SEA/Env.San./168

THE BANGALORE PUMP

Report prepared for the
Government of India
by the
WHO South-East Asia Regional Office

WORLD HEALTH ORGANIZATION
Regional Office for South-East Asia
NEW DELHI
March 1976

WORLD HEALTH ORGANIZATION

ORGANISATION MONDIALE DE LA SANTE

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WHO Project: IND BSM 002

CONTENTS

I. INTRODUCTION

This document is based on reports emanating from the work carried out in Bangalore, Karnataka State, India, in 1973 to 1975 under the Government of India project "Village Water Supply". This project has received and continues to receive financial and technical assistance from UNICEF and WHO.

Within this national project, of which the objectives are primarily to provide safe drinking water to rural communities, a sub-project was specifically formulated to develop an improved deep-well handpump suitable for community use, and to investigate ways and means of reducing the cost of such a pump. A WHO sanitary engineer, Mr V.J. Emmanuel, acted as project co-ordinator and chief research officer, and he was assisted by national engineers deputed by the Chief Engineer, Minor Irrigation and Public Health Engineering Department, Government of Karnataka. Additional assistance was given in the collection, compilation and analysis of statistical data. The Mechanical Engineering Research and Development Organization, Madras, collaborated in the project, prepared certain working drawings, produced the prototype cylinder assemblies and executed the construction of the accelerated testing device. Support and financial assistance were provided by UNICEF. Annex 1 lists by name the various persons who have contributed directly to the project.

The data summarized in this report are taken principally from the "Report on Deep-Well Handpump Development: Project IND BSM 002", prepared by Mr Emmanuel. This draft report is in four volumes. Volume One identifies the problem, lays down the plan of investigation, analyses the statistical data, describes the development of the pump and analyses the results of the tests. Volume Two consists of detailed plans of all the pumps studied; Volume Three contains the statistical data collected in field surveys. The detailed drawings of the improved cylinder assemblies, improved hand-operated pump head and foot-operated pump head make up Volume Four. Volume One was prepared in eighteen copies for limited distribution to Chief Engineers of States in India,who have considerable requirements for deep-well handpumps,so that they could provide comments; copies were also provided to UNICEF. Very few copies of Volumes Two and Three were prepared, but they are available with the WHO Regional Office in New Delhi, India, for purposes of reference. Volume Four was distributed to a limited number of persons,but copies of selected parts were made available through UNICEF to a number of potential manufacturers in India. These volumes have not received general clearance from the Government of India, but it may be possible to distribute certain extracts to serious enquirers.

As a considerable part of the time spent on the project involved the study and evaluation of the different existing deep-well handpumps available, it was evident that the good features of several types would need to be combined in an improved version. As it turned out, the design of a cylinder produced by the project depended very little on existing models, as,for the improved cylinder,the use of plastic components was adopted and all parts in brass or machined metal were eliminated. However, for the pump head, the single pivot chain-link arrangement, first devised in India by the Jalna pump manufacturers and subsequently modified in the Sholapur pump, was adopted, some modifications being made to bearings and the roller chain. The origin of this design is recognized and acknowledged as being a considerable advance on older systems.

In recognition of the assistance given by the Government of Karnataka, the name "the Bangalore Pump" has been selected to designate the improved handpump system described in this document.

II. BACKGROUND

The need to develop a suitable deep-well handpump for use in the national, drilled-well, rural water supply programme become apparent early in the operation of the WHO/UNICEF assisted village water supply project. Starting in 1954, when the Government of India initiated its National Water Supply and Sanitation Programme with the objective of providing safe water supply and basic sanitation facilities to urban and rural communities of the country, assistance was provided to State Governments to take initial steps to identify the problems and draw up a phased programme of investigation, design and construction.

Since the beginning of the Fourth Five-Year Plan (1969-1974), the Government of India has placed increasingly greater emphasis on the need to provide safe water supplies - in the first instance, to all rural communities in the country. The concept of a safe water supply in the hard-rock areas had been to provide a piped community water supply, the quality of the water meeting accepted national standards. It was found, however, that the cost of constructing piped water supplies to all rural communities in India would be of such magnitude as to make it impractical to invest so much money in a relatively short period purely as a social service. A change of strategy was consequently required.

It was realized that meeting the basic water needs in rural communities would have to depend on the exploitation of ground water, as,in many areas, surface water sources were not available, were only seasonal or were grossly polluted. The development of ground water sources presented a problem in that most of the areas with acute water scarcity were underlain by "hard rock", thus making excavation of wells by hand practically impossible.

It had been feasible for many years to drill wells in such hard-rock areas using percussion or cable-tool rigs. Generally these methods required three to six months per well, depending on the nature of the rock and the depths drilled. Since these wells had to depend on the water contained in the faults and fissures in the rock, there was an element of uncertainty, and the success rate was sometimes of the order of only 30 to 40 per cent. Such a method was thus expensive and unsuited to a country-wide programme. The two difficulties faced were therefore: (a) the location of fissures containing the water, and (b) the drilling of holes to the depth required in a reasonably short time.

WHO and UNICEF,agreeing to increase substantially their technical and financial support to the Government for implementation of the rural water supply programme, signed a plan of operation with the Government in October 1970. Under this agreement UNICEF was to provide the equipment necessary for geophysical exploration of ground-water, special drilling equipment of the pneumatic hammer type and all the necessary ancillary equipment such as air compressors, laboratory field kits, etc., and transportation; in the past few years, the efficacy of using drill rigs of this type, capable of drilling wells in two to three days, had been demonstrated in connexion with drought relief programmes. WHO agreed to provide technical assistance to help the States develop their village water supply programmes based on drilled wells. Criteria for the selection of villages were: (a) preliminary surveys confirming the availability of water at accessible depth; (b) a chronic water scarcity or a high incidence of water-related disease in the area; (c) suitable locally manufactured rigs not being readily available, and (d) hand-dug wells being unable to meet the need.

The programme benefiting from this assistance has been in operation since mid-1970 and now involves ten States with extensive hard-rock areas. Several thousand wells have been drilled and put to use. In keeping with the Government's strategy of meeting the basic water needs of rural communities, the drilled wells were provided with deep-well handpumps, and by virtue of the depth from which water was drawn, it was expected that these wells would supply safe water at the pump.

Although considerable attention was paid to the technological aspects of the location of the wells and the drilling, insufficient thought was given to the means of extracting the water from the drilled wells, as it was assumed that the indigenously manufactured deep-well handpumps would be satisfactory for use in the villages. When the programme had been in operation for some time, however, it was found, to the consternation of those who were involved in the programme, that this handpump, which had originally been developed for household use, could not stand up to the wear and tear of use by a community.

It had been intended initially that one well and one handpump would be provided for about 250 persons. Subsequent studies showed, however, that, in practice, a single pump was sometimes used by as many as 500 to 1000. This situation arose from the Government's policy, which was revised during drought conditions to give priority to the drilling of one well in each stricken village irrespective of the population. The resulting strenuous use to which the pumps were put caused frequent breakdowns and considerable hardship, forcing people to travel long distances for water or to revert to other, polluted sources nearer at hand. Such a situation obviously defeated the objectives of the programme.

After about a year of operation, the percentage of pumps out of order at any given time rose to an alarming level. Several reasons can be given for the failure of the pumps, such as incorrect installation, inadequate (or non-existent) maintenance and lack of well-defined responsibility for carrying out repairs, but it became apparent that the one outstanding reason was the fact that the deep-well handpumps manufactured in India were not designed for the sort of duty to which they were being put. WHO and UNICEF were concerned lest the massive investment in expensive geophysical and drilling equipment be wasted, as all of the efforts would have been in vain unless the delivery of the water could be improved. It became apparent that the entire programme depended on the handpumps' being kept in working condition.

The State Governments themselves were confronted with technical and procedural difficulties in trying to choose one of the pumps available on the local market. These difficulties stemmed from the fact that there is no standard specification in India (or elsewhere in the world) for a deep-well handpump, and that the governmental tender procedure is cumbersome and does not lend itself readily to the purchase of the best equipment on the market; price is usually the overriding factor.

Thus the urgent need to develop a deep-well handpump suitable for use in the village water supply programme, as well as to standardize the pumps and to establish satisfactory testing procedures and facilities, was already apparent to the State Governments. At this point, the Government of Karnataka suggested that WHO and UNICEF set up a sub-project to look into this matter. When the State Government put forward this request, a WHO sanitary engineer was already working in Bangalore, and this study was therefore started with the State Government's agreeing to provide local staff and meet local expenses, WHO to provide the sanitary engineer's services to manage the project, and UNICEF to contribute up to $10 000 for the necessary materials and equipment.

III. PRELIMINARY ACTIVITIES

1 Review of Handpump Development

Before a new pump could be designed, a considerable amount of preliminary work was required: to study the existing reports on the subject; to make field observations of the problems encountered and of patterns of usage; to study the available indigenously made and imported pumps in order to identify strong and weak points in design and construction, and to analyse the data collected for determination of design criteria.

A study of the literature reveals that the reciprocating pump was invented by a certain Ctesibius in 275 BC[1], and that in the intervening period of some 2250 years, little has been done to improve it. This is particularly true in respect of the hand-operated reciprocating pump, which has found less and less use with the advent of the centrifugal pump, internal combustion engine and electrical energy. As industrialized countries have thus virtually lost interest in this type of device, there has not been much published on the subject, and it is now left to the larger developing countries, where there is still considerable need for such a pump for community use, to pursue its development.

The most significant contribution to the improvement of the deep-well handpump which has so far been seen has been the work done by the Batelle Memorial Institute, Ohio, for the U.S. Agency for International Development. This work is described in two reports, dated September 1967 and August 1970.[2,3] In these reports, the problems in connexion with the deep-well handpump have been clearly identified and design principles laid down. The studies made covered wear and tear on components using various types of cylinders, and identification of the reasons for the differences in performance. The project also experimented with plastic coatings on the cylinder walls and with synthetic cup washers. The information collected in this study in respect of the metallurgical aspects, particularly of the cast-iron components, is adequate, and no additional investigation is necessary. It was felt, however, that the reports did not contain adequate data on patterns of use from which design criteria might be derived and that this question needed further field investigation. Further, not much attention had been given to the improvement of valve performance. While the use of better materials in the flap valves was considered, the use of balls in the valves also was discussed, and the comment made that American manufacturers do not recommend ball valves because of the "distortion of the valve seats caused by the pounding of the heavy ball checks".

A further report of some relevance was the one prepared for WHO by the All-India Institute of Hygiene and Public Health, Calcutta,[4] in 1973. Although this report dealt with shallow-well handpumps for community

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[1]Eubank, The Story of the Pump and Its Relatives, 1972.

[2]Frink, D.W. and Fannon, R.D. Final Report on the Development of a Water Pump for Underdeveloped Countries, Batelle Memorial Institute, Ohio, 1967.

[3]Fannon, R.D. and Frink, D.W. Final Report on the Continued Development and Field Evaluation of the AID Hand Operated Water Pump Batelle Memorial Institute, Ohio, 1970.

[4]Majumdar, N. and Sen Gupta, J.N. Final Report on Study of Handpump (Shallow Tubewell) for WHO/UNICEF-assisted Projects and Other Rural Water Supplies, AIIHPH, Calcutta, 1973.

use, defects similar to those appearing in the deep-well handpump were found. This report, supported by work done at the Central Mechanical Engineering Research Institute in Durgapur, corroborates the findings about metallurgical aspects which were described in the Batelle studies.

2 Field Study

The initial purpose of the field study carried out was to obtain information on the way the pumps were being used, the principle defects and the requirements of the users. It was hoped that in the study it would be possible to collect data on frequency of stroke, length of stroke and diameter of cylinder, which would be useful as a basis for design.

A sample size of 100 pumps and 20 users per pump was decided on as being probably adequate to give representative information. All pumps had similar pump heads, and the cylinders were 2-1/2", 3" and 4" in diameter, the 3" size being the most common.

During the collection of field data, some modifications were made to the plan for the surveys,as other factors appeared to have some bearing on the investigation. (For example, the height of the individual user in relation to the height of the pump-handle fulcrum appeared to have a bearing on the efficiency of the operation of the pump.) An attempt was also made to measure efficiency, as it became evident that to operate different makes of pump a varying degree of effort was necessary.

Data collection was carried out for the field study over a one-month period, with the help of four junior engineers and twenty students employed by the State Government of Karnataka. Some delay was experienced through the need to repair a number of pumps which were out of order. The following data were collected:

(1) Number of users per pump (from 0500 to 2000 hours). Classified as men, women and children.

(2) Average length of stroke. Top and bottom of each stroke performed by the user in filling his pot of water measured, using a device attached to the pump rod.

(3) Frequency of stroke. Number of strokes performed by the user to fill the pot counted by means of a stroke counter fitted to the pump rod. The time taken checked with two stop-watches and the stroke frequency calculated.

(4) Rate of pumping. Quantity of water pumped in a given time measured.

(5) Height of user. Recorded for each user.

(6) Overall efficiency. An attempt made with each pump to make a comparison of efficiency by recording the dead weight necessary, when applied at 0.70m from the handle fulcrum, to move the handle through 0.25m in five seconds.

(7) Well data

(a) static water level in well
(b) make of pump

(c) diameter of cylinder
(d) depth at which cylinder was installed
(e) size of riser pipe.

In addition to these tests carried out on a sample of pumps and users, observations were made on the general problems being experienced in the field and on the cause of pump breakdowns. It was found that most of the breakdowns seemed to occur in the pump head. Wear and tear were made worse by the excessive tolerances at all the working or moving points. (This factor is dealt with further in Section 4 below.) It is apparent that the pump head must be a robust piece of equipment to be able to take the continuous daily use and abuse to which it is subjected in community life. At least for the time being, the inadequacy of pump maintenance organization must be accepted, and equipment should be designed so that it can operate with reasonable efficiency with a minimum of maintenance.

Cylinder problems arise mainly when cup or bucket washers wear out. Excessive wear and tear on the leather washers may be attributed to poor surface of the cylinder wall, incorrect treatment of the leather or tilting of the piston assembly in the cylinder. The leather washers examined do not conform to the standard specification of the Indian Standards Institution for these items, which states that the leather should be impregnated with wax which has a 60°C melting point. Such wax impregnation will produce a leather washer which is not water-absorbent and which will maintain its form and suppleness, wet or dry. The leather cup washers examined were water-soaked and pressure formed in hand presses. They absorb water and swell, adding to the friction and are too stiff when dry but too soft when wet.

Another serious defect in the leather washers is that they are not of uniform diameter, and the hole punched in the floor of the cup, to enable it to be mounted over the follower, is often eccentric, sometimes by as much as 1.5 mm.

Lack of guides for the connecting rod also causes damage to the cups. In operation, the piston assembly carrying the cup washers tilts in the cylinder, resulting in greater friction and uneven wear.

Pumps also fail through disconnexion of the long connecting rod within the rising pipe. The induced torque from the whip of the rod, combined with the impact at the end of each stroke, tends to unscrew a connecting rod at one of the connectors after some time. Such failure can occur even when the connectors are "locked" satisfactorily at the time of installation. The provision of guides at intermediate points on the connecting rod and at the top of the cylinder should overcome this problem.

Most Indian pump manufacturers have adopted a pump head design which uses guide pillars and a guide to prevent lateral thrust on the piston rod when the handle is operated over a long stroke. The fulcrum link compensates for this movement. (See Drawings Nos. 1 and 2, pp.9-10, showing typical handpumps and the names of the different parts. Plates 7 and 8 on p.16 may also be helpful.) It was observed in the field that this guide system produced considerable friction owing to poor accuracy in manufacture and that, in any case, the double-hinged fulcrum link could compensate for this thrust. As a check, the guide was removed on a few pumps, and the operation proved to be much smoother and to require less force. It is of interest that a recently manufactured pump head from the USA, which was received through UNICEF, no longer incorporates the guide and pillars, which were supplied with earlier models.

It was observed that the energy level required to operate a handpump was not excessive when the cylinder was no lower than 30 meters below ground level and the static water level in the well about 10 to 12 meters below ground level. At greater depths the pumps were difficult to operate, and where the pumps had to take this higher stress, applied to lift the water a greater distance, early failure often occurred. This observation was particularly true of the single-pivot, chain-link type of pump head (see Drawing No.2, p.10).

While most pump heads of the conventional design are of the same height, they are installed on foundations of different heights. When the pump handle is released at the bottom of its stroke, it rises sharply upwards to its highest position because of the dead weight of the connecting rod string. Apart from the potential accident hazard, it was found that often this top position left the handle beyond the reach of children. It seemed in the study that for each user there were two heights of pump handle which were comfortable, (a) when the handle was high enough for the user to apply body weight and (b) in the low position, when a "stiff-arm" operation could be used. Plates 1, 2 and 3 (p.11) show settings of the pump handle as high, low and intermediate.

In the course of the field study many faulty installations were noticed. As examples, Plates 4 and 5 (p.12) show where the incorrect mounting of the pump led to early breakdown by not having a solid foundation to which the pump was bolted. In both cases the foundation is crumbling, and there is no apron or leadaway drain for excess spill water. In such cases, the excessive movement of the pump, when used, contributes to early wearing out of parts. A further problem is shown in Plate 6 (p.12), which indicates a pump located in an insanitary position, which may create a health hazard.

3 Analysis of Field Study Observations

3.1 Height of user

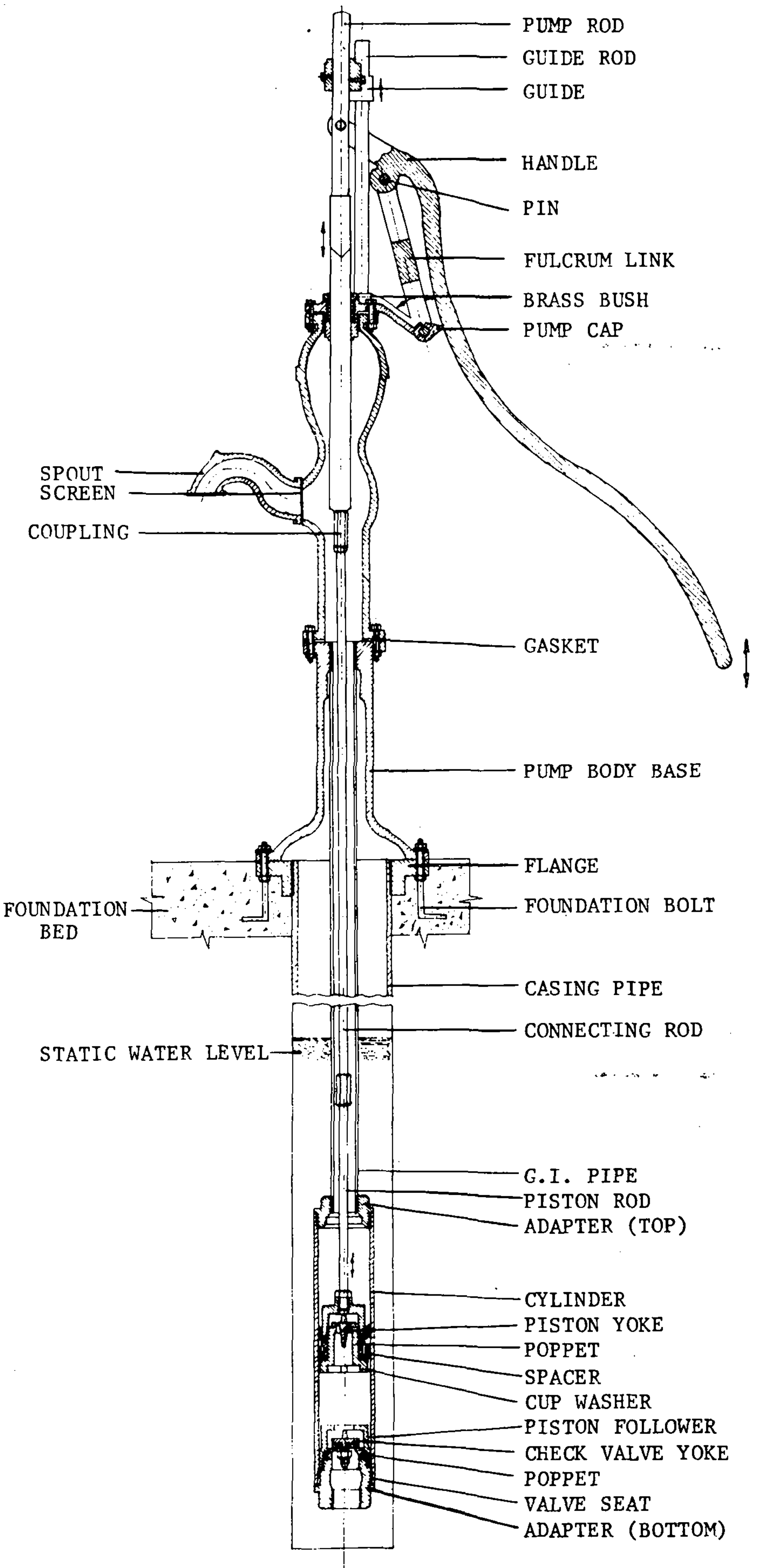
The heights of 2000 users of handpumps were recorded. As was to be expected, there was considerable variation, between 926 mm and 1875 mm, with a mean value of 1512 mm. Although an attempt was made through an additional controlled experiment to establish a statistical relationship between the height of the user, the height of the pump fulcrum and the efficiency of the pump, this was not conclusive. It seemed that there was a human compensation factor which came into play, which made a purely statistical analysis unrealistic.

3.2 Stroke length

For the total number of observations, the average stroke length recorded was 114 mm. Some variation was measured in the mean stroke length

DRAWING No.1

NOMENCLATURE DRAWING OF DEEP WELL HAND PUMP



DRAWING No.2

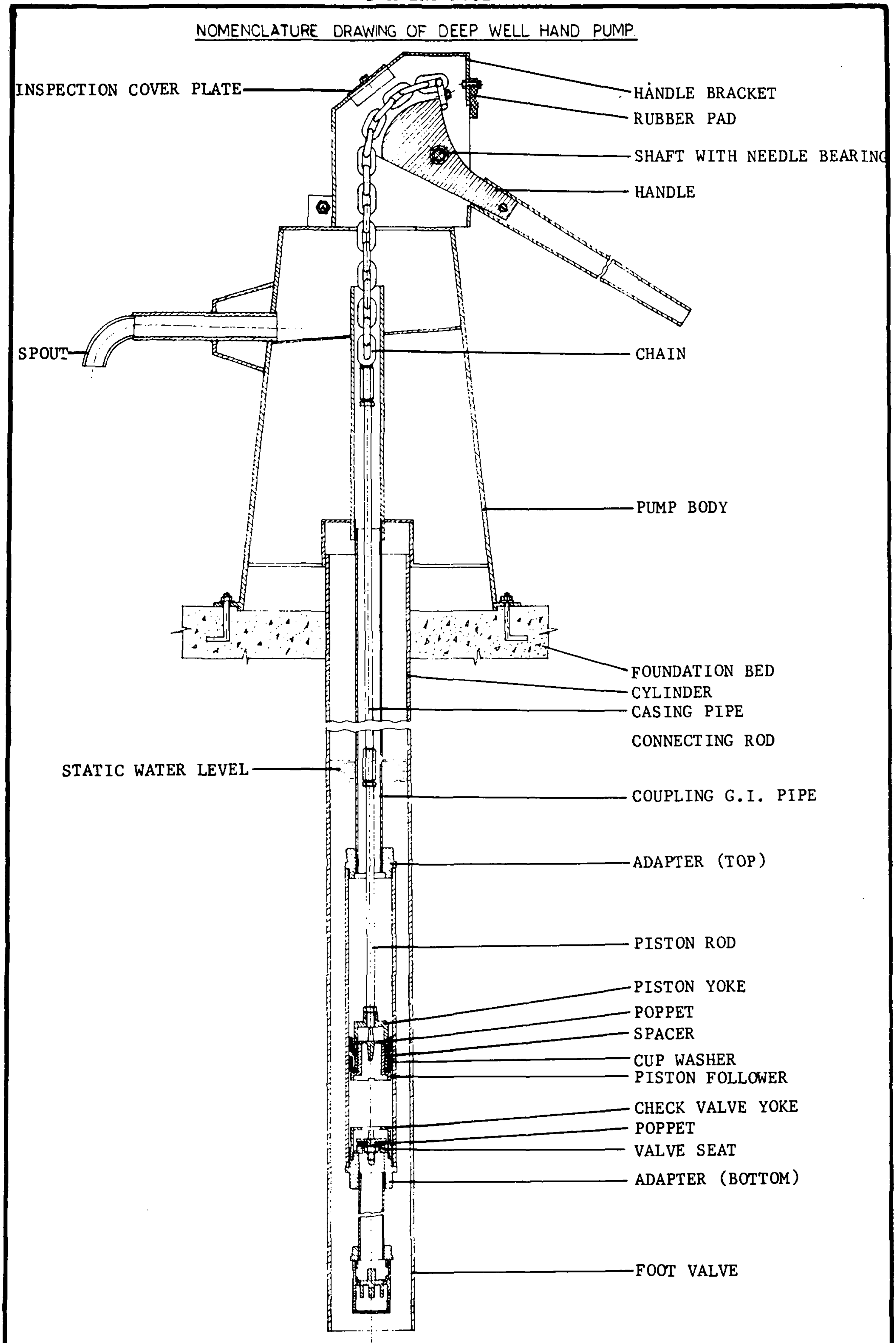

NOMENCLATURE DRAWING OF DEEP WELL HAND PUMP
INSPECTION COVER PLATE
HANDLE BRACKET
RUBBER PAD
SHAFT WITH NEEDLE BEARING
HANDLE
SPOUT
CHAIN
PUMP BODY
FOUNDATION BED
CYLINDER
CASING PIPE
CONNECTING ROD
STATIC WATER LEVEL
COUPLING G.I. PIPE
ADAPTER (TOP)
PISTON ROD
PISTON YOKE
POPPET
SPACER
CUP WASHER
PISTON FOLLOWER
CHECK VALVE YOKE
POPPET
VALVE SEAT
ADAPTER (BOTTOM)
FOOT VALVE

Plate 1

Pump handle with high setting.

Plate 2

Pump handle with low setting.

Plate 3

Pump handle with intermediate setting.

Plate 4

Poor pump foundation without apron and drain to soakage pit.

Plate 5

Crumbling pump foundation without bolts. No apron or drain.

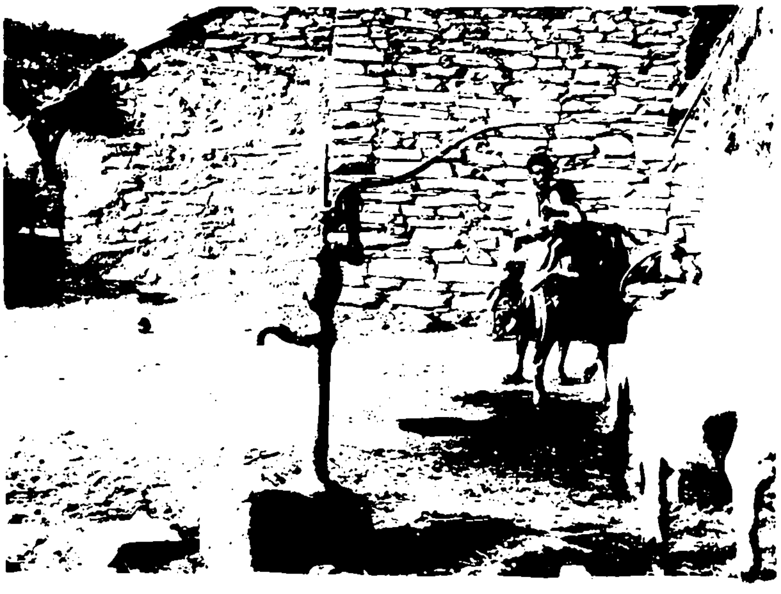


Plate 6

Insanitary location for well surrounded by animal dung.

according to the different cylinder size: for the cylinders of 2-1/2" diameter, the length recorded was 117 mm; for 3" diameter cylinders it was 116 mm, and for 4" diameter cylinders it was 101 mm. This indicates a further element of human compensation in reducing the length of stroke for the greater load to be lifted.

3.3 Stroke frequency

This was measured by counting the number of strokes taken for the pot to be filled and by timing this operation. Here again there was a natural tendency for the user to match his energy capacity to the rate of pumping, since mean frequencies for pump cylinders of 2-1/2", 3" and 4" diameter were found to be 64.0, 58.1 and 47.9 strokes per minute.

3.4 Time of pumping

The time of pumping ranged between 10 and 72.5 seconds. Averages for the different cylinder sizes were 26.0, 26.0 and 23.4 seconds for the 2-1/2", 3" and 4" cylinders respectively. The distribution tended to have a positive skew.

3.5 Pump output

The water delivered by the pump for each user was recorded, together with the time of pumping. The output was calculated for each of the three sizes of cylinder and was found to average 26.9, 30.0 and 34.8 litres per minute for the 2-1/2", 3" and 4" cylinders respectively. On this basis, considering the time of pumping calculated earlier, the average quantity of water drawn by villagers is about 13 litres. It is, perhaps, interesting to note that to draw as much water from a tap in the high-pressure area in Bangalore city would take more than twice as long.

3.6 Classification of pump users

It is generally believed that women and children make up the main body of users, and that men would not be expected to constitute more than 10%. According to the data collected between the hours 0500 and 2000 in this study, however, women made up 37.4%, children 34.8% and men 27.8%. The number of persons using the pump per day ranged from below 240 to above 1340, with an average of 683, for the 100 pumps studied.

3.7 Design criteria derived from the survey

The basic design criteria and conclusions derived from the field survey are as follows:

(1) It is obviously impossible to select a pump height which will suit the entire range of users. The most suitable height of pump for the average-size users was selected as 1.00 m, exclusive of the height of the foundation, which should be limited to 100 mm above platform level.

(2) Since there is undoubtedly an element of comfort involved in the relative height of the user and the pump, if one could evolve a pump head of which the operation was independent of the individual's stature,

this would seem to be an advantage. From this reasoning, the concept of a foot-operated pump head was derived.

(3) The most advantageous size of cylinder is 2-1/2" diameter. This conclusion is based on the following considerations:

(a) the smaller diameter cylinder has a strong cost advantage;

(b) this size appears to have the highest efficiency;

(c) the output is better matched to the energy which the user can supply, and

(d) field observations have shown that pumps with the smaller cylinders require less frequent maintenance.

(4) The stroke length should be about 114 mm (equivalent to 4-1/2").

(5) The stroke frequency for design purposes is taken as 50 strokes per minute (likely to be somewhat higher in practice, but this is not of particular consequence in the design of the pump).

Table 1. Summary of Analysis of Field Data

Item	Unit	Cylinder diam.			
		2-1/2"	3"	4"	Total
Number examined	No.	13	65	22	100
Average stroke length	mm	117	116	101	114
Average stroke frequency	Strokes/ minute	64.0	58.1	47.9	56.6
Average time of pumping	Secs.	26.0	26.0	23.4	25.4
Average collected output	l/min.	29.9	30.0	34.8	30.6

4 Workshop Study

4.1 Preparation

The workshop study was carried out on a series of sample pumps purchased and provided by UNICEF. It consisted of two parts. As a first stage, detailed drawings were made of the pumps and cylinders and of each component. (These, comprising nearly 200 sheets, are compiled in Volume Two of Mr Emmanual's report.) The second part of the study consisted of a critical analysis of the design and manufacture of available pump heads and cylinders.

The conventional pump head is shown in Drawing No.1 (p.9), which also gives the names of the component parts. This pump head has a cast-iron body, and the verticality of the pump-rod is maintained by a guide-pillar and guide arrangement. Drawing No. 2 (p.10) shows the components of a single-pivot chain-link type of pump head such as developed in India under the names"Jalna", "Jalvad" and "Sholapur". This type of pump has a body fabricated of mild steel sheet, and the pump handle is linked to the connecting rod by means of a roller chain which rides over a quadrant.

Typical examples of these pump heads are shown in Plates 7 & 8, and an exploded view of typical cylinder components is given in Plate 9 (see p.16).

4.2 Conventional pump head

The following defects were frequently recorded for pump heads similar to the one shown in Drawing No. 1 and Plate No. 7. (Plates No. 10 and 11 show some of the defects described):

(1) The moving parts are poorly matched. Tolerances and fits are excessive, allowing the handle and fulcrum link to rock sideways.

(2) The guide pillars are not fitted true to vertical. They are not locked in the pump head cap and therefore tend to work loose.

(3) The holes in the guide have too high a tolerance, with the result that the guide tends to tilt and foul the pillars.

(4) *Some makes of pump have a forged 1" square section handle between* the linkage with the piston rod and the fulcrum link. The fork at the point of linkage with the piston rod is formed by welding pieces of mild steel flats on either side of the square section. These strips are then spread to accommodate the pump rod, but the technique tends to distort the bearings and to produce uneven wear.

(5) The pivot pins are not truly horizontal in their bearing housings.

(6) The guide is held in position on the piston rod by a 6 mm set screw, which often works loose, allowing the guide to ride up and down the pillars, carried by the linkage point of the handle.

(7) The spout is shaped like an inverted P-trap to prevent the introduction of sand and pebbles by children. A piece of mesh screen is also included to protect the pump. The design is not effective in many cases, and sand, etc., can still be pushed inside until the spout is choked. Further, the off-set of the spout is often inadequate, causing spillage of water.

(8) The holes provided in the flanged base are generally for 10 mm diameter foundation bolts, which are not large enough.

(9) One of the imported pumps has a weak point where the pump rod joins the connecting rod. Failure at this point has been observed.

(10) In several models of one imported pump head, the nipple provided inside the pump body, to which the riser pipe is connected, has fractured. Since this nipple is threaded both inside and outside, the wall thickness is inadequate.

(11) One pump manufacturer provides a screw-type mounting flange for 4" and 6" diameter casing pipe to match the base flange of his pump head. This requires the end of the casing to be threaded to receive the flange. Certain serious difficulties are encountered, viz., (a) unless the casing pipe is perfectly vertical, the corresponding non-verticality of the pump head will create additional stress on the pump; (b) the provision of screwed ends on the casing pipe may involve having to weld on a special threaded piece. The threaded end is very susceptible to damage, resulting in poor mounting of the pump head.

4.3 Single-pivot chain-link pump head

The following points of critical observation are made on the models of this type inspected, similar to those shown in Drawing No.2 (p.10) and Plate 8 (p.17).

(1) The mild steel fabricated body is imprecisely formed. Welding runs are not continuous, and the base flange is not flat.

(2) Most ground waters from hard rock areas are slightly acidic, and the mild steel sheet forming the pump body is liable to become corroded.

(3) There is a mild steel sheet welded across the pump head section to serve as a stiffener and act as a discharge tray. The sheet is sloped, finishing 10 to 20 mm below the level of the spout, so that water collects at this point, which is particularly affected by corrosion.

(4) There is inaccuracy in the fabrication of the bracket carrying the handle, and frequently the pivot point is not located so that the chain is vertically central over the riser pipe.

(5) The quadrant is sometimes imprecisely formed, so that the pivot point is off-centre of the quadrant, resulting in malalignment in some positions of the handle.

(6) Mild steel sheet fabrication is not a manufacturing procedure or technique which is suitable for mass manufacture.

4.4 Cylinders

The cylinder provided by all manufacturers is of brass. The trueness and surface finish of these cylinders are not of a high order, and this has been commented on by the Batelle Institute, Ohio, and by CMERI, Durgapur (see Part III, 1). The poor surface finish of the brass cylinder produces rapid wear of the leather washers. The components such as the pump yoke, follower, check-valve body, etc., are crudely cast in brass and individually machined, with very little quality control in regard to dimensioning. The result is that manufacturers do not produce components that conform to reasonable tolerance limits. Castings are of poor quality, with blow holes and eccentricity as common features. Scrap brass is often used for these castings.

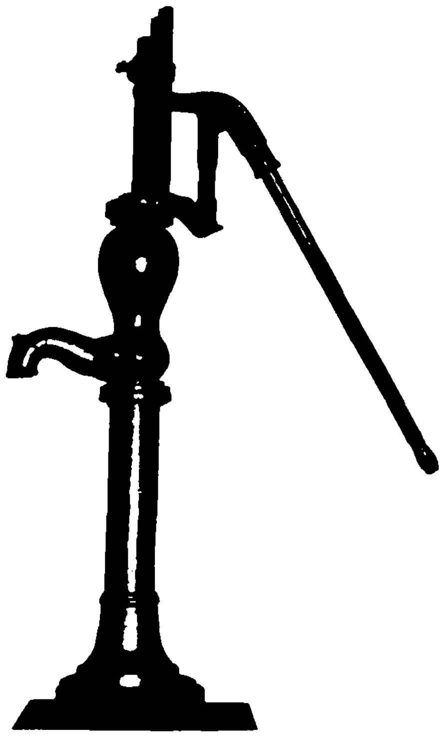


Plate 7

Example of conventional type of deep-well handpump pump head, of indigenous manufacture.

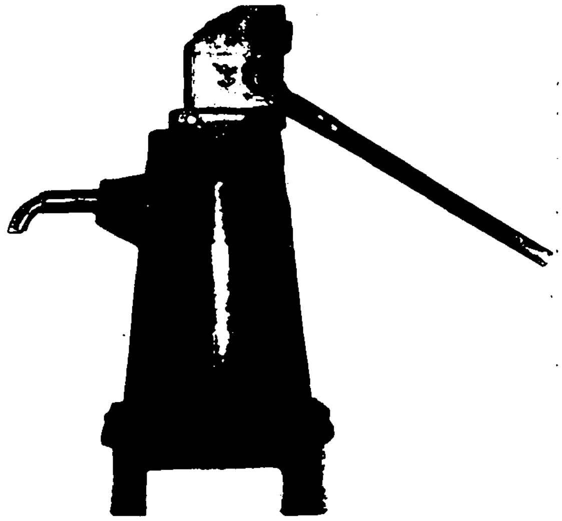
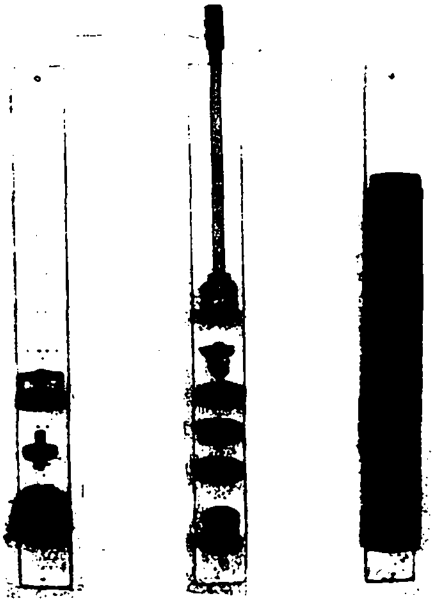


Plate 8

Example of pump head for deep-well handpump of single-pivot chain-link type, or "Jalna" type.

Plate 9

Exploded view of typical cylinder components.



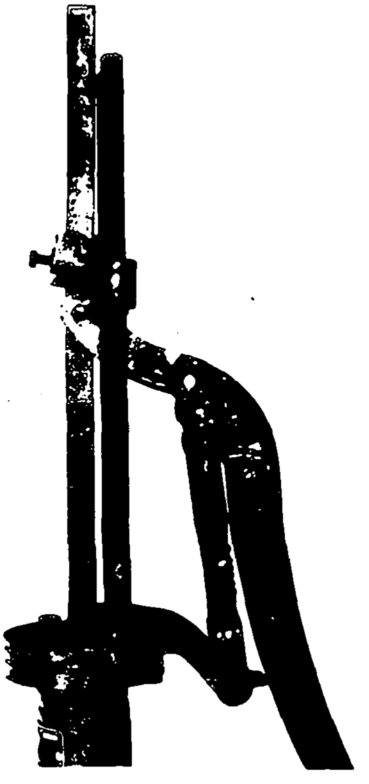


Plate 10

Manufacturing and design defects shown in locally manufactured deep-well handpump: non-verticality of guides and high friction on guide in upper position.

Plate 11

Manufacturing and design defects: pillars not vertical, high tolerance between handle fork and piston rod, pin bushes of handle fork poorly aligned, and pin not horizontal.

An additional factor is that brass is an expensive material in India, and the cost of the cylinder adds considerably to the overall cost of the pump. There is a great demand for scrap brass on account of the extensive cottage brass-foundry industry. It is a common experience for brass components to be "lost" when a pump is dismantled for repairs.

The leather bucket washers used are of very inferior quality, and the leather itself does not satisfy Indian Standards Institution (ISI) standards, as already mentioned.

IV. CYLINDER DEVELOPMENT

In developing a design which will perform the required duty, four aspects have to be considered, viz.,

(a) the fundamental design criteria based on usage patterns,
(b) the hydro-dynamic considerations effecting the design,
(c) the factors affecting mechanical design and
(d) the choice of materials of construction.

1 Design Criteria

The design criteria for the pump have been established by the field survey described earlier.

2 Hydro-dynamic Considerations

The hydro-dynamic considerations have been dealt with at some considerable length in Mr Emmanuel's draft report (see Introduction, page 1). The phenomena described are, however, rather complex, and there is some disagreement as to what forces actually come into play in the operation of the deep-well handpump. For this reason, and because the theoretical considerations do not appear to be as important as the practical ones in this instance, it has been decided not to include in this document any theory of the hydraulics involved, although it may be of interest to take this up elsewhere. In practice, the working of the valves is of major importance to the operation of the pump, and the two valves encountered in the single-acting deep-well handpump are the check valve and the piston valve.

The check valve, as indicated in Drawing No.1 (p.9), is at the bottom of the cylinder assembly. The conventional check valve uses a brass poppet with metal-to-metal seating or, in some cases, a rubber-to-metal seating, where a rubber lining is provided on the underside of the brass poppet. Since the specific gravity of brass is high (about 8), some advantage can be gained by using a material of lower specific gravity to facilitate the upward passage of water when the piston is raised. Further, it is generally agreed that a ball valve gives better performance than a poppet type, but some authorities have expressed the view that the pounding of the ball valve on closure may cause damage to the ball and to the seat. This would apply possibly to metal balls of high specific gravity, but by selecting a material of lower specific gravity this objection can be overcome. Nylon balls (imported), loaded to give an effective specific gravity of 4.5, have been used in the prototype experiment with excellent results. Equally good results could be expected from a synthetic rubber ball which could be formed over a steel core to give the desired composite specific gravity. The ball sits on a moulded synthetic rubber seat with inclined shoulders. The rubber ball could have a shore hardness 60, and the rubber seat could have a slightly higher shore hardness.

The piston valve is incorporated in the piston assembly, as shown in Drawing No.1 (p.9). A type of ball valve similar to that described above can be used. In this case the specific gravity could be lower (about 4.0), as the valve is actuated by the reciprocating motion of the piston itself.

3 Mechanical Design

The factors which require consideration, in so far as the mechanical design is concerned, are:

(a) preventing the piston assembly from tilting in the cylinder,
(b) dampening the impact of the piston at the top and bottom positions,
(c) preventing disconnexion of the piston rod from the piston yoke, and
(d) facility of dismantling the cylinder assembly.

The first requirement is met by providing a plunger rod guide at the top of the cylinder assembly. This guide may be of high density polyethylene (HDP) or unplasticized poly-vinyl chloride (uPVC), and may be bushed in resin-impregnated fabric. This material is water-lubricated, and the bush may be replaced as required.

The second problem may be solved in one of two ways: by providing a spring buffer over the piston yoke and rubber buffer over the check valve, or by so arranging the limits of the stroke that the piston does not hit the check valve at the bottom or the rod guide at the top.

Disconnexion of the piston-rod from the piston yoke has been overcome by moulding the first 25 mm length of the connecting rod into the piston yoke.

Dismantling is simplified by having all components of the cylinder assembly made so as to be fitted sequentially into the galvanized iron (G.I.) cylinder body. They are held in position by the G.I. reducing socket at the top and the G.I. cap at the bottom. Drawing No.3 (p.22) shows the component parts of the improved cylinder.

4 Choice of Materials

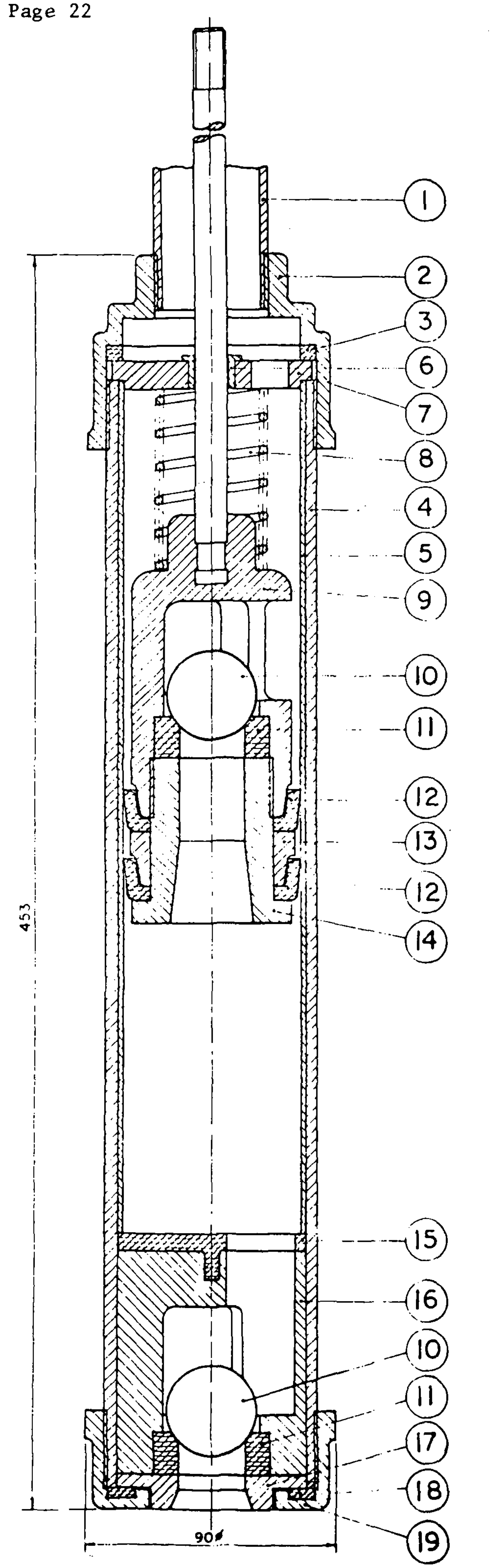
The guiding consideration in the choice of materials has been the unsuitability of brass for the cylinder and the cylinder components, partly on account of the cost and partly on account of the methods of production used. The fact that brass components are likely to be stolen has also been kept in mind. There is little doubt that mass production techniques such as die-casting and hot-stamping could be used in manufacturing some of the brass components, but this is not done in practice, possibly due to the high initial cost of the dies and the short production runs required.

The ideal cylinder sleeve should have the following characteristics:

(a) It should be non-corrodable since it remains immersed in water;
(b) It should have a good finish (smooth cylinder wall) at low production cost;
(c) It should have high abrasion resistance;
(d) It should have a low coefficient of friction against the material of the bucket washer;
(e) It should be water-lubricated;
(f) It should have adequate structural strength;
(g) It should have low water-absorption and should not swell;
(h) It should be easily available locally, and
(i) It should be relatively cheap.

DRAWING No. 3

CYLINDER ASSEMBLY
FOR
DEEP WELL HAND PUMP



19	1	03-01-16	VALVE SEAT RETAINER CAP	G I	STD
18	1	03-01-17	SEALING RING	HARD RUBBER (NEOPRENE)	
17	1	03-01-16	VALVE SEAT RETAINER	HIGH DENSITY POLYTHENE	
16	1	03-01-15	CHECK VALVE BODY	HIGH DENSITY POLYTHENE	
15	1	03-01-14	BUFFER	HARD RUBBER (NEOPRENE)	
14	1	03-01-13	FOLLOWER	[illegible]	
13	1	03-01-12	SPACER	HIGH DENSITY POLYTHENE	
12	2	03-01-11	CUP WASHER	[illegible]	
11	2	03-01-10	VALVE SEAT	HARD RUBBER (NEOPRENE)	
10	2	03-01-09	BALL VALVE	NYLON	
9	1	03-01-08	PLUNGER YOKE BODY	[illegible]	
8	1	03-01-07	SPRING (COMP.)	SPRING STEEL TS 15 55 Si 2 Mo 90/EN 45	
7	1	03-01-06	PLUNGER ROD GUIDE	HIGH DENSITY POLYTHENE	
6	1	03-01-05	BUSH	NYLON	
5	1	03-01-04	CYLINDER SLEEVE	[illegible]	
4	1	03-01-03	PIPE 2-1/2"	G I	STD
3	1	03-01-02	SEALING RING	HARD RUBBER (NEOPRENE)	
2	1	03-01-01	REDUCER CAP	C I	
1	1	—	PIPE $1\frac{1}{4}$"∅	G I	STD

In considering substitute materials for the cylinder sleeve, it is evident that there is no justification for the cylinder body to have a longer life with respect to corrosion than the pipe string by which the cylinder is suspended in the well. Since the pipe string is generally of galvanized iron, the cylinder body could also be constructed in a standard size of G.I. pipe and pipe specials.

The inside finish of the G.I. pipe is unsuitable for use as the cylinder wall, and it is necessary to have a "sleeve" or "liner" which can be used inside the G.I. cylinder body to provide the desired surface. This arrangement has an added advantage in that the G.I. cylinder body provides structural support to the cylinder liner, thereby reducing the need for high structural strength of the liner. A cylinder liner capable of withstanding the wear and tear of about one year's use by a community would be satisfactory. The Batelle Memorial Institute, Ohio, has experimented on various coatings on mild steel pipe. These coatings have been bonded to the pipe to provide on integral cylinder body. Vinyl, epoxy and uralkyd coatings have been tried, and some have shown promise of long life. It has, however, been necessary for the entire cylinder body to be discarded when a replacement is required. There therefore appears to be a distinct advantage in using a cylinder sleeve with a sliding fit,which can easily be replaced in the field at a nominal cost. This approach has been used to produce a suitable cylinder.

The most common types of plastic tubing commercially available are poly-vinyl chloride (uPVC) and high density polyethylene (HDP). These materials do not have the abrasion resistance which is required in a community pump, although they could very well be suitable in a pump which is limited to single-family use. Such materials as acrylonitrile butadiene styrene (ABS) and epoxy resin-impregnated fiber-glass mat are good materials but have not been given serious consideration on account of difficulty of availability and relatively high cost. A rolled tube, based on medium-weave cotton fabric and impregnated with an epoxy resin, is manufactured in India on a commercial scale, is available in several standard diameters and wall thicknesses and could be made to any dimensions if the order were big enough. The greatest application of the epoxy-impregnated fabric is in bearings and bushes, where its water lubrication properties are needed. As the tubes are rolled on accurately machined mandrels, they can be produced to acceptable tolerance with good surface finish. This material, which bears the trade name in India of "Hylam TF 2211", has high tensile and cross-breaking strength. The tubes are produced in standard lengths of 1.09 to 1.25 metres, at a price of Rs 45.50 per length of 64 mm internal diameter tube (equivalent to approximately US$ 5.70). At this rate a cylinder sleeve would cost less than Rs 12 ($1.50). (For comparison, the cost of a brass cylinder of similar size would be about Rs 60 ($7.50).

This material thus satisfies most of the criteria laid down for the cylinder sleeve. The outside diameter of the tube required is limited by the inside diameter of the G.I. pipe, which would have to be rough-ground to remove beads of zinc. A slight increase in diameter may be expected. The outside diameter of the resin-impregnated fabric tube should lie within the limits of 0.23 and 0.34 mm less than the inside diameter of the G.I. pipe, which should be between 0 and 0.5 mm greater than the stipulated diameter.

The piston yoke is subject to considerable stress, mainly in tension, since it carries the dead weight of the column of water and the connecting rod, and is also subject to impact loads. The dead load may range to about 60 or 100 kg depending on the depth of the cylinder from ground level. A safety factor of 5 or 6 is desirable to ensure that this component does not suffer failure. The only materials which seem suitable for use in this component are glass-fibre mat impregnated with epoxy resin, and medium-weave cotton fabric impregnated with epoxy resin. The latter is preferred on account of its lower cost and greater ease in moulding. The structural properties of this material have been described above,and it will be seen that it is suitable.

The washer spacer, follower and check valve body are not required to take high stresses nor to have any special characteristics. The considerations of cost and mouldability are the most important factors. HDP and uPVC are both suitable for use in these cases.

While leather, properly treated, is an excellent material for the cup or bucket washer, the washers available on the Indian market are of very poor quality. The characteristics to be looked for in a good washer are:

- low water-absorption
- negligible swelling
- equal suppleness, wet or dry
- low coefficient of friction
- low cost
- availability
- ease of production and reproducibility to correct sizes.

Since plastics are generally being proposed for use in the cylinder components, it would be consistent to seek a plastic material which would be suitable. Neoprene and acrylonitrile rubber are both satisfactory, the latter with the advantage of having a good moulded surface. The process of manufacture of moulded items lends itself to a high level of quality control and the production of a perfectly concentric and accurately dimensioned component, thus overcoming the problems commonly encountered with the leather cup washer.

Details of the proposed new cylinder are shown in Drawing No.3 (p.22), and the choice of materials from the various components is given in Table 2 (see next page).

Table 2. Specifications for Materials

(Specifications laid down for the cylinder components, on the basis of this study)

Item	Material	Remarks
Cylinder top coupling	G.I.	Standard G.I. reducer socket, 2-1/2" x 1.25"
Cylinder body	G.I.	Standard G.I. Pipe 2-1/2" dia., medium quality
Piston rod guide	HDP or uPVC	Bushed in Hylam TF 2211 or nylon
Cylinder sleeve	Hylam TF 2211	Resin-impregnated fabric
Piston yoke	Hylam TF 2211	
Cup washer	Acrylo-nitrile rubber or neoprene	
Follower	Hylam TF 2211	
Valve seat	Butyl rubber or neoprene	Shore hardness 60
Ball (piston valve)	Nylon or rubber	Loaded to give Sp.Gr. of 4.0
Buffer	Rubber	
Check valve body	HDP/uPVC	
Valve seat retainer	HDP/uPVC	
Cylinder bottom cap	G.I.	
Ball (check valve)	Nylon or butyl rubber	Loaded to give Sp.Gr. of 4.5

V. PUMP-HEAD DEVELOPMENT

1 General

The breakdowns in the pump head may be classified broadly as being caused by either excessive wear at one or more of the pivot points, resulting in immobility or increased friction at these points, or fracture of the cast-iron components of the pump head.

Fracture of the cast-iron components has been reported in the handle and the pump-base flange. A few cases of failure of the pump body and the spout have also been reported. These fractures have clearly been identified as resulting from the high phosphorous content of the cast iron, and precautions should be taken to keep this below 0.2 per cent.

Most manufacturers do not now use cast iron in the handles, but have substituted a handle with a forged fork end and a pipe handle.

Since most failures occur in the pump head, no attempt has been made to reduce costs by cutting down on the sections. Rather, certain areas have been strengthened and the design altered to widen the base along the line of stress. Cast iron and sheet steel are the only possible materials in this case, and cast iron is considered to be better both from the corrosion point of view and from that of feasibility for mass production.

Although attempts were made to correlate efficiency of the pump with the height of the hand pivot above ground level and the average height of the user, these, as reported earlier, were not successful. For purposes of design, a pump height of 1.50 m is being used as being the most suitable height for most persons. This is based both on the data collected and the physical observation of the "human compensation factor" mentioned earlier. This is, of course, applicable only to the hand-operated pump head.

2 The Hand-Operated Pump Head

Field experience over the last three years, supported by the field and workshop studies undertaken under this project, has shown that the pivot points and moving points of the conventional pump head are weak points in the pump and are generally the points at which breakdowns occur. The conventional pump has shafting steel pivot pins riding in cast-iron "bearing" holes. Various reports have stressed that breakdowns are caused by poor maintenance. It has been found, in the course of the accelerated test conducted in connexion with proving materials and design for the improved pump, that even with good lubrication the type of pivot bearings provided shows relatively high wear.

The reduction of pivot points and moving parts has been achieved to a considerable extent in the Jalna and Sholapur type pumps (Drawing No.2,p.10), which use the single-pivot and roller-chain linkage arrangement, the chain riding over a quadrant placed tangentially to the connecting rod at the end of the handle. This type of pump, however, uses a mild steel-sheet fabricated body, which is not favoured for the reasons given in Section III, 4.2. The conventional pump, on the other hand, uses a tubular casting which requires higher machining costs.

The design evolved and proposed by this project utilizes the single pivot roller-chain linkage system with an open cast-iron frame. This frame simplifies casting, gives easy access to the pipe system and reduces machining costs to the minimum. The proposed improved pump head is shown in Drawing No.4 (p.29) and in Plate 12 (p.18).

3 The Foot-Operated Pump Head

It has been demonstrated that it is impossible to select a single pump height which will cater satisfactorily for the large range of user heights. A logical approach is to evolve a pump head which is independent of this parameter. A foot-operated pump head will not depend on the height of the individual and should give equally consistent performance over the entire range of heights of users. The foot-operated pump head also has an advantage in that the user brings to bear a part of his body weight to operate the pump and is not required to apply muscular energy. Since the pump will not require more than 5 kg. to operate, it will fall within the physical capacity of the average child who would be called upon to draw water.

The foot-operated pump head lends itself to a counter-beam arrangement for providing the reciprocating movement to the piston (see Drawing No.5,p.30). Such an arrangement reduces shock loads on the cylinder and pump-head components,thereby increasing their life. Since the stroke limits are controlled, the spring buffer could be omitted, thus effecting a slight reduction in cost.

The addition of a counterweight on the treadle beam actuating the piston rod will allow for smoother operation of the pump and make for better balance between the delivery stroke and suction strokes. The introduction of the counterweight greatly reduces the effort or pressure on the foot treadle of the pump which is required. A feature of the foot-operated pump head is that the drive is carried on an independent cast-iron T-section frame, while the riser pipe is screwed to the tubular pump pillar, which sits snugly in a socket in the base plate of the pump body. This gives accessibility to the riser pipe string and cylinder, without any need to dismantle the cast-iron frame.

4 Details of Components

4.1 Bearings

The conventional pump uses cast-iron bearing housings with shafting steel pivot pins, while the "Jalna" type pumps use either a heavy needle bearing (from a Willys Jeep water pump) or a pair of standard ball-bearings. Whereas the bearings in the conventional pump are very inefficient and show wear in less than 100 hours of use, the bearings in the Jalna pump are good, but comparatively expensive. Some problems with these pumps have been experienced owing to poor alignment or lack of horizontality of the bosses in which the shaft is housed.

Ball-bearings are generally used for high speed and high load conditions, neither of which requirements is found in the case of the hand pump. The principal objection to the use of ball-bearings is their cost, which could be justified only in the absence of an appropriate alternative, and there is such an alternative in this case. Both the hand and the foot-operated types of pump heads evolved in this project have been provided with sintered bearings, manufactured by Messrs Mohindra Sintered Products, Poona (Types MSP-409 and MSP-135), and provision has been made for oil reservoirs.

Sintered bearings, as manufactured in India, are quite inexpensive. They should give excellent service if the pivot pins are turned to the recommended tolerances and the bearings are lubricated twice a year. Grade SAE 30 oil, mixed with 5 per cent 300 mesh graphite powder, is recommended as lubricant. These bearings are mass manufactured in high precision dies by a process of powder metallurgy involving forming and sizing operations. They are guaranteed to close limits of accuracy on diameters, length and concentricity. The adoption of standard sizes of bearings leads to higher efficiency, greater economy and readier availability. The insertion and extraction of the sintered bushes can be carried out in the field,using simple tools developed for this task.

4.2 Pump base

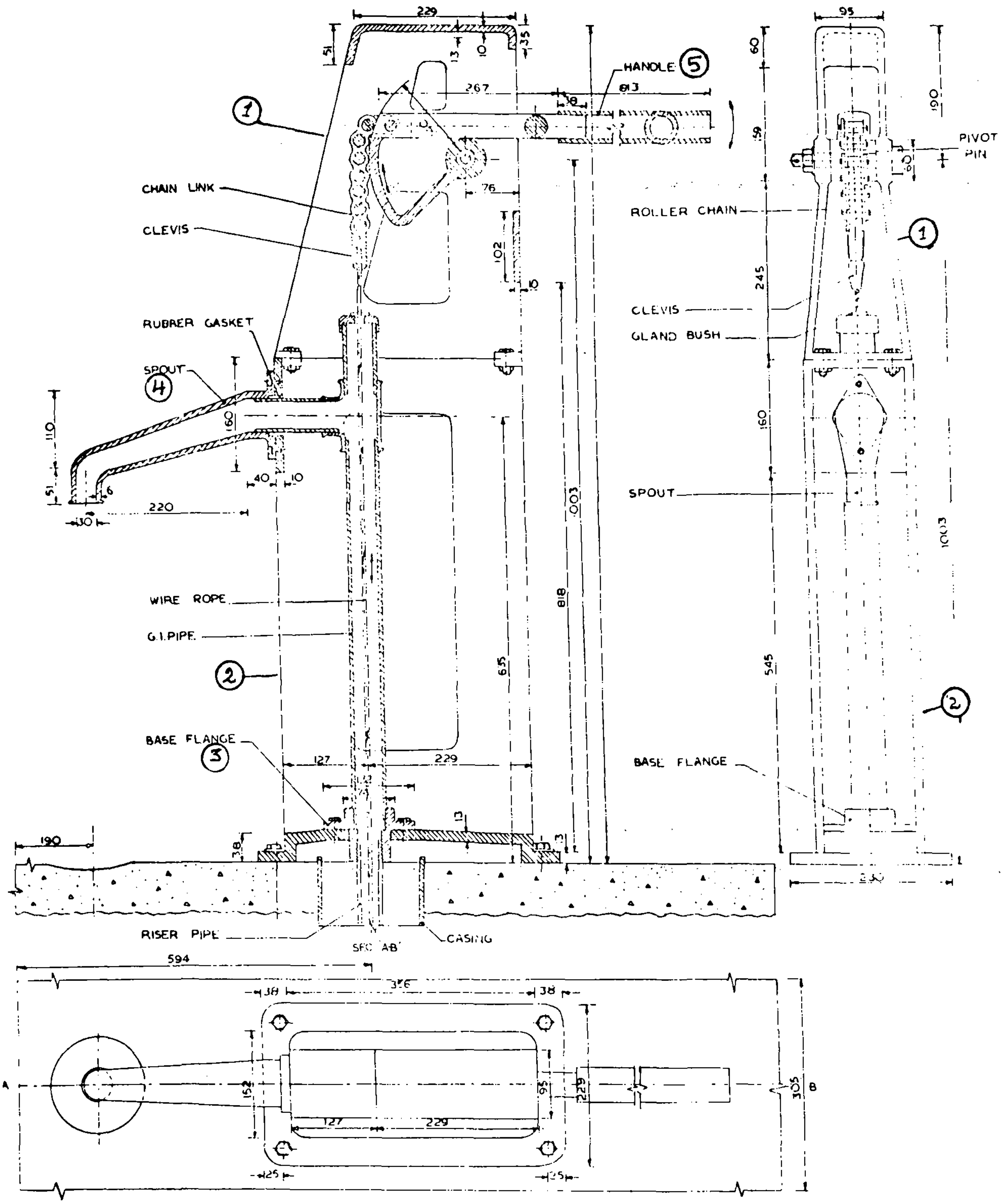
The base mounting for both the hand-operated and the foot-operated types of pump is rectangular in shape, with the axis of the longer side on the stress line. The larger bearing area provides stability for the pump head. Customarily 10 mm diameter foundation bolts are used for anchoring the pump to the foundation. These have been found to be inadequate, and provision has been made in the improved design for four bolts, 16 mm in diameter, to be used.

4.3 Pump spout

The improved design of the pump head provides a change of design in the pump spout. Of the pumps examined, both indigenous and imported, the outlet of the pump spout was only 150 mm from the pump pillar. This distance is inadequate to allow the centre-line of discharge to coincide with the centre-line of the water pot in common use in India. Considerable spillage occurs because of this fact, aggravating the problem of waste water disposal and increasing the energy input required of the user. The spout provided on the improved pump head stands 200 mm away from the pump pillar, overcoming this problem.

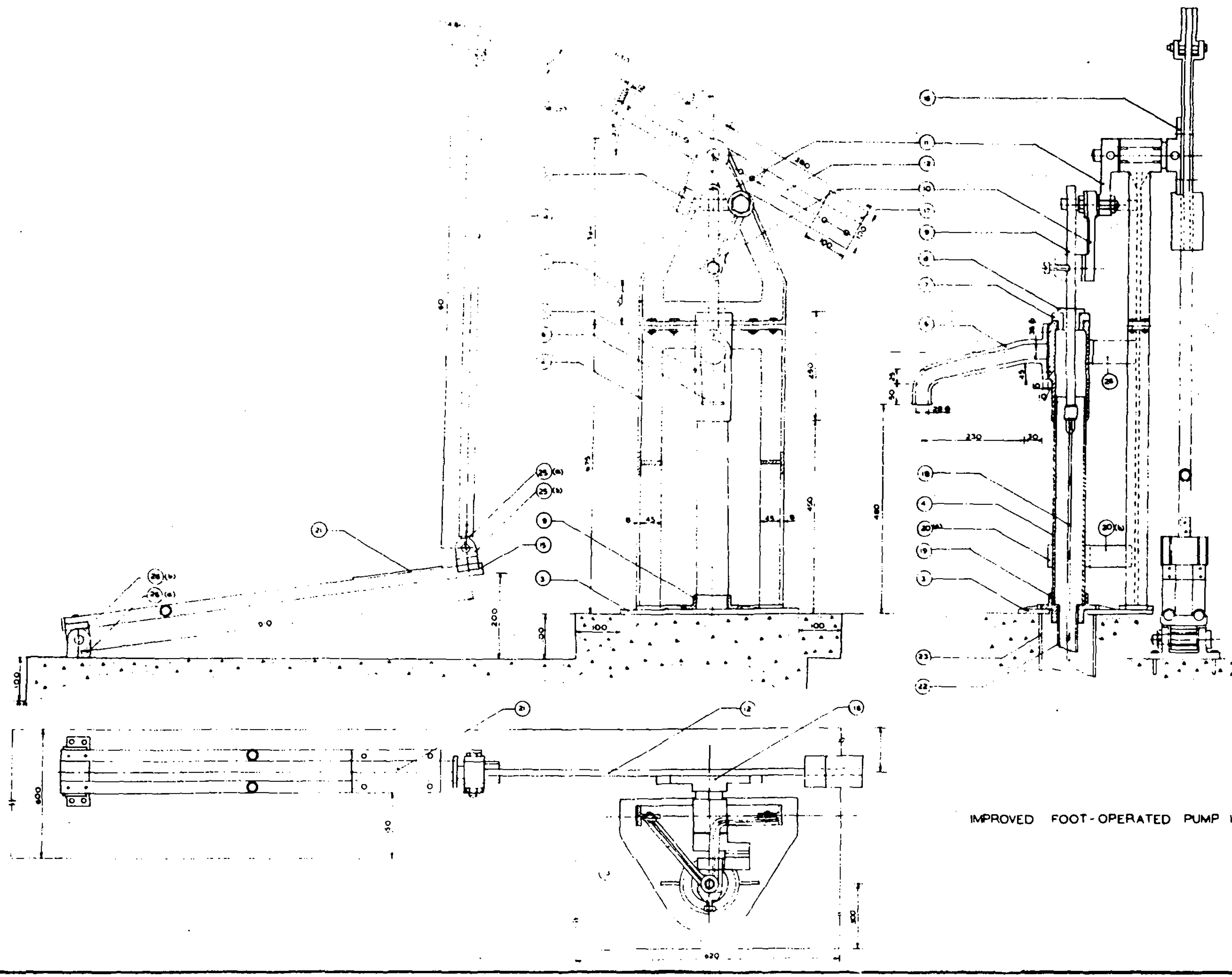
The earlier design of the spout had a "P" bend to prevent the introduction of sand or pebbles through the spout into the pump. In addition, a mesh screen was provided. This created a problem when the material inserted accumulated against the screen. The new design provides a spout that slopes away from its point of fixture to the pump head, ending in a vertical mouth which is 50 mm long. Any sand or pebbles shored upwards into the mouth of the spout will travel only part of the way and will then roll out of the mouth.

DRAWING No.4



IMPROVED HAND-OPERATED PUMP HEAD

DRAWING No.5



IMPROVED FOOT-OPERATED PUMP HEAD

4.4 Connecting rod

Most pumps use a mild steel connecting rod of 1/2" diameter. These rods are generally supplied in short lengths of 10'-6" to facilitate installation. The G.I. riser pipe usually comes in 10'-0" lengths. Connecting rods are joined by couplings, and it is usual for a coupling to be spot-welded to one end of each connecting rod and to lock the other end to the next rod by means of a lock nut.

There have been so many failures of pumps caused by disconnexion of the connecting rod at one of the connectors that this source of failure is worthy of serious attention. In addition, the installation of the riser pipe in conjunction with the length of connecting rod makes installation cumbersome. It is also necessary for the overall length of the connecting rod to be of a specific length in order to be able to provide the maximum stroke with the handle travelling through the most convenient range of height.

When a connecting rod whips on the down stroke, inducing torque, it results in disconnexion of the connecting rod at a coupling when the rotation of the rod is anti-clockwise. This can be prevented by the use of intermediate rod guides, which may be placed 10 metres apart in the riser pipe string, wedged in a pipe socket on either side by the G.I. pipes. The rod guide is made of nylon, with a central hole fitted loosely over the rod.

The use of a steel wire rope (6 mm diam. 2-tonne breaking strain) is proposed as a substitute for the connecting rod. This substitution is possible because the downward movement of the piston is produced by the dead-weight of the water column in the riser pipe and the weight of the connecting rod (wire rope), and the stiffness of the rod is not a necessary factor. The downward drag can be improved by the use of counterbalance weights, as proposed for the foot-operated pump head described earlier. The wire rope can be cut to the exact overall length required, and fitted with a clevis at either end, enabling connexion to the piston rod at one end and to the pump rod at the other. The use of a wire rope as a substitute for the connecting rod has the following advantages:

(a) It can be cut to a pre-determined, exact length;

(b) Since it is in a single length, there is no problem of couplings, *in situ* dethreading of connecting rods, or disconnexion;

(c) The installation of pipe lengths is made easier by the flexibility of the wire rope;

(d) Pipe lengths of standard length can be used, thereby reducing labour costs in threading and installation, and

(e) Intermediate rod-guides can be dispensed with.

There is very little financial advantage to be gained from substituting wire rope for the 1/2" diameter mild steel connecting rod, but the advantages listed above make wire rope a worth while substitute.

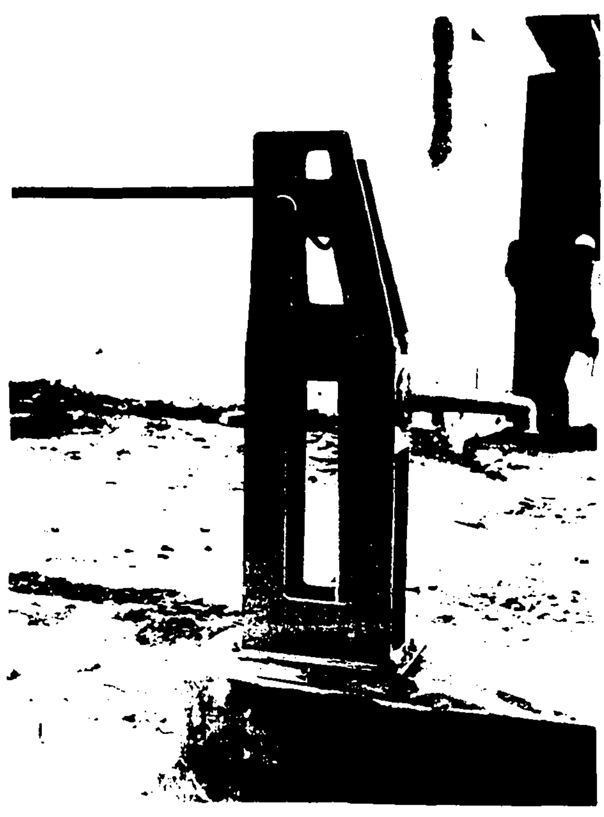
The use of the industrial-type roller chain to link the pump handle to the piston rod is an improvement, but a 200 mm length of 1" pitch roller chain costs over Rs 40, which is rather expensive, and it is difficult for government agencies to ensure that the chain provided is new. With a modified handle, in which the wire rope can be anchored directly to the quadrant, these difficulties can be overcome.

4.5 Riser pipe

Most state governments use 1-1/2" diameter G.I. pipes as the riser pipe. The argument generally given is that such pipes are sturdier than those of a smaller diameter and that there is less wear and tear on the threads when the pipe string is dismantled frequently for the repair of the cylinder. With the introduction of the improved pump, it is likely that the cylinder will not have to be withdrawn from the well more frequently than once (or, possibly twice) a year. In the circumstances, there is a strong cost advantage in using a 1-1/4" diameter pipe instead of the 1-1/2" pipe. From purely hydraulic considerations, a 1" diameter pipe would have been adequate if it were not for the space taken up by the connecting rod or rope.

Plate 12

The improved hand-operated pump head, prototype assembled from welded mild steel plate.



VI. TESTING

1 Testing of Cylinder Assembly

1.1 Preparation of the test

The prototype cylinder was manufactured by the Mechanical Engineering Research and Development Organization (MERADO), Madras, a regional branch of the Central Mechanical Engineering Research Institute, Durgapur, to designs and material specifications provided to them by the project. MERADO was also instrumental in preparing the draft detailed working drawings of the cylinder, as reproduced in Drawing No.3 (p.22). Their assistance was of great value to the development work.

Although the design provided for the compression/injection moulding of the cylinder components, the components for the prototype were machined out of solid stock. This procedure was adopted to avoid the initial expense of a manufacture of dies and tools which might have to be rejected on the basis of subsequently required modifications. The process of machining such a material as epoxy resin-impregnated cotton fabric greatly reduces the strength of the material in tension, as the continuity of the longitudinal fibres is lost. One must depend on the bonding strength of the epoxy resin for the necessary strength. Much greater strength of the components may be expected when they are compression-moulded.

For reasons of availability of material and machinability, many of the cylinder components, such as the washer spacer, the check valve body and the valve seat retainer, were turned out of resin-impregnated fabric. In production runs they would be injection-moulded in uPVC or HDP.

It was initially planned to manufacture two prototype cylinders and to test them both, one at MERADO and the other at the project office in Bangalore, and the assistance of the Chief Engineer, Tamil Nadu Water and Drainage Board, was obtained for drilling a tubewell in MERADO premises to serve as a test well. Unfortunately, several set-backs were experienced, and the well was not completed before the close of the project. It was decided, nevertheless, to proceed with testing one cylinder on the test well made available to the project in Bangalore by the Chief Engineer, Minor Irrigation and Public Health Engineering, Government of Karnataka. MERADO scientists were associated with the tests and made several visits to study the results.

1.2 Nature of test

The objectives of the test may be summarized as:

(1) to determine the suitability or otherwise of the various types of plastics selected for the components, and

(2) to check whether or not the changes in design provided the advantages expected and, if not, to determine the changes in design that would provide the desired results.

Since the purpose of the study was to determine how the improved pump would stand up in actual use, the test was devised to simulate, as closely as possible, actual field use. With this in view, the design criteria collected from the field survey were reproduced, i.e. the pump was arranged, by use of an electric motor and a belt drive, to operate at approximately 48 strokes per minute, with a 114 mm(4-1/2") stroke, the pumping pressure being applied at a point where the handle would be held by the average user. A conventional pump head was used for this exercise, and the pumping device was motorized to run continuously for 1000 hours, this period representing about four months of actual field use. The accelerated test took one third of this time.

The stroke frequency and output were measured every day at the same time, and the results recorded. The uniformity of output was used as an indirect index of pump efficiency. The experiment was held up several times by a breakdown in one component or another, but throughout the test the cylinder gave no trouble whatsoever.

The breakdowns did, however, provide an opportunity for examination of the cylinder during the trial.

1.3 Observations

During the course of the trial, the following observations were made:

(1) Although the conventional pump head used for this test was greased twice a day, measurable wear was noticed after 100 hours of running;

(2) The output of the pump increased slightly in the course of the test, from initially about 21.5 litres/minute to over 24 litres/minute, but was reasonably uniform throughout the 1000-hour test;

(3) Some variations in the stroke frequency were recorded, due partly to voltage fluctuation and partly to wear of the drive belt;

(4) The pump gave a lower output when motorized than when operated by hand, indicating that simulation was imperfect.

The connecting rod became disconnected after 534 hours of operation. At this time the cylinder was dismantled for inspection, and again this was done at the end of the test, after 1000 hours of use. On these occasions the following observations were recorded:

(5) There was no damage to the balls, valve seats or any other components as a result of pounding;

(6) Apart from a polished appearance, there was no alteration to the surface of the cylinder, and the wear was less than one thousandth of an inch, and

(7) On both occasions the diameter of both cup washers was measured as 79.80 mm, although initially one had a diameter of 80.70 and the other 80.40 mm. (It should be mentioned that the synthetic rubber washers, manufactured by the compression/heat technique, were initially made at 81 mm

diameter, whereas the internal diameter of the cylinder was 80.77 mm. As they fitted too tightly, they were ground down to about 80.7 mm to avoid the cost of a further set of moulds, and a slight difference in the finished diameters was observed.)

1.4 Conclusions

It was possible to draw the following conclusions from the test results:

(1) Epoxy resin-impregnated cotton fabric (Hylam TF 2211) is a suitable material for use as a cylinder sleeve;

(2) Epoxy resin-impregnated cotton fabric is a suitable material for use in the piston yoke;

(3) Neoprene is a suitable material for the cup or bucket washer (acrylonitrile rubber may be better). The diameter of the washers should provide a 0.2 mm clearance fit, as a closer fit retards efficiency rather than improving it. The design of the bucket washer and the seat should permit the washer to "spread" during the upward stroke, when hydraulic pressure is exerted on the lip of the washer, and it should retract on the downward stroke;

(4) Although nylon is quite suitable for the balls in the piston and check valves, synthetic rubber could be a good substitute (The Central Institute for Plastics Technology has undertaken to make the mould for this purpose, and MERADO will have the loaded rubber balls made outside. These could then be tested), and

(5) Although Hylam TF 2211 was used in the washer spacer, follower, check valve body and valve seat retainer, these components should preferably be injection-moulded in rigid PVC or HDP.

2 Testing of Pump Heads

2.1 The hand-operated pump head

The improved hand-operated pump head was installed over a pipe string with the improved cylinder located at 30 metres below ground level, connected to a "tandem" cylinder* placed 12 metres below ground level by the conventional 12 mm diameter mild steel connecting rod. The cylinder was connected to the pump rod by means of a 6 mm diameter wire rope, using a clevis as designed for the purpose.

It was found that installation of the pipe lengths, using the wire rope as "connecting rod", was decidedly easier. The installation of the pump head was found to be simpler than in the case of the conventional head. It was noteworthy that the new pump head was installed by mechanics who had considerable experience in installing the conventional head and that they were

*The project report, referred to earlier, deals at some length with the development of a "tandem" cylinder to be used when the static water level exceeds 18 metres below ground level. The components of this tandem cylinder are in most cases the same as for the improved cylinder. The details of this arrangement are omitted from this summarized report, but the use of a tandem arrangement when the water level is low deserves further investigation.

installing the new head for the first time. They agreed without reservation that the new pump head was easier to instal and take down than the conventional pump head.

The pump handle was connected to the accelerated testing device in the same manner as in the previous test, and the pump was run continuously for 100 hours. The pump gave a steady output of 15 litres in 35 seconds throughout the period of the test, during which there was no breakdown.

At the completion of the test the following examinations were carried out:

(1) Sintered bearings: no measurable wear in sintered bushes was found. The lubricant in the reservoir remained at practically the same level while the bearings were well lubricated.

(2) Clevises: both clevises were examined for possible failure of the clevis or the wire rope at this point. There was no evidence of any alteration or of pulling out of the wire rope.

(3) Cylinders: no measurable wear on cylinder lining or on valves.

It is claimed that, within the scope of the test conducted, the hand-operated pump head worked satisfactorily.

2.2 The foot-operated pump head

The model tested was a modification of an indigenous pump which had originally had a disc-cam actuating the pump rod with a wheel driving the cam-shaft. The unit was modified by providing a counter beam to actuate the pump rod, while the treadle was connected to a treadle beam loaded at the far end to compensate for the weight of the treadle arrangement. A counter-weight of about 8 kg was used.

The counter-beam rested at a lower position of 15° to the horizontal, and could be raised by the treadle to provide a 114 mm stroke. The treadle beam rested at 30° to the horizontal, the treadle travelling through 114 mms to produce a stroke of the same length. The pump output was comparable to that of the hand-operated pump head, but the operation of the treadle seemed easier on account of the application of body weight.

In this case, too, the cylinder was placed at 30 metres below ground level, connected to a tandem cylinder at 12 metres below ground level, which was linked to the pump rod by means of a 6 mm diameter wire rope. Because of shortage of time, this pump head was not put under continuous test, but the similarity of treatment in regard to design seems to indicate that it would work satisfactorily. Although this pump head will cost more than the hand-operated pump head, it is not unlikely that it would have application where water has to be lifted from depths exceeding, say, 45 metres.

VII. PRODUCTION AND COST ANALYSIS

1 Production

It is considered that the stage has now been reached where the pump should be manufactured in sufficient numbers to enable field tests to be conducted in a number of States, under varying conditions, over a long enough period for defects to become apparent and minor improvements to be made. Contact has been made with the Government of India undertaking, Messrs Richardson & Crudass Ltd., Madras, and this firm has expressed an interest in the manufacture of handpumps for rural areas on a commercial basis at nominal profit. The firm has good foundry and workshop facilities, and has experience in injection-moulding techniques.

If an initial batch of pumps can be produced for supply to the various States, they may be put into operation for a period of about six months, under careful control with regard to maintenance requirements, breakdown or wear of parts, acceptability to the user and general performance. After this period of field-testing, and after such modifications as may be found necessary have been made, the design could be passed on to any pump manufacturer who might care to produce it. It is desirable that at least one pump manufacturer in each State be encouraged to produce the pump.

It is suggested that assistance from UNICEF may be sought to support the manufacture of the first batch of pumps for free distribution to the States now involved in the drilling programme.

2 Quality Control

It is necessary that some quality control system be established to ensure that the quality of materials and quality of production are maintained. State government departments responsible for the village water supply programme are generally not equipped to carry out tests on quality.

As mentioned already, the Mechanical Engineering Research and Development Organization, Madras, which is a branch of the Central Mechanical Engineering Research Institute, Durgapur, has been associated with the project from its early days and was responsible for producing the prototype cylinder and the accelerated testing device. MERADO and other branches of the CMERI, located in different parts of the country, are equipped to undertake quality control tests. A possible solution would be for government departments to insist that all tenders for supply of the pump should obtain a certificate from any branch of the CMERI to the effect that their product conforms to specifications laid down on the basis of the recommendations made in this report. Any fees payable to the CMERI for this service should be borne by the pump manufacturer.

3 Cost Analysis

Though it is difficult to give accurate costs for the cylinder components of the improved pump, since the material costs are uncertain and the injection-moulding techniques to be employed become more economical when large runs of items are produced, fairly conservative estimates of the various parts can be made. Table 3 gives a list of cylinder components, recommended material and estimated cost based on die costs, where applicable, being amortized over a production run of 4000 of each item. The total cost of the cylinder comes to Rs 79.95, or approximately US$ 10.00. This compares very favourably with the costs of conventional brass cylinders, which, from five different suppliers, gave the following range:

2-1/2" cylinder	Rs 150 to 210
3" cylinder	280 to 320
4" cylinder	350 to 400

Table 3. Cost Analysis of Improved Cylinder Assembly

	Component	Material	Estimated Cost (Rs)
1.	Cylinder body	G.I. pipe	9.00
2.	Reducing socket cap	G.I.	6.00
3.	Sealing ring	Rubber or neoprene	1.50
4.	Spring buffer	Steel wire	3.00
5.	Piston rod guide	HDP	2.20
6.	Piston rod guide bush	Hylam TF 2211 or nylon	0.60
7.	Piston yoke	Hylam TF 2211	14.00
8.	Cup washers (2 No.)	Acrylo-nitrile rubber or neoprene	6.50
9.	Spacer	HDP	2.50
10.	Ball (2 No.)	Steel core, rubber covered	10.00
11.	Valve seat (2 No.)	Neoprene	6.00
12.	Follower	Hylam TF 2211	3.00
13.	Buffer	Rubber	1.65
14.	Check valve body	HDP	4.00
15.	Seat retainer	HDP	3.50
16.	Sealing ring	Rubber or neoprene	1.50
17.	Retainer cap	G.I.	5.00
		Total	Rs. 79.95 = US$ 10.00

Likewise, an estimated cost analysis of the improved hand-operated pump head is given in Table 4, giving a total cost of Rs 306, or US$ 38.25. The comparable prices for conventional heads offered ranged between Rs 375 and Rs 425.

Table 4. Cost Analysis of Improved Hand-Operated Pump Head

	Item	Estimated Cost (Rs)
1.	Cost of casting pump head 50 Kg at Rs 3.50 per Kg.	175.00
	machining	25.00
2.	Cost of handle, including MSP bushes	60.00
3.	Cost of pivot pin and nut	10.00
4.	Cost of hex-head screws for spout	2.00
5.	Cost of pipe and tee	20.00
6.	Threading collar and providing bush	10.00
7.	Cost of 4 No. 16 mm dia. bolts and nuts	4.00
		Rs.306.00 = US$ 38.25

As mentioned earlier, little or no saving would be gained from the use of steel wire rope in place of the more conventional connecting rods, although use of the rope would have certain advantages in practice. With the proposed improved pump, however, and the thinner wire, it would be possible to make a saving by using 1-1/4" G.I. pipe in place of the more usual 1-1/2" pipe. At current prices of Rs 4.20 and 4.75 per foot run respectively, this saving could be considerable over a large number of installations.

To summarize, assuming a cylinder is installed at depths of 18 metres and omitting costs of foundation, platform and casing, the cost of an improved pump head and cylinder, with wire rope and 1-1/4" pipe, might be about Rs 770, and that of the conventional installation about Rs 1020. The saving might therefore be about Rs 250 in each installation.

VIII. ACKNOWLEDGEMENTS

Acknowledgements are due to the following individuals who contributed in one way or another to the development of the deep-well handpump project in India, which has resulted in the presentation of the system recognized as "the Bangalore Pump". Their contributions in support, interest, encouragement, comments and advice are recognized and appreciated. In addition, gratitude is expressed to many persons not mentioned here who have also given valuable service to the project in assisting with data collection, field testing, drafting, preparation of reports, etc.

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EPILOGUE

Since the preparation of Mr V.J. Emmanuel's report, which has been summarized in this document, further developments have taken place which require comment.

1 Bangalore Workshop

From 24 to 26 June 1975, a workshop was held in Bangalore at which the Chief Engineers of the States in which deep-well handpumps are used in large numbers assembled together with representatives from administrative and village organizations to discuss problems associated with rural water supply. In particular the objective was to study the improved Bangalore handpump which had recently been developed. Representatives of the Government of India, MERADO, UNICEF and WHO also attended. An opportunity was given to participants to examine the component parts of the prototype cylinder and pump head and, later to test the assembled pump.

At the end of the meeting the participants recommended, inter alia, that "a few hundred Bangalore pumps should be manufactured and distributed to the various States for carrying out extensive field trials for a maximum period of six months, to determine their suitability for large-scale use in the rural water supply programme in India"*.

2 UNICEF Assistance

The Government of India in July 1975 formally requested UNICEF assistance in the production of 1000 Bangalore pumps on the basis of the draft report and working drawings, which had been distributed to the Chief Engineers and discussed at the Bangalore Workshop. UNICEF subsequently called for bids, and by November 1975 offers had been made. At the same time, however, a number of snags came to light, related to both the cylinder and the pump head, which made it necessary to carry out further development work before a large number of pumps could be manufactured. At the end of 1975, therefore, UNICEF agreed that Messrs Richardson and Crudass, in collaboration with MERADO, should prepare the necessary dies for the moulding of cylinder parts and should proceed with the manufacture of a number of complete cylinders for testing in Tamil Nadu State (Madras area). Subject to the satisfactory operation of these parts, detailed working drawings will be prepared and a sufficient number distributed to be tested in different parts of India. Initially, it is proposed that the cylinder be tested using the currently available Sholapur pump head, and the improved pump head developed separately.

3 Comments on the Bangalore Pump

Whereas all Chief Engineers and a number of other persons in India were invited to comment on the design of the pump as presented in the draft report, few written comments were received. The subject was, however, discussed at some length during the June workshop and subsequently, and comments have been received from WHO Headquarters in Geneva and from UNICEF.

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*Extract from mimeographed document entitled "Report on Government of India/ World Health Organization Workshop on Deep-Well Handpumps in the Rural Water Supply Programme", Bangalore, India, 1975.

As mentioned in Section IV, paragraph 2 of this document, the chapter on hydraulic phenomena in the draft report aroused some controversy, which caused a delay in the issue of this summarized report. At this stage no attempt is made to discuss the theoretical analysis of the hydrostatic and hydrodynamic forces which come into play. Certain issues are still unsettled and may be discussed in a later document.

Generally, comments were very favourable and complimentary to Mr Emmanuel and his co-workers. In particular, the improved cylinder has been seen to have considerable advantages in terms of economy, durability, need for maintenance, and replaceability of parts. The pump head has been criticised in some quarters as being:

(1) very heavy as a casting,
(2) easily cracked or broken if dropped or during fastening down,
(3) subject to breakage from the handle banging on the top piece, and
(4) subject to interference with the top being open.

It is expected that further trials will demonstrate whether these criticisms are valid and what modifications may need to be made.

Certain problems with the wire rope were noticed when the prototype pump was set up in Bangalore, but they were partially overcome when the rope was connected to one full length of pump-rod attached to the cylinder, thus giving it the necessary rigidity at the bottom. This modification seems to be justified.

Progress in the development of the pump for widespread use is, therefore, rather slow, but, with the enthusiasm of those directly concerned in the production and testing, it is to be hoped that, in due course, the first models of the Bangalore pump will be available to the public as an improved model and at a reasonable cost.