 ft-lb at 500-psi pressure drop and 12,000 ft-lb stall torque.

Mud Motor Typical Operating Ranges

Formation: No limit–depends on drilling tool used

Depth Range: No limit

Rate of Penetration: Not applicable

Limitation

Appropriate nozzles and hydraulics must be run in the drilling tools (e.g., underreamers, bi-center reamers, and tricone drill bits) to provide pressure and flow rate to operate the mud motor.