Cranfield UNIVERSITY
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DESIGN REVIEW OF THE POUNDER RIG, FOLLOWING FIELD TRIALS OF THE PROTOTYPE

a human-powered drill rig for shallow small diameter wells
for domestic and agricultural water supply

developed in Uganda and UK through project funding and support from
Government and People of Uganda, DFID, Danida, Sida, and Unicef

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Reference as: Ball, P (1999) Design review of the Pounder Rig, Following Field Trials of the Prototype. Report of DFID KAR Project R7126 “Private Sector Participation in Low Cost Water Well Drilling”, Cranfield University. ISBN 1861940 564.

CONTENTS

ABSTRACT

Field trials of the prototype Pounder Rig were undertaken in Mpigi District, Uganda in the second half of 1999. The first phase of these trials gave rise to an initial evaluation of the equipment, which is included here as an Appendix. The trials themselves are fully reported under separate cover (Ball, P and Danert, K (1999) Field Trials of the Prototype Pounder Rig, Uganda, 20th August – 13th November, 1999. Report of DFID KAR Project R7126 "Private Sector Participation in Low Cost Water Well Drilling", Cranfield University).

This document is a review of the design of the Pounder Rig, and a discussion of pertinent aspects of its use and management, following the completion of the trials. It forms the basis for the move from prototype to production model. The main proposed modifications to the prototype are:

- the replacement of the existing superstructure with a welded frame to ease setting up, ensure hole verticality, and direct return fluid flows;
- the replacement of existing drillpipe ("AQ" wireline) with a larger diameter carbon steel pipe ("BQ" wireline);
- the acquisition of drill bits with properly hardened steel bodies;
- the introduction of the option of simultaneous casing;
- the option of in-line valves to facilitate cuttings removal and enable in-situ test pumping;

The transport options are considered in some detail, and the logic, and costings, of using a pickup are set out.

The likely business profile of a Pounder Contractor, who is likely to need start-up capital of around USh10-20 million, is presented.

Issues of standardization through the Uganda National Bureau of Standards are discussed.

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The Project Team consists of Dr Richard Carter (Project Manager), Eng Kerstin Danert (Team Leader – Uganda), Mr Peter Ball (Drilling Consultant), Mr Ezron Rwamwanja (Community Water Supply Specialist), and Mr Jamil Ssebalu (Small Business Specialist).

INTRODUCTION

This document reports the technology design issues brought up for consideration during field trials of the Pounder Rig in Uganda (August – November 1999), and provides the basis for the design of the production machine.

Most comments received from stakeholders relate to the capacity of the equipment and its general application as it is still early days in the equipment's introduction and use in Uganda with a lot of practical experience still to be obtained and indeed seen and assessed by the interested parties.

SELECTED COMMENTS FROM LOCAL STAKEHOLDERS

These were largely sought informally and are reported anonymously – in any event many people repeated effectively the same points. Some points are mutually contradictory!

- *It is the potential low cost per well that is the target not the lowest cost of a set of drilling equipment.*
- *The geology of Uganda and the occurrence of groundwater are varied – a drilling method should ideally retain capacity to cope with collapsing ground and laterite. It will be difficult to define and build a market for a limited range of drilling.*
- *Offering a comprehensive drilling solution drives up the complexity and cost of the base machine and the effect will be to direct the market away from bottom rung contractors – this is ground that might never be recovered.*
- *A Pick-up truck must not be assumed to be a pre-requisite of the Pounder driller – it should retain capacity to be moved by non motor vehicle means.*
- *Adequate testing. Has enough been learned with the existing equipment? It has drilled in a restricted area near the lake shore and more can be learned.*
- *A new variation must be adequately tested.*
- *The drive for privatisation in Uganda is from the top down – 'the down' are not necessarily ready for it or want it.*
- *The Pounder will not survive beyond the project if it stays within the DWD/WES programme.*
- *Ignore production rate during the test period the success of the Pounder will be measured in the production rate possible in 5 years from now.*

Asked about depth capacity – is a maximum 30m completion depth essential? A mixture of answers all quite non-committal:

- *Officially DWD regard a hole greater than 25m as a 'deep well'*
- *+ 20m seemed a good target – but few examples of such shallow wells were offered*
- *Lots of 12, 15 & 18m completions thought to be about the working capacity.*

GENERAL CONCEPT

The key proposal is to continue to move away from the extreme basics of the North Indian sludging operation using bamboo – farm harvested at drill site more often than not and plain galvanised water pipe as drillpipe. The heavy weight drillpipe, the sludging valve, the counterbalance indicate a more technological approach to extend the drilling capacity.

One basic change is to move away from using scaffold poles as pivots and braces and move to a purpose built structure – a complete base frame to act as foundation to the structure and foundation for the required bracing. The frame would also double up as a carry/storage frame for the packed up machine and drillpipe.

One feature of the frame is that it provides a totally rigid set up with no possibility of adjustment. The frame will require levelling on site – this would be accomplished best by assembling the central pivot and braces and lever bar – hanging the chain down with a drillpipe attached. The frame will be exactly level when the drillpipe is dead centre of the table bush hole. More importantly, in this state the set-up geometry will be perfect to allow the drill string, and therefore the borehole, to remain vertical.

Revisiting the current Pounder set up at Mpigi District HQ drilling 20m + test hole it was noted that the crew were busy re-adjusting the pivot, counterbalance and lever at 10m depth to get the geometry right when they were well into a hole – it is difficult (but not impossible) to hammer in a pivot at 'plumb' and set up mechanically sound and accurate framework but it does require time and a skill level.

By replacing ground anchors with a frame, the need to check the integrity of such anchors is removed. Without a rigid frame, a ground anchor may be deployed but is it in the right place and solid enough to deal with the required loadings?

DRILLPIPE

The current pipe is AQ wireline 44.5mm OD x 34.9mm bore, 14kg per 3m.

The early (September 1999) drilling trials in Uganda revealed an effective 'stall' in the flow of the circulating water at hole depth of 22m. However vigorously the pipe (AQ wireline) was sludged no or little water emerged through the valve. With the only assumed variable being length it was surmised this flow loss was due to friction. In November a hole was drilled to 18m before the 'stall' became effective and then uPVC pipe of 2" 61 x 50mm bore and 1½" 48 x 38mm bore were inserted into the hole to compare the flow – the 1½" pipe gave a low but very nominal flow, while the 2" pipe gave a much improved flow easily capable of lifting cuttings.

Conclusion – to sludge much beyond 20m is impossible with the AQ wireline.

Why did we reach 22m in September and stopped at 18m in November? The November hole had been rested over a Sunday and the crew had added a very thick mix of polymer to the hole – it is assumed this thick mixture of dirty water affected the depth the internal friction took effect.

Alternative pipe

- BQ, the next wireline pipe size is 55.6mm OD x 46mm bore – 18kg per 3m. This is a perverse size created by the drilling industry and works with a varied range of core barrels, recovery spears and drillbits. It is perverse to general engineering usage but with a near guaranteed future from the drilling industry. It is close to being continually ex-stock available in UK & South Africa as a standard threaded product. To combine with a footvalve and piston will require special design.

- 60mm x 50mm bore ST52. This is very similar grade of material and is a popular cylinder material held by UK steel stockists. A wireline style tapered thread could be created on this tube size. The big advantage of this material is that it would allow complete standard Afridev & Malda pistons and footvalves to work inside as test pump, or development tool.

It would seem feasible to design footvalve and piston with similar attributes as one for 50mm bore inside 46mm – 4mm hopefully is not too big a step down.

DRILL BITS

Use of both styles has continued with some 35m drilling wear being put on both the 75mm and 100mm button shoes. A visual comparison of both bits shows the buttons are seemingly contoured as they were new but the bit body has eroded near the tip below the nitride hardened layer. The 75mm shoe has taken most wear. The immediate conclusion is that the body is required to be more wear resistant.

An alternative bit design has surfaced from a South African manufacturer – a mass producer of all manner of tungsten button bits for the South African mining market has suggested modification of a range of standard reaming bits used on blast hole applications. These have body arrangements of buttons to drill 64, 76 ,89, 102 & 127mm diameter holes. This suggestion arose having been presented with existing button shoe drawings and being concerned about drilling the button holes on the 6mm machined radius. Whilst adoption of these new bit styles would be a departure from our current shoes they do come with a proven integrity of construction and design – ie they are standard product arranged to drill hard rock efficiently otherwise the competitive mining market would have ditched them. One fact gleaned from walking around South African drill bit factories is that the entire bit bodies are through hardened by heat treatment prior to drilling the button holes. Project shoes were only nitride case hardened after drilling for buttons as this offered least distortion.

Initially approaches had been made to the UK drill bit market to adapt standard bits, with little enthusiasm from manufacturers to get involved in anything but completely standard products.

Adopting up to a 127mm diameter bit does open the door to constructing 4” cased well – in certain ground conditions this might be preferable to a direct install design.

SIMULTANEOUS CASING

A system of simultaneous casing has been devised to drive 1m lengths of 4” flush thread jointed casing 114mm OD x 103mm bore. (This represents about the minimum wall thickness it is possible to thread with flush couplings). The casing would be lightly driven by a steel-casing driver fitted under the sludging valve – this would impact against a steel casing anvil. The drive force would be the combined weight of the casing driver and the drillstring in the hole.

The water flooded hole would provide support and lubrication inside the hole, and the suction effect of the lifted cutting shoe should promote a good casing drive.

The ability to drive casing is a feature of the ground resistance imposed by both soil strength and friction, and the force used to drive it. A civil engineering pile is deemed deep enough when it does not advance further.

Given the soft wet valley bottoms and the experience of lost circulation and collapsing ground it is proposed to test a 10m string of casing as an experiment to determine the Pounder rig’s ability to drive casing. An eccentric bit to work with this is could be simply achieved by threading the drillpipe connection off centre – eccentric to the drillbit face.

TABLE ASSEMBLY AND CONDUCTOR CASING

The prototype uses a 0.8m length of 4” plastic casing with a long slot. The proposal is to make this from steel – as per 4” steel casing - allowing threaded cutting shoe and a cap piece that will act as table bush and flange to prevent the casing dropping through the table.

SPLASH COVER

The drilling end of the frame will be sheet metal covered to effectively replace the plastic concrete mixing spot. This plate can be contoured to hold up drilling debris to aid logging and settlement of circulation water. This will benefit from the necessity of drilling with a level frame – draining will work reliably as the splash cover will be level.

DRILLPIPE REMOVAL

It is anticipated that there will be a need to combine conventional sludging with an in-line bailer type valve to push up water from lower – where a natural water table takes over from a surface flooded hole.

In this case drillpipe will need to be removed from the hole several times during a drilling shift. To allow this the drilling lever can be swung sideways by 15 degrees to provide clearance. This will allow the drillpipe to be worked out of the hole using the main lever and plenty of manpower.

The base frame can be used for mounting a rope turn pulley so that the lift/drop lever can be by a horizontal rope pull – this will allow a string of labour to assist each side. Assuming load is in balance this string of people could be equal numbers of people ranging from children through to adults of varying energy and body strength. The current arrangement of tee bar and counterbalance lever does lead to some strange unnatural operating positions taken up by operators – whilst allowing the machine to function it does not address best safe working practice with regard to protecting lower backs from damage.

Once arranged it will be worth experimenting with moving the rope inwards. If the counterbalance is in operation, moving the rope towards the centreline of the drilled hole (ie towards the counterbalance) will mean the lift and drop can be faster.

COUNTERBALANCE OPERATION

A half 200 litre barrel seems a practical solution – they are universally obtainable and about the right size. The barrel will be held better in the production rig as its lifting chain will run on an arc, so keeping the lift vertical . The base frame will also allow for guide tubes to be easily arranged.

The best ballast is gravel pack; this ensures its constant availability on site for construction.

Pivot Pin: in Kampala there is a shop, AutoSprings, that specialises in spring components for vehicles (a sure moneymaker considering the state of the roads and tendency to overload vehicles). They stock a range of hardened spring pins with central greaseways and hardened steel bushes. A suitable size 28mm dia pin and bush costs USh16,000 (£6.50). With a M20 bolt of suitable length in Kampala costing USh8000 (£3.25) the cost of this ‘engineered pin’ with off the shelf availability is too good an opportunity to miss. An alternative is the 20mm diameter U3 pivot pin costing USh8000 (£3.25).

SLUDGING VALVE

This valve essentially remain unchanged in its form and function. It remains a leather covered rubber flap on a 30 degree seat. The valve will however move to a two leg support and the swivel will incorporate the tee bar fixings above the swivel. This will allow the drillpipe and bit to rotate 360 degrees to keep string threads tight during drilling. It is proposed to use tee bar handles of 1” water pipe to bring a little flexibility into the down stroke The emphasis will be on inducing downward velocity to get the hardest rock strike.

A form of metal bucket will be used to direct flow.

TEE BAR – STRENGTH/ATTRIBUTES

During November the Mpigi Drill Crew were sent to drill rock – a shallow hole only some 3m deep into consolidated hard granite. The 48mm OD x 40mm bore 2.2m long scaffold tube clamped to the AQ drillpipe bent in the middle turning down some 470mm. The drillcrew use this tee bar to throw the drillpipe down the hole – they do not hold onto it as it hurts their hands when it strikes the rock. The scaffold clamp often slips and need very hard tightening and packing out with leather to prevent slippage.

With penetration rate into the rock being very low one assumes a deal of energy is being reflected up the drillpipe. What energy is required to make this tee bar yield? How does this energy 'being seen' translate into base drillpipe strength. How do we engineer the tee bar – do we go to a stronger material or go to a lighter more energy absorbent material?

IN-LINE VALVES AND BAILER

Assuming adoption of South African reamer style bits, or keeping with our own design and adopting BQ wireline rod, the minimum drill bit size would be 60mm. Production bits of 76mm and 102mm diameter would suit direct install pumps best.

It is proposed to design a bailer body of less than 75mm OD and one less than 100mm OD to maximise the internal storage capacity for debris. The valve would closely resemble a percussion clack valve on the basis this is tried and tested in dealing with drilling debris.

In addition a removable foot valve will be designed for installation inside the drillpipe, to try and induce the maximum 'suck' at the drillbit and maximise the drawing in of debris in between trips out of the hole to empty the bailer. These valves can be used with a piston design to allow test pumping at will during the drilling operation with a suitable piston working inside the BQ pipe

TRANSPORT

Pertinent to the final design of the Pounder Drill is how the drilling contractor will deploy the equipment to his chosen sites. Institutional owners of equipment often hide transport coists within general overheads or can divide the cost of transport across a range of projects. A Pounder Contractor has to effectively cover the cost of transport within his quoted drilling rates.

The normal model for NGO/Government department would certainly be to utilise motor vehicles to transport the bare Pounder rig. At 500kg no examples of any other appropriate form of equipment mobilisation have been realistically suggested in Uganda.

The Pounder consolidated package at 3m length x 1m width weighing 500kg (inclusive of full 30m drill string of drillpipe) could be made suitable for road towing, manual towing or potentially cycle or motorcylce towing. There are 'World' examples of each of these in common use – but few in Uganda.

The Economics of Owning a Pickup Truck

A new pickup truck would cost USh30-40million (£12-15K). In private service this would probably last 10 years and have a residual value of say USh3-6million (£1200-2400). This could equate to a write off cost over 10 years, assuming working or earning over say a maximum 225 days per year, of USh12-14,000 (£4.80-£5.60) per working day. This would need to be absorbed as a business cost – in addition to meeting vehicle running costs.

It is unlikely a potential Pounder Driller will contemplate purchase of a brand new pick-up to support the drilling operation.

A rapid study of the second hand pick-up market in Kampala reveals the following costs.

These costs assume a considerable amount – few Ugandan drivers contemplate comprehensive insurance and different owners will manage the asset of the vehicle in different ways. The economics of a Pounder driller should allow him to recover from a total loss of vehicle.

The Very Bottom Rung

A worn out 15 years old vehicle, with probably 300,000+kms on the clock, smoky, dented, rattling, and sad looking can be found at USh2million (£800). It would run, although its reliability would be dependent on fortune and onboard mechanical skills. This vehicle might easily cost USh1-2million (£400-800) per year to keep it on the road in addition to normal wear and tear. It is unlikely to be available working for all 225 nominated annual work days. Its residual value after a short period of use might have fallen a little – if regular maintenance had been carried out.

Say cost of USh1-2.5million over a year of 225 work days = USh4,444-11,111 (£1.77-4.44).

The Middle of the Road

A tidy well looked after vehicle probably run for 2-3 years from 'Japanese secondhand import' is reckoned to cost USh4-6million (£1600-2400). This would be a good runner for 2-3 years and then could be re-sold at around USh2-4million (£800-1600).

This vehicle should offer better reliability and be available for more days.

This equates to USh0.5-1 million over a year of 225 work days = USh2,222 – 4,444 (£0.88-1.77).

Top of the Range

A newly imported pick-up, cleaned and made ready for auction sale costs around USh7–9 million and will run for a good 3-4 years depreciating to a resale value of USh4–6 million.

The extra purchase price should gain the owner a longer efficient period of travel free motoring.

This equates to USh0.5-1million over a year of 225 work days = USh2,222 – 4,444 (£0.88–1.77).

Figures like these are open to constant manipulation of perceived circumstance placing different factors into the formula. The conclusion though is that a day's business has got to produce a surplus of cash of USh2,500-10,000 (£1–5) just to meet the depreciation cost of operating a vehicle.

Any pickup will require money to pay for standard wear and tear – tyres, batteries, oil changes, brake linings, bulbs, etc - this could be USh0.5-1 million per year, equating to a further USh2,000-4,500 (£1-2) per working day.

Effects of Pickup Ownership on the Pounder Drilling Costs

The decision to own and operate a pickup truck would be made against the supposition that in doing so the potential drilling contractor can mobilise faster and drill quicker than a competitor that mobilises by hand trailer or similar. Otherwise to own a pick-up is to be uncompetitive.

Just what advantage could be supposed?

A rural based rig mobilising by hand might reasonably be expected to complete annually 10-20 wells of say 15m average depth - some 150-300m net drilling.

By moving more quickly between sites and having the facility to carry and fetch could double the annual production to say 20-40 wells – 300-600m net drilling.

Transport in the Context of Pounder Drilling Costs as Known

Taking a 15m hole drilled through soft material into 1m of hard rock, the direct costs add to a total of USh850,000 plus transport. Assuming the drilling takes 3 days and the job consumes 5 working days @ USh5,000-15,000, transport then adds USh25,000-75,000 to the base drilling costs. – equating to 3-9%.

Assuming that the contractor would add 40% for profit and overheads, this takes a well at USh850,000 + USh50,000 transport to a cost of USh1.2 million. A business with potential of generating annually a turnover of USh24–48 million.

With these sort of trading figures ownership of a pick-up costing USh6-9 million seems reasonable. There is enough scope to allow the generation of cash to survive a total vehicle write off

Transport – the Way Forward

A full set of road wheels, tyres and springs could be fitted to the base frame and the unit be road towed behind any vehicle from private car upwards. The downside to this is that towing is not common in Uganda, so vehicles are not ordinarily fitted with tow brackets and there are no readily available road trailers.

The market and shops in Kampala have a range of barrow wheels from 250mm diameter to 400mm diameter some with plain steel hubs through to ones incorporating bearings. The price per wheel ranges from USh8,000 (£3.20) to USh200,000 (£80.00). A 330mm dia 15mm dia axled wheel used on a timber sack barrow in the market is reputedly good to carry 12 x 25 litre jerry cans (300kg).

The favoured solution would be to make a light steel 'undercarriage' for the base frame – the 'undercarriage' would lift the frame about 600-700mm off the ground and be arranged to allow the front to be propped up to a height of 1000mm. This undercarriage can then be used to conveniently wheel the unit to site on all metal 300mm dia type wheels. The undercarriage can be wheeled up a pair of timber planks into the back of a pick-up and arranged with part of the frame held over the cab and the rear over the tailgate.

Below is a table of measurements taken from Kampala examples of pick-up trucks – the target would be to design a universal undercarriage that could be used on most pick-ups.

Table: Typical Pickup Tray Dimensions as found around Kampala

	A		**B**		**C**		**D**		**E**		**F**	
Pickup	**Height behind cab**		**Tailgate height**		**Full length**		**Full width**		**Between wheel arches**		**Ground to floor of tray**	
	ins	**mm**	**ins**	**mm**	**ins**	**mm**	**ins**	**mm**	**ins**	**mm**	**ins**	**mm**
Nissan Datsun 1 tonne	36.0	914	17.5	445	73.0	1854	57.5	1461	42.0	1067	27.0	686
Nissan Datsun ½ tonne	36.0	914	17.5	445	65.0	1651	57.5	1461	42.0	1067	27.0	686
Toyota Hilux 1 tonne	37.0	940	16.5	419	72.0	1829	58.0	1473	42.0	1067	26.0	660
Toyota Hilux ½ tonne	37.0	940	16.5	419	64.0	1626	58.0	1473	42.0	1067	26.0	660
Landrover 109	40.0	1016	21.0	533	69.0	1753	50.0	1270	36.0	914	27.0	686
Mazda	34.0	864	17.0	432	68.0	1727	57.0	1448	40.0	1016	24.0	610
Ford	39.0	991	17.0	432	73.0	1854	59.0	1499	44.0	1118	28.0	711
Toyota Hilux 4WD	36.0	914	20.0	508	72.0	1829	58.5	1486	42.0	1067	28.0	711
Landcruiser flat tray	37.0	940	20.0	508	75.0	1905	59.0	1499	50.0	1270	29.0	737

This directs the design to conveniently using a pick-up truck – as a 500kg load, this is a natural conclusion. As the undercarriage will be universal it can be used with hired or owned pickups.

PROFILE OF A POUNDER DRILLER

It is important to have in view the sort of person and business which is likely to operate the Pounder equipment. The design and technique being deployed has moved along from the Indian Mistry cycling to site with his few drillpipes and screen making materials.

Pounding remains a very physical activity taking hours of laborious construction. Development of the technology makes it possible to extend the equipment capacity, but it adds weight and complexity to the machinery. Who is going to buy and use this equipment, and how will they do so? Will an owner operator take this on who will commit himself to long hours of site work or will it be a layered business with a hired crew doing the operating? Whatever happens in Uganda will this be the model for elsewhere or will a completely different uptake occur?

A picture emerges from this document of an investor of some USh10-20 million (£4000-8000) who can buy a basic set of equipment and a pickup truck, probably organise some office space and storage facilities, purchase some well drilling material stock and begin to tender and take on contracts for work. He will need to produce work to the value of USh40-60million per annum, a high proportion of this being re-sale of well drilling consumables and hand pumps. This level of turnover is at the top end of 'small business' grouping for Ugandan tax purposes.

This picture implies a business with a proper financial structure with a set of books, and with VAT registration. Or at least the Pounder driller will have to be affiliated very closely to this sort of business.

UGANDA NATIONAL BUREAU OF STANDARDS

As we know the U2 and U3 exist as written up Ugandan standards based on the India MKII and MKIII. These standards were created by impetus from Victoria Pumps and Donors such as DANIDA.

A meeting was held with UNBS to discuss any design implications that might exist, eg metrication of fasteners, dimensions and materials standards of steelwork, for which there are no overall engineering standards in place. The message was to work to any available international standard!

There is an open route to having the Pounder Rig and technology made a Ugandan national standard. Clearly the specification needs to be prepared suitable for issue as a standard with complete drawings and engineering specification, and this could extend to approved well constructions. To be adopted as a Standard there would have to be unanimity amongst a broad spectrum of stakeholders - in our case DWD, Importers and Manufacturers, Pounder Users, Local Government & NGOs.

It would seem we are well on track to this all being put in place following more experience with the equipment in the field.

THE NEXT POUNDER EQUIPMENT

It is proposed to implement the build of the production rig in the following way:

- The new machine will move away from AQ and the current range of drillbits. Since we have just about two sets of equipment inclusive of some 30 No drill bits, it is proposed that AQ versions of the new equipment are made to convert the existing equipment sets to most of the new features. This will keep the AQ still ‘in play’ with its drillbits and enable us to continue learning from this equipment in terms of capacity and strength. It will allow a control model to ensure the full features of the BQ system are effective.

- A prototype frame and structure will be made in the UK to allow the functionality of the design to be checked and proven. UK work might well be required to refine the bailers and in-line valves.

- New equipment sets will then be purchased and shipped into Uganda, probably largely procured from South Africa. The Frames would arrive as kits of steel for local assembly and finishing possibly. This new equipment will be imported by a commercial partner and the equipment rented or sold to contractors involved with its testing. This firmly moves the equipment availability and use into the private sector.

APPENDIX

Comments following first phase of trials, September 1999

INTRODUCTION

These notes contain an **informal** summary of how the Pounder rig design has performed in the initial phase of trials, and outlines directions in which the rig could go. This is a difficult area to 'visit' and deal with. There are many directions and avenues that could be explored to extend the Pounder rig's abilities and capacity. It becomes an issue of which ones to choose! On the one hand this document contains a host of ideas that could revolutionise the drilling of holes in the ground; on the other hand the design should represent a set of affordable equipment which a Ugandan villager could buy & transport on a bicycle.

The key issue throughout these discussions is selecting and defining exactly what we expect of the equipment, rather than how it will do everything.

The Pounder rig was perceived as being a hand operated drill method capable of constructing water production holes using a minimum of capital equipment and installation materials to arrive at a 'Low Cost Drilling Method'. The very broad target is that it should be capable of drilling holes up to 30m depth, as well as drill through unconsolidated materials. It would specifically address the construction of holes in consolidated rock laterites and weathered horizons if not fresh fractured rock.

SLUDGING VALVE

The current design utilises a flush mounted swinging flap of thin leather (chamois car washing leather) covering a 6mm neoprene and steel reinforcement plate. It is held together with contact adhesive. The result is a freely hinging flap that has the ability to seat deeply onto the valve seat creating a tight seal. Without the leather covering, the neoprene wears too quickly.

This basic valve worked through about 40 metres, averaging 500 strokes per metre – some 20,000 strokes. At this point the leather covering was holed in a couple of places.

The water exiting is mucky and abrasive, carrying whatever material is being drilled. The valve does open and shut reliably for 30 to 50 strokes on average. It then might require cleaning to remove some bit of debris bridging between the valve and the seat.

When striking harder material, there is a tendency for the valve to bounce off its seat. An elastic band can be used to resist this bounce but this also seems to reduce the water flow.

A very good contact has been made with Henry Ndawula, Manager of Uganda Shoe Company Ltd. Several samples of locally tanned leather have been provided to search out the best material for a Ugandan made valve. The favourite is 3mm thick cow hide which hinges quite easily and can be fixed to the steel plate by contact adhesive or rivets. Early tests have not been conclusive. There is a need to fully saturate the leather before use. The chamois leather takes up water very quickly, becoming very soft, whereas thicker leather will need longer to become fully saturated. However, it is clear that Uganda is not short of raw material to perfect the best hardest wearing sludging valve.

Incorporated into the sludging valve is a tripod of steel which allows the valve to be hung under the pivot on a chain. This arrangement could be simplified by moving to just two support rods. The sludging valve can also swivel under the lever bar by means of an eyebolt and brass bush. This brass bush disintegrated during enthusiastic drilling of hard laterite. The drillcrew have a technique of snatching back the chain after it is loose on the bottom of the hole to snap the drill bit off hole bottom This breaks with a suction pressure that has influence in clearing drilled debris. A stronger pivot arrangement is required.

From very early on, an inverted plastic bucket was used to cover the valve to contain the exiting water. The bucket worked superbly, not only stopping the spread of the water around the site but allowing it to drop onto the pad and drain back into the pit. The conical shape of the bucket seemed to distribute the water in a ring and did not direct flow back down the borehole annulus between the 4" surface casing and drillpipe. A plastic bucket is cheap and light and a simple solution. However the plastic is flimsy. If it were steel fabricated, it could be more robust and also used to push the drillpipe down when it appears to be a bit sticky. Further, the bucket ought to be shortened so that a pipe wrench can be locked on to the sludging valve to allow unthreading.

PIVOT AND FULCRUM

The Pivot

In valley bottoms in Mpigi district the ground is very soft, 'swampy' and wet, making it easy to push the pivot tube into the soil. Despite clamping to a supporting scaffold crossbar, the pivot would lower itself into the soil. This was rectified by welding a 2” angle iron 400mm long at 1800mm below the pivot hole. This prevented it from sinking further. The pivot pole needs support, and this is best provided by a low crossbar which is positioned to mount the drillpipe guide. This is OK on its own for say the first 6 to 8m of drilling, but after this depth, the pivot tube needs support by one or two cross braces. They should be set at 45 degrees and splayed out 45 degrees either side of the uprights and fastened with swivel scaffold fixings to the scaffold tube ground pegs.

The Lever - Manual Operation

This works with a 2:1 ratio; 0.5m from pivot to drillpipe centre, and 1m length to the cross handle. The pivot is an M20 bolt running in 20mm diameter sintered brass bearings. The chain is linked to a grab hook and is a bit of a fiddle to shorten, an operation required every time the drill pipe advances. An alternative chain anchor plate could be incorporated into the lever. Also the free end of the chain swings about during the sludging operation. This will need cutting to just the right length.

At one point, the chain was coupled to the sludging valve with a conventional shackle to allow easy connection and disconnection. The pin of the shackle deformed indicating it was operating above the yield point.

The Counterbalance Lever

This replaces the manual operation lever, and allows a counterbalance weight (half an oil barrel) to be hung on one side (500mm from the pivot). The drillpipe is supported on the other side (also at 500mm). It is possible to balance the drillpipe load by weighing down the barrel with sand. This allows an oscillation up and down which is virtually free of load. Ropes with pull handles (2 on each end) are used to ‘see-saw’ the lever bar giving up to 600mm (24”) stroke on the drillpipe. The handles are pulled down evenly, hard and fast. With this arrangement, the chain remains taut on the downstroke indicating that the lever is not able to overcome gravity.

The arcing of both the drillpipe and counterbalance weight off their given centrelines is noticeable, particularly for the long stroke. This arcing of load on the 500mm radius could be removed by using 500mm radius arcs of steel to allow the chain to roll from a fixed centre. This would remove lateral movement, making both the drilling action and the counterbalance more central. For the future, this counterbalance could be arranged in a number of ways. The favourite method would be to have a central shaft possibly sunk 750mm into the ground to guide the counterbalance and prevent it from swinging on the lever. It would also be interesting to move the counterbalance weight further outwards to gain more mechanical advantage for the weight added. This is provided that it can be kept clear of the operators. However, this will result in a larger movement that might prove hard to contain.

The choice of counterbalance weight material should ideally to be something which is already carried to site, rather than having to carry special weight material. Water is possible but the densest material is gravel pack, with a density of approximately 2000kg/m^3. Thus, a half barrel of 100 litres capacity could carry approximately 200kg of counterbalance weight.

DRILL STRING

The drill string is carbon steel flush coupled wireline coring drillpipe. It is essentially the strongest pipe that money can buy. The rod threads are drilling industry standards - square form cut on a 5 degree taper. The tube OD is 44mm with 5mm wall, giving a bore of 34mm. Each 3m length weighs 13 kg.

Ultimately, the strength of the tube will be tested on future test holes in harder consolidated rock material.

The loss of fluid circulation as the drill string goes deeper is discussed in the main narrative. Experiments are required to prove whether or not this is connected to friction losses in the drillpipe. These will determine if the same circulation loss is experienced at the same depth through a 50mm (2”) pipe. This will entail drilling a deep hole until water circulation slows (one assumes circa 20m with 75mm drill bit with existing pipe). This should then be replaced with 2” galvanised or even plastic pipe uPVC or HDPE and then a flow comparison made. This will require special adaption pieces to 2”, i.e. use of one of the first sludging valves from the Cranfield trials. For consistency, the drilling shoe of 75mm should be maintained.

If the drill string diameter were to be increased, a commonly available steel is a 60mm OD x 50mm bore pipe. This would increase the drillstring weight by 40%, taking the weight per 3m length from 13 to 18kg. The weight of 30m of drill string would increase from 130kg to 182kg.

Other than overriding the supposed friction limitation, the following factors would influence the decision to change to a larger diameter pipe.

Internal Area

- A 75mm diameter bit would be the minimum usable with the 60mm OD pipe rather than the current 50mm hole diameter as is used on the 44mm OD pipe.
- Whilst the drillstring weight is increased by 40%, adding more weight behind the drill bit, the area of 'curf' between a 50mm/24mm drill bit and 75mm/50mm drill bit is 50% greater. Thus the effective drilling action on the cutting edge of the smallest drill bit would be slightly reduced.

Test Pumping Yield

The bore area of the 60/50mm drillpipe is 220% of that of the 44/34 rod. Would this double the capacity of spoil removal? Further, with promotion of the Malda & Afridev hand pumps, it would be possible to use the drillpipe as a 'pump rising main' in a stable hole. A Malda/Afridev footvalve and piston could be fitted to pump test the yield. Note that Afridev & Malda pumps use a rising main of nominal 50mm bore.

The sludging action with a 600mm (24") stroke should allow a potential water supply to be 'overpumped' i.e. a flow higher than that intended for the installed hand pump. This leads to better well development and more certain well yields. If water yield is insufficient after a test pump, then drilling could re-commence quickly to seek a fresh fissure/aquifer, having removed the foot valve and piston.

This introduces an excellent and unique method of properly quantifying well yield whilst drilling in stable ground. The rotary compressed air driller can often determine the depth to first water strike and measure the volume of water being blown out of the hole. It is difficult to ascertain reliable information about eventual well yield and to pick up accurate information on subsequent water strikes, as pumping rate is affected by depth of submergence of the drillpipe under water rest level.

It may even be possible to use Afridev/Malda foot valves to assist drilling circulation when mud pit and borehole cannot be kept flooded. A similar valve system in the 44/34 mm rod is feasible, but difficult to work up to produce a hand pump flow *and* have the capacity to pass dirty water.

SURFACE CASING

Loose, unstable ground above consolidated material could be cased off with 4" steel or plastic casing, and if required allow a telescopic placement of screen inside the 4" to create a conventional borehole. This would require the introduction of say a 125mm drilling shoe.

BOTTOM BALL VALVE

This was once used in the initial drilling trials as a pump footvalve in conjunction with the flap valve to remove water from about 7m deep in a 12m deep hole. It did pump water, but not at significant volumes or anywhere near hand pump yield.

This valve will be required when drilling in consolidated ground, i.e. rock or laterite, where it is not possible or desirable to keep the borehole flooded. The bottom ball valve will enable the sludging valve to flush water in such conditions. See comments on use of drilling fluids.

DRILL BITS

Two broad drill bit designs are being utilised.

The first is a 45 degree internal cutting shoe made from high quality heat treated steel with a nitride hardened top layer of 0.25mm. After initial use with a 75mm cutting shoe over some 50m of drilling in 5 holes, wear was noticeable. In fact the hard layer of nitrided steel had eroded completely. The cutting bit however retained its 'edge' and performed well.

The alternative shoe design is a 12mm hemispherical 'curf' and is set with 8mm tungsten buttons - the base material and buttons comply with the materials that would make a down-the-hole hammer percussive drill bit. If Pounder drilling wears these bits in rock, it will prove hard to improve on the basic strength and wear characteristics.

When drilling soft clays, the shoes form the malleable material into cylinders 50 to 150mm long which slide up to the surface inside the drillpipe. It is probably more suction and internal bit geometry which forces this to happen, rather than the sharpness of the cutting edge.

More drilling metres and time are required to monitor ongoing wear and performance.

It is hoped to rationalise the number and types of drillbits which a drill crew might need.

DRILL FLUID ADDITIVES - GROUND STABILISATION AND POUNDER OPERATION

The Effects of Water

The Pounder technique relies on two aspects of the circulation of water.

First, keeping the hole flooded to the ground surface from a flooded mud pit. A column of water of nominal head 3+ metres above any water rest level in the borehole will keep the borehole walls stable from collapse. Water bearing 'running sand' will remain stable provided that the 3metre + head is maintained over it.

Second, the sludging technique of spoil removal relies on a minimal head difference between the mud pit level and sludging valve outlet. The closer this distance, the higher the water flow. It works acceptably up to 3m total difference but flow is noticeably more when distance less than 1m.

In a hole liable to collapse, the rule is simple: keep the water level in the hole topped up and site holes where it is known water rest level in the underlying aquifer is 3+ metres below the surface. If water losses into the hole are faster than fresh water can be added at the top, add water faster! It is hoped this is a role for the community simply to bring water as required.

A rotary driller in similar ground using mud circulation relies on additives to the water to slow this water loss. The rules of application could apply equally to Pounder drilling.

Polymer

A natural viscous fibre. When mixed with water at low mix ratio of approximately 0.5 to 1% will produce a viscous fluid that will slow its flow into the porous formation. Advantage is the polymer effect is broken naturally by bacteria in 2-3 days thus reverting the ground to its former permeability (assuming it has not been blocked with fines from the drilling operation).

Use of Polymer on Pounder holes will have a profound effect on borehole costs. Most polymers cost $5.00 per kg or more - each hole possibly requiring 1-3kg.

Bentonite/Natural Clays

Some clays can be mixed with water to build a similar viscous water mix (drill mud) to the polymer. This will very effectively line the borehole walls with a wallcake to stop water loss into the formation. There are two major drawbacks to using clays. The first is that they take many hours (almost days) to build the initial viscosity, during which time the borehole has collapsed or the water carriers have became exhausted. Secondly, the wall cake is a natural barrier added to the wall of the well. Thus if the water bearing layer is sealed, this will need physical removal before the well can become productive.

Physical removal - this can be achieved with some very aggressive surging of water - after putting in the well screen and preferably without using a gravel pack. With the pounder rig on a direct drilled hole, this could be achieved by pumping a hole without the footvalve being fitted or using a similar piston type device to move water into and out of the hole. It might take many hours of diligent work to slowly break down the wallcake.

Lost circulation Material

Grain husks – the fibrous by-product of grain milling (if density is close to water) will block off a porous layer. This once more requires physical removal to allow the water into the well, with the added hazard that the fibre will block the screen openings as effectively as the ground formation. The grain husks are added by mixing 1/4 bucket of grain husks and 3/4 bucket of water or polymer/bentonite mixed mud and then pouring the mixture into the hole. The fluid will flow out into the porous formation pulling after it the fibre which then blocks against the formation. (Visualise the metal grid over a city storm drain - debris bags & paper and wood quickly block an uncleaned grid and allow flowing water to back up behind it - it is the same effect these materials are creating in the borehole.)

Sawdust - alternative to above - same problems

Cow Manure - works excellently. Apply as above - all the problems as above plus generally not so acceptable a material to be used in a drinking water supply hole.

Cement - added wet to a hole will block off a permeable layer permanently.

All these materials really come into play to seal ground above the water table but preferably not the aquifer with the intended water supply which is going to be developed. These materials should not be used in the water bearing zone of a new well.

DRILLING IN CONSOLIDATED ROCK HOLES - WITHOUT FLOODED MUD PIT

A specific problem arises in a stable hole that is not in danger of collapse, e.g. a laterite aquifer, which is quite a productive water bearing zone and might require a lot of bunging up to allow the water head to be maintained to ground level. How do we ‘un-bung’ such a layer after drilling the hole past it?

Ideally, the laterite and any consolidated aquifer needs to be left to freely produce water flow into the hole as it is being drilled, thus allowing itself to be test pumped and continually monitored until sufficient well yield has been located. This means that the use of the top sludging valve with a flooded hole has to be abandoned and replaced with an alternative water circulation system. A clear advantage of the Pounder system circulating the drilling debris up the centre of the drillpipe is that the muck and debris will not plaster the hole walls, potentially blocking off small fissures as could be experienced on a conventional rotary drill package.

The need to sweep the face of the drill bit clear of debris is perceived essential as this allows the drillbit to strike unbroken ground fresh on each stroke. The sludging valve exerts a very powerful suck to pull in a great deal of debris.

Water circulation can continue by putting a valve mechanism down the hole rather than using the top mounted valve. It is possible to pump/suck the water, provided that the in hole valve is near, (say within 3m of) the water rest level. However, it is harder to maintain the in hole valve function i.e. an airtight suction seal on each drill stroke, when passing the drilling debris. Note that this is impossible with the top sludging valve, which requires a finger to clean out odd bridging bits of debris every 50 strokes or so.

This all leads to some choices:

- Is drilling clean holes in consolidated material a key objective for the Pounder rig? In other words, is the above a problem worth solving?
- Should we design a valve that is fully competent at passing drilling debris?
- If immediately behind the drillbit, it could 'leak water'. However, if it retained accumulated solids for physical cleaning out it could perform as a percussion bailer.
- If the valve was mounted say 3 or 6m up from the drill bit, it could be used to suck up water and cuttings. Provided the air seal remained, the tube could retain the drilling debris under suction, like a very large hypodermic syringe. The key would be that the tube would have to be full of water mixed with cuttings, and the valve needs to be airtight. Insufficient water or an air leak would cause the debris to drop out resulting in frustration of the drill crew as they will have to re-insert the drillpipe to collect debris once more.
- To improve the above, a water diffuser/filter could be utilised to pass only water and minimal solids. This might aid valve reliability. 3 metres of 44/34mm rod could retain a volume of 2.7 litres whereas the 60/50 rod could retain 5.9 litres. A 75mm hole equates to 4.4 litres/m. A 100mm hole 7.8 litres/m. Allowing for volumetric expansion of material when pounded into debris of a factor of 3 (the earth digging trade use this figure) this could mean drill string removal several times per metre.
- Leading on from all of the above is the design of a type of conventional cable tool bailer, threaded to take the Pounder drilling shoes. The top needs to be threaded to take the Pounder drillpipe bailer and would have a leather flap valve. The volume should be as large as allowed by the hole diameter, in order to collect the largest possible volume of debris between emptying.

RE-EVALUATION OF POUNDER TECHNIQUE COMPARED TO CONVENTIONAL CABLE TOOL

When drilling in consolidated rock, the Pounder is operating closer to the method of a conventional cable tool than the original reverse circulation fluid rig. Would a cable tool be more efficient?

The essential difference between the two methods is that a cable tool hangs its chisels and bailer onto a cable and has a winch to lower them to hole bottom. The winch mechanism is also used to effect the reciprocating action. The Pounder is connected top to bottom by drill rod and these are physically reciprocated by the lever.

The cable tool can reciprocate a chisel to break the rock, and then hoist the chisel out of the hole and replace with a bailer which trips in to bail up the debris drilled. The hole is advanced by swapping backwards and forwards between the two operations.

The Pounder will reciprocate its drilling bit, cutting rock and, by nature of its water valves and built in bailer, clear the debris away from the bit face. This maximises the effect of each drill bit blow onto the fresh uncut rock. When the system is fully water primed, the suction is a powerful force.

The effect of the rigid pipe connecting the drill bit to the surface is to provide a large mass behind the drill bit. However, it should be noted that not all this puts a full percussive effect on the drill bit and it would be more effective to gather this mass up into one large lump directly behind the drill bit. The rigid string also allows a 'push' from above to accelerate the dropping load faster than gravity. This is something which the drill crew instinctively practice. (To hit something harder with a hammer, the operator technique will be to swing further and faster looking to achieve maximum velocity at point of strike.) This is all the positive side. The negative aspect is that when the bailer is full of debris, the entire drill string needs to be removed from the hole to empty it, whereas cable tool just winds up its winch.

In theory, the two methods could be combined - by lowering the drill bit and bailer and some pipe sections into the hole on a length of chain, the reciprocating lever could reproduce the same action of the cable tool and water could be pulled into the bailer by a valve. Once full, the whole lot could then be retrieved by pulling up the long chain. A sprocketed anchor type wheel could facilitate this.

As any auger driller knows, depth is the big variable here. To remove 100kg comprising 12m of drillstring requires removal of 4 x 3m rods and takes little time. Eight pipes from 24m requires more effort & time.

SIMULTANEOUS CASING

The only alternative to using fluid of 3 metre + head to stabilise soft ground from collapsing is to use casing to line the hole.

The Pounder progresses its hole in 1m stages, so it would be possible to drive 1m lengths of steel casing simultaneously with the drill bit . The lead casing could have a hardened steel shoe and the top casing a drive plate, to allow it to be driven from an anvil plate fixed to the sludging valve. Water would need to be pumped into the centre of the casing, (assuming the water could not find its way down between the casing surface and driven hole) to allow the spoil to continue to be removed by sludging action.

A suitable casing would be a 113mm OD, 104mm bore steel tube with a flush coupled thread similar to the drill rods. This would weigh about 12kg/m length.

Lighter casing could be produced by fabricating thicker pipe ends onto a thinner middle section. This will be more expensive, requiring more labour to manufacture. The possible weight reduction is only 20 to 30%.