Drilling and Sampling of Embankments Using the Sonic Drilling Method

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Abstract

This Technical Note introduces the advantages of using the Sonic Drilling Method to drill holes through existing embankment dams. The technique is given perspective by reference to the wide range of conventional overburden drilling techniques, many of which are disallowed from being used on federal structures at least. Several major remedial dam grouting projects have recently been completed, featuring tens of thousands of meters of overburden drilling quickly, economically and safely conducted, in full compliance with environmental regulations.

1. Introduction

Grouting for new or remedial dam construction will require the drilling of holes through fill, overburden, concrete, and/or rock. Such holes will be required for exploration, verification and monitoring, as well as for actual grout injection. Holes are typically 50 to 200 mm in diameter and are rarely more than 100 m deep. They may range in inclination from vertically upwards to vertically downwards, although most holes in grout curtains are within 30° of vertical. Although rock and concrete masses are naturally variable in terms of strength and structure, overburden and fill – from the drilling viewpoint – usually pose far greater difficulties to the drilling contractor. Such material may range from soft and loose to hard and dense, and from dry to saturated. Overburden may contain alien and/or atypical inclusions or horizons which will be problematical to penetrate. Special care is warranted in certain situations, for example when penetrating the embankment of an existing dam.

Such variability in site and ground conditions will pose difficulties to the drilling contractor who will naturally want to drill the holes as quickly as possible and with the minimum possible "footage" cost. Equally, however, specific project needs may impose significant restrictions or performance requirements. For example, the drilling of rock anchor holes through and under high concrete dams often demands holes of unusually tight deviation tolerances, while the drilling of holes through earth embankments is a sensitive issue, and indeed is the subject of a U.S. Army Corps of Engineers Regulation (1997). This very important document first notes that "in the past" compressed air and various drilling fluids have been used as circulating media while drilling through earth embankments and their foundations. Despite widespread success, there have been isolated problems resulting from pneumatic or hydraulic fracturing, and/or erosion. The Regulation therefore mandates the following:

1. Strong technical experience qualifications are required for all personnel involved in the design or construction of such drilling works.
2. "Drilling in embankments or their foundations using compressed air (including air with foam) or any other gas or water as the circulating medium is prohibited."

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The Regulation does permit auger drilling (no flush), cable tool (churn), or rotary drilling with “an engineered drilling fluid (or mud).” A separate appendix details acceptable practices for rotary drilling. However, for logistical, technical and/or economic reasons, this permissible array of methods may not, itself, be sufficient and, in recent projects involving the drilling of tens of thousands of meters through existing embankment dams, the rotary-sonic method has proved particularly attractive.

2. Overburden Drilling Systems, Methods and Applicability

2.1 Common Features

Effective drilling systems for overburden and fill must be capable of permitting continuous, adequately straight penetration in materials which may vary from very soft to extremely hard and from homogeneous to heterogeneous. They must be capable of providing a constant diameter, stable (or temporarily stabilized) path full depth, from which the drilling debris has been wholly removed, and which is consistent with the needs of the specific grouting operation they serve. Effective drilling systems will employ appropriate combinations of thrust, torque, rotary speed, percussive effort, and flush parameters to economically reach target depth within acceptable deviation limits. They must optimize the effectiveness of the flushing medium used. They must ideally be dictated by the ground conditions, cost notwithstanding, although historical bias and regional experience are often powerful factors. Application should determine technique, and methods should be left to the discretion of the contractor as far as possible. Methods must also satisfy project environmental restraints including noise, vibrations, and flush control and disposal. The hole must be used for its intended purpose as soon as possible after drilling to minimize any time-dependent deterioration of its walls and any opportunity for contamination. Above all, the drilling process must not cause harm of distress to any structure being penetrated, or any adjacent structure. Within the typical range of borehole diameters used, the exact diameter selected owes most to practical issues such as the availability of equipment, dimensions of tooling, ease of flushing, packer sizes, hole stability, hole deviation, and so on.

In principle, the prime technical controls over the choice of drilling method should ideally be the ground conditions, and the hole depth and diameter. Other considerations such as hole linearity and drill access restraints may also have significant impact on choice (and cost) on any given project.

2.2 Classification

Drilling through fills or overburden can be more complex and difficult than rock drilling, and is often more controversial when consideration is given to levels of environmental acceptability. Reflecting the fundamental control exerted by the *stability* of the drilled hole (i.e., its ability to maintain shape and size without detriment to the surrounding ground after withdrawal of the drilling system), Figure 1 provides a basic selection guide to drilling methodology. It must be noted that this guide relates only to routine production drilling for geotechnical construction purposes: core drilling in overburden is not viable in this context although it can be an integral part of many exploration and verification projects.

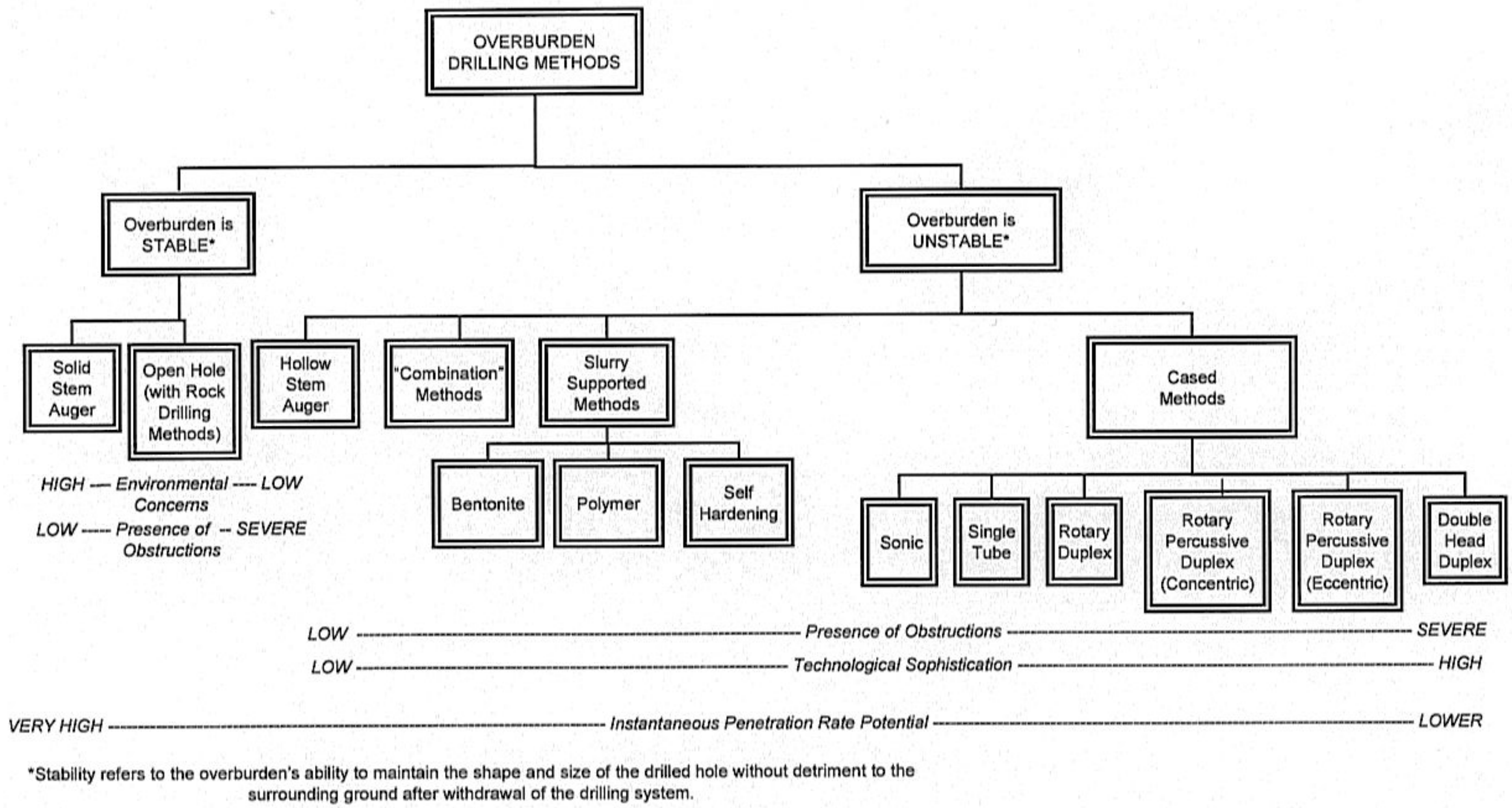

Figure 1. Basic drill method selection guide for overburden (Bruce, 2003).

Equally important in the selection of the appropriate overburden drilling method may be one, or a combination, of the following:

- Cost considerations (per lineal meter, and as related to project scale).
- Drill rig access restraints.
- Hole depth, diameter, and inclination.
- Flush collection and disposal concerns; noise; vibrations.
- Possible impact of method on subsequent ability of hole to satisfy the project goals (e.g., bentonite slurry must not be used to stabilize holes which must later transfer peripheral bond, as in the case of rock anchors, although this may be perfectly acceptable for grout hole drilling).
- Regional preference, and contractor paradigms, experience, and resources.

Given that thorough reviews may be found in several sources (Bruce, 1984 and 2003; Houlsby, 1990; Weaver, 1991; Xanthakos et al., 1994; Kutzner, 1996; Australia, 1997; Rao Karanam and Misra, 1998), the following discussion provides only brief notes on the various techniques cited in Figure 1.

3. The Rotary Vibratory (Sonic Drilling) Method

This technique was first researched separately in the U.S. and the Soviet Union in the late 1940s and was developed commercially in the U.S. in the 1960s by the oil well drilling industry to speed investigation programs. It is considered by one of its developers, Ray Roussy, "to be the only true innovation to come to the drilling industry since the Chinese invented cable tool drilling some 3000 years ago" (Roussy, 2002). In 1985, a current division of Boart-Longyear became the first U.S. firm to use the technique for environmental drilling and it is now becoming very popular in the construction industry where strong regulatory and environmental restrictions are in force.

It is a dual cased system that uses high frequency mechanical vibration to provide continuous core samples, or simply to advance casings for other purposes, such as grout holes themselves. The string is vibrated by a hydraulically powered drill head at continuously adjustable frequencies between 50 and 150 Hz, and is rotated slowly in harder formations (e.g., sandstone, limestone, shale, and slate) to evenly distribute energy and bit wear. The frequency is adjusted to achieve maximum penetration rate by coinciding with the natural resonate frequency of the drill string (Figure 2). Resonance provides extremely high energy to the bit, and in soil it also displaces the particles laterally, greatly facilitating penetration rate. Penetration is optimized by varying frequency and thrust parameters.

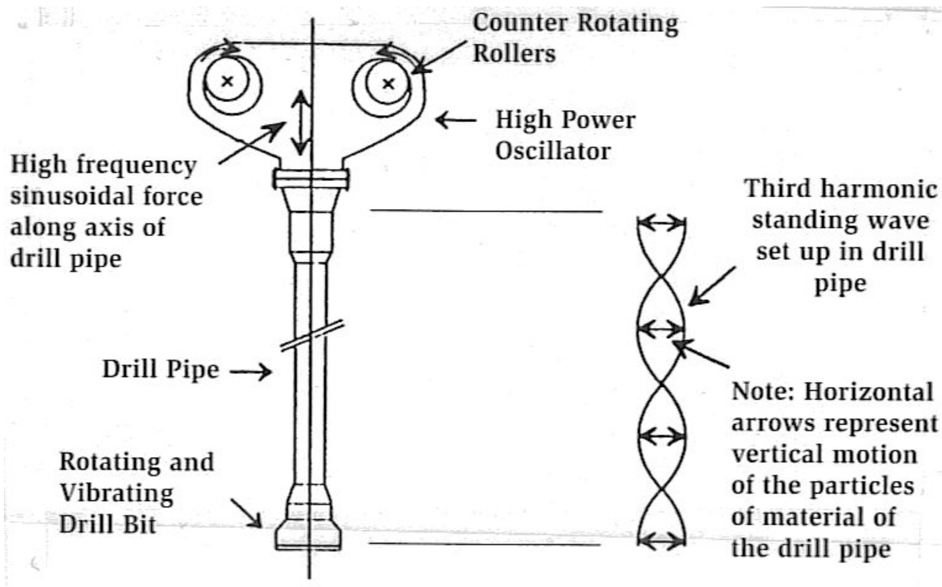

Figure 2. Principles of sonic drilling (Roussy, 2002).

The oscillator uses two eccentric counter-rotating balance weights, or rollers, that are timed to direct 100% of the vibration at 0º and 180º, while an air spring system in the drill head insulates the vibration from the drill rig itself. The outer casing can either be advanced at the same time as the core barrel and inner drill rods, or over them, or after the core barrel has moved ahead to collect the undisturbed core sample and been pulled out of the hole. Depending on the type of ground, degree of surface contamination, and the sampling objectives, the core barrel advancement can range from 0.3 to 9.0 m increments.

Regarding its advantages for dam embankment drilling, sonic drilling

- Can provide continuous, relatively undisturbed cores in soils (typically 75- to 250-mm-diameter) without using flushing media, at very high penetration rates (up to 18 m/min in many formations);
- Can readily penetrate obstructions (natural and artificial), including boulders, wood, and concrete;
- Has been used to depths of 600 m although most applications have been to less than 120 m;
- Can easily convert to other types of rock or overburden drilling; and
- Requires no flush in overburden, and only minor amounts in rock, or to enhance penetration rates to greater depths.

Dustman et al. (1992) provided the data of Figure 3 as a comparison of drilling rates for various sample methods.

4. Final Comments

Several geotechnical construction-related applications have been recorded to date including drilling through dam embankments on several major federal structures. The sonic system has exceptional potential for soft and/or hard ground drilling in certain combinations of circumstances such as the remediation of existing embankment dams. In the clever promotional words of its developers, it may be indeed be "the wave of the future" in drilling technology for many applications, especially those of a remedial nature. A view of the standard equipment is provided in Figure 4 bearing in mind that a low headroom "mini-sonic" drill rig has recently been developed by Boart Longyear Company (Figure 5).

Drilling Method	feet/day	Sample Method
Hollow-stem Auger	18	Split-spoon (5 ft.)
Cable Tool	20	Bailer
Air Rotary	95	Split-spoon (10 ft.)
Sonic	**160**	**Continuous Core**

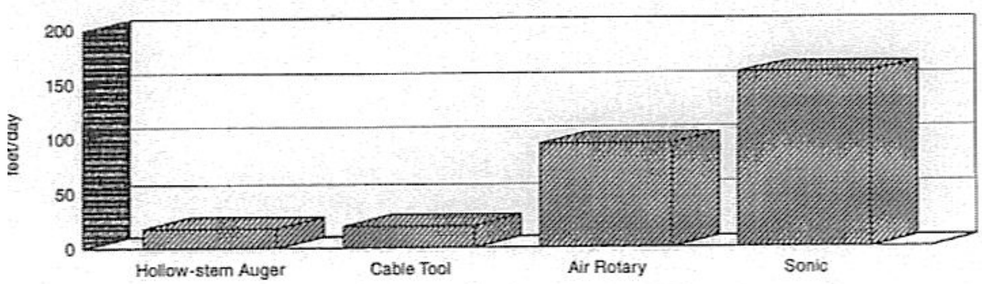

Figure 3. Comparison of drilling rates and sample methods (Dustman et al., 1992).

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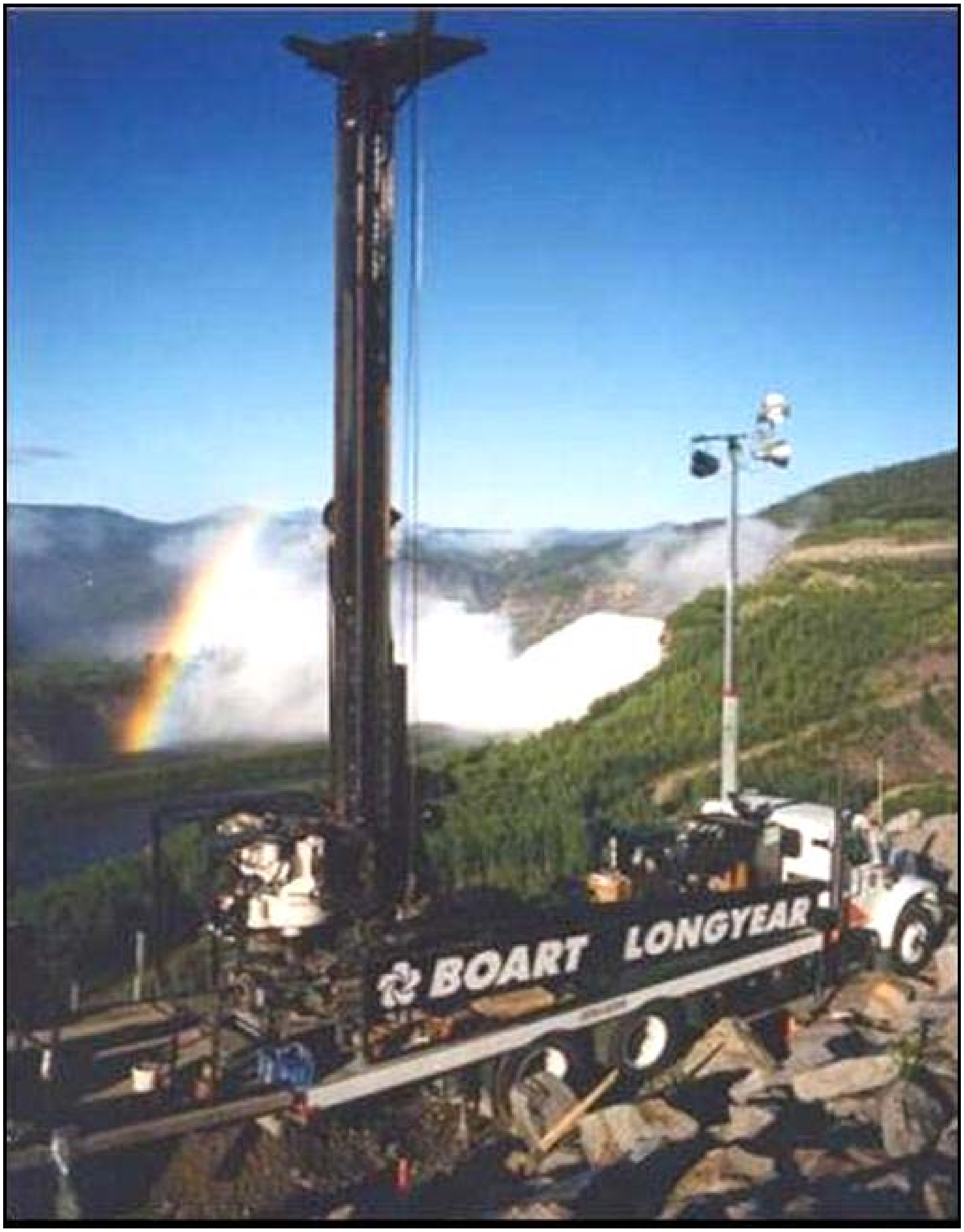

Figure 4. Typical truck mounted sonic drill rig (Courtesy of Boart Longyear Company, 2003).

Figure 5. Track mounted “mini sonic” drill rig for low headroom applications.