LOW PRESSURE FLOW CONTROL MECHANISM FOR FLOOD IRRIGATION

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The Evaluation Committee which was responsible for this project is listed below.

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EXECUTIVE SUMMARY

The overall efficiency of flood irrigation is generally considered to be quite low, and is typically considered to be in the order of only 50%. Any small improvement in the efficiency of flood irrigation practices would thus, by implication, have a significant effect on the overall water use for agriculture in the country.

One of the main problems currently experienced in flood irrigation is to ensure a constant flow rate from small "balancing dams". Normally the discharge from these dams would vary from a maximum when the dam is full to minimum when the dam is nearly empty. To rectify this situation the flow control valve requires continuous adjustment thereby complicating the management and use of flood irrigation systems. The objective of the project, therefore, was to develop and test a flow control mechanism that would automatically ensure a discharge rate constant within plus or minus 10% of a pre-selected value. Such a mechanism would simplify the management of flood irrigation systems and should effect significant water savings.

As a first approach the modification of one of the existing valve types to function as a constant discharge flow control mechanism was considered. At a very early stage, however, it was obvious that this approach would not result in a robust mechanism required for farming conditions and, in addition, that it would be a relatively expensive piece of equipment requiring skilled maintenance attention. Consequently this approach was discarded.

The mechanism finally decided on and developed and evaluated during this project, consists of a nozzle fitted to an inclined pipe which acts as an enclosed canal. One end of the pipe is

connected to the dam outlet whilst the other end (to which the nozzle is fitted) is suspended at a certain depth below the water surface by means of a float arrangement. The depth at which the nozzle end of the pipe is suspended depends on the required discharge rate. By keeping this depth constant and by ensuring free discharge of the nozzle in the enclosed canal, a constant rate of discharge is the end result. Fig. 1 schematically shows the construction of the floating nozzle flow control mechanism.

The need for free discharge of the nozzle in the enclosed canal became obvious during the trials. If not, siphoning starts to take place resulting in increasing flow rates, especially when the balancing dam is relatively full. To eliminate this problem a vent pipe is fitted to the nozzle housing. By ensuring atmospheric pressure in the enclosed canal, the siphoning action is prevented thereby eliminating increases in discharge at full balancing dam situations.

The trials also indicted that the size of the float supporting the nozzle should be sufficient to ensure a relatively constant suspension depth, irrespective of the water level in the balancing dam. It was observed that as the inclination of the enclosed canal varied with variations in the depth of the water in the dam, the flow depth in the canal, and therefore the mass of the canal plus water, varied. Consequently there was a tendency for the nozzle to be at a shallower depth as the inclination increased, with an accompanying effect on the discharge. In order to reduce the effect of this tendency, the buoyancy of the float relative to the buoyancy of the enclosed canal plus water, should be relatively large. The report explains the procedure to be followed to determine the required float size for a specific set of conditions.

The trials proved that the floating nozzle flow control mechanism meets the objective of controlling the discharge rate from a balancing dam for varying depths of water in the dam, to within

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limits better than the 10% prescribed at the onset of the project. Fig.2 graphically indicates the discharge characteristics of a floating nozzle flow control mechanism fitted with a float of adequate size.

The report includes a set of design graphs, a design procedure to be followed to determine the correct dimensions of the nozzle and float for a given set of conditions, as well as recommendations for the construction of the mechanism.

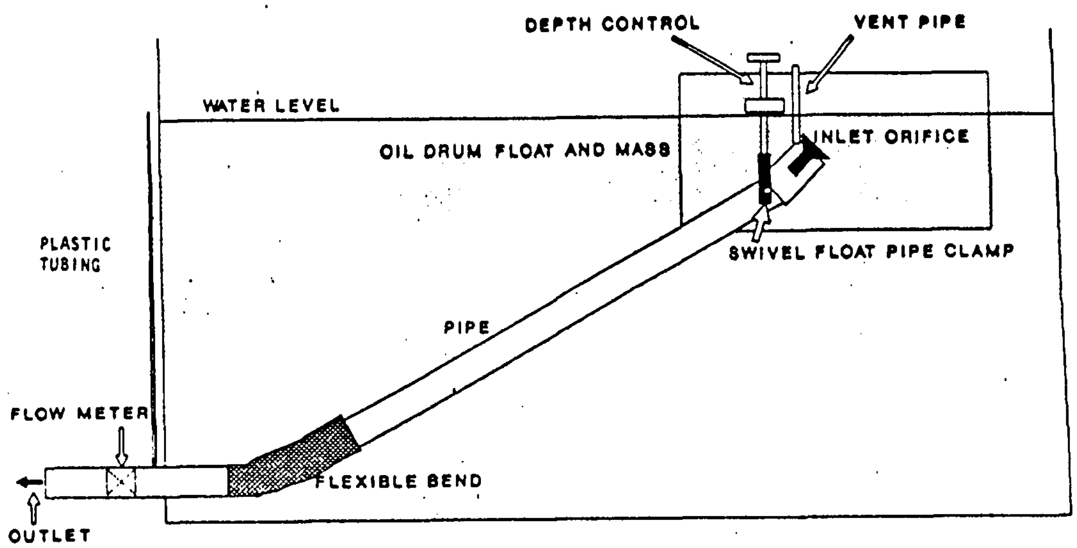

Fig 1: **CONSTRUCTION OF THE FLOATING NOZZLE FLOW CONTROL MECHANISM**

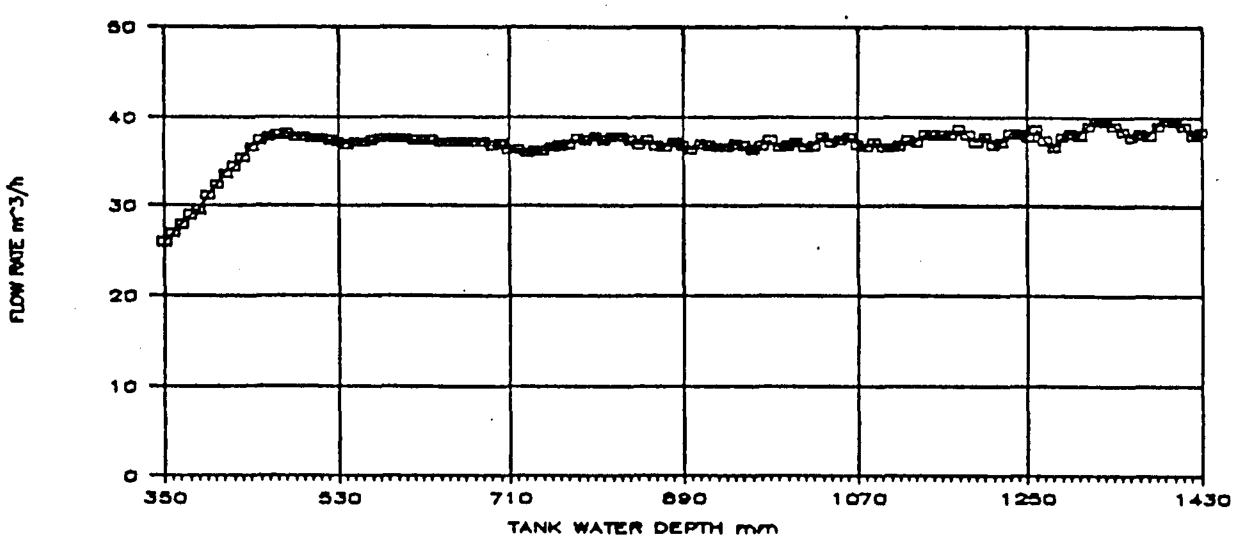

Fig 2: **DISCHARGE CHARACTERISTICS OF AN 80mm FLOATING NOZZLE IN A 160mm PIPE AT A DEPTH OF 150mm**

LOW PRESSURE FLOW CONTROL MECHANISM FOR FLOOD IRRIGATION

1. INTRODUCTION

A national survey of the total water use in the Republic of South Africa, which was held in 1986[2], showed that about 54% of our water was used for irrigation purposes. This represented a total area of about one million hectares of land, of which an estimated 55% was under some type of flood irrigation at the time.

The deduction could thus be made that flood irrigation accounted for about 30% of the total water use in South Africa in 1986.

The overall efficiency of flood irrigation is generally considered to be quite low, and is typically considered to be in the order of only 50%[7]. Any small improvement in the efficiency of flood irrigation practices would thus, by implication, have a significant effect on the overall water use in the country. Such savings are possible by simply improving, inter alia, the water control practices which are being used for flood irrigation.

This report shows how the application of basic hydraulic principles could be used to solve the problem of water flow control from small balancing dams which are being used for flood irrigation purposes, thus providing a means for effecting significant water savings.

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2. THE PROBLEM

The time and rate of flow of available water from a water source seldom coincides with the operational water requirements for effective flood irrigation. A dam or reservoir is normally required to balance the availability from the water source with the irrigation requirements. The storage capacities of these balancing dams may vary between the extremes of impounding run-off water during the rainfall period of a year for later use during the irrigation season, to a daily requirement where the time and rate of supply from a canal or bore hole is inadequate for direct irrigation application. The problem being addressed in this report relates to the latter type of situation and further discussion is confined thereto.

The water level in a balancing dam will normally be at the full supply level (FSL) of the dam at the start of a daily irrigation cycle, and will gradually decrease during the irrigation cycle to reach a minimum supply level (MSL) at the end of the day. In practice this daily variation of the water level in a typical balancing dam is mostly in the order of about 2 metres. The discharge flow rate from a dam outlet is determined by the head of water above the outlet and, as will be shown in this report, a variation of 2m in this head would cause the flow rate to vary by a factor of about 3. (See paragraph D, page 49).

This variation in flow rate directly influences the depth of water applied to a land during an irrigation cycle. This could cause an uneven distribution of water onto the land, resulting in crop losses due to inadequate water application or, conversely, due to drainage problems developing from over-irrigation. These problems are common on many large irrigation projects in the country which are managed by the Government or by Irrigation Boards[3].

3. OBJECTIVES OF THE PROJECT

A workshop on the engineering aspects of irrigation application systems which was arranged by the Water Research Commission in 1983, identified and prioritized a number of research projects in this facet of irrigation (1). Included in the list was research on the development of a type of valve which would be capable of providing a fairly constant flow rate from the outlet of a typical balancing dam with a varying water level as is typically encountered in flood irrigation in South Africa.

The Department of Agricultural Engineering of the University of Pretoria submitted research proposals on this matter to the Water Research Commission in 1986. The following general and specific objectives were identified as requirements for the development of a suitable valve.

3.1 General objectives

(a) Improvement of the general efficiency of flood irrigation in South Africa.

(b) Simplification of irrigation management practices for the farmer.

(c) Improvements in the effectiveness of water distribution on large irrigation projects.

(d) Provision of the necessary aids to promote the adoption of more scientific approaches for the design and management of flood irrigation schemes.

3.2 Specific valve objectives

(a) Maintenance of a fairly constant flow rate at dam water levels which could vary between 0,250 m and 2 m.

(b) Easy adjustment to provide a constant flow at different heads.

(c) Regulation of flow variations to within 10% of any predetermined flow rate.

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(d) The valve should also be suitable to serve as a shut-off valve for the dam outlet.

(e) The valve should be of simple design and easy to manufacture.

(f) The valve should be affordable and a target of R800 at June 1986 price levels was set for the 250 mm diameter valve.

3.3 Note

During the research phase of the project it became apparent that the mechanism which had to be developed to meet the stated objectives, would not necessarily be a valve in the general concept of this term. To avoid confusion it was thus decided to adopt the term flow regulator when referring to the mechanism which had to be developed to meet the stated objectives.

4. THEORETICAL AND PRACTICAL ASPECTS OF FLOW CONTROL

4.1 The basic formulae and equations which are used in the text of this report are the standard formulae and equations which are used in general hydraulic and irrigation engineering design. Hence the proof of and reference to the origin of these formulae are not given but may be found in numerous handbooks on these subjects.

4.2 The basic objective of this project centered around the development of a practical and inexpensive method to control the flow rate through a dam outlet in such a manner that it will not be influenced by varying water depths in the dam. The accurate field measurement of flow and water head could be extremely difficult and such measurements would be considered to be of a high order of accuracy if they are within approximately 5%[(4)] of the values determined theoretically and/or by means of sophisticated calibration equipment. Liberty was taken to simplify the reading and understanding of the written text in stating equivalence in some formulae or derivatives thereof by using the equivalent (=) sign, even though this may only be approximately true and then only for the purpose intended. Such cases are identified by an asterisk (*).

4.3 The quantities used in the text, as well as tables and graphs, are generally stated in the units which are most often used in irrigation practice. Care should therefore be taken to convert such units to the basic, SI, metric units when using them in formulae.

4.4 The parameters which were used for calculation and reference purposes in the text are based on the project objectives in combination with other practical and field requirements, and are as follows:

(a) The balancing dam is considered to be an earth wall type with a crest width of 2,0 m and a relative water level (RL) of 3,00 m. Both the upstream and downstream embankment slopes are at gradients of 1,5 : 1 (see figure 4.1).

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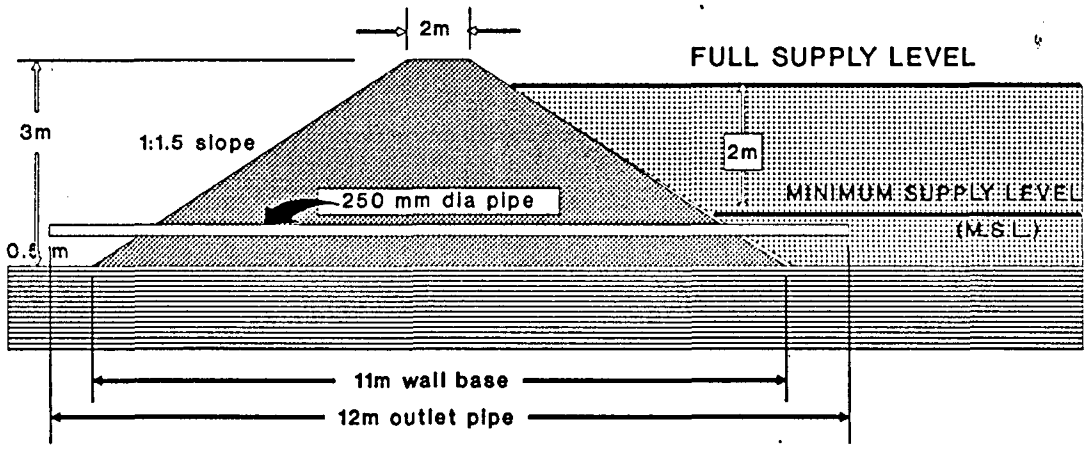

FIG. 4.1. CROSS SECTION OF A TYPICAL BALANCING DAM.

b) The dam outlet pipe is taken as 12,0 m in length with a nominal internal diameter (ID) of 250 mm, and is installed in such a manner that the external gate valve will be at a RL of 0,50 m, measured from the pipe centre.

(c) The FSL of the dam is taken as 2,75 m and the MSL is taken as 0,75 m, giving a total depth variation of 2,00 m or available water heads of 2,25 m and 0,25 m for hydraulic calculations.

(d) Pipe friction is calculated from the Lamont equation and other losses by using the equivalent pipe length method. In the latter case the shock inlet and outlet losses have respective coefficients of 22 and 45 and a value of 5 is taken for a fully open gate valve.

The dam outlet losses are thus calculated for a pipe length of 12m plus an equivalent pipe length allowing for losses of (22 + 45 + 5) x 0,25 = 18m (where 0,25 is the pipe diameter in m).

(e) The flow rate to be regulated is determined by the minimum available head of 0,25 m and is found to be 300m^3/h.

(f) Any flow greater than 300 m^3/h which will occur under a water head in excess of 0,25 m should be regulated automatically by the flow regulator and any smaller flow rate would have to be preset on the outlet mechanism.

(g) From the Bernoulli (8) equation it may be determined that the flow rate from a short level pipe under different heads, will vary by approximately the square root function of the head differential. $\{Q_1/Q_2 = (H_1/H_2)^{0,5}\}$*.

(h) To maintain a constant flow rate to within 10% of a required flow rate, the water head above the outlet should not fluctuate by more than 49%. ie: $\{(H_1/H)^{0,5} = 1,1Q/0,9Q\} = 1,22$ thus $H_1 = 1,49H$. From this it also follows that the head above the dam outlet should not fluctuate by more than 22,5 mm from 250 mm (i.e. MSL) to maintain a constant outflow rate of 300 m^3/h (± 10%) from a 250 mm outlet as described.

(i) To restrict the loss of irrigable land commanded by the dam to a minimum, the flow regulator should operate satisfactorily when water from the dam is delivered to land lying between the full and minimum supply levels of the dam, thus irrigating the land between these levels from the available head at the FSL.

This highest level of land is taken to be at a RL of 2,25 m in which 0,25 m has been allowed for the outlet losses already mentioned and 0,25 m for distribution head losses to the land edge.

(j) The required flow rate from the dam should be delivered automatically. Hence no manual manipulation of the regulator should be required during operation.

(k) The mechanism should be robust, capable of handling raw water, resistant to damage by inundation, be simple in operation for use by unskilled labour and the flow rate should be measurable. In the latter case, using the known volume of the dam and timing the outflow to determine this rate, is also considered acceptable if it is practical under field conditions.

[* See page 48 for a list of commonly used hydraulic equations.]

(l) The cost of the mechanism should not exceed R800 at June 1986 price levels or R1 500 at 1990 price levels and, in determining this cost, the cost of permanent civil structures is deemed to be excluded, forming part of the cost of the dam structure.

(m) These guidelines are primarily applicable to the practical situation and any deviation, as would be the case for laboratory tests, should be stated where necessary.

(n) It has not been deemed necessary to prove the practical application of the flow regulator in the field under all conditions, as laboratory methods were used which were repeatable. These laboratory tests were conducted at flow rates which coincided with the practical field flow rates which were required. Field tests could also not be undertaken to the same degree of accuracy as that of the laboratory tests unless major construction works were carried out, which was not included in the scope of this project.

5. FLOW CONTROL WITH VALVES

When this project was initiated it was known that many types of valves which were already commercially available, could theoretically be adapted for the required duty. Investigation into all these possibilities would however require fairly extensive and sophisticated laboratory and field research facilities, a fair amount of time and substantial financial assistance. The objectives of this project were thus defined fairly implicitly and basically around the further development of the so-called "Haise valve"[6] already used to a limited extent in South Africa. This research was effectively completed when it was proven in theory and in practice that a modified Haise valve could be used under most circumstances for the purpose intended. Hereafter the literature studies, field surveys and product research was extended to include other valve types which held possibilities for adaptation to suit the objectives. A new idea for flow control was developed, and became the prime objective of this research project. Further study into the use of existing valves for flow control was thus discontinued. The results of the research on the existing valves are nevertheless included in this report.

5.1 Types of valves

One of the main purposes of valves in pipelines is to regulate the flow of water by constricting the flow area. Several types of valve, operating on different principles, may be used for this purpose and a brief description and sketches of the more common valves follows (4):

Gate type: A sliding wedge shaped leaf, moving in side slots within the valve body and at 90° to the flow direction, is used. The movement is primarily a sliding action in combination with a screw or gear mechanism to facilitate operation (Fig 5.1A).

Butterfly type: This type of valve consists of a disc, mounted on a shaft within a valve body and bisecting the flow area. Shutoff is achieved by a rotary movement of the shaft through 90° (Fig 5.1B).

Needle type: A cone shaped tapered plunger (called the needle) moving axially within a nozzle forming part of the valve body, is used. The movement is primarily a sliding action in combination with a screw or gear mechanism or hydraulic power. The sliding action of the needle is automatically enhanced by a reduction in pressure, caused by the flowing water which tends to draw the needle into the nozzle (Figure 5.1C).

Globe type: A plug (as in a bath) or membrane, moving against a seat forming part of the valve body, is used. The flow direction is normally changed by 90° within the valve body and flow control is achieved by throttling the water. The plug may be moved by a screw or gear action or by hydraulic power. In the latter case a flexible membrane is often used in lieu of a plug (Fig 5.1D).

Ball type: A tapering cylinder or ball with a waterway through

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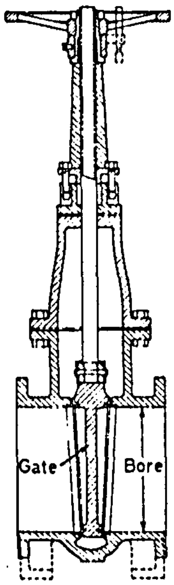
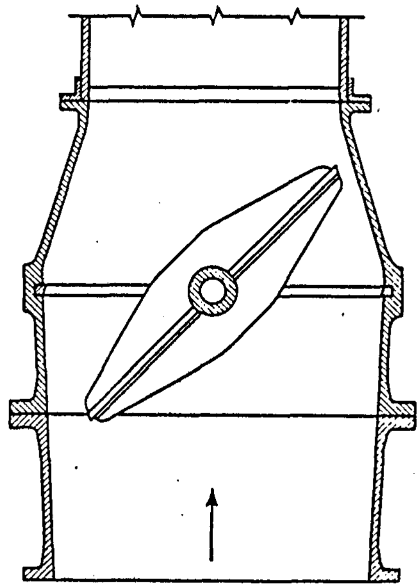
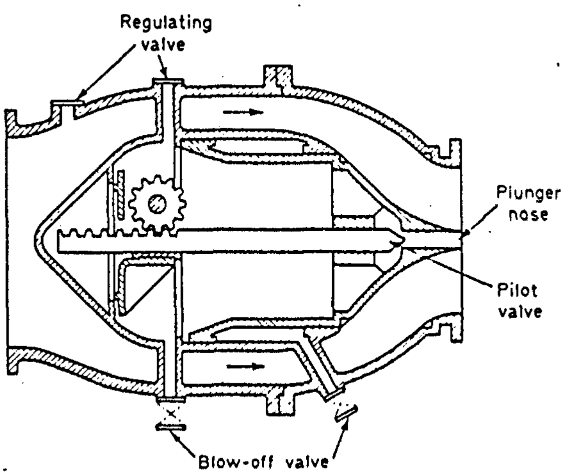


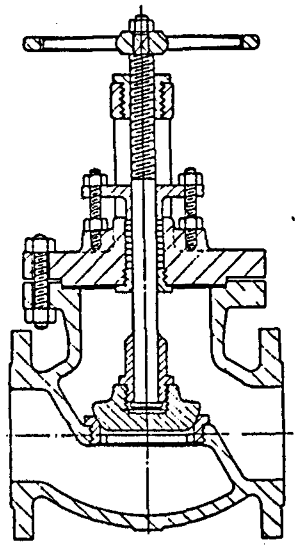
A: Sliding gate valve



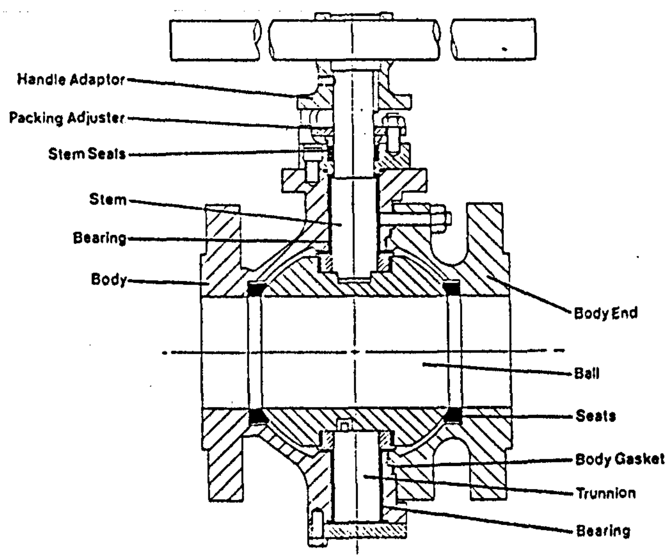
B: Butterfly valve



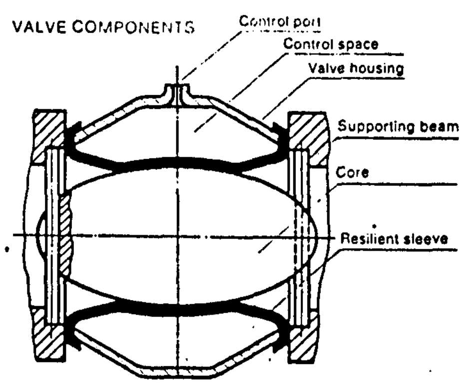
C: Needle valve



D. Globe valve



E: Ball valve



F: Pinch valve (Inball type)

FIGURE 5.1: BASIC VALVE TYPES

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its centre is mounted on a shaft and housed within a watertight seal within the valve body. In the fully open position the waterway is aligned with the pipe bore and rotary movement of the shaft through 90° shuts off the flow (Fig 5.1E).

Pinch type: In its most elementary form, this valve type is essentially a length of flexible pipe which, when compressed, will shut off the flow. In practice the flexible pipe is constricted around a cone set within the pipe bore. This valve can only be operated hydraulically, but is ideally suited to any type of automatic activating mechanism (Fig 5.1F).

5.2 Automatic operation of valves

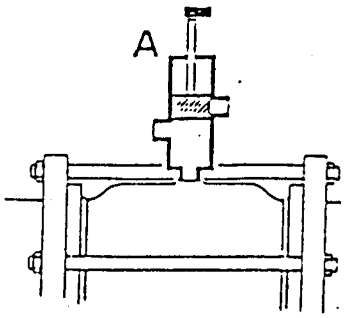
From the foregoing it follows that the operating element of a valve is basically moved either by a sliding or a rotating action or a combination thereof. This prime movement may in turn be coupled to a lever, piston, bellows, screw or gear mechanism to enhance the manual or mechanical operation of the valve.

Automatic operation is achieved by coupling the prime and/or secondary movements of a valve to a servo-motor, solenoid, hydraulic or pneumatic mechanism and the latter to a sensor unit. The sensor unit is triggered by sensing and reacting to a difference in water level or to hydraulic pressure, the latter case also including flow velocity actuation. An infinite number of combinations are thus possible for developing automatic valves to suit a particular purpose. (Fig 5.2)

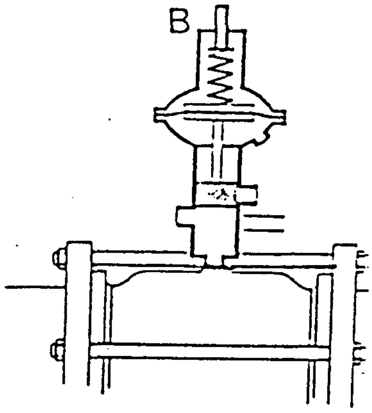
In the present case a combination of factors effectively ruled out the use of automated versions of the basic valve types for the purpose intended. Some of these factors are:

(a) The cost constraint.

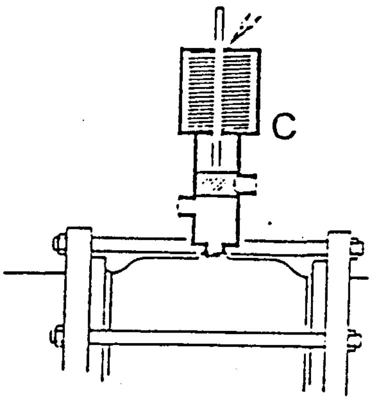
(b) High head losses in the valve mechanism.



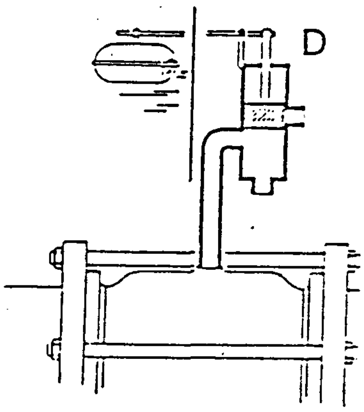
A: Manually operated, easy turning, open-close and throttling control clock.



B: Automatically operated by line pressure pilot valve.



C: Electrically operated, solenoid pilot valve.



D: Float operated control valve.

<u>FIGURE 5.2: VALVE ACTIVATORS</u>

(c) Inherent defects in the valve mechanism for effective flow control at very low pressures.

(d) The problem of adequately balancing the sensitivity of operation with inertia forces due to the mass to be activated.

(e) The use of electrically activated sensors and valve mechanisms is impractical for the purpose intended.

(f) The use of commercially available, hydraulically activated sensors is very limited due to the low heads available for operation.

(g) The use of a float type valve as water level sensor in the dam is impractical. When such a float valve is used below the dam, this application is limited to operating under free flow conditions, when irrigating land below the MSL of the dam.

The following table was compiled from several sources and is intended to merely illustrate some of the above statements. The hydraulic information given should not be used in calculations as the stated values in the available literature differ significantly.

TABLE 5.1: HYDRAULIC INFORMATION ON A NUMBER OF VALVE TYPES

DESCRIPTION	TYPE OF VALVE; 250 MM					
	GATE	BUTTERFLY	NEEDLE	GLOBE	BALL	PINCH
K-value for open valve	0,1-0,5	0,5-1,0	0,5-0,7	5,0-10,0	0,1-0,3	0,1
Suitability for shut-off only	Good	Fair	Good	Good	Good	Fair
Suitability for flow control	Fair	Fair	Good	Good	Poor	Good
Price for manual operation (R) at December 1989 price levels	2 348	1 167	4 000+	2 284	NA	4 086

5.3 The Haise Valve[6]

This valve was developed by Dr Howard Haise, formerly of the Colorado State University, to automatically control the outflow of water under low pressure for flood irrigation from a pipeline. Activated hydraulically by the low pressure in the pipeline, the application of this valve to automatically regulate the outflow of water from a small balancing dam is obvious. The current project was initiated with the object of adapting the valve for this purpose. The following description and diagram serves to illustrate the basic construction and operation of an adapted Haise type valve. (See figure 5.3)

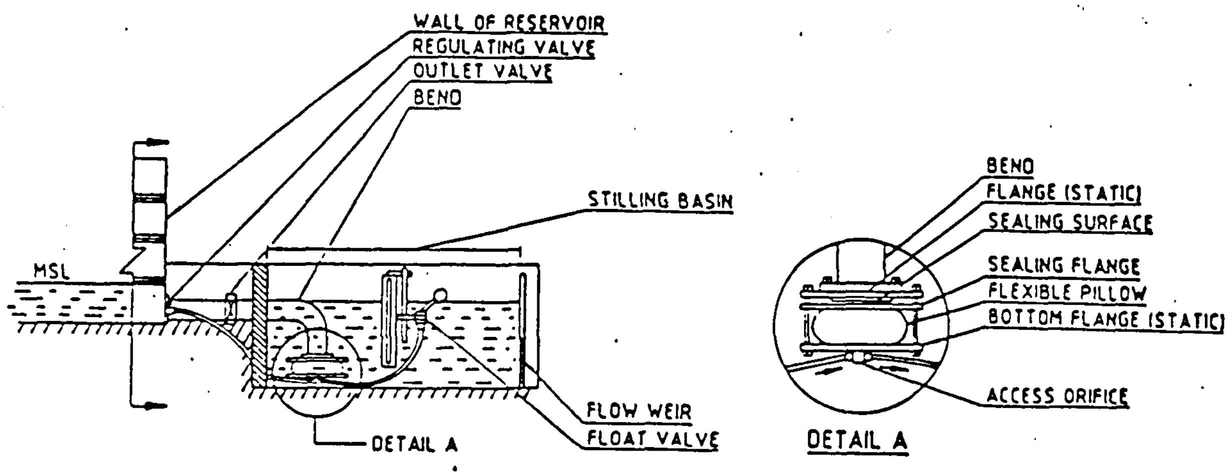


FIGURE 5.3: THE HAISE FLOW CONTROL VALVE

Construction of the valve

A 90° bend is fixed to the dam outlet with the open end facing downwards. To this is fixed a flange with the extended rim of the nozzle cut true to serve as a face for shutting off flow. Long, smooth-shanked bolts are firmly fixed to this flange and another smooth-faced, blank flange is slid onto these bolts to form a seal against the rim of the top flange. Gasket material may be bonded to the flange to improve watertight closure. An inflatable, pillow-shaped flexible membrane, with an access nozzle for inflation, is fitted into the cage formed by the bolts and kept in place by a third flange, firmly fixed to the bottom of the bolts. The dimensions of the flanges and the spaces between them will depend on the size of the outlet pipe and of the pillow in the inflated and deflated state and these dimensions must be determined experimentally.

The pillow is inflated by water pressure tapped from the dam outlet pipe upstream of the outlet valve and deflated by releasing water from the pillow through a float valve, actuated by a regulating water level in the stilling basin of a flow gauging weir located in the headworks of the canal serving the area to be flood irrigated.

Operation of the Haise valve

The operation of the valve can be explained by hydrostatic principles (4). From hydrostatics it is known that the force (F) exerted to the base of a column of water, is expressed by the equation:

$$F = \Gamma \times g \times H \times A \quad \text{............................ eq 5.1}$$

where F = Force in Newton (N)

Γ = Density of water (Taken as 1 000 kg/m^3)

g = Acceleration due to gravity (9,81 m/s^2)

H = Head of water (m)

A = Base area (m^2)

Substituting in the above

F_1 = Force exerted from outlet nozzle to top of sliding flange

F_2 = Force exerted to bottom of flange by inflated pillow

A_1 = Area of nozzle

A_2 = Area of inflated pillow

H = Head of water in dam

Γ & g= Constant, by definition.

Consider that the water flowing to the pillow is tapped off the outlet pipe just above the outlet nozzle and that the thickness of the pillow could be disregarded. The effective head of water on either side of the flange is then = H. To keep the flange closed (flow shut-off) the force $F_2 > F_1$ and this can only be achieved if $A_2 > A_1$.

This is indeed the case where the area of the pillow is greater than the nozzle area.

Tests which were conducted by Haise during the development of the valve indicated that the area of the sliding flange and the pillow should be at least 30% greater than the area of the outlet nozzle.

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Releasing water from the pillow at a flow rate greater than the rate of inflow to the pillow, will cause the pillow to deflate and release water from the nozzle. This open-close operation is automatically regulated by a float valve.

The rate of outflow from the balancing dam outlet is determined by measuring the depth of water flowing over the crest of the gauging weir installed in the headworks of the canal system for this purpose. This water level is converted to a flow rate by using appropriate formulae or tables. In this manner the level of water required at the weir in order to pass a predetermined flow rate from the dam over the weir and into the canal system below it, could be determined.

The height of the float valve at the gauging weir is adjusted by trial and error, to close when the actual flow rate from the outlet exceeds the required flow rate. This causes the pillow to inflate and shut off the flow of water. The float valve will release water as the water level drops and, in this manner, a fairly constant flow rate could be maintained. The accuracy to which this flow rate could be maintained is obviously related to the accuracy to which a constant water level in the stilling basin could be regulated, and the rate at which the water could inflate or deflate the pillow. The following advantages could be obtained if the greatest possible difference in water level is available for regulating the flow rate.

(a) The correct setting of the float valve would not be critical.
(b) The valve itself need not be unduly sensitive.
(c) Ripples on the water surface would not cause unnecessary activation.
(d) The cost of the civil works would be reduced to a minimum.

These benefits would, however, have to be considered against the disadvantage of the head loss incurred at the different water levels.

Three prototypes of this valve were manufactured and installed for field tests on farms in the Vaalharts Government Water Scheme near Kimberley.

The valves operated as anticipated but further research into refining the mechanism was discontinued for the following reasons:

(a) The mechanism was not generally acceptable to the farmer but no specific and valid reasons for this could be found. Objections were however stated on the need to construct a stilling basin and measuring weir.

(b) Unacceptable differences in excess of 10% in outflow were noticed. This could possibly be rectified by regulating the inflow to and outflow from the pillow more effectively.

(c) The mechanism will only operate under free flow conditions, that is, when the highest level of the land to be irrigated is at an elevation below the inlet to the canal.

Conclusions

(a) The modified Haise type valve described here, could be used to control the outflow rate of water from a balancing dam automatically if the bottom of the dam is higher than the land, but differences in outflow were unacceptable.

(b) The operation of the valve is based on the fundamental principle of counteracting the force exerted by the water on the closing plate of the valve, by a larger force acting in the opposite direction. For this reason it is not deemed necessary to provide data and design details of these valves to suit all conditions.

(c) Any innovative person with access to limited workshop facilities could construct the valve mechanism described to suit his particular requirements.

(d) The design of the civil work required at the dam outlet, including the correct choice of gauging weir, is best left to a competent designer.

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5.4 The needle valve[8]

The needle type valve is ideally suited to control the flow of water within or emerging from a pipeline. During this project limited research and experiments were conducted with this valve merely to determine in which manner this valve could possibly be adapted for the required purposes.

The control of the valve (shown in figure 5.4) is effected by moving a cone shaped plunger (called the needle) axially within a nozzle to reduce the flow area. The flow passage through the valve remains streamlined throughout the open-to-close movement, thereby reducing turbulence and resulting in low head losses and a favorable flow rate to movement ratio. Operation of the valve is enhanced by the fact that, upon closure, the flow velocity between the needle and nozzle will increase to cause a reduction in pressure tending to draw the needle into the nozzle and thus reducing the closing effort. This velocity actuation feature of the valve was recognized as a possible means for automatic valve control to regulate a constant flow rate under varying heads upstream from the valve.

By applying the Bernoulli and other basic flow continuity equations to a system consisting of water in a dam being released through a needle valve, it may be shown that the pressure in the nozzle section of the valve will decrease with an increase in head and thus also of flow. This decreased pressure tends to draw the needle into the nozzle as already stated. By controlling the axial movement of the needle through a retarding spring, it should thus be possible to maintain a constant flow rate through the valve automatically. The relationship between the rate of travel of the needle with pressure variation is however not linear, hence a variable spring tension would be required to operate the mechanism.

Tests were conducted to determine the required spring tensions for varying operating conditions. Difficulties were experienced in controlling the needle movement effectively under operating heads of between 1 and 2 meters, due to the very limited movement of only a few millimetres of the needle at these heads. The travelling distance of the needle increased at operating heads which varied between 0,3 and 0,5 meters and flow control was also improved.

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Further research was discontinued due to the cost constraint which limited further research on the development of such a flow control mechanism.

5.5 General comment

During the literature study it was found that the hydraulic data quoted on valves in authoritative handbooks (4, 5 and 8) and manuals differed remarkably, and it would appear that further research in this regard would be warranted. (See table 5.1 page 19).

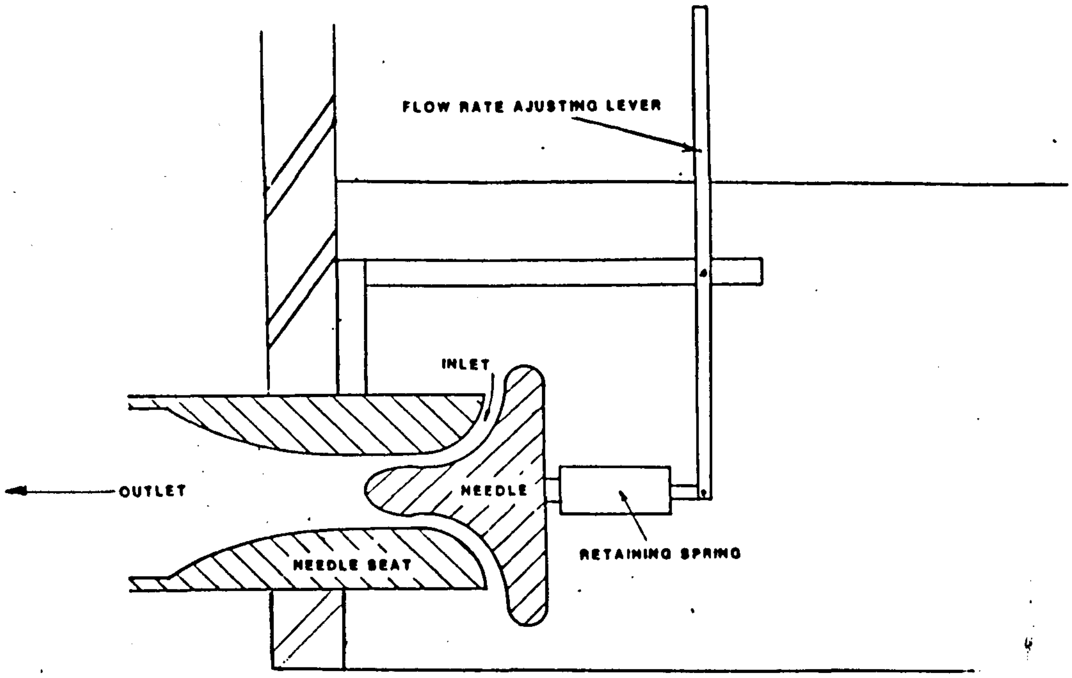

Figure 5.4: DETAIL OF NEEDLE VALVE

6. FLOATING ORIFICE PRINCIPLE

The fact that a normal 250 mm cast iron gate valve, used to control water manually, cost R1 500 in 1987, meant that any modification of such a valve would naturally raise the total cost to a much higher level than the then specified cost limitation of R800. The principle of a modified valve was thus not economically viable and had to be discarded.

The principle which was adopted, and on which this report is based, consists of the use of a submerged nozzle just below the water surface in the dam at the one end of an inclined pipe which in turn is connected to the dam outlet. The idea behind this principle is to keep the free flowing nozzle at a constant depth beneath the surface of the water in the dam, thereby creating a constant rate of discharge. The nozzle discharge point must be free flowing and should not be submerged.

It could be expected that siphoning would take place and that the flow rate would increase as the dam water level rises. To eliminate this problem a vent pipe is used at the nozzle housing so that the inclined connecting pipe actually serves as an enclosed canal, and not as a siphon.

The size of the float which supports this nozzle should be sufficient to keep the nozzle at a constant submerged depth, irrespective of the water level of the dam, while the flow depth in the pipe, and therefore its mass, would vary as the inclination of the pipe varies in accordance with the depth of water in the dam.

The following illustrations (Fig 6.1 to 6.6) give an idea of the lay-out of this system.

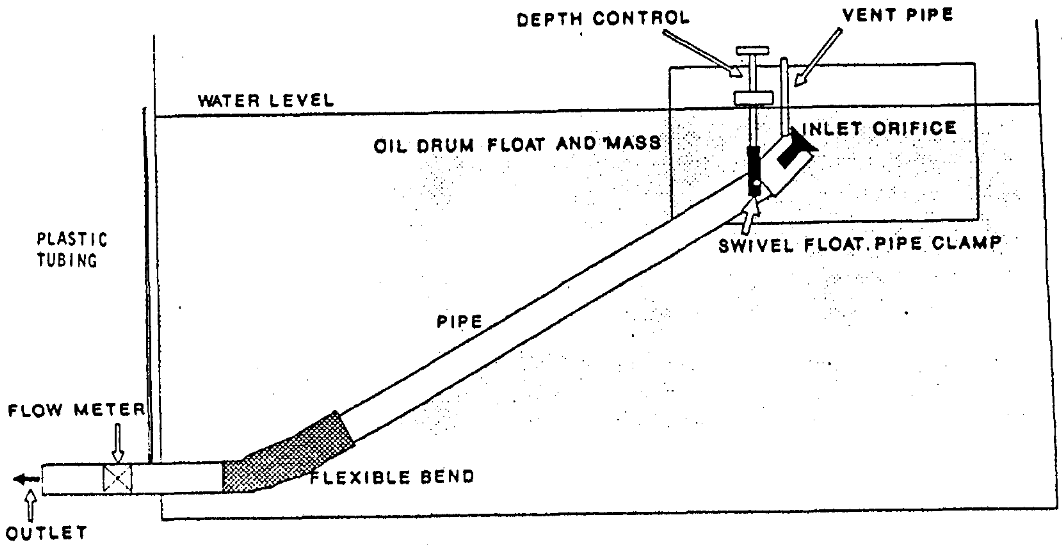

Figure 6.1: SCHEMATIC CONFIGURATION OF FLOATING NOZZLE PRINCIPLE

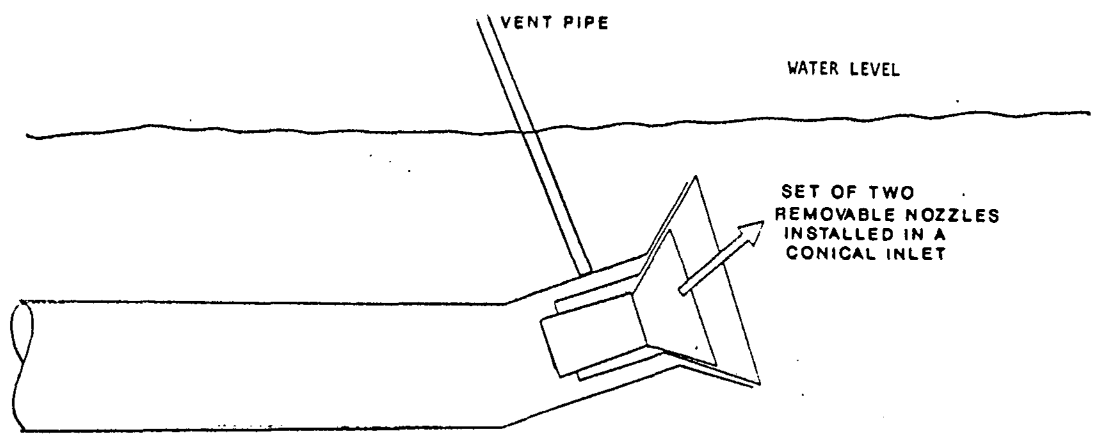

Figure 6.2: NOZZLE, INLET AND VENT PIPE DETAIL.

The arrangement in Fig 6.2 will cope with three flow ranges, ie that of the formed pipe and of the two separately installed nozzles of smaller sizes than the pipe diameter.

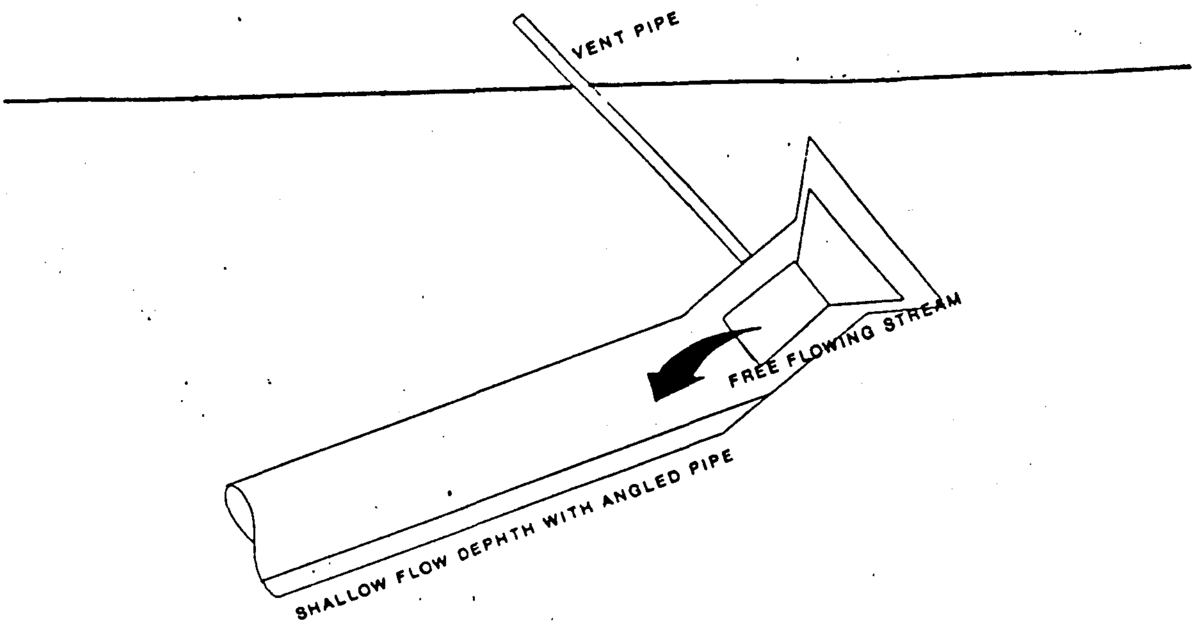

Figure 6.3: ILLUSTRATION OF THE NOZZLE FLOW WHEN THE DAM IS FULL

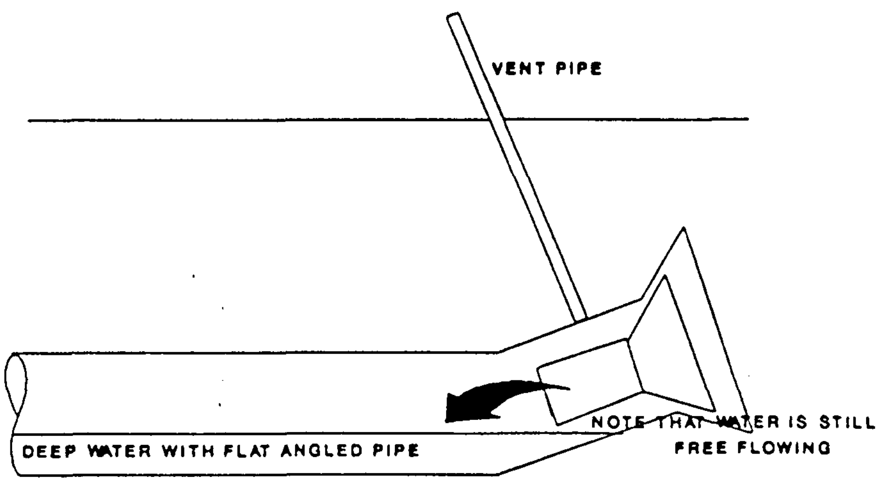

Figure 6.4: ILLUSTRATION OF THE NOZZLE FLOW WHEN THE DAM IS NEAR ITS MSL.

NOTE THE FREE FLOWING CONDITIONS FROM THE ORIFICE INTO THE CONNECTING PIPE OR THE SO-CALLED CANAL.

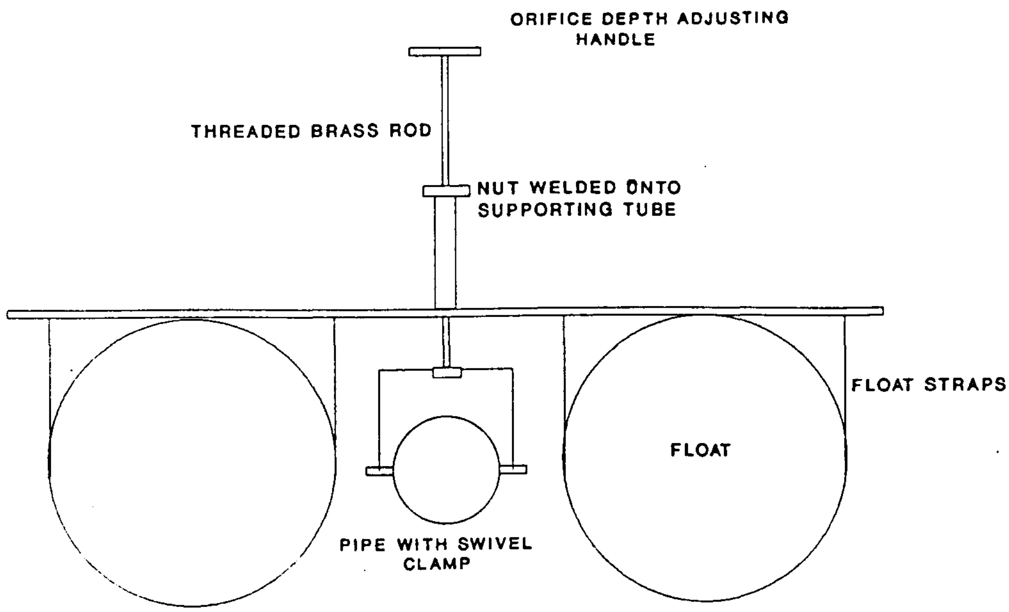

Figure 6.5: END VIEW OF FLOAT AND CLAMPS.

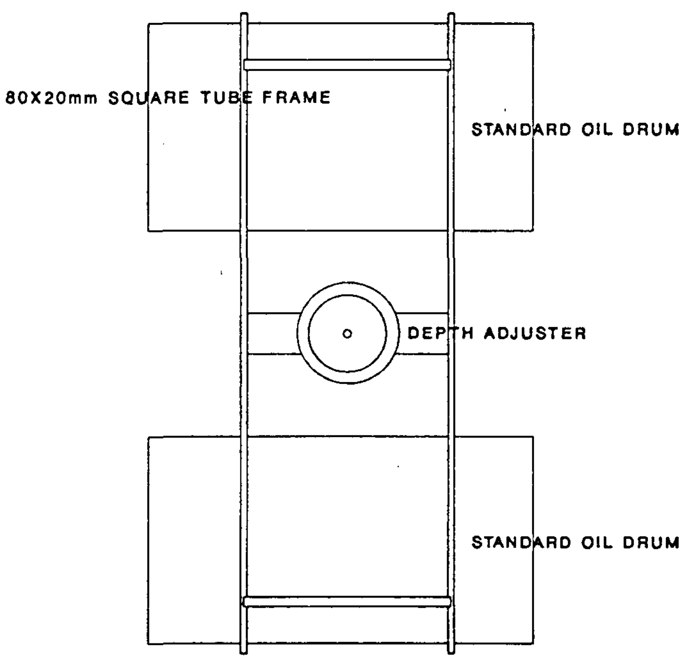

Figure 6.6: PLAN VIEW OF FRAME AND FLOAT.

6.1 Vortices

Tests indicated that vortex formation at the inlet could be a problem due to the relatively high flow velocity when the pipe is flowing at full capacity. The nozzle inlet should ideally be bell-mouthed, or at least conical, to reduce the inlet velocity and thus the incidence of vortex formation. It was found that the influence of vortices could be reduced by breaking them up into smaller vortices by placing a 6 mm wire mesh at the water surface above the nozzle.

A literature study indicated that it was extremely difficult to predict the action of vortices and that it would be simpler to attempt to eliminate them or to reduce the influence that they may have by using the above precautions.

6.2 Orifices

Observations during the initial tests indicated that the diameter of the nozzle should not be more than half the diameter of the pipe used so that the pipe will only flow 20% full. The reason for this requirement centres around the requirement that the nozzle needs a free discharge for predictable flows. The alternative, which was employed in the design after some trial and error observations, was to incorporate a slight upward bend at the end of the pipe where the nozzle was installed.

The use of conical or bell mouthed nozzles (in order to reduce the formation of vortices) could lead to an increase of 17% in the flow rate through the nozzle as compared to a sharp edged orifice (5).

The size of a conical nozzle for a particular flow rate can be calculated from the following well known relationship:

$$Q = CAV \quad \text{..................................eq 6.1, where}$$

Q = Flow rate in m^3/s
C = Discharge Coefficient (approximately 1 for a conical nozzle.)
A = Discharge area of the nozzle in m^2.
V = Flow Velocity in m/s (= $(2*g*h)^{0,5}$).
g = acceleration due to gravity = 9,81 m/s^2.
h = Depth of submergence in m.

Example

What would the flow rate be through a 130 mm conical nozzle when submerged to a depth of 400 mm?

$$Q = CAV$$
$$= 1 * 3{,}1416 * (0{,}065)^2 * (2*9{,}81*0{,}4)^{0{,}5}\ m^3/s$$
$$\text{or} = 133{,}86\ m^3/h$$

A range of sizes is presented in graphical format in fig 6.7 for ready reference.

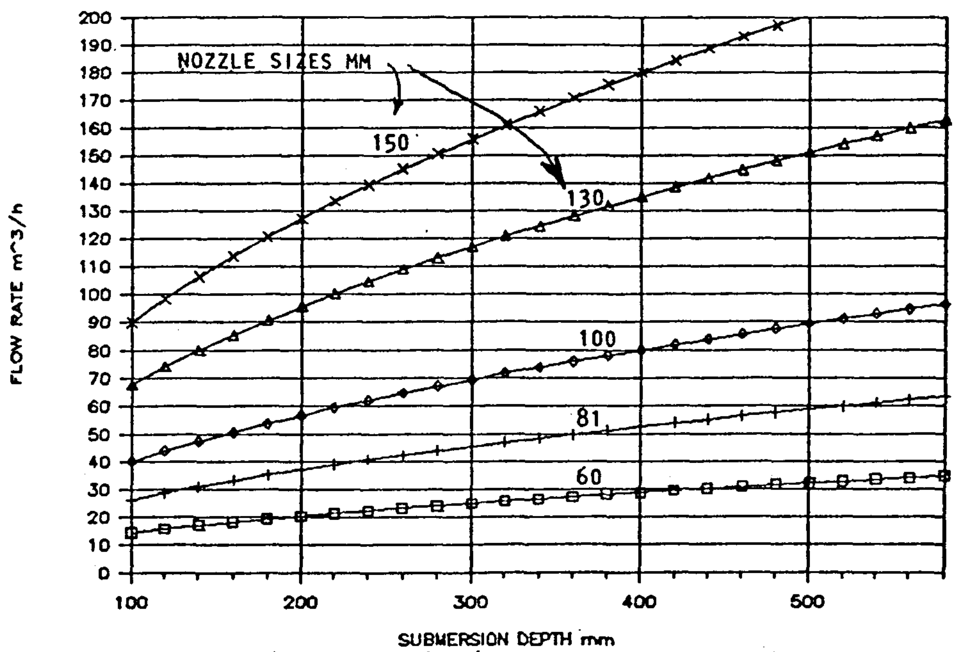

Figure 6.7: DISCHARGE CHARACTERISTICS OF CONICAL NOZZLES UNDER VARYING SUBMERSION DEPTHS

6.3 Pipes as canals

Originally a flexible pipe was used to connect the nozzle unit to the dam outlet. This flexible pipe, however, gave unsatisfactory results. The reason for these unsatisfactory results were found to be trapped air, some of which was drawn into the pipe through the formation of vortices, as it was only acting as an enclosed canal. The flexibility of the pipe and the

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trapped air along with the moving water lead to uncontrolled movement of the pipe itself. It was subsequently decided that the pipe should be rigid in order to direct any air entrapped in this enclosed canal through the vent pipe. Fiber cement, UPVC, steel or any other suitable material may be used for the pipe. UPVC pipe was used in the research because of its lightness and workability.

6.4 Float size

It is to be expected that, with the nozzle at the high water level, the depth of flow of the water in the pipe will be less than would be the case when the nozzle is at the lowest water level position. The reason for the variance in the flow depth could be found in the fact that the slope of the enclosed canal at high water levels, will be larger than at the low water level. The difference in flow depth could result in a buoyancy differential at the different slopes of the pipe which will in turn affect the depth of the nozzle beneath the surface of the water and hence the flow through the nozzle itself. As already indicated, the design should be such that the pipe will never flow full, ie it must act as an enclosed circular canal, well-ventilated by the vent at the inlet.

The size of the float must therefore be of such a magnitude that it could create sufficient buoyancy to keep the nozzle under the water surface at practically the same level regardless of the level of the water in the dam.

The depth of water flow in the pipe had to be determined in order to predict the balancing mass as well as the required float size. The following basic Chezy formulae for canal flow, were used for these calculations:

$$A = (D^2/8) * (B - \sin B) \quad \text{.......... eq 6.2}$$

$$P = (D / 2) * B \quad \text{.......... eq 6.3}$$

$$R = (D / 4) * \left(1 - \frac{\sin B}{B}\right) \quad \text{.......... eq 6.4}$$

$$V = (R^{0,667} * S^{0,5})/n \quad \text{.......... eq 6.5}$$

$$Q = A * V \quad \text{.......... eq 6.6}$$

$$\text{Flow depth} = (D/2) * [1 - \cos (B / 2)] \text{ in meters} \quad \text{.......... eq 6.7}$$

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Where A = Flow area in m^2

P = Wetted perimeter in m

B = Subtended angle of flow in radians

R = Hydraulic radius in m

V = Velocity in m/s

Q = Flow rate in m^3/s

S = Slope of the canal (m/m)

n = Manning's coefficient of roughness, taken as 0,009 for UPVC pipe in these calculations.

D = Internal pipe diameter in m

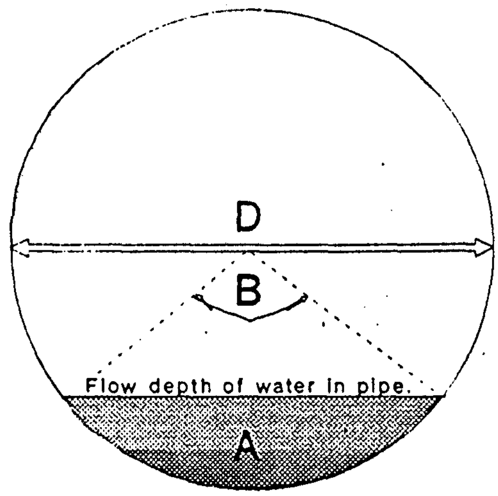

Figure 6.8: ILLUSTRATION OF SYMBOLS USED

Example

The buoyancy or upward thrust exerted on a submerged 160 mm UPVC pipe with an internal diameter of 150 mm, 6 m long when inclined at a 3% slope for a flow rate of 70 m^3/h can be calculated as follows:

Using equations 6.2, 6.4, 6.5 and 6.6, the value of B is determined as 3,1 radians through an iteration procedure, using the following values, i.e.

D = 0,15 m

n = 0,009

S = 3/100

Q = 70/3600 m^3/s

Flow depth (in m) is $= D/2 * [1 - \cos(B/2)] = \frac{150}{2} \times [1 - \cos(\frac{3,1}{2})]$

$= 73,44$ mm

or $= 73$ mm (see point M in Fig 6.9)

The area of flow $A = 0,008602$ m^2 (using eq 6.2)

The internal area of the pipe is $= 3,1416\ D^2/4$ m^2
$= 0,017671$ m^2

Thus the area of air in the pipe is $= 0,009069$ m^2

The buoyancy of a 6 m pipe, when the wall thickness material is ignored (In this case UPVC pipe has almost unit density) will be

= 0,009069 * 6 * 1000 kg
= 54,44 kg (See point N in Fig 6.9)

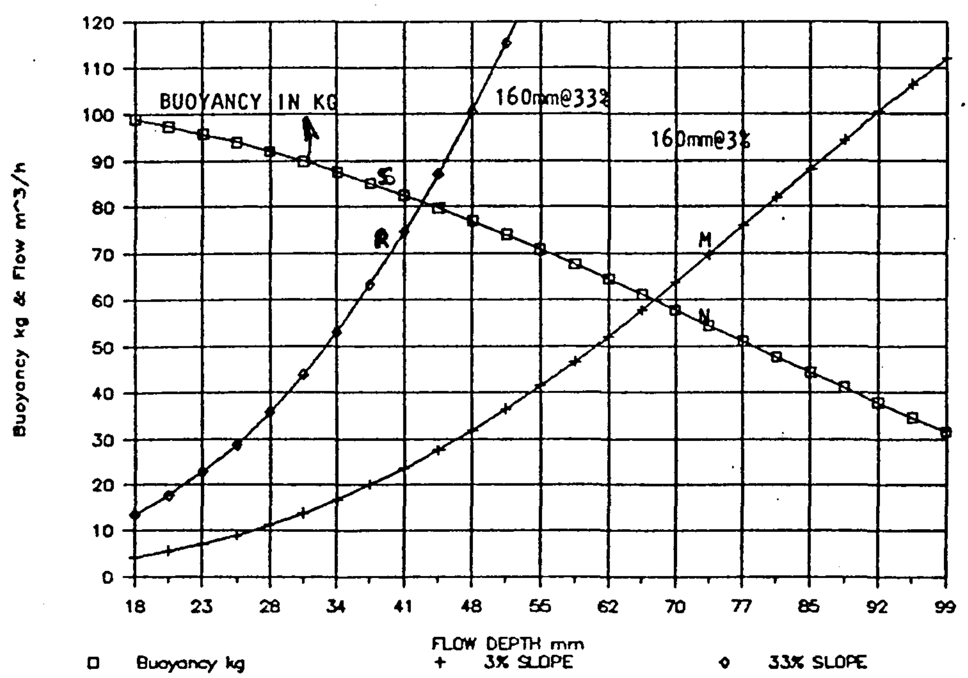

Figure 6.9: BUOYANCY AND DISCHARGE CHARACTERISTICS OF A 160 MM PIPES AT 3% AND 33% SLOPES

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To determine the size of the float, the depth at which the nozzle is to be submerged for the required flow rate, as well as the difference in buoyancy mass that the float has to support between the high water level and the low water level, should be used in the calculations. Furthermore, to achieve an accuracy of control of say 10% in the flow rate, where the depth of submergence is say 200 mm, the area of the float should be such that the depth will not vary by more than approximately 42 mm, as is calculated from the following basic relationship:

$$Q_1/Q_2 = (H_1/H_2)^{0,5}$$
$$H_2 = (Q_2/Q_1)^2 * H_1$$
$$= (1,1/1)^2 * 200$$
$$= 242 \text{ mm}$$

The permissible maximum depth variation is thus 242 - 200
= 42 mm

In the above example the flow depth and balancing force of the pipe at a slope of 3% was determined. The same calculations may be made for a slope of 33% and a flow rate of 70 m^3/h. From Fig 6.9 it could be determined that the flow depth is 39mm at point R and, reading from the flow depth it could be noted that the expected buoyancy will be 84 kg. (Point S).

The float area must therefore be sufficient to ensure that the difference of the buoyancy between 84 kg and 54 kg (which is 30 kg) will keep the float within the prescribed depth variation of 42 mm for pipe slopes between 3% and 33%.

This buoyancy which acts on the whole length of the pipe will however have to be supported by the float and the hinge connecting the pipe to the dam outlet. The float should therefore have a mass of approximately 30/2 = 15 kg.

The size of the float can be calculated as follows:

Mass = Volume * Density, and
Volume = Area * Height
Assuming water has a density of 1000 kg/m^3, we find

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$$15 = \text{Area} * \frac{42}{1\ 000} * 1\ 000$$

$$\text{Area} = 15/42 = 0{,}36\ m^2$$

For practical reasons a standard oil drum, which is normally available, may be looked at as a possible float.

A standard oil drum is 0,6 m in diameter and 0,9 m high, giving a maximum area of 0,54 m^2

Therefore one drum half full of water, lying on its side, is sufficient as 0,54 m^2 is greater than the 0,36 m^2 required.

The shut-off requirement of the valve, as stated in the original requirements, could be obtained by lifting the pipe so that the nozzle will be out of the water resulting in an empty pipe. To ensure that the whole float mechanism is not lifted out of the water completely it should be heavy enough to hold at least half of the empty pipe under water. In our example this will require a mass of:

$$3{,}1416 * (D^2/4) * L * 1000 = 3{,}1416\ (0{,}15^2\ /\ 4) * 6 * 1\ 000 = 106\ kg$$

The mass of a drum half filled with water

$$\text{is}\quad 3{,}1416\ (0{,}6)^2/4 * \frac{0{,}9}{2} \times 1\ 000 = 127\ kg.$$

These calculations are based on a 10% differential in flow rate through the mechanism. Where a smaller differential in flow rate is required, ie 5%, the same calculations could be made and it will be found that two drums would be sufficient to meet the requirements. Should the float have a larger area than required in the calculation, the accuracy of flow control would naturally be superior.

6.5 Swivel connection

The pipe is connected to the outlet of the dam by means of a flexible tube, acting as a swivel connection, the stiffness of which should be such that it would not affect the buoyancy of the float supporting the nozzle. The flexible tube should, on the other hand, also have sufficient shear strength to withstand the lifting action of the pipe when it is only flowing partially full, or when it is empty and in the shut-off position. The last requirement of the flexible tube is that it should be able to allow a 90° turn, so that the whole mechanism could be pulled to the side of the dam wall for access if the flow rate has to be adjusted through the replacement of the different nozzles (that is if one assumes that the outlet is in the middle of the one wall of the dam).

7. TEST PROCEDURE

Monitoring operations

The tests were conducted at the Department of Agricultural Engineering at the University of Pretoria. Initially the test results were manually recorded by using the magnetic flow meter, and the water level was read from scaled transparent plastic tubing. (See Fig. 6.1)

It was found, however, that many readings had to be taken at different water flow depths, different nozzle depths under the water surface, different water levels in the test tank and at different back pressures caused by flow restriction of the magnetic flow meter. It was subsequently decided to computerize the monitoring operations. A 20 kPa pressure transducer was purchased along with the necessary analog to digital cards, and all the subsequent pressure readings and flow rate monitoring were done by the computer.

The test results, as depicted in the following graphs of some of the tests, were gathered in a matter of minutes due to the relatively high flow rates of 10 to 50 m^3/h and the relatively small testing tank (12 m^3 of which only about 50% could be utilized. Each point depicted on the curves is the average of 100 readings recorded.

Due to the short duration of the tests and the relatively high flow rates, wave action was picked up by the sensors which manifested itself as apparent uneven flows in some of the graphs. (The word "apparent" is used here, because averages obtained from repeated tests showed that the average flow rates were much smoother). The results were stored on disc and reworked with the aid of a spread sheet.

Procedure

For a specific set of conditions such as nozzle size and submergence depth, preliminary observations were made to ensure that this depth was maintained.

All the measuring units were then checked for correctness of operation and water was pumped into the tank. As the level in the tank dropped, the pump was switched off and the tank was emptied. This data was then rearranged with a worksheet and the graphs, as depicted on the following pages, were plotted.

The maximum depth of water in the tank did not reach 2 m as would have been preferable when starting from the minimum recordable depth in the tank. The reason for this is that the size of the water sump which was used was less than the volume of the tank. It was noted, however, that flow rate variations at 1 m to 2 m depths were less than the variations in flow rate for measurements at depths of under 1 m. This could once again be ascribed to the fact that the action of wave motion in the half full tank was more severe than the wave motion in a full tank. Another point to be considered is that the flow rate variances should be more from minimum to 1 m depth than they would be from 1 m to 2 m as the flow passages through the nozzle and enclosed canal would be more critical at the shallower depths as was discussed earlier.

Water was pumped from the sump into the container, and flowed through the submerged nozzle and pipe via the flexible bend and flow meter back into the sump. The water level in the container as well as the flow rate and back pressure of the water at the flow meter were recorded simultaneously by the computer. The data was subsequently reworked in graphic form, and averages of 100 readings each are depicted on the following pages. A full cycle, where readings were taken from empty to maximum depths in the container, took 3 to 10 minutes to complete.

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8. TEST RESULTS

Fig. 8.1 shows the discharge through the floating nozzle at different water depths in the tank where no vent is used. The pipe simply acts as a siphon where the flow rate increases with the height of the water in the tank as well as the nozzle size. This increase in flow rate results in vortices being formed, resulting in suction spurts and unpredictable flow rates. After the pipe reached a slope where the flow out of the nozzle was of a free flowing nature the flow became controlled. (Point A, Fig.8.1) At larger depths the influence of suction leads to increased flow (Point B) in the absence of a vent pipe.

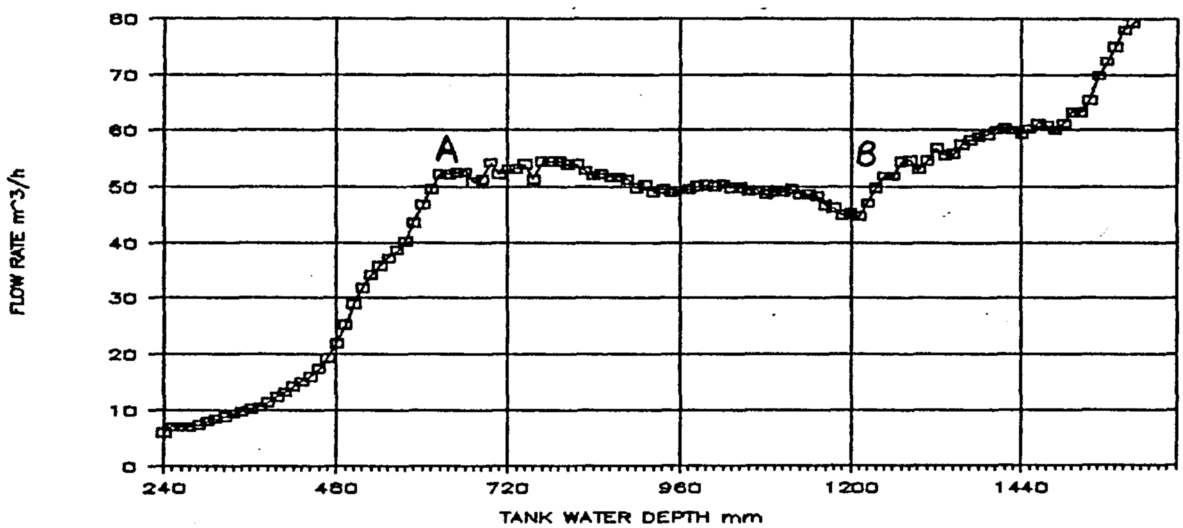

Figure 8.1: DISCHARGE THROUGH AN 80 MM NOZZLE, 150 MM DEEP, WITH NO VENT PIPE.

Fig. 8.2 illustrates the flow rate at different tank water depths with a nozzle which has been placed in line with the centre line of the pipe and not SET at an upward angle as recommended. The initial discharge through the nozzle which is partially submerged and the flow rate increases very gradually after point A with an increase in the depth of the water in the tank. At point B (Fig. 8.2) the nozzle is free flowing and the flow rate is controlled. To ensure that free-flow occurs over a wider range of slopes the nozzle should not be mounted in line with the centre of the pipe, but at a slight angle. An elevated position could be obtained through a slight upward bend in the pipe which will ensure that the water will always discharge freely into the pipe, even when the pipe is almost horizontal.

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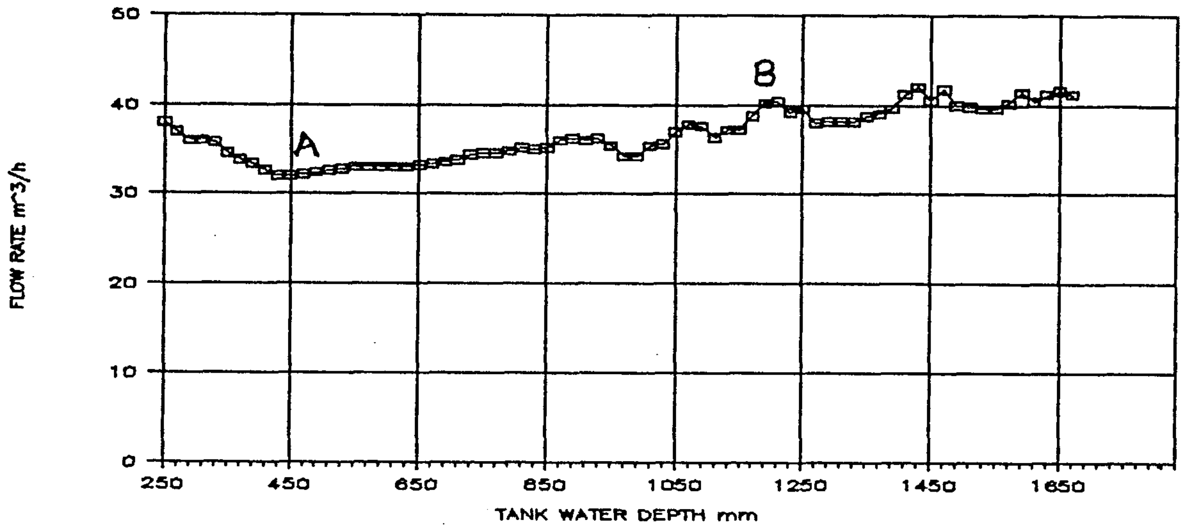

Figure 8.2: TYPICAL DISCHARGE CHARACTERISTICS OF A 60 MM NOZZLE, 300 MM DEEP WHEN THE NOZZLE IS IN LINE WITH THE CENTRE OF THE PIPE.

Fig. 8.3 illustrates the discharge characteristics at different tank water depths under conditions where the float mass is not sufficient to keep the nozzle at a constant depth. The buoyancy of the pipe under increased water depths in the tank will tend to lift the nozzle closer to the water surface and the flow of water through the nozzle is thus reduced after point X.

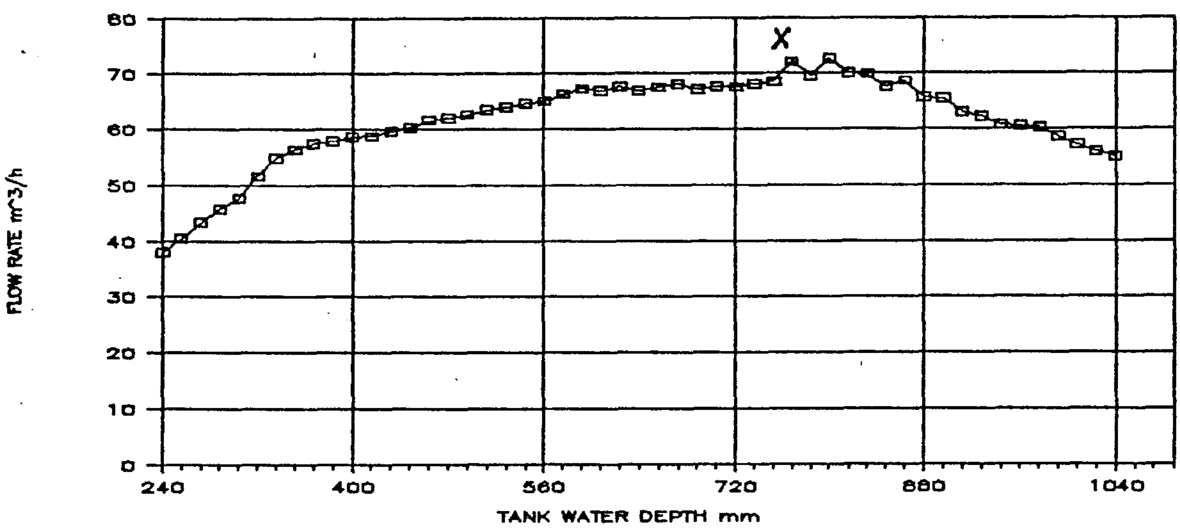

Figure 8.3: DISCHARGE CHARACTERISTICS OF 150 MM NOZZLE, 250 MM DEEP, WITH INSUFFICIENT FLOAT MASS

Figures 8.4 to 8.7 illustrate that the floating nozzle discharge mechanism could satisfy the conditions specified in paragraph 3.2, page 9. 60 mm and 81 mm floating nozzles were mounted in a 4 m UPVC pipe of 160 mm diameter, and tested in the laboratory test unit at various depths.

In Fig 8.4, for example, control at a discharge of 20 m^3/h was achieved between 370 mm and 1350 mm water depth in the tank. Figure A1 in the appendix indicates that the 60 mm nozzle should theoretically discharge 20 m^3/h at 200 mm depth. Figure A7 indicates that with the 160 mm pipe at a 3% slope, the subtended angle was 2,1 radians (point A) and that the mass required to keep this pipe under water would be 85 kg in the case of a 6 m pipe. (Point B).

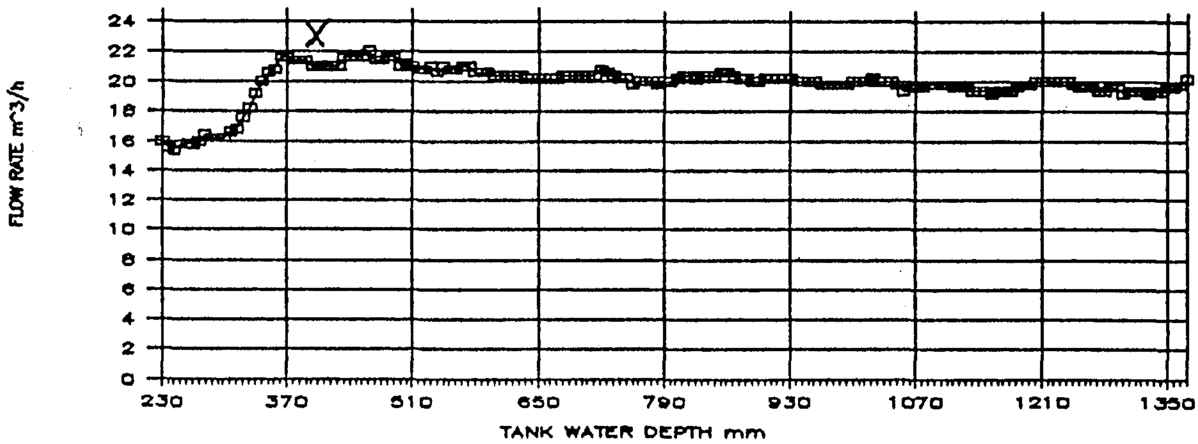

Fig. 8.4: DISCHARGE CHARACTERISTICS OF A 60 MM FLOATING NOZZLE IN A 160 MM PIPE AT A DEPTH OF 150 MM. (FLOAT MASS ADEQUATE.)

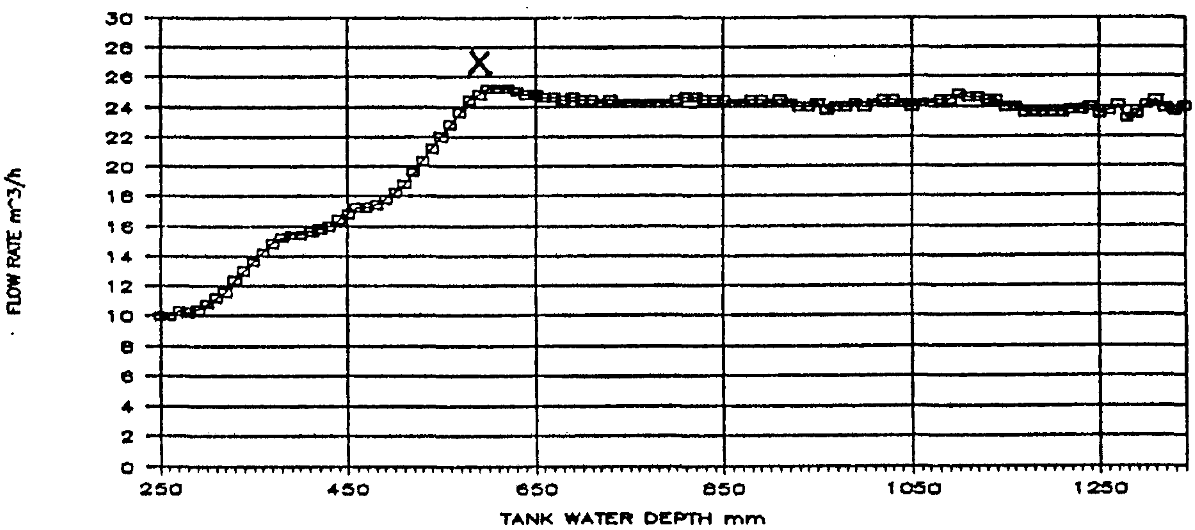

Fig. 8.5: DISCHARGE CHARACTERISTICS OF A 60 MM FLOATING NOZZLE IN A 160 MM PIPE AT A DEPTH OF 250 MM. (FLOAT MASS ADEQUATE.)

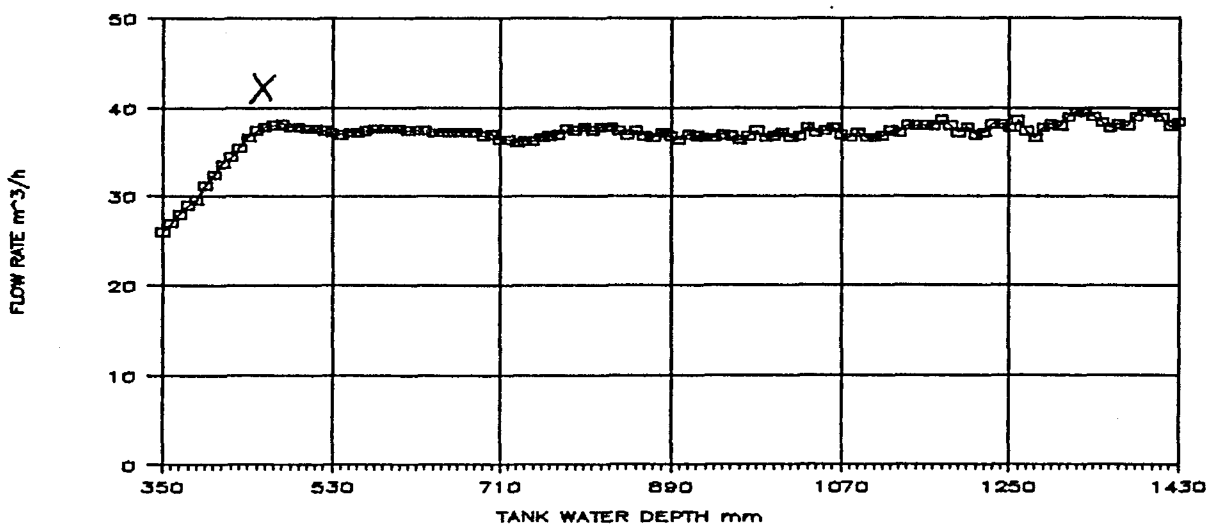

Fig 8.6: DISCHARGE CHARACTERISTICS OF AN 80 MM FLOATING NOZZLE IN A 160 MM PIPE AT A DEPTH OF 150 MM. (FLOAT MASS ADEQUATE.)

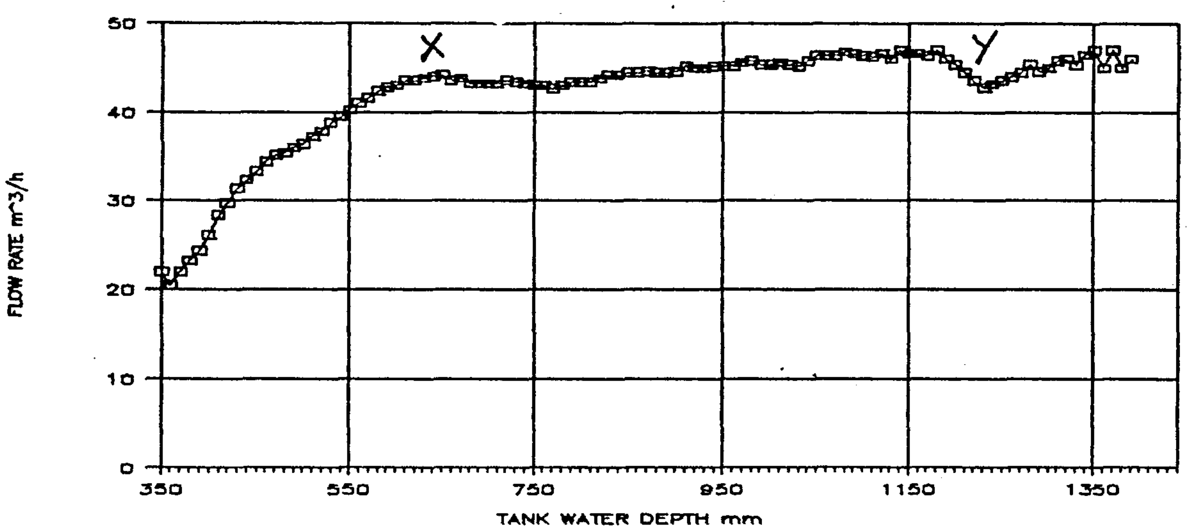

Fig 8.7: DISCHARGE CHARACTERISTICS OF AN 80 MM FLOATING NOZZLE IN A 160 MM PIPE AT A DEPTH OF 250 MM. (FLOAT MASS ADEQUATE.)

Tank depth:

Note (Fig. 8.4) that the flow rate increases from 16 m^3/h at 230 mm tank depth to 21 m^3/h at 370 mm tank depth. From the latter point the flow rate is controlled up to 1350 mm tank depth, above which the sump could not supply any more water. The tank depth under reference is the depth above the point at the outlet, before the flow meter, where the pressure transducer was installed. The flow meter has an inherent friction loss which increases with the square of the flow rate. Any further reference to tank depth must therefore be read in this context rather than the effective tank depth with a free discharge to the atmosphere.

Fig. 8.5 shows that the flow control starts at a tank depth of 550 mm and this is held to a depth of 1300 mm. The reason for the delay in control, which only starts at this increased depth, is that the flow rate increases from 20 m^3/h (Fig. 8.4) to 24 m^3/h in Fig. 8.5. This increased flow rate increases the back pressure in the flow meter at the outlet. The same applies to Fig. 8.6 and Fig. 8.7.

Fig. 8.7 shows a large variation in the flow rate with a 250 mm nozzle depth (Point Y). The only reason for this was the formation of waves in the tank at these larger flow rates. It could be expected that this variation will be eliminated in practice due to a more constant water level in a dam and the absence of waves. It should be noted that the total test period was only 3 to 5 minutes for each of these curves.

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9. DESIGN EXAMPLE

Assume that the flow required for a certain set of conditions must be adjustable between 100 and 150 m^3/h.

Figure 9.1 indicates that the 150 mm conical nozzle would meet the above requirements when submerged respectively at 120 mm (A) and 280 mm (B). The choice of a smaller nozzle will result in a larger depth of submergence which in turn would mean that too much dam level would be lost.

The pipe size may be determined from Fig 9.2 as follows:

With a dam water level of only 200 mm, which will result in a 3% slope of a 6 m pipe, a flow rate of 100 m^3/h will result in a flow subtended angle of 3,6 radians (Point A). The flow depth at this subtended angle will mean that the pipe is flowing almost half full, as a subtended angle of 6,3 radians is full flow. Note that for 150 m^3/h the condition is still worse.

The 200 mm pipe with a 3% slope and at 150 m^3/h on the other hand, will result in a subtended angle of 3,35 radians (Point B), which is half full flow and therefore acceptable. At this condition the buoyancy of the pipe will be 70 kg (Point C).

At a 33% slope and a flow rate of 100 m^3/h through the 200 mm pipe, the subtended angle will be 2,05 radians (Point D). At this condition the buoyancy will be 130 kg (Point E).

The float size must now be determined:

In order to use this mechanism as a shut off valve, the nozzle must be raised above the water surface and this requires that the float mass must be more than the buoyancy of this 200 mm * 6 m pipe with no water.

Volume of 6 m * 200 mm pipe	=	0,1885 m^2
Therefore the buoyancy	=	0,1885 * 1000
	=	188 kg

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Half this buoyancy will however be borne by the flexible coupling.

Therefore the mass of the float must be at least 94 kg.

The shallowest setting of the nozzle for a flow rate of 100 m^3/h was determined at 120 mm (above).

Permitting a 10% flow rate differential will require restricted variation of the nozzle depth. (See page 34).

$Q_1/Q_2 = 1,1/1 = (H_1/H_2)^{0,5}$

Therefore $H_1/H_2 = 1,21$

Maximum permitted nozzle depth = 1,21 * 120
= 145 mm

Permitted float level difference = 145 - 120
= 25 mm

Maximum float level variation must therefore be 25 mm for a buoyancy difference of 100 m^3/h at 33% slope and 150 m^3/h at 3% slope.

That is (130 - 70) / 2 = 30 kg (See above).

Float area therefore = 30 / (1000 * 0,025) (See page 34)
= 1,2m^2

A standard oil drum is 0,6 m diameter * 0,9 m high which when half filled with water, covers an area of 0,6 * 0,9 = 0,54 m^2.

The number of drums required will therefore be 1,2 / 0,54 = 2,22 drums.

Therefore 3 drums on their sides, half filled with water, will have a sufficient mass to keep the pipe in the water and will give adequate buoyancy to maintain the nozzle within the required depth variations.

Should the required flow rate be smaller than that used in the above example, a set of smaller nozzles could be chosen. These nozzles should all be made conically with a short tail pipe and should be easily interchangeable. UPVC molded nozzles could be interchanged in a matter of minutes if they are attached with self tapping screws.

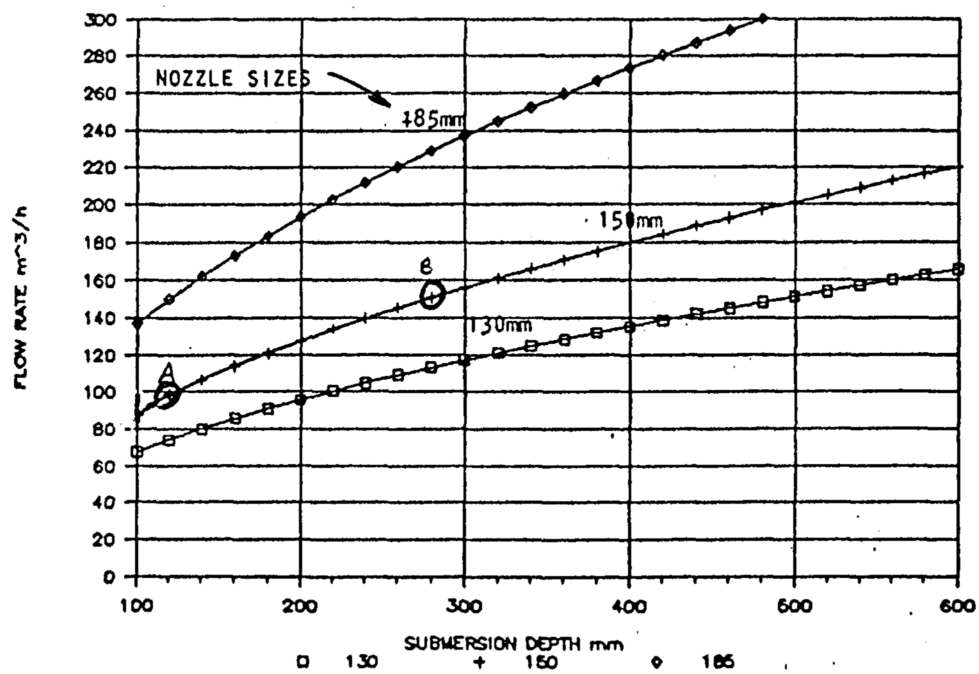

FIG.9.1. DISCHARGE CHARACTERISTICS OF CONICAL NOZZLES AT VARYING SUBMERSION DEPTHS.

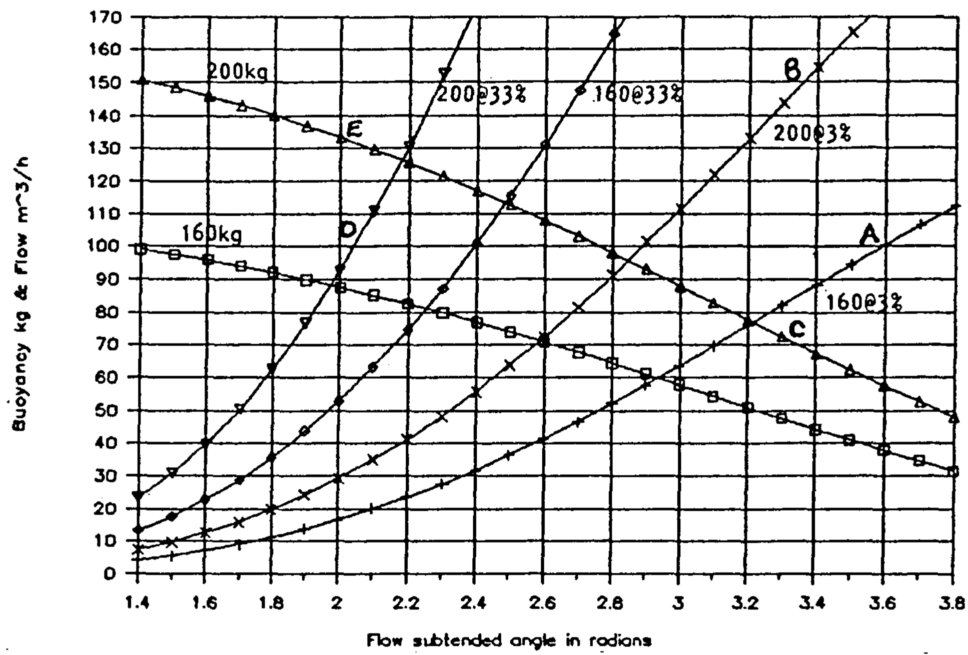

FIG.9.2 BUOYANCY AND DISCHARGE CHARACTERISTICS OF 160 AND 200 MM PIPES AT 3% AND 33% SLOPES.

Figures A1 to A10 are included for design purposes.

10. <u>CONSTRUCTION</u>

The type of pipe to be used is not very critical except that it must be rigid. In the case of fiber-cement pipes no stiffening beams will be required. Conical or bell mouthed nozzles formed with UPVC pipe are preferred since they result in less vortex formation and easy interchangeability if other nozzle sizes are required to alter the flow rate. Vortices can be further controlled by locating a 6 mm wire mesh horizontally at the water surface above the nozzle inlet. A suitable connecting swivel between the pipe and the outlet at the bottom of the dam can be made out of suitable flexible hose.

This mechanism can also be used as a shut-off valve if the nozzles are mounted in such a way at the float that the nozzle itself could be lifted above the surface of the water.

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11. CONCLUSIONS

The flow rate from a dam with variable water levels can be held constant with the flow control mechanism designed in this project. Apart from practical construction problems there is no limit to the flow rate or depth of the dam under which these requirements could be met. Where control is required down to practically zero levels of the water in the dam, it can still be achieved through the construction of a canal in the floor of the dam in instances where this is possible. This canal will be required in order to allow the pipe to be sunken into the dam floor. This mechanism can be built in the farm workshop for less than the specified R800 (1990 prices), if second hand materials are used. With new materials the total construction cost of the control valve will be about a R1 000 for a flow rate of 200 m^3/h.

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12. EQUATIONS

The following equations were used under section 4.

A. LAMONT EQUATION

$$H_f = b*L* Q^p/d^r$$

where:
H_f = Friction loss (m)
b = A constant, being 0,00086 when Q is in m^3/s for UPVC pipe
L = Pipe length (m)
Q = Flow rate (m^3/s)
p = A constant, being 1,77 for UPVC pipe
d = Pipe diameter (m)
r = A constant, being 4,77 for UPVC pipe

B. CALCULATED DISCHARGE RATE FROM 250 mm OUTLET WITH HEAD OF 0,25 m:

By Lamont, for: H_f = 0,25 m; d = 0,25 m and L = 30 m
Q = 309 m^3/h, taken as 300 m^3

C. BERNOULLI EQUATION:

$$(V_a^2/2g) + H_a + Z_a = (V_b^2/2g) + H_b + Z_b + H_f$$

where: V_a & V_b = Mean velocity in pipe at positions (a) and (b) (m/s)

g = Acceleration due to gravity (9,81 m/s^2)

H_a & H_b = Head at positions (a) and (b) (m)

Z_a & Z_b = Elevation of pipe at positions (a) and (b) (m)

H_f = Friction loss (m)

D. DISCHARGE FROM 250 mm DAM OUTLET FOR VARYING HEADS

Use H_f = 0,25 m; 1,00 m and 2,25 m in Lamont equation, then

Q_1 = 309 m^3/h @ H_1 = 0,25 and $H^{0,5}$ = 0,50

Q_2 = 678 m^3/h @ H_2 = 1,00 and $H^{0,5}$ = 1,00

Q_3 = 1 072 m^3/h @ H_3 = 2,25 and $H^{0,5}$ = 1,50

From which also follows that:

Q_3/Q_1 = 1 072/309 = 3,47 for $(H_3/H_1)^{0,5}$ = $(2,25/0,25)^{0,5}$ = 3,00

Q_2/Q_1 = 678/309 = 2,19 for $(H_2/H_1)^{0,5}$ = $(1,00/0,25)^{0,5}$ = 2,00

This approximate square root relationship between Q and H will improve upon reduction in friction losses or by using the Darcy equation for the same calculation. In any case the result is adequate for stating that $Q_2 = Q_1(H_1/H_2)^{0,5*}$ for the purpose intended.

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APPENDIX

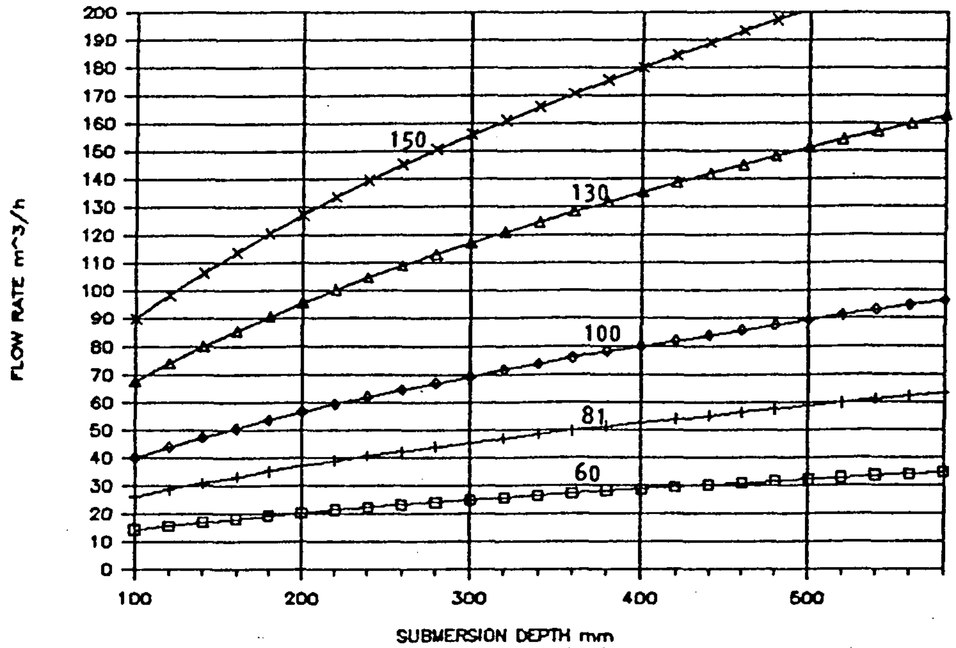

FIG. A1. NOZZLE DIAMETER MM FOR SMALL FLOWS.

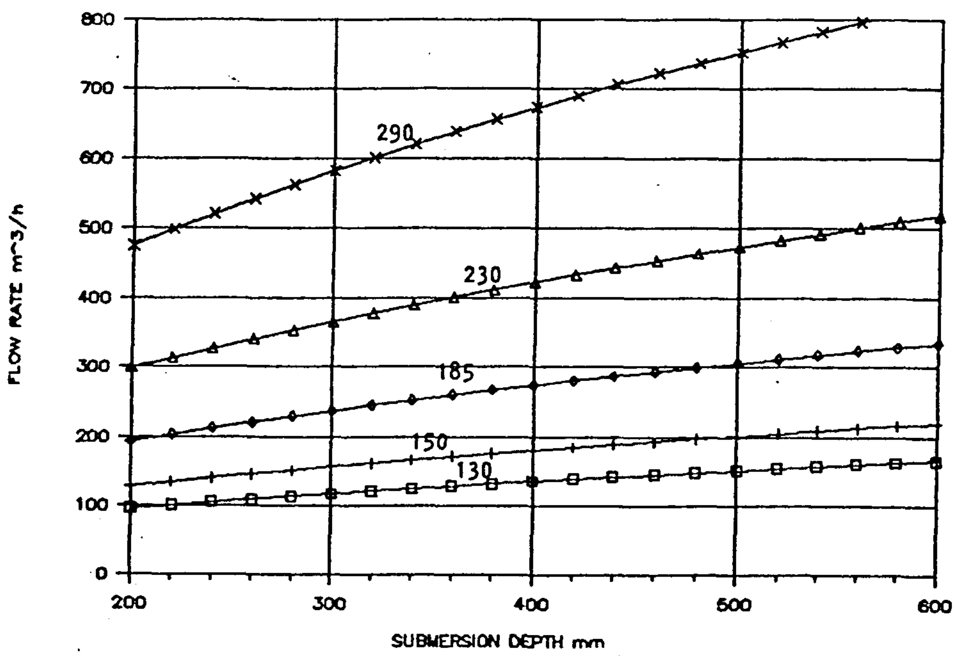

FIG. A1. NOZZLE DIAMETER MM FOR LARGE FLOWS.

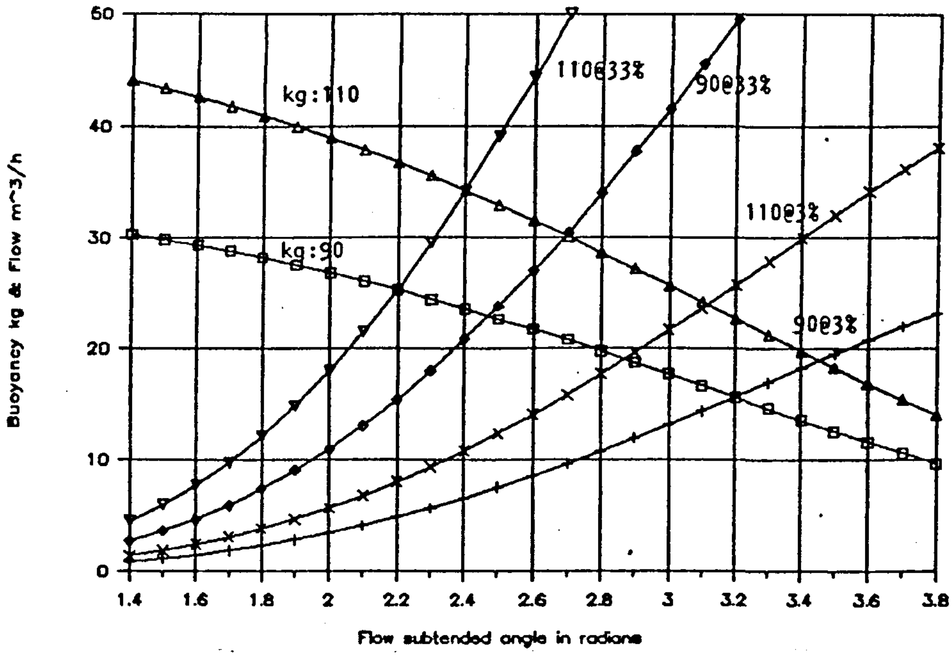

FIG. A3. BUOYANCY AND DISCHARGE CHARACTERISTICS FOR 90 AND 110 MM PIPES @ 3% AND 33% SLOPES AT VARIOUS FLOW SUBTENDED ANGLES

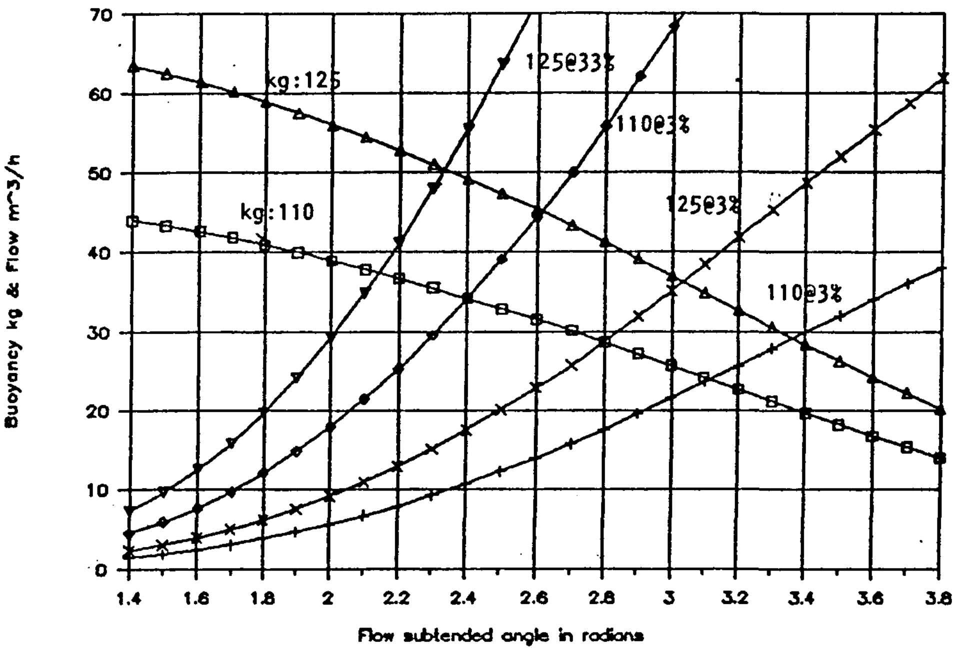

FIG. A4. BUOYANCY AND DISCHARGE CHARACTERISTICS FOR 110 AND 125 MM PIPES @ 3% AND 33% SLOPES AT VARIOUS FLOW SUBTENDED ANGLES

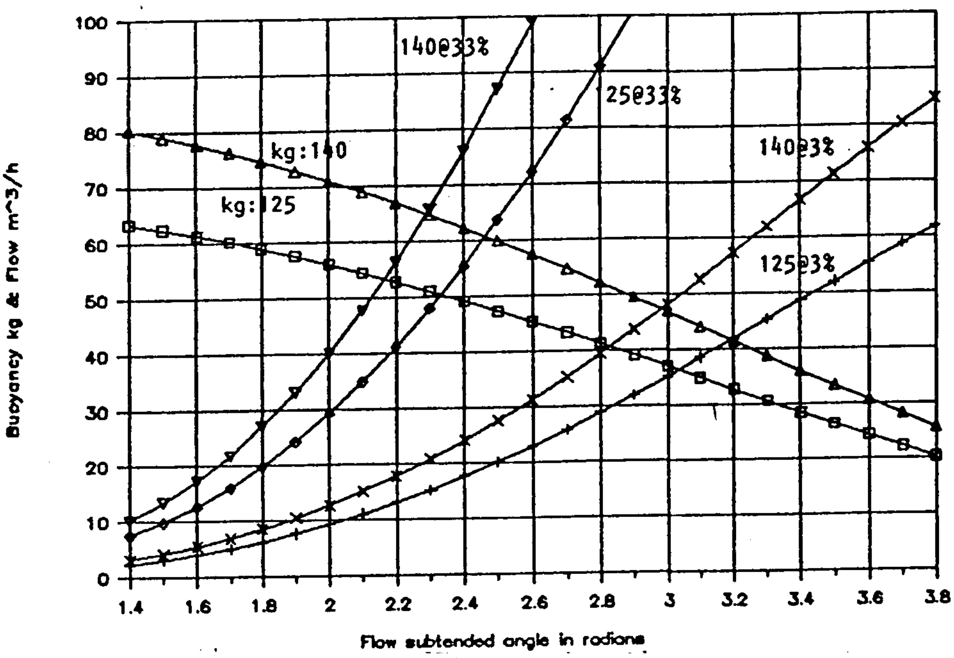

FIG. A5. BUOYANCY AND DISCHARGE CHARACTERISTICS FOR 125 AND 140 MM PIPES @ 3% AND 33% SLOPES AT VARIOUS FLOW SUBTENDED ANGLES

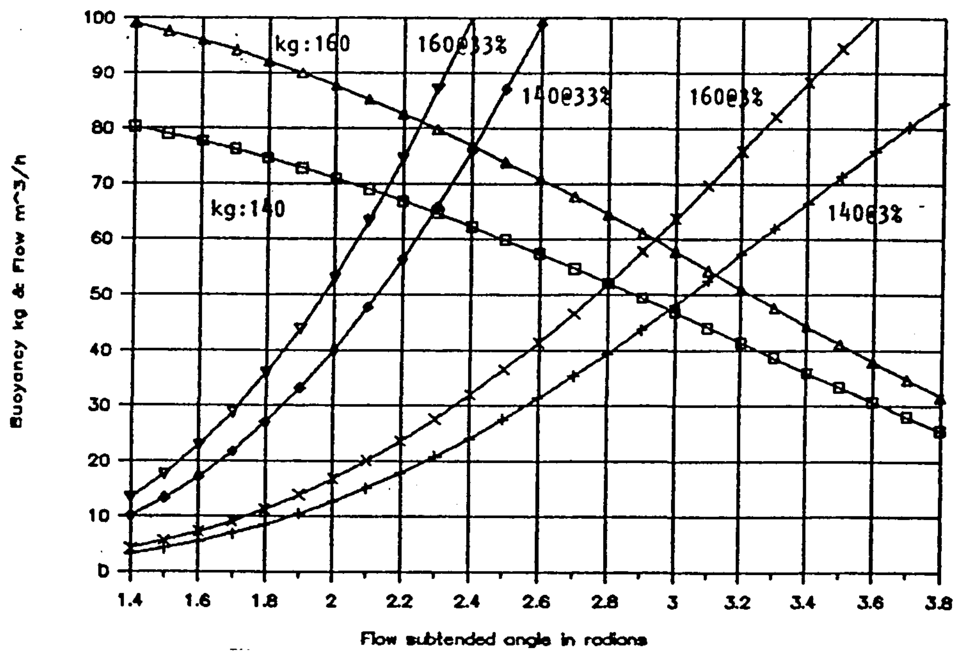

FIG. A6. BUOYANCY AND DISCHARGE CHARACTERISTICS FOR 140 AND 160 MM PIPES @ 3% AND 33% SLOPES AT VARIOUS FLOW SUBTENDED ANGLES

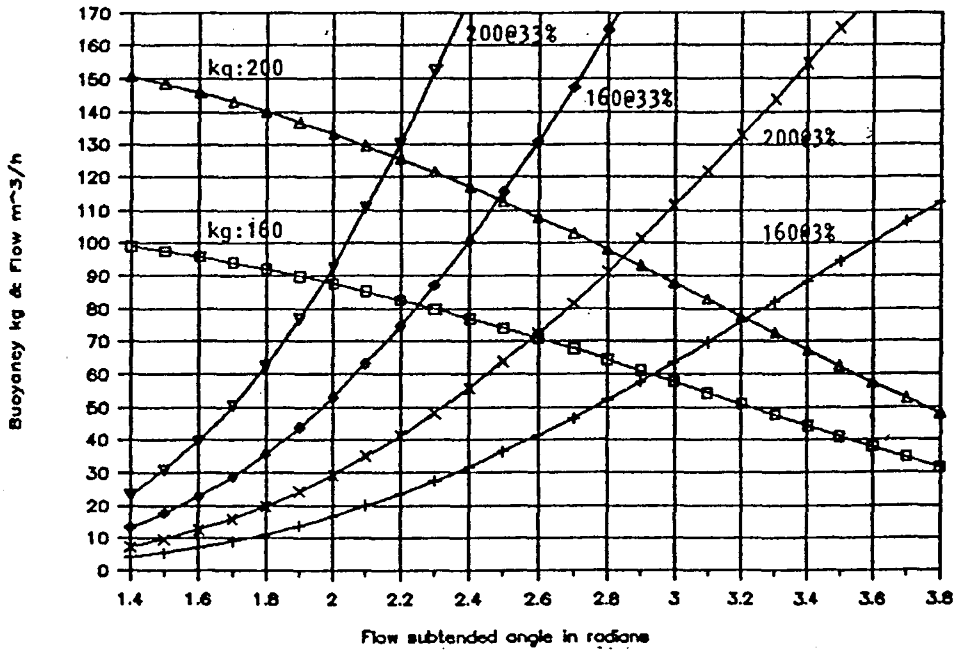

FIG. A7. BUOYANCY AND DISCHARGE CHARACTERISTICS FOR 160 AND 200 MM PIPES @ 3% AND 33% SLOPES AT VARIOUS FLOW SUBTENDED ANGLES

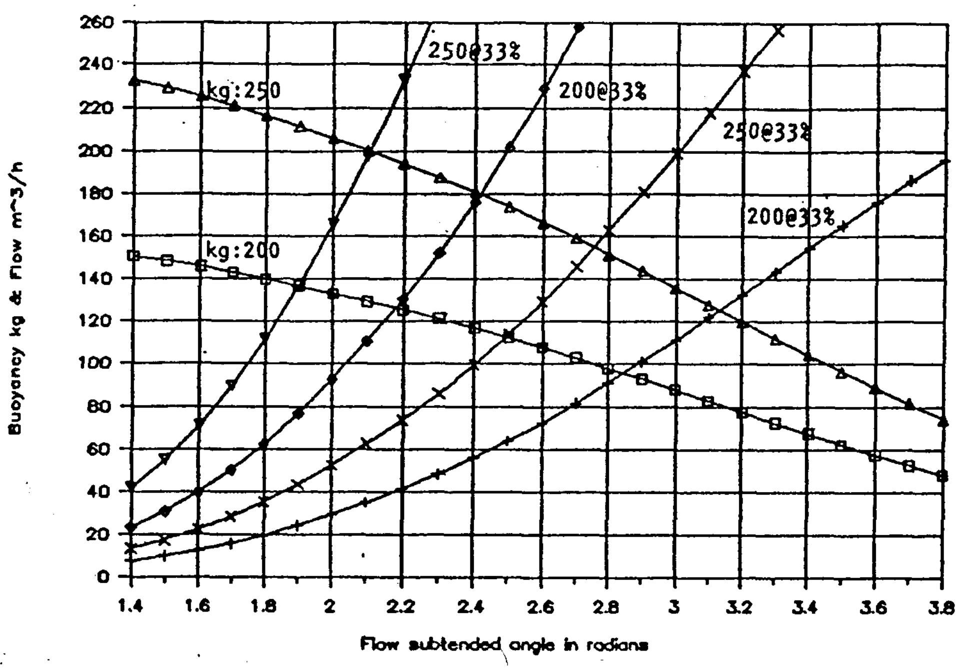

FIG. A8. BUOYANCY AND DISCHARGE CHARACTERISTICS FOR 200 AND 250 MM PIPES @ 3% AND 33% SLOPES AT VARIOUS FLOW SUBTENDED ANGLES

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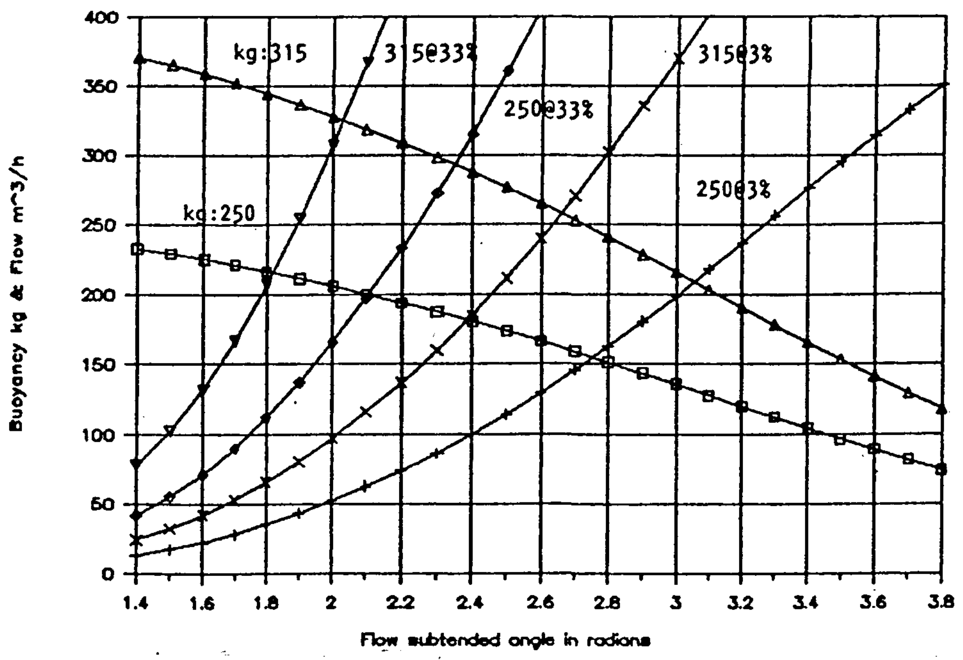

FIG. A9. BUOYANCY AND DISCHARGE CHARACTERISTICS FOR 250 AND 315 MM PIPES @ 3% AND 33% SLOPES AT VARIOUS FLOW SUBTENDED ANGLES

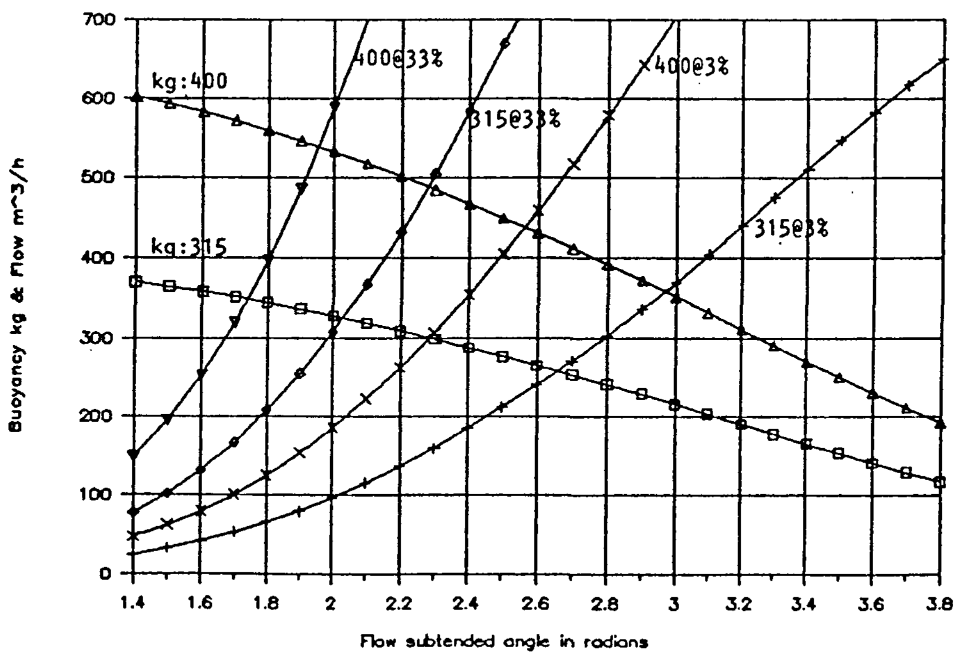

FIG. A10. BUOYANCY AND DISCHARGE CHARACTERISTICS FOR 315 AND 450 MM PIPES @ 3% AND 33% SLOPES AT VARIUOS FLOW SUBTENDED ANGLES