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UDK 628.14
ISBN 951-720-584-8
ISSN 0357-8860

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Tampereen teknillinen korkeakoulu
Rakennustekniikan osasto
Vesitekniikka

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PIPE MATERIALS IN TRANSMISSION MAINS

by C.R.W. Kayombo

A thesis submitted for a
degree of Master of Science
(Engineering) at the Tampere
University of Technology,
Finland

March 1981

TABLE OF CONTENTS

ABSTRACT

In this paper the author has confined himself to a discussion on pipes in rising mains. The manufacturing process and characteristics of the different pipe materials have been covered. The study also looks at some problems encountered in pipelines. A brief survey of the use of different pipe materials (viz. PVC, A-C and Steel) in Zambia has been included. The paper ends with guidelines to the use of different pipe materials in Zambia taking into account previous experiences.

1. DEVELOPMENT OF PIPES

1.1 Historical Factors

Water Supply Engineering originated with the growth of ancient towns or trade centres. Inspite of the time at which they were constructed the structures were of a complex nature and remnants of some of them are monuments of great magnitude. Some of the notable ones are the aqueducts of Rome and her empire. Indeed Sextus Julius Frontinus (5) who was water commissioner of Rome in AD 97 reported the existence of nine aqueducts supplying water to Rome. These varied in length from 10 to over 80 km and varying in cross section from 0.5 to 5sq.m. Clemeus Herschet (5) a hydraulic engineer (1842-1930) estimated the total capacity of the aqueducts at over 400,000m^3/d.

However, quality control in water supply is of recent origin. It too originated with the growth of cities. Developments in science and engineering in the eighteenth and nineteenth centuries created industrial centres which attracted people. The sanitary facilities of these mush-rooming towns were soon over stretched. Whereas before water was simply drawn from streams and wells, then distributed through stand pipes, the fatigue of fetching water from these stand pipes caused the inhabitants to restrict its use to the most important usage - food - neglected everything else including cleanliness.

There was therefore need to develop a system of distributing safe water and with it, the disposal of wastewater. Although cities were provided with drainage systems fecal and other wastes were not allowed into these systems. They left the drainage systems to carry storm water only. Surprisingly this practice continued well into the nineteenth century. Eventually human excrement was allowed into these open storm drains. It was this filthy sight and general unhygienic conditions of this system that notable characters like Sir Edwin Chadwick (a lawyer by profession 1842) called for a crusader for health. In 1849 Dr. John Snow[5] demonstrated the role of fecal pollution of drinking water in the epidemicity of cholera.

Eventually John Roe accepted Chadiwick's advice and constructed sewer lines of vitrified tile pipe. Thus industrial developments coupled with increase in the demand for proper sanitation forced the ancient scientists and engineers to improve on the methods of water supply and wastewater disposal. This required the use of pipes for the transmission and distribution in case of water and for the collection and transmission in case of wastewater.

1.2 Community Water Supply

Water is supplied to municipalities for many purposes such as (1) drinking, (2) bathing and laundry, (3) for watering lawns and gardens, (4) industrial use, (5) for fire fighting and (6) for wastewater removal. To provide for all these varying uses the supply must be satisfactory in quality and quantity. It must also be cheap to the user. In Zambia 150 lpcd is used frequently in designing community water supply.

Therefore, when a choice of what pipe material to use is to be made consideration should be given as to the total cost of the pipes, including the transportation and installation costs; their capability to transmit the desired quantity and their chemical effect, if any, on the water. Masonry and most metal pipes transmitting water to communities may be attacked by the water they convey and thereby change its quality. Therefore every designer should adjust the pipe materials used to the quality of the water, or adjust the quality of the water to the pipe material used.

1.3 Transmission

Water supply conduits transporting water from the source to the community form an important link. Conduits may be designed for open channel or closed conduit pressure flow. Open channels follow the hydraulic grade line or dug out canals. On the other hand pressure conduits may depart from the hydraulic grade line and cut through valleys and hills. Size and shape of the conduit are determined by hydraulic and economic factors. The same is true when one has to decide on which pipe material to be used for any given scheme.

2. FLUID FLOW AND PIPE MATERIAL REQUIREMENTS

The structural design and indeed the choice of pipe material will be governed by factors such as the hydraulics of the flow system and the prevailing local conditions. Usually the capacities of commercial pipes vary considerably from theoretical values. It is therefore a common practice to design pipeline system for maximum discharges at non-silting and non-erodable velocities to minimize friction losses. The local conditions will vary from place to place and the magnitude will depend on factors such as soil type, dissolved chemicals in water, traffic, etc.

2.1 Formulae in Fluid Transport

Resistance to flow, which is related to the pipe material plays an important role in pipeline design. And in rising (transmission) mains this frictional resistance is more important than resistance caused by appurtenances. In dealing with this problem a number of rational formulae and their solutions have been developed. Starting off with the original Chezy's proposal (1775) to the present Darcy Weiback. In Table 1 three common formulae have been tabulated.

In field practice, however, the engineer is free to choose the formulae which suits his conditions. For many practical conditions the Hazen-Williams formulae is popular and well documented. It is also reasonably accurate over a range of pipe diameters and flows. The weakness lies in the estimates of C in the absence of measurements of head loss and velocity. On the other hand Mannings formulae has the

Table 1: Formulae in Common Use

Originator	Velocity	Frictional Head Loss
Darcy-Weibach	$\bar{V} =$ (m/s) $\sqrt{\frac{h_f}{\ell} \cdot \frac{d}{f} \cdot 2g}$ $= 4.429\sqrt{\frac{d}{f} \cdot s}$	$h_f = s\ell$ (m) $f \cdot \frac{\ell}{d} \cdot \frac{\bar{V}^2}{2g}$ $= \frac{f}{19.62} \cdot \frac{\ell\, v^2}{d}$
Mannings	$\frac{1}{n} R^{\frac{2}{3}} \ \frac{H^{\frac{1}{2}}}{L}$ $= \frac{0.397\ d^{\frac{2}{3}}}{n} \cdot S^{\frac{1}{2}}$	$\frac{6.34\ n^2 v^2 \ell}{d^{1.33}}$
Hazen-Williams	$0.355CR^{0.63}.S^{0.54}$	$\left(\frac{1.170}{c_h}\right)^{1.852} \ \frac{\ell\ \bar{V}^{1.852}}{d\ 1.167}$

Where:

S = gradient

f = friction coefficient

ℓ = length of pipe

H = head

d = diameter

n = Mannings constant

C_h = Hazen's constant

R = Hydraulic radius

advantage that 'H' is directly proportional to v^2. It is more accurate than the Hazen-Williams formulae in estimates of high flows in rough surfaced pipes. That is why the Mannings formulae is mainly used in open channel flow. The Darcy-Weibach formulae is mainly used in distribution systems.

Its advantage is that for constant 'f' H is directly proportional to 1/d. Tables 2 and 3 show different formulae constants for different materials.

Table 2 : Values of Mannings 'n' for Various Materials (15)

Smooth metallic	0.010
Large welded steel pipes with coal-tar lining	0.011
Smooth concrete or small steel pipes	0.012
Rough Concrete	0.017
Old rough or tuberculated G.I pipes	0.02-0.035

Table 3 : Values of Hazen-Williams Coefficients of Roughness C_h (3)

Excellent condition cast iron and steel pipe with cement or bituminous linings.	
Plastic pipes. Cement asbestos pipes	140
Older pipes listed above	130
Old unlined or tar-dipped cast iron pipe in good condition	100
Old cast iron pipe severely turberculated or any pipe with heavey deposits	40-80

Fig.1 shows the relationship between 'f' and Reynolds number 'R'. Knowing 'R', the pipe material (giving K_s value) and the diameter is is possible to obtain values of 'f' for use in the Darcy-Weibach formulae. This diagrame known

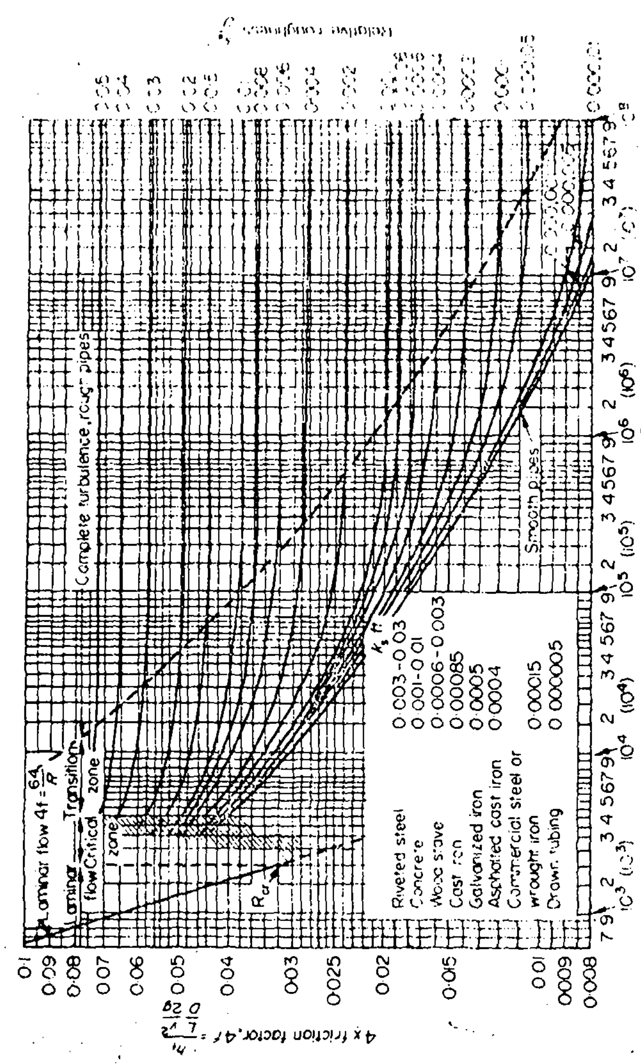


Fig. 1.: Pipe friction diagram (4)

as the Hunder House[4] resistance diagram is used for flow in uniform conduct.

2.2 Material Requirements

Before consideration is made as to what type of pipe to be used the first step is determining the total consumption. The hydraulic and economic factors will follow in deciding the minimum workable size of pipe. Structurally the pipes must overcome the following forces:

1) Temperature-induced expansion and contraction.
2) External loads in the form of traffic, backfill and their own weight between supports.
3) Unbalanced pressures at bends, contractions and closures.
4) Water hammer
5) Internal pressures equal to the full head of water

2.3 Problems Commonly Encountered in Pipelines

2.3.1 Forces on Pipes

Soil: Buried pipes have to cope with, among other things, crippling of the walls caused by external soil pressure. This may be crushing or buckling. The pipe may also suffer from deflection or change of diameter because of the compression of the soil. In pipeline design ring deflection is often very important. Crackling is primarily a function of ring deflection. Marston[6] calculated maximum load on buried pipes and came up with a formulae for the load on buried pipes. The formulae is in imperial units.

It is therefore necessary to convert the dimensions whenever using the formulae

$$W = C \rho B^2$$

where W = load on pipe lb/ft

C = load coefficient as function of depth, trench width and type of soil

ρ = density of backfill lb/ft

B = width of trench at top of pipe (ft)

Expansive soils have apercuilar property. By definition expansive soils are soils that swell (upon wetting), or shrink (upon drying). The process is generally referred to as volume changes. Various clays (e.g. kaolinites, montmorillonites, etc.) behave this way. The following characteristics may indicate a potential expansive soil if it:

- becomes very hard upon drying and also cracks.
- becomes very sticky upon wetting
- absorbs water slowly
- fine grained.

These soils can damage structures on or within them. In underground piping the failure is more of beam break in strong-rigid type pipes and ring-crash in weak rigid type pipes. Construction of a trench for the installation of a pipeline attracts water from the surroundings into the trench. Shallow cover over the pipe in expansive soils which thereafter suffer from long dry periods may promote pipe damage because of pressure differences above and below the pipe. Damage to the external pipe coating may occur due to shrinkage. As the soil shrinks it grips the coating and peels it off, thus exposing the pipe.

Traffic:

Traffic loads are a nuisance to pipelines. In general 'weak' pipes like plastics and asbestos cement pipes have to be protected with either concrete pipes or cast iron pipes whenever they encounter roads or railways. Accordint to studies undertaken by the Transport and Road Research Laboratory [12], most severe loads on pipes occur during the construction period when heavy trucks transverse pipelines. It was also established that the impact factor increases with speed of vehicles. But the relationship between impact factor and speed was found to be independent of pipe size, type of pipe and backfill material.

Water Hammer:

Regardless of the pipe material a water hammer can occur in any pipeline as a result of a rapid change in flow. This induces a pressure wave which hauls back and forth. Typical causes of sudden change of fluid velocity are:

1) Quick opening of line valve
2) Quick closing of a line valve
3) Sudden starting of a pump
4) Sudden stopping of a pump.

When for example flow in a pipeline is suddenly stopped, in less time than is required for a pressure wave to make one round trip, the non-compressible liquids rebounding produces a very high pressure. The kinetic energy so produced must be dissipated or absorbed by either compressing the liquid or stretching the walls of the pipe. The tensile strength of the pipe material therefore plays an important role in overcoming surge pressures. Surge pressure may be calculated as follows [13]. Again units have to be changed before using the formula:

$$P_s = \frac{aV}{2.31g}$$

where P_s = Surge pressure (psi)

a = Wave velocity feet/sec

V = Velocity change, occurring with the critical critical time 2L/a where L is pipe length in ft

g = gravitational acceleration f/s^2

The wave velocity may also be calculated from the following; formular:

$$a = \frac{4660}{(1 + KD/Et)^{\frac{1}{2}}}$$

where a = wave velocity f/s

K = bulk modulus of water (294,000) psi

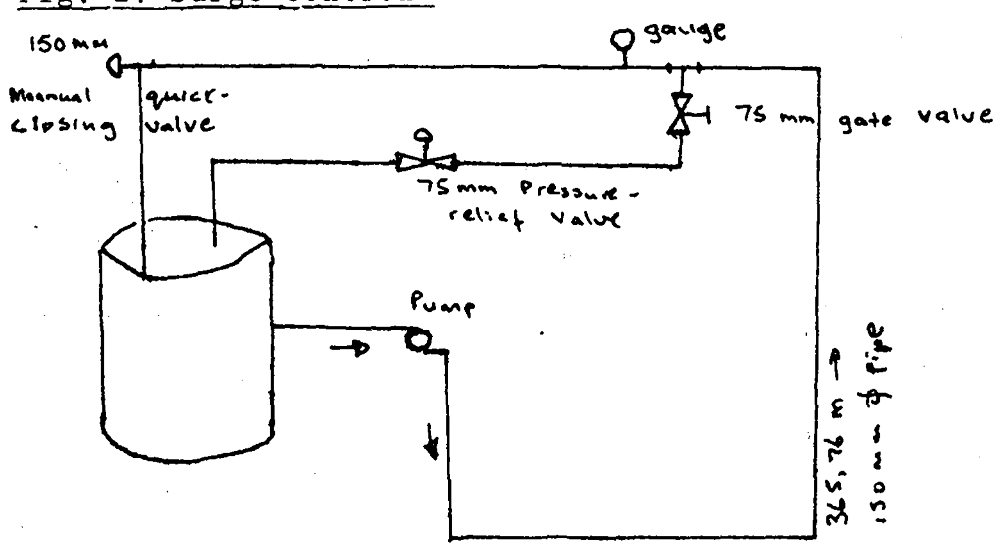
D = pipe inside diameter (in.)

E = pipe modulus of elasticity (psi)

t = pipe wall thickness (in.)

It must be emphasized that the surge pressure created is independent of the service pressure of the line. It is simply a function of the rate of velocity change of the fluid and should therefore be considered as additional to the normal static system pressure. Use of surge-control valves can reduce surge peaks considerably. The simplest form of a Surge Control Valve is the pressure relief valve (Fig.2) (7)

Fig. 2: Surge Control

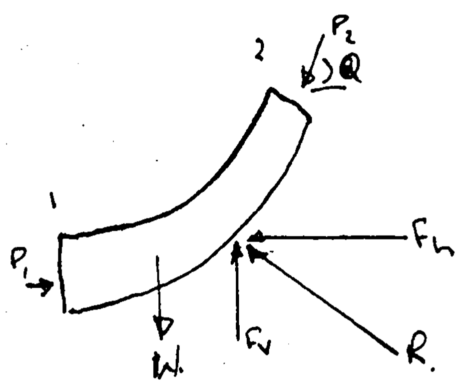


The 150 mm angle pattern valve fully closes in 6 seconds. At a flow rate of 45 l/s velocity in the 150 mm pipe is 1.98 m/s. The pumping pressure is 1930 N/m^2. When the relief-valve is isolated from the system, surge pressures rise to between 1.79 and 1.82 x 10^6 N/m^2. With the relief-valve in service surge pressure peak is between 4.8 and 5.5 x 10^6 N/m^2. The response is not always as straight forward as that.

Thrust:

There are two main forces exerting internal thrust on any fittings or bend. These are the static pressure force and the velocity or kinetic force. In water supply lines usually the velocities are not so high as to produce force comparable to pressure force. Professor Dake, J.M.[4] analysed the resultant force 'R' on a control volume in a reducing below:

Fig. 3: Analysing forces on bend in a pipeline



P_1 and P_2 = Pressure forces

F_v and F_h = Vertical and horizontal force component

W = Weight

The resultant force R is the force required by a thrust block placed on the bend.

Horizontally - $P_1 - P_2 \text{ Cos } Q - F_h = m\bar{v}_2 \text{ Cos } Q - m\bar{v}_1$ (1)

Vertically - $P_2 \text{ Sin } Q - W + F_v = m\bar{v}_2 \text{ Sin } Q$ (2)

where $m = P_1 A_1 \bar{V}_1 = P_2 A_2 \bar{V}_2$

Thus 1 becomes $F_h = P_1 A_1 \bar{V}_1 (v_1 - v_2 \text{ Cos } Q) + P_1 A_1 - P_2 A_2 \text{ Cos } Q$

2 becomes $F_v - W = P_1 A_1 \bar{V}_1 \bar{V}_2 \text{ Sin } Q + P_2 A_2 \text{ Sin } Q$

$$R = (F_h^2 + F_v^2)^{\frac{1}{2}} \quad \text{inclined at } \tan^{-1} \frac{F_v}{F_h}$$

Others:

In some places other external forces such as those caused by earthquakes are common. T.M. Mikaoka[11] reports on some damages caused by earthquakes in Japan. See Table 4. Other forces may be freezing of water in pipes especially in cold climates. This usually is due to either to (a) pipes not buried sufficiently deep, or (b) above-ground-surface pipes insufficiently protected. The water may be melted by either electrical thawing or using steam.

2.4.2 Corrosion.

Corrosion has long been a concern to the water works and the pipe industry. Despite the technological advances that have reduced the susceptability of pipes to corrosion the problem has continued to be a serious and costly one. Indeed there are many factors involved when talking of the corrosive quality of water. Each case must be examined individually. Metalic pipes are the principal targets of corrosion.

Theory of Corrosion

Basically the highly complex phenomenon of corrosion is analogous to a dry-cell battery. Most common dry-cells are made up of carbon and zinc electrodes separated by an electrolyte. There is chemical reduction at the zinc (cathode) electrode, and chemical oxidation at the carbon (anode) electrode. Most metals have small amounts of impurities. In addition the surfaces are not homogenous, but have in essence, microcells. The exposure of metals to

Table 4 : Examples of Damage on Pipes due to Earthquakes (11)

	Grey Iron Pipe	Steel Pipe	Ductile Iron Pipe	Asbestos Cement Pipe	PS Concrete Pipe	Cocrete Pipe	PVC Pipe
Water Pipe	Slipping out of socket and sprigoat lead caulked joint slipping out of mechanical joint Breakage of pipe barrel. Breakage and crack of pipe fitting	Breakage or crack of welded joint leakage at expansion joint bending of pipe barrel	No damage	Breakage of pipe barrel leakage at Gibault joint, slipping out of joint. Washed away together with road	Leakage at joint	Breakage of pipe barrel longitudinal crack on pipe barrel slipping out of joint	Breakage of joint
Industrial water pipe		No damage	No damage		Breakage of socket slipping out of joint. Leakage at joint		
Gas	Slipping out lead or yarn caulking	Breakage of bend					Breakage of tee or nipple
Power Plant Pipe			Leak at the special joint (Closure joint)				
Plant pipe	Leakage at the special joint slipping out of socket and spigot joint. Crack on flange joint Breakage of threads of tap. Longintudinal crack on pipe barrel	Buckling of tees. Breakage of bend '					

an aqueous solution allow chemical reductions and oxidations. Table 5 shows some corrosion reactions in chemical reactions.

Table 5: Chemical Equations of Corrosion Reactions

$Fe + \frac{1}{2}O_2 + 2H^+$	$\rightarrow$	$Fe^{++} + H_2O$
$Fe + H_2O + \frac{1}{2}O_2$	$\rightarrow$	$Fe(OH)_2$
$Mg + 2H^+$	$\rightarrow$	$Mg^{++} + H_2$
$Zn + 2H^+$	$\rightarrow$	$Zn^{++} + H_2$
$Cu + \frac{1}{2}O_2$	$\rightarrow$	CuO

Factors leading to corrosion include the following:

a) low pH value of water;

b) a high CO_2 content

c) alkalinity

d) presence of dissimilar metals

Bacterial Corrosion

There is a type of bacteria called sulphate reducing bacterial existing in anaerobic condition. This bacteria is capable of feeding on mineral diet. The metabolism so involved results in the production of hydrogen sulphide which attacks iron and steel pipes.

Effects of corrosion

In water system the effects of corrosion are:

a) loss in hydraulic carrying capacity of pipes and fittings;

b) possible structural failures;

c) poor quality of water.

Table 6 : Condition of Pipes Subjected to Corrosion in Zambia [1]

Town	Location	Size (in)	Pipe Material	Internal Pipe Condition	Remarks
Lusaka	Musandile Road	3	GI	Pipe leaking, heavy internal coating, badly pitted inside and outside	Pipe age not known
Lusaka	Chula Road	6	AC	White deposit, very light coating all round, When dry otherwise good condition	Pipe age not known
Lusaka	Lumumba Road	8	Steel	Top of inside blistering	Pipe age not known
Kitwe	Tafuna Drive	12	AC	Hard, light brown scale around pipe periphery pipe condition good	Pipe installed 7 years ago
Kitwe	22 Avenue	8	Steel	Hard, rust build - up all around the pipe up to 18 mm thick. Estimated reduction in pipe flow capacity to 40%	Pipe installed about 23 years ago

Table 6 shows examples of pipes subjected to corrosion. Loss in carrying capacity and structural failures are economically important. One form of corrosion that may easily be overlooked is that due to dissolved copper. It may be in small concentration as low as 0.01 mg/l. This type of corrosion is common with iron pipes or galvanized iron pipes. A piece of iron or galvanized iron is a very efficient collector of dissolved copper. Not only will copper plate on the metal but also once plated out, the copper forms an active galvanic cell. However, this type of corrosion is common in new pipes. The problem can therefore be avoided by providing a protective coating for new piping systems. This should be of interest on the Copperbelt region of Zambia.

Control of Corrosion

The first and foremost method of corrosion control is the choice of corrosion resistant pipe material. Other methods include:

- Addition of lime to increase pH
- Aeration to remove free carbon
- Addition of lime also removes CO_2, although this tends to increase carbonate hardness.

Thus: $2CO_2 + Ca(OH)_2 \rightarrow Ca(HCO_3)_2$

Sodium hexametaphosphate (usually called calgon) in dosages of 1 to 2 mg/l can be used in removing carbonate hardness. It also reduces tuberculation. The latter process from when mounds of corrosion products collect on the surface of metal:

- avoid having two metals with a high electropotential difference
- coatings and linings of pipes will prevent both anodic and cathodic reactions

Since bacterial corrosion can also occur from outside protective coating (e.g. with bitumen) will help prevent this. Also packing gravel or sand outside will free drain water and thereby prevent anaerobic corrosion.

2.4.3 Health Aspects

Although lead pipes are used in the distribution system, it is advisable to note that water of low pH value should not be conveyed in such pipes because when taken into solution lead is a poison. Some authorities have raised fears over the use of asbestos-cement (A-C) pipes for health reasons. A ten-year study by the Norwegian Institute for Water Research (8) have shown that calcium removal from A-C pipes caused pipe deterioration of 0.3mm/year but the rate reduced rapidly from the first year onwards. There is evidence that persons exposed to airborne asbestos experience higher than expected rates of peritoneal, nesothelioma, gastric cancer. However, H. Wister Meigs, M.D (10) reports on a forty-year period study of independent variables related to drinking water using A-C pipes and the occurrence of cancer. The discussion concludes in part that "there is no consistent indication that use of A-C pipe in Connecticut Public Water supplies has been followed by increases either of cancer's or of individual sites studied".

3. PIPE MATERIALS

3.0 Development

Increases in population, industrial activities and agricultural developments have resulted in increased water consumption. Consequently, this has demanded good control of leakages, high pressures as well as trench loadings in the operational requirements of pipelines. Whereas in earlier periods pipes were thick and rigid, today's manufactureres have, with improved technology, developed high strength materials. For example, the thick-walled pipes were able to withstand vertical loads under normal installation. In the thin-walled pipes, the supporting effect of soil is taken into consideration.

In general selection of pipe materials is based on the following:

1) Strength of pipe, as measured by the capacity to withstand internal and external pressure.
2) Durability in the face of cracking, erosion, corrosion and disintegration.
3) Safety
4) Easy or difficult in handling and transportation.
5) Availability of related resources.
6) Costs.

3.1 Plastics

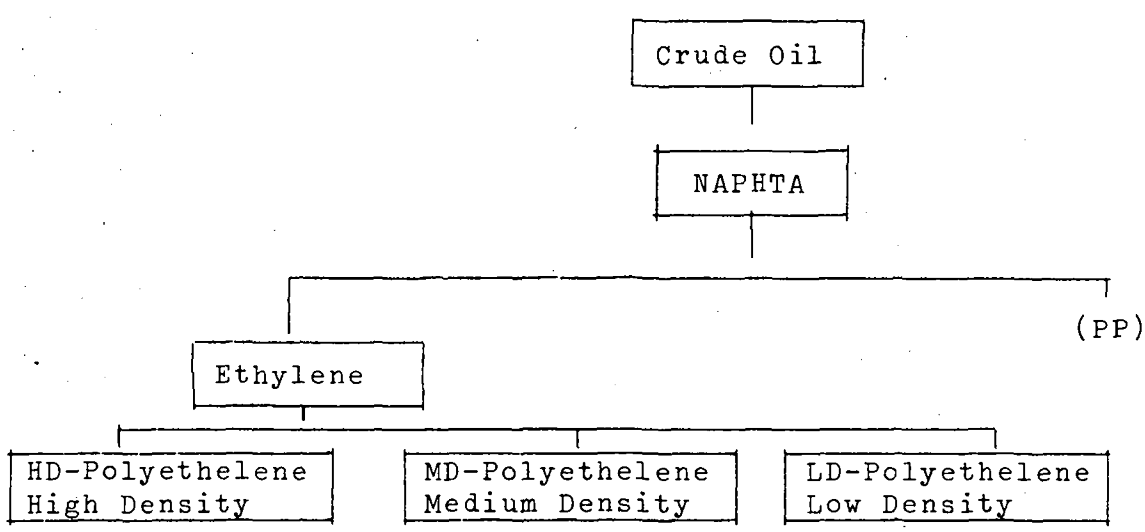
Manufacture

In recent years use of plastics has greatly increased. Composition depends on the type and these come in different forms. Some of the known plastics are Poly Vinyl Chloride (PVC), Polyethelene (PE), Polyproplene (PP) and Acrylonitrile Butadiene-Styrene (ABC). Because of their frequent use in public water supplies the first two have been discussed here.

Polyethelene

Basically polyethelene is a by-product of crude oil. Fig. 4 shows what may be termed as the 'Oil' - Connection.

Fig. 4. Path of the Manufacture of Polyethelene (16)



HD-Polyethelene (HDPE) is produced through a low pressure process. MD-Polyethelene (MDPE) and LD-Polyethelene (LDPE) are obtained through a relatively high pressure method in which the quality of the product depends on the pressure. The raw material also plays an important role. In the HDPE the crystallinity of the raw material is more than that of the LDPE and this accounts for the hardness in the former.

Poly Vinyl Chloride

Poly Vinyl Chloride (PVC) is made from the Vinyl Chloride monomer which undergoes polymerization (linking together).

Small molecules to form large ones (9)

$$n\left(\begin{array}{ccc} H & & Cl \\ | & & | \\ C & = & C \\ | & & | \\ H & & H \end{array}\right) \longrightarrow \left(\begin{array}{ccc} H & & Cl \\ | & & | \\ C & - & C \\ | & & | \\ H & & H \end{array}\right)_n$$

Vinyl Chloride (Monomer) → Poly Vinyl Chloride (Polymer)

The monomer itself can be obtained from petroleum. In the manufacture of PVC pipes several other ingredients are added to the polymer: Lubricants - These are mostly soaps. They ease the flow through the equipment; Heat stabilisers - these are mainly metal compounds. They improve the thermal stability of PVC during the manufacture process and during the service life; Modifiers - These are organic compounds which give PVC its engineering properties.

In the manufacturing process everything is mixed in a high speed mixer (between 1500 - 3000 rpm) at approximately 120°C before being cooled to about 50°C and then finally through the extrusion process. There are two types of PVC:

- rigid PVC (or unplasticised PVC - uPVC)
- plasticised PVC. This has plasticisers added during the manufacture process that make it safe and more flexible than uPVC.

Characteristics

The main characteristics of plastic pipes which give them an advantage over other pipes are: freedom from corrosion, light weight and flexibility. They are also known to withstand attacks from acids and alkalis as well as bacterial attack. PE pipes are suitable for laying under the water. The reasons being that they easily bend and the welded joints are water tight. Fig 5 shows some of the engineering properties of PE pipes. Plastic pipes are graded as B, C, D and E. The classes differ only in pipe wall thickness.

Table 7: PVC Pipes to BS. 3505

		Bore to Nearest mm			
Nominal Bore	Outside Diameter to nearest (mm)	B 60 m Working Head	C 90 m Working Head	D 120 m Working Head	E 150 m Working Head
100	114	107	105	102	99
150	168	159	155	151	146
225	244	232	226	220	214
300	324	308	301	294	286
450	457	434	424	412	-
600	609	580	566	-	-

Table 7 shows the relative differences between the external and internal diameters of the various classes. The expected design life of these pipes is estimated at over 50 years (2).

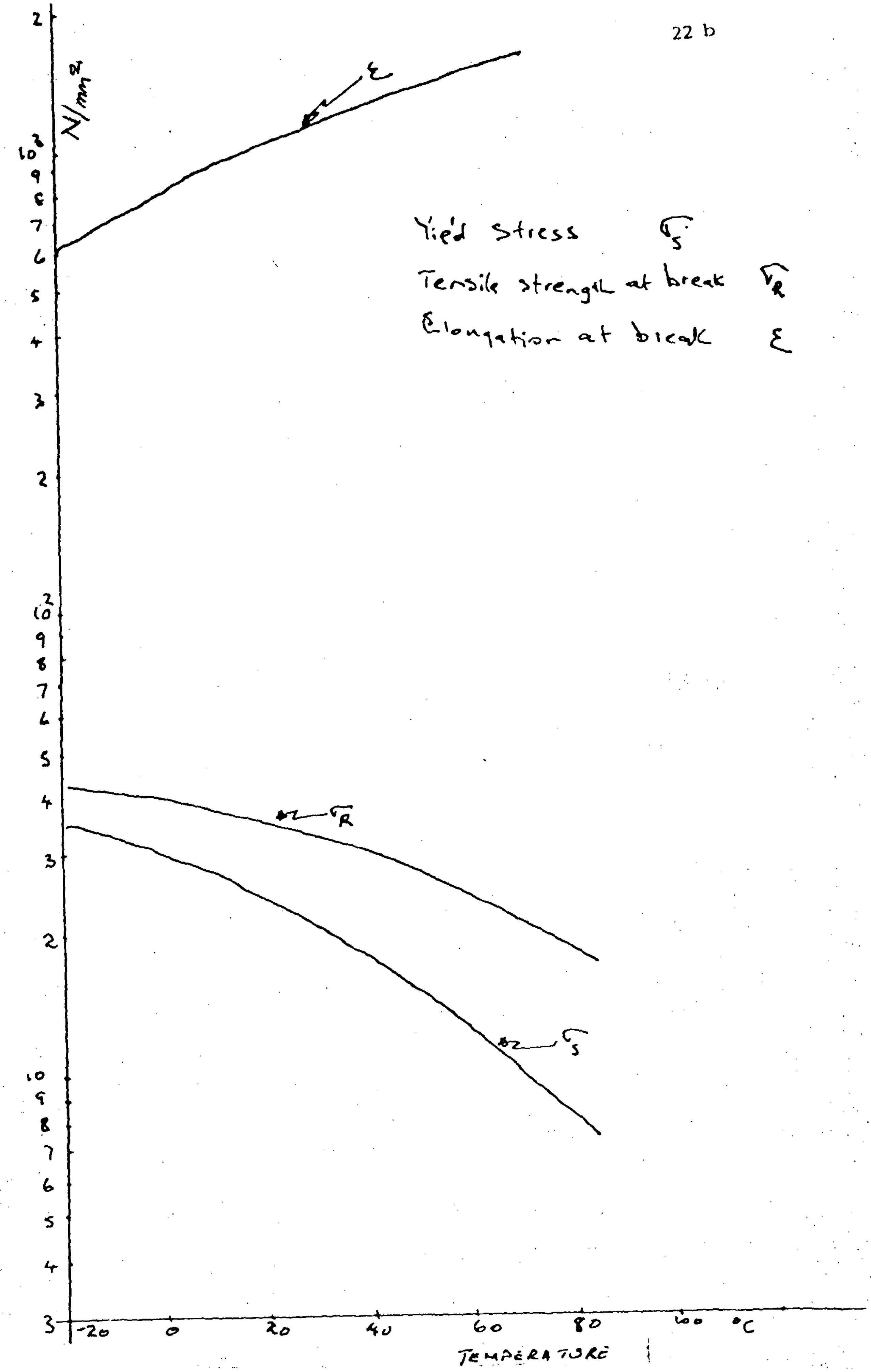


Fig 5. Engineering properties of Polyethelene

Impact strength decreases with lowering temperature while tensile strength decreases with increasing temperature and these facts should be borne in mind when using these pipes under extreme temperatures. Fig.4 shows a graphical representation of these characteristics. PVC tends to embrittle when exposed to direct sunlight while Polyethelene is affected by ultra violet rays.

Joints

PVC is usually joined by using solvent cement or rubber 'O' rings. On the other hand welding is common in joining PE pipes. It must, however, be emphasized that this requires special equipment and skilled personnel. Couplings made of plastic or other materials may be used. Fig.6 shows connections of metal tubes to PE pipes. Connections to

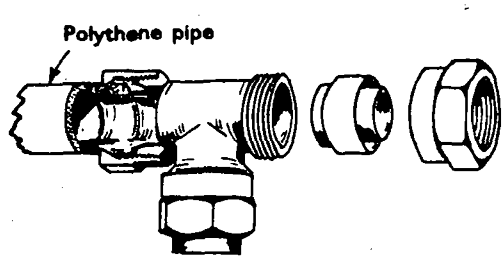


Fig. 6. Connection of metal tube to PE pipes(10)

other structures depend on the type of plastic as well as the size and material of the other structures.

3.2 Pre-Stressed Concrete

Manufacture

Pre-stressed pipes are made by tensioning 'high' tensile wire around a cylindrical core. The core may consist of either longitudinally prestressed concrete or a thin steel cylinder which has a thin spun concrete lining to the interior. The latter are referred to as 'cylinder prestressed concrete pipes' and the former 'non-cylinder'. After the wires have been wound and stressed a thick coat of concrete is pneumatically poured externally onto the pipe evenly as it is rotated. The design procedure for this pipe consists of the calculation for different amounts of prestressing steel. For each one, the geometrical and material characteristics of the pipe and the admissible working pressure is obtained. It is then possible to draw the curve 'admissible working pressure versus steel quantity' and finally from the required working pressure to find the necessary steel section.

Characteristics

By increasing the number of prestressing steel it is possible to raise the pressure capability of the pipe. The main advantage of prestressed concrete pipes is that they are cheaper than steel for diameters of 300 mm and above. They are also able to withstand certain corrosive conditions that would attack iron and steel. However, it has to be protected against stress corrosion of the prestressing steel. Since corrosion failure of the steel requires the existence of water in contact with the steel surface, the best way to avoid stress corrosion is to avoid the contact of water with the prestressing steel. This may be achieved either by making a waterproof mortar coating of the pipe or protect the steel with sythetic resins. Other disadvantages include weight and the fact that it is almost impossible to make connections after the pipe has been laid because of the need to cut into the prestressing wires.

Joints

Joints for prestressed pipes are usually the lock joint-push-in type where the socket and spigot may be made of steel or prestressed concrete collars. Also the Viking Johnson coupling shown in Fig. 8 may be applied.

3.3 Asbestos Cement

Manufacture

Asbestos cement (A-C) pipes are made of cement and asbestos fibres mixed into a slurry and then deposited layer upon layer around a cylindrical mould-like structure. When the required thickness is reached the pipe is steam or water cured.

Characteristics

A-C pipes have the characteristic property of being resistant to corrosive conditions that would otherwise be disastrous to cast, iron or steel. They also possess good water tightness. Hence, they are used in transmission mains. Compared to, say, concrete pipes they have relatively low wall thickness. They do not tuberculate.

However, these pipes suffer from a number of disadvantages. The major one being that the pipes tend to be brittle and therefore liable to be easily damaged under impact loads.

Special parts are made from metal (see Fig. 7a) especially at take-off points. It is for this reason that when cast iron is used on joints the pipeline must be protected with bitumen if used in aggressive soils. In general A-C pipes should be bitumen coated if magnesium sulphate in the soil is greater than 2000 mg/l. Table 8 showes the relative difference in internal and external diameters for different classes of pipes.

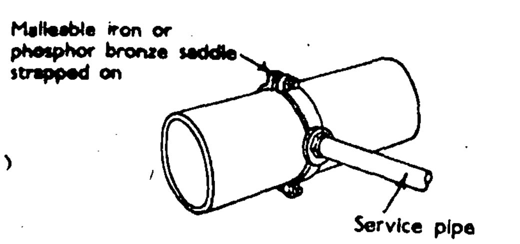
Table 8 : Asbestos Pipes Sizes for Various Classes

Nominal Diameter (mm)	External Diameter (mm)	Nominal External Diameter (mm)				
		A Working Head 30m	B Working Head 60m	C Working Head 90m	D Working Head 120m	E Working Head 180m
50	69.1	-	-	-	-	50.9
100	121.9	-	102.1	99.5	95.9	93.9
150	177.3	-	155.5	149.3	142.3	138.7
200	232.3	208.4	204.2	196.3	187.4	183.0
250	286.0	259.6	255.6	242.8	231.2	226.6
300	345.4	316.4	308.4	293.6	280.8	273.8
450	507.0	474.0	453.2	432.8	425.8	-
525	587.2	551.6	524.8	502.4	495.2	-
600	667.0	627.8	598.0	581.6	-	-

Joints

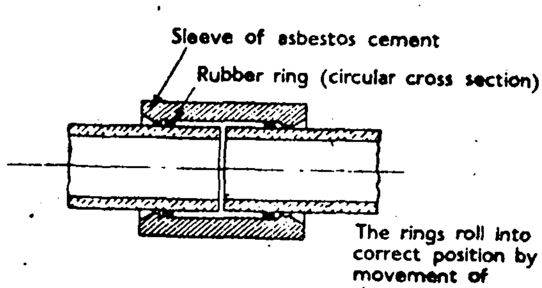
The most common joint for this pipe comprises the use of a rubber ring using a double collar..

(a)



Service connection to asbestos cement pipe

(b)



Simplex joint for asbestos cement pipes

Fig 7 (a) Service Joint (b) Simplex joint for A-C Pipe (10)

Common examples are the simplex joint (also known as the 'Fluid-Tite' joint) shown in Fig. 7b. The socket and spigot joint, common in steel pipes, is not so common in A-C pipes since most pipes are manufactured with plain ends.

3.4 Cast Iron

Manafacture

There are basically two types of cast iron pipes, vis., Grey cast iron and spun iron. The latter is often called Ductile iron. Basically both of them are composed of iron. The difference comes in the manufacture, whereas grey iron pipes are cast vertically in sand moulds. On the other hand 'spun iron' is prepared by pouring molten cast iron into a horizontal water-cooled rotating mould. The centrigugal forces flings the molten metal outwardly and evenly. The metal solidifys after a few spins and is then drawn red. After removing from the mould the pipe is again heated and then cooled slowly to reduce stresses induced by chilling.

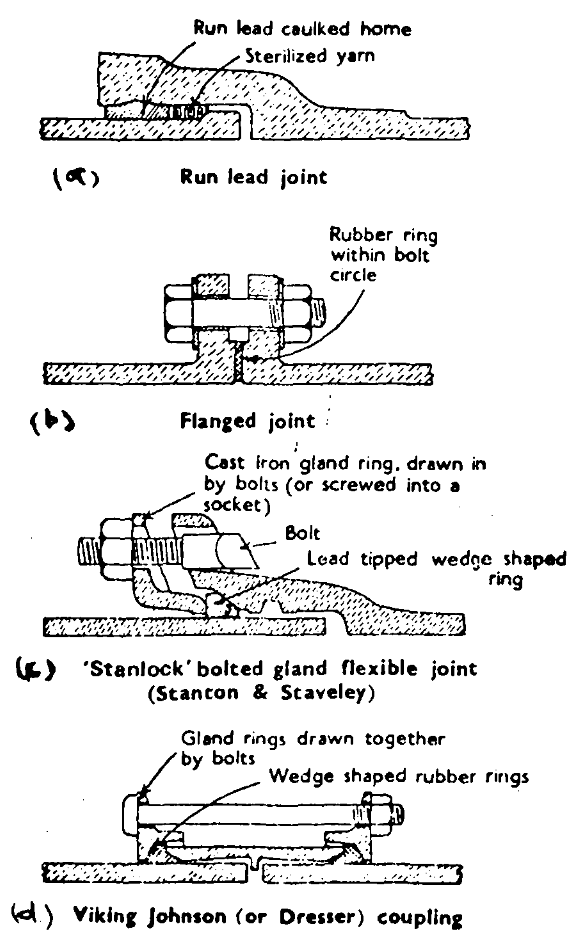
Characteristics

The spun iron pipes are of higher density and tougher than the grey iron pipes. Both pipes have the disadvantage of being heavy and liable to corrosion. Hence there is need to coat them inside and outside. The practice is coal tar pitching and sheathing with plastics. Grey iron is rather rigid while spun iron is ductile. Consequently the American Water Works Association has for Grey Iron AWWA H1 standard for rigid pipes structure and for Spun Iron AWWA HS standard for which takes into account the ductility of the material. Both types of pipes are suitable for large diameter pipeline.

Joints

The most common type of joints are shown in Fig.8 (15). These are based on British Standards.

Fig 8: Joints for Cast and Spun Iron Pipes (15)



(a) Run-end-joint: Not so popular now but still in use. It requires high class workmanship. The lead which makes the grip has to be initally heated to 400°C. the joint is rigid.

(b) Flanged joints: Special care must be taken to ensure alignment before inserting bolts to avoid fracture of the pipe or frange. The rubber rig between the flanges must lie inside the bolt circle and not intrude into the pipes. Cleanliness must be observed.

(c) Compressed gasget joint: As can be seen from Fig. 8 (c) the principle is that of forcing the load tipped rubber into an annular space.

(d) Viking Johnson Coupling: Commonly used for steel pipe coupling. The principle is simply another version of compressing rubber rings into the annular space. Except there is no socket or spigot.

3.5 Steel

Manufacture

Usually steel pipes in rising mains are of large sizes. These are made from steel plates bent to circular form. The edges of the plate are either lap welded or bult welded. Smaller sizes (32 to 450 mm) known as 'seamless' are made from ingots of hot steel which are pierced and then rolled into cylinders of required dimension.

Characteristics

There are no standards for steel pipes because there must be a minimum thickness to prevent bending of shape for buried pipes or collapse of pipe, under partial vacuum conditions. There must also be a minimum paractical thickness to withstand corrosion. Table 9 gives minimum thickness.

Table 9 : Minimum Thickness of Steel Pipes

Diameter	Thickness
300 - 600 mm	6.3 mm
675 mm	7.1 mm
750 - 900 mm	8.0
1050 - 1200 mm	9.5 mm

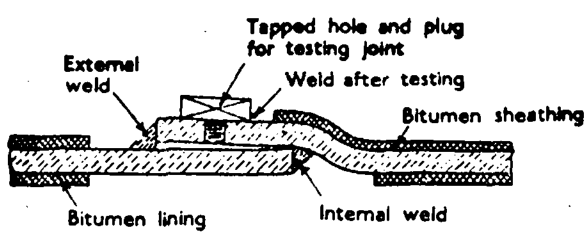
Steel pipes have the advantage of strength to take high operating pressures as well as ability to withstand impact load. Like cast iron pipes the main drawback is their weight, and being prone to corrosion. Protection against corrosion is therefore a must. External protection can be achieved by applying a first coat of bituminuous compositions followed by a second coat of hot bitumen and fibres. Internally the pipes are again protected by a 'bituminuous' compound layer the thickness of which depends on the corrosionness of the water to be transmitted. The range is from 1.6mm to 8mm for very corrosive water. Epoxy is also used for internal protection.

According to tests performed on the Los Angeles rising main after failures in 1971, conclusions were that steel under low operating temperature has very little notch toughness[9].

Joints

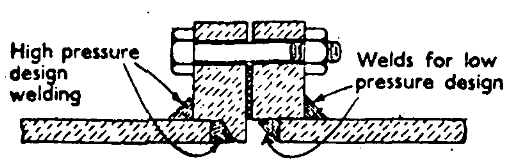
Common joints for steel pipes are the Viking Johnson coupling described in Fig.7. Another type is the welded socket and spigot joint which is shown in Fig 9.

Fig. 9: Joints for Steel Pipes (10)



Sheathing and lining made complete after test

Welded socket & spigot joint for steel pipe



Flanged joint for steel pipes

Pipes may also be bevel-ended for bult welding. The common flanged joint is also shown in Fig.8.

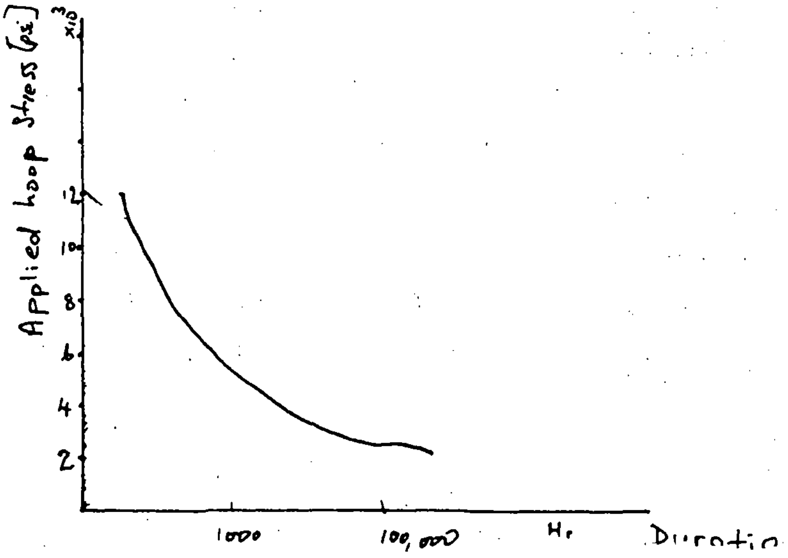
3.6 TABLE 10: Comparative Summary of Characteristics for Various Pipe Materials

	Ductile Iron	Grey Iron	Steel	Prestressed Concrete	Asbestos Cement	Polyvinyl Chloride
Tensile Strength (MN/m^2)	420	18-40	340-420	214	22.5	45-60
Youngs Modulus (GN/m^2)	165	100	207	30	23.5	4
Elongation	7-10%	<1%	According to grade	0.5%	Nil	40% min
Beam Strength (MN/m^2)	500	95	According to grade	-	24	92
Compressive Strength (MN/m^2)	300	6.5	According to grade	40	45	68
Design Safety Factor	2.5	2.5	2-2.5	1.8-4	4 bursting 2.5 crushing	1.5 min
Density (Kg/m^3)	70×10^2	70×10^2	78×10^2	$26\text{-}28 \times 10^2$	22×10^2	18×10^2
Diameter Range (mm)	80-1200	80-700	60-2140	400-3000	50-900	12.5-600
Rated Working Pressure (bar)	25/40	10/16	16/70	4/18	7.5/12.5	6/15
Types of Joints	Mech, pushin flange, couplings	Lead, Push-in couplings	Weld,Push-in couplings	Push-in couplings	Push-in, collar couplings	Push-in solve[illegible] Weld
Expected life in years						
Minimum	50	50	30	50	50	50
Maximum	100	100	100	100	100	67
Average	65	80	56	73	65	Not available

3.7 Safety Factors Considerations

Although an attempt has been made in Table 10 to compare safety factors of various materials this should not be regarded as rigid. This is because different materials have different failure modes, and their response to different external and internal forces are different. For example, pressure rating for asbestos cement is calculated by dividing quick burst pressure by a safety factory of, say, 4.0; While the pressure rating for cast iron pipes is calculated by dividing the combination of maximum trench load and quick burst pressure by a safety factor of 2.5. It must be pointed out that in establishing these safety factors it is assumed that the products response to short term as well as long term pressure loads are not substantially different. On the other hand PVC being a thermoplastic responds to an applied stress in a manner that is affected by plastic flow or creep. The rate of creep in response to an applied stress decreases slowly with time. The response may take the form displayed in Fig 10.

Fig. 10: Stress Regression Curve



This means that the safety factor should be established for long hours of stress application. Using, for example 100,000 hour stress application, the design stress upon which pressure rating is based is then defined by dividing the 'hoop' stress established on the stress regression curve at 100,000 hour by a chosen safety factor.

3.8 Standards

There are many standards for the manufacture and installation of pipes adopted by individual countries. In Zambia mainly British Standards are used. Extracts from these British Standards for the pipes commonly used in Zambia have been tabulated in Tables 11 to 15. Other International Standards are:

ISO/R13	Cast iron pipes for pressure mains
ISO/R160	Asbestos-cement pressure pipes
ISO/R559	Steel pipes for gas, water and sewage
ISO/R1165	Plastic pipes for transport of fluids
ISO/R2531	Ductile iron pipes for pressure pipes
ISO/R2785	Guide to the selection of A-C pipes subject to external loads.

It should be mentioned that there is a trend of change to ISO Standards.

Table 11: BS 3505 1968 : PVC Pipes

Classification at 20°C

Class	Head of Water (m)	Colour Coding According to BS 4159
B	60	Red
C	90	Blue
D	120	Green
E	150	Brown

Heat Reversion Test

After immensing in a heat transfer medium at 150 ± 2°C for a specified time (according to wall thickness) the pipes length should not change by more that 5%. Other tests are:

1) Hydraulic test, short and long term
2) Impact strength test at 20°C
3) Test for resistance to sulphuring acid
4) Test for resistance to acetone

Table 12: Wall Thickness of PVC BS 3807

Nominal Size	Outside Diameter		Wall Thickness (minimum) (mm)					
			B		C		D	
	Min	Max	Min	Max	Min	Max	Min	Max
2"	60.2	60.5	-	-	-	-	3.1	3.4
3"	88.7	89.1	2.9	3.3	2.8	3.1	4.6	5.1
4"	114.1	114.5	3.4	3.8	4.6	6.0	6.0	6.6
6"	168.0	168.5	4.5	5.0	6.6	7.3	8.8	9.7
8"	218.8	219.4	5.3	5.8	7.8	8.6	10.3	11.3
10"	272.6	273.4	6.6	7.3	9.7	10.7	12.8	14.1
12"	323.4	324.3	7.8	8.6	11.5	12.7	15.2	16.7
16"	405.9	406.9	9.7	10.7	14.5	16.0	19.0	20.9
18"	456.7	457.7	11.0	12.1	16.3	17.9	21.4	23.6
20"	507.5	5.08.5	12.2	13.4	18.1	19.9	-	-
24"	609.1	610.1	14.6	16.1	21.7	23.9	-	-

Table 13: Minimum Gricknesses of Welded Steel Pipes BS 534 1966 (Amendment 1970)

Outside Diameter (mm)	Thickness (mm)	Weight Plain End Kg/m	Hydraulic Test Pressure Kg f/cm^3	Imperial Nominal Diameter ins
76.1	3.2	5.8	-	3
168.3	3.6	14.7	70	6
219.1	4.0	21.4	50	8
273.0	4.0	26.7	40	10
323.9	4.0	31.8	34	12
457.2	4.9	54.3	28	18
609.6	5.4	80.3	24	24
762.0	6.3	118.0	22	30
914.4	8.0	178.0	23	36

Table 14: Specifications for A/C Pipes BS 486 1966 Classification

Class	Head (m)	Equivalent (kg/cm^2)
A	60.9	6.07
B	121.9	12.19
C	182.8	18.28
D	243.8	24.38

Table 14 (Continued)

Lengths

Nominal Size(mm)	Length(m)
50 and 75	3.048
100 to 250	4.0
300 to 610	(4.0 (5.0
675 to 900	5.0

Manufacture

When the pipes and bends have hardened sufficiently, they shall be immersed in water for seven days. They shall also be subjected to a further period of seven days as part of the fourteen days required to mature before being tested. Working pressure shall be 50% of test pressure.

Hydraulic Bursting Test

No end restraint to be applied. Internal pressure to be applied at a steady rate of 20 to 30 lbf/in^2 (1.38×10^5 to 2.07×10^5 Pa) per second and the bursting pressure recorded with a gauge that has a stop pointer to indicate the failure pressure. Other tests under this standard are:

- water absorption (18 hours)
- Solubility in acid (24 hours in acetic acid)
- crushing test
- ball and plug test
- longitudinal bending test

Table 15: BS 486 1972 for A-C Pipes

Classification

Class	Working Pressure N/mm^2
15	1.5
20	2.0
25	2.5

Thicknesses

Nominal Bore (mm)	Outside Diameter (mm) 0.5	2.0	2.5
100	-	-	122
200	232	252	240
250	286	286	295
300	334	345	356
400	448	463	478
600	654	672	691

This revised BS 486 (1972) in line with International Standards (ISO/160). However, pipes manufactured in Zambia are still using BS 486 1966.

4. PIPE MATERIALS : THE ZAMBIAN EXPERIENCE

4.1 Manufacture and Distribution

It can be generally said that three types of pipes (viz: steel, asbestos cement, and PVC) are widely used in Zambia. Cast iron pipes may be found in some old installations especially in the mining areas. However, galvanized iron pipes of small diameters have been using throughout the country in the distribution networks. Originally all these pipes were imported. However, industrial development within the last fifteen years or so has made it possible to manufacture the three types locally. Fig.11 shows the distribution of factories and distribution centres in the country.

4.1.1 P.V.C.

PVC pipes are manufactured by a company called PLASTICO in Lusaka. PROPORITE of Kitwe acts as the distribution agent on the Copperbelt. The manufacture process used at the Lusaka factory is the extrusion process mentioned in Chapter 3. Raw materials are ordered from Germany, United Kingdom and Italy. The company has had some success in exporting their pipes to neighbouring Malawi. The pipe sizes are 6 m length and diameters range from 2 inches (50 mm) to 6 inches (150 mm). They are using imperial units.

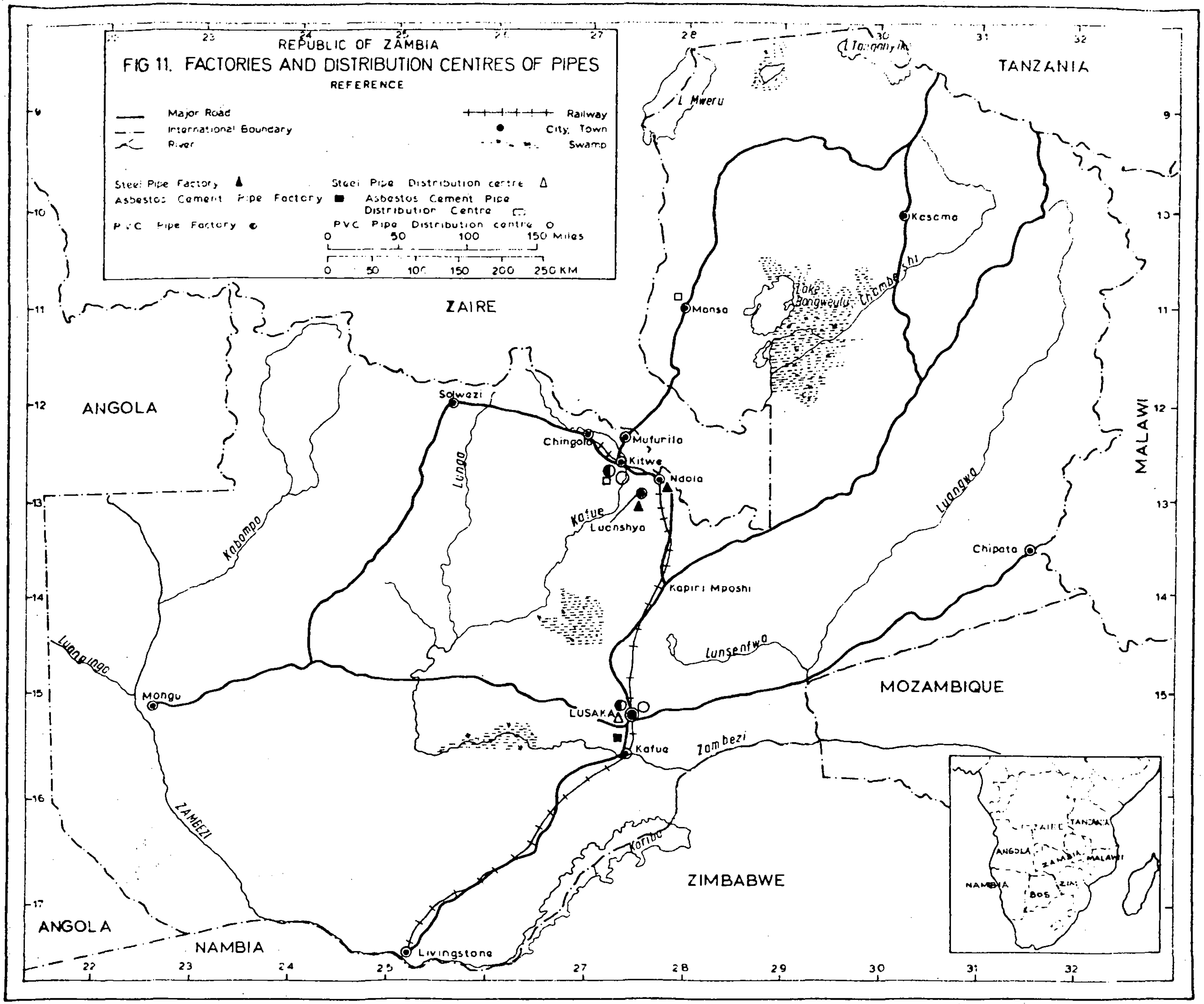


Fig. 11. Factories and dibtribution centres of pipes.

4.1.2 Asbestos Cement

Asbestos cement pipes are manufactured by TAP of Chilanga a few kilometres south of Lusaka. The company has its own distribution centre in Kitwe. The House of Mansa, although not officially an agent of TAP, supplies users in Luapula Province with A-C pipes. The manufacture process is the same as mentioned in Chapter 3 using British Standards BS 486. Only asbestos is imported, the cement is locally produced. The products' size range from 50 mm to 600 mm.

4.1.3 Steel

Steel pipes are manufactured by two companies in Zambia, viz: Hume (Zambia) Ltd. of Luanshya and Robert Hudson of Ndola. Both companies apply arc welding using cold rolled steel plates. However, the methods are slightly different in the sense that Robert Hudson make spiral folding of the steel plates while welding inside and outside. On the other hand Hume only makes one fold and weld only outside in a straight line. In both cases pipes are subjected to hydraulic pressure tests and in some cases the pipes are X-Ray tested in Kalulushi. Pipes are manufactured according to British Standards BS 534 and BS 3601. Raw materials are ordered from West Germany, Japan and Swaziland. For pipe protection various forms are used depending on the requirements of the customer. Most of the manufactured pipes are protected with spun bitumen with fibre glass wrap and coal tar expoxy.

It should be mentioned here that Hume (Zambia) Ltd. also manufacture concrete pipes. However, the bulk of their products are meant for low pressure applications. Reinforced concrete pipes may be manufactured on request. Pipe range from 150 mm to 914 mm.

4.2 Users' Experiences

4.2.1 Users' distribution

As indicated in Section 4.1, three pipe materials are mainly used in the rising main of most schemes in Zambia. The users are evenly distributed throughout the Republic. Fig.12 shows the main water supply schemes in Zambia. This does not include village schemes, some of which (e.g. in Luapula Province) are quite big and private schemes owned by religious institutions. As far as the distribution of the three materials is concerned, it has followed the pattern of the development of the towns. The selection for the particular type of material was sometimes governed by the people who designed the schemes. For example, Luanshya, Mansa and Mbala were designed by one consultant who recommended PVC pipes from his home country. It can be said, however, that use of steel pipes has been mainly restricted to areas of high population densities like the major Copperbelt towns and cities. Fig. 13 showes the distribution of the three pipe materials in the provinces. This is by no means absolute but rather indicative. It is also worth mentioning here that in most areas where PVC was used it is slowly being replaced by steel pipes. Also

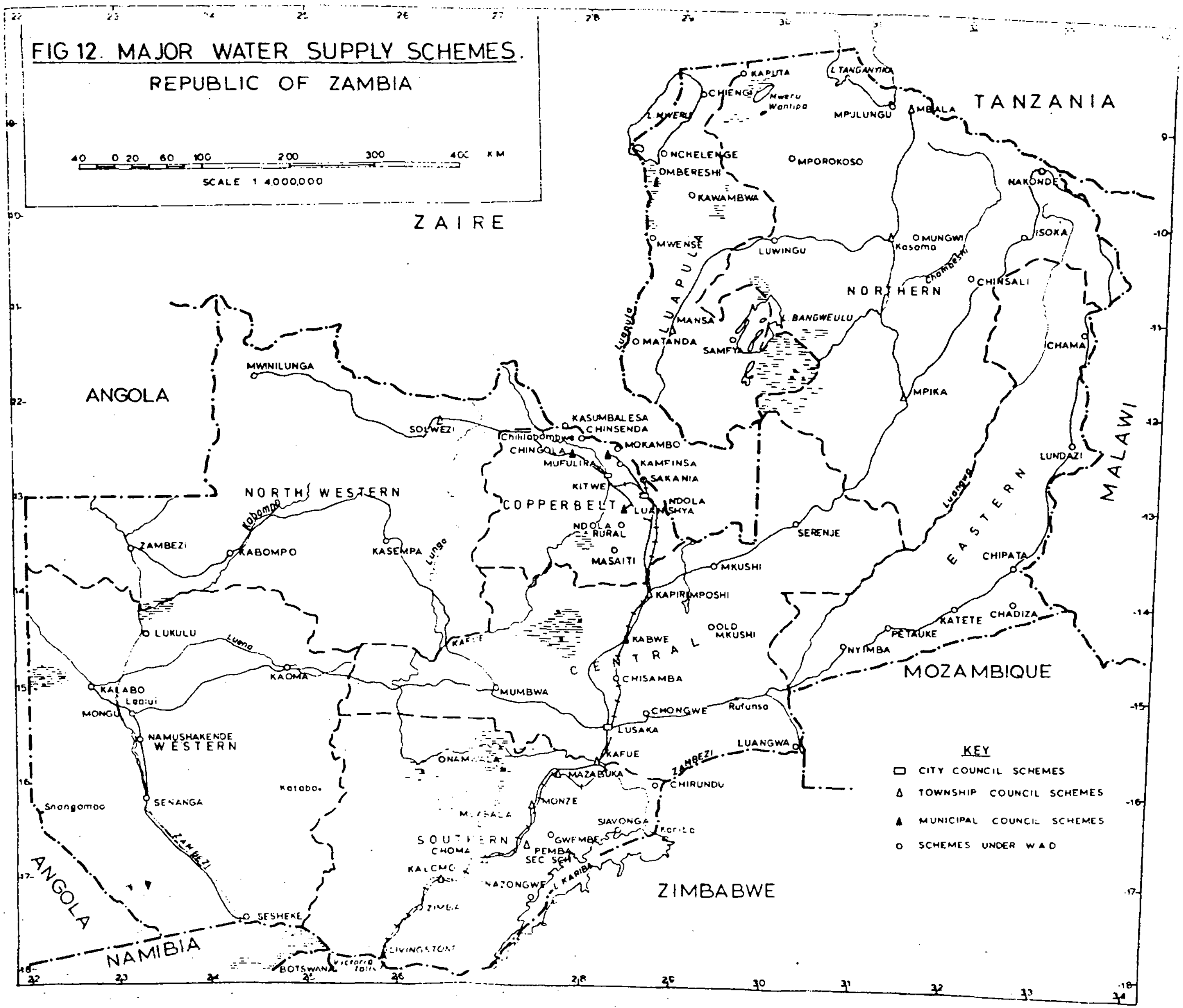


FIG 12. MAJOR WATER SUPPLY SCHEMES.
REPUBLIC OF ZAMBIA

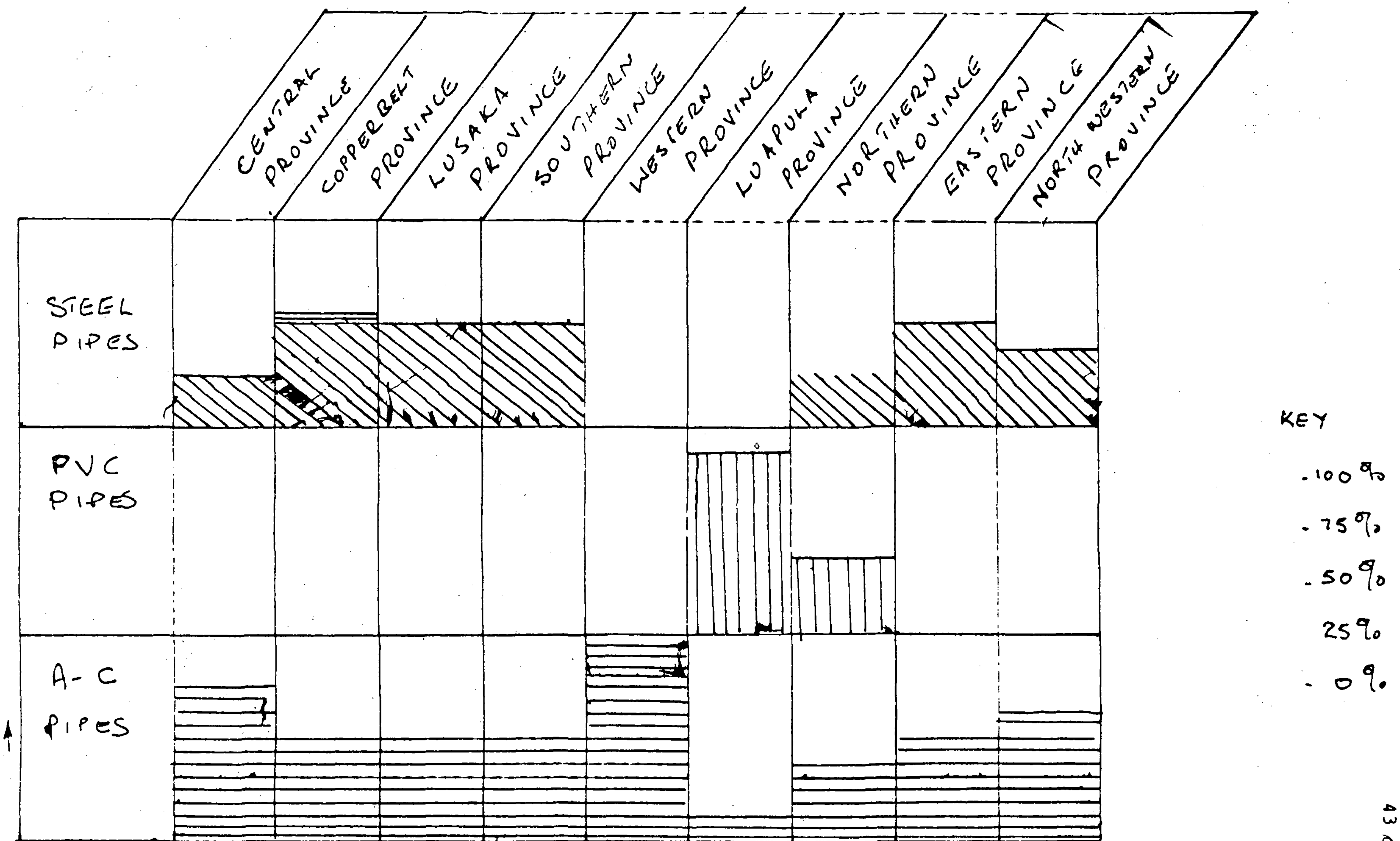


Fig. 13. Use of different pipe materials in Zambia

because of the decline in the use of PVC, the use of asbestos cement pipes has been on the increase. The replacement of PVC by steel pipes has been greatly influenced by the local people.

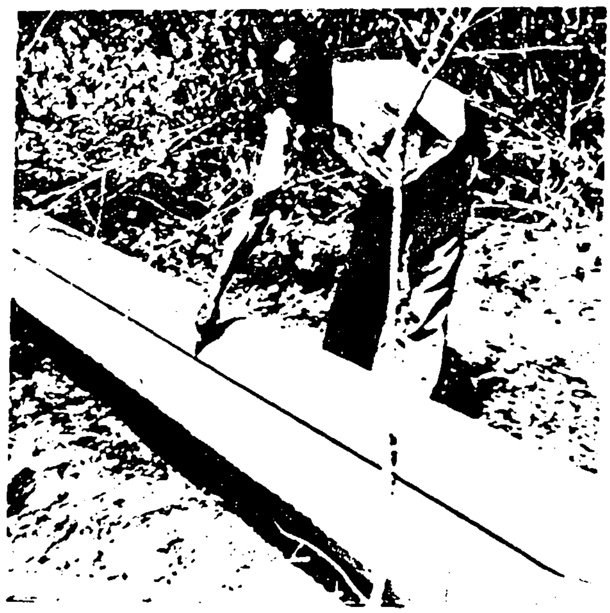
4.2.2 Problems

Like any other engineering installation pipelines, employing different pipe materials, have had problems of varying magnitude. As may be expected the least troublesome have been the steel pipes. Proper protective coating has saved most steel pipe installations from corrosion. In fact the only recorded corrosion cases have been in the distribution networks where galvanized iron pipes are mostly used. In the rising mains there have been isolated reports of leakages at the joints. The Lusaka City Council has registered leakages (about 5%) on the 49 km long rising main from Kafue River. The pipeline of 36 inches (914.4 mm) diameter is all steel with cast iron fittings and takes up pressure between 30 and 35 bars. Similarly users of asbestos cement pipes have experiences minor problems. Again like the stell pipes the common problem has been associated with the joints. The popular 'Fluid-Tite' joint has failed more often than the cast iron collar joints. The failure usually starts with the wearing out of the rubber rings ending up with disintegration of the pipe ends (see (1) also. The Lusaka City Council, for example, has had to replace about ten pipe lengths per year because of this type of pipe failure. This is on their 15" (381 mm) transmission line from the High Court reservoir to Chelston.

Users of PVC pipes have experienced the worst problems in Zambia; namely, bursts. A number of townships (vis: Mansa, Kasama, Mbala, Mongu and Luanshya) were all supplied with PVC pipes for their water supply schemes. All these townships have experienced similar problems. Examples are: Kasama - More than 60 bursts from 1976 to 1980; Luanshya - 244 bursts from 1976 to 1979; Mansa - about two bursts per day at the peak of the bursts. This is not to mention the large number of bursts experienced in the distribution networks. For example, bursts have occurred in Kabulonga, Matero, Chipata and Garden Compounds of Lusaka. The Ndola City Council has experienced bursts on its gravity main supplying Ndeke Township. About 30 bursts have been experienced on this line since installation. Plate 1 shows examples of burst pipes indicating the mode of faiture. In 1979 a number of tests were conducted on samples of these pipes from Luanshya at the University of Zambia. Since it is the same pipes which were supplied to Mansa and Kasama (by the same manufacturer) the results obtained in these tests have been used here in computation on the Mansa and Kasama schemes.(9) Constants used:-

K = bulk modulus of water	= 20.33×10^8 N/m^2 at 15°C
E = test value (average)	= 5.873×10^8 N/m^2
UTS = Minimum test value	= 0.21×10^8 N/m^2

PLATE 1(a)



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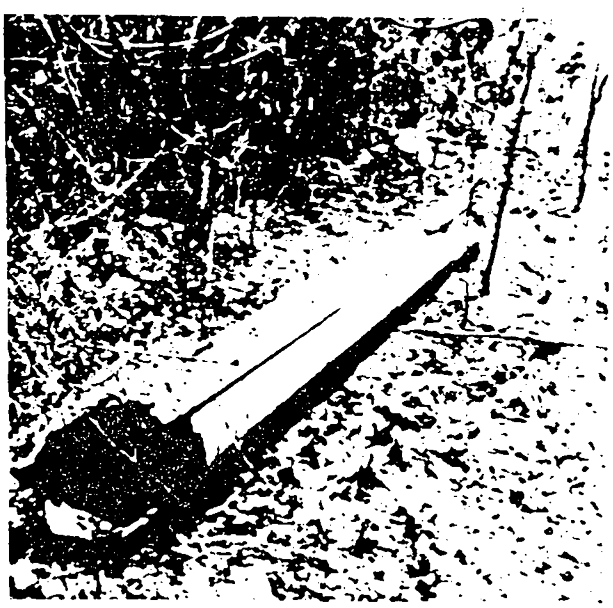


Case 1

Mansa Water Supply Scheme: Material - PVC

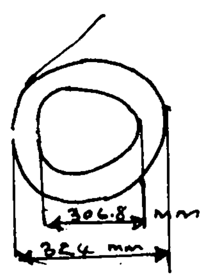
This scheme has never functioned properly since it was commissioned. Most bursts occurred in the large section containing Class B. Fig. 14 shows the longitudinal profile of the scheme.

d = (12") 306.8 mm

Pumped Head = 85.65 m

Working head for Class B PVC = 60 m = 0.588×10^6 N/m^2

Assume maximum wall thickness for pipes not measured.



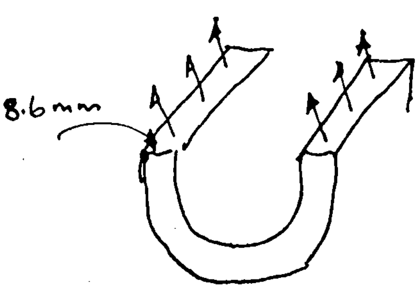
Bursting Pressure = 0.588×10^6 N/m^2 x 0.307 m x 1 m

= 0.1805×10^6 N/unit length

Resisting Force : Use UTS value from test

Resisting Force = $2(0.21 \times 10^8 \times 0.0086) \times 1$

= 0.36×10^6 N/unit length



Therefore safety factor

$$= \frac{0.36 \times 10^6}{0.1805 \times 10^6}$$

= 2

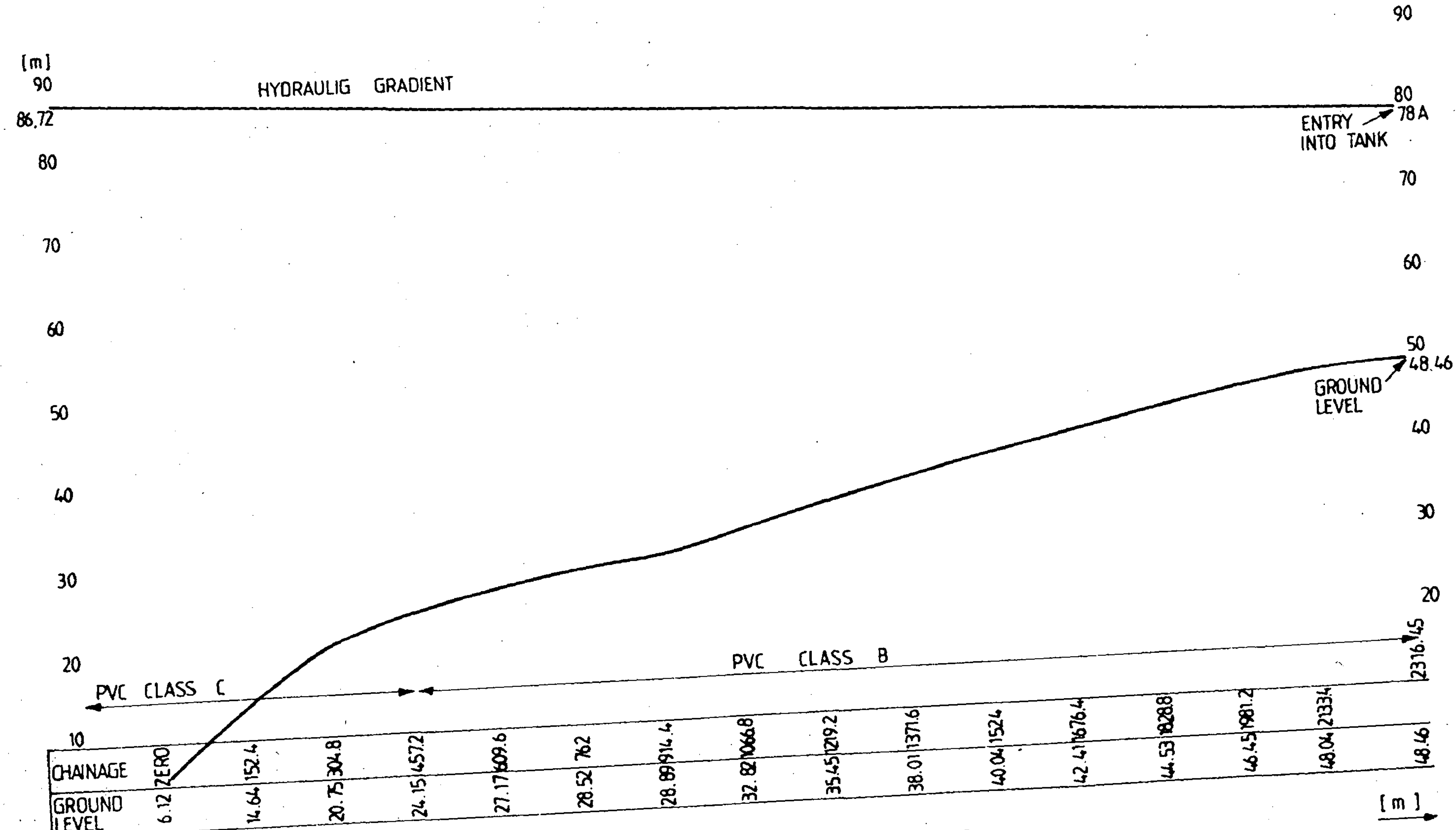


FIG: 14 PROFILE FOR MANSA WATER SUPPLY SCHEME

This safety factor is reasonable and one would have expected the pipeline not to experience as many bursts as it did. Unfortunately the pipeline was NOT Pressure Tested before use. It is also clear from available information that the pipes were subjected to pressures higher than the recommended working pressure.

Case 2:

Kasama Water Supply Scheme

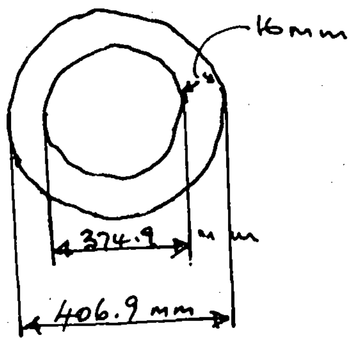
Like the Mansa case this scheme has had several bursts. Information supplied by the pump operators indicate that the bursts occur at the time of changing the pumps. There are two pumps each operating separately for six hours. It is therefore possible that one of the causes is that the pipes are not able to take the surge pressure created by the fast closing and opening of the valves.

$Q = 0.0632\ m^3/s$

Head = 158.5 m

Diameter = 16" ≈ 400 mm

Material: PVC Class C



The velocity of the pressure wave in the pipeline can be calculated from the following formula:

$$C = \sqrt{\frac{K.g/\alpha}{1 + \frac{K}{E}.\frac{d}{t}}}$$

where:

d = pipe diameter = 0.3749 m

t = thickness of pipe = 0.016 m

E = from test = $5.873 \times 10^8 N/m^2$

K = from test = $20.33 \times 10^8 N/m^2$

α = 999 Kg/m^3

g = 9.81 m/s^2

Velocity in the pipe before closure of the valve

$$= \frac{Q}{\frac{\pi d^2}{4}}$$

Therefore $\bar{V} = \dfrac{0.0632}{\frac{\pi \times (0.3749)^2}{4}} = 0.57$ m/s

$$C = \sqrt{\frac{20.33 \times 10^8 \times 9.81/999}{1 + \frac{20.33 \times 10^8 \times 0.3749}{5.873 \times 10^8 \times 0.016}}}$$

$= 0.0158 \times 10^4$ m/s

= 158 m/s

In the event of a hammer occurring the extra head created

$$\Delta H = \frac{C\bar{V}}{g}$$

$$= \frac{158 \times 0.57}{9.81}$$

$$= 9.18 \text{ m}$$

Working Head for Class C PVC = 90 m

Therefore head = 99.18 m

$= 9.72 \times 10^5 \text{ N/m}^2$

Therefore Bursting Force $= 9.72 \times 10^5 \times 0.3749 \times 1$ N

$= 0.3644 \times 10^6$ N/unit length

Resisting Force $= 2(0.21 \times 10^8 \times 0.016) \times 1$

$= 0.672$ N/unit length

Available Safety Factor $= \frac{0.672}{0.3644}$

$= 1.8$

Not high enough

From the above it is clear that a combination of factor lead to the failure of these particular PVC pipes. As a further confirmation eleven samples of the Kasama pipeline were tested at the Institute for Industrial Research and Standards in Dublin, Ireland. Nine of the eleven samples showed evidence of spider line damage. A further seven samples were tested. Four out of seven again showed spider line damage. This is a manufacturer's fault. In conclusion therefore it is felt that the failures experienced in the two case studies and other similar problems were the result of a combination of the following:

- A fault in the manucature of this particular pipe
- Bad pipeline design (no provision for surge control)
- Pipes were subjected to too high pressures
- Bad workmanship on the part of the contractors and consultants concerned
- Poor operations
- Poor handling and storage (exposed to the sun for too long).

It is unfortunate that the problems experienced with these particular pipes have rendered PVC pipes unpopular among the local people and politicians.
Given - proper; manufacturing, installation
- pipeline design, handling and storage, PVC pipes as alternative material should be used.

5. ECONOMIC CONSIDERATION

5.1 Material Costs and Selection Basis

In pipeline design and indeed in the selection of pipe material each alternative that is considered should as far as possible be expressed in monetary terms before a final decision is made. Other factors (so called intangibles) that may not be practical to reduce to money units should be compared in physical terms.

Conclusions made from comparison of costs are influenced by the interests rates used in the computations. With a low interest rate (e.g. 2 percent) a proposed investment would appear to be economical even though the same investment would seem costly with a higher interest rate (e.g. 8 percent). For persons subjected to tax this should be treated as investment charges.

In Zambia the prices of pipe materials like any other commodity has been rising steeply over the past few years. For example the average price of asbestos cement pipes has been as follows:

Year	Pipe Material	Cost
1978	Asbestos 100 mm	K4.74/m
1980	Class B	K5.75/m

Other pipe materials have likewise experienced similar increases. Fig. 15 shows relative costs (based on 1980 prices) for the different materials. It is not technically correct to compare the cost of steel pipes with PVC and A-C of lower grades because of the differences in pressure ratings, which also affect the prices. However, the graphs should be taken merely as indicative of the variations of prices with diameter

5.2 Transportation Costs

In discussing transportation costs priority has been given to the users in the rural areas away from the line of rail.

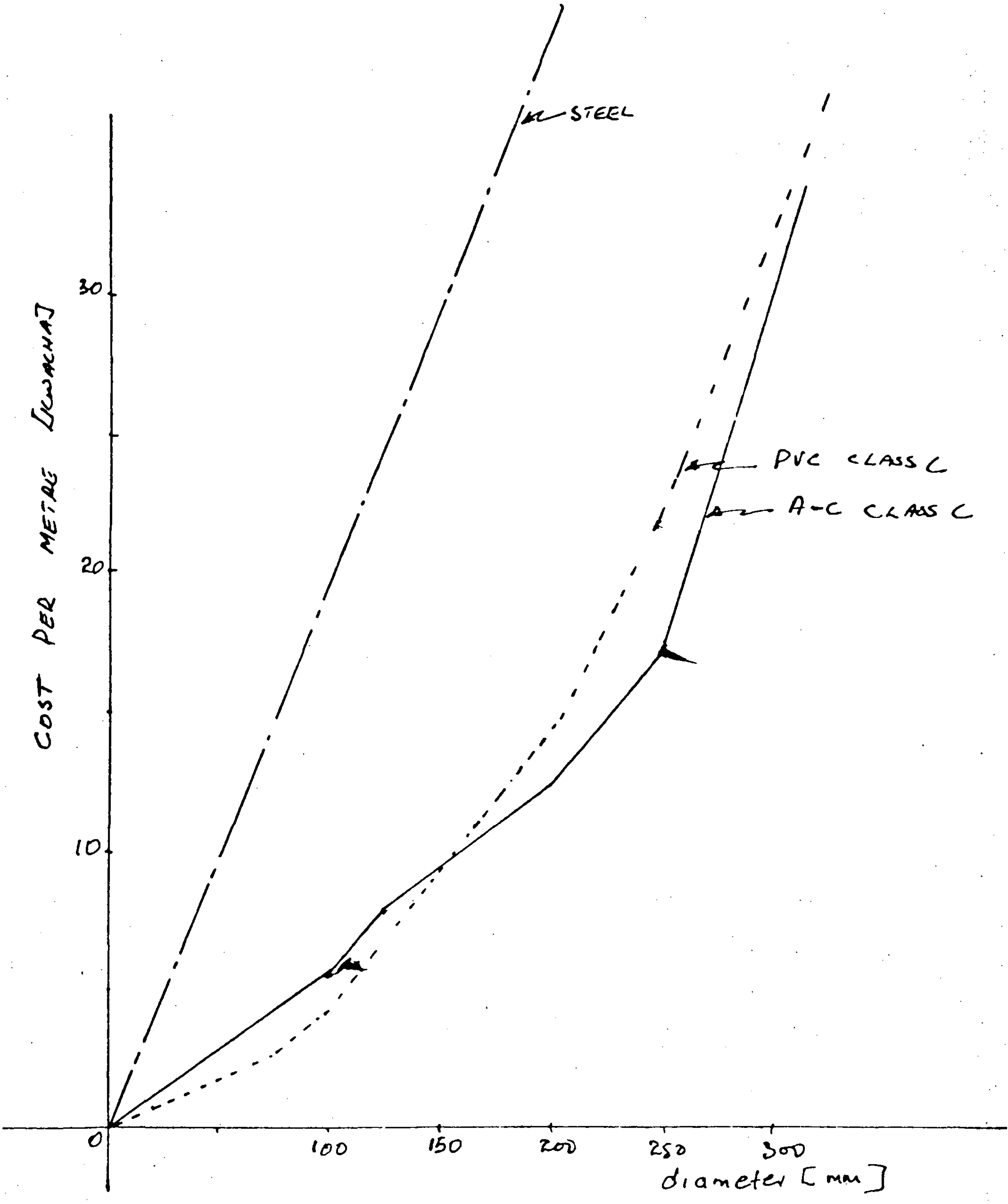


Fig. 15. Variation of costs with pipe diameter

This is because of the Government's emphasis on rural development and the fact that sometimes manufacturers (e.g. Hume (Zambia) Limited) deliver pipes to the customers on the Copperbelt and Lusaka without extra charge. The word 'sometimes' must be emphasized because it depends on the relationship between the manufacturer and the customer. The quantity of pipes also matters. The usual practice is for the customer to find his own transport. When the manufacturer makes delivery he charges between 20 ngwee and 30 ngwee per kilometre. And again this is applicable only on the Copperbelt and Lusaka. Private and semi-government transporters have two systems of charging, viz:

1) A fixed sum per tonne per kilometre to any place in Zambia. Fig 16 shows the cost of transporting 1000 m length of 150 mm pipes for different materials.

2) Different rates for different places. Apparently this is because of the different road conditions. This is a relatively expensive system. For example (with reference to Fig. 11), transporting pipes from Lusaka to Kasama the rate is K95.00 per tonne. Lusaka to Mbala the rate is K103.00 per tonne. Mbala is just 163 kilometres after Kasama. Fig. 17 shows the effect of this system.

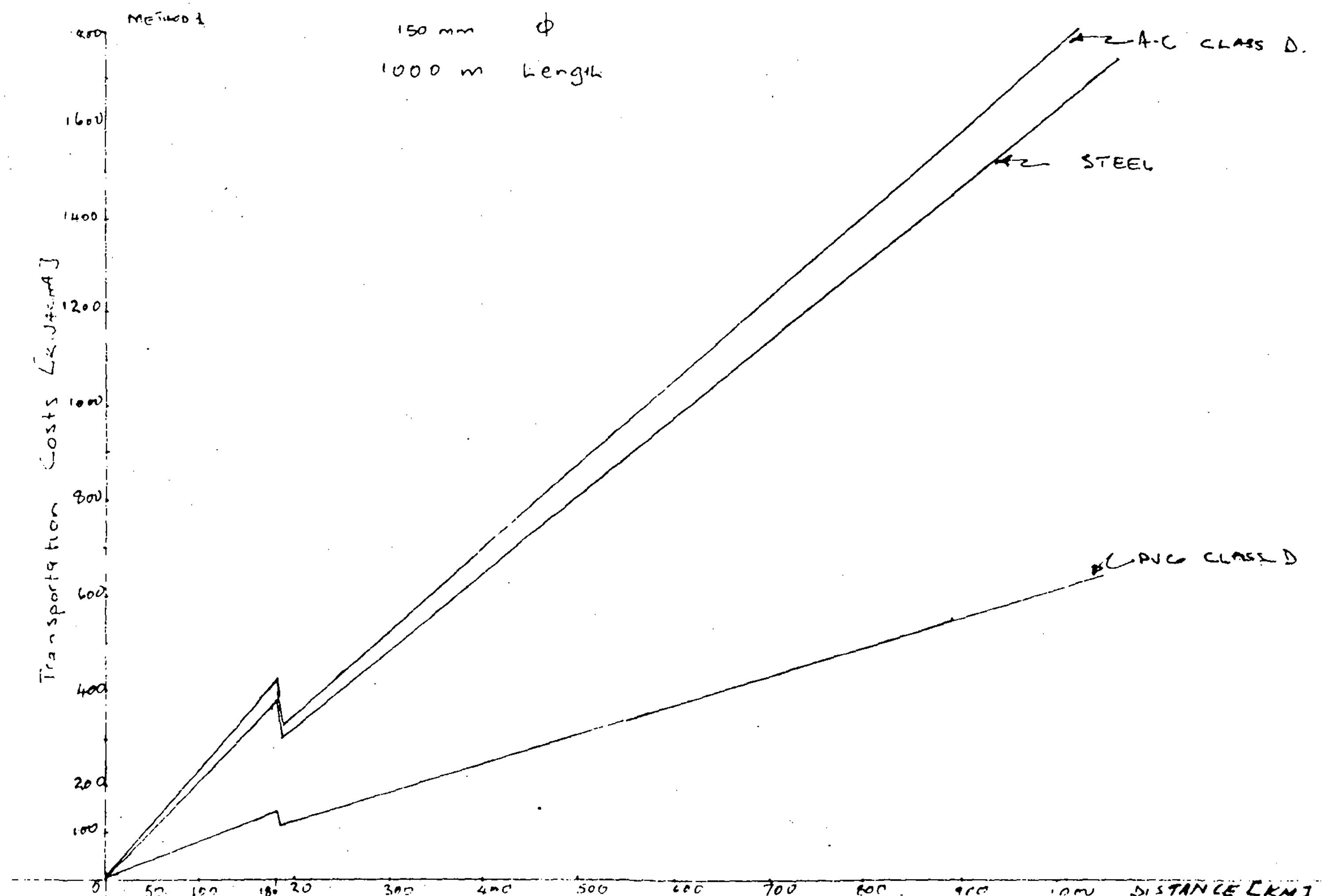


Fig. 16. Transportation costs vs distance (for charges per tonne pe km)

METHOD 2.

150 mm ϕ
1000 M Length

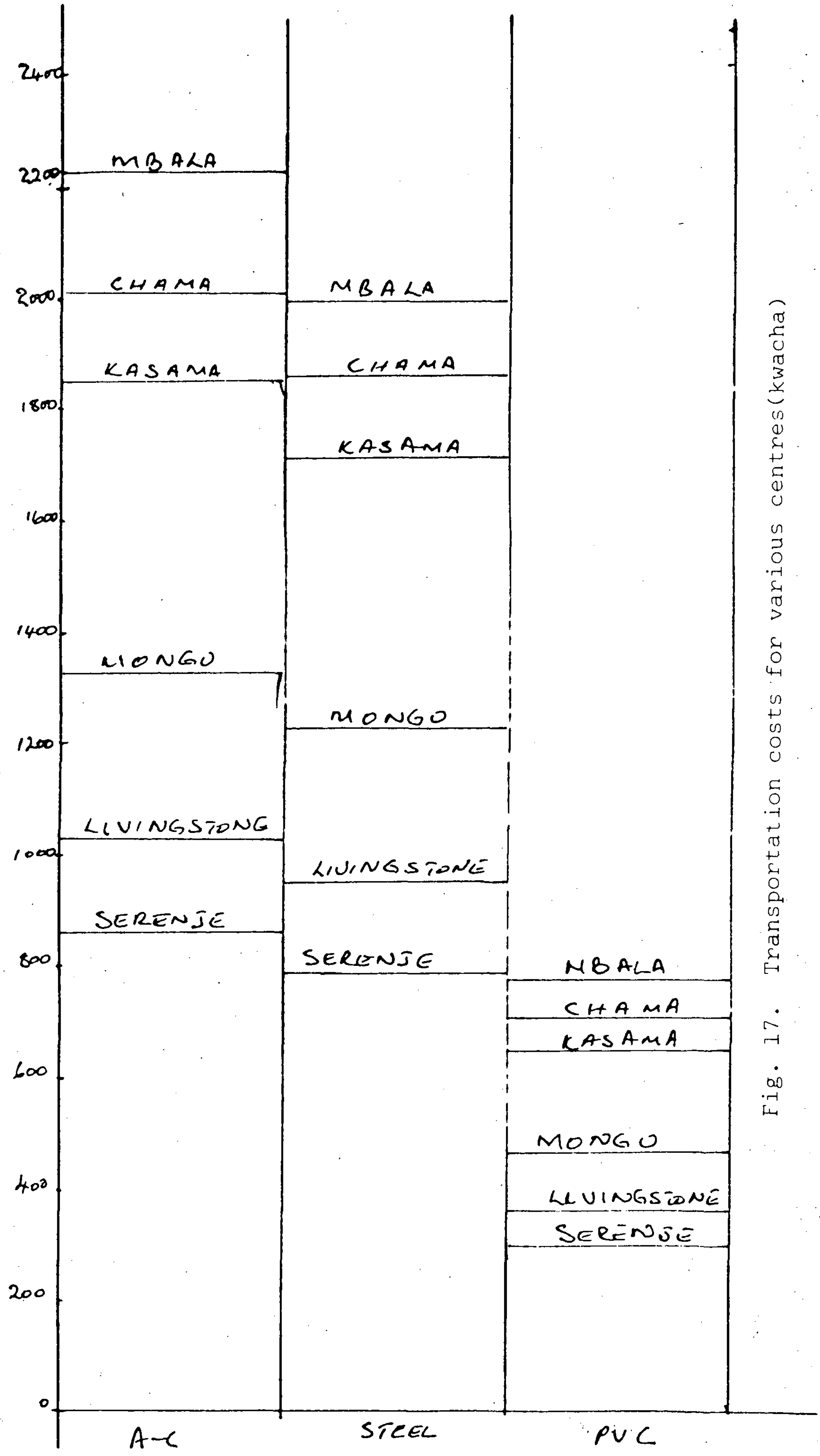


Fig. 17. Transportation costs for various centres(kwacha)

5.3 Installation Costs

Laying costs of pipes are not fixed. That is to say a contractor cannot tell off-hand the cost of laying, say, 100 metres regardless of material type. Of course the cost of laying steel pipes for example will be more than the cost of laying PVC pipes. However, the actual cost will be a function of:

- <u>Location</u>

In Zambia work of this type is mostly done manually. Since the cost of labour in urban areas is more than in rural areas it follows that the laying costs will be influenced by the location. Even when machinery is to be used, the cost of transporting machinery to whatever location will have a bearing on the overall cost.

- <u>Total Cost of Scheme</u>

If a contractor is employed merely to lay, say, 100 metres of pipeline the overall cost of laying will be higher than if he were employed to undertake other jobs connected to the scheme like installation of pumps and tanks.

- <u>Competition</u>

This is very important in tendering engineering works. The more competitors there are the lower are the costs. This can be clearly seen in big projects.

It is for the above reasons that no fixed rates are available for laying different types of pipes. Each scheme

Table 16: Costs of a Pipeline at Nakonde

Pipe Type	Quantity	Diameter	Rate			Total
			Excavation	Laying	Pipe	
A.C. Class C	1013 m	200 mm	3.00/m	2.05/m	17.45/m	22792.50
A.C. Class D	1566 m	200 mm	3.00/m	2.45/m	22.05/m	43065.00
A.C. Class B	5 m	100 mm	2.50/m	0.65/m	5.85/m	45.00
Fittings_	Total for bends, valves, toes, and adaptors					3520.00
TOTAL						69,422.50

1Kwacha ≃ 1.2 US$

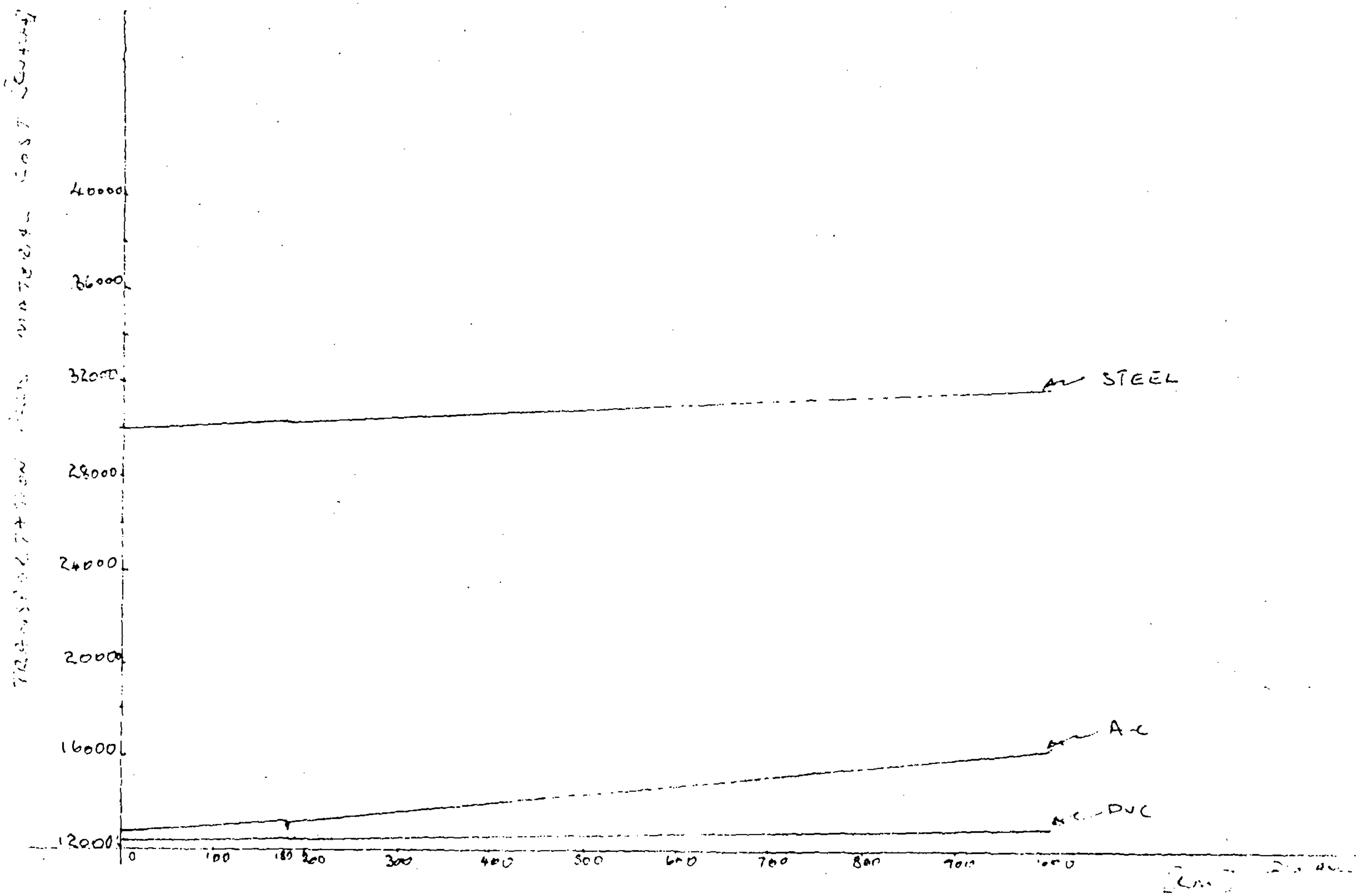


Fig. 18. Transportation plus material costs vs distance

is defferent from another. Table 16 gives an example of the overall cost for a pipeline scheme in Northern Province. The project was carried out in 1979. The costs exclude backfilling and trimming.

The effect of putting the different costs together in making economic comparisons can be seen by looking at Fig. 16 and Fig. 18 . In Fig. 18 the effect of material costs has been included. It shows that although it is more expensive to transport A/C pipes than steel pipes when you take into account the material costs; the cost of using PVC or A/C is almost the same while the cost of using steel is rather prohibitive. Incidentally the dip in the graphs is caused by the fact that between 0 and 200 km the charge is K0.12/km and K0.09/km above 200 km. The scale in Fig. 18 was changed to accommodate the graph for steel pipes.

5.4 Economic Comparisons

Making economic comparisons of projects is a complex exercise for the simple reason that so many factors or variables are involved. To make a good comparison of the costs involved in choosing one pipe material type from the other it is necessary to consider:

- the present cost
- life expectancy
- trend in costs. For example, the rising cost of oil greatly influence the cost of plastic pipes.

The differences between different pipe materials in the actual cost of a particular project will also be influenced by the hydraulic characteristics of the material. Take a hypothetical case of three types of pipes wanted to pump against a static head of 50 metres:

	A	B	C
Static head	55	55	55
Friction head	10	20	30
Total head on pumps	65	75	85

Since the cost of pumping is directly proportional to the head the annual cost of pumping through pipe C is obviously high. On the other hand the question of life expectancy is a very important one in the sense that it is necessary to know how often one has to replace the line. Take another hypothetical case of three types of pipes:

Item	Pipe A	Pipe B	Pipe C
Estimated useful life years	25	50	100
Initial cost per metre (in Zambian Kwacha)	K35	K40	K45
Present worth of 4% interest rate:			
Initial cost	K35	K40	K45
25 yr replacement cost	13.00	-	-
50year replacement cost	4.90	5.50	-
75yr replacement cost	1.80	-	-
	K54.80	K45.60	K45

In the present social and political situations, it is worth to note that decisions reached on the basis of economic considerations may be over-ridden by political or social influences. For example, PVC pipes have become unpopular in Northern and Luapula Provinces of Zambia for reasons stated in Chapter Four. It is, however, hoped that the analysis of the problem in this paper will help to change the attitude of the public towards this pipe material.

6. GUIDELINES

Facts presented here are based on conclusions drawn from the discussions in the previous chapters. It must be emphasized that what is stated here is not absolute but rather gives a guide as to the use of different pipe materials in Zambia.

6.1 Material Selection

For a user at any place in rural Zambia pipe material selection is influenced by:

- Hydraulic properties
- Costs

Other factors, for example, aggressive soils or corrosive water, will be included in considering alternatives.

From Chapter Four it is clear that previous users of PVC were careless. It is therefore felt that use of this type of pipe in distant places should be encouraged. However, usage should be limited to small scale schemes in terms of consumption and static head. This is because experience has shown that operators in 95% of cases have no proper training. Consequently, pipeline systems are subjected to pressures to which they were not designed for. In terms of costs PVC for small scale schemes is fair. A scheme serving up to a population of 10,000 falls in this category.

The deterioration of rubber rings in asbestos cement pipes need further investigations to determine the real cause. However, the cases studied showed that this failure caused pipe replacement of about 0.1% of installed length per year. In terms of costs A-C has an upper hand over steel. A-C pipes would therefore do well for medium size schemes. Schemes serving between 10,000 and 30,000 people fall in this category. For schemes designed to take very high pressures steel pipes should be recommended. Also to be included in this category are big schemes serving over 30,000 people.

6.2 Handling and Storage

The simple and geneal rule is handle and store all pipe materials with care. However, the fact that A/C pipes may break on sudden impact while plastic pipes may break or deform calls for extra care in handling them.

Plastic Pipes

When handling plastic pipes it must be remembered that the impact strength decreases with the fall in temperature; the surface may easily get damaged when dragged on the ground.

The above fact is also true when transporting these pipes. When loading ensure that:

- Pipes are bound tight together
- The transporting bed is smooth
- No point loads on the pipes

During storage again ensure that:

- the bed is smooth
- the pipes are not stocked in piles of over three metres
- the pipes are not left in direct sunshine. Store in cool place.

Asbestos-Cement Pipes

In a way most of what has been said for PVC pipes may also be applied to A-C pipes in as far as handling and storage are concerned. Differences occur on the fact that sunshine or sun heat do not have the same adverse effect on A-C as on PVC pipes. It should also be remembered to remove the rubber rings (and store them in a cool place) that may be inserted in advance if there is considerable time anticipated between dispatch and installation.

Steel Pipes

- Ensure that the protective coating is not damaged during transportation and storage
- Avoid storing steel pipes in places of high humidity for a long time.

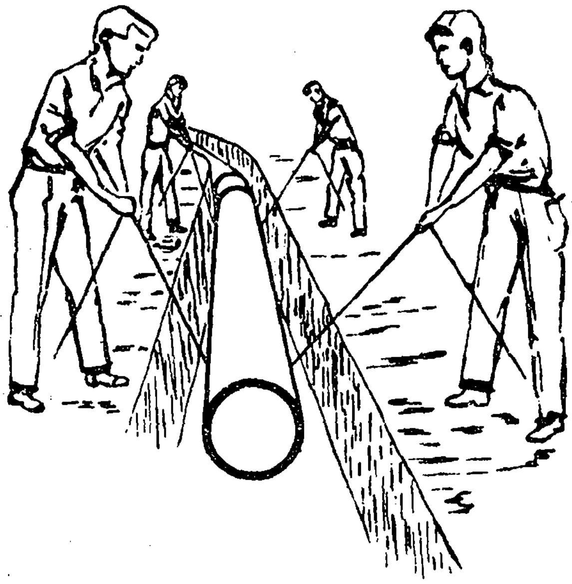
6.3 Installation

Installation practices vary from country to country and may in fact vary from engineer to engineer depending upon one's point of view. However, there are a number of general factors that must be observed during installation:

- First and foremost is careful handling. It does not serve any useful purpose to transport and store a pipe carefully only to damage it during installation. Pipes should NOT be DROPPED into the trench, but should be literally laid. Fig. 19 gives one example.

Dimentions of the trench are a function of the pipe diameter and some times soil conditions. In general the trench should not be deeper than 1.5m and trench width may be pipe diameter plus 20cm on both sides at the bottom of the trench. (14)

- Ensure that the ends are clean before joining.
- Minimize the time between the time for excavating the trench and backfilling.
- In some areas because of soil conditions or traffic it may be necessary to support the trench.



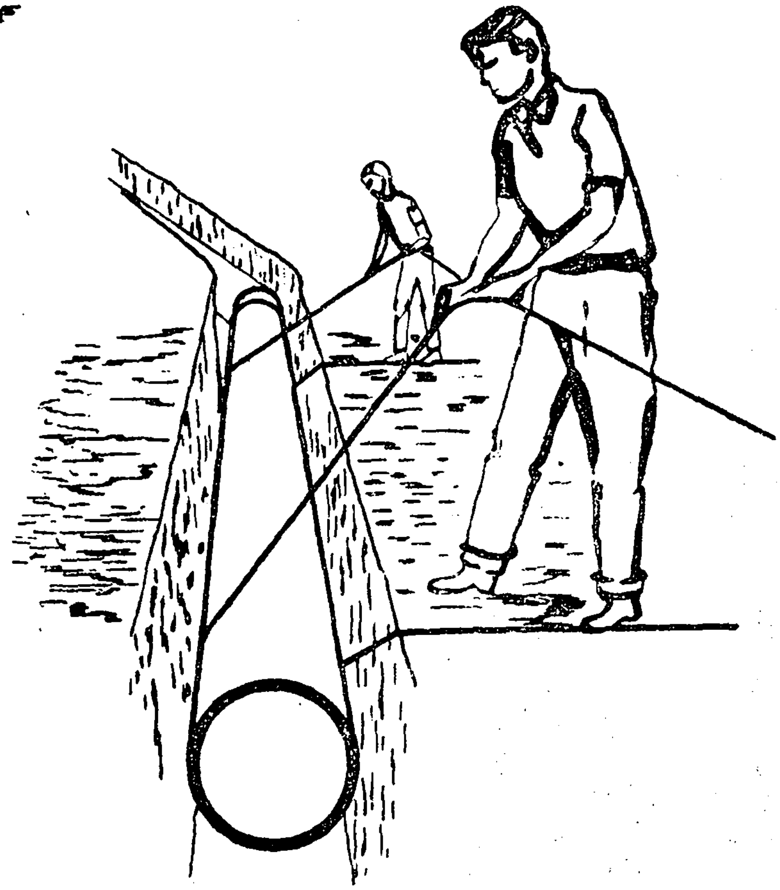


Fig. 19. Installation of pipes

- The trench bottom should also be strengthened in areas where differential settlements of the bottom may cause more deformations in the longitudinal direction than allowed for the particular pipe material. These settlements occur usually where pockets of uncompacted soil remain after removing gravel or stones. When laying PE pipes under water or for that matter any other pipe the bearing capacity of the bottom must be determined. (14)

- It may be necessary to add weight to the pipe to keep it in position. But make sure the pipe is already filled with water before laying and is air free.
- Care should be taken to protect the joints when laying pipes. Fig.20 shows some methods of achieving this.
- In the Zambian conditions it is a must to allow for expansion when making joints.

6.4 Remarks

The Ministry of Agriculture and Water Development should prepare a manual for the selection and design for pipelines suitable to Zambian conditions. This will help standardise the work done. As it is now the different consultants, contractors and even manufacturers apply British Standards to suit their needs.

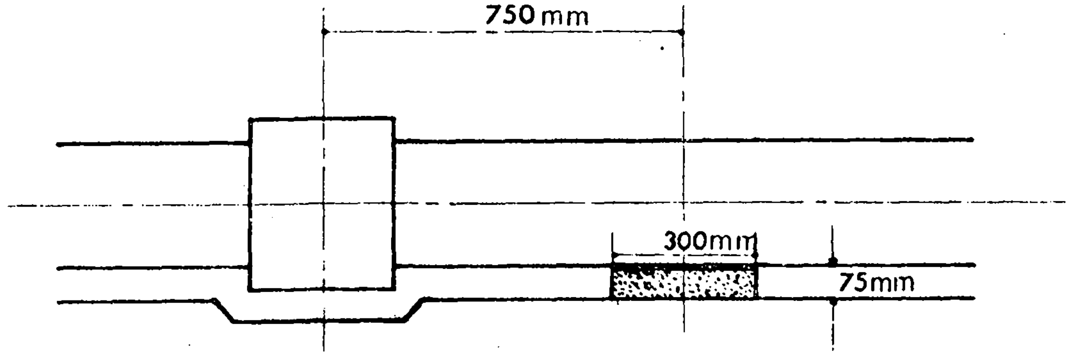
During the research period of this paper the writer was unable to find old or new 'Cost Indices'. It is therefore felt that the Ministry of Works and Supply should publish monthly or quarterly building and construction cost indices.

From this study it is clear that contractors and consultants have taken advantage of the lack of technical knowledge by the users in the rural areas. It is therefore felt that a design manual should be accompanied with a proper inspection procedure from the Government side.

It may not be too late to introduce PE pipes especially in areas like western province where in the Zambezi plains the pipes may have to be under water for some months in the year.

METHOD 1

Should be used for pipes 50mm to 300mm inclusive. The trench should be dug 75mm deeper than the pipe level. The pads should be placed 750mm from each end of the pipe and should be 300mm wide, 75mm high and the full width of the trench. The pads should be composed of screened soil or sand and should be water tamped (see fig 3.)



METHOD 2

We recommend this method for pipes from 375mm upwards as being the speediest one as it enables the pipes to be put into alignment very quickly. The wedges should be placed under the pipe as it is being lowered into the trench and adjusted as required. The wedges should be placed 750mm from the end of the pipe in the manner shown in figs 4 & 5. After the pipe has been laid, earth should be rammed and tamped underneath it so that the wedges can be withdrawn for reuse.

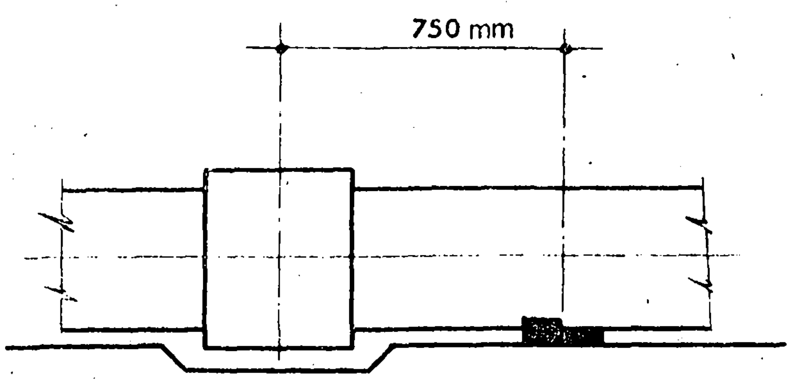


FIG.4

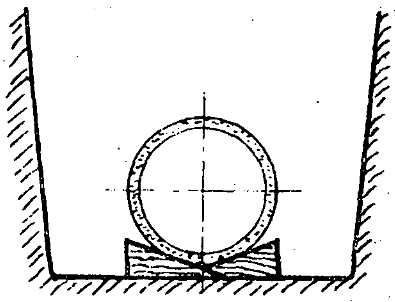


FIG.5

Fig. 20. Protecting Joints

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