

1. Table of Contents

2. Glossary.....	2
3. Introduction.....	4
4. Overview.....	5
5. Design choices	8
6. Pitfalls to Avoid.....	12
7. Technical Preparation	13
Structural Drawings	
Shop Drawings for Special Equipment	
8. Construction Manual.....	15
Appendix A Equipment List for Hand Dug Well Construction	35
Appendix B Specification for Hand Dug Wells.....	41
Appendix C Bill of Quantities	50
Appendix D Bibliography.....	53
Appendix E Acknowledgements.....	54
Appendix F About the Author.....	55

2. Glossary

Word	Definition
Apron	A concrete floor outside the head wall of a well. The apron provides a relatively clean environment around the well, and controls drainage of spilled water away from the well.
Aquifer	A water bearing channel or cavity in the soil or rock. Aquifers may be relatively open cavities, or consist of porous material with water moving in the interstices.
Base Plate	Bottom portion of a caisson ring mould, used to support the side forms, maintain circular shape and spacing, and to form the lower rebate edge.
Bedrock	Horizontal layer of consolidated rock formation extending much beyond the limits of the well.
Bucket Pump	A device for lifting water with a bucket without the removal and reinsertion of the bucket.
Caisson Binding Rods	Rods used to attach the bottom 3 - 6 caissons together during construction.
Caisson Lifting Bar	A device for lifting caisson rings. The bar is inserted into two holes in the inner surface of the caisson ring. A triangle of steel rod allows lifting with minimal stress on the bar.
Caisson Ring	Also Caisson or Ring; A cylindrical liner, usually pre-cast concrete or steel, which may be placed in an existing hole, or sunk in place by undercutting or other methods.
Caisson Sinking	A method of well digging consisting of undercutting pre-cast liners (caissons) to lower them in place and concurrently deepen the hole.
Capping Ring	The upper portion of a caisson ring mould, used to maintain circular shape as well as form the upper rebate edge.
Concrete	A mixture of portland cement, sand, and gravel. Other additives are sometimes used.
Contamination	Introduction of pathogenic organisms or toxic chemicals into the water.
Cutting Ring	A ring placed below the caissons to facilitate undercutting and sinking. Usually of concrete, it should have a concave bottom surface, and a slightly greater outer diameter than the caissons. It is usually not necessary if the caissons are suitably designed and used.
Destabilized Soil	Soil which has been disturbed, and is therefore at risk of collapsing or washing into the well.
Digging Hoe	A short handled broad hoe, approximately 20 cm square, with 65 -70 cm handle at right angles to the blade. Called a Powerah in India, it also exists in many indigenous forms in Africa, Latin America, and some parts of Europe.
Drawdown	The amount the water level is reduced below the static water level, at a

	given pumping rate.
Drilled Wells	Wells constructed with a variety of rotary and percussive mechanisms, usually power driven. Drilled wells may have diameters as little as 5 cm, or as large as 90 cm, but are more commonly between 10 and 30 cm.
Ground Water	Water which has been stored and filtered in the soil and rock below the surface. Such storage and filtration usually results in purification from biological contaminants. Sub-surface flows may however result in biological contaminants being carried to a well in groundwater contaminated by the mixing of surface water or other contaminants at some distance away.
Hand Dug Wells	Wells excavated and lined by human labour, generally by entering the well with a variety of hand tools. They may be as small as 80 cm diameter, and in some traditional cultures, as large as 15 metres diameter.
Hand Pump	A device for lifting water from the well without the use of buckets and ropes, and powered by human labour.
Head Frame	A structure placed over the well to prevent loose articles or soil being knocked in, to support a working platform, and usually to support a lifting apparatus such as pulley or windlass.
Head Wall	The portion of the well liner which extends above the ground level or above the surface of the apron.
In-Situ Lining	Casting a lining in place between the soil and an inner mould.
Lifting Calipers	Devices used to grip the top edge of a caisson ring for lifting purposes.
Lifting Holes	Holes left part way through the caisson wall to attach lifting bar or binding rods.
Light Lifting Head Frame	A combination of a protective head frame with a windlass for lifting and lowering material and sometimes workers
Logging	The process of recording the soil and rock conditions, aquifers encountered, and other relevant data on the well construction which may be of relevance in contract administration, maintenance, or in construction of other wells.
Modern Hand Dug Well	A well with improved depth, yield, lining materials, surface drainage, and/or other enhancements.
Moulds	Forms used for casting shapes such as caisson rings from concrete.
Perforations	See Weep Holes
Permeable Mixture	Porous Concrete mixture. It is unnecessary and dangerous in the case of caisson lining.
Rebate Edge	Overlapping joint edge of a caisson ring or culvert tile, used to assure better alignment of one segment with the next. Does not provide a water tight joint unless cement is used to join the segments.

Shuttering	Inner moulds used in in-situ casting of lining, or a temporary liner to support soil during excavation.
Soil Overburden	The layers of various soils encountered above bedrock.
Spawl	The tendency for surface layers of concrete to chip off and break away from the main body of concrete. One common cause for this is the corrosion and consequent expansion of reinforcing steel.
Static Water Level	The level of the water in a well that has not been recently pumped. It is normal for the SWL to change seasonally.
Surface Water	Water consisting of surface flows and therefore bearing surface contamination. If drainage conditions are not suitable, surface water may find its way into the well.
Tripod	A three-legged structure used for lifting heavy loads such as the weight of the caisson ring. The tripod is usually combined with lifting devices such as winches or block and tackles.
Undercut	Of caisson rings, the process of deepening the well by sinking the caissons as the hole is deepened.
Unstable Soils	Sands, silts, and other soil mixtures which may flow or collapse when one side is unsupported.
Weep Holes	Holes formed all the way through concrete liners to permit the free flow of water. In the case of pre-cast or caisson linings these are usually not necessary.
Well Cap	Usually a round concrete slab used to cover the well. The cap must be suitably reinforced. Pump mounting bolts and access hatches are cast into the cap as appropriate.
Well Head	The structural components of the well above grade level. Ie. Apron, Head Wall, Cap, and drainage.
Winch	A lifting device intended for greater lifting capacity combined with slower motion. May consist of a drum to wind cable, linked to a crank through a gear mechanism to achieve greater mechanical advantage.
Windlass	A lifting device consisting of a cylinder to wind rope on, and a crank mechanism. Usually has a light to moderate lifting capacity combined with relatively fast motion.
Yield	The quantity of water that can be drawn continuously from a well. The yield, measured in litres per minute, or gallons per hour, must normally be specified at some acceptable drawdown.

3. Introduction

There are several excellent books and articles about well digging, which were written in the 1960s and 70s.¹ With great appreciation for these works and their authors, we undertook this

¹ Two of the most notable examples are “Hand Dug Wells and their construction”, by S.B.Watt and W.E.Wood, and “Wells Construction”, by Richard E. Brush. The Bibliography contains a more complete list.

effort to provide some practical guidance on the choice and completion of technologies introduced in those documents.

A few important techniques and tools have been left out of the previous books in the field. Additional information is needed on the caisson sinking component, which is needed for completion of most improved yield wells. Giving credit where credit is due, those early texts very amply cover the topic of in-situ lining, while we barely mention it, leaving that topic instead to those who know it best.

Most of the earlier books were written as a sort of anthology of the various methods in use. Several construction methods were included which are not the most practical approach, and which are damaging to the finished wells, and/or dangerous for the diggers. Relatively little guidance was provided for choosing technologies, and even less guidance for mixing and matching components. In this document, we point out some necessary choices among these technologies and some of the pitfalls of inappropriate combinations.

We present designs for some of the essential equipment, optimised for durability, safety, and lower cost. These include; simpler, cheaper, more flexible, and surprisingly more durable caisson moulds, along with a light lifting head frame, a tripod, caisson lifting apparatus, and caisson binding rods.

Similarly the caisson wall thickness is optimised to avoid structures that are too heavy to be manipulated safely, or too thin to be easily reinforced without exposing the rod.

The author hopes that this contribution will help to resolve some of the problems and frustrations encountered by those attempting to use the caissoning methods in recent years with insufficient information.

4. Overview

4.1 A Brief History of the Modern Hand Dug Well

Hand dug wells have been used by humanity since before recorded history. Most civilisations that needed them had, and many still have traditional methods for well digging. In modern times some of the methods, equipment, materials, expectations, and standards for well construction have been improved to allow better and more permanent yields, depths suitable for modern pumping, and better protection from contamination.

Between the early 1930's and today, the dug well has evolved in some places from minimal, unlined holes to concrete lined structures with specified depth and yield, and with improved headworks and drainage.

A brief chronology includes the following:

- Africa; 1930's; In-situ cast concrete linings to avoid collapse and to exclude contamination. Other lining methods included bricking and stone masonry.
- India; early1950's; Caisson lining methods to meet the need for simpler and lower cost construction technologies. Entire wells were lined by this method.
- India; early1950's; Caisson sinking as a very effective method of deepening wells beyond unstable soils and beyond the water table.

- Africa; 1960's and 70's; Caisson lining methods to deepen wells that were mostly built with in-situ cast linings. Much of the caisson sinking method was lost in the transfer. Not much was done to rediscover it, as the writers of the time, and the users of the recent past did not realise the technology was missing.

The concept of the modern dug well, evidently changes with time, and with our own priorities. For most workers in the field it now includes: durable liners, usually of concrete; ample depth, achieved through caisson sinking techniques; improved yield, resulting from the greater depth; and improved headworks and drainage.

4.2 Comparison: Unlined vs. Caisson Lining vs. In-situ with Caisson Finishing

Lining Method	Unlined Well	In Situ Cast, Caisson Finished	Caisson Lined Well
Contamination	Almost impossible to exclude due to lack of headwall.	Can be prevented with suitable backfill, headwall, apron, drainage channel, and access method.	Can be prevented with suitable backfill, headwall, apron, and drainage channel, and access method.
Depth	Usually small due to lack of stability.	Final depth depends on finishing by caisson sinking.	Final depth depends on continuation of caisson sinking.
Volume of excavation	May be very large depending on soil instability	1.76 m ³ / metre of depth.	0.95 m ³ / metre of depth.
Volume of concrete	Not applicable	0.5 m ³ / metre of depth (in addition to headworks).	0.25 m ³ / metre of depth (in addition to headworks).
Labour required	Variable depending on depth	Approx. 4 – 8 Person days per metre of depth	Approx. 2 - 3 Person days per metre of depth

4.3 Comparison of Dug Wells (lined) with Drilled Wells or Boreholes

In some societies the modern dug well has gone almost unnoticed as the convenience of drilled wells came on the scene too soon. Drilled wells offered fast, standardised, relatively predictable results. Unfortunately they were also relatively expensive, and the necessary skills and equipment were not available at the community level.

Drilled wells have also led to some very wrong conclusions about the availability of ground water. Drillers trained to exclude water encountered in the soil overburden have logged the first suitable aquifers as being many metres below the surface of bedrock. In many instances this has led engineers and project administrators to conclude that dug wells were not feasible. In some instances it was later noted that large numbers of traditional dug wells already existed in the

same area.

	Drilled Well (Borehole)	Modern Hand Dug Well
Typical Cost	\$5,000 - \$12,000	\$400 - \$1,200
Typical Depth	15 m – 90 m Typical	8 m – 15 m Typical 6m – 25 m Effective limits
Water Quality	Greater chance of Salinity problems	Slightly greater chance of contamination
Access to Water	Requires hand pump or high tech pumping and power source	Allows full range of access and pumping options.
Community Involvement	Very low; Might involve attendance at some meetings arranged by outside animators	Typically high; May involve planning of site, contribution of cost, contribution of material, contribution of labour, direct participation
Small Contractor Involvement	Usually involves only larger contracting firms due to high capital investment; \$200,000 - \$400,000	Can involve very small firms and individual contractors, sometimes through hire/purchase of equipment; \$500 - \$2,500

What dug wells can do is access the water found in relatively shallow aquifers above the bedrock, and to a lesser extent, in the upper layers of bedrock. In our experience this is often more successful than drilled wells.

Because of their larger diameter, dug wells can be used where a community is unable to afford a pump. With suitable design, windlass, bucket pumps, or a variety of other low technology pumps can be used in place of a commercial hand pump.

Dug wells encourage entrepreneurial construction at a local level, owing to very low capital investment requirements. Because they are easily replicated, they place the project control back in the hands of village elders and civic minded individuals.

4.4 Caisson sinking at the heart of the hand dug well

Caisson sinking is one essential that makes improved and more consistent yields possible.

In parts of Africa where shuttering and pouring of concrete liners were introduced in the 1930's, caisson sinking has been added to that technology to make greater yields possible.

In India where caisson sinking was introduced in the 1950's and 1960's as a method of well construction from the “ground down”, it remains the most successful method of digging modern wells.

Caisson sinking is a method of deepening the well safely through unstable soils. It can also be used in stable soil conditions, and is the more effective for having been started before problems of instability developed. In addition to providing an efficient, permanent, cost-effective lining

material, it stabilises the well shaft, protecting the workers and the well itself during excavation. Achieving these benefits, however, depends on provision of the necessary tools and equipment, quality of the caisson moulds themselves, and on the training of the diggers.

4.5 The need for basic training in caissoning

It is important to recognise the key role of caisson sinking, especially in designing training programmes for well diggers. When used in combination with other technologies such as shuttering, the caisson sinking is done at the end of the digging process. It is therefore treated as a supplementary and trivial technology rather than the most important activity of all. A common feature of intensive training programmes for well diggers, is that there is so much to teach and learn that the "supplementary or trivial" gets postponed until the last half-hour. At this point the instructors say something like "...and then you put in the caissons, disinfect the well, cap it and you are finished". This trivialisation can lead to disappointing and sometimes disastrous results.

If the methods of sinking caissons are not clearly understood or the appropriate equipment is not provided, then the caissons are worse than useless. We have met well diggers who detested caissons, because they thought they were to dig through the unstable conditions below the water table and then lower the caissons into the hole before it washed in. This usually can not be achieved. What is worse, it makes it difficult or impossible to centre and level the caissons, and creates a serious risk of caving in the well shaft. Others delayed putting the caissons in place until far too late even though they knew the risks, because they had never tried sinking them with the appropriate tools. It is virtually impossible to fill a bucket with soil, with a long shovel, inside a caisson ring, especially under water. With a digging hoe, however, it is easy.

4.6 The efficiency of caisson lined wells

The ultimate efficiency of caisson lining methods is dependent on having the correct equipment and training. We have seen caissoning completely stalled due to lack of equipment and understanding. We have also seen wells constructed entirely with caissons, in less than ten days with 3 workers, where an equivalent well with in-situ cast lining would take about two months with a crew of 5. What is more important, it is done much more safely with the caisson sinking method.

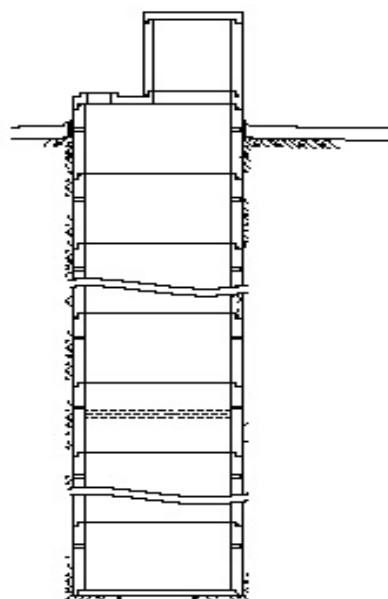
5. Design choices

5.1 Upper segment lining methods

As has been noted above, the choice of technology for well is relatively fixed. If the intake is to be deepened, continuous and dependable source in all seasons, or to caissons will usually be needed. In the top section of the author of this manual has his own preference, as v

5.1.1 Caissons all the way

When suitable preparations are made, there is a consi



Cross Section of a Caisson Lined Well

methods for the whole well as is eventually planned for the intake section. Caisson sinking provides a safe working environment, a superior and very cost effective method of lining, and simpler and less costly equipment purchase. Using only the one technology also allows a simpler, more concise and uniform training curriculum. Caisson sinking, an essential for the completion of the well, is a skill which must be taught in any case, but has often been neglected in the past owing to the perceived need to teach the in-situ casting technique first. In much of India and in other parts of the world where caisson sinking has been taught as the primary method of lining, there is no compromise of safety in digging an unlined, unstable shaft and then lining it. There is no trade-off between preliminary lining techniques and finishing techniques.

To those not accustomed to the sinking of caissons, there are a variety of disadvantages in the caisson sinking method, including the need to work in a more confined space and the need to manoeuvre the heavy caissons, both on the surface and down the well. Often the workers prefer to work in the larger diameter of the unlined hole used with in-situ casting, but this attitude is largely dispelled when the correct digging tools are introduced.

5.1.2 In-situ casting

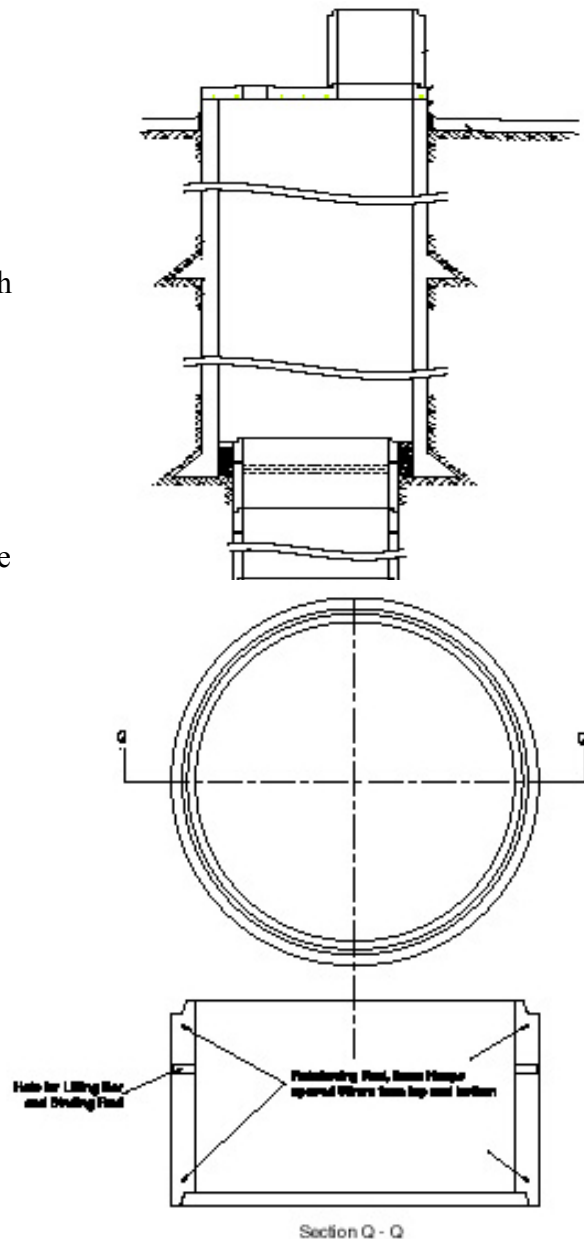
In-situ casting of the well liner is another method of placing a concrete liner in the well. In this method, the undisturbed soil of the outside of the hole is used as the outer mould. Shutters, or inner moulds are assembled in the well, centred, and levelled, and then the space between them and the wall, is filled with concrete. There are several disadvantages with this technique:

In the first place, digging must be stopped while the casting takes place. There is always the temptation to delay the casting a little longer and continue digging in an unlined shaft. The material requirements are much greater, as the wall thickness is greater, and the inner diameter must be large enough to permit the insertion of caisson rings through the upper section lining. Each section cast in place must be poured below the previous section, which creates problems in filling the moulds, and prevents the previous section above it. Lower sections cast and fall in, especially after unstable conditions.

There is a larger volume of soil to be removed to increase wall thickness. The walls must be sacrificed owing to the uneven wall thickness.

5.2 Caisson and cutting rings

Suitable design of caissons and where applicable



Plan and Cross Section of Caisson Ring with Rebate Edge

economy of materials, productivity, and above all, safety. A caisson ring with an OD of 110 cm, a wall thickness of 7 cm, and height of 60cm is light enough for three to four workers to manipulate. It is large enough for the same number to tip or roll safely in most environments without getting in each other's way. Increasing the wall thickness to 10 cm makes its weight too great to be manipulated by the number of people who can safely gather around it. This is one instance where thicker is neither safer nor more durable. One well digging project in Sri Lanka has successfully demonstrated that the caisson walls can safely be reduced to 5 cm, but we do not recommend this extreme reduction owing to the increased precision required in placement of reinforcing materials.

If rebate edges are used, then the caisson rings should be inserted with the narrow rebate edge at the top. This creates a natural filter in each joint and stops flows of sand and silt from entering the well, but more importantly, it makes it very much easier to undercut the ring without the use of a cutting ring. Some early illustrations of caisson rings with rebate edges presented in West Africa, showed the caissons inverted. Lacking any contrary information, these illustrations have been followed almost universally in the area, causing very serious problems.

Suitable moulds for producing the rebate edges have not been generally available in the past, and very poor substitutes have been commonly used, further complicating the difficulty of using this form of caisson. The use of base plates and capping rings, an innovation which allows the production of a more suitable rebate edge is described in the next section of this document.

There is almost never any need for perforations of the caisson rings or for the use of permeable mixtures of cement. The water enters easily through the joints between caissons and from the bottom. Some workers in the field have speculated on the need to use porous caissons in the intake section of the well. Such misconceptions likely result from the very real need for these measures in the case of In-Situ lining. In India in the 50's and 60's, only solid concrete caisson rings were in use for well construction. We are not aware that the water ever had any difficulty entering the wells.

Those who felt it necessary have tried both porous concrete, and weep holes cast in the caisson walls. We do not encourage the use of either of these solutions, as one weakens the concrete drastically and can cause spawling due to corrosion of the reinforcing rod, and the other vastly complicates and increases the cost of the necessary moulds. If designers insist on using porous caissons, however, we suggest they opt for the use of weep holes, as the use of porous concrete is far more dangerous.

If the caisson moulds are sufficiently accurate, and rebate edges are correctly oriented, then there is usually little or no need for a cutting ring. If cutting rings are used, there are several design principles to be followed in order to avoid serious problems: The outer diameter of the cutting ring may be made about 2 - 3 cm greater than that of the caisson rings, but must not be made more than this. Too great a wall thickness of the cutting ring makes under-cutting much more difficult, and perhaps more importantly, creates a thick layer of destabilized soil which is very difficult to restabilize if a flow should start on the outside of the caissons. The tapered edge of the cutting ring should be steeply inclined, and be concave rather than convex.

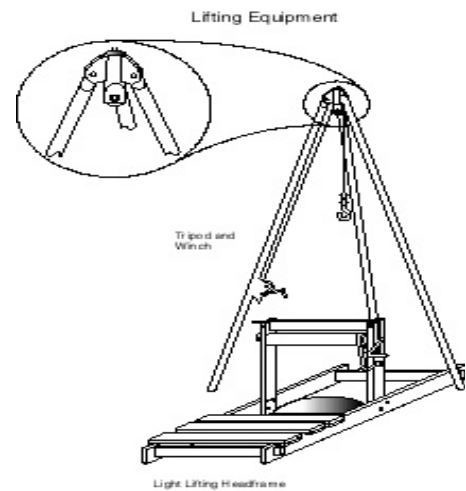
The caisson moulds presented in the shop drawings allow the outer mould to be made larger by the insertion of a wooden block in one or both of the joints. The base plate and capping ring each include a secondary seat to fit the enlarged outer mould, in order to make a cutting ring on the same mould that forms the rest of the caisson rings.

5.3 Caisson mould design

Caisson moulds were not always as complicated in design as they have become in recent years. In India, in the 1950s, caisson moulds were introduced that were made of simple hoops of 14 gauge or 2 mm steel sheet, with the ends bent at 90 degrees or angle iron riveted on to form bolt flanges. These moulds were much more flexible than many of the more complicated stiffened forms in the field today. Interestingly, the caissons were rounder with the old flexible forms, and the moulds never wore out.

The stiffened forms that have been introduced since that time are generally not sufficiently precisely built to offer a rounder product, but they are much more costly to produce and much more vulnerable to damage owing to their rigidity and the weakness of welded joints.

A design for caisson moulds has recently been introduced, which takes advantage of the lower cost and durability of flexible moulds, combined with rigid rebate edge moulds incorporated into a base plate and capping ring, to offer much rounder products. Draughtings of these moulds are presented in the [Equipment Shop Drawings](#), Section 5.5.

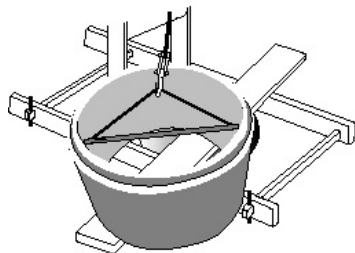


5.4 Other useful equipment See [Equipment Shop Drawings](#)

Designs for several additional pieces of equipment are presented in the shop drawings:

The Tripod is optimised for size and strength. This means that it is not only strong enough to lift two or more caissons together without buckling, but it is light enough to be erected safely by three or four workers, and large enough to operate over the head frame.

The Light Lifting Head Frame provides a windlass, with sufficient mechanical advantage to safely assist a worker from the bottom of the well, a convenient working platform over the well, and a frame around the well to prevent objects from being accidentally knocked into the excavation. The legs on the inactive side of the frame are sufficiently long to allow the windlass component to slide out of the way and still provide protection and support as the caisson rings are lowered through it.



Lifting Caisson over Well

Caisson Lifting Bar is a light weight triangular structure which attaches to the two lifting holes in the upper inside walls of the caisson ring to lift it. It fastens positively and yet flexibly to the caisson. It also causes less stress on the caisson itself than other devices like lifting callipers, for instance.

Caisson Binding Rods attach the bottom 3 to 6 caissons together to avoid separation during digging. These rods take advantage of the same lifting holes used by the caisson lifting bar.

5.5 Well head design See [Structural Drawings](#)

The well head structure consists of the head wall, well cap, and apron. Depending on the well cap design, it may also include an access hatch cover, and / or an access hatch extension. The

design presented here comes in two variations depending whether it is to be applied to a 1.5 m OD In-Situ cast well liner, or a 1.1 m OD caisson type well liner. The design is intended to provide maximum flexibility between the use of a hand pump, or the need to access the well for occasional maintenance or for regular use of a bucket. It may be seen that specialised moulds are needed to produce the pump base, the access hatch lip, the access hatch extension, the access hatch cover, and possibly the apron.

6. Pitfalls to Avoid

A series of problems resulting from inadequate specification, or through the application of inappropriate designs to caisson lined wells:

Where someone drew the caissons the wrong way up...

In West Africa, two visiting European engineers in 1989 introduced a drawing of a well with caisson rings at the bottom. The caisson rings were shown upside down. That Drawing was passed from agency to agency as a national hand dug well program was introduced in that country. Very many caissons were fitted upside down in about the next seven years. Among other problems, this made the caissons near impossible to sink without the use of a cutting ring.

But if the cutting ring design too was wrong...

The drawing of a cutting ring, most readily available, was one intended for use with caissons constructed from “H-blocks”, which are much thicker than a simple concrete caisson. The additional thickness and poor contour that resulted from the use of this design, made undercutting of the caissons about five times as difficult as it might have been if the caissons had been fitted the right way up in the first place. Worse still, the cutting ring destabilized a much greater thickness of soil on the outside of the caissons than is normal, with the result that when naturally unstable soils were encountered, it was far more difficult to cause the flows to settle out and restabilize.

And materials specifications are copied over from another lining specification entirely...

One of the techniques which may be necessary in in-situ casting of linings, that is totally unnecessary in the case of caisson linings, is the use of concrete with little or no sand in order to produce a porous wall. When this method is replicated in the case of pre-cast caissons, the resulting weakness and instability is a serious hazard for the workers.

When the project provides or specifies the wrong tools...

The shovel or spade, which is only a moderately usable tool in the large diameter hole excavated for in-situ lining, is completely unsuitable for caisson sinking. The handle of the shovel can not be tipped down in order to lift the soil to the bucket. In northern Ghana, one contractor showed off an incomplete “improved well”; incomplete because he could not cause the caissons to sink with the spade and pickaxe provided. The same contractor “moonlighted” digging traditional wells, about 80 cm diameter when lined, using the traditional local digging hoe. He was extremely successful and efficient in completing the traditional wells because he was using his own tools. Foremost among these was the digging hoe!

And so forth...

The list of case histories could go on much longer, but the point of all of this is to review our assumptions in the field. As an administrator or engineer sitting at a desk we can not easily see

the results of our choices, and they may not be reported back to us for many years. We need to remain vigilant for errors. There is a significant lack of guiding literature on caisson lining and caisson sinking techniques, and there is great danger in simply adopting the technologies used with other lining methods, for use with caissons.

7. Technical Preparation

The following sections are prepared on the assumption that dug well construction is to be organised on a regional basis.

7.1 Equipment Lists

Whether from the point of view of project management for a regional programme, or of a contractor or entrepreneur, it is equally critical that the correct equipment purchases be made. The attached lists are intended to facilitate appropriate selection of tools and equipment. See [Appendix 1](#).

7.2 Specifications

A set of precise and clear specifications is a prerequisite for bidders to respond realistically and competitively to the requirements of the Employer without qualifying or conditioning their bids. They serve to present a clear statement of the required standards of workmanship, materials, and performance for the goods and services to be procured.

[Appendix 2](#) presents a sample set of Specifications for procurement of well digging services.

7.3 Bill of Quantities

The objectives of the Bill of Quantities are as follows:

- a. To provide sufficient information on the quantities of Works to be performed to enable bids to be prepared efficiently and accurately, and;
- b. When a Contract has been entered into, to provide a priced Bill of Quantities for use in the periodic valuation of Works executed.

[Appendix 3](#) presents a sample Bill of Quantities format

7.4 Structural Drawings

The following links will open the structural drawings in PDF (Acrobat) Format

S-01 Caisson Lined Well	S-07 Cover Slab with Pump and Acc Cover
S-02 In-situ Lined Well, Most Common	S-08 Cover Detail (110 cm)
S-03 In-situ Lined Well, Variation 1	S-09 Cover Detail (150 cm)
S-04 In-situ Lined Well, Variation 2	S-10 Access Hole Extension
S-05 Caisson Ring Detail	S-11 Access Hole Cover

S-06 Cover Slab with Access Extension	S-12 Drainage Detail
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7.5 Shop Drawings for Special Equipment

The following links open the Shop Drawings in PDF (Acrobat) Format

S-05 View of a finished Caisson	E-08 Caisson Binding Rod Assembly
E-01 Caisson Mould Assembly	E-09 Binding Rods and Pegs Details
E-02 Caisson Inner Mould	E-10 Light Lifting Head Frame
E-03 Caisson Inner Mould Inserts	E-11 L. L. Head Frame Side and End Rails
E-04 Caisson Outer Mould	E-12 L. L. Head Frame Tower & Platform
E-05 Base Plate Detail	E-13 L. L. Head Frame Crank and Roller
E-05a Methods for Forming Base Plates	E-14 L. L. Head Frame Brake Assembly
E-06 Capping Ring Detail	E-15 L. L. Head Frame Brake Components
E-06a Methods for Forming Capping Rings	E-16 Tripod Components
E-07 Caisson Lifting Bar	

8. Construction Manual

8.1 Safety Issues

A general awareness on the part of the diggers and the site co-ordinator, of the hazards in and around the well is probably the most important requirement for the operation of a safe site. A knowledge and continuous awareness of well site organisation, discussed in the next section, is also crucial in preventing accidents. A basic knowledge of first aid, and a *practised* skill in the emergency evacuation of a casualty from the well are very important. Finally conscious and serious concentration on the job and avoidance of casual or joking behaviour on the work site may save lives.

Appropriate equipment is equally important to prevent accidents and mitigate the effects of both major and minor emergencies when they do occur. Suitable design of light and heavy lifting equipment for the routine raising and lowering of buckets as well as for the heavy tasks of manipulating caisson rings will greatly reduce the risk of accidents. Protective clothing, especially a suitably designed helmet, is very important. First aid equipment and escape and rescue equipment are needed on site in case of minor and major accidents.

8.1.1 Hazards of dug well construction

Falls and falling objects

The risk of serious accidents at the well site as well as the more minor cuts and bruises can usually be avoided through understanding the situations that can lead to such misadventures.

Poor organisation of the well site can lead to numerous mishaps including loose objects being knocked in upon the worker at the bottom. The next section of this document presents recommendations for avoidance of such mishaps.

Inattention while assisting from above can result in objects or workers falling into the well, possibly through loss of control of the rope or lifting head frame. While quiet good humour on the job is desirable, loud or boisterous behaviour on the part of the workers should be forbidden. Other distractions and casual visitors should be avoided. A brief discussion on mood and behaviour around the well site is provided in the section on site organisation.

Exhaustion of the workers can lead to serious falls while entering or leaving the well. Such exhaustion must be avoided, but also the preparations for entering and leaving the well should be such that even an exhausted or injured worker can get out or be assisted out without risk. Suitable design of the light lifting head frame allows workers at the top to lift the weight of a worker leaving the well without loss of control. Various forms of ladders are used for entering or leaving the well unassisted. These need to be suitably constructed to be easily gripped even in wet or slippery conditions. Rope ladders are not easy to use when one is exhausted. They can be improved considerably by suitable design and careful construction. Keeping the rungs small enough to fit comfortably in the fist and keeping the rungs exactly parallel, for instance.

Moving heavy objects

One of the serious hazards of well construction results from the need to manipulate heavy objects, most particularly pre-cast caisson and cutting rings. A part of the risk can be eliminated by the provision of suitable heavy lifting equipment.

In many instances we have encountered heavy lifting apparatus that was so heavy and unwieldy that it increased the risk of accidents.

A careful design can prevent much of the hazard, by balancing minimal weight with the needed strength. Oversized caisson rings concentrate so much weight in one place that sufficient workers to manoeuvre or lift one side of the ring are unable to gather safely around it. Reducing the diameter to 110 cm OD, and the wall thickness to about 7 cm, results in a caisson ring that can be safely tipped up, rolled into place, and tipped down at the edge of the well, by about three to four workers without interfering with each other.

Suitable design for both caissons and heavy lifting apparatus are discussed in the section entitled Design Choices, and further illustrated in the [Equipment Shop Drawings](#).

Air Quality

Poisonous gasses are occasionally found to occur naturally in deep excavations, but far more frequently they result from engine driven pumps, generators, or compressors used at the well site. Carbon monoxide laden exhaust is heavier than air, and therefore sinks down the well, pooling at the bottom. It is not sufficient only to avoid placing engines in the well. They should not be operated upwind of the well, or within about 8 metres in any other direction.

Workers should always enter the well with caution, mindful of any odours, malaise, or weakness that they experience. The team members above should also remain vigilant to assist the worker in the well without delay when needed. Any rescuers entering the well in the case of unexplained

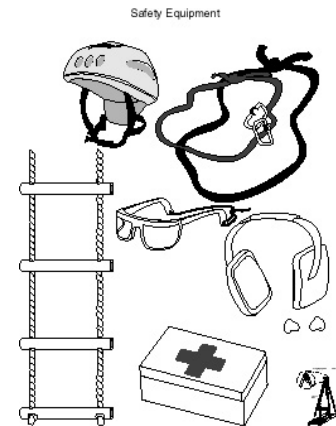
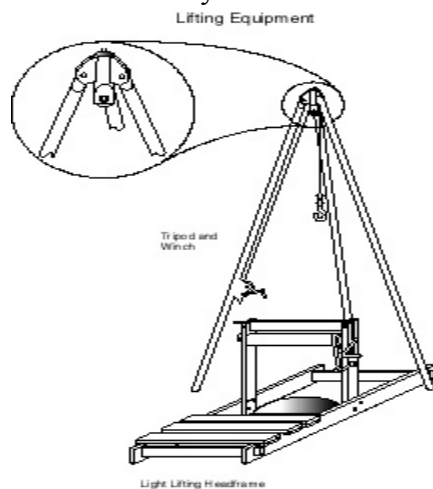
weakness or loss of consciousness should remain attached to a safety line themselves in case they should also succumb. See the section on escape and rescue.

When the air quality is known to be poor in an excavation, blowers can be used with flexible polyethylene duct to carry fresh air to the bottom. The blower may be as simple as a manually operated forge blower. If a blower is found to be necessary, it should be operated continuously by one full time worker who can both crank the handle, and also ensure that no kinks or blockages occur in the flexible duct.

8.1.2 Equipment for Safety

A responsible contractor will ensure that the appropriate safety equipment is at site and in use. In some instances the right choice of equipment increases production, as is the case with the lifting apparatus. In other cases careful purchasing will prevent impediments to production, as is the case with the climbers' helmet.

In all cases they will avoid work stoppages, prevent needless suffering and loss of life or limb, and incidentally ensure a good record for the contractor him/herself.



8.1.3 Light and heavy lifting apparatus

A well built light lifting head frame or “windlass” provides fast, safe efficient means of lifting soil, tools, and even personnel from the bottom of the well. In addition the frame provides a safe platform for the workers, and a protective wall to avoid dropping rocks, soil, or tools in on the worker below. See the design of the head frame, E-10, in the [Equipment Shop Drawings](#).

A tripod and winch are used for lifting and manipulating heavy objects such as caisson rings, into the well. The tripod should be appropriately sized for both strength and convenient use. For strength the height should be limited, and the legs should be of good quality 2" or 2.5" galvanised pipe. For convenience of use the height and weight should be such that three men can safely erect and move it. The winch must be appropriately sized to enable lifting at least 500 kg without undue strain, yet light enough and fast enough to avoid discouragement with its use. See the tripod design, E-16 in the [Equipment Shop Drawings](#).

If the tripod and windlass are built to the optimum dimensions then it is possible to operate each without removing the other completely from the well. This is a great convenience and also increases safety by removing the temptation to use the wrong lifting apparatus for any particular job. The tripod also provides an additional anchor for ropes and pulleys in the case of rescue operations.

8.1.4 Protective Clothing

Helmet or hard hat

The helmet is the most critical part of the protective clothing. A common but unsuitable practice is to provide the workers with ordinary construction hard hats. These fall off when working down the well, and thus are only in the way. The most suitable design for well digging is climbers' helmet. This is fitted with a chinstrap to avoid falling off at awkward moments. Climbers' helmets may be difficult to procure locally. They can be ordered from most sporting goods stores that cater to climbers. Some other sports helmets may also be suitable. i.e. Lacrosse, hockey, handball, etc, provided that they are fairly compact and fitted with chinstraps.



Climbing Helmet

Hearing protection

Where noisy equipment is used, particularly compressor driven breakers and drills, hearing protection is very important. These can take the form of earplugs or the headphone type ear protection. If earplugs are used, then provision should be made to replace lost or worn out plugs. They generally do not last forever. If headphone type hearing protection is used, it must integrate well with the helmet.



Hearing Protection

Eye Protection

Safety glasses are essential where any chipping work is being performed. Open type glasses are better for this purpose, due to the tendency for closed goggles to fog up in the well.

Boots

Whether boots are appropriate protective clothing depends somewhat on cultural norms. Probably it is appropriate to provide wellington (rubber) boots. It is not uncommon for workers to request leather work-boots because they represent a greater bonus or have greater status. The feet are most vulnerable when working under water, and the leather work-boots do not serve in that environment. Even with rubber boots it may be noted that the workers will remove their boots to go down the well. This may be because they are used to working barefoot. If so, they may in fact be safer in bare feet.

Gloves

Gardening gloves or other work gloves may be provided. It is unlikely that they will be used down the well, especially after water is reached. In any event rubber gloves should not be provided, as they can not be kept dry inside, and only interfere with awareness of hazardous conditions.

8.1.5 First Aid Kit

When mishaps do occur, it is essential that a basic first aid kit be available on site. A suitable first aid kit would contain the following list of bandages and antiseptic solution.

Adhesive Bandages	25
Adhesive Tape	1
Sterile Gauze Compress	10
Gauze bandages	5
Triangular bandage	2
Iodine solution	1
Soap	1
Scissors	1
Tweezers (forceps)	1

First aid supplies should be replaced when used. If the kit is not checked regularly to ensure that the full complement of supplies is present, they will not be available when needed.

A supply of aspirin or other drugs is not an appropriate first aid kit, nor should it necessarily even be included in a first aid kit.

8.1.6 Escape and Rescue Equipment

Ladders

Ladders have the advantage of enabling the down hole workers to get out of the well unassisted. They should never be seen as an excuse for not preparing to assist workers from the well. Badly designed or badly built ladders are a danger. Rope ladders in particular can be a serious hazard.

It is very important that the rungs of ladders be not only strong, but also sufficiently small in diameter to be firmly grasped in the fist of the climber. Eventually the workers will be climbing with mud on their feet, and the resulting slime on the ladder makes it extremely hard to grasp the vertical parts or rungs that are too large to fit in the closed hand.

Rigid ladders may be provided for shallow wells. If they are used, it is particularly useful to fasten ladders to the side of the well, as this prevents the situation where they are removed because they are in the way, and must be replaced by workers above before the down hole worker can get out.

Rope ladders can be provided for deeper wells, but it should be recognised that they are an additional stress for an exhausted worker, generally encountered after he/she has already reached the limit of his/her endurance. Rope ladders must be manufactured from known materials. The rungs must be kept small, and therefore must be of strong wood. The ropes must be chosen from materials that do not stretch over time. The knotting and assembly of the ladders should be done with great precision to avoid unequal or sloping steps, which can be extremely hazardous when slippery.

Harness

[How to Make a Hasty Harness](#)

[How to Use a Hasty Harness](#)

Two sets of rescue harness should be available at the well site,



Hasty Harness

in order to remove exhausted, injured, or unconscious workers from the well. The harness should be easy to apply to oneself or to another person. There exist a variety of manufactured harnesses, but most of them are confusing and awkward to apply, especially to a casualty.

Fortunately the “hasty harness”, one of the easiest forms of harness to apply to oneself or another person, is also one of the simplest and cheapest. It consists of two loops of webbing, which are applied as a seat harness around the legs and waist, and a chest harness crossed behind the back. It is important that all the workers at the site practice regularly applying the harness to themselves and to each other. This practice can be accomplished in conjunction with the lifting head frame, in the course of the digging work.

Extra Ropes

It is common to operate a well site with only one rope, which is normally in use to lift buckets of earth during the digging. A second strong rope should be provided at the site for rescue purposes. A suitable length for this rope is roughly double the normal anticipated depth of a completed well.

8.1.7 Mood and Conduct at the well site

The conduct of any one worker can affect the safety of the whole team. Good humour on the site is important, but excessive joking or casual behaviour is to be avoided. In the context of the well site, loud and boisterous behaviour is the same as careless behaviour. The results can be disastrous.

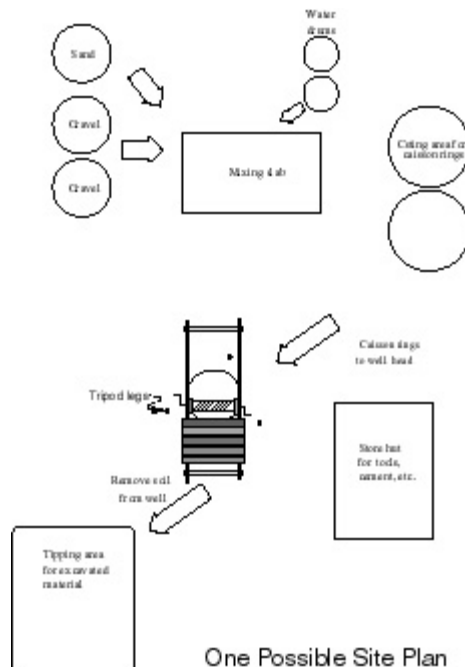
When a worker is in the well, at least one supporting worker at the top should be engaged in visual contact and quiet conversation with them at all times. Loud or joking behaviour among workers outside the well impairs this essential contact. Workers at the well head and other parts of the work site should move with cautious efficiency, never run if it can be avoided.

Alcohol and drugs must be avoided at the well site at all cost. A worker who comes to work inebriated, or drinks or takes drugs at the site, should be sent home immediately. Work should stop until they are gone and a suitable replacement has taken their place.

Casual and untrained visitors at the well site should be avoided. If dignitaries, villagers, or simply curious children come to the construction site, then the co-ordinator or a designated worker must take charge of their behaviour. They must explain the situation, either sending them away or showing them where they may safely stand or sit to observe without risk to themselves or to the workers.

8.1.8 Well Site Organisation

Good well site organisation is as important for productivity as it is for safety. The illustration shows one possible site layout. One important feature of the layout is to avoid over-crowding. Tidiness and cleanliness of the tools is equally important. Ropes should be coiled when not in use, and tools should be stored a convenient distance from the well head in order to avoid the



danger of tripping or knocking objects into the well.

The supporting activities such as concrete mixing and casting of caisson rings should be sufficiently far away from the well head to avoid crowding, and to allow safe storage of the caissons while curing.

Safety equipment should be equally as accessible as the production tools. First aid kits and rescue equipment are not adequately accessible if they are in a locked box when an emergency develops, therefore they should not be locked up during digging operations.

The well site organisation can deteriorate very quickly if it is forgotten. It should be a part of the normal discipline of the site leader, and his/her team members, to review the organisation at each rest break as well as at the start and end of each day.

8.2 Casting Caissons

Caissons can be cast on site, or at a central yard. Where there exist problems of access or transportation, it is likely to be simpler to transport the moulds and materials to the site and cast the caissons there. If they are to be cast on site, then it is important to start early enough that a supply of sufficiently cured caissons be available when needed. Assuming that the caissons are to be added when the excavation reaches about 3 metres depth, and that the caissons should cure for about 6 days before lowering in the well, then the casting should begin about 4 days before the excavation.

It is important that the forms are cleaned, lubricated, and assembled, and that the reinforcing steel be bent and ready before concrete mixing is begun. This is because much of the strength of cast concrete can be lost if it is not used promptly when it is mixed. As a general rule the concrete should be discarded if not used within 30 minutes after addition of the water.

The moulds are kept centred and round by assembling the inner and outer hoop mould on the base plate (lower rebate edge mould).

Two hoops of 6 mm reinforcing steel, wired shut, are prepared in advance. For maximum benefit they should be inserted roughly 50 mm above the upper surface of the lower rebate edge, and 50 mm below the lower surface of the upper rebate edge. Specially bent hooks of the same steel can be used to keep the reinforcing hoops centred and at the right height.

After the lower reinforcing hoop is in place, then the pegs that form the lifting holes can be added. At this same stage, if required (not recommended), the pegs to form the weep holes can also be added.

Temporary spacer blocks are used between the inner and outer moulds during the filling, and removed as the concrete level reaches them. The most convenient design for the spacer blocks consists of 25 mm by 25 mm lumber cut to 12 cm lengths, with a saw cut placed 7 cm from one end, so that the block can hang on the upper edge of the outer mould.

The capping ring (upper rebate edge mould) is added to the upper mould after it is filled to the lower surface level. The small amount of concrete needed to complete the upper rebate edge is added through the gap remaining inside the capping ring.

The concrete should be made with fresh dry cement, and with clean graded aggregate and clean sand (see [Specification](#)).

The mixture of cement, sand, and aggregate is prepared in the proportion 1: 2: 4, and clean water is added, cautiously to avoid making it too wet. The total volume of concrete needed for each caisson mould as described in the shop drawings, is 136 litres. Allowing 10% for losses, this volume can be conveniently mixed with a single 50 kg bag of cement. A corresponding gage box for the measurement of sand and aggregate, would be a 33 litre box, or a box with internal dimensions of 32 cm x 32 cm x 32 cm.

The concrete should be added equally all the way around the mould, in order to prevent distortion. It should be rodded as it is added, carefully in order to avoid damaging the base plate. The mould should be tapped with a soft mallet in order to vibrate the concrete into all corners and spaces in the mould.

The caissons should be kept moist for the first week after casting, or until used in the well, by sprinkling with water several times daily and by covering with wet cement bags.

8.3 Cutting Rings

When caissons with rebate edges are correctly orientated, there is usually little or no need for a cutting ring. Nevertheless, cutting rings may be found useful in certain soil conditions. The caisson moulds described in this document can be used to produce cutting rings when needed. This is accomplished by adding 47mm thick wooden blocks in each of the joints of the outer mould to increase its diameter by 30mm. This allows the outer mould to be mounted outside the base plate, and the capping ring to be mounted inside the outer mould. This in turn creates a cutting ring of 3 cm greater diameter, or 1.5 cm greater radius than the caisson rings.

8.4 Excavation

8.4.1 Caisson Lining Methods

There are two methods for lining a well with caissons. One is the “Dig First Line Later” method, which is similar to the In-Situ casting method, except that finished caissons are lowered down the hole in place of shutter moulds. The second and perhaps more important method is the “Caisson Sinking” method.

It is common to use both methods in one well, digging the unlined hole to a comfortable depth in stable soils, then lining that section with caissons and proceeding to sink them in order to deepen the well to greater depths and in unstable soils. What is most important is that the workers should be familiar and comfortable with the Caisson Sinking method in order that they should not postpone placing the caissons in the hole until it is too late.

8.4.2 Moving and lowering caissons

Improperly handled, the moving and lowering of caissons are two of the riskiest components in the well digging process. Done correctly and with adequate preparation, there is very little risk involved. In the first place the tasks should be undertaken with the essential number of workers, not more, and especially without crowding. It is not uncommon for spectators to rush to help when the caissons are to be moved. They should be warned to stay back.

Tipping caissons on edge

The caisson can be tipped safely by three or four workers. If it is resting on a hard surface a

small lever and spacers may be needed to make space for the workers' fingers. On a soft surface they can usually get their fingers under the edge. Small blocks of wood should be placed nearby to prevent rolling once the caisson is raised, especially on sloping ground. The caisson is raised by main force until the balance point, then held back so that it settles slowly onto its edge. This should be accomplished in one smooth action without pausing at the balance point. If the caisson is to be left on edge then blocks should be placed to prevent rolling. Workers, spectators, and especially children should be warned to stay off them.

Rolling the caissons

Caissons can be rolled by two to three people in most instances. If they must be moved up or down slopes then additional workers may be used judiciously, provided that crowding is avoided. One or two workers can be stationed ready to insert blocks to prevent rolling when the others are resting.

To roll up steeper slopes, a rope can be tied off at the top of the slope, placed under the ring, and drawn back over the top. Several workers can then pull from above while four workers steer from the sides, and one is stationed with a block to insert in case of need. This operation must be planned and laid out carefully so that the rope is laid straight up the centre of the path of the caisson. The caisson itself must be carefully steered to stay centred on top of the rope.

A similar method can be used to descend steeper slopes, but here the planning must be all the more careful. The rope can not be safely placed once the caisson is on the slope. It must be done before. The rope handlers must keep the rope centred above the caisson as it descends. There must be adequate length of rope to enable the caisson to reach the bottom of the slope without crowding the workers. It is very important that the route of the caisson be planned in detail, including where it would end up in case of mishap. If a safe direct route can not be found, then consider taking a round about route to avoid the steep slope.

Tipping the caisson over the well

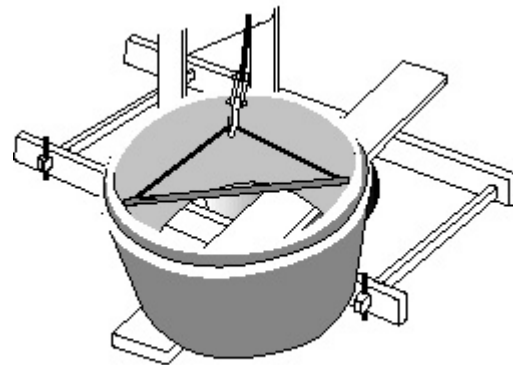
Settling the caisson over the well can be extremely dangerous if proper preparations are not made in advance. When the method is known and preparations are made, there is very little risk. In the first place, no worker should be in the well when this work is being done!

A simple temporary support structure is placed over the well to receive the caisson. A side rail of the head frame can be used as a part of this structure if the caisson is to be lowered through it. The head frame is slid along sufficiently to allow clear access to the well. If the head frame is not in place, then a single pole about 3 metres in length should be placed over the near edge of the well in roughly the position that the near rail of the head frame would be. Now a second pole of similar length is placed across the well resting on top of the first pole or the head frame as the case may be. The cross pole should have ample overhang above the soil on each side of the well. The thickness and weight of the poles will depend on the strength of the local woods. Ten-cm by ten-cm square cross section will be adequate if strong hardwood timber is used.

Now the caisson is rolled into position beside the well with the lower edge facing towards the well and the near rail of the temporary support. It is manoeuvred into a position such that its near lower edge is about 50 cm (in the case of 110 cm OD rings) away from the top edge of the near rail.

The caisson is tipped slowly towards the well, and lowered as slowly as possible onto the temporary support. In this, the additional height of the head frame is a considerable advantage, as the caisson has less distance to fall. In the case where sufficient height is not achieved by the temporary support to lower the caisson slowly into place, the cross pole may be raised by one or two workers on the other side of the well to meet the caisson, preventing it from falling onto the support. In this case the workers must exercise caution to avoid shifting the support structure out of its final position, and to avoid sliding the cross pole into a precarious position.

The resulting position of the caisson is near horizontal, with about one half of its diameter projecting over the edge of the well. This is sufficiently close to lift it without risk of tipping the tripod over.



Lifting Caisson over Well

Lifting and lowering caissons

It will be noticed that very little lowering of caissons is necessary when caisson sinking is used from the surface down. When the in-situ casting method is used, a deep hole may be prepared before the first caisson is lowered in. What is more, in this instance all of the caissons must be lowered almost the same distance.

A tripod and winch are used for lifting and lowering caissons. There are various methods for attaching the winch to the caissons: Ropes wrapped around the bottom of the caisson should be avoided for several reasons: The caissons supported by ropes under them are inherently unstable, and hang crooked. Once removed, it is very difficult to reattach the ropes in order to manoeuvre the caissons down the well if needed. The wear and tear on the ropes is very costly.

In this document we describe a caisson design with two lifting holes placed above the centre line, and a lifting bar which is inserted in these holes. This apparatus can be manufactured at little cost in most competent machine and welding shops. It is more secure and exerts less stress on the caisson itself than is the case with lifting callipers.

The tripod, winch, and lifting bar should all be inspected each time they are used to ensure safe operation. The winch cable must be wound carefully and smoothly on its spool to achieve long life and safe operation. The tripod should be firmly based, with its legs equally spaced and its feet at equal elevation. Ideally the legs of the tripod should be inclined at about 60 degrees from the horizontal. The top of the tripod should be centred over the well. With careful placement, it should be possible to operate the tripod over top of the head frame, without interference, one with the other.

In the event that it must be moved, it is useful to mark the position of each foot so that it can be returned to the same spot each time. It is possible to move the tripod short distances by walking the legs short distances, one at a time. Moving more than one leg at a time is very dangerous. In any event the roughly equal placement of the legs should be maintained for stability.

Caissons must never be lowered into the well with a worker below! The winch is attached to the lifting bar, and the cable is tightened to carefully lift the caisson off the temporary support. A

rope may be attached to prevent an uncontrolled slide toward the centre as the caisson is lifted.

The worker operating the winch must be familiar and prepared to use its braking capability during lowering. In some instances two workers may operate the winch as a team. Maintaining control of the winch handle during lowering is of paramount importance. Once control is lost, it is unlikely to be regained, as the handle may spin at dangerous speeds, and can not be caught without injury to the worker.

If the lowering depth exceeds the safe operating length of the winch cable, then the caisson must be suspended part way down while an extension is added to the cable. For this purpose, chains are the most convenient. It should be noted that not one, but two chains are needed, one to suspend the caisson, and the other to extend the cable. This is mentioned because the greatest probability of accident and injury results from makeshift methods of extending the cable or suspending the caisson.

8.4.3 Placing and levelling the caissons

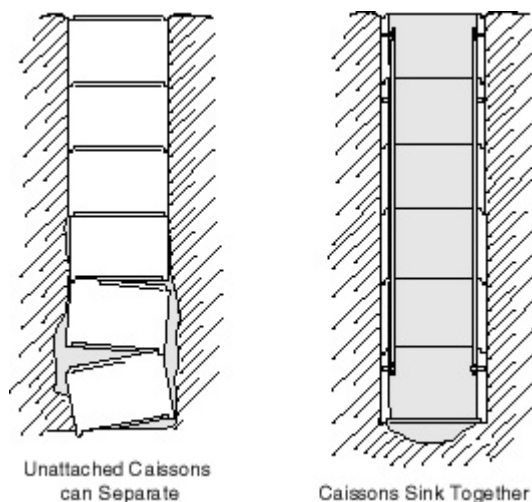
If some excavation has been completed before the first caissons are added to the well, then it is important to prepare the existing shaft. It must be large enough for the caissons to be lowered, vertical enough to avoid tilting the column of caissons (although final trimming can be made as the caissons are placed if necessary), and levelled at the bottom to provide the caissons with a suitable temporary base.

It is not advisable to join the caissons together with mortar until one is fairly confident that the final rings are being installed. The top three metres of caissons in the finished well should be joined with mortar in order to seal out potentially contaminated surface water. It may be possible to estimate which caissons will be in the final three metres after the water table has been reached, but not before.

Before caisson sinking begins, the existing column of caissons should be well fitted, vertical, and fastened together. Careful undercutting to level the bottom caisson, and trimming of the side walls as necessary to allow the stack to stand vertically, should enable workers to achieve a vertical and well fitted column fairly easily.

8.4.4 Attaching caissons together

One of the greatest challenges in caisson sinking is to prevent the bottom ring in the stack from falling out of line. In order to sink the caissons, they must be undercut. Without suitable precautions, one side of the bottom ring can fall ahead of the other. When this happens, that side tends to fall inwards. When the other side is induced to come down, it tends to move outwards so that the caissons are no longer aligned. After this happens it is very difficult to correct the situation or to prevent it from worsening. There is, however, a simple and effective method to prevent the problem.



During caisson sinking the bottom three to six caissons are temporarily bound together with steel rods. Various methods are available to attach the rods to the caissons. In this document we describe attaching the rods to pins placed in the same holes used for lifting the caissons, as this method leaves the bottom edge of the bottom ring free and does not interfere with digging. The binding rods also provide a convenient place to hook tools out of the way when they are not in use.

It is recommended that the binding rods be attached as soon as there are more than two caissons to join together. When problems develop it is already too late. In the event that one side of the bottom caisson separates before the rods are in place, the excavation should be stopped while the attempt is made to lift the bottom ring back into place and attach it.

8.4.5 Digging and caisson sinking

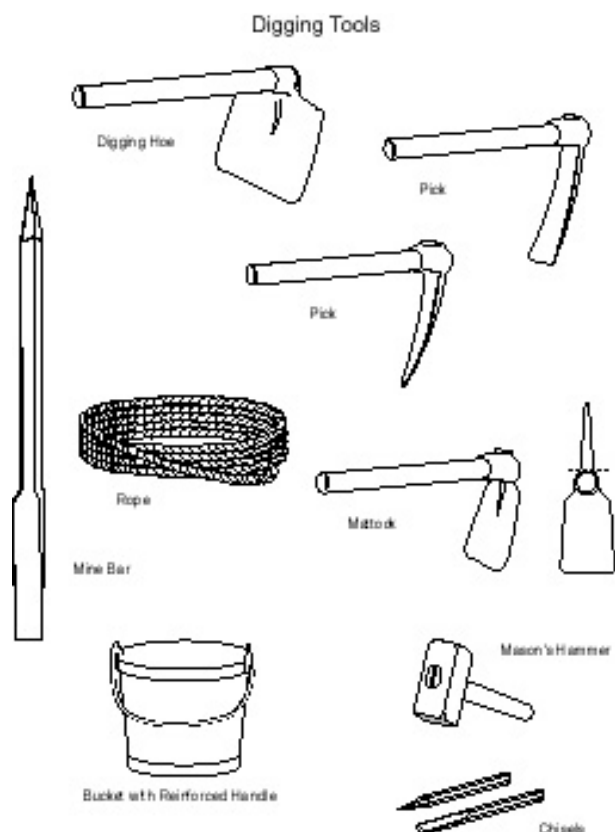
As is the case in any trade, including other aspects and methods of well digging, caisson sinking can be taught in one or two weeks of training, preferably in two or more sessions. The learning curve, however, will endure for years. The diggers develop a feel for their trade, which includes an intuitive understanding of the best methods to undercut a caisson in soft or unstable conditions, hard soil conditions, rocky conditions, etc, which will be refined over a period of years.

At a more elementary level, it is necessary to begin with the correct tools and suitable designs. One of the pitfalls of the last decade and a half of well digging projects has been that engineers and project managers have provided shovels and pickaxes for excavation in an environment where they simply can not be used. Digging in the more confined space of a caisson ring is virtually impossible if the only tool available to fill the bucket is a shovel. Undercutting is extremely difficult if caissons with rebate edges are inserted the wrong way up, if caissons are too thick, or if a cutting ring of poor design is used.

Tools for caisson sinking

While a more complete equipment list is presented in Appendix 1, it may be useful here to clarify what tools are appropriate for digging in confined spaces. Several conventional and modified tools are useful items for caisson sinking.

There is one essential, however, without which the job becomes near impossible. A short digging hoe is probably the most important tool for digging and filling buckets. A shovel will not accomplish these purposes. The digging hoe is a broad hoe with a head approximately 20 cm x 20 cm. In India it is called a "powerah"; in West Africa, simply a hoe (although this describes several local digging implements, some of which are very suitable, and some of which are too light for the purpose). The handle



should be about 55 - 60 cm long. The digging hoe is used for soft digging, collecting and scooping up loosened soil, and loading the bucket.

A second essential tool is the pick. If it is unavailable in its simple form, it is useful to modify the pickaxe that is almost universally available by cutting off its pointed tine and shortening the handle to 55 - 60 cm. If a pointed tine is desired for excavating in very hard soil or soft rock, then a second pickaxe can be modified by cutting off the flat tine.

A digging bar, commonly called a mine bar or crow bar is sometimes useful for excavating in hard soil, but shortened to about 90 cm, it will be useful for loosening stones in the confined space of the caisson ring.

A spirit or water level, about 60 cm long is needed to ensure that the caissons are sinking level, especially at the start of the sinking process. When the column of caissons becomes much longer, a plumb bob will serve the same purpose.

Digging in confined spaces

There is nothing particularly difficult about digging in the confined space of a caisson ring, once the correct tools are chosen. While the soil is loosened with a pick, the bucket can be pulled up above the worker's head, and the digging hoe can be hooked behind one of the binding rods where it is out of the way. When it is time to load the bucket, the pick can be hooked behind the binding rods, while the bucket is tucked between the digger's legs. It is a simple matter to scoop up the soil and drop it in the bucket. Once again, it is the choice of tools that makes all the difference.



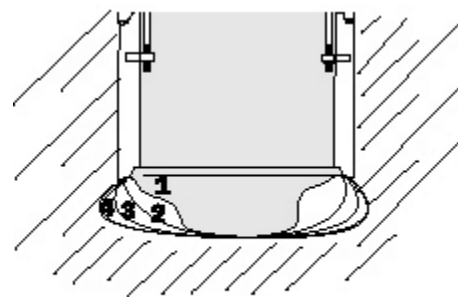
Filling Bucket with Digging Hoe

Elementary caisson sinking

With experience, diggers will find that caisson sinking is not significantly more difficult than digging an unlined hole. In many ways it is easier, owing to the smaller volume of earth to be excavated, and to the elimination of a centring and truing cut and the lining phase which are required in other methods of well lining.

When the first caisson is placed in the hole it is important to centre and level it. Periodic checking of the level, especially as the first few caissons are added, will save much difficulty later on.

The sinking begins with excavation of a small hole at the centre of the well. This hole is then expanded outwards until the inner edge of the caisson is reached. The most comfortable shape of the bottom of the hole during undercutting will depend slightly on the type of soil being excavated. In soft or unstable soil, it will be useful to keep the bottom profile very flat, while in very hard soil it is worthwhile to advance a bit more at the centre before undercutting. Useful methods for a variety of soil conditions are discussed in the following sections.



Undercutting the Caisson

When a comfortable bottom profile is achieved, it is time to start undercutting. This is usually

done with the flat pick. It is useful to undercut about 7 to 10 cm at a time, unless unstable flows of sand or silt have been encountered, in which case the undercut is reduced to 5 cm or less. The under cut is balanced on all sides of the well, and continuously expanded until the caisson sinks down.

The centre cut, excavation to a suitable bottom profile, and undercutting are then repeated until most of the first ring is submerged in the new hole. The level should be carefully checked and corrected before the second ring is added.

When the second caisson is added, it is useful to add one or two more at the same time, and attach them together with the binding rods. This will ensure that the stack moves together and that the first ring does not get out of line. The level should be used periodically during the sinking of this initial stack to ensure that the initial hole is plumb. As digging proceeds,

Experience shows that slightly different digging strategies are needed depending on the soil conditions at the bottom of the well. As different strata are reached the diggers will have to recognise the changes and adapt their techniques to suit. The following sections provide some initial hints for the various conditions.

Soft soil conditions

As was mentioned in our initial discussion of the basics of caisson sinking, the bottom profile will be slightly different depending on the soil conditions. In the case of soft soil, it is not advisable to advance too far below the leading edge of the caisson ring. A suitably controlled subsidence of the ring may be achieved with the bottom dished about 15 to 20 cm below the leading edge. In very soft soil, it may be necessary to reduce this to only about 10 cm, or even less in the case of flowing sand, silt, and mud. See the section on stopping sand, silt, and mudflows below.

Hard soil conditions

In hard soil conditions it is permissible to advance the centre of the hole somewhat farther ahead of the leading edge. In this case it is all the more important that the bottom three to six caissons in the column are securely fastened with the binding rods, and that the undercutting is restricted to a section not exceeding 5 - 10 cm deep immediately below the leading edge of the caisson ring. Again, in the case of flowing sand, silt and mud, The dishing of the bottom should be limited in an effort to have the leading edge cut through the flow and cut it off. See the section on stopping flows below.

Rocky conditions

In rocky soil, a great variety of conditions might prevail. Consolidated layers of rock, or occasional boulders of various sizes.

(i) Consolidated rocky strata

In the case where a consolidated layer of progressively harder rock is encountered, the decision might be taken to carve a level seat in the top of the rock on which to rest the bottom caisson. The workers may then proceed to hollow out the rock at the inner diameter of the caissons. This forms a natural lining, and the prognosis for success or failure of the well is best determined from local experience. It is possible that a small source of water will have been encountered just above the rock, and that all that is required is a small reservoir excavated in the rock to take advantage of this source. On the other hand, local experience may show that fractures or

changes of strata may be encountered at not too great a depth, and thus the excavation proceeds in search of sources of water at greater depths. This work progresses from pick work to hammer and chisel work as the rock becomes harder. Provision of a hammer and chisels of sufficient quality may allow a substantial water source to be carved from the rock. It is found that in many cases the local experience consists of constructing small reservoirs in the top of a consolidated rock layer. In such cases the provision of suitable hammers and chisels may make the difference between a minuscule source that must be dipped by hand, and a substantial reservoir capable of serving several families with improved methods of accessing the water.

(i) Isolated rocks or boulders

Where isolated rocks are encountered during excavation, they must be freed from the soil around them and pulled out of the well. In many cases they can be simply put in the bucket and hauled up. In other instances they must be attached to the rope from the windlass or even the winch cable. In the latter case, of course, the workers must attach the rope and leave the well before the rock is lifted.

Rocks of significant size can be encountered in many different ways during caisson sinking. When found in the centre of the well they present relatively little problem, except in the amount of labour required to break them free from the surrounding soil. Often they will be encountered under the edge of the caisson ring, in which case it is important to remove the rock into the well before undercutting the rest of the circumference of the caisson. Usually it is possible to undercut enough to tip the rock into the well.

When rocks are encountered outside the wall of the caisson, a crucial decision must be made to determine whether the caissons can safely pass by. If there is any doubt at all, then the rock should be undercut and removed into the well. Sinking the caissons further might make this task much more difficult. Often the size of the rock can be approximately determined by digging around its upper parts. The removal, however, can only be accomplished by thorough undercutting, and sometimes, even excavation behind the stone.

In the case of boulders too heavy to lift out with the winch, or too large to remove through the well, it is occasionally possible to break off enough of the boulder to allow the rings to pass freely. It should be noted that blasting with the boulder in direct contact with the caisson ring is likely to break the ring as well.

In the event that the boulder is centred in the well, or for other reasons can not be removed, it may be necessary to abandon the well and start again a short distance away. In this case it is usually possible to salvage most of the caisson rings. Obviously in the case of in-situ casting, the well lining must be abandoned.

Stopping sand, silt, and mud flows

One of the greatest advantages of caisson sinking is that it is possible to excavate through a mud or sand flow and cut it off so that the well construction can continue. It is important to stop such flows, both in order to achieve a clean and maintainable well, and to avoid contamination through sub-surface funnels. Of greater immediate importance, is that if there is a section of in-situ casting above the flow, then the cavity created by the flow can cause the anchors of the lining to be undercut, and the lining to subside or fall right into the well.

There are a variety of techniques that can be tried in order to more effectively cut off the flow of liquid mud or dry sand or silt into the well. First and foremost is to attempt to settle the rings as

much as possible by undercutting all sides in addition to the portion where the flow is entering. The dishing of the bottom should be reduced and the vertical depth of the undercutting should be minimised, especially on the side towards the source of the flow.

If this method fails, a decision may be taken to allow some of the material to accumulate in the well. Stopping the excavation for up to several hours, or overnight, may allow the solids in the flow to settle out and stabilise, once the flow is slowed down by the back pressure of accumulated material within the well. Dewatering should be stopped during the pause, as the back pressure of the accumulated water will also help to slow the flow and allow the solids to consolidate.

If the flow can be seen from above, around the outside of the caissons, it may be possible to slow it sufficiently by pouring coarse dry sand down into the portion where the flow sinks along the side of the caisson. Occasionally pushing brush foliage into the flow can also be effective. It should be noted, however, that this foliage is difficult to remove after the flow is stopped. If left in place, it will decompose behind the wall of the caisson, and may cause an unpleasant taste and odour to the water for many months after the well is completed.

Persevere. If one of these methods does not work, proceed to the next, and attempt them repeatedly.

8.5 Dewatering During Construction

One of the main objectives of an improved dug well, is a substantial water source of a quality suitable for pumping, and dependable during particularly dry years. In order to achieve these conditions, it is necessary to continue excavating and caisson sinking, typically 2 - 3 metres below the water table. In some areas where the water table is known to fluctuate more than this, even more depth is required. As the deepening proceeds, it is necessary to remove more and more water along with the soil. At the beginning the lifting head frame and bucket may be sufficient to achieve this purpose. As the work progresses, however, a point is reached where excavation can not continue without mechanical means of dewatering. There are several possible methods of dewatering, and they are not all equally safe or equally effective.

8.5.1 Engine driven centrifugal pumps

In the case of very shallow wells, a simple, gasoline driven centrifugal pump may be used. This should be one of open impeller design to allow some solids to pass. It should be self-priming or easy to prime. It should have sufficient intake hose to permit the pump to be placed back from the well, down wind, and preferably behind a shallow dike to prevent the exhaust fumes from entering the well.

A centrifugal pump has some serious disadvantages. It is usually difficult to throttle down sufficiently, and so must be shut off when the well runs dry. It is inconvenient to start and prime, and gets progressively more difficult as the depth increases until a point, typically around 7 metres depth, where they can not function. There will be a temptation to move the pump closer to the well or even to lower it into the well. This must not be permitted, as the exhaust fumes are one of the most serious dangers encountered in well digging.

8.5.2 Electric submersible pumps

Electric submersible pumps are available in a great variety of qualities. They may be used in dewatering, if suitable attention is given to protecting the electric cord, and to grounding the generator to avoid shock hazard at the bottom of the well. A submersible sump pump or mine dewatering pump design is suitable because of the open impeller design and the built in exclusion screen to prevent too large particles from fouling the impellers. Sufficient pumping head must be available at the anticipated flow rates. Size is also a concern, as too great a size will interfere with the digging operations.

Reliance on external float switches can be awkward in the confined space of the well. If a built in float switch is removed or broken, then the wire ends must be very thoroughly sealed and taped out of harm's way.

Generators purchased to operate a submersible pump should be selected for the necessary power conditions, but also of portable design. It is important that sufficient cord be provided to allow the generator to be installed well back from the edge of the well, down wind, and preferably over an embankment of soil. The cord should be of sufficient capacity to accommodate the extra length, and of industrial quality insulation for safety. Worn extension cords must be replaced regularly

8.5.3 Compressor driven pumps

Compressor driven pumps are available in both centrifugal and diaphragm types.

The centrifugal design tends to be extremely hardy against external shocks, dirty water, etc. Their capacity is usually too high for the dewatering purpose and they are not easy to throttle down for slower continuous operation.

Diaphragm type pumps are available in a variety of sizes. They can be more successfully throttled down for continuous operation. Nevertheless, excess size should be avoided in order to allow room for the digging to continue during pumping. These pumps should be fitted with an intake structure with screen near the bottom, to avoid blockage. The diaphragm design is sometimes sensitive to levelling, and operates less efficiently when sloped to one side or the other.

Compressor driven pumps have air motors that are sensitive to dirt in the air provided. Air hoses should be kept clean, and the ends capped when not connected to the compressor and pump.

Compressors should be selected with sufficient pressure and volume capacity to operate the implements selected. It may be more difficult, however, to identify compressors with low enough capacity for capital and fuel savings, as well as portability to the well site.

Compressors should be supplied with sufficient air hose to allow them to operate well back from the work site, preferably down wind and beyond an earth embankment.

8.6 Finishing the Intake Section

Caisson sinking should continue until the well has achieved sufficient depth of water and sufficient flow. These conditions should be estimated in the late dry season to ensure that there is still sufficient capacity and depth. Typically this should be specified as a minimum 2 - 3 metres of water depth, and 10 to 20 litres per minute of recharge. (i.e. Minimum standards may

be set at 3 metres with 10 litres per minute, 2.5 metres with 15, or 2 metres with 20 litres per minute.)

Initial fill and levelling the bottom

Once the final depth has been reached, an effort should be made to ensure that the bottom caisson is well seated all around. It is good practise, then to level the bottom and clean out remaining loose mud and silt. Before this operation is undertaken, it is useful to add a few buckets full of the clean gravel intended to backfill the water-bearing zone of the well. This will allow some of the aggregate to migrate down into any soft mud, sand, or silt flows in the water-bearing zone. The gravel fill should not be overdone, and should not rise far above the water-bearing zone. See the section on initial backfill below.

Bottom plugs

Bottom plugs serve very little practical purpose in the functioning of the well. Engineers have occasionally proposed that they would help to prevent materials from rising from the aquifers into the wells. There are few cases where this is desirable. Any material in the aquifer that is mobile enough to rise in the well should be allowed to do so. It is much more likely to harm the well if it is blocked in some manner.

One purpose that bottom plugs do achieve is to facilitate occasional cleaning of the well. Ten centimetres of clean gravel make a suitable separation with which to identify the limits of the well during occasional cleaning. Concrete plugs should be discouraged as unnecessarily costly and complex.

Initial backfill

The initial backfill completes the intake section. It consists of fine gravel or other permeable aggregate, in the water-bearing zone. It is often not possible to add much aggregate to the very bottom sections, as sand or mudflows may already have sealed off that portion of the well. The final seating (sinking) of the caissons may help the gravel to migrate into these flows during completion of the intake section. Some gravel can generally be added, at least to the top of the water-bearing zone. It should not be overdone, and in any event should not approach the sealed section in the top 3 metres of lining.

In the case of caissons used to complete an in-situ cast well, the gravel filter can be filled in up to about 15 cm below the top of the top caisson, and above the level of the bottom edge of the in-situ casting. The final 5 cm may then be filled with a weak concrete plug achieved by a 1:5:8 mixture of cement, sand, and gravel.

In the case of caisson lining to the surface, clean soil selected from the material taken from the well can be used as backfill above the water table. More permeable materials can be used near the bottom section, and impermeable materials near the top.

8.7 Sealing the Upper Shaft

While avoidance of surface water does not guarantee safe drinking water, it helps a great deal. It is normal practise to seal the top 3 metres of well liner, and to exercise caution in the top section of the back filling and drainage to prevent short-circuiting of the surface water to the unsealed section below.

Evidently, in the case of in-situ casting, the top section is automatically sealed, provided that the

upper 3 metres were cast in one lift, and with sufficient care taken to achieve a bond between courses of concrete.

In the case of caisson lining in the upper sections, this seal is not automatically achieved, and must be placed manually. This can be done in several possible ways:

Surface plastering over the joints between caissons can be used, forcing as much plaster as possible into the joint and then smoothing over the surface around the joint.

It is sometimes easier to anticipate the need to seal the top caissons before the final excavation is reached and to place a weak mortar in the joints as the caissons are added. If the need is not anticipated, the upper caisson rings can be lifted again to place a cement sand mix in the joints.

Where the above methods are used to seal the caissons, the upper portion of the shaft can be back filled with impermeable soils, mounding the soil above the surface somewhat to encourage drainage away from the well.

An alternate method of sealing the top portion of the shaft is to pour a weak concrete mix in the space around the caissons. This method can only be used where the gap is narrow, resulting from careful excavation or caisson sinking from the surface. If subsidence or caving has caused large gaps around the caissons near the surface, then these caissons should be sealed by the previously mentioned methods, and the remaining holes filled with impermeable soils mounded above the surface some 10 cm to cause drainage away from the well.

8.8 Construction of the Head Wall

In the case of caissoning to the surface, the head wall can be constructed by simply adding additional caisson rings and partial rings until the desired height is reached. These rings can be cemented in place with a weak cement sand mix.

In the case of in-situ lining, the head wall can also be cast in-situ with the addition of an outer mould for the aboveground section.

The head wall height will be determined either by standardised designs, or by the decision to use a hand pump, hose and bucket pump, windlass, etc. See [Structural Drawings](#)

8.9 Construction of the Apron and Drainage

A suitable apron and drainage are essential parts of any improved well. The requirements may vary considerably depending on the pumping methods and purpose the well is to be used for.

If a mechanical pump is to be fitted, it may be sufficient to mound the soil around the head wall, and to add a cast top with a manhole cover for maintenance access.

If people are to go to the well to fetch water, a concrete apron or platform around the head wall and sloping away from the well is essential. A raised edge on the outer rim of this apron collects the water and channels it to a lined drainage channel that carries the water away from the well.

See [Structural Drawings](#)

The most important consideration in construction of the apron and drainage is to determine on which side of the well the natural drainage would run. i.e. Which is the lower side? If it is found that water would not naturally drain away from the well, it is necessary to provide additional earth fill, using the earth accumulated in the excavation of the well. This soil can be built up

around the wellhead to raise the apron to an elevation that can be drained away from the well. The soil mound can be shaped roughly to the same slope intended for the eventual apron. This will conserve concrete in casting the apron, and also ensures that there exists a seal and a slope away from the well, even under the apron.

One final detail is that the apron is likely to resist cracking from uneven settling better if the concrete is not poured directly against the head wall. A layer of clay plastered on the headwall before the apron is cast can help to maintain a flexible joint. The top of this soil plug can later be scraped out and replaced with a seal of tar or bitumen.

8.10 Disinfection

When the well is new, or after workers have entered the well for maintenance and cleaning purposes, it is advisable to disinfect it. This is done by scrubbing the inside surfaces that might have been exposed to contamination with a mild chlorine bleach solution, and by treating the water in the well with sufficient chlorine to achieve 5 ppm free chlorine in the known volume of water. While this concentration is only about one sixth of that recommended by many professionals, it is also seven times the maximum level recommended for water treatment, and will successfully disinfect any surface contamination that water is in contact with.

The practise known as shot chlorination, raising the chlorine concentration to highly toxic levels, and periodic chlorination of the well are to be discouraged. Raising the chlorine concentration to toxic levels disrupts the natural environment of the well and aquifer, without achieving significantly more decontamination than is achieved by chlorinating within the potable concentration range. Periodic chlorination, again, disrupts the natural environment of the well without providing any protection beyond the hour or two in which the chlorine remains in the well.

In the event that the well is known to be contaminated or small organisms are found in the water, the source of the contamination should be found and corrected before decontamination. Simply killing off the existent organisms with chlorine compounds produces an offensive taste and odour, resulting from unnatural decomposition processes, without preventing re-contamination from the original source.

Appendix A Equipment List for Hand Dug Well Construction

The following list of equipment is intended for the guidance of those setting up a regional well digging program for the construction of approximately 100 wells per year, through hiring of multiple contractors.

The number of each item desirable is estimated by region, by contractor, or by well site, depending on the normal deployment of the equipment. An asterisk (*) following the number indicates that item should be regarded as essential, and mandatory for the contractor to qualify for a contract.

	Description	No.	Unit	Reqd. Per	Class	Comments
	1. Safety Equipment					
1	Helmet (Climbers' model)	2 *		Site	Minor	Import if unavailable
2	Rescue harness	2 *	set	Site	Minor	Import webbing if unavailable
3	Locking Carabiner	4 *		Site	Minor	Import if unavailable
4	Rope ladder or alternative	1 *		Site	Minor	Quality controlled local
5	Goggles	2	pair	Site	Minor	Essential with power tools
6	Ear Protection	2	pair	Site	Minor	Essential with power tools
7	Work gloves	2	pair	Site	Minor	Depending on Culture
8	Wellington (rubber)boots	2	pair	Site	Minor	Depending on Culture
	Light lifting head frame	*				See Lifting Equipment
9	2. First Aid Kit	1 *		Site		Comprised of the following:
	Adhesive Bandages	25 *		Site		
	Adhesive Tape	1 *	roll	Site		
	Sterile Gauze Compress	10 *		Site		
	Gauze bandages	5 *	roll	Site		

	Description	No.	Unit	Reqd. Per	Class	Comments
	Triangular bandage	2 *		Site		
	Hand soap	1 *		Site		
	Scissors	1 *		Site		
	Tweezers (forceps)	1 *		Site		
	3. Measuring Tools					
10	Spirit level	1 *		Site	Minor	
11	Plumb bob	1 *		Site	Minor	
12	Plumbing String	100 *	feet	Site	Minor	
13	Tape measure, 16 ft. (5 m)	1 *		Site	Minor	
14	Tape measure, 100 ft.(30 m)	1		Site	Minor	Optional
	4. Additional Measuring Tools for In-Situ Lined Wells					
15	Plumbing Rod	1		Site	Minor	
16	Trimming Rods	1	pair	Site	Minor	
	5. Digging Equipment					Sketch of Digging Tools
17	16mm Rope	100 *	feet	Site	Minor	
18	Bucket (heavy duty handle)	3 *		Site	Minor	
19	Digging hoe	2 *		Site	Minor	Either Local or Import*
20	Pick, flat blade	2 *		Site	Minor	Modified Pickaxe*
21	Pick, pointed	2		Site	Minor	Modified Pickaxe* Optional

	Description	No.	Unit	Reqd. Per	Class	Comments
22	Mattock	1		Site	Minor	Optional
23	Miners' bar (90 cm)	1 *		Site	Minor	Large bar modified by smith
24	Masons' hammer (4 lb)	1 *		Site	Minor	
25	Cold chisel, flat blade	1 *		Site	Minor	
26	Cold chisel, pointed	1		Site	Minor	Optional
27	Wheel barrow	1		Site	Minor	Optional
	6. Additional Digging Equipment For In-Situ Lined Wells					
28	Moore (sledge) hammer	1		Site	Minor	Optional
29	Spade (short handle)	1		Site	Minor	Optional
	7. Lifting, Binding Equipment					Sketch of Major Components
30	Light lifting head frame	1 *		Site	Int	Local Manufacture
31	Tripod & Winch	1 * 1 *		Site	Int	Local manufacture Import M&F ast or equivalent
32	Caisson lifting bar	1 *		Site		Local manufacture
33	Caisson binding rods	1 *	set	Site		Local manufacture
	8. Concrete Mixing & Casting					
34	Shovel	2 *		Site	Minor	
35	Masons' trowel	2 *		Site	Minor	
36	Float	1 *		Site	Minor	
37	Wire brush	1 *		Site	Minor	
38	Rubber mallet (1 - 2 lb)	1 *		Site	Minor	For tapping forms

	Description	No.	Unit	Reqd. Per	Class	Comments
39	Head pans	2 *		Site	Minor	
40	Guage box	1 *		Site	Minor	
41	Water barrel or equivalent	1 *		Site	Minor	
42	Sieves	1	set	Contr.	Minor	Optional
43	Cement mixer or mixing pad	1		Site	Int	Recommended
	9. Miscellaneous					
44	Hacksaw and spare blades	1 *		Site	Minor	
45	Pliers	1 *	pair	Site	Minor	
46	Spanners (combination wrenches)	1 *	set	Site	Minor	To fit all mould, head frame, and tripod bolts
47	Vicegrips	1 *		Site	Minor	Recommend Peterson 10WR
	10. Caisson Moulds					
48	Caisson ring mould	2 *	set	Site	Int	Manu.& Financial assist.
49	Base plate / Rebate mould	6 *		Site	Int	Local manufacture
50	Capping Ring / Rebate mould	2 *		Site	Int	Local manufacture
51	Moulds to form base plate and capping ring	1	pair			Optional
	11. Additional Moulds for In-Situ Lined Wells					
52	Lining mould, inner	4		Site	Int	

	Description	No.	Unit	Reqd. Per	Class	Comments
53	Lining mould, outer	2		Contr.	Int	
54	12. Well Head Moulds	1	set	Contr.	Int	Optional, Comprised of:
	Apron form	1				Optional
	Pump base mould	1				Optional
	Inspection hatch base mould	1				Optional
	Inspection hatch cover mould	1				Optional
	Insp. hatch extension mould	1				Optional
	13. Carpentry Tools					
55	Carpenters' hammer	1		Site	Minor	
56	Try square	1		Site	Minor	
57	Hand saw	1		Site	Minor	
58	Pry bar (Crowbar)	1		Site	Minor	
59	Carpenters' chisel	1	set	Site	Minor	
60	Plane	1		Site	Minor	
	14. Dewatering, Breaking, etc					
61	Compressor or generator dewatering, breaking, drilling set (small)	1	Set	Contr.	Int	Electric generator with dewatering pump, breaker, and hammer drill <i>All components must be selected with extreme care to match generator capacity with pump and tool requirements. Suppliers should be asked to demonstrate compatibility of</i>

	Description	No.	Unit	Reqd. Per	Class	Comments
						<i>components before delivery.</i>
62	Compressor dewatering, breaking, drilling set (big)	5	Set	Regio.	Major	Atlas Copco XAS 32-36 compressor with ARO 1" non-metalic diaphragm pump, Atlas Copco TEX 14PS and TEX 18PS breakers, and Atlas Copco BBD 12T-01 rock drills <i>Substitutions should be made with consideration for size and air requirements of each component.</i>

For purposes of calculation, we would suggest that the number of active digging sites may be estimated as approximately 0.25 to 0.33 of the total number of sites that the contractor is expected to complete in the whole digging season.

Appendix B Specification for Hand Dug Wells

Below are modified specifications extracted from a Ghana CWSD bidding document. Modifications have been made to permit the following initiatives:

- To permit optimisation of caisson designs with smaller wall thicknesses, and to permit the use of caissons above the water table, whether in stable or unstable conditions.
- To introduce more specific standards for testing of yields
- To allow for variation of slope to achieve drainage to one single outlet. Apron slope has been reduced to 2 - 5% from the original fixed 5%.
- Apron overall dimensions have not been changed although 4.75 m square or diameter appears excessive. Such standards should be established on a project by project basis.
- To revise the old standard requiring that concrete be used within two hours after being mixed. The corrected standard reads “within 30 minutes”
- To reduce the concentration and contact time of chlorine during disinfection. (Some agencies will argue against this change, because shot chlorination has become common practice. See section 7.10 on Technical Preparation above, for the author's views on this.)

1. Site selection

- 1.1 Site selection will be made by the community with the assistance and support of the regional rural water supply engineer and the zonal hydrogeologist. Where geophysical conditions in an area are particularly favourable, well siting will be based on observation of local geologic conditions and existing water wells. If there is uncertainty that a dug well can be successfully constructed, a small diameter test hole may be bored; and if a test hole can not be constructed, and the likelihood of constructing a successful well is below about 75%, a geophysical survey will be conducted.

2. Site Preparation

- 2.1 The community shall clear and roughly level a minimum working radius of 12m measured from the centre of the proposed well. Such clearing, however, should not consist of tree cutting except as absolutely necessary. The community shall also provide shelter to store cement and hand tools.

3. Excavation

- 3.1 The excavation of the well shall be to the dimension specified in the drawings.
- 3.2 The centre line or axis of excavation must be vertical to within 10mm per meter of depth of the well.
- 3.3 Unless soil conditions allow otherwise the first lift should be excavated to a depth of not more than 5.0 meters before the start of in-situ lining with concrete or precast caisson

lining. The final trimming of the walls shall be done not more than 24 hours before the casting of in-situ concrete lining. The finished diameter of excavation shall be as specified in the drawings. ie. 1.5 metres dia for in-situ lined shaft, and 1.1 metres diameter for caisson lined shaft, and shall be maintained constant about the axis.

- 3.4 Excavated material shall be placed at least 4 meters away from the edge of the excavation in order not to interfere with construction. Excess excavated materials will be disposed of by individual communities as agreed in their Facilities and Management Plans.
- 3.5 If rock is encountered during excavation, the contractor must give notice in writing to the Project Manager that he has encountered rock and that he intends to claim payment. He must state the equipment he intends to use. Rock is defined as solid material which can be removed by chisel and hammer, blasting, or use of pneumatic tools and includes only boulders larger than 0.5 metres diameter.

4. Lining

In-situ lining

- 4.1 In-situ lining shall have a minimum thickness of 100mm and a finished inside diameter of 1.3m. It shall be cast in-situ from concrete having a 1:2½:5 mix if cement, sand, and aggregates.
- 4.2 The shuttering shall have a maximum deflection from vertical of 10mm per meter height. It shall be fixed to alignment and securely braced to withstand, without displacement or deflection, the pressure of wet concrete while it is being cast and tamped. It shall be constructed in such a manner that there shall be no leakage of mortar.
- 4.3 A gap of 15 cm shall be left between lifts, to be filled later, to facilitate the pouring of concrete for the lining of the next lower lift.
- 4.4 The surfaces of the shuttering must be free from encrustations, and must be cleaned and oiled with approved commercial oil, free from toxic substances, that will effectively prevent sticking and will not stain the concrete surface. Edible oil products may be used for this purpose, subject to the engineers' approval.
- 4.5 Each lift shall have a curb at its base and at intervals as shown in the drawings.
- 4.6 Concrete shall be placed behind the shuttering in layers 200mm deep and air bubbles removed by rodding with a piece of reinforcing steel and by tapping the form work with a hammer.

- 4.7 To form watertight joints between lifts, the surface of the concrete at the top of the shuttering shall be left level but rough. About 4 hours after placement of the concrete the surface shall be sprayed with water and brushed to expose the coarse aggregate. Brushing shall be carried out carefully so as not to disturb the coarse aggregate particles. The surface is wetted with a cement slurry immediately before pouring the next section of lining.
- 4.8 Lining shuttering shall be left in place for a minimum of 24 hours after the concrete is poured.

Caissons

- 4.9 Below the water table and in unstable formations above the water table, the lining shall be made of open-ended caissons, pre-cast from concrete having a 1:2:4 mix of cement, sand and aggregates. The caissons shall have a minimum thickness of 70mm and a finished inside diameter of 0.95 metres. If caissons are used within 3 metres of the surface, their joints and weep holes (if present) shall be sealed with cement mortar.
- 4.10 Caissons in the water bearing zone may optionally be cast with weep holes formed by pegs of 10 - 13mm steel rod spaced at 150mm vertical intervals (ie. Three rows per ring), and about 370mm horizontal spacing (ie. Eight equally spaced weep holes per row). Position of weep holes should staggered by a horizontal offset of 185mm in successive rows.
- 4.11 Weep holes must all slope upward towards the center of the ring at a minimum angle of 30 degrees above horizontal.
- 4.12 Rebate edges shall be provided at the upper and lower edges of each caisson to provide good joints between caissons. Caissons shall be oriented so that the rebate joint slopes upward toward the centre of the well. During excavation of top of the caissons shall not be allowed to sink below the bottom footing of cast in-situ lining. On completion of the well the caissons shall overlap the cast in-situ lining by at least 300mm and the space between the caissons and lining filled with gravel (6-19mm).

Bottom Lining

- 4.13 The bottom of the well shall be lined with graded aggregate (6-19mm) having a minimum thickness of 15cm.

5. Depth and Yield of Completed Wells

- 5.1 The well shall be deemed sufficiently deep, subject to the approval of the engineer, when the nominal targets of depth and yield are met. At least 3 metres of water and a minimum

yield of 10 litres per minute, or 2.5 metres of water and 15 litres per minute, or 2.0 metres of water and 20 litres per minute may be deemed the nominal targets depending on the conditions encountered. The engineer will authorise the completion of lining and head works when these conditions and the standards of quality are met to the his satisfaction. Yield test methods are described in section 8.

- 5.2 In cases where hard rock prevents further progress, and at the discretion of the engineer, the nominal targets may be revised to permit the completion of a well that is deemed to be a good potential source even though the nominal targets are not met.
- 5.3 The wells will be designated as “provisionally completed” until the final depth and yield are tested at the end of the dry season. This testing will be ordered and evaluated by the engineer. At this time further deepening may be ordered by the engineer if the yield or depth is deemed to have reduced beyond acceptable limits.

6. Headworks

Head Wall

- 6.1 The cast in-situ or caisson lining shall be continued above ground level to form a head wall. The height of this headwall shall be 250mm above the original ground level.

Well apron

- 6.2 After the well lining is completed, an apron 4.75 metres x 4.75 metres, sloped (2 - 5%) to drain radially outwards shall be constructed with curb as shown in the drawings. Excavated material low in clay content and free of organic matter shall be used to fill the void space on which the apron will be cast. This material shall be dampened and well compacted. The apron shall have a minimum thickness of 75mm and shall be made of concrete with a 1:2½:5 mix of cement, sand and aggregates.
- 6.3 The platform reduces contamination of the well by providing a surface above the ground level that is easier to keep clean, and a place to put containers when being filled with a hand pump. A plinth shall be constructed under the hand pump discharge on which to rest the containers while filling.

Well cover slab

- 6.4 Wells to be fitted with hand pumps shall be provided with a cover slab as shown in the drawings. The well cover slab shall be of 75mm thick reinforced concrete having a 1:2:4 mix of cement, sand and aggregates. Reinforcement shall be with 10mm diameter (3/8 inch) iron rods at 15cm spacing as shown in the drawings.
- 6.5 A round opening 550mm dia with a removable concrete cover shall be provided in the

well cover slab to allow access for cleaning the well. A 600mm high optional extension shall be provided as shown in the drawings, in case the access hatch must be used for drawing water. The joint between the cover slab and the extension shall be rebated as shown in the drawings. The access hatch and extension shall be made from a 1:2:4 mix of cement, sand and aggregates.

- 6.6 A second opening of 150mm diameter shall also be provided in the well cover slab for the hand pump rising main. It also shall be bordered by a raised lip as shown in the drawings to prevent spilled water from entering the well. A standard base plate design for mounting an approved shallow hand pump shall be used as instructed by the Project Manager

Drainage Channel

- 6.7 A drainage channel shall be constructed from one corner of the well apron to collect drainage water and then convey it to a cattle watering trough (optional) and soakaway, as is shown in the design drawings, from 1:2½:5 mix of cement, sand and aggregates.

Watering Trough (optional)

- 6.8 A watering trough dimensioned as shown in the drawings and made from a 1:2½:5 mix of cement, sand and aggregates shall be constructed for watering livestock.

Soakaway

- 6.9 A soakaway shall be constructed as shown in the design drawings.

7. Quality of Materials

Sand and aggregates

- 7.1 Sand shall be clean, coarse-grained, river sand with a maximum grain size of 4mm. Sand shall contain no more than 5% silt, and shall be free of soil, clay, organic matter or other impurities.

- 7.2 Aggregates shall be hard, clean and free of all organic material, and shall be well graded between 6mm and 19mm in size. Samples of all aggregates shall be brought to the Project Manager for approval before delivery to the site.

Water

- 7.3 The contractor shall provide all water needed on the site. Water used for mixing concrete shall be clean and free from oil, salt or suspended clay.

Reinforcement Rods

- 7.4 The reinforcing steel shall be free from oil, grease, dirt and paint. Any loose rust must be removed before use. All reinforcement bars shall be fixed and placed as indicated in the

drawing.

Concrete

- 7.5 No concrete shall be placed until form work, embedded parts, and surface preparation have been approved by the Project Manager.
- 7.6 Batching of concrete shall be done by means of approved gauge boxes. Hand mixing of concrete shall be done on a mixing platform of weak concrete of at least 2.5 metres diameter. Optionally, a portable mixing platform or mixer may be brought to the site.
- 7.7 Mixing shall continue until there is a uniform distribution of the materials and the mass is uniform in colour and consistency.
- 7.8 Concrete shall be used within thirty (30) minutes of mixing, otherwise it shall be discarded.
- 7.9 Concrete shall be placed in all cases as nearly as practicable directly in its final position and shall not be allowed to flow in a manner to cause segregation.
- 7.10 Concreting shall be carried out continuously between and up to predetermined joints.

Curing

- 7.11 All concrete head works, including the head wall, cover slab, apron, drainage channel and watering trough shall be protected from rapid drying for 7 days by covering with heavy duty polythene sheeting, 25mm of frequently moistened sand, or the method approved by the Project Manager.

8. Testing and Cleaning

Water Quality

- 8.1 When ground water enters the well to a depth of 500mm a water sample shall be taken for chemical analysis by GWSC's Community Water and Sanitation Division. If the water quality is not acceptable the well may be abandoned.

Water Yield

- 8.2 The well shall be tested for water yield when it has been excavated 3 metres below the water table, or sooner as directed by the Project Manger. The yield estimation is primarily based upon recovery rate following three hours of evacuation by pumping or bailing.

- 8.3 Pumping or bailing may cease after three hours whether the well has been emptied or not. The water level shall be measured and recorded when pumping ceases and every half hour thereafter for 12 hours or until the water level is within 100mm of its starting position. The yield estimation shall be based upon the first half hour interval measured after the water level exceeds the minimum depth of 0.5 metres above the bottom of the well. The yield in litres per minute shall be calculated by dividing the estimated volume recovered in this interval by 30.
- 8.4 If the recharge rate does not exceed 10 litres per minute, the Project Manager may request the well to be deepened. However, when working in rock the minimum requirement shall be that the water depth rises at least 1.5 metres in 12 hours.

Cleaning and disinfection

- 8.5 After the water yield has been measured and accepted by the Project Manager, the well lining shall be scrubbed clean and the water bailed or pumped until it is clear. After the entire well is accepted by the Project Manager, the well shall be disinfected by dosing the water in the well with hypochlorite to give a concentration of 5 grams of chlorine per cubic metre. During the 2 hour period after dosing, no water should be drawn from the well. After 2 hours the well shall be pumped or bailed until the water no longer tastes of chlorine and is clear.

9. Safety

- 9.1 Safety helmets shall be worn by persons working in the well, and to the extent possible, also by all workers on the construction site. Goggles and dust masks should be worn for stone cutting, and ear protectors for air hammering. First aid equipment should be available at the site at all times.
- 9.2 A rope ladder or equivalent means of ascent shall be provided so that workers may quickly escape from the well.
- 9.3 Harnesses for lifting exhausted or injured personnel and for rescuers shall also be available at all times.
- 9.4 A light lifting head frame shall be provided , and all workers shall be trained in its use.
- 9.5 When workers are in the well at least one person shall always watch them from the top of the well.
- 9.6 There must be agreed signals for indicating if a worker is in distress and for normal works. All workers shall be trained to use and interpret these signals.

- 9.7 The area around the well shall be kept clear of tools, ropes, rocks, cement bags etc.
- 9.8 All workmen must be aware of the possible release of poisonous gases and low oxygen levels in wells. No smoking shall be allowed in the excavation.
- 9.9 Petrol and diesel pumps shall be operated downwind of the well and at least 5m from the edge of the well. Exhaust gases are heavier than air and will sink to the lowest levels possible. Under no circumstances shall combustion engines be lowered into wells to facilitate dewatering or for any other purpose. This leads to a build-up of carbon monoxide which will cause the death within seconds of anyone present in the well.
- 9.10 At night or when work in the well has been suspended the mouth of the well shall be securely covered.
- 9.11 The tripod, winch, and cable used to place the concrete caissons in the well must be strong enough to carry their full weight. Its capacity shall be checked by the contractor in the presence of the Project Manager.
- 9.12 The use of explosives for well blasting shall only be carried out by fully competent and trained personnel since the storage, handling, placing and detonation of explosives is a dangerous operation requiring a specialist. It is crucial following the use of explosives to purge the well of all toxic fumes remaining after detonations. Locally made explosives using fertilizers, diesel oil, home made gun powder or similar improvisations should not be used because of their haphazard and erratic performance.

10. Well Construction Records

- 10.1 The contractor shall keep a works diary on the site at all times, which must be shown to the Engineer if he requests it. The following information shall be recorded in the works diary on a daily basis:
- Names of workers on the site
 - Record of accidents
 - Record of visitors
 - Record of Rainfall
 - Delivery of materials to the site
 - Details of concrete mixes and quantities
 - Description of work, including depth of well excavated
 - Signature of engineer for all required approvals

- 10.2 The contractor shall also keep a well record to provide information for maintenance and construction of future wells.
- Strata through which the well has been sunk
 - The level and thickness of aquifers encountered
 - The depth of rock encountered (To be confirmed by the engineer)
 - The length of lining and caissons
 - Top and bottom levels of the permeable section of the shaft
 - Whether water enters through the side and/or bottom
 - Thickness of gravel lining at the bottom of the well
 - Mark reference point from which depth has been measured on concrete apron with chisel.

11. Community Interaction

- 11.1 Interaction with the community leaders regarding siting and site clearance shall be flexible and participatory.
- 11.2 The contractor shall be encouraged to make his own arrangements for hiring of local labour.
- 11.3 Consultation and, where necessary, conflict resolution with the community leaders, partner organisations, etc. shall be practiced throughout the process, culminating in the handover process.

12. Drawings

You must have Adobe Acrobat Reader loaded in order to read the following drawings.

The following links will open the structural drawings in PDF (Acrobat) Format

S-01 Caisson Lined Well	S-07 Cover Slab with Pump and Acc Cover
S-02 In-situ Lined Well, Most Common	S-08 Cover Detail (110 cm)
S-03 In-situ Lined Well, Variation 1	S-09 Cover Detail (150 cm)
S-04 In-situ Lined Well, Variation 2	S-10 Access Hole Extension
S-05 Caisson Ring Detail	S-11 Access Hole Cover
S-06 Cover Slab with Access Extension	S-12 Drainage Detail

Appendix C Bill of Quantities

The following is a modified Bill of Quantities document extracted from a Ghana CWSD bidding document.

Modifications have been made to permit the following initiatives:

- To permit bidding on either in-situ cast liners, caisson liners, or both.
- To permit bidding on the revised head works structure.

1. Provisional Sums

1.1 A general provision for physical contingencies (quantity overruns) may be made by including a provisional sum in the Summary Bill of Quantities. Similarly, a contingency allowance for possible price increases should be provided as a provisional sum in the Summary Bill of Quantities. The inclusion of such provisional sums often facilitates budgetary approval by avoiding the need to request periodic supplementary approvals as the future need arises. Where such provisional sums or contingency allowances are used, the Contract Data should state the manner in which they will be used, and under whose authority (usually the Project Manager's).

1.2 The estimated cost of specialised work to be carried out, or of special goods to be supplied, by other contractors, should be indicated in the relevant part of the Bill of Quantities as a particular provisional sum with an appropriate brief description. A separate procurement procedure is normally carried out by the Employer to select such specialised contractors. To provide an element of competition among the bidders in respect of any facilities, amenities, attendance, etc., to be provided by the successful Bidder as prime Contractor for the use and convenience of the specialist contractors, each related provisional sum should be followed by an item in the Bill of Quantities inviting the Bidder to quote a sum for such amenities, facilities, attendance, etc.

ITEM	DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT
1.	<i>Mobilisation</i>				
1.a	To site for well construction	Each	10		
1.b	To site for well deepening	Each	5		
	SUB-TOTAL I				

2.	Setting up / Excavation				
2.a	Site Preparation	Each	10		
2.b	Excavation above water table (0 - 4 metres)	M	40		
2.c	Excavation above water table (4 - 8 metres)	M	40		
2.d	Excavation above water table (over 8 metres)	M	20		
2.e	Excavation below water table (3 metres)	M	30		
2.f	Excavation below water table (deepening 2 metres) (Provisional)	M	10		
2.g	Excavation in hard rock (extra for hard rock conditions)	M	10		
	SUB-TOTAL II				
3.	Well Lining				
3.a	Well Lining above the water table (0 - 4 metres)	M	40		
3.b	Well Lining above the water table (4 - 8 metres)	M	40		
3.c	Well Lining above the water table (over 8 metres)	M	20		
3.d	Caisson Lining below the water table (3 metres)	M	30		
3.e	Caisson Lining below water table (deepening up to 2 m) (Provisional)	M	10		
3.f	Graded gravel inlet filter	Each	10		
	SUB-TOTAL III				

ITEM	DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT
4.	Head Works				
4.a	Head walls	Each	10		
4.b	Well cover slabs	Each	10		
4.c	Access extensions	Each	10		
4.d	Access hatch covers	Each	10		
4.e	Aprons	Each	10		
4.f	Drainage channel	Each	10		
4.g	Trough and soakage pit	Each	10		
	SUB-TOTAL IV				

SUMMARY

ITEM	ACTIVITY	SUB-TOTAL
1	Mobilisation /Setting up	
2	Excavation	
3	Well Lining	
4	Head Works	

GRAND TOTAL:

Appendix D Bibliography

The following books have inspired many previous workers in the field, including the author of this document. They deserve the greatest credit for their contribution to the hand dug well field. If we appear to criticise certain aspects of these works, it is with the intent of increasing their usefulness to their readers.

1. *Hand Dug Wells and Their Construction*, by Watt, S.B. and Wood, W.E. (Intermediate Technology Publications, 103/105 Southampton Row, London, UK WC1B 4HH) (1979).
This is one of the best books available on hand dug well construction. With considerable coverage of the in-situ lining method, literally one short paragraph and one illustration are offered on the sinking of caissons. Be wary of the proposal to use porous cement for caissons. Such porosity, while necessary for in-situ lining, is quite unnecessary for caisson lining, and the weakened caisson rings can be very dangerous. Add caisson-sinking tools to the equipment lists.
2. *Wells Construction, Hand Dug and Hand Drilled* by Brush, Richard E. (Action/Peace Corps, Washington, D.C., USA)(1979).
This is the other best book on hand dug and hand drilled wells construction. It provides the most complete appendices on related technical issues such as concrete, pumps, water treatment, etc. Be wary of the extremely high concentrations of chlorine recommended for disinfection of wells. Somewhere between a tenth and a third of these concentrations would be sufficient and less environmentally damaging. Three full pages are dedicated to the sinking of linings, but beware of the tools illustrated in this section. A shovel or spade has no place in caisson sinking. A short digging hoe should be substituted. Again avoid the use of porous concrete, which is unnecessary in the case of caisson liners.
3. *Wells Manual - Program and Training Journal* edited by Luzzato, Francis A. (Action/Peace Corps, Washington, D.C., USA) (1974).
Comprised of various papers on relevant experience in well digging, this book is in many ways a predecessor of number 2 above.
4. *The Construction and Maintenance of Water Wells* (VITA Publications, College Campus, Schenectady, N.Y., USA)(1969)
An excellent compilation of various technologies for well digging, this book has an illustrative format that is refreshing.
5. *Village Technology Handbook* (VITA Publications, College Campus, Schenectady, N.Y., USA)(1970)
A more generalised handbook on technologies for small rural communities in developing countries, this book is easy reading.
6. *Construction of Hand-Dug Well* (HELVETAS, St. Moritzstrasse 15, Postfach, CH-8042 Zuerich, Switzerland)(1994).
Another excellent book, this one is written as a construction manual with blueprints. Beware of the illustrations of caisson sinking which would place the worker in a dangerous position below the unstabilised caisson ring. Be very wary of the porous concrete mixture. The designs presented are interesting because they reduce the caisson wall thickness to 5 cm. This is not an undesirable change, provided that the reinforcing placement and concrete filling can be accomplished with sufficient precision.

7. *A Safe Economical Well*, by Dr. E.V. Abbott, M.D, DPH. (Mimeographed reproduction) (American Friends Service Committee, Philadelphia, PA, USA)(1956)
Dr Abbott introduced and refined the use of caissons in eastern India between 1952 and 1956 in an area with stable soils. The document describes a specific variation of the caisson lined well. Caisson sinking had not yet been introduced, as it was unnecessary in this part of India.
8. *Dug Wells Have a Future for Irrigation*, by E.V.Abbott, MD, DPH, Hoshangabad MP, India (Mimeographed reproduction)(1963) Out of print. The Author has kindly provided a copy.
An article written for the Canadian Friends' Service Committee and the Friends' Service Council, after the author had spent some seven years developing and refining caisson sinking techniques in central India. These articles are referenced because although the techniques described spread rapidly and successfully in India, they were never published internationally, resulting in some erroneous caissoning practices being adopted elsewhere.
9. *Preparation of Forms for Casting Concrete Well Rings*, by E.V.Abbott, MD, DPH, Hoshangabad MP, India (Mimeographed reproduction)(Revised Sept1965) Out of print
See the comments on reference #8 above.
10. *Method of Casting Reinforced Concrete Well Lining Rings*, by E.V.Abbott, MD, DPH, Hoshangabad MP, India (Mimeographed reproduction) (Revised Sept1965) Out of print
See the comments on reference #8 above.
11. *The Dug Well Subheadings: The Rasulia Type Well; The Barpali Type Well; Deepening of Wells; Special First Ring for Use in Sand*, by E.V.Abbott and Peter Stein, Hoshangabad, MP, India (Mimeographed reproduction) (1965) Out of print
See the comments on reference #8 above.
12. *Specifications and Drawings for Hand Dug Wells* by ISODEC for Community Water and Sanitation Division, Ghana Water and Sewerage Corporation (June 1996)
13. *Hand Dug Well Construction, A manual for the construction of an improved Hand Dug Well* (ISODEC, P.O.Box 8604, Accra North, Ghana)

Appendix E Acknowledgements

The author would like to thank all of the authors of the above documents, the co-workers he has worked with in the field, and most especially, Tay Awoosah, and Namps.

Appendix F About the Author

Steve Abbott spent 12 years as a child and young adult in India, living, playing, and eventually working alongside his father, Dr. Edwin Abbott, in dug well construction, rural sanitation, and a variety of other projects.

In 1965 the family returned to Canada. There, Steve Abbott completed his high school education, and two university degrees in Mechanical Engineering, specialising in fluid mechanics, energy conversion, and solar energy topics.

In 1974 he began to travel abroad to do voluntary work in Central America. In 1983 he travelled to Africa, as technical advisor, and then team leader of a water project in Northern Ghana.

Since that time, Steve has worked on water and sanitation projects and relief efforts in Somalia, Nepal, Ghana, Alaska, Goma Zaire (now DR Congo), Nicaragua, Costa Rica, El Salvador, Honduras, Haiti, Peru, Bolivia, Ivory Coast, West Bank, and Gaza. He has evaluated water, sanitation, and relief efforts in Ethiopia, Kenya, Angola, and Peru, and assessed for drought responses in the semi-arid regions of Brazil, for hurricane response in Bolivia, Honduras, and Cuba, and for Tsunami response in Tamil Nadu, India.