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Experiences with International Well Drilling

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Introduction

The authors have had experience in recent years in drilling water wells in a remote village in northern Kenya using a simple drilling system. This work was done as part of an on-going project of the Engineers Without Borders chapter at Valparaiso University. While their experiences have been limited to Sub-Saharan Africa, the problems that they encountered and the solutions they developed are typical of this sort of endeavor regardless of location.

This paper will first briefly outline the need for drilling wells in developing nations and then discuss the basics of well drilling. Next the work performed during the authors' project is outlined. A list of recommendations for similar endeavors will be presented. Finally, the educational impact experienced by students involved with the Engineers Without Borders – Valparaiso University project will be discussed.

The Need For Wells

The need for safe drinking water is an international dilemma that has been recognized by the United Nations. In its September 12th, 2003 press release, the United Nations declared the decade of 2005-2015 as the International Decade for Action – Water for Life[1]: "Access to safe drinking water is an indispensable component of primary health care and a precondition for success in the fight against poverty, hunger, and child deaths. It is also a basic human right. The human right to water is necessary for leading a healthy life in human dignity. It is a prerequisite to the realization of all other human rights."

There are approximately 1.1 billion people worldwide without access to safe drinking water. According to the United Nations Statistics Division, only 45 percent of the population in the Sub-Saharan region of Africa has sustainable access to improved water sources. This is the second lowest percentage of any population, only surpassed by the Oceania region. Other concerns relating to the United Nations' Decade for Action include: integrated water resources, access to basic sanitation and hygiene, and wastewater collection and treatment. In many regions the effort towards better living conditions includes most of the topics above. However, in the region where the author's experiences are based, the focus is providing basic access to sufficient clean water to ensure the survival of the local population.

In order to provide acceptable drinking water, especially in dry environments, it is necessary to tap into underground aquifers, which contain groundwater. This access to groundwater requires the use of wells ranging from less than ten to several hundred feet in depths. Wells of this sort can be easily installed using a modern drill rig. The problem facing people in remote portions of developing nations is that it is often nearly impossible to obtain access to a drill rig, and when it is possible, the cost is usually prohibitive. In less remote areas of developing nations rigs are more easily obtained, but may still be cost prohibitive.

As a result of the difficulty in obtaining a modern drill rig, much drilling in developing nations is done with simple, portable drill frames. These frames usually consist of a metal frame that holds a small motor, such as might be used on a lawnmower in the United States. The motor is connected to a gear reducer that then drives the actual drilling tool. Due to the low power capacity of the motor, these systems usually operate as a mud rotary method of drilling, rather than turning solid or hollow stem augers. A description of the system used by the authors is included later in this paper.

The Basics of Well Drilling

There are numerous ways to construct a well. They can be dug by hand using shovels and other hand tools or drilled by hand or animal power using a simple auger. The two most common methods to mechanically drill a well are augering and mud-rotary drilling.

Augering involves using either a solid-stem (similar to a large diameter drill bit) or a hollow-stem (similar to corkscrew constructed around a hollow pipe) auger to create the hole in the subsurface. Because of the large amount of torque necessary to turn the auger through the substrata, augering does not readily lend itself for use in small, portable drill rigs. The main advantage of augering, especially hollow-stem augering, is that it is relatively easy to keep the hole open in cohesionless material such as sand and gravel.

A mud rotary drilling process is also used to drill wells. A mud rotary system is relatively inexpensive, mobile, and uses few complicated components. Additionally, it requires far less torque to drill an equivalent hole. This leads to lower power requirements for the drilling apparatus.

A mud rotary drilling apparatus uses a rotating drill rod to advance a drill bit. A fluid consisting of water and bentonite clay is pumped through the drill bit and flows up the borehole to the surface where it is collected, filtered and recirculated back down the borehole. The drilling fluid serves two purposes: the first is to stabilize the walls of the borehole and prevent collapse, and secondly to bring the cuttings created by the drill bit to the surface where they are removed.

When drilling in cohesionless materials such as sands and gravels it is often necessary to use casing to keep the hole open, even if drilling fluid is being used. Casing is usually a steel pipe slightly larger than the drill bit which is lowered or hammered into the drill hole to keep the walls from sloughing into the boring. Sloughing is particularly a problem in areas of high ground water flow, where the water running into the hole tends to carry the surrounding soil with it.

Once the hole has been drilled, the well is constructed. This involves placing a length of pipe equal to the depth of the well into the hole. The pipe used is slotted below the water table to allow water to enter the well and solid above to prevent soil from entering. Once the pipe is in place, the annulus around the slotted portion is filled with permeable sand and the annulus around the unslotted portion is filled with soil to fill the void and steady the pipe. A pump is then either lowered into the well or attached to a pipe that is lowered into the well. This pump is then used to remove water from the well. McCarthy[2] provides an excellent overview of drilling and well construction.

EWB-VU's Work To Date

The Engineers Without Borders – Valparaiso University (EWB-VU) chapter's project is located within the community of Nakor, in the Turkana region of Northwestern Kenya. The community has been severely impacted by drought. Its drinking water supply is primarily taken from shallow, open wells and there is no long-term water storage for crop irrigation. The goal of the project is to provide clean drinking water and develop a sustainable form of irrigation to allow villagers to grow crops throughout the whole year.

Since May 2004, EWB-VU has made two trips to the region to work with the local people and install wells, windmills, and irrigation systems. Each year approximately a dozen students and three or four adults (including the authors) have traveled to the village for an approximately ten-day stay. A more detailed outline of the work performed and some of the lessons learned are provided by Polito and Husfeld[3].

Drilling for the wells was performed using a simple-frame-mounted, mud rotary drilling unit. The components used in the drilling process include: the drilling apparatus, several tanks and buckets, piping, a rotary pump, and a water source to begin and supplement water flow during the process.

A five-horsepower, vertical-shaft lawnmower engine powers the drilling apparatus used. Lawnmower engines typically run at high RPM, but for this application a gearbox is used to reduce the RPM to a nominal 120-RPM. Further speed adjustments are made using a throttle on the engine itself. Attached to the output shaft of the gearbox is a swivel connector, which allows the introduction of drilling fluid into the drill pipe.

The set up of the system first involves mounting the frame over the desired borehole location. The frame of the drilling apparatus is supplemented with a second, larger frame, which in turn is secured into place by burying the base of each leg and using a series of rope tie downs as seen in Figure 2. The external frame, which is in the form of a collapsible tripod, serves both to stabilize the drilling unit and to provide a pulley for use in lifting casings and pipe for lowering into the drill hole.

Next holes are dug for the buckets, with one hole being deeper than the other, with each being deeper than the top of the well hole. The purpose of these buckets is to filter the drilling fluid that has come up through the drill hole bearing cuttings before it is pumped back into the hole again. Each bucket (often half a 55-gallon drum is used) is filled with water and then the water in the higher of the buckets is mixed with bentonite. This creates a viscous fluid with a unit weight of perhaps 70 lb per cubic foot that will assist in clearing the borehole of cutting. Once the buckets are filled and the bentonite is mixed, the mixture is sucked out of the buckets via a rotary pump. The rotary pump pushes the water into a swivel connector on the drilling apparatus, where it flows through hollow drill rod to the bit.

The type of bit used is dependent on the soil being drilled. The Nakor site consists of a mix of sand and silty-clay layers, therefore, step or roller bits are used. At the bottom of the well, the bit cuts away at the soil. The drilling fluid flows out of the drill bit and "grab" the cuttings. The cuttings are then brought to the surface and settle to the bottom of the first bucket before the water flows back into the lower bucket and the process begins again.

Problems and Solutions For Drilling in Remote Areas

In a perfect world, the above drilling description works without any problems. All of the components are in working order and everything flows smoothly. Unfortunately for EWB-VU and for any organization assisting with development, that is not the case. The purpose of this paper is to share our drilling experiences and give advice to aid fellow international organizations who drill wells to assist developing countries. Typical problems encountered will be described and possible solutions suggested.

Equipment Problems

The problem that has the largest effect is problems with equipment. During the past two project trips to Kenya, EWB-VU has had two rotary pumps, the swivel connector, and the drilling apparatus engine each cease to function properly. Many times the breakdown of these components cannot be avoided. However, by bringing the proper repairing equipment, down-time can be minimized. For engines and pumps, purchase extra oil and air filters, extra O-rings, extra oil, and most importantly a quality tool set. The tool set should include several sizes screwdrivers, ratchets, sockets, pliers, vice-grips, and adjustable wrenches in both metric and English units.

Remember that the nearest place to obtain parts and tools may well be hours, or even several days' travel away. Prior to traveling, check on the availability of tools in the country of destination. It might be best to purchase tools (and occasionally engines and pumps) in the United States. Don't forget to check with the airline as to shipping regulations.

When using a rotary pump, check to see whether the pump only accepts pure water or whether it has the ability to pump sludge. As with any pump, the water being pumped needs to be properly filtered. If the water being pumped is not properly filtered, the rotary pump will quickly fail. As described before, drilling fluid is filtered by way of a two-bucket system as seen in Figure 4. The purpose of the first bucket is to accept the water from the borehole and let the cuttings settle out. The second bucket holds the water for the rotary pump to use. This setup alone is not enough to completely filter the pump's water because of outside contaminates such as bugs and animal feces, which many times float. To avoid these peripheral contaminates, semi-fine screen can be used as a secondary filter. The screen should be placed over the top of the buckets and at the input and output of the first bucket. The pump's input tube should also be covered with a fine screen to further avoid objects from entering the pump. Because of the suction of the pump, the fine screen will need to be kept clean during pumping so that the largest amount water can be pumped. Because the water is the central element of a mud-rotary drilling system it is important to conserve as much water as possible.

Water conservation during drilling is important because the drilling project is most likely being performed in an area where water is a commodity difficult to obtain. The best way to conserve water during drilling is properly directing the flow of water. It is very difficult to direct water flowing from the borehole back to the buckets without losing some water. The use of a half-section of pipe to carry the drilling fluid from the borehole to the first bucket and from the first bucket to the second bucket is suggested. The output from the first bucket and the input to the second bucket must be properly sealed so that water is not able to flow around the input or output. As soon as water begins to flow around the input and output the surrounding ground is quickly disintegrated and the whole flow has broken down and water is lost. The flow can be directed using local materials such as sticks, branches, stones, and clay. The goal is to keep the water flowing where it's supposed to flow.

Problems with Drilling in Clay

Unless the clay in question is extremely dry and hard, drilling through clay should pose relatively few problems. Due to the cohesiveness of the soil, the borehole should stay open through the clay with minimum collapse.

In the case of very hard clay, it may be necessary to drill a pilot hole through the layer using a smaller (perhaps two- or four-inch) bit. The hole is then subsequently expanded using a larger (six- or eight-inch) bit.

Problems with Drilling in Sand and Gravel

Drilling through sands and gravel, especially below the water table is difficult under the best of circumstances. The best way to proceed is to use casing if at all possible, alternating drilling and driving the casing.

Below the water table, sand or gravel may be found to be heaving up into the auger. This is usually found to be caused by water flowing into the hole. This can be minimized by maintaining a water level inside the casing that is higher than the level of water outside the casing. This creates a higher head inside the casing that results in flow of water out of the casing, which will minimize soil intrusion into the casing.

If casing is not available, drilling will be much more difficult. The best advice the authors can offer is to drill very, very slowly, perhaps as slowly as a couple of feet per hour. Advancing the drill bit a few inches, then pulling back the bit several feet to allow the drilling fluid to circulate may prove helpful, as will low drilling RPM, adding more clay to the drilling fluid, and circulating the drilling fluid at a rate only slightly faster than a trickle.

Additionally, avoid leaving the drill bit at the base of the hole for long periods of time. This can lead to the drill bit being trapped when the borehole collapses. In the event that the drill bit gets trapped, it can be retrieved by slowly spinning the bit and exerting upward pressure. If this fails, jetting water down the drill pipe may help to loosen the bit.

Problems with Casing

When used either for drilling or for well construction, casing can present its own set of problems. These problems can occur either during driving the casing into place or while removing it.

Driving the casing into the borehole is usually necessary as the diameter of the casing must be larger than the diameter of the drill bit to allow withdrawal of the drill bit through the casing. The casing can be driven using a simple drop hammer and anvil combination such as that shown in Figure 1. The hammer consists of a 12 to 24-inch length of steel pipe with a 12-inch diameter steel plate welded onto one end. A bent piece of rebar welded to the opposite end is used as a handle. A two-foot length of one-inch pipe is welded to the steel plate as a guide rod. The six-inch diameter section of pipe can be filled with wet sand at the drilling site to increase its weight and driving capacity.

In order to protect the top of the casing, an anvil should be used. A simple anvil can be constructed by welding a steel plate to two concentric one-foot sections of pipe a half-inch larger or smaller than the outer and inner diameters of the casing. This allows the anvil to fit snuggly over the top of the casing. A two-inch hole in the plate accepts the guide rod from the hammer.

Once the casing is in place with the anvil over the top, the hammer is lifted using a pulley, and the guide rod is inserted into the hole in the anvil. The hammer is then raised and dropped in order to advance the casing as seen in Figure 3. If manpower is limited, a cathead can be fashioned from a tire rim, attached to a truck and used to help lift the hammer. This will also allow for the used of a heavier hammer.

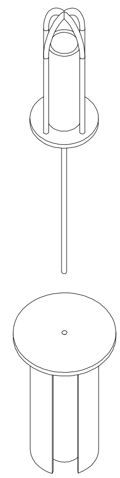

Figure 1: Drop hammer and anvil combination

In sandy soils, jetting can greatly increase the drivability of the casing. If water is freely available, a jet can be fashioned using the pump and a length of flexible tubing. A hole in the side of the casing (near the bottom of the anvil) will allow the tub to be inserted inside the casing and pushed to the bottom of the drill hole. By turning on the pump and forcing the tip of the tubing into the soil while driving the casing will greatly increase the progress. This happens because the jet raises the pore pressures in the soil, lowering both its effective stress and its strength

When the time comes to remove the casing, it may be found to be stuck in the hole. Holes drilled through the sides of the casing near the top of each section will allow for a steel rod to be slipped through the casing. Once this is done, the casing can be jacked out of the ground using high lift truck jacks. In sandy soils, jetting may also prove helpful in the removal.

Educational Impacts

Hands-on service projects such as the well drilling described in this paper serve as excellent preparation for the challenges that students will face during their careers in industry. During these projects, students are faced with open-ended, and often unexpected, problems for which engineering solutions must be conceptualized and executed within a difficult series of environmental, economical, and cultural constraints. The remoteness of the operation usually prevents the problem from being easily solved simply by ordering new parts or running to the hardware store, thus requiring the students to use the materials and funds that are available. The fast paced project environment requires quick decisions and clever solutions.

Gaining valuable engineering decision-making skills is only one aspect of the educational benefits of a service project as described in this paper. In addition, students gain a sense of how using their abilities and skills can impact an entire community. The idea of engineering as a vocation teaches the student to think of engineering not just as a job, but also as a medium of public service to impact the lives of others.

Conclusions

With the growing need for water in developing countries, the need for simple effective drilling methods for installing wells will also increase. The authors have outlined the need for drilling wells in developing nations, and their experiences drilling in Africa. Finally, a list of recommendations for handling the problems that commonly arise during drilling under such conditions were discussed and potential solutions presented.

References

[1]United Nations (2003) http://www.un.org/waterforlifedecade/

[2]McCarthy, David, (2006) *Essentials of Soil Mechanics and Foundations, Basic Geotechnics*, 7th edition, Prentice Hall, 2006.

[3]Polito, C.P., and Husfeld, R. (2005) "Lessons Learned From An International Service Learning Project," Paper 2005-1536, American Society for Engineering Education 2005 Conference, April 1-2, 2005, Portland, Oregon

Figure 2: Drilling Setup

Figure 3: Drop Hammer

Figure 4: Bucket System