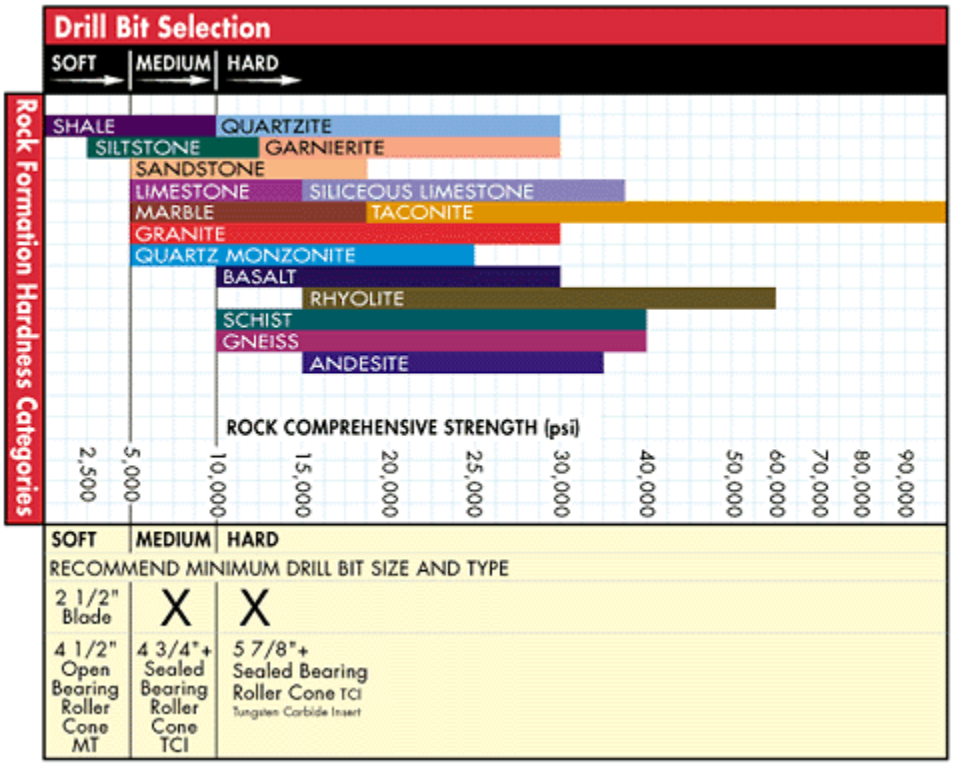
Boring Hard Rock With Small to Mid-Size Directional Rigs

by Frank McKenney

Horizontal directionally drilled installations in hard rock have been feasible since about 1988. While previously completed with large boring rigs, advancements in drilling tools, practices, and boring machines have expanded this market application to small and midsize rigs.

This article will discuss the equipment required and limits for cost-effective hard rock drilling with these smaller rigs. To better understand these applications, “hard rock,” rig size, and project scope must be defined.

Hard Rock. This term can vary subjectively by individual, geographic area, and rock type. Rock compressive strengths range up to 90.000 psi. Luckily, the hardest rock types found near the earth’s surface rarely exceed 40,000 psi. The chart below can help eliminate the subjectivity in classifying rock hardness.



Rig Size Categories. The chart below categorizes the three rig sizes offered by the trenchless industry.

This chart categorizes the three rig sizes as defined by the trenchless construction industry.

Rig Size	Pull/Push Capacity (lbs)	Drill String Size (OD)	Pump Rate GPM
Small	to 25,000	to 2-7/8"	30 and below
Medium	25,000 to 100,000	2-3/8" to 4-1/8"	30 to 200
Large	100,000 and up	4-1/8" and Larger	150 and above

Project Scope. Bore length,pilot hole, product line size and rock hardness will all effect the cost of a project. Harder formations may reduce a rig's performance capabilities, and the equipment limits must be known.

To evaluate what is required to efficiently drill rock means the key components of the drilling package must be examined, including the bottom hole assembly (BHA) (drill bits, drill motors, drill strings, reamers) and the rig and its hydraulic systems.

Drill Bits. The drill bit is the smallest but most important component of the drilling package. All of the other components must be engineered to support its task.

There are three general types of drill bits:

a) Fixed-head blade bits: These range from two inches and up, are economical ($80 to $400), and are ideal for drilling soft formations.

b) Diamond bits: These are very expensive ($4000 and up) and are suited for homogenous sedimentary and some igneous formations. Conglomerate rock formations and cobbles will quickly destroy diamond bits, making them impractical for trenchless construction.

c) Roller cone bits: These generally come in numerous types for a wide variety of formations. Prices range from $300 to $10,000. Their ruggedness and versatility make them the most cost-effective for hard rock crossings.

An assortment of bits available for drilling rock: (clockwise from left) Two chevron blade bits, milled-tooth tri-cone roller bit, step blade bit, and scratcher blade bit.

Drill Motors. Steerable drill motors rotate and guide the drill bit by converting hydraulic energy from mud pumps into rotary power at the bit. Optimum penetration rates are achieved by operating them at recommended flow rate, bit size, weight on bit ranges, etc.

Recommended Drill Motor OD for Rig Size/Min. Flow Rate.	
Small Rigs	**2-1/16, 2-3/8, 2-7/8 in./10-30 gpm**
Medium Rigs	**2-7/8, 3-1/2, 3-3/4, 4-3/4 in./30-100 gpm**
Large Rigs	**4-3/4, 5-1/2, 6-1/2, 7-3/4 in./100-350 gpm**

Drill Pipe. This key component of the BHA provides push weight on drill bits, pull weight on back reamers, rotary torque, and hydraulic power. The drill pipe OD is important to be able to provide enough strength for the weight and torque required to drill rock. The ID should be large enough to carry the required flow rate to the motor and bit.

Drill Rig. The BHA required to drill medium to hard rock dictates the rig size required. For example, drilling “hard” rock automatically raises the requirement of rig size to medium.

Rigs not equipped to provide these drilling parameters can often be retrofitted with the necessary equipment. This is extremely useful to contractors who need to drill only occasional rock jobs.

Following is a drilling recommendation package chart for rock formations.

Recommended Rock Drilling Packages.

Rock Type			Bit Sizes	Motor	Drill String-OD	GPM	WOB** Lbs	Rig Sizes
Soft	Medium	Hard						
x	.	.	2-1/2" to 3"	2-1/8"	1-3/4" to 2-1/8"	20 - 40	<3,200	Small
x	.	.	3" to 3-1/2"	2-3/8"	2" to 2-3/8"	20 - 40	<3,200	Small
x	.	.	3-1/2" to 4"	2-7/8"	2-3/8" to 2-7/8"	30 - 90	<6,000	Small
x	x	.	4-3/4"	2-7/8"	2-3/8" to 2-7/8"	30 - 90	<6,000	Small-Medium
x	x	.	4-3/4"	3-1/2"	2-7/8" to 3-1/2"	80 - 110	<7,000	Medium
x	x	x	5-7/8"	3-1/2"	2-7/8" to 3-1/2"	80 - 110	<7,000	Medium
x	x	x	5-7/8"	4-3/4"	4-1/8" to 3-1/2" *	100 - 250	<25,000	Medium
x	x	x	6-1/2"	4-3/4"	4-1/8" to 3-1/2" *	100 - 250	<25,000	Medium
x	x	x	7-7/8"	4-3/4"	4-1/8" to 3-1/2" *	100 - 250	<25,000	Medium

* Internal Flush * *WOB - Weight on Bit

Back Reamers. An average rule for reamers is to back ream with at least 1,000 lbs. per inch of hole diameter at the rock face. Rotation should be in the 40 to 90 RPM range. Small rigs can efficiently open pilot holes to 9 7/8 or 12 inches. Mid-size rigs can open pilot holes to 17 1/2 in. and possibly even 26 in. Of course, as the bore length increases, the rig’s ability to open larger holes decreases. Torque and drag

factors should be calculated for project feasibility. Size staging multiple reamer passes can help reduce torque and overloading the bore with cuttings.

In hard rock formations quality reamers should be utilized. Proper caution should be used in the reamer fabrication process to prevent breakage, shortened life and loss of cones downhole.

Whereas pilot hole drilling separates medium-size rigs from small rigs in cost effectiveness, reaming operations will separate medium rigs from small rigs when drilling rock. This is basically due to the number of reaming passes required for larger bore sizes and the difference in rate of penetration. To install a 16 in. line in a 24 in. bore in granite, a mid-size rig would need to drill a 5 7/8-in. pilot, then ream back in stages of 12, 17 1/2, and 24 in. A large rig would drill a 9 7/8 in. pilot, then ream back 17 1/2 and 24 in., thus eliminating several days on another pass. Penetration rates would also be significantly higher.

C&B Associates, Inc., a directional boring contractor in Mineral Wells, Texas has completed 225 bores for over 77,000 ft since 1992. Over 50 bores were drilled in rock with 2 7/8 to 3 1/2 in. motors and 4 3/4 to 5 7/8 in. roller cone bits.

Deborah Clark, vice president of C&B, admits the learning curve for drilling the frequent limestones, chert and cobbles around Texas wasn't easy. "Three out of out first few bores were in rock and had to be aborted, but we could go back and complete these projects with what we know now."

Another drilling contractor, Michels Pipeline Construction, Inc., Brownsville, Wis., began in 1960 as a gas pipeline construction company and has since diversified into telephone cable and underground utilities. In 1988 Michels entered the directional drilling industry and now operates a fleet of 10 rigs ranging from 6900 lbs. to 839,000 lbs of thrust.

The following case histories completed by C&B and Michels are examples of this rapidly growing application.

Case Histories.

C&B Associates
Location: Ingram, Texas - Fall Creek, Hill Creek, Henderson Branch.

Application: Install one 4-in. HDPE conduit for fiber optics lines to prevent contamination of Edwards aquifer recharge zone. (Total of four bores on project.)

Scope: 420 ft by 4-in. line by 5 7/8 in. bore; 38-ft elevation changes entry to exit; narrow one-ft right-of-way; 8 ft. below creek bed.

Formation: Limestone; 8000 to 12,000 psi.

Bit: 5 7/8-in. TCI roller cone.

Motor: 3 1/2- in. OD with two-degree bent housing.

Flow Rate: 70 - 80 gpm, with bentonite & water with gels.

Results: This bore was completed in one day and met all directional requirements. Two similiar rock bores and one soft formation bore were also successfully completed on this project.

Michels Pipeline Construction
Location: Elk Mound, Wis. (single bore project.)

Application: Install one 4-in. gas line by directional drilling under railroad crossing with three fiber optics cables.

Scope: 250 ft by 4-in. line by 6 in. bore; 4-ft elevation changes entry to exit; 10-ft right-of-way; 12 ft. below railroad tracks.

Formation: Sandstone

Bit: 4 3/4-in. TCI roller cone, backreamed to 6 in.

Motor: 2 7/8- in. OD with two-degree bent housing.

Flow Rate: 30 - 60 gpm, with bentonite & water.

Results: This bore was drilled to target in 4 hrs, 20 min.

Conclusion.

Drilling rock formations can be cost-effective by engineering, planning and selection of a proper overall drilling package. The contractor must realize the limit of each component of the drilling package and operate within those parameters.

Small rigs should be limited to the “soft” category of rock; basically sedimentary shales, siltstone, limestones, and sandstones in compressive strengths under 5000 psi.

Medium-size rigs can drill pilot holes in the 5 7/8 to 7 7/8 in. range in as hard rock as large rigs. Reaming holes open to larger than 17 1/2 in. warrants cost-effective comparison to large rigs.

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