3. Drilling with compressed air

Drilling with compressed air uses an air compressor, invariably a diesel-engine-powered piece of construction plant, to produce and blow compressed air down through the centre of the drill-pipe and up through the annular space formed between the larger drill bit diameter and smaller drill pipe diameter. The rising column of air carries borehole debris to the surface and when matched with a down-the-hole hammer introduces energy directly to the hole bottom to smash the hardest of rocks.

3.1 Air volume required

The size of an air compressor is linked to the possible borehole diameter; it is essential to the drilling process that the air travels up the hole fast enough to carry debris with it. Note that this speed is considerably faster than water/fluid circulation because air is less able to support material than water (Tables 3.1 & 3.2). Air Volume is specified by compressor manufactures in units of free air delivered M^3/Minute

Up-hole velocity should range from 900–1200 metres/minute and the required compressor size can be calculated using the following formula:

$(D^2 - d^2) \times 0.5 =$ Metres^3/minute

where:

D = drill bit diameter in inches
d = drill pipe diameter in inches

This gives the minimum flow requirement; add one third of this value for maximum or optimum flow requirement

Example:

A 6” (150mm) diameter hole drilled with 3” (75mm) diameter drill pipe.

$(6^2 – 3^2) = (36 – 9) = 27 \times 0.5 =$ 13.5 Metres^3/minute.

Table 3.1 Formula to calculate required air Compressor capacity

Compressor Volume			***Maximum Drillbit Diameter***					
m^3/min	litre/sec	CFM (feet^3/min)	Drillpipe diameter 58mm (2.1/4")		Drillpipe diameter 75mm (3")		Drillpipe diameter 88mm (3.1/2")	
			mm's	inch's	mm's	inch's	mm's	inch's
3	50	100	85	3"				
5	80	175	100	4"	115	4.1/2	125	5"
7	120	250	115	4.1/2"	125	5"	140	5.1/2"
10	175	375	125	5"	140	5.1/2"	150	6"
13	210	450	140	5.1/2"	150	6"	165	6.1/2"
17	280	600	150	6"	165	6.1/2"	175	7"
Useful Conversion figures:								
m^3/min			x 16.66	= litre per second				
m^3/min			x 35.31	= cubic feet per minute (CFM)				

Table 3.2 Maximum drillbit size for specific compressors

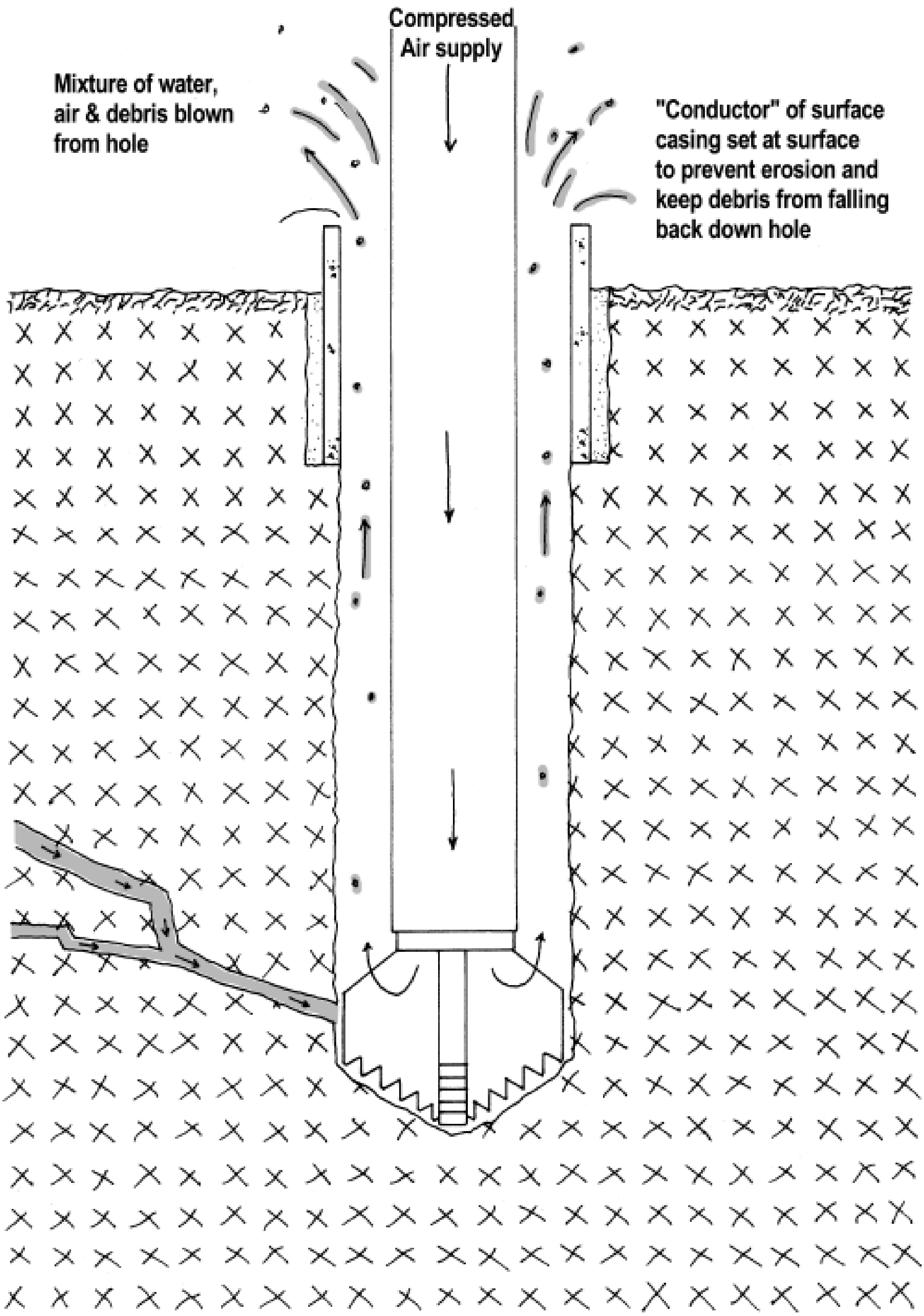

Figure 3.1 Compressed Air Drilling Schematic

(Cubic Metres delivered per minute) Litres/sec or CFM – Cubic Feet per minute. All these are units of flow or volume and not pressure or force.

3.1.1 Air Pressure

The other attribute specified by compressor manufacturers is the pressure a unit can develop in Bar or psi (pounds per sq inch). Most industrial units will develop a minimum of 6 bar (100psi) with specialist units able to develop pressures of 20 Bar (300psi). It is the air volume that cleans the hole and is the most essential requirement of a drilling compressor. Pressure allows more energy to be delivered to the piston of a down-the-hole hammer – thus imparting more energy to the drill bit and allowing a faster penetration rate. Pressure is also required to lift clear any resting column of water from a borehole – A 6 Bar compressor will just about lift a 60 m column of water from the base of a hole. Therefore reasonably deep holes in rock with a high groundwater rest level might require deployment of a high-pressure air supply just to be able to lift clear stored columns of water.

3.1.2 Safety

Compressed air (pressurised air), particularly when available in high volumes as on drilling operations can be and has proven to be lethal. Typically a hose bursting or an end-fitting breaking will cause the broken hose end to snake around with considerable random force and speed. Ensure all connecting hoses and fittings are of adequate pressure rating – most good quality hose will have a pressure rating written on its outer sheath. In Europe, safety law insists hose are 'whip checked' that is fitted with safety chains or steel cable fastened independently to the connected machine and hose outer sheath. Look after flexible hose that joins a compressor to a drilling rig – avoid mechanical damage such as squashing or kinking – check hose couplings are fitted tightly and that bolts remain tight. Replace any hose that has become visually weakened by use and age, for example by having a cracked outer sheath.

3.2 Hole stability

Unlike water/fluid drilling, air provides no protection from collapse of borehole walls. Indeed, if air is used in soft formations the walls easily erode and the drilling process has to stop. It is important to protect the top lip of the hole from erosion and ensure the diameter of the hole is evenly maintained from the base to the top. A short piece of casing pipe with bore just a few mm larger than the drill bit should be set as a 'conductor casing' at the top of the hole it should be set at a depth of 500mm and protrude 100-300mm above the ground. By having a lip protruding allows debris to blow clear but not drop down the hole when airflow is turned off. Much longer lengths of casing are, of course, required when the top surface is soft for some depth (Figure 3.1).

3.3 Hole completion

It is often said the harder the geology – the rock - the easier the drilling construction is – this is true assuming the correct tools are used.

In consolidated rock it is normally possible to leave the drill-pipe at the bottom of the hole blowing the discovered water to the surface. The water will initially be contaminated with borehole debris but will gradually clean up until it is crystal clear (Figure 3.2). 'Surging' might help holes with low a flow, which is accomplished by turning the air supply on and off repeatedly. The resultant rising and falling column of water will clean the borehole walls, washing into and out of water bearing fissures and clearing them of the borehole debris.

Figure 3.2 Drilling with compressed air – having "struck" water

3.4 Down-the-hole hammers

The use of compressed air provides a method of introducing considerable energy into the hole-drilling process. As discussed earlier, in a soft formation this energy is misplaced and is likely to lead to extensive hole erosion or collapse. Just imagine for a moment the effect of pointing a high-pressure air jet at a pile of loose sand. However, when this energy is harnessed to an appropriate tool – a down-the-hole hammer (Figure 3.3) – the energy will be directed to smash and pulverise hard rock and then blow it clear of the hole.

3.5 Drag blade drill bits

If the formation is soft enough to be cut with a drag blade drill bit but hard enough to support itself it can be drilled using a drag blade with air flush to blow clear the debris. A hammer is only essential when the rock cannot be efficiently cut with a drag blade drill bit.

3.6 Power to crush

The down-the-hole hammer is an invaluable complementary tool for all sizes of rotary drilling machines. All that is needed is to place a nominal down load on the hammer and rotate at a low speed. The compressed air energy will be able to drill the very hardest rock, which is impenetrable using conventional drill rig power.

These are highly developed mass-produced tools pioneered in the rock quarry and mining industry, where the cost per metre of drilling blast-holes in hard rock makes a huge commercial impact. The drilling bit is a hardened-steel, domed percussive shaped bit with shaped passages for compressed air to flush debris from the hole bottom. Its face is set with tungsten carbide buttons. The drill bit is fitted by loose fitting splines to the base of the down-the-hole hammer and the whole unit is pushed lightly against the rock face at hole bottom and rotated slowly so the tungsten buttons are able to strike across the entire hole base. The hammer device comprises of an air distribution network in a steel cylinder, which is arranged to pass air from alternate ends to an internal heavy sliding steel piston. With the drill bit pushed against the hole bottom, the piston is picked up by the air supply delivered through the centre of the drill pipe and then thrown down on top of the percussive drill bit, delivering a huge 'hammer blow' of percussive energy into the drilling bit. This sequence is repeated several times a second. The higher the compressor pressure, the faster the piston will be thrown on to the bit and the more energy will be delivered to the drill bit.

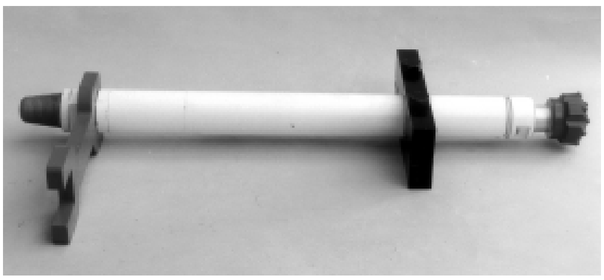

Figure 3.3 Down-the-hole hammer – with stripping clamp and spanner

To stop the piston hitting the percussive drill bit, the hammer attached to the drill pipe is lifted a few cm and the drill bit slides out of the hammer body, changing the effective air ports. The piston remains stationary and the compressed air is discharged continuously through the drill bit allowing the borehole to be flushed. Indeed as the piston is working the compressed air is exhausted through the drill bit blowing debris clear of the hole bottom during the drilling action.

3.7 Hammer types

There are two types of down-the-hole hammer construction: 'valved' and 'valveless'. The 'valved' hammer has a flap valve to regulate compressed air to control the piston stroke and is restricted to low operating pressures. It is also prone to becoming choked with too much foam/water addition (see foam drilling). Valveless hammers now predominate. They have contoured pistons and cylinders to control airflow, and are suitable for work at high pressure and allow foam/water injection to pass through easily

A hard dry rock can be drilled constantly and the air discharged through the hammer will lift all the material being cut to the surface, particularly if the compressor is sized generously for the hole diameter being drilled. At the hole base, after a drill pipe has been completely drilled, the hammer bit can be lifted clear of hole bottom and the increased volume of flushing air will remove the remaining particles in a few seconds. When a hole is meeting water and becoming sticky, or the ground is broken or soft, the regular removal of spoil will stop. In this situation addition of foam or water injection might help, but the driller might have to lift clear the hammer each half metre to use the increased air flush to clean the hole.

However powerful a down-the-hole hammer is capable at smashing into hard rock, it can take a very insignificant rock particle or damp collared layer of fine dust above the hammer to jam it tight in a hole.

3.8 Non return valve

When drilling 'under water' after water has been struck it is essential that the hammer is fitted with a non-return valve. This allows air to be delivered through the drill pipe to the hammer but does not allow air to pass through the hammer back into the drill pipe. This allows drill pipe to be disconnected to add further pipes, and prevents water dirty with borehole debris from entering the hammer piston and valve mechanism. Most modern hammers always have these valves fitted but they need to be kept in good working order.

3.9 General tips for reliable hammer operation

3.9.1 Lubrication

Hammer manufactures universally like to see their products continually lubricated with a mist of special fine lubricant added into the air supply. Airline lubricators are often part of modern drilling packages. In practice, down-the-hole hammers continue to operate reliably without the special oil required, which can be difficult to obtain means that it is common to see a hammer operation without the benefit of continual lubrication particularly in remote locations. Invariably the water-well driller will like and prefer to use water/foam injection to keep the hole being drilled clean and non-sticky and in part the water injection provides some lubrication.

One common practice, in place of a functioning airline lubricator, is for the drill crew to pour a small capful of clean oil into the centre of the drill pipe each time a new drill pipe is added – this helps maintain some lubrication and quickly becomes an established drill crew routine.

The compressed air needs to be delivered clean to the hammer. Ideally drill pipe used for mud drilling should be kept separate from drill pipe used for hammer drilling. If this is unavoidable and the same drill pipe has to be used for both types of drilling, it will help to keep the pipe as clean as possible internally – using threaded plastic end caps help a lot. Often drill crew adopt the routine of blowing through each new pipe added to the drill string . This is done by adding a drill pipe to the rotary head first and then covering the drill pipe already in the hole at the rig table. A blast of a few seconds of compressed air will blow through the worst of any contamination in the new drill pipe.

On completion of a hole and when the hammer has been bought back to surface a small cupful of oil should be poured into it and air blown through to lubricate the sliding parts this is particularly necessary when it has been used with water/foam injection. As the hammer is removed or added to the rig it can be turned over end to end by hand to check the piston is able to freely slide up and down the inside the hammer body it will make a dull thunk as it moves up and down – choose a moment when engines are turned off! Many drill crews will check the hammer is operating correctly before inserting into the hole by connecting it to the rotary head and hammering a few blows against a short stout piece of timber -never use steel because it will break the tungsten buttons.

3.9.2 Rotation speed

Rotation speed should be from 20/30 revs/minute on most small hammers. Rotation is required only to allow the tungsten carbide buttons to strike the hole bottom uniformly. Rotating too fast adds nothing to the drilling performance. Evidence of running to fast can be seen by looking at the outer row of buttons of a worked button bit will show wear and flattening significantly before the inner buttons.

3.9.3 Maintenance of drill bits

The tungsten buttons can lose their specific shape – and be reshaped using diamond cutting shoes and bit regrinding tools. This procedure is often more appropriate to large expensive drill bits required to drill at high performance.

3.9.4 Hammer stripping

It is inevitable that the hammer will stop working one day or another. A drill crew, therefore, should have the tools and skills to strip the hammer clean and inspect and reassemble it in the field. In many cases the hammer will stop functioning because the piston is slightly stuck. The hammer body is threaded together and manufactured from hardened steel and in use can become very tight. Strong tools are required to grip the cylinder and hammer ends. Many hammers have large spanner flats that can be held with purpose made flame cut steel spanners to unthread. Conventional stilsons and chain wrenches are of limited use because they cannot bite teeth into the hardened steel hammer components to give a strong grip. To hold the cylinder clamps or clamping type spanners are required. The spanners and clamps to unthread are best arranged to give the threaded joint a jar with a blow from a sledge hammer rather than just a steady pull.

Alternatively, a hammer is best unthreaded while it is still able to work. Hammering the unit – turning on the compressed air with the hammer under the rig rotary head with the drill bit placed onto a piece of thick hardwood with no rotation or even reverse rotation – will shock and loosen the threads to allow the hammer to come apart easily.

Remember in which order the few components are stripped and the exact position they were assembled, re-assemble with the components clean, oiled and sliding freely.

A hammer will wear – most manufactures include with their operating instructions acceptable wear rates, say between piston and cylinders, and some hammer models have features of replaceable pistons and cylinder liners. Operated in a clean environment a hammer used on water-well construction should last a year or two at least before its performance drops off markedly. In general they have been perfected for near continual work in the harsh competitive environment of rock-quarry production-drilling in hard rock at ultimate performance, and in most case serve a lower production water-well operation with ease.

3.10 Precautions with other parts of the drilling operation

There are precautions to be taken when using a hammer. These particularly concern operation on small drilling equipment, but are of concern to any drilling operation.

The large percussive force, which is generated by the hammer piston being thrown on to the percussion button bit, that breaks rock so effectively will be transmitted in part up the drill-pipe, putting stresses and strains on components. Welded joints will suffer most because the welding process in particular often affects the material condition of the steel, creating stress points that could lead to failure/breakage during drilling. Evidence of this ‘kinetic’ energy will often be seen on the rotary head components, with threaded bolts and screws loosening. Equipment continually used with down-the-hole hammers will need specific servicing and replacement of parts to ensure continued serviceability.

Particular recommendations for a down-the-hole hammer operation

3.10.1 Shock absorbers

Use in-hole shock absorbers mounted directly above the hammer to reduce some of the shock passing up the drill pipe into the rig components.

Appropriate drill pipes

Use drill pipes engineered for the job. Any joints between lightweight body tube and threaded ‘tool joints’ should be designed and specified with consideration given to the effects of heat generated during the welding process, which affects basic material strengths and properties, together with the effect of alloying (mixing) dissimilar steels and the mechanical stresses involved.

3.10.2 Correct adaptors

Threaded adaptors used to join the hammer to drill-pipe or drill-pipe to rotary head should be machined as a single component from a strong grade of carbon steel. Avoid repairing or making up connections by welding.

3.11 Energy Efficiency

On working out a few examples of various compressed air requirements for specific diameter holes, it will be seen that appreciably high volumes of air can be required (see table 3.1). Compressed air is notoriously inefficient to produce, taking about 1 kw to produce 2 litre/second. Consequently, unless hole diameters are limited to an absolute minimum, the air compressor can dominate a drilling equipment package in terms of cost, size and technological content.

3.12 Difficult drilling – 'boulders'

The hardest ground formation faced by the rotary driller figure 3.4 & 3.5 – particularly with limited power – is terrain at the base of substantial mountains with a formation consisting of a matrix of large rounded boulders interfilled with loose fine material. The individual boulders – upwards of 100 mm to several metres in diameter well rounded from being tumbled down a mountain and individually hard.

A drag blade will cut and move the small soft interfill and can wash clear pebbles up to 30/50mm diameter, but the cutting edge will not penetrate or cut the larger boulders – by placing weight on the drill bit the boulder will be pushed into the soft matrix of surrounding material. Fluid or foam drilling offer no solution.

A down-the-hole hammer will easily smash the boulders but the compressed air jet exhausting from the hammer will blow out the soft interfilled

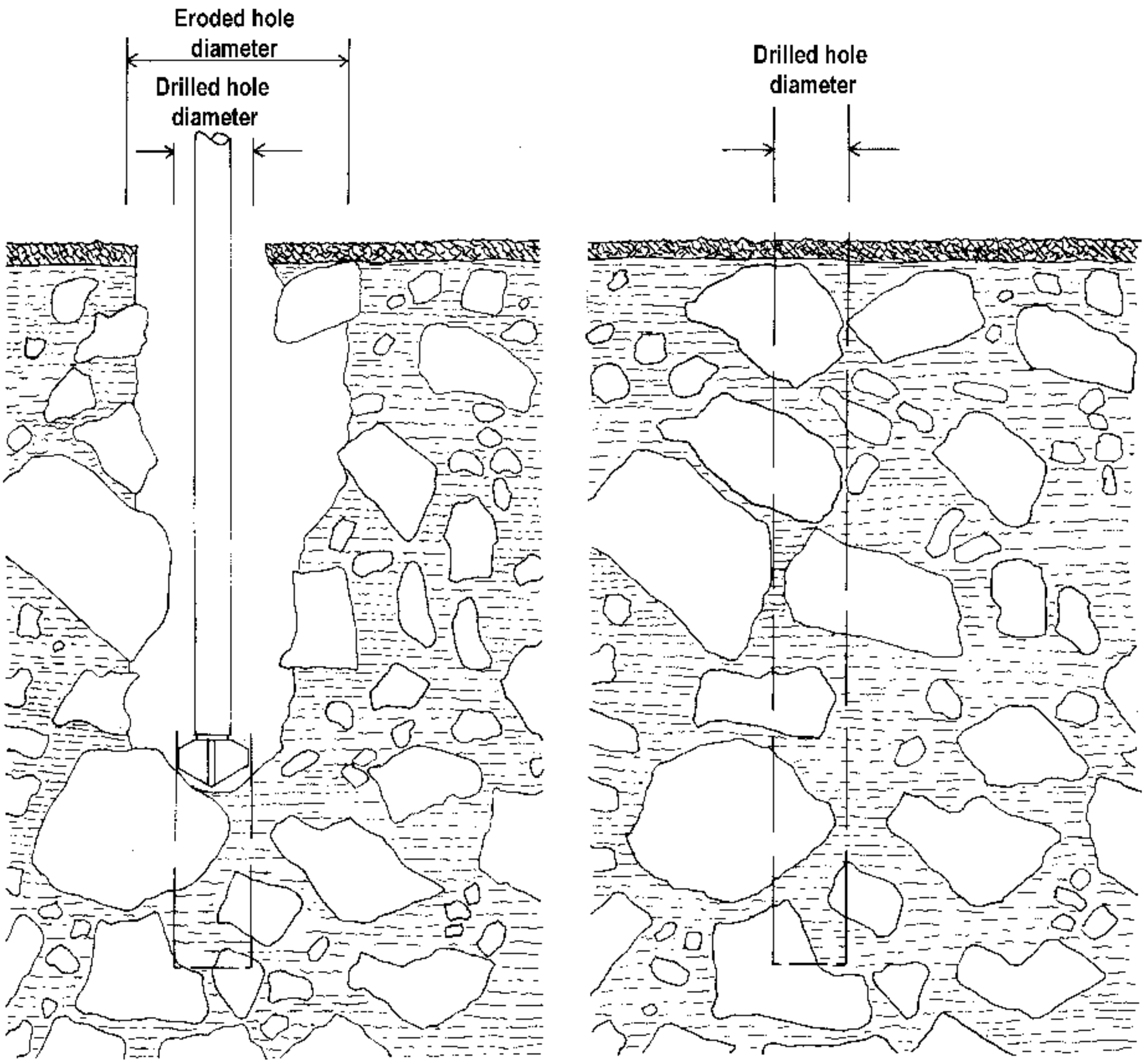

Figure 3.4 Difficulties of drilling boulder-filled ground

material. A potentially worse situation could be that the hammer bit will smash and pass through a boulder and the cracked piece will collapse and fall in behind the drill bit, with potential to wedge the hammer bit.

3.12.1 Solutions

Foam injection can stabilise the softer material and allow a hammer to pass through and make a hole stable enough to allow casing to be inserted. The hammer should be backed out (lifted up) regularly to keep the hole well flushed – maybe cutting back the airflow to prevent high degree of erosion.

An open matrix of boulders or a partially drilled hole can be cement filled – cement will flow into the gaps and, when hardened, will hold the formation to allow it to be penetrated more easily with a down-the-hole hammer. This operation might have to be repeated several times to penetrate a considerable depth of material.

The accepted method of dealing best with this difficult formation is to use a simultaneous casing system – supplied by most down-the-hammer manufactures. This allows steel casing, with threaded or welded joints, to be dragged or pushed directly behind the hammer to shield the walls from collapse. The hammer is fitted with a special oversized bit that has a hinged part that swings out to drill oversize and is able to swing in to allow it to be retrieved up inside the placed casing. To use this method a rig should have a mast strong enough to handle the weight of the casing and long enough to handle useful lengths of casing – supported with additional power to push and rotate.

Other specialist tools such as reverse-circulation hammers might apply – these allow debris to flush up the centre of a dual-skin drill pipe. This will not erode the fragile hole walls – but requires expensive and heavy double-wall drill pipe.

Figure 3.5 Boulder-filled formation