Cranfield
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# Private Sector Participation in Low Cost Water Well Drilling

## Knowledge and Research (KAR) Project R7126

## A Mechanism for Percussion Drilling of Low Cost Water Wells in Developing Countries

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## Abstract

Large scale irrigation schemes have failed to meet the agricultural demands of many farmers in much of sub-Saharan Africa. In recent years attention has focused on small scale irrigation allowing individual farmers or farmer's groups direct responsibility for control of the schemes. Rural communities also often suffer from a lack of safe, reliable drinking water as the excessive costs of infrastructure improvements leads to a reliance on traditional unprotected and often drought-prone surface water sources.

In order to exploit convenient shallow groundwater resources for small scale irrigation and drinking water the cost of drilling a borehole must be bought within reach of local farmers and communities. The high cost and sophisticated technologies of conventional water well drilling rigs precludes most African entrepreneurs from entering either the manufacturing business or setting up contractor services and means a prohibitively high borehole price for farmers and communities.

The aim of this thesis was to examine low cost water well drilling techniques and suggest a drilling technique suitable for future development to produce a water well drilling rig capable of producing very low cost water wells.

This was carried out by the designing a test model of a drive mechanism suitable for such a drilling rig, field testing the model and recommending necessary development to finalise rig design.

The drive mechanism investigated provided a reciprocating action suitable for percussion drilling techniques. It is also shown that within the limitations of human power sufficient tooling capabilities to drill a variety of ground formations can be achieved. This showed the development potential of the mechanism to provide an effective hand-powered water well drilling rig.

Martin Worth
Silsoe College 1998

# 1 Introduction

## 1.1 Background and Context

Seventy percent of sub-Saharan Africans are farmers and the overwhelming majority are smallholders with ninety six percent of farms covering less than ten hectares. Landlessness and the unequal distribution of land do not contribute to rural poverty to the same extent as in Asia or Latin America - only 7% of African agricultural households were landless in 1980 well under half the Asian and Latin American levels.(Harrison 1987)

African poverty and malnutrition are in part a result of the inability to produce enough to meet family needs for food or cash. Farmers need to optimise the productivity of their land to begin to meet their needs. Irrigation and good management of water resources are vital to the small holding farmer as he tries to get the best from his land and break the cycle of poverty.

Large scale, formally structured irrigation schemes have failed to meet the agricultural needs of Sub-Saharan Africa. Food production targets are not met, development costs are high and there are many technical and management problems. (Kay et al 1985))

For example, in Nigeria 15 years of massive investment had led to expected expansion of irrigated land of between 100,000 - 300,000 ha. by 1982. The reality was only 30,000 ha. (Carter et al 1983)

Among the common problems encountered in African irrigation schemes have been;

- extremely high capital costs ($10-20,000 per ha being common)
- over optimistic benefit projections and development rates.
- insufficient account taken of indigenous farming systems, skills and incentives.
- a lack of practical and management skills and the necessary attitudes on the part of national staff
- the underprovision of operation and maintenance costs by Governments, lending agencies and donors. (Carter 1988)

The problems encountered by these large scale, formally structured irrigation schemes which are usually under government control with an almost exclusively 'top-down' approach, has turned attention to the informal sector. This is irrigation by individual farmers usually on a small scale ( a couple of hectares), at low cost and with little or no government support. Informal irrigation may be defined as " those schemes which are under local responsibility, controlled and operated by the local people in response to their felt needs". (Underhill 1984) This is in contrast to the definition of formal irrigation as "the development and management of irrigated agriculture in a structurally formal way, usually by a government body....Formal irrigation projects planned or under construction are large scale (up to 100,000 ha each); they are often established with very little prior involvement from farmers or landholders; and are usually managed by a structured government organisation on behalf of resettled small holders (or labourers in the case of sugar estates)." (Underhill 1984)

The advantages of informal, or small scale irrigation (SSI), are summarised by Underhill as initiating a development process rather than a planned development action leading to self reliance and sustainability. Local technical, managerial and entrepreneurial skills are used with low external input and little infrastructure requirements since investment is more in terms of social inputs such as extension, training and guidance.

Villages and small communities, as well as farmers, will be able to benefit from low cost drilling technology. Generally, surface water ( in rivers, lakes, pools ) is bacteriologically unsafe and will require some form of treatment to make safe for drinking. This involves high investment costs, energy costs, chemical costs and requires skilled personnel to operate and maintain the plant. These conditions result in a preference for groundwater over surface water, therefore the first step in improvement to community water supply is to move from traditional unprotected, untreated and often drought-prone sources to a well or borehole with handpump. By locating wells at strategic points in the community there is no need for expensive distribution systems, capital costs can be spread by constructing one well at a time to the required provision level, typically no household further than 250 metres from the nearest well.

There are two major problems associated with handpump schemes the first being failure of the pump means the village is left without water. This problem is being addressed by the introduction of VLOM ( Village Level Operation and Maintenance/Management) handpumps.

The second problem is the cost of borehole drilling. In Africa a 50 metre deep borehole generally costs between $5000 to $15000, many time the cost of a similar well in India about $1500 to $2000. ( Arlosoroff 1987) The difference is due to the equipment used and can also be influenced by unrealistic foreign currency exchange rates. In the past donors have often supplied sophisticated drilling rigs which have not achieved theoretical drilling rates. India, on the other hand, has a strong indigenous manufacturing industry and large numbers of private contractors which make it possible to drill boreholes at a cost comparable with those in developed countries.

Hand operated, very low cost drilling rigs can substantially reduce the cost of producing a well. Boreholes in the soft alluvial plains of Bangladesh for example, cost only $200 to drill using hand powered methods leading to a cost of around $2 per beneficiary for a finished well. ( Knight 1995)

### 1.2 Low Cost Water Well Drilling At Silsoe

In order to practise SSI farmers must be able to utilise water sources. One of these is classified as 'non-seasonal'(Kay et al 1985) and involves the exploitation of groundwater to a depth of 15 metres. Farmers must be able to afford the cost of drilling and construction of the well. Research has shown that the highest cost in the construction of a well is the cost of drilling the bore hole. The cost and sophisticated technology of conventional mechanised drilling rigs precludes most African entrepreneurs from either entering the manufacturing business or setting up contractor services. In order for the farmer to be able to afford the price of a borehole, and therefore fully utilise the groundwater resource through SSI, low cost drilling technologies must be employed giving a realistically affordable price per borehole. What is needed is an approach which involves local stakeholders and appropriate technology, which can be manufactured in country, afforded by local contractors and produce wells which can be afforded by local farmers and communities. (Carter 1998)

Although very low cost drilling methods are described in much of the literature concerning self help water wells and village technology, they are not available as "off the shelf" hardware. The exception is the Vonder Rig hand augering machine which was developed by the Blair Institute in Zimbabwe, manufactured in that country and used widely across Africa. (Morgan 1990)(Appendix 1) Other than the Vonder Rig there is no other widely available very low cost drilling rig manufactured or supplied in Africa. Any Contractor or Project Manager wishing to use such techniques first has to construct his own machine and experiment with the details of the design, effectively wasting time "re-inventing the wheel".

Research and development on the subject of very low cost drilling, as well as the ability and willingness of small farmers to pay for low cost tubewells, has continued through Masters degree projects at Silsoe College over several years. This has led to a low cost water well drilling project at Silsoe with funding from DFID (Department for International Development). The purpose of the project is to design a new very low cost drilling rig and bring about its local manufacture and adoption by local contractors. The new rig will be complementary to the Vonder Rig and will extend the range of ground conditions that can at present be drilled by the Vonder Rig to include hard layers and unstable foundations.

It is widely recognised that the private sector, both manufacturing and contractor businesses, represent an under-utilised potential in water supply provision in developing countries. It is the aim of the project to capitalise on some of this unused potential by introducing very low cost water well drilling technologies to small private businesses. This scale of technology has been selected to match the likely level of capital available to potential manufacturers and contractors, especially in Africa. (Carter 1998)

### 1.3 Objectives

This thesis aims to :

- set out design criteria for very low cost drilling rig suitable for Less Developed Countries.
- review previous work on very low cost drilling and suggest appropriate drilling technology for development.
- design and build test model of drilling technology.
- recommend design development for final design.

# 2 Well And Borehole Construction

## 2.1 Hand Dug or Drilled Wells?

Hand dug wells are those wells of large diameter (over 1 metre) which allow the workmen inside room to excavate. The well may be lined with concrete rings or masonry or unlined if the formation is stable enough. The finished well may be covered with a concrete slab and fitted with a hand pump or rely on more traditional methods of water lifting such as rope and bucket. The advantages of hand dug ring wells are:

- They can be constructed where soil conditions make drilling difficult such as very hard formations or the presence of boulders.
- Where the permeability of the aquifer is too low to allow sufficient flow to a small diameter tubewell and storage capacity is required in the well for overnight recharge, a ring well may be the only alternative.
- In the event of hand pump failure water can still be drawn from the well using a bucket (although there is a risk the water may be contaminated by the use of dirty buckets).
- It is argued that the greater number of people involved in the construction of the ring well would contribute to an increase in village participation.

The disadvantages of hand dug wells can be summarised as:

- Drilling a borehole is much easier than digging since no dewatering of the hole is required during construction.
- Installation of PVC screen and lining is simpler and less dangerous than lowering concrete rings.
- More reliable water bearing formations and those less likely to surface contamination below the shallow top aquifers can be reached.
- Availability of cement for construction of rings is often a problem.
- Compared to hand drilling techniques, hand dug wells are relatively expensive. From a depth of 6 to 7 metres where normal suction pumps cannot be used for dewatering and more expensive high capacity pumps are required, there is a sharp increase in well costs.
- The cost of labour and transport of rings increases rapidly with depth.
- For an average depth of 8 - 10 metres a ring well is approximately 2 to 2.5 times more expensive than a tube well.(Blankwaardt 1984)

## 2.2 Approaches To Well Drilling

There are three approaches to well drilling ( as opposed to well digging ), these are;

1. Firstly, large, sophisticated, usually hydraulic, drilling rigs which are expensive in both capital and recurrent terms. Also complex to manage and maintain in remote areas, it is almost impossible to achieve low per-well cost with this type of rig.
2. Secondly, small rigs such as small cable-tool rigs, small trailer mounted hydraulic rigs and unconventional mechanical rigs such as the Eureka drill system and the Oxfam Portarig, which can provide a significantly lower cost option which is appropriate in many situations.
3. Thirdly, very low cost human operated techniques such as hand-augering, hand-percussion, sludging and well jetting. These techniques keep costs and technical sophistication to a minimum. Inevitably, applications are more restricted than with powerful, conventional rigs, nevertheless there is still significant potential for both drinking water supply and irrigation well construction using these techniques.

| Approach | Description | Notional Rig Cost | Notional Well Cost | Constraints |
|---|---|---|---|---|
| Large Rigs | Typically truck mounted hydraulic rig with several support vehicles: management and logistical support complex and demanding | £100k+ | In Africa, often £5000+ | • Access to remote sites difficult.<br>• Management support complex<br>• High costs |
| Small Rigs | Typically mounted on a 2-wheel trailer; rig mechanically or hydraulically driven; rig uses conventional drilling processes (cable-tool, mud rotary, down-the-hole hammer) | £10-20k | £1000 | • Rig maintenance and consumables supply may still be poor.<br>• Capital may not be available to small contractors |
| Very low cost systems | "Traditional" drilling techniques such as "sludging", hand-augering, and hand percussion; "improved" techniques such as well jetting (washboring), or combinations | £1000 | £100 | • Ground conditions limiting, and max depths of 20-30m.<br>• Only one process exists as readily available rig. |

*Table 1. Approaches to Well Drilling.(Carter 1998)*

## 2.3 Well Drilling Methods

The basic techniques for drilling wells are summarised as:

- **Rotary fluid circulation.**

  This method consists of cutting a borehole by means of a rotating bit and removing the cuttings by the continuous circulation of a drilling fluid as the bit penetrates the formation. The fluid used may be air, foam, mud (bentonite) or polymers. There are two basic layouts;

1. Direct Circulation where the drilling fluid is pumped down to the bit through the drill pipe and returns along with the cuttings up the annulus between drill pipe and wall. The advantages of direct circulation are that there is no limit to the depth of drilling, it is fast, and no temporary casing is required since the mud prevents hole collapse. The disadvantages are a high technology rig so expensive mobilisation and operation, may need a large area for rig and mud pits, can use a lot of water, and may leave mud-cake build up on well walls making development difficult.
2. Reverse Circulation where the fluid moves down the annulus between wall and drill pipe and returns with the cuttings up the drill pipe. The advantages of reverse circulation are there is no mud-cake build up, rapid drilling at large diameters in coarse unconsolidated aquifers. The disadvantages are again high technology expensive rig and the need for large quantities of water.

- **Rotary Percussion (Down-the-Hole Hammer)**

  Relies on the pneumatic hammer action of special bit at the drill face. The bit is supplied with compressed air via the drill pipe which drives the hammer action as the bit rotates. Rotation of 10 - 30 rpm ensures that the hole is straight and circular in cross section. Cuttings are carried to the surface by the circulating air. This method is especially appropriate for very hard rock formations and is fast. The disadvantages are high tool costs, the need for an air compressor and an experienced crew to operators and maintain the rig.

- **Percussion Drilling**

  This technique is the oldest drilling method. It was developed by the Chinese 3000 years ago. The principle involves the lifting and dropping of a string of tools suspended on a cable which breaks up the formation, and the removal of spoil from the hole. Excavations are bought to the surface in the form of slurry using a bailer. Depths of hundreds of metres can be achieved through a variety of rock formations. The equipment is simple to operate and maintain. The disadvantages of this technique are it can be slow, the equipment can be heavy and unstable rock formations can cause a problem.

  Percussion drilling techniques use a variety of tools for penetrating different formations, for example chisel point tools for hard formations and clay cutters. Tools known as 'Shells' or

'Bailers' are periodically used to bring cuttings to the surface. (Appendix B) The standard technique is to operate the tools within some temporary steel casing which itself is fitted with a sharpened leading edge or shoe. As the tool cuts and removes the material from the bottom of the hole the temporary casing drops, either under its own weight or by hammering on the top edge using the weight of the tools. The necessity to be able to remove the heavy temporary casing once the hole is completed demands heavy lifting power from the rig. However it is possible to remove temporary casing once the hole is complete using jacks lifting against clamps fixed to the outside of the casing. This would reduce the lifting requirement of the rig. Using a viscous drilling 'mud' to keep the hole open and drilling through the mud would remove the need for heavy temporary casing.

- **Jetting (Washboring)**

  This method uses low pressure water flow either through a plain pipe or special nozzle (jet), to scour the soil and wash it up the annulus between jetting pipe and wall of hole. In fine to medium sands depths of up to 30-40 m are achievable. The main constraint is the ability of the operators to handle the weight of the pipes. Progress can be quick in ideal ground conditions i.e. alluvial sands. Thousands of irrigation wells have been sunk using this method for example in northern Nigeria. Very slow progress is made in clays, loss of the circulating fluid in coarse sand and gravel restricts progress, and the process is not suitable for hard rocks. The need for often large amounts of water to circulate may also prove to be a major constraint in many locations.

- **Hydraulic Percussion (Sludging)**

  A combination of mechanical and hydraulic action is used to excavate the hole. The hole is kept full of water and a chisel edge cutting bit attached to the bottom of a string of pipes. The pipe string is alternatively raised and dropped. Pressure due to the impact of the bit and the inertia of the water causes a mixture of water and cuttings to enter the pipe. The full pipe overflows the water and cuttings mixture at the ground surface. A check valve near the cutting bit prevents the mixture flowing out of the pipe as it is raised. The cuttings from the mixture can be settled out in pools at the surface and the water recirculated. This method is limited to fine formations since coarse materials will not be carried up through the pipe by the water. Also cannot penetrate hard formations.

A traditional method of hydraulic percussion drilling is practised in Asia and is known as 'sludging'. Here the check valve is replaced by a hand of one of the operators which seals the top of the pipe on the upstroke and is removed on the down stroke to allow overflow. Pipes may be made of hollowed bamboo and the raising and lowering action provided by several operators pushing on a lever.

- **Bored or Augered Drilling.**

  This method consists of cutting material from the bottom of the hole by rotation of a cylindrical tool with one or more cutting edges. The process is analogous to boring a hole in wood with an auger or drill. The auger is rotated into the ground and then withdrawn to removed excavated material. This method is inexpensive and simple to operate and maintain. The disadvantages are it is slow requiring constant raising of the auger to clear the cuttings, there may be problems with unstable formations either from collapsing holes or from cuttings not adhering to the auger for removal, and is only suitable for unconsolidated formations.

- **Driven.**

  The well screen is fitted with a taper point and driven directly into the aquifer by percussive pressure. Analogous to driving a nail into wood. This technique relies on sufficient force being applied to drive the screen into the ground. Can be used to sink boreholes very quickly in the right conditions. The disadvantages are the need for a well screen, pipes and couplings which are strong enough to withstand the driving pressure which tends to make them specialist and expensive (although it is possible to fabricate well points). Also supplying sufficient driving force may require heavy equipment. Cannot penetrate hard layers and, since material is pushed aside rather than excavated, there is no indication of the sub-surface formation.

### Low Cost Well Drilling.

Of the basic techniques for well drilling outlined above, some of them, singly or in combination, are suitable for adaptation to human power. Table 2 is a summary of methods for drilling small diameter wells which can be adapted to low cost drilling. Diagrams of handpowered drilling techniques are shown in Appendix 1.

**Table 2. A Summary of Methods for Drilling Small Diameter Wells (Koegal 1985)**

| Method | How Penetration Is Accomplished | Minimum Equipment Required | Removal Of Material From Hole | Advantages/Disadvantages, Limitations |
|---|---|---|---|---|
| **Augered or Bored** | Cutting lips of a rotating auger shave or cut material loose from the bottom of the hole. | Auger, detachable tubular extensions, and a handle for rotating. | Auger must be removed from the hole whenever it is full of cuttings. This necessitates uncoupling extensions. | Equipment is simple and can usually be fabricated or adapted locally. Cannot penetrate hard formations. Uncoupling extensions slows work and greater depths. Usually cannot be used below the water table |
| **Driven** | A point on the lower end of a string of pipe allows the pipe to penetrate as it is driven on the upper end. | Drive point which usually also includes a well screen above it, special drive pipe with couplings, drive cap, and driver. | Material is not removed from the hole, but is forced out laterally as the drive point is forced through it. | Fast and simple. Special well points and heavy drive pipe may not be available locally. Hard formations cannot be penetrated. Limited to small diameters, but multiple well points may be connected to a common pump. |
| **Jetted** | A high velocity stream of water coming out of a vertical pipe washes away material ahead of it as it is lowered. | Pipe equipped with jetting orifice(s) at lower end, couplings, suitable pump (hand or motor powered), flexible connection between pump and pipe, and supply of water. | The water used for drilling returns to the ground surface by way of the annular space around the jetting pipe carrying the material removed with it. | Fast. Cannot penetrate hard formations. Difficulty in bringing large gravel or boulders to the surface. Drilling equipment can be fabricated locally, but a pump and a source of water are required. |
| **Hydraulic Percussion (Sludging)** | The hole is kept full of water. The alternate raising and dropping of a string of pipe with a cutting bit at the bottom allows penetration by a combination of mechanical and hydraulic action | Hollow drill bit with water inlets and a check valve, string of pipe, devices to aid raising and dropping. A man's hand over the top of the drill pipe may be substituted for the check valve. | The raising and dropping action in conjunction with the check valve causes water to be pumped up the inside of the drill pipe carrying the cuttings with it. | Equipment can be fabricated locally or purchased. Water required. Traditionally used in some area, thus understood by local well drillers. Hard formations cannot be penetrated. Difficulty in bringing large gravel or stones to the surface. |
| **Cable Tool Percussion** | A heavy cylindrical weight equipped with a cutting edge at the bottom and with a rope or cable attached to the upper end is alternately raised and dropped. Impact pulverised material at the bottom of the hole. | Heavy drill bit, rope or cable, devices to aid raising and dropping. | The pulverised cuttings are mixed into a slurry with water during drilling. These are removed using a bailer. | All formations can be penetrated at varying rates. Some water required. Commercially built rig is expensive and requires considerable skill to operate, but a simple set of tools can be fabricated locally and adapted to man or motor power. |
| **Bail Down** | A long, cylindrical bucket with a check valve at the bottom and a rope or cable attached to the top is alternately raised and dropped in a hole partially filled with water. Penetration is accomplished by a combination of hydraulic and mechanical action. | Bailer, rope devices to aid raising and dropping. | Slurry of cuttings and water enter the bailer as it is repeatedly dropped. These are prevented from leaving the bucket by the check valve. The bucket is raised to the surface for emptying. | Equipment can be fabricated locally. Frequently used in conjunction with other methods such as percussion. Hard formations cannot be penetrated by the bailer alone. |
| **Hydraulic Rotary** | A hollow drill bit with either a fixed cutting edge or toothed rollers is rotated at the bottom end of a string of pipe. Material is scraped, abraded or chipped away by mechanical action. | Drill bit, drill pipe, circulating pump, device for rotating drill pipe. | Water or "mud" is pumped down the hollow drill stem to lubricate the bit and to carry the cuttings up to the surface through the annular space around the drill pipe. The circulation may also be in the reverse direction | Commercially built rig is expensive and requires considerable skill to operate. However, small adaptations using either man power or small engines have been devised. A water supply is necessary. It is difficult to drill in loose formations. |

# 3 Drilling Rig Criteria

## 3.1 Design Specification

A design specification for the low cost drilling rig was drawn up (Table 3). This was the first step to outline the design criteria and performance of the final design.

**Low Cost drilling Rig Design Specification**

**Performance**

- Rig must be able to drill through:
  1. Unconsolidated Formations - gravel, sand, silt, clay, sand with pebbles or boulders.
  2. Low to medium strength formations - shale, sandstone.
  3. Medium to high strength formations - limestone, igneous (granite, basalt) metamorphic (slate, gneiss).
  4. Rock with fractures or voids.
- Rig must be capable of drilling a hole to allow a 100 mm (4 inch) diameter well screen/casing to be installed.
- Rig must be capable of drilling to depths of 20 metres.
- Rig must be capable of drilling above and below the water-table.
- Design must include some method of ensuring the borehole is vertical.
- Design must have capability of removing temporary casing if used.

**Cost**

- Rig should retail at a maximum cost of £1500.
- Running costs of rig should be kept to a minimum.
- The capital and running cost of the rig must be such that it is economically viable for the operator to be able to drill a successful bore hole for maximum £300.
- The costs of any fuel, lubricant or drilling fluids must be included in the costing of bore holes.

**Manufacture**

- Must be manufactured from materials considered to be standard engineering materials, i.e. bar, tube and box section, plate and sheet.
- Materials, tools and parts must be generally available in country.
- Rig must be manufactured to design specification using standard fabrication techniques: ( welding, forging, turning, drilling, cutting, threading, milling ) i.e. require no specialist tools or techniques.

**Maintenance**

- Day to day maintenance of the rig must require no specialist tools, techniques or materials.
- Basic maintenance must be able to be carried out by operator trained in rig use.
- A maintenance schedule must be provided with the rig.
- The rig must be designed to require the minimum of maintenance or replacement parts.
- Any replacement parts needed during the normal working life of the rig must be readily available in country or able to be manufactured from materials available in country.

**Operation**

- The rig must be able to be operated to full design capacity using a team of no more than three people.
- The operating team must be able to carry out all aspects of transportation, operation, assembly and disassembly of the rig.
- No aspects of the rig's operation and use should require physically demanding, uncomfortable or unsafe practices.

**Mobility**

- Rig and any associated kit necessary to operated rig at full design capacity but not including any pipes, pumps or casings, must be able to be transported by a single jeep without adversely affecting the jeep's performance.
- The rig must be able to be packed, transported and set up by the operating team alone and require no specialist tools or materials.
- Any trailers, roof-racks or other transportation devices must comply with the same specifications as for the rig outlined in Manufacture (above).
- The cost of any transport devices or vehicle modifications, excluding the vehicle itself, must be included in the price of the rig.

**Finish**

- All parts of the rig must be free from burs, sharp edges or other conditions which may cause a possible hazard to operating team's safety or comfort.
- All parts must be painted or plated or otherwise suitably protected from corrosion.
- All handles or grips must be adequately cushioned for operator safety and comfort.
- The rig must be supplied with all necessary tools and equipment needed to begin drilling.
- A full set of operation and maintenance manuals must be supplied and included in price of rig.

**Safety**

- Moving or turning parts must have sufficient clearance to prevent trapping or pinching of operator during use.
- All nuts, bolts, levers or other parts requiring adjustment or operation during use must be accessible and give adequate safe working space away from other moving parts.
- Drilling structure must be designed for stability

**Spare parts**

- Any replaceable parts must be readily available in country.

**Power Source**

- Any power source used must be able to be bought, maintained and serviced in country.
- Motor/engine/power source spare parts must be readily available in country.
- Any fuel, oils or lubrication needed must be readily available in country.

**Drilling Fluids**

- Any drilling fluids or lubricants necessary should be readily available in country.
- The use of drilling fluids or lubricants must be included in cost consideration.

**Materials**

- Materials used in construction must possess suitable strength and durability.
- Variability in quality of locally available material must be taken into account during manufacture.

**Environment**

- Manufacture or operation of the rig must not result in any waste products generally considered to have an environmentally detrimental effect.
- Any oils, lubricants or drilling fluids used in operation must not pollute any aspect of the environment.

**Durability**

- All working parts of the rig must have a design life of 10 years under normal working conditions.
- All parts must be suitably protected from corrosion, decay or other destructive elements for the design life of the rig.

**Testing**

- The rig must be fully tested to ensure operation performance, maintenance, safety and all aspects covered in specification comply with specified criteria.

**Quality Assurance**

- Design drawings must specify manufacturing tolerances in line with locally available manufacturing practices.
- Design and manufacture must take into account any commonly encountered variability of locally available construction material.
- Tolerancing and design specification must reflect locally available materials and manufacturing techniques.

**Locally available/In country.**

- Locally available and in country is taken to mean materials, goods and services which are normally for sale or hire in major towns or can be supplied/ordered from other towns/cities from normally available stocks without recourse to specially imported goods/services.

*Table 3. Low Cost Drilling Rig Design Specification.*

A rig design must consider the following aspects of drilling; the method of cutting the formation, the method of cleaning excavated material from the hole, a method of hole support to prevent collapse during drilling and a structure to support the drilling tools, pipes or other machinery used in the drilling process. This paper will concern itself with the mechanism by which the tools will be driven in order to carry out drilling and make reference to the aspects of cutting tools, cleaning and support of hole and drilling rig structure.

The common hand powered drilling methods of hand augering, jetting, sludging and driving although well proven, are limited to fairly soft, unconsolidated formations. In gravel formations there are problems with loss of fluid circulation with jetting and sludging, and difficulties in removing the cuttings with hand augers. As stated above the aim of the Low Cost Drilling Initiative is to extent the range of ground conditions that can be drilled by the Vonder Rig to include hard and unstable formations. The drilling method which is capable of drilling the widest range of consolidated and unconsolidated formations and has potential for hand powered operation is percussion drilling. (Anon 1995) For this reason percussion drilling was the method chosen as the technique most likely to fulfil the design criteria laid out in the specification.

**Percussion Drilling**

The operation of a percussion drilling rig requires a raising and dropping action. This reciprocating motion may be achieved on large scale percussion rigs by a cable fixed at one end running over a pulley at the end of a pivoted arm reciprocated by a crank and connecting rod. This system is known as "walking beam" or "spudding beam". Another method is to raise the weight on a powered winch fitted with a free-fall clutch arrangement which, as the name suggests, allows the tools to drop freely on the free spinning winch drum. The "Dando 150" drilling rig uses this method. (Appendix 3)

There are several hand powered methods of achieving reciprocating motion described in the literature, the simplest being a man lifting a tool on a rope or cable, via a pulley over a tripod, by walking backwards and letting go. ( Anon 1995).

Another method involves a group of men pulling down on an anchored horizontal rope which runs over a pulley and supports the tool down the hole. By pulling down and releasing in unison a reciprocating motion is achieved. Other methods used include a lever pivoted over a horizontal axis with the rope and tools attached to the shorter end and several men applying a reciprocating action to the longer end; a spring board or pole both of which involve the rope and tools fixed to a springy wooden board or pole and which is made to oscillate and provide the reciprocating motion. (Koegal 1985). Diagrams of these methods of providing reciprocating motion are shown in Appendix 2.

Although these traditional methods achieve reciprocating motion they still require the driller to waste time "re-inventing the wheel", they may also be inefficient either in terms of manpower or time taken to drill a borehole.

### 3.2 Test Model

One method of providing reciprocating motion examined ( J. Kilgour. Pers. Comm.) was one using a collar free to rotate on a shaft with an arm fixed to the collar and extending at right angles from the shaft. Another collar fixed to the shaft had a bar extending parallel to the shaft. As the shaft is turned using a handle the fixed bar pushes the arm around the shaft until the arm reaches the top of the shaft and free falls down. If the shaft continues to turn the fixed bar catches up with the arm and pushes it up again to the top of the stroke. A cable holding the tools and running over a pulley is positioned so that the rotating arm raises the cable and thus the tools, before letting them drop freely as the arm drops clear. The basic layout of the mechanism is shown in figure 2 below. A test model of the mechanism was built and tested.

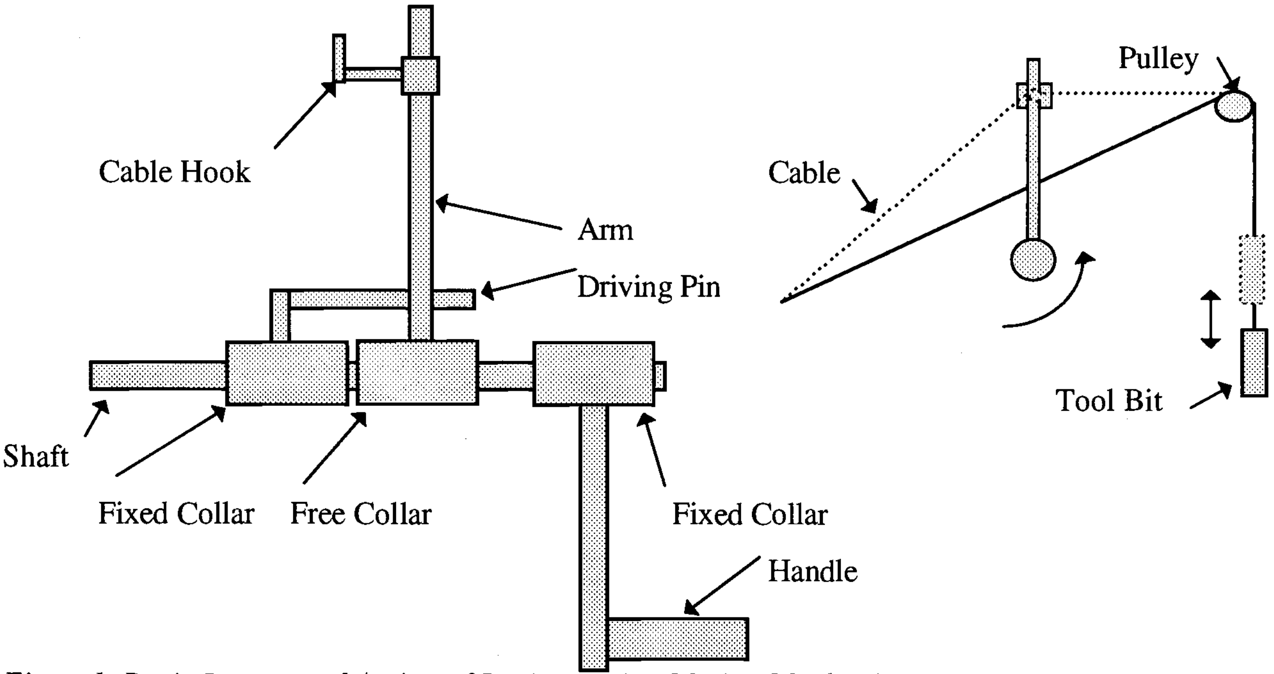


*Figure1. Basic Layout and Action of Reciprocating Motion Mechanism.*

### Model Test Results

Initial tests carried out on a model of the mechanism shown in figure 2 indicated that the mechanism provided a good reciprocating action, lift and free drop, from a circular motion input, i.e. turning a handle. The two variables under test during initial trials using the model were the weight of tools which could be lifted and the height to which they could be raised and dropped. It was assumed that the longer the arm length the greater the height the tools would be raised but the pay-off would be in the loss of mechanical advantage at the handle and therefore increased effort by the operator to move the tools. A tool of known weight was fitted to the cable, the length of arm measured, the force required to turn the handle was measured with a spring balance and the height to which the tools were raised also recorded.

Starting with a 500 mm handle length which was ergonomically comfortable for the operator, and an arm length of 500 mm, the handle required 7.5 Kg of force at the handle and raised the tool 395 mm. It was found that a figure of around 15 Kg was a comfortable force for the operator to apply to the handle and one which could reasonably expected to be sustained throughout a days working. It soon became apparent from the model that the mechanical advantage offered by the handle was greater than expected. This was very promising from a feasibility viewpoint and a further investigation was begun.

### 3.3 Mechanical Analysis

A mechanical analysis of the mechanism was carried out with the objective of investigating what weight of tool could be lifted comfortably and consistently by human power using the mechanism described above, and if this offered a feasible drilling method for the criteria laid out in the specification. The mechanical analysis was carried out as follows:

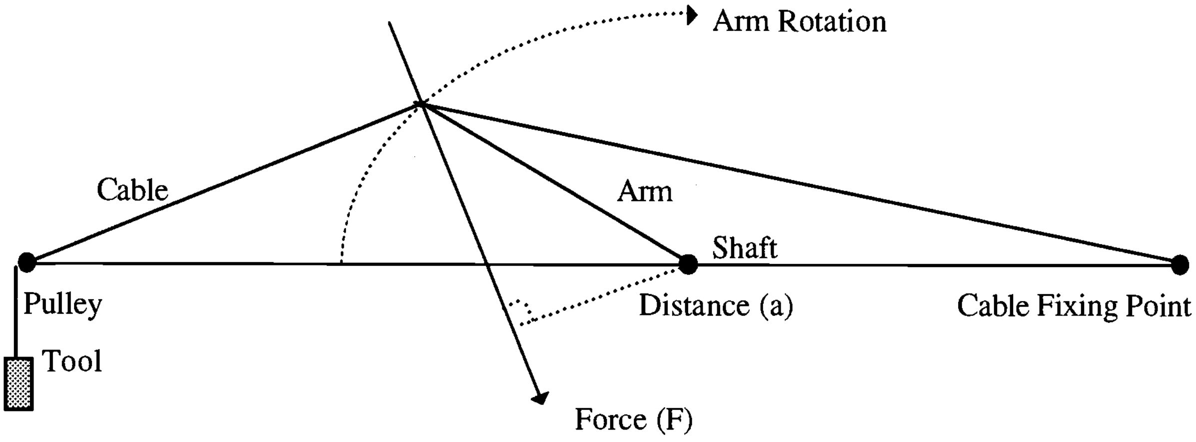


*Figure 2. Mechanism Layout*

The mechanism was drawn as in Figure 2 above. The following assumptions were made:

- The pulley, shaft and cable fixing point are all in line.
- Friction in pulley or shaft is negligible.
- Weight of cable and arm is negligible.
- The torque in the shaft equals the force (F) times the distance (a).
- The force in the cable is equal on both sides of the arm and is equal to the weight of tools.
- Line of force (F) bisects the angle formed by both sides of the cable due to the arm position.
- The force acts on the shaft through a distance (a) at right angles to the line of force.

Nomenclature used in formula in the mechanical analysis are:

$\phi$ = Angle of arm rotation (degrees) $\alpha$ = Angle between cable and pulley (degrees)

$\beta$ = Angle between cable and perpendicular from arm (degrees)

$\theta$ = Angle between perpendicular from arm and line of force (degrees)

$\theta_l$ = Angle between horizontal and right angle to line of force (degrees)

r = Length of arm (metres) F = Force (Newtons)

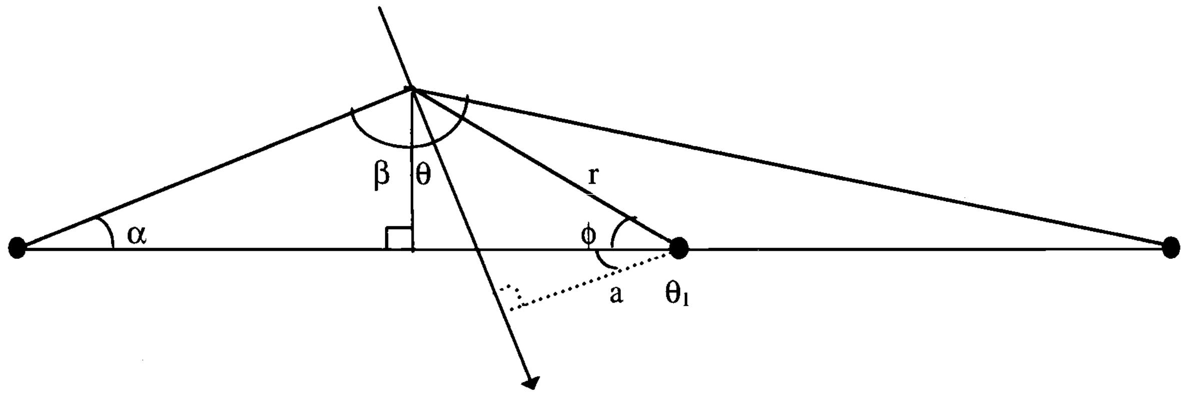


*Figure 3. Distance Diagram*

To find distance a:

$\theta$ = Angle between line of force and cable - $\beta$ Also $\theta = \theta_l$

Therefore Distance $a = r \times \cos \phi + \theta_l$

From Figure 3. the distance (a) from the pivot the force acts can be calculated for any given position of the arm and dimensions of mechanism. In order to find the turning moment at the pivot the force (F) must be known since the turning moment equals force times distance. To find the force on transmitted to the arm through the cable by the weight of the tools carried a force diagram was drawn.

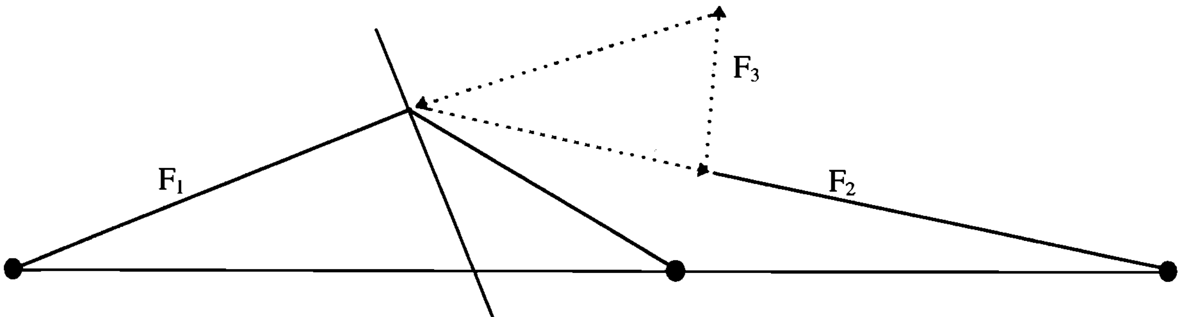


*Figure 4. Force Diagram*

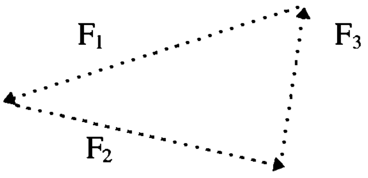


*Figure 4.1 Triangle of Forces*

To find force (F):

Since the force in the cable is taken to be the weight of tools (neglecting the weight of the cable), and is equal either side of the arm i.e. $F_1 = F_2$ . From Lami's theorem (Ogrodnik 1997) the forces in the static mechanism ( Figure 4 ) gives the triangle of forces in Figure 4.1. Again using angles measured from a scale model force diagrams were drawn and the magnitude of force ($F_3$) calculated by scaling from the force diagram. This was repeated for a variety of mechanism layouts and arm rotations. Using data from the scale model a computer model was designed which analysed the torque in Newton metres (Nm) acting on the shaft for a variety of configurations. The height to which the tool would be raised was calculated from the total increase in the length of the cable through one handle rotation measured from the scale model. From this model it was possible to predict the forces involved in lifting tools and the distances through which they could be raised. Sample calculations are shown in Appendix 4.

**Summary of Mechanical Analysis Results.**

The computer model showed that a substantial mechanical advantage of up to 80% was available from the layout of the mechanism allowing tools to be lifted very efficiently. Increasing the distance between shaft and pulley also increased lifting efficiency, up to a 16% improvement per metre increase. However the distance the tool was raised reduced as the length of arm decreased and/or the distance between shaft and pulley increased. Table 3. gives a summary of results from the mechanical analysis of the mechanism. The force at the handle required to lift the tool is based on a handle length of 0.5 metres which was considered ergonomically comfortable for the operator. From experiments carried out in the workshop, a figure of 15 Kg was considered as the maximum load which could be expected from a human operator consistently and comfortably throughout a days working.

| Tool Weight (Kg) | Maximum Force At Handle ( Length 0.5m) To Lift Tool (Kg) | Arm Length (m) | Distance From Shaft To Pulley (m) | Height Tool Raised (m) |
|---|---|---|---|---|
| 20 | 4.04 | 0.5 | 3 | 0.11 |
| 20 | 3.91 | 0.5 | 4 | 0.1 |
| 20 | 8.95 | 0.75 | 3 | 0.23 |
| 20 | 9.00 | 0.75 | 4 | 0.19 |
| 20 | 15.73 | 1.0 | 3 | 0.38 |
| 20 | 13.38 | 1.0 | 4 | 0.35 |

*Table 4. Summary of Mechanical Analysis Results.*

### 3.4 Tool Requirements.

Analysis of the percussion rig mechanism as outlined in 3.3 above gives some indication of the kinds of forces required on a handle of given length to lift a tool and the kind of distances the tool can be raised. The analysis suggested a 20 Kg tool dropping 0.4m was a realistic figure to expect from the hand powered mechanism. This raised the question "Exactly what tool weights and drop heights are required to drill a borehole using percussion drilling"? Literature on the subject of percussion drilling tends to be large scale (tool weights of over 1500lb) from American mining and petroleum engineers, (Bonham 1955) or vague statements like "heavy weight 50 kg+" (Anon 1995).

Since percussive drilling bits attack the rock by impact, the compressive strength of the rock will control the resistance to indentation by the drill bit. Not all reference books agree on absolute values for rock compressive strengths due to the errors inherent in testing disturbed samples under laboratory conditions. Also all rocks at depth exist under a state of imposed stress and the effects of this confining pressure will have an effect on compressive strength. Many reference books list rock compressive strengths at no greater than $2.75\text{-}3.45 \times 10^8$ N/m$^2$ (40,000 - 50,000 psi) (Cambell & Lehr 1973), although there are a number of rocks listed with values up to $6.82 \times 10^8$ N/m$^2$ (99000 psi) (Wuerker 1969). For the scope of this paper the compressive strengths quoted are taken from table 5.

| **Material** | **Compressive Strength (N/m$^2$)** |
|---|---|
| Very Strong Soil or Extremely Weak Rock | $7.8 - 9.8 \times 10^5$ |
| Very Weak Rock | below $1.23 \times 10^6$ |
| Weak Rock | $1.23 - 5.0 \times 10^6$ |
| Moderately Weak Rock | $5.0 - 12.5 \times 10^6$ |
| Moderately Strong Rock | $12.5 - 50.0 \times 10^6$ |
| Strong Rock | $50.0 - 100.5 \times 10^6$ |
| Very Strong Rock | $1.00 - 2.01 \times 10^8$ |
| Extremely Strong Rock | over $2.01 \times 10^8$ |

*Table 5. Unconfined Compressive Strength of Rocks. (Blyth & de Freitas 1974)*

**Cutting force available from dropped cable tools.**

The cutting force available from dropped cable drilling tools was calculated. The objective was to determine what forces are required to drill rock and whether or not enough force could be generated by tooling within the proposed mechanisms capabilities. It is important to note that all analysis carried out assumed the tool dropping in air. Buoyancy and frictional forces will act on a tool falling in water or other fluids, for example drilling 'muds', and influence the result impact force.

The potential cutting force available from dropped tools was analysed in the following way:
Nomenclature used in formula in the cutting force analysis are:

$s$ = Distance (metres)
$t$ = Time (seconds)
$v_1$ = Initial velocity (m/s)
$v_2$ = Final velocity (m/s)
$\Delta p$ = Impulse (Ns)
$m$ = Mass (Kg)

To find the impact force of a dropped tool of known weight:
Example 1: A 20 kg tool dropped 0.5m
Time taken to drop;
From $s = v_1 t + 1/2\, at^2$ $t = \surd\, 2 \times 0.5/9.81$ $= 0.319$ seconds
Velocity at Impact
From $v_2 = v_1\ at$ $v_2 = 0 + (9.81 \times 0.319)$ $= 3.13$ metres/sec
Impulse
From $\Delta p = m(v_2 - v_1)$ $\Delta p = 20 \times (3.13 - 0)$ $= 62.6$ Ns

Impulse = Force x Time, so in order to find the average force exerted by the tool at impact a time the tool is in contact with the rock is required. Experiments on cutting rates of percussion drill bits at Silsoe College (Knight 1996) show a penetration of between 0.1 mm to 0.6 mm per strike. These results were obtained using a 65 Kg tool string with a variety of tool bits, ( chisel, serrated hardened coupling, standard and sharpened couplings), with 0.5 metre drop, cutting into concrete test blocks ranging in strength from 13.7 - 22.8 x $10^6$ N/$m^2$ putting them in the moderately weak to strong rock categories from table 5 above.

Using these penetration rates as a guideline, the contact time between tool and rock was estimated. Therefore the force imparted at impact for the tool in example 1 above becomes;

a) Contact Time Penetration 0.1 mm per Stroke
= 0.1 mm / 3.13 m/sec = 3.2 x $10^{-5}$ seconds
Force imparted = 62.6 Ns / 3.2 x $10^{-5}$ = 1.9 x $10^6$ N
b) Contact Time Penetration 0.6 mm per Stroke
= 0.6 mm / 3.13 m/sec = 1.9 x $10^{-4}$ seconds
Force imparted = 62.6 Ns / 1.9 x $10^{-4}$ = 0.3 x $10^6$ N

It can be seen from this that the greatest force is exerted on the rock by the tool when the penetration is lowest. This is explained by the impulse acting over a shorter contact time.

The force available to crush rock at the tool bit will depend on the surface area of the cutting tool which comes into contact with the rock, i.e. the area of the cutting edge, and the impulse at impact. For example, a chisel tool with a 150 mm wide blade 5 mm thick will have a cutting edge surface area of 7.5 x $10^{-4}$ $m^2$. To exceed the compressive strength of very strong rock (2.01 x $10^8$ N/$m^2$ from table 5) the tool would need to impact the rock with a force of 150750 N. Similarly a coupling tool with a diameter of 150 mm and a wall thickness of 5 mm with a surface area of 2.28 x $10^{-3}$ $m^2$ will require 457797 N of force at impact to exceed the compressive strength of the same rock.. This shows the importance of tool selection in being able to reach the necessary force to break the rock. This is illustrated in figure 5 which shows the weights and drop heights of these two tool types necessary to achieve the required force at impact to exceed the compressive strength of very hard rock.

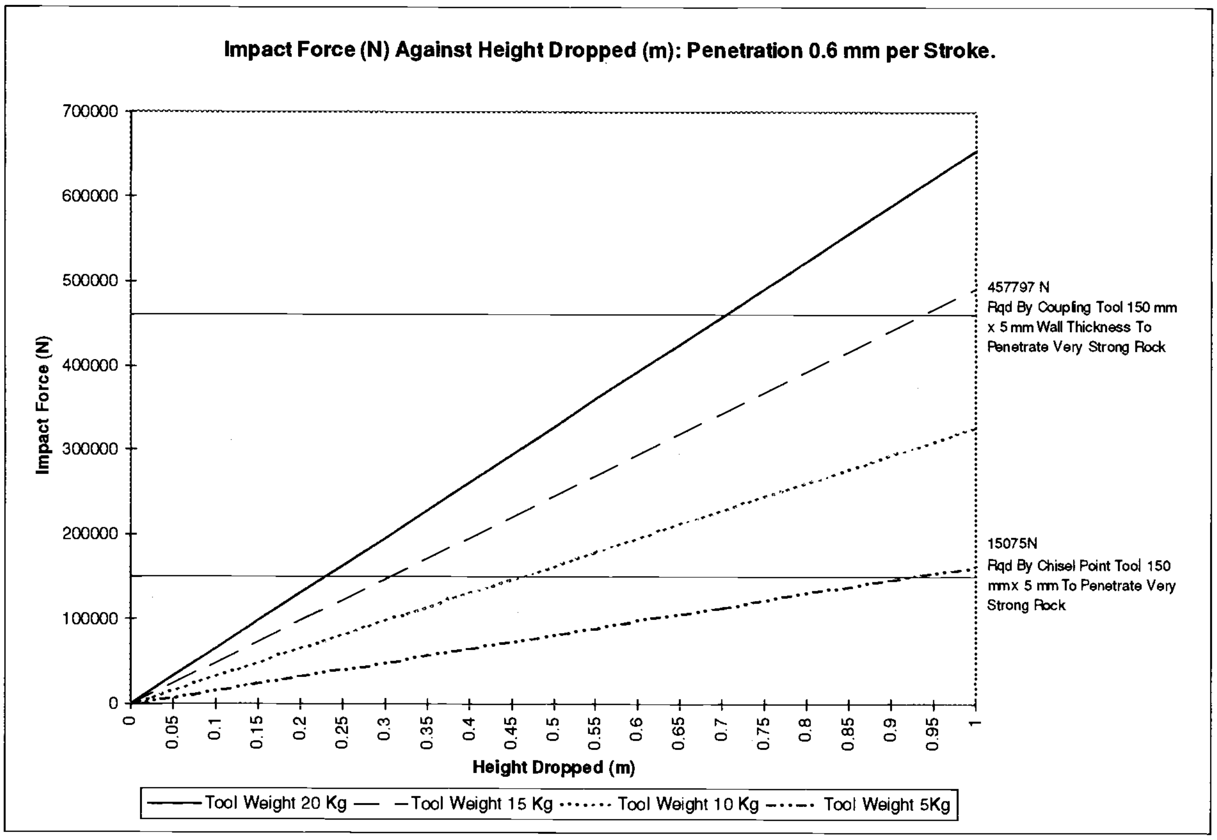


*Figure 5. Graph Of Impact Force (N) Against Height Dropped (m) Penetration 0.6 mm per Stroke. Showing Forces Required To Exceed Compressive Strength of Very Hard Rock (2.01 x $10^8$ N/$m^2$) For Chisel Point and Coupling Tool Bits.*

From figure 5. it can be seen that given the right tool i.e. chisel point with low surface area, cutting forces exceeding the compressive strength of Very Hard Rock (Table 5) can be reached within the limitations laid down in 3.3 above i.e. a 20 Kg tool dropped 0.4m. This is based on a penetration of 0.6 mm per stroke.

**Summary of Results Of Mechanical Analysis.**

The results of the mechanical analysis showed that the human powered mechanism gave a tooling capability of around 20 Kg dropped 0.4 m. - and that this capability with correctly shaped tools, had the potential to penetrate hard rock which was considered the worst case formation.

## 4 Main Experiments

### 4.1 Methodology

In order to test the drilling rig's performance the following methodology was carried out;

1. Design and build a test model of the reciprocating action mechanism
2. Measure effort required to lift a variety of different tool weights through a variety of distances for different test model layouts.
3. Compare results with results of mechanical analysis (3 above).
4. Set test model layout to optimum performance position.
5. Field test mechanism.
6. Record results
7. Comment of performance and recommend design modifications.

### 4.2 Test Model Design

Having established the feasibility of the drilling technique a test model rig was constructed to carry out field tests (Appendix 5). Several features were to be included in the model to assist in testing for optimum design. These included an adjustable shaft to pulley length to investigate further the relationship between distance and mechanical advantage and adjustable handle/arm positions to allow the optimum position for power application and comfortable operation. The model was also fitted with two hand positions on the handle, one giving an effective handle length of 0.5 metres the other 0.95 metres. This was seen as a method of increasing the mechanical advantage i.e. a longer handle length used during tool lifting, and shorter, ergonomically comfortable handle length to turn the shaft during non-loaded segment of rotation.

### Cost Of Test Model.

The model of the drilling rig was designed to test the feasibility of the mechanism and is not considered a finalised design. The model was constructed using standard sections and readily available materials from the Silsoe College workshops. This is in keeping with the design specification requiring the rig to be produced from standard material sections and not require specialist parts or processes. For this reason an exact breakdown of cost is not possible, however a parts list and approximate cost of the model is outlined (Appendix 6) and this gives a figure of £734.

### 4.3 Model Test Results.

The tool lifting performance of the model was tested in the workshop by measuring the force at the handle using a spring balance, to lift a selection of tool weights up to 30 Kg. The height the tools were lifted was measured. Forces were measured at the two handle positions giving effective handle lengths of 0.5 and 0.95 metres. This was carried out for two positions of the pulley, one at a shaft to pulley distance of 2 metres and one at 3 metres. The results of the tests were represented graphically and compared with results from the mechanical analysis. A sample of the graphs produced are shown below,( Figs. 6 & 6.1) a complete set can be found in Appendix 7. A sample of test results compared with mechanical analysis results is shown in table 6. below.

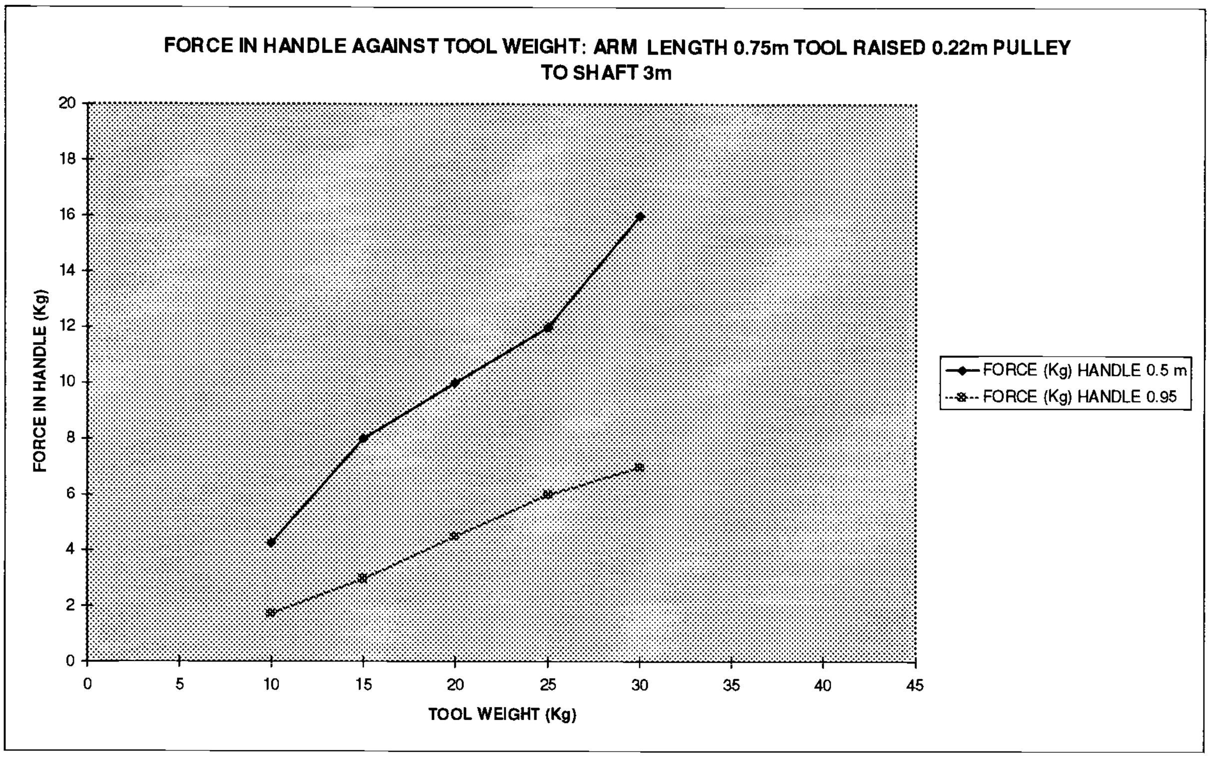


*Figure 6. Graph Of Force Required At Handle To Lift Tool Against Tool Weight. Arm Length 0.75 m, Tool Raised 0.22m. Shaft To Pulley Distance 3 metres.*

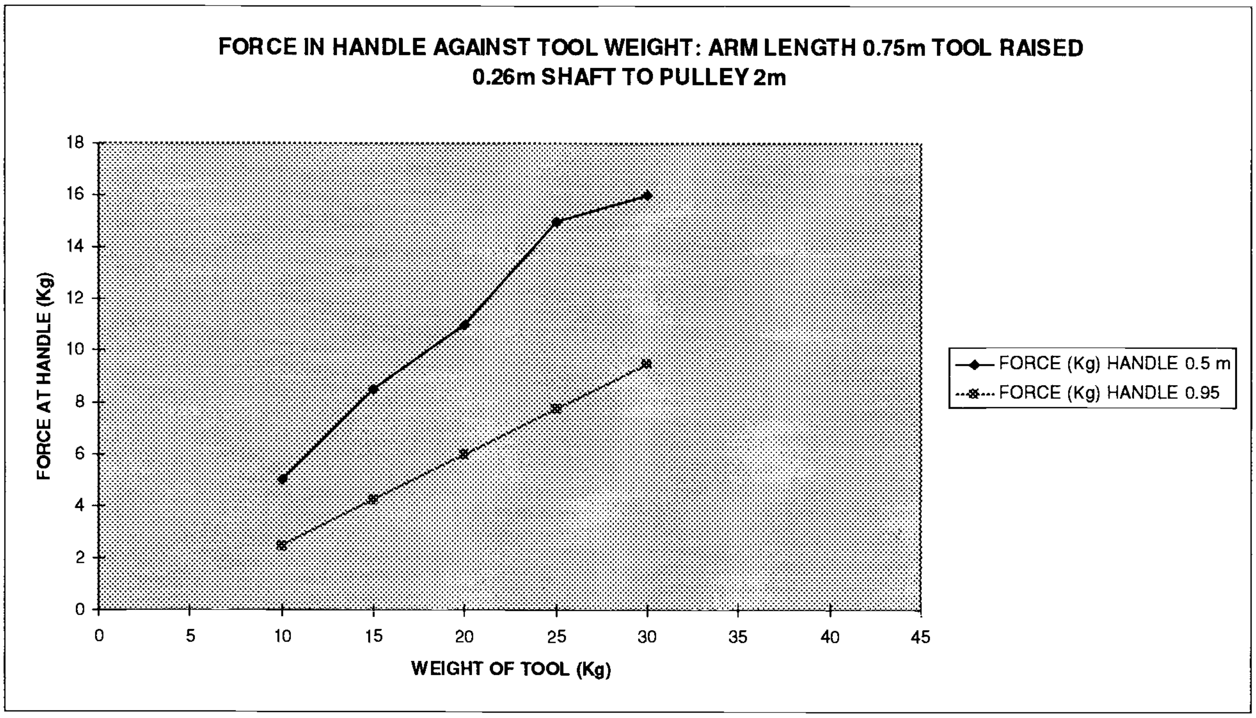


*Figure 6.1. Graph Of Force Required At Handle To Lift Tool Against Tool Weight. Arm Length 0.75 m, Tool Raised 0.26m. Shaft To Pulley Distance 2 metres.*

| | Force At 0.5 metre Handle (Kg) | | Tool Raised (m) | |
|---|---|---|---|---|
| | Test Results | Mech. Analysis | Test Results | Mech. Analysis |
| Tool20Kg.Arm 0.75m<br>Pulley to Shaft 3m | 10 | 8.9 | 0.22 | 0.23 |
| Tool20Kg Arm 0.75m<br>Pulley to Shaft 2m | 11 | 11.07 | 0.26 | 0.27 |
| Tool 20Kg Arm 1 m<br>Pulley to Shaft 3 m | 15.5 | 15.73 | 0.37 | 0.38 |
| Tool 20Kg Arm 1m<br>Pulley to Shaft 2 m | 23.5 | 19.22 | 0.46 | 0.5 |

*Table 6. Sample of Test Results Compared to Mechanical Analysis Results.*

The results recorded from testing the model were very close to the results obtained from the mechanical analysis as table 6 above shows. Discrepancies can be explained by measurement errors (a spring balance was used to measure the force required at the handle), friction between cable, pulley and cable hook, the weight on the cable and slack in the cable in the case of height raised. Improvements in the height the tool was raised was off-set by increased effort at the handle as the distance from shaft to pulley decreased.(Figs. 6 & 6.1) The recommended maximum handle force of 15 Kg was just exceeded (15.5 Kg table 6 above) raising a 20 Kg tool 0.38 m with a shaft to pulley distance of 3 metres. This figure rose to 23.5 Kg when the shaft to pulley distance was reduced to 2 metres, but gave a lift of 0.46 m. This represented a 17.4% increase in distance lifted. The addition of a handle grip giving an effective handle length of 0.95 m reduced the force required to 10 Kg at this layout therefore bringing this tool weight and lift within the ergonomically acceptable load of 15 Kg.

### Summary of Main Experiment Results.

The test results showed the mechanical analysis results to be valid and allowed the optimum design layout to be predicted and tested. Results showed that a 20 Kg tool could be raised and dropped through a distance of 0.5 metres within the ergonomically acceptable human power input (15 Kg).This had been predicted by the mechanical analysis and used as the basis for required rock cutting force calculations in 3.4 Tool Requirements.

## 5 Field Experiments.

### 5.1 Objectives and Methods

Having proved the test model's tool lifting capacity in the workshop the model under went field trials. The objectives were:

1. To test the rigs performance under field conditions.
2. To test the ergonomic design.
3. To ascertain how tool weight and height dropped within the rig's capacity translated to cutting through a variety of ground conditions.

The field trials were carried out at the Silsoe College site in two locations. The first test was carried out on a concrete test sample and the second on the clay soil at the College borehole site. The rig was set up on site, the appropriate tool connected to the cable with a shackle, and drilling carried out.

**Tooling.**

A set of tools was specially made for the rig.(Appendix 8) and used in the field tests These were:

- Flat chisel Weight 17 Kg.
- Cross Blade Claycutter Diameter 150 mm Weight 15 Kg
- Bailer Diameter 150 mm Weight 8 Kg.

### 5.2 Observations.

Once drilling began in earnest it became clear that the most comfortable handle position was to have the handle up high, just past its vertical position, as maximum weight was applied to the arm. The handle was adjusted to this position, at approximately a $70^0$ angle between arm and handle, and fixed in place on the shaft with a split pin. This position allowed the operator to apply a downward force at maximum load which was the most ergonomically appropriate position.

The tool needed to be guided at the cutting face since it tended to swing, a length of pipe was positioned to act as a conductor pipe allowing the tool to move inside the pipe and strike consistently at the face.

The two handle grip positions made operation very comfortable. The inner grip (0.5 metres) was used to turn the handle until the driving pin had driven the arm around to take the tool weight, the outer handle (0.95 metres) was then used through a small arc to lift the tool. This arrangement allowed a balance between the ergonomics of having to turn a handle (over 0.5 metres becomes uncomfortable), and mechanical advantage offered by a greater handle length. The maximum length of the handle (0.95 metres) was governed by the distance from shaft to ground. This was designed to be 1.2 metres which was considered ergonomically comfortable. Using the chisel point tool (weight 17 Kg) with the arm set at 1 metre giving a stroke of 0.46 metres, a drilling rate of between 15 - 20 strokes per minute was comfortably achieved and maintained.

After several hours of drilling the collar holding the arm seized onto the shaft under the load. This necessitated disassembly of the mechanism, enlarging the clearance between shaft and collar and adding lubrication to prevent a repeat. However this increased clearance gave an increase in the lateral movement of the arm which led to the cable hook missing the cable on occasion. This slowed down the drilling rate as the operator had to take care that the arm had picked up the cable.

Under heavy loading there was a tendency of the rig to 'twist' about its lateral axis. This led to the cable hook being off centre and contributed to the problem of missing the cable.

The action of the cable over the cable hook during operation caused an immense amount of wear on the cable hook. After only an hour's drilling damage to the cable hook necessitated removal and repair. A hard nickel face was applied to the cable hook to prevent further damage and allow trials to be completed.

## 5.3 Field Test Results

### 1 Concrete Drilling.

It was not possible to ascertain the compressive strength of the concrete test piece before drilling began since a pre-cast concrete slab used to demonstrate down-the-hole hammer drilling was used. However it was assumed a standard C20P concrete mix was used giving a compressive strength in the region of $20 \times 10^6$ N/m$^2$. This places the concrete in the Moderately Strong Rock category from table 5.

Using a 17 Kg chisel point tool with the shaft to pulley distance set at 2 metres and a stroke rate of between 15-20 strokes per minute, the following results were obtained:

a) Without conductor pipe;

| Stroke (m) | Number of Strokes | Penetration (mm) | Penetration per Stroke (mm) |
|---|---|---|---|
| 0.29 | 100 | 4 | 0.04 |
| 0.29 | 200 | 7 | 0.035 |
| 0.46 | 100 | 9 | 0.09 |

*Table 7. Summary of Results of Concrete Drill Test. Shaft to Pulley 3 metres, 17 Kg Chisel Point Tool. No Conductor Pipe.*

Table 7 shows the results of the concrete drill test without conductor pipe. That is the chisel tool was dropped directly onto the test piece with no guidance. This gave a certain amount of swing to the tool which resulted in the chisel not always striking same area of the concrete test piece. Table 8 show the results obtained using a conductor pipe which was a piece of pipe with an internal diameter slightly larger that the chisel width, set up directly under the model's pulley on the test piece. The chisel was raised and dropped with the conductor pipe onto the concrete. This had the effect of eliminating swing from the tool and concentrating the cutting effort at one point. Table 8 shows the improvement in the cutting rate with the addition of a conductor pipe.

b) With conductor pipe.

| **Stroke (m)** | **Number of Strokes** | **Penetration (mm)** | **Penetration per Stroke (mm)** |
|---|---|---|---|
| 0.46 | 100 | 12 | 0.12 |
| 0.46 | 200 | 26 | 0.13 |

*Table 8. Results of Concrete Drill Test. Shaft to Pulley 3 metres, 17 Kg Chisel Point Tool. With Conductor Pipe.*

### 2 Clay Drilling.

Drilling was carried out on the Gault clay at the College site. It was hoped to reach the underlying sandstone formation which is at about 4 metres depth. Drilling was conducted using a cross blade clay cutter (weight 15 Kg). Using a conductor pipe to guide the tool at the face it was found that although the tool penetrated the clay it did not pick up the clay allowing clearance of the cuttings. Water was added to the hole to make a slurry and the bailer tool (weight 8 Kg) used to try and clear the cuttings. A variety of stroke lengths were tried. Some success was achieved but progress was slow, about 1 metre drilled in 3 hours. Part of the reason for this slow rate was due to the problems encountered with lateral movement in the arm as described in 5.2 above. This slowed down the drilling rate substantially. The test also showed that although the rig could comfortably deal with the weight of the tool (15Kg), extra force was required to lift the tool from the clay after each strike. This put extra strain on the arm resulting in some bending of the arm and contributing to the seizing of the arm as described in 5.2 above.

## 5.4 Discussion

The drilling tests showed that the rig was capable of penetrating hard layers of rock at an average rate of 0.12 mm per stroke. This represents a drilling rate of 7 hours per metre at 20 strokes per minute, this rate would be further reduced by time taken to clear the hole of cuttings. Although this is a slow drilling rate it was concluded from trials in solid concrete. Further trials in formations more similar to the ones likely to be encountered in the field, for example hard layers within alluvial formations, are suggested to see if the drilling rate improves.

The field tests showed that the rig was easy to transport and assemble at site. It could easily be carried (without tools) by two people, and took only a couple of minutes to set up. The only tool required for setting up of the rig was a spanner to tighten the nuts of the supporting bars. After a little practice a comfortable drilling rate of 15-20 strokes per minute with a 17 Kg tool dropping 0.46 metres was possible from the operator. This work rate did not place excessive strain on the operator and it was felt, could be maintained with breaks, for an average working day. The rig was operated with the pulley to shaft length at 2 metres. It was found that the effort required by the operator was not excessive and the increased drop height improved cutting. This raises the question of the dimensions of the final rig design. The shorter pulley to shaft length of 2 metres would reduce material requirements and improve stability. But reducing the pulley height may interfere with the assembly of temporary casing during drilling if used.

## 6 Recommendations

Further trials are necessary to determine the rigs performance in a greater variety of ground formations. The use of drilling muds to avoid the need for temporary casing should be investigated since this would greatly influence the final design of the rig in terms of dimensions and lifting capacity.

The field trials highlighted several areas in the rig's design which require development. The recommendations suggested by this project fall into two categories; the reciprocating action mechanism and other aspects which, whilst not directly under investigation in this paper, are concerned in well drilling rig design and were considered during design and trials of the test model.

## 1 Reciprocating Action Mechanism

The following recommendations are made concerning the design of the reciprocating action mechanism;

- a bearing fitted between arm and shaft to avoid seizure under load and prevent lateral movement.

  strengthening of the arm to prevent failure especially under the increased load caused by clearing the tool from the formation i.e. clay.
- improvement to cable hook to ensure efficient cable pick-up. Possible design to incorporate cable pick up hook full width of rig body. Adjustment of hook position on arm moved to shaft end of arm.
- roller on cable hook to prevent wear by cable.
- guides to ensure both cable and cable hook pass smoothly between rig supports.
- pulley fitted at lower end of rig replacing the prototype's steel ring to allow smooth movement of cable between winch and top pulley.

## 2 Other Aspects

In order to keep the cost of the rig low, two alternatives are suggested. Firstly if temporary casing is used it is lifted out using hand jacks lifting against clamps on the casing. This removes the requirement of expensive heavy lifting capabilities and in fact, is often used with conventional percussion rigs where the winch is not powerful enough to remove the casing because it is stuck due to a non-vertical hole or excessive wall friction.

Secondly the possibility of drilling using drilling fluids or 'muds' should be investigated. These viscous fluids hold the borehole open due to hydrostatic pressure and are commonly used in conventional rotary drilling. The use of muds means expensive and heavy temporary casing is not needed and greatly reduces the lifting requirements of the rig. This would also allows the pulley height to be reduced since the necessary clearance to assemble temporary casing would not be required. The effect of drilling muds on the tools cutting force will require further investigation. Other recommendations made are;

- a guard fitted to prevent contact between moving parts and rig crew or operator. This is especially important for the arm both for operator and crew around the borehole.

- provision for painting, coating or other corrosion protection methods as well as lubrication of bearings and moving parts would need to be made in the final design.
- central support to prevent flexing of the rig. This could take the form of support legs from rig body to ground.
- the general finish in terms of sharp edges, handle grips or other parts which may present a hazard to crew during operation or assembly/disassembly.
- the use of a 'work table' similar to the one supplied with the 'Vonder Rig'. (Appendix 1) This consists of a section of pipe which acts as a conductor pipe to guide the tool into the hole, which is fixed in position before drilling commences. This ensures efficient drilling and helps with verticality of the drilled hole.
- swivel fittings between cable and tool to ensure rotation of tool during drilling which ensures drilling is carried out over entire diameter of hole.
- design of a set of cutting tools suitable for use with the rig and adequate for all ground formations anticipated.

It is recommended that modifications are made as necessary to the current test model using the guidelines above, and further field testing carried out in order to finalise the design. Successful completion of this stage will allow for the finished rig to be designed with confidence in its performance and compliance with design specification

# Appendices

# Appendix 1

## Hand Powered Drilling Techniques.

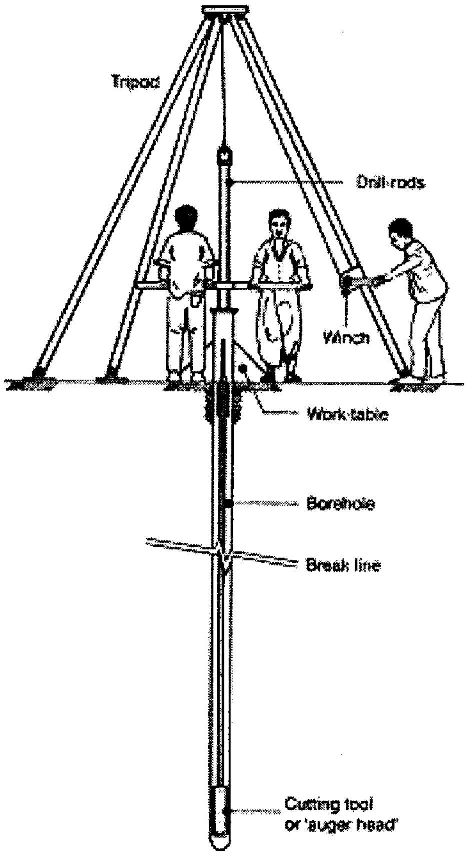


Fig 1.1 Hand Auger Eg "Vonder Rig"
The Cutting Tool (Auger) Is Rotated To Cut Into Ground Then Withdrawn To Remove Cuttings. Inexpensive And Simple To Operate And Maintain. Slow And Unsuitable for Consolidated Formations

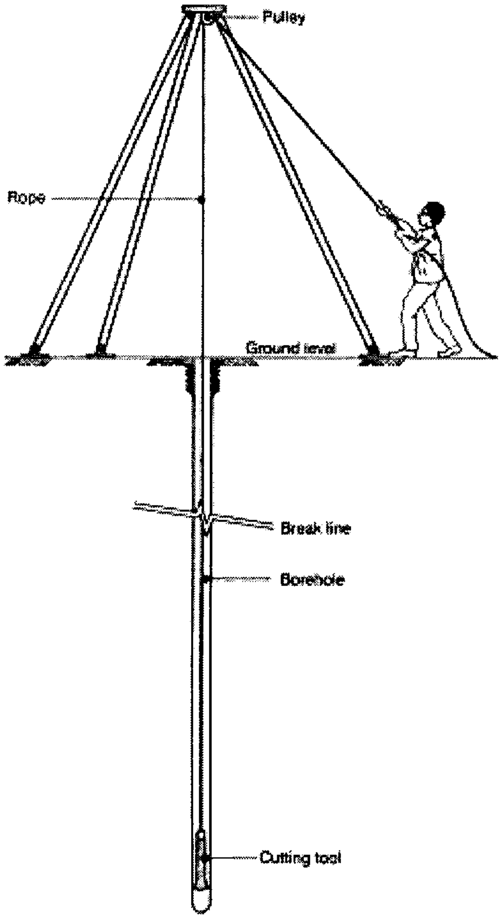


Fig 1.2 Percussion Drilling.
The Lifting And Dropping Of A Cutting Tool Will Chip And Excavate Material From The Hole. Simple To Operate And Maintain. Suitable For A Wide Variety Of Rocks To Considerable Depth. May Be Slow And Encounter Problems In Unstable Formations

# Appendix 1

## Hand Powered Drilling Techniques.

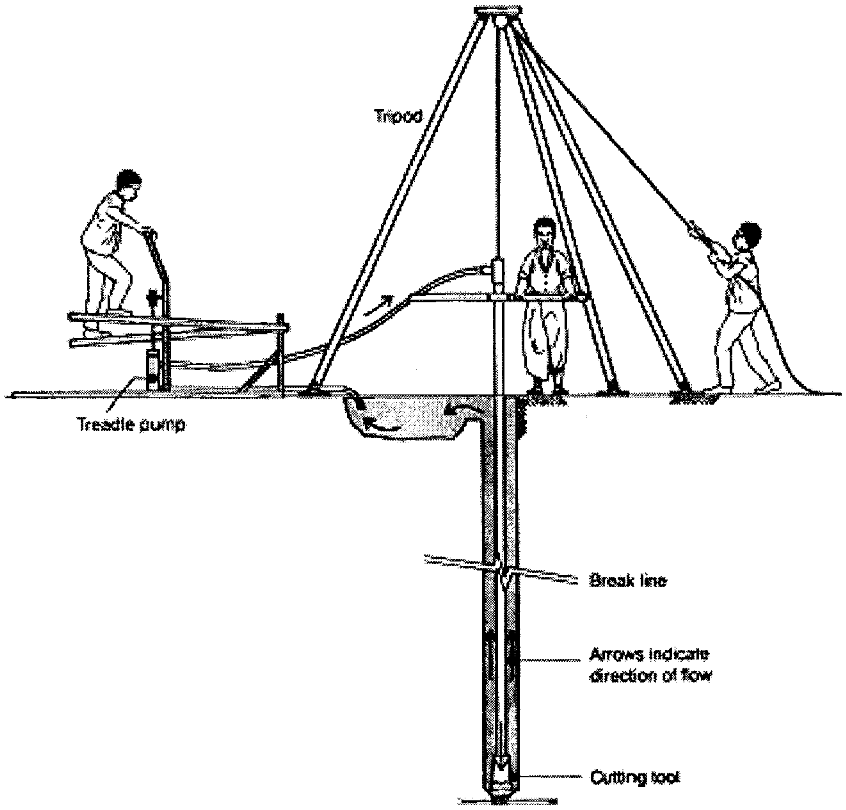
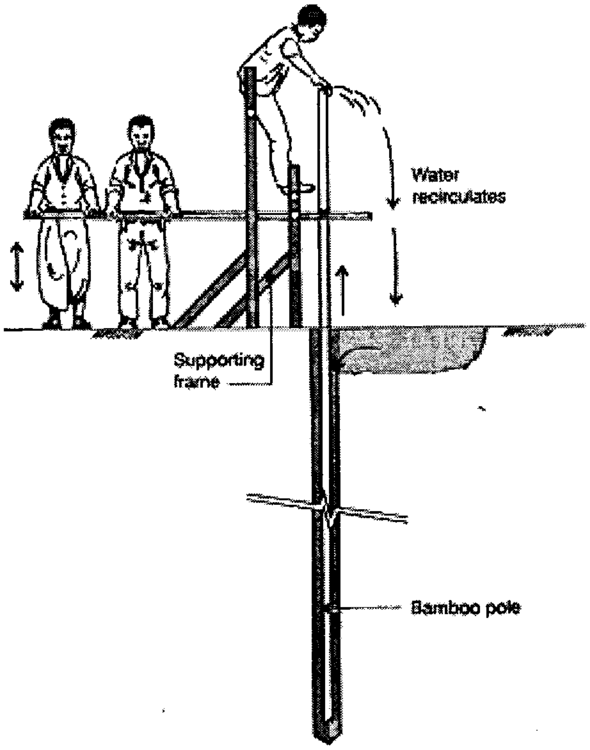


Fig 1.3 Jetting
Water Is Pumped Down The Centre Of The Drill Pipe Emerging As A Jet. The Water Returns Up The Borehole Bringing Cuttings. A Treadle Pump Or Small Internal Combustion Pump Are Suitable. Simple Equipment And Can Be Quick. Suitable For Unconsolidated Formations Only

Fig 1.4 Sludging
A Hollow Pipe Which May be Bamboo or Steel Is moved Up And Down In A Water Filled Hole. A One Way Valve Which May Be The Operator's Hand, Provides A Pumping Action. Water Flows Down The Borehole Annulus And Up Throught The Pipe Carrying Cuttings To The Surface. A Metal Bit At the Bottom Of The Pipe Improves Cutting Efficiency. Equipment Is Simple To Use And May Be Made From Local Low-Cost Materials. Only Suitable For Unconsolidated Formations, Boulders May Prevent Progress.



Reference Waterlines 1995

# Appendix 2

## Percussion Drilling Techniques

## 1 Reciprocating Motion

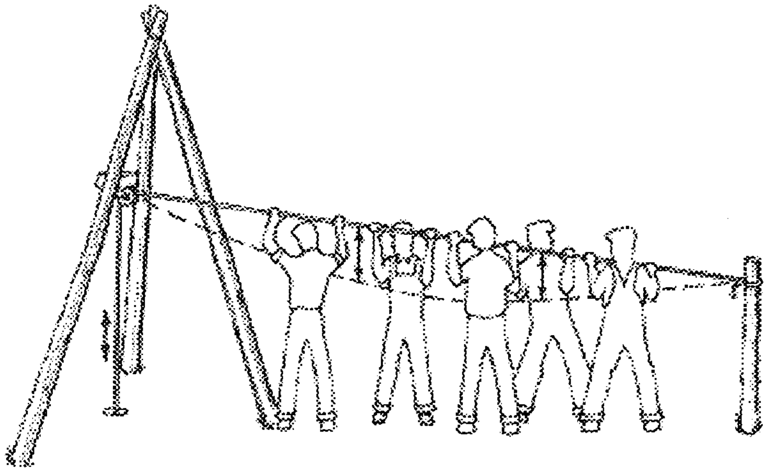


Fig 2.1 Pulling On Anchored Rope To Obtain Reciprocating Motion.

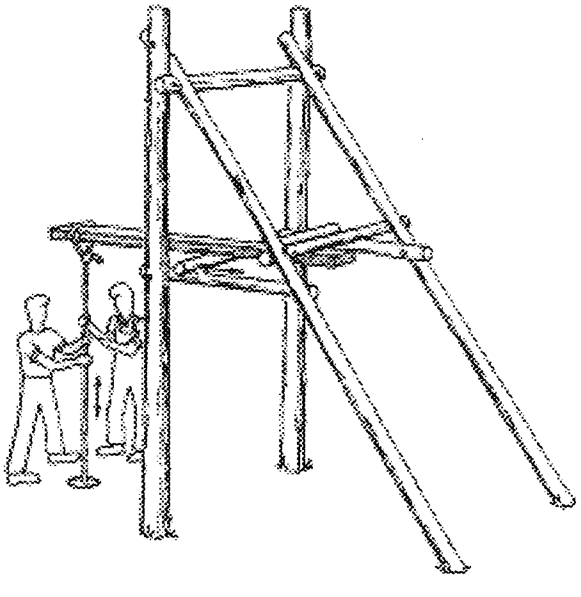


Fig 2.2 Spring Board For Obtaining Reciprocating Motion.

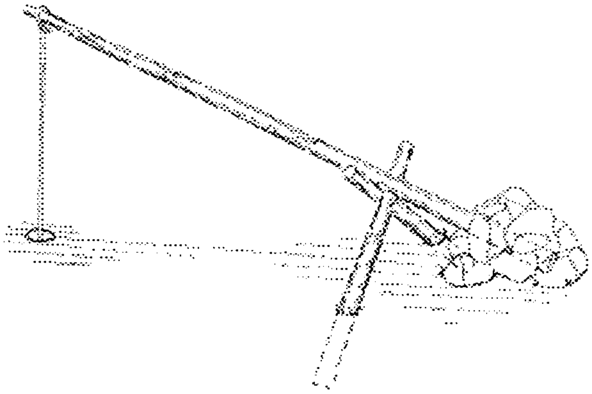


Fig 2.3 Spring Pole For Obtaining Reciprocating Action.

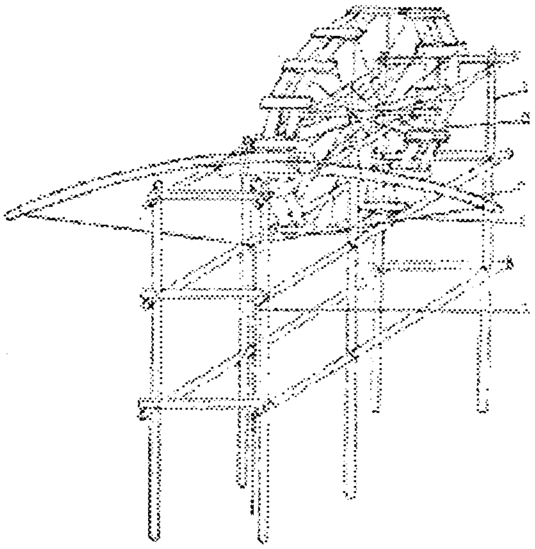


Fig 2.4 Traditional Chinese Drilling Equipment. Rig With Bow For Obtaining Reciprocating Motion.

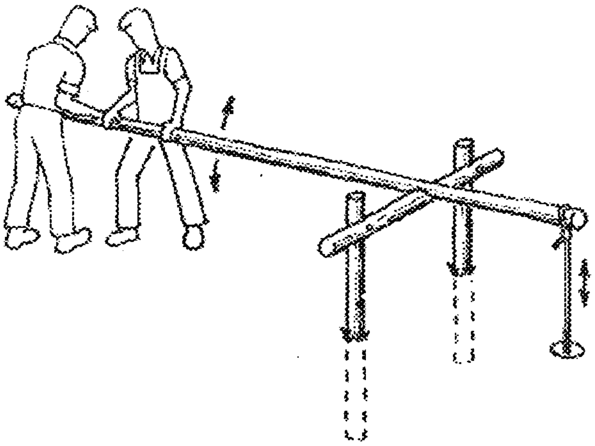
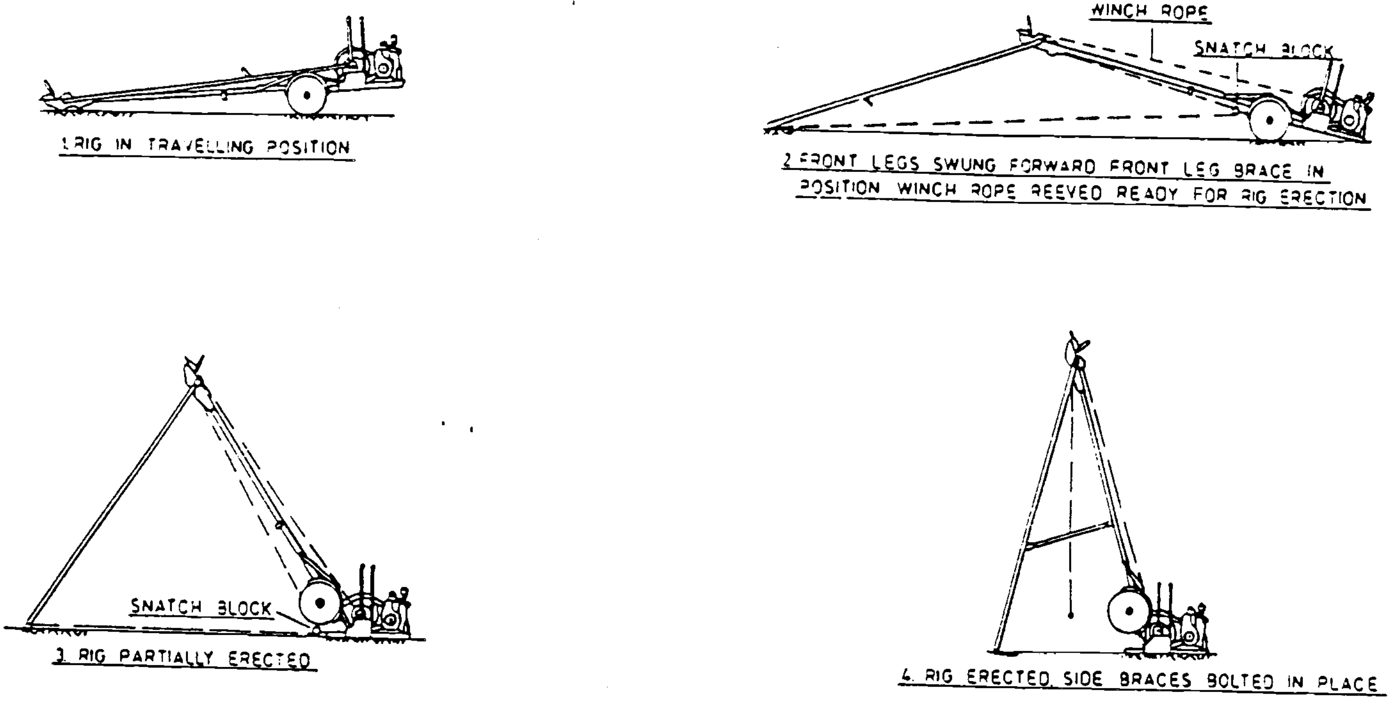


Fig 2.5 Using Lever To Obtain Reciprocating Motion

## Appendix 5
## Dando 150 Percussion Drilling Rig

150/2



1 RIG IN TRAVELLING POSITION

2 FRONT LEGS SWUNG FORWARD FRONT LEG BRACE IN POSITION WINCH ROPE REEVED READY FOR RIG ERECTION

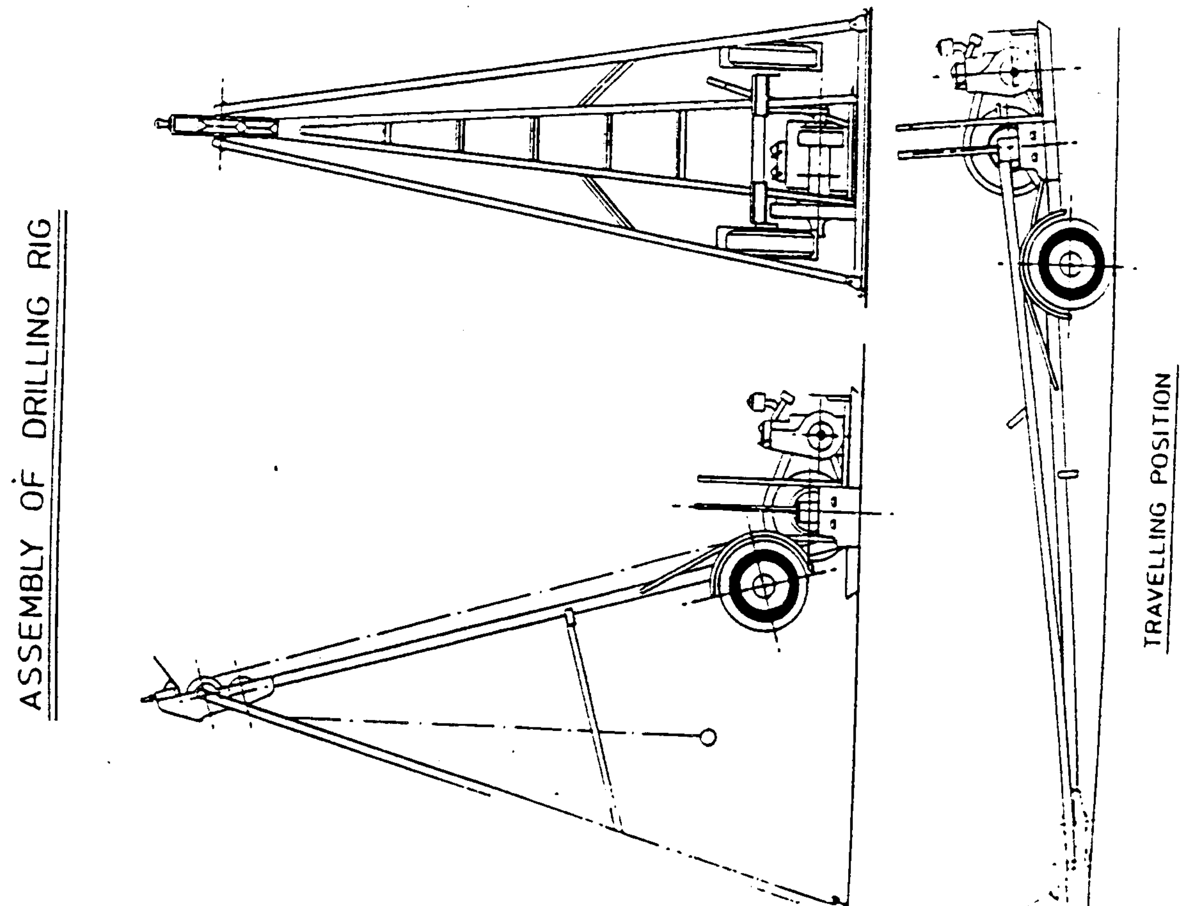
3 RIG PARTIALLY ERECTED

4 RIG ERECTED SIDE BRACES BOLTED IN PLACE

STANDARD METHOD OF ERECTING INVESTIGATOR BORING RIG

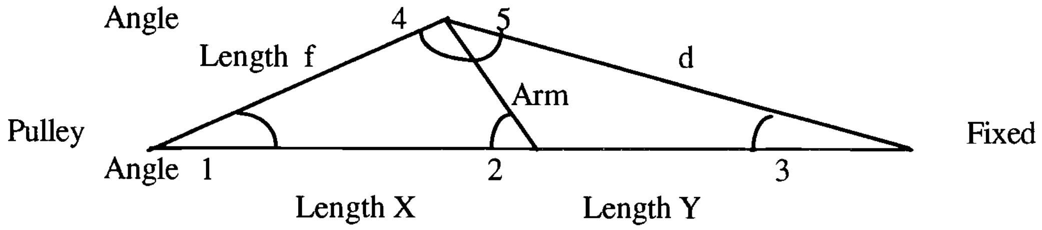
FIG 1

Issue 1



# Appendix 4

## DRILLING RIG DESIGN DATA SHEET - MODEL TEST RESULTS



| Angle 1 Degrees | Angle 2 Degrees | Angle 3 Degrees | Angle 4 Degrees | Angle 5 Degrees | X m | Y m | Arm m | f m | d m |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 180 | 0 | 2.0 | 2.0 | 0.75 | 1.25 | 2.75 |
| 5.5 | 10 | 2.5 | 164 | 9 | | | | 1.27 | 2.74 |
| 9.5 | 20 | 5.5 | 150 | 15 | | | | 1.32 | 2.73 |
| 15.5 | 30 | 8.5 | 136 | 22 | | | | 1.40 | 2.70 |
| 19 | 40 | 11 | 120 | 30 | | | | 1.51 | 2.62 |
| 20 | 50 | 12.5 | 110 | 37 | | | | 1.61 | 2.56 |
| 21 | 60 | 14 | 100 | 44 | | | | 1.74 | 2.49 |
| 20 | 70 | 16 | 90 | 52 | | | | 1.87 | 2.38 |
| 20 | 80 | 18 | 78 | 61 | | | | 2.00 | 2.27 |
| 19 | 90 | 20 | 70 | 70 | | | | 2.12 | 2.15 |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

Tool Raised 0.27m

# Appendix 4

X = 2M Y = 2M

ARM 0.75 M

HANDLE 0.5 M

| ARM ANGLE | ANGLE 1 | ANGLE 2 | ANGLE 3 | ANGLE 4 | DISTANCE A | F/W | FORCE (N) | ARM ANGLE | ARM TORQUE | HANDLE FORCE Kg | % OF LOAD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 90 | 90 | 0 | 0.75 | 0 | 196.2 | 0 | 0 | 0 | 0.0 |
| 10 | 5.5 | 86.5 | 84.5 | 2 | 0.733610701 | 0.138 | 196.2 | 10 | 19.863 | 4.05 | 20.2 |
| 20 | 9.5 | 82.5 | 80.5 | 2 | 0.695387891 | 0.288 | 196.2 | 20 | 39.293 | 8.01 | 40.1 |
| 30 | 15.5 | 79 | 74.5 | 4.5 | 0.618094641 | 0.4 | 196.2 | 30 | 48.508 | 0.88 | 4.4 |
| 40 | 19 | 75 | 71 | 4 | 0.53950485 | 0.513 | 196.2 | 40 | 54.301 | 11.07 | 55.4 |
| 50 | 20 | 73.5 | 70 | 3.5 | 0.44611709 | 0.588 | 196.2 | 50 | 51.467 | 10.49 | 52.5 |
| 60 | 21 | 72 | 69 | 3 | 0.340492875 | 0.6375 | 196.2 | 60 | 42.588 | 8.68 | 43.4 |
| 70 | 20 | 71 | 70 | 1 | 0.244176116 | 0.675 | 196.2 | 70 | 32.337 | 6.59 | 33.0 |
| 80 | 20 | 69.5 | 70 | -0.5 | 0.1367 | 0.725 | 196.2 | 80 | 19.442 | 3.96 | 19.8 |
| 90 | 19 | 70 | 71 | -1 | 0.013089305 | 0.725 | 196.2 | 90 | 1.862 | 0.38 | 1.9 |
|  |  |  |  |  |  |  |  | 100 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 110 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 120 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 130 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 140 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 150 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 160 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 170 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 180 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 190 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 200 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 210 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 220 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 230 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 240 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 250 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 260 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 270 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 280 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 290 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 300 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 310 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 320 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 330 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 340 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 350 | 0 | 0.00 |  |
|  |  |  |  |  |  |  |  | 360 | 0 | 0.00 |  |

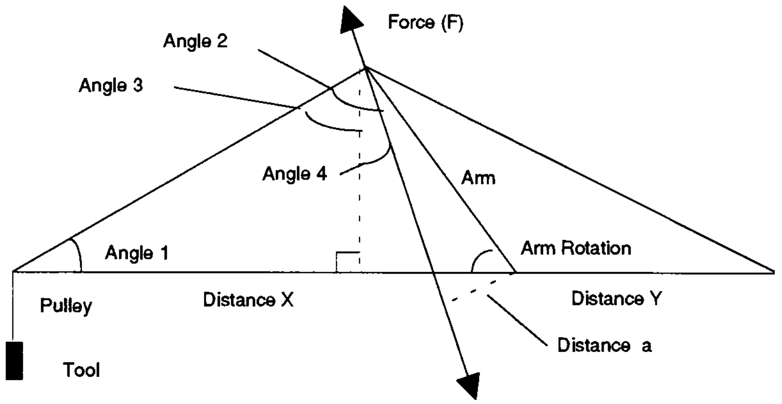
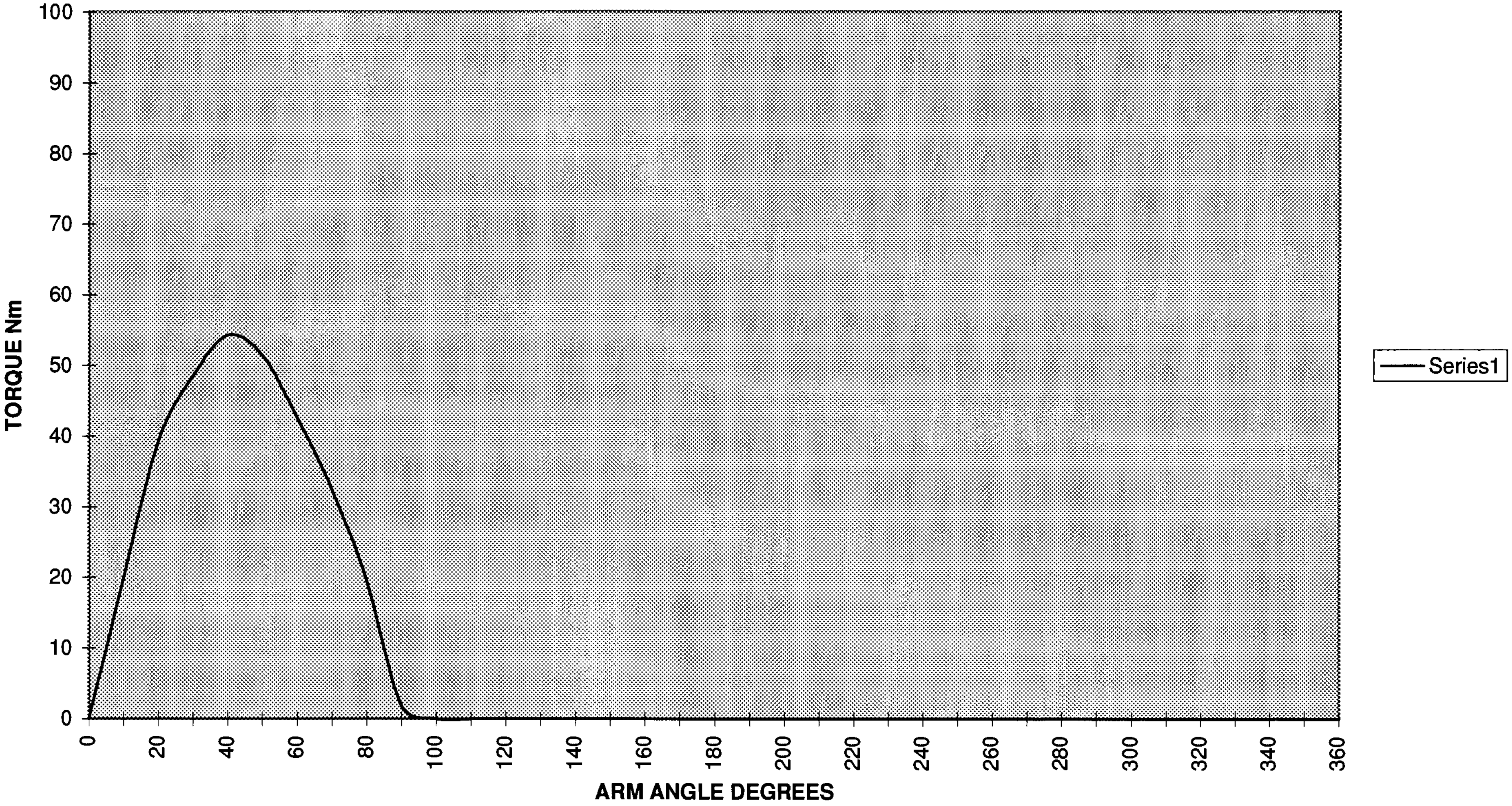
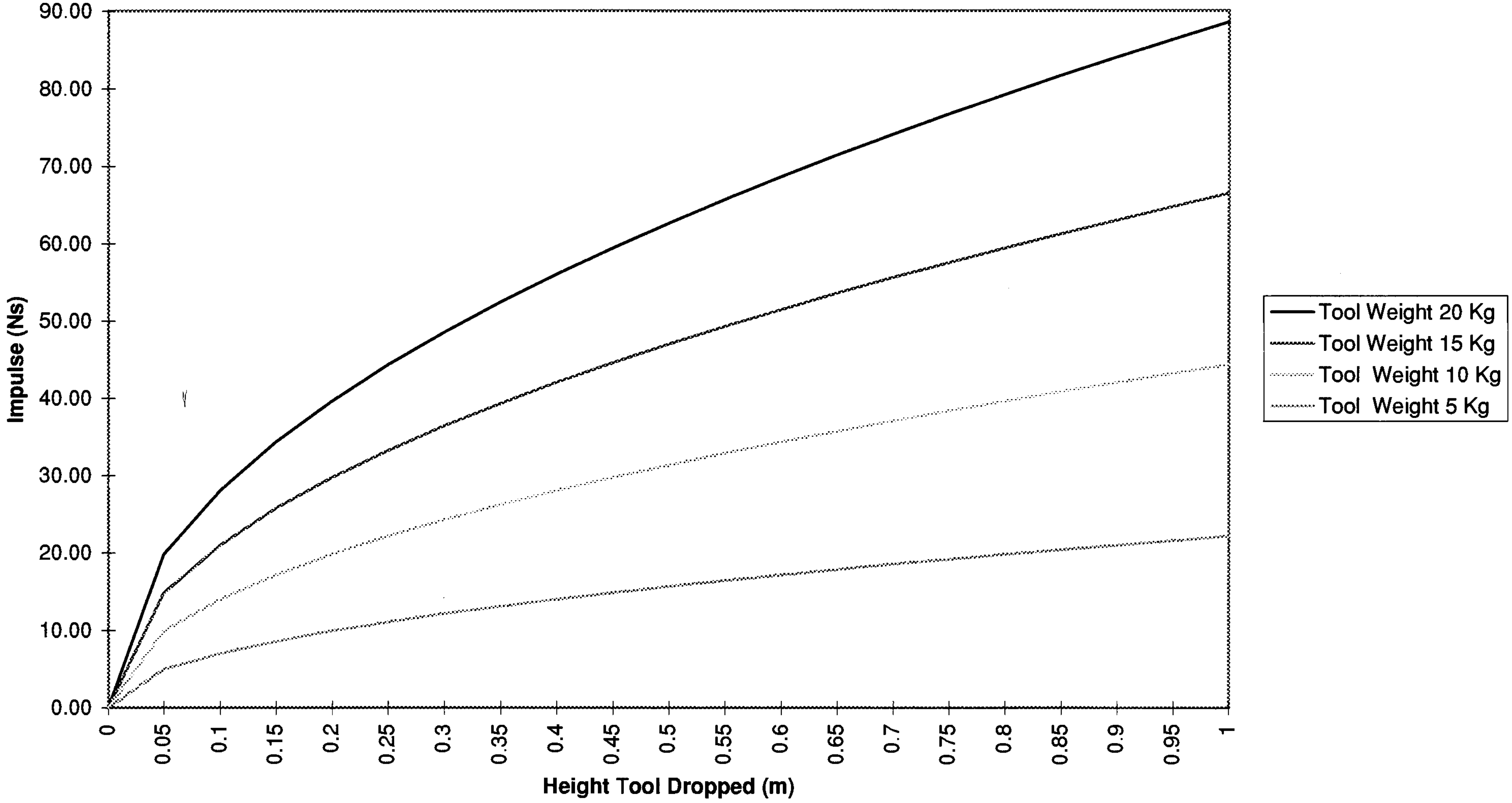


Diagram Of Mechanism
Key To Figures Used In Analysis.

## Appendix 4 LOW COST DRILLING RIG: TORQUE AT SHAFT AGAINST ARM ANGLE- ARM 0.75M
## X=2m Y=2m TOOLWEIGHT=20KG



# Appendix 4
## Impulse (Ns) Against Height (m) Tool Dropped



# APPENDIX 4

FORCE DIAGRAM

ARM = 0·75M

SHAFT TO PULLEY = 2M  SHAFT TO FIXED POINT 2M

SCALE 70MM = 1M.

Ex. AT ARM ANGLE 50°

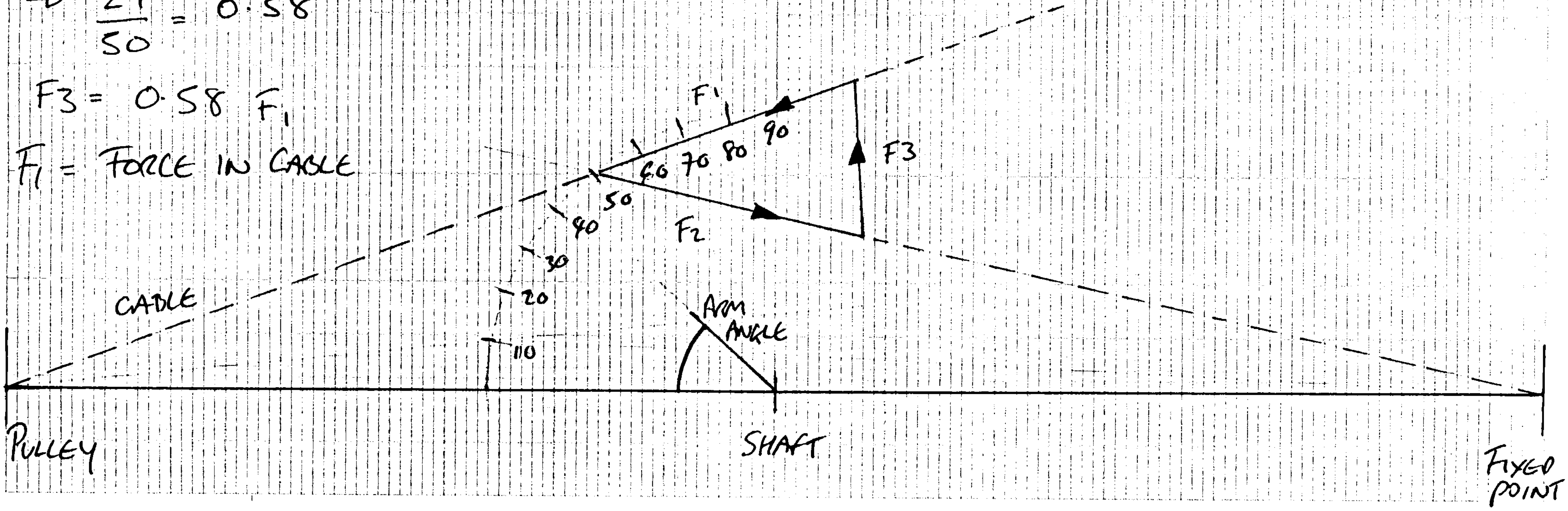
$F_1 = F_2 = 50$ MM

$F_3 = 29$ MM

$\Rightarrow \dfrac{29}{50} = 0{\cdot}58$

$F3 = 0{\cdot}58\ F_1$

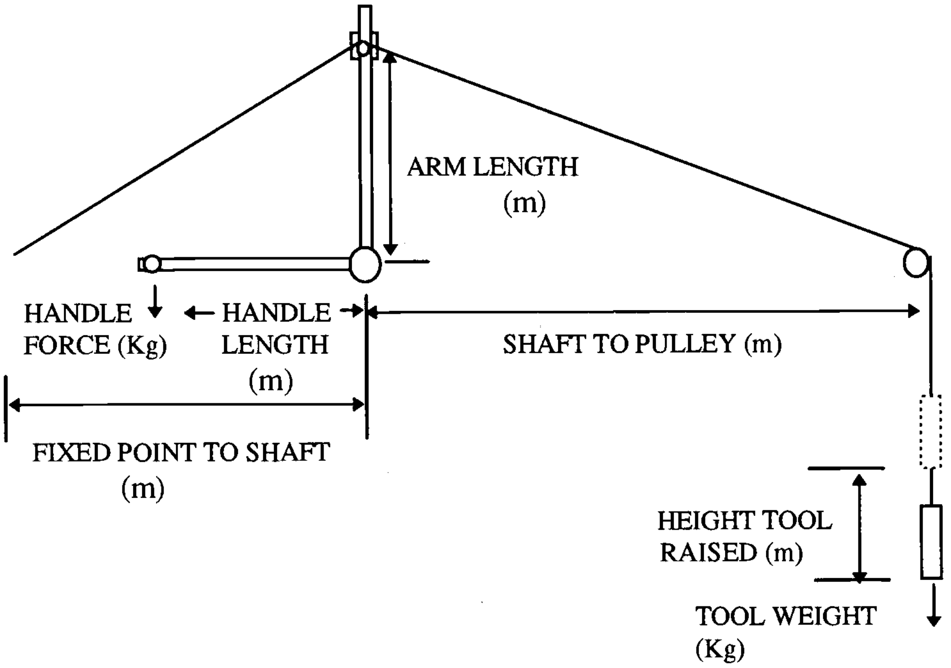
$F_1$ = FORCE IN CABLE



# Appendix 4

**LOW COST DRILLING RIG**
**TEST DATA SHEET 2**
**PROTOTYPE PERFORMANCE.**

**SHEET 1 OF 4**
**RECORDED BY: M. Worth**
**DATE: 4/8/98**

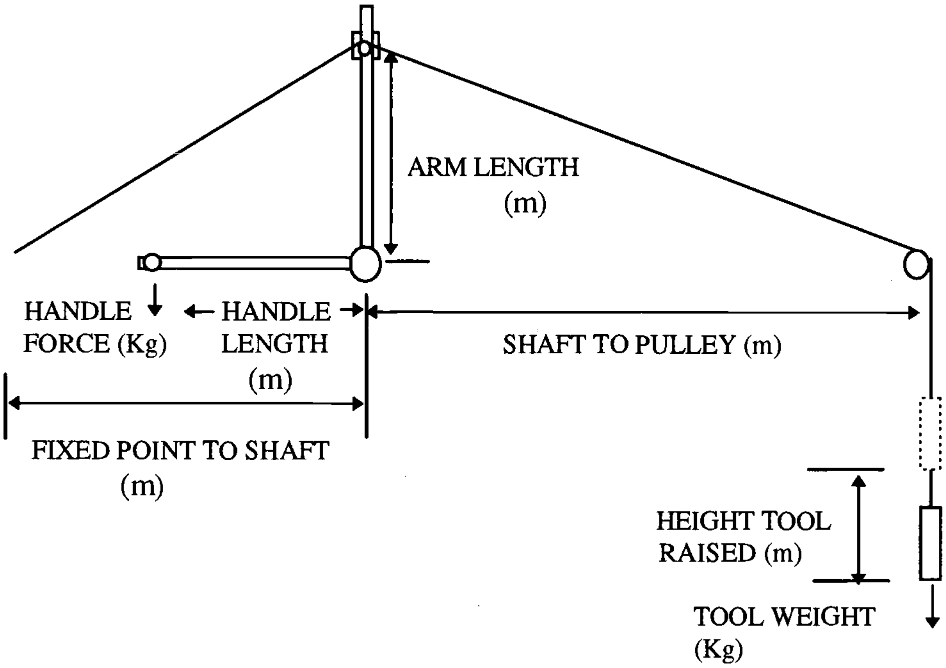


| FIXED POINT TO SHAFT (m) | SHAFT TO PULLEY (m) | ARM LENGTH (m) | HANDLE LENGTH (m) | FORCE ON HANDLE (Kg) | TOOL WEIGHT (Kg) | HEIGHT TOOL RAISED (m) |
|---|---|---|---|---|---|---|
| 1.92 | 2.47 | 0.5 | 0.5 | 2.0 | 10 | 0.085 |
| | | | 0.95 | 0.5 | 10 | |
| | | | 0.5 | 3.0 | 15 | |
| | | | 0.95 | 1.0 | 15 | |
| | | | 0.5 | 4.0 | 20 | |
| | | | 0.95 | 1.5 | 20 | |
| | | | 0.5 | 4.75 | 25 | |
| | | | 0.95 | 2.0 | 25 | |
| | | | 0.5 | 6.5 | 30 | |
| | | | 0.95 | 2.75 | 30 | |
| | | | | | | |
| | | 0.75 | 0.5 | 4.25 | 10 | 0.22 |
| | | | 0.95 | 1.75 | 10 | |
| | | | 0.5 | 8.0 | 15 | |
| | | | 0.95 | 3.0 | 15 | |
| | | | 0.5 | 10.0 | 20 | |
| | | | 0.95 | 4.5 | 20 | |
| | | | 0.5 | 12.0 | 25 | |

# Appendix 4

**LOW COST DRILLING RIG**
**TEST DATA SHEET 2**
**PROTOTYPE PERFORMANCE.**

**SHEET 2 OF 4**
**RECORDED BY: M. Worth**
**DATE: 4/8/98**



| FIXED POINT TO SHAFT (m) | SHAFT TO PULLEY (m) | ARM LENGTH (m) | HANDLE LENGTH (m) | FORCE ON HANDLE (Kg) | TOOL WEIGHT (Kg) | HEIGHT TOOL RAISED (m) |
|---|---|---|---|---|---|---|
| 1.92 | 2.47 | 0.75 | 0.95 | 6.0 | 25 | 0.22 |
| | | | 0.5 | 16.0 | 30 | |
| | | | 0.95 | 7.0 | 30 | |
| | | | | | | |
| | | 1.0 | 0.5 | 8.5 | 10 | 0.37 |
| | | | 0.95 | 4.0 | 10 | |
| | | | 0.5 | 11.0 | 15 | |
| | | | 0.95 | 6.0 | 15 | |
| | | | 0.5 | 15.5 | 20 | |
| | | | 0.95 | 8.5 | 20 | |
| | | | 0.5 | 19.0 | 25 | |
| | | | 0.95 | 4.25 | 25 | |
| | | | | | | |
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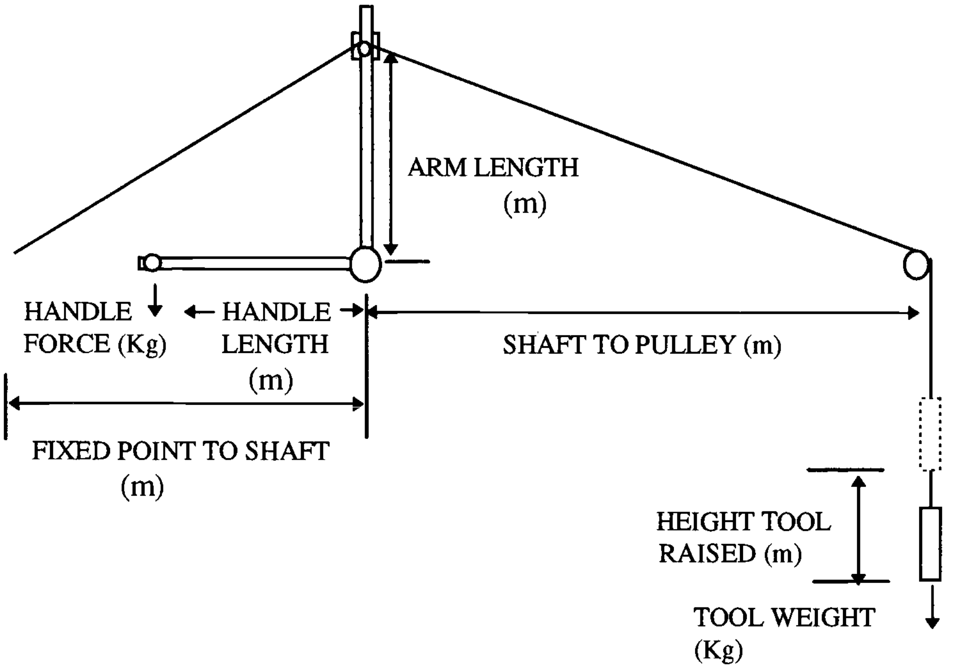
# Appendix 4

**LOW COST DRILLING RIG**
**TEST DATA SHEET 2**
**PROTOTYPE PERFORMANCE.**

**SHEET 3 OF 4**
**RECORDED BY: M. Worth**
**DATE: 4/8/98**

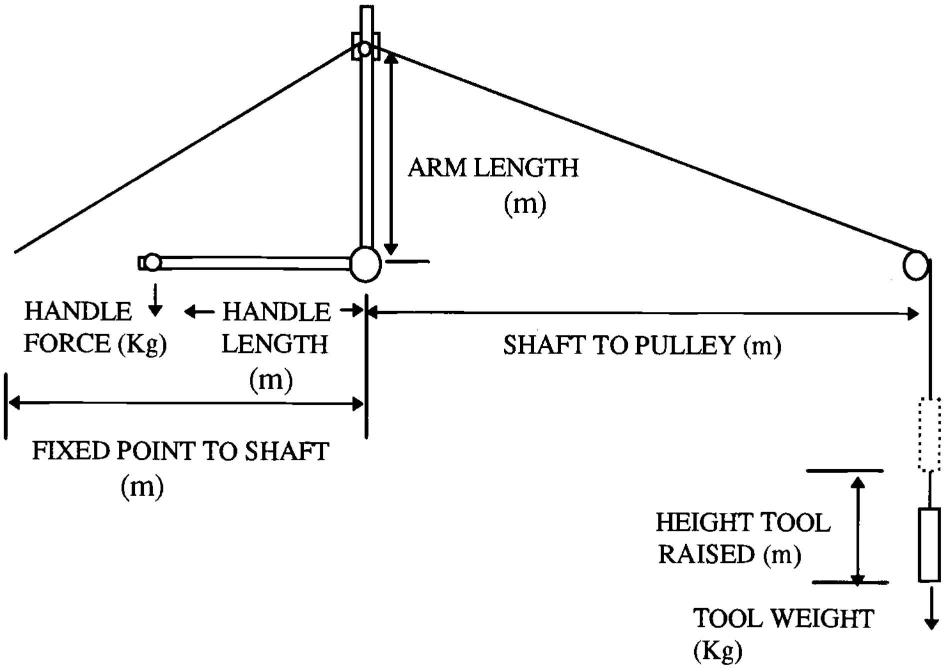


| FIXED POINT TO SHAFT (m) | SHAFT TO PULLEY (m) | ARM LENGTH (m) | HANDLE LENGTH (m) | FORCE ON HANDLE (Kg) | TOOL WEIGHT (Kg) | HEIGHT TOOL RAISED (m) |
|---|---|---|---|---|---|---|
| 1.92 | 1.80 | 0.5 | 0.5 | 2.75 | 10 | 0.12 |
| | | | 0.95 | 0.75 | 10 | |
| | | | 0.5 | 3.0 | 15 | |
| | | | 0.95 | 1.5 | 15 | |
| | | | 0.5 | 4.5 | 20 | |
| | | | 0.95 | 2.25 | 20 | |
| | | | 0.5 | 5.75 | 25 | |
| | | | 0.95 | 3.0 | 25 | |
| | | | 0.5 | 7.75 | 30 | |
| | | | 0.95 | 3.75 | 30 | |
| | | | | | | |
| | | 0.75 | 0.5 | 5.0 | 10 | 0.26 |
| | | | 0.95 | 2.5 | 10 | |
| | | | 0.5 | 8.5 | 15 | |
| | | | 0.95 | 4.25 | 15 | |
| | | | 0.5 | 11.099 | 20 | |
| | | | 0.95 | 6.0 | 20 | |
| | | | 0.5 | 15.0 | 25 | |

# Appendix 4

**LOW COST DRILLING RIG**
**TEST DATA SHEET 2**
**PROTOTYPE PERFORMANCE.**

**SHEET 4 OF 4**
**RECORDED BY: M. Worth**
**DATE: 4/8/98**



| **FIXED POINT TO SHAFT (m)** | **SHAFT TO PULLEY (m)** | **ARM LENGTH (m)** | **HANDLE LENGTH (m)** | **FORCE ON HANDLE (Kg)** | **TOOL WEIGHT (Kg)** | **HEIGHT TOOL RAISED (m)** |
|---|---|---|---|---|---|---|
| 1.92 | 1.80 | 0.75 | 0.95 | 7.75 | 25 | 0.26 |
| | | | 0.5 | 18.0 | 30 | |
| | | | 0.95 | 9.5 | 30 | |
| | | | | | | |
| | | 1.0 | 0.5 | 10.0 | 10 | 0.46 |
| | | | 0.95 | 5.25 | 10 | |
| | | | 0.5 | 17.0 | 15 | |
| | | | 0.95 | 7.0 | 15 | |
| | | | 0.5 | 23.5 | 20 | |
| | | | 0.95 | 10.0 | 20 | |
| | | | 0.5 | 30.0 | 25 | |
| | | | 0.95 | 20.0 | 25 | |
| | | | | | | |
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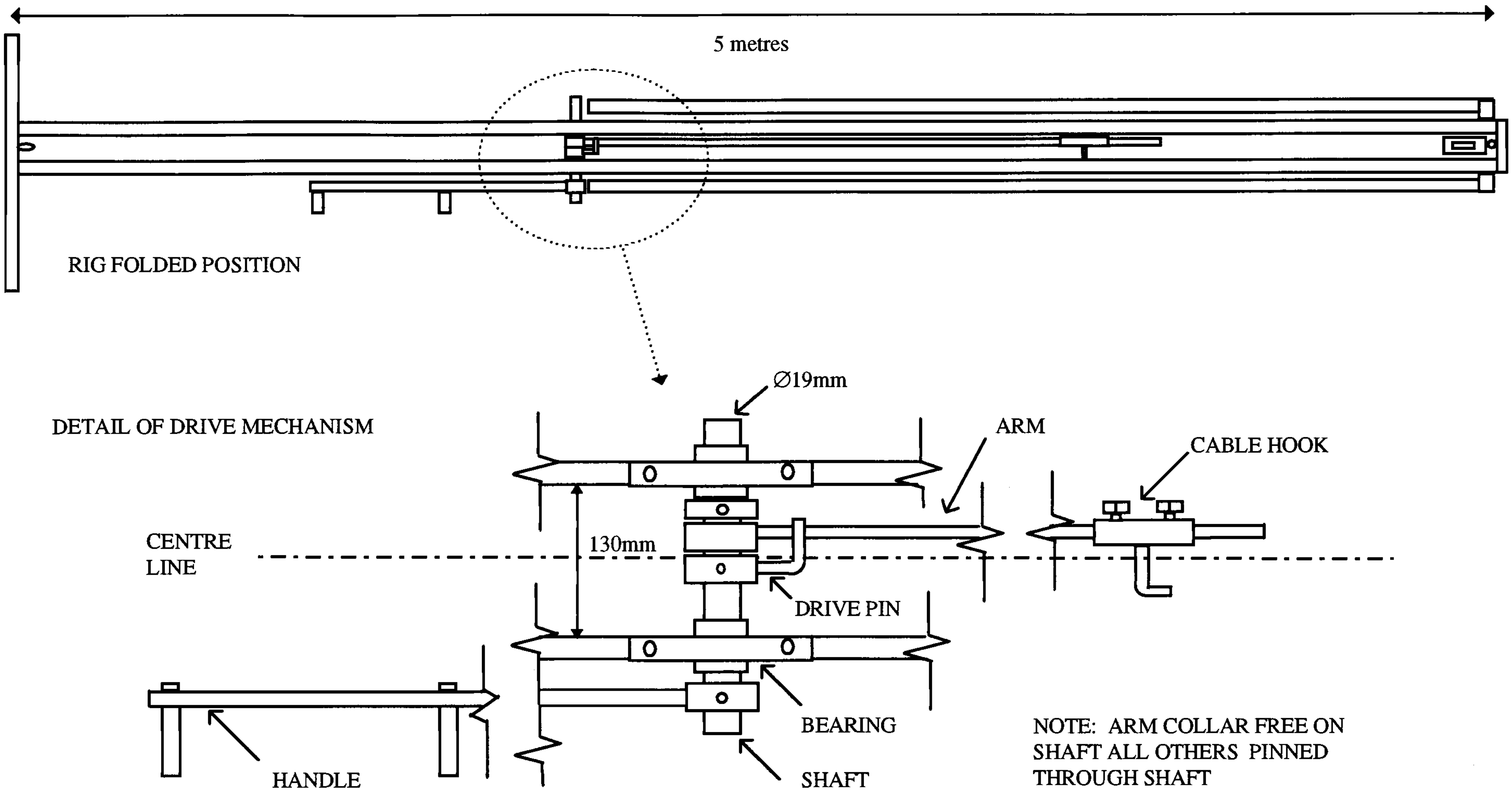
| | | | | | | |



NOTE: ARM COLLAR FREE ON SHAFT ALL OTHERS PINNED THROUGH SHAFT

# Appendix 5

LOW COST DRILLING RIG
DRG. NO. DR01

TITLE: FOLDED POSITION AND DRIVE MECHANISM DETAIL

DRAWN: MARTIN WORTH
Date: 17/8/1998

# Appendix 6

## PARTS LIST AND APPROXIMATE COST OF MODEL TEST RIG

### 1 Parts List

| Part | Quantity | Total Cost |
|---|---|---|
| Pulley | 1 Off | £40 |
| Winch | 1 Off | £50 |
| Cable 20 metres x 4mm Dia | 1 Roll | £30 |
| Box Section 30 x 30 x 3 8m Length | 2 Off | £30 |
| Nuts & Bolts (Various) | 20 Off | £8 |
| Bearing Blocks Dia 20 mm | 2 Off | £50 |
| Welding Rods (Various) | | £5 |
| Shaft Dia 20mm x 300mm | 1 Off | £2 |
| Collars Dia 40 mm x 30 mm | 5 Off | £2 |
| Steel (Various) | | £15 |
| Handle 25 x 25mm x 1m Box Section | 1Off | £2 |

| | |
|---|---|
| **Total Parts** | **£234** |

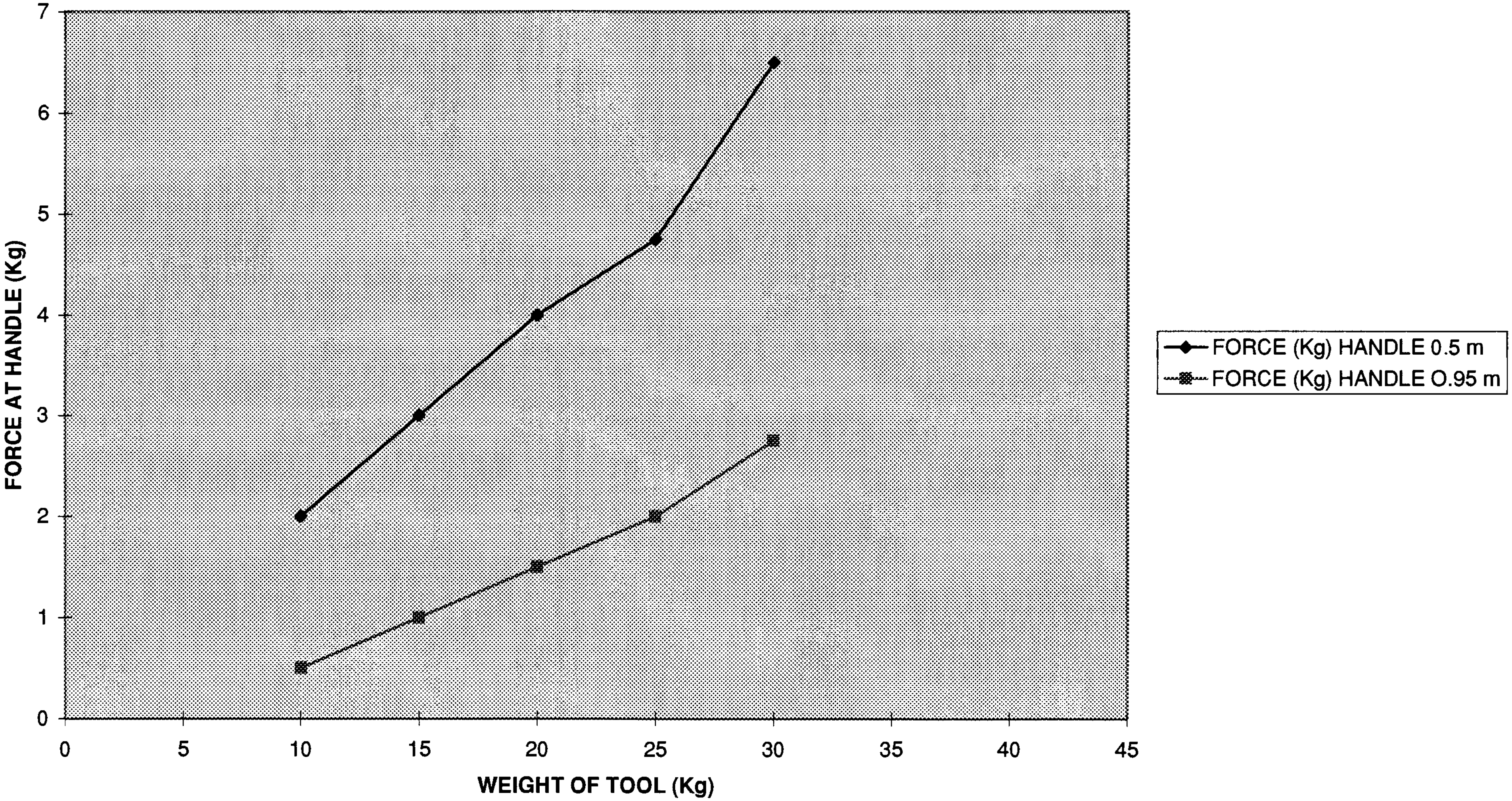
### 2 Labour ( Based on Skilled Labour rate of £100 per day)

| Process | Time | Cost |
|---|---|---|
| Marking Out | 0.5 days | £50 |
| Cutting & Drilling | 1.5 days | £150 |
| Turning | 0.5 Days | £50 |
| Welding | 1.5 Days | £150 |
| Assembly & Modifications | 1 Day | £100 |

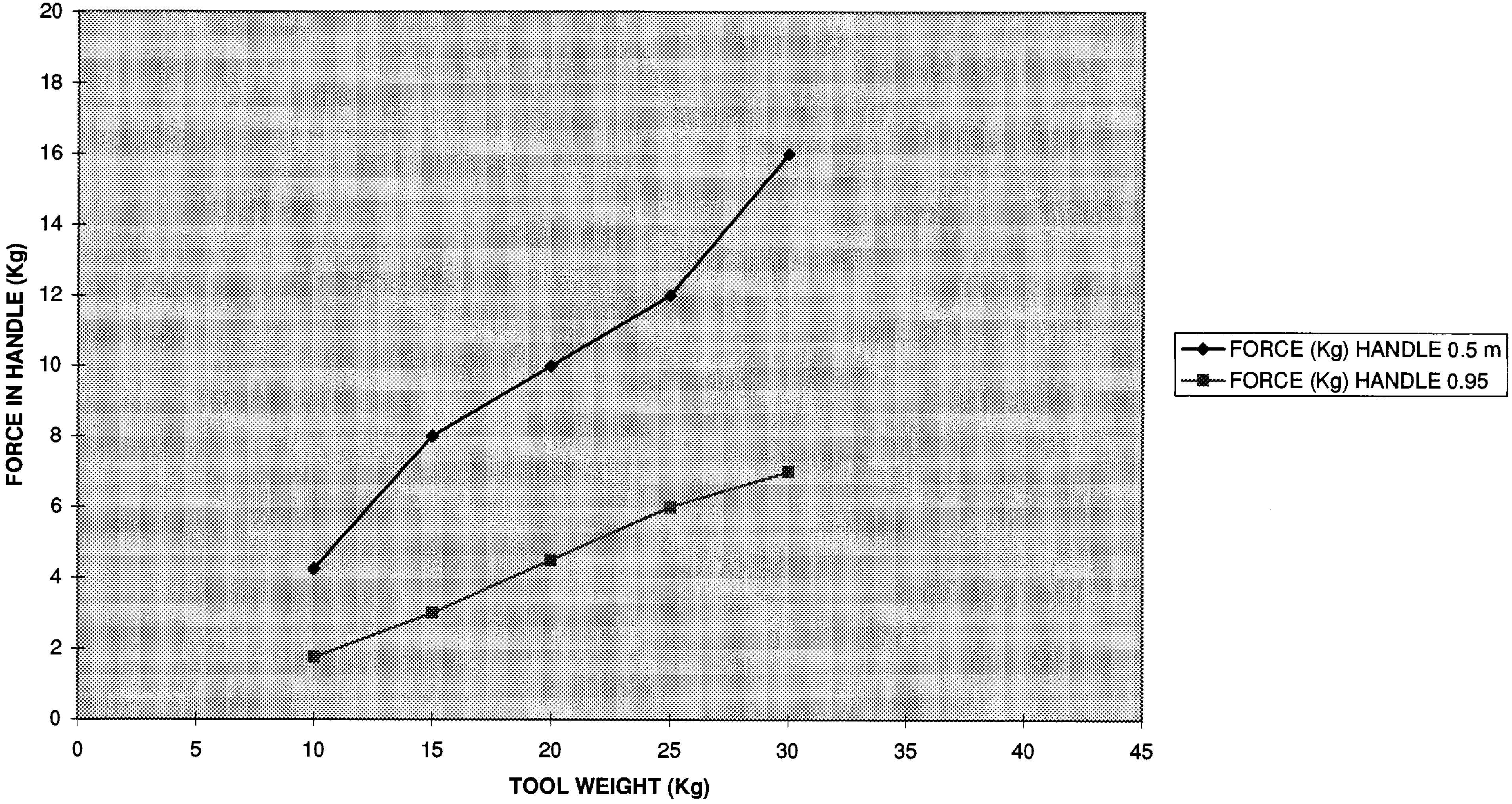
| | |
|---|---|
| **Total Labour** | **£500** |

| | |
|---|---|
| **Total Parts & Labour** | **£734** |

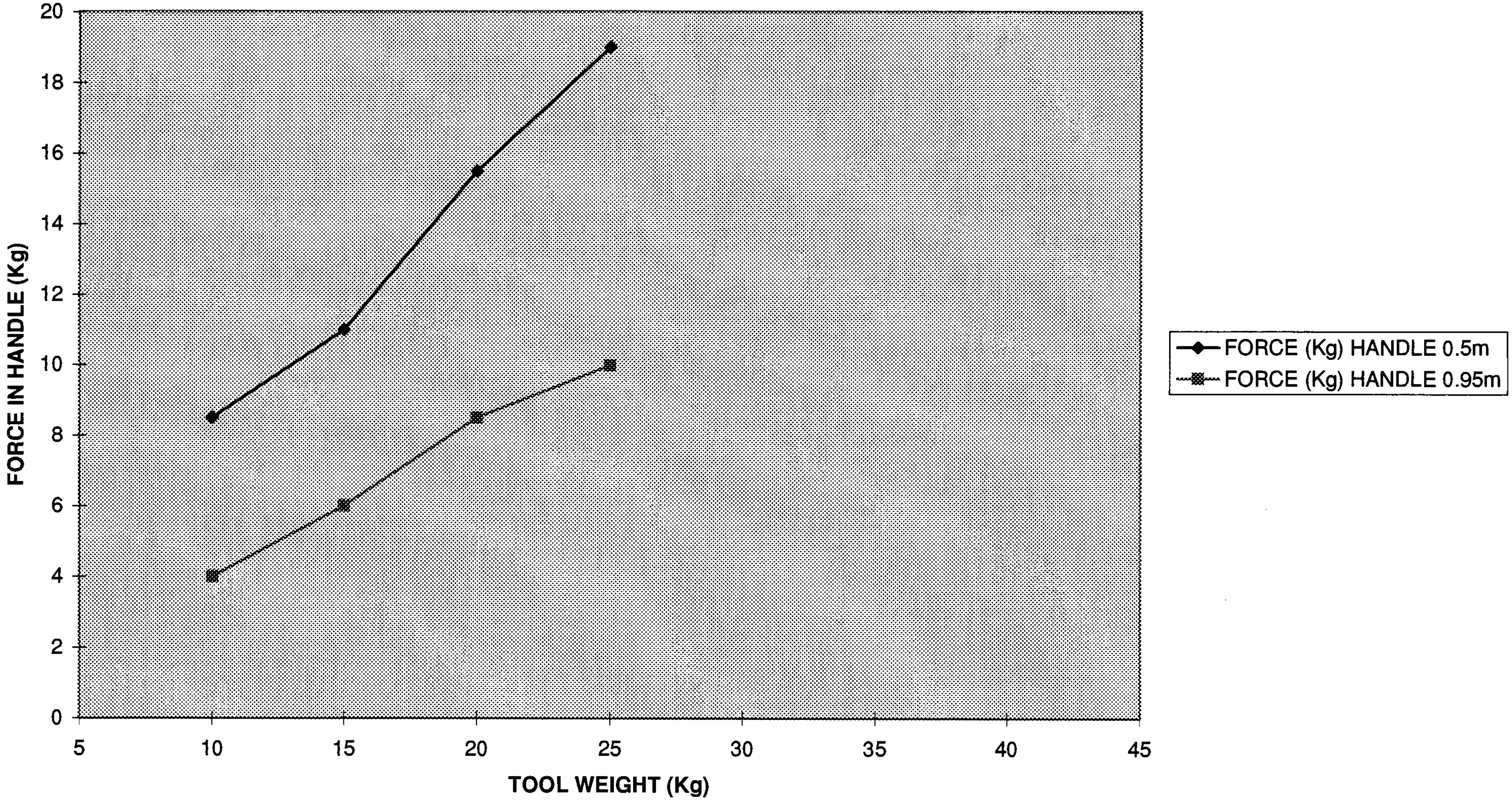
## Appendix 7. FORCE IN HANDLE AGAINST TOOL WEIGHT: ARM LENGTH O.5 m TOOL RAISED 0.085 m PULLEY TO SHAFT 3m



## Appendix 7 FORCE IN HANDLE AGAINST TOOL WEIGHT: ARM LENGTH 0.75m TOOL RAISED 0.22m PULLEY TO SHAFT 3m

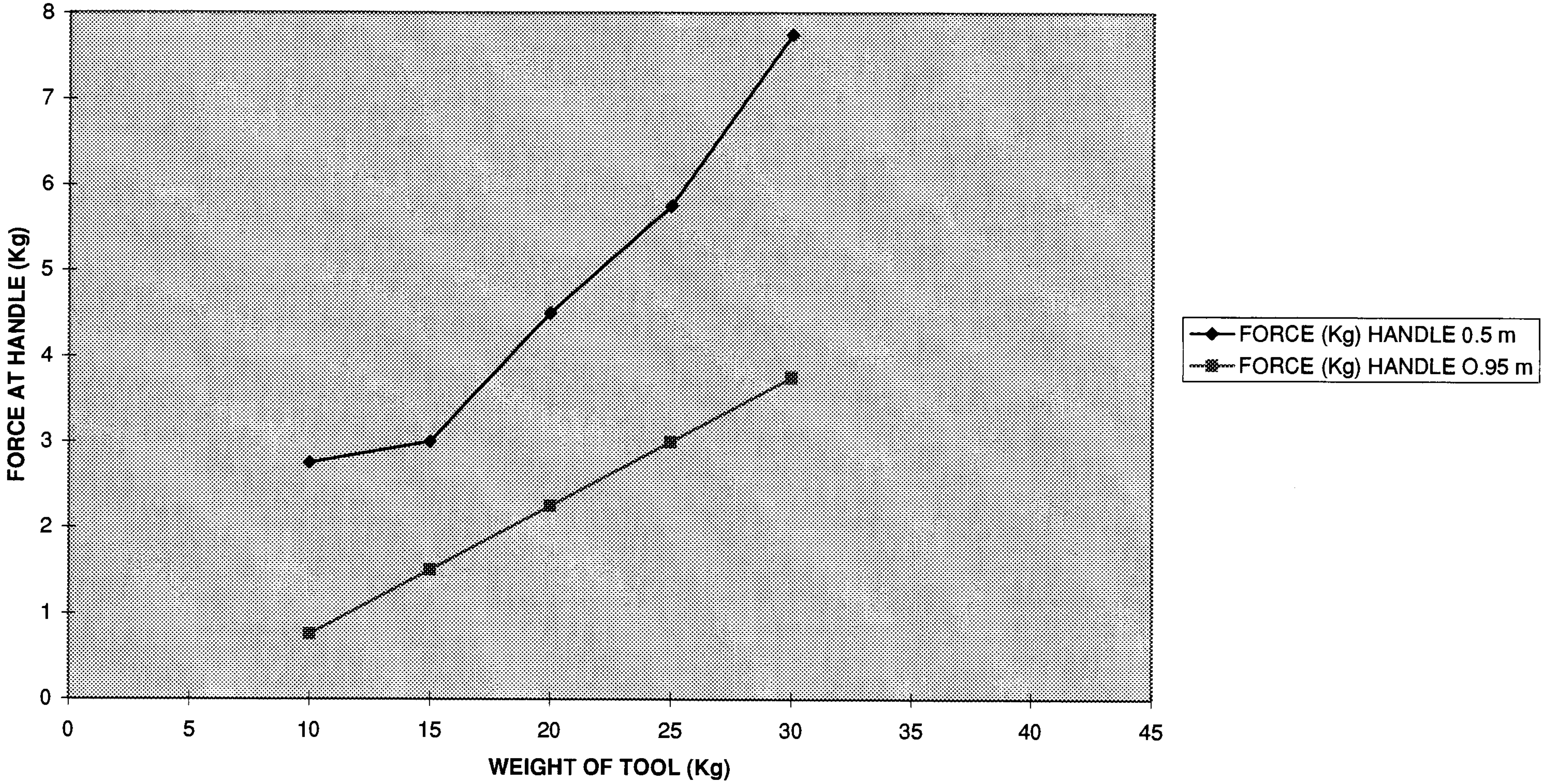


## Appendix 7 FORCE IN HANDLE AGAINST TOOL WEIGHT: ARM LENGTH 1.0m TOOL RAISED 0.37 m PULLEY TO SHAFT3m

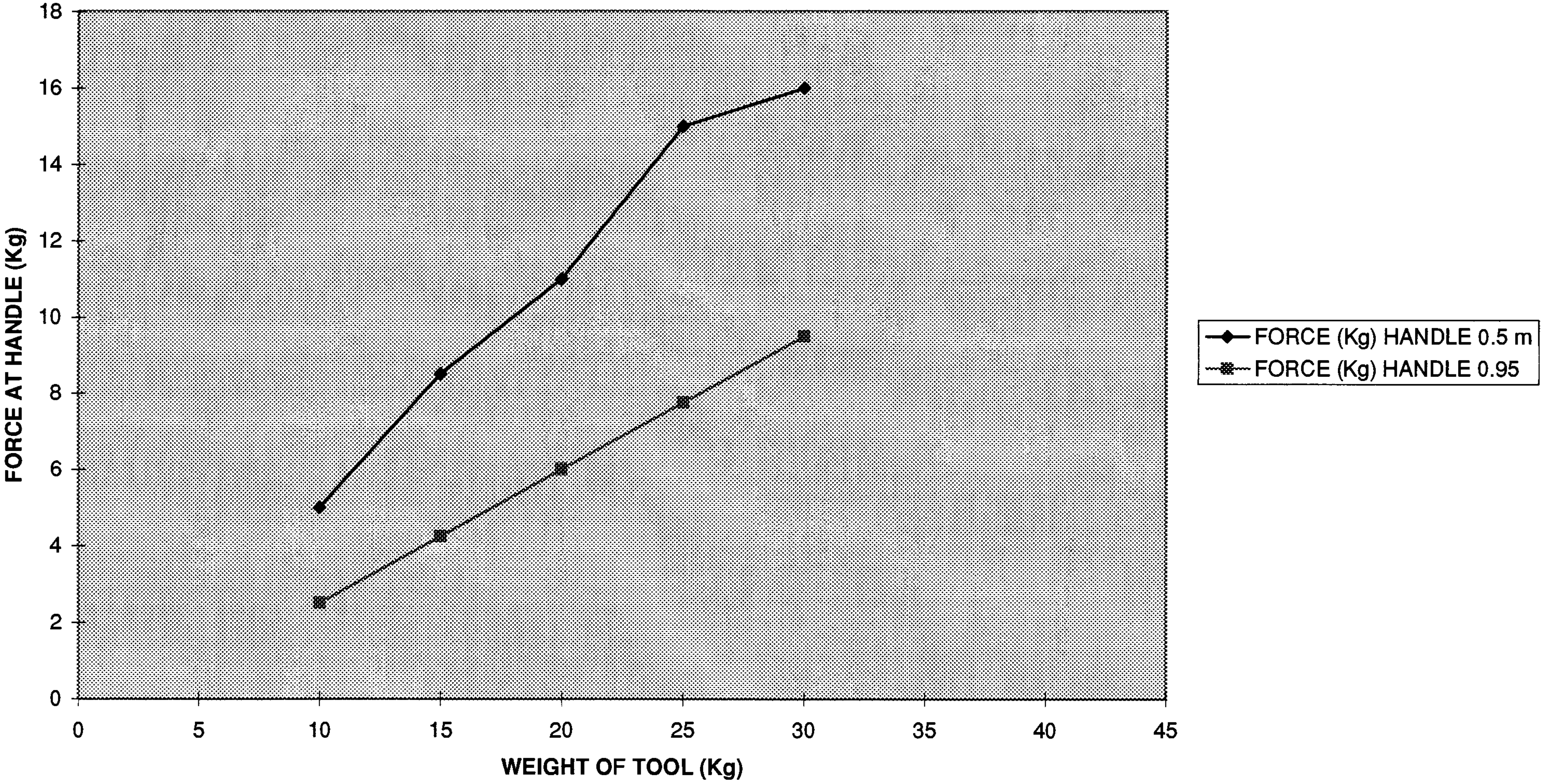


## Appendix 7

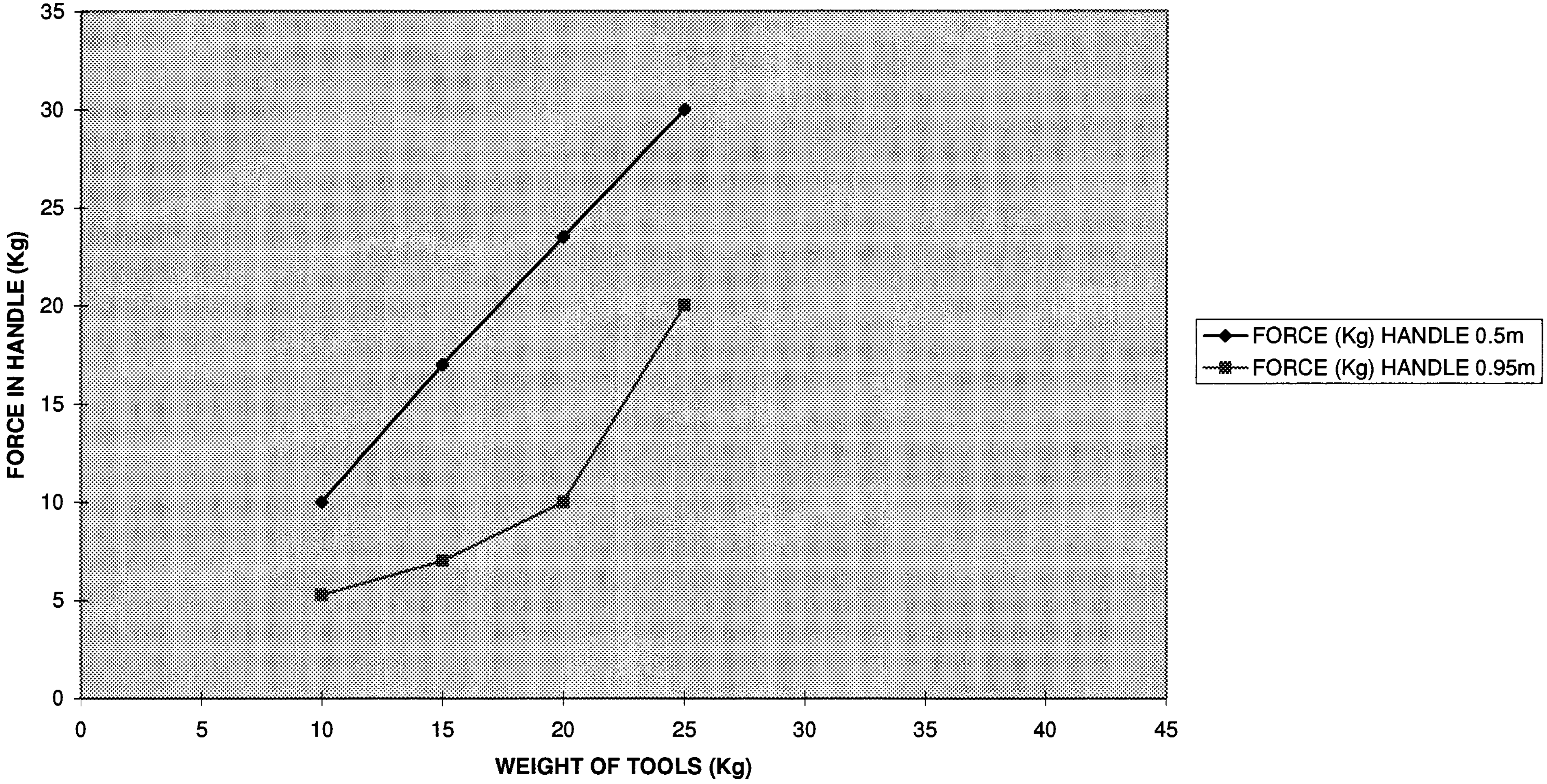
## FORCE IN HANDLE AGAINST TOOL WEIGHT: ARM LENGTH 0.5 mTOOL RAISED 0.12m SHAFT TO PULLEY 2m



## Appendix 7 FORCE IN HANDLE AGAINST TOOL WEIGHT: ARM LENGTH 0.75m TOOL RAISED 0.26m SHAFT TO PULLEY 2m



## Appendix 7 FORCE IN HANDLE AGAINST TOOL WEIGHT: ARM LENGTH 1m TOOL RAISED 0.46m SHAFT TO PULLEY 2m



# Appendix 8

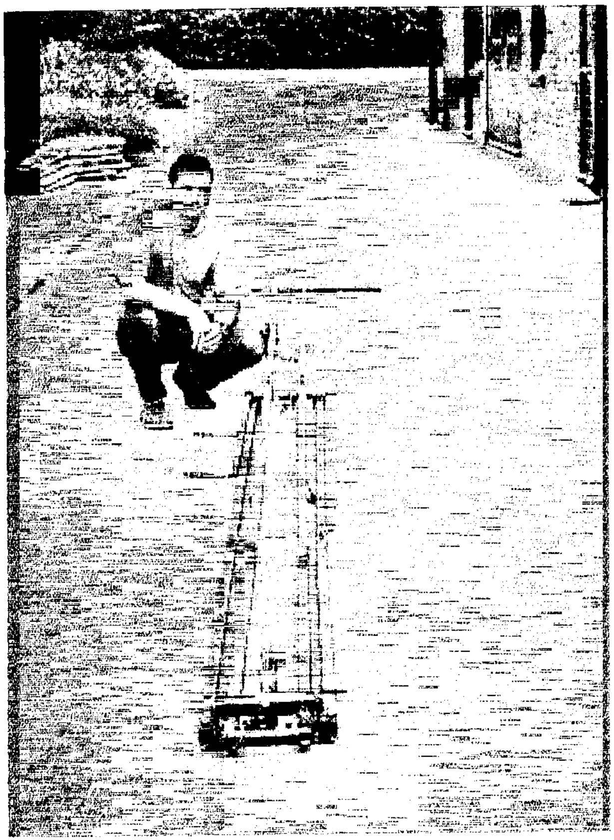


Fig. 8.1 Rig in Folded position

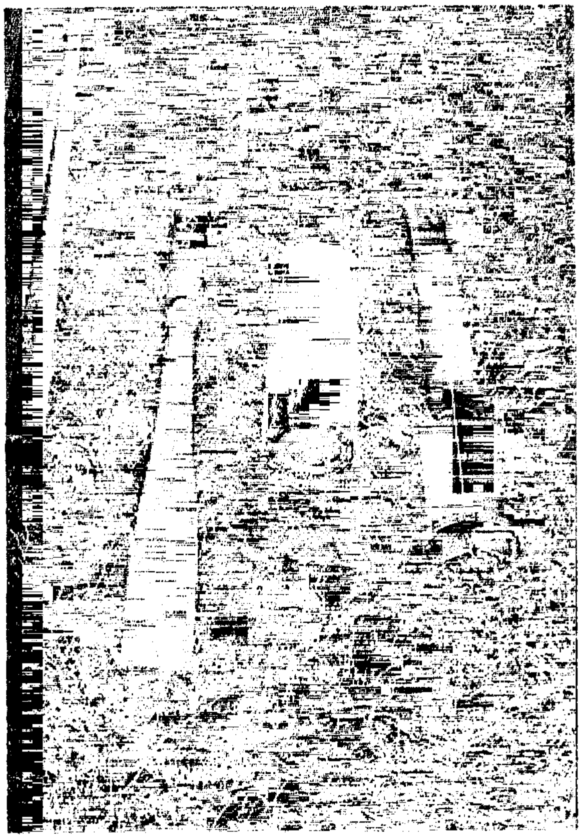


Fig. 8.2 Chisel, Bailer and Clay Cutter Tools

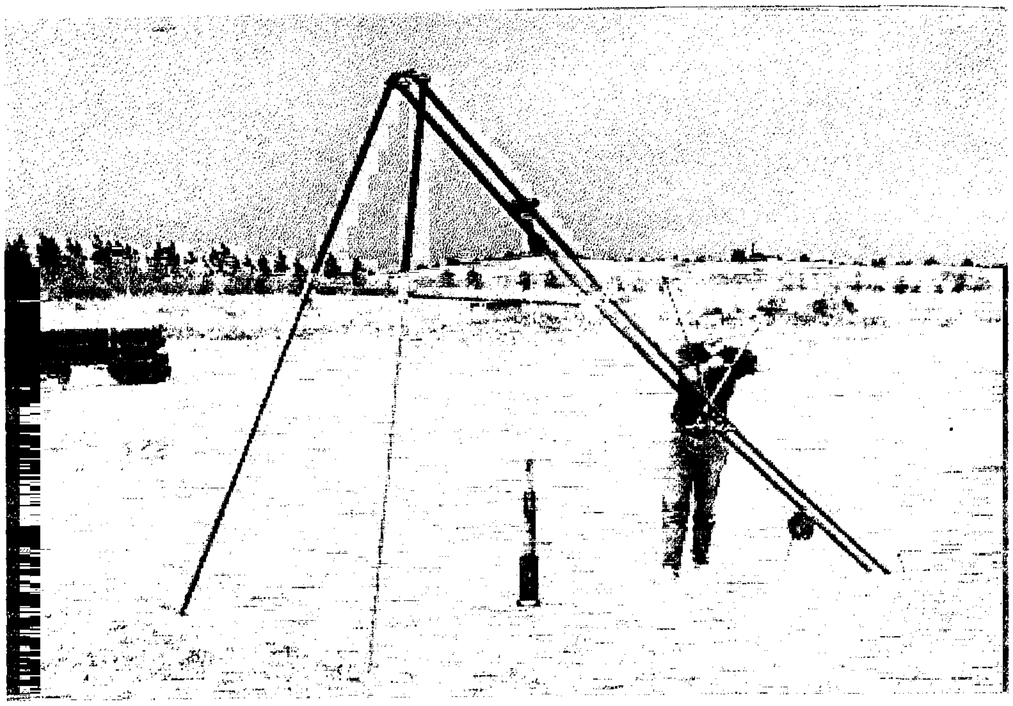


Fig 8.3 Rig Assembled Ready For Drilling.

# Appendix 8

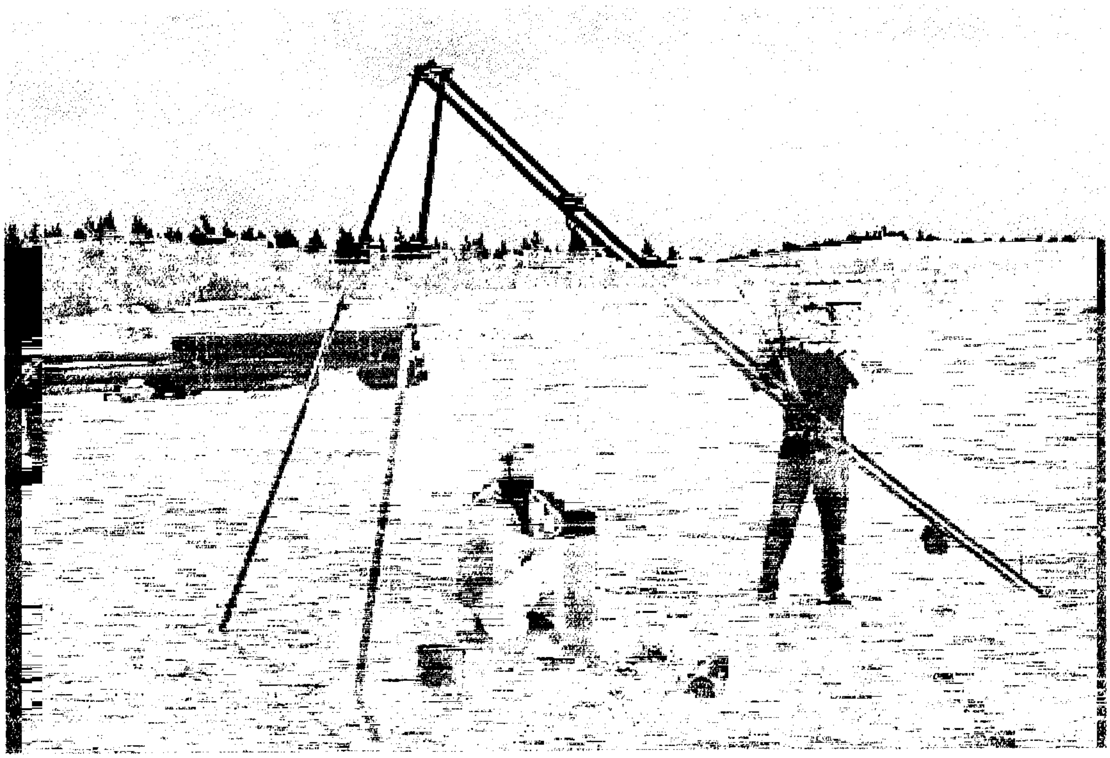


Fig 8.4 Drilling In Progress In Clay At Silsoe College Site. Clay Cutter Tool Using Conductor Pipe

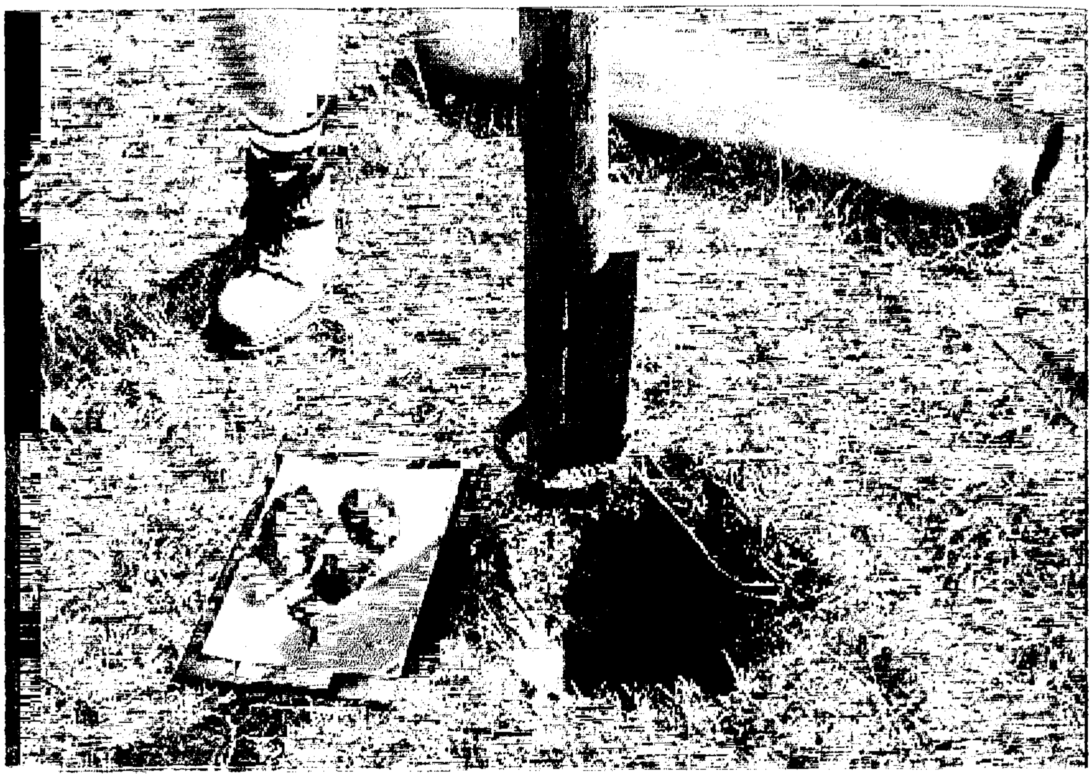


Fig 8.5 Detail Of Clay Cutting Tool And Borehole Showing Cuttings Cleared From Tool.

# Appendix 8

Fig 8.6 Detail Of Concrete Test Piece. Penetration 26mm, 17Kg Chisel Point Tool, 200 Strokes.

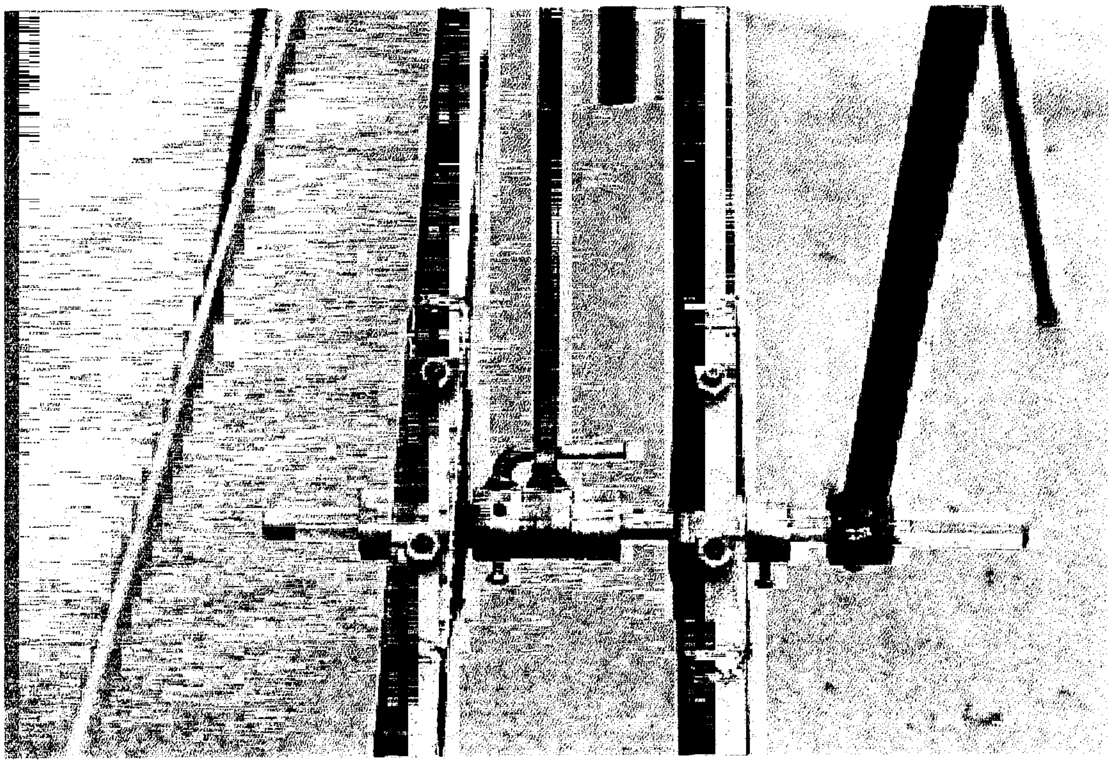


Fig 8.7 Detail Of Drilling Rig Mechanism. Showing Handle (Right) Shaft With Arm And Drive Pin (Centre)

# Appendix 8

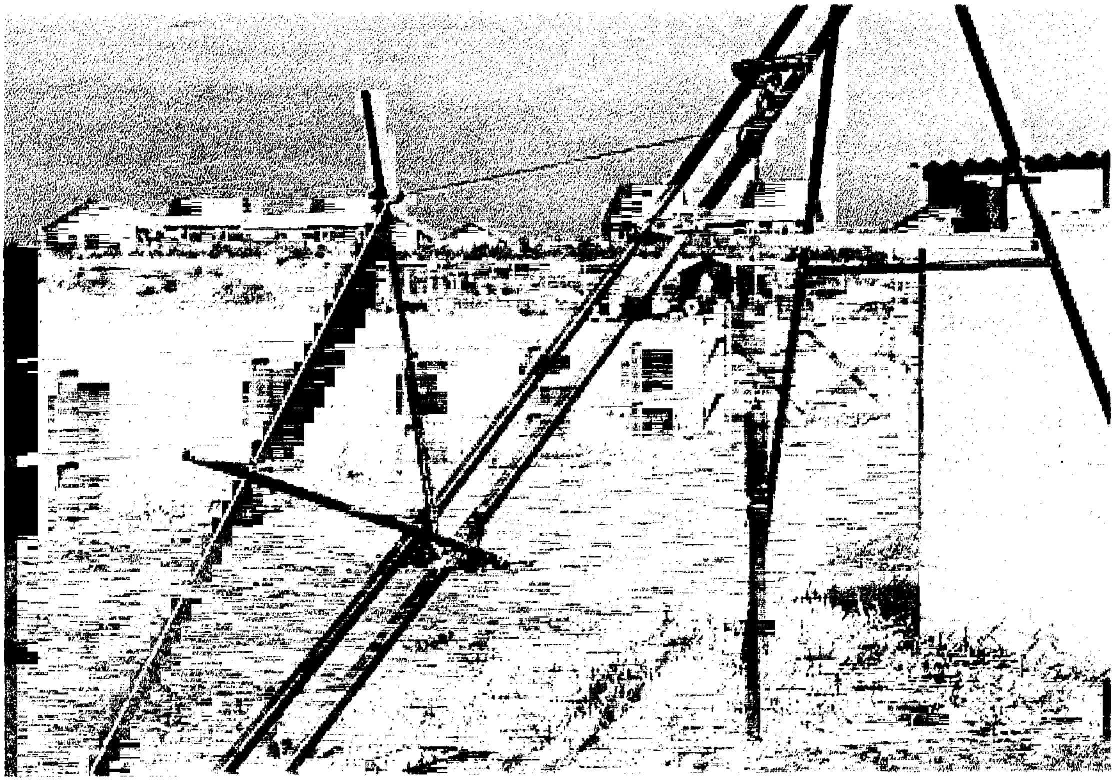


Fig 8.8 Chisel Tool In Raised Position Showing Cable Running Over Cable Hook, Arm And Handle Raised.

Fig 8.9 Detail Of Arm And Handle In Rest Position Showing Cable Winch.

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