Well Drilling for West Africa

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Abstract:

The purpose of this project is the exploration of hand powered well drilling techniques that can be manufactured in small work shops in Burkina Faso. The ultimate goal of the project is to develop a variety of well drilling techniques that will enable rural people of Burkina Faso to meet their water access needs through the creation of their own wells. The project's client is Dokimoi Ergatai Water Access Group. Members include Joel Foster, Anthony Beers, Kevin Messick, and Brian Martin. The Messiah College Faculty Advisor for this project is Dr. Timothy Whitmoyer.

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1 Introduction:

1.1 Description:

The focus of the project was the investigation of sustainable methods of constructing wells for drinking water and irrigation. Our objective was to produce a written document that details a procedure for the production of appropriate well drilling equipment, well sighting, and well construction for development personnel and rural villagers in arid regions.

The project explored two well drilling techniques: Hand auguring and percussion drilling. The major emphasis on this year's project work was the use of a hand auguring system and the design and construction of a percussion drilling system.

1.2 Literature Review:

There are three different classes of drilling rig that encompass water well drilling operations worldwide: Modern Industrial drilling, environmental/civil engineering research, and village level development. The first of these possesses the most technically advanced equipment ranging from cable-tool rigs to reverse rotary rigs. These rigs are usually truck mounted or pulled by large trucks. The environmental/civil engineering research arena possesses shell and bucket augers, which are rugged lightweight portable percussion rigs that are used to sample soils and create test wells. These rigs run off smaller engines than their industrial counter parts and can be set up over terrain that is more adverse. The final category includes many of the technologies that were the predecessors to the modern industrial techniques. These village-based technologies often rely on human power and are limited in the depth that they are able to attain.

Of the industrial rigs, the most technologically advanced are the down-the-hole hammer method and the rotary methods. In the down-the-hole hammer method a heavy drill string is lowered down the borehole. This is attached to the surface unit by a heavy steel cable and a string of pneumatic hoses. The bit at the end of the drill string is made of a hardened steel face plate covered with carbide buttons. This face rotates and moves in a reciprocal motion much like a hammer drill used for masonry. This motion is achieved through pneumatic action, and the waste air is used to blow the pulverized fragments of the subsoil up the shaft to the surface. This is one of the fastest methods of penetrating hard rock formations. Rotary drilling is comparable in speed and uses either water to drive the cuttings form its tri-cone bit to the surface. Often bentonite is mixed with the water to form drilling mud which seals the outside walls of the borehole to prevent the lost of pressure necessary to maintain a hole full of water. The water bentonite mixture serves also to lubricate the tri-cone bits and to suspend the cuttings and float them to the surface. At the surface, the mud enters a settling pool to remove the excess cuttings and is pumped back into the borehole. The machinery used in both of these methods are extremely expensive and require intensive maintenance which make them poor choices for the developing world, also since they require a truck to transport them it becomes difficult to transport them to places that are lacking well developed infrastructure.

At the village/development level there is a wide range of techniques that vary from ancient/traditional methods to new innovative techniques. The oldest methods of creating wells are hand dug methods, which persist today. These methods require manual digging with various hand implements in order to create large diameter holes or tunnels that penetrate the aquifer. These structures are then reinforced by concrete, brick, stone, or wood to prevent their collapse. Various forms of percussion drilling have been in practice for the past four thousand years. Originally developed by the Chinese, this method has been largely over looked by many NGO's and other development organizations. Another method of creating village sustainable wells is hand auguring. This method has been gaining prominence in countries such as Niger due to efforts by Enterprise works. This method is attractive because the rig its self is very light weight and can be easily carried by three men into any location. The depth is limited to 20m maximum and the system is only capable drilling through unconsolidated soils. Some of the new and exciting methods of creating low cost wells are coming from the combination of already existing methods and adaptation of modern industrial methods. Some of these include hand powered jetting, the appropriate development analog of rotary drilling, and stone hammer/rota-sludging, which combines the Indian sludging technique with percussion drilling. The latter is a very recent development, which shows great promise but is still largely in the development stage.

Our percussion rig has its place among other percussion rigs used for self-help wells. Much of its design was borrowed from the concepts surrounding the shell and auger rigs used for civil engineering and also from large hand auguring rigs. These design predecessors set this rig apart from other percussion rigs. we believe that these design ideas will make for a stronger rig frame. Our innovative rock bit design(two top flanges of railroad rail welded together) should achieve better penetration better through water than the hydraulic cylinder rods that have previously been used due to its large water course. We hope that the documentation for this project will be a welcome addition to the existing body of literature on self-help wells and a blessing to the development community.

1.3 Solution:

Two well drilling techniques were chosen for investigation based off of their simplicity, and their low energy and water inputs. Hand Auguring was favored because it has proven its worth in other projects implemented in the Sahel by Lutheran World Relief and Enterprise works. As a result of these efforts, DE was able to purchase one of these rigs in Burkina Faso for `$600 US. This rig was used to gain valuable information about the soil surrounding the village of Mahadaga during a DE January implementation trip. Along with this field test, many observations were made regarding local geology. This helped us in our design and choice of drilling techniques.

The other well drilling method explored, percussion drilling, was chosen based on the wide rang of strata through which it can drill, its simplicity in concept and design, and its 3000 year history of success. Both industrial and appropriate well drilling rigs currently in use influenced our design. We modified these designs in order to approach our final goal of producing an effective and sustainable rig. Specifically we redesigned the Frame, rock bit, and Clay cutter bit to increase durability and efficiency.

2 Design Process:

2.1 Augers

Most of the research on auger design was based off of the books Hand Augered Garden Wells, Shallow Wells, and Hand Drilled Wells. Additional information was obtained through a personal interview with Jon Naugle and by investigating vendor literature from Eijelkamp. Our first prototypes were made out of 3 inch pipe using only a hack saw, bastard file and heating gun. Two models were made one riverside auger and one stony auger. We tested the prototypes by filling an eight-inch PVC pipe with various materials: fine sand, coarse sand, and gravel. These we tested changing the amount of water in each sample to see what could be drilled through and what would offer enough cohesion to remove the soil from the borehole. As a result we made some minor changes to the riverside bit and decided to abandon the manufacture of the stony auger. We then proceeded to produce a riverside auger, percussion auger, and spiral auger.

We had planned to construct a set of steel pipes with male and female fittings on them and to make a set of handles and clamps for drilling with these bits, but we discovered that they could be manufactured in Ouagadougou and had them made there instead.

2.2 Frame

Preexisting frame designs were investigated by looking at literature concerning both civil engineering shell and auger rigs and appropriate technology rigs used for large diameter hand auguring. Both types used a tripod design with a double back leg. This double back leg allowed for a convenient location to mount the winches or engines used on these light weight rigs. We constructed hot-glue straw models for both double leg and single leg designs. After testing the deflections in these models visually, we came to the conclusion that the double back leg model was over built for our purposes.

Frame design started with and Ideas 10 frame model. Our main concern was the deflection in hinge pin since had the smallest cross section and would experience the highest stresses. From our analysis we determined that a one inch diameter pin would be sufficient to allow only .005 inches of deflection with a 1000 pound loading. We also wanted to use wooden posts instead of two inch steel pipes in order to cut down on costs. To do this the equivalent cross section strength was calculated showing that a 4-inch diameter solid post would have the same strength as 2-inch pipes.

The frame was manufactured in the Messiah college model shop. Although we would have like to limit our tooling to the drill press, band saw and welder, we did have to use the horizontal milling machine in order to drill the 1 3/8 inch holes through the legs that allow for the hinge pin and pipe hinges to pass through.

2.3 Bailer

The bailer is a tool used to remove or "bail" the broken up sand, clay and rock created by the clay cutter and the rock bit. The key component necessary to construct a functional bailer is the one-way valve located on the leading end. Making the bailer out of commonly available steel parts and scrap metal was the main goal in designing the bailer.

Bailer design began by using resources described previously written by Josiah Tilton titled Ghana West Africa Missions (GWAM): Drilling Water Wells by Hand, and The field guide to water wells and boreholes, by Clark. Both sources describe bailers that made from steel pipe and have a one-way valve in the impacted end. After reviewing these sources we chose initial designs for the bailer. All bailers have three main components: the main body, the jar loop, and the one-way valve.

Our initial design of the bailer included choosing six inch nominal diameter steel pipe for the main body. It is common among drillers to use bailers with the following specifications, for consolidated materials: D_B (diameter of bailer) = D_H(diameter of borehole) and for unconsolidated materials: $D_B > D_H$. However, the cost of purchasing enough six-inch steel pipe for the main body was more than we felt necessary. It is for this reason that we decided to choose four-inch nominal diameter steel pipe with a ¼ inch wall thickness for the main body. We decided that four-inch pipe would be sufficiently large enough to remove material in a six-inch diameter borehole in order to reduce the cost of the bailer. After selecting the pipe size we wanted, we modeled the pipe using I-DEAS in order to use finite element analysis to subject the bailer to loads ranging from 200-500 pounds. The bailer will never experience these loads, but a major concern in constructing the bailer is to increase the mean time between failures. Four-inch nominal pipe with ¼ inch wall thickness is more than sufficient to withstand the normal wear and tear of well drilling and bailer operation.

In designing the one-way valve we had two main ideas which were both tested with a simple simulation. The test used to evaluate both valves included using a 6 inch diameter PVC pipe which encased sand to simulate the bailing conditions. We added water in order to create a slurry. After creating a slurry each bailer prototype was dropped into the slurry multiple times. Each time we noted visually what to the valve and the approximate amount of material. The first design idea used both sheet steel and leather flap to seal on rim seen in the appendix. We initially believed that leather flap would act as seal, which would be useful in bailing fine sand. However, during testing of this valve it was determined that the leather was to bulky to allow material into the bailer and the leather would eventually wear out. So to increase the mean time between failures a second design was made without the leather flap as a seal. The second design appeared to allow more material to flow into the bailer and appeared to close better, although it had some difficulty collecting sand. We also noted that it would be necessary to use the shape for the valve seen in appendix A2 in order to allow the valve to open more which would theoretically allow more material and rocks to flow in to the bailer. During the construction of our final prototype we initially had decided to make a hinge using ¼ inch steel tube and a ¼ inch pin but it was easier for us to simply buy a small hinge than find inch steel pipe/tube. It should be noted that in Burkina Faso it would be possible to find these materials and assemble them as a hinge for the one-way valve.

During use of the bailer at our drill site located on campus we were able to remove clay, coarse sand, and rock. At no time did the bailer fail during operation, it was even able to remove large amounts of water even given the poor sealing characteristics of the valve.

2.4 Clay Cutter

While researching the design of clay cutter bits we encountered two prominent designs, one using a cross or star formation, and the other using a circular tooth fashioned from steel pipe. In order to determine which would be the most successful we made star bit head that could be press fit into a four-inch circular tooth. This was then attached to a one inch steel bar and tested qualitatively using each type in both the orange clay of the Yellow Breeches Creek and the dense grey clay found in a small perennial stream behind Frey Hall. The circular bit seemed to perform more efficiently in each instance. This test apparatus was then welded together and attached directly to the drill bit body that we fashioned from several sections of one-inch steel pipe. The one-inch pipe was chosen because we had an excess of it from or prior plan to construct a hand auguring rig.

During testing we found the there was not as much slop in our drilling operations as we had expected and our four and a half inch drill bit on cut a five-inch borehole instead of a six inch borehole. This forced us to remove the four-inch cutting head and make a 6-inch one from some scrap well casing and some steel straps that we salvaged from a junk yard. The 6-inch bit seemed to cut more efficiently that the four-inch bit since it had a larger open are in its center making it less restricted by the straps.

2.5 Rock Bit

The rock bit is used to break up substrata that are too hard for the clay cutter to penetrate. The major design considerations for the rock bit were weight and cost. We knew that a good rock bit would need to have a significant amount of weight. The problem was how to make something of this size at a reasonable cost.

Our initial plan was to weld pieces of plate steel to one another to obtain a reasonable weight. This bit would have been four feet long and about three inches thick. It tapered from being smallest (3″) at the top to widest (5 5/8″) at the bottom. We used finite element analysis with a 2000 pound load to determine that the bit would hold up to any loads that we would be able to put on it. We were not able to do any type of impact analysis. When we looked at purchasing the steel needed to build a bit of adequate size we saw that we would have to be resourceful because the required plate steel would to cost us well over 200 dollars.

Instead of using plate steel to build a rock bit we were able to purchase used railroad rails out of a scrap yard for 90 dollars. We cut the railroad rails down the length in between the flanges. We cut them so that the two upper halves of each rail could be welded together to get a 5 and 5/8 inch outside diameter. This new bit was four feet long and heavier than our original design. This bit also proved to be quite hard as it had been work hardened by years of use by the rail road industry. The hardness would insure that our bit would hold up to any wear it might receive while drilling. The new shape of the railroad rail, rock bit also proved to be advantageous. The cross sectional "barbell" shape allows for water and mud to pass by it as it drives through to strike its target.

On the end of the new rock bit we created a chisel shape by cutting and grinding a tip onto the railroad rails. The tip was then smoothed and covered with an abrasive resistant surface weld. We did this because the end of the railroad rail did not have the same work hardening as that of the top flange. For this reason we decided that it would be beneficial to increase the hardness of the chisel end of our bit.

We hot bent 1/2 inch round mild steel and welded it to the other end of the rock bit so that it could be attached to our jar. Our rock bit will have a respectable tool life as long as our welds hold that join the two halves of the bit together. This is dependant upon the quality of the weld and can only be reasonably tested through tool usage. These welds will need to continually be monitored as the rock bit is used. If the bit does fail it will likely not fail all at once. Therefore when cracks are spotted in the welds the bit will need to be split and re-welded.

2.6 Winch

The winch was created in order to reduce the force needed to raise and lower the different drill bits from the hole. Once the need was realized, we set out to design and model what we thought would be an ideal winch. The first iteration was based upon and common winch found on a boat trailer. We chose to over design the winch in order to ensure that it would not fail. Failure of the winch would lead to many problems, the most important being the possibility of having a drill bit stuck many feet beneath the ground surface.

The initial design that we came up with called for the use of a large piece of sheet metal measuring approximately 12" x 36" x .25". Also included in this design were two gears, a catch mechanism, and a handle. There were two axles feeding through the sides of the frame, one axle housing the handle, small gear, and catch mechanism, and the other containing the spool and the large gear. There were all modeled as idealized parts, what we thought would allow for the most efficient use of the winch.

After the initial design was completed, we then decided to look at the feasibility of creating such a winch, and the costs associated with doing so. Also at this stage, we looked at the needs for those in West Africa. These needs included local availability and environmental considerations.

Looking at these constraints led to several changes from the initial design. The first change was in the frame material. After researching the cost of acquiring the needed piece of sheet metal, it was decided that it was too expensive to use a plate steel for the frame. Since the frame design changed, it was also important to find a new method in which to attach the two axles to the frame. Lastly, the sandiness of West Africa would cause problems if the winch was to use two gears to turn the axles.

Since angle iron is cheap available in West Africa, it made an ideal choice for the frame material. The cost savings over sheet metal were significant. Four self-aligning bearings were purchased so that the axles would easily align, whether or not the holes were perfectly drilled. The third area of improvement was in the gears. Since West Africa is often a dry and dusty place, it is not ideal for gears, since sand can cause premature wear, as well as making it more difficult to operate, as individual grains can make clearance an issue. To solve this Dokimoi Ergatai donated a chain and sprocket set to the project, which not only reduced costs, but gave a more reliable drive train solution, as sprockets are less susceptible to wear by sandy conditions than gears. These changes are all included on the completed winch, which is performing as planned.

2.7 Drilling Procedures

Just as our tooling underwent various design changes so did our test drilling procedure. We began our testing raising and lowering the tools into the borehole and spudding the tools with the help of the winch. Allowing the winch to free fall put a lot of wear on our catch mechanism and the 3:1 gear reduction proved very inefficient with respect to time. Our second drilling process included the addition of a piece of rebar that was used to pull on the cable between the winch and the pulley. The winch was still used to raise and lower the tools into the borehole. This lead to the immediate decision to add a free floating pulley in place of the rebar along with a length of 3/4″ rope. This decreased friction and wear on the cable and the rope allowed many men to pull on the drill string simultaneously.

3 Documentation manuals:

One of our major objectives was the completion of a set of construction and users manuals that will allow our clients to construct, modify, and operate our well drilling equipment.

3.1 Construction:

3.1.1 Rig Frame:

Materials:

Item	Quantity
4″ blk iron pipe	48″
2″ blk iron pipe	48″
1″ blk iron pipe	13″
1″ mild steel round bar	17″
2.5″ inner clearance clevis	1
0.375″ steel plate	1.25″x 1.25″
1″ ID washers	2
0.5″x 6″ carriage bolt	6
0.5″ ID washers	12
4″x 10′ wooden post	3
0.125″ DIA x 1.5″ cotter pin	1 (extras necessary)

Step 1:

Cutting instructions for blk iron pipe

4″ blk iron pipe,

Cut into three 16″ sections

2″ blk iron pipe

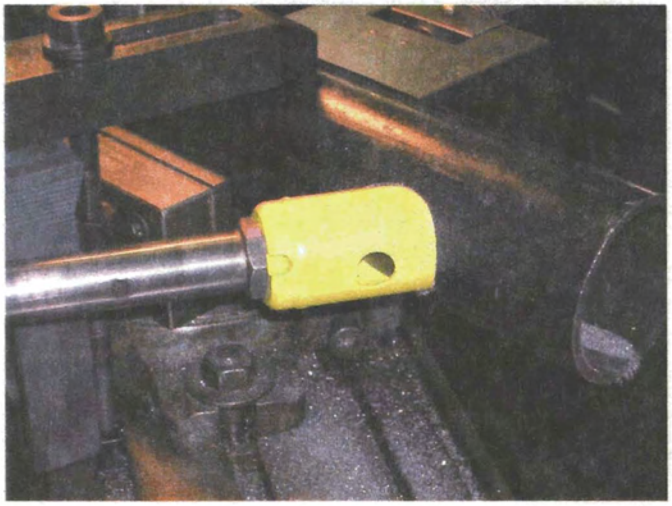
Cut into three 16″ sections

1″ blk iron pipe

Cut into one 2″ section and two 5.5″ sections

Step 2:

Using a 1.375″ DIA hole saw, cut through the two inch popes ##″ from the top. The center leg will need to be drilled perpendicular to the long axis of the pipe, and the outer legs must be drilled at a 30-degree angel wit respect to the long axis of the pipe.



Step 3:

Insert the 2″ and 5.5″ pieces in to the straight and angled holes respectively. Center each long wise in the holes and weld the 1″ pipes together around the outside of the holes.

Step 4:

Weld the 0.375″ steel plate to one end of the 1″ mild steel round bar, make sure that the plate is centered.

Note: the .375″ plate can be a piece of scrap steel and needs only to be roughly the dimensions stated above, we used a scrap plug from a hole saw cutting.

Step 5:

Drill a .125″ hole centered through the round bar 1″ from the end of the bar opposite the steel plate. The hole should be perpendicular to long axis of the bar.

Step 6:

Create two wooden spacers 1.5″ thick with a 4″ OD and 2.5″ ID
A piece of 2″ blk iron pipe should fit snuggly inside the spacer and the spacer should fit snuggly inside of a piece of 4″ blk iron pipe.

Step 7:

Slide both wooden spacers onto one of the 2″ pipes about2 inches from the bottom then insert the 2″ pipe with the spacers on it into the bottom of one of the sections of 4″ blk iron Pipe such that 6″ of the 2″ pipe are encase within the 4″ pipe.

Step 8:

Clamp the assembly securely and drill a 0.5″ DIA hole through both pipes 1″ from the top edge of the 4″ pipe. Rotate the pipes 90 degrees and drill another 0.5″ hole 5″ from the top edge of the 4″ pipe.

Step 9:

Remove the wooden spacers and bolt the two pipes together.

Step 10:

Drill a hole near the bottom of the 4″ pipe to allow for a lag bolt to pass through it into the wooden legs.

Repeat steps 7-10 for each leg.

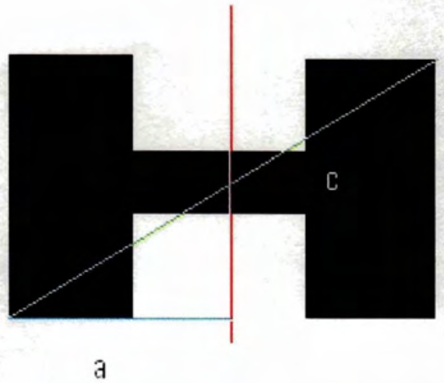
3.1.2 Rock Bit:

Materials

Item	Quantity
4′ section of RR Rail	2

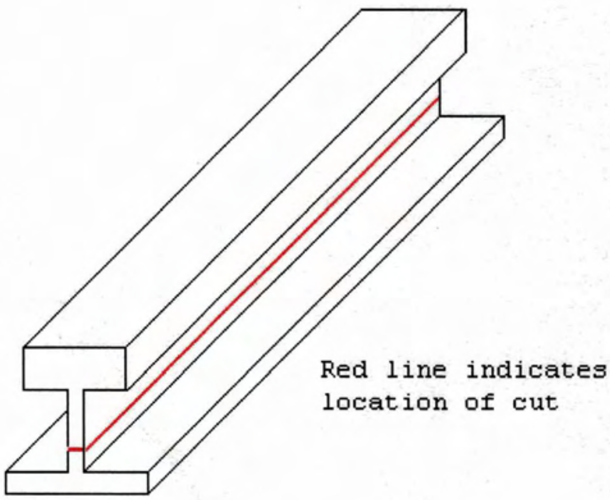
Step 1:

Determine the distance form the top Flange into the web of the rail (dimension a) at which the rail must be cut in order to make the bit create the desired hole diameter (dimension c).



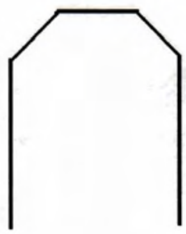
Step 2:

Mark the "a" dimension along the long axis of the RR rail. Cut the rail in two pieces with a cutting torch.



Step 3:

Grind bevels into the cut edges of the web in order to prepare for welding.



Grinding Profile for end of web after removing the bottom flange

Step 4:

Carefully weld the two halves of RR rail together.

Note: Because the RR rail is composed of high carbon steel (1080) special care must be made in welding it. If the weld cools too quickly, the welds will form brittle martencite and crack. To combat this either preheat the rail to 400 degrees Fahrenheit beforehand and insulate it after welding or use a low hydrogen stick being care full not to get over penetration of the weld.

Step 5:

Once the bit has bee welded together a blunt chisel point should be made at the one end. A sharp profile should be avoided to prevent chipping.

Step 6:

Carefully weld impact resistant surface welding onto the tip of the bit. (optional)

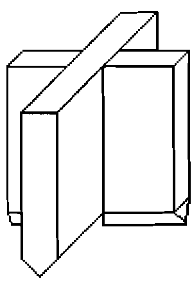
3.1.3 Clay Cutter:

Materials

Item	Quantity
5′ of 1″blk iron pipe	1[1]
4′ of 1″blk iron pipe	4
1″ mild steel round bar	24″
0.5″x 2.5″ steel bar[2]	8″
4″ blk iron pipe	3.5″

Step 1:

Cut a set of teeth from the 0.5″x 2.5″ steel bar. The cross configuration should fit well in the cutting shoe and it should be centered.



Assembled inner cutting shoe
Note: length of each part will depend on the exact size of the pipe used to make the out part of the cutting shoe

Step 2:

Sharpen the teeth on both sides to make about a 55-degree angle at the point.

Step 3:

Grind an edge on the inside of the four inch pipe.

Step 4:

Press fit the 0.5″ thick steel blades into the 4″ steel pipe such that they form an "x″ inside the pipe.

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[1] The 1″ blk iron pipe and 1″ mild steel round bar may be replaced with any sufficiently massive object that can be welded to the cutting teeth and is less than 4″ in diameter.
[2] The harder the steel the better

Step 5:

Weld the tooth assembly together.

Step 6:

Weld the four 4′sections of 1″blk iron pipe to the outside of the 5′ section of 1″ blk iron pipe. The pipes should be arranged symmetrically according to the figure below:

Step 7:

Drive the 1″ mild steel round bar in the end of the 5′ pipe that extends past the 4′ pipe segments.

3.1.4 Bailer

Materials

Item	Amount
4 inch nominal Dia. Steel pipe	4 ½ feet
3 mm plate steel	25 sq. inches
1 ½ inch hinge	

Step 1:

Cut 4 inch steel pipe to four feet (use hack saw)

Step 2:

Cut a 3 inch long segment from remaining four inch pipe

Step 3:

Bevel inside edge of one end of the 3 inch section of pipe. Approximately 30-45 degree taper. (This is necessary to allow the bailer to penetrate the soil with less resistance from wall thickness)

Step 4:

Layout 3 mm steel to cut a 4 ½ inch disc from (See appendix- Bailer schematics)

Step 5:

Out the 4 ½ inch disc cut a disc in the pattern shown in appendix- (a ring and disc will remain)

Step 6:

On the section of the ring where the cutting began, grind half of the thickness away from a 1 ½ inch length. (This will allow the hinge to sit flush against and aid in the assembly process)

Step 7:

On the remaining disc cut ¼ inch of two sides away shown in appendix- (The removal of this material will help the valve open and close inside the 4 inch steel pipe.)

Step 8:

Weld the hinge to one end of the flap (clamp so its line of symmetry is synonymous to that of the plates)

Step 9:

Tack weld the 3mm steel ring to the end of the 3 inch section that has not been beveled on the side.

Step 10:

Tack weld flap with hinge onto the 3 inch section (Tack on reverse side of hinge).

Step 11:

Line up 4 foot length of 4 inch pipe and the newly constructed 3 inch section and clamp with a c-clamp at the center of the pipe.

Step 12:

Tack weld in four equidistant locations around the pipe

Step 13:

Remove clamp and proceed to weld the two sections together. (Weld with slight back and forth movement perpendicular to the seem for the best weld.)

Step 14:

Weld Jar loops to inside of Bailer pouring end

Step 15:

Cut a V-shaped spout for improved pouring between jars (cut need only be approximate) - use grinder with a cutting wheel.

3.1.5 Jars

Materials:

Item	Quantity
40″ of 1/2″ steel rod	3
1 1/2″x1 1/2″x1/2″ steel	3
20″x1/2″x2 1/2″ steel	2
2 1/2″ of 1″ steel rod	2

Step 1

Using a torch or forge heat up the center of the 1/2″ rod to a straw color and bend it around a 1″ steel pipe until the bend is 180 degrees.

Step 2

Weld one of the steel blocks 17″ from the bend such that it ties the two sides of the rod together.

Step 3

If necessary heat the free ends of the bar and bend each according to the position required to attach the loop to the drill bit. This should be done as symmetrically as possible.

Step 4

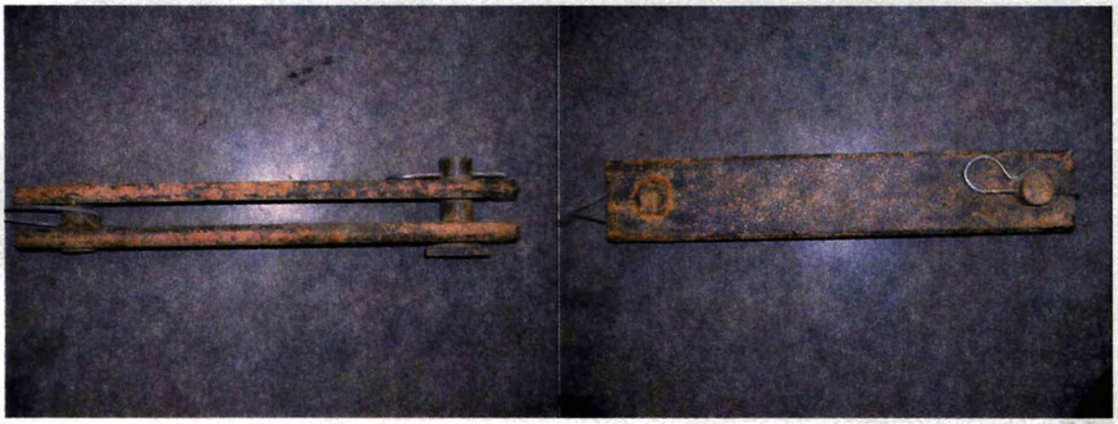
The loops should now be welded to their respective drill bit (one must be made for each drill bit used)

Step 5

Drill 2 one inch holes in the 2 1/2'x1/2" steel bars with a hole saw, these should be centered and located 1" from each end.

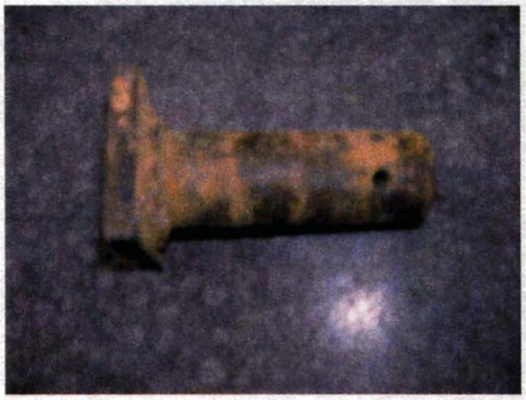
Step 6

With a jar loop between the two bars insert the 1" rods in the holes to make a large chain link. Be sure there is enough room for the loop to slide feely. Weld the one rod into place on both bars.



Step 7

Remove the other 1" rod and make a pin out of it in the same manner as the hinge pin for the frame.



3.1.6 Winch:

Materials:

Item	Quantity
1.5″ Angle Iron	110″
.75″ Diameter Steel Rod	32″
.75″ Diameter Self-Aligning Bearings	4
2″ Diameter Steel Pipe	12″
6.375″ Diameter Steel Circle, .25″ thick	1
4″ Diameter Steel Circle, .25″ Thick	1
3/8-16 UNF Bolt	8
3/8-16 UNF Nut	8
0.5″ ID washers	16
Lock Collars	4
Common Door Hinge	1
Sprocket and Chain Set	1
.25" x 1 " x 4.5" steel bar	1
Handle	1

Step 1:

Cutting instructions for all materials

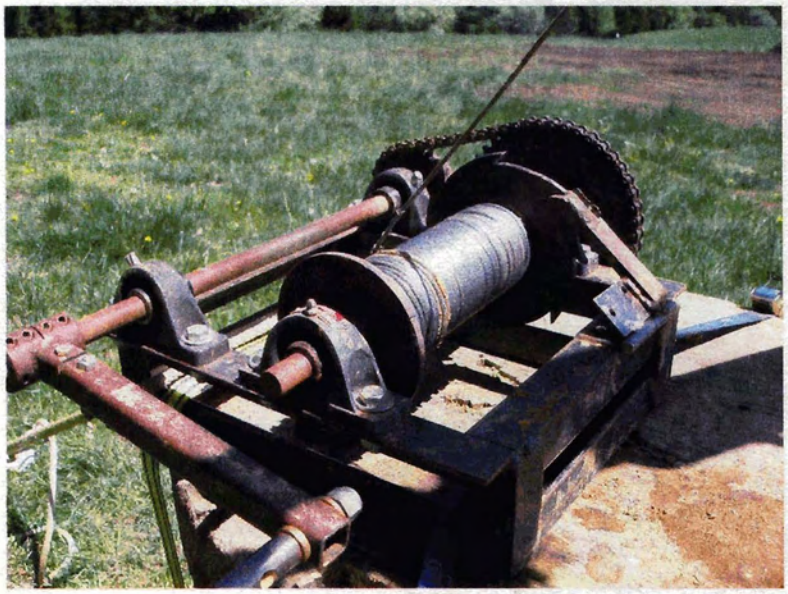
1.5″ Angle Iron,

Cut into eight 12″ sections and 4 3.5″ sections.

.75″ Diameter Steel Rod

Cut into one 14″ section and one 18″ section

Step 2:



Construct the frame by welding the angle iron into the frame shown above. Any contacting edges must be welded, to ensure no failures in the field.

Step 3:

Place each section of 3/4" steel rod through a set of two bearings. Attach a sprocket to an end of each rod. Place the four bearings on top of the frame rails. Attach the chain to the sprocket set and pull the rods apart so they are both parallel and taught.

Step 4:

Once the bearings are in the correct places, mark the top of the frame rails for drilling. At the middle of each bearing hole, mark a spot for a 25/64" hole. The exact location of each hole is not critical, as the bearings are self-aligning.

Step 5:

Once the hole locations have been determined, it is time to drill eight holes in the top of the frame. By using either a hand drill or drill press use a 25/64" drill bit and drill at the center of each of the eight locations. These holes will serve as the mounting points for each of the four bearings.

Step 6:

On the 6 3/8" steel circle, use a band saw to create eight teeth in the disk. The inner diameter of the teeth is 6 inches, and the angle of each tooth is approximately 30°. This process is lengthy, and it is important to ensure that relief cuts are made so that the band saw is not twisted at too small a radius.

Step 7:

After the teeth have been cut out, a .75" hole needs to be removed from the center of the disk. This hole needs to be large enough for the axle rods to fit through. Once cut, insert the rod into the axle that contains the large sprocket. It's position should be within one inch of the frame rail. Once on position, weld the disk onto the rod on both sides.

Step 8:

Once the catch has been attached to the axle, the spool needs to be attached as well. The 2" diameter pipe will serve this function. To attach this part, slide the pipe over the axle with the catch disk, and center it. Weld the pipe onto the catch, again making sure to get complete penetration as to avoid failure in the field.

Step 9:

Take the 4" pipe and cut a hole .75" in diameter in the center of the disk. Once cut, place the disk onto the pipe that was welded on in the previous step.

Step 10:

While the spool assembly and second axle are on top of the frame, it is time to center each axle on the frame. To do this, place the bearings in the correct spots on the frame. With the bearings in the correct places, center the spool on the frame. Once centered, place two lock collars on the axle. Place one on the inside of each bearing. (This may require removal of the sprocket and/or bearings to do so.) Repeat the process for the front axle, however leave ample room on the side opposite the gear for placement of the handle.

Step 11:

After the spool has been completely constructed, it is time to attach the bearings to the frame. To do this, take the eight bolts, place a washer on each, and thread them through the bearing slots and the holes drilled in the frame. Place a washer on the bottom of each bolt, and then tighten a nut onto each bolt. Make sure to tighten each nut completely, as the axles will want to "walk" if not tight enough.

Step 12:

Take the door hinge and place it on top at the end of the frame. Position it so that the center (approximately) is in line with the catch disk. Once in position, weld the hinge to the frame, making sure to weld every possible edge for maximum strength. If desired, it is possible to drill through winch frame the three holes in the hinge and secure the connection further by three nuts and bolts of the correct size.

Step 13:

Take the steel bar, and place it with the 1″ sides facing up and down. At one end of the bar, create a tapered end, approximately 30°. This can be done using a band saw, or it can be ground down. This piece will become the catch lever.

Step 14:

After the winch lever has been completed, attach it to the top of the hinge, so that the tapered end faces the catch disk. Center the bar on the disk, making sure there is at least ¼ inch on each side of the disk. Then adjust the bar lengthwise, again making sure that the tapered end fits nicely into the teeth of the disk. Once in place, weld the bar onto the hinge, using as many edges as possible to secure the connection.

Step 15:

The last step involves attaching the handle to the winch. Since the handle used for this project was donated, it came with its own connection method. For other applications, attach the handle to the small sprocket axle, utilizing the extra length for safety. Make sure the connection is solid as this is a place of high stress.

3.2 Drilling manual:

3.2.1 Siting:

Siting wells is an important step to drill a well as you might imagine. There are three to four phases that most hydrologists recognize as necessary steps to locate potential well sites. This information was gathered from The Field Guide to Water Wells and Boreholes written by Lewis Clark, Water Wells: Implementation, Maintenance and Restoration written by Michael Detay, and Hand Dug Wells and Their Construction written by S.B. Watt and W.E. Wood. Each source identified ways to site wells that were very similar. A collaboration of the processes described in the mentioned texts leaves three phases. In order, *preliminary studies, field studies,* and *implementation* are the possible phases to carry out during well siting. The action of carrying out successive steps depends on the amount of information gathered from the previous step. In some cases it may not be necessary to carry out the rest of the steps, or it might be advantageous to skip steps, if enough information is available from a given step.

Beginning with the first phase *preliminary studies*, there are several possible actions one can do to begin investigation. It is always a good idea to begin by looking for hydrological data of the region you will be drilling. Countries often provide knowledge of the local conditions through the geological survey department. Geological survey departments are likely time saving places to start. One should find any geologic maps of lithology and any other data previously connected. Questions will most likely arise which the next phases will likely answer

Field Studies is the next phase and includes exploration drilling, and making supplemental observations. Exploration drilling must not take place without purpose, because as one might guess, drilling takes time. Exploratory holes must answer a question like, "how thick is the aquifer?" Or if no geologic data is available, what types of geology are present? Supplemental observations involve area reconnaissance of old wells and current wells. Look for the presence of springs, which will indicate aquifers. Also consult the local communities members, especially in developing nations where hydrogeologic data is scarce, to raise support for the new well. Another possibility if available is photo interpretation. Arial photography can help supplement topographic maps when identifying landforms like plateaus, drainage basins, and large outcroppings of rock. These landforms will be useful in determining the best place to drill a well. In locations where there are large outcroppings of rock drilling is probably a bad idea. Topographic maps, if used, will help determine the drainage patterns. A great place for a well would be located in a place with a large amount of drainage potential. Examples of this would include valleys and locations below hills. This phase will probably be most helpful. If a geology expert is available he or she will be a very valuable resource. Move to the next phase at the most logical time.

Once enough data has been collected on the area, and the location of an aquifer is known to high degree of certainty, the next step is to implement the well.

3.2.2 Setup:

The set up for the rig is rather simple, first one erects the fame being careful to ensure that the legs are evenly spaced. One must plan out the site in order to keep things out of ones way, space should be allocated for the soil removed from he well, a 50 gallon drum of water and a place to set the drill bits. Finally the pulley should be mounted on the frame with the rope and drilling can begin.

3.2.3 Drilling:

After the drilling equipment has been properly set up, it is time to start digging the actual hole. Before starting the hole, it is important to recheck the center of the tripod, as this will be the final location for the hole.

The hole is started by a conventional clamshell digger or similar mechanism. This is due to the fact that there is no room to actually drop the various bits into the ground. A hole roughly one to two feet deep needs to be dug. This will allow the bits to have clearance between the bottom of the hole and the top of the frame, enough so that spudding can occur.

Bits are attached to the cable via a jar. Mentioned earlier, it is the component which allows for easy changing between the three different bits used to dig.

Once the proper bit has been chosen and attached to the jar and cable, it is time to lower the components to the bottom of the hole. Once at the bottom of the hole, the process called spudding can take place. Spudding consists of the bit being raised approximately one foot above the bottom of the well and letting it free fall. Spudding is performed by multiple persons pulling on the cable or rope to provide the upward force needed to raise the bits. This motion works the bit into the ground, and breaks up the hard packed substrata at the bottom of the well. This raising and dropping motion is repeated until significant progress has been made into new soil. Water is sometimes added while spudding to create mud, which makes the process easier and more efficient, making the already loose ground to be more easily penetrable by the current bit.

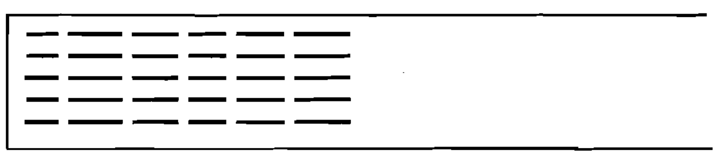
After a period of spudding, the downward progress is checked. If significant, the current bit will be removed from the hole and set aside. It is then time to attach the bailer to the drill string and lower it into position. The purpose of the bailer is again to remove material out of the well. Once at the bottom of the well, the bailer is spudded in the same manner as the clay cutter and the rock bit. This up and down motion of the bailer causes mud to rise into the bailer, where it is held in place by a check-valve mechanism. After the bailer has moved itself further into the ground or has gained weight, it is time to remove the material. The persons operating the cable will pull the bit out of the hole, and place the top of the bailer onto the ground. The bottom is then raised and the mud poured out through the top of the bailer. The process is then repeated until all loose material has been removed, and then it is time to repeat the process again. The process remains the same for all depths, and progress continues until a suitable water source has been found.

While drilling, it is important to have a supply of water on hand. This is very important when it comes time to remove clay, sand, etc. from the well. The right consistency of mud is very important in determining whether or not the bailer will actually retain material and remove it from the well. Too thick of a consistency will result in the material not flowing into the bailer, and too much water will result in all the mud seeping back into the well after it has been collected. This is due to the imperfect nature of the bailer; it cannot perfectly seal the entire bottom of the homemade check valve.

3.2.4 Finishing:

Once one has established a bore hole that yields a desirable amount of water, it is time to establish its permanence. In order to do this one must consider three important factors: function, durability and sanitation..

If pre-manufactured well screens and casings are not available or too expensive, then they can be manufactured from heavy PVC pipes two inches in diameter smaller than the size of the borehole. The first step is to make a well screen to allow water to flow into the well and to keep soils out. This is done with by cutting slits in the casing with a hack saw. These should be oriented in columns down the casing such that there are evenly spaced linear regions of the casing that do not have slits. This will help preserve the strength of the casing.



Well Screen Diagram

It is important that the slotted region of the pipe is only the same height as the depth of the water standing in the bottom of the well this will help prevent contamination. This section of pipe goes at the bottom of the well. The next step is to flange out the end of next piece of pipe so that it will fit over the end of the well screen. This can be done by boiling some cooking oil and placing the end of the pipe in the boiling oil for a few minutes. The plastic pipe will then soften so that it can be forced onto the end of the well screen. This should be done to the bottom of each piece of well casing needed to reach the surface. The pipe should be lowered carefully into the well one section at a time gluing or screwing the sections together as you go. Once the casing is in place one should gather together several buckets of stones that are large enough that they will not get lodged in the well screen, these can be sifted out and sorted using window screen. These should be carefully poured around the out side of the casing to a depth slightly greater than the depth of the well screen. The next step is to dump clay around the out side of the well casing until it is within 3 meters of the surface this will help to keep contaminated water away from the well. Finally, cement should be poured around the casing until it reaches the surface. It is important for sanitary reasons that a cement pad be made around the top of the well so any buckets used in collecting the water will not be sitting on the bare ground. Also the pad should be sloped in one direction, preferably down hill and have a lip around its outside edges in all other directions so that any excess water flows away from the well. It is a very good idea to create a drainage ditch (lined with concrete) and a rock filled pit at its end to prevent stagnant water from lying around. This will discourage water born illnesses such as malaria.

3.2.5 Developing:

Once the well is drilled and cased in unconsolidated formations, it is likely that it will yield water with a large amount of sand or clay in it. This is problematic because it can lead to increased wear on the pump also pumping the well may cause the small particles around the well to clog the well screen for this reason it is important to develop the well. This is a simple process that utilizes a surge block and a pump. A surge block is essentially a foot valve from a pump that fits tightly against the sides of the well casing and forces water in the well backward through the well casing. For shallow wells these can be mounted on the end of a metal pole, in deep wells they can be attached to the bottom of a heavy drill bid

The surge block is lowered into the well until it reaches its bottom and is then spudded in the same manner as the drilling bits this will arrange the grains of the soil near the casing so they do not clog the well screen, and increase the efficiency of the well.

Finally, the pump should be installed and the well should be pumped for several hours until the water leaves the well unclouded by sediment.

4 Schedule:

See appendix for hard copy of schedule

See well drilling project plan file for electronic copy

5 Budget:

Project Budget

Material	Source	Amt.	Price
1" blk iron pipe	Lowes	60'	$82.68
2" blk iron pipe	Lowes	10'	$28.41
132 gauge RR rail	Kovalchick corp.	8'	$95.93
4" blk iron pipe	Peight's welding shop	10'	$55.00
3" blk iron pipe	Peight's welding shop	2'	$6.50
1" round bar steel	Peight's welding shop	4.5'	$4.80
1/2" round bar steel	Peight's welding shop	10'	$4.20
1x5" clevis	Tractor Supply Co.	1	$20.00
1/4" plate steel	Engr Model Shop	Scrap	
1 1/2" angle iron	Engr Model Shop		$31.25
4" pulley	McMaster		$24.25
180' of 3/8" cable	McMaster	160'	$77
		total	$430.02

6 Conclusions:

In conclusion we found that we can produce an effective well drilling system in the United States for under $300. This system is capable of drilling a six-inch borehole through both consolidated and unconsolidated soils. We found that our rig can be operated with human power while penetrating sandstone at a rate of six inches per hour and sands and clays at a rate of 2 feet per hour. The system will create a 4 inch diameter finished tube well that can be used for potable water supplies and under the correct hydrological conditions be used for irrigation purposes.

Our design is quite flexible, and can be altered to meet specific manufacturing and material availability needs in a wide variety of rural settings. It is our sincere prayer that this information is imparted to future generations of Dokimoi Ergatai and that it will be implemented wisely for the benefit of our friends and partners who desire to create self help wells.

7 Future Work:

Before this project can be implemented, there are some important modifications that must be made. First investigations involving the construction of the legs to the frame must be made. Our design incorporates a four inch diameter sleeve that is mounted to the frames hinge made of two inch pipe. This allows for the use of wooden legs. Depending on local availability of materials and available capital it may be more beneficial to forgo this connection and use two inch steel pipes for the legs. It is also important to note that if wooden legs are used, they should be coated with motor oil or some other treatment to prevent termite infestation. Another design consideration that needs attention in regard to the frame, is the two outer legs which attach to the frame though two 1 3/8 inch holes that are drilled at a thirty degree angle with respect to the long axis of the pipe. This operation requires an interrupted cutting process into a non-planar surface. This process is difficult and required the use of a horizontal milling machine. We would like the holes to be drilled normal to the long axis of the pipe and perhaps have the legs cold bent or hot bent in order to attain the desired 30 degree angle. This should preferably be preformed with a preexisting bender, or using an small forge (simulated with a torch) and a standard anvil horn (can be modeled with a piece of pipe).

The second area of major investigation regarding the percussion rig is the rock bit. We decided as a result of our testing and research regarding the Burkinabe rail road, that our drill bit is too heavy. It is both difficult to lift and made from a gauge of rail that is not available in Burkina Faso. By using a lighter gauge rail a faster rate of penetration may be achieved using less energy. Another major concern with this bit is the four feet of very difficult welding. Since the base alloy for the railroad rails is a 1080 super alloy steel it requires special considerations during welding, either preheating or the use of a low hydrogen stick. We would be very interested in testing to determine exactly how much welding is necessary to hold the bit together. We propose that one could weld the first several inches or foot at the drilling end, and the last couple inches or foot at the jar loop end. Testing will be necessary to determine how much weld is necessary to ensure failure will not occur. This is especially important since failure of the rock bit will prove expensive in time and capital, and could force the failure of the well site.

Finally and perhaps most importantly during our research, DE purchased a well drilling rig that is currently stored on the grounds of Handicapes en Advant. This a hand Auguring rig that is built to the same specifications as those described in Jon Naugle's book Hand Augered Garden Wells. This rig is currently without drill bits that will be needed to drill the wells these can be easily designed through the use of the before mentioned book and a little bit of environmental engineering product research. It was recommended to s from Mr. Naugle that the enclosed auger should not be made, and that the valved percussion auger, a sort of toothed bailer would be a wise investment. [It may not be wise to use a leather valve on the bottom of the flap unless it is fastened with epoxy, bolting it there did not work.] A full set of full size bits should be constructed for this tools set along with construction manuals, there is a copy of Hand Augered Garden Wells in French that is believed to be in the care of Dr. Ray Norman. (Dr. Norman also possesses several other books that will be of great benefit)

Bibliography

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Groundwater Hydrology. Third edition, 2005.

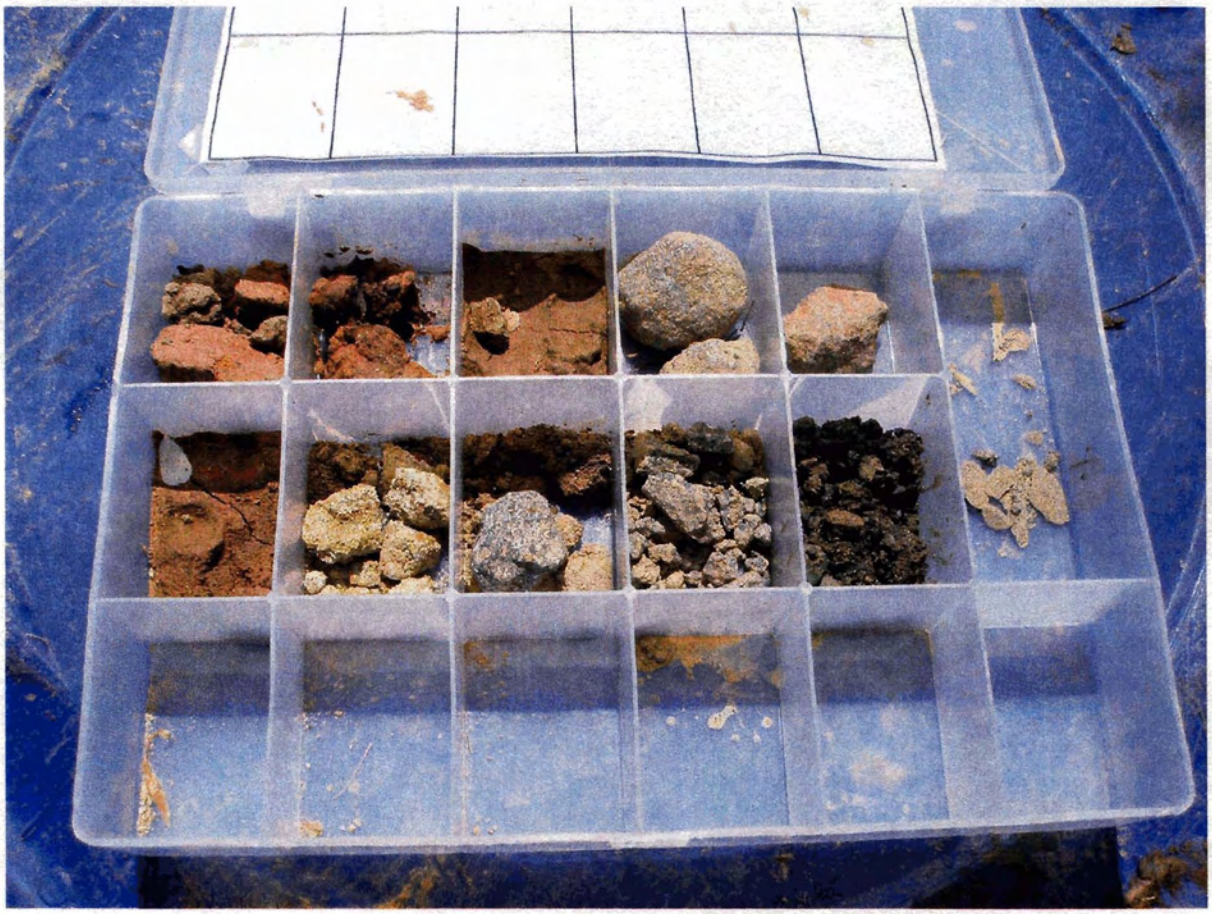
Wells and Boreholes: A Field Guide to Drilling Wells and Boreholes. 1992.

Appendices

A1 Drilling log

Depth	Soil Type	Drill Bit	Rate
0-9ft	Orange Clay	Clay Bit	2 ft/hr
9-14ft	Sand*	Clay Bit	2 ft/hr
14-17ft	Sand Stone	Rock Bit	1/2 ft/hr

*Sand started out very fine and gradually progressed to very coarse probably due to the weathering of the underlying sand stone. Also random small stones were found in both the clay and sand layers.

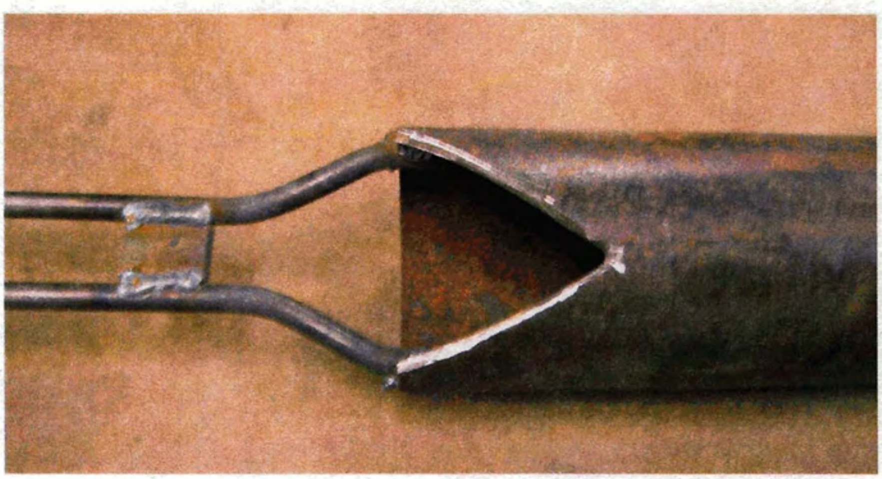


A2 Drawings

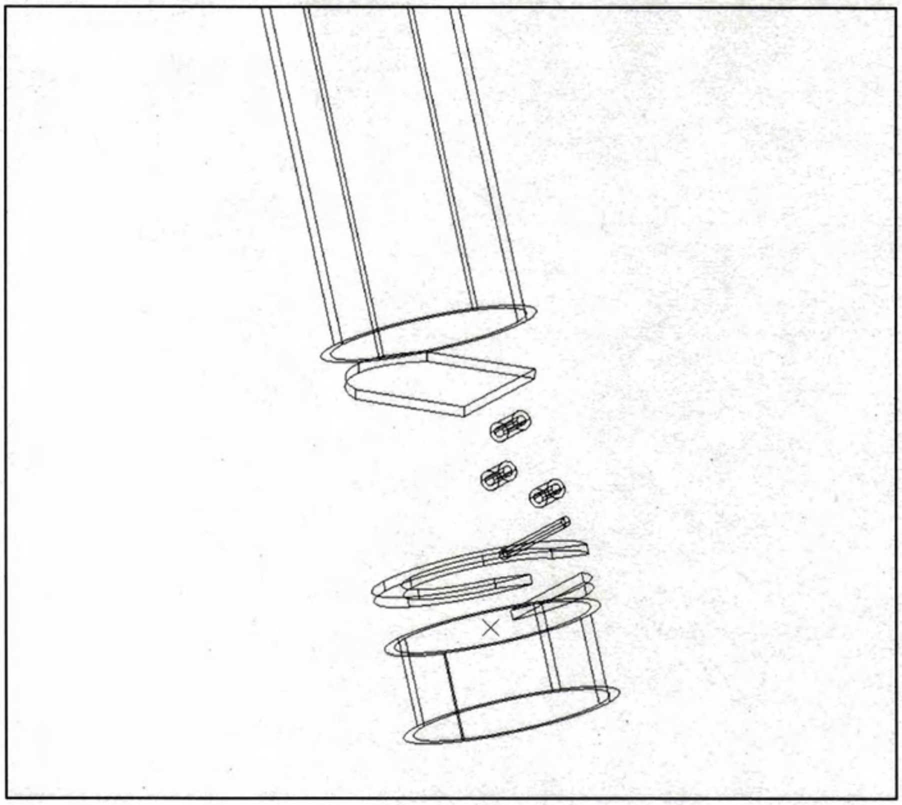
Bailer

Shows full length of bailer

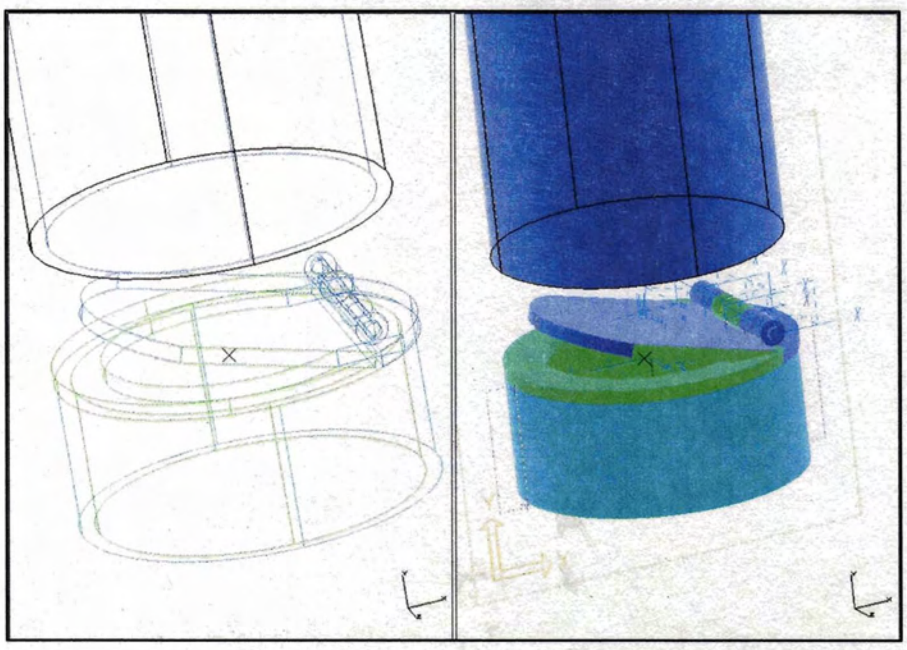
Shows the bailer's dumping end. The notch is to help the material in the bailer flow out of the pipe more easily. Also seen is the jar loop which has been welded to the inside of the pipe



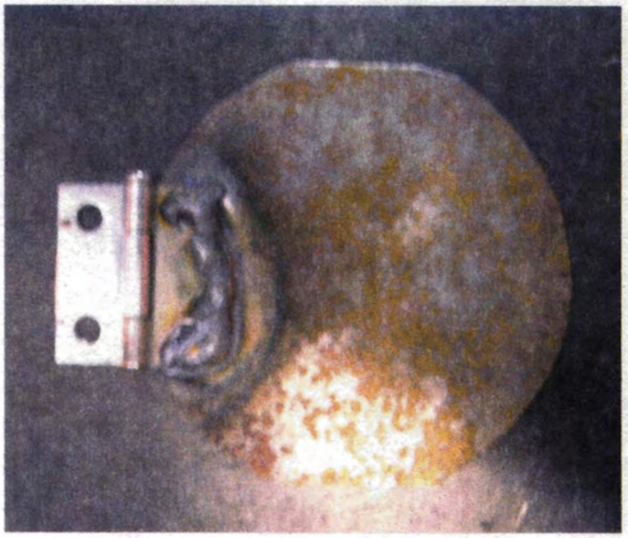
The exploded view of the one way valve of the bailer



The valve assembled while the main body of the bailer is in-line in the position it would be connected to valve



A prototype valve design, hinge is welded to 3mm sheet steel



The dimensions of the valve flap

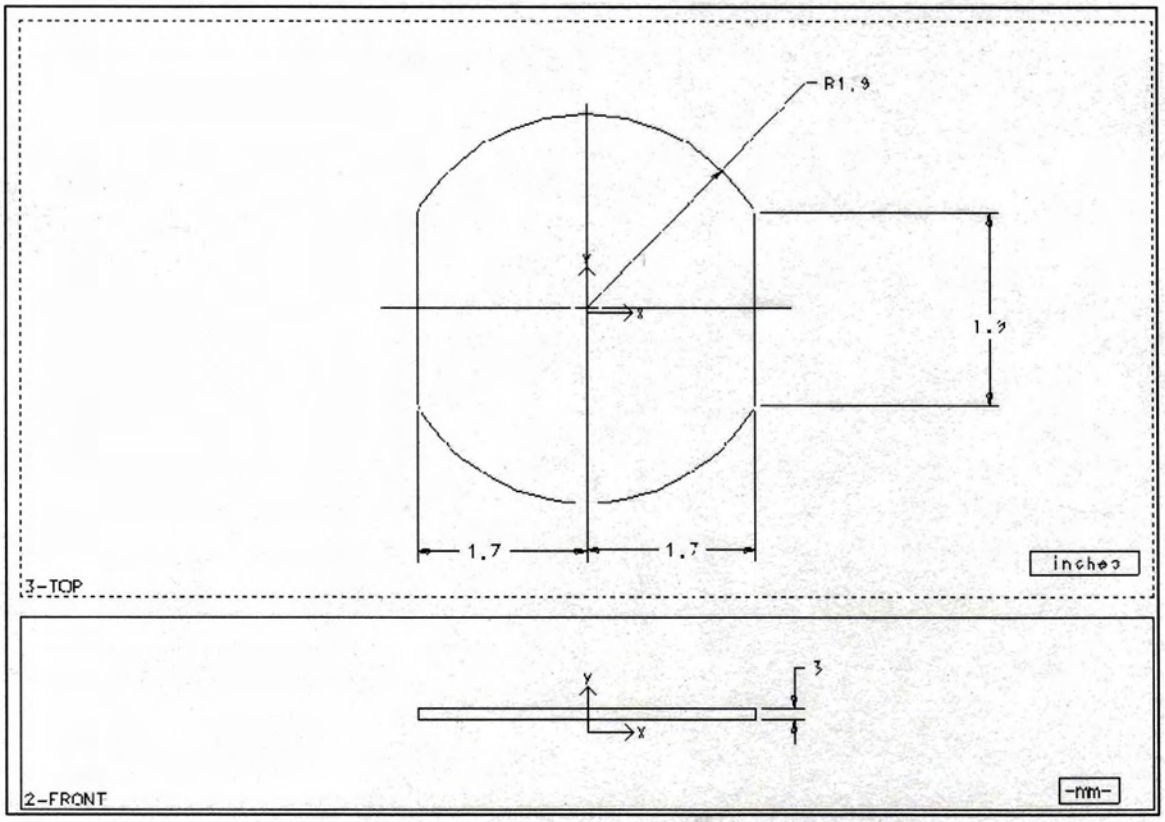
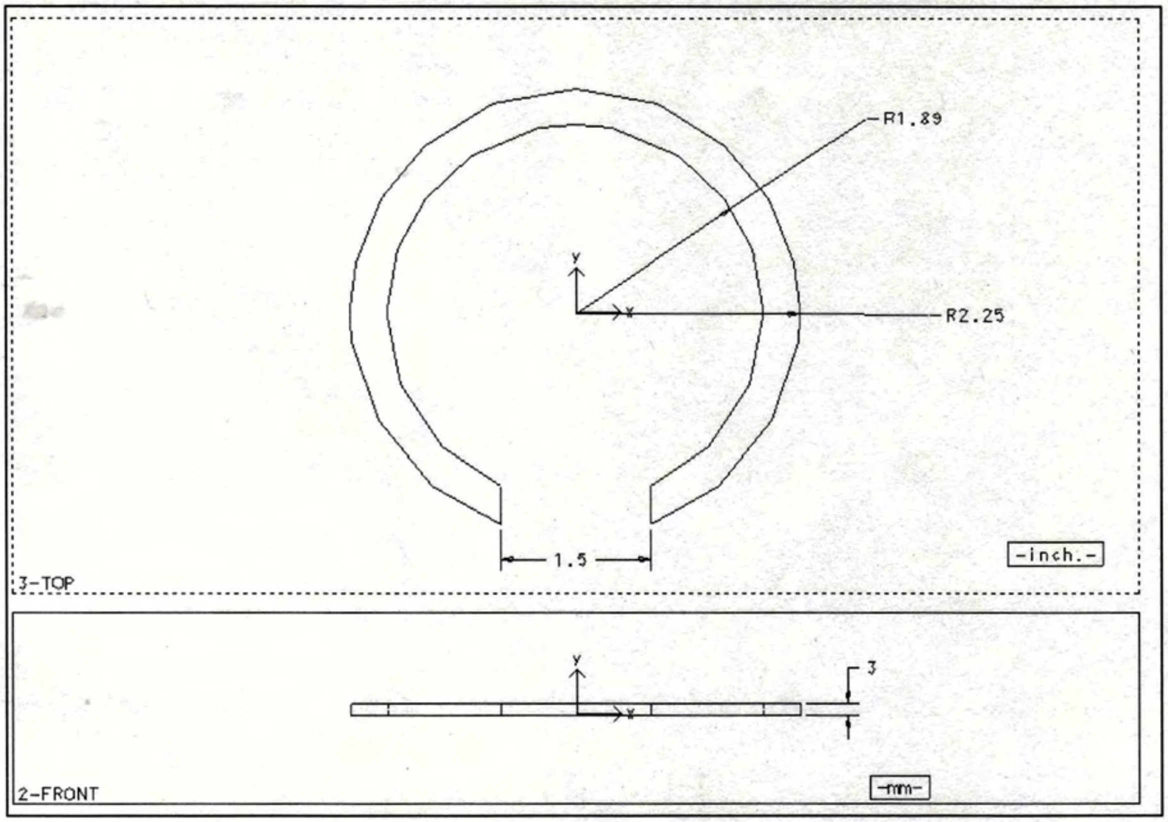
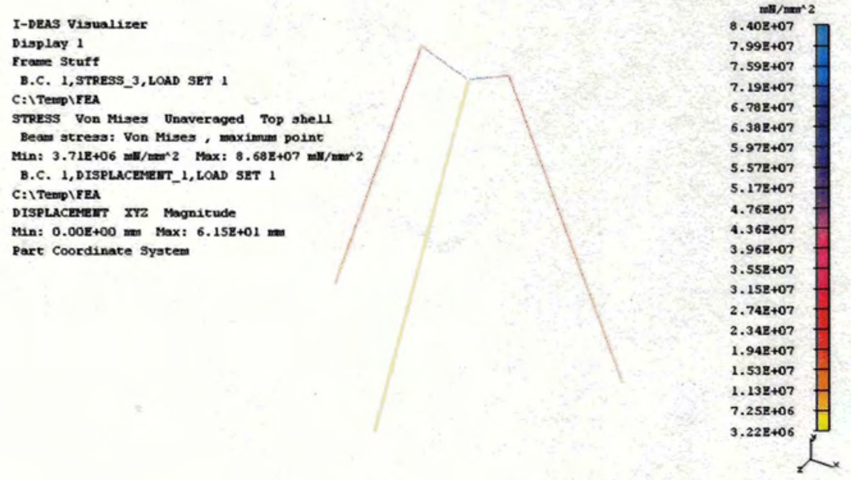


Figure - Shows the dimensions of the valve spacer



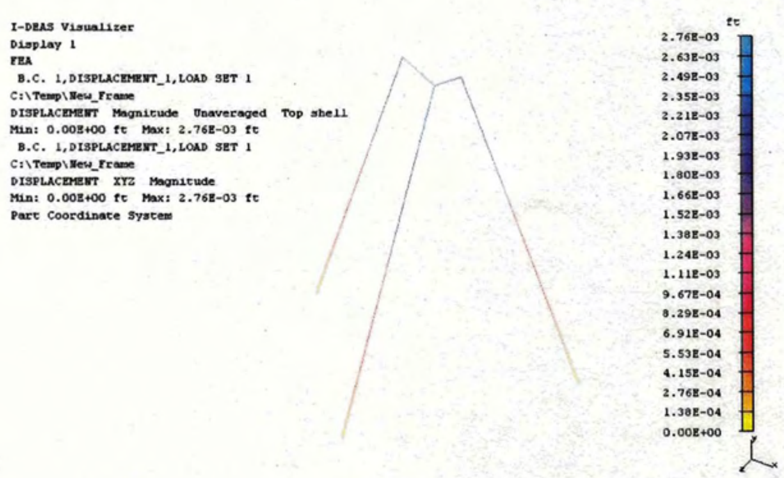
Frame Analysis 1



Comment:

We feel as though the stress in the cross member is too high for our application. The member itself is too long and deforming too much. The stress is also very large. We feel that if we shorten the cross member, more stress will be transmitted to the supports and give a more even stress distribution. Then the deflections will be within an acceptable range.

Frame Analysis 2

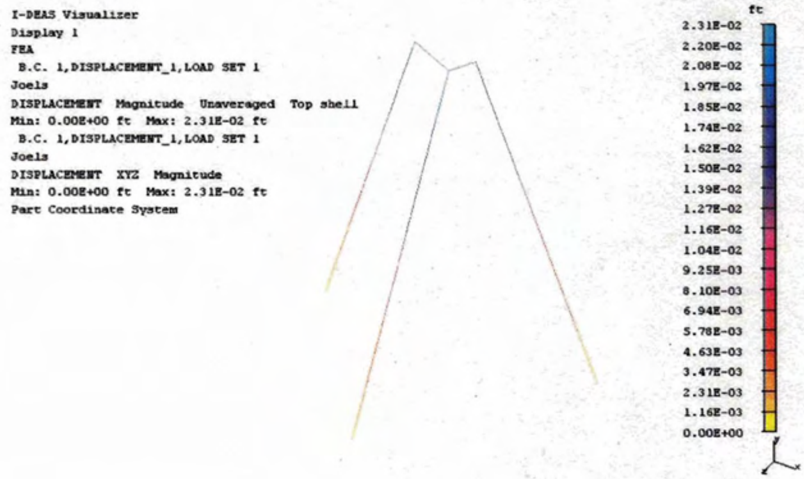


Comment:

In this instance we shortened the overall cross member length by 1 foot. Or 6 inches on each side. We also changed the units to feet for easier node placement. As seen, the deflections are very small, less than .003 feet. This equates to about .8mm. We feel that this would be sufficient strength for any load less than 3500 pounds. This model uses only steel pipe that has an outside diameter of 2.5 inches and a thickness of ¼″.

We tried to model a solution which involved shortening the steel sections drastically, and inserting wooden beams into the steel. This proved to be difficult, because wood is anisotropic and complete properties are not available online. Each time we tried to solve the model, errors were encountered, and the analysis was meaningless.

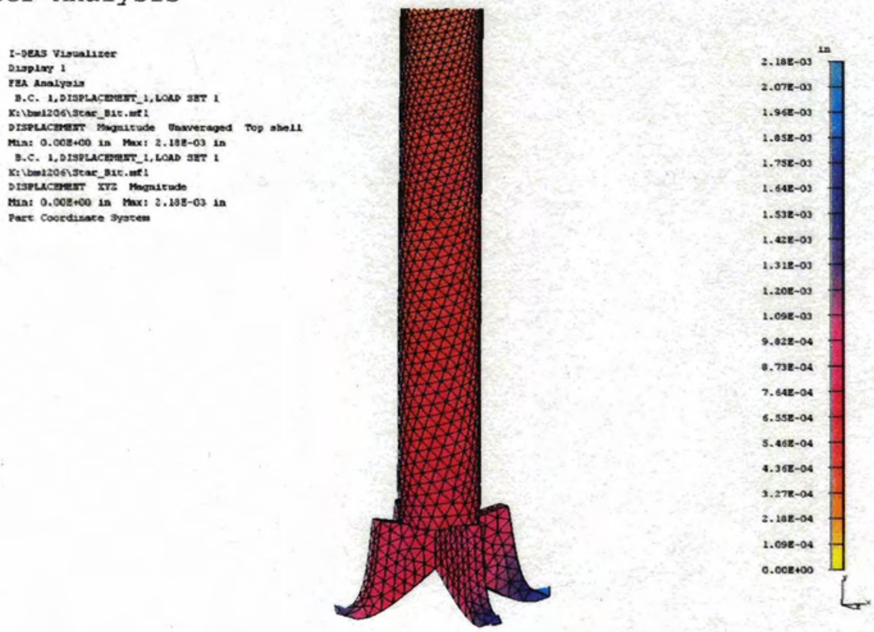
Frame Analysis 3



Comment:

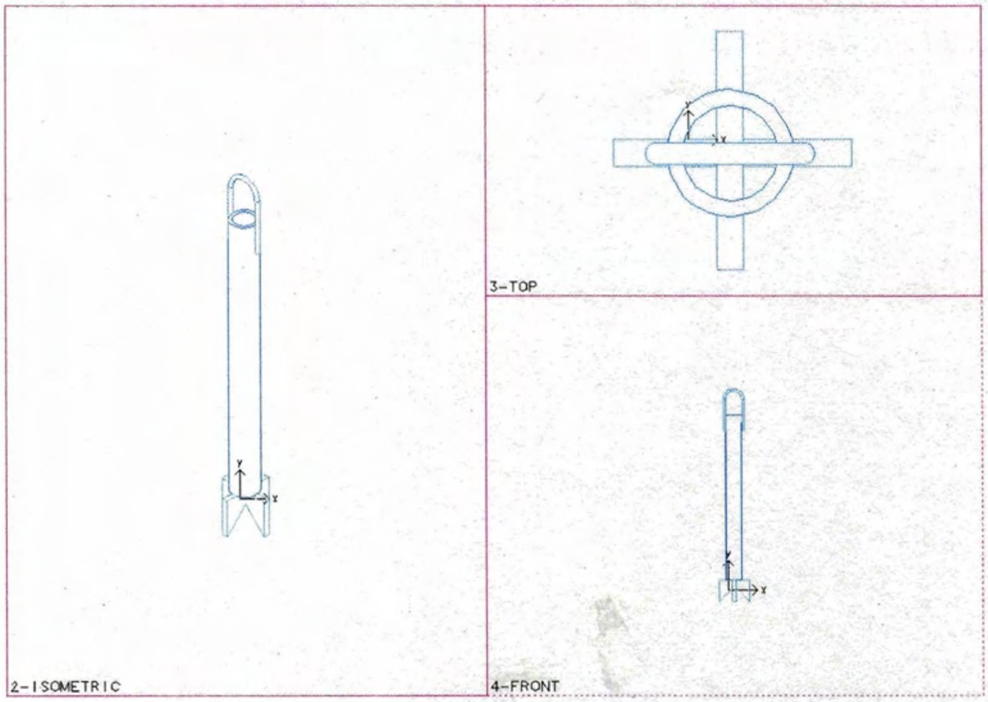
In this FEA model, we once again changed the characteristics of the top member, creating a simulated threaded rod instead of a larger steel pipe. As expected, the amount of deflection increased slightly, but remained within reason, rising to .58mm. We feel that when it comes time to actually make the frame, we may shorten the top member even more, thus allowing for even less deflection. We also attempted to add a wooden member to the bottom 3 pipes, but the orthotropic properties of wood combined with the difficulty in modeling that in IDEAS proved to be too much. According to a simpler set of equations, we feel as though the safety factor for larger wooden beams would remain the same as the steel pipes.

Clay Cutter Analysis



Comment:

This FEA analysis uses the default generic isotropic steel found in the IDEAS program. Since the exact material to be used is yet unknown, this should be a good place to start. The forces acting on the bit are four 500lb forces acting at the centers of each point. The top of the bit has boundary conditions applied to have zero displacement and zero moments of inertia. As shown in the figure, the displacement of the bit is very minimal, 2.18e-3inches. The corresponding pressure to this load and displacement is also well within the bounds of the given steel properties. I feel as though this bit will perform well when drilling through normal ground, and will survive many cycles before a failure occurs.



ID		Task Name	Duration	Start	Finish
1	✓	Low-Cost Well Drilling for West Africa	189 days?	Mon 8/29/05	Tue 5/9/06
2	✓	**Paper Work**	**182 days?**	**Mon 8/29/05**	**Fri 4/28/06**
3	✓	Project proposal	2.5 days?	Wed 9/21/05	Sat 9/24/05
4	✓	**EDR**	**44 days?**	**Fri 10/21/05**	**Thu 12/15/05**
7	✓	MEB Scholarship Day	164 days?	Tue 9/13/05	Thu 4/20/06
8	✓	**Presentation**	**182 days?**	**Mon 8/29/05**	**Fri 4/28/06**
9	✓	compiling documentation	9 days?	Wed 3/22/06	Mon 4/3/06
10	✓	Fall Oral Presentation	12 days?	Mon 11/14/05	Mon 11/28/05
11	✓	organizing/ formatting information	7 days?	Tue 4/4/06	Wed 4/12/06
12	✓	**Spring Presentation**	**1 day?**	**Mon 8/29/05**	**Mon 8/29/05**
13	✓	Take Video of Drilling	1 day?	Mon 8/29/05	Mon 8/29/05
14	✓	**Powerpoint presentation**	**12 days?**	**Thu 4/13/06**	**Fri 4/28/06**
15	✓	peer review	5 days?	Thu 4/13/06	Wed 4/19/06
16	✓	Practice - Time goal - 20 minutes	8 days?	Wed 4/19/06	Fri 4/28/06
17	✓	**Rig Frame**	**71 days?**	**Tue 9/6/05**	**Tue 12/6/05**
18	✓	**Design Rig Frame**	**27 days?**	**Tue 9/6/05**	**Tue 10/11/05**
25	✓	**Construction of Rig Frame**	**28 days?**	**Thu 11/3/05**	**Tue 12/6/05**
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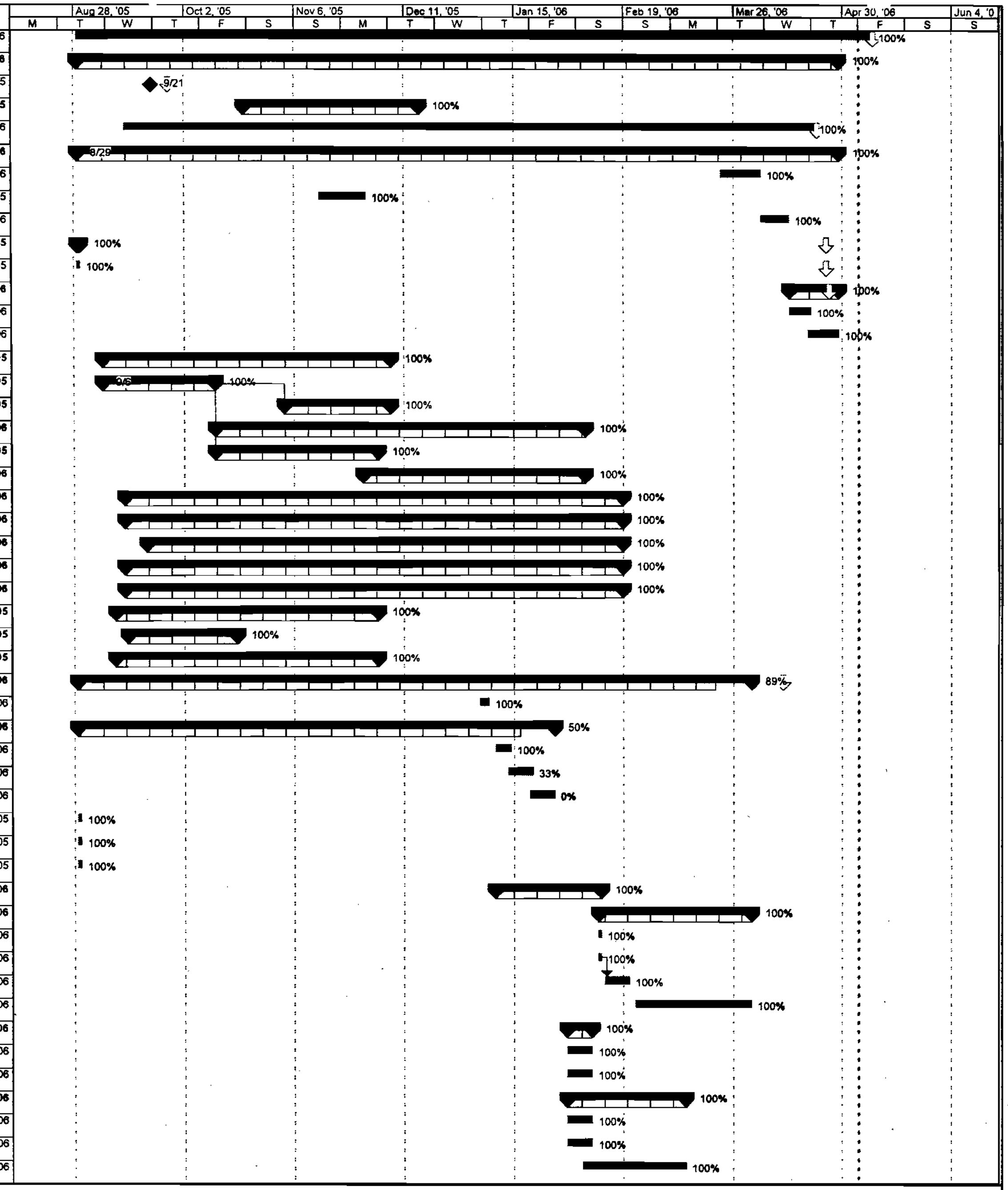
53	✓	**bailer**	**115 days?**	**Tue 9/20/05**	**Sat 2/18/06**
61	✓	**clay cutter**	**120 days?**	**Tue 9/13/05**	**Sat 2/18/06**
69	✓	**rock bit**	**120 days?**	**Tue 9/13/05**	**Sat 2/18/06**
77	✓	**Survey tools**	**64 days?**	**Sat 9/10/05**	**Fri 12/2/05**
78	✓	**Design Set**	**25 days?**	**Wed 9/14/05**	**Tue 10/18/05**
84	✓	**Build set**	**64 days?**	**Sat 9/10/05**	**Fri 12/2/05**
91		**Well Drilling**	**182 days?**	**Mon 8/29/05**	**Fri 3/31/06**
92	✓	Locate drilling site/s	3 days?	Wed 1/4/06	Fri 1/6/06
93		**Develop tests**	**115 days?**	**Mon 8/29/05**	**Fri 1/27/06**
94	✓	Fatigue Tests	5 days?	Mon 1/9/06	Fri 1/13/06
95		Develop mean time between failures analysis	6 days?	Fri 1/13/06	Fri 1/20/06
96		Portability	6 days?	Fri 1/20/06	Fri 1/27/06
97	✓	Drilling in various materials	1 day?	Mon 8/29/05	Mon 8/29/05
98	✓	Useful life of cable tools	1 day?	Mon 8/29/05	Mon 8/29/05
99	✓	Winch ergonomics	1 day?	Mon 8/29/05	Mon 8/29/05
100	✓	**Well Preparation**	**26 days?**	**Mon 1/9/06**	**Sat 2/11/06**
105	✓	**Drill Well**	**37 days?**	**Sat 2/11/06**	**Fri 3/31/06**
106	✓	Transport Drilling Equipment to Site	1 day?	Sat 2/11/06	Sat 2/11/06
107	✓	Set up Drilling Equipment	1 day?	Sat 2/11/06	Sat 2/11/06
108	✓	Troubleshoot Drilling Equipment	7 days?	Mon 2/13/06	Mon 2/20/06
109	✓	Drill	27 days?	Thu 2/23/06	Fri 3/31/06
110	✓	**January Trip Review Meeting**	**6 days?**	**Wed 2/1/06**	**Wed 2/8/06**
111	✓	Discuss Tony's findings	6 days?	Wed 2/1/06	Wed 2/8/06
112	✓	Discuss Action steps	6 days?	Wed 2/1/06	Wed 2/8/06
113	✓	**Substrata Documentation Procedure**	**30 days?**	**Wed 2/1/06**	**Fri 3/10/06**
114	✓	Summarize Tony's findings of Burkina's substrata in document	6 days?	Wed 2/1/06	Wed 2/8/06
115	✓	Summarize Tony's procedure used to survey in Burkina Faso in document	6 days?	Wed 2/1/06	Wed 2/8/06
116	✓	Use info gathered to create optimum Data collection process	27 days?	Mon 2/6/06	Fri 3/10/06



Project: Well Drilling Project Plan
Date: Fri 5/5/06

Critical		Task		Baseline		Milestone		Project Summary	Deadline
Critical Split		Split		Baseline Split		Summary Progress		External Tasks	
Critical Progress		Task Progress		Baseline Milestone		Summary		External Milestone	

77 **Survey tools**
Used in Burkina Faso in January 2006 by Anthony Beers

91 **Well Drilling**
We were able to test each of the bits (rock and clay cutter, as well as the bailer) We actually took 2.5 weeks longer to begin and complete the well drilling test

93 **Develop tests**
This will now be part of the future work of this project

113 **Substrata Documentation Procedure**
Tony's documents for this can be located in the January Burkina trip report of 2006