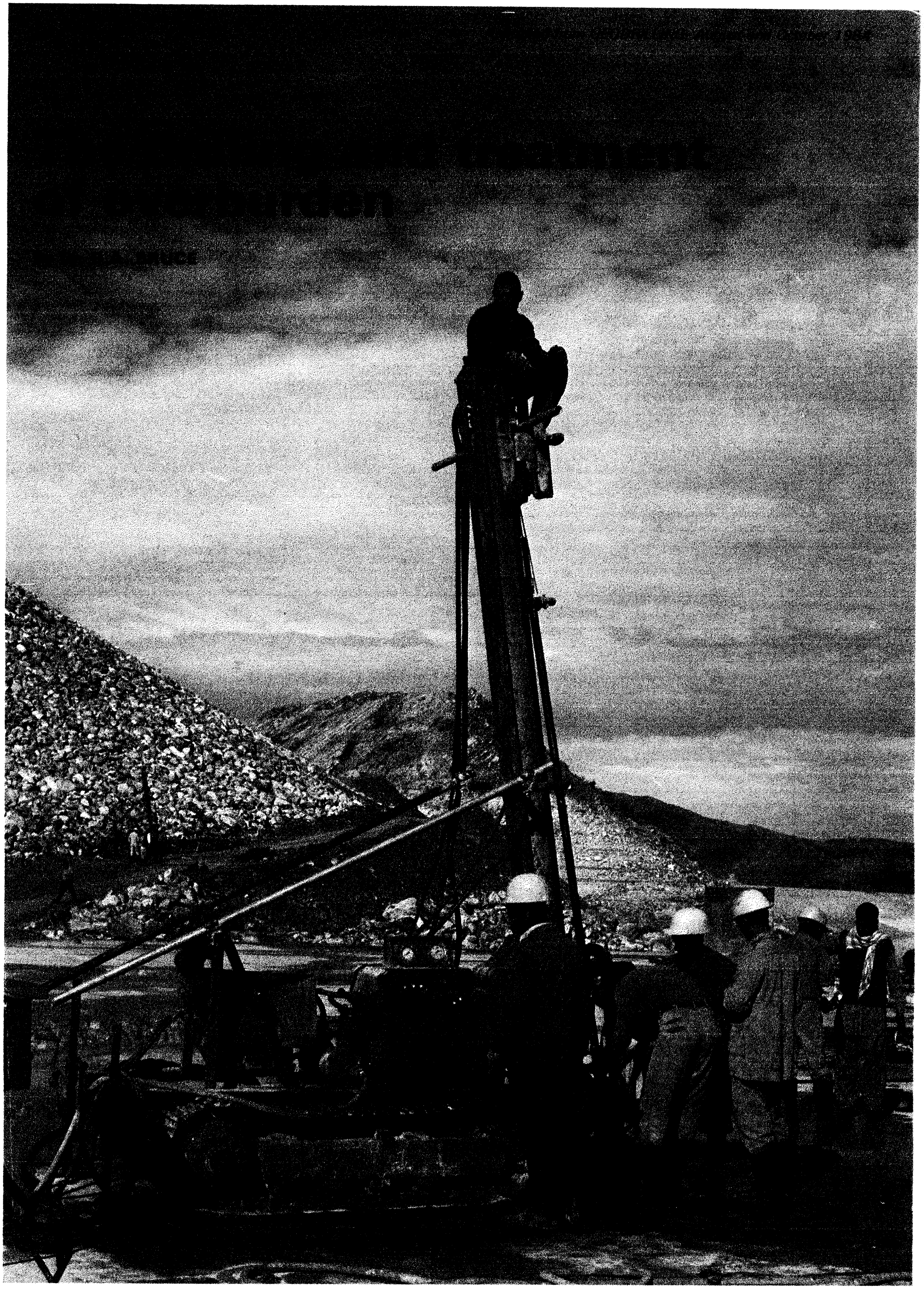

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The drilling and treatment of overburden[†]

By Dr. D.A. BRUCE[*]

1. Introduction

We are required to drill materials classified as overburden either to provide a stable path to underlying competent strata or to enable treatment of the overburden itself, for example, by grouting or anchoring. However, as a consequence of the great range of processes – both natural and manufactured – which have combined to create overburden the nature of the material is itself therefore very variable.

Where it can be "open holed", i.e. when the holes do not have to be cased as drilling proceeds, overburden can be drilled using similar techniques and methods as in rock drilling. It is not intended to review these options in this paper nor the complementary role of foam or mud stabilised drilling as discussed comprehensively by England (1978) or Rowles (1982). Rather, attention will be focussed on systems to combat unstable and sensitive soils or similar materials with matrices grading from clays to gravels, occasionally under adverse hydrogeological conditions, and often containing random hard major inclusions such as boulders, construction debris or industrial waste.

In addition, the discussion will relate to the scale of operations most often encountered in specialist geotechnical processes within the sphere of onshore civil engineering contracting, viz, anchoring, minipiling, grouting and dewatering. This is, therefore, synonymous with drilling holes of diameters 50 to 250mm to a depth rarely in excess of 100m.

Given the wide range of frequently ingenious methods and systems of overburden penetration, it is necessary to further limit the current review to include only those which may be regarded legitimately as prospective "production" orientated tools, and those which depend on rotation or percussion or both as their operating principle. In this case therefore forced or vibratory systems are not discussed, although they should clearly not be dismissed in a wider ranging survey of ground penetration options as being of no relevance. Likewise, pure diamond drilling is also excluded on grounds of cost effectiveness although in the earlier days of difficult mixed overburden drilling it was a reliable, albeit very slow and expensive, expedient.

Bearing in mind the excellence of current texts and publications on the selection of drilling method with respect to anticipated ground conditions (e.g. Littlejohn 1979) this paper will not attempt a duplication in the guise of a summary. Instead, wherever possible the operational limits or advantages of the respective systems are highlighted to provide a fair basis for the decision making processes which encompass technical, economic and logistic facets.

The descriptive data on the systems are drawn from the manufacturers' brochures and it is strongly recommended that they be directly approached for their opinions on the suitability and performance potential in any given instance. Also, although particular systems are credited to certain named manufacturers in the following sections, it should be noted that the competition in the more popular systems is very widely based and is of proven competence.

2. General development trends

As background to the detailed discussion of the different systems (sections 3 and 4) it is of value to review briefly major points on the operating plant and equipment.

2.1. Drilling Rigs

Although the extreme usefulness and effectiveness of air-powered drilling rigs as base machines for overburden drilling has been evident for over two decades it is clear that in the present drive for "bigger, better, faster, quieter, cheaper", their scope for further development is practically limited. Instead, the potential now lies with hydraulically powered machines, whether

MODEL	SIZE & MASS		FEED			POWER	
	Travelling Dimensions (m)	*Mass (kg)*	*Thrust (kg)*	*Pullup (kg)*	*Head Travel (m)*	*Type*	*Output (HP)*
Hands England HERO 30C	4.9 x 2.2 x 1.9	5600	2000	3000	3.5	4Cy Ford	67
Halco 450H	7.1 x 2.2 x 2.2	8500	1100	5270	4.0	5Cy Deutz	70
Casagrande C6	7.0 x 2.1 x 2.3	9000	2700	6000	4.0	6Cy Deutz	Normal operating maximum 105
Krupp DHR80 A	6.7 x 2.4 x 2.3	7700	2500	4500	4.0	6Cy Deutz	
Atlas Copco ROC601	5.6 x 2.2 x 1.7	4380	2000	2000	3.5	Air powered 600cfm at 7bars	–

TABLE 1: Summary details of some popular diesel hydraulic drilling rigs, with air powered ROC601 for comparison (Source: Manufacturers' Brochures)

MODEL	MASS (kg)	PERCUSSION MECHANISM		ROTATION MECHANISM		ENERGY REQUIREMENTS
		BPM (Nr)	*Energy/ Blow (m kg)*	*RPM (Nr)*	*Max Torque (Nm)*	
AC BBE57	170	1910	23	50-100	350-800	Min 400 cfm air at 7 bars
AC BBE53	250	1950	21	40-50	1085-1220	Min 553 cfm air at 7 bars
Krupp HB101	240	2200	27	0-150	950	Perc. 70-85l/min oil at 150-170 bars Rot. 75l/min at 150 bars
Krupp HB103	270	1800	27	0-40	4000	Perc. 70-851/min at 150-170 bars Rot. 60l/min at 170 bars
Krupp HB105	370	1800	27	40 80	6000 in parallel 3000 in series	Perc. 70-85l/min at 150-170 bars Rot. 120l/min at 150 bars

TABLE 2: Summary comparative data on rotary percussive heads as manufactured by Atlas Copco (pneumatic) and Krupp (hydraulic): (Source: Manufacturers' Brochures)

[†] *This paper was presented at the Drillex '84 Conference.*

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activated by diesel or electric power. In addition, the operating principle allows drilling rigs to be created out of a wide range of potential carriers including excavators, tractors, rough terrain vehicles and lorries. However, regarding purpose-built drilling machines, Table 1 illustrates key features of certain commercially available rigs in popular use today. Such machines of course are used throughout other aspects of the drilling industry such as quarry drilling, water well drilling and so on. However, given the higher mechanical efficiency of hydraulic systems, rigs of this type appear the logical choice provided the initially higher capital outlay can be accommodated.

Another particularly useful development reflecting again the application of higher torques and generally heavier drilling and casing strings is the growing popularity of foot clamps and casing breakers mounted at the mast toe and hydraulically operated. Another aid to good production becoming increasingly evident is the use of an on board flush pump either hydraulically or electrically operated and typically rated at 180 litres per minute at 25 bars or 360 litres per minute at 15 bars.

2.2. Heads and Hammers

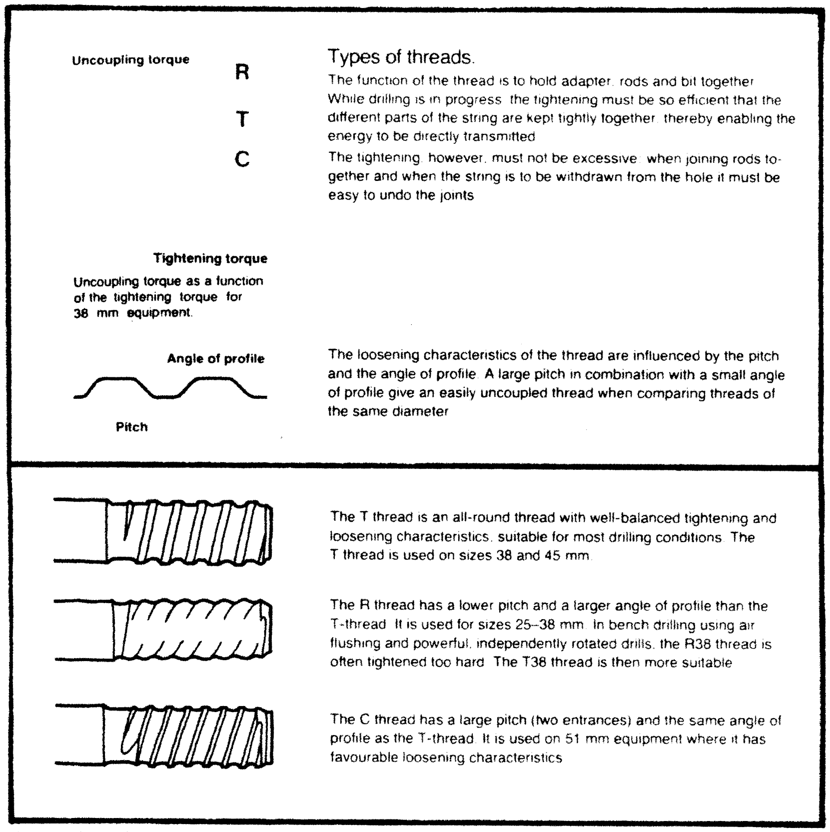
For identical reasons, the deployment of hydraulically powered heads and hammers for overburden drilling is increasing. In purely rotary applications, the Hands England H2 series heads are typical and well proven examples: the FS having a maximum torque of 2 200mN with speeds of 50, 87, or 153rpm and the FD having a maximum torque of 6 300mN at 17, 30 or 53rpm. Likewise the higher torque options offered by, for example, the Krupp HB series hydraulic top hammers over the last 12 years in comparison to the well proven Atlas Copco BBE air powered models are clear from Table 2.

Generally, these high torque hammers require a shank adaptor of 55mm diameter compared with the former standard 38 or 45mm sizes.

Another significant development has been the use of multi-component flushing head arrangements. These permit different casing sizes to be accommodated by changing only one element of the head as opposed to the former alternative of having to replace completely what is a major and expensive drilling consumable. Similarly it is not necessary to scrap the whole device if for example a shank adaptor does break and the rump cannot be extricated from the flushing head.

2.3. Extension Drill Steels

As advised by Atlas Copco, there are three basic thread types formed on the percussive drill steels of diameters up to 51mm which are now most commonly employed in overburden drilling methods. It is acknowledged that thread components must be tightly mated to reduce energy loss. However, overtightening will clearly lead to difficulties in uncoupling and so cause time delays and potentially accelerated wear characteristics. Again, this phenomenon of over tightening is particularly relevant with the growing use of high torque hammers. The loosening characteristics as illustrated schematically in Figure 1 (a) are dictated by the pitch and the angle of profile. The large pitch, combined with a small angle of profile, gives a more easily uncoupled thread. As illustrated in Figure 1 (b) the thread classification is as follows:—



Types of threads.

The function of the thread is to hold adapter, rods and bit together. While drilling is in progress the tightening must be so efficient that the different parts of the string are kept tightly together, thereby enabling the energy to be directly transmitted.

The tightening, however, must not be excessive: when joining rods together and when the string is to be withdrawn from the hole it must be easy to undo the joints.

Uncoupling torque as a function of the tightening torque for 38 mm equipment.

The loosening characteristics of the thread are influenced by the pitch and the angle of profile. A large pitch in combination with a small angle of profile give an easily uncoupled thread when comparing threads of the same diameter.

The T thread is an all-round thread with well-balanced tightening and loosening characteristics, suitable for most drilling conditions. The T thread is used on sizes 38 and 45 mm.

The R thread has a lower pitch and a larger angle of profile than the T-thread. It is used for sizes 25–38 mm. In bench drilling using air flushing and powerful, independently rotated drills, the R38 thread is often tightened too hard. The T38 thread is then more suitable.

The C thread has a large pitch (two entrances) and the same angle of profile as the T-thread. It is used on 51 mm equipment where it has favourable loosening characteristics.

Fig. 1. (Top) Tightening and loosening characteristics of thread forms (Below) Details of T, R and C thread forms (Atlas Copco)

T. Thread: Described as "an all round thread" with well balanced tightening and loosening characteristics suitable for most drilling conditions. Preferred for use on 38 and 45mm rods.

R. Thread: Has a lower pitch and larger angle profile. Best used for systems incorporating 25 and 32mm rods. Driven by hammers with integral rotation, e.g. Atlas Copco BBC 120F.

C. Thread: Has a large pitch with two entrances but the same angle of profile as the 'T' thread. This thread is now recommended for 51mm diameter rods in heavy torque applications often with mechanised rod handling.

To accommodate the water flush characteristics of most overburden drilling systems, central flush holes in rods should be 16 to 19mm in diameter as opposed to the 12mm holes usually employed from the early 70's.

3. Review of popular overburden drilling systems

3.1. Drive Drilling (Lancing)

In appropriate ground conditions, to fairly shallow depths, drive drilling is the simplest,

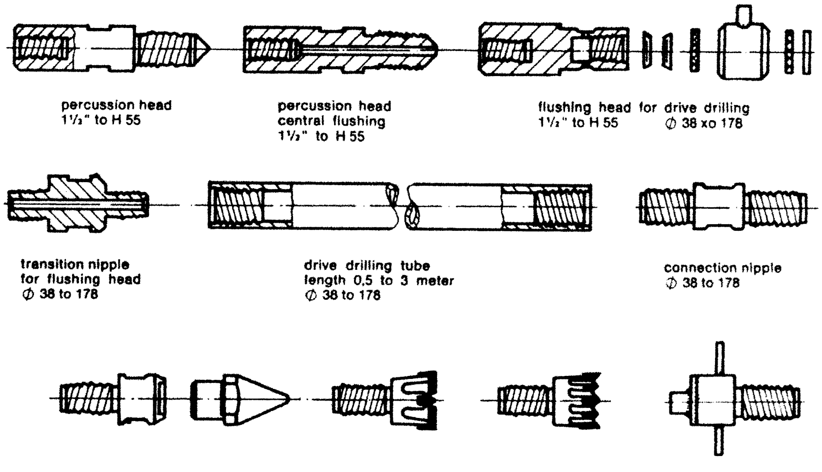


Fig. 2. Drive drilling equipment (Hutte)

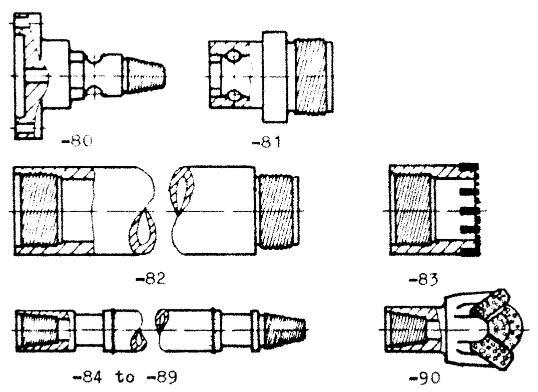
cheapest and fastest method. It is in principle a rotary percussive system in which a tube is drilled with the leading end terminating in either a drive shoe, bit or crown (Figure 2). Water flush is most commonly used. Rotation is necessary to prevent the string uncoupling (usually L.H. Threads) and to reduce deviation (recorded for the 76.1mm size as being as much as 1 in 7.5).

A standard range of sizes, as provided by Hutte, is shown in Table 3.

System Designation: o.d. (mm)	i.d. (mm)	**Recommended tube lengths** *(must be portable by 2 men)*
42.4	15	3.0m
51.0	18	3.0m
63.5	35	3.0m
76.1	50	3.0m
88.9	64	2.5m
101.6	72	2.0m
108.0	82	2.0m
114.3	88	2.0m
133.0	108	2.0m
177.8	150	1.5m

TABLE 3: Standard Drive Drilling sizes (Hutte)

Rarely, however, are sizes over 88.9mm o.d. practical, except in very loose gravelly conditions, and the 76.1 System appears to be the optimum in terms of cost effectiveness. Production figures of up to 250m/day are claimed for this size in "favourable" conditions, to maximum depths of 40m. Whereas 38mm shank adaptors are satisfactory on the smallest sizes, 55mm adaptors are necessary for the others. Typical applications include holes for small capacity bar anchors, micropiles and for grout holes.



Order-no.	Name
178-80	transition flange with Wirth-thread 63,5
178-81	ejection flushing head 63,5 x 177,8
178-82	tube 177,8 x 900mm
178-83	casing crown button type 178 x ø 180mm
178-84	tube 63,5 x 900mm
178-85	tube 63,5 x 1500mm
178-86	tube 63,5 x 2000mm
178-87	tube 63,5 x 2500mm
178-88	tube 63,5 x 3000mm
178-89	tube 63,5 x 3500mm
178-90	rotary bit ø 149,2mm with transition to tube 63,5

Fig. 3. Duplex drilling equipment, size 177.8 (Hutte)

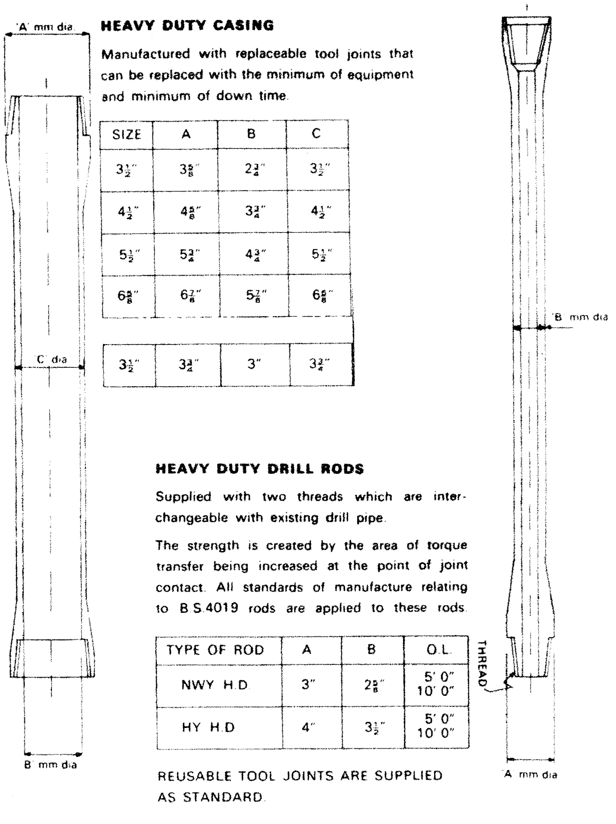
3.2. Rotary Duplex

In the most common situations, when ground conditions and job requirements combine to eliminate the "easy option" of single tube advancement some method featuring the simultaneous advancement of rod (with bit), and casing (with shoe) must be adopted. Such methods may collectively be referred to as "duplex".

The basic method, which most frequently carries the term "Duplex" is purely rotary, and relies for its penetration performance on variations of rig thrust, head torque and speed, and flushing characteristics, other factors being equal. The major components are illustrated in Figure 3 (for a typical minipile drilling operation), and are

- Outer casing (rotated)
- Casing crown
- Inner drill rod (rotated)
- Drill bit (usually tricone)
- Duplex head/transition flange, connecting to the rotary head of the rig.

If a large number of hard obstructions are found, it is possible to exchange a down-the-hole hammer for the rotary bit, to hopefully fragment the obstruction and so permit the



HEAVY DUTY CASING

Manufactured with replaceable tool joints that can be replaced with the minimum of equipment and minimum of down time.

SIZE	A	B	C
3½"	3⅝"	2¾"	3½"
4½"	4⅝"	3¾"	4½"
5½"	5¾"	4¾"	5½"
6⅝"	6⅞"	5⅞"	6⅝"
3½"	3¾"	3"	3¾"

HEAVY DUTY DRILL RODS

Supplied with two threads which are interchangeable with existing drill pipe.

The strength is created by the area of torque transfer being increased at the point of joint contact. All standards of manufacture relating to B.S.4019 rods are applied to these rods.

TYPE OF ROD	A	B	O.L.
NWY H.D	3"	2⅝"	5' 0" 10' 0"
HY H.D	4"	3½"	5' 0" 10' 0"

REUSABLE TOOL JOINTS ARE SUPPLIED AS STANDARD.

Fig. 4. Heavy duty Duplex casing and rod sizes (Euro-Drill). Note that the recommended rock bit maximum sizes for the four major casing types are 2⅝in, 3½in, 4½in and 5¾in, respectively

Size	o.d. *(in)*	Wall thickness *(in)*	Typical Lengths *(ft)*	T.P.I.
4	4½	0.312	5/20	4
5	5½	0.312	5/20	4
6	6⅝	0.375	5/20	4
8	8⅝	0.375	5/20	4
*10	10¾	0.438	5/20	4
*12	12¾	0.438	5/20	4
*13	14	0.438	5/20	4
15	16	0.500	5/20	4
18	19	0.500	5/20	4
21	22	0.500	5/15	4
24	25	0.500	5/15	4
27	28¼	0.625	5/15	⅜in pitch
30	31¼	0.625	5/15	⅜in pitch

*½in wall tube recommended due to tube availability

TABLE 5: Standard casing sizes of Water Well Casing, to B.S. 879 (Inch Sizes). (Euro-Drill)

casing to be rotated down with less resistance (e.g. Bruce and Yeung 1983). Equally, in other difficult ground conditions, reverse circulation may be used.

The system is most commonly used as a high production tool in anchor, coal or grout hole drilling in what are often "difficult" ground conditions, and usually with powerful hydraulic rotary heads. As a consequence, most British contractors favour rather more robust systems than as illustrated in Figure 3 and, as example, Figure 4 shows the "Heavy Duty" range as manufactured by Euro-Drill Equipment (UK) Ltd.

However, where conditions are less onerous, or environmental restraints are significant, Standard Flush Coupled or Jointed Casing (to BS4019, Table 4), or Water Well Casing (to BS879, Table 5) with appropriate rod types (to BS4019) may be used.

Designation	**o.d.** *(mm)*	**i.d** *(mm)*
Flush Coupled		
AX	57	48
BX	73	60
NX	89	76
HX	114	100
PX	139	125
SX	168	150
UX	194	177
ZX	219	205
Flush Joint		
AW	57	48
BW	73	60
NW	89	76
HW	114	101
PW	139	123
SW	168	153
UW	194	177
ZW	219	209

TABLE 4: Standard casing sizes, to BS4019/ D.C.D.M.A./Standards (Euro-Drill)

3.3. Rotary Percussive Duplex

This method, typified by the Atlas Copco OD72 System, is a duplex method wherein both rods and casings are simultaneously percussed and rotated (Figure 5). In its early years of use it was driven by mainly air-powered hammers with relatively restricted torque capacity. Therefore applicability was regarded as limited, and other methods, notably ODEX, with far less emphasis on rotational power was developed. More recently, however, there is clear evidence of a resurgence of the method as a result of the increasing availability of higher torque hydraulic top hammers. By way of illustration, it may be noted that rotary percussive duplex is the preferred production drilling tool of all the major contractors on MTRC related works in Hong Kong, where ground conditions are extremely onerous, featuring gritty decomposed granites with large fresh rock relicts. This market, for tube à manchette installation alone, is conservatively estimated at about 200 000m of drilling per year. It was also the favoured method for drilling the infill (ranging from clay to 30m^3 fresh granite boulders) at Castle Peak Power Station where options featuring over 100 000m of tube à manchette installation were formally proposed.*

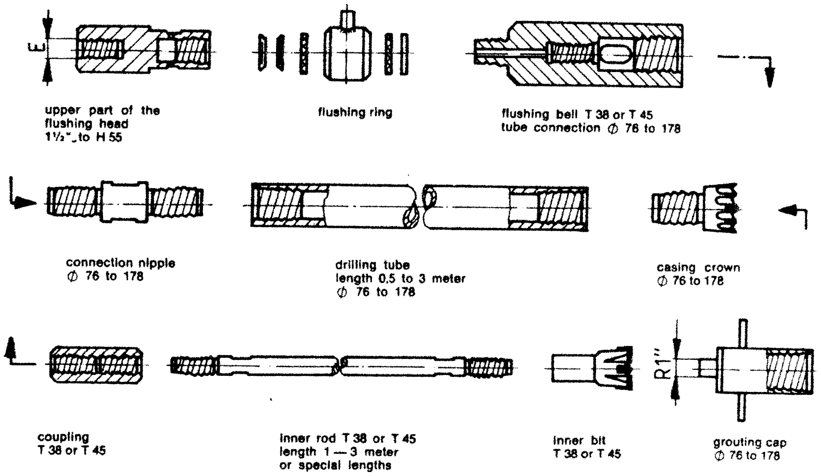


Fig. 5. Rotary percussive Duplex drilling equipment (Hutte)

Although the Atlas Copco System is available in only one size, other manufacturers can supply sizes as in Table 6.

o.d. casing *(mm)*	**min i.d.** *(mm)*	**bit dia.** *(mm)*
88.9	65	60
101.6	72	67
108.0	82	77
114.3	88	83
133.0	108	103
177.8	146	140

TABLE 6: Standard Percussive Duplex Sizes (after Hutte)

The casings are, of necessity, high quality steel, have rope form threads, and wall thicknesses of around 15mm (as opposed to 6mm for ODEX). One consequence is that the unit weight is high, and normally 2m casing lengths are used in the larger sizes. Drilling on with the rods into rock or other stable strata is accomplished without the necessity to change the bit. Both insert and button types are available for bits and casing shoes.

In especially bad ground, the bit is retracted behind the casing shoe, to minimise cavitation of the ground and promote good flush return, and the opposite is done in particularly good ground. Flushing water is best introduced via an external flushing device and should have a characteristic of about 100-150l/min at 15-20 bars. To further improve flush return, sleeving can be inserted between adjacent couplers on the rod string to present a constant annular volume and reduce local "pressure drops" and resultant blockages.

Assuming that sufficient torque (say to 6 000Nm) is available at the hammer, and adequate pull-up force can be applied (say around 4 000kg) then rotary percussive duplex may be regarded realistically as a viable and robust production method for holes to 60m depth. Clearly, however, for the deeper drilling associated with water well drilling or mineral prospecting it may not be the most cost effective option.

3.4. ODEX System

Restricted in terms of torque availability but faced with the increasing demand for a system to reliably penetrate the difficult Scandinavian boulder clays, Atlas Copco and Sandvik jointly developed the very successful ODEX system. This percussive duplex variant features a pilot bit with eccentric reamer, which cuts a hole of diameter slightly larger than the casing. The manufacturers state that its performance is not impaired by gross changes in the ground from loose soil to fresh igneous rocks; the method cuts straight through obstructions or shoulders them aside. Early experience in Britain (Patey, 1977) has also confirmed its ability to deal reliably with artificial obstructions such as slag and other foundry spoil, typical of fill

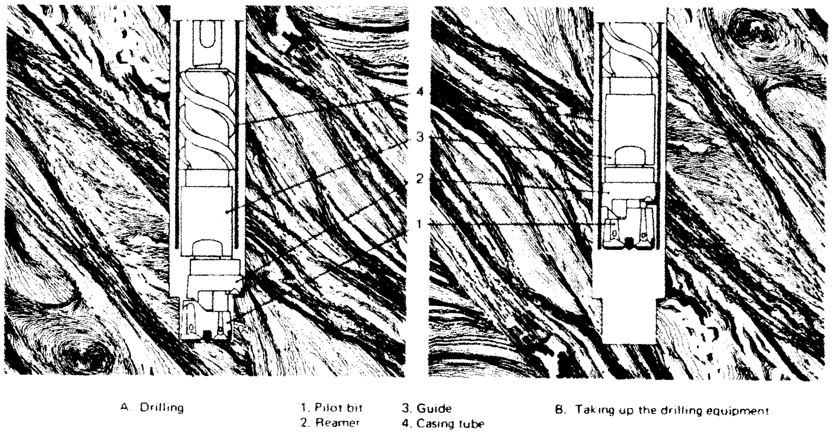


Fig. 6. The principle of the ODEX method (Atlas Copco)

For reasons not wholly related to technical or economic grounds, a large diameter bored pile solution was — unfortunately — adopted finally.

deposits in old industrialised areas. Good results in loose scree type deposits, rip rap, and through old piled foundations have also been confirmed.

The principle of the operation is illustrated in Figure 6. In Figure 6 (a) the single piece pilot bit (concentric) is shown drilling beneath the casing; rotation has been applied, swinging out the reaming device (eccentric) which is enlarging the hole so facilitating the advancement of the casing (percussed only). The reamer is held in the correct position by stop lugs during drilling. Cuttings are transported upwards past the guide device, inside the casing to exit via ports at the driving cap. Flush is usually water, although air can be used, and foam* is common for depths over 30m. When drilling is complete (Figure 6 (b)) the rods are counter-rotated, so felling in the reamer and thus permitting the withdrawal of the rods and bit assembly. Drilling on into rock must then be done with a suitable rock bit. The ODEX principle can operate with both top hammer and down-the-hole options and selection reflects ground conditions, hole diameter, hole purpose, and the type of rig and head available. In the former case, (Figure 7 (b)) part of the percussive energy is transferred from the top hammer, via a shank adaptor, to a driving cap above the casing. For down the hole drilling (Figure 7 (b)) the percussive energy is transferred to the casing from the hammer by a special 'bit tube' with driving (or impact) shoe. The casing is therefore pulled down, again without rotation, from its lower end.

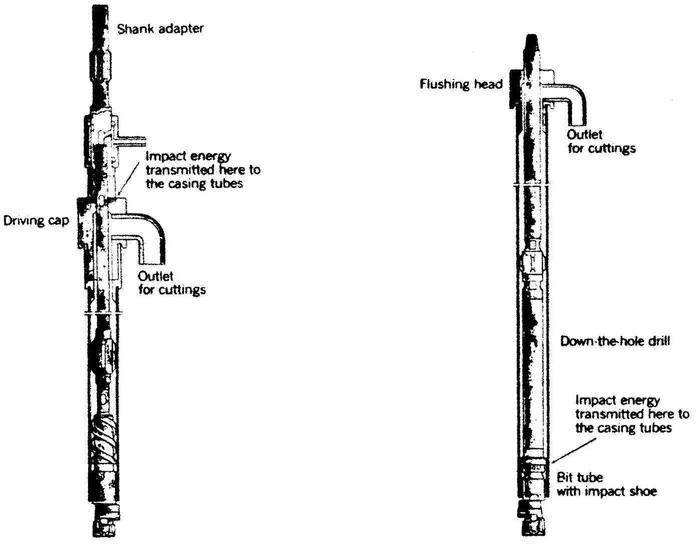
In both cases, however, the steel must be strong enough to resist the percussive energy of the hammer either in compression – ODEX 76 and 127, or in tension – ODEX 115 and 165. Also, where it is to be extracted, the threaded casing must also have sufficient tensile strength, particularly in the threaded zones, and this parameter often dictates the practical depth to be drilled under any given conditions. Indeed, where ODEX 76 has been employed as a production drilling tool under adverse conditions, the typically thin-walled rotary casing of the standard system has had to be altered by specialist contractors, within, of course, the limits imposed by the geometry of the other elements of the system.

Regarding the anticipated longevities of the key components of the ODEX and OD systems (for comparison), Atlas Copco have published the indicative guidelines reproduced in Table 7.

ODEX System	
Pilot Bit	200- 600 drilled metres
Reamer	100- 300 drilled metres
Guide	400-1200 drilled metres
The various items are normally consumed in the following ratios: 1 guide; 2 pilot bits; 4 reamers.	
OD System	
Extension Tube	1000-1500 drilled metres
Tube Coupling	800-1000 drilled metres
Ring Bit	150- 400 drilled metres
Adaptor Sleeve	1000-1200 drilled metres
Cross-Bit	300- 500 drilled metres
ODEX and OD Systems	
Shank adaptor, flushing head, driving cap	800-1000 drilled metres
Extension Rods	1000-1500 drilled metres
Coupling Sleeves	800-1000 drilled metres

TABLE 7: Indicative guideline longevities for Atlas Copco OD and ODEX Systems components (Atlas Copco)

Typical foam flush requirements are 3-5l/min, compared to water at up to 30l/min; advantageous when drilling in remote, arid locations.



ODEX 76 for top hammers

This equipment drills a 96 mm (3 25/32'') hole with rotation to the left leaving room for casing tubes with an external diameter of 84 mm (3 5/16'') and a goods thickness of 3.5 mm (9/64''). Drilling can then continue in rock with button bits or bits with conventional inserts with a maximum diameter of 76 mm (3'').

ODEX 127 for top hammers

The equipment drills a 162 mm (6 3/8'') hole with rotation to the left leaving room for casing tubes with a maximum external diameter of 142 mm (5 9/16''). The goods thickness should be 5–6 mm (13/64 – 15/64'') to avoid deformations. Drilling can continue in rock with button bits or bits with conventional cutting inserts with a maximum diameter of 127 mm (5'').

ODEX 115 for Atlas Copco down-the-hole drill COP 4

The equipment drills a 152 mm (6'') hole with rotation to the right making room for casing tubes with a maximum external diameter of 142 mm (5 9/16'') and a goods thickness of 5–6 mm (13/64 – 15/64''). Drilling can then continue in rock with a standard drill bit with a maximum diameter of 115 mm (4 1/2'').

ODEX 165 for Atlas Copco down-the-hole drill COP 6

The equipment drills a 212 mm (8 1/2") hole with rotation to the right making room for casing tubes with a maximum external diameter of 196 mm (7 11/16") and a goods thickness of 5–7 mm (13/64 – 1/4"). Drilling can then continue in rock with a standard drill bit with a maximum diameter of 165 mm (6 1/2").

Fig. 7. Details of the ODEX method, with top hammers (left) and with down-the-hole hammers (right) (Atlas Copco)

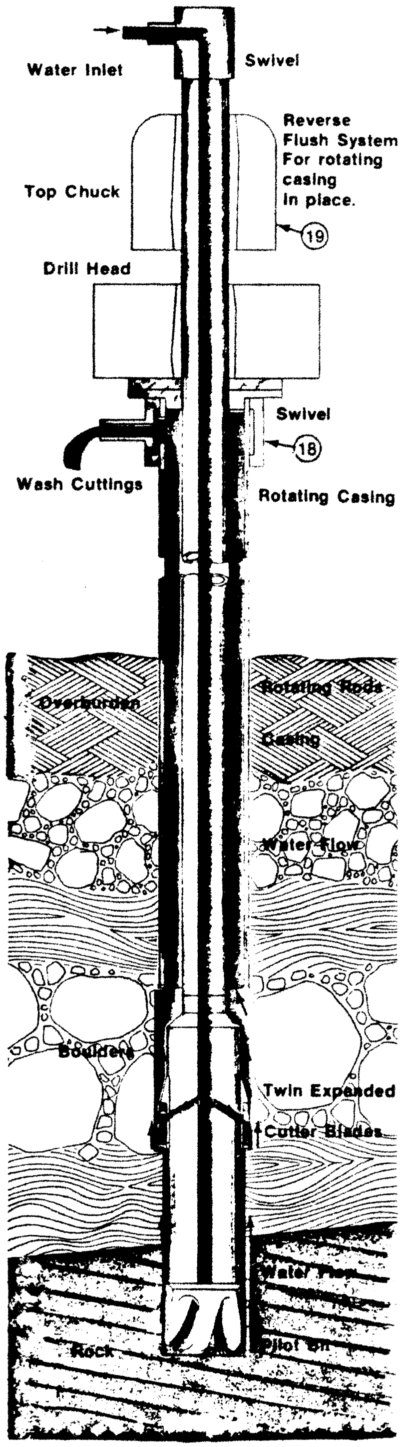


Fig. 8. Casing underreamer (Acker Drill)

In summary, a major attraction of the ODEX system is that the effective efficient depth of penetration is not primarily dependent on driving torque, since the presenter of the greatest steel/ground contact area, i.e. the casing, is not rotated. However, the system remains relatively sophisticated, and its success is very sensitive not only to operator skill and expertise, but to the quality of the casing and its jointing mechanism, and also to the nature of the flushing regime.

3.5 Rotary or Driven Duplex Underreaming

Several such systems have been conceived and employed with varying degrees of technical and commercial success in recent years. One of the more successful – the Casing Underreamer, of the Acker Drill Co. Inc., – is taken as a typical example. In principle, an oversized hole is cut by a bit, and the following casing is either driven or rotated. As shown in Figure 8 the underreaming is not conducted by the eccentric bit system of ODEX, but by activating outwards cutting blades above the pilot bit. These are opened by reaction to the penetration of the bit. Thus if the overburden is soft, resistance is low, the blades remain retracted and the casing advances in the simple duplex manner.

However, when hard layers are encountered the blades open and cut the clearance necessary for the advancement of the casing. At final depth, thrust is removed from the drill string, the underreamer blades fell in, and the string can be extracted. The system permits either subsequent or concurrent advancement of the casing, relative to the rods.

Two sizes (Table 8) are available, designed for heavy duty applications and the installation of NW or HW flush jointed drill casing.

Diamond type cutter blades are available for replacing the twin carbide insert blades when drilling extremely hard material. Diamond pilot bits are also used to replace roller rock or drag type pilot bits commonly used for drilling average overburden materials.

The Underreamer is operated at speeds normally used for rock roller bits or drag bits. The thrust required for the 117.4mm underreamer is about 4 000N and for the 92.0mm is about 2 000N. The water requirements are similar to those for rock roller bit drilling. The system is capable of penetrating boulders, rock debris, timbers and steel.

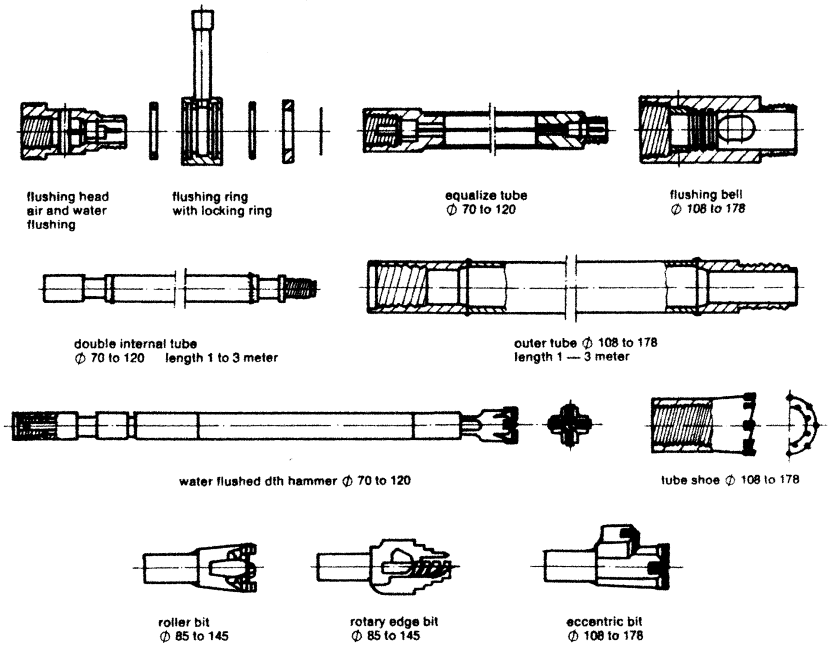


Fig. 9. Double Head drilling equipment (Hutte)

Sizes	**NW Casing**	**HW Casing**
Pilot Hole or Bit Diameter	73.0 mm	95.2 mm
Underreamed Hole Dia (Max)	92.0 mm	117.4 mm
Pin Connection	"NW" Rod	"HW" Rod
Pilot Bit Connection Box	"NW" Rod	2³/₈ API
Feed Pressure to Operate	29.1kg/sq cm	65.8kg/sq cm
Optional Feed Pressure	14.0kg/sq cm	32.4kg/sq cm

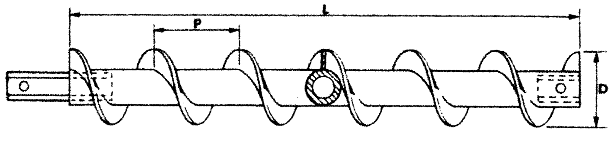
Assembly Description	**Size NW**		**Size HW**	
	Part No	*Weight*	*Part No*	*Weight*
Underreamer (less Pilot Bit)	21145	12.2kg	21144	18.5kg
Optional Underreamed Hole Dia's	To 111.1 mm		To 152.4 mm	

TABLE 8: Specifications for Casing Underreaming system (Acker Drill Co Inc)

	Continuous Flight Diameter (D)					Hole dia (Bit cutting dia.)
	Auger Series					
	'125' mm (in)	'200' mm (in)	'250' mm (in)	'350' mm (in)	'400' mm (in)	mm (in)
	115 (4½)	– –	– –	– –	– –	130 (5)
	140 (5½)	140 (5½)	– –	– –	– –	155 (6)
	160 (6¼)	160 (6¼)	– –	– –	– –	180 (7)
	– –	205 (8)	205 (8)	– –	– –	230 (9)
	– –	255 (10)	255 (10)	– –	– –	280 (11)
	– –	305 (12)	305 (12)	305 (12)	305 (12)	340 (13½)
	– –	– –	355 (14)	355 (14)	355 (14)	395 (15½)
	– –	– –	405 (16)	405 (16)	405 (16)	460 (18)
	– –	– –	– –	460 (18)	460 (18)	510 (20)
	– –	– –	– –	510 (20)	510 (20)	570 (22½)
	– –	– –	– –	560 (22)	560 (22)	620 (24½)
	– –	– –	– –	610 (24)	610 (24)	690 (27)
	– –	– –	– –	– –	660 (26)	740 (29)
	– –	– –	– –	– –	710 (28)	800 (31½)
	– –	– –	– –	– –	760 (30)	850 (33½)
Hexagon Coupling Nominal size across flats	1⅛"	1½" or 1⅝"	1⅞" or 2"	2¼"	2¾"	

Note: Auger and hole diameters have been rounded to nearest ¼".

Min i/d centre tube mm	(in)	o/d H.S. Auger Flight mm	(in)	o/d Auger Bit mm	(in)
60	(2½)	145	(5⅝)	160	(6¼)
100	(4)	215	(8½)	240	(9½)
130	(5)	255	(10)	280	(11)
150	(6)	305	(12)	340	(13½)



Standard lengths (L) 1.0, 1.5, and 3 m (3.3, 5 and 10 ft); other lengths and auger diameters readily available

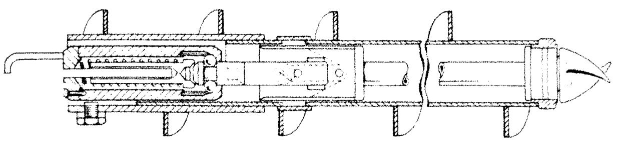


Fig. 10. Standard sizes of continuous flight, and hollow stem, augers (Hands-England)

3.6 "Double Head" Drilling

This rotary duplex method is claimed to be especially quiet, to offer minimal ground disturbance, and consistent cost effective penetration to over 70m. It is distinguished from conventional rotary duplex by the fact that the rods, and casings, are simultaneously rotated but in opposite senses. The drill string, with Left Hand rotation in the Hutte system (Figure 9), carries either a down-the-hole hammer (air or water activated) in hard conditions, or some form of rotary bit in soft ground. Typical rotary requirements are 2 500Nm torque at 40-60rpm.

The casing, with Right Hand rotation, terminates in a substantial crown which cuts a slightly oversized hole, thus, reducing casing/crown resistance. Rotational speeds are lower than in conventional duplex drilling, (20-30rpm) to the advantage of the torque availability (to 8 000Nm). However, the benefits of the counter rotation are that the combined action of the casing and rod cutting is enhanced, and the prospect of flush debris blockages in the casing/rod annulus is minimised due to its dynamic boundaries. (Flush typically 40-60l/min at 10bars).

In especially hard conditions it is also possible to fit an eccentric reaming bit on the rods.

Typical standard sizes are shown in Table 9.

CASING		RODS		
o.d. *(mm)*	Crown o.d. *(mm)*	o.d. *(mm)*	Standard Bit o.d. *(mm)*	Eccentric Bit o.d. *(mm)*
108	112	70	85	110
133	135	90	110	135
177.8	182	120	155	180

TABLE 9: Standard sizes for "Double Head" drilling (Hutte)

3.7. Auger Drilling

Auger drilling is a long established method of drilling cohesive soils with the minimum of hard inclusions, and features the rotation of what is basically a screw into the ground. The continuous flight auger may be in one part (as used in bored piling works) or in connecting sections in, for example, anchor or minipile applications.

The basic method uses a solid stem (or core) and excavates a hole, which, when the auger is withdrawn will remain open only due to the natural competence of the ground, and the absence of ground water pressures. As noted in Section 1, such methods are not included in this discussion.

Much recent development has focussed on hollow stem augers, which permit water, and/or grout to be pumped to the bottom of the hole, allow placing of anchor bars and grout tubes, or enable drilling on into underlying strata for soil sampling or rock socketing.

Generally, however, as emphasised by the range of standard sizes (Figure 10) and the capacities of typical rotary head models (Figure 11), the whole concept of augering is more related now to the larger diameter fields of cast in-situ piles, prebored pile holes and sand drains. Common base machines are excavators, piling frames and crawler-mounted cranes.

To reduce power requirements and allow adequate clearance for the flights, auger bits (or cutting heads) cut a hole 10-12 per cent larger than the auger diameter. The pitch of the flights is 60-80 per cent of the outside diameter of the auger to reduce the tendency of the cuttings to roll back down the hole.

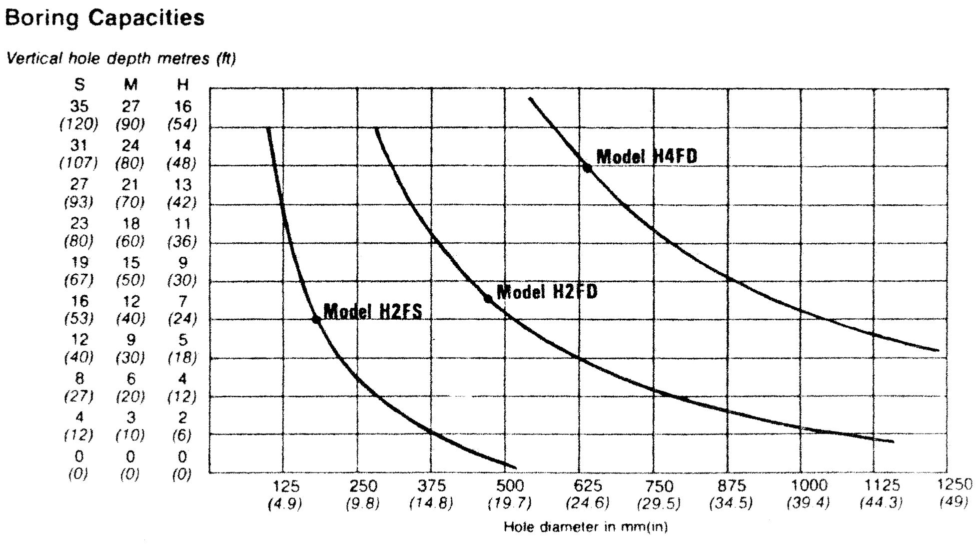
The leading auger section (0.2-0.5m), and fitted with the appropriate bit or drive shoe, is often armoured to reduce wear on following flights.

Expanding auger bits are available for use with continuous flight augers for boring inside casing. The auger bit has an outside diameter equal to the continuous flight auger, but expanding wings increase the cutting diameter to the outside diameter of the casing. During drilling the auger is positioned so that the wings are just below the lower edge of the casing which may then be advanced as cutting proceeds. Reversing the rotation causes the wings to fold back, enabling the auger and bit to be withdrawn without disturbing the casing.

For applications within our field of interest, Table 10 shows typical sizes for hollow flight auger systems.

Hole dia. *(mm)*	Stem o.d. *(mm)*	Stem i.d. *(mm)*
140	76.1	50
155	88.9	64
170	101.6	72
190	108.0	82
230	114.3	88

TABLE 10: Standard hollow stem auger sizes (Hutte)



* Formation Classification:		
	S Sand, Fine Gravel, Soft Clay	For horizontal holes increase depth by 40 per cent.
	M Medium Clay, Soft Shale	For horizontal holes in casing increase depth by 100 per cent.
	H Stiff Clay, Shale, Soft Limestone	

Note:- As sub-surface conditions are so variable this chart is offered as guide only and is in no way a guarantee of performace.

Fig. 11. Boring capacities for Hands-England rotary heads (Hands-England)

4. Treatment of Overburden

It is not the purpose of this section to review the *design* or *execution* of overburden grouting projects; not only is this a vast and complex subject outside the scope of this lecture, but it is already the subject of major books (e.g. by Karol, 1983), conferences (e.g. New Orleans, 1982), and technical papers (e.g. Cambefort, 1977 and Littlejohn, 1983). Rather this section focusses on systems of grout hole *installation* i.e., the drilling related aspects of grouting projects.

4.1. End of Casing Injections

Where the ground is suspected as being very open and there is no recognised need for sophisticated multiphase or multi material injections in any one hole, then the simplest group of methods may be grouped as "end of casing". In essence, the casings are installed to the final depth, and grouting conducted through them, via a top hole grouting cap, as the casings are slowly withdrawn. All the forms of drilling outlined in Section 3 can be used for this purpose. Typical examples would range from drive drilling (for shallow grouting of railway embankments) through percussive duplex (for deeper consolidation, as in mine shafts) to rotary duplex (for grouting of anchors or minipiles). In addition, grouting through the drill rods again during withdrawal, is often conducted for hole stabilisation or watertightness, prior to redrilling.

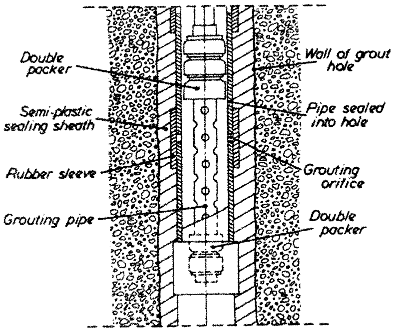


Fig. 12. General arrangement of the tube à manchette grouting system

4.2. Tube à Manchette

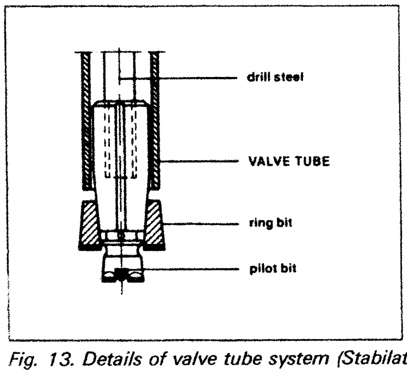
It is generally recognised in Europe and North America that the most appropriate method of overburden treatment is the tube à manchette (or sleeved tube) system (Figure 12). Essentially it permits multiphase injections of various materials with a great apparent degree of control over the grouting variables (Bruce, 1982). The method does, however, depend for its performance, on the successful and economic installation of the plastic or steel grouting tubes. In general, some form of duplex method is used to penetrate to the required depth. The inner rods are withdrawn, the casing topped up with bentonite-cement "sleeve" grout, the sealed grouting pipe inserted, and the casing withdrawn. Recently, increasing use has also been made of hollow stem augers for this purpose. Clearly, the casing must have sufficient bore to permit its extraction without damaging the delicate tube or its rubber sleeves. However, too large a bore will give an unacceptably large annulus of sleeve grout, making a subsequent opening of the sleeves a question of very high initial rupture pressures.

In addition, drilling methods must be selected to ensure minimum disturbance to the surrounding ground during drilling: observations of exposed tubes in the MTRC tunnels in Hong Kong usually showed less disturbance (i.e. smaller annulus) around tubes drilled by rotary percussive duplex, than around those drilled by ODEX, other things being equal.

On a typical tube à manchette contract, perhaps 40% of the total valuation relates directly to the drilling, and installation of tubes à manchette. However, unless this is accomplished by technically the most appropriate drilling method — and not necessarily the cheapest or fastest — the execution and profitability of the cement and chemical injections constituting the balance of the contract value will invariably be compromised, especially if moderate or high grouting pressures are envisaged.

Drilling

— a non-rotating casing — the VALVE TUBE — is driven simultaneously with the drill steel, for example using a crawler tracked drilling unit. The drill bit is in two parts — a pilot bit, attached to the drill steel, and a non-retrievable ring bit. After drilling the VALVE TUBE is left in the ground.



4.3. Valve Tube system

In many ways similar to the tube à manchette system in terms of its grouting capabilities, this system, developed by Stabilator of Sweden, in the middle 1960's, has one major difference. The steel grouting pipe, equipped with spring loaded grouting ports doubles as the drill casing, and as such has a non-retrievable crown (or ring bit) (Figure 13). The casing is not rotated during driving. Clearly the initial lineal cost per metre installed is high, but this is claimed to be offset by the high rate of installation, in which no time must be spent extracting temporary casing, as in the case of tube à manchette

Grouting

— The VALVE TUBE has apertures at 300—500 mm centres which are protected by leaf springs. Without further preparation the grout tube can be lowered into the VALVE TUBE and positioned at the desired level. Self-locking packers ensure that the grout is directed through the correct apertures.

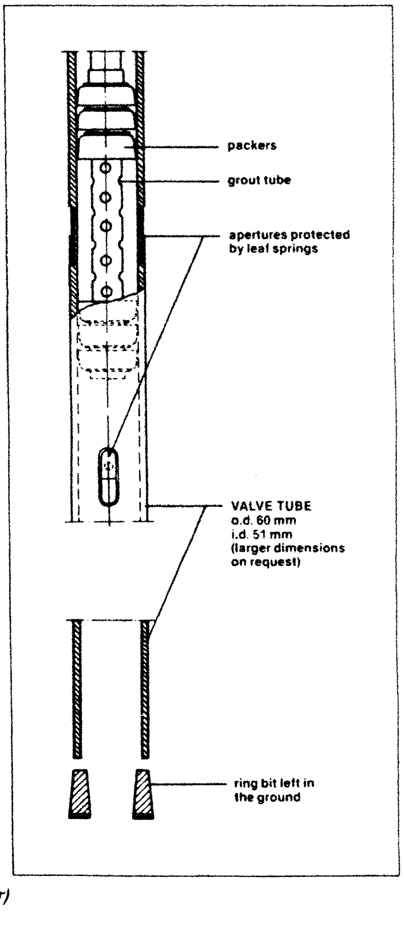


Fig. 13. Details of valve tube system (Stabilator)

grouting, for example. Several successful major applications have been recorded throughout the world with a particularly good description provided by Lamberton (1982).

4.4. Jet Grouting

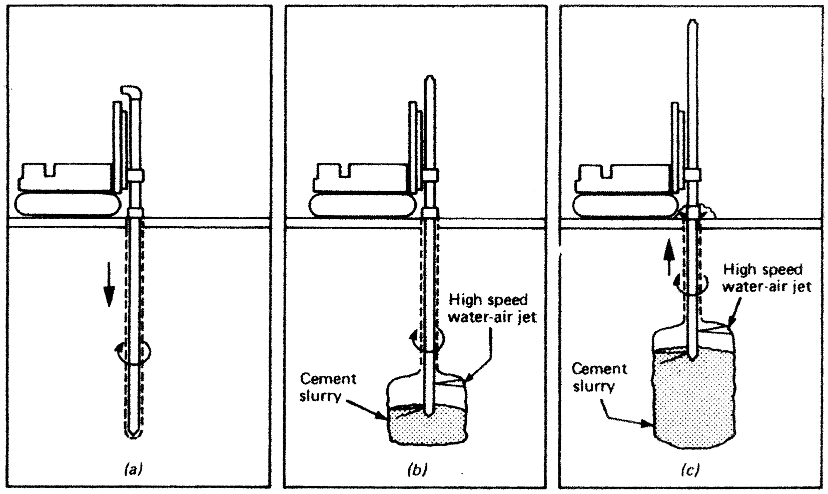
The three groups of techniques described above generally introduce grout into an otherwise undisturbed ground mass by *permeation* or *claquage;* essentially the geotechnical properties of the mass are enhanced as a result of work done to its fabric in-situ. Conversely, jet grouting and similar Japanese techniques improve ground properties by the total or substantial *replacement* of discrete volumes by stronger materials, e.g. cement grout. This is particularly valid in those soils which due to their particle and pore size characteristics cannot be permeated or hydrofractured to an extent that significant overall improvement can be guaranteed. Typical examples are the fine, soft marine deposits of Singapore and Japan where great tunnelling activities are currently underway.

Early work instigated by Cementation in the early 1960's was developed by Kajima of Japan, who recently, through their Chemical Grouting Company, licenced the system in Britain to G.K.N. Keller Foundations. Other systems, such as that now offered by Colcrete, have European origins, but the basic operating principles are common.

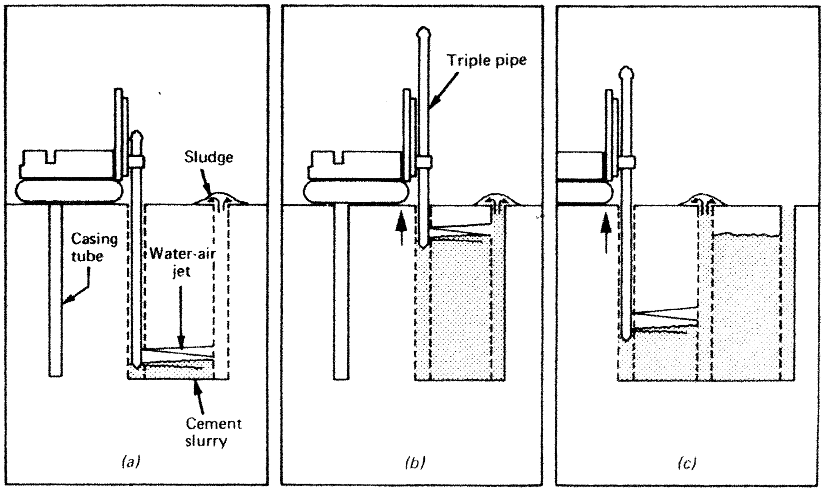
Conventional drilling methods are used to "provide the pilot bore" (Anon. 1982) to a nominal diameter of 150mm. A complex triple phase drill assembly (the "monitor") of up to 130mm diameter (Figure 14) is then installed to full depth. As extraction commences (up to 4m/min) high pressure water is pumped down the centre passage to an upper 1.8mm diameter nozzle where it is boosted by higher pressure air passed down a concentric annulus. The combined jetting pressure may be up to 400bars. The system is rotated at 5-10rpm during continuous withdrawal, and the nozzle cuts and fractures a cylindrical volume of up to 3m diameter. A lower 7mm diameter nozzle (about 500mm below) injects grout into the base of this jetted zone at about 40bars and so fills and consolidates it. Most of the displaced soil is displaced upwards by the air flush. A column of appreciable strength (Table 11) results.

	Granular soils	**Cohesive soils**
Column formation		
Diameter	0.5-3.0m	0.5-2.5m
Unconfined compressive strength, kN/m^2	5,000-10,000	1,000-5,000
Minimum shear strength, kN/m^2	500	300
Modulus of deformation, MN/m^2	500	100
Coefficient of permeability, cm/sec	10^{-6}-10^{-9}	10^{-6}-10^{-9}
Panel formation		
Thickness, mm	150-300	50-100
Coefficient of permeability, cm/sec	10^{-6}-10^{-9}	10^{-6}-10^{-9}

TABLE 11: Design values for Jet Grouting (G.K.N. Keller)



Column jet grout construction. (a) A guide hole is sunk to the depth at which a column is to be made. (b) Jetting is started when the monitor is rotated. (c) The monitor is rotated and lifted, and sludge is discharged from the guide hole



Panel jet grout construction. (a) The monitor is lowered into a guide hole sunk by boring and is directed towards a sludge-carrying hole to start jetting. (b) The monitor is lifted and the sludge is discharged from the hole. (c) When one panel is completed, the monitor is transferred to another hole

Fig. 14. Operating principle of jet grouting for piles and panels (GKN Keller)

This method is environmentally attractive in terms of noise and vibration and so is ideally suited for underpinning purposes (e.g. Shibazaki and Ohta, 1982). Success is claimed "over the whole range of soil types, from silts and clays up to weak rock", to practical depths of about 45m.

Minor variants include panel jet grouting (PJG) wherein the nozzles are located vertically above each other and the rod is *not* rotated during withdrawal, and wing jet grouting (WJG) which is similar but has its nozzles fixed at 90° to each other thereby forming a fan shaped grouted mass. Another similar type — Chemical Churning Pile (CCP) is now rarely used since its effective diameter (to 0.5m), as a result of water-only jetting, has rendered it less attractive commercially.

It must be emphasised that despite its apparent attraction as a concept, the strictest site controls are essential in ensuring an adequate end result, especially when the enormously high jetting pressures are recalled. High quality is ensured in Japan for example by a very tightly controlled licensing system. Typical plant requirements in the Kajima/G.K.N. Keller method are shown in Figure 15.

In terms of cost per cubic metre of treated ground, jet grouting methods are approximately 2 to 3 times costlier than the tube à manchette system. However, for certain purposes involving either comparatively high strength (underpinning) or resistance to very high hydraulic heads (deep tunnelling) then they do offer a very positive and reliable solution when properly executed.

4.5 Limited Area Grouting (LAG)

In the last 20 years there has been a startling growth in tunnelling and deep foundation projects in Japan. This is reflected in the high reputation currently held by the Japanese as soft ground tunnellers — several British companies now use their methods and machines – and as developers of novel ground treatment systems, of which LAG is one of the commonest (Figure 16 (a)).

It essentially features the rotary drilling by a small hollow spindle rig of a fixed concentric rod-casing assembly, followed by the injection of a flash setting (5secs) grout via one exit port during rotated withdrawal (20rpm at about 2m/min). With respect to Figure 16 (b), passage A carries the base component (silicate solution) and B the reagent. These are mixed and ejected at the port (D), which during drilling is kept closed by a spring arrangement. A diameter of treatment of 0.6-1.0m per hole is designed upon.

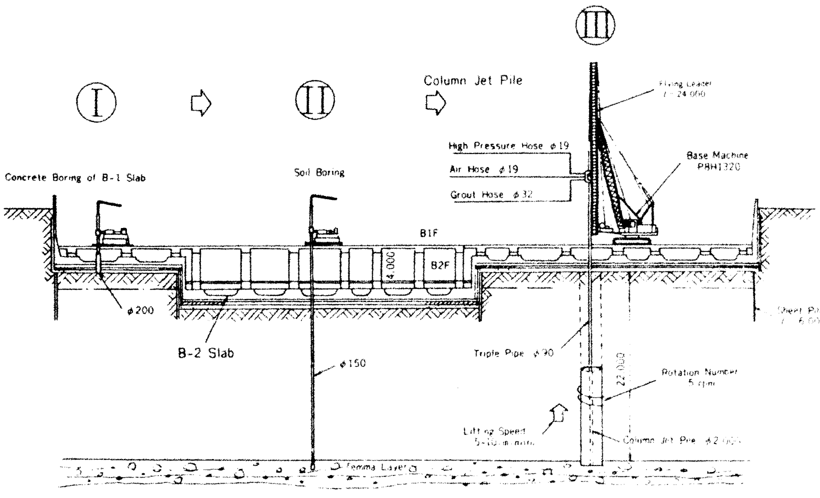
Typical ground conditions suited to LAG are clays, silts, sands and fine gravels. It is notable that the tube à manchette system is relatively little used in Japan due to its (i) relative cost and complexity (ii) potential for dilution and dispersion of grout under dynamic ground water conditions, (iii) leaving in of tubes after completion of treatment and (iv) possibility of water supply contamination due to comparatively large lateral grout travel resulting from high pressures and longish gel times (e.g. Tokoro et al, 1982).

Grouted ground strengths of 0.2-0.5N/mm^2 are common, and this system accounts for 20% of the Japanese domestic market but a larger proportion of the work executed by their specialist companies elsewhere in S.E. Asia (e.g. MTR in Hong Kong, MRT in Singapore).

The system is protected by at least six patents, one Association, and is about 20% cheaper than tube à manchette, all things being equal.

4.6. DDS (Double Tube Drilling and Seepage)

The system is in some ways similar to LAG. It features the rotary insertion of a fixed rod-casing system (42mm o.d.) with water flush down each. At the terminal depth a small plug is activated against a retaining spring by grouting pressure: this exposes six nozzles (Figure 17) through which fast setting grout (10-30secs) is ejected. As in LAG the grout consists of silicate plus reagent, with final mixing occurring only at the nozzles. No rotation is required during extraction. Water flush characteristics of 15-25l/min at 10bars give a diameter of influence of up to 1m. Withdrawal rates of around 15mins/m are common, with grouting pressures to 15bars.



Operations to improve the load-bearing of existing foundations on poor ground using the Kajima method: I. Boring through the concrete slab. II. Boring through subsoil to load-bearing strata. III. Formation of grout column

Application	Nomenclature of machine	Kind of machine	Maker	Capacity	Scale			Power	Weight
					Width	Length	Height		
Guide hole for installation	Boring machine	Megaro - 150	Japan Longyear	50 - 500 M	1,170	2,280	1,450	11kW	1,500 kg
	Boring pump	MG - 10	Mineral Research Drilling Co., Ltd.	30 kg/cm^2 105 ℓ/min	540	920	1,000	7.5	250
Jet pile	Ultra high-pressure pump	PG - 75 BB	Mineral Research Drilling Co., Ltd.	100 kg/cm^2 67 ℓ/min	1,200	2,300	1,100	55.0	2,500
	Grout pump	MG - 25	Mineral Research Drilling Co., Ltd.	63 kg/cm^2 200 ℓ/min 60 kg/cm^2 125 ℓ/min	840	2,720	1,485	18.5	1,000
	Grout mixer	PM - 18	Mineral Research Drilling Co., Ltd.	500ℓ x 2 tanks	1,295	2,520	2,212	15.0 (7.5 x 2)	1,400
	Compressor	PDR - 370	Hokuetsu Industries, Co., Ltd.	7 kg/cm^2 105 m^3/min	1,690	4,200	2,000	PS 110	2,800
	Rotary equipment	Boring machine	Japan Longyear	50 - 500 m					
	Lifting equipment	Megaro- 150							
	Truck crane			16 t					
Water supply and discharge equipment	Turbine pump	TK - 100	Takasago Machine Co., Ltd.	ϕ100 Two stage 1000 ℓ/m				11 kW	
	Water pump	OS - L	Takasago Machine Co., Ltd.	ϕ 50 200 ℓ/mℓ					
	Bond pump	T - 610		ϕ150 200 ℓ/mℓ ϕ100 1000 ℓ/mℓ					
	Water bath			20 m^3/Right					
Others	Cement silo		Koyo Machine	30 t 500 kg/min	3,000	4,500	12,000	2.7	6,000
	Truck Crane			16 t					

Tabulation of equipment employed in the foundation improvement operations illustrated

Fig. 15. Details of jet grouting equipment (Kajima/GKN Keller)

Presently, 50-70% of the Japanese domestic chemical grouting market features DDS, which, per cubic metre of treated ground, is about 30% cheaper than tube à manchette.

Again, small hollow head drilling rigs, (say up to 20HP) are adequate, and their quiet and vibration-free operation makes them very

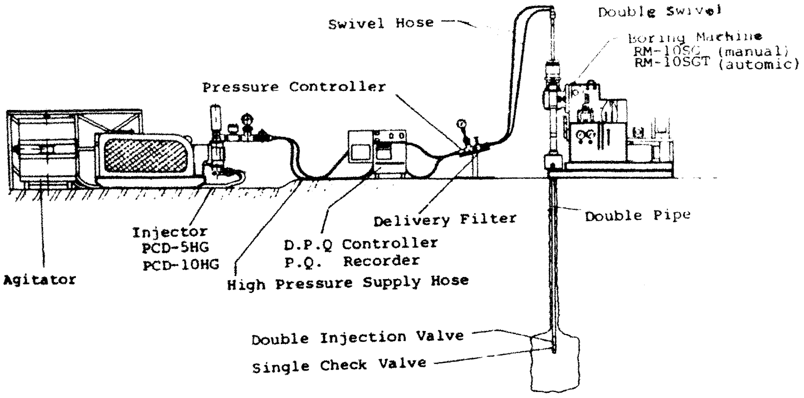


Fig. 16a. Operating principle of LAG grouting method

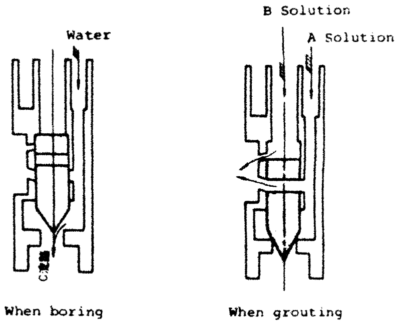


Fig. 16b. Arrangement of injection system (Nissobo)

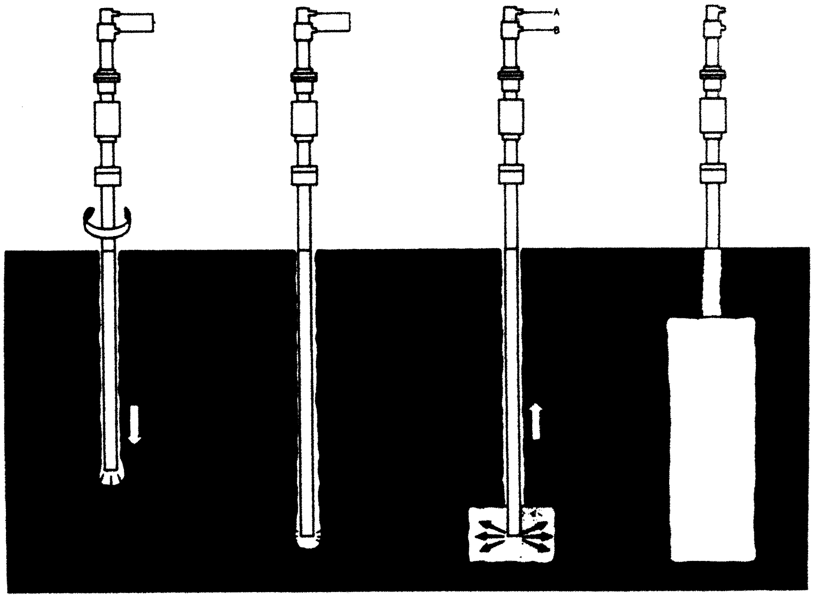
popular in urban or underground grouting works.

It should be noted that there are several other variants of this type, e.g. SGR ("Space Grouting Rocket System"), in Japan, where environmental and geotechnical considerations clearly favour this approach. However, their market share is small, and the other systems described above would appear to be of far wider relevance to us in Europe.

5. Final Remarks

The general conclusion drawn from a survey of popular overburden drilling techniques is that a wide range of reliable variations is available to the contractor. It is clear that it is not possible to recommend any one method as being *"best"*. However, within this range the most *"appropriate"* method can be selected upon consideration of the drilling plant projected, the anticipated ground conditions, and cost-effectiveness. No major innovations are foreseen, but a trend will continue towards the development of those systems which directly benefit from the growing availability of high torque hydraulic heads and hammers. Hence it is suggested that rotary, and rotary percussive duplex systems now have the greatest potential for further exploitation.

Regarding drilling for the treatment of overburden, the complexities of grouting soft ground, often for widely differing purposes, have fostered numerous fundamental approaches. The choice is being further enlarged by the efforts of the research chemists offering stronger, thinner and "faster" grouting materials. As a general conclusion, however, it would seem that the hitherto unchallenged supremacy of the tube à manchette system (originally conceived in 1929) must soon be seriously tested by the alternative methods now available as a consequence of oriental necessity and ingenuity.



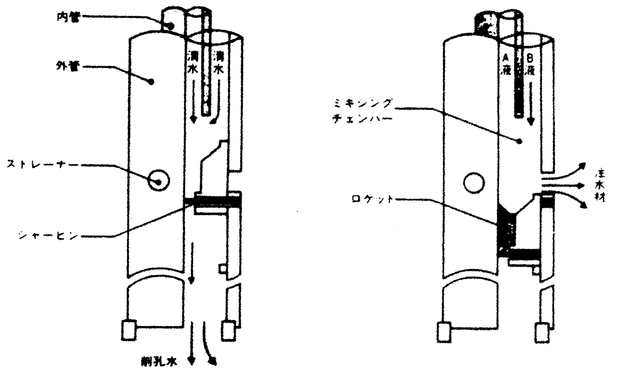


Fig. 17. Operating principle, and details of the injection system, of the DDS method (Acker Asia)

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Technical and Commercial Brochures

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