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HYDRAULIC RAMS FOR RURAL WATER SUPPLY SCHEMES IN SELECTED AREAS IN TANZANIA

By

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ABSTRACT

This paper presents one of the many efforts made by the Faculty of Engineering and the Institute of Production Innovation of the University of Dar es Salaam towards the realization of the International Water Supply and Sanitation Decade. Special reference is made to the use of hydraulic rams along with some simple water treatment methods. Besides the account of theoretical and practical work done to-date in the field of water supply, a further evaluation of the theoretical model presented is recommended so as to enable a judgement of the present hydraulic ram designs to be done. Tests on a typical locally made hydraulic ram which should lead to better marketing of possibly an improved design accompanied by performance charts can be easily done.

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Nomenclature

A	-	Cross-section area of flow in drive pipe
A_p	-	Cross-section area of delivery valve throat
A_d	-	Cross-section area of drive valve throat
D	-	Diameter of drive pipe
DANIDA	-	Danish International Development Agency
f	-	Friction factor
F	-	Load on drive valve
g	-	Gravitational acceleration
h	-	Delivery head measured from water level in supply reservoir
H	-	Drive head
HRF	-	Horizontal Flow Roughing Filter(s)
IRCWD	-	International Reference Centre for Wastes Disposal
K	-	Bulk Modulus of Water
K_p	-	Head loss coefficient of discharge valve
K_d	-	Head loss coefficient of drive valve
L	-	Pipe length, drive pipe length
m_p	-	Pumped mass flowrate
m_t	-	Total mass flowrate
N_p	-	Combined pump flow head loss factor of system
N_d	-	Combined delivery flow head loss factor of system
N_r	-	Combined reverse flow head loss factor of system
NORAD	-	Norwegian Agency for International Development
p	-	Pressure
Q_d	-	Wasted volume per cycle
Q_p	-	Pumped volume per cycle
s	-	Stroke of drive valve
SSF	-	Slow Sand Filtration/Filter
t	-	Time
UDSM	-	University of Dar es Salaam
V	-	Average velocity in drive pipe
ϕ	-	Force coefficient
ρ	-	Density of Water

η	-	Efficiency
γ	-	Cycle frequency
WHO	-	World Health Organization
z	-	Elevation

1 INTRODUCTION

For several years now members of staff of the Faculty of Engineering and the Institute of Production Innovation at the University of Dar es Salaam have been working on simple water treatment and pumping systems. This paper gives a brief summary of detailed investigations carried out in this field. Extensive documentation of these activities can be found in references (1), (2) and (3). Tanzania has known the hydraulic ram for at least five decades, but most of the many pumps initially installed have now disappeared although the simplicity of operation and its relatively negligible requirement of maintenance are technical factors which highly favour the application in remote, hilly or mountainous rural areas, let alone the fact that these pumps draw their motive power from the water source they are pumping from. Besides being used in the Northern part and Usambara area, in the Southern highlands (i.e. Mbeya and Iringa), the arrival of Christian missionaries brought with them hydraulic rams in small water supply schemes which they constructed for the missions and the villagers living nearby. Both authors remember very well, as children how fascinated they were by the numerous thumping water pumps which could be found along many streams and brooks.

2 A SHORT HISTORY OF THE HYDRAULIC RAM

Invention of the hydraulic ram is credited to an English man Mr. John Whitehurst whose first machine was installed in a brewery in 1773. The drive valve tap was operated manually by a child (4), In 1779 Joseph Michael de Montgolfier developed the self-acting hydraulic ram.

On his machine it was found that over a period of time, the air in the air vessel was gradually absorbed by the water passing through it and the working of the ram affected. This problem was solved by the younger brother of Montgolfier who added the snifter valve to keep the vessel supplied with air.

Since then quite a number of types of hydraulic ram have been put on the world market, some have disappeared while others are still being manufactured. Quite a lot of work has been invested in the theoretical approach (3), (5) and (6). It seems though that up to date the manufacturers and the theoreticians have hardly ever got down to working together in an attempt to optimize the performance and use of the hydraulic ram in water supply systems.

3 APPLICABILITY OF HYDRAULIC RAMS IN WATER SUPPLY SCHEME

Regarding the possibility of introducing hydraulic ram in drinking (or small scale irrigation) water supply schemes, as long as topographical and hydrological requirements are satisfied, they can be used to pump either raw water from a source into the treatment plant or as a single stage pumping from a pretreatment unit into the main treatment facilities. However, it is not very common to use hydraulic rams for pumping treated water to storage tanks since the conventional design would involve wastage of a big proportion of the treated water which would have to pass through the drive valve during the pumping cycles unless the quality of raw water does not need any treatment before distribution besides disinfection which can be conveniently done in the storage tank if no contact reservoir is provided.*

In essence, this means that hydraulic rams (hydrams) can be very suitably applied in schemes whose source is lower than the end user but topography allows supply of water to the consumers by gravity after a single stage pumping via the treatment plant or storage tank, such a cross section is shown in Fig.1 below.

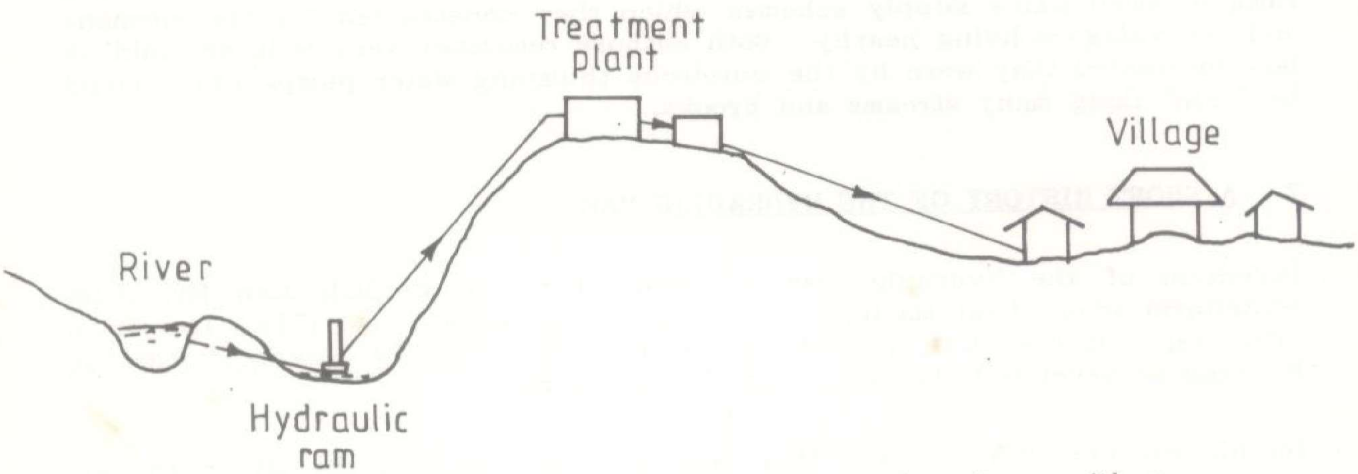


Fig.1 Schematic cross section of a village water supply scheme with a hydraulic ram pump.

To make the water supply scheme design of Fig.1 meaningful in the practical sense, the designers of the same have to ensure that;

(1) Simple and acceptable treatment techniques should be applied. The use of locally trained manpower should be given top priority.

(2) The water supply scheme caretakers are trained to operate the hydram and the treatment plant before commissioning of the same. Whenever possible they should live either within the neighbourhood of the treatment plant and hydram or in the closest village to the pump and/or plant.

* It must be noted here that Rams are available that can utilize untreated water to pump clean water.

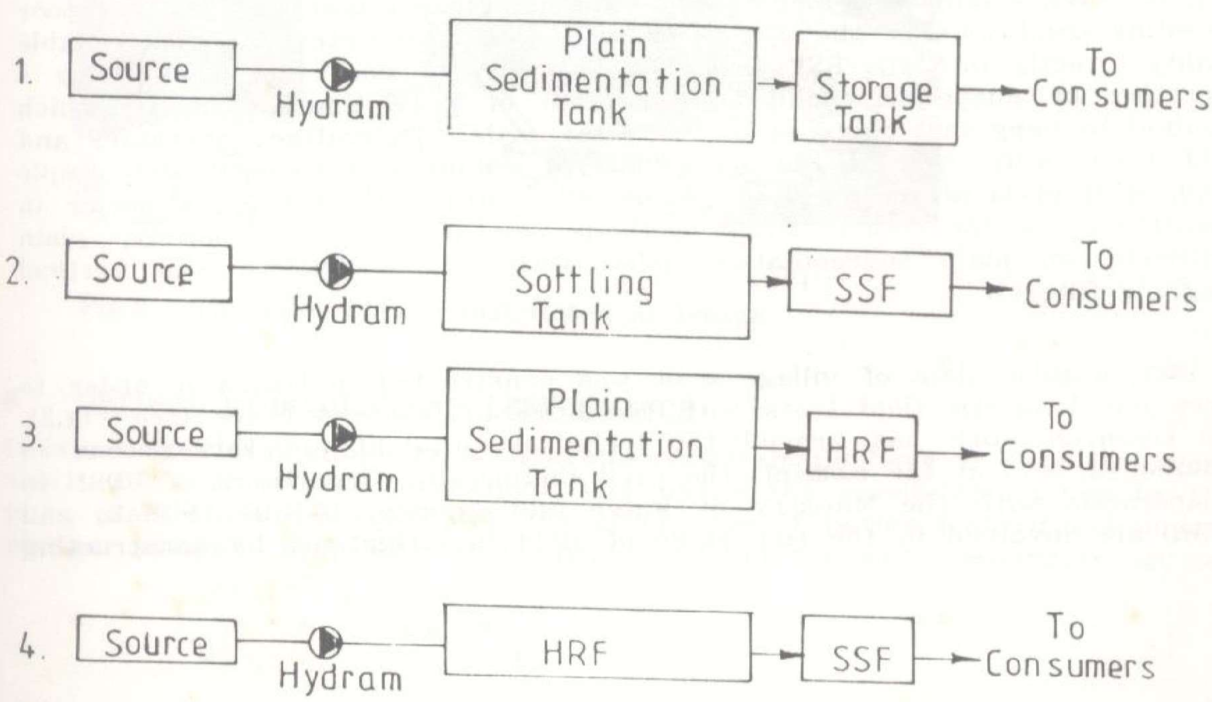
(3) The treatment plant demands very little maintenance and be can constructed from locally available materials as far as possible.

Besides considering the topographical and hydrological factors, water quality aspects should not be overlooked, especially with respect to the need of ensuring judicious design of the intakes. For spring sources, the intake should exclude debris from entering into the drive pipe by for example designing double chambers with coarse screens in between them and providing fine screens on the drive pipe mouth.

In case of rivers or streams, proper location and siting of the intakes should consider the silting pattern. The best location of an intake is usually at the straight portions of the river, if none exists in the neighbourhood then one would locate it at the outer side and beginning of a river bend where the bank has to be fixed to check any further erosion. Sometimes, sandtraps can be used to reduce the silt load in the raw water which will be pumped by the hydraulic ram.

4 HYDRAULIC RAMS IN SIMPLE TREATMENT PLANTS

In cases where raw water has to be treated or improved to acceptable levels before distribution to consumers, the use of hydraulic rams along with some simple treatment or pretreatment methods can ensure the reliability and appropriateness of the whole scheme in remote rural areas. Examples of simple pretreatment techniques are plain sedimentation, plain sedimentation aided by lamely plate settlers, and roughing filtration, in particular Horizontal Flow Roughing Filtration (HRF). A Slow Sand Filter (SSF) is a good example of a simple and appropriate treatment process. The flow charts Nos. 1-4 below give some of the options of simple treatment systems for raw water pumped by hydraulic rams.



These systems are very suitable for rural water treatment in developing countries like Tanzania whose local drinking water standards (for rural areas) are usually even more relaxed than the International standards as stipulated by WHO. Following the order of presentations one finds that: the flow chart No.1 is suitable for raw water having low bacterial pollution and low physical impurities, it is suitable for relatively clean and clear water having only few settleable particles. The flow chart No.2 is suitable for treatment of raw water with average amounts of settleable particles and bacterial pollution while flow chart No.3 is suitable for treatment of raw water with low or negligible bacterial pollution and relatively high settleable matter which are not that much as to interfere with the operation of the hydraulic ram. The flow chart No.4 is suitable for treatment of raw water having high bacterial pollution and high turbidity as long as the filtration rates used are limited to acceptable levels (1), (2).

It must however be noted that, in all the four cases considered here, it is assumed that the raw water has very few or no foreign chemical pollutants since the effect of human activities on water pollution is not yet that much pronounced in rural areas of most developing countries. Investigations of adsorptive capacity of charcoal as a HRF medium have been initiated by the Civil Engineering Department of UDSM at Iringa pilot plant. This has been sought after realizing that HRF have negligible effect on such chemical quality parameters like pH, alkalinity and hardness.

5 RESEARCH IN PRETREATMENT FOR SLOW SAND FILTERS IN TANZANIA.

The Department of Civil Engineering of the UDSM has been conducting an extensive research in pretreatment of Slow Sand Filters (SSF) by Horizontal Flow Roughing Filters (HRF) since 1979 after getting reports of poor performances of most of the SSF built in different parts of Tanzania. To this end, the Civil Engineering Department first established that the cause of poor operating conditions of the SSF was feeding of raw waters of unacceptable quality directly into the SSF (i.e. with turbidity of more that 50 NTU for a long time or suspended solid concentration of more than 10 (mg/l) which resulted to very fast clogging of the filter beds. Thereafter, laboratory and field tests were carried out in order to establish the best and simple biophysical pretreatment methods before SSF. HRF proved to be superior in comparison to the other three methods investigated (8) (namely, plain sedimentation, plain sedimentation aided with lamella settlers and vertical roughing filters).

In 1981, a pilot plant of village scale was constructed in Iringa in order to carry out longterm field tests with the HRF-SSF systems there (see Fig.2). The research work has proved the technical suitability of this method in practise (2) and at the moment, the Civil Engineering Department of UDSM in collaboration with the Ministry of Water and Energy, DANIDA, NORAD, and IRCWD are involved in the last stage of field investigations by constructing and monitoring the operation of a number of village demonstration schemes in the regions of Mbeya, Rukwa and Iringa in order to gain more experiences with this technique of water treatment.

In addition, this program will enable the assessment of acceptability, suitability and community participation aspects in practise to be made. NORAD has already started construction of one such a scheme with hydraulic ram pumps, HRF and SSF in the village of Kasote in Rukwa region. More information about the research work in HRF - SSF systems carried out at UDSM can be obtained from ref. (1) and (8). The present state of the art is such that, research in the field of rural water supply schemes with respect to water treatment is already in its advanced stages. Simple and reliable water supply schemes can be maintained if the manufacturers of hydraulic rams could give the designers of water supply schemes more precise and dependable performance prediction charts for any topographical and hydrological conditions.

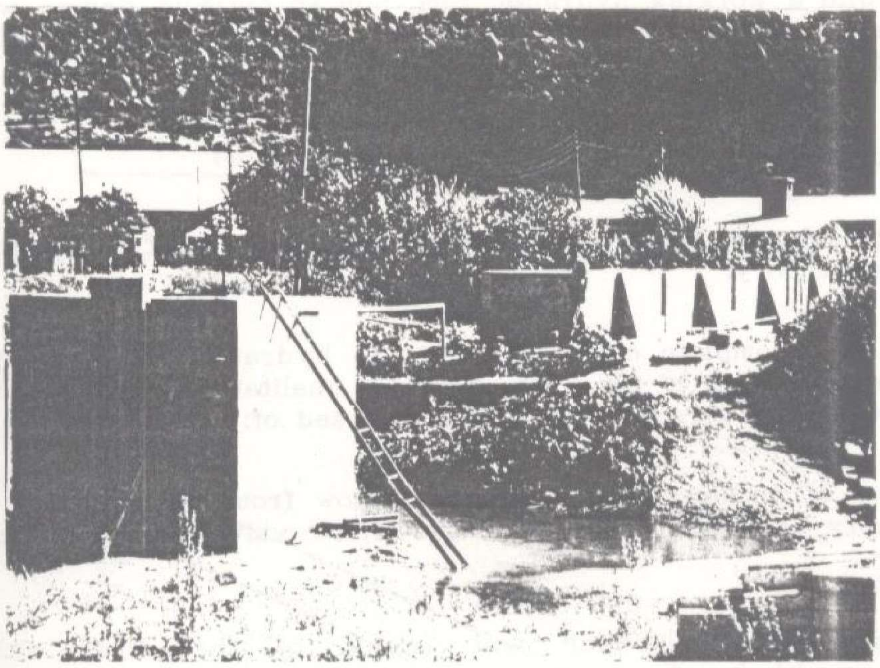


Fig.2. The pilot plant constructed at Iringa

6 OPTIMAL HYDRAULIC RAM PERFORMANCE

It is our idea that suppliers of hydraulic rams should have at hand for every size a set of charts that will help fully utilize the possibilities given by the pump as is common practice for any other type of pumps (centrifugal pumps, plunger pumps). Only with such charts in hand can water engineers set out to design good water supply systems with hydraulic rams. Since 1976 the Department of Mechanical Engineering of the Faculty of Engineering and later the Institute of Production Innovation both at the UDSM have been analyzing theoretical approaches and also have been following the activities of Jandu Plumbers in Arusha who build hydraulic rams of the Blake type very competently. We are aware of the fact that there is still a lot of scope for improvement and that it is possible to develop a new generation with yet better and truly predictable performance, possibly competitive enough for export to neighbouring countries.

7 DEVELOPMENTS IN THE FIELD OF HYDRAULIC RAM RESEARCH

Based mainly on two published papers (5), (6), which to our view give sufficient theoretical background to the design engineer for a good optimization of dimensions, performance and end use we have formulated a theoretical model in 1980 (3) that to the present date has been refined only to a certain extent. A full evaluation of the model requires the use of quite a powerful computer with a plotter and still remains to be done.

It is very easy to build a working hydraulic ram, but an optimum design with predictable performance can only be made once the evaluation of a theoretical model has taken place.

7.1 The Theoretical Model

For the following elaboration we assume that the reader is familiar with basic hydraulic ram theory:

All of the period of a complete cycle of events in hydraulic ram operation is demonstrated with the aid of Fig.3 which shows qualitatively the average velocity in the drive pipe versus time. It is composed of:

(a) the period of acceleration of the drive flow from zero velocity to the velocity at which closure of the drive valve starts to take place.

(b) the period of acceleration and motion of the drive valve terminating with its closure during which the velocity of the drive flow remains constant.

(c) the period of deceleration of the pumped flow from the time of simultaneous opening of the discharge valve with closure of the drive valve until the pumped flow reaches zero velocity.

(d) the period of expansion of the compressed column of water in the drive pipe starting with closure of the discharge valve and terminating with the opening of the drive valve.

(e) the period of deceleration of reverse flow through the drive pipe until the flow reaches zero velocity to initiate another period (a).

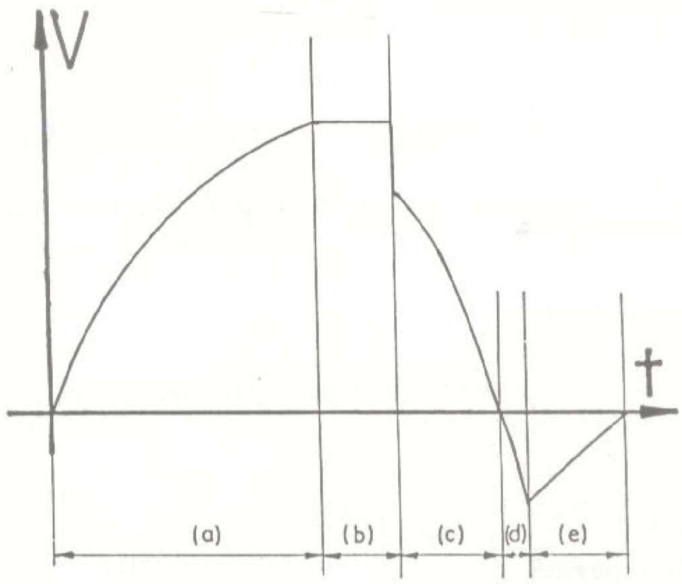


Fig.3 Average velocity in Hydraulic Ram Drive Pipe Versus Time for the Period of One Cycle.

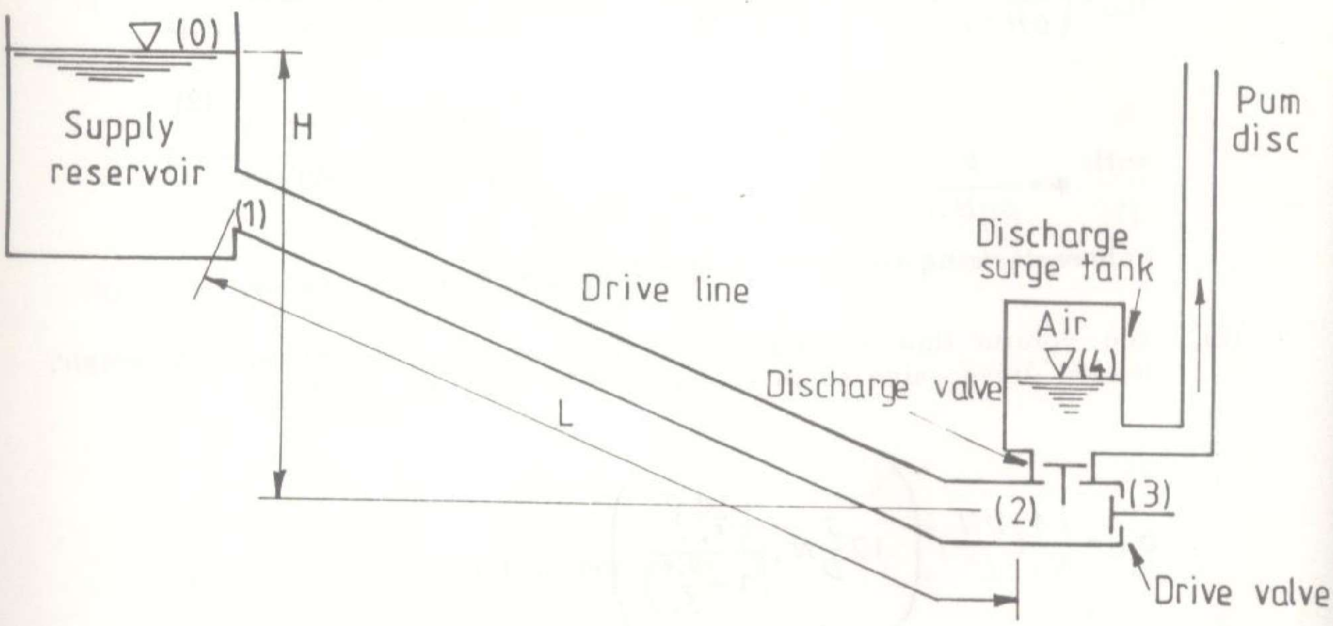


Fig.4 The Hydraulic Ram Control Positions

As shown in Fig.4 control positions (0) to (4) are introduced. Assuming that the effects of short period pressure fluctuations can be ignored an analysis can be made considering only the time dependent effects caused by the average drive head and the average discharge head. The drive and discharge flows are treated by means of the usual one-dimensional unsteady flow approximation.

$$-\frac{dp.}{g\rho}-dz\frac{fV^2}{2gD}dL=\frac{dV\,dL}{dtg} \qquad (0)$$

Formulating this equation for the above mentioned periods in connection with Fig.3 and Fig.4 one arrives at:

(1) the volume flow during period (a)

$$Q_{(a)}=\frac{LA}{N_d}\ln\left(\frac{1}{1-\frac{N_d\Phi}{K_d}}\right) \qquad (1)$$

and the duration of this period

$$t_{(a)}=\left(\frac{2L^2}{gHNd}\right)^{\frac{1}{2}}\tanh^{-1}\left(\frac{N_d\Phi}{K_d}\right)^{\frac{1}{2}} \qquad (2)$$

with $\Phi=\frac{F}{\rho gHA}$

characterizing the load on the drive valve.

(2) the volume flow during period (b) assuming for example a weight loaded drive valve as in reference (6)

$$Q_{(b)}=\frac{LA}{N_d}\left(\frac{DH}{L^2}\right)^{\frac{1}{3}}\left(12\frac{S}{D}N_d\frac{\left(\frac{N_d\Phi}{K_d}\right)^{\frac{1}{2}}}{\left(1-\frac{N_d\Phi}{K_d}\right)}\right)^{\frac{1}{3}} \qquad (3)$$

and the duration of this period

$$t_{(b)} = \left(\frac{2L^2}{gHN_d}\right)^{\frac{1}{2}} \left(\frac{DH}{L^2}\right)^{\frac{1}{3}} \left(\frac{3}{2}\frac{S}{D} N_d \frac{\left(\frac{N_d \Phi}{K_d}\right)^{\frac{1}{2}}}{\left(\frac{1 - N_d \Phi}{Kd}\right)} \right)^{\frac{1}{3}} \tag{4}$$

(3) the volume flow during period (c)

$$Q_{(c)} = \frac{LA}{Np} \ln\left(\frac{Np\Phi}{K_d \frac{h}{H}} - \left(4Np\frac{Np\Phi}{K_d}\frac{\rho g H}{2K}\right) + Np\frac{h}{H}\frac{\rho g H}{2K} + 1 \right) \tag{5}$$

and the duration of this period.

$$t_{(c)} = \left(\frac{2L^2}{gHN_d}\right)^{\frac{1}{2}} \left(\frac{N_d}{Np}\cdot\frac{H}{h}\right)^{\frac{1}{2}} \tan^{-1}\left(\frac{Np\Phi}{K_d \frac{h}{H}} - \left(4Np\frac{Np\Phi}{K_d}\frac{\rho g H}{2K}\right)^{\frac{1}{2}} + Np\frac{h}{H}\frac{\rho g H}{2K} \right)^{\frac{1}{2}} \tag{6}$$

(4) the volume flow during period (d) which is of no real interest for the analysis and the duration of this period.

$$t_{(d)} = \left(\frac{2L^2}{gHN_d}\right)^{\frac{1}{2}} \left(\frac{\rho g H}{2K}\right) N_d^{\frac{1}{2}} \tag{7}$$

(5) the volume flow during period (e)

$$Q_{(e)} = -\frac{LA}{N_d}\left(\frac{N_d}{Nr}\ln\left(\frac{Nr\left(\frac{h}{H}\right)^2 \rho g H}{2K} + 1 \right)\right) \tag{8}$$

and the duration of this period

$$t_{(e)} = \left(\frac{2L^2}{gHN_d}\right)^{\frac{1}{2}} \left(\frac{N_d}{Nr}\right) \tan^{-1} \left(\frac{Nr\left(\frac{h}{H}\right)^2 \rho g H}{2K}\right)^{\frac{1}{2}} \quad (9)$$

And from here one arrives at

(I) the volume of water pumped during one pumping interval

$$Q_p = Q_{(e)} \quad (10)$$

(II) the volume of water wasted during one drive interval

$$Q_d = Q_{(a)} + Q_{(b)} + Q_{(e)} \quad (11)$$

(III) the time required for the full sequence of events

$$t = t_{(a)} + t_{(b)} + t_{(c)} + t_{(d)} + t_{(e)} \quad (12)$$

(IV) the efficiency of the system between positions (O) and (4) in Fig.4.

$$\eta = \frac{Qp}{Qd}\frac{h}{H} \quad (13)$$

7.2 Evaluation of the Theoretical Model

Full evaluation and verification of the model still need to take place. Further development of the started work would have to consist of the following steps:

1. Formulate a computer program to calculate and plot performance charts of hydraulic rams.
2. Construct a test stand for some typical size hydraulic rams, take measurements and compare with calculated values.
3. If necessary further streamline the theory and/or the programme.
4. Produce plotted performance charts for all typical hydraulic rams.

How rewarding the expected results might be is demonstrate in Fig. 5,6,7,8 and 9 which compare η, Φ, y, m_p, m_t of twelve different rams on a 3-inch (75mm.) diameter drive line and with a weight loaded poppet type drive valve with a stroke 0.125 of the throat diameter. The rams differ with respect to delivery valve and drive valve area. The presented figures are the result of a tedious effort to program the theoretical model on an electronic calculator followed by manual plotting.

Assuming a 3-inch diameter drive line and a drive head of 1m for different combinations of Ap/A = 0.25, 2, 8 and A<u>d</u>/A = 0.25, 1, 2, 8,

- L has been increased from L = 1m to L = 1000 m
- h/H has been increased from (h/H) = 3 to h/H = 40

with Φ varying in any point (L, h/H) to maximize efficiency.

Fig. 5 suggests that especially for rams with small valves operating at low delivery heads, drive pipes must be very long if operation is to take place at maximum efficiency. Drive pipe lengths can be reduced considerably if concessions of a few points are made. Points representing maximum efficiency less two percent have been joined up in Fig.5 to demonstrate the effects of changing valve geometry.

It would be unwise at this point to maintain that Fig.5, 6, 7, 8 and 9 present the performance of rams with valve configurations as stipulated above more than qualitatively correctly. A glance at Fig.6 reveals that especially for large drive valves the force coefficient Φ changes in steps. In an attempt to squeeze the program into available storage space and to maintain reasonably low calculation times a very crude method of efficiency maximization in any point (L, h/H) was used.Its effects can be seen most clearly in Fig.7 and 8 presenting ram frequencies and total mass flows.

Nevertheless, what does become clear is that for any configuration of drive pipe diameter D and drive head H there are ideal discharge valve and drive valve throat areas depending on the operational head ratio h/H. Viewing Figures 5 and 8 we are tempted to maintain that among the presented rams the discharge valve throat area need not be more than two times larger and the drive valve throat area must be at least two times larger for small head ratios (h/H = 3) and eight times larger for higher head ratios (h/H = 6-40) that the drive pipe cross section area.

8 CONCLUSIONS:

Two conclusions can be drawn from the above elaborations.

1. From the point of view of water supply design the hydraulic ram can only then be incorporated confidently when performance data for existing rams are available.

2. A promising theoretical model for the analysis of hydraulic ram performance does exist. It needs to be verified, possibly stream lined and put to use.

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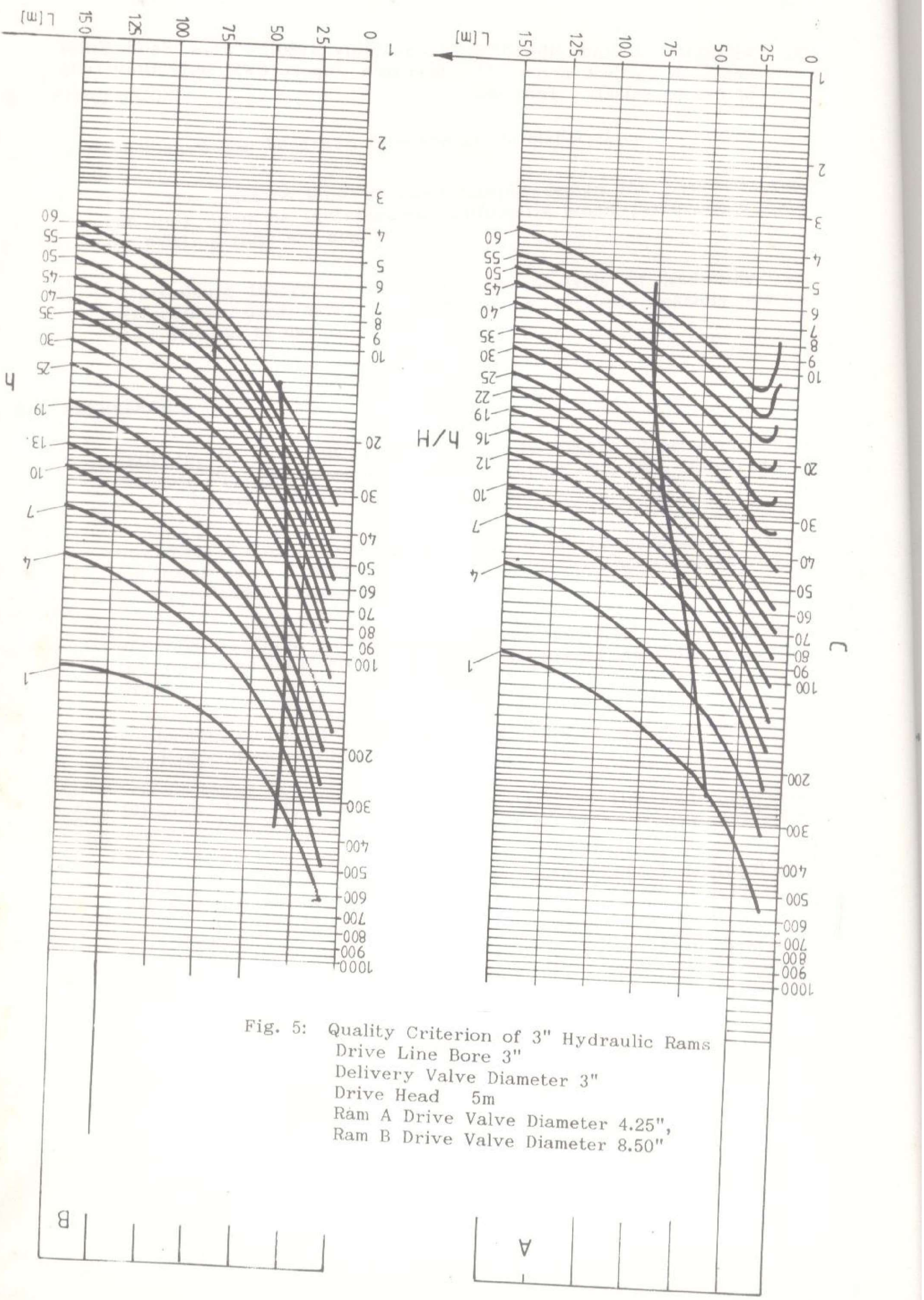

Fig. 5: Quality Criterion of 3" Hydraulic Rams
Drive Line Bore 3"
Delivery Valve Diameter 3"
Drive Head 5m
Ram A Drive Valve Diameter 4.25",
Ram B Drive Valve Diameter 8.50"

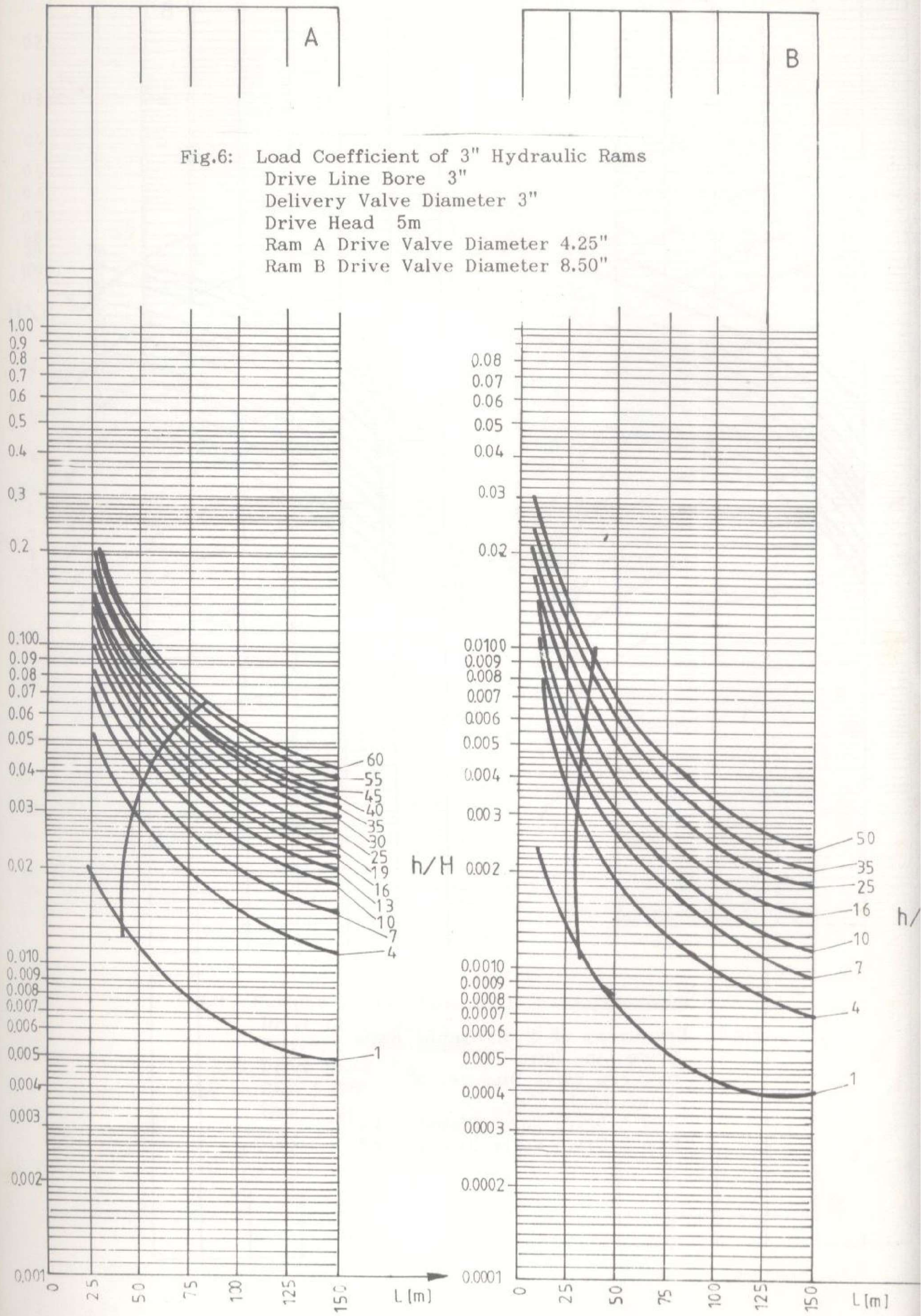

Fig.6: Load Coefficient of 3" Hydraulic Rams
Drive Line Bore 3"
Delivery Valve Diameter 3"
Drive Head 5m
Ram A Drive Valve Diameter 4.25"
Ram B Drive Valve Diameter 8.50"

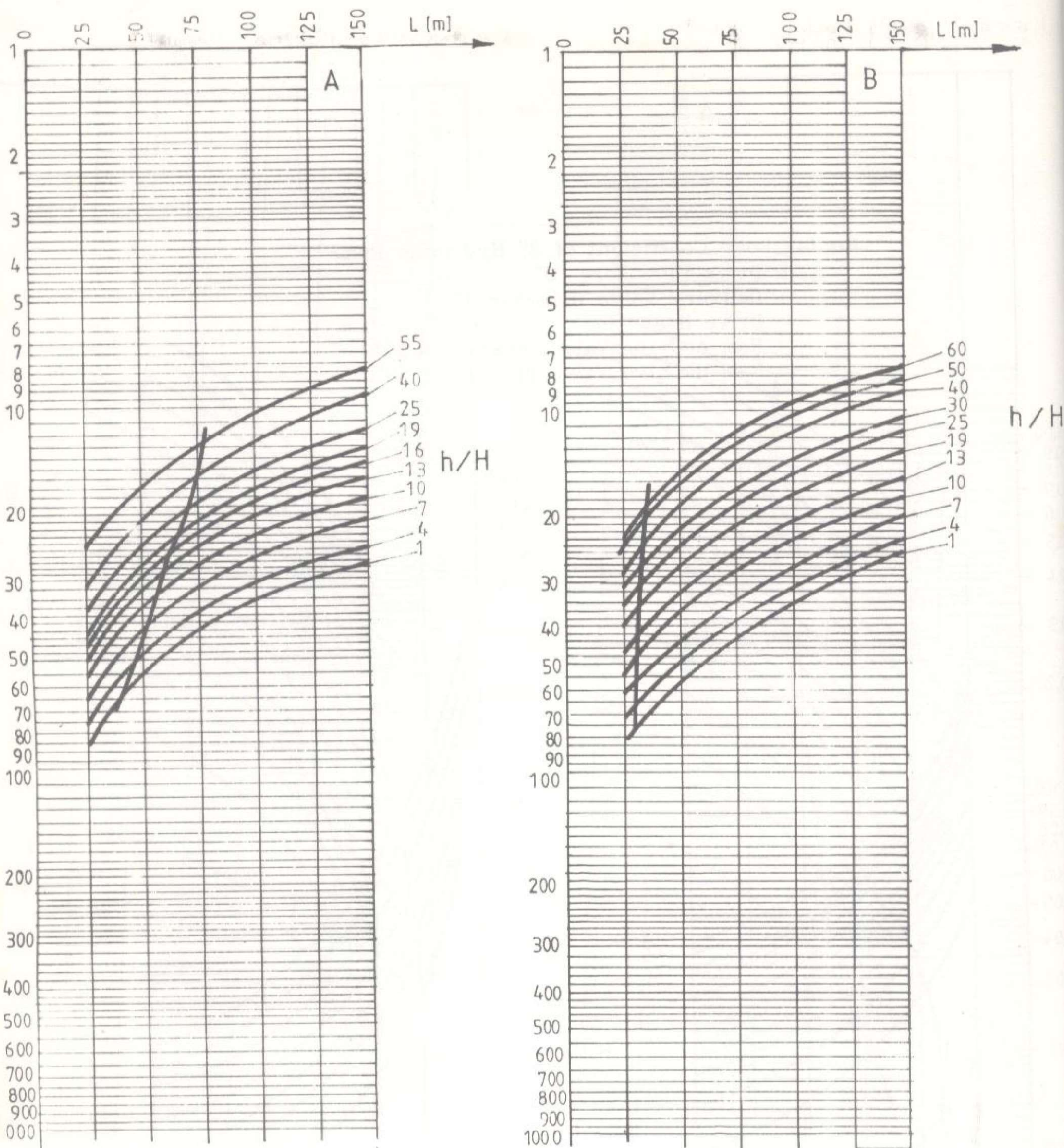

Fig.7: Frequency of 3" Hydraulic Rams
Drive Line Bore 3"
Delivery Valve Diameter 3"
Drive Head 5m
Ram A Drive Valve Diameter 4.25"
Ram B Drive Valve Diameter 8.50"

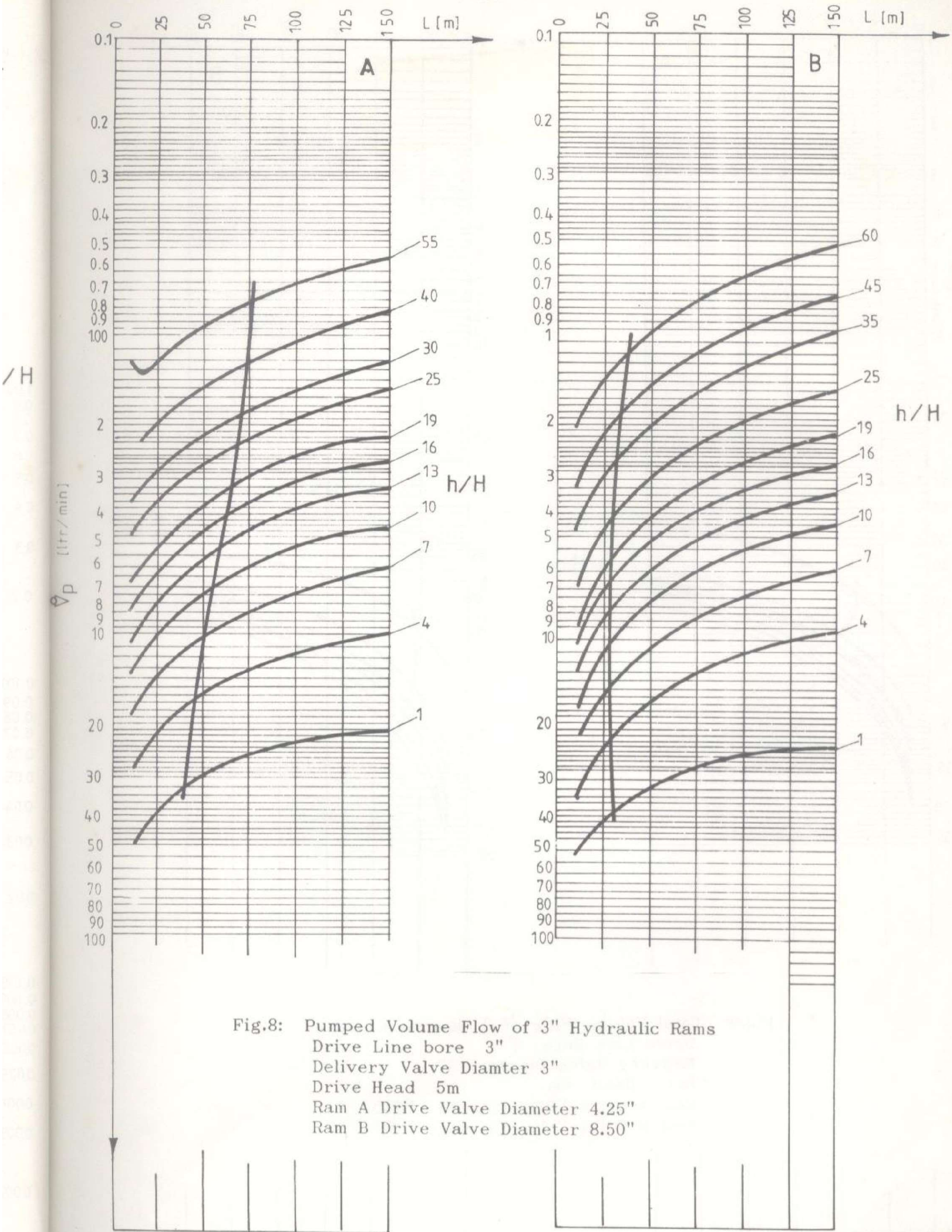

Fig.8: Pumped Volume Flow of 3" Hydraulic Rams
Drive Line bore 3"
Delivery Valve Diamter 3"
Drive Head 5m
Ram A Drive Valve Diameter 4.25"
Ram B Drive Valve Diameter 8.50"

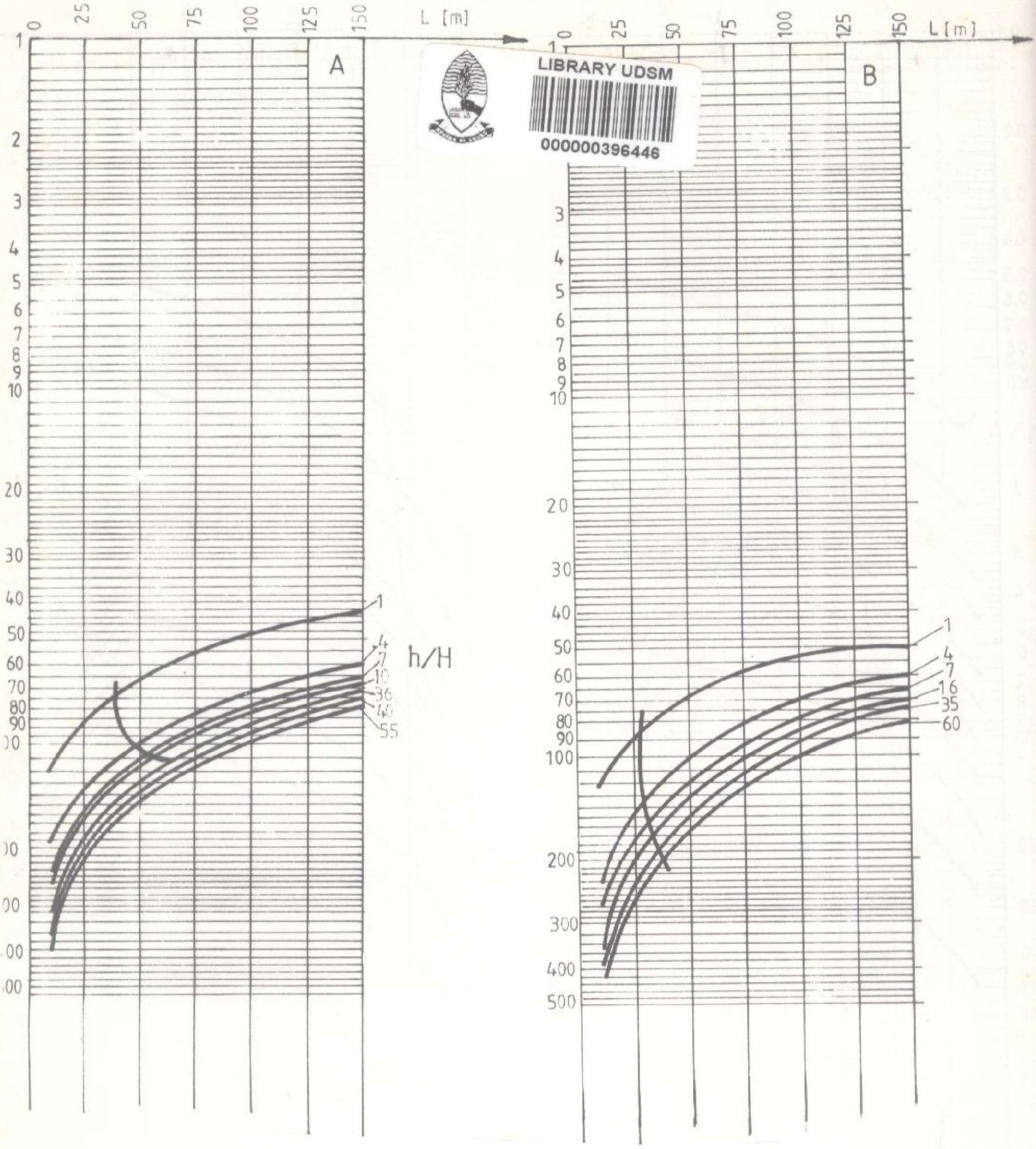

Fig.9: Total Volume Flow of 3" Hydraulic Rams
Drive Line Bore 3"
Delivery Valve Diamter 3"
Drive Head 5m
Ram A Drive Valve Diameter 4.25"
Ram B Drive Valve Diameter 8.50"