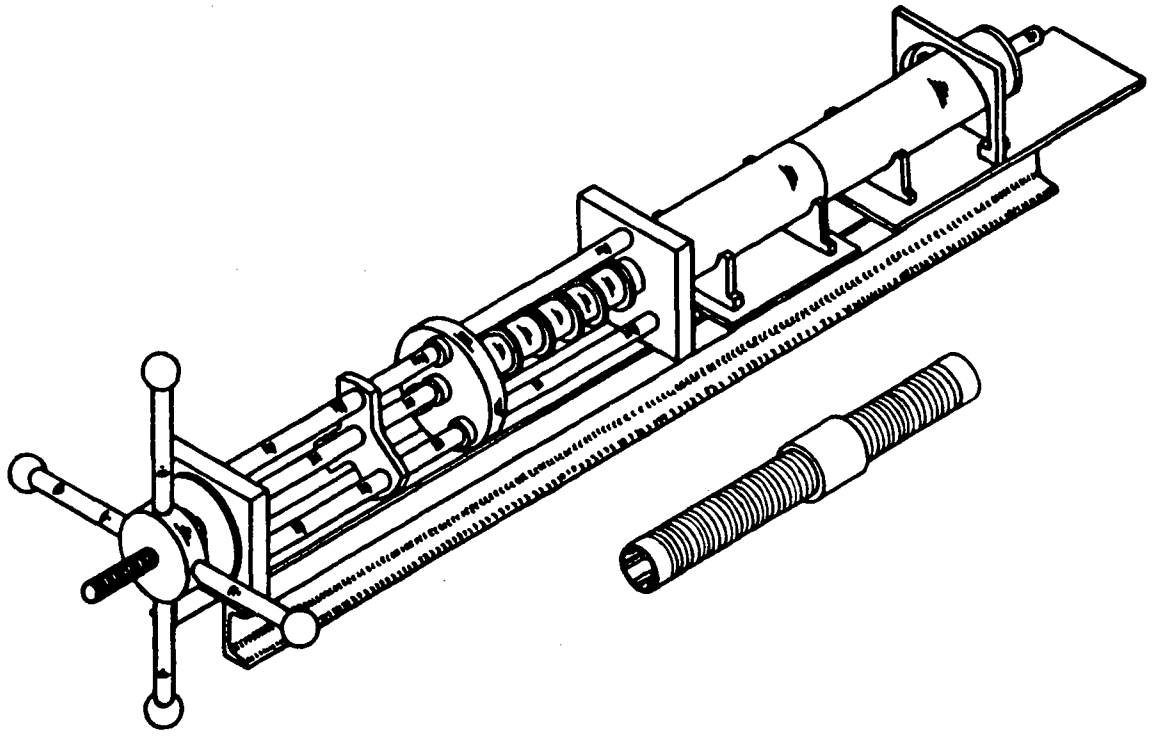
FINAL REPORT

ON THE

DEVELOPMENT OF THE

BROACHED ROBOSCREEN



AN APPROPRIATE TECHNOLOGY DEVICE

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FINAL REPORT

on the

DEVELOPMENT OF A BROACHED ROBOSCREEN

Prepared for

The U.S. Agency for International Development

by

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SUMMARY

A new technique to convert standard PVC pipe (Schedule 40) to screen for use in wells, infiltration galleries, etc., has been developed. The two-step technique employs a broaching unit (cutters) for the removal of predetermined segments of plastic material from the inner circumference of the pipe and thereby forming ribs or stiffeners. The second step is to spirally cut the broached pipe using a simple lathe.

Three broaching units (1 1/2, 2, and 3 inch) were constructed and used to manufacture 150 feet of broached screens. The cost of material and labor for manufacturing Broached Roboscreen is substantially less than that of commercially available screens. Broached Roboscreen manufacturing is labor intensive, requires low initial capital and utilizes machines that are commonly available in LDC's. This simple approach is especially applicable to the generation and development of cottage industries.

Broached Roboscreen exhibits large open area (about 25%) and is suitable for shallow well installation (less than 150 feet). Comprehensive tests to evaluate the behavior of the screen under field conditions are recommended.

INTRODUCTION

In many regions throughout the world, alluvial aquifers of great extent are used for water supply. These aquifers are composed of unconsolidated materials that range from silts, clays, and fine sand to gravel and boulders. In aquifers where fine sand is the predominant constituent, screens must be provided to prevent the sand from entering the pump. Well screen is a recognized and accepted technique to control the migration of soil particles carried by the water from the aquifer, through the various well and pump components into the discharge side of the pump.

Water will pass more freely through a screen with a large total open area than one with a small open area because of the lesser resistance to the flow. For a given discharge a large open area also ensures low entrance velocities through the screen which results in smaller head losses and lower drawdown.

Commercial screens are currently manufactured from either metal or plastics. Metal screens have a range of openings from 0.006 inches to 0.25 inches, exhibit a large open area (20 - 35%), and are rugged. Commercial metal screens are expensive (3-inch stainless steel screen costs approximately $40.00 or more per foot) and, therefore, have only limited application in LDC's. In addition, very few LDC's have capabilities of producing good quality metal screens and therefore, have to utilize foreign exchange for the purchase of metal screens.

Commercial plastic screens are less expensive than metal ones, (3 inch continuous slot ABS screen costs approximately $20.00 per foot) but also have smaller open area (8 - 10% maximum). Commercially available plastic screens are produced by either perforating a plastic pipe by cutting slots (rectangular openings of various sizes), drilling holes into it, or by winding and spot welding a continuous filament of plastic material around a set of fixed stiffeners (technique used by Johnson Screens, for example). The former is used by a number of small manufacturers and requires relatively simple production machinery. The latter requires sophisticated equipment and is produced by a few large manufacturers. Spirally wound plastic screens have the required rigidity and collapse strength for depth setting of 300 feet, but their high foreign exchange cost coupled with their relatively low open area limits their widespread use for LDC's.

Perforated or slotted screens are inexpensive, but in general, exhibit low open area (1 - 5%), i.e., open space through which water enters the screen. Because of the dificulties encountered in sawing the plastic pipe to produce the slots, the minimum slot size is about 0.05 inches. The slots are not uniform and attempt to increase the open area by providing additional slots results in a weak screen that may collapse under normal operating conditions. Perforated screens are produced by drilling holes in the plastic pipe. This type of screen has limitations on the minimum size hole, strength and intake efficiency.

A new type of PVC well screen, called extruded Roboscreen, was previously developed by Sternberg and Knight in 1978.[1] The screen is produced by slotting or cutting an extruded modified PVC pipe that includes internal strengthening ribs. The extrusion of the modified pipe, shown in Figure (1), appears to present no particular technical problems. About 500 feet of 3" diameter Roboscreen have been extruded as part of the Roboscreen development project, sponsored and funded by the World Bank. Plans are currently underway to produce Roboscreen in the Philippines, Ecuador and Tunisia. Slotting of the Roboscreen is done on a lathe equipped with a grinding head, as shown in Figure (2). Short section of Roboscreen (about one foot) are mounted on an expanding mandrel, as shown in Figure (3). The mandrel is then mounted on a lathe and a helical continuous slot is cut in the pipe wall using a small circular saw mounted on the grinding head (the circular saw replaced the grinding wheel). Extruded Roboscreen is rugged, has a large open area (approximately 25%) and appears highly competitive with PVC screens available commercially. To date, no tests have been conducted to ascertain the behavior of extruded Roboscreen under field conditions.

Many developing countries currently have their own PVC manufacturing industry, usually from imported polymer. A number of countries, primarily in

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[1] Sternberg, Y. and R. Knight. Development of PVC Well Screens for Local Febrication in Developing Countries. IBRD, Public Uitlities Department, P.U. Report No. Res. 14, April 1978.

Figure 1. EXTRUDED ROBOSCREEN

Figure 2. SLOTTING OF EXTRUDED ROBOSCREEN DONE ON A LATHE EQUIPPED WITH A GRINDING HEAD

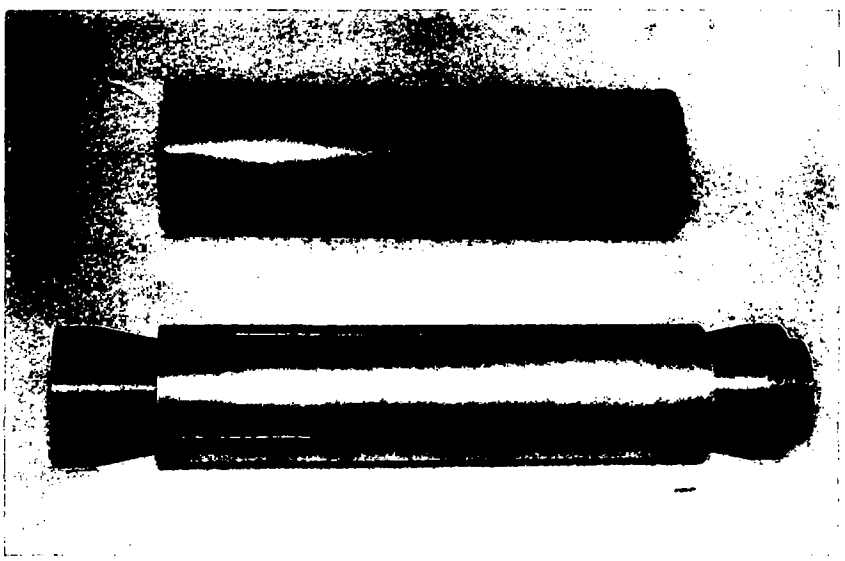


Figure 3. EXPANDING MANDREL FOR EXTRUDED ROBOSCREEN

Africa, do not have such capability as yet. If extruded Roboscreens were to be utilized in the countries not having PVC production, extruded Roboscreen would have to be imported (slotted or unslotted). Furthermore, the manufacturing of extruded Roboscreen requires the fabrication of a special extrusion die for each diameter of well screen required. The extrusion die is a device made of steel through which the molten plastic is extruded to form the desired configuration of a pipe with strengthening ribs. In countries where the demand for well screens is limited, manufacturers may be reluctant to produce extruded Roboscreen because of the costs of making the dies. The cost of unslotted extruded Roboscreen might be about twice that of standard PVC pipe of the same nominal diameter, depending on the quantities of screen required. For example, for a 3-inch nominal diameter, the addition of the strengthening ribs increases the raw material requirements by about 30%, whereas the die cost could add from 10% to over 100% depending on the number of feet of screens produced.

Thus, although extruded Roboscreen appears to be an excellent screen it is effectively limited to countries having PVC extrusion capabilities, die production capabilities, and large demand for screens. PVC pipes of various diameters are available in almost all developing countries. These pipes, domestic or imported, are primarily used to convey water. Because of its desirable physical characteristics, ease in handling and construction, and relative low cost when compared to other pipes, the use of PVC pipes in

developing countries is continuously increasing. The almost universal availability of PVC pipes has prompted the search for a technique to transform an ordinary PVC pipe into a low cost, efficient, well screen or infiltration gallery screen.

The objective of this research and development project was to develop the production technology, methodology, and associated hardware necessary for making screens from commercially available PVC pipe (Schedule 40) utilizing a broaching technique. A broach is a tool with knife edges which enlarge a given hole as the tool is pulled through the hole. Circular broaches are used to remove predetermined amounts of plastic material from the inner circumference of standard schedule 40 PVC pipe, as shown in Figure (4). The resulting configuration is a pipe with ribs or stiffeners. The slotting operations of the broached pipe require the use of simple and commonly available equipment in most LDC's. Typical installations of broached Roboscreen are given in Appendix II.

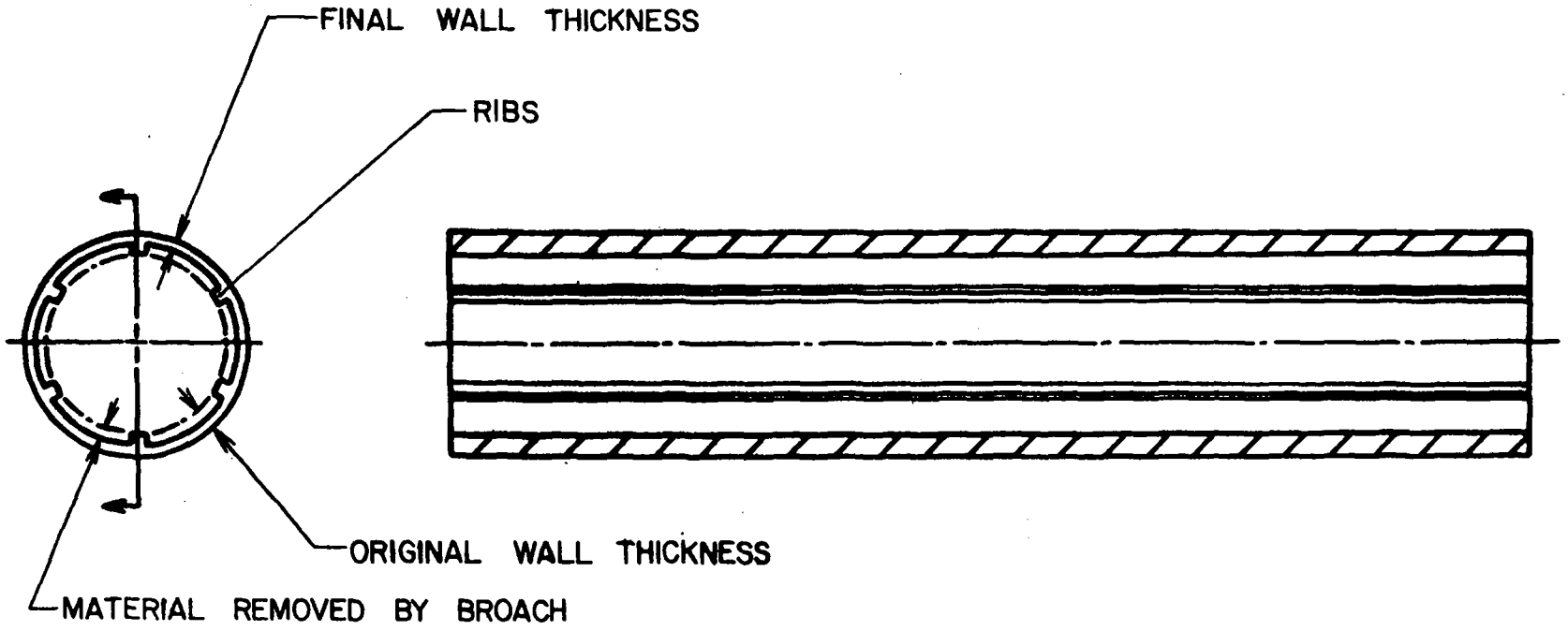


Figure 4. BROACHED ROBOSCREEN SECTION

INITIAL DEVELOPMENT

The most common technique of converting a standard PVC pipe to a screen is by slotting. Various slotting techniques and tools have been used in order to achieve a rugged screen with large open area. Experience has shown that increasing the open area above 5% (by drilling holes or cutting slots with a saw) decreases the strength of the screen. The methodology developed in this project is based on decreasing the side wall thickness in selected areas while keeping the originial size intact in others. This process results in a section shown in Figure (4) with internal ribs or stiffeners whose thickness is the same as the original side wall of the pipe.

Experience gained from development of the extruded Roboscreen indicated that the function of the ribs is: (1) to provide strength to the pipe section, and (2) to hold the resulting helical rings in place. The apparant collapse resistance of the broached Roboscreen (its resistance to external horizantal loads which may crush the screen) is derived from the strength characteristics of the individual helical rings.

Initially, a ten-inch length of 3" PVC was machined to produce the cross section shown in Figure (4). The Pipe segment was securely placed in the chuck of a lathe and a narrow tool mounted on the tail stock was used to remove plastic material from the inner circumference of the pipe. When the desired amount was removed (about 0.070 inch) the pipe segment was rotated and the above operation repeated. At six locations spaced 60^{o} no material

was removed and these formed the ribs. This machining was a time consuming and painstaking process. It did, however, prove that an ordinary piece of PVC pipe can be transformed into a good well screen using the slotting technique developed for the Roboscreen. No detailed laboratory testing was done on the initial 3" sample because of the difficulties encountered in broaching a pipe without a proper circular broach. It was concluded that the thrust of the development work should be directed toward developing a broaching technique which is simple, inexpensive, and suitable for cottage industry in medium to large size communities.

Discussions with representatives of various international organizations confirmed that PVC pipe is available in almost all LDC's. Samples obtained from a number of manufacturers indicate that the gage or side wall thickness of PVC pipe produced in LDC's is somewhat lighter than standard (Schedule 40). The extrusion, however, was generally good with concentricity between the outside diameter and bore equal to, or better than, PVC pipe produced by various manufacturers in this country. The concentricity issue (or how close are the internal and external diameters to perfect circles) is important because broaching a non-concentric pipe using simple devices is an extremely difficult task. Specification for the schedule 40 PVC pipes used in this study are given in Table I.

Development of the Broached Roboscreen was viewed as a two-phase operation; the first phase was the development of the broach and associated

TABLE 1

ASTM Standards D/785-73 for PVC Plastic Pipe
Schedule 40, Inches

Nominal Pipe Size	Outside Diameter	Minimum Wall Thickness	Tolerance
1 1/2	1.900	0.145	+ 0.020
2	2.375	0.154	+ 0.020
3	3.500	0.216	+ 0.026

hardware for the removal of predetermined segments of plastic from the inner circumference of the pipe and thereby forming ribs or stiffeners. The second phase was slotting the broached pipe to form a screen. Since the slotting operation using a circular saw was developed in an earlier project, the major emphasis was to develop the technology for broaching.

EXPERIMENTAL WORK

During the early stages of the development work, it was envisioned that the necessary equipment for broaching the PVC pipe would consist of: (1) a support frame that holds the work piece (pipe segment) and provides the required guide for the broach, and (2) a broach with two or more cutters as required powered by a hydraulic jack. A hydraulic jack is a device which permits a small force applied to a small piston to produce through fluid pressure a large force on a large piston. Hydraulic jacks are commonly used to lift cars, are manually operated, and are widely available in developing countries. The broaching operation included loading the work piece into the support frame and driving the broach one complete stroke using the hydraulic jack as a power source.

Broach Development

The purpose of the broach is to remove segments of PVC material from the inner circumference of the pipe leaving intact selected areas which act as ribs or stiffeners. Preliminary theoretical calculations, summarized in Table 2, suggested that 0.070 inches of material removed will form ribs of sufficient strength. A number of options were investigated and tested prior to the selection of the present broach. Initially, broaching was attempted using two broaches (cutters), each designed to remove 0.035 inch cut. The force needed to broach 1 1/2 inch diameter PVC using the above two cutters was 2,000 lbs.

TABLE 2

Theoretical Collapse Pressure of
Broached Roboscreen

Nominal Pipe Size, in	Outside Diameter, in	Average Wall thickness, in.	d/t	Collapse Pressure Pc, psi
1½	1.900	0.095	20.00	136.8
2	2.375	0.100	23.75	80.4
3	3.500	0.150	23.33	84.9

Note: theoretical collapse pressure analysis based on the following ASTM Standard F 480-77 equation.

$$Pc = \frac{2E}{(1-\mu^2)(d/t)(d/t-1)^2}$$

Where: Pc = Collapse pressure, psi
E = Elastic modulus=(440,000 psi)
μ = Poisson's Ratio (0.33)
d = Outside diameter, in.
t = Wall thickness, in.

A hydraulic jack was used to push the broaches, but keeping the broaches concentric was difficult. Also, a total travel length of about 16 inches was required (12-inch sample plus 2 inches for each cutter and spacer), a distance which exceeds the travel of most common hydraulic jacks. Broaching using the jack included pushing the broaches the full length of travel of the jack, lowering it and inserting extensions, and reapplying the load. Specimens obtained in this fashion were of poor quality. The depth of ribs and cuts were uneven due to the noncontinuous motion of the broach pushed by the hydraulic jack piston.

It was concluded that a cut of 0.035 inches was probably too heavy and should be limited to not more than 0.015 inches. Increasing the number of cutters to five or six with approximately one inch space between cutters made the broach about 23 inches long. Attempts to broach samples using a hydraulic jack by pushing the long broach were not successful. Attempts were made to secure a pull hydraulic jack of sufficient load capability, but this avenue was not fruitful because such jacks are not common in LDC's; their cost is relatively high, and the availability of spare parts was judged inadequate.

The experimental phase during which the hydraulic jack concept was used suggested that pulling the broach rather than pushing it would alleviate the concentricity problem (i.e., uneven cuts encountered heretofore). A number of devices for pulling the broach were fabricated and tested prior to the

selected device shown in Figure (5). The broaching mechanism consists of a broach and a loading frame that holds the work piece in place. The broach consists of 5 cutters (6 for the 3-inch diameter pipe) and spacers mounted on a shaft. The configuration of a cutter, derived from experimentation, is shown in Figure (6). The shaft assembly is connected to a threaded rod equipped with a large nut and handles as shown in Figure (7). The loading frame that holds the work piece is shown in Figure (8). The frame consists of a base, two end plates, three guides and a floating support disk equipped with ball bushings that travel along the three guides. The materials used in the construction were aluminum, mild steel, and tool steel. The cost of materials for the construction of 1 1/2 inch (A), 2-inch (B), and 3-inch (C) broaching units are given in Table 3.

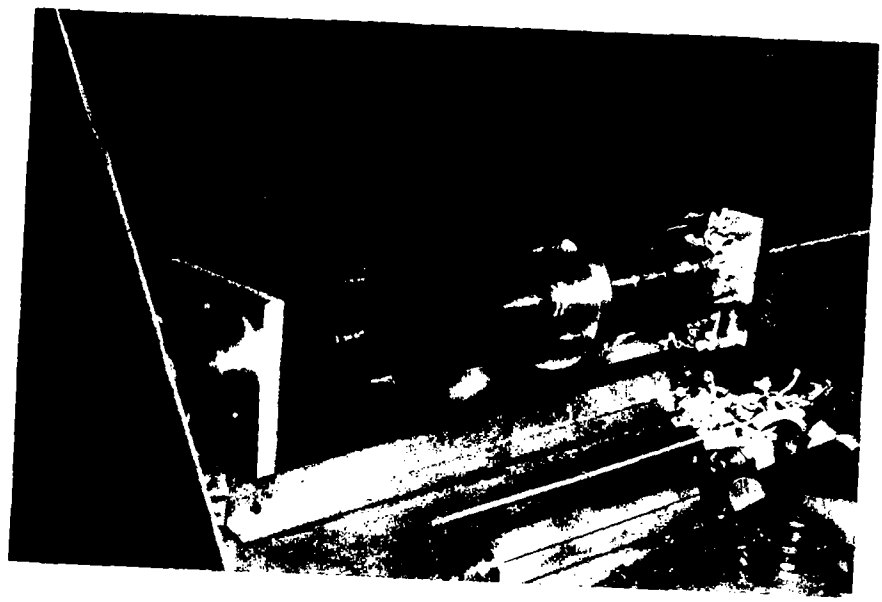


Figure 5. BROACHING DEVICE (3")

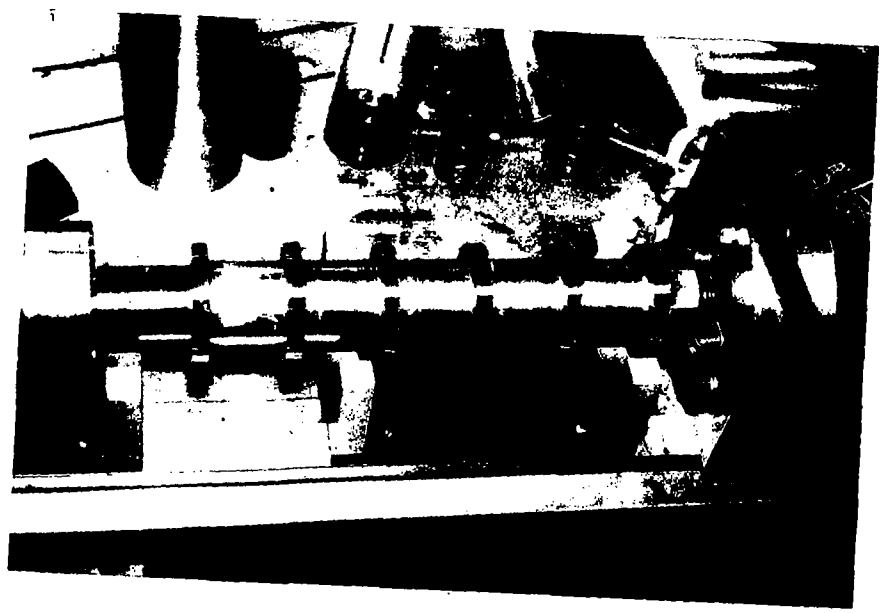


Figure 6. CUTTERS CONFIGURATION OF BROACHING DEVICE

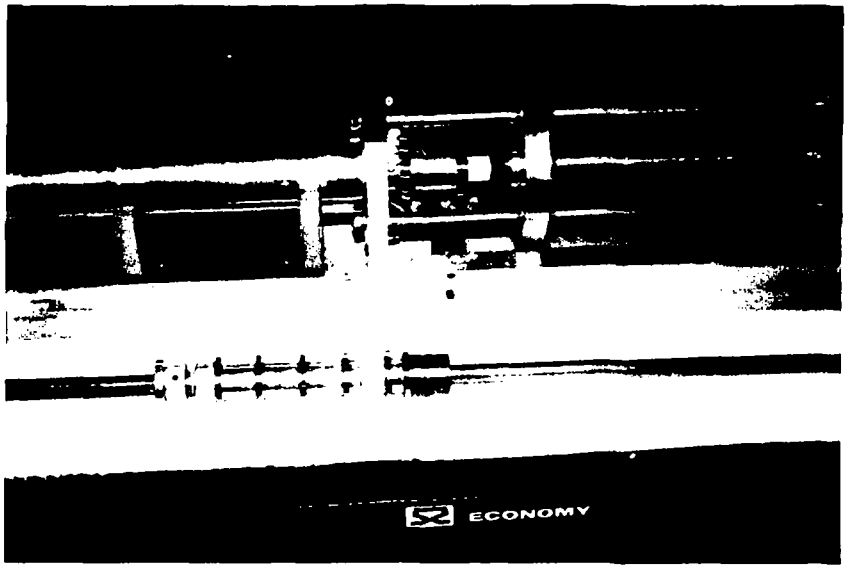


Figure 7. LEAD SCREW CONNECTED TO SHAFT ASSEMBLY

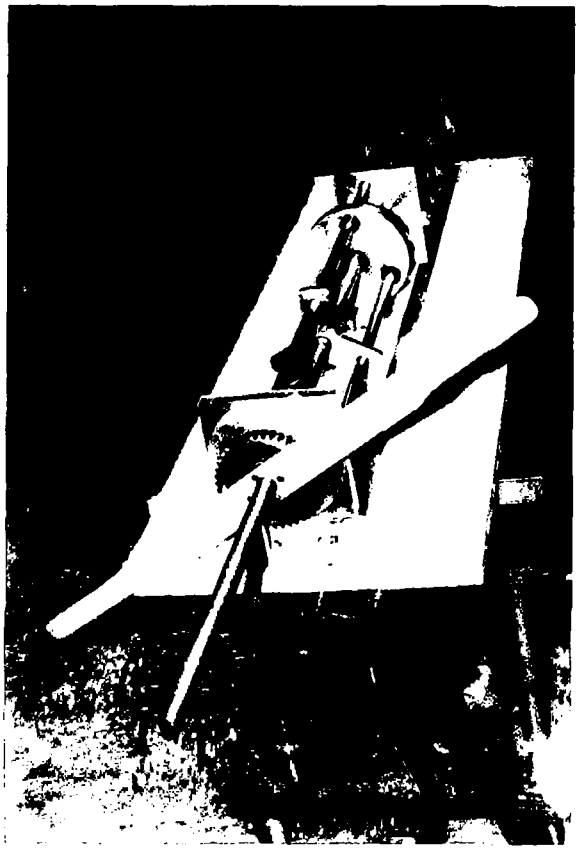


Figure 8. BROACHING DEVICE LOADING FRAME AND HANDLE

TABLE 3

Materials Cost and Labor Requirement for the Manufacture of the 1 1/2", 2" and 3" Broaching Devices

Part name and number (Appendix I)	Description of material	1 1/2" (A)			2" (B)			3" (C)		
		material required	material cost (total)	labor hours	material required	material cost (fotal)	labor hours	material required	material cost (total)	labor hours
load frame guides (2)	mild steel round stock	28"x3/4"	8.92	2	28"x3/4" (3 pieces)	8.92	2	34"x3/4" (3 pieces)	10.83	2
load frame (3 and 4)	Aluminum structural channel	110"	31.37	4	110"	31.37	4	120"	34.22	4
Cradle base plate (5&6)	Aluminum plate	25"x6"x 1/2"	24.41	3	25"x6"x 1/2"	24.41	3	25"x6"x 1/2"	24.41	3
Sleeve clamp (7)	Aluminum plate	5"x6"x 1/2"	4.88	2	5"x6"x 1/2"	4.88	2	6"x6"x 1/2"	5.85	2
cradle (8)	Aluminum plate	5"x2 1/2" x1/2" (4 pieces)	7.16	3	5"x2 1/2" x1/2" (4 pieces)	7.16	3	5"x3"x 1/2" (4 pieces)	9.76	3
breech (9)	Aluminum round stock	3"x12"	27.55	4	3"x12"	27.55	4	4"x12"	49.00	5
Bearing support sleeve (10)	Aluminum round stock	3"x12"	27.55	4	3"x12"	27.55	4	4"x12"	49.00	5
Bearing housing (11)	Aluminum round stock	3"x1"	2.29	2	3"x1"	2.29	2	4"x1"	4.08	3
Bronze bush (12)	Bronze round stock	1"x3/4"	0.25	0.5	1"x3/4"	0.25	0.5	1 1/4"x 3/4"	0.29	0.5
Ball Bushing (13	Thomson A-122026 Thomson B-162536	4 0	27.00	-	4 0	27.00	-	3 1	20.25	-
Front end plate (15)	Aluminum plate	6"x6"x1"	11.71	4	6"x6"x1"	11.71	4	7"x7"x1"	15.94	5

Rear end plate (14)	Aluminum plate	6"x6"x1"	11.71	4	6"x6"x1"	11.71	4	7"x7"x1"	15.94	5
Anti rotation plate	Aluminum plate	6"x6"x 1/2"	5.85	2	6"x6"x 1/2"	5.85	2	6 1/2"x 6 1/2"x 1/2"	6.87	2
floating support disc	Aluminum plate	6"x6"x1"	11.71	3	6"x6"x1"	11.71	3	7"x7"x1"	15.94	3
Broach arbor (18)	mild steel round stock	52"x3/4"	5.52	5	52"x3/4"	5.52	5	59"x3/4"	6.26	6
Cutters (19-23)	high speed steel round stock	1 3/4"x 1 3/4" (5 cutters)	4.44	15	2 1/2"x 1 3/4" (5 cutters)	7.35	15	3 1/4"x 3" (6 cutters)	26.29	20
Scraper (24)	Aluminum round stock	-			2 1/8"x 1/4"	0.37	0.5	-		
Leader (25)	Aluminum round stock	2"x 1/2"	0.51	0.5	2"x1/2"	0.51	0.5	2"x3/4"	0.76	0.5
Spacers (26 & 27)	Aluminum round stock	1 1/2"x 1 1/2" (4 required)	2.19	2	1 1/2"x 1 1/2" (4 required)	2.19	2	2 1/4"x2" (5 required)	3.12	2.5
Handle (29-31	mild steel bronze	65"x1" 4"x4"x 1 1/4"	48.01	2	65"x1" 4"x4"x 1 1/4"	48.01	2	65"x1" 4"x4"x 1 1/4"	48.01	2
Mandrel's sleeve (34)	Aluminum round stock	1 3/4"x 12"	9.39	5	2 1/4"x 12"	15.50	5.5	3 1/8"x 12"	21.32	6.0
Expander (32)	mild steel and aluminum round	15"x1/2" 2"x6"	0.70 6.12	1 4	15"x1/2" 2"x6"	0.70 6.12	1 4.5	15"x1/2" 2 1/2"x6"	0.70 9.57	1 5
Thrust Bearing (33)	EW-1-1/2 (Thomson)		8.32			8.32			8.32	
Misc. fasters & assembly			10.00	8		10.00	10		10.00	12
	TOTAL		$304.06	80		$313.45	83.5		$403.23	97.5

Note: The following unit costs were used to determine the cost of materials:

Mild steel round stock	-	$.85/lb.
Aluminum plate	-	$3.32/lb.
Aluminum channel	-	$3.42/ft.
Tool steel	-	$3.73/lb.

RESEARCH RESULTS

Three broaching units were constructed and used to broach 50 feet each of 1 1/2", 2", and 3" diameter PVC schedule 40 pipe. Specifications for the broached screen manufactured are given in Table 4. The 1 1/2" unit was the first unit constructed following the experimental phase of the investigation. The length of the work pieces is 12 inches (one foot), and it takes approximately 20 minutes for an individual to broach the above piece of pipe. Turning the handle which advances the cutters through the pipe is not difficult. The long handles permit two individuals to work in unison thereby speeding the broaching process. Broaching can also be performed by using an external power source such as an electric motor. Loading of the broaching fixture is quite simple; a piece of PVC schedule 40 pipe, 12 inches long, is inserted into the breech or pipe holder, as shown in Figure (9). The cutters are positioned so that the first cutter just touches the work piece. The broach arbor is then coupled to the lead screw. The rear bearing is installed and clamped. The handle and nut assembly is mounted on the lead screw and broaching commences by turning the handle in a clockwise direction. When the last cutter emerges from the pipe the unit is dissembled in a reverse order and another piece is inserted for broaching. The time required for unloading the completed piece, reloading the broach and resume broaching is about 5 minutes.

The broaching units for the 2-inch and 3-inch diameter pipes are similar to the 1 1/2-inch model. The width of the cutters, cutter configuration, and

TABLE 4

Specification for Manufactured Broached Roboscreen, inches

Nominal Pipe Size	Average wall thickness		Average rib dimensions	
	before broaching	after broaching	depth	width
1½	0.155	0.095	0.060	0.25
2	0.165	0.100	0.065	0.25
3	0.225	0.150	0.075	0.25

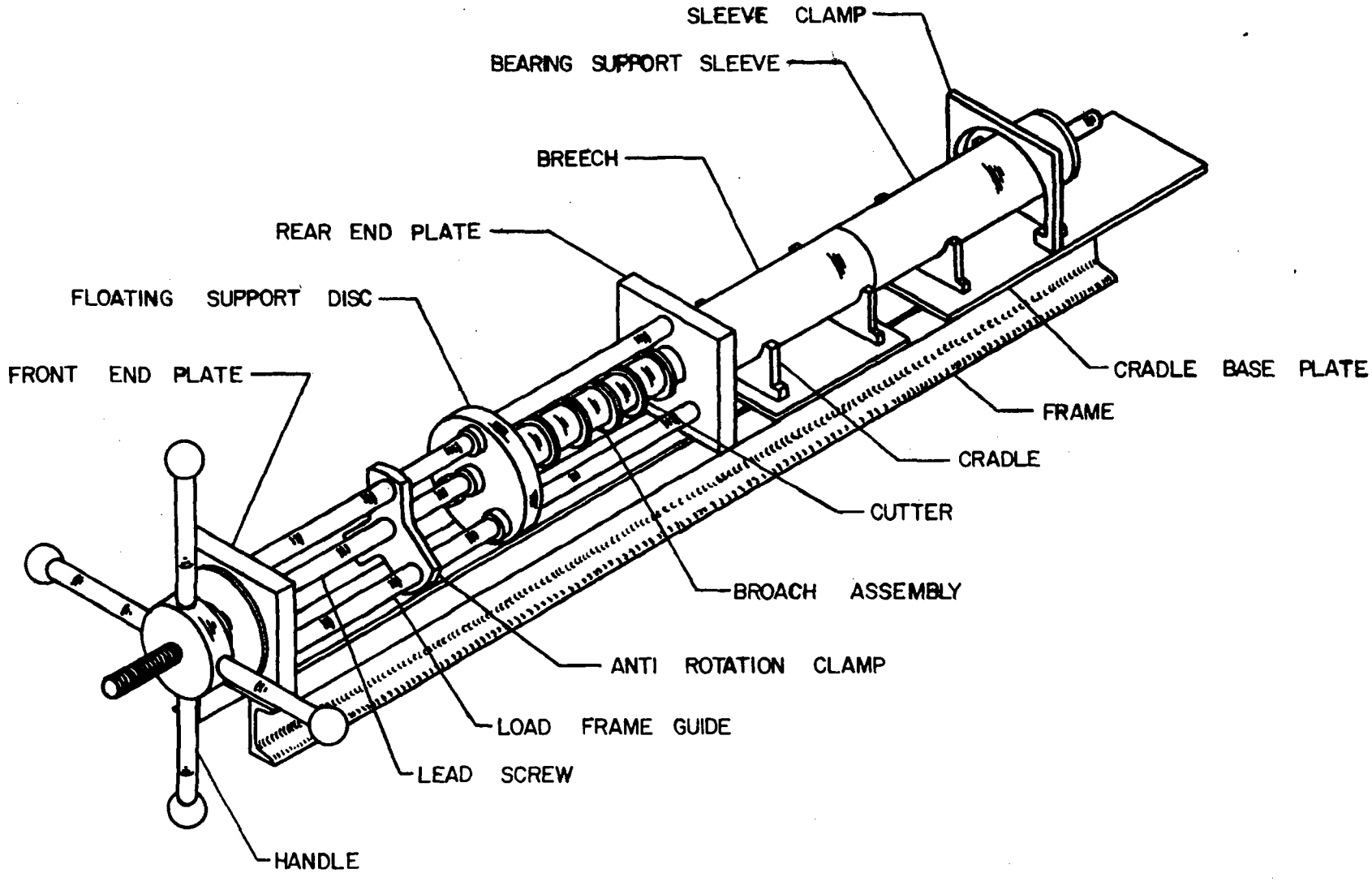


Figure 9. SCHEMATIC DIAGRAM OF BROACHING DEVICE

distance between cutters for the three models vary slightly. Also, the 3-inch model has six cutters, while only five cutters are employed in the other two models.

Each broaching unit was used to broach fifty feet of PVC schedule 40 pipe in one-foot segments. The size of the work pieces was arrived at following an experimental phase. Shorter pieces were easier to broach, but considered impractical for field installation. Larger pieces are probably more suitable for field work, but would require a more complicated device due to the longer broach required. Therefore, the one-foot long work piece was selected as the desired length. Construction drawings for all three broaches are given in Appendix I. The detailed drawing in Appendix I should be sufficient to construct the desired broaching unit.

The recommended construction steps are:

1. Determine the broaching unit size desired and consult the drawings in Appendix I.

2. Secure the required materials.

3. Machine parts and fabricate loading frame.

4. Machine parts for broaching tool. Cutters should be rough turned to plus 0.030" in diameter. After hardening to 60-64 Rockwell (C-Scale), cutters should be ground parallel then mounted on the broach arbor for finish grinding on the O.D.

5. The only other point which may not be self-explanatory from the drawings is the leader and scraper guides which help to keep the cutters axial with relation to the bore of the PVC. The guides should be made of some soft material such as aluminum and have a diameter of 0.010"-0.020" less than the inside diameter of the extruded pipe to be broached.

Slotting Procedure

The technique for slotting the screen has been developed by trial and error during the development work of the Roboscreen. Particular points of interest are:

Equipment Needs - The lathe and grinding head are unsophisticated and commonly available in developing countries. The expanding mandrel is available or can be easily fabricated from the drawing given in Appendix 1.

Only the slitting saws may need to be imported. The slitting saws used in this study are manufactured by Brown and Sharpe, and cost approximately $9.00 per saw (0.020 inch).

Cooling Methods - PVC has a low melting point (about 275-300°F) and the work piece needs to be cooled. Air-cooled (by means of and air hose attached to a household vacuum cleaner) was found to be a satisfactory, and far less messy, than water-or-oil-cooling. The air-cooled system is shown in Figure (10).

Slitting Saws - The saw blades used were high speed steel, 2 3/4" diameter, with thicknesses of 0.020". It was found that high speed sawing or the use of blades with too many teeth, were unsatisfactory. The cutting speed of 2,000 RPM was adopted and saws with no more than 32 teeth are recommended. Care must be taken to align the saw exactly with the helix angle, to prevent frictional heating against the side of the slot.

Work Piece Feed Rate - The workpiece feed rates should not exceed 6 to 8 surface feet per minute. On many lathes, which are not geared down to this speed, this means that the workpiece will have to be advanced manually.

Equipment Required

- One engine lathe (a 9" South Bend is currently being used).
- One grinding head compatible with the lathe.
- A selection of slitting saws to match the desired slot widths

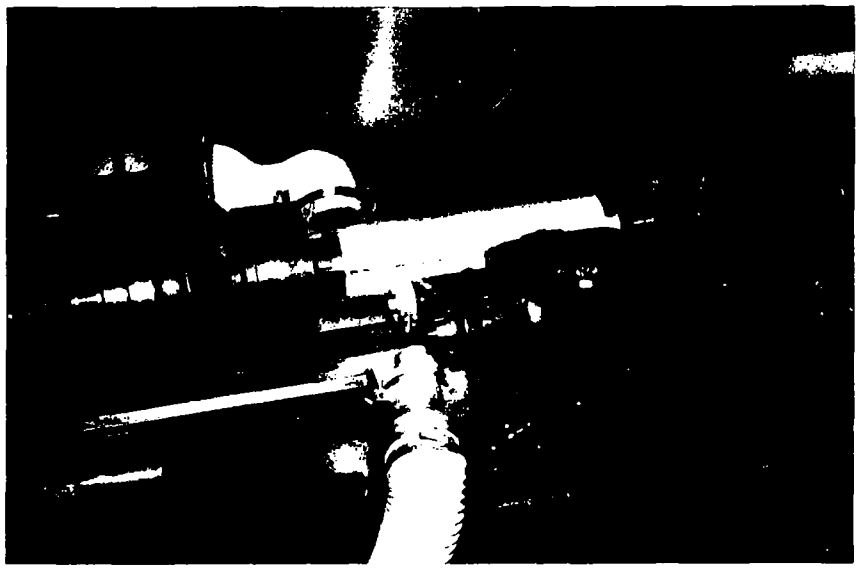


Figure 10. SLOTTING OF BROACHED ROBOSCREEN SHOWING HOSES FOR AIR COOLING

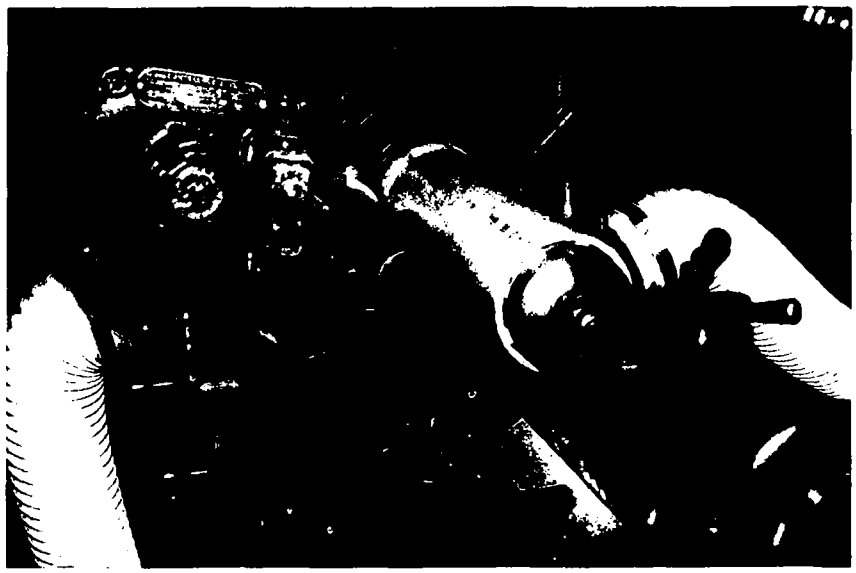


Figure 11. BROACHED ROBOSCREEN MOUNTED ON MANDREL DURING SLOTTING OPERATION

- Expanding mandrel, of suitable sixe. (See Appendix I parts 32 and 34).

Lathe Preparation

Remove tool post and install the grinding head. Substitute a slitting saw of the correct thickness for the grinding wheel. Select the required pitch (slots per inch) and pre-set the leadscrew accordingly.

Operation

The workpiece, which is a 12" length of broached PVC pipe, is mounted on the mandrel, shown in Figure (11). Location is at the crowns of the stiffeners. This ensures concentricity and provides ample clearance for the slitting saw to cut through the side wall of the pipe. The workpiece and mandrel is now supported between the lathe centers ready for slotting. The grinding head, complete with slitting saw, is now set at the starting position. Now switch on the grinding head and feed the cutter into full depth, i.e., until the saw cuts through the side wall of the pipe. Start the lathe and the air cooling system. As the mandrel and pipe revolve, the grinding head will traverse the length of the work piece. Shut off the lathe when saw reaches about one-inch from end of pipe (total slotted section in a 12-inch section is about 10 inches). Now withdraw the cutter and remove the mandrel. Separate the work piece from the mandrel. This completes the slotting operation. The time required to remove the completed screen, insert a new broached pipe in the lathe, and resume cutting, is about 5 minutes.

Using these techniques, it has been found possible to slot the screen satisfactorily with slots as fine as 0.018 inches, and as wide as 0.032 inches (wider slots appear to present no problem; the width shown was the maximum blade thickness readily available). The lathe is set so that the land (material remaining between the slots) is about twice the slot width; the screen therefore has a theoretical open area of 33%. At present, it is impractical to machine screen lengths longer than 12 inches; in the field these lengths would be joined by solvent-welded (PVC cement) couplings to make up the total screen length required. Use of one 2-inch wide coupling for each 12-inch length of screen reduces the available open area to about 25 percent. This is still 2.5 to 3 times the open area available on commercial PVC screens.

The complete slotting process for each 12-inch length takes about 15-20 minutes. All the screens needed for a typical well/hand pump installation could therefore be made in about one hour. This suggests that a further advantage of the broached Roboscreen may be that the slot openings can be precisely tailored to the actual aquifer conditions found during well sinking, rather than relying on pre-specified material. The cost of labor for manufacturing various quantities of broached Roboscreen are given in Tables 5, 6, and 7.

TABLE 5

Labor Cost for Manufacturing Broached Robocreen
1½ inch Diameter

labor cost per hour, dollars	Feet of Screen				
	100	500	1000	2000	10,000
$.10	4.50	22.50	45.00	90.00	450.00
.25	11.25	56.25	112.50	225.00	1,125.00
.50	22.50	112.50	225.00	450.00	2,250.00
.75	33.75	168.75	337.50	675.00	3,375.00
1.00	45.00	225.00	450.00	900.00	4,500.00

Note: Labor costs do not include equipment, pvc pipe and coupling. Estimated total time for broaching and slotting one foot of screen including reloading and loading broach and lathe is 0.45 man-hours.

TABLE 6

Labor Cost for Manufacturing Broached Roboscreen
2 inch Diameter

labor cost per hour, dollars	Feet of Screen				
	100	500	1000	2000	10,000
$ .10	5.00	25.00	50.00	100.00	500.00
.25	12.50	62.50	125.00	250.00	1,250.00
.50	25.00	125.00	250.00	500.00	2,500.00
.75	37.50	187.50	375.00	750.00	3,750.00
1.00	50.00	250.00	500.00	1000.00	5,000.00

Note: Labor costs do not include equipment, pvc pipe, and coupling. Estimated total time for broaching and slotting one foot of screen including reloading and loading broach and lathe is 0.50 man-hours.

TABLE 7

Labor Cost for Manufacturing Broached Roboscreen
3 inch Diameter

labor cost per hour, dollars	Feet of Screen				
	100	500	1000	2000	10,000
$.10	6.00	30.00	60.00	120.00	600.00
.25	15.00	25.00	150.00	300.00	1,500.00
.50	30.00	150.00	500.00	1,000.00	3,000.00
.75	45.00	225.00	450.00	900.00	4,500.00
1.00	60.00	300.00	600.00	1,200.00	6,000.00

Note: Labor costs do not include equipment, pvc pipe, and couplings. Estimated total time for broaching and slotting one foot of screen including reloading and loading broach and lathe is 0.60 man-hours.

FIELD TESTING OF BROACHED ROBOSCREEN, BROACHING DEVICE, AND METHODOLOGY

Broached Roboscreen has not been subjected to any field testing as yet. A comprehensive field testing program should be undertaken in order to:

(a) determine its strength characteristics in comparison to that of commercially available screens.

(b) investigate its hydraulic and filtering efficiency under field conditions.

(c) evaluate its acceptability by LDC consumers.

(d) work with interested national governments to stimulate production of broached Roboscreen in LDC's.

In order to obtain maximum information from the proposed field testing, the following program is suggested:

(a) select a total of five LDC sites for broached Roboscreen testing; preferably the sites should have diverse acquifer characteristics and depth to ground water. Locally, each selected LDC site should manufacture the necessary length of screen with the appropriate slot size.

(b) the team that developed the broached Roboscreen will visit each site and extend technical assistance to interested parties on manufacturing of the screen to include manufacturing of broach and broaching methodology.

(c) the team will instruct the LDC implementing organizations on the installation and monitoring of broached Roboscreen. The type of data required, collection frequency, data forms, etc., will be worked out with the implementing organizations. Data will be forwarded to the implementing organizations in the LDC's on a regular basis. Review and analysis of the data will be jointly done by the implementing organizations and the team. Periodic technical assistance visits by the team to the various sites are recommended as appropriate to monitor adaptation requirements.

(d) modification and adaptation, if necessary, will be proposed by the team in cooperation with the LDC implementing organizations. At the end of the field testing program, some of the broached Roboscreens will be removed, checked, and reinstalled. A final design version of the broach and associated hardware will be distributed to interested national governments and water resources development agencies. Field testing will occur over a period of three years.

CONCLUSION AND RECOMMENDATIONS

A screen for use in wells and infiltration galleries can be successfully produced from PVC pipe (Schedule 40) using the broaching technique developed. The broaching device is constructed from mild steel and aluminum. Detailed drawings for the construction of a broach are provided. The broaching process can be performed manually by unskilled labor, or by an external power source (electric motor). Unskilled labor will require a training period of only a few hours. The slotting process requires a lathe, grinding head, and slitting saws. The broached Roboscreen is easy to produce, is rugged, inexpensive, and exhibits an open area of approximately 20 to 25%.

A total of 150 feet of broached Roboscreen, 50 feet each of 1 1/2", 2", and 3" internal diameter, have been produced to test the broaching device and technique. Manual broaching presented no particular problems, and 1-foot pipe sections can be broached by one or two individuals in about 20 minutes.

The following recommendations are presented in order to transfer the technology developed to LDC's:

1. The methodology for producing broach Roboscreen and the equipment developed should be transferred to several LDC's to stimulate local manufacture and testing of the screens under field conditions.

2. The 150-feet of broached Roboscreen produced under this contract should be sent to the field for limited preliminary user acceptance studies.

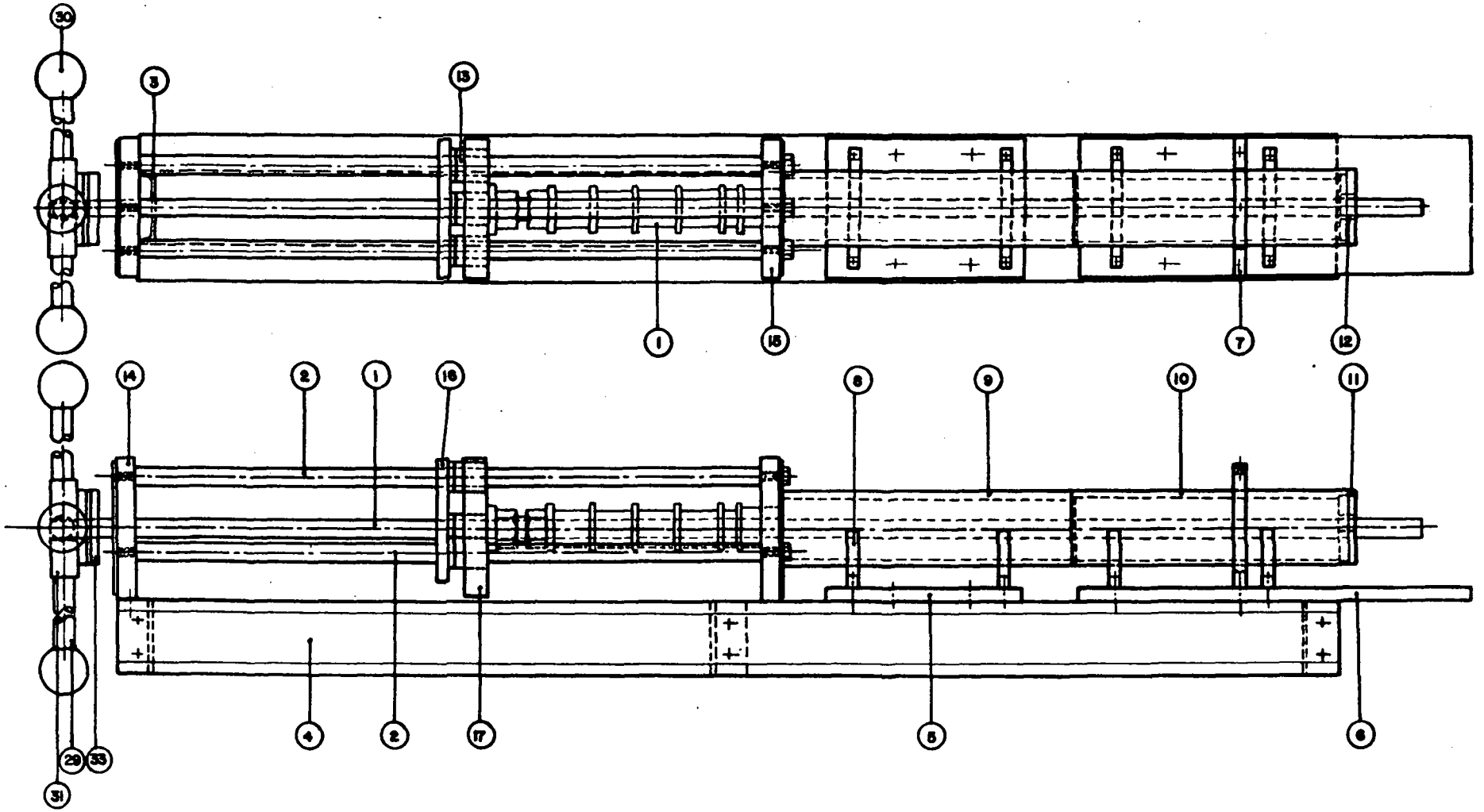
3. U.S.A.I.D. should enter into information dissemination of this appropriate technology device to other United States, private and international organizations involved in technology transfer in the area of water supply.

4. Further optimization studies (laboratory and field) should be considered depending upon preliminary user acceptance field studies.

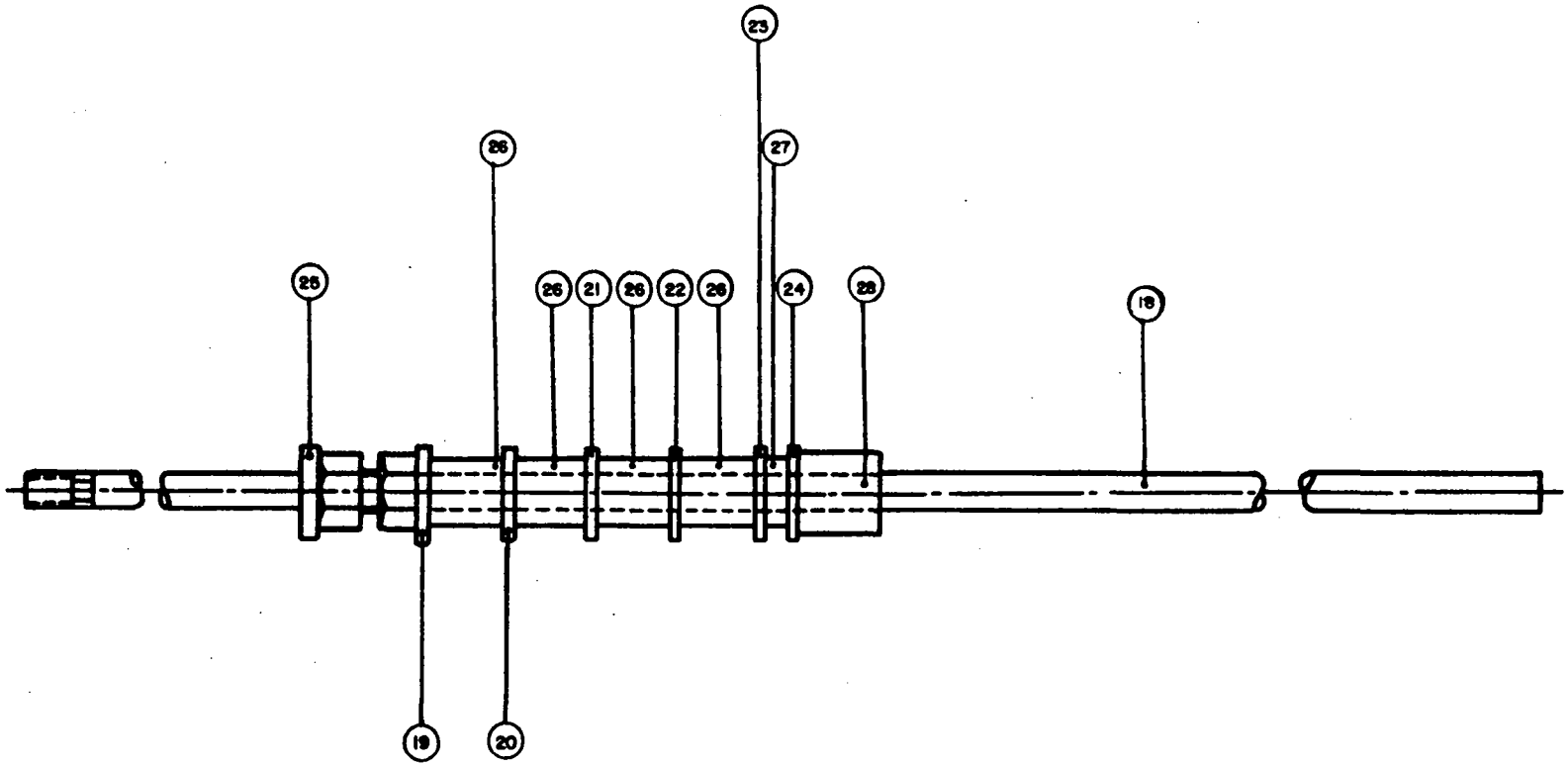
APPENDIX I

CONSTRUCTION DRAWINGS FOR BROACHING DEVICE

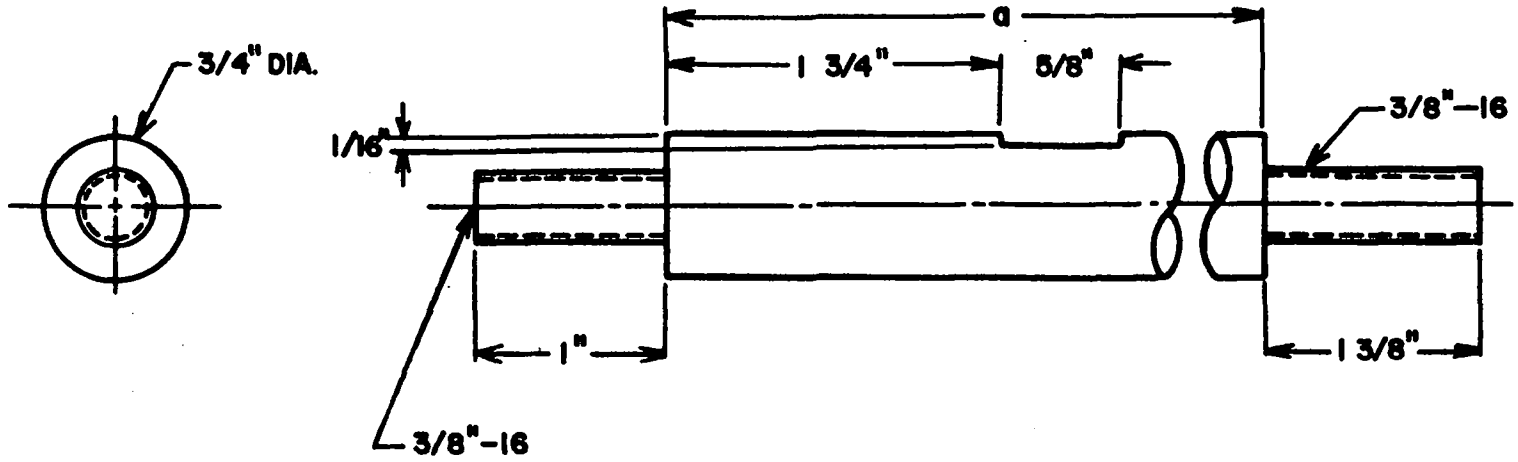
Note: The designation A, B and C is used for the 1 1/2", 2" and 3" units, respectively



BROACHED ROBOSCREEN		LOAD FRAME
SCALE: 1/4"= 1" (B)	DATE: 6-20-80	DRAWN BY: S. C. NG

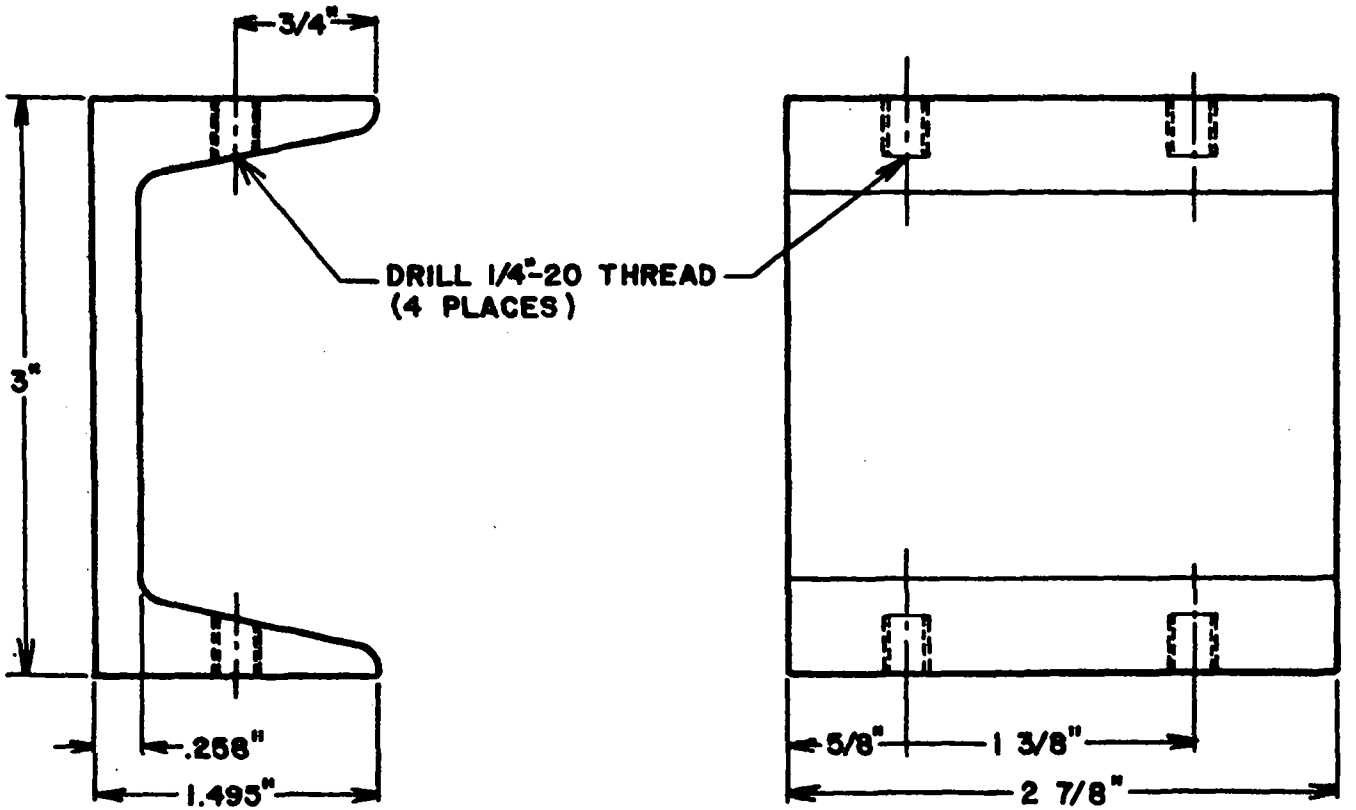


BROACHED ROBOSCREEN		BROACH ASSEMBLY	PART 1
SCALE: 1/4"=1"	DATE: 6-19-80	DRAWN BY: S. C. NG	REQUIRE 1

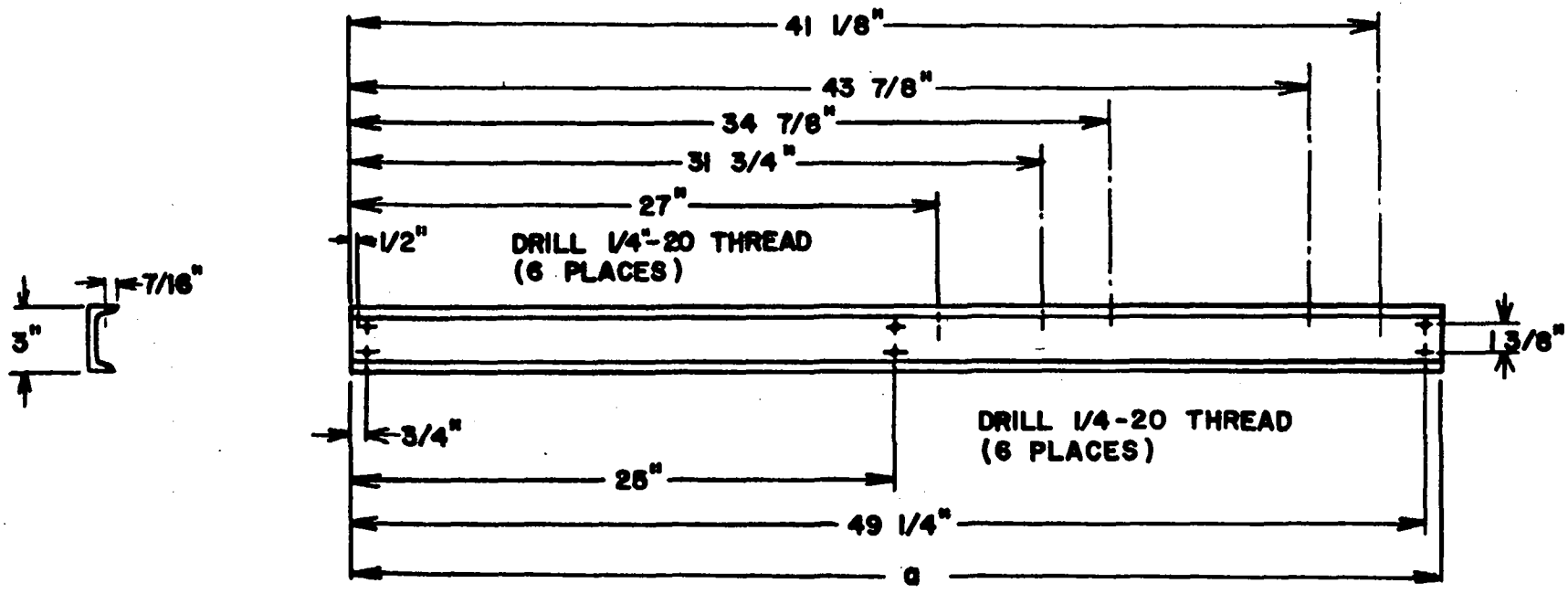


	A	B	C
a	25 1/2"	25 1/2"	31"
REQUIRE	3	3	3

BROACHED ROBOSCREEN		LOAD FRAME GUIDES	PART 2
SCALE: FULL (B)	DATE: 6-18-80	DRAWN BY: S. C. NG	

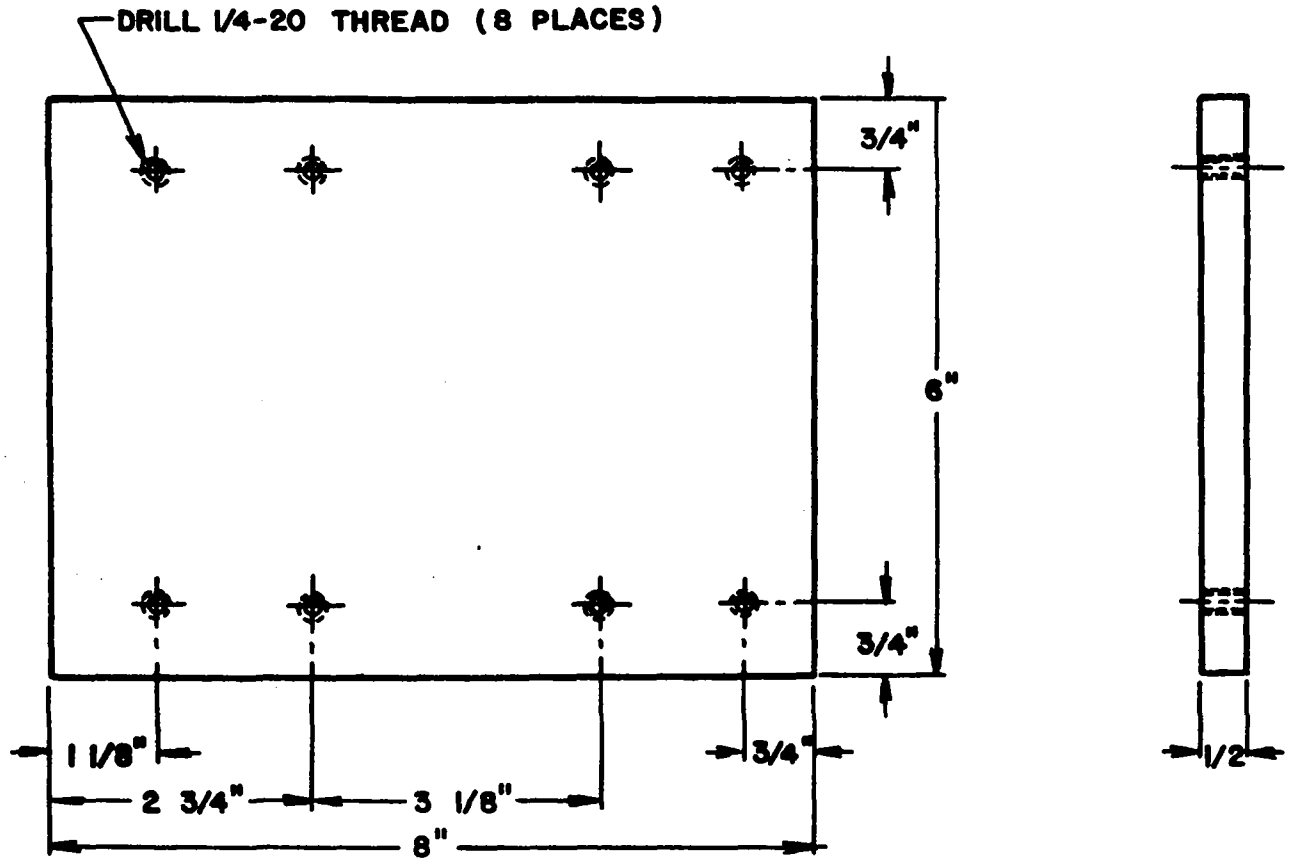


BROACHED ROBOSCREEN		AMERICAN STANDARD CHANNEL C 3X5	PART 3
SCALE: FULL (B)	DATE: 6-18-80	DRAWN BY: S. C. NG	REQ. 3 EA.

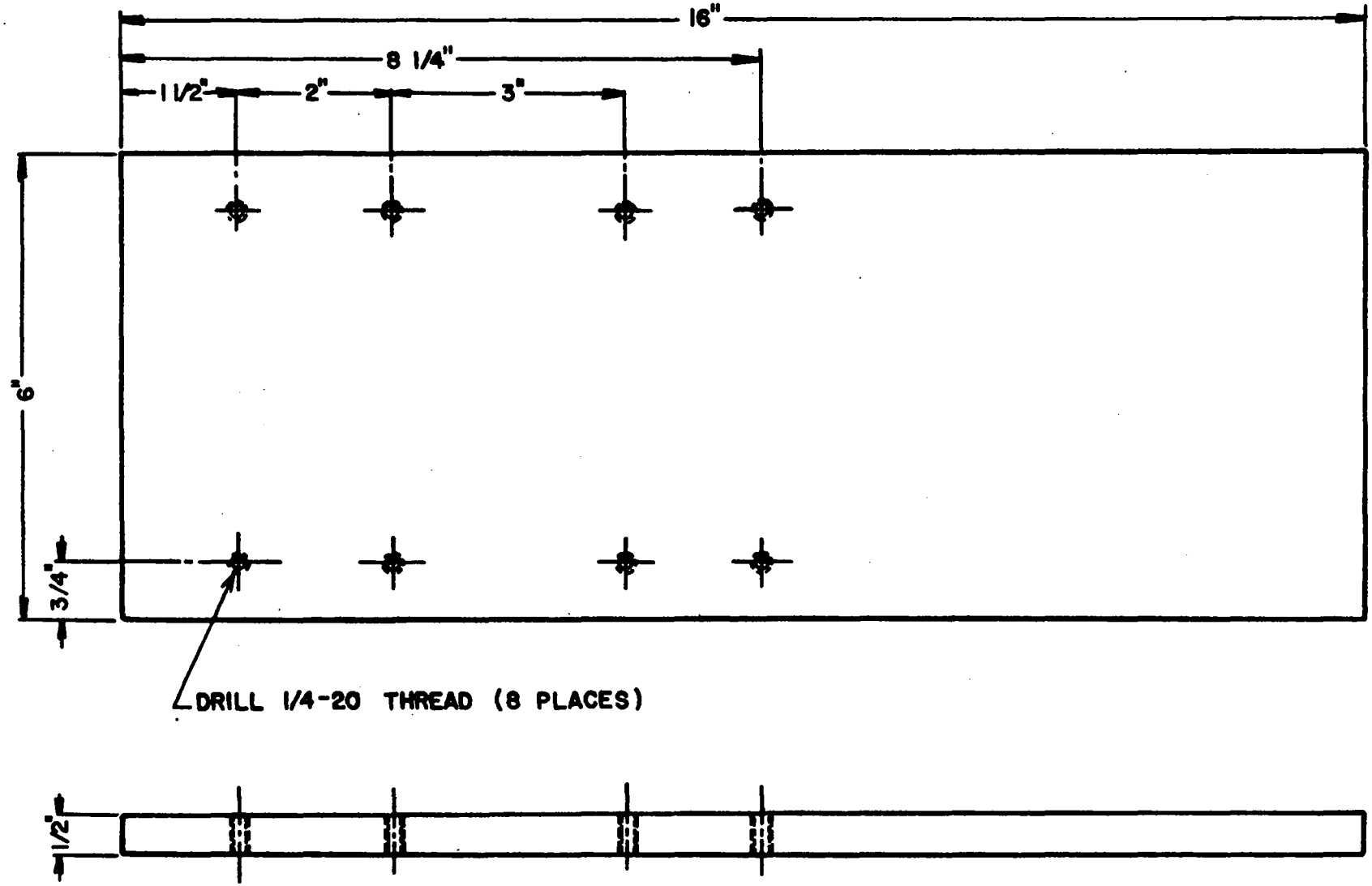


	A	B	C
a	50"	50"	60"

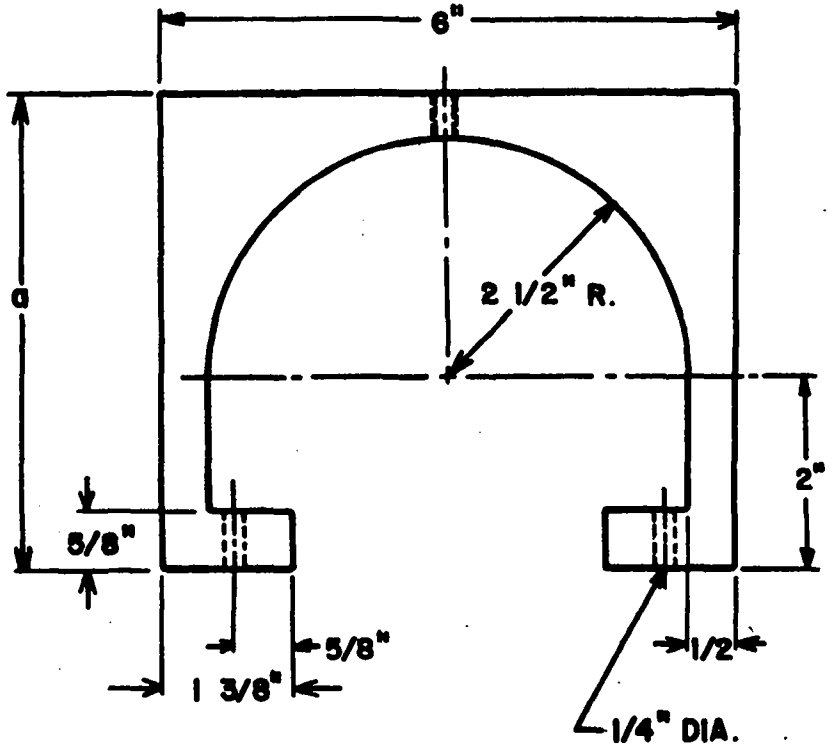
BROACHED ROBOSCREEN		AMERICAN STANDARD CHANNEL C 3X5	PART 4
SCALE: 1/8" = 1" (B)	DATE: 6-18-80	DRAWN BY: S.C. NG	REQ. 1 EA.

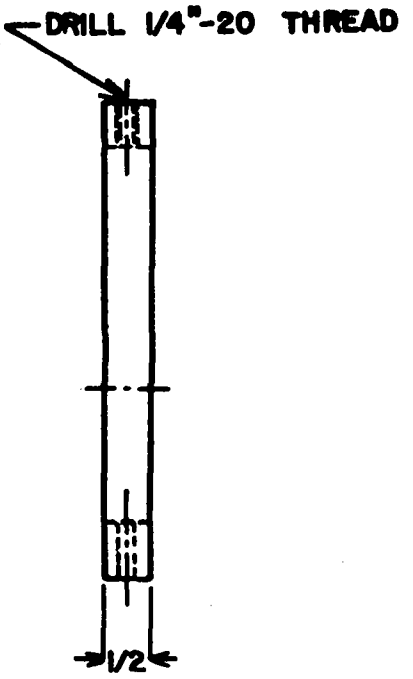


BROACHED ROBOSCREEN		CRADLE BASEPLATE	PART 5
SCALE: 1/2"=1" (B)	DATE: 6-18-80	DRAWN BY: S. C. NG	REQ. 1 EA.



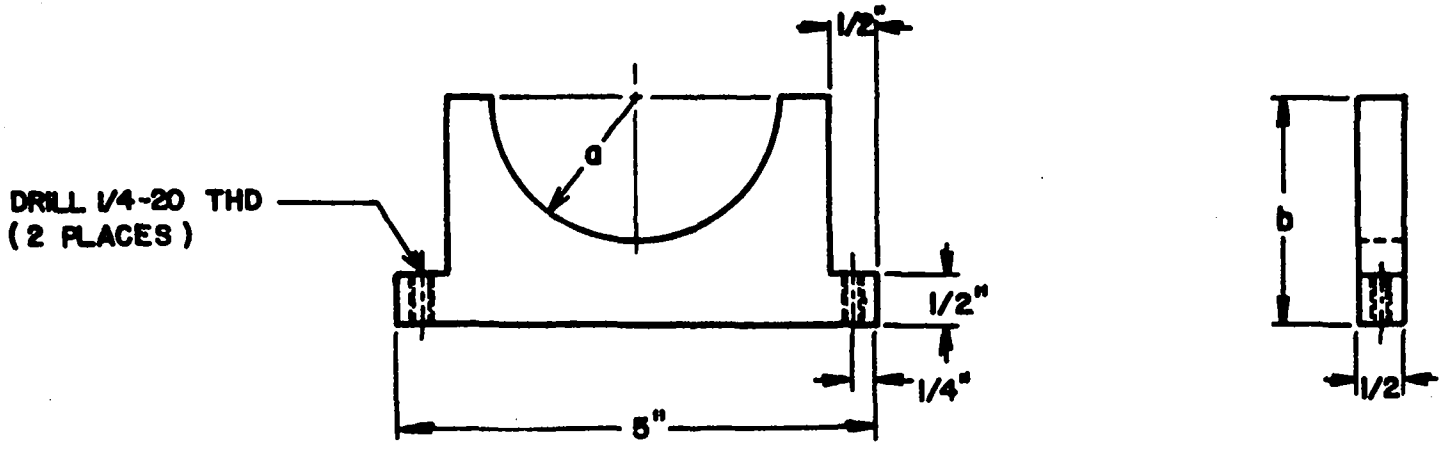
BROACHED ROBOSCREEN		CRADLE BASEPLATE	PART 6
SCALE: 1/2" = 1" (B)	DATE: 6-20-80	DRAWN BY: S.C. NG	REQD. 1 EA.





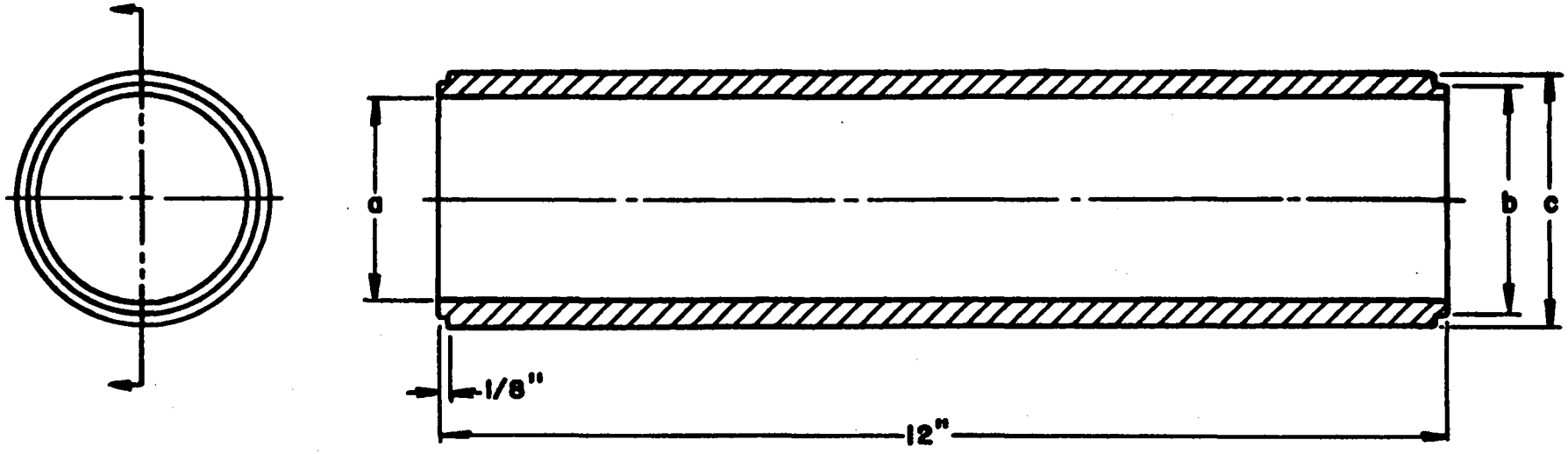
	A	B	C
a	5"	5"	6"
REQUIRE	1	1	1

BROACHED ROBOSCREEN		SLEEVE CLAMP	PART 7
SCALE : 1/2" = 1" (B)	DATE : 6-19-80	DRAWN BY : S.C. NG	



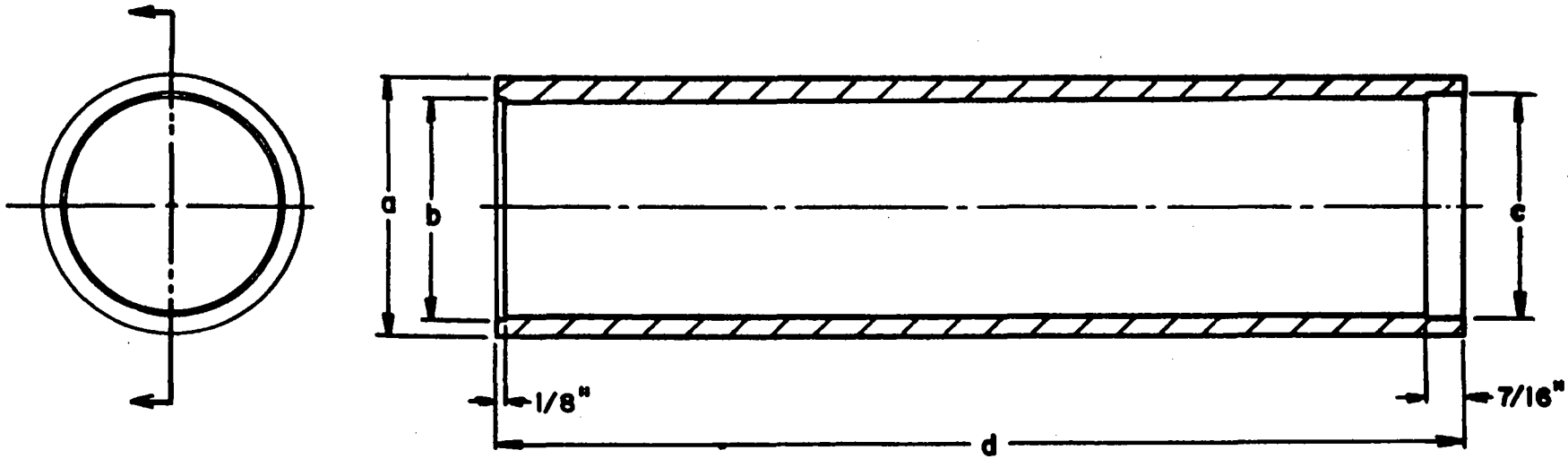
	A	B	C
a	1 1/2" R.	1 1/2" R.	2" R.
b	2 3/8"	2 3/8"	2 7/8"
REQUIRE	4	4	4

BROACHED ROBOSCREEN		CRADLE	PART 8
SCALE: 1/2" = 1" (B)	DATE: 6-18-80	DRAWN BY: S. C. NG	



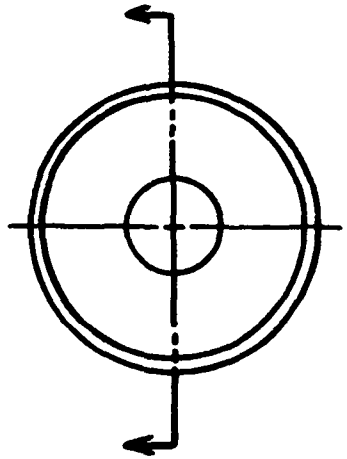
	A	B	C
a	1 7/8" D.	2 3/8"D.	3 1/2" D.
b	2 3/4" D.	2 3/4" D.	3 7/8" D.
c	3" D.	3"D.	4"D.
REQUIRE	1	1	1

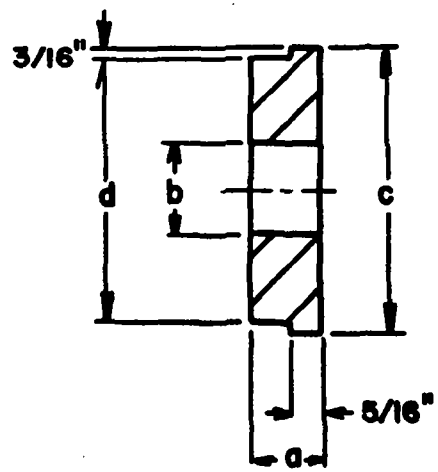
BROACHED ROBOSCREEN		BREECH	PART 9
SCALE: 1/2"=1" (B)	DATE: 6-20-80	DRAWN BY: S. C. NG	



	A	B	C
a	3" D.	3" D.	4" D.
b	2 25/32" D.	2 25/32" D.	3 7/8" D.
c	2 9/16" D.	2 9/16" D.	3 11/16" D.
d	11 1/4"	11 1/4"	17"
REQUIRE	1	1	1

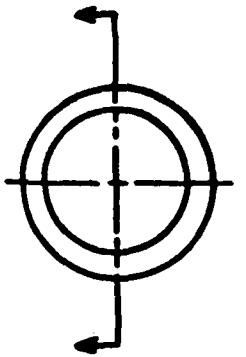
BROACHED ROBOSCREEN		BEARING SUPPORT SLEEVE (REAR)	PART 10
SCALE: 1/2" = 1" (B)	DATE: 6-19-80	DRAWN BY: S. C. NG	

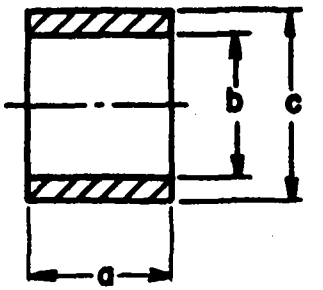




	A	B	C
a	3/4"	3/4"	3/4"
b	15/16" D.	15/16" D.	1 3/16" D.
c	3" D.	3" D.	4" D.
d	2 9/16" D.	2 9/16" D.	3 11/16" D.
REQUIRE	1	1	1

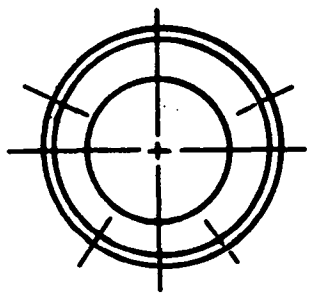
BROACHED ROBOSCREEN		BEARING HOUSING (REAR)	PART 11
SCALE: 1/2" = 1" (B)	DATE: 6-20-80	DRAWN BY: S. C. NG	

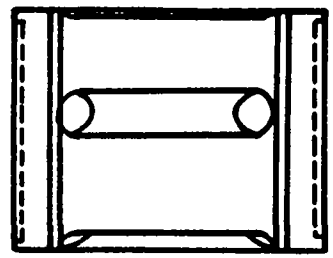




	A	B	C
a	3/4"	3/4"	3/4"
b	3/4" D.	3/4" D.	1" D.
c	15/16" D.	15/16" D.	1 3/16" D.
REQUIRE	1	1	1

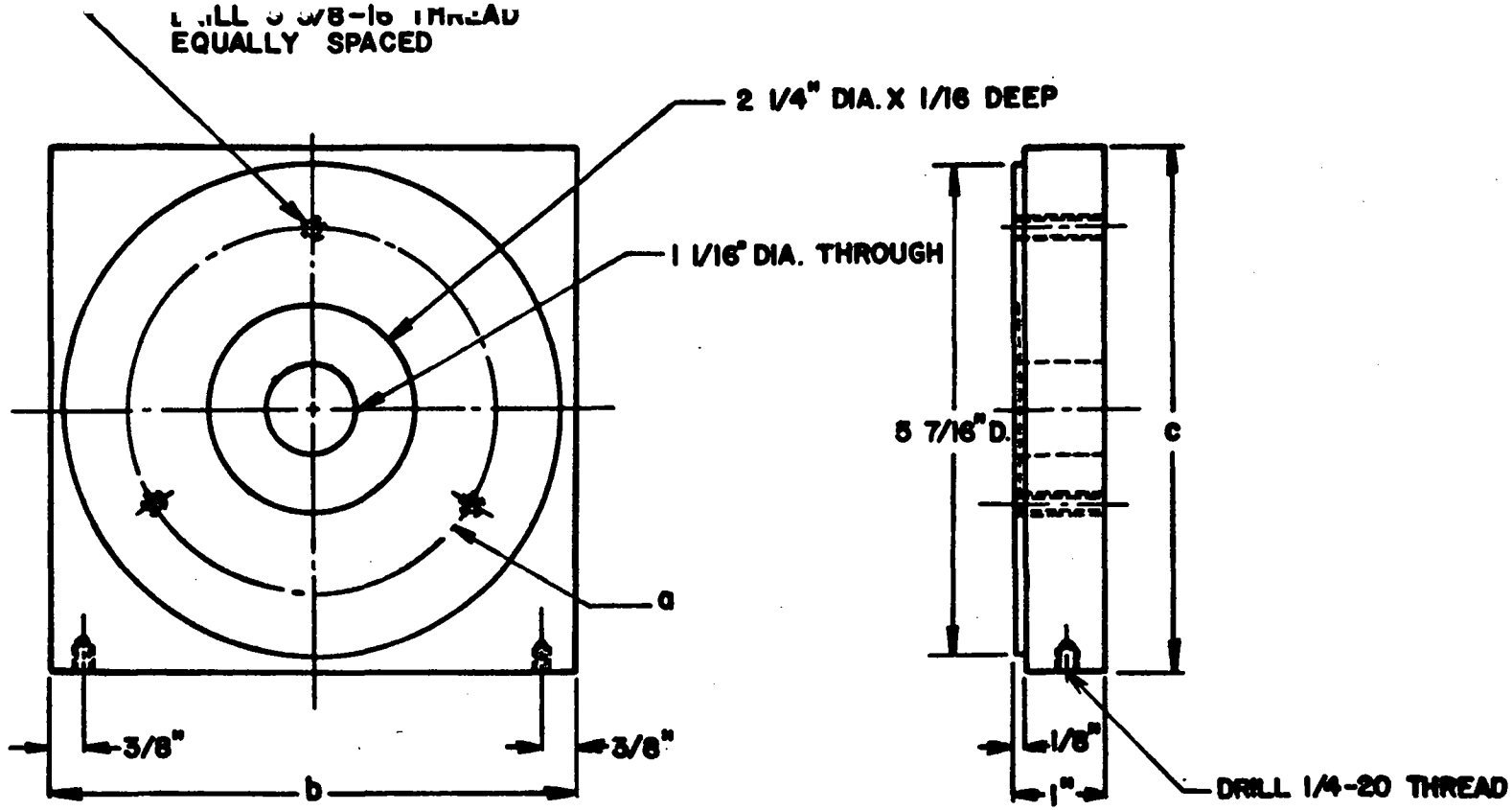
BROACHED ROBOSCREEN		BRONZE BUSH	PART 12
SCALE: FULL	DATE: 6-18-80	DRAWN BY: S. C. NG	





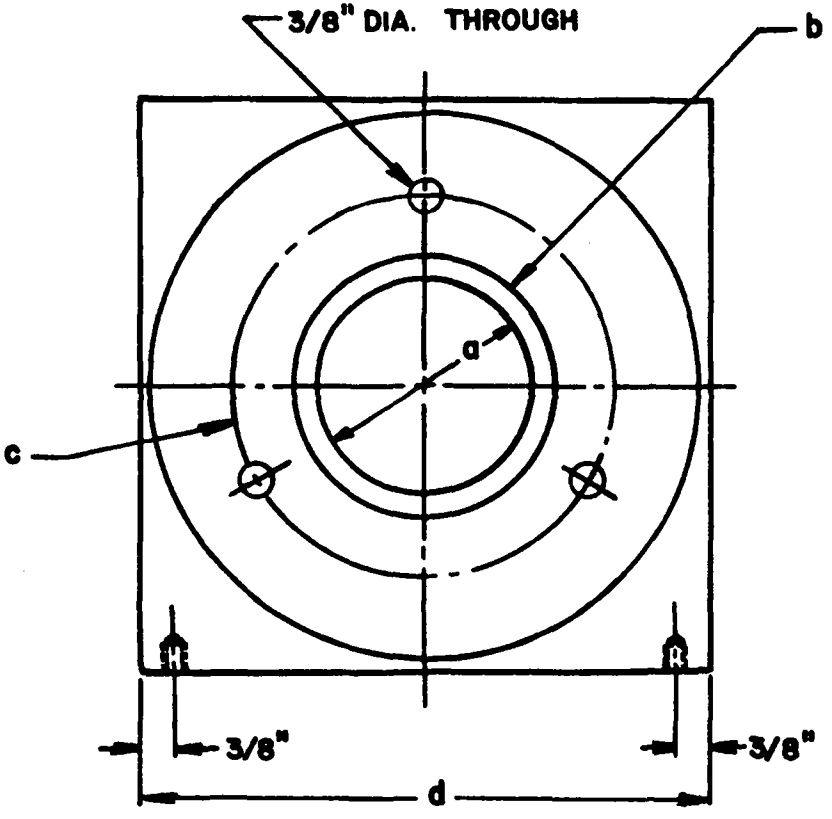
	A REQUIRE	B REQUIRE	C REQUIRE
A-122026	4	4	3
B-162536	0	0	1

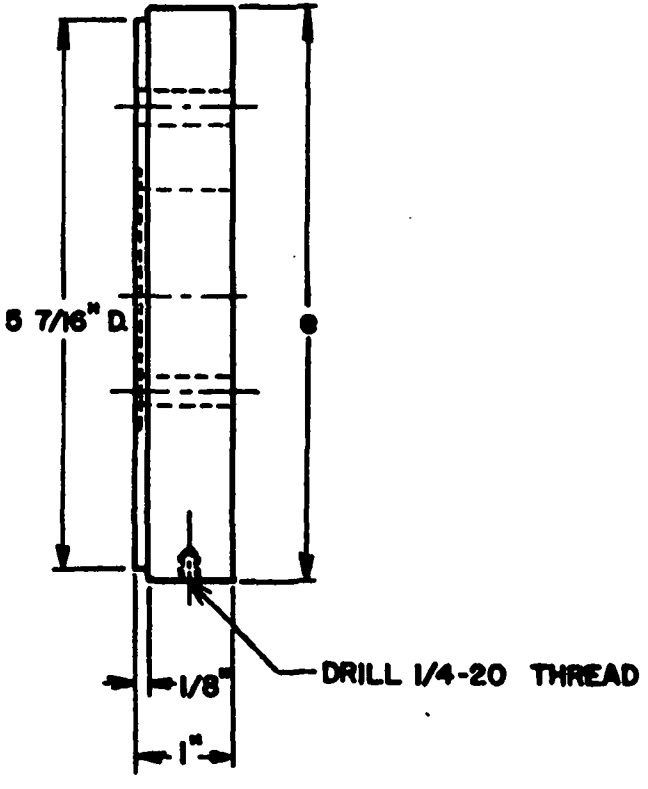
BROACHED ROBOSCREEN		THOMSON BALL BUSHING	PART 13
SCALE : FULL (B)	DATE : 6-19-80	DRAWN BY : S.C. NG	



	A	B	C
a	4"	4"	5"
b	6"	6"	7"
c	6"	6"	7"
REQUIRE	1	1	1

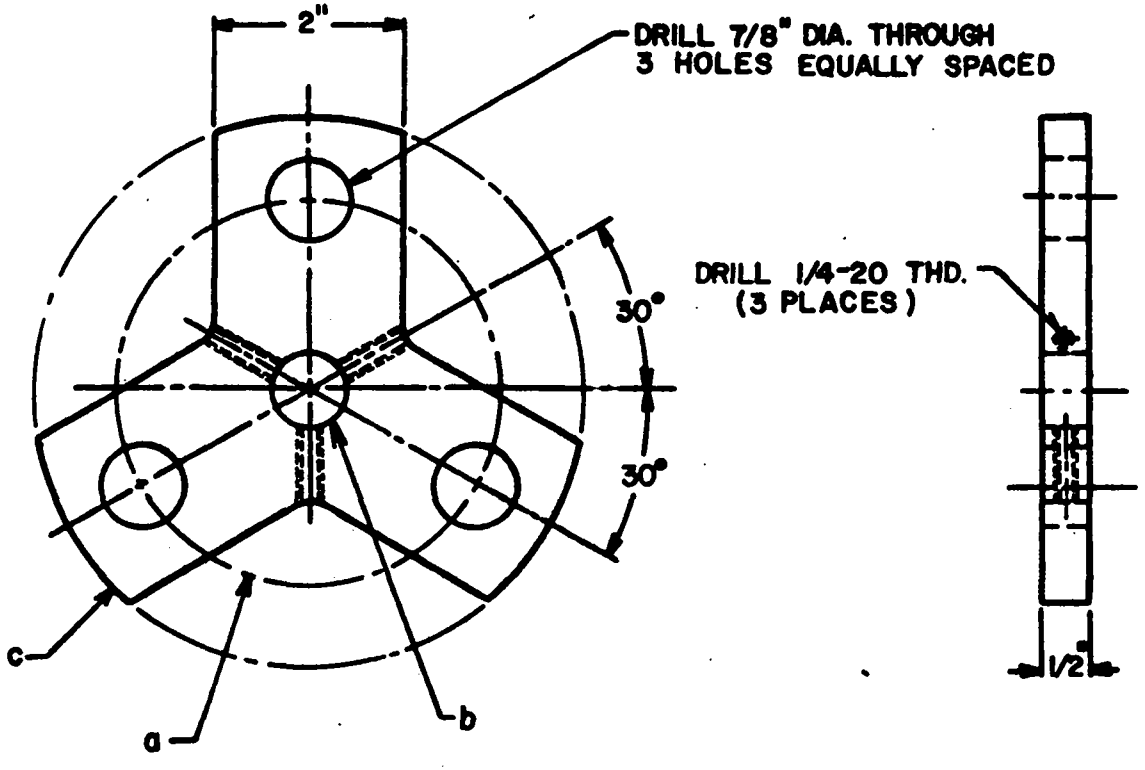
BROACHED ROBOSCREEN		FRONT END PLATE	PART 14
SCALE: 1/2"= 1" (B)	DATE: 6 18 80	DRAWN BY: S. C. NG	





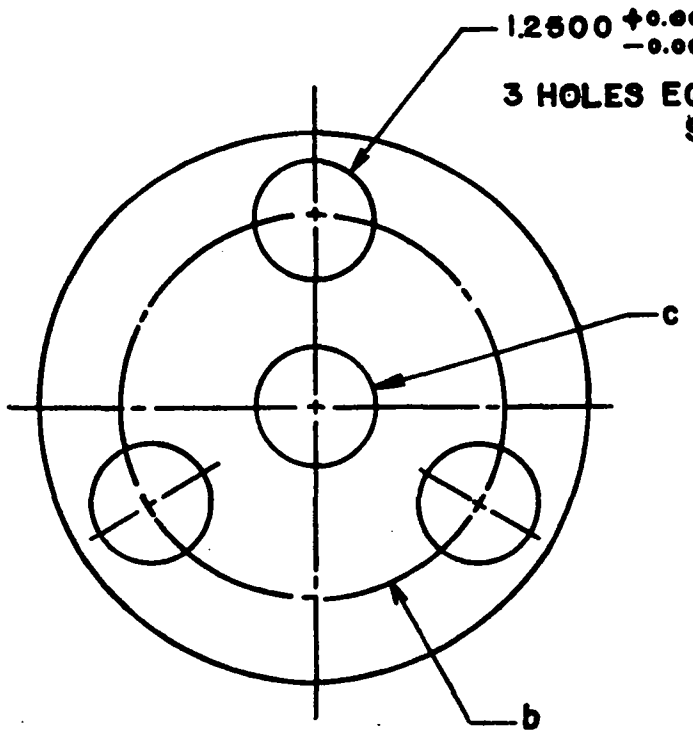
	a	b	c	d	e	REQUIRE
A	1 3/4" D.	2 3/4" D.	4" D.	6"	6"	1
B	2 15/16" D.	2 13/16" D.	4" D.	6"	6"	1
C	3 1/4" D.	3 7/8" D.	5" D.	7"	7"	1

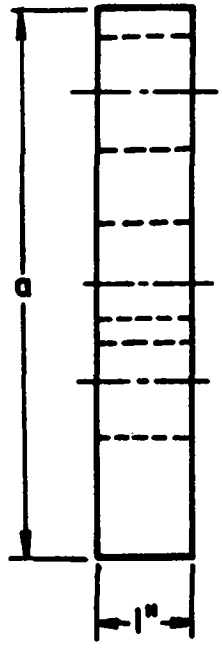
BROACHED ROBOSCREEN	REAR END PLATE	PART 15
SCALE : 1/2" = 1" (B) DATE : 6-18-80	DRAWN BY : S. C. NG	



	A	B	C
a	4" DIA.	4" DIA.	5" DIA.
b	3/4" DIA.	3/4" DIA.	11/16" DIA.
c	5 3/4" D.	5 3/4" D.	6 3/4" D.

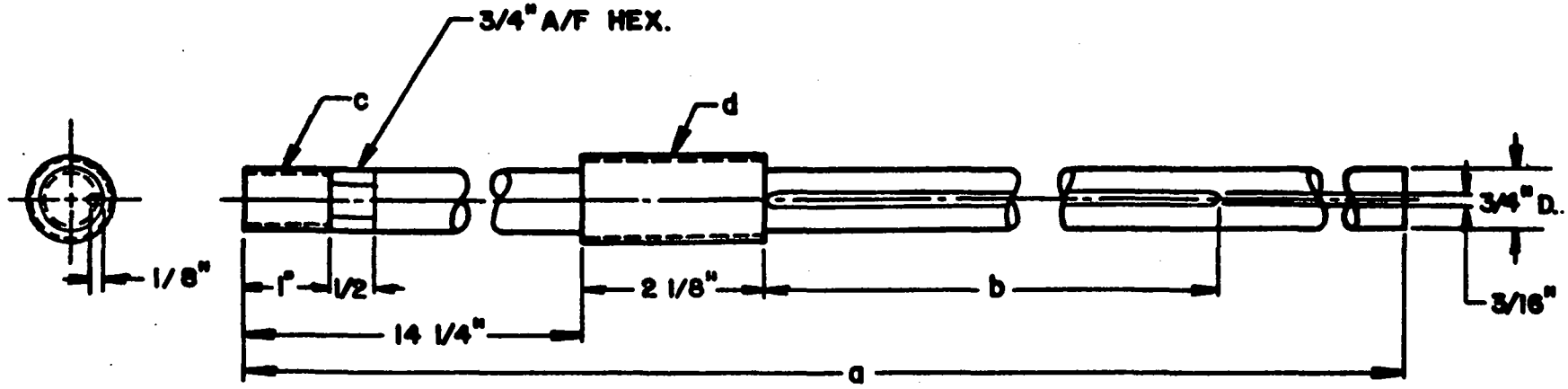
BROACHED ROBOSCREEN		ANTI-ROTATION CLAMP	PART 16
SCALE: 1/2" = 1" (B)	DATE: 6-18-80	DRAWN BY: S.C. NG	REQUIRE 1





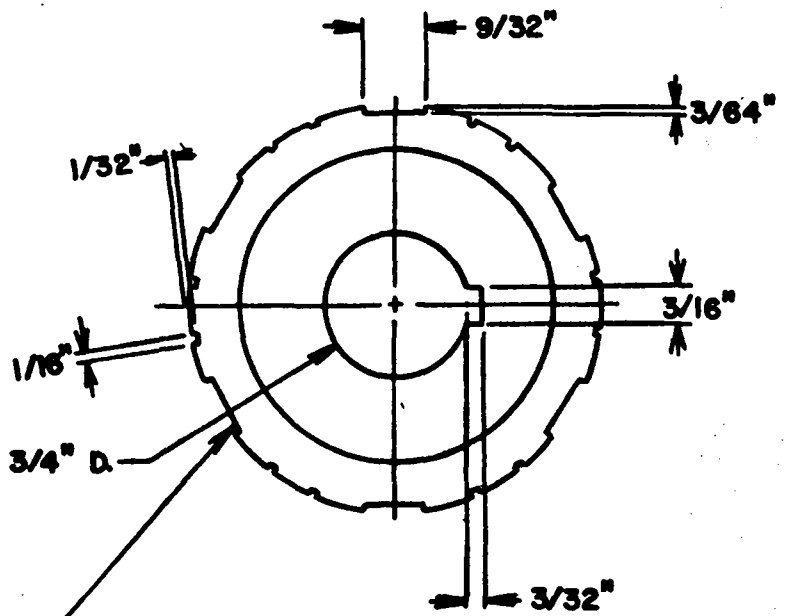
	A	B	C
a	5 3/4"D.	5 3/4"D.	6 7/8"
b	4" D.	4"D.	5"D.
c	1.2500 +.0000 −.0005	1.2500 +.0000 −.0005	1.2500 +.0000 −.0005
REQUIRED	1	1	1

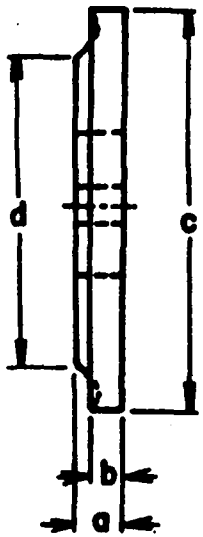
BROACHED ROBOSCREEN		FLOATING SUPPORT DISC	PART 17
SCALE : 1/2"= 1" (B)	DATE : 6-19-80	DRAWN BY : S. C. NG	



	A	B	C
a	51 7/8"	51 7/8"	59"
b	9 7/8"	9 7/8"	12 3/4"
c	3/4"-10	3/4"-10	1"-8
d	1"-14	1"-14	1 1/4"-7

BROACHED ROBOSCREEN		BROACH ARBOR	PART 18
SCALE: 1/2" = 1" (B)	DATE: 6-20-80	DRAWN BY: S.C. NG	REQ. 1 EA.

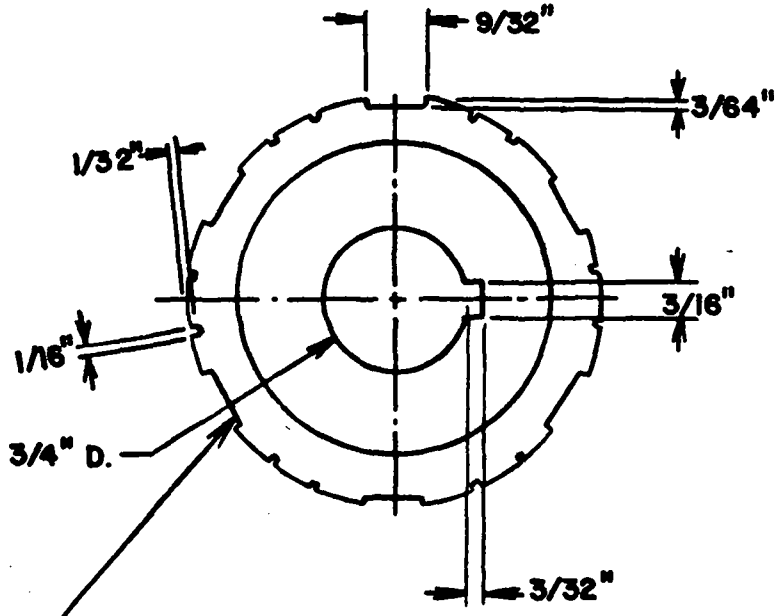


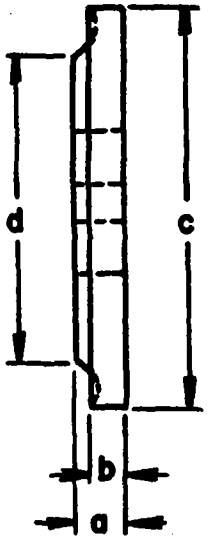


NOTE: MODEL C TO BE RELIEVED AT 8 EQUAL PLACES (45°)

	A	B	C
a	1/4"	1/4"	3/8"
b	3/16"	3/16"	5/16"
c	1.707" D.	2.180" D.	3.170" D.
d	1" D.	1 5/8" D.	2 3/8" D.
REQUIRE	1	1	1

BROACHED ROBOSCREEN		CUTTER NO. 5	PART 19
SCALE : FULL (B)	DATE : 6-19-80	DRAWN BY : S. C. NG	

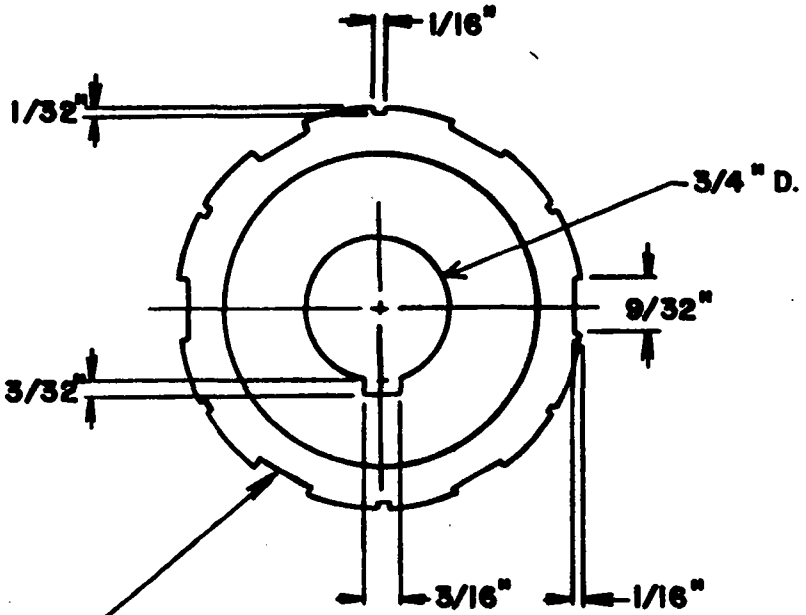


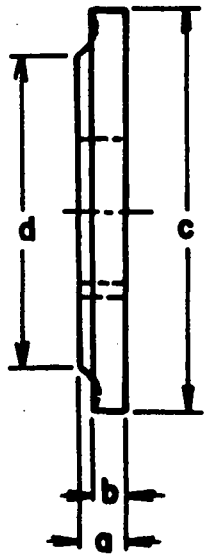


NOTE: MODEL C TO BE RELIEVED AT 8 EQUAL PLACES (45°)

	A	B	C
a			3/8"
b			5/16"
c			3.198" D.
d			2 3/8" D.
REQUIRE	0	0	1

BROACHED ROBOSCREEN		CUTTER NO. 6	PART 19A
SCALE: FULL	DATE: 6-19-80	DRAWN BY: S. C. NG	

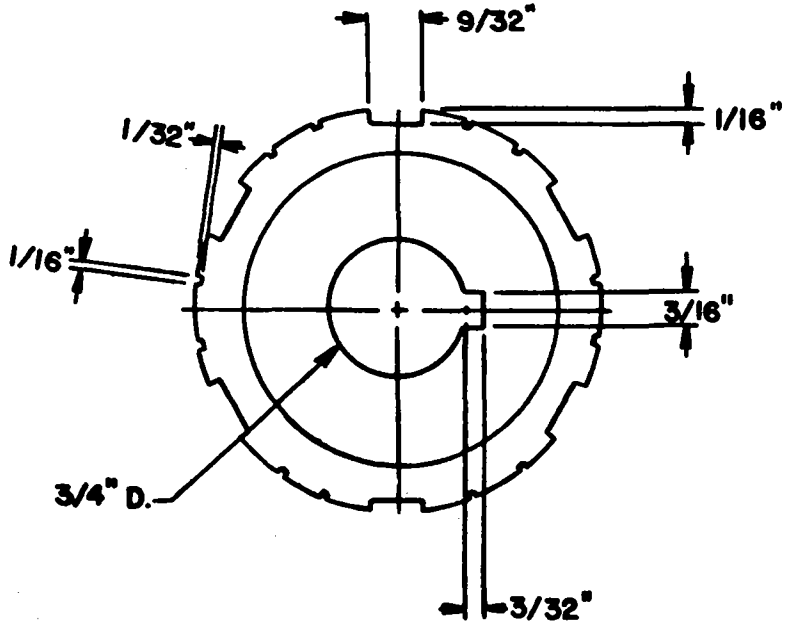


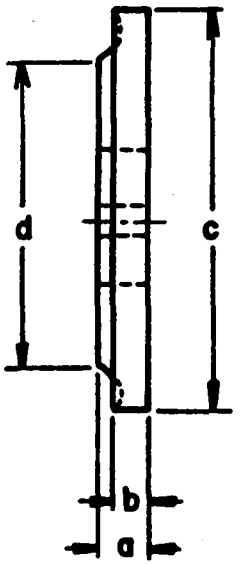


NOTE: MODEL C TO BE RELIEVED AT 8 EQUAL PLACES (45°)

	A	B	C
a	1/4"	1/4"	3/8"
b	3/16"	3/16"	5/16"
c	1.696" D.	2.152" D.	3.142" D.
REQUIRE	1	1	1
d	1" D.	1 5/8" D.	2 3/8" D.

BROACHED ROBOSCREEN		CUTTER NO. 4	PART 20
SCALE: FULL (B)	DATE: 6-19-80	DRAWN BY: S. C. NG	

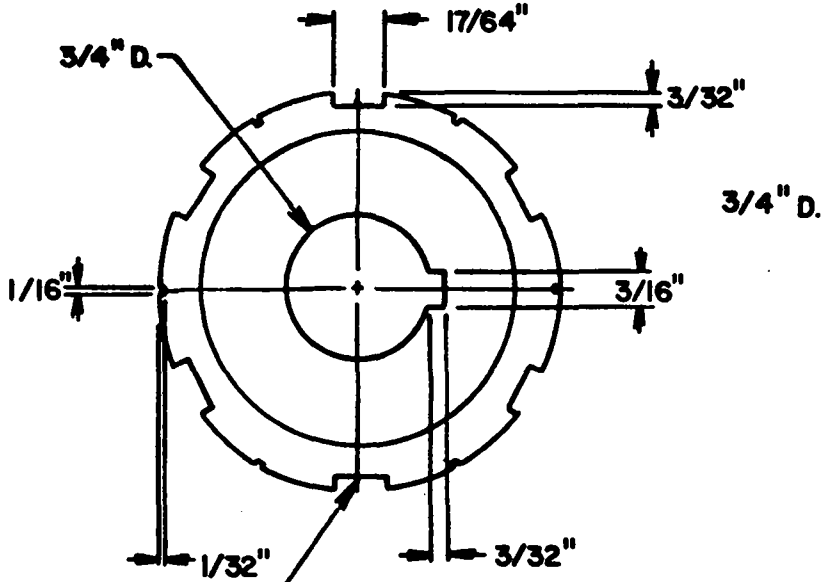


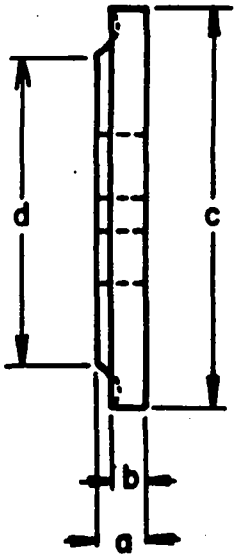


	A	B	C
a	1/4"	1/4"	3/8"
b	3/16"	3/16"	5/16"
c	1.658"D.	2.096"D.	3.086"D.
d	1"D.	1 5/8"D.	2 3/8"D.
REQUIRE	1	1	1

NOTE: MODEL C TO BE RELIEVED AT 8 EQUAL PLACES (45°)

BROACHED ROBOSCREEN		CUTTER NO. 2	PART 21
SCALE: FULL (B)	DATE: 6-19-80	DRAWN BY: S.C. NG	

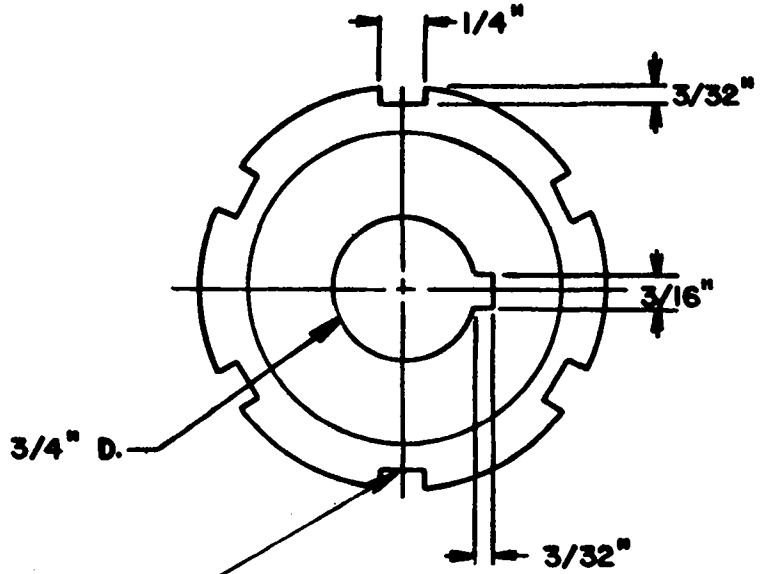


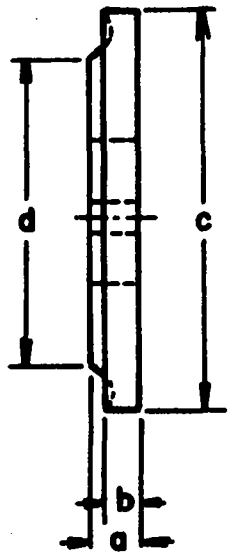


NOTE: MODEL C TO BE RELIEVED AT 8 EQUAL PLACES (45°)

	A	B	C
a	1/4"	1/4"	3/8"
b	3/16"	3/16"	5/16"
c	1.676" D.	2.124" D.	3.114" D.
d	1" D.	1 5/8" D.	2 3/8" D.
REQUIRE	1	1	1

BROACHED ROBOSCREEN		CUTTER NO. 3	PART 22
SCALE: FULL (B)	DATE: 6-19-80	DRAWN BY: S. C. NG	

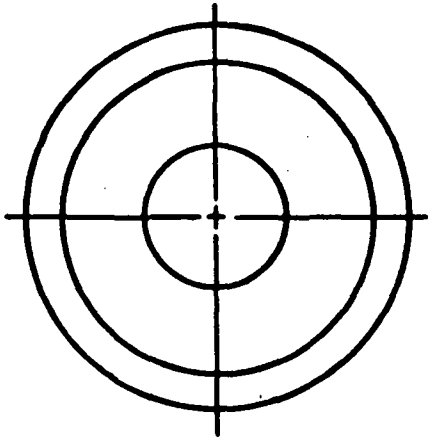


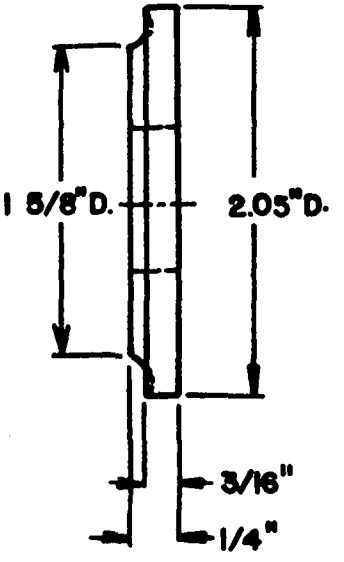


NOTE: MODEL C TO BE RELIEVED AT 8 EQUAL PLACES (45°)

	A	B	C
a	1/4"	1/4"	3/8"
b	3/16"	3/16"	5/16"
c	1.640" D.	2.068" D.	3.086" D.
d	1" D.	1 5/8" D.	2 3/8" D.
REQUIRE	1	1	1

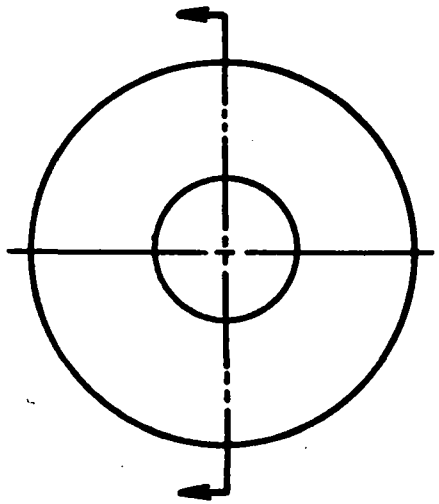
BROACHED ROBOSCREEN		CUTTER NO. 1	PART 23
SCALE: FULL (B)	DATE: 6-19-80	DRAWN BY: S. C. NG	

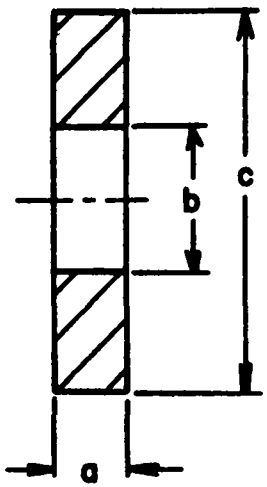




NOTE: ONLY FOR MODEL B

BROACHED ROBOSCREEN		SCRAPER	PART 24
SCALE : FULL (B)	DATE : 6-20-80	DRAWN BY S.C. NG	REQUIRE 1

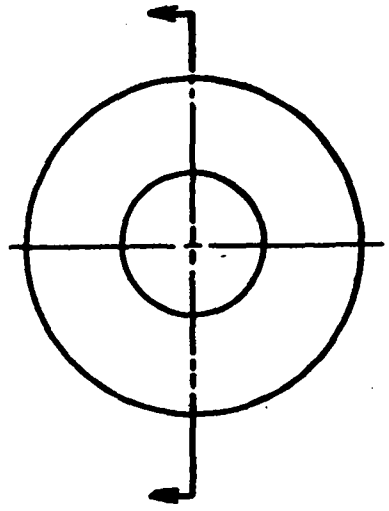


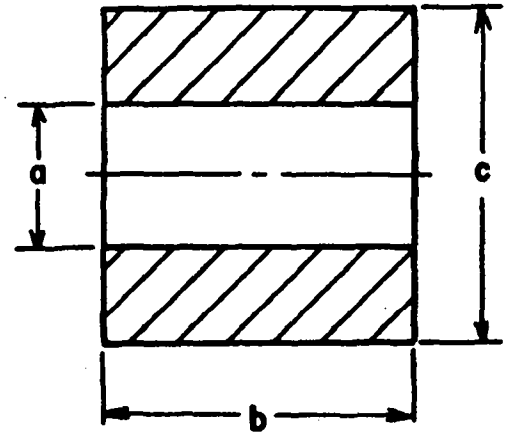


	A	B	C
a	3/8"	3/8"	1/2"
b	3/4" D.	3/4" D.	1" D.
C*	2"	2"	2"
REQUIRE	1	1	1

* NOTE: MAKE c TO SUIT BORE OF EXTRUDED PIPE

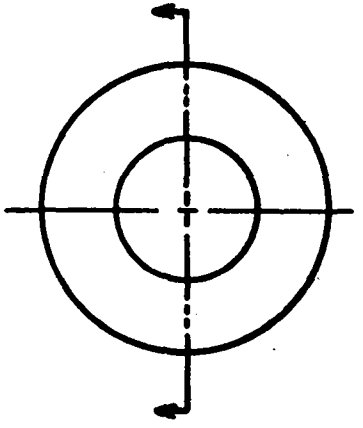
BROACHED ROBOSCREEN		LEADER	PART 25
SCALE: FULL (B)	DATE: 6-19-80	DRAWN BY: S.C. NG	

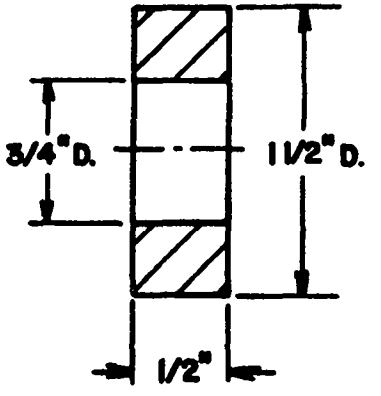




	A	B	C
a	3/4" D.	3/4" D.	1" D.
b	1 11/16"	1 11/16"	2"
c	1 3/4" D.	1 3/4" D.	2 1/4" D.
REQUIRE	4	4	5

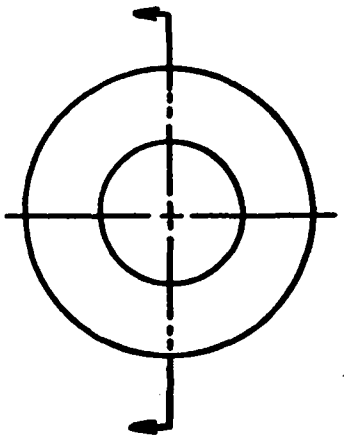
BROACHED ROBOSCREEN		SPACER	PART 26
SCALE: FULL (B)	DATE: 6-20-8	DRAWN BY: S. C. NG	

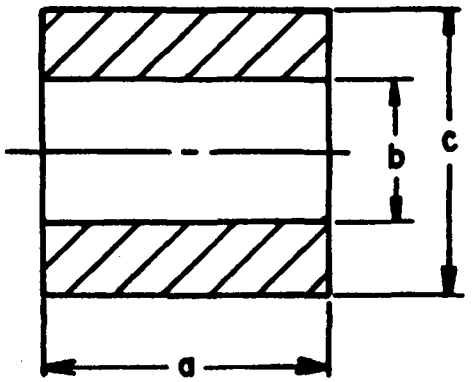




NOTE: FOR MODEL B ONLY

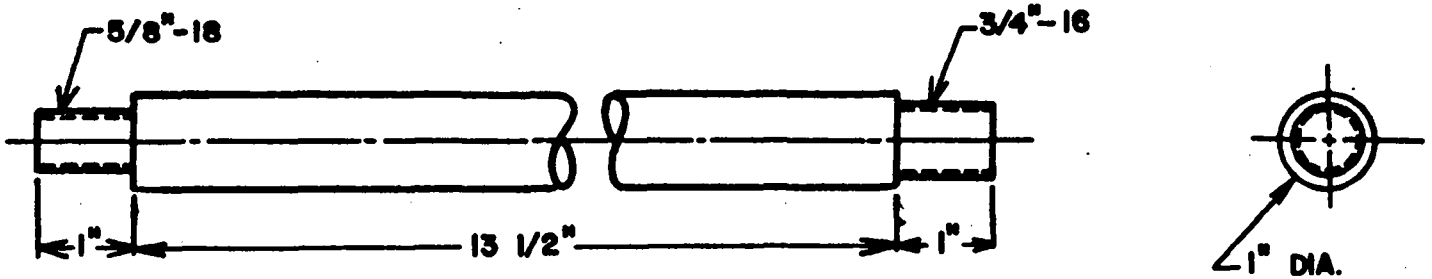
BROACHED ROBOSCREEN		SPACER	PART 27
SCALE: FULL (B)	DATE: 6-19-80	DRAWN BY: S.C. NG	REQUIRE 1



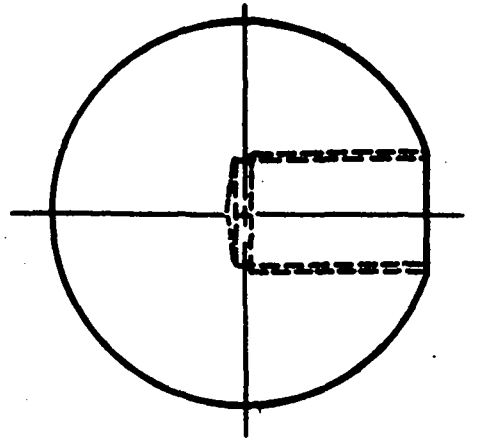


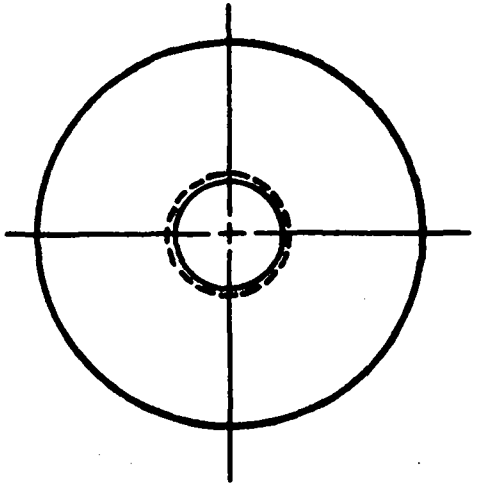
	A	B	C
a	1 1/2"	1 1/2"	2"
b	3/4" D.	3/4" D.	1" D.
c	1 1/2" D.	1 1/2" D.	2 1/4" D.
REQUIRE	1	1	1

BROACHED ROBOSCREEN		SLEEVE	PART 28
SCALE: FULL (B)	DATE: 6-19-80	DRAWN BY: S.C. NG	

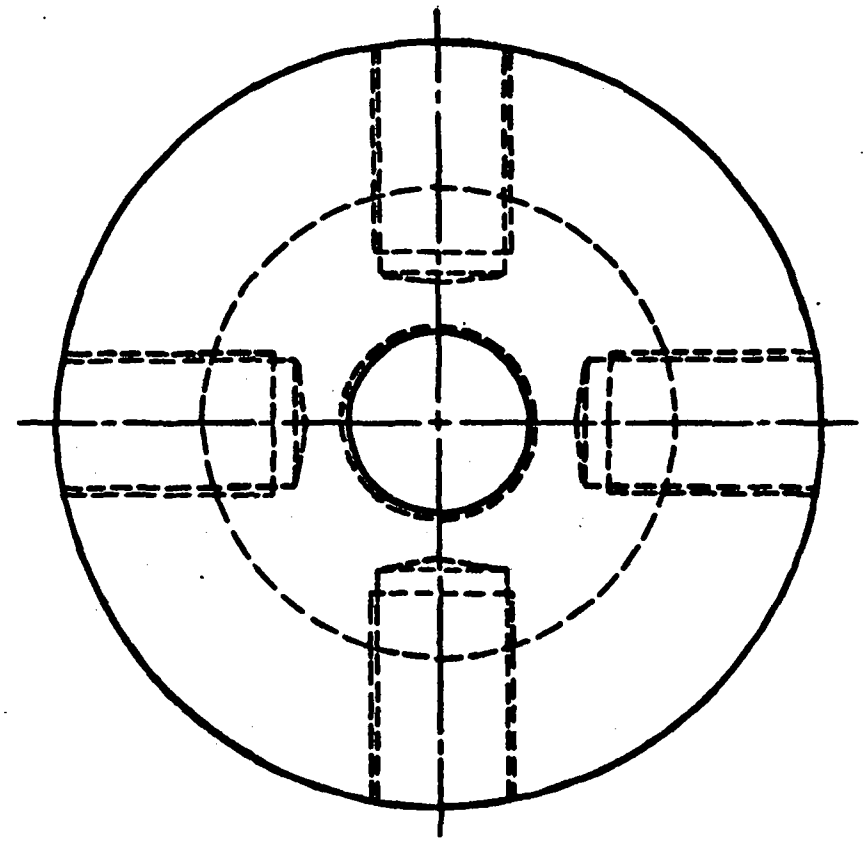


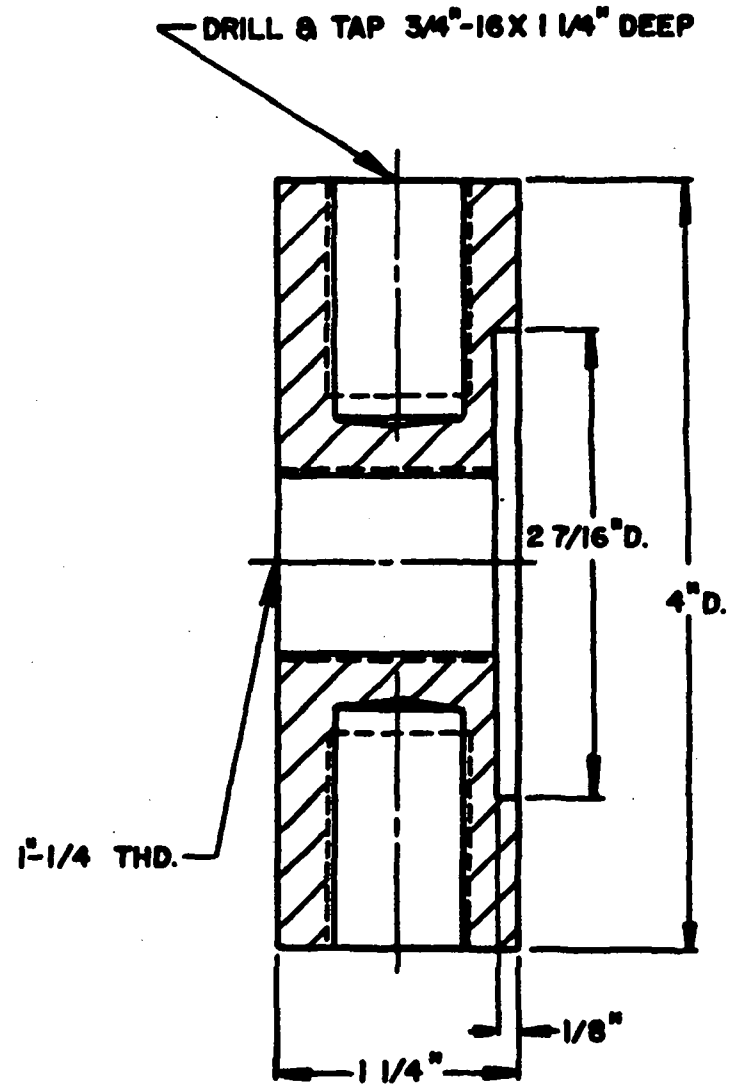
BROACHED ROBOSCREEN		HANDLE	PART 29
SCALE: 1/2" = 1"	DATE: 7-2-80	DRAWN BY: S.C. NG	REQ. 4 EA.



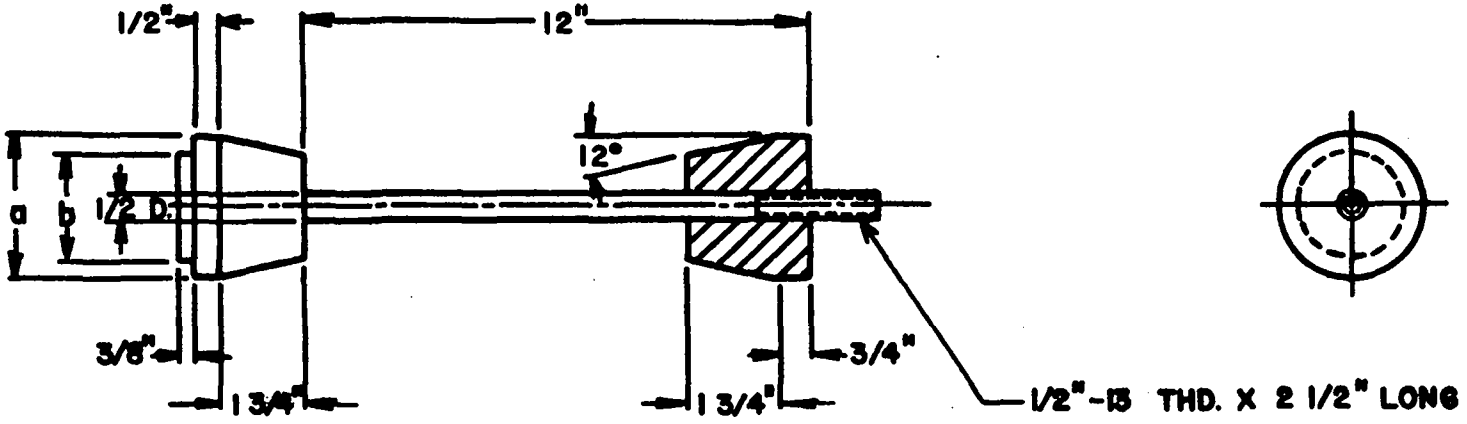


BROACHED ROBOSCREEN		STANDARD 2" PLASTIC KNOB	PART 30
SCALE: FULL	DATE: 7-2-80	DRAWN BY: S.C. NG	REQ. 4 EA.



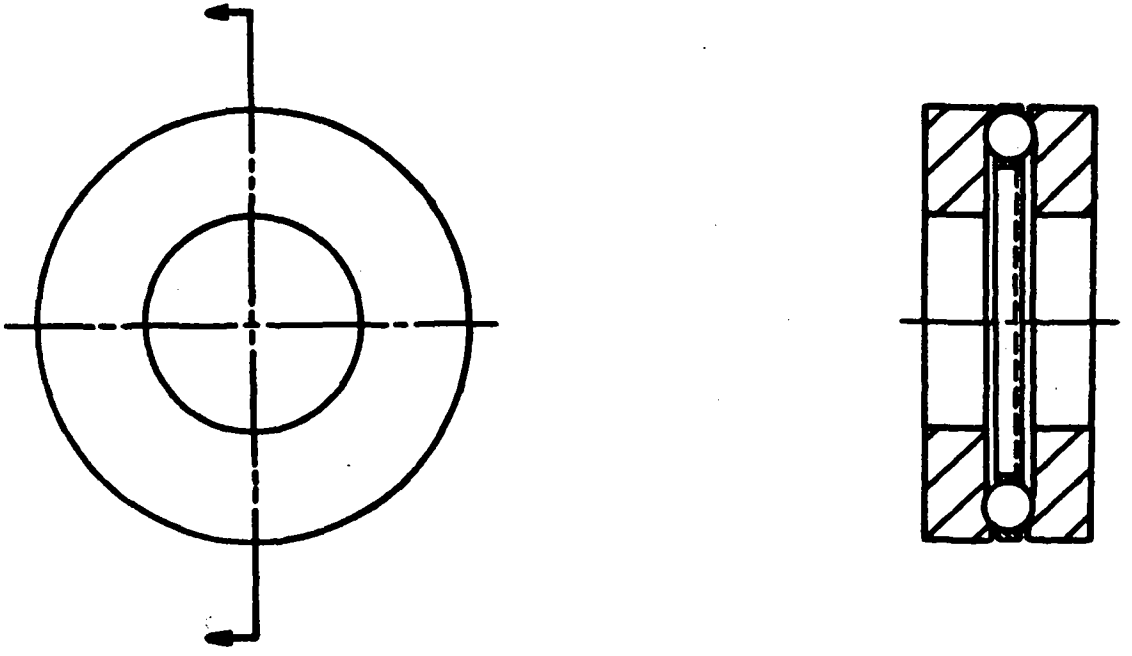


BROACHED ROBOSCREEN		HANDLE	PART 31
SCALE: FULL	DATE: 7-2-80	DRAWN BY: S. C. NG	REQ. 1 EA.

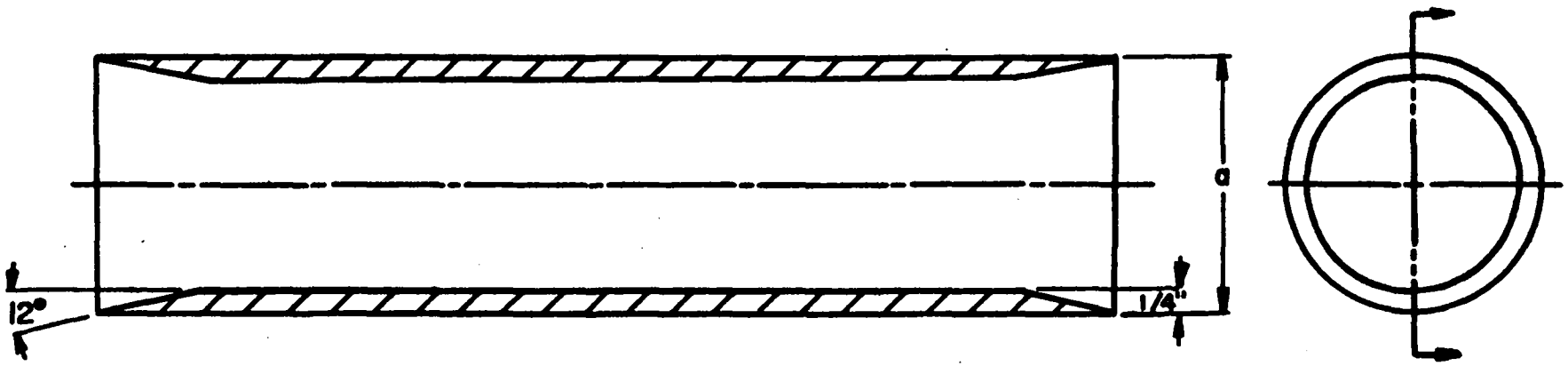


	A	B	C
a	1 9/16" D.	2" D.	2 31/32" D.
b	1 1/4" D.	1 1/2" D.	2 1/4" D.
REQUIRE	1	1	1

BROACHED ROBOSCREEN		EXPANDER	PART 32
SCALE: 1/4" = 1" (C)	DATE: 7-2-80	DRAWN BY: S. C. NG	



BROACHED ROBOSCREEN		THRUST BEARING EW-1-1/2	PART 33
SCALE: FULL	DATE: 7-3-80	DRAWN BY: S. C. NG	REQ. 1 EA.



	A	B	C
a	1.600 $^{+.000}_{-.010}$ D.	2.035 $^{+.000}_{-.010}$ D.	3.020 $^{+.000}_{-.010}$ D.
REQUIRE	1	1	1

BROACHED ROBOSCREEN		MANDREL SLEEVE	PART 34
SCALE : 1/2" = 1" (C)	DATE : 7-2-80	DRAWN BY : S.C. NG	

APPENDIX II

TYPICAL INSTALLATIONS OF BROACHED ROBOSCREENS

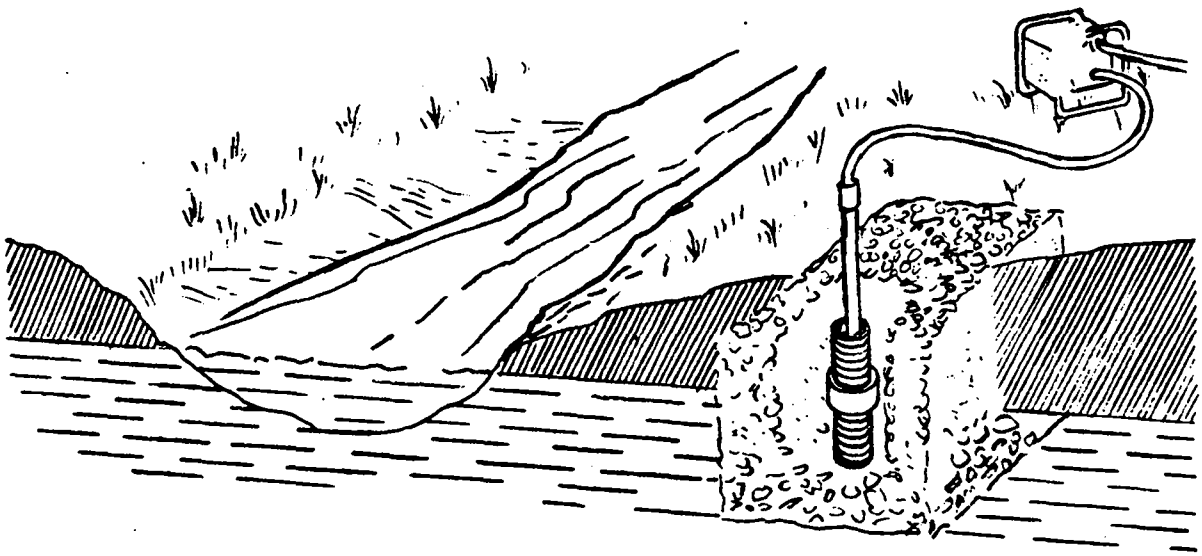


Figure II - 1 Gravel-Filled Infiltration Gallery with Broached Roboscreen Intake

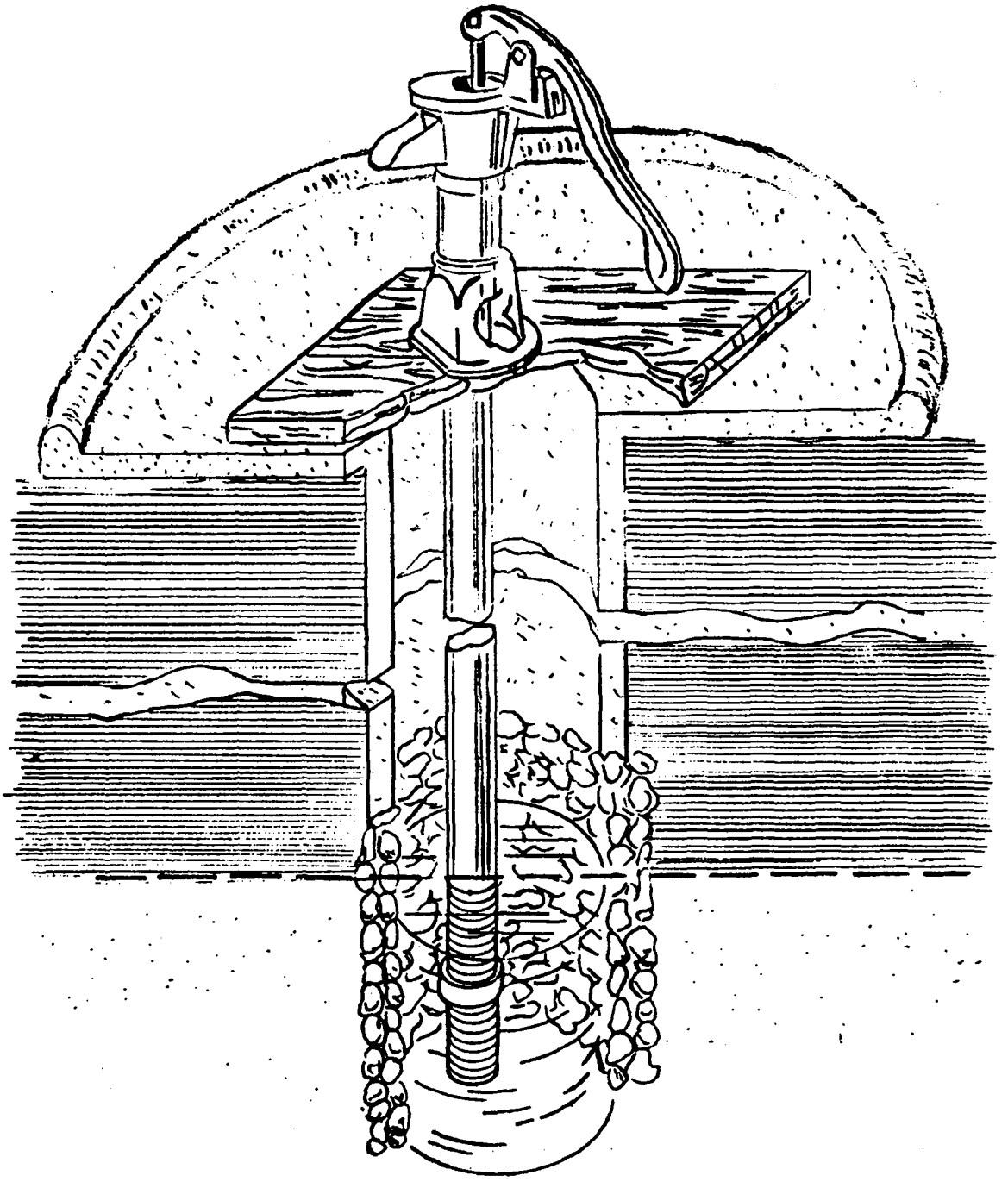


Figure II - 2 Typical Dug Well (Rock Lining) with Shallow Well Pump and Broached Roboscreen

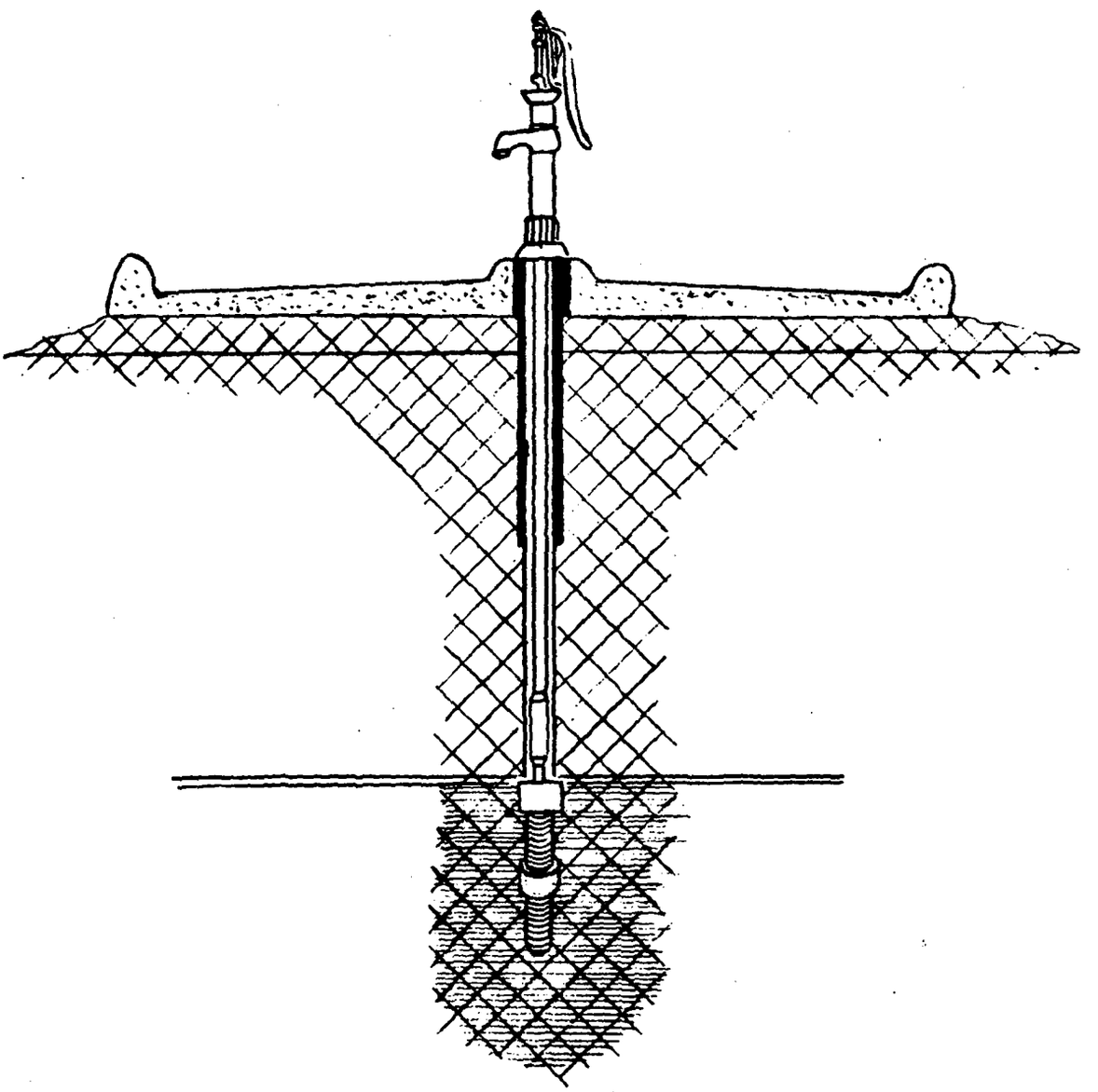


Figure II - 3 Drilled Well Constructed with Broached Roboscreen Intake

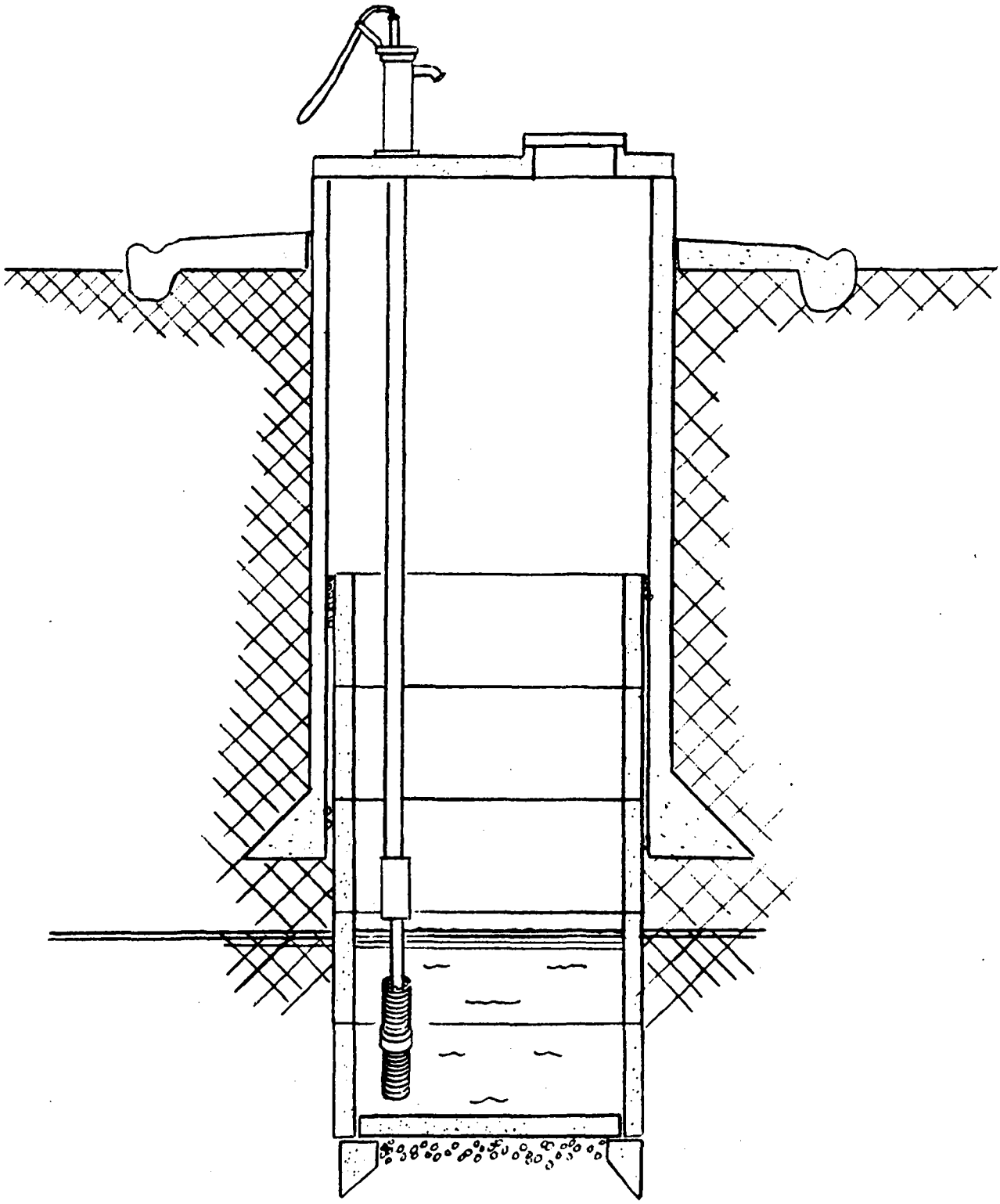


Figure II - 4 Typical Dug Well (Concrete Lining) Equipped with Broached Roboscreen