NEW TECHNIQUES FOR LARGE DIAMETER BORED PILE DRILLING OPERATIONS IN ROCK

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ABSTRACT

Currently in Hong Kong Down the Hole Hammer Drills (DTH) are effective at rock socketing bored and "H" piles but generally limited to diameters up to 600mm. The larger piles sizes, 2.0 to 3.0 meter diameter, use Reverse Circulation Drills with Rock Roller Bits but the output is slow.

Recently introduced to Hong Kong are two rock drilling techniques, which combine the advantages of both systems, enabling 1.0 to 2.5 meter diameter rock sockets to be constructed using high drilling rates with economic use of energy.

This paper describes the methods and provides technical details and case histories that may be of use on future projects where rock drilling, or rock socketing is required irrespective of the depth or difficulty in ground condition.

1. CURRENT EQUIPMENT IN USE FOR ROCK SOCKETING

1.1 DOWN THE HOLE HAMMER DRILLING

Down the hole hammer drills had been in use in Hong Kong for many years to form prebored holes for driven piling and more recently to form rocks sockets for mini piles and rock socketed H piles. These hammer drills by their action of driving a button drill bit using compressed air vertically and repeatedly on to the rock in a hammer action have proved very effective in drilling through rock. Production can be from 1.0 to 2.0 meters per hour or more in grade II to III rock.

Unfortunately this technique has limitations. Compressed air is used to drive the drill bit at the base of the pile and the air when expelled from the hammer is used to blow the cuttings from the pile bore. The technique whilst economic has these main disadvantages.

a. Firstly when drilling below the water table the air pressure has to compete with the ground water pressure and normally this prevents the technique from being used at depth 30 to 40 meter below ground water level.

b. Secondly again when used below the water table the action of blowing the cuttings from the pile bore also blows out groundwater thereby effectively dewatering the soil. This effect can cause settlement, which on some works in Hong Kong has been substantial, and seriously affected adjoining properties.

c. The third disadvantage is that the cuttings are blown free into the air at ground level. This is an environmental nuisance and has been known to injure passers-by and cause some damage to adjoining properties.

d. Normally for down the hole hammer drills relying on removal of cuttings by air, the larger cuttings fall back to be re-crushed by hammer before removal. In some cases this action can jam the drill head.

1.2 REVERSE CIRCULATION DRILLING USING ROCK ROLLER BITS

Traditionally in Hong Kong to form a larger diameter rock socket reversed circulation drills (RCD's) have been employed using rock roller cutters for excavation into the rock. The method is to rotate and grind the roller cutter bits on the rock surface whilst employing a downward force. The cuttings are removed by reverse circulation. That is the name given to removing the water suspension from the base of the pile by a central drill pipe whilst replacing clean water into the pile shaft at ground level to achieve circulation of the drilling water. Flow is usually generated by air lifting the water and cuttings through a central drill pipe, this pipe is also used to rotate the drill at the base of the pile and the assembly is referred to as the drill string. The main disadvantages with this technique are as follows:

a. The operation is slow; production at 100 to 350 millimeters per hour for a grade II to III rocks is usual.

b. Bit damage is high as the special steel used in button bits are fractured easily on rotating the cutters on uneven rock surfaces.

c. A high bit force is required to facilitate the grinding action on the rock. Normally 10 to 15 tons force is required per cutter, and with say 12 cutters per drill head gives a total force of 110 + tons. This force is normally termed the crowd force. The crowd force has to be accommodated by clamping the drill frame to the temporary pile casing of the pile shaft. Reliance is then made on the weight of the rig and casing, and the skin friction between the ground and the temporary casing to prevent the casing from rising out of the ground during drilling. It is for this reason that the normal RCD drills cannot work in shallow rock conditions.

d. Again for the reasons given in (c) the RCD, using high crowd forces, cannot work initially on sloping bedrock. Such a condition normally requires first using a chisel to form a horizontal rock surface for the roller cutters to work.

e. Again for the reasons given in (c) high wear and tear occurs on the drill head, drill string, and all moving parts of the system.

f. This system is also used to form bellouts in rock. The down crowd has to be transmitted horizontally onto side acting roller cutters that expand outwards as the rock is removed. In uneven rock conditions or sloping bedrock the system breaks down due to the uneven distribution of force on the cutters. In addition it is less economic in energy terms than vertical drilling using the roller cutters. Although this system is widely used it is time consuming and sometimes produces unstable conditions.

2. NEW EQUIPMENT CURRENTLY IN HONG KONG FOR ROCK SOCKETING

2.1 REVERSE CIRCULATION DOWN THE HOLE DRILLS

The recent introduction of a drill head using a cluster of down the hole drills in conjunction with reverse circulation for removal of the cuttings combines all the advantages of the down the hole hammer drill, and reverse circulation for cutting removal, whilst removing the above disadvantages of each system.

The reverse circulation down the hole drills are capable of:

a. Achieving drilling speeds in Grade III to II rock of between 1.0 and 1.5 meters per hour.

b. Efficient removal of the cuttings, which are of a larger size as no grinding action, associated with the rock roller bits, or secondary crushing by the normal DTH drill is required. The direct drill head blow and it's following upward suction movement of this new type of drill means that the cuttings are pulled upward and swiftly removed by the flow of the reverse circulation. The cutting size is seen to increase from the 2 – 5 mm using rock roller bits to 5 – 20 mm for the RCD DTH drills. The improved efficiency of reverse circulation for the DTH drills action during cutting removal means a larger cutting size and consequently less bit wear leading to greater production efficiency.

c. The cluster of down the hole drills in the drill head only require a crown force of around 7 tons for the 2.0 meter diameter drill. This force is easily accommodated by the self-weight of the drills headgear. The advantages are that the drill can work in shallow rock conditions and on sloping bedrock.

d. The conditions of a sloping rock head gives rise to many of the problems associated with large diameter bored piles founding on rock. The temporary casing cannot normally be entered into rock; therefore on sloping bedrock part of the piles circumference is exposed to soil or decomposed rock. Using heavy chisels to level the rock causes vibration and inevitably the soil on the exposed side collapses into the pile creating voids behind the casing. This condition can affect pile integrity on concreting and in some cases can prevent the pile from being constructed. The RCD down the hole drill is able to form a socket on sloping bedrock. Because of the low crowd force, and slow or no rotation requirement, the drill doesn't have to be forced onto the rock and can be positioned to cut on one side of the bore only. This enables the drill to enter sloping bedrock without vibration or loss of material.

A typical general arrangement of the site set up is given in Fig. 1 and closely resembles that of the traditional RCD. However the main differences are in the drill head, which incorporates the down the hole drills. The drill head is substantially longer and heaver than the normal RCD head arrangement. Another difference, which is an option, is the use of a suction pump instead of the more normal airlift for cutting removal. The suction pump has some advantages over the latter in that it can normally remove larger cutting size and enables better screening of cuttings, as the flow is constant and free of air.

A possible disadvantage of the RCD DTH drill system is that it requires one compressor for every drill mounted in the drill head. The nominal two meter diameter drill with eight drill heads therefore requires eight compressors. These are linked to a common air feed pipe, which is connected via an air swivel to the air feed pipe incorporated in the drill string and drills. However the additional cost of the air supply over the conventional system is more than compensated by the increase in production, and even including the capital expenditure cost of the drill head, the overall cost per meter of rock drilled is comparable with that of the traditional RCD using rock roller cutters.

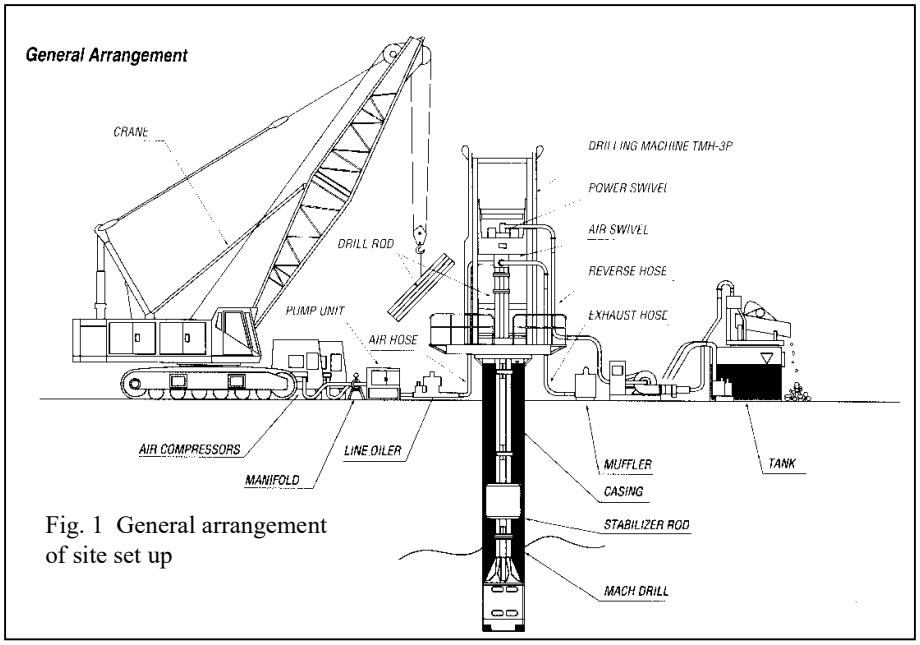


Fig. 1 General arrangement of site set up

RCD DTH drill specification

Drilling diameter actual	0.80, 1.00, 1.40, 1.45, 1.85, 2.40	meters
Drilling Depth	100	meters
Air pressure - Drill Head	5 to 10	kg/cm2
Torque	1 to 3	t-m
Crowd Load	1.5 to 10	tons
Drill Rotation	0 or 1 to 1.5	rpm

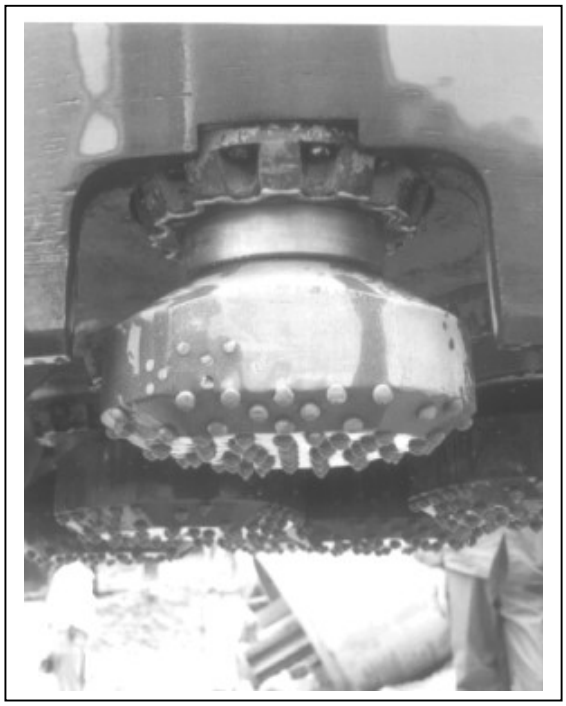
2.1.1 JOB RECORD IN HONG KONG

At a new development on the old Hilton Hotel car park site in Central, at the lower end of Garden Road, 20 No. rock socketed large diameter bored piles were required to be constructed to 35 meter depth in Grade III / II granite rock having a socket length of between 6 meters and 13 meters with an average length of 10 meters. The site is not large and is in a particularly sensitive area being bordered by the masonry structure of St. John's Cathedral on the south and the brick built Court of Final Appeal on the West side. Both structures have mass retaining walls adjoining the site. For the contractor, program was a major restraint, and faced with having to work four to five conventional

RCD's on the site would not only affect other operations but also put severe pressure on programme completion. For the engineer vibration was a major concern because of the sensitivity of the adjoining buildings. Alternative drilling methods were sought, and the decision was made to use one RCD DTH drill then currently on a project in Korea. On a site visit it was established that this type of drill met both the program requirement and reduced the vibration and noise levels to acceptable limits.

The drills work commenced in November 99 and by mid- December the 200 meters of rock socketing work was completed at drilling progress of between 0.9 and 1.5 meters per hour. Since this completion the drills have been employed on KCRC site at Lai Chi Kok. Site photographs of the drill are given below:

Picture 1 - showing the drill head



Picture 2 - showing the DTH drill bit

2.2 ROCK CORING BUCKETS ON PILE ROTARY DRILLING EQUIPMENT

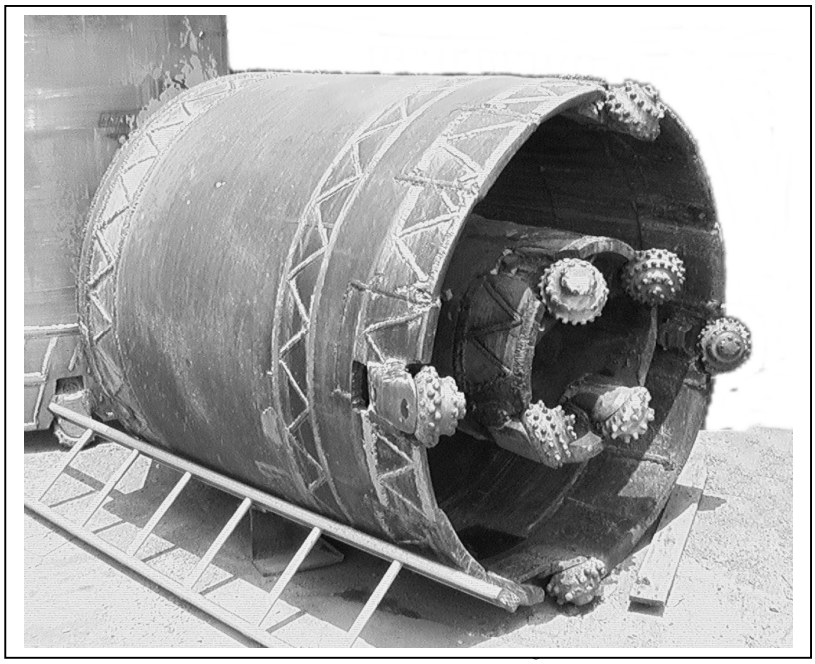
Although used worldwide for many decades the adoption of high torque rotary drilling rigs to excavate rock sockets has only been recently introduced to Hong Kong. The system uses hydraulic rotary equipment to turn a telescopic Kelly bar that is equipped with various drilling tools to suit the material to be excavated. The drilling rig itself provide sufficient down force for the drilling thus removing the need to install a long lengths of temporary casing to provide weight and skin friction as for an RCD. The system therefore works most efficiently in conjunction with short lengths of temporary casing and the use of a stabilizing fluid (water, polymer, bentonite, etc.) for excavation below the casing.

Rocks sockets are formed using a variety of tools including coring buckets armed with roller bits (see picture 3), cross cutters, and excavation buckets. Flushing of the excavation is not necessary with material being removed by bottom opening of buckets. Drilling rates of between 0.2 and 0.5 m per hour depending on the socket diameter, are achievable in grade III and II rock. The system is capable of drilling piles up to 100 m in depth and 3 m in diameter. Rock sockets of up to 15 m length have been formed for piles of 2.5 m diameter in Hong Kong.

Advantages of the system include:

a. Since water is not used for flushing the drilling, very little wastewater is generated.
b. The same drilling rig is used for both soil and rock excavation. The changing of drilling tools to suit the material to be excavated is undertaken in moments.
c. Using a short length of temporary casing removes the problems associated with installing casing in areas of sloping bedrock or through areas of intermixed layers of soil and rock. Furthermore, the short casing can be extracted after concreting has been fully completed, thereby removing the problems associated with extracting sections of casing during concreting.
d. The system does not require the use of chiselling equipment; rotary drilling equipment thus minimizes vibration in all rock boring.
e. The array of drilling tools available allows obstructions and sloping bedrock to be overcome whilst maintaining pile verticality.
f. Where geological conditions allow, large size samples of rock can be removed intact from the excavation for examination, a typical example is shown in picture 4.

A further advantage is soon to be realised in the new Hong Kong Code of Practice for Foundations to be published by the Buildings Department, (Choy and Pang 2004). In this code permissible side friction values for rock sockets are given and the combined value of end bearing and side friction values for sockets up to two times the pile diameter are allowed. This allowance will relieve engineers of the necessity to form bellouts in rock and lead to better pile reliability for the transfer of load for bored piles.



Picture 3

Rock coring bucket with rock roller bits

Picture 4a & b core samples removed from the rock socket

2.2.1 Job record in Hong Kong

The system has been used on a variety of infrastructure projects in Hong Kong over the past five years including the KCRC's West Rail and East Rail Extension projects, Route 8 Highway in Ngong Shuen Chau and Shatin sewage treatment plant.

The Route 8 Highway in Ngong Shuen Chau involves the construction of over 400 large diameter bored piles with diameters ranging from 1.5 to 2.5 m and rock sockets up to 10 m in length in Grade III and II rock. Many of the piles have been constructed directly adjacent to a major infrastructure including the KCRC's West Rail, MTRC's Airport / Tung Chung line and the West Kowloon Expressway. Piling in these areas had to comply with strict vibration and movement specifications and the surrounding infrastructure was subject to a comprehensive monitoring program. The piling works commenced in August 2002 and is due for completion by the end of 2004.

3.0 CONCLUSION

Reverse circulation down the hole drills (RCD DTH) have been available (Nakayama 1989) and used in Hong Kong during the 90's. At Ho Tung Lau station, and for the Jubilee Gardens project, a 1.5 meter RCD DTH drill was used to form the rock sockets between the live rails of the KCRC track and on the platform. Also at the redevelopment of the Jewish Recreation Club, mid-levels in central a number of 1.0 meter diameter drills we used to form friction bored piles for the tower block's to a depth of 80 meters through the boulders and the deep colluvium deposits that exist in the area. However the new generation of RCD DTH drills adds several improvements over their predecessors. Reliability, and ease of maintenance, added to improved capability and increase in drilling diameter, which have brought cost saving advantages now comparable with the conventional RCD systems. Where space is at a premium, and vibration, noise, and nuisance, need consideration the direct advantages of this rock drilling system are realized to the full.

Rotary bored pile drilling rigs are not new and have been used successfully in Hong Kong and elsewhere for a number of years in forming friction bored piles (Pickes et al 2003). However with increased power and torque these rigs are now fitted with rock coring buckets and other specialist drilling tools to allow pile sockets to be efficiently formed in rock. The technique has successfully been adopted in several major infrastructure projects in Hong Kong in recent years and can be used very close to the existing utilities and infrastructure.

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