THE DEVELOPMENT OF A PVC HANDPUMP

PHASE I

A report submitted to the World Health Organization by the Faculty of Engineering, Chulalongkorn University.

Mechanical Engineering Department
Chulalongkorn University
Bangkok 5, Thailand.

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SUMMARY

A PVC suction type handpump, based on VITA design, which were fabricated by the Agricultural Engineering Division was tested and evaluated under laboratory conditions. The piston cup seals failed prematurely from rolling back of the cup lips due to piston tilting and excessive extrusion clearance. The poppet discharge valve stuck open randomly because the valve was unguided. The piston assembly has been modified so that the piston is guided more positively. The extrusion clearance is also reduced. A rubber flex valve is used as the discharge valve. The modified piston was tested and found to be superior than the original one.

A cheap locally made brass foot valve was tested and proved to be as good as a well design and expensive PVC footvalve providing that screening is made to exclude the defective ones.

The modified piston with the original cylinder promises to be a cheap reliable and easily repaired handpump. It is suitable for a dugwell up to 6 metres deep and expected to last more than 1 million cycles.

CONTENTS

1. BACKGROUND INFORMATION

The World Health Organization (WHO), in conjunction with the Department of Health, Thailand, is searching for a low-cost, dependable and easily-repaired handpump for their rural water supply projects in Thailand. They have adopted a PVC suction type handpump, originally described in a VITA (Volunteers In Technical Assistance) publication, which was fabricated by the Rural Water Supply Division, Department of Health and the Agricultural Engineering Division, Department of Agriculture, Thailand. A limited number of these pumps are now undergoing a field trial in Lumpang and Saraburi Provinces in Thailand. Concurrently, the WHO has contracted the Faculty of Engineering, Chulalongkorn University to carry out a laboratory testing program on a PVC handpump. The program is divided into three phases:

Phase 1 is to study and modify the existing PVC suction type handpump for using in a dugwell with a water level not exceeding 6 metres below the ground level.

Phase 2 is to develop a PVC lift type handpump suitable for a deep dugwell.

Phase 3 is to develop a PVC handpump, or to modify the phase 2 handpump, for using in a small diameter tubewell.

The duration of each phase is six months. This report concerns the phase 1.

2. OBJECTIVE

2.1 To test and evaluate the original PVC suction type handpump supplied by the Department of Health.

2.2 To modify or redesign the weak components so that the pump will be more reliable.

3. DESCRIPTION OF THE ORIGINAL PUMP

Fig. 1 shows the main parts of the original PVC suction type handpump supplied by the Rural Water Supply Division, Department of Health. The assembly and detail drawings are shown in drawing no. 1,2 and 3. The pump body is made entirely from standard, water piping class, PVC pipes and fittings available in Thailand. The pump head, incorporated with the piston cylinder, is made from 80 m.m. (3 in.) PVC pipe 0.5 metre in length. A 48 m.m. hole is drilled in the side wall at a distance of 170 m.m. from the top and a piece of 48 m.m. (1½ in.) PVC pipe, 380 m.m. long, is welded perpendicular to the cylinder to form the discharge pipe. At the lower end, the cylinder is cemented to a 80 m.m. X 40 m.m. (3 in.X1½ in.) PVC reducer which in turn is connected to a short piece of pipe with a female thread coupling at the end. A suitable length of the suction pipe with a PVC footvalve at the bottom is then connected to the pump cylinder after installation.

The piston assembly consists of the piston body made from 2 pieces of 40 m.m. galvanized steel pipe. These two pieces of pipe are welded to each side of a steel ring, 67 m.m. OD, 30 m.m. ID, 5 m.m. thick, which acts as a seat for the upper leather cup and also as a seat of the discharge valve. Two 8 m.m., in-line holes are drilled in the upper tube, 6 m.m. from the top end to accomodate the piston pin. Two triangular saw cut openings are made on the side walls of the upper tube just above the discharge valve seat to ensure free flowing of water from the discharge valve. Two 76 m.m. diameter leather cups are employed as the piston seals. The upper cup is seated directly under the ring at the middle of the piston. The lower cup is seperated from the upper cup by a steel ring, 67 m.m. OD, 12 m.m. thick. Another steel ring of the same diameter but only 6 m.m. thick is placed under the lower cup. A lock nut made from a piece of sawn off 40 m.m. steel pipe coupling 15 m.m. thick is then tightened on the thread cutting on the piston bottom end. The discharge valve is a poppet type made from a rubber disc, 40 m.m. in diameter, 6.5 m.m. in thickness, with an M8X76 m.m. steel bolt and nut clamped through the centre of the disc. The valve is installed with the bolt tail (valve stem) pointed downward. It has no valve guide and the valve lift is limited by the piston pin near the top of the piston.

The piston is connected to the handle by a piston rod made from stainless steel, 9.5 m.m. in diameter, with steel yoke at both ends. The piston side yoke is welded to the rod, but the handle side yoke is clamped between two lock nuts. Care must be taken to ensure that the two yokes lie in the same plane otherwise the piston rod will bend when the handle is actuated.

The handle is made of hard wood, 50 m.m.X45 m.m.X1.80 m. in length. The *distance between the piston rod pin and the fulcrum is 405 mm..The mechanical advantage of the handle is approximately 3.2:1.The fulcrum is made from two 100mm.X50mm. hard wood poles erected from the ground with a sufficiently large block of concrete cast around the pole footing.A 13 mm. steel bolt is employed as the fulcrum pin.The handle is in the horizontal position when the piston is at the bottom of the stroke.The maximum stroke length is approximately 265 mm..A hard wood cap with a small slot to permit free movement of the piston rod is used to close the top of the pump cylinder.An additional steel ring is placed on top of the cap.The ring covers the slot and moves from side to side as the piston rod is actuated,therefore it helps to minimize the contamination of the well.*

4. TESTING AND MODIFICATION

A test rig was built in the stairway of the laboratory as shown in fig.2,3 and 4.The pump was driven by an induction motor via a 30:1 reduction gear so that the crank mechanism was running at a constant speed of 50 revolutions per minute.The static head was selected at 7.50 m.which is beyond the maximum practical suction head of reciprocating handpumps (6.91 m.at mean sea level and at 15.6 C) recommended by McJunkin (1).The water dis charge from the pump was directed into a volumetric tank equipped with a stop cock at the bottom.When the flow rate was not measured the stop cock was partially closed so that the water level was kept at the overflow pipe. An electronic liquid level switch was installed in the tank in order to stop the motor whenever the flow rate of the pump decreased significantly. A mechanical counter,driven by the pump lever,was installed for counting the number of the pumping cycles.The measurement of the force on the pump handle was not included in the test due to the limitation of the fund and lacking of the monitoring equipments.

The two original pumps supplied by the Department of Health were tested. The best mean pumping rate was 1.13 litres/cycle.This gives a slip at 11.02% for the piston swept volume of 1.27 litres.The peak flow rate was achieved during the first few thousand cycles after that the flow declined steadily as seen in fig.5.The test was terminated at 150,000 cycles when the slip reached 40.95%.The piston was inspected periodically and found *that the main failure mode is due to the rolling back of the cup lips on one side as shown in fig. 6. It is believed that the side trust initiated by the tilting of the piston rod in the upward stroke, the short distance between the upper and lower cup seal and the excessive clearance of the original cups are the main factors that cause the piston to tilt excessively during each upward stroke. These together with the excessive clearance between the supporting rings at the back of the cups allowed the cup lips to roll back and failed prematurely. If the allowable maximum slip is 15 % as suggested by reference 1, the original pump would last approximately 50,000 cycles only.*

The original piston was then tested with larger cups of zero clearance. The test showed the same trend, the slip reached 15 % at 150,000 cycles. During these two series of tests, it was also observed that the discharge was abnormally low on some cycles intermittently. This defect was found to be the discharge valve sticking in the open position. This is because the discharge valve is unguided therefore it wanders and sometimes stick to the side wall of the piston. Consequently, the valve tilts and fails to close during the next upward stroke of the piston. One of the supplied pump exhibited this defect very strongly and it was found that the bolt used as the valve stem is shorter than the specification therefore the valve tends to tilt easily.

The PVC footvalve for the pump is locally made. The body casing is made in two pieces, the upper and the lower shell, clamped together at the mating flanges by four bolts and nuts. The valve seat is situated in the lower shell therefore the hydrodynamic force acting on the valve during closing is transmitted through these flanges. Two of these valves cracked at the corner of the flange, as shown in fig. 7, after 700,000 and 200,000 cycles respectively. It is believed that inferior material and stress concentration due to inferior design contribute to failure of this type of check valve. Another type of locally made PVC footvalve with shell casing joining together by screw-thread, as described in drawing no 3, was tested and found to work satisfactorily for 900,000 cycles. Finally a locally made brass footvalve was also tested. It is approximately U.S. $ 2.50 cheaper than the PVC footvalves. The brass texture was found to be inferior with numerous voids. A few voids were also *found on the machined valve seat. Consequently, the valve leaked heavily upon the first trial. The valve worked satisfactorily after the seat had been resurfaced on the lathe.*

The piston has been modified as shown in drawing no. 4 and 5. The distance between the cups are lengthened from 16 mm. to 77 mm. so that the piston is less prone to tilt. The external diameter of the supporting ring at the back of each cup is also increased from 67 mm. to 76 mm.. This reduces the extrusion clearance down to 1.5 mm. which is still twice the clearance recommended by Neale (2). The supporting rings are made from sawn-off 76 mm. ODX51 mm. ID (3"X2") bronze bearing sleeve, available off-the-shelves from hardware shops, without any machining process needed at all. This economic reason together with the condition that the maximum pressure difference across the cup is low, compared with the value given in reference 2, rule out the necessity of reducing the extrusion clearance down to 0.5 mm.. Plastic ring is thought to be superior to bronze in term of wear and tear. It may be cheaper than bronze if ordered in large quantity. The piston pin is lower to just above the center of the piston in order to distribute the side thrust more evenly between the two cups that guide the piston.

The discharge valve of the modified piston is screwed to the bottom of the piston. The body is made from a standard 40 mm. steel pipe coupling 20 mm. in length. A steel ring with an internal diameter of 36 mm. is welded to the bottom of the body to form the valve seat. The valve is made from a synthetic rubber disc, 40 mm. in diameter, clamped diametrically by a slender bar to the seat. The valve body is also acted as a lock nut for clamping the piston cups against the upper shoulder of the piston.

The modified piston was tested with the pump cylinder of the original dimensions. The best mean pumping rate is 1.15 litres/cycle which gives the slip value of 9.45 %. The slip increased slowly to 12.6 % at 500,000 cycles and after that it remained steady up to 1.2 million cycles. The piston was inspected periodically and found to be in satisfactory condition. The cups showed no sign of rolling bach and wore evenly as shown in fig. 8. The supporting rings appeared to touch the cylinder wall slightly as suggested by bright streakes on its sidewalls. The cylinder wall showed very small wear *as confirmed by reference 3. The wall surface is well polished from rubbing action apart from a few small grooves thought to be the effect of small foreign particles in the water. The discharge valve seems to work well since no sign of missing upstroke was observed during the test. The valve rubber disc is still ingood condition with no sign of crack from fatigue after 1.2 million cycles. The only observed drawback is its small free flow area. When pumping manually, the force required to push the piston downward increases noticiably at high pumping rate.*

Finally the pump was tested with the suction pipe size reduced from 40 mm. to 25 mm.. It was unsatisfactory since the slip is approximately 40 %.

The modified piston is found to be superior to the original one. Under laboratory testing, the cup service life increases more than five folds. The new piston is no doubt more expensive than the original one, but it is difficult to estimate and compare the nominal prices of these two pistons since the most expensive part, the supporting ring, may be produced very cheaply from injection molding plastic.

The basic design of this pump is very good. It promises to be a cheap, dependable and easily-repaired handpump. All the materials are locally available. Fabrication processes and equipment or tools needed are within capability of virtually all machine shops in the country. A man with the minimum technological knowledge should be able to repair and maintain the pump with a few number of basic tools.

No attempt has been made to modify the handle since the stress level is considered to be low for the suction type pump. When using in a well deeper than 4 metres, it is suggested that the mechanical advantage of the handle should be increased to around 4:1 with the stroke reduced accordingly.

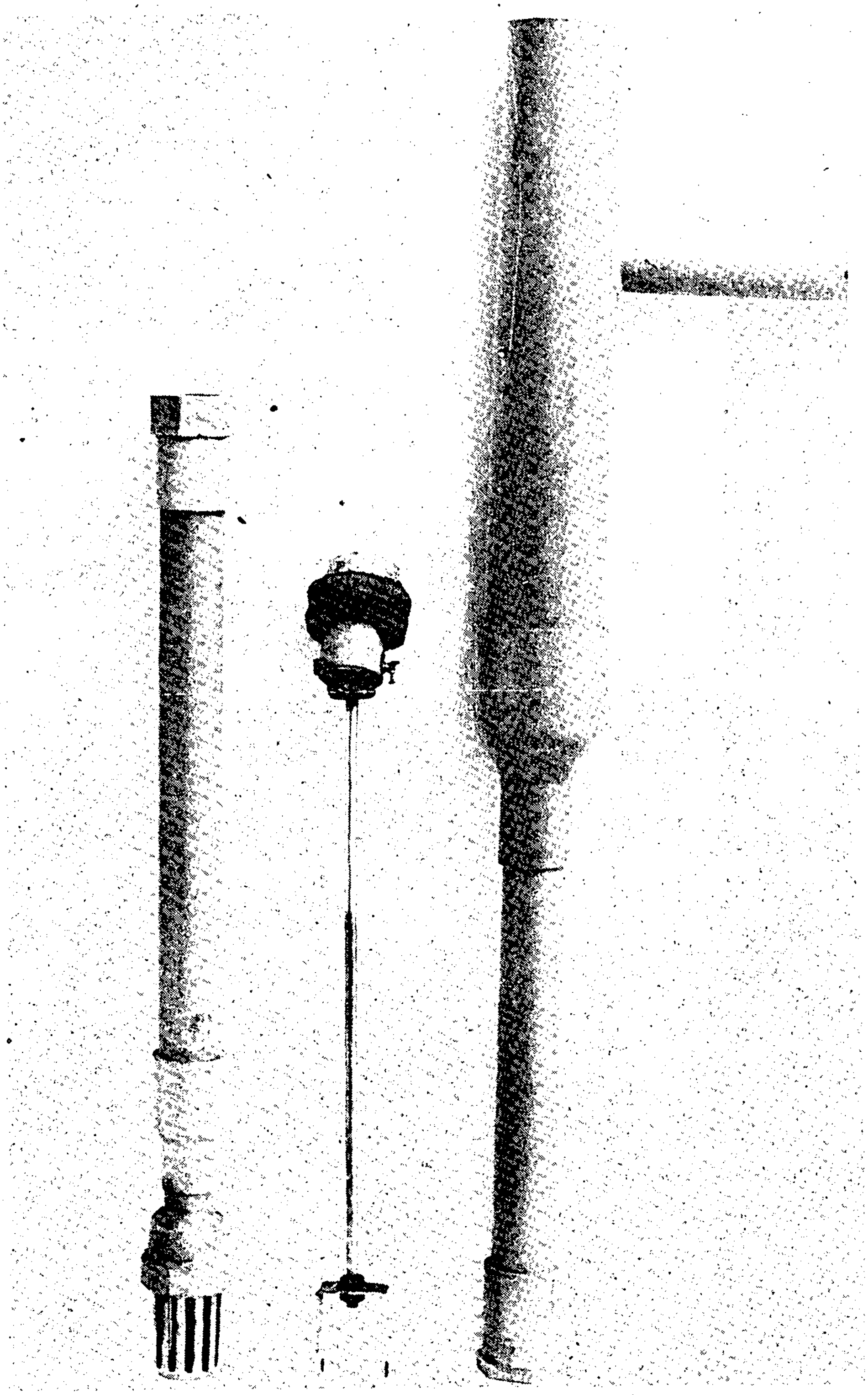


Fig.1 Main components of the original pump

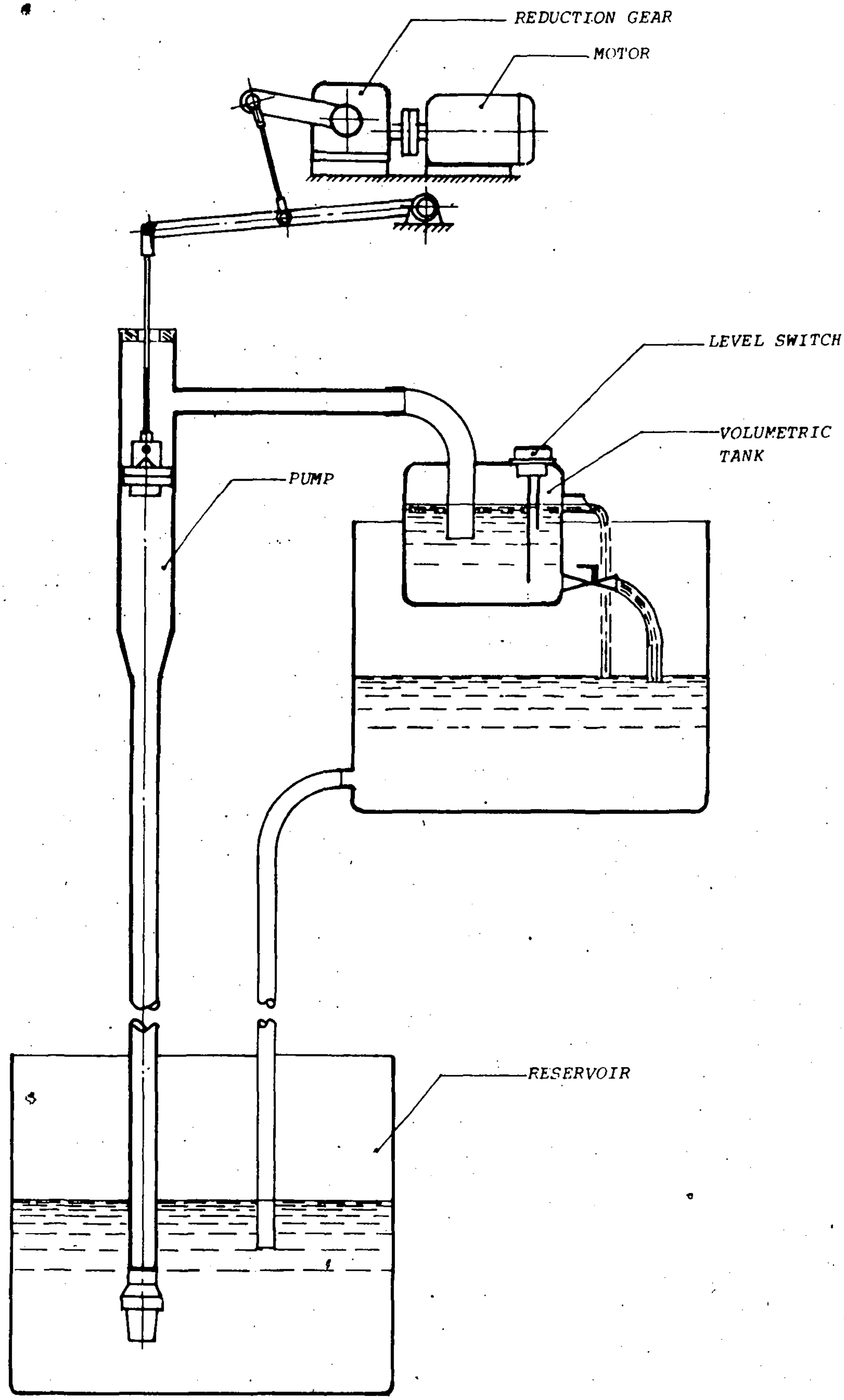


Fig. 2 A sketch of the test rig.

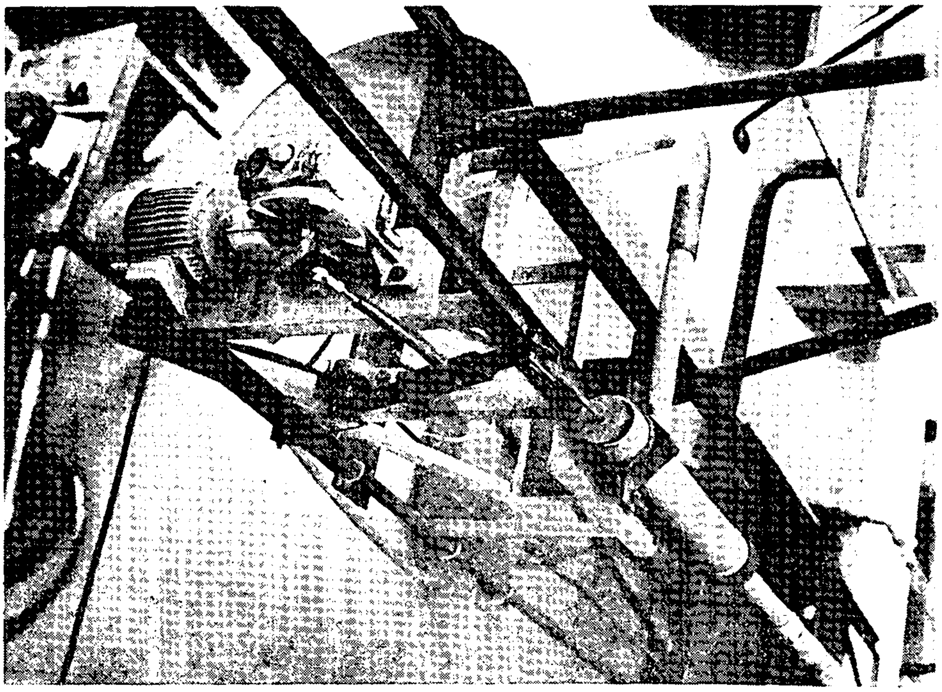


Fig.3 The test rig.

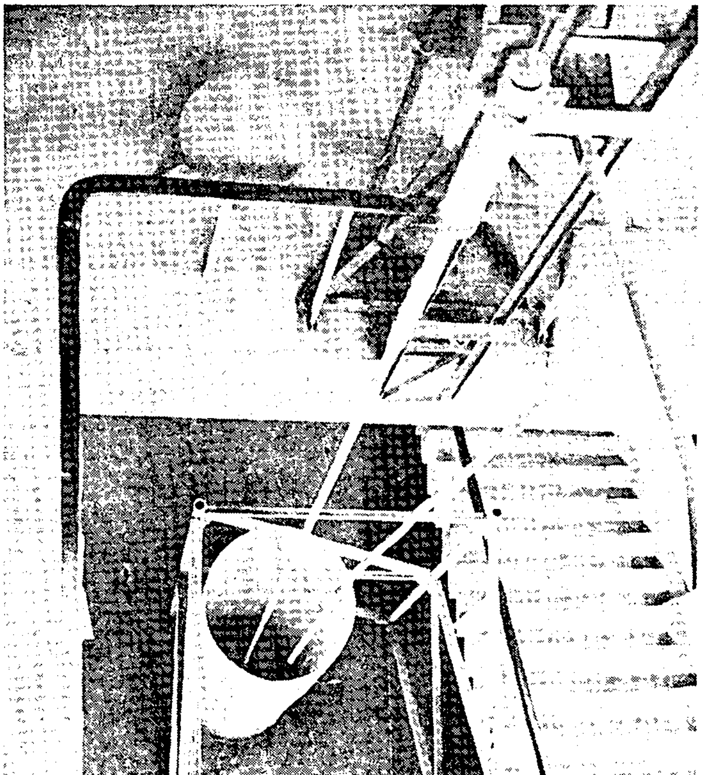


Fig.4 The test rig..

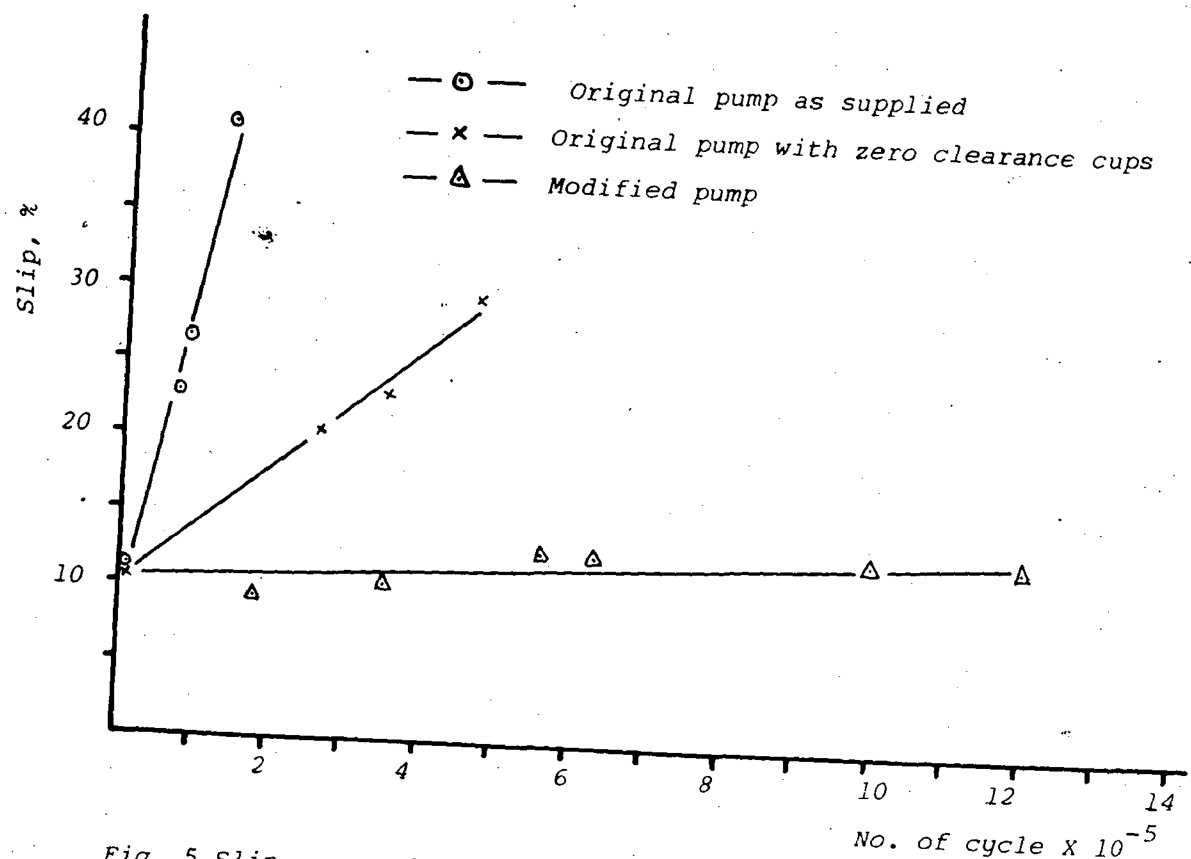


Fig. 5 Slip vs. cycle of operation.

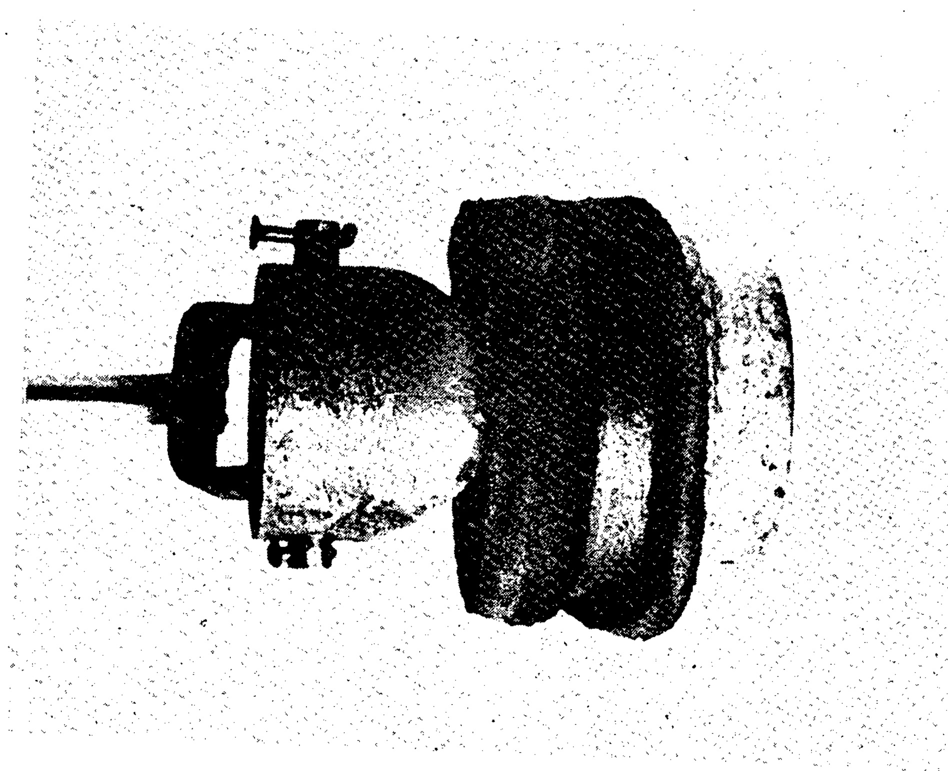


Fig.6 The original piston after failure.

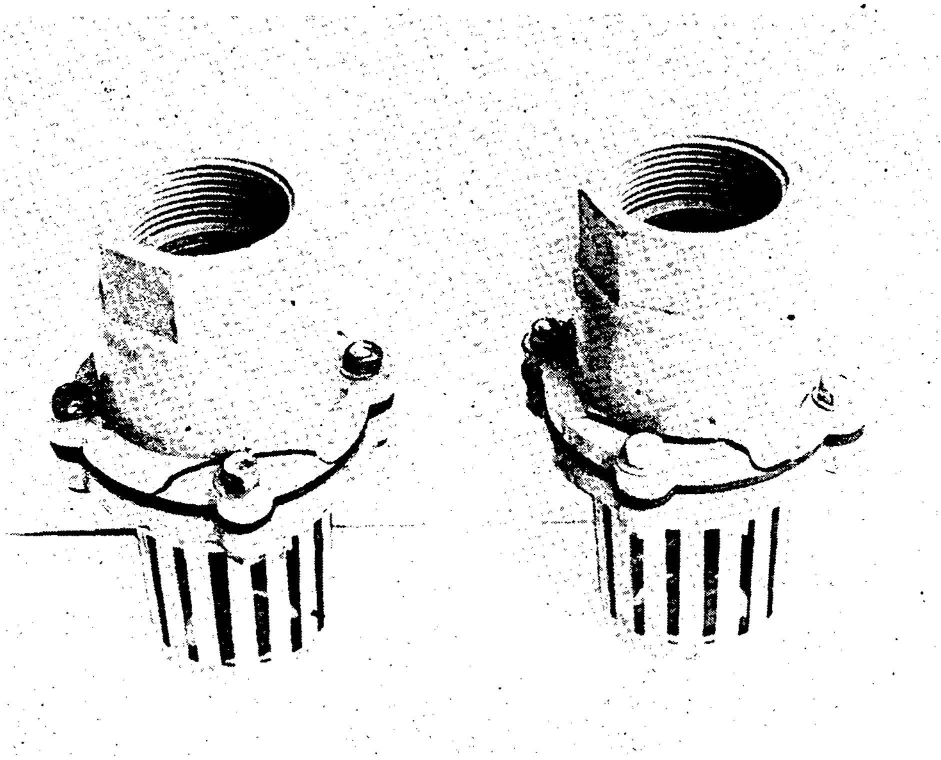


Fig.7 The PVC footvalves after failure.

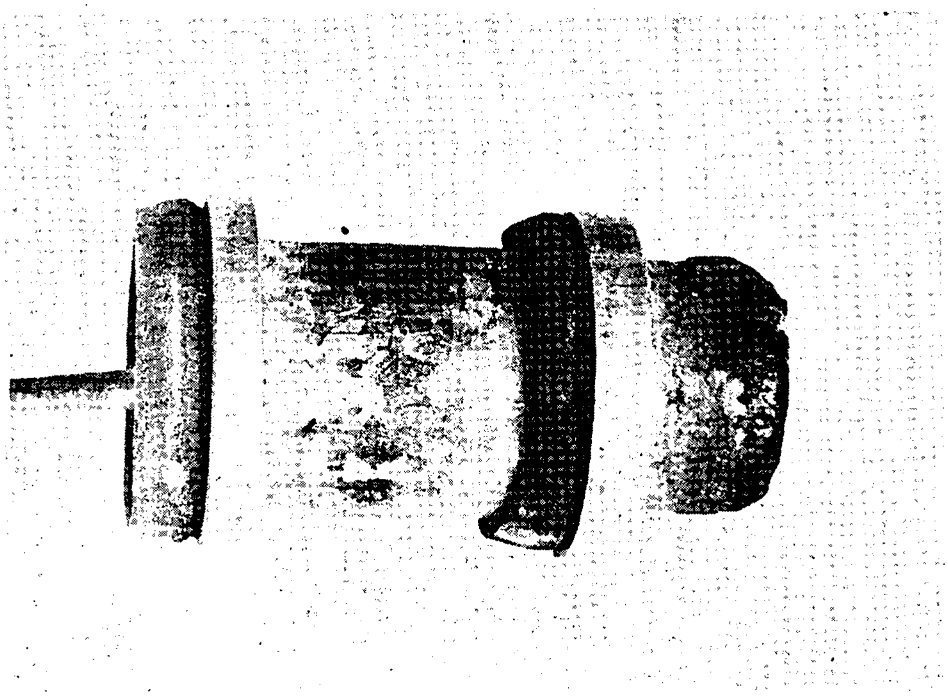
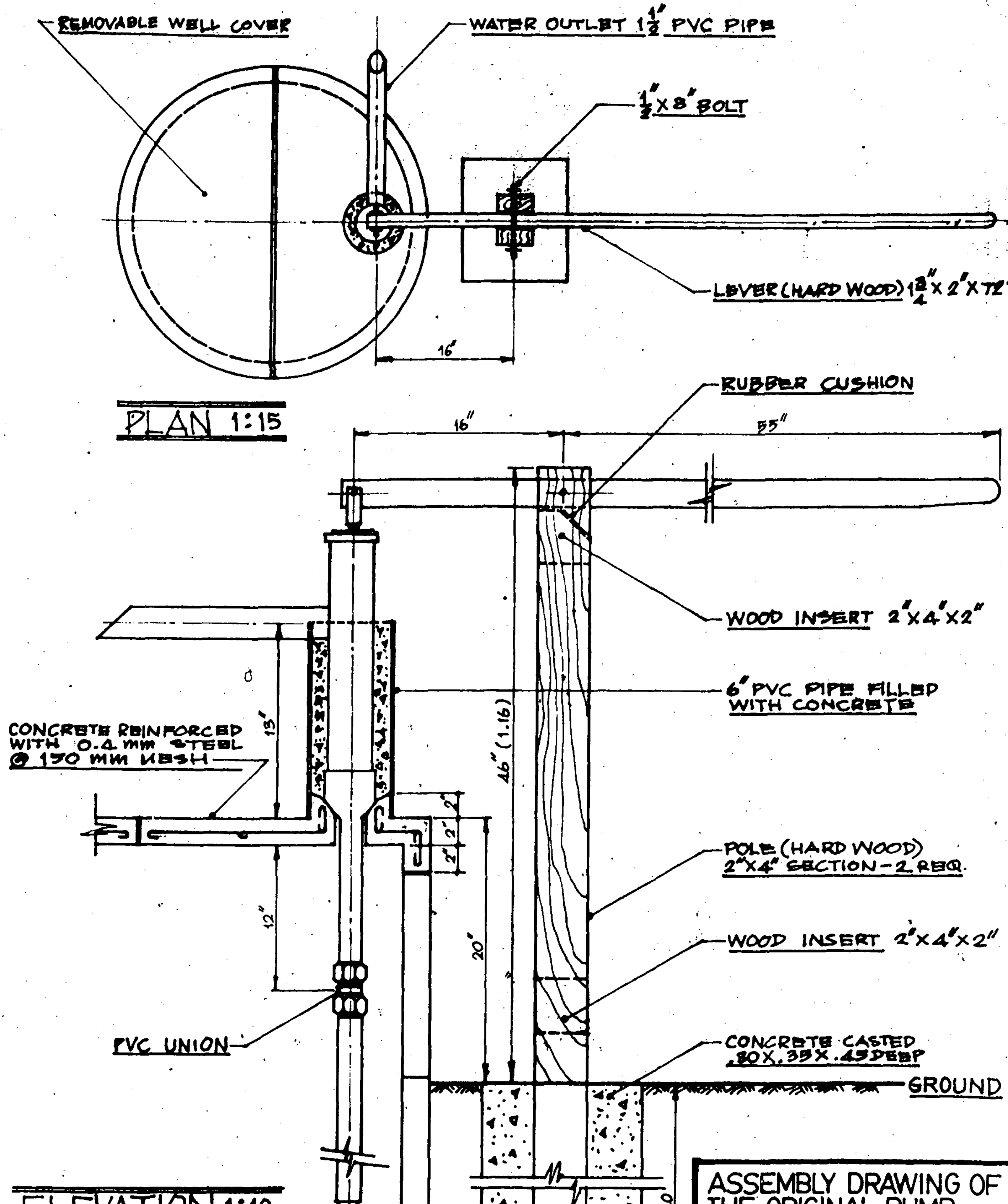
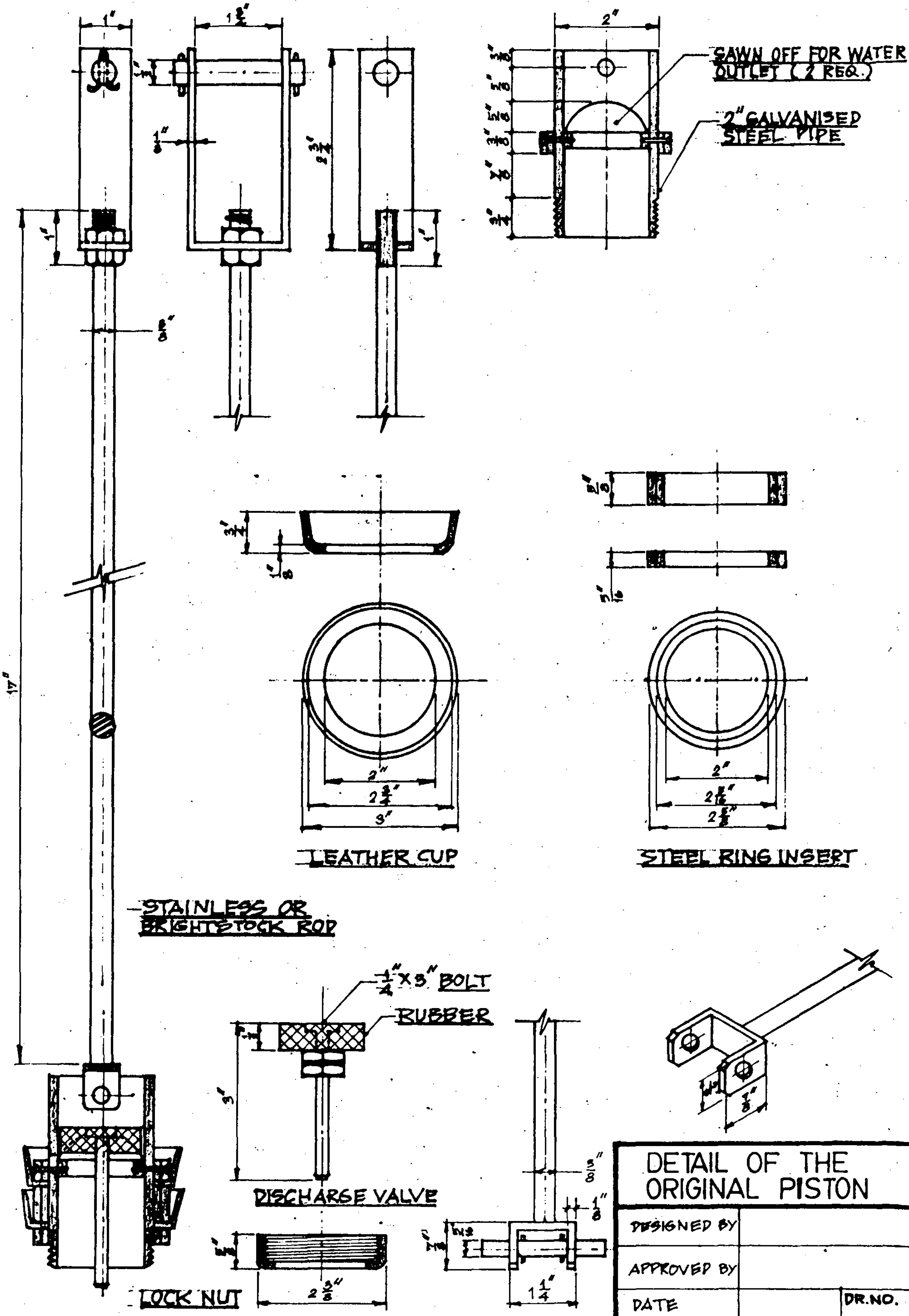


Fig.8 The modified piston after 1.2 million cycles.



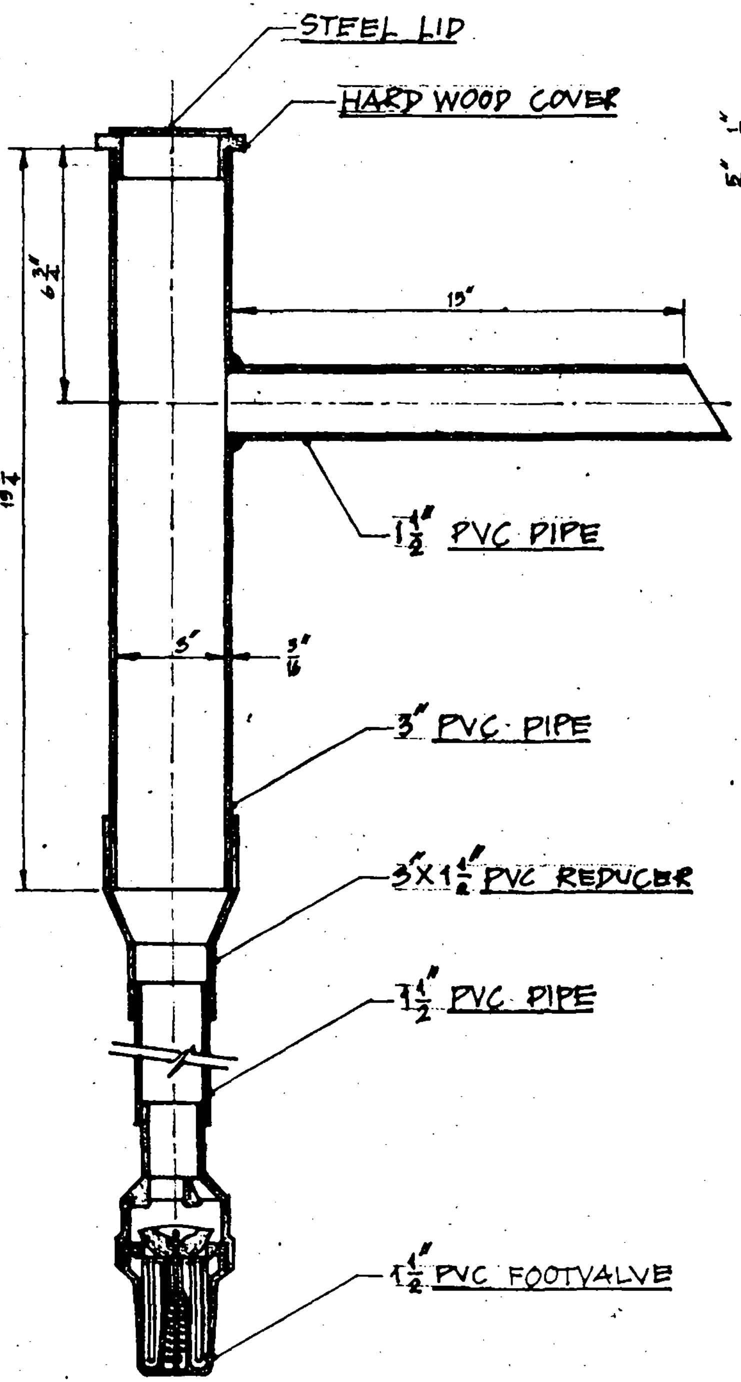
ASSEMBLY DRAWING OF THE ORIGINAL PUMP

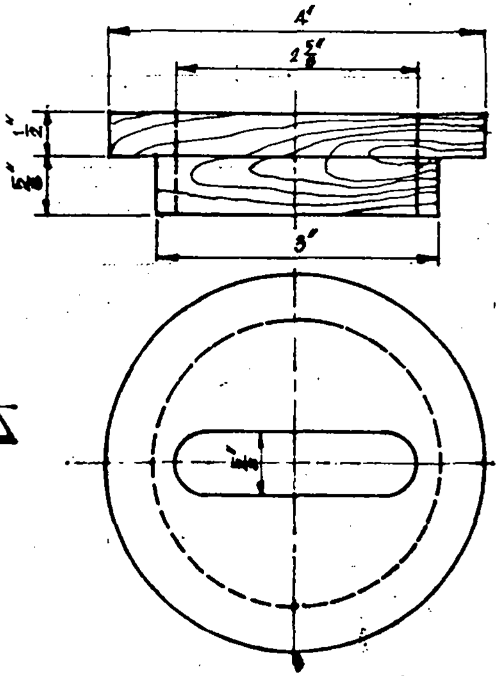
DESIGNED BY	
APPROVED BY	
DATE	DR. NO. 1



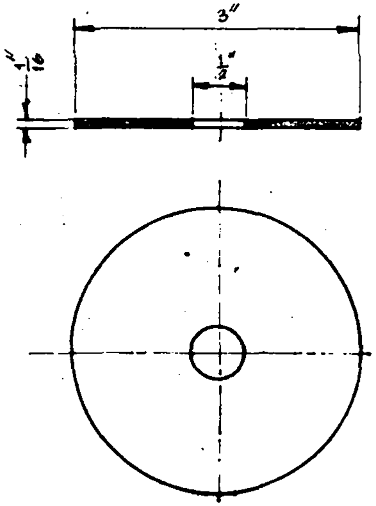
DETAIL OF THE ORIGINAL PISTON

DESIGNED BY	
APPROVED BY	
DATE	DR.NO. 2





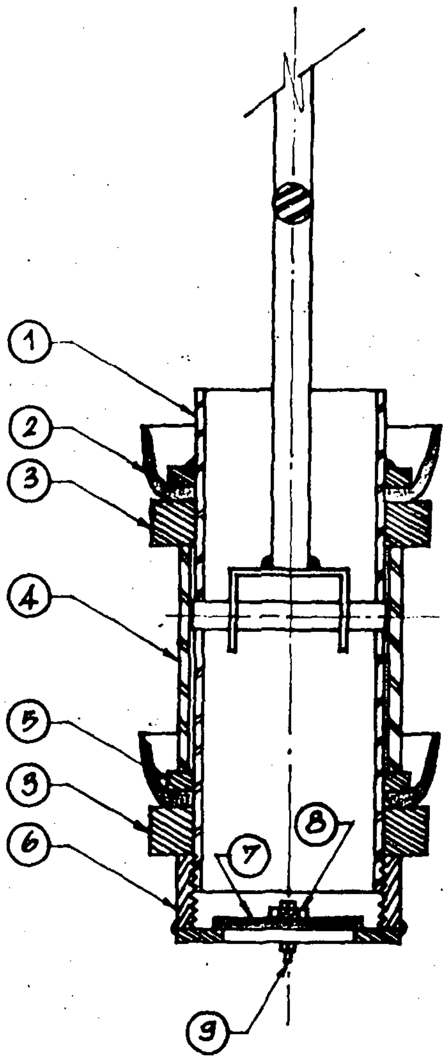
HARD WOOD COVER



STEEL LID

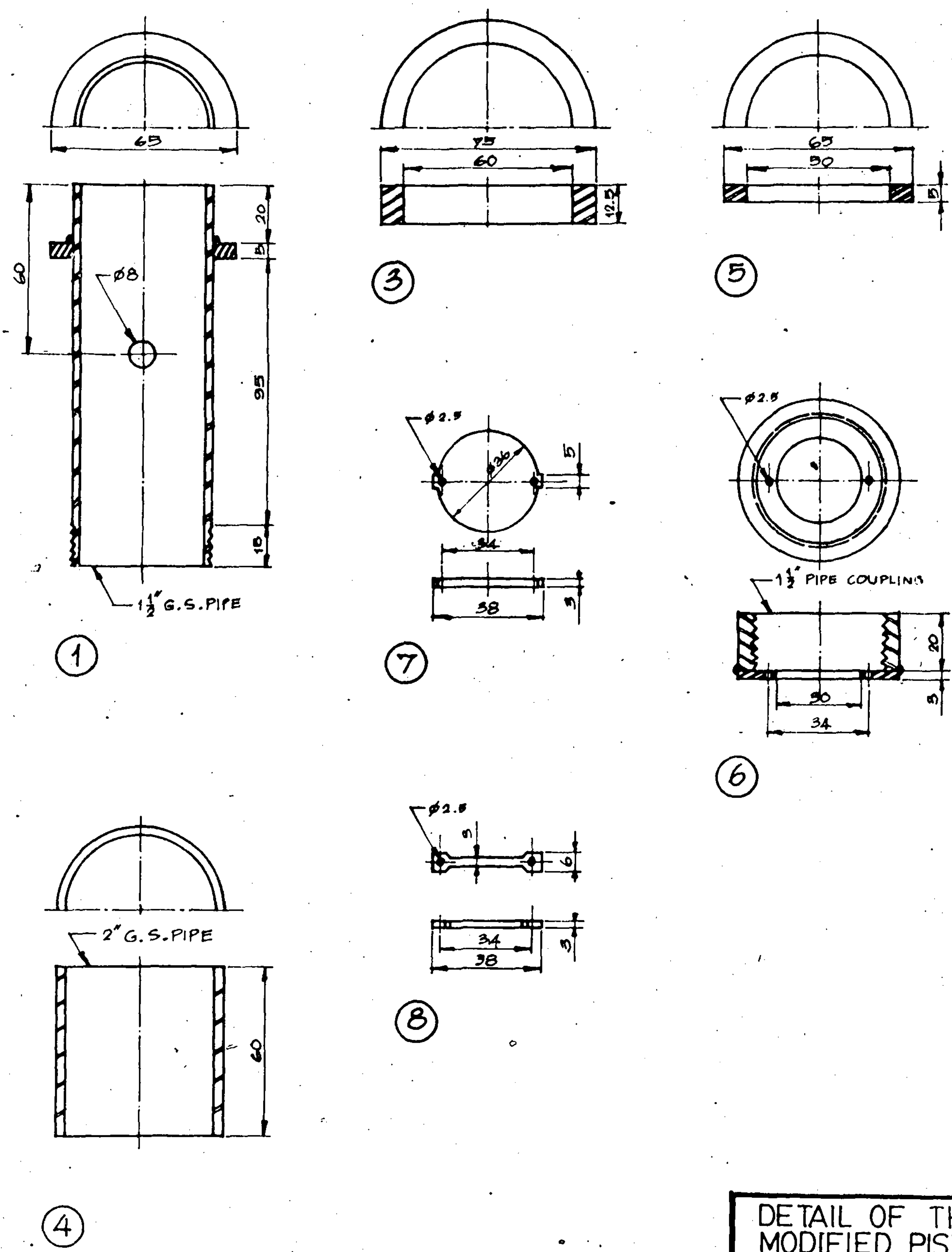
DETAIL OF THE PUMP CYLINDER	
DESIGNED BY	
APPROVED BY	
DATE	DR. NO. 3

PART NO.	DESCRIPTION	MATERIAL	QUAN.	REMARKS
1	PISTON BODY	G.S. PIPE	1	MADE FROM 1½" G.S. PIPE
2	CUP	LEATHER	2	
3	ANTIEXTRUSION RING	C.I.	2	
4	SLEEVE	G.S. PIPE	1	MADE FROM 2" G.S. PIPE
5	WASHER	C.I.	1	
6	LOCK NUT	G.S.	1	MADE FROM 1½" PIPE COUPLING
7	DISCHARGE VALVE DIAPHRAGM	SYNT. RUBBER	1	
8	DIAPHRAGM HOLDER	STEEL	1	
9	BOLT	STEEL	2	M8×1.0



ASSEMBLY DRAWING OF THE MODIFIED PISTON

DESIGNED BY			
APPROVED BY			
DATE		DR. NO.	4



DETAIL OF THE MODIFIED PISTON

DESIGNED BY			
APPROVED BY			
DATE		DR. NO.	5

5. CONCLUSION AND RECOMMENDATION

1. The original pump body is of a very good design. No modification is suggested. When fabricating the pump, care must be taken to select a superior brand of PVC pipe and fitting since the qualities of material, manufacturing and design of local PVC pipe and fitting vary drastically among various manufacturers.

2. The piston assembly should be modified as shown in drawing no 4 and 5. The leather cups are recommended since it is cheap and available throughout the country.

3. If the production volume is high enough, the supporting ring behind each cup should be changed from bronze to that of the injection molded plastic such as nylon.

4. Switching from PVC footvalve to brass footvalve may reduce the initial cost substantially providing that the brass footvalves are screened to exclude the defective ones.

5. When used in a well deeper than 4 metres, the handle with a higher mechanical advantage of 4:1 or higher with shorter piston stroke is recommended.

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3. *International Bank For Reconstruction & Development; P.U. Report no. RES 9; A Hand Pump For Rural Areas Of Developing Countries, Annex 5 & 7, October 1976.*

ACKNOWLEDGEMENT

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