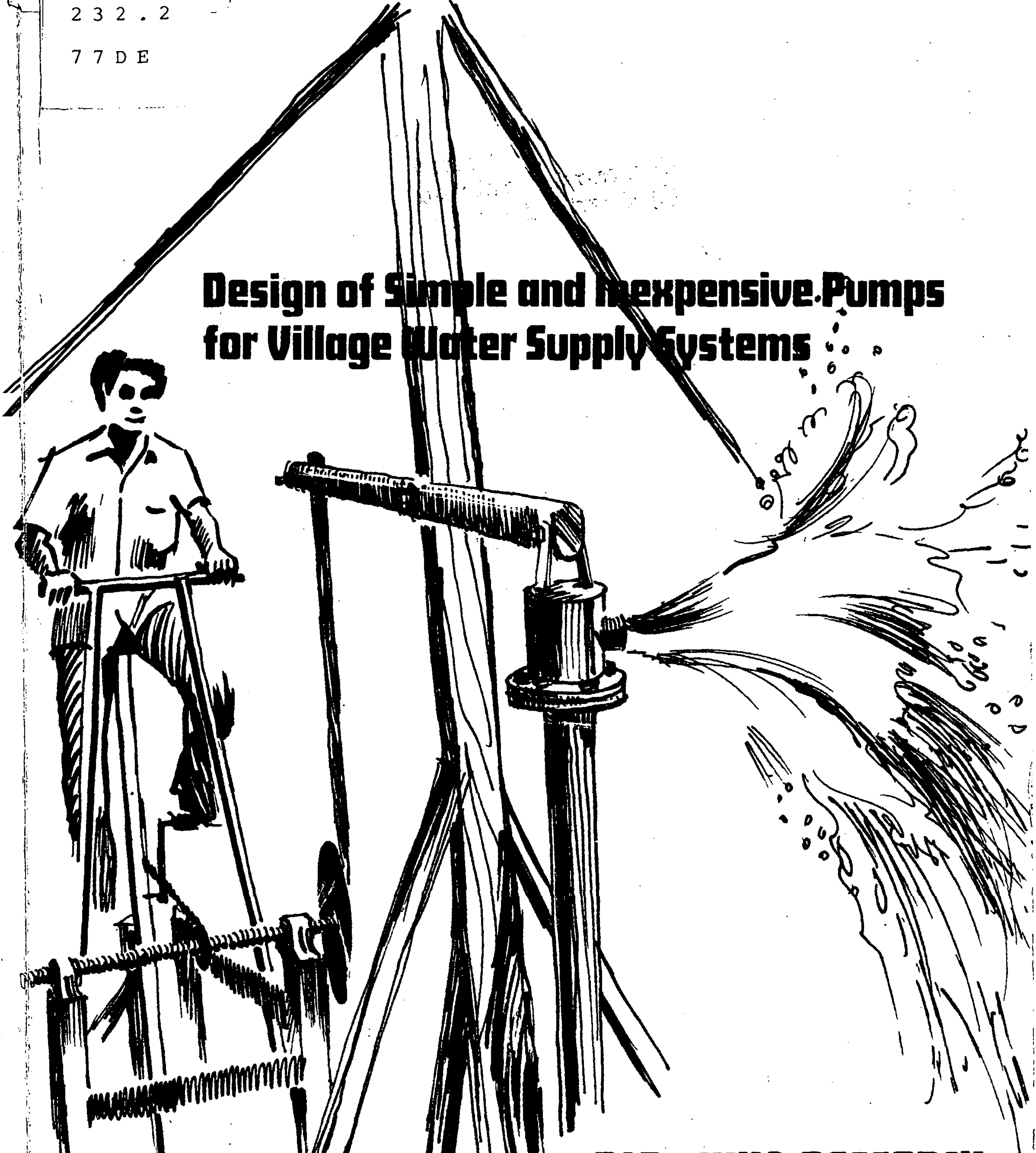
Design of Simple and Inexpensive Pumps for Village Water Supply Systems



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FINAL REPORT No. 67

ON

DESIGN OF SIMPLE AND INEXPENSIVE PUMPS FOR VILLAGE WATER SUPPLY SYSTEMS

by

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The study would not have been possible without the efforts and contributions of many people. Thanks are due to MM. Nguyen Cong Binh, Md. Uddin Nizam and Vu Anh Tuan, former Research Associates in the Environmental Engineering Division of AIT. Thanks are also due to Dr. E.A.R. Ouano for his assistance in revising the final report of this study.

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I INTRODUCTION

A water treatment system plagued with frequent breakdowns is as much of a threat to public health as no treatment at all. It has been recognized that the most common cause of breakdown of small water supply systems is pump failure. Most community water supply systems currently operating in the rural areas use either gasoline or electric pumps. Occasional pump failures inevitably occur in all cases. Repair and maintenance of these pumps require the services of technically skilled personnel. Such specialized skills are, however, not readily available in most rural areas in the region. It, therefore, becomes necessary, when pump failures occur, to take the units to the nearest town where repair facilities are usually located. Experience indicates that quite often this entails total disruption of water supply extending over several days or even weeks. Provision of stand-by pumps is beyond the financial resources of most villages since these pumps, being mostly imported items, are rather expensive. In order to minimize disruption of water supply due to pump failure it appeared that the pump should be simple enough so that repairs could be carried out by the villagers themselves at the point of use.

Many rural areas, even in the less developed parts of Asia, are today endowed with a supply of electricity and/or gasoline which are the most common sources of power for the commercial pumps. Consideration of more primitive sources of energy such as human or animal power for purposes such as water lifting might, from this point of view, seem rather out of date. However, when one recognizes the fact that the hardware using electric or gasoline power as energy source necessarily consists of sophisticated components, too complex for production and maintenance locally, it is seen that this is not the case. A supply of human labour can generally be relied upon in most areas of Southeast Asia, where mass unemployment is a major problem.

Apart from the above considerations, dictated primarily by the technological and economic limitations of the rural areas, the pump selection process is also influenced by the specific requirements of the contemplated services to which it is to be put. The primary source of water in the Southeast Asian region is surface water requiring some form of treatment prior to consumption. The water supply system can, therefore, be expected to incorporate a central treatment facility, such indeed is the case in many of the existing systems. The service required of the pump is then to raise the water from the surface source to the inlet of the treatment unit. The volumetric capacity and lift of the pump should be such as to be suitable for this duty.

The objective of the present study consisted of designing simple pumping devices suitable for rural water supply systems that would not be subject to the same limitations as those of the conventional types of commercially available pumps. Specifically, the pumps were to be of simple structure, easily understood and assembled by village artisans and requiring little skilled attention so as to minimize breakdown in water supply due to pump failure. In order to ensure simplicity of design and construction, manual operation was preferred to conventional motive power - gasoline or electricity. As previously proposed in the Progress Report [1], two types of pumps were designed and tested in this study: a bellow pump and a bicycle-type-drive inertia pump.

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[1] THANH, N.C., PESCOD, M.B. and VENKITACHALAM, T.H. (1975) Progress Report on Evaluation of Simple and Inexpensive Pumps for Community Water Supply Systems, Asian Institute of Technology, Bangkok.

II THE BELLOW PUMP

The idea of a very simple water lifting device utilizing a pair of flexible bellows as the pumping element was originally evolved at the International Rice Research Institute (IRRI), Philippines, where a prototype pump design was developed for use in irrigation [1/]. The bellow pump investigated in this study was a modified version of the original design and was constructed at the Asian Institute of Technology.

2.1 Pump Description

The IRRI design was such that the pump body needed to be partially submerged during operation. Since this might not often be desirable for pumping from the usual sources of surface water supplies the design of the pump was modified by providing external suction lines to deliver water to the bellows. Foot-valves on suction lines were substituted for the flapper valves provided in the IRRI pump. Fig. 2.1 schematically illustrates the pump configuration adapted for the present work.

The basic components of the bellow pump consisted of:

- a supporting frame and a base plate
- a pair of metal-reinforced flexible canvas bellows
- a discharge box
- a pair of suction lines and foot-valves, and
- a pair of foot rests

The bellows constituted the basic pumping element and consisted of an outer layer of cotton canvas and an inner layer of rubber lining stuck together with rubber cement. The rubber lining served to render the bellows impermeable while the cotton canvas sheet was tough enough to withstand the pressures generated during pumping. The bellows were

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[1/] KHAN, A.M. and DUFF, B. (1975), Agricultural Mechanization Technology Development at the International Rice Institute, Special Report, The International Rice Research Institute, Los Banos, Laguna, Philippines.

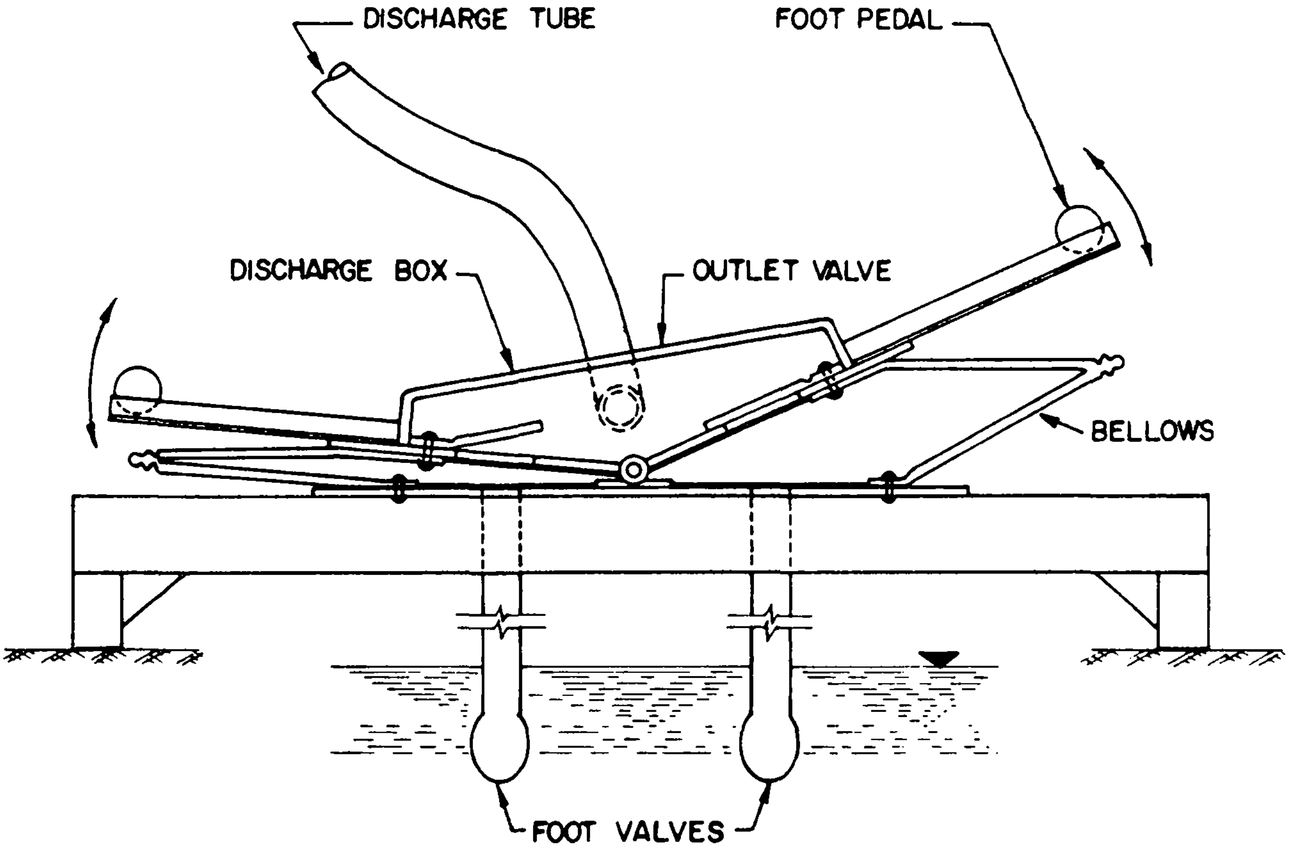


FIG. 2.1 MANUALLY OPERATED BELLOW PUMP
FOR RURAL COMMUNITY WATER SUPPLY

reinforced with galvanized-iron (GI) metal plate inserts between the inner and outer layers to prevent it from deforming during operation. The bellows were supported at the bottom by the base plate fixed to the wooden frame. The suction lines deliver water to the bellows and these discharge into the discharge box which in turn is connected to the delivery pipe.

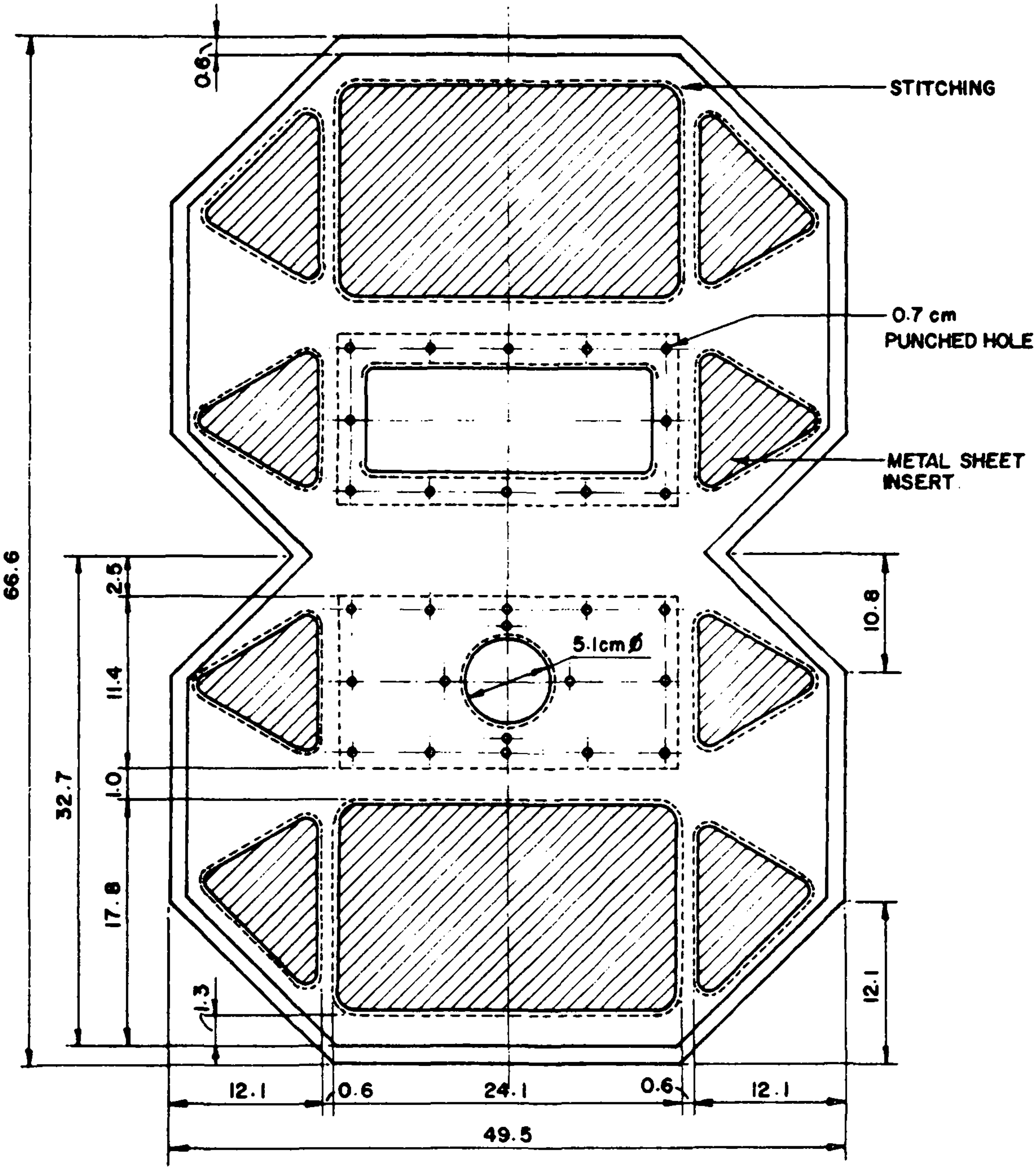
The base plate as well as the discharge box having a volume of about 3 ℓ were made of GI sheets. Flow of water between the bellows and the discharge box was controlled by a pair of flapper values also made of GI sheets, lined with cotton canvas. During compression of the bellows the flapper valves open and allow water to flow up into the discharge box. The valves close during the suction stroke preventing water from flowing back into the bellows from the discharge box. The discharge box was provided with a 5 cm spout to which the delivery pipe was connected.

The foot-valves for the suction lines were 2.5 cm in diameter and were procured from the local markets. These being standard fittings for the conventional types of pumps, are easily available in most areas. The foot rests for the operator to stand on while pedalling the pump were made of wooden planks.

Detailed specifications for the component parts of a prototype pump model are shown in Fig. 2.2 to Fig. 2.2 to Fig. 2.9.

2.2 Pump Operation

The bellow pump is easy to operate. The operator stands on the foot-rests and merily shifts his weight from one foot to the other thus expanding one bellow while compressing the other. The expanding bellow sucks in water from the source while that in compression forces water out into the discharge box. By alternatively shifting his weight in a rythmic manner, the operator pumps a continuous flow of water. Fig. 2.10 shows the pump in operation.



ALL DIMENSIONS ARE IN CENTIMETERS

FIG. 2.2 SPECIFICATION OF A BELLOW

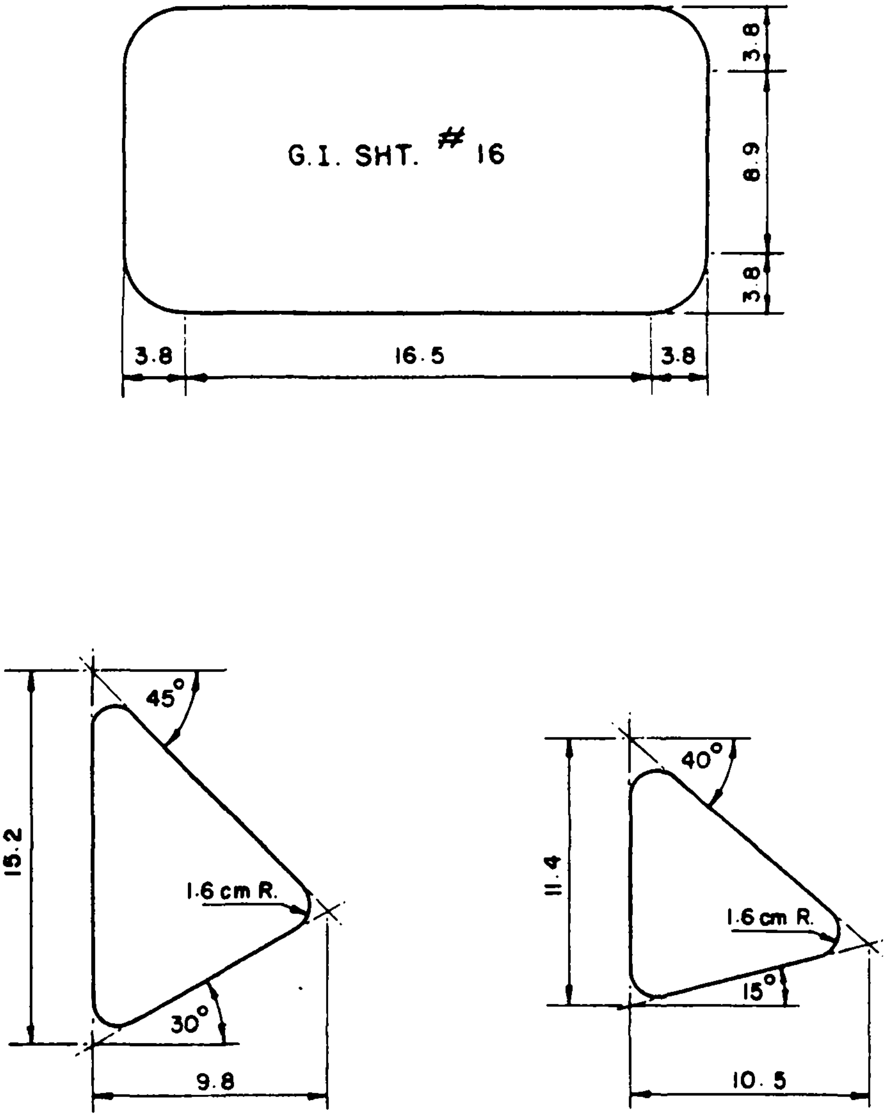


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FIG. 2.3 METAL INSERTS FOR BELLOW REINFORCEMENT

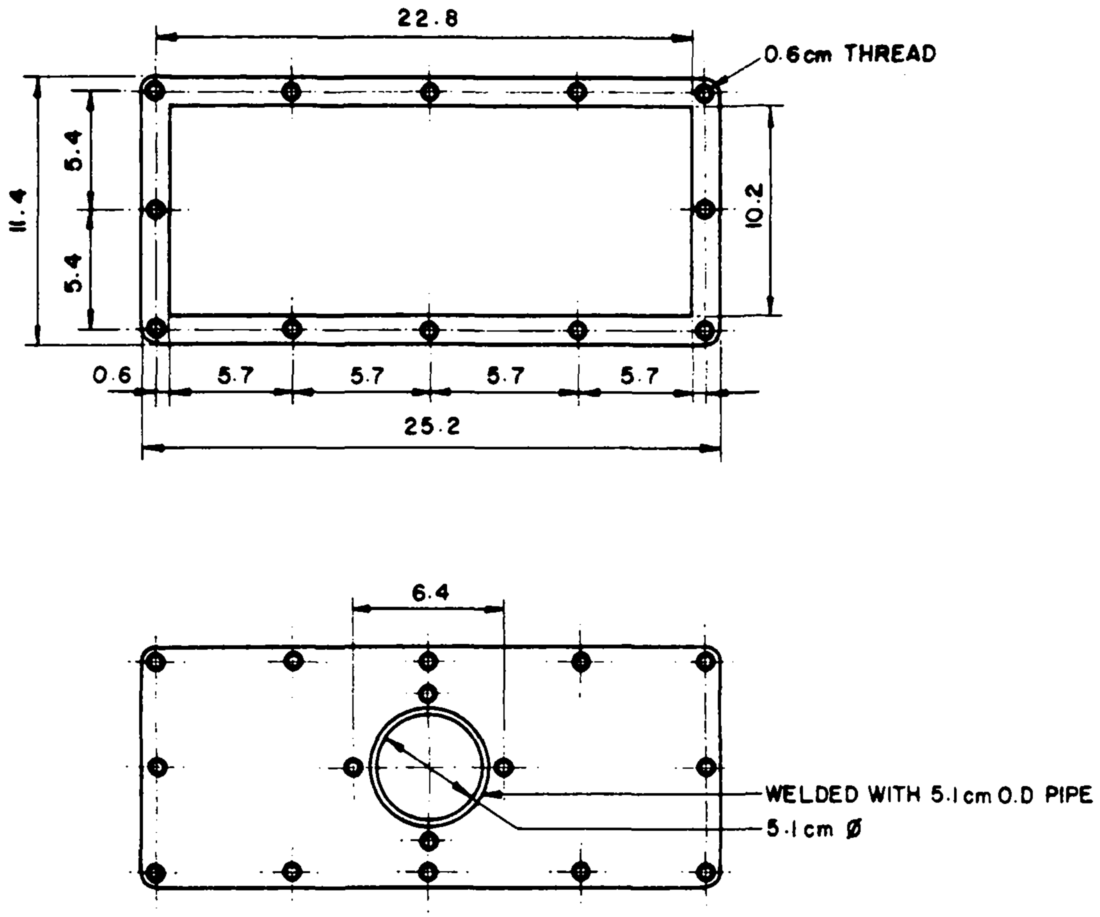

FIG. 2.4 BELOW CLAMPS

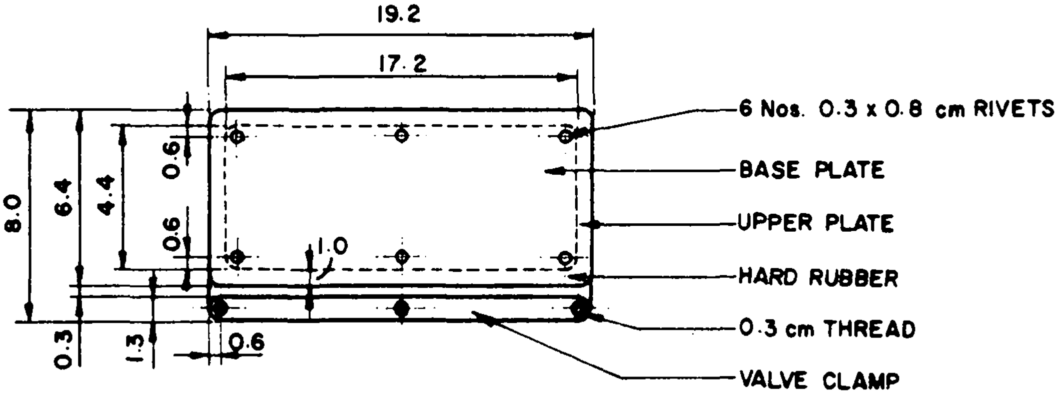

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FIG. 2.5 FLAPPER VALVE

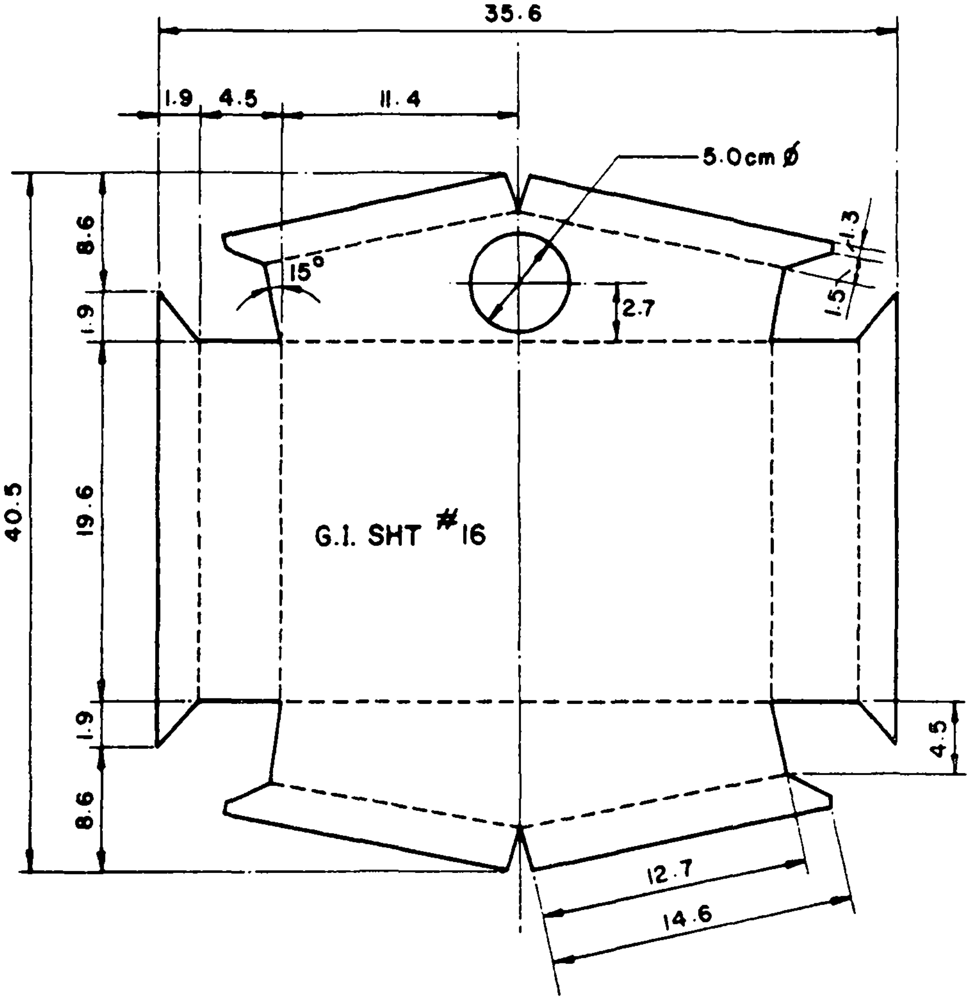

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FIG. 2·6 DISCHARGE BOX

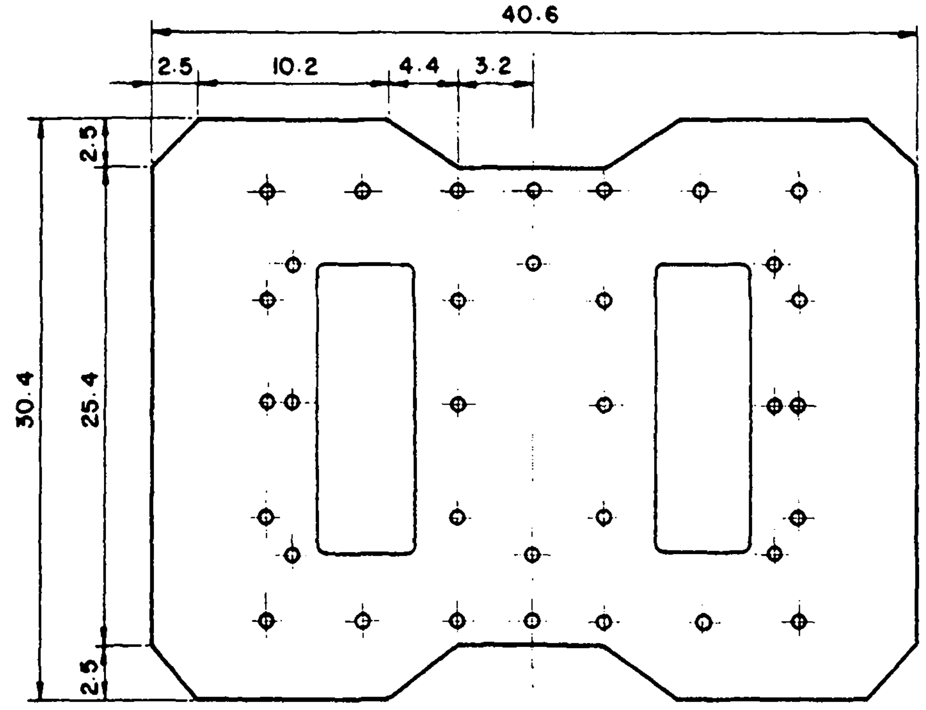

FIG. 2.7 BOTTOM OF DISCHARGE BOX

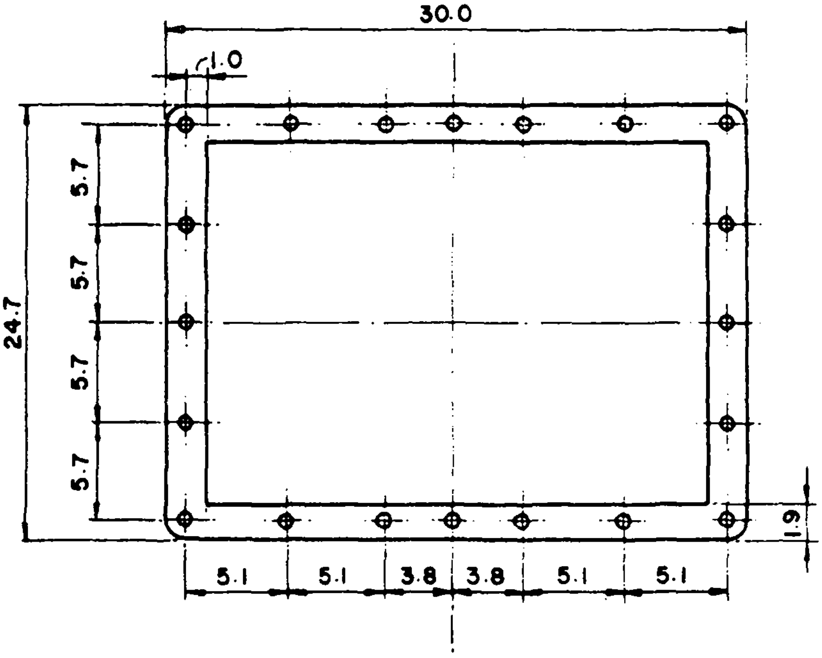

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FIG.2.8 RUBBER TIE FOR DISCHARGE BOX

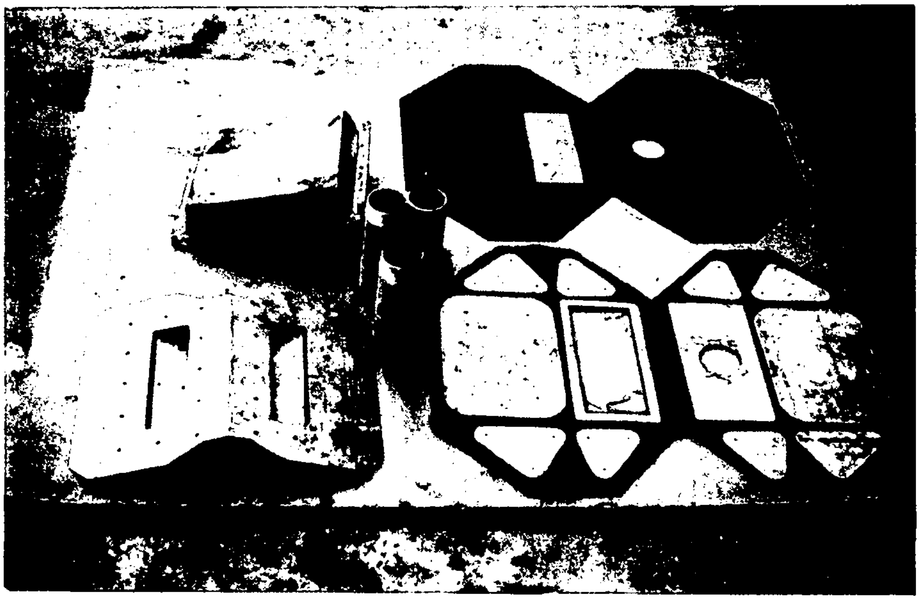

Fig. 2.9 - Anatomy of the Bellow Pump

Fig. 2.10 - Operation of the Bellow Pump

2.3 Experimental Testing of Pump Performance

Tests for evaluating the performance of the bellow pump were carried out at the drainage canal of the Regional Engineering Experimental Centre of the Asian Institute of Technology, Bangkok. A labourer was asked to operate the pump and the volumetric discharge capacity of the pump was noted as a function of total static head through which water was lifted. The pump was operated at three levels of static head - 1.5, 2.5 and 3.5 m. Different operators were asked to work the pump, each of them weighing between 50 to 53 kg. Normally a single operator pedalled the pump during each test run, but the increase in pump output when two operators simultaneously worked the pump was also recorded. Initially it took about five minutes for the operator to develop a stroke rythm. Once the operator established the stroke rythm, the pump output was recorded by cumulating the discharge over fifteen minute periods and computing the mean discharge rate from several samples. Continuous operation of the pump for extended periods was tiresome for the operator, but with a five to ten minute rest after every half hour of operation, the pump could be worked over a period of several hours.

2.4 Results and Discussion

For each operating head several test runs were carried out and the mean volumetric discharge rate of the pump recorded when one and two operators pedalling the pump. These data are tabulated in the Appendix A. The results of the tests using a single operator are summarized in Table 2.1. Pump output at 1.5 m head ranged from 77 to 100 ℓ/min with a mean of about 89 ℓ/min. At 2.5 m static lift the range was 73.3 to 76.7 ℓ/min while at 3.5 m head the discharge obtained was between 37.1 and 40.3 ℓ/min. The observed decrease in pump output with increasing head was to be expected since the work done in raising a given quantity of water increases with head while the energy input remains more or less the same. The head-discharge relationship for the bellow pump is presented graphically in Fig. 2.11. It has been estimated that the

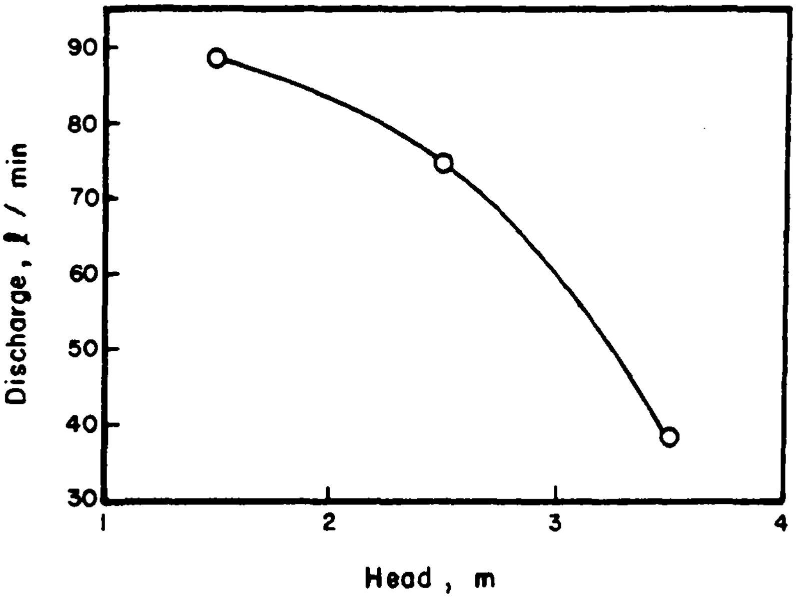

Fig. 2.11 Head-Discharge Relationship for Bellow Pump

energy output from sustained human labour is of the order of 0.1 hp [1]. This value was used for the average energy input in computing the values of overall efficiency of the pump at various operating heads, shown in Table 2.1 and plotted in Fig. 2.12. The pump efficiency was calculated as follows:

Useful work done W, in raising Q liters of water per second through a total head of h meters is given by:

$$W = Q \rho h \text{ kg-m/sec}$$

where, ρ = the density of water, kg/ℓ

If the average energy input is taken to be at a rate of 0.1 hp (7.604 kg-m/sec), the overall efficiency is given by:

$$= \frac{Q \rho h}{7.604}$$

It may be noted that the optimum utilization of input energy by the pump occurs when the operating head on the pump is about 2.5 meters. Thus from the point of view of energy economy it would appear best to operate the pump at this head.

Table 2.1 - Bellow Pump Performance with One Operator*

Total Operating Head m	Mean Volumetric Discharge Rate ℓ/min	Overall Pump Efficiency %
1.5	88.9	29.2
2.5	75.0	41.1
3.5	38.7	29.7

* The operator weighed between 50 and 53 kg.

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[1] VITA (1973) Village Technology Handbook.

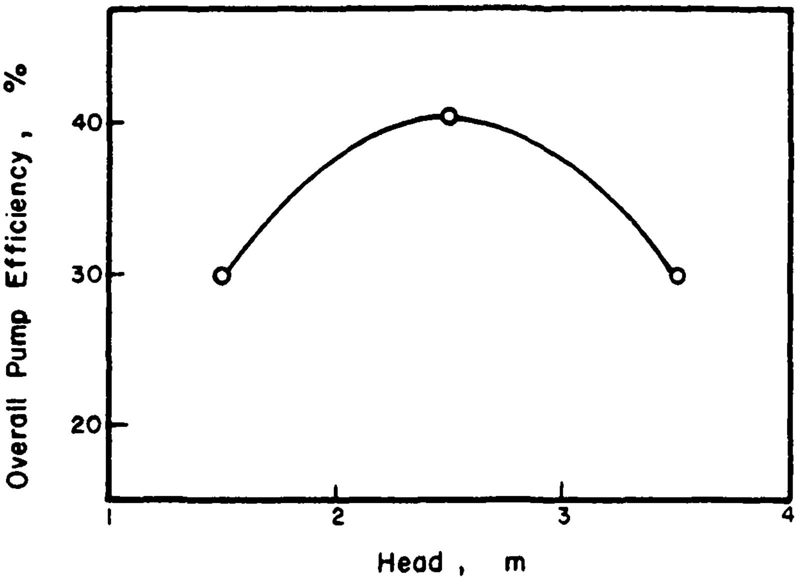

Fig.2.12 Overall Bellow Pump Efficiency versus Head

Actual operating experience with the pump indicated that the best operating schedule should let the operator rest for five to ten minutes after about 30 minutes of continuous operation. In this way the operator was saved from undue fatigue and could produce a more or less uniform output over several hours of pump operation.

The foot rests of the pump was large enough for two operators to stand on it and simultaneously pedal the pump. The performance of the pump when operated in this manner is summarized in Table 2.2. It was found that operating the pump using two operators simultaneously resulted in only about 27 percent increase in the pump output. Although the operators tired less easily in this arrangement, especially at 3.5 m head, from the point of view of energy economy simultaneous operation by two workers appeared undesirable. Furthermore, the 30 minute operation followed by a 5 to 10 minute rest suggested earlier for a single operator appeared, on the whole, to be quite satisfactory for the optimal operating head of 2.5 m.

Table 2.2 - Bellow Pump Performance with Two Operators

Operating Head m	Mean Volumetric Discharge Rate ℓ/min	Increase in Discharge Over that with a Single Operator %
1.5	115	29.4
2.5	94.2	25.6
3.5	49.2	27.1

Recently THANH and PESCOD [1/] have reported on the development of low-cost series and dual-media filter units for small rural community

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[1/] THANH, N.C. and PESCOD, M.B. (1976) Application of Slow Filtration for Surface Water Treatment in Tropical Developing Countries, Research Report No. 65, Asian Institute of Technology, Bangkok.

water supply systems. Each of these units was estimated to serve a population of about 250 people and required the water to be lifted from a surface source through about 4 to 5 meters. Using a figure of 30 ℓpd for the per capita water consumption by rural population, it can be seen that two bellow pumps, considered in this study, arranged in series, each operating at the optimal head of 2.5 m, could deliver the daily water requirement of two filter units (or a population of 500) in 3 to 4 hours of daily operation.

Operational experience with the pump also throws some light on the problems to be expected with this device. Operation at a head exceeding 2.5 m, in addition to quickly exhausting the operator, also resulted in significant leakages along the sticking on the bellows. This could be due to poor sticking which can perhaps be improved with experience. Rusting of the mild steel rod forming the hinge between the bellows was also a problem causing excessive friction loss. This could be largely alleviated by frequently lubricating the hinge and smoother pedalling could be achieved.

2.5 Conclusions

On the basis of the results and discussions presented above it may be concluded that the modified bellow pump developed in this study can form an integral part of small rural community water supply systems in Southeast Asia. The essential characteristic of the pump is the relative simplicity of its construction and maintenance compared to conventional pumps. It is reasonably expected that any necessary repair work can be easily carried out by the village artisans, which would minimize disruption of water supply caused by pump failure. Even where conventional types of pumps are provided as regular equipment, the bellow pump may be used as a dependable and economical stand-by unit. Incorporation of the pump into typical village water treatment systems may require an arrangement of two or more pumps in series in order to achieve the desired lift. The optimal operating head for the pump is about 2.5 m.

At this head the pump can deliver approximately 75 ℓ/min, sufficient to satisfy the daily requirement of about 500 people in 3 to 4 hours of operation.

The stitching of the bellows should be done with care in order to achieve water-tightness and minimize leakages. Frequent lubrication of the hinge can control nesting and ensure smoother operation.

III INERTIA PUMP

The inertia pump, perhaps the simplest pumping device so far designed, was originally conceived from the mud-lifting tube that is used for digging shallow tube wells in many parts of the world. The main pump body (riser) consists of a long pipe with a check valve and a discharge spout located near the top end. The name of the pump derives from the belief that part of the function of water lifting by this device is due to the inertia of the mass of water held in the riser. The design of an inertia pump for use in irrigation has been reported earlier by DAWSON in 1969 1/. In the present study the basic pump design was modified to incorporate a prime mover assembly consisting of a bicycle-type drive and a flywheel with a view to achieve more efficient pump performance, as shown in Fig. 3.1.

3.1 Pump Description

In this study, the initial design for an inertia pump, designated here as IP-1, consisted of a riser made of 8 cm diameter cast iron (CI) pipe. The upper end of the riser pipe was plugged and fitted with a bracket to which the pump handle was attached using a 7 mm bolt. Near the top end of the riser at an angle of 30 degrees another short CI tube, also 8 cm in diameter, was welded on to serve as the pump outlet. At the mouth of this tube was attached a 6.4 cm flapper valve seated in a flange followed by another short length of 8 cm CI piping. The design details of the pump are given in Fig. 3.2.

During operational testing some difficulties (to be discussed subsequently) were encountered with the above design necessitating some modifications. In the modified version the flapper valve was located in the riser instead of in the spout as in the previous design. Two

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1/ DAWSON, R.W. (1969) Inertia Hand Pump, Paper presented at a Workshop on Rural Water Supply, University College, Dar es Salaam.

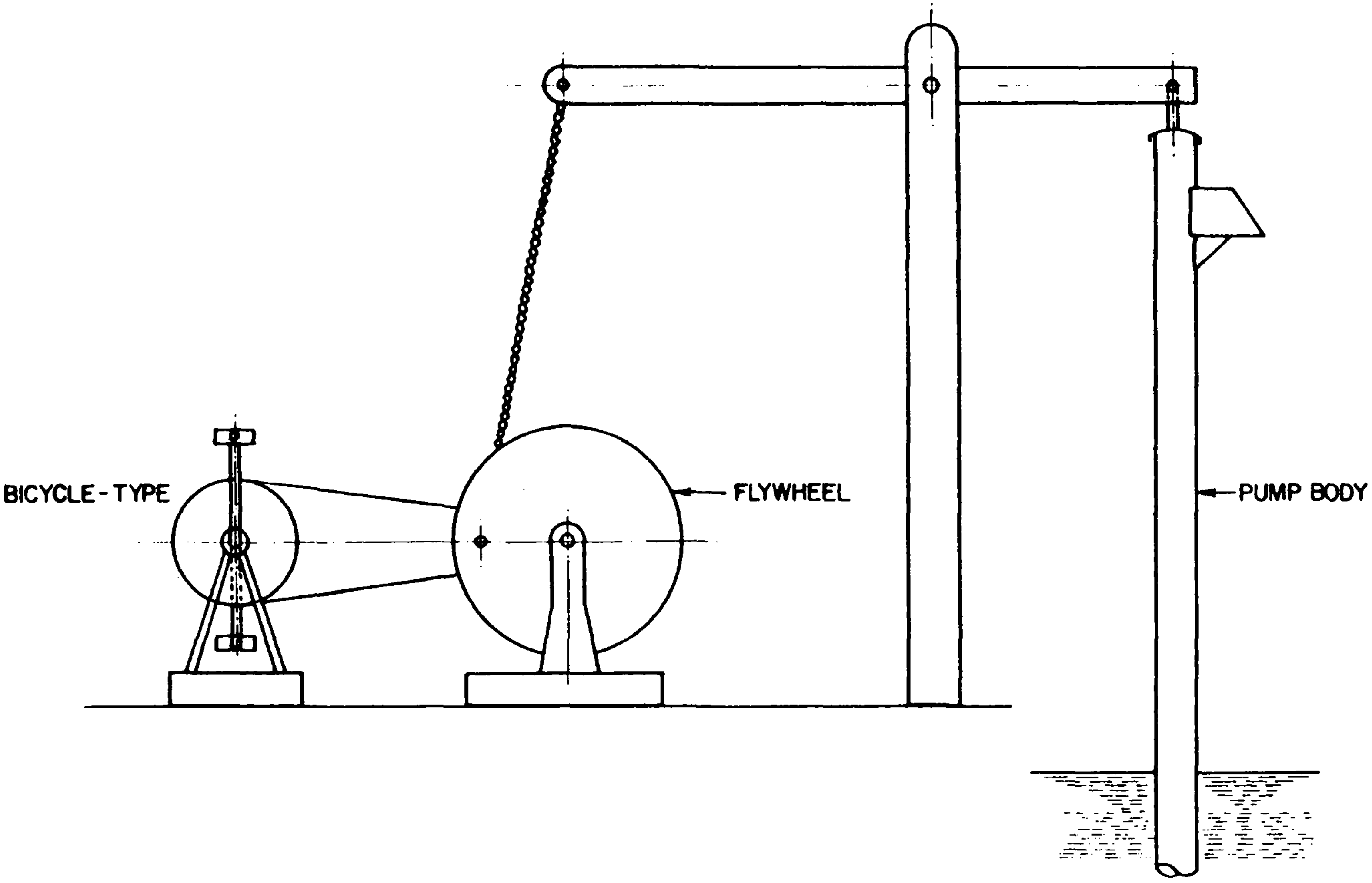
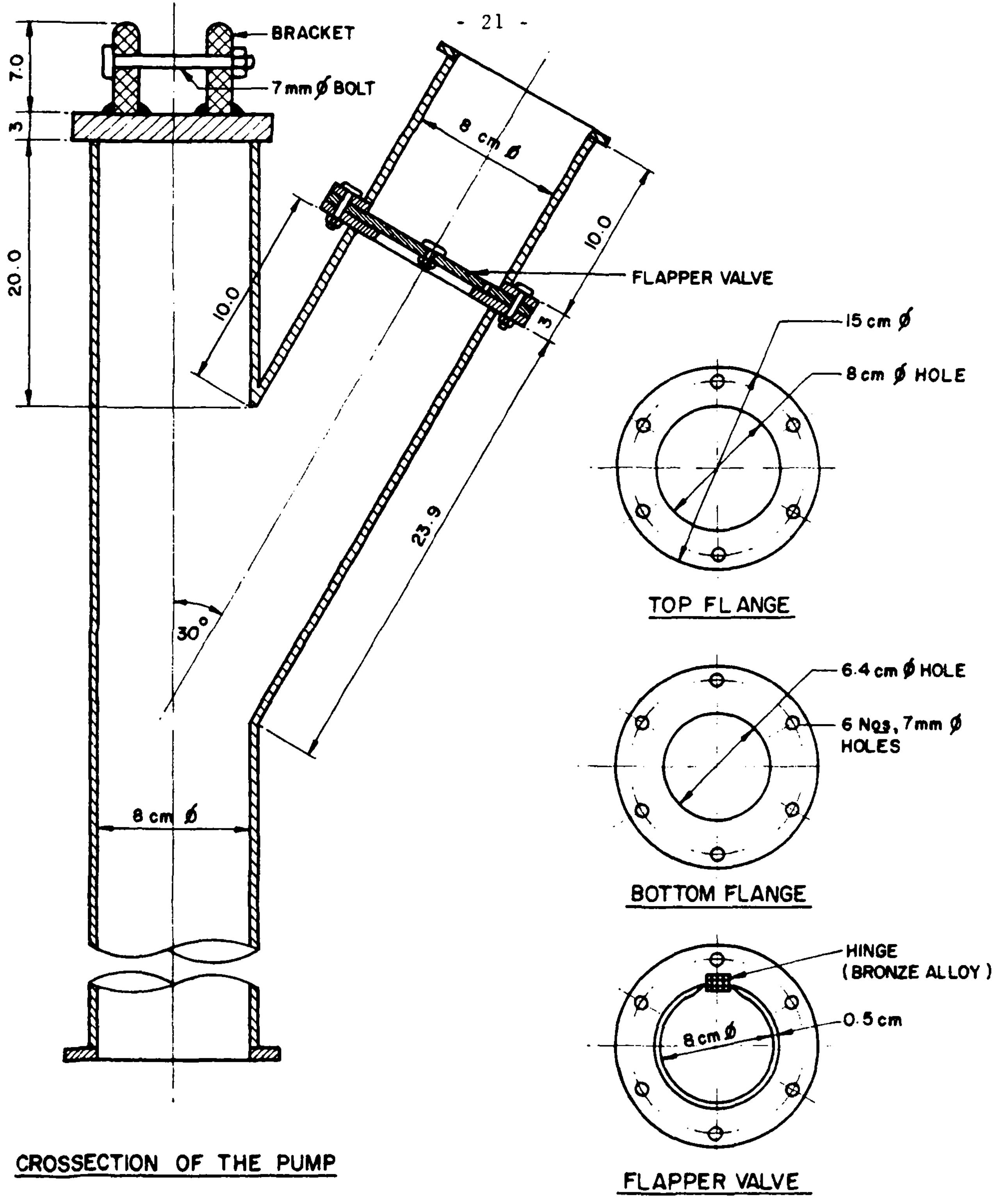


FIG. 3.1 MODIFIED INERTIA PUMP WITH FLYWHEEL AND A BICYCLE – TYPE DRIVE



CROSSECTION OF THE PUMP

TOP FLANGE

BOTTOM FLANGE

FLAPPER VALVE

NOTES:

1. All dimensions are in centimeters
2. Flanges are made of 5.0 mm thick cast iron.
3. Flapper valve is made of rubber

FIG. 3.2 DESIGN OF INERTIA PUMP IP -1

pumps were constructed, one with a 5 cm diameter riser and the other with a 7.6 cm diameter riser, both of cast iron piping. Another short CI piping welded at right angle onto the riser near the upper end, 2.5 cm above the valve seating formed the spout. The pumps were designated as IP-2 (5 cm riser) and IP-3 (7.6 cm riser). A 5 cm diameter flapper valve was used in each of these designs. A third unit of the modified inertia pump designated as IP-4, was also constructed using a 7.6 cm riser and a 6.4 cm flapper valve. Design specifications for the three inertia pumps are shown in Fig. 3.3 and 3.4 while Fig. 3.5 shows a dismantled unit.

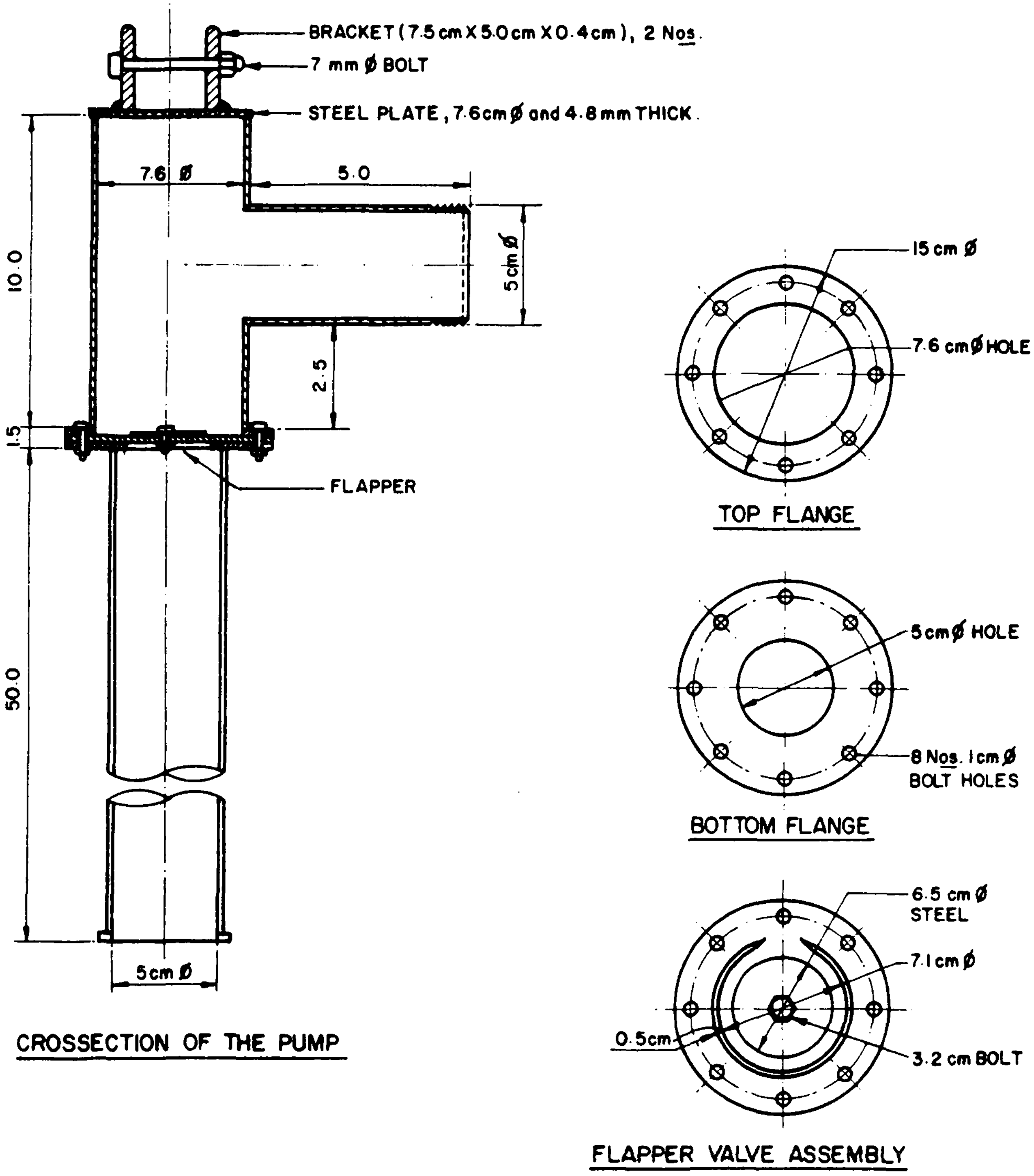
3.2 Prime Mover Assembly

The prime mover assembly consisted of a triangular wooden supporting frame on which was mounted a bicycle-type drive mechanism including pedals, chain and a sprocket as shown in Fig. 3.6. A seat for the operator as well as a handle-bar were also provided so that the operator would assume a position approximating that on a bicycle. At one end of the driving shaft on which the sprocket was mounted was a flywheel with a disc crank. The pump handle was connected to the disc crank through a wooden connecting rod.

3.3 Pump Operation

Operation of the inertia pump consists of causing a steady up and down motion of the pump body with the lower end of the riser immersed in water. In the present designs the rotary motion of the prime mover is converted into reciprocating motion by the disc crank and transmitted to the pump handle and to the pump through the connected rod. In the downward stroke the pump returns to its lowest position under the force of gravity. The function of the flywheel is to help recover some of the otherwise lost energy when the pump is on the down stroke.

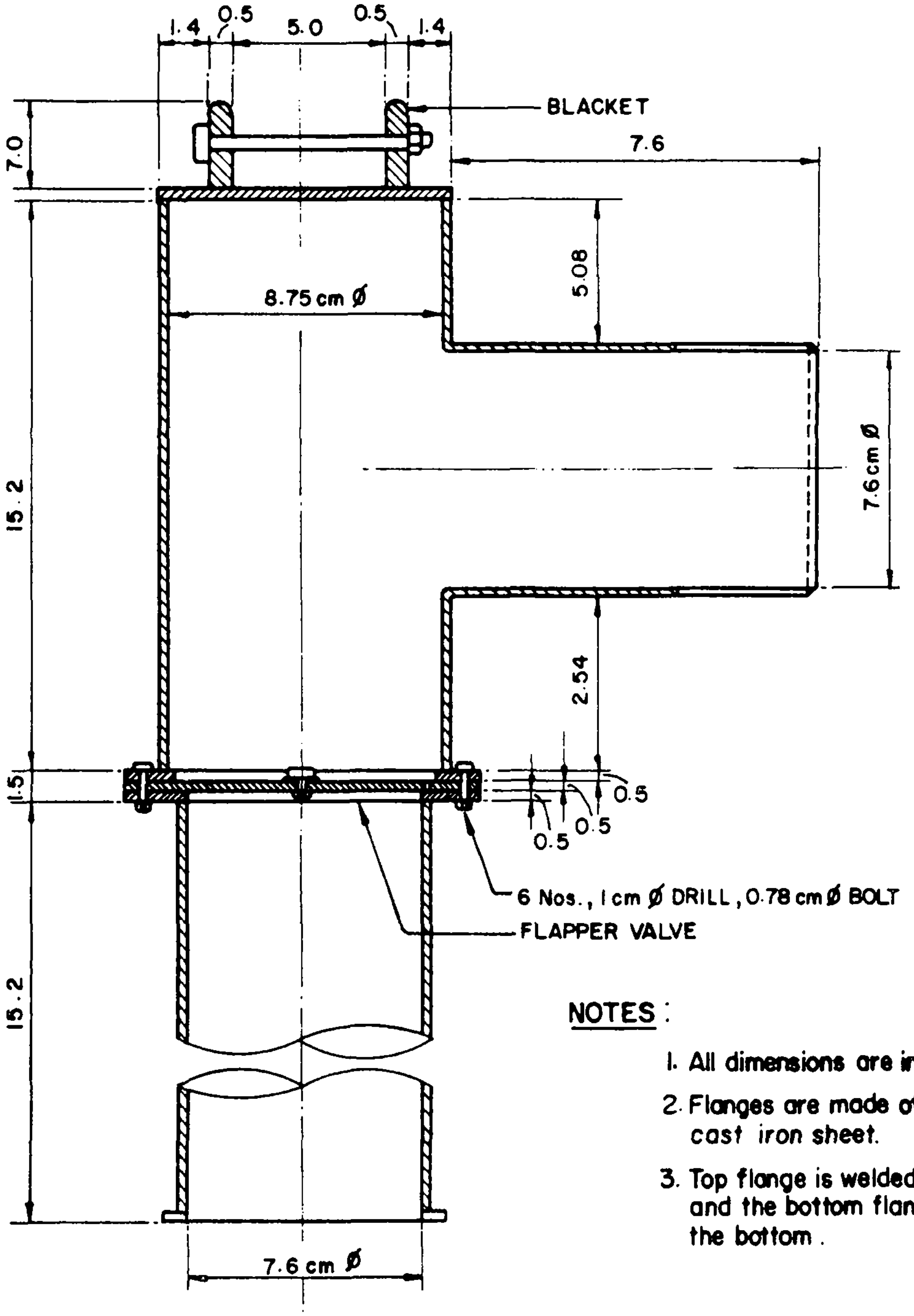
Two fundamental forces are believed to exist during pump operation. When the pump body moves down a portion of air or water leaves through



NOTES :

1. All dimensions are in cms.
2. Flanges are made of 5.0 thick Cast Iron.
3. Flapper valve is made of rubber and strength end with 6.5 mm. Ø steel sheet.

FIG. 3.3 DESIGN OF INERTIA PUMP IP-2



NOTES :

1. All dimensions are in cms.
2. Flanges are made of 0.5 cm thick cast iron sheet.
3. Top flange is welded to the top tube and the bottom flange is welded to the bottom .

CROSSECTION OF THE PUMP

FIG. 3.4 DESIGN OF INERTIA PUMP IP-3 & IP-4

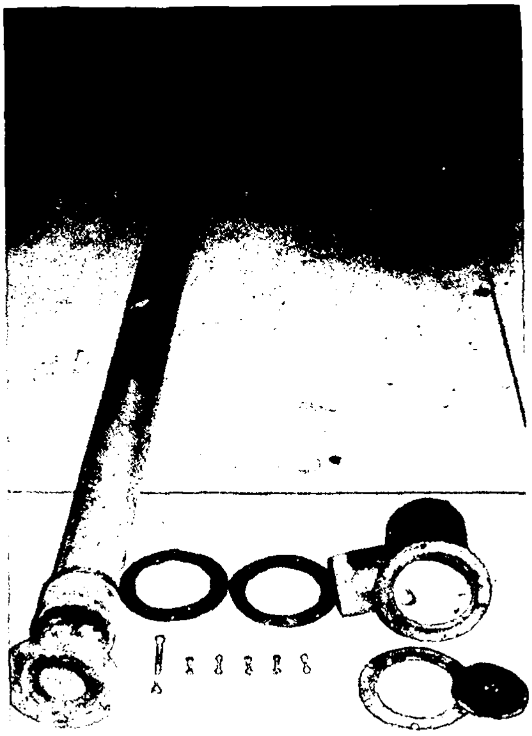


Fig. 3.5 - Inertia Pump IP-4 Disassembled

Fig. 3.6 - Bicycle Type Drive for Inertia Pump

the flapper valve. During the upward stroke the flapper valve is closed under atmospheric pressure, creating a suction inside the riser which forces water up into it from the source. In the downward stroke water is apparently pushed up in the riser due to the inertia of the mass of water held in the river. It is this force that helps open the flapper valve and force water out through the spout.

Fig. 3.7 shows the inertia pump in operation.

3.4 Experimental Testing

Experimental testing of inertia pump performance was carried out at the Regional Engineering Experimental Centre of the Asian Institute of Technology. The testing procedure was primarily aimed at determining the relationship between the operating head and output of the pump as well as to examine the best stroke length and operational speed for working the pump over extended periods. As in the case of the bellow pump a labourer was asked to operate the pump.

3.4.1 Testing of Inertia Pump IP-1

A few preliminary test runs using IP-1 pump were carried out to determine the best stroke length and speed of operation at three levels of operating head, namely, 1.0, 1.5 and 2.0 meters. A riser of appropriate length was used for operation at a particular head. Segments of CI piping were joined together by welding to yield a riser of required length. Several operational difficulties were encountered during these trial runs leading to abandoning of the design and development of modified designs as noted earlier. Further detailed evaluation of pump performance was not therefore undertaken for this unit.

3.4.2 Testing of Inertia Pumps IP-2, IP-3 and IP-4

Pumps IP-2, IP-3 and IP-4, based on a modification of pump IP-1, were evaluated with respect to stroke length in the range of 10 to 20 cm and operating speed in the range of 140 to 200 strokes per

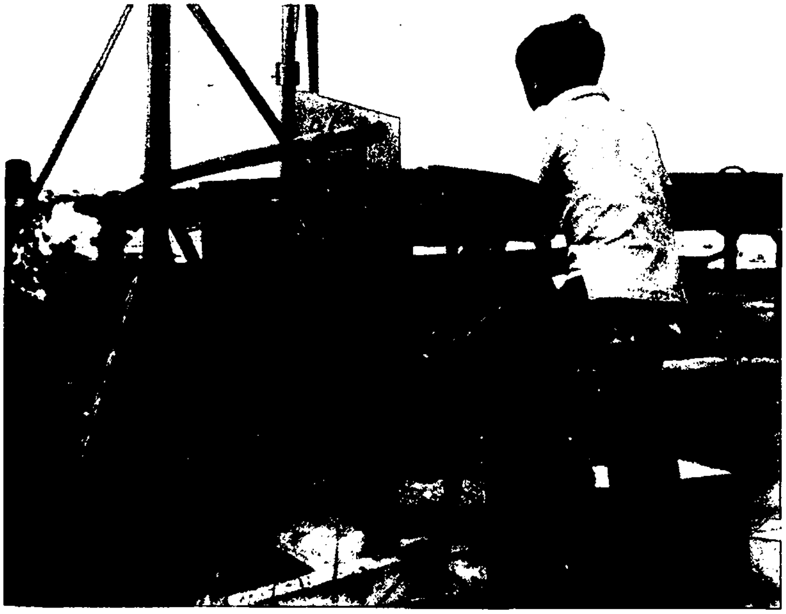


Fig. 3.7 - Operation of the Inertia Pump

minute at three levels of operating head of 1.5 m, 2.0 m and 2.5 m. The stroke length was varied by using different diameters of disc crank. In these test runs a constant operational speed was maintained for long periods of operation by using a variable speed DC motor to drive the pump. For a given run at specified values of stroke length, operating speed and head, the pump output was recorded by cumulating the discharge over fifteen minute periods and computing the mean discharge rate from several samples. Subsequently the pumps were manually operated to determine the most favourable stroke length and operating speed for various values of operating head. The maximum value of operating head investigated here was 2.5 m since a pump body longer than this created excessive weight problem.

3.5 Results and Discussion

3.5.1 Evaluation of Pump IP-1

Based on a few trial runs, the most suitable operating speed for manual operation was determined to be in the range of 120 to 150 strokes/min for pump IP-1. The volumetric discharge of the pump for various operating heads and stroke lengths are tabulated in Table 3.1.

Table 3.1 - Performance of Inertia Pump IP-1

Head / Stroke Length	Mean Discharge, ℓ/min at		
	1.0 m	1.5 m	2.0 m
20 cm	80	66	60
15 cm	113	93	70
10 cm	59.5	56	53

Contrary to expectations, the output of the pump did not monotonically increase with stroke length for any operating head. On the other hand, the best output was obtained for a stroke length of 15 cm, the performance at 20 cm and 10 cm being inferior. With the information on hand it was not possible to assign a specific reason for this behaviour, but probably it was due to poor design of the valve assembly leading to increased slip. Even the best performance of the pump was inferior to that of the bellow pump although it was expected that energy utilization by inertia pump would be better than in the bellow pump on account of smaller losses due to friction.

Several other drawbacks in the design were noted during operation of the pump. The eccentric load due to the heavy inclined arm forming the valve seat and discharge spout caused the pump to swing about its vertical axis leading to difficulties in pedalling and damaged the bolt connecting the pump body to the pump handle. The necessity of a large side arm to house the flapper valve also unnecessarily increased the weight of the pump resulting in a necessary reduction in the maximum length of the riser. Furthermore the location of the valve in the inclined arm prevented it from closing tightly thus decreasing the discharge capacity of the pump. In view of these shortcomings in later designs of inertia pump IP-2, IP-3 and IP-4 the valve assembly was located in the riser pipe and the length of the spout was minimized.

3.5.2 Evaluation of Inertia Pumps IP-2, IP-3 and IP-4

Test runs were carried out for each set of values of operating head, stroke length and speed of operation within the range specified previously and the mean volumetric discharge rate of each of the pumps recorded. These data are tabulated in the Appendix B. Each of the operational parameters investigated affected pump performance to a greater or lesser degree. In addition, each pump design gave a different performance under a given set of operating conditions.

Fig. 3.8, 3.9 and 3.10 show the effect of operating speed upon pump discharge for pumps IP-2, IP-3 and IP-4 respectively. It is seen that for a specified head and stroke length, the discharge for each pump was a linear function of operating speed in the range studied. Thus when other operating parameters are held constant a given increase

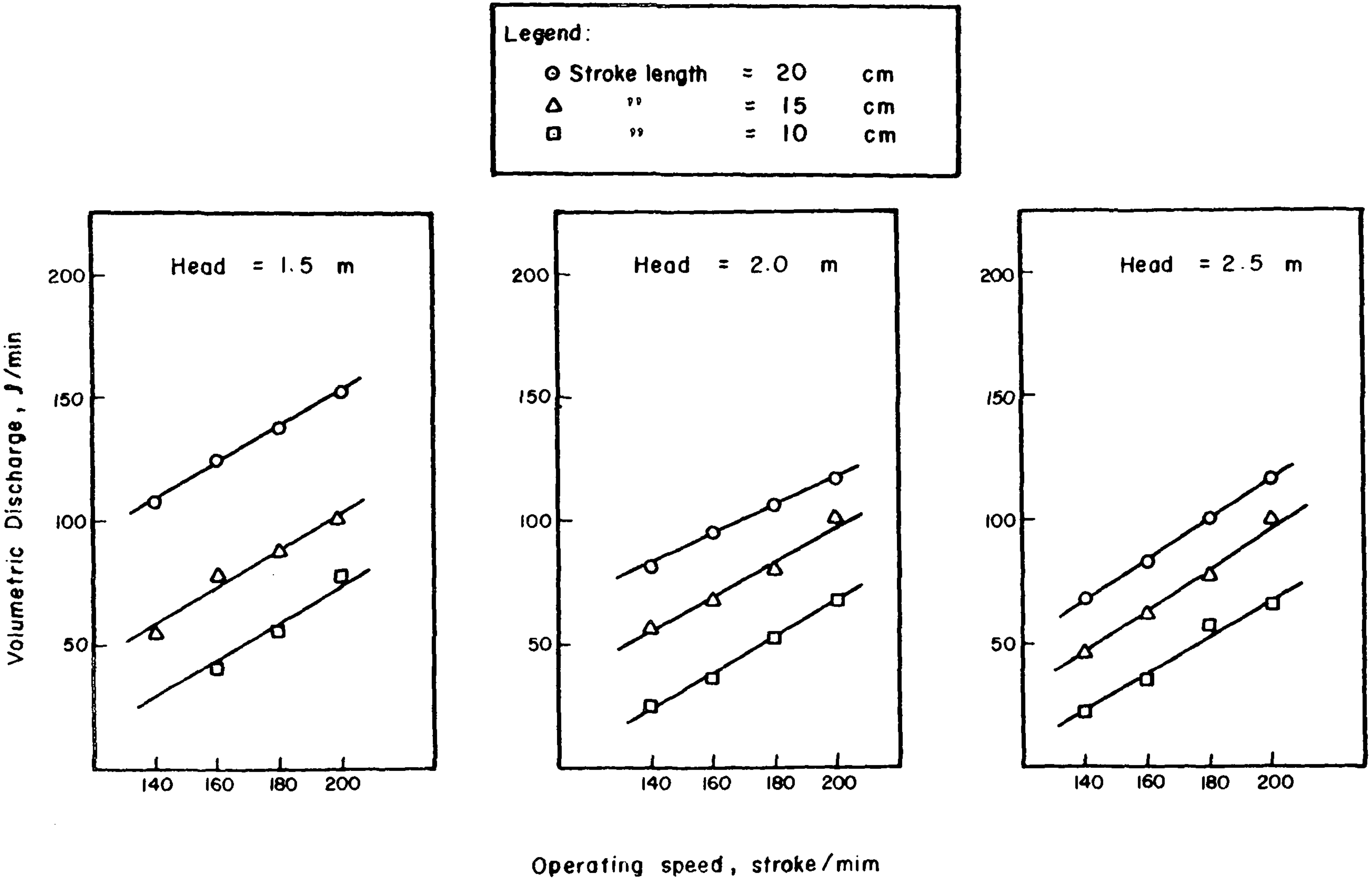


Fig. 3.8 Speed – Discharge Relationship for Pump IP – 2
(5 cm diam riser, 5 cm flapper valve)

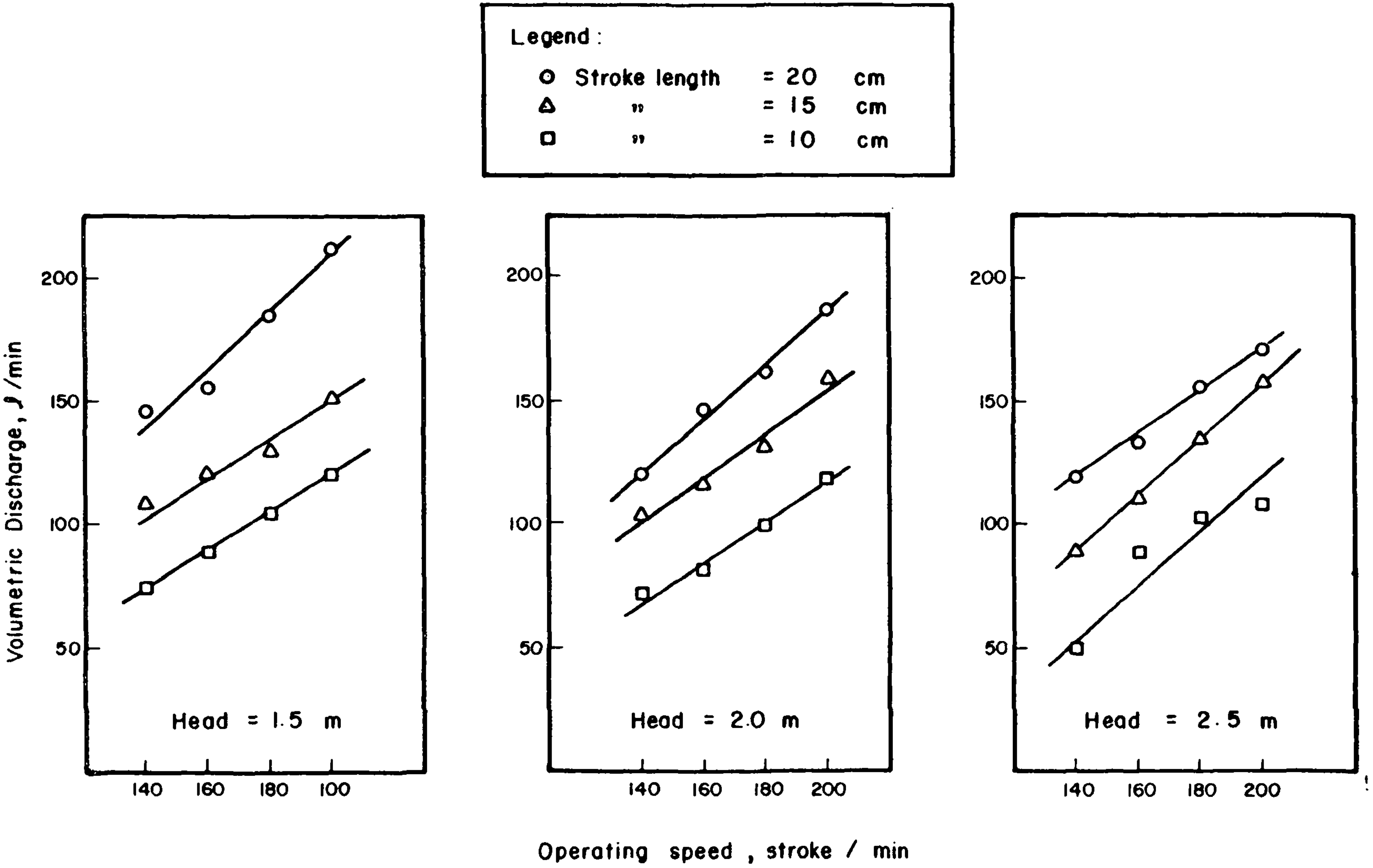


Fig. 3.9 Speed - Discharge Relationship for Pump IP-3
(7.6 cm diam riser, 5 cm flapper valve)

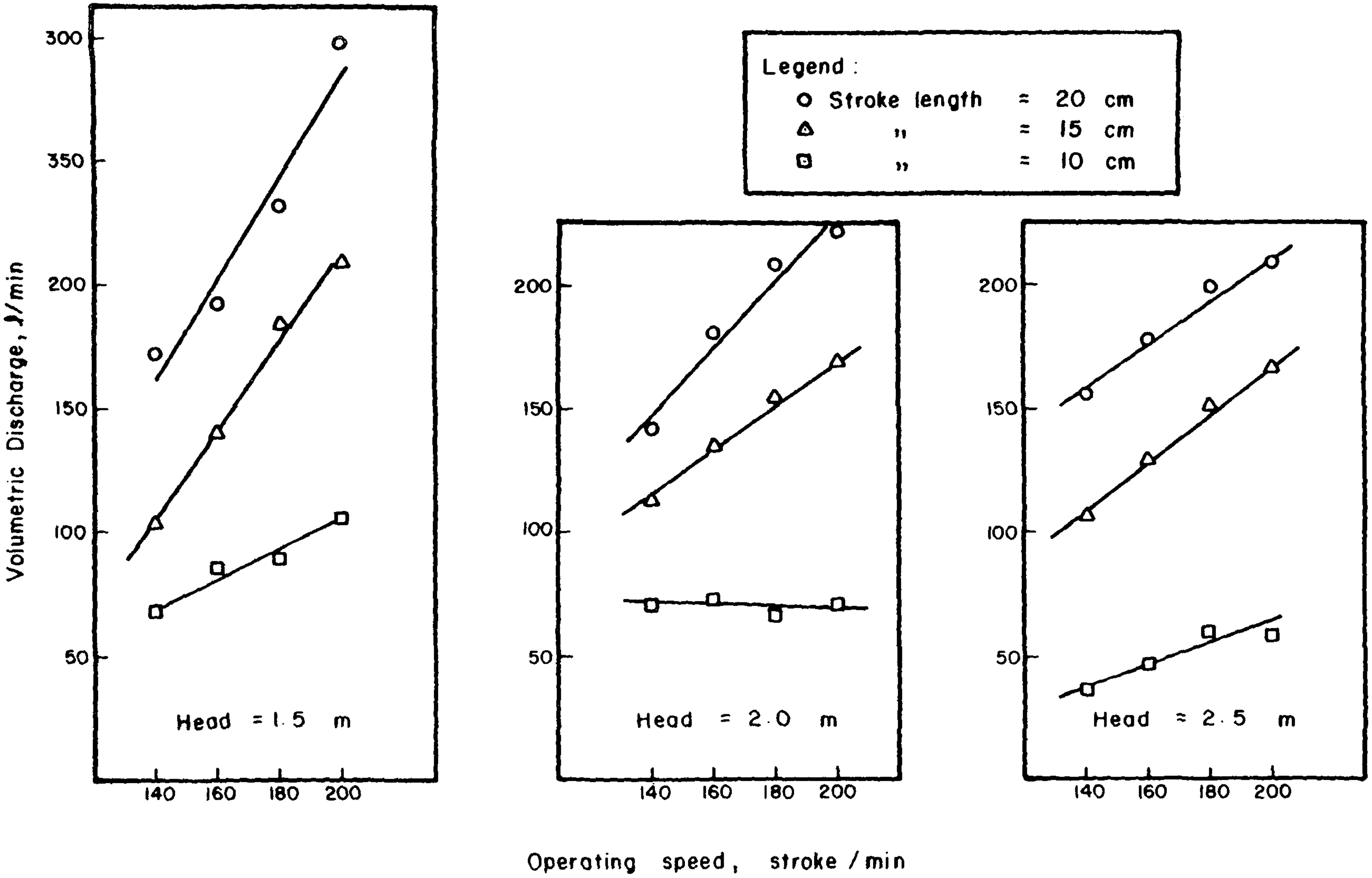


Fig. 3.10 Speed - Discharge Relationship for Pump IP - 4

(7.6 cm diam. riser, 6.4 cm flapper valve) in pumping speed could be expected to result in a constant increase in discharge over the entire speed range considered. Since energy input is directly proportional to speed of operation, this means that the overall efficiency of the pump remains more or less constant over the speed range studied provided the other operating conditions are not altered.

Fig. 3.11 to 3.13 present the relationship between static head and pump discharge. In general, a decrease in the discharge rate was observed with increasing head for each of the pumps operating at a specified stroke length. Although this relationship was approximately linear in many cases, a generalization to this effect could by no means be deduced.

Table 3.2 shows a comparison of performance of the three pumps for a stroke length of 15 cm and pumping speed of 160 strokes/min. Pump IP-2 had a 5 cm diameter riser while IP-3 had a 7.6 cm riser, other features being exactly the same in both. It is seen that the pump with the larger diameter riser yielded a larger output than the other. Since water is forced out of the inertia pump due to the inertia of the water held in the riser, it would seem that the discharge would be directly related to the mass of water in the riser, or in other

Table 3.2 - Comparison of Performance of Pumps IP-2, IP-3 and IP-3*

	Mean Discharge ℓ/min at		
Head / Pump No.	1.5 m	2.0 m	2.5 m
IP-2	79	68	62
IP-3	121	116	111
IP-4	141	135	129

* Stroke length = 15 cm; pumping speed = 160 strokes/min

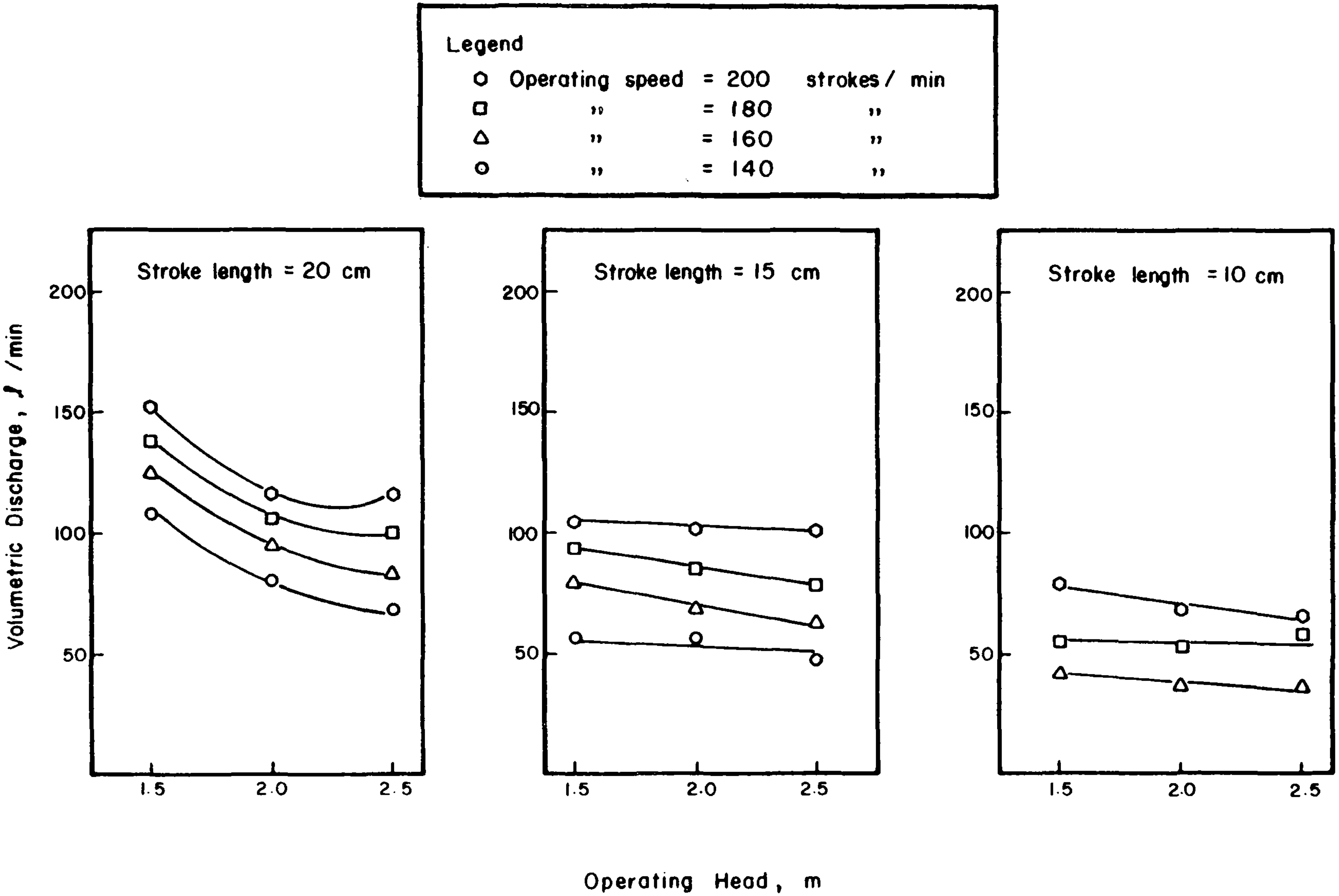


Fig. 3.11 **Head – Discharge Relationship for Pump IP-2**
(5 cm diam. riser, 5 cm flapper valve)

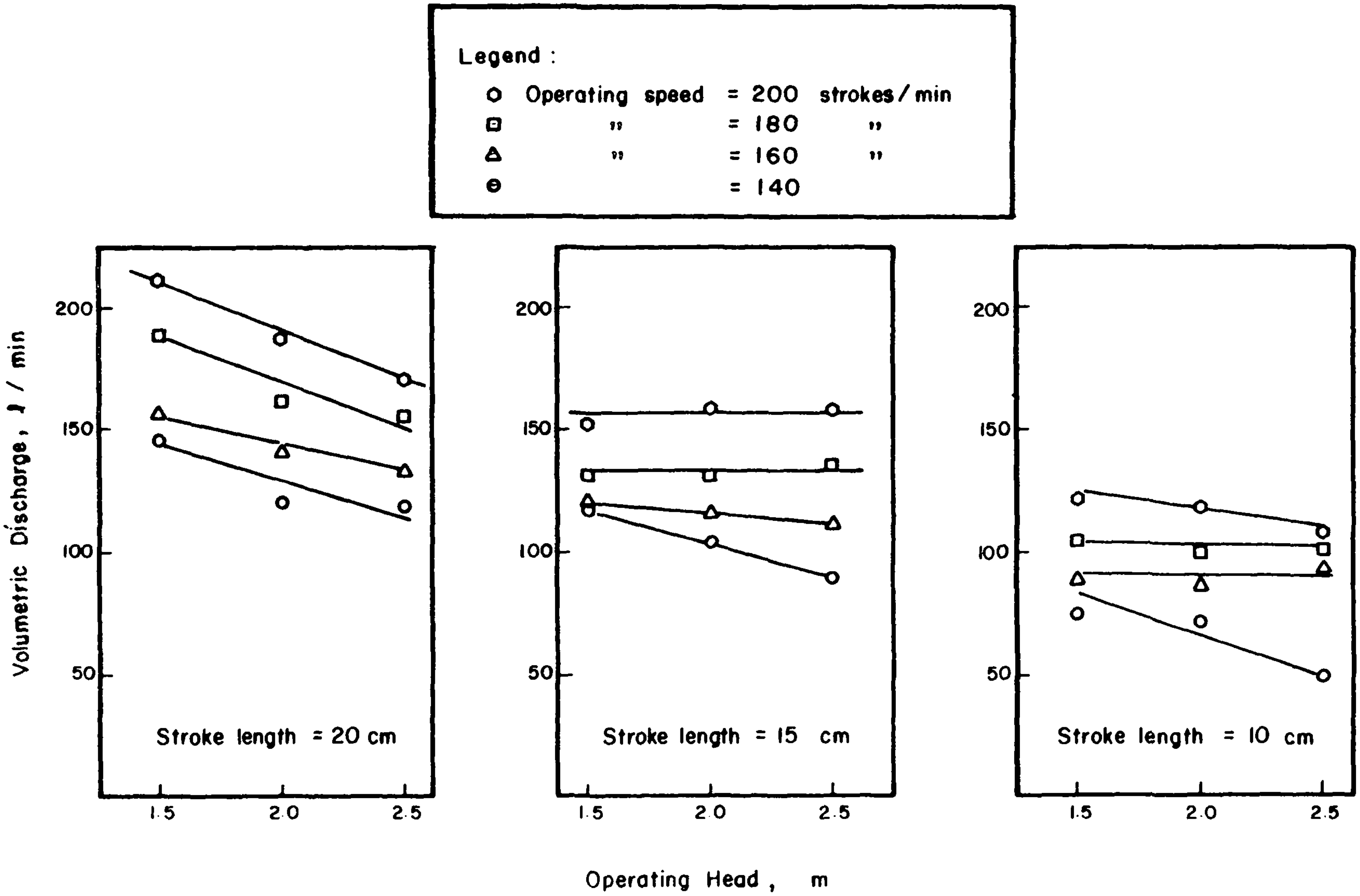


Fig. 3.12 Head-Discharge Relationship for Pump IP-3

(7.6 cm diam. riser, 5 cm flapper valve)

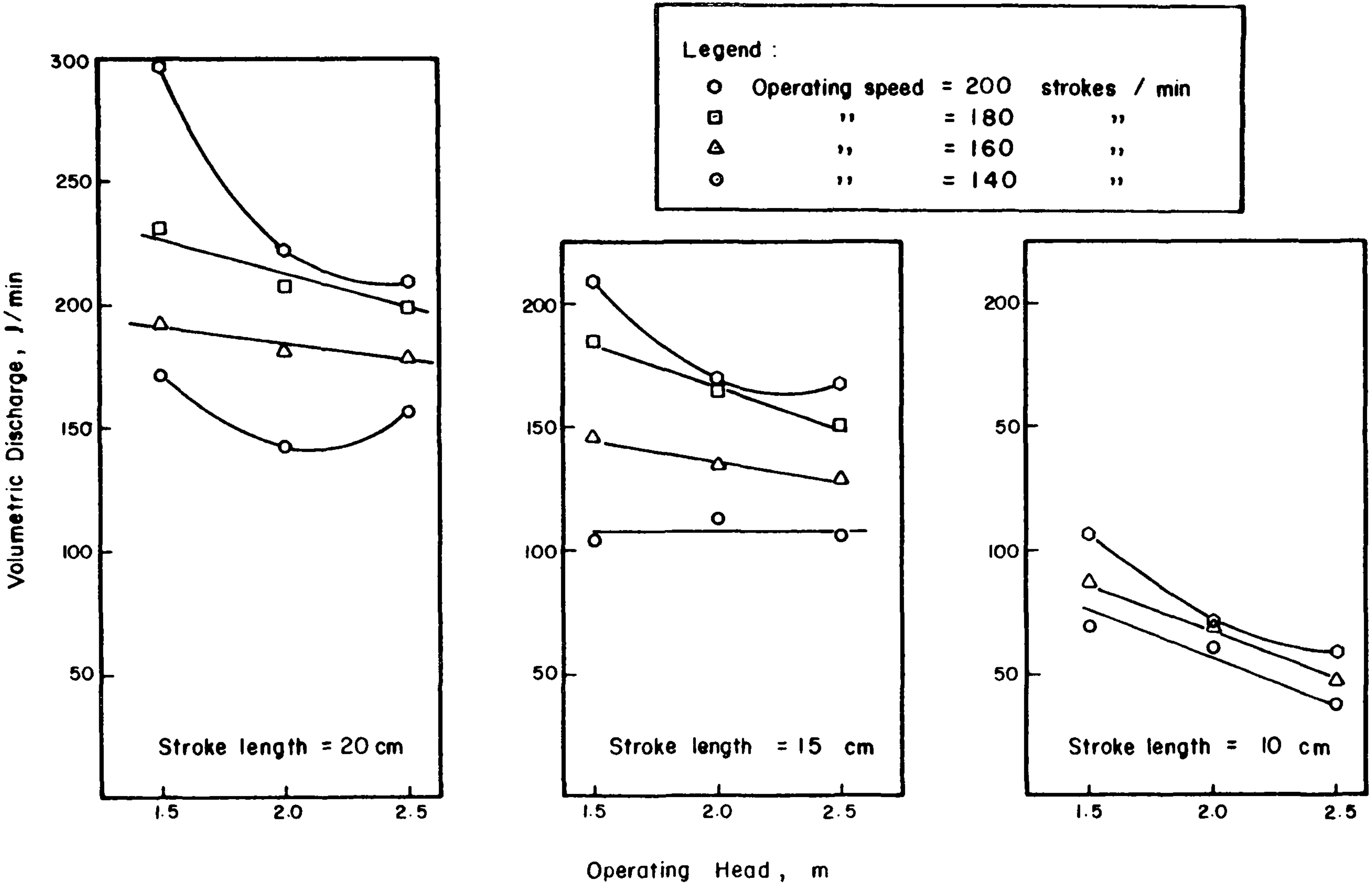


Fig. 3.13 Head - Discharge Relationship for Pump I P - 4
(7.6 cm diam. riser, 6.4 cm flapper valve)

words, to the volume or diameter of the riser. Pumps IP-3 and IP-4 differed only in that the former had a 5 cm flapper valve while the latter had a 6.4 cm valve. It is seen that the increased size of the valve resulted in increased pump output. This could be due to decreased resistance of larger valve opening to flow of water. Similar results were obtained for the other values of stroke length and pumping speed.

Examination of Fig. 3.8 to 3.13 also shows that for a given operating head and pumping speed, the volumetric discharge increased with stroke length in the range studied for each of the pump. The best stroke length as well as the pumping speed should in practice be selected based on experience with manual operation of the pump, keeping in view the requirements of head and discharge for the application on hand. Manual operation of the pumps investigated here showed that pumps IP-3 and IP-4 could be operated for extended periods, without the operator getting excessively fatigued, at a speed of 140 to 160 strokes per min and a stroke length of 15 cm. Operation at 20 cm stroke length appeared to tire out the operator after a short while. Pump IP-2 could on the other hand be operated for long periods at 20 cm stroke length and a speed of 140-160 strokes/min. Table 3.3 presents the discharges to be expected from the pumps at various operating heads under these optimal operating conditions. Comparison of the performance of the

Table 3.3 - Expected Performance of Pumps IP-2, IP-3 and IP-4 when Manually Operated

	Mean Discharge, ℓ/min, at			Remarks
Head / Pump No.	1.5 m	2.0 m	2.5 m	
IP-2	116.5	88	75.5	140-160 strokes/ min 20 cm stroke
IP-3	120	110	100	140-160 strokes/ min 15 cm stroke
IP-4	122.5	124	117.5	140-160 strokes/ min 15 cm stroke

inertia pumps with that of the bellow pump (Table 2.1) shows that the inertia pumps are superior to the bellow pump. At 1.5 m static head the volumetric capacity of each of the inertia pumps is significantly (31 to 38 percent) higher than that of the bellow pump. At 2.5 m head the output of pump IP-2 is comparable to that of the bellow pump while IP-3 and IP-4 yield, respectively, 33% and 56% higher output.

3.6 Conclusions

The initial design of an inertia pump IP-1, with the valve assembly located in an inclined side arm, is not only inferior to the bellow pump in performance but is also difficult to operate because of a tendency to swing. The later designs IP-2, IP-3 and IP-4, in which the valve is housed in the riser, are free from the shortcomings of the earlier model. The construction and maintenance of the inertia pump is much simpler than that of the bellow pump. In addition, each of the three designs studied is in general superior to the bellow pump in performance. The inertia pump therefore appears to be a superior alternative to the bellow pump for incorporation into small rural water supply systems. It may be necessary to use two or more pumps in series if the total lift required is greater than about 2.5 m. The output of pump IP-2 is sufficient for the daily requirement of about 500 people with the pump operated 3 to 4 hours daily. Pumps IP-3 and IP-4 are capable of serving a larger population.

Volumetric output of inertia pump increases with increased riser diameter and size of valve opening. Other operating conditions being maintained constant, increasing the speed of operation of the pump linearly increases pump discharge. The discharge also increases monotonically with increased stroke length. At constant stroke length and operating speed the discharge decreases with increasing head on the pump.

For manual operation, a pumping speed of 140 to 160 strokes per minute is most suitable for extended periods of operation with a bicycle type drive assembly. A stroke length of pump IP-2 may be operated at 20 cm stroke length while a 15 cm stroke was found to be optimal for IP-3 and IP-4.

APPENDIX A

Table A1 - Bellow Pump Performance with a Single Operator

Run No.	Head on the Pump m	Mean Discharge Rate ℓ/min
1	1.5	100
2	1.5	76.7
3	1.5	90
4	2.5	73.3
5	2.5	76.7
6	3.5	37.4
7	3.5	40

Table A2 - Bellow Pump Performance with Two Operators

Run No.	Head on the Pump m	Mean Discharge Rate ℓ/min
1	1.5	113.3
2	1.5	116.7
3	2.5	93.3
4	2.5	95
5	3.5	53.3
6	3.5	45

Table B1 - Mean Volumetric Discharge Rates (ℓ/min) of Inertia Pump IP-2 under Various Operating Conditions

Head	1.5 m				2.0 m				2.5 m			
Operating Speed Strokes/min Stroke Length, cm	140	160	180	200	140	160	180	200	140	160	180	200
20	108	125	138	152	81	95	106	116	68	83	100	116
15	56	79	88	102	56	68	79.5	101	47	62	78	100
10	-	41	56	78	25	36	53	68	23	35	58	66

Table B2 - Mean Volumetric Discharge Rates (ℓ/min) of Inertia Pump IP-3 under Various Operating Conditions

Head	1.5 m				2.0 m				2.5 m			
Operating Speed Strokes/min Stroke Length, cm	140	160	180	200	140	160	180	200	140	160	180	200
20	146	156	184	212	120	146	162	187	119	133	156	171
15	119	121	131	152	104	116	131	159	89	111	135	158
10	75	84	105	121	73	82	100	119	50	89	103	108

Table B3 - Mean Volumetric Discharge Rates (ℓ/min) of Inertia Pump IP-4 under Various Operating Conditions

Head	1.5 m				2.0 m				2.5 m			
Operating Speed Strokes/min Stroke Length, cm	140	160	180	200	140	160	180	200	140	160	180	200
20	172	192	232	298	142	181	208	222	156	178	199	209
15	104	141	185	209	113	135	165	169	106	129	151	167
10	69	86	90	106	61	73	67	71	37	47	61	59