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Islamic Republic of Iran  
Ministry of Energy

in cooperation with

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANISATION

SF/IRA/92/001  
014/009

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**Industrial & Domestic Water  
& Wastewater Management**

Contract SF / IRA / 92 / 001

**PIPE & PIPELINE CONSTRUCTION  
SUBCONTRACT  
Final Report**

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May 1995



**MONTGOMERY WATSON**

with Iranian counterpart



**RAYAB CONSULTING ENGINEERS**

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**Islamic Republic of Iran**

**Industrial & Domestic Water & Wastewater Management**

**PIPE & PIPELINE CONSTRUCTION SUBCONTRACT**

**Final Report**

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May 1995

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Issue	Date	Description	Prepared by (Author)	Authorised by
1	20/12/94	Draft for Discussion	A. Taghavi	
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**MONTGOMERY WATSON**

*Serving the World's Environmental Needs*

**INDUSTRIAL AND DOMESTIC  
WATER AND WASTEWATER MANAGEMENT  
CONTRACT No. SF/IRA/92/001  
PIPE & PIPELINE CONSTRUCTION SUBCONTRACT  
FINAL DRAFT REPORT**

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## LIST OF ABBREVIATIONS

AC	Asbestos Cement
AFNOR	Association Française des Normes (French Standards Association)
API	American Petroleum Institute
ASTM	American Society for Testing & Material
AWWA	American Waterworks Association
BS	British Standard
CCTV	Closed Circuit Television
CIS	Commonwealth of Independent States (ex Soviet Union)
DI	Ductile Iron
DIN	Deutsches Institut für Normung (German Standards Institute)
DM	Deutschmark
ECR	E-Type Glass Corrosion Resistant
EPA	Environmental Protection Agency
EPDM	Ethylene-Propylene-Diene Modified Rubber
FRP	Fibre Reinforced Plastic
GRE	Glass Reinforced Epoxy
GRP	Glass Reinforced Plastic
GRTR	Glass Reinforced Thermosetting Resin
HDPE	High Density Polyethylene
HPPE	High Performance Polyethylene
IEPA	Iranian Environmental Protection Agency
ISO	International Standards Organisation
LDPE	Low Density Polyethylene
LLDPE	Linear Low Density Polyethylene
MDPE	Medium Density Polyethylene
MWL	Montgomery Watson Limited
PE	Polyethylene
PN	Nominal Pressure
PRV	Plastique Renforcé de Fibres De Verre (Fibre Reinforced Plastic)
PSC	Pre-Stressed Concrete
PVC	Polyvinyl Chloride
QA	Quality Assurance
RBC	Rotating Biological Contactor
RPM	Reinforced Plastic Mortar
SBR	Styrene-Butadiene Rubber
SO <sub>4</sub>	Sulphate
SR	Sulphate Resisting
SRC	Sulphate Resisting Cement
STW	Sewage Treatment Works
UAE	United Arab Emirates
UNIDO	United Nations Industrial Development Organisation
uPVC	Unplasticised Polyvinyl Chloride
WWTP	Wastewater Treatment Plant

## SECTION 1 SUMMARY

### 1.1 OVERVIEW OF PROJECT

The overall aim of the co-operation project with UNIDO is to develop a *Strategy For Water and Wastewater Management* and for the local *Manufacture of Pipes*. This Stage I consultancy is being conducted by Montgomery Watson with RayAb as its nominated Iranian counterpart. The Terms of Reference recognise the complexity of the overall task; this consultancy is limited to small inputs and is intended to summarise current circumstances and to define further larger studies and demonstration projects to be conducted under Stage II.

For this *Pipe and Pipeline* sub-contract the specific duties required are to:

1. collect and review available data within the country
2. check the effectiveness of existing government policies:
  - towards pipe selection, rationalisation and ultimately efficiency and cost effectiveness
  - towards pipe manufacturing standards and installation specifications
3. develop recommendations for further studies to determine more accurately the present status
4. develop recommendations for development of comprehensive strategies and policies aimed at improving the present situation.

This report summarises the activities listed above, the preliminary conclusions drawn and the recommendations for Stage II.

### 1.2 OVERALL OBJECTIVES

Iran has requirements for pipes and pipelines for many purposes including, potable water transport, irrigation, sewerage systems, natural gas and oil transport. There is a significant pipeline manufacturing capability within the country, but with widely different standards of manufacture, quality control and capacities. The *National Strategy on Pipeline Manufacturing and Use*, of which this study is a first stage, will rationalise the types and sizes of pipes to be used for each demand type, and develop a tailored and efficient production and installation capability of high quality and to internationally acceptable standards throughout the country.

The objectives of this preparatory study were to:

- (i) Assess the existing production capabilities and current manufacturing qualities of different pipe types
- (ii) Assess pipeline manufacturing needs over the next 25 years for water and sewerage projects
- (iii) identify and evaluate existing standards and policies and their applicability to current Iranian needs, and recommend procedures for development of a national policy towards the setting of manufacturing standards and the development of guidelines and regulations for pipe selection and installation

- (iv) Recommend appropriate materials and technologies to be used for manufacture of each pipe type
- (v) Make preliminary recommendations on the needs for new and/or expanded pipeline manufacturing plants in relation to demand and economic considerations

This study has been limited to short specialist inputs and is necessarily at a reconnaissance level. Some of the information presented is subject to further data collection/analysis, but a good overview has been achieved enabling recommendations to be made for Stage II which will lead to the development of a national strategy and guidelines for pipeline manufacturing in Iran.

### 1.3 OVERVIEW - OUR APPROACH

Figure 1.1 is an illustration of the approach taken to this Preliminary Study. A flow of activities has involved the resident team from RayAb consulting engineers in collecting data over a period approaching twelve months. The most intense period of activity was from October to December 1994 when Montgomery Watson's Project Manager was resident in Tehran and supported by specialist visits of varying duration.

The various activities can be summarised in the following key stages:

***Definition of National Water and Wastewater Needs*** - data was collected from the Ministries and Iranian consultants on projects in the water and wastewater sectors requiring the supply and installation of pipes for the next two to three decades. The data was collated and summarised and reviewed by specialists.

***Existing Manufacturing Capability*** - information was collected from each of the pipe manufacturers in Iran and selected factories were visited to assess their manufacturing capabilities, quality standards and performance.

***Quality Assessment*** - data collected has been analysed and reviewed and pipeline installation contracts visited in order to assess quality assurance in terms of:

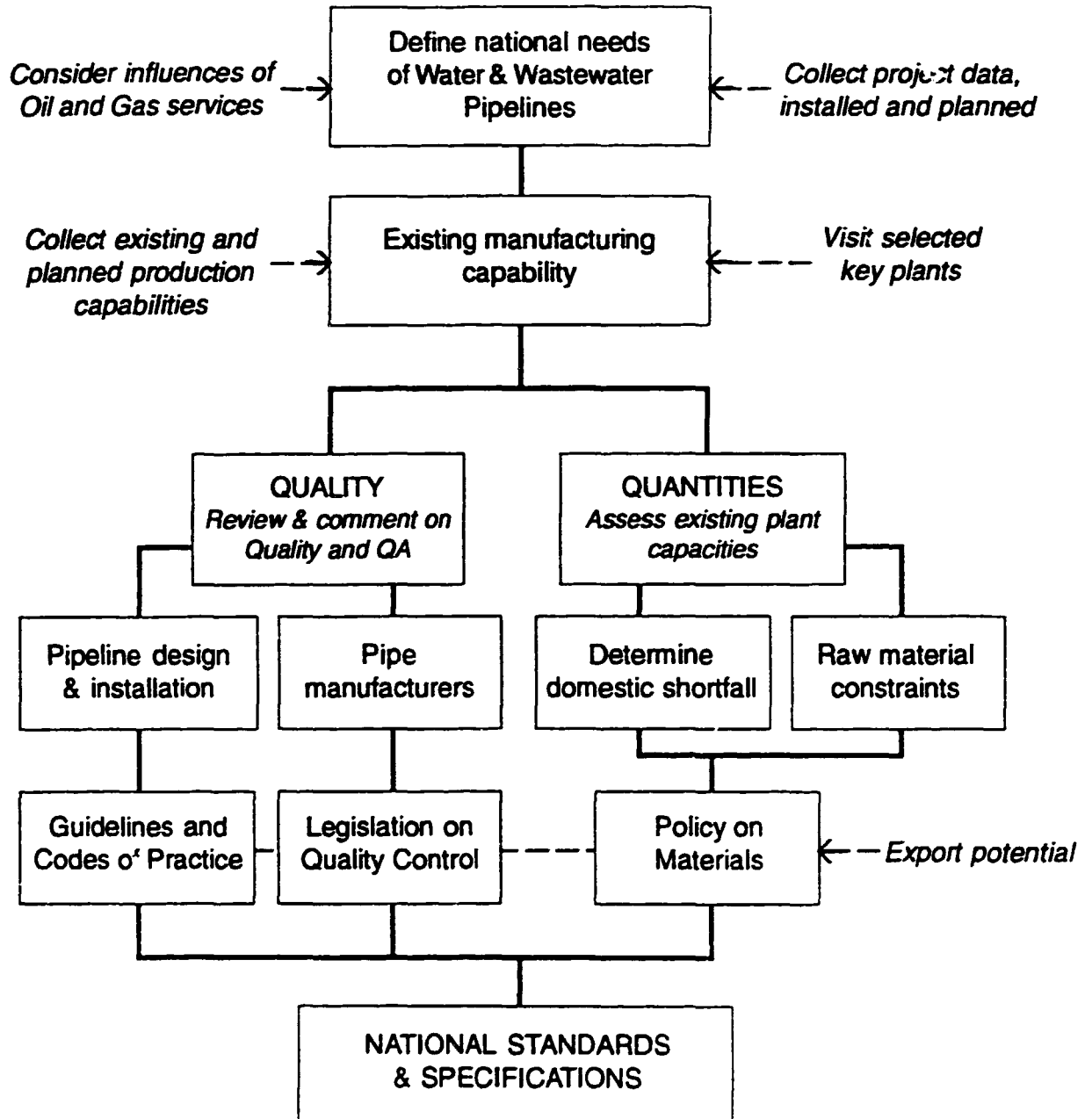
- product quality control
- use of appropriate manufacturing standards
- pipeline design involving pipe strength, materials and pipeline installation and support legislation and guidelines

***Quantity Assessments*** - a review of the pipe demand in each region of the country has been related to appropriate available materials and a first assessment made of any over- or under-capacities. Recognition of the potential for export has also been taken into account in recommending a more detailed study to determine National Regional Policy on pipe use in the water industry.

***National Standards and Specifications*** - the need for a rational approach to the adoption of appropriate manufacturing standards is recognised and the suggestion made for a study to develop a National Specification for Pipeline Materials Supply and Installation.



Figure 1.1  
**APPROACH**



#### 1.4 PRELIMINARY PIPE MATERIALS SELECTION POLICY

At the conclusion of Stage I, it is inappropriate to make firm recommendations as to long-term pipe materials selection policy. Nevertheless, it is instructive to consider what form such recommendations might take, and to suggest which pipe materials might be appropriate, based on the information available at this stage and the experience of other countries in the region.

Tables 1.1 and 1.2 indicate possible recommendations for pipe materials selection for sewers and water mains respectively. These tables consider the four geographic divisions of Iran discussed in this report, and group them into two pairs, based essentially on considerations of maximum ambient temperature and typical topographical features affecting sewage retention times.

Temperature is important for sewer pipe materials selection because of the hydrogen sulphide corrosion problem which arises, particularly where temperatures approaching 30 ° Centigrade or more are likely to be sustained for significant periods. High temperatures influence the selection of pipe materials for water mains because of the reduction of water pressure capability of the thermoplastic materials (Polyethylene and uPVC). At the stage, possibility of using plastic-lined concrete pipes has not been considered, but should be reviewed at a later stage.

Table 1.1 suggesting sewer pipe materials incorporates a size distinction at around 450 mm diameter, which is dictated by the economics and quality assurance considerations of pipe production. Table 1.2 covering water main materials incorporates five separate pipe diameter ranges and two water pressure ranges. These reflect various pipe production and pipeline design considerations. It is recommended that alternative materials are included in the National Policy for both sewers and water mains to encourage competition and to avoid dependence on a single source.

It must be stressed again that the pipe materials suggested in these tables are derived from limited information, and that considerable refinement could and should be made in the light of more detailed investigations. The materials suggested also represent significant shifts in current practice away from the use of asbestos cement and concrete for smaller diameter sewerage pipelines to the use of uPVC and clay. This policy recognises the world-wide trend against the production of asbestos cement pipes due to concern of the hazards to factory workers. It also relies on the development of a clay pipe industry in Iran which is currently under consideration but is subject to further investigation.

Table 1.1  
Possible Application Policy for Sewerage Pipe Materials

Region	Smaller Diameters up to about 450 mm dia.	Larger Diameters approx 450 mm dia. & over
Caspian Sea and Mountain Areas	uPVC, Clay Concrete	Concrete
Central Plains & Gulf Coast	uPVC, Clay	GRP

**Table 1.2**  
**Possible Application Policy for Water Mains**

<b>Region</b>	<b>Lower Pressure up to about 9 bar</b>	<b>Higher Pressure Approx. 10 bar &amp; over</b>
Caspian Sea and Mountain Areas	up to DN150: PE.uPVC, AC DN150-300: PE.uPVC.AC,DI DN300-600: AC,DI,GRP DN600-1000: GRP,DI DN1000/over: GRP,Steel,PSC	up to DN150: Galv Steel, AC DN150-300: AC,DI DN300-600: DI,GRP DN600-1000: DI,GRP DN1000/over: GRP,Steel,PSC
Central Plains and Gulf Coast	up to DN150: Galv steel, AC DN150-300: AC,DI DN300-600: AC,DI,GRP DN600-1000: GRP,DI DN1000/over: GRP,Steel,PSC	up to DN150: Galv Steel, AC DN150-300: AC,DI DN300-600: DI,GRP DN600-1000: DI,GRP DN1000/over: Steel,PSC

## 1.5 RECOMMENDATIONS FOR STAGE II

The following are the actions considered necessary as stages in the development of a *National Strategy for the Manufacture of Pipes*:

- Economic Study**
- to evaluate the export potential for different pipe materials in the region with particular emphasis on the Gulf countries, the CIS states and eastern-bordering countries of Iran - determination of the impact on the manufacturing potential within the country.
  - to verify the data on internal shortfalls of pipes and to confirm the regional policy outlined in this study
  - to confirm gas and oil demands and influence on water industry pipe manufacture.
  - to review the relative costs of transporting pipes of different materials with a view to optimising pipe manufacturing development locations

- Materials Study**
- to investigate the potential for clay pipe manufacture as an alternative to concrete and asbestos cement in those regions of the country prone to sulphide generation in sewers.
  - to review the concrete pipe manufacturing industry in Iran and to recommend standardisation and improvement of manufacturing equipment and procedures.
  - to investigate the potential for GRP pipes in the water (and oil/gas) industries in Iran and in neighbouring countries with a view to assessing the potential of the material for the Iranian market and the relative benefits of local manufacture against importing from other Gulf GRP plants.
  - to confirm for all plants their nominal and production capacities and to ensure that maximum benefit is obtained from existing plant installations

**Condition Assessment** In Esfahan, which has one of the most developed sewerage systems in the country, pipe corrosion is already recognised as a problem. There, and elsewhere where corrosion or other forms of deterioration are occurring, systematic sewer condition surveys are desirable, utilising Closed Circuit Television (CCTV) and other modern techniques.

Such condition surveys need to be related to a structural condition classification system, and Montgomery Watson already has considerable experience in using established systems designed for temperate climates, and in developing new classification systems more appropriate to climatic regions where hydrogen sulphide corrosion is occurring.

- Policy & Standards**
- to propose a *National Policy on Pipe Materials* for the water and wastewater sectors embracing all aspects of pipeline engineering including pipe material selection, pipeline design and pipeline installation guidelines - the product might take the form of a *Ministry Guideline Manual* for issue to all regional authorities and consultants working on water and sewerage projects.
  - to develop *National Specifications for Pipe Manufacturing and Installation* embracing multi-national standards for manufacture and testing of pipes at factory and for pipeline testing in the field. This might be part of a broader study to develop a complete National Specification for utility or for water/wastewater contracts embracing all materials and installation/construction requirements. The development of product standards for concrete pipe manufacture and installation is particularly urgent.

## 1.6 REPORT CONTENTS

The remainder of this report describes the individual study stages identified in our approach in the following sections:

**Section 2** **Existing Manufacturing Capability** presents a summary of the Iranian pipe manufacturing capability as investigated with the data available during the study period. Comments are made on the quality and standards as well as the range of materials and production capacity for each.

**Section 3** **Domestic Forecast Demand and Shortfall** includes an analysis of the pipe requirements for the sewerage and water supply industries and presents an overall summary of compatibility which identifies a number of mismatches.

**Section 4** **Factors Affecting Future Policy** is a discussion section identifying some of the critical issues affecting the development of a National Policy for pipe materials and installation. It includes consideration of issues such as; *regional needs and variations; ease and cost of transportation; merits of manufacturing technologies for the key materials; relative production costs and total pipeline costs; regional demand and export potential.*

- Section 5**      **Recommendations** identifies the main elements for further study and project development for Stage II of the project and addresses the priorities for training visits related to the development of a *National Strategy for Pipe Manufacture*.
- Appendix A**    **Visit Reports** gives notes on each of the factory visits made during the study
- Appendix B**    **Materials for Sewer Pipelines** is a review of the main pipe materials currently available for sewer construction and where necessary renovation.
- Appendix C**    **Materials for Water Supply** gives general descriptions of the pipe materials currently adopted in the world pipe supply industry with reference to commonly used international manufacturing standards.

## 1.7      **ACKNOWLEDGEMENTS**

Preparation of this report has involved the collection and assimilation of a large amount of data in a relatively short period of time. This would not have been possible without the co-operation of a large number of individuals from the public and private sector too numerous to mention.

Montgomery Watson is grateful for all assistance given and in particular acknowledges the co-operation of:

- His Excellency, Mr Manoucheri, the Deputy Minister and other staff of the Ministry of Energy
- Mr Kuchechian, Managing Director and the appointed UNIDO project team of RayAb Consultancy Engineers.
- Iranian consulting engineers who gave information on future project requirements and particularly Dr S Nairizi of Toos Ab who gave considerable time to assist our team.
- Management of Pipe Manufacturers throughout Iran.

## SECTION 2

# EXISTING MANUFACTURING AND INSTALLATION CAPABILITY

### 2.1 CURRENT SITUATION OVERVIEW

#### 2.1.1 Existing Pipe Industry in Iran

There are a large number of pipe manufacturing plants in Iran producing pipes of all commonly used materials, including *steel, Ductile Iron, Polyethylene, Glass Reinforced Plastic (GRP), uPVC, Concrete, Reinforced Concrete, Prestressed Concrete*. There are currently several pilot clay pipe manufacturing plants in Iran, and it is high on the government list of future possible plants. A sample of a clay pipe which was understood to have been produced as part of a pilot scheme was shown to our team in Mashad.

The factories are distributed around the country, although there are concentrations in industrial centres such as Tehran, Esfahan, Ahwaz, Mashad and Shiraz. Figure 2.1 shows the location of present plants within Iran.

In this section we include sub-sections describing the nominal and the current production capacity of each material. Each sub-section includes a summary table. Those plants which have been visited are highlighted in italics in the tables and visit notes are included in Appendix A. The visit notes include comments on the factory production, quality of production and quality control. Manufacturing standards, where they exist, are usually those of the parent company (usually from Europe) or equipment supplier.

The following sub-sections give an analysis of manufacturing capabilities, production quality, and general comments on each pipe type produced in Iran. The tables presented refer to nominal and production capacities. Nominal capacity refers to the theoretical maximum rated capacity of the plant, whereas production capacity is the plant output as limited by technological factors, economics, availability of raw materials, and plant age.

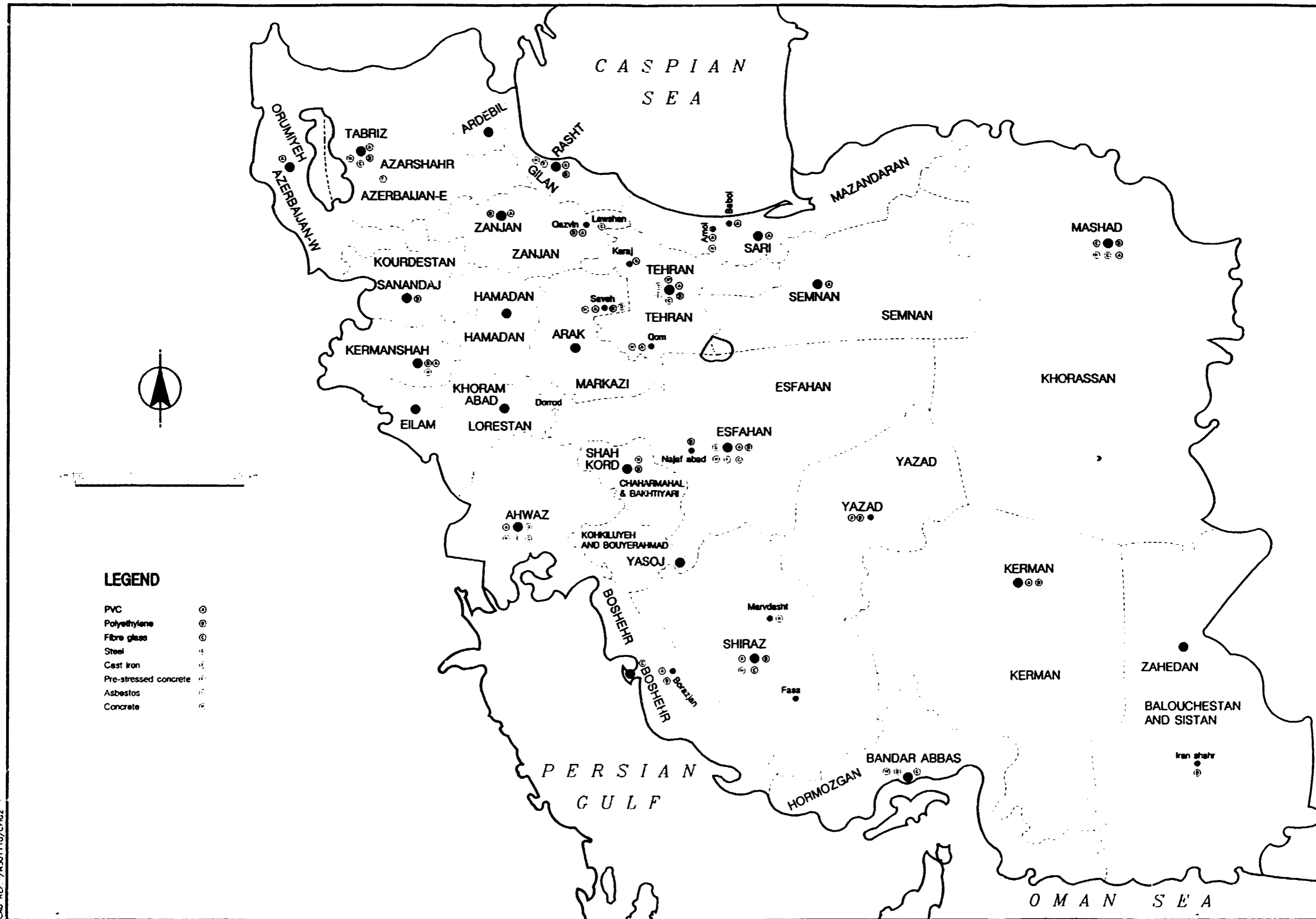
This Section is complemented by Appendices B and C which are an analysis of the materials available for water supply and sewerage pipeline applications.

#### 2.1.2 Climatic Zones and Impact

Iran comprises a series of distinct and different climatic zones which will affect the suitability of different pipe materials for both water supply and sewerage:

- (i) The relatively temperate Caspian Sea region
- (ii) The Alborz and Zagros Mountains with long periods of freezing conditions
- (iii) The central plains with typical desert conditions - extreme hot and cold conditions
- (iv) The Persian Gulf region with consistently warm to hot conditions throughout the year

Temperature is important for sewer pipe materials selection because of the hydrogen sulphide corrosion problem which arises, particularly where temperatures approaching 30 ° Centigrade or more are likely to be sustained for significant periods. Temperature is not the only factor - the time of concentration in the sewers is also critical and hilly terrain with steep gradients will reduce the tendency to sulphide generation compared to flatter regions. Experience in some of



LEGEND

- PVC ○●
- Polyethylene ○—
- Fibre glass ○|
- Steel ○/
- Cast iron ○+
- Pre-stressed concrete ○—●
- Asbestos ○|●
- Concrete ○●—

CAD REF. /N301110/CFG2

the flatter desert plains such as Esfahan is already demonstrating extensive corrosion of sewer pipes.

High temperatures also influence the selection of pipe materials for water mains because of the reduction of water pressure capability of the thermoplastic materials (Polyethylene and uPVC).

Cement-based pipes with no internal corrosion protection are not suitable for use in the latter region, and experience in some of the desert regions, notably Esfahan, suggests that their use there is inadvisable also.

## **2.2 DATA COLLECTION AND ACCURACY**

Data presented in this section of the report has been assembled from data collected from circulars and telephone calls to factory managers. Whenever site visits to factories were made data was checked and a large number of anomalies have been identified. Conclusions must therefore be considered tentative and subject to verification, but the overall picture is thought to be sufficiently clear for this stage of the Project. Further comment on the veracity of the data, with particular reference to plastic pipes, is made in Section 3.

## **2.3 CEMENT-BASED PIPES**

### **2.3.1 Susceptibility to Corrosion**

Cement based pipes are susceptible to corrosion in certain circumstances. In regions where ambient temperatures are high, typically 30-40°C, and where sewers are laid to shallow gradients due to the topography, serious corrosion can occur within 10-15 years of the pipe being installed. This is due to the production of hydrogen sulphide in the sewage which is converted by bacteria in the slimes on walls to sulphuric acid that attacks the concrete. This is exacerbated at shallow gradients where contact times are long.

This problem has occurred in the countries to the South of the Persian Gulf, where extensive sewer replacement programmes are now under way on systems installed less than 20 years ago. The same problem is occurring in some parts of Iran, notably the Gulf Coast region and areas of the central plains. Specific reference was made in discussions during visits to Esfahan to the existence of corrosion to the concrete sewerage pipes and manholes. Since cement-based pipes are being proposed and installed for many other towns and cities, the conversion problem needs to be addressed seriously.

### **2.3.2 Concrete**

Plates 1, 3, 4, 5 and 6 all illustrate concrete pipe production and installation.

#### **Application**

Concrete pipes, both reinforced and unreinforced, are generally suitable for gravity applications only, because they have limited internal pressure capacity. Hence their application is exclusively in sewerage. Normal practice in Iran is for circular pipes below about 600 mm diameter to be unreinforced, with larger pipes reinforced. Ovoid (egg-shaped) pipes are generally reinforced. These latter are used for sewerage in areas where large variations in flow are expected, and the design is such that sufficient velocity is maintained at low flows to ensure transport of solids.



Concrete pipes are heavy and transport costs are high in relation to the value of the pipe itself. Therefore it is uneconomic to transport concrete pipes for long distances, say more than 100-150 km. The radius of supply for concrete pipes is therefore limited, and it is normal for small to medium sized plants to be found at all major urban locations. This appears to be the case in Iran.

### Current Production

The present production of concrete pipes in Iran is as follows:

Location	Nominal capacity (km/year)	Production capacity (km/year)	Diameter range (mm)
Ahواز (3) (2 visited)	250	150	250-2000
Bandar Abbas	260	190	250-2000
Esfahan	130	130	250-1400
Ghom	65	50	250-600
Kermanshah	65	50	250-600
Marvdasht	65	65*	250-600
Mashad (3)	200	115	250-1500
Orumieh	65	50	250-600
Rasht (2)	85	15	250-1500
Saveh	60	27	300-1000
Shahr-e-Kord	65	65	150-600
Shiraz	50	20	150-1600
Tabriz	147	50	150-2000
Tehran	65	65*	250-2400
<b>Total</b>	<b>1572</b>	<b>1042</b>	

\* In the absence of information, assumed production at full nominal capacity.

The available nominal capacity for concrete pipes in Iran is currently 1572 km/yr, whereas the current production capacity is of the order of 1042 km/yr. The range of diameters is adequate for the applications of these pipes, ranging from 150 mm, which could be suitable for house connections, to 2400 mm which could be used for interceptor sewers.

Two of the factories, located at Bandar Abbas and Esfahan, with a nominal capacity of {390}km, or {25%} of the total, are located in the regions of the Central Plains and the Persian Gulf, where corrosion of concrete, as discussed above, is a risk. The continued use of these factories should, therefore, be reviewed in the light of national policy. Options would be:

- (i) Change to a lined pipe system (uPVC or coating)
- (ii) Convert to a corrosion resistant material
- (iii) Relocate the factory plant to a region where unlined concrete pipes can be used for sewerage
- (iv) Close factories

In Mashad, trunk sewerage is being installed using concrete pipes made in semi-circular cross sections and joined in the trench (Plate 1). This practice is uncommon and whilst the quality of installation appeared high, the methods of joining the pipes with grout at the invert and crown is felt to be a possible source of defect and potential corrosion in the future.

## Quality

The concrete pipes that we were able to inspect whilst in Iran were of extremely variable quality, as was the in-situ concrete seen at various sites. This leads us to question the quality of concrete pipes in general, and hence the advisability of their extensive use unless the quality can be assured to acceptable international standards. Many factories are producing basic, commodity sewer pipes to no clear product standards. Concrete is the mainstay of the sewerage network in most Iranian cities, and there is considerable scope for improvement of the pipes produced if standards can be established.

Some factories visited did, however, produce generally good quality concrete pipes. These included those in the Khuzestan region where there are strong investment incentives and, as a result, there has been investment in equipment capable of producing concrete pipes of quality consistent with internationally accepted technical standards.

## Raw Materials

Raw materials required for production are available from within Iran with no reported supply difficulties.

### 2.3.3 Asbestos Cement

#### Application

Asbestos cement pipes are widely used throughout Iran for sewerage and also for water supply. Pressure pipe for water supply is produced with pressure ratings up to 12 bar. The material has several advantages over concrete, being both lighter and stronger, but is prone to the same corrosion mechanism as described above for concrete when used in sewerage. The reservations expressed above about concrete pipe apply equally to asbestos cement pipes.

Asbestos cement pipes are lighter at similar diameters than concrete pipes, thus the constraints on radius of supply due to transport costs are less important. It is our understanding that asbestos cement pipes are available throughout Iran.

Asbestos is widely regarded as a hazardous material, and some concerns have been expressed about its safety for use in potable water supply. Asbestos is carcinogenic when inhaled. The risks to health are therefore created when asbestos fibres are free in the atmosphere, which occurs during the manufacture and cutting of the pipes. At present, there are no indications and/or published reports that good quality pipes in use present any health hazard through drinking the water that has passed through them.

#### Current Production

The major producers in Iran are Iranit and Farsit. Iranit is a joint venture with St. Gobain of France. It also exports a significant proportion of its output, mainly to the United Arab Emirates, even though there is sufficient demand in Iran to consume all its output. The present Iranian production of Asbestos Cement pipes are as follows:

Location	Nominal capacity (tonnes/yr)	Production capacity (tonnes/yr)	Diameter range (mm)
Esfahan	30,000	24,000	100-1000
Ahwaz	60,000	48,000	100-300
Bandar Abbas	50,000	50,000*	not available
Tehran	34,000	30,000	80-1000
Tabriz	30,000	28,000	150-1000
Dorud	60,000	45,000	100-600
Mashad	40,000	20,000	100-400
Lawshan	20,000	18,000	150-400
<b>Total</b>	<b>324 000</b>	<b>263 000</b>	

\* In the absence of information, assumed production at full nominal capacity.

The available nominal capacity is 324,000 tonnes, whereas actual production capacity is reported at approximately 263,000 tonnes, or just 81% of nominal capacity. The range of diameters is adequate for the needs in water and waste water applications.

Three of the plants, in Bandar Abbas, Esfahan and Tabriz, representing 110,000 tonnes, or 34% of potential output, are located in regions prone to acid corrosion of cement-based pipes and as with the concrete pipes their continued production is questionable.

#### Raw Materials

The major constraint on production is occasional shortages of asbestos, which is imported mainly from the Central Asian Republics.

#### Production Quality

Quality of production inspected was to a generally acceptable standard but concern for safety of workers in plants was less than satisfactory. The trend in recent years has been to close asbestos cement plants due to high public concern for the safety of workers.

### 2.3.4 Pre-stressed Concrete

#### Application

Pre-stressed Concrete (PSC) pipes are manufactured to have pressure capabilities, and their application is in water supply. Most usage is in water transmission, as pre-stressed concrete pipes are most cost-effective to produce in the larger diameters which are required for this application. Pressure capability up to 15 bar can be provided.

#### Current Production

Of the three factories in Iran manufacturing PSC pipes, two are using the French SOGEA process whilst the third, at Azarshahr, uses the Casagrande process from Italy. The present Iranian production of PSC pipes is as follows:

Location	Nominal capacity (km/year)	Production capacity (km/year)	Diameter range (mm)
Esfahan	16	14	800-1400
Rasht	10	7	800-1400
Azarshahr	60	25	600-2000
<b>Total</b>	<b>86</b>	<b>46</b>	

Although these are higher value pipes than gravity concrete or Asbestos Cement, so that transport costs are less important than for basic sewer pipes, demand for these pipes is such that most are used in the regions in which they are produced.

Current production is only 54% of nominal capacity.

#### Raw Materials

The total nominal capacity is 86 km year. The pre-stressing wires are at present imported from Europe, and supply of these can constrain production. We understand that a project is under way to establish production of suitable wire in Iran, but the material is highly specialised and it may not be economic to produce it in the required quantities.

#### Production Quality

Quality of the product at the Esfahan plant visited was high and there was evidence of good quality control.

## 2.4 PLASTIC PIPES

### 2.4.1 Glass Reinforced Plastic (GRP)

#### Application

GRP pipes are manufactured from polyester resin reinforced with glass fibres, with sand and aggregate as fillers in some cases.

GRP pipes are extremely strong, capable of withstanding internal pressures as high as 24 bar, and, provided they are carefully and correctly installed, are resistant to corrosion. Because of their pressure capability, a common use of GRP pipes is in water supply, but the corrosion resistance has also led to their being widely used in sewers in the Middle and Far East where cement-based pipes are not suitable. Manufacture can be of either gravity or pressure grade pipes.

#### Current Production

GRP pipe manufacture in Iran is limited to two sites, at Shiraz in the South and at Mashad in the North East. The Mashad factory is at present in the commissioning stages and has yet to produce commercial pipes. (Plate 2 shows the production.)

Location	Nominal capacity (km/year)	Production capacity (km/year)	Diameter range (mm)
Shiraz	200	200	150-2400
Mashad	N/A	N/A	250-3000
<b>Total</b>	<b>200</b>	<b>200</b>	

The higher value and more specialised applications of GRP pipes are such that transport costs have less impact than for the lower value concrete pipes. Radius of delivery is therefore relatively wide, and a small number of factories can supply a large country such as Iran efficiently.

#### Raw Materials

Raw materials for GRP pipes are predominantly glass fibres and polyester resins. The raw materials are specialised, and it should be noted that polyester is not a polyolefine (i.e. not derived entirely from oil) but is produced in Iran. Supplies of polyester resins are also prone to interruption due to lack of capacity in their manufacture. The Arak Petrochemical Complex is the principal supplier in Iran. Glass fibres are not produced in Iran, and therefore have to be imported.

#### Production Quality

The new plant at Mashad did not yet have quality testing and control in operation but the product was visually of a good general quality with a few surface faults which could be improved as experience develops.

### 2.4.2 uPVC

#### Application

uPVC pipes are in widespread use throughout Iran and are manufactured at many sites. The applications are diverse, covering, *inter alia*, water supply, sewerage, house connections, and ducting for underground cables. uPVC pipes are light and easy to handle. The material is durable and resistant to chemical attack and is allowable for potable water usage. It is also relatively cheap, and the raw materials are largely derived from oil, which is plentiful in Iran, but require also a supply of chlorine.

There has been some environmental concern over uPVC generally, especially in extremely environmentally sensitive countries such as Germany. There, most Federal States prohibit the use of uPVC in the public sewerage systems, although it is still the dominant material for house connections. The ban is part of a blanket ban on using uPVC in buildings because of the carcinogens given off when it burns. The folly of this argument in relation to uPVC water and sewerage pipes, which are underground and frequently full of water, is now being recognised. In terms of energy use, another key environmental criterion, uPVC uses less energy in its manufacture than most other pipe materials, especially those such as iron, steel and clay in which high temperatures are required.

## Current Production

The present production of uPVC pipes in Iran is as follows:

Location	Nominal capacity (tonnes/yr)	Production capacity (tonnes/yr)	Diameter range (mm)
Ahwaz (3)	4,970	4,900	12-200
Amol	800	500	8-75
Babol	10,800	3,500	20-315
Borazjan (2)	6,500	4,500	2-400
<i>Esfahan (4) (1 visited)</i>	<i>13,460</i>	<i>11,160</i>	<i>20-315</i>
Ghazvin	21,400	7,500	20-315
Golpayegan	1,300	1,000	20-100
Karaj (2)	10,300	10,300	20-250
Kerman	6,700	6,700	20-400
Kermanshah	6,000	5,000	20-160
Mashad	6,000	3,000	20-250
Orumieh	2,700	2,600	20-110
Qom	6,000	4,000	20-160
Rasht	15,700	7,800	20-350
Sari	1,200	1,000	15-100
Saveh (2)	17,600	7,000	20-315
Semnan	13,000	7,000	20-630
Shiraz	7,500	300	20-315
Tabriz	2,700	2,600	20-315
Tehran (4)	10,000	7,650	11-200
Yazd (2)	6,500	4,500	20-400
Zanjan (2)	4,950	4,300	20-200
<b>Total</b>	<b>176,080</b>	<b>106,810</b>	

Total nominal capacity is 176,080 tonnes, yet actual production capacity stands at just 106,810 tonnes, or approximately 60% of potential. Whilst uPVC production is relatively easy in small plants, uPVC pipe production could benefit from economies of scale, and the finished product is relatively inexpensive to transport over long distances.

The range of diameters appears to be adequate for the potential applications. There appears to be considerable potential capacity in the range of 20-150 mm diameter, suitable for water supply, and 150-400 mm, suitable for sewerage, including house connections.

## Raw Materials

From the table above it is evident that several plants are operating well below nominal capacity, and this is mainly due to shortages of raw materials. The uPVC resins are produced in Iran by the Petrochemical Complexes at Abadan, Bandar Imam and Arak, but the capacity is very limited and this is constraining the capacity in downstream activities in the plastics industry, including pipe manufacture.

### 2.4.3 Polyethylene (PE)

#### Application

Polyethylene pipes are generally manufactured from medium density polyethylene (MDPE) or high density polyethylene (HDPE), which produce a strong, durable and flexible pipe that is easy to handle and install. It is widely used throughout the world for gas distribution systems.

at low to medium pressures. Since water supply has many characteristics in common with gas distribution, PE has become established in this sector as well. We expect, however, that the demand for this material is and will be driven by the gas industry. Use of PE pipe for water supply could, however, benefit from economies of scale such that the marginal cost of additional production for the water sector may be relatively small.

### Current Production

The present Iranian production of PE pipes is as follows:

Location	Nominal capacity (tonnes/yr)	Production capacity (tonnes/yr)	Diameter range (mm)
Ahwaz (2)	4,000	2,000	80-315
Borazjan	1,100	1,000	80-200
Esfahan (2) (1 visited)	6,000	4,800	80-315
Ghazvin	2,000	1,500	80-315
Gilan	1,400	1,000	80-180
Iranshahr	2,000	2,000	80-250
Kerman	1,100	500	80-250
Kermanshah	1,200	1,000	80-200
Mashad (2)	4,600	4,000	80-450
Najafabad	2,600	2,600*	
Sanandaj	2,000	2,000	80-250
Saveh	3,600	3,000	80-400
Shahr-e-Kord	3,600	2,500	80-400
Shiraz (3)	11,000	11,000	80-315
Tabriz	200	200*	
Takestan	3,000	2,500	80-250
Tehran (5)	6,470	5,000	80-400
Yasouj	3,600	3,500	80-400
Yazd	1,000	1,000	80-180
Zanjan	2,000	2,000	80-250
<b>Total</b>	<b>62,470</b>	<b>53,100</b>	

\* In the absence of information, assumed production at full nominal capacity.

Total potential nominal capacity is approximately 62,500 tonnes annually, whereas actual capacity stands at 53,000 tonnes, or some 85% of potential. As with uPVC there are potential economies of scale in PE pipe manufacture.

### Raw Materials

Polyethylene is a polyolefin which is produced by the petrochemical industry without further additives. It is, therefore, readily available in Iran subject to the overall production of the petrochemical industry. Also in parallel with uPVC, many plants are running well below capacity due to shortages of raw materials. The sources and constraints are as for uPVC.

## 2.5 METAL PIPES

### 2.5.1 Ductile Iron

#### Application

Ductile iron is a form of cast iron in which the carbon is entirely present as spheroidal graphite. This gives it ductility compared with the brittleness of cast iron. As pipe, it is durable and strong, and it has long been a standard pipe material for water supply networks. The present Iranian production of Ductile iron pipe is as follows:

Location	Nominal capacity (tonnes/yr)	Production capacity (tonnes/yr)	Diameter range (mm)
Ahwaz	55,000	35,000	80-800
Tehran	35,000	32,000	100-1000
Total	900,000	67,000	

Whilst ductile iron is heavy and thus costly to transport, it is of high value so remains economic to transport throughout the country from just two locations. The diameter range available appears adequate for the needs of water supply systems, since ductile iron becomes uncompetitive with steel at diameters greater than about 900 mm.

#### Raw Materials

There are two factories in Iran, and we understand that all the output is used for water supply applications. Iran also imports ductile iron pipe, whilst both plants are working below capacity. The below capacity production is believed to be due to a shortage of pig iron, which until recently all had to be imported.

### 2.5.2 Steel Pipes

#### Application

Steel pipe, either produced in seamless form for small diameters, or welded from plate or strip in larger diameters, is a well-established material for pressure pipeline applications.

The ability of steel pipes to withstand very high water pressures is potentially its most valuable characteristic. Furthermore, when the individual pipes are jointed on site by a method which can transfer tensile forces along the pipeline, the need for thrust blocks and anchorages can be eliminated. For larger diameter pipes, tension-carrying joints are provided by welding, but this is difficult for pipe diameters below about 1,000 mm. For steel pipes up to about 250 mm diameter, tension-carrying joints can be provided by the use of screw couplings, and these, together with hot-dip galvanizing for corrosion protection, produce very successful water distribution pipelines. In some countries, for example Jordan, where such pipelines are widely used, their great strength has enabled them to be laid on the surface of the ground in rocky areas, thus eliminating the need for very expensive excavation.



## Current Production

The present production of steel pipes in Iran are as follows:

Location	Nominal capacity (tonnes/yr)	Production capacity (tonnes/yr)	Diameter range (mm)**
Esfahan	100,000	100,000*	16-80
Ahwaz	500,000	252,000*	6-56
Bandar Abbas	50,000	50,000*	16-80
Tehran (2)	320,000	140,000	***
Saveh	60,000	50,000	150-350
<b>Total</b>	<b>1,030,000</b>	<b>592,000</b>	

\* In the absence of information, assumed production at full nominal capacity.

\*\* Diameter ranges quoted locally in inches, but converted for uniformity of report to mm.

\*\*\* Larger diameter pipes are believed to be manufactured spiral welded.

Total potential nominal output is 1,030,000 tonnes. Further information is needed on the diameter ranges in order to assess their adequacy.

## 2.6 PIPELINE INSTALLATION

Successful pipelines are dependent not only on quality pipe manufacture, but equally on:

- adequate pipeline design
- careful and accurate installation of the "pipeline" elements; bedding, pipes, surround and backfill.

In the short time available for visits for this study, observations were made and discussions held of as many pipe installations as possible. A wide range of situations was observed, some of which are illustrated on the coloured plates:

### Plate 1: Mashad Sewer Project:

- Good workmanship - straight trench and pipeline
- Reasonable traffic/pedestrian protection
- Poor trench support - flimsy timbers
- Unconventional pipe; filling in-situ invert and crown

### Plate 6 - Abadan Sewer Project:

- Good workmanship - straight pipeline and jointing
- Reasonable trench support - metal sheetpiles
- Mortar joints are not favoured

### Plate 7 - Abadan Sewer Construction

- Very poor trench construction
- Inability to dewater ground
- Unsafe trench support
- No pedestrian barriers

**Plate 8 - Abadan Surface Water**

- Careless handling of good pipes
- Risk of damage

These are only illustrative of a few good and bad examples, but they do demonstrate the need for the development of national guidelines and specifications embracing the installation of pipelines to ensure that:

- pipelines will have the longest possible effective operating lives
- pedestrians and traffic are adequately protected during construction.

## SECTION 3

### DOMESTIC FORECAST DEMAND & SHORTFALLS

#### 3.1 SEWERAGE

##### 3.1.1 Demand Projections

Data on planned sewerage projects has been collected for a total of 93 cities in Iran, covering the period up to 2021 AD (1400 Hedjri Shamsi), or approximately 27 years from the present. Detailed data has been analysed on 73 cities, representing an urban population of 38.1 million people, from which the correlation between population and sewer length has been calculated. Whilst this is based on a sample, it is sufficient to gain a view of the broad level of demand to be expected. In addition, this projection of demand is modified using population proportions for the sample data and actual projected urban population. Figure 3.1 shows the location of the planned sewerage projects that are used in demand projections.

Extrapolation for a projected urban population of approximately 74 million, both for the demand as a whole and divided into diameter segments, suggests that the total requirement for public network sewer pipes in Iran between now and 2021 will be between 45000 and 50000 km. This equates to between 1700 and 1900 km per annum over the period.

Analysing the requirement by diameter shows the following estimated needs:

Diameter Range (mm)	Estimated Annual Pipeline Length (km)
200 - 250	1550 - 1700
300 - 350	48 - 53
400 - 500	44 - 50
600 - 700	34 - 38
800 - 900	34 - 38
1000 - 1200	20 - 25
1300 - 1600	9 - 12
1600 - 2000	14 - 18
>2000	9 - 12

By far the major requirement is in the small diameter local collector sewer network, and this is likely to be matched in volume by the need for house connections. J.D. & D.M. Watson, a forerunner of Montgomery Watson, in 1978 estimated a need of 0.833 m/head for house connections in urban locations in Iran. On the same population projection as above, this would produce an annual need for house connections of between 2200 and 2300 km, in addition to the above figures.

##### 3.1.2 Suggested Materials

House connections and local collector sewers up to 300 mm in diameter could be served by PVC pipes. The same collector sewers, and those up to 600 mm in diameter could also be installed in concrete pipe, provided that the risk of corrosion is recognised in the appropriate areas. Asbestos cement pipes could equally serve this sector, with the same constraints in corrosion-prone areas.



An effective material for this application in areas where cement based pipes may be subject to acid corrosion is clay, which is economic to produce at these diameters. At present there is no commercial clay pipe production in Iran. Section 6.2 and Appendix B discuss this in more detail.

The above annual demand values have been calculated on the basis of a constant level of activity through the period, since we have no data on planned timings of projects. In reality, this is unlikely to be the case, and short term fluctuations in activity will cause similar fluctuations in demand.

## 3.2 WATER SUPPLY

### 3.2.1 Demand projections

Data has been gathered on a total of 168 water supply projects planned in Iran between now and the year 2021 AD (1400 Hedjri Shamsi). This gives a robust view of the transmission needs, which are clearly defined, and sufficient information to estimate distribution needs. Correlations between population and length for water mains are not strong, particularly for transmission where in many cases transmission distances are long due to the nature of water resources distribution in Iran.

Our estimates for required lengths of pipe for these applications over the period to 2021, i.e. over 27 years, is:

Water transmission	7,000 - 8,000 km
Water distribution	15,000 - 17,000 km

In terms of diameter, the annual requirements are forecast to be:

>DN200	260-300 km/year
DN200 and smaller	560-530 km/year

The estimates for distribution include estimates of both planned extensions to the system and of planned rehabilitation and strengthening of existing systems to meet increasing population needs. Figure 3.1 shows the locations of planned water supply projects upon which the demand projections are based.

### 3.2.2 Suggested Materials

The materials required for water supply will vary for transmission and distribution. For transmission, high pressures and large diameters are the norm. The materials most likely to be used are prestressed concrete, steel and ductile iron. In water distribution, the pressures are lower, and lower flows also lead to smaller diameters being adequate. Thus asbestos cement, ductile iron, and plastic pipes are most commonly used.

The above annual demand values have been calculated on the basis of a constant level of activity through the period, since we have no data on planned timings of projects. In reality, this is unlikely to be the case, and short term fluctuations in activity will cause similar fluctuations in demand, particularly in the case of large diameter pipes used in major transmission projects.

### 3.3 DEMAND AND SUPPLY COMPATIBILITY

In order to analyse the supply capacity in relation to demand, it is necessary to estimate the capacity in length terms for those materials for which it is reported in tonnes, and also to estimate the proportion of total output available for water and wastewater applications. Based on experience in other areas of the world, we estimate the available annual capacity to be as follows:

Material	Production Capacity (km)
Concrete	900
Asbestos cement	1000
Prestressed concrete	104
Ductile iron	680
PVC	2300
Polyethylene	2100
Steel	325
GRP	200
<b>Total</b>	<b>7,609</b>

The upper boundaries of the annual demand ranges estimated in Sections 3.1 and 3.2 above are as follows:

Application	Annual Length (km)
Sewers	1900
Sewer connections	2300
Water transmission	560
Water distribution	370
<b>Total</b>	<b>5,130</b>

The initial indication is that supply, overall, is sufficient to meet demand. Findings in Iran, however, do not support this conclusion. With sewer pipes in particular there is a severe shortage, and the supply appears barely able to meet demand in water supply projects.

The data provided on thermoplastic and steel pipes is insufficient to calculate the actual lengths used in water and waste water applications.

uPVC pipe is used for cable ducts, gutters, down pipes, irrigation and interior plumbing. Polyethylene pipe is used for interior plumbing and for gas distribution. Steel pipe is used for many industrial and process applications, as well as for oil and gas transmission both on and offshore. Our major concern over the data is in the supply capability, notably that in uPVC and PE. Our investigations in Iran found this sector operating at very low utilisation levels due to raw material shortages, but the data supplied on actual versus nominal output suggest much higher levels of capacity utilisation. As a result, both the actual outputs and the amounts available for these applications could be significantly lower than reported.

We have been provided with no data on the usage of pipe in the oil and gas industries, and these may account for the great majority of PE and steel pipe demand, leaving relatively little for water and waste water. We have based our estimates of the proportion of total pipe output

used for water and waste water applications on experience in other countries in order to arrive at an estimate of the lengths of steel, PE and uPVC pipe used for these purposes in Iran. These estimates are as follows:

Steel	5%
Polyethylene	20%
uPVC	10%

If the available lengths for uPVC and PE are excluded from the demand/supply analysis due to the unreliability of the data, the shortfall is clear. Total capacity is reduced to 3209 km, or just 63% of demand. The actual supply figure is likely to be greater than this, because there is some output of plastic pipes for these applications, but even on the assumption that the full output of 2300 km of uPVC pipe is available and all used for house connections, the shortfall in sewers remains around 300 km per annum, or 16% of the estimated need.

The capacity in prestressed concrete, ductile iron, asbestos cement and GRP pipe appears in total to be sufficient to meet water supply needs. Shortages are most likely to be due to the locations of the factories in relation to the demand, especially for transmission projects. The reported outputs and capacities of these materials also require checking in stage 2, however, as the sample of data that could be checked at this stage revealed several inaccuracies.

It must be stressed that the above estimates are only as accurate and reliable as the data provided in Iran on which the analysis is based. Our reservations concerning this data have already been expressed and it is, therefore, recommended that a more comprehensive study and verification exercise is conducted early in Stage II.

A comparison of Figures 2.1 and 3.1 shows the geographic distribution of manufacturing plants and of project-defined demand, respectively. Again, this needs more detailed analysis in Stage II for each of the materials.

## SECTION 4

### FACTORS AFFECTING FUTURE POLICY

#### 4.1 THE NEED

##### 4.1.1 Current Situation

One of the aims of this project is to develop a national policy for pipeline use, that limits the choice of materials for water supply, distribution and waste water collection systems. In the absence of a policy, choices are currently made individually on the grounds of engineering needs, performance requirements and availability. Each designer has slightly different approach to specification and choice of materials based on his particular experience. In addition, pipe availability, cost, and other competing projects often dictate the use of a particular pipe type in the project. Thus, the lack of national policy has created little or no consistency in choice of materials for water supply, distribution and sewerage projects.

This section of the report is a preliminary review of and comment on the factors which can affect the development of a National Policy for Pipeline Manufacture and Use. These include:

- Engineering Policies
- Import and Export Potential
- Economic Factors
- Manufacturing Technologies

Finally, in this section consideration is given to the foundation of a National Policy based on:

- Manufacturing Standards Rationalisation
- National Materials and Installation Specifications

##### 4.1.2 Experience in other Countries

The most important lesson to be learned from a review of pipe materials usage internationally, is that differences in the manufacture of pipes, even pipes of nominally the same material, and in the service conditions of the pipelines, can have dramatic effects on the performance of the pipelines.

The following examples are intended to show how such influences have worked with some pipe materials, but comparable examples can be found with all pipe materials.

**uPVC Pipes:** When uPVC pipes are manufactured, very small quantities of materials other than uPVC are added to the basic resin in order to assist the extrusion process. After many years it was discovered that the type of additive used, greatly affected the resistance of the pipes to cracking. Thus many failures of uPVC pipes occurred in the United Kingdom during the first 15 years of use of such pipes, whilst in the USA, where different additives were used, far fewer failures occurred.

**Concrete Pipes:** Concrete pipes have been used very successfully for the construction of sewers in temperate climates, for more than 100 years. When used in hotter climates, however, even good quality pipes have often failed after only a few years in service, as a result of attack by the sulphuric acid generated when septic conditions develop in the sewage. In some countries, attempts have been made to solve this problem by providing the pipes with an



internal plastic liner, but this is difficult to do with some manufacturing processes, and also introduces problems during site work.

**GRP Pipes:** Experience has shown that when GRP pipes are installed with a bed and surround of gravel, they can be expected to perform well, but that reliable performance is much more difficult to ensure when the pipes are bedded and surrounded in sand. The reasons for this are to be found in the different sensitivity of gravel and sand to moisture content, coupled with the different response of sand and gravel to the application of compaction energy.

Experience such as that embodied in the above examples has often been gained at great cost, and has led to caution in the formulation of national policies regarding pipe materials selection.

Increasingly, the approach is to formulate at national level a procedure by which materials use can be decided at regional level, so as to take account of regional conditions and requirements. The success of such an approach does depend on the use of pipe product standards which ensure that pipes of all materials are of similar quality. In addition, pipeline design and construction must also be carried out in accordance with codes of practice which ensure that the full potential performance of each type of pipe will be fully realised.

## 4.2 ENGINEERING INFLUENCES

International Codes of Practice in use in Iran provide guidance to designers but do not prescribe or constrain choice of materials. The government, however, can influence and prescribe the use of pipe materials through National Manufacturing and Use Policy, as well as policies such as:

- **Water Resources Policy**, for example, may be based on a small number of major schemes such as the Lar scheme serving Tehran, from which high pressure transmission pipelines carry water over very long distances to the consumers. Alternatively, local groundwater resources may be used, so that much less water transmission pipework is needed.
- **Sewerage Policy** will also have an impact in cases such as the many small communities in the Caspian Sea region. These may be served by either small local sewage treatment facilities or by large centralised works. The latter would clearly require significantly more interceptor sewers or transmission force mains than the former, and policy would therefore influence pipe needs.

## 4.3 IMPORT AND EXPORT POTENTIAL

### 4.3.1 Iranian Imports

As the domestic pipe production does not meet the demand, Iran is required to import various manufactured pipes. The information on the volume and origin of these imports was requested from the Ministry of Industry, but was not available at the time of preparation of this report. However, it is believed that most of the imports are large diameter steel pipes for oil and water transmission. For smaller diameter pipes, the steel plates are imported and rolled into pipes at domestic plants. Currently there is a shortage of supply for other pipe types as well, which can be met by import in the short term.

### 4.3.2 International Manufacturing

The majority of pipe producing capacity in the world is centred, not surprisingly, on the developed countries, i.e. Western Europe, North America and Australia. Due to declining domestic demand, these countries all have considerable capacity which is directed towards the export market.

The most rapidly growing market for pipes is the Middle East region, and it is to there that many western pipe manufacturers export their products. To reduce high transport costs and to promote development of the Middle East economies, there is a trend for pipe factories to be built near to the points of demand. Some of these factories are operated by local manpower, but considerable doubt has been raised about the quality of some of their products and the standards to which they manufacture. Others are operated by consortia of experienced pipe manufacturers and local interests. The pipes produced by this type of enterprise seem to generally have had little difficulty in meeting international standards. The Middle East plants normally only have the capacity to meet the local market demands, thus leaving little surplus capacity for exports. This means that many countries in the region will continue to depend on the traditional foreign suppliers for a considerable time. Iran is currently not an exception to this fact and is required to import pipes to meet the domestic market demands. Table 4.1 shows the countries which have traditionally supplied pipes for water supply and sewerage to the Middle Eastern countries. Some countries, such as the UK, export many types of pipes, whereas others tend to specialise in particular materials.

### 4.3.3 Export Market

Given the scale of water supply and sewerage projects in the next 25 years, it is not economical that Iran imports the pipes to meet the market demands. It is more cost effective to set up plants in Iran. The economic advantage is greatly enhanced by the potential to export to other countries and it is considered to be essential to address this potential in some detail, in view of its impact on the viability of certain materials. Further studies should therefore address:

- the regional demand with particular emphasis on neighbouring CIS/ex-Soviet states, but also looking to the Gulf which might easily be served by shipment from Iranian Gulf ports. Qeshm Island Free Zone might, for instance, prove a viable manufacturing location with export potential,
- the regional supply currently in place with the Gulf and from the Indian sub-continent,
- the practicalities and relative economics of transportation.

## 4.4 ECONOMIC FACTORS

### 4.4.1 Ex-Factory Costs

A preliminary assessment has been made of the ex-factory costs of different pipe materials and these are presented in graphical form on Figures 4.1 - 4.3. The relative cost of pipe manufacturing in Iran at various diameter ranges is typical of the industry internationally.

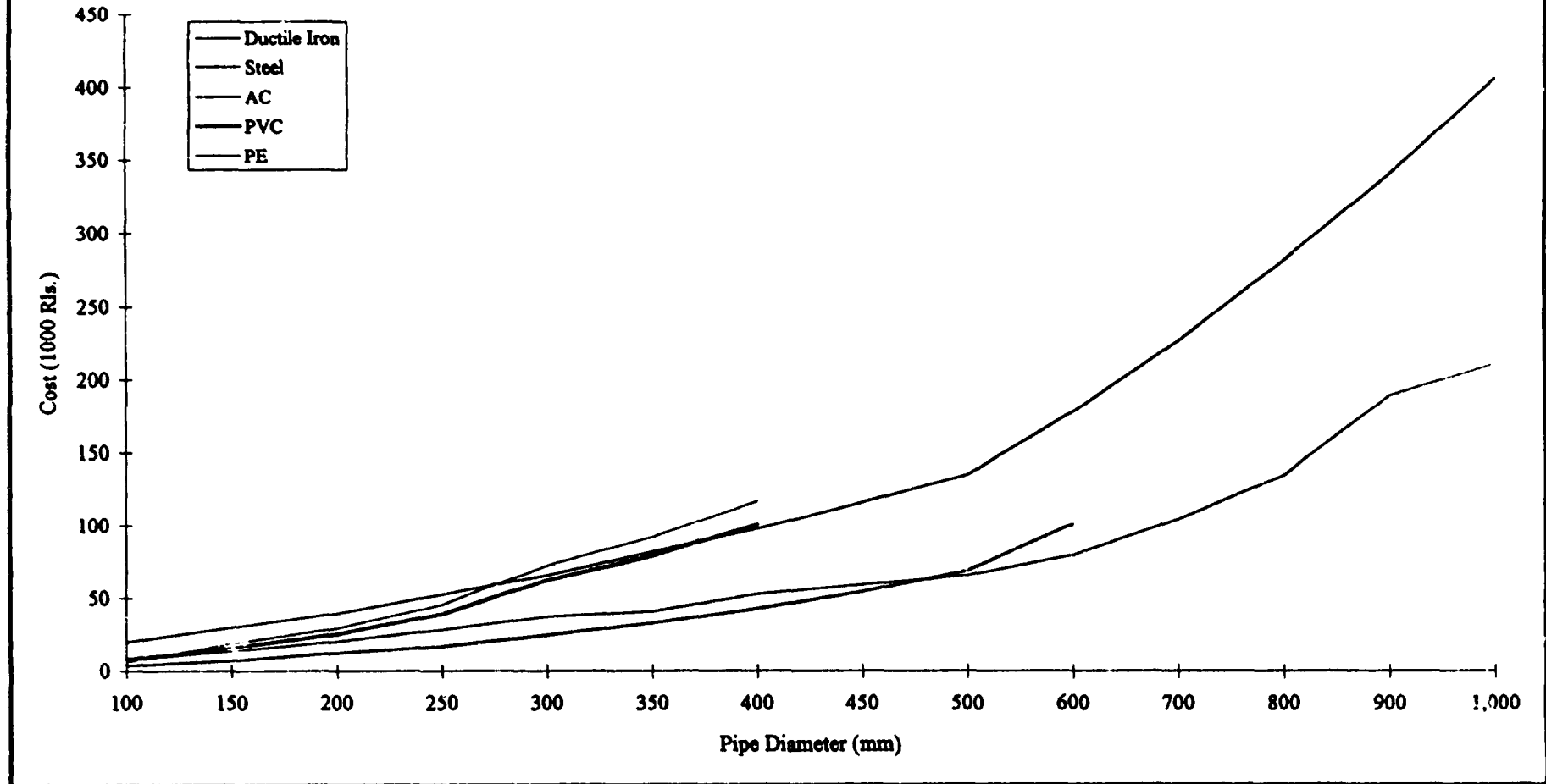
Extensive work has also been undertaken within the Ministry of Energy, but no back-up data and reports were available to the team to assess or verify the data. The costs shown are, therefore, indicative of relative costs and are strongly influenced by transportation costs (as

**Table 4.1**  
**Major Manufacturing Countries of Sewage and Water Pipes**

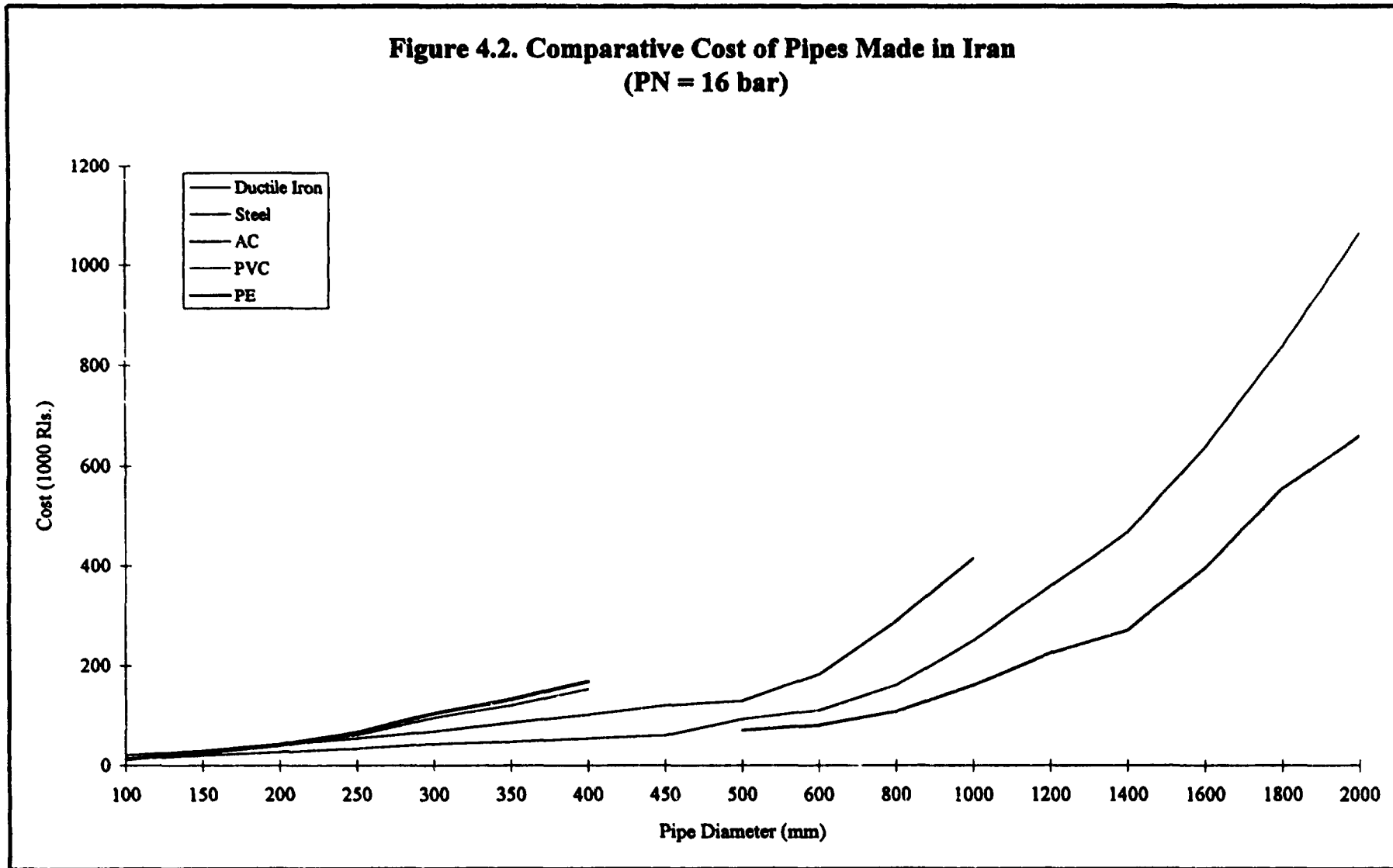
Country	Type of Pipe						
	Clayware	Steel & Iron	GRP	PVC	Asbestos Cement	Polythene	Concrete (PVC Lined)
Australia	*	*	*	*	*	*	*
Belgium	*			*	*		
Finland			*	*		*	
France		*	*	*	*	*	
Holland			*	*		*	
India	*	*	*	*	*	*	
Italy	*	*	*	*	*	*	
Japan		*	*	*	*		
Lebanon			*	*	*		
Malaysia	*	*	*	*	*	*	
Norway			*	*		*	
Pakistan		*		*	*		
Saudi Arabia	*		*	*	*		*
Singapore		*		*			*
Sweden		*	*	*		*	
Switzerland	*	*	*	*		*	
UAE			*	*	*	*	
UK	*	*	*	*		*	
USA	*	*	*	*	*	*	*
Germany	*	*	*	*		*	

**Note:** Table excludes former communist block countries for which limited data is available.

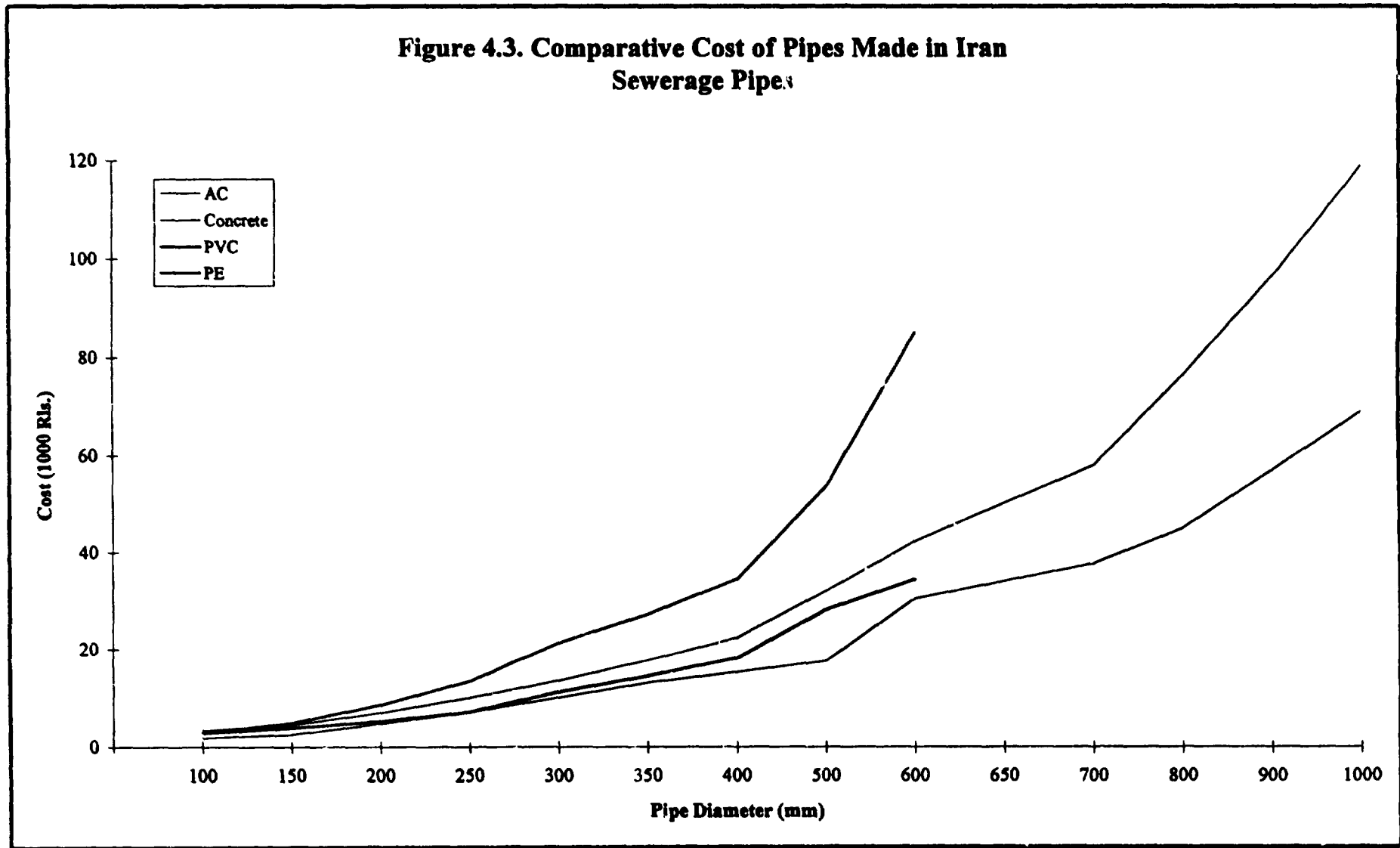
**Figure 4.1. Comparative Cost of Pipes Made in Iran  
PN = 10 bar**



**Figure 4.2. Comparative Cost of Pipes Made in Iran  
(PN = 16 bar)**



**Figure 4.3. Comparative Cost of Pipes Made in Iran  
Sewerage Pipes**



discussed in 4.4.2). relative import and export costs (Section 4.3) and other factors such as longevity of materials in service.

A thorough economic study is, therefore, a pre-requisite to making firm recommendations.

#### 4.4.2 Influence Of Transport Costs

Transport costs are an important component in the overall cost of pipes. It is not uncommon for transport costs for certain types of pipe to be greater than the ex-works prices of the pipes, thus more than doubling their delivered cost. In aiming for cost-effective utilisation of pipes, and optimum future development of the pipe manufacturing industry to meet the country's needs, transport costs must be considered in detail. Discussion of the impact of transport costs is given below for each pipe material, but detailed study of the situation in Iran is necessary to define the economic radii of coverage more accurately, since the competitive position in transport markets is very locally variable.

##### Concrete

Concrete sewer pipes are the most vulnerable to high transport costs. The pipes themselves are of relatively low value and are heavy, with an average weight of over 100 tonnes per km length. Moreover, because concrete pipes are generally greater than 200 mm in diameter, there is a large volume of empty space being transported, so transport is relatively inefficient. As a result, the economic radius of coverage of a standard concrete sewer pipe plant is not greater than 100-150 km in most circumstances.

This limits the economic scale of factories, and means that any economies of scale cannot be exploited unless there is enormous demand within the area of coverage. This industry is also characterised by the large number of small companies operating in it. These are generally small companies with just one plant manufacturing undifferentiated products for a local market. It is normal for concrete pipe markets in large countries to be characterised as a series of local markets because of the limitations on delivery area imposed by the transport costs. Thus any increased production in concrete pipes needs to be targeted at, and located in, defined areas of need in order to be effective.

##### Asbestos Cement

Asbestos cement pipes suffer similar limitations due to high transport costs. The situation is not so acute, however, for three reasons. Asbestos cement pipes are higher in value per unit of both length and weight than concrete pipes, thus the level of transport costs is more favourable. The economic range of diameters for asbestos cement pipes also begins at smaller sizes than for concrete pipe, so the volume/weight trade off is also more favourable. The result is a wider economic delivery radius, as much as 200-300 km being the upper limit in most countries. Nevertheless, this again serves to limit the economic scale of production.

##### Prestressed Concrete

Prestressed concrete pipes are high value products manufactured to higher specifications than sewer pipes and for more demanding applications. Although they are heavy and the diameter range is such that the weight/volume trade off is unfavourable, their value and product price is sufficiently high for transport costs, even over significant distances, to have much less impact on the economics of their use. The three factories are, however, located in the West of the country and all at some distance from Tehran. The result may be that their use in Tehran and the East, for example Mashad, may be uneconomic at present but occurring because of needs that cannot be met with any other materials.

the East, for example Mashad, may be uneconomic at present but occurring because of needs that cannot be met with any other materials.

#### **GRP**

GRP pipes fall into a similar range as prestressed concrete in this context. High value pipes, generally of larger diameter, and to high specifications for demanding applications. They are lighter per unit length and diameter than prestressed concrete, and the economies of scale of production dictate larger plants, with the result that the economic radius of delivery is larger. As with prestressed concrete, there are few plants and they are located away from some of the main regions where there is high demand, such as Tehran and the South West. Their use in these areas may be uneconomic but occurring because of needs that cannot be met with any other materials.

#### **Thermoplastic Pipes**

The plastic pipes, PVC and PE, are light in relation to their unit length and can be transported economically over large distances. A small number of factories of a size to exploit scale economies in production can serve a large country. In Iran, there is a large number of factories producing both PVC and PE pipe, covering all areas of the country, so all major areas are within economic reach of production facilities. As already mentioned in Section 2, some rationalisation may lead to economies of scale from fewer factories.

#### **Ductile**

Ductile iron pipes are similar to prestressed concrete, in that they are high value, high specification, and used for specific pressure applications in water supply. Transport costs, though high, are small in relation to the product value. Transport over long distances is therefore economic, although with just two factories in Iran, much of the country will suffer high transport costs in utilising ductile iron pipe. As for prestressed concrete and GRP pipe, some usage may be uneconomic but occurring because the needs cannot be met any more economically with other materials.

#### **Steel**

Steel pipe is relatively little used in these applications, but is not expensive to transport in relation to the product value. Thus transport over long distances is economic. Information received on steel pipe capability gives little on diameters relevant to water and waste water applications, but the distribution of steel pipe mills around Iran leaves large areas of the country at considerable distances from them, such that usage, as for certain other materials, may be at the margins of economy.

### **4.5 MANUFACTURING TECHNOLOGIES**

The major need for new capacity in Iran is in sewer pipes. The materials most widely used, and which should be considered for increased production, are concrete, clay and GRP. All of these are suitable for sewerage use, and could meet the needs for sewer pipes in Iran.

#### **4.5.1 Concrete Pipes**

Concrete pipes form the major part of the sewer network in Iran, and their continued use is essential if disastrous short term capacity shortfalls are to be avoided. In addition to improving the quality and throughput of existing manufacturing facilities, new capacity will be required.



Concrete pipe manufacture is most commonly undertaken using vertical casting equipment. Typical examples of this are already in operation in Iran. The two main types of machine are vibrator and packerhead types. Within these two types, however, there is a large range of quality and quantity capabilities. Certain machines can produce large volumes of low quality pipe, whereas others can produce lower volumes of higher quality pipe. Variations such as stationary, rising, rotating or jumping core for vibratory machines, and single, double, or contra-rotating heads for packerhead machines can have significant impacts on both quantity and quality, or the trade-off between the two.

In many instances purchasers reduce their capital outlay by buying equipment which is more versatile, but this tends to result in lower quality pipe as the machinery is an inevitable compromise between various objectives. For example, with a pallet fitting inside the mould, varying lengths of pipe can be manufactured on a single machine, but there is significant grout loss which does not occur if the pallet is locked and sealed under the mould. In this latter case, however, only one length of pipe can be produced. Similarly, too great a range of diameters produced on one machine means that the machine settings cannot be optimised for any diameter resulting in a compromise that reduces both capacity and quality.

In addition to the pipe machines themselves, there will be a requirement for ancillary equipment, including cage making machines, curing equipment, pipe handling equipment, batching plant, fresh concrete distribution system and mould cleaning equipment.

Cage making machines may range from hand welding jigs to fully automated machines, and need to be compatible with pipe making plant in terms of length and diameter range, output volume, finish quality etc. For example, a pipe making process that requires the cage to stand on its end means that the cage end has to be cut square. An apparently minor point but such aspects need to be considered when making large capital expenditure in order to ensure a cost-effective result.

Pipe handling equipment is also extremely important. Pipes are moved from the machine, often without moulds, whilst the concrete is still fresh, and poor handling at this point will cause considerable damage and/or distortion.

Curing also requires attention. Relatively thin-walled products can dry too quickly, especially in hot, dry climates such as that in Iran. Steam curing can be used to accelerate curing, but if the pipes have been demoulded steam cannot be applied until some time after the concrete has set otherwise the semi dry concrete will become plastic and the pipe will collapse.

Many manufacturers of pipe making equipment offer a range of machines and also of special features that can tailor a machine to customers' particular requirements. Thus it is important to identify both quality and quantity needs in advance of specifying machinery. Achieving a balanced capability in terms of all equipment operating optimally is also important.

Suitable equipment for making the required quantities and qualities of concrete sewer pipe is obtainable from several manufacturers. Those whose equipment was seen working in Iran are typical and they offer a range of suitable machinery. They are Pedershaab (Denmark), Pfeiffer (Germany) and McCracken (USA). There are also several others in Europe and North America.

It should be noted that the provision of plastic liners, as internal corrosion protection against hydrogen sulphide attack, is relatively simple with some manufacturing processes, but

extremely difficult with others. This option will, therefore, require more detailed study at a later stage.

#### 4.5.2 Clay Pipes

The basic process of making clay pipes requires moulding of the clay in suitable moulds followed by firing in kilns to a certain temperature and for a certain time in order to ensure a fully fired pipe. Controlled cooling is also essential in order to avoid distortion or localised stressing of the pipes.

Transport costs for clay pipes are relatively high, so the radius of delivery is limited. Similarly, because of the cost of transporting raw materials it is usual for the clay pipe factories to be located close to the sources of clay. Hence the use of clay pipe in any region depends on locally available deposits of suitable clay in addition to the existence of pipe making capability.

At present, we understand that there are no clay pipe manufacturing facilities in Iran. A recent study has investigated the feasibility of establishing a plant in the Mashad region, and we understand that suitable clay deposits have been identified in the Tehran and Ahwaz regions. The Ahwaz region, with the problems of acid corrosion of concrete sewer pipes, is one in which clay pipes may offer a cost-effective alternative.

The major investment for clay pipe manufacture is in the firing kilns. The most suitable type depends on the level of output required. The most energy efficient kilns are roller kilns for small diameter pipes and tunnel kilns for large pipes, but these are large continuous process items which need as much as 1000 tonnes per week of throughput to be economical. This equates to between 20 and 24 km/week, or 1000 to 1200 km per year. Tunnel and roller kilns require significant capital investment and the process is such as to be capital rather than labour intensive.

Smaller, beehive kilns can be run economically at between 50 and 100 tonnes per week, representing between 50 and 120 km per year of pipe. These, however, require more energy per tonne of output. They can also be operated in batch mode where greater flexibility of output is required but this further increases the energy requirement because there is a large fixed energy need each time a kiln is fired up. Beehive kilns are less capital intensive than tunnel kilns, and there is a greater labour requirement per unit of output.

#### 4.5.3 GRP Pipe

Glass Reinforced Plastic (GRP) pipe is suitable for use in sewers and is also not susceptible to acid corrosion. GRP is, however, an expensive material for pipes, and it is more cost effective at larger diameters, generally in excess of DN750. There are considerable economies of scale in manufacture so it is usual to erect large factories with output sufficient for a large area. The low transport costs in relation to the value of the pipe mean that it is economical to cover large areas from a single factory.

At present there are two factories producing GRP pipe in Iran, the second of which is expected to commence commercial production early in 1995. Projected capacity of this plant, in Mashad, is not known, but this may provide sufficient output to meet the needs in Iran for the short to medium term. The raw materials for GRP pipe manufacture are relatively expensive and are not readily available in Iran, therefore foreign currency would be required to pursue GRP pipe production. If the raw materials were to be available from Iranian sources, there would also be an opportunity cost of foreign exchange foregone if it were used within Iran.

Within the range of GRP pipes, there are two principal manufacturing technologies: filament winding method and the Hobas centrifugal method. The factory at Mashad uses the filament winding method, and this is the more common system in use throughout the world. Both require substantial capital expenditure to establish and have similar scale economies.

## **4.6 PRELIMINARY OVERVIEW OF NATIONAL POLICY**

### **4.6.1 Recommendations for Iran**

In accordance with the above it is considered that Iran, which already has a substantial pipe manufacturing capability, should develop national standards covering pipes manufactured from all relevant materials, and also covering pipeline design and construction.

Such standards can be based initially on existing international standards (in some cases national standards may be appropriate), but these should be kept under review by Iranian committees, so that any lessons of local experience can be incorporated where appropriate.

Given a framework of pipe and pipeline standards, national guidelines for the development of regional pipe materials selection policies can be developed. It is further suggested that any such guidelines should not completely preclude the selection of materials other than those recommended. Other materials could be permitted, subject perhaps to the approval of a central co-ordinating committee, which would oversee pipeline policy at a national level.

A further area to be considered when formulating national policy is that of economics. Self-sufficiency, both in the supply of pipes, and in the obtaining of raw materials, is an obviously desirable objective for economic reasons. At the same time opportunities for exports to neighbouring countries should be investigated when considering the economic implications of investment in pipe manufacturing facilities.

Where pipe export is adopted as an objective, the need to produce pipes to standard specifications which are internationally recognised becomes particularly important.

### **4.6.2 Manufacturing Standards**

The two important functions of pipe product standards have already been referred to and are summarised as follows:

- To ensure comparability between pipes of different materials when considered in competition for use on Iranian projects.
- To ensure acceptability in export markets.

Future policy on product standards can also have a significant effect on the future supplies of pipes. At present there appear to be sound standards to which most supply sectors are working, but they are inconsistent. Some manufacturers are producing to ASTM standards, some to ISO, some to DIN and others to AFNOR. Often this depends largely on the country from which the pipe making equipment has been purchased. Many of the concrete sewer pipe manufacturers are producing pipes to prescriptions supplied by the equipment manufacturers rather than to any performance or product standard.

It is suggested that product standards for pipes of various materials might, initially at least, be adopted as follows:

#### **Concrete Pipes**

There is no international standard for concrete pipes, but a European standard is under development and might well be appropriate for Iran, since the pipe manufacturing equipment at the various Iranian concrete pipe factories itself comes from a variety of European countries.

#### **Asbestos-Cement Pipes**

International standards have been in use for asbestos cement pipes for many years, covering both pressure and non-pressure pipes, and these form the basis of the national standards in most countries.

#### **Ductile Iron Pipes:**

Ductile iron pipes are covered by International Standard ISO 2531, and this would seem appropriate for both internal and export use.

#### **Steel Pipes:**

Although there is an International Standard for steel water supply pipes (ISO 559), Specification API 5L of the American Petroleum Institute is more widely known and used world-wide, and is indeed effectively the international standard for steel pipes in general.

#### **GRP Pipes:**

Despite many years work on the subject, the International Standards Organisation has still not produced an agreed international standard and, in the absence of such, American standards have been most widely used internationally. For non-pressure sewer pipes, ASTM D3262 is the relevant standard, whilst for water supply pipes, AWWA C950 is preferred.

#### **Polyethylene and uPVC Pipes:**

For neither of these two pipe materials are there international standards. This is, at least in part, due to the fact that water pressures which pipes of these thermoplastic materials can safely sustain, depend on the temperature of the environment.

Other problems in the agreement of international standards have come from differing national experience, with the problem of crack resistance, and also from commercial pressures influencing the selection of design factors used in establishing pressure ratings.

It may well be that Iranian standards for uPVC and polyethylene pipes will need to be developed, taking account of several existing national standards, as well as Iranian experience.

#### **Clayware:**

If clay pipe production is commenced in Iran, then it may be appropriate to base the national standard on the European Standard (EN 295) for reasons similar to those applying to concrete pipe manufacture and standardisation.

### 4.6.3 National Specifications for Pipeline Design and Installation

The adoption of appropriate specifications for pipes is important both for pipeline construction within Iran and for potential export opportunities.

Pipes are, of course, the most important component of pipelines, but it is essential to appreciate that good quality pipes do not automatically guarantee good quality pipelines. In addition to using good pipes, a successful pipeline must also be properly designed, structurally as well as hydraulically, and properly installed. Experience of the investigation of pipeline failures has shown, as would be expected, that failures are sometimes caused by poor quality pipes, sometimes by faults in pipeline design and sometimes by poor workmanship in the construction of the pipeline.

Pipe quality can be assured by the adoption of sound standards, coupled with independent inspections and testing to ensure that the pipes produced do comply with the standards. This is briefly discussed in Section 4.6.2. Good workmanship in pipeline construction can best be achieved by employing experienced contractors, requiring them to work to realistic and technically sound installation standards, and by providing independent supervision of site construction to ensure that the installation standards are complied with.

Pipeline design is often approached in an unbalanced way. Considerable attention is, rightly, usually given to hydraulic design, whilst structural design is virtually ignored. It is worth remembering, therefore, that whilst a fault in hydraulic design might lead, for example, to a 10% shortfall in capacity, a fault in structural design will normally result in 100% loss of capacity.

For these reasons, the adoption of pipe product standards in Iran should be accompanied by the development of pipeline design and construction standards appropriate to the pipes which will be used, and to the conditions under which the pipeline will be constructed and operated.

In the same way that pipe product standards need to ensure a similar level of quality for pipes of all materials, so also must the pipeline design and installation standards ensure that the completed pipelines will offer similar levels of reliability, irrespective of the materials. For this reason, the development of the design and installation standards cannot be left to the pipe manufacturers, but must be co-ordinated at a national level.

## SECTION 5 RECOMMENDATIONS

This section outlines the conclusions we have drawn relating to the needs for development of this part of the project. They are indicated roughly in sequence and not in terms of importance. i.e. the development of a policy and standards (5.4) depends on the conclusions of the earlier stages of economic (5.1), materials (5.2) and condition studies (5.3). The Study Tour (5.5) could take place at any time.

### 5.1 ECONOMIC STUDY

- **Export Potential** - The export potential of different pipe materials to other countries in the region, in particular to the Persian Gulf, the CIS countries, and countries to the east of Iran need to be investigated, and analysed.
- **Verification of Data** - The estimates made at this stage of the study are based on statistical analysis of small samples. This has been sufficient for this stage of the study. Additional data, especially on supply side capacities, will allow these first stage estimates to be refined in the second part of the study so that they are sufficiently accurate to support the more detailed activities at that stage.
- **Confirmation of gas and oil demands and influences on pipe industry**- The gas and oil industries in Iran are likely to be major users of pipes manufactured from steel and polyethylene. The capabilities of these sectors of the industry to meet the demands of these applications should be investigated, as should the demand levels in relation to the production capacity. Both the oil and gas industries are likely to be more demanding technically than water supply, so the technical capability required for water pipes may already exist. The actual demand levels need to be identified so that the available capacity for water applications can be more accurately defined, and any additional capacity requirements calculated.
- **Review of relative costs of transport** - This stage of the study has discussed the influence of transport costs of pipe in general terms, identifying its influence on radius of economic coverage of production facilities for the various materials. Actual transport costs in Iran need to be established for all pipe types so that the economics of the usage of different pipe materials in various regions can be quantified. This will assist in defining the optimum locations for any additional production capacity.

### 5.2 MATERIALS STUDY

The following specific recommendations are made regarding clay, concrete and GRP pipes:

- **Clay pipes** - Clay is widely used throughout the world for sewer pipes. Clay provides a strong, resistant pipe which is easy to lay and which has a long service life. At present,

there is no clay pipe in Iran, with the result that almost all small diameter public sewerage is installed using concrete pipe. In certain regions, as discussed above, concrete is not the most suitable material for this application due to its susceptibility to acid corrosion. The introduction of clay pipe manufacture into Iran would be a major step towards eliminating this problem and would strengthen the Iranian pipe industry.

We recommend that a thorough investigation into the establishment of clay pipe production in Iran be undertaken. This should include identification of the raw material sources, estimation of the likely demand, and evaluation of the most appropriate manufacturing technologies. Capital investment requirements and the economics of plant operation to ensure profitability should also be investigated.

- **Concrete pipe manufacture review** - Concrete pipes are the mainstay of the sewer pipe industry in Iran, and their continued use is necessary if the plans are to be met. Several measures may be taken to improve the supply capacity of this industry, the quality of pipes produced, and the suitability of these pipes for their intended purpose. It is likely that improving this sector of the industry can be achieved more quickly and cost-effectively than adding capacity in other materials to substitute them for concrete.

In order to develop plans for the concrete pipe industry, a detailed survey of existing capabilities will be required. This should cover the following aspects.

1. Identification of existing equipment and its current condition. This will encompass the production machinery itself, any ancillary equipment, moulding equipment, cage making equipment, batching plant and mobile plant. For the pipe machines the survey should identify the type, make and model of machine together with any modifications or additions that have been made, and should consider the compatibility of the process with the provision of plastic linings.
2. Identification of the capacity of existing equipment and the reasons why, where applicable, this is below the nominal capacity. This will enable proposals to be made on improving the capacity to the optimum for each plant. The most common reasons for a concrete pipe manufacturing plant performing below optimum capacity are: poor management; machines in poor condition; ancillary equipment not suitable; high defect rate; poor concrete availability; and poor production planning.

From this survey, detailed recommendations can be made on the ways to optimize capacity. In certain plants, for example, the equipment may be suitable for upgrading whereas, in others, it will be past its useful life. Other plant may not be able to produce pipes to any new specifications that may have developed, whilst some may be able to meet such specifications with little or no adaptation. Some plants may be capable of receiving a new lease of life by adding new equipment, and others may benefit from the addition of mechanical handling, automation, on-line testing etc.

This survey will allow the existing capacity to be optimized and thence plans made for additional capacity to meet forecast outstanding demand in each region.

- **GRP pipe investigation** - Clay pipes are economic to manufacture and use up to approximately 600 mm diameter. At larger diameters they are seldom manufactured, but the same requirements can be met economically at these diameters by GRP pipe. Since the technical need driving the requirement for GRP pipes exists at the full range of diameters, a similar study to that proposed for clay is recommended. This will differ, however, in that the transport economics of GRP pipe make it viable to sell from a single factory across a wide region, and there may be attractive export potential to neighbouring countries. The capacity in the region should also be investigated for its potential to meet short term needs by importing. In the longer term, Iran may find export of GRP pipes, as added value products, more advantageous than potential export of the raw materials (resins).
- **Optimization of existing capacity** - Because of the widespread nature of concrete pipe manufacture, the detailed study of optimization of this sector of the industry has been identified as a key recommendation in its own right. Similar studies of the other materials are also recommended. This is necessary in order to establish, for individual plants, the critical factors constraining output at levels below full capacity. These factors can then be specifically addressed in the National Policy to be developed enabling existing capacity to be optimized.

### 5.3 CONDITION ASSESSMENT

- **Existing System Quality Audit** - Since the existing sewer pipes in Iran may be suffering from unsatisfactory quality, it is necessary to implement a quality audit program in the areas that the system is degrading. This audit program includes visual and physical inspection as well as monitoring with Closed Circuit Television (CCTV) system, to determine the severity of the problem, and the rate of advancement of the problem. This program will determine location, extent, and severity of the quality degradation (e.g., corrosion) problem.

### 5.4 POLICY AND STANDARDS

- **National Policy on Pipe Materials** - Rationalization of the materials used for different applications in the different regions of Iran would support more efficient usage of the existing and planned pipe manufacturing capacity. At present the materials specified vary according to the experience of the specifying authority, local preference or perceived effectiveness. As a result, there is no consistent pattern of pipe usage for specific applications in Iran, nor even within specific regions. A national policy defining the most cost-effective and technically acceptable materials for each application and region, encompassing design, material selection and installation guidelines would encourage more consistent specification patterns. Such a policy, whilst meeting technical requirements, should be developed to ensure that materials chosen are such as to make optimum use of the supply capabilities of the regional pipe manufacturing industry.
- **National Standards for Pipe Manufacture** (based on international standards and local Iranian experience and practices) - Development of an Iranian Standard specifically for concrete pipes for sewers is perhaps the single most important action that can be taken in



the short term. Initial consideration should be given to using an established concrete pipe standard as a basis, for example BS5911. The base standard would need to be adapted for Iranian conditions and needs and should include:

1. Materials specifications
2. Jointing specifications
3. Laying and bedding specifications
4. Manufacturing tolerances
5. Finished product specifications
6. Physical and chemical resistance requirements

The Standard will serve as an objective in determining the production and capacity optimization needs.

Similar standards are necessary for other pipe materials to ensure consistent pipes of the required quality. In some instances, such as the pre-stressed concrete pipe sector, manufacture is already to established international standards, and these could be adopted with relatively minor amendments as Iranian Standards. In other cases, European or other international standards could serve as the basis for developing Iranian Standards. These standards should cover all aspects of pipe manufacture, from raw material properties to installation and in-situ testing.

## **5.5 TECHNICAL STUDY TOUR**

It may be of great benefit for key staff of the National Water and Waste Water Engineering Co. to visit countries in the region that have implemented similar policies, or particular aspects of them. Bahrain, for example, developed a comprehensive policy on pipes for water and waste water applications at the beginning of its sewer installation programme some 20 years ago, under the auspices of specialist consultants in the field. The results of this, and the experiences of the Bahraini authorities in implementation, may be instructive to the people in Iran who will be responsible for introducing this policy.

## **Appendix A**

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### **Visit Reports - Pipe Manufacturing Plants**

**A1 TEHRAN, Luleh va Mashinesazi  
Ductile Iron Pipe Plant**

9 Nov 94

**Present:** ..... Plant Manager  
*Tom Sangster* MW Specialist  
*David Bailey* MW Specialist  
*Azadeh Peyman* RayAb UNIDO Office Manager  
*Ali Tavassoli* RayAB Staff

**Production:** This plant produces ductile iron pipes, all of which are used for water supply within Iran.

**Technology:** The process is the conventional centrifugal casting.

**Current Capacity:** 60000 tonnes per year but actual output is around 40000 tonnes, of which 2000 tonnes is fittings. The managers claim that it is the largest DI pipe plant in the Middle East and can convert 150 tonnes/day iron to pipe.

Diameter range is 100-1000mm

Demand for DI pipe in Iran exceeds supply, and the plant could sell all its output if it were running at full capacity. Iran is at present importing DI pipe for water supply projects.

Output for the year 1993-4 by diameter was as follows:

Diameter (mm)	Tonnes	Length (m)
100	32.25	2000
150	1083.5	44000
200	116.35	3500
250	872.5	20000
300	745.0	13000
350	1855.0	26000
400	4895.0	60000
500	1232.0	11000
600	4308.9	30000
700	7252.0	40000
800	4501.0	20000
900	1014.65	3500

**Raw Materials:** The reason for the low output is lack of raw materials. Pig iron has to be imported from Canada or Brazil, and lack of foreign exchange limits the amount that can be imported. An iron foundry has recently been commissioned in Esfahan which should relieve this problem to some extent.

**Quality:** Pipe quality itself appears good, but the bitumen coating process, which is to dip the heated pipe into molten bitumen, is poor and gives an uneven coating.

**A1 TEHRAN, Luleh va Mashinesazi *Cont'd***

**QA:** The pipe is produced to ISO 2531. Each pipe is pressure tested to 1.5 times working pressure. Pipe is sold ex-works, but customers from all over Iran purchase from this site.

<b>Present:</b>	<i>Dr Nairizi</i>	Tooss Ab
	<i>K Takavou</i>	Tooss Ab
	<i>Ali Taghavi</i>	MW Project Manager
	<i>Peter Lawrence</i>	MW Project Director
	<i>Miss Marham</i>	Plant Manager
<b>Plant Ownership</b>	40% Gruppo Sarplast of Italy, 60% Iranian - Private ownership	
<b>Sponsorship</b>	Khorassan Water Board, Tooss Ab.	
<b>Technology</b>	Sarplast - MT4 machine installed.	
<b>Technical Specs</b>	Design to ASTM. Mandrel and Fittings all made in Iran to Sarplast pattern Resin - Isophthalic 266/268. Glass C- internal and E- outside Resin-rich layer - 2 squeezing mats with C-glass mat between. Double-ring spigot and socket joint.	
<b>Current Capacity</b>	Temporary building. Manufacturing 400 and 500 dia at present. Job-by-job - current supply for <i>Ferdus</i> Water Supply - 100 km of 10 bar	
<b>Planned Capacity</b>	Second machine within 3 months - <i>Everest Cat</i> - capability up to 3m diameter. New building planned.	
<b>Raw Materials</b>	Local resins (Arak Petrochem Complex), squeeze mats and plastics-only fibres will be imported.	
<b>QA</b>	No testing facilities in operation but field testing of first runs will be undertaken within 3 weeks. 400 and 500 diameter only at present. In-factory testing of all normal mechanical features - stiffness, hoop-tension etc. 250 to 1600mm is planned normal range with capability to 3m.	
<b>Quality</b>	Some resin runs evident Some surface unevenness. No certainty over resin-rich inner layer thickness. Despite above general visual quality is high but no testing yet undertaken.	

- Present:**
- |                               |                    |
|-------------------------------|--------------------|
| <i>Mr Mohammad Reza Shams</i> | Plant Manager      |
| <i>Ali Taghavi</i>            | MW Project Manager |
| <i>Tom Sangster</i>           | MW Specialist      |
| <i>Ali Tavassoki</i>          | RayAb Staff        |
- Production:** This plant is 1 of 3 in Iran producing prestressed concrete pipe for water supply usage. It is 17 years old. The process is licensed from SOGEA, of France, and involves spinning a longitudinally prestressed pipe, then wrapping with tensioned wire and covering with a 24mm mortar protective layer. Dia range is 800-1400mm and there is a plan to increase this capability to 2000mm dia at sometime in the future. Working pressure range is 4-15 bar.
- Capacity:** 28 km/yr of pipe, subject to the supply of wire, which is limited by hard currency availability. A project is under way to establish a supply within Iran in 1-2 years.
- Demand for the pipes is very high, with most usage local. All production at present is sold to the regional water transmission company, which is part-owner of the factory. The application is water transmission, as the distribution systems use AC and DI. The other 2 plants in Iran producing similar pipe also sell it all for water supply. The plant at Rasht also uses the SOGEA process, whereas that at Tabriz uses the Italian *Casagrande* process.
- Raw Materials:** The key component is the prestressing wire, purchased from Somerset Wire in the UK and exceeding BS5896:1980 with a breaking stress of 1710N/mm<sup>2</sup>. All cement used is SRC to ASTM type 2 at a rate of 440kg/m<sup>3</sup> for the core and 480kg/m<sup>3</sup> for the outer cover layer. Pipes are 7 metres long and all are pressure tested to 1.5 x working pressure.
- Quality:** Pipe quality appeared to be good, with evidence of care in curing the concrete properly.
- QA:** Pipe is produced to AFNOR standards.

**A4 ESFAHAN Pedershaab Concrete  
Pipe Factory**

**12 Nov 94**

- Present:**
- |                      |                     |
|----------------------|---------------------|
| <i>Mr Mateghi</i>    | Plant Shift Manager |
| <i>Ali Taghavi</i>   | MW Project Manager  |
| <i>Tom Sangster</i>  | MW Specialist       |
| <i>Ali Tavassoli</i> | RayAb Staff         |
- Production:** Concrete sewer pipes 250-1600mm dia, and ovoid 600/900 to 1150/1850. Smaller sewer pipes can be produced flat-bottomed externally for ease of laying. All ovoid pipes and the circular ones above 600 dia are reinforced. Pipes are 1m, 1.25m or 2.50m in length. 250mm dia pipes are produced for stock, others to order.
- Capacity:** The factory has 5 Pedershaab vertical casting machines, 1 for large diameters and 4 for smaller pipes. These latter each produce a 1.25 m long pipe in 2-3 minutes. Capacity is 700m/month/shift at large diameters and 1000m/day/shift for the small diameters. Average monthly output is 25-27km with 2 shifts. Full capacity is 40km/month but the equipment is old and cannot run at this level. Constraint on capacity is equipment rather than raw materials or demand, which is sufficient to justify working at full capacity if this were possible. All pipe is sold to the Esfahan Water & Wastewater Co.
- Quality:** Generally poor, with lots of honeycombing in evidence. Little attempt is made to cure the pipes properly.
- QA:** The product is not produced to any performance standard. They claim to produce to a Pedershaab standard Cement used is SR to ASTM type 2 or 5.

- Present:**
- |                       |                            |
|-----------------------|----------------------------|
| <i>Mr H Arabie</i>    | Plant Shift Manager        |
| <i>Tom Sangster</i>   | MW Specialist              |
| <i>Azadeh Peyman</i>  | RayAb UNIDO Office Manager |
| <i>Tali Tavassoli</i> | RayAb Staff                |
- Production:** Iranit produces AC pipe at this factory and another in Tehran. They have over 50% of the Iranian market and also export, mainly to the UAE.
- Technology:** The company is a joint venture with St. Gobain of France, which has one member on the board. There is also a technology transfer protocol with St. Gobain covering *waste minimisation*.
- Capacity:** Capacity of the 2 factories is 64000 tonnes per annum of pipe. All could be sold in Iran, but it is a company policy to export 50% of output to earn hard currency. Dia range is 100-1000mm in Esfahan and 100-600 in Tehran. Esfahan factory could produce up to 1200mm if required. The plants are presently running at **full capacity** and a second line is to open in Esfahan in 1995. Equipment has been delivered and civil works are under way. **This will increase capacity dramatically.**
- Usage:** Usage of the pipes is both water supply and sewerage - both gravity and pressure rated pipes are produced. Production is claimed to be to AFNOR and ISO standards.
- Pipes are sold ex-works, but are transported throughout Iran. There is a predominance of sales agent in the Caspian Sea region, but this is due to the demand there for asbestos sheeting for roofs, rather than pipes. It is a very wet region.
- Raw Materials:** At present they are no problem, but shortage of asbestos is a concern in relation to the new line. Asbestos is imported from the Central Asian Republics to the North of Iran (60%), Canada, Brazil and South Africa. Hard currency purchase is again the problem. Other raw materials are sourced within Iran and are no problem.
- Quality:**
- QA:** Pressure pipes are all tested to 2x working pressure in the plant. Pressure ratings are 6, 9 and 12 bar for different classes of pipe.



- Present:** ..... Plant Manager  
*Tom Sangster* MW Specialist  
*Azadeh Peyman* RayAb UNIDO Office Manager  
*Ali Tavassoli* RayAb Staff
- Production:** Both PVC and HDPE pipes. PVC dia range is 20-315mm, and is used for water supply and sewerage as well as guttering, downpipes and cable ducts. PE is all used for water supply. They are not aware of its use in gas distribution in Iran.
- Capacity:** Output can be either 20T/day of PVC or 10T/day of PE. Current output is less than 25% of capacity, just to keep the plant ticking over, due to chronic shortage of raw materials. This is a serious problem.
- Capacity in 63-150mm range is 5T/day, as is capacity above 150mm. Plant can produce 1800m/day of large sizes in PVC at full capacity. Pressure rating is up to 6 bar for water supply.
- Raw Materials:** The key issue is supply. There are 3 sources, all within Iran: Emam Petrochemical complex, Arak Petrochemical complex and Abadan Petrochemical complex. None is consistently able to supply, and this has been the case for 3-4 years. It affects all manufacturers in Iran equally. Apparently the problem is insufficient processing capacity at the oilfields through neglect of the process plant. Prices of the raw materials have been rising in Iran as world prices have been dropping, but inability to pay in hard currency distorts the market.
- Quality:** The product is of good enough quality to export, but output is so low that they do not do so.
- QA:** Pipe is produced to DIN standards for PVC and either ASTM or DIN for PE. Coverage is all of Iran. Iranian demand could account for full output.

<b>Present:</b>	<i>Mr Shojaei</i>	Plant Manager
	<i>Mr Jahangiri</i>	Production Manager
	<i>Mr Farazmand</i>	Public Relation Manager
	<i>Mr Karimi</i>	Technical Office Manager
	<i>Ali Taghavi</i>	MW Project Manager
	<i>Tom Sangster</i>	MW Specialist
	<i>David Bailey</i>	MW Specialist
	<i>Azadeh Peyman</i>	RayAb UNIDO Office Manager
	<i>Shahin Mostafaie</i>	RayAb Staff

**Production:** This factory, which is privately owned, produces both asbestos cement and concrete pipes. Considerable investment is being made in expansion and upgrading of the plant, using the significant investment incentives from the Government in this Khuzestan region which was badly affected by the war with Iraq.

**Quality:** It is a well run operation with good management and produces generally good quality products in both materials. Mr Shojaei proudly showed us a letter of commendation from the Government on the performance of the company.

### CONCRETE PIPES

**Technology:** 2 production lines, the first using McCracken machinery but the most recent line is to their own design based on the McCracken equipment, with improvements.

**Product Range:** Unreinforced concrete pipe 400-600mm dia and reinforced pipes 700-1000mm dia. All are circular and used for gravity sewers. All pipes are 2.5 metres long, and there is a cage welding machine to make the reinforcing cages.

**Capacity:** 54000 tonnes annually, and they are running at full capacity. All production is sold in the Khuzestan province, where there is excess demand. They would like to sell further afield but local demand is so strong that there is no scope to do so. They could produce jacking pipe but there is no installation capability in Iran. The region in general has little existing sewerage, with current projects among the first major schemes. The vertical casting process only has vibration for the socket end, with a rising former for the inside face.

Equipment has been delivered from the USA for a new line in a new factory currently under construction which will increase capacity by 150000 tonnes per annum (i.e. they will quadruple capacity) starting in mid-1995. Dia range will be increased to 300-1200mm, with future additions to 2400mm then 3000mm.

**Raw Materials:** There are no raw material supply problems.

## **A7 AHWAZ Farsit Concrete and AC Pipe Factory *Cont'd***

**Quality:** Appeared good, with rejects stated as 5%, mainly due to poor ends

**QA:** Pipes are produced to ASTM standards, and cement is SR to type 5 of ASTM.

### **ASBESTOS CEMENT**

**Capacity:** 2 production lines, 1 making 100-150mm dia pipe 3 m long with a capacity of 13000 tonnes per year, and 1 making 100-300mm dia pipe 5 m long with an annual capacity of 22500 tonnes, giving a total annual capacity of 35500 tonnes. Actual output is approx. 85% of capacity, or 30000 tonnes.

**Raw Materials:** The reason for production being below capacity is occasional shortage of raw materials, which are imported from the Central Asian Republics, Canada and S. Africa.

**QA:** Output is of sewer pipes to ASTM C428 and pressure pipes to ISO391. Cement used is type 2 or 5 SRC.

**Usage:** The pipes are used in water supply and sewerage, with sales throughout Iran. 80% of sales, however, are within Khuzestan province due to strong demand there. They could sell all their capacity in Khuzestan. They have no scope to export due to high local demand, but state that there is no import of AC pipes into Iran.

**A8 AHWAZ Steel Rolling Mill****15 Nov 94**

**Present:**

<i>Mr Alidadi</i>	Plant Technical Officer
<i>Ali Taghavi</i>	MW Project Manager
<i>Tom Sangster</i>	MW Specialist
<i>David Bailey</i>	MW Specialist
<i>Azadeh Peyman</i>	RayAb UNIDO Office Manager
<i>Shahin Mostafaie</i>	RayAb Staff

**Production:** Diameter range is 13-150mm, and none of the output is used in the water and sewerage. Some of the output is used in gas distribution, in diameters up to 50mm.

**Capacity:** The plant has a nominal capacity of 100000 tonnes, of which 60000 tonnes is pipe.

**A9 AHWAZ Khuzestan Pipeline Manufacturing Co****15 Nov 94**

**Present:**

<i>Mr Shariati</i>	Plant Manager
<i>Ali Taghavi</i>	MW Project Manager
<i>Tom Sangster</i>	MW Specialist
<i>David Bailey</i>	MW Specialist
<i>Azadeh Peyman</i>	RayAb UNIDO Office Manager
<i>Shahin Mostafaie</i>	RayAb Staff

This factory refused to answer any questions or to allow a tour of the plant. Mr Shariati, the Managing Director, met us later at the airport to apologise, and would have been pleased to help us had the correct authorisations been obtained in advance.

**Present:**

<i>Mr Hashemi</i>	Plant Owner and Manager
<i>Ali Taghavi</i>	MW Project Manager
<i>David Bailey</i>	MW Specialist
<i>Azadeh Peyman</i>	RayAb UNIDO Office Manager
<i>Shahin Mostafaie</i>	RayAb Staff
<i>Tom Sangster:</i>	<i>unable to attend due to sickness</i>

**Establishment:** This is a private company operating in a 2 year old plant. There is a *Liebherr* batching plant and two *Pfeiffer* vertical casting machines for pipes. A visit to a sewerage construction site on the following day saw these pipes being installed, and there were some problems with the joints being badly formed and needing caulking on site.

An investment of DM 1.5 million has been made in this plant. There are strong incentives to invest in this war region and the site and building are available at preferential rates. Moreover, there are no concerns about a market, which can take all that is produced and more.

**Production:** The plant produces reinforced concrete pipes in diameters from 1000 to 2500mm. All are circular and used for gravity sewer applications.

**Capacity:** 60000 tonnes per year, but actual output is 46000 tonnes because there is no cage welding machine and this constrains production. The plant, if it had a cage welding machine, could be run by 5 people per shift at full output. All of the output is sold in the South Western provinces of Iran, with 80% sold in Khuzestan province itself. Demand is very strong.

**Specification:** Output is to DIN standards (the equipment is German) and SR cement is used to ASTM type 5. Pipes up to 1600mm dia are 2.0 metres long and larger diameters are 3.5 metres in length. No jacking pipe is produced, although it is clear that this plant has the capability to do so given the correct designs.

**Lining:** The corrosion problem exists in this region, and they have looked at casting a PVC liner into the pipes, but the Regional Waste Water company was concerned at the additional price (DM100/m<sup>2</sup> of surface area) so they have not done it. They have also considered adding a material called Zypex to the mix to give resistance to acid corrosion at 2500 Rials/m<sup>2</sup> surface area, but have yet to do so.

**Quality:** The operation is overall very impressive and produces generally good quality pipe.

## OTHER RELEVANT VISITS

### A11 ESFAHAN Regional Water Board

12 Nov 94

- Present:**
- |                                 |                             |
|---------------------------------|-----------------------------|
| <i>Mr Mohammad Ali Dehghani</i> | Board Specialist            |
| <i>Ali Taghavi</i>              | MW Project Manager          |
| <i>Peter Lawrence</i>           | MW Project Director         |
| <i>Tom Sangster</i>             | MW Specialist               |
| <i>David Bailey</i>             | MW Specialist               |
| <i>Azadeh Peyman</i>            | RayAb UNIDO Officer Manager |
| <i>Ali Tavassoli</i>            | RayAb Staff                 |
- Institution:** The Esfahan Water Company is responsible for water transmission in the Esfahan region. Distribution is the responsibility of the Water & Sewerage Co, which also looks after all wastewater and sewerage. This division of responsibilities is normal in Iran, and all the Water & Sewerage Companies are under the responsibility of the National Water & Wastewater Co in Tehran.
- Water Network:** The distribution system in Esfahan is 35 years old. The first pipes were AC and steel, but DI has become the mainstay in recent years. Sewers are predominantly in concrete and the acid corrosion problem is known to exist in this area.
- Transmission:** Water transmission uses large dia. prestressed concrete pipes manufactured locally. As an indication of scale of demand, a current major project has already used 200km of 1000 and 1400 dia pcc pipe, and will use a further 130km. The neighbouring city of Yazd has a requirement for 3-400km.

**OTHER RELEVANT VISITS *Cont'd***

**A12 ESFAHAN South STW**

**12 Nov 94**

<b>Present:</b>	<i>Mr Hossein Khani</i>	Plant Manager
	<i>Ali Taghavi</i>	MW Project Manager
	<i>Peter Lawrence</i>	MW Project Director
	<i>Tom Sangster</i>	MW Specialist
	<i>David Bailey</i>	MW Specialist
	<i>Azadeh Peyman</i>	RayAb UNIDO Officer Manager
	<i>Ali Tavassoli</i>	RayAb Staff

**STW:** This is the first and largest plant in the region and had been constructed in 3 phases, the first 26 years ago. It now has a capacity of 893000 pop. eq. and can handle up to 13000 cu.m./hr of sewage. Standards are set by the Esfahan EPA, part of the Ministry of Health.

**Sewerage:** The network serving this plant is extensive. House connections are PVC, connecting to concrete collectors up to 400 mm dia. These run into larger concrete interceptors and trunks culminating in 1500 and 2000mm dia pipes at the plant. The whole system runs under gravity. The current system is 1450 km in length. Asbestos cement is not used.

**Comment:** The condition of the network is poor. Acid corrosion of the crown of the pipes is becoming common, and the sewage is heavily diluted by ground water infiltration (gw table is high). There is some thought of specifying lined pipes for certain applications in the future. A major trunk sewer 20km long to a new STW is expected to be of concrete, and acid corrosion due to low gradient and septic sewage is almost certain.

Present

*Ali Taghavi*

MW Project Manager

*David Bailey*

MW Specialist

*Azadeh Peyman*

RayAb UNIDO Officer Manager

*Shahin Mostafaie*

RayAb Staff

A visit was made to the site where current work is in progress on a new trunk sewer to the proposed STW to serve a section of Abadan. 1,600 mm reinforced concrete pipe sections were being utilised. Jointing was not good due to pipe quality. Joints required caulking with sisal rope and mastic to seal completely. Cement mix used to finish-off.

The pipes were given an external coating of bitumen to avoid SO<sub>4</sub> corrosion.



## **Appendix B**

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### **Materials for Sewer Pipelines**

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## APPENDIX B MATERIALS FOR SEWER PIPELINES

### B1 INTRODUCTION

In this Appendix, a short review is presented of all the main pipe materials available for use in new or replacement sewer construction and renovation. The different materials of necessity are produced by different manufacturing techniques. The different methods of manufacture whilst contributing to the strength and properties of the materials can also result in potential faults. The various manufacturing processes are therefore described.

The faults which can occur, if pipes are made without proper attention to quality control, are also described, and in addition the various advantages and disadvantages of each type of pipe are outlined.

When any pipes are used for the construction of a pipeline, the success of that pipeline depends not only on the quality of the pipes, but also on the skill and attention given to its design, and the care applied to its construction.

In order that a pipeline can be properly designed, the designer must understand the properties, behaviour and limitations of the particular type of material and pipe. Similarly, at the construction stage, installation must be supervised by Engineers who understand how the design is intended to work, and how the installation process can itself affect the subsequent performance and durability of the pipeline. Analysis of pipeline failures for all materials, has shown that a high proportion of such failures are directly attributable to poor quality of installation and lack of understanding of the above principles.

Different categories of pipe material require different design procedures in order to ensure that the appropriate limit states are not exceeded, and these are identified below.

### B2 CATEGORIES OF PIPES AND PIPE MATERIALS

Pipes are often referred to as being either 'rigid' or 'flexible', and sometimes as being 'semi-rigid', or alternately 'semi-flexible'. Allocation of a particular pipe to one of these categories can be done by either of two significantly different criteria: the resistance of the pipe to deformation, or the amount of deformation required to cause failure.

The resistance of a pipe to deformation is described as its stiffness. The importance of stiffness is the influence it has on the process of soil-structure interaction, and hence on the magnitude and distribution of soil pressure on the pipe. Rigid pipes can be defined as pipes whose stiffness is so high that they incur a soil load greater than the geostatic soil pressure because little deformation occurs. Similarly, flexible pipes can be defined as pipes whose low stiffness results in approximately equal vertical and horizontal soil pressures, which are approximately equal to the geostatic pressure. This uniformity of pressure distribution results from the ability of flexible pipes to deform and hence redistribute soil pressures.

The amount of deformation which can occur before a pipe fails is important because, if it is large, the deformation can adversely affect the performance of the pipeline, often long before final structural failure has occurred.

When considered from this point of view, a 'flexible pipe' can be defined as one which is capable of deforming to such an extent. The design of pipelines using flexible pipes must ensure that the deformation of the finished pipeline is within acceptable limits. 'Rigid pipes', on the other hand, can be defined as pipes which fail by breaking, without experiencing prior deformations which would affect their performance.

The distinction between 'flexible' and 'rigid' pipes would perhaps be better appreciated if 'rigid' pipes were termed 'breakable' pipes instead of rigid pipes.

Either of the terms 'semi-rigid pipe' or 'semi-flexible pipe' can be used to describe pipes such as ductile iron, which can deform sufficiently to produce a substantial redistribution of soil pressure, but which nevertheless ultimately fail by fracture of the material. Very large diameter asbestos cement pipes can also be regarded as 'semi-rigid', and so perhaps can Glass Reinforced Plastic (GRP) pipes, when their failure is by strain-corrosion.

Pipe materials can be usefully classified into four groups; clay, cementitious, metal and plastic. Clay and cementitious pipes range from 'rigid' to 'semi-rigid', whilst metal and plastic pipes range from 'semi-rigid' (or 'semi-flexible') to 'flexible'. Each of the main pipe materials is now described.

### B3

#### CLAY PIPES

Clay pipes have a history of over 5000 years, very much greater than any other material. Important changes have been made, over the years, to the method of manufacture, and also the type of clay used varies according to location. These changes and variations can affect the properties of the finished pipe.

The manufacturing process for clay pipes consists basically of forming wet clay into the required cylindrical shape, and then firing the pipe in a kiln to drive out the moisture and vitrify the clay. In modern factories, the wet clay is formed into the pipe shape by extrusion, whilst the firing is carried out either in tunnel kilns or roller kilns.

In the past, glazes were often applied to the surfaces of vitrified clay pipes, but modern pipes are often left unglazed.

Roller kilns are capable of producing pipes of high quality more consistently because the pipes are rolled, one behind the other, along the flat floor of the kiln, ensuring that, provided the temperatures in the kiln are correctly maintained, each pipe receives exactly the same amount of heat. Even more importantly, a roller kiln makes it easier to ensure that the rate of heating, and cooling is exactly the same for every pipe. In a tunnel kiln, however, the rates of heating and cooling may vary depending on the position of the pipe on the trolley which carries it through the kiln.

Clay pipes are fired at a temperature of about 1100°C and the rate at which they are cooled from that temperature is crucially important. If the rate of cooling is too rapid, it can lead to dunting, which is a form of cracking caused by volumetric changes of the vitrified clay as it passes through key transition temperatures.

Pipes which have suffered dunting are normally already cracked when they leave the kiln, and are thus easily identified as faulty. Another form of cracking associated with too rapid cooling is sometimes referred to as 'stress release', and this, though having its causes in the manufacturing process, may not take effect until a considerable time later.

'Stress release' cracking can not be detected visually and if present can result in unacceptable reductions in pipe strength. It is essential therefore that affected pipes should be identified before they leave the factory, and this can be done by soaking sample pipes in water, or by applying steam, prior to testing their strengths in a crushing machine. Clay pipes should not be accepted unless such tests form part of the routine quality assurance procedures of the factory and such requirements must be incorporated into Contract Specifications.

It is likely that the glazing of vitrified clay pipes makes the 'stress-release' problem, if and when it exists, more difficult to identify, and this argument against glazing probably outweighs any possible argument in its favour.

Well made clay pipes have excellent corrosion resistance and durability and are usually available in a wide range of diameters up to a maximum of 700 to 1000 millimetres depending on the factory. The problems described above tend to increase in frequency as the pipe diameters and wall thicknesses become greater. Also, the nature of the material, even when well made, tends to make the pipes brittle, and accidental breakages during handling and transportation tend to be more frequent than with some other materials. These facts have led to more robust, or lighter materials being generally preferred for use in larger sewers, but there is no doubt that clay pipes are an excellent material for the construction of sewers up to about 700 millimetres diameter.

## **B4 CEMENTITIOUS PIPES**

### **B4.1 Cement Pipes**

Concrete has been used for sewer construction for about 2000 years, and like clay, therefore, it can claim a proven track record. Indeed, in terms of the actual number of years over which specific individual concrete sewers have continued in service, concrete probably surpasses clay.

Concrete pipes are made by casting wet concrete into moulds, which may be either vertical or horizontal. Vertical moulds have both inner and outer forms, between which the concrete is mechanically compacted. Horizontal moulds have only outer forms, and the concrete is compacted against the outer mould by the centrifugal force generated by rotating the mould at high speed.

In order to permit the pipes to be removed from the moulds as soon as possible after casting, and hence increase the production rate, the concrete used normally has a very low water : cement ratio, typically 0.4 or less. As well as permitting early removal from the mould, this has the additional benefit of producing very durable concrete. Nevertheless, concrete, or more specifically its cement mortar matrix, is vulnerable to attack by acids. Consequently, concrete pipes cannot be regarded as suitable for carrying septic sewage, because this promotes the

formation of sulphuric acid.

A solution to this problem can be found, however, in the use of acid resistant plastic linings to separate the concrete from the sewage. Most frequently, such plastic linings consist of flexible or rigid PVC sheets fixed into the concrete by ribs on the back of the sheets. Like any lining, such sheets will only be effective if they are continuous over the area at risk, and completely free from holes. The avoidance of holes or gaps demands that the linings of adjacent pipes should be connected, after the pipes have been installed in the ground, and this is usually done by welding the PVC. As an alternative to welding, PVC clipping strips are sometimes offered, but although these avoid the potential problems of welding, there will, of course, exist the risk that the clipping strips might themselves be incorrectly installed.

The acid attack associated with septic sewage conditions normally occurs at the crown of the pipe, and on the sides of the pipes at the waterline. Because of this, protective plastic linings are often not applied over the full 360 degrees of the pipe circumference. Provided the unprotected part of the pipe is at the invert, and does not extend above the water line, this solution is theoretically acceptable. In practice, however, it does introduce various risks, particularly at joints, and complete 360 degree linings are likely to be more reliable.

Whichever method is used for joining the PVC lining sheets, it is likely to require men to enter the pipeline, either to carry out the work, or to inspect and test it if it has been carried out by a remotely controlled machine. Welding requires clean and dry conditions to be successful and this may often be difficult to achieve under site conditions particularly in the sizes below 1000 millimetres diameter.

Concrete pipes are usually 2 or 2.5 metres long, and a concrete pipe sewerage system may therefore contain thousands of joints. Reliability is therefore vital for the jointing of the lining, and the use of PVC lined concrete pipes smaller than the normally accepted one metre diameter limit for man entry must be considered questionable.

A possible solution to this problem is to lay unlined concrete pipes and immediately insert a cured-in-place liner to the completed pipe length.

Concrete pipes of 600 millimetres diameter or larger are normally steel reinforced, and pipes with extremely high strengths can thus be produced. In order to fulfil its structural function, the reinforcement must be accurately located in the pipe wall. With careful manufacture, this is not a problem, but misplacement of the reinforcement can occasionally occur, causing either loss of strength, or corrosion of the reinforcement because of lack of cover.

Like clay pipes, concrete pipes are unquestionably classified as 'rigid' for design purposes, but unlike clay pipes, they are extremely robust, and are thus very tolerant of mishandling during transport and installation. The only slight exception to this relates to the surfaces of the pipe sockets and spigots, which, if chipped or spalled can prevent the joint sealing ring from providing a water tight seal.

There is no doubt that well made concrete pipes are an excellent material for the construction of sewers carrying non-septic sewage, and, if reliable linings and lining joints can be provided, also for carrying septic sewage, in sizes of 1000 millimetres diameter or greater.

## **B4.2 Asbestos Cement Pipes**

Asbestos cement pipes consist of a cement mortar matrix, into which are mixed large quantities of asbestos fibre. Pipes of this type were first introduced about 70 years ago, and found wide acceptance for both non-pressure (sewer) and pressure (water supply) purposes. In recent years, however, their use has declined considerably, because of the health risks associated with working with asbestos fibres.

The pipes are manufactured by forming the asbestos - cement mix, in its wet state, into thin mats, which are then wound onto mandrels to form pipes. Because of the strength obtained from the reinforcing effect of the large number of asbestos fibres, the pipes have much thinner walls than equivalent size concrete pipes. Consequently, they can be made in longer lengths without their weight becoming a problem. Lengths of 4.5 metres are typical, but these can lead to problems due to the development of large bending moments if the support obtained from the pipe bedding is not uniform along the length of the pipeline.

Like concrete pipes, asbestos cement pipes are corroded by acids and severe corrosion has occurred in many places where asbestos cement pipes have been used for sewers carrying septic sewage. Unlike concrete pipes, plastic sheeting cannot easily be used for the lining of asbestos cement pipes, because the asbestos fibres make it difficult to key the anchorages of the sheets into the pipe wall. Epoxy coatings have been tried as anti-corrosion linings, but were unsuccessful, because the exothermic heat generated by the liquid epoxy resin, as it cured, caused the air in the surface pores of the asbestos cement to expand, creating bubbles which eventually burst, leaving uncoated pinholes at which acid attack could take place. Preheating the pipes so that the air was already expanded prior to application of the epoxy resin has been suggested as a possible solution to this problem, but the reliability of this solution has not so far been proved.

Because of the various problems associated with asbestos cement pipes, their use has declined rapidly, especially in locations where septic sewage conditions exist. Asbestos cement pipes do not have any special advantage which would justify the costs which would be incurred in making them viable for sewerage systems in hot climates.

## **B5 METAL PIPES**

The high inherent strengths of metals make them very suitable for use in pressure pipelines such as sewage rising mains, or water mains. The high strength, however, means that metal pipes have relatively thin walls, which combined with their vulnerability to corrosion make them unattractive for sewer construction in normal circumstances. In a few special circumstances, however, both ductile iron and steel pipes have been used for sewers.

### **B5.1 Ductile Iron Pipes**

Weight for weight, ductile iron is very much cheaper than steel, and hence relatively thicker pipe walls are economic, with the result that very high strength pipes can be produced. Such pipes occasionally find applications in sewers where exceptionally high structural loadings may develop, for example where sewers have to be constructed at very shallow depths below roads. Ductile iron pipes are also frequently used for the internal pipework of sewage pumping stations. Being a ferrous metal, ductile iron will corrode in the presence of air and water, even without the addition of sulphuric acid from septic sewage. High quality internal linings are therefore essential if ductile iron pipes are to be used for sewers, and these are normally

provided by coatings of polyurethane or epoxy. The absence of air pores from the surface of ductile iron pipe means that the problem of pinholing, which occurs when liquid epoxy coatings are applied to asbestos cement or concrete surfaces, is greatly reduced.

Where ductile iron pumping station pipework is exposed to the atmosphere in a sewage wet-well, severe corrosion can rapidly take place. High quality anti-corrosion coatings are therefore essential in such locations.

Ductile iron is the modern form of 'cast iron', and has almost completely superseded the old 'grey cast iron'. Some foundries do, however, still manufacture grey iron pipes, and particularly grey iron fittings, such as those that are sometimes used as tee-junctions on asbestos cement pipelines.

## **B5.2 Steel Pipes**

Steel pipes, except for diameters of 150 millimetres or less, have relatively very thin walls. Not only does this increase their vulnerability to corrosion but it also results in pipes with very low stiffnesses (often less than the typical stiffnesses of plastic pipes). As sewer pipes therefore, they can be regarded as having the disadvantages of plastic pipes, without the advantage of good corrosion resistance.

Nevertheless, steel pipes do find an application in sewer construction in particular circumstances. They are ideal for installation by certain trenchless construction methods, such as pipe ramming, where their combination of high strength with very thin walls makes them ideal for driving through the ground. Invariably, however, where they are used for the construction of sewers by such methods, they are used only as casing pipes, through which a second, corrosion resistant pipe, is subsequently installed and grouted as the permanent sewer.

Because of their high beam strength, steel pipes are well suited to the construction of above-ground pipelines, either supported on piers, or slung under bridges. The high beam strength means that the supports can be widely spread, thus reducing the cost of the installation.

## **B6 PLASTIC PIPES**

Plastic pipes of various types have successfully been used for the construction of both sewers and water mains for about 30 years. Being relatively new materials, it is perhaps not surprising that teething troubles have been experienced, for example strain-corrosion in GRP pipes, and slow crack growth leading to brittle failure of PVC pipes. These problems have now been thoroughly researched, and the results of this research enable them to be used with confidence. The results of the research are available though wide spread dissemination of the information has not taken place within the industry.

Plastic pipes can generally be regarded as 'flexible pipes', and consequently pipelines constructed from them are required to be designed using different techniques from those used for the design of rigid pipe sewers. Flexible pipe design methods have been subject to a great deal of research over the last 20 years, and so many papers, often contradictory, have been published that, unless studied very thoroughly, the position can appear confused. Indeed, it is probably true that there has been too much theory, and not enough attention to practical considerations, such as the influence of construction procedures on the structural behaviour



of flexible pipes. This is particularly true in the case of GRP pipes, where unproven theories are frequently used as the basis for advocating solutions to problems, even though the circumstances of the problems have not been thoroughly investigated first.

The following comments on various types of plastic pipe are based on extensive experience of their use, coupled with similarly extensive studies of the theoretical work which has been published.

#### **B6.1 Glass Reinforced Plastic (GRP) Pipes**

Glass reinforced plastic pipes were first produced around 40 years ago, and began to come into use for sewers about 25 years ago. The materials from which the pipes are made are basically thermosetting resins, and glass fibres, which are used as the reinforcement.

Two very different manufacturing processes can be used to produce GRP pipes, the first being centrifugal casting and the second filament winding.

With centrifugal casting, often referred to as the 'Hobas' process, the glass fibres are in relatively short lengths, called chopped glass strand. These are inserted, together with the liquid resin, into a rapidly spinning, horizontal cylindrical mould. The centrifugal force generated by the rotation compresses the materials against the side of the mould while the resin hardens. In this way, pipes can be built up in several layers, and very thick walled pipes can easily be produced. The thickness is often increased by including in the middle of the pipe wall, layers of sand and resin. This enables high stiffness pipes to be made without using large quantities of expensive glass reinforcement. A potential problem can arise, however, in that the use of sand in this way, if taken to extremes, can result in pipes being made which, although retaining high stiffness, have such relatively small quantities of glass that their other strength properties are inadequate.

Filament wound pipes are made by pouring the resin onto a slowly rotating mandrel, and winding continuous glass fibre rovings onto the mandrel at the same time, to provide the reinforcement. This method is used in the Veroc/Drostholm process for example. The addition of sand as a filler to produce thick walled pipes, is more difficult with this process since, if the sand is added in large quantities, it tends to fall off the mandrel as it rotates. A solution to this problem which is sometimes used, is to apply the glass reinforcement in the form of a woven glass fabric, similar to a bandage. If wound onto the bottom of the mandrel, the woven glass fabric can hold greater quantities of sand onto the pipe than can individual glass fibre rovings.

GRP pipes have two potential advantages : their weight is extremely low in comparison with similar diameter pipes of other materials, and they can have excellent corrosion resistance. The light weight of GRP pipes enables them to be manufactured in long lengths, which reduces the number of joints, assisting installation, and reducing the potential for leakage.

Until about ten years ago, GRP pipes relied entirely on the resins for their corrosion resistance, and the glass fibres were in fact vulnerable to corrosion by acids, such as the sulphuric acid which develops in sewers carrying septic sewage. This process of glass corrosion resulted in many failures in early GRP pipes, particularly those made by filament winding, which process can easily result in the glass fibres being located close to the internal surface of the pipe walls. The acid reaches the glass by diffusion through the resin covering, and thus the thickness of the inner resin lining was very important for the corrosion resistance of early GRP pipes.

The time taken for the acid to reach the glass was, of course, greatly reduced if the resin liner was cracked, and it was found by research that the time taken for a GRP pipe to fail as result of corrosion of the glass by acid depended on the magnitude of the strain in the pipe wall. The higher the strain, the greater the extent of microcracking in the resin lining, and hence the shorter the time required for corrosion of the glass to cause pipe failure. Out of this research was developed the strain-corrosion test, which enabled the safe lifetime of the pipe to be predicted, provided the magnitude of the strain in the pipe wall was known. In order to use this information in the design of GRP pipelines, it was therefore necessary to predict the magnitude of the strain which would develop in the pipe walls when they were buried underground.

If the cross-sectional shape of the pipes, after completion of installation can be kept perfectly circular, then the bending strain in the pipe walls will be zero. Unfortunately, this situation is very difficult to achieve if the material in which the pipe is embedded requires a large amount of energy for its compaction: the problem is that some of the compaction energy is converted into strain energy in the pipe walls. This effect can be reduced by using relatively high stiffness pipes, and consequently the use of pipes with stiffnesses of 5,000 Newtons per square metre is frequently recommended, if the pipes are to be embedded in sand. Although widely advocated, this solution has yet to be proved in practice, and there appears to be a risk that the high initial stiffness of the pipes may serve only to hide any inadequacies in the compaction of the sand leading to early failure since the result is that high strains may subsequently develop in the pipe as its deformation increases with time, due to settlement of the inadequately compacted sand, and creep of the pipe material which effectively reduces its stiffness with time.

An alternative solution, which has been proven over periods of 15 years service, is to embed the pipes in suitably graded gravel, or broken stone, instead of sand. The advantage of these materials is that they require much less energy for compaction to the state which will avoid long term settlement. Consequently, both of the potential sources of strain are simultaneously reduced. Relatively low stiffness pipes, typically 1,000 to 2,000 Newtons per square metre, have proved successful when used this way.

Some 10 years ago, a new type of glass fibre, known as ECR glass, became available, which greatly increased the resistance of pipes to strain-corrosion, and it is now normal to specify the use of this type of glass. Obviously this is a very beneficial development, but it has to be remembered that the ability of modern pipes to sustain higher strains without suffering from corrosion, does not mean that the other adverse effects of excessive deformation are similarly avoided. Increased risk of collapse due to buckling, and increased risk of joint leakage are perhaps the two most likely such adverse effects.

Several different types of thermosetting resin can be used for the manufacture of GRP pipes. Isophthalic polyester resin is most commonly used in sewer pipes, and resins of this type generally have good all round performance. Epoxy resins are quite often used for process plant pipework, and occasionally also for sewer pipes. Pipes made with epoxy resin are sometimes referred to as 'GRE' (Glass Reinforced Epoxy), and their performance, in terms of sulphuric acid resistance, is similar to or slightly better than that of isophthalic polyester resin pipes. In cases where very much higher performance, in terms of acid resistance, is required, then Bisphenol or Vinyl Ester resins are sometimes used. Vinyl Ester, in particular, is quite often used in sewer pipe manufacture, one example being for the inner surface of pipes which are mainly made from isophthalic polyester resin.

The use of high performance materials, such as ECR glass, and vinyl ester resin, can greatly improve the performance of GRP pipes, and for this reason their use is increasingly specified. Checking that the specified materials have actually been used in the finished pipes, however,

is extremely difficult to achieve by inspection or chemical analysis. Consequently, it may be desirable to carry out periodic strain-corrosion performance tests on random pipe samples, for quality assurance purposes.

Throughout the period of nearly 20 years over which Montgomery Watson has designed and supervised installation of GRP pipes, we have always specified gravel or broken stone for the pipe embedment, and none of the pipelines so constructed have experienced the problems of strain-corrosion or excessive deformation which have sometimes occurred elsewhere, with pipes embedded in other materials. Where gravel or broken stone is used for the embedment of GRP pipes and the native soil in which the pipe trench is located consists of sand, or other types of fine grained soil, the surround material should be separated from the native soil by a geotextile filter fabric membrane. This is to prevent soil migration into the surround, which might be caused by groundwater movement, for example, and causing voids to develop which could lead to collapse of the pipe bed and surround through loss of support. Such a membrane should be installed in all cases not just where the pipeline is below the groundwater table.

The aspects of GRP pipeline design and construction described above have consistently enabled pipelines to be successfully constructed, even when the pipes were manufactured using the earlier type of glass reinforcement. The improved type of glass now used for pipe manufacture further increases the confidence which can be given to GRP pipes, provided, of course, that the pipelines are properly designed and constructed in accordance with the above principles.

## **B6.2 PVC Pipes**

Although first produced nearly 60 years ago, PVC pipes have only come into general use over the last 30 years. They are now widely used for both non-pressure (sewer) applications, and pressure (sewer and water) applications.

PVC, or polyvinyl chloride to give it its full name, is a thermoplastic material, which means that both the basic material, and products made from it, will become soft if heated. This property of thermoplastic distinguishes them from thermosetting materials, such as GRP, which retain almost all their stiffness when heated. The loss of stiffness which PVC and other thermoplastic materials undergo when heated is accompanied by a similar loss of tensile strength, and consequently, when these pipes are used for pressure applications, the allowable pressure depends upon the temperature at which the pipeline will be operated.

The material used for pipe manufacture is often referred to as 'unplasticized PVC' (frequently abbreviated to uPVC or PVC-U). This distinguishes it from plasticized PVC, which is PVC to which additional chemicals (plasticizers) have been added so as to make it very flexible.

PVC pipes are made by heating the raw material (PVC granules) until it melts, and then extruding the molten material through a cylindrical die, whose internal diameter matches the external diameter of the pipes. All PVC pipes of a particular nominal diameter have the same external diameter, and changes of wall thickness, to produce pipes of different stiffness classes, are achieved by fitting varying sizes of central die concentrically within the hollow cylindrical external die of the extrusion machine. The central die is held in position by radial ribs, so that the molten PVC has to flow around the ribs as the pipe is extruded. The separation of the PVC material as it flows round the ribs can produce lines of weakness if the material does not fully fuse together again, on the downstream side of the ribs. Provided the extrusion process is correctly operated, no problems of this type will develop, but if the manufacturing process is not correctly operated, for example by using incorrect temperatures, then the extruded pipes

may have the longitudinal lines of weakness, which are sometimes referred to as 'spider lines' if they are visible.

During the early years of their use, PVC pipes sometimes experienced premature failures, which could not immediately be explained by engineers. Research into this problem showed that failure was being caused by a process of slow crack growth, in which concentrations of stress at local points in PVC pipes were causing cracks to develop. The rate at which these cracks propagate is initially very slow, making them difficult to detect, until they reach a critical length, at which the rate of propagation accelerates rapidly, leading almost instantaneously to pipe failure. The resistance of a material to this form of cracking is called its fracture toughness and specifications for PVC pipes now often stipulate minimum required values of fracture toughness, which can be proven by tests.

For structural design purposes, PVC pipes are regarded as 'flexible' and hence design and installation practices must ensure that excessive deformations do not occur. As with GRP pipes, the most reliable way of installing PVC pipes has been found to surround them in suitably graded gravel or broken stone with a geotextile membrane, the use of this type of embedment material is now the standard practice in many parts of the world.

That PVC pipes which have been left for some time in direct sunlight will be degraded by the ultra-violet radiation, is well known. The property of the pipes which is most affected by this process is their impact strength. Other strength properties have been found to be much less reduced, even in pipes which are severely discoloured as a result of long exposure to sunlight.

PVC has a high coefficient of thermal expansion, and consequently, if left in the open, the sunlit side of the pipe expands much more than the shaded side, causing the pipes to become curved. This can be dealt with by laying the distorted pipes with their curvature alternatively to the left and to the right. After backfilling, however, the all round shade will make the pipes try to straighten, but this will be resisted by the backfill, resulting in longitudinal bending stresses being set up. Although these stresses will slowly relax with time, it is better to avoid their development, by keeping the pipes completely shaded at all times.

Although PVC pipes have been made in diameters up to about 1000 millimetres, they have been most successful in smaller sizes, 300 millimetres diameter or less. In this size range, and when installed in gravel or broken stone beds and surrounds, PVC pipes can be regarded as a proven form of sewer construction.

### **B6.3 Polyethylene Pipes**

Polyethylene pipes were first manufactured about 40 years ago, and were initially used mainly for small diameter water supply pipelines. The material used for these early pipes was known as low density polyethylene (LDPE) or 'polythene'. A somewhat different type of polyethylene, known as high density polyethylene (HDPE) was introduced a few years later, and this had considerably greater strength than LDPE. Later still, medium density polyethylene (MDPE) was introduced.

Although the different types of polyethylene were originally classified according to their densities, it should be appreciated that the actual differences in density are small, ranging from 0.925 grammes per cubic centimetre for LDPE to 0.965 grammes/cubic centimetre for HDPE.

The recent development of yet more types of polyethylene, such as 'linear low density polyethylene' (LLDPE) and 'high performance polyethylene' (HPPE) has further confused the classification system, to such an extent that the standard pipe specifications currently being

developed in Europe will not attempt to use complicated names or initials. Instead, they will refer only to 'Polyethylene', and will define grades according to the strength of the material.

Polyethylene is a thermoplastic material and pipes are most commonly made by extrusion, in exactly the same way as has been described for PVC. Because the material is easier to process, however, polyethylene pipes can be extruded in much larger sizes. Pipes with external diameters up to 1600 millimetres are made in this way.

An alternative method of manufacturing polyethylene pipes is to wind strips of the material into helical coils, and to weld the edges together so as to form a cylindrical pipe. Very large diameter pipes can be made by this type of process, and consequently it is also sometimes used for the manufacture of storage tanks. Spirally welded polyethylene pipes have been used for over 20 years, and in diameters up to 2000 millimetres or more.

The modulus of elasticity of polyethylene is very much lower than that of PVC, and consequently the pipes are very flexible, unless they have extremely thick walls, which of course increases their cost. For this reason, extruded polyethylene pipes are not often used in diameters greater than 1000 millimetres, even though larger pipes are available.

Spirally welded polyethylene pipes, however, can be given increased stiffnesses without using greatly increased quantities of material. This is achieved by using strips of polyethylene with hollow, or ribbed cross-sections to form the spiral. This type of construction is particularly suitable for polyethylene pipes with diameters greater than 1000 millimetres.

Because polyethylene pipes are flexible, pipelines constructed from them should be designed and constructed generally in accordance with the practices already described for GRP pipes. Polyethylene pipes can sustain higher strains or stresses than GRP, and hence, when used in non-pressure installations such as sewers, the objective is to limit the overall deformation of the pipe cross-section. If this is done, the local stresses and strains at specific points in the pipe wall will be well below the allowable levels. It should be noted that in the case of pressure pipelines, in which the stresses produced by the conveyed fluid pressure can be high, it is necessary to calculate the stresses caused by the pipe deformation, since these, when added to the fluid pressure stresses, can cause the limiting stresses to be exceeded.

Polyethylene pipes have not been widely used for the construction of new sewers, but for sewer renovation, as well as for water main construction, they have been successfully used for many years. The fact that they have not been widely used for new sewer construction does not necessarily mean that they are unsuitable, and is more probably explained by the fact that they do not offer any great advantages over other corrosion resistant plastic materials such as PVC and GRP.

## **B7 PIPELINE RENOVATION MATERIALS**

Of the materials described above, concrete, GRP and polyethylene are the three which are regularly used for the construction of sewer linings.

Concrete linings can be applied by spraying ('gunite' or 'shotcrete'), by casting behind shutters erected inside the sewer, or by erecting precast segmental linings which include glass reinforced cement linings. In sewer renovation work, they are only used in very large sewers, and in particular, they are not suitable for use in systems where septic sewage conditions can give rise to sulphuric acid attack, unless they are themselves provided with a corrosion resistant lining.

GRP is used for sewer renovation in various forms. The simplest of these consists of inserting a complete, prefabricated GRP pipe into the old sewer. Alternatively, GRP segmental linings can be erected inside the sewer, and jointed by the use of liquid resin. When either complete pipes, or segmental linings are used, it is normal to grout the annulus between the lining and the old pipe.

In addition, thermosetting resins are sometimes used, without glass or other reinforcement, to provide thin, non-structural, acid-resistant anti-corrosion coatings, or, by application under pressure, to plug leaks in pipes or fill cavities which have developed on the outside of the pipes adjacent to defects.

Cured-in-place linings use similar resins to those used in GRP pipes, with reinforcement provided either by glass fibres (for example in the 'Inpipe' system) or by synthetic felt (for example in the 'Insituform' system). The effect of both approaches is to produce a reinforced plastic pipe, which follows the contours of the existing pipe, making grouting unnecessary. In order to prevent escape, or contamination of the resin before it is fully cured, a very thin internal skin is sometimes used to separate the liner from the hot water which may be used for curing. These skins serve only a temporary function, and whether they are removed or left in place has no effect on the design life of the properly cured liner.

Because cured-in-place liners, provided they are correctly dimensioned, exactly match the cross-sectional shape of the existing pipes, they will not experience bending strains unless the renovated pipeline undergoes further deformation. In most cases, deformation after lining is unlikely, but where it may take place, stress or strain analyses should be carried out to ensure that the allowable limits for the particular type of lining are not exceeded.

Where substantial deformations are likely to occur after renovation, cured-in-place linings are likely to be unsuitable lining materials since their stress and strain limits are relatively low. Thermoplastic liners, such as polyethylene or polypropylene are likely to be more suitable in these cases, since they can tolerate extremely high strains, and because stress is not a consideration, since it relaxes with time in thermoplastics.

The polyethylene pipes used for sewer renovation by conventional sliplining or short-pipe insertion are essentially similar to the extruded pipes used for new pipeline construction. Spirally welded polyethylene pipes have not so far been used for sewer renovation. As an alternative to polyethylene, polypropylene is sometimes used for the manufacture of liner pipes. The two materials are very similar, both chemically, and in respect of their physical properties. Polypropylene is slightly stronger than polyethylene, and it also retains its properties rather better at elevated temperatures.

Sliplining using folded pipes (e.g. the 'Nu-Pipe' and 'U-Liner' systems) makes use of either polyethylene, or PVC pipes. The formulation of the materials is modified, however, so that they retain their folded shape until after insertion, and then, with the application of heat and pressure, revert to a circular cross-section.

All types of spirally-wound liner developed to date have used PVC, in the form of a long, flat strip.

## B8 PIPE JOINTING SYSTEMS

Pipelines are constructed by jointing together individual pipes. The only exception to this general rule exists with cured-in-place liners, which can be manufactured in very long lengths.

Since joint leakage can be a common problem in pipelines, the absence of joints from cured-in-place liners can be regarded as an advantage of that type of renovation system.

Virtually all new pipeline construction, and several types of pipeline renovation systems, require the connection, on site, of a series of individual, relatively short, factory made pipes. Many types of jointing system have been developed and some can be used with many different types of pipes, whilst others are applicable to pipes of one material only.

Before discussing the various types of joint, it is appropriate to consider the various functions which a jointing system is required to fulfil. The first of these is to permit the construction of the pipeline to the required dimensions. This fundamental requirement effectively eliminates many types of joint from consideration in pipeline renovation work, because the overall diameter of the joint is so much larger than that of the pipe itself.

The second requirement of pipe jointing systems is that they should prevent the development of longitudinal bending moments exceeding the strength of the pipes. This is particularly important in small diameter rigid pipes, which often have a very low longitudinal bending strength, whilst in pipes of flexible materials, such as steel or thermoplastic it is usually unnecessary, because the pipes can relieve the moments by bending.

Finally, the pipe joints should remain watertight, preventing leakage or infiltration, whilst accommodating any movements which the pipeline might undergo. Loss of watertightness at the joints can be a common problem in pipelines, and in sewers can cause groundwater pollution, or infiltration which wastes sewer and sewage treatment plant capacity.

The various types of jointing system can be grouped into two fundamental categories : continuous (non-flexible) joints, and mechanical (flexible) joints. In this context, 'flexible' indicates a joint which effectively provides a hinge in the pipeline.

#### **B8.1 Continuous (Non-flexible) Joints**

Non-flexible joints do not permit any relative movement between adjacent pipes, other than by bending of the pipes themselves. In effect, therefore, they create a long continuous beam from a series of short pipes, and this can be useful for pipelines installed above ground, since longer spans are possible, and hence fewer supports are required.

In the case of pipelines installed below ground, however, continuous long spans are likely to lead to the development of large longitudinal bending moments which are unacceptable in clay, concrete, asbestos-cement and ductile iron pipes. Other pipe materials, such as steel and plastics, can accommodate the high bending moments to varying degrees, by bending so as to follow the ground movements, or uneven foundations, which caused the moments to develop.

Non-flexible joints are useful in the construction of pressure pipelines in soft ground, where their ability to transmit tensile loads obviates the need for thrust blocks. They are seldom used in the construction of new sewers, though for some types of lining used in sewer renovation work they are essential to the installation process.

The following are the main types of non-flexible joint :

#### **B8.1.1 Flanges**

Flanges are frequently used with metal pipes, both steel and ductile iron, but normally only in above ground or plant installations. Because of the difficulty in obtaining perfectly flat faces to the flanges, they normally employ gaskets of compressible material between the two flange faces.

Flanges are also occasionally used with plastic pipes, though again seldom in underground installations such as sewers. They are useful, however, for making joints between plastic pipes and pipes of other materials.

#### **B8.1.2 Screwed Joints**

Screwed joints are sometimes used on small diameter steel pipelines, as used in high pressure pumping or water supply systems. They are not used in any pipe systems used for new sewer construction, but are a feature of some short polyethylene pipe insertion systems used in sewer renovation work.

#### **B8.1.3 Filler Welding**

For the past 80 years, filler welding has been the most usual method of jointing large diameter steel pipelines for underground installations.

Filler welding can also be used for the jointing of some thermoplastic pipes, and in recent years this technique has been particularly developed for jointing large diameter polyethylene pipes.

#### **B8.1.4 Fusion Jointing**

Fusion jointing is similar to welding, but no filler material is used to bridge the gap between the ends of the adjacent pipes. The technique is widely used for jointing polyethylene, and other polyolefin pipes such as polypropylene, and involves heating the jointing surfaces of adjacent pipes until they soften, and then bringing them together under controlled pressure.

A variation of the technique, which is increasingly used with small diameter polyethylene pipes, is electrofusion jointing. This involves the use of a sleeve coupling, also made from polyethylene, which incorporates a coil of wire to serve as a heating element. After insertion of the two pipe ends into the sleeve coupling, an electric current is passed through the coil, heating the polyethylene to melting point, and thus causing both pipe ends to fuse to the coupling. The control of electrofusion jointing can be largely automated, reducing the risk of human error.

#### **B8.1.5 Solvent Welding**

Solvent welding is jointing method which at one time was widely used with PVC pipes. It involves applying a liquid solvent to the jointing surfaces of adjacent pipes, causing them to soften, and then bringing them together under pressure. In practice, it has been found very difficult to achieve reliability with solvent welding since, if too little solvent is used, the joint will be incomplete, and will leak, whereas, if too much solvent is used, the pipe material will be permanently weakened. For this reason, solvent welding is now only recommended for small diameter, non-pressure, PVC plumbing pipework.



### **B8.1.6 Adhesive Jointing**

Adhesive jointing is occasionally used with small diameter GRP pipes. The jointing surfaces of pipe sockets and spigots are coated with liquid adhesive, and brought together for the adhesive to harden.

Like solvent welding, adhesive jointing tends to be unreliable, and when used, it is often combined with overlay laminating.

### **B8.1.7 Overlay Laminating**

Overlay laminating is sometimes used with small diameter GRP pipes, particularly in process plant applications. It involves the manual application of a GRP laminate to encompass the ends of the two adjacent pipes in a single wrapping application. To be successful, the work must be very carefully carried out under controlled conditions.

## **B8.2 Mechanical (Flexible) Joints**

Flexible joints, which permit relative movement of the two pipes at a joint without the transmission of bending moments, are far more widely used for both sewers and water mains than are continuous, non-flexible joints.

For clay, concrete and asbestos-cement pipes, flexible joints are universally used. They are also the most commonly used joints for PVC, GRP and ductile iron pipes, and are also sometimes used with steel and polyethylene pipes.

All types of flexible joint rely on some form of compressible material to maintain the seal between the jointing surfaces of adjacent pipes, whilst permitting movement to take place.

The main types of flexible joints and sealing materials are described below.

### **B8.2.1 Socket and Spigot Systems**

Socket and spigot joints, or 'bell and spigot' as they are called in American parlance, are the simplest form of flexible jointing system. They are the most common form of joint used with concrete, ductile iron and PVC pipes, and are sometimes also used with other types of plastic pipe, and with some clay pipes.

Early socket and spigot joints were sealed by caulking with materials such as lead or tarred hemp, and many old pipelines jointed with these materials remain in use today. Because they have little resilience, these materials tend to leak increasingly with time, and for pressure pipeline service, have been progressively superseded by rubber seals over the last 120 years, whilst for sewer service cement mortar became widely used, effectively as an interim measure, until rubber seals began to be used for non-pressure sewer joints about 50 years ago.

In order that the seal of a socket and spigot joint should work effectively, the internal diameter of the socket, the external diameter of the spigot, and the thickness of the rubber seal must be maintained within very close dimensional tolerances. If the annular gap between socket and spigot is too large for the rubber seal, then the joint will leak, and if the gap is too small, then excessive compression of the seal can burst the sockets of clay or unreinforced concrete pipes.

Close dimensional control of sockets and spigots is relatively easy to obtain with pipes which are cast in moulds, such as concrete and ductile iron, but is extremely difficult to achieve with clay pipes due to the shrinkage of the material which occurs during firing. For this reason, the rubber ring seals of socket and spigot clay pipes are often supplemented by polyethylene or polypropylene fairings. Despite the use of this expedient, however, there is an increasing trend to abandon the use of socket and spigot joints for clay pipes.

#### **B8.2.2 Double Socket Couplings**

Double socket couplings are the normal jointing system for asbestos cement pipes, and the most commonly used system for GRP pipes. As with socket and spigot joints, the seal efficiency depends on accuracy of the dimensioning of the jointing surfaces and the rubber seal.

Couplings are often already fitted to one end of each pipe at the factory, effectively turning them into socket and spigot pipes.

#### **B8.2.3 Sleeve Joints**

Sleeve joints are increasingly being used with clay pipes, so as to avoid the problems which can arise when socket and spigot joints are used with clay pipes.

Sleeve joints consist of a short tube of elastomeric material, into which the ends of the two clay pipes are inserted. The sleeve is then clamped onto the pipe ends by stainless steel rings.

A very similar system is used for sealing leaking joints in old pipelines. In this case, the elastomeric sleeve is inserted inside the pipeline, placed across the joint gap between pipes, and compressed against the inner surfaces of the pipe walls by expanding stainless steel rings.

#### **B8.2.4 Scrolled Sleeve Couplings**

'Straub' and 'TeeKay' couplings are examples of this type of jointing system, which basically consists of a plastic coated, stainless steel sleeve which has been cut, lengthwise at one point on its circumference. This enables the coupling to be scrolled outwards, enlarging its diameter to permit the pipe ends to be inserted, and then scrolled inwards so as to grip the pipe ends.

The scrolling of the coupling, inwards and outwards, is accomplished by means of stainless steel nuts and bolts permanently attached to the outside of the coupling.

Scrolled sleeve couplings are very versatile, and can be used with virtually any type of pipe, in large and small diameters, and in both pressure and non-pressure applications.

#### **B8.2.5 Loose Flange Couplings**

'Viking Johnson' and 'Dresser' couplings are examples of loose flange couplings. These consist of two loose flanges, which are passed over the ends of the two pipes, and a steel sleeve into which the pipe ends are then inserted. The flanges are then drawn together by long bolts, compressing gaskets inside each end of the sleeve, so that the gaskets grip the ends of the two pipes and provide the seal.

Couplings of this type are very versatile, and can be used with pipes of all diameters and pressure ratings used in water industry applications. Variations of this type of coupling can be used to connect pipes of different diameters and materials.

'Flange adaptors' are a development of this type of coupling, used to connect pipes, one of which has a fixed flanged, whilst the second pipe is plain ended.

### **B8.2.6 Joints for Jacking Pipes**

The essential additional requirement for jacking pipes is that the external diameter of the joint should not exceed the external diameter of the pipe barrel.

Two types of joint are used to meet this requirement : ogee joints, and sleeve joints. Ogee joints may be regarded as socket and spigot joints, in which both the socket and the spigot are formed within the normal pipe wall thickness. This is normally only possible with pipes having very thick walls, for example large diameter concrete pipe.

Sleeve joints for jacking pipes utilise thin-walled sleeves, usually manufactured from either stainless steel, or GRP. The outside diameter of the sleeves is matched to the outside diameter of the pipe barrel, and the pipe ends have slightly reduced diameters, so that they fit into the sleeves. Rubber rings are used to seal the gap between the outside of the pipe ends and the inside of the sleeves. Sometimes, one end of the sleeve is positively fixed to one end of each pipe, effectively forming a socket, into which the spigot end of the next pipe is inserted, and sealed by a rubber ring.

### **B8.3 Joint Sealing Materials**

As already described, lead, hemp and cement mortar, which in the past were used for caulking pipe joints, have now been superseded, almost universally, by rubber.

Natural rubber was first used for jointing pipes more than 100 years ago, and proved very successful until changes of the additives used to assist processing of the rubber reduced its resistance to biological degradation about 50 years ago. By this time, various synthetic rubbers had been developed, and many of these have been tried for pipe jointing.

Research and experience have shown that, at least in temperate climates, ethylene-propylene-diene modified rubber (EPDM) has the best all round combination of properties for water industry pipe jointing. Styrene-butadiene rubber (SBR) has also been found to perform well in sewer pipe joints.

Rubber ring seals for pipe joints function in one of two ways. Most commonly, the seal depends on the contact pressure between the rubber ring and the jointing surfaces of the pipes, or couplings, being greater than the pressure of water. The magnitude of the contact pressure depends, of course, on the extent to which the rubber is compressed, and this is why the dimensional accuracy of the joint components is of great importance. Unfortunately, all types of rubber are subject to stress relaxation, and thus the contact pressures of the rubber ring in a joint slowly reduce with time, increasing the risk of leakage.

The second type of rubber ring seal for pipe joints attempts to avoid the problem of stress relaxation by not relying on compression of the rubber for the seal, but by utilising the pressure of the water itself to force the rubber ring against the jointing surfaces. These types of rubber rings are known as 'lip seals', and incorporate a flap of rubber, which functions in the same way as the flap of a non-return valve. Some pipe jointing systems now incorporate both compression and lip-seal functions.

## **Appendix C**

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### **Materials for Water Supply Pipelines**

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## APPENDIX C MATERIALS FOR WATER SUPPLY PIPELINES

### C1 NON-CYLINDER PRESTRESSED CONCRETE PIPES

#### C1.1 General Description

These pipes are so named because they do not employ a steel cylinder in their design. They are, in theory, the simplest form of prestressed concrete pipe, representing the natural development from unreinforced concrete.

A non-cylinder prestressed concrete pipe consists of a longitudinally prestressed cylindrical concrete core, around which are wound, under very high stress, circumferential prestressing wires of very high tensile strength steel. These wires are then covered by a layer of cement mortar, whose function is to protect them against mechanical damage and, most importantly, against corrosion.

Although simple in theory, non-cylinder prestressed concrete pipes are complicated to design, and difficult to manufacture reliably. The use of longitudinal, as well as circumferential, prestress makes the stress analysis necessary for design complicated, and the accurate control of the amount of prestress applied during manufacture is difficult.

There are one or two manufacturers who have shown the ability to produce thoroughly good pipes of this type on a reliable basis. It has to be said, however, that there are several countries where the use, and consequently manufacture, of this type of pipe has been discontinued. National standard specifications for this type of pipe exist in Britain, Japan and India. The best known of these is probably the British Standard, BS 4625, but this will soon be superseded by European Standard EN 642.

#### C1.2 Method of Manufacture

Manufacture normally commences with the concrete core, which is centrifugally cast in a rotating mould, within which the longitudinal prestressing wires have already been fixed under tension. Since the pipe depends upon the concrete core for its watertightness, it is essential that the core be centrifuged for a sufficiently long time to achieve high density and low porosity. It is also of crucial importance that the core is not removed from its mould until the concrete has gained sufficient strength to take over the anchorage of the longitudinal prestressing wires from their original fixings to the mould. If removed too soon, the tension in the longitudinal wires will cause their ends to move inwards, disrupting the concrete in the vicinity of the pipe ends, and thus forming leakage paths.

The second stage of manufacture consists of the winding of the circumferential prestressing wires. The crucial problem in this stage is the accurate maintenance of the correct tension in the wires. The original method of wire tensioning was to draw the wires through a die, thereby reducing their diameter and applying tension. This method of tensioning is, however,

extremely unreliable, because of wear in the die, and because of the temperature rise in the wire which is generated. The die-drawing method must now be regarded as unacceptable, and wire tensioning should be achieved by the use of a tensioning machine which continuously controls, measures and records the applied tension.

The third stage of manufacture is the application of the mortar coating. A very high quality is required of this coating because the type of steel used for, and the high stresses in, the circumferential wires make them particularly prone to corrosion. Various methods are employed for applying the mortar and these fall into two main categories. In the first of these, the mortar is propelled against the pipe by processes akin to guniting or shotcreting. The required high density of the mortar is achieved by applying the mortar particles at high velocity. In the second group of processes, the mortar is vibrated against the pipe to achieve the required density. With both types of process the pipe is rotated during application in order to distribute the mortar over the surface. Problems can occur with large diameter pipes because, if rotated slowly, the mortar has time to flow or slump, whilst, if rotated rapidly, the centrifugal force can cause the mortar to detach itself from the pipe. These problems are more difficult to control with the first type of application method, where the mortar is propelled against the pipe, and may limit the thickness which can be applied.

The final stage of manufacture is curing of the concrete. Whilst proper curing of concretes and mortars is always desirable, it is of particular importance with this type of pipe because the retention of the water, under pressure, in the pipe, depends upon the integrity of the concrete.

### **C1.3 Sizes and Pressure Ratings**

Normal manufacturing size ranges are 300 to 2 200 millimetres diameter. Pipes of 3 400 millimetres diameter have, however, been employed on at least one occasion.

Similarly, the pressure ratings of the standard ranges of pipes offered by most manufacturers extend to about 12 bars, though pipes up to at least 22 bars working pressure have occasionally been produced.

### **C1.4 Joints and Fittings**

Joints on non-cylinder pipes are normally of the rubber ring sealed socket and spigot type. Sliding rings are to be preferred to rolling rings, because they are less likely to be mislocated during jointing, or blown out in service or test.

Fittings, such as bends, branch and junction pipes and so on, cannot readily be made by the non-cylinder processes, and consequently resort is usually made to the steel cylinder type of design for fittings.

### **C1.5 Corrosion Resistance**

Mention has already been made of the propensity for corrosion of the high tensile circumferential prestressing wires. The majority of pipe failures in service have been from this cause, though the pipes are not immune from failure by other causes.



Corrosion of the wires is normally caused by water gaining access to them, either from the inside or the outside of the pipe. This should be prevented by the achievement of a high degree of impermeability in the core concrete, and the mortar coating. Furthermore, the concrete and mortar themselves must be protected against attack, lest their own deterioration should permit water to gain access to the prestressing wires.

Internal attack of water supply pipelines is not normally likely to constitute a problem, unless the water has an exceptionally low pH. External attack of underground pipelines, however, is a very real possibility, and it may therefore be dangerous to take the view that additional protection should only be provided where aggressive conditions have been shown to exist. It is prudent to specify that sulphate resisting cement should be used for manufacture of both the mortar and core concrete, unless it has been conclusively established that aggressive ground, or groundwater, conditions do not exist, and cannot in the future develop, at any point along the pipeline, and that similarly there is no possibility of the conveyed water becoming aggressive.

Sulphate resisting cement should therefore be the norm for noncylinder prestressed pipes, and further protection should be provided if an aggressive environment has been identified. Such additional protection should take the form of bitumen or coal tar coating in more extreme circumstances.

It is, of course, of fundamental importance to ensure that internally generated corrosion, such as alkali-aggregate reaction in the concrete, or chloride action at the mortar-wire interface, cannot occur. Careful selection of materials, and a high level of quality control, are therefore essential.

#### **C1.6 Handling and Laying**

Prestressed concrete pipes, of both the non-cylinder and steel cylinder types, are extremely heavy. Their transport to, and handling on, site therefore demands the use of heavy duty plant, which in some circumstances may itself have difficulty gaining access to the site.

Although a well made mortar coat should have reasonable resistance to mechanical damage, the paramount need to preserve its integrity, so that it can perform its corrosion prevention function, dictates the use of particular care when moving the pipes.

The great weight of the pipes makes their laying in soft ground conditions difficult, and also complicates the fine adjustments in position required during jointing.

#### **C1.7 Pipe Bedding Requirements**

As indicated above, temporary support during laying, particularly in soft ground, can be a problem with prestressed concrete pipes. The normally great strength of the pipes theoretically means that they often require little assistance from the bedding. As with all types of pipes, it is desirable to ensure even support along the length of the pipe, so as to prevent the development of large longitudinal bending moments. The longitudinal prestressing of non-cylinder pipes will normally endow them with a very high beam strength, and this consideration underlines the importance of ensuring that prestress is not lost by removal of the concrete core from its mould before sufficient strength has been obtained.

## **C2 STEEL CYLINDER PRESTRESSED CONCRETE PIPES**

### **C2.1 General Description**

Like non-cylinder pipes, steel cylinder prestressed concrete pipes employ a core, around which high tensile circumferential prestressing wires are wound, and to which a protective coating of mortar is then applied.

The difference between cylinder and non-cylinder pipes lies in the construction of the core. In the steel cylinder type, the core is formed from a complete cylinder of steel, the inside of which is given a thick concrete lining, applied normally by centrifuging. This concrete lining assists in providing rigidity and crushing strength to the pipe but does not have to resist the internal water pressure in the way that the core concrete of the non-cylinder pipe does.

The steel cylinder provides a totally impermeable barrier to the internal, pressurised, water, it eliminates the need for longitudinal prestressing and it enables circumferential prestressing to be carried out safely without waiting for the core concrete to achieve such a high strength. It thus eliminates several of the potential sources of trouble which can exist with non-cylinder pipes.

The dependence of the steel cylinder type of prestressed concrete pipe upon the mortar coating, for protection of the circumferential prestressing wires, remains the same as with the non-cylinder type.

Cylinder type pipes are made in many countries, and there are several well developed national standard specifications. Prominent amongst these is the American Water Works Association standard, AWWA C301, and the British Standard BS 4625, although the latter will soon be superseded by European Standard EN 642.

### **C2.2 Method of Manufacture**

Manufacture commences with the steel cylinder for the core. Since it is only lightly stressed, relatively low grade steel can be employed, and this is welded, normally with horizontal seams to form what is, in effect, a simple steel pipe. This steel cylinder is then rotated at high speed to form the concrete lining by centrifugal casting. Alternatively, and particularly with large diameter pipes, where the cost of the spinning plant can be high, the concrete lining of the core may be formed by vertical casting, using a removable inner form.

Once the core has been produced, manufacture of steel cylinder type pipes proceeds in a similar manner as does that of non-cylinder pipes. The only difference, as indicated above, is that circumferential prestressing can be carried out sooner. In some cases, however, an initial concrete coating is applied to the outside of the steel cylinder prior to winding on the circumferential prestressing wires.

### **C2.3 Sizes and Pressure Ratings**

The sizes of pipes normally manufactured vary considerably from one country to another, for example, the largest sizes regularly made in Britain, France and the USA are 1 800, 3 200 and 4 500 millimetres diameter. Minimum sizes are seldom less than 600 millimetres diameter. Pressure ratings of 25 bar are easily achievable with steel cylinder type prestressed pipe.

## **C2.4 Joints and Fittings**

Steel cylinder type prestressed pipes are normally manufactured with the core cylinder being rather longer than the inner and outer concrete. Jointing the pipes thus becomes a question of jointing the steel cylinders. This can, and sometimes is, done by butt welding the ends of the pipes on site. It is generally preferred, however, to employ rubber ring sealed socket and spigot pipes, because these permit much more rapid construction. The sockets are normally fabricated as steel bells, and welded onto the steel core cylinder at the factory.

Fittings are readily made by fabricating the required bend or junction out of welded steel pipe. The basic steel structure is then given an internal and external initial coating of concrete, by guniting or shotcreting, and, in the outside layer reinforcement is applied. The reinforcement is normally in the form of a non-prestressed cage, because of the difficulties of winding wires under tension onto a non-cylindrical body.

## **C2.5 Corrosion Resistance**

Corrosion of the circumferential prestressing wires is the main risk, as with the non-cylinder type of pipe. The possibility of water from the inside of the pipe reaching the wires is eliminated, by the presence of the steel cylinder.

The steel cylinder is very much less vulnerable to corrosion than the prestressing wires, because it is manufactured from relatively low grade steel, and is lowly stressed. Adequate protection of the cylinder steel is therefore normally provided by the concrete lining and coating. Even if water can reach the steel core cylinder via cracks, corrosion of the low grade low stress steel will normally be prevented by the alkaline environment, provided that the crack is narrow enough to prevent any flow of water.

Corrosion protection therefore consists of protecting the prestressing wires from external attack, where the considerations are as discussed in Section C1.5, and protecting the protruding ends of the steel cylinders at the joint. This protection is normally provided by filling the joint gap, internally and externally, with mortar, after jointing the pipes. The fact that this mortar may crack, due to shrinkage, joint movement or some other cause is not significant, for the reasons given above, provided that the cracks are not wide.

## **C2.6 Handling and Laying**

These considerations are essentially similar to those applying in the case of non-cylinder pipes, and described in Section C1.6. Jointing is a more time-consuming operation, sometimes because of the need for welding, but, in any event, with both welded and socket and spigot joints, because of the need to fill the internal and external joint gaps with mortar.

## **C2.7 Pipe Bedding Requirements**

The requirements and considerations for cylinder type pipes are exactly the same as for the non-cylinder pipes, as discussed in Section C1.7.

It should be noted, however, that the longitudinal beam strength of the steel cylinder type pipes is more reliable, since it derives directly from the tensile strength of the steel, and does not depend upon the prestressing process.

## **C3 STEEL CYLINDER REINFORCED (AND PRETENSIONED) CONCRETE PIPES**

### **C3.1 General Description**

These two types of pipes are sufficiently similar to be described jointly in this section. Essentially they are comprised of similar components to those employed in steel cylinder prestressed concrete pipes, that is : a steel core cylinder with internal concrete lining, hoop steel reinforcement outside the cylinder, and a final mortar coating.

With both types of pipe, the hoop reinforcing steel assists the steel cylinder in carrying the internal pressure. In the pretensioned pipe, the hoop reinforcement is wound onto the steel cylinder under tension, and thus the steel cylinder itself needs to carry only a small proportion of the hoop stresses. In the steel cylinder reinforced pipe, the hoop reinforcement is not prestressed. This enables it to be assembled as a separate, cylindrical, reinforcing cage which is fixed, concentrically, around the steel core cylinder prior to application of the external concrete. In this type of pipe, a much higher proportion of the hoop stresses is carried by the steel core cylinder, and the pipe can be regarded as virtually a steel pipe with a reinforced concrete outer protection.

These pipes have been particularly developed in the USA and France. In the past, French manufacturers generally followed the American standard specifications, which are: AWWA C303 for the steel cylinder pretensioned concrete pipe, and AWWA C300 for the steel cylinder reinforced concrete pipe. A new European Standard, EN 641, has recently been developed, however, and will soon come into use.

The pretensioned type of pipe is classified as semi-rigid for structural design purposes. This means that external loading is calculated as for a rigid pipe, but that pipe deflection has also to be checked, taking account of lateral soil support, as for a flexible pipe. The reinforced pipe is usually classified as rigid.

### **C3.2 Method of Manufacture**

Manufacturing procedures for the pretensioned pipe are essentially similar to those employed on steel cylinder prestressed concrete pipes.

The only difference, in the case of the steel cylinder reinforced concrete type, is the method of applying the hoop reinforcing steel, and this has been described in Section C3.1.

### **C3.3 Sizes and Pressure Ratings**

The pretensioned type of pipe is normally made in diameter up to 1 000 millimetres in the USA, and 1 500 millimetres, in France. Pressure ratings of well over 20 bar can be achieved, but this type of pipe is not usually cost competitive for pressure ratings beyond 12 bar.

The reinforced type of steel cylinder concrete pipe is produced over a very wide range of diameters. In France, from 250 to 3 500 millimetres diameter, and in the USA, up to about 4 500 millimetres diameter. There is virtually no limit to the pressure ratings which can be achieved with this type of pipe in theory, but again for economic reasons, pressure ratings do not often exceed 9 bar.

### **C3.4 Joints and Fittings**

Jointing methods, and the methods of manufacturing fittings, are similar to those employed with steel cylinder prestressed pipes, and are as described in Section C2.4.

### **C3.5 Corrosion Resistance**

Since the hoop reinforcement of the pretensioned pipes is manufactured from mild steel, and the pretensioning involves only a modest stress, corrosion considerations for both types of pipe are similar.

Protection of both cylinder and reinforcement is generally adequately provided by the concrete lining and coating, for the reasons described in Section C2.5, referring to corrosion of the steel cylinder of prestressed pipes.

Protection of the concrete against internal or external attack may be necessary for the reasons described in Section C1.5, and would follow the same procedures, such as sulphate resisting cement, and bitumen, coal-tar, or epoxy coating.

### **3.6 Handling and Laying**

These types of pipes, particularly the pretensioned type, are rather lighter than prestressed, and even asbestos cement pipes. Because of the better corrosion resistance of the reinforcement, occasional slight cracking of the outer mortar may be accepted, and handling need therefore not be subjected to such severe restrictions as with prestressed pipes.

The protruding ends of the steel cylinders are vulnerable to impact damage, and care is required to avoid this.

### **C3.7 Pipe Bedding Requirements**

Considerations for the more rigid, reinforced type of pipe, are similar to those applying to the prestressed pipes. The semi-rigid, pretensioned pipe, as mentioned in Section C3.1, may depend to some extent on lateral soil support.

Extra care in the placing and compaction of bedding material beneath, and at the sides of the pipe is therefore appropriate. Compared with the very flexible materials, such as thin walled steel, and the plastics, the additional bedding requirements of pretensioned pipes are not onerous.

## **C4 STEEL PIPES**

### **C4.1 General Description**

Steel has a long history of widespread use as a material for the manufacture of water pipes. Its main advantages are high tensile strength, enabling high pressures to be carried by thin walled pipes, adaptability, enabling bends and fittings to be fabricated to suit particular circumstances at short notice, and impact resistance, enabling pipes to withstand a measure of mishandling.

The main disadvantage of steel pipes is their vulnerability to corrosion. Because of this, unless laid in very favourable conditions, such as permanently dry sand, steel pipelines require elaborate anti-corrosion protection systems.

The wide varieties of steel types, and pipe duties, which exist, have led to the development of numerous specifications, in many countries. Probably the most widely followed specification is that for steel line pipe developed by the American Petroleum Institute, specification API 5L, although International Standard ISO 559 can also be used. The corrosion protection systems, which are virtually essential to any steel pipeline, themselves constitute a wide ranging and complicated subject, for which many specifications have also been developed.

#### **C4.2 Methods of Manufacture**

In the larger sizes, with which we are here concerned, steel pipes are manufactured by forming strip, sheet or plate steel to the required cylindrical shape, and welding together the edges to form the pipe.

There are two basic methods of forming and welding steel pipes. In the first, sheets or plates of steel are rolled to produce the correct curvature for the required pipe diameter, and assembled by welding together the edges of adjacent sections. In the second method, a single, continuous, strip of steel is helically wound into the cylindrical shape of the pipe, and then welded along the spiral seam produced by the helical winding.

In theory, the same quality of pipe should be achievable with either system, and will depend upon the consistency of the material, and of the welding. Manual welding is a tedious process, into which human error can easily intrude, and, for this reason, automatic welding can be expected to be more reliable. Since the spiral welding process is much more suited to execution by automatic equipment, there may be grounds for regarding this type of steel pipe as more reliable.

Since the corrosion protection system is an essential part of a steel pipeline, its application should be considered as part of the pipe manufacturing process. Of the numerous systems available, some can only be applied at the factory, for example fusion bonded epoxy coatings, others, such as cathodic protection, only on site, whilst some, like cement mortar lining, can be applied at either location.

#### **C4.3 Sizes and Pressure Ratings**

Most manufacturers of spirally welded steel pipes produce pipes up to a maximum diameter of just over two metres. Sheet or plate fabricated pipes are often subject to a similar size limit, if factory made, but do permit larger diameters to be achieved if site fabrication is employed. In this case, the sheets or plates can be brought individually to site, having been rolled to the required curvature in the factory. The high tensile strength of steel permits very high pressure ratings to be achieved by relatively thin walled pipes. Steel pipes can readily provide any pressure rating likely to be required in a water supply pipeline.

#### C4.4 Joints and Fittings

Steel pipes are most frequently jointed by welding, and this can have a considerable advantage for water pipelines operating under pressure, in that the ability of a welded joint to transmit tensile loads acting along the line of the pipes can eliminate the need for structures to resist bend thrusts.

Although butt welding can be employed for steel pipe joints, it is more common to employ sleeve or collar joints, with fillet welds applied internally or externally or both. Where welds are used at each end of the sleeve, a tapping can be made, enabling pressure to be applied to the annular space in order to test the welds. Sleeve or collar joints also assist in locating the two pipe ends prior to welding, and can also permit a measure of angular deflection of the pipeline.

Steel pipes can also be jointed using flanges, and detachable mechanical couplings. Most steel pipelines employ some joints of these types, even though the majority of their joints are welded.

Fittings of virtually any desired configuration can be fabricated, as a result of the ease of cutting and welding steel. Application of coatings and linings to complicated fittings can sometimes present more problems than the original fabrication.

#### C4.5 Corrosion Resistance

Steel corrodes in many waters likely to be conveyed in supply systems, although the rates of corrosion may vary. In some waters deposition may occur, and against this, as against corrosion, precautions should be taken.

Three types of materials can normally be used for internal protection : bitumen, cement mortar and plastics. Bitumen linings have relatively short lives, whereas there are numerous examples of cement mortar linings which have lasted over fifty years with negligible deterioration. Because of the risk of damage to cement mortar linings during transportation and laying of steel pipes, they are best applied on site, after pipelaying. In a few cases, such as with steeply graded pipelines, application of mortar linings may be difficult or impossible. In these cases, a plastic lining, which is largely applied before pipelaying, may be appropriate.

Corrosion of steel pipelines by external environmental attack is a complicated subject. Essentially, corrosion is associated with the flow of an electric current around a circuit, of which the pipe is part. The potential causing the current can be generated electrochemically at the interface between the pipe and its surrounding environment, that is the soil in which it is buried. Corrosion will occur at anodic points on the pipeline, that is, at points where the current leaves the pipe. At the cathodic points, where the current rejoins the pipe to complete the circuit, there is no problem. Corrosion will occur at the anode, whatever the length of the circuit. It may be very short, across a pit forming in the pipe surface, it may be from top to bottom of the pipe, if the bottom of the trench is wet and the top dry, or between points widely separated along the length of the pipeline.

Corrosion protection systems work by isolating the pipe from the soil, or other aggressive environment, or by ensuring that the pipe is cathodic, or by preventing current flow along the pipeline.

Coatings can be applied to the pipes either as liquids, powders or wrappings (tapes or sleeves). The main problems are in ensuring complete coverage of the pipe by the coating, and in avoiding subsequent damage to, or breakdown of the coating. The main types of coatings are bitumen, coal tar enamels, and polymers, which may be applied in liquid or powder form bonded directly onto the pipe surface, impregnated into tapes wound onto the pipe, or as sheets wrapped or extruded around the pipes.

Whilst certain coating systems may be regarded as having superior all-round performances, it is often the case that certain systems are particularly suitable, or unsuitable, for certain conditions. Although many systems can be applied at the factory, this cannot be done if the pipes are fabricated on site. Furthermore, factory coatings cannot be applied to the ends of pipes where they would subsequently be destroyed by the welding of the pipe joints. The coating of the joints has therefore, inevitably, to be done on site, and must provide equal protection to that provided by the factory applied part of the coating system.

Cathodic protection systems are those which ensure that the pipe is always cathodic with respect to its surrounding environment. This is achieved by connecting the pipeline either to a direct current source, which will impress onto the pipeline a current from the soil, or to a sacrificial anode buried in the soil, which will cause the pipeline to become cathodic. Cathodic protection is widely used in conjunction with other systems, and has been particularly successful in the oil industry. It does, however, introduce its own particular problems, and can even accelerate corrosion in certain circumstances. Water pipes are harder to protect successfully by cathodic means than are oil pipes, since water is a better conductor, and the necessary circuit may be completed by an internal route. For this reason, internal cathodic protection is sometimes used, but this is a difficult procedure.

#### **C4.6 Handling and Laying**

Bare steel pipes are easily handled, being relatively light, strong and very resilient. Normal handling of bare steel pipes creates few problems, but where steel is coated or lined for corrosion resistance care must be taken to ensure that the lining or coating is not damaged.

#### **C4.7 Pipe Bedding Requirements**

Depending on the ratio between pipe diameter and wall thickness, steel pipes may range from being very flexible to semi rigid. The greater the flexibility, the more the pipe will depend on the support from the soil in which it is embedded to resist buckling. Excessive deflection is a further potential problem with flexible pipes and, although the problems are often less severe with pressure pipes, because the internal pressure tends to restore the circularity of the pipes, deflection can still be a problem if installation circumstances restrict the rerounding process. For example, if a long period elapses between pipelaying and the first application of pressure, the backfill settlement which will have taken place will reduce the amount of rerounding which can take place. It is therefore desirable to employ a bedding material which can easily be compacted to a high density during construction, so as to minimise subsequent settlement. It is often also desirable to establish the suitability of the proposed bedding material, and compaction techniques, in a trial section, before using them in permanent work.



## **C5. DUCTILE IRON PIPES**

### **C5.1 General Description**

Ductile iron pipes have been developed from the earlier vertically cast, and spun, grey iron pipes, which they began to supplant some 20 years ago. The improvements in strength and impact resistance enable ductile iron pipes to approach the performance of steel pipes in these respects and, although they remain prone to corrosion, being made from the same basic material as steel, they are markedly less so than are steel pipes themselves.

The basic material cost of ductile iron is appreciably lower than that of steel, and hence it is economic to employ greater thicknesses in the pipe walls. Since the elastic modulus of ductile iron is only 20 per cent less than that of steel, the stiffness of ductile iron pipes, for a given duty, is usually significantly higher, bringing benefits in installation.

Ductile iron pipes are widely made in Europe, Japan the USA and elsewhere. European and Japanese pipes are made in accordance with various national standard specifications, all of which are based on the International Standards Organisation specification ISO 2531, which is most appropriate for international tendering. American pipes are normally made to comply with the AWWA specification C151. Various corrosion protection systems are available.

### **C5.2 Methods of Manufacture**

Ductile iron is metallurgically formulated so that the graphite included in the material is in the form of spheroidal nodules, rather than the flakes which tended to introduce planes of weakness into grey iron pipes, making them brittle.

Ductile iron pipes are made in foundries by centrifugal casting. The high temperatures involved, and thick walls employed, lead to high residual stresses being induced during initial cooling. It is consequently necessary to anneal the pipes, after removal from the mould, to relieve these stresses.

### **C5.3 Sizes and Pressure Ratings**

The capital costs of setting up ductile iron pipe foundries increase markedly with pipe diameter, and the maximum sizes offered by various manufacturers differ substantially. The upper limits of the main European manufacturers range from 1 200 to 2 000 millimetres, whilst in Japan the range is from 2 000 to 2 600 millimetres.

Manufacturing considerations tend to limit the wall thicknesses which can be reliably employed, and these thicknesses dictate the allowable working pressures which can be achieved. In the larger sizes of pipe, maximum working pressures are usually 16 bar, whilst in the smaller pipes, ratings of 24 bar or more are achieved.

### **C5.4 Joints and Fittings**

Joints are normally highly developed versions of the rubber ring sealed, socket and spigot type. Where pipes are to be operated at particularly high pressures, and may be subject to movement at the joints, bolted gland joints may be used. In this type of joint, the sealing ring or gasket is prevented from being forced out of the pipe socket, and is also compressed against the socket and spigot pipe ends, by an iron ring slid along the spigot pipe end until in contact with the gasket, and then drawn home by bolts bearing on the socket pipe end. Detachable

mechanical joints may also be used on occasions, and flanged joints are available, though expensive and normally only used for pipework within structures.

Fittings are made by casting, but since centrifuging of unsymmetrical shapes is not feasible, greater wall thicknesses are normally employed to counteract the possibility of lower densities occurring in the material. Wide ranges of bends and junctions are offered by most manufacturers, but because of the high cost of moulds, it is not practicable, as with steel and glass reinforced plastic, to fabricate bends to any precise angle of deviation.

#### **C5.5 Corrosion Resistance**

Although less prone to corrosion than are steel pipes, ductile iron pipes have been shown, by experience, to be far from immune from attack. It was originally thought that the corrosion resistance of ductile iron was superior to that of cast grey iron, and that the bitumen internal and external coatings, which were traditionally employed with cast iron pipes, would be adequate for ductile iron. Although this has indeed provided adequate protection in many cases, it has proved necessary to introduce progressively more sophisticated systems such as loose polyethylene sleeving, zinc coatings and extruded polyethylene coats. Because of the relatively short history of use which ductile iron pipes have, the necessary criteria for selection of protection systems are not yet as well developed as might be wished.

#### **C5.6 Handling and Laying**

The moderate weight of ductile iron pipes makes their handling reasonably easy. Although the robustness of the metal makes it generally fairly tolerant of rough handling, this is somewhat offset by the vulnerability of the cement mortar linings which are normally used. The ductility of the iron also means that it may only distort, where cast iron would have fractured. Consequently, damage to spigot ends of pipes can pass undetected, and give rise to joint sealing problems at later stages.

Like steel, ductile iron pipes can normally be cut, on site, to more or less any required length, and their ease of jointing, enables them to offer most of the advantages of steel pipes, without the difficulties of making welded joints.

#### **C5.7 Pipe Bedding Requirements**

Although ductile iron pipes of typical pressure ratings are sufficiently flexible, in diameters of 800 mm and above, for flexible pipe theory to apply, they are usually appreciably stiffer than plastic pipes and thin walled steel pipes. This stiffness, together with their high beam strength, make them relatively undemanding of special bedding requirements. Nevertheless, by comparison with rigid pipes, ductile iron pipes do require more care in the selection, placing and compaction of bedding material. Additional care is also required in order not to damage any external protective coatings.

## **C6. GLASS REINFORCED THERMOSETTING RESIN PIPES**

### **C6.1 General Description**

Glass reinforced thermosetting resin (GRTR) pipes is the more accurate name which covers pipes variously known as glass reinforced plastic (GRP), reinforced plastic mortar (RPM) and fibre reinforced plastic (FRP) etc. In French, the material is usually known as plastique renforcé de fibres de verre (PRV), which similarly could be made more accurate by adding the words "résin thermodurcissable".

Pipes of this type were first introduced in the late 1950's and their use has become progressively more widespread ever since. In the water industry they tended first to be used for industrial effluents and then for sewers in hot climates, where septic sewage was common and caused acidic attack on concrete and asbestos cement pipes.

The structure of the pipes is that of a composite, in which glass fibres provide tensile reinforcement of a resin matrix, and also serve as crack arresters, resisting the propagation of cracks through the resin. By the incorporation of sand into the inner resin layer, or layers, the pipe wall thickness can be increased without the use of excessive quantities of expensive resin. The increased thickness lengthens the lever arm of the glass reinforcement, enabling greater stiffnesses to be achieved.

The ability to vary the respective amounts of resin, glass and sand filler, enables the stiffness and pressure rating of pipes to be varied independently. This adaptability of design permits pipes to be matched to various combinations of duty in a way which is not possible with other materials.

Detailed national standard specifications for GRTR pipes have been developed in the United Kingdom, where BS 5480 covers all types of pipe in a single specification, and the USA, where the AWWA specification C950 covers pipes specifically intended for water supply applications.

### **C6.2 Methods of Manufacture**

There are two basic methods of manufacture, filament winding, and centrifugal casting. In the former the pipes are built up on a rotating mandrel, onto which liquid resin is poured, and around which continuous strands, or filaments, of glass fibre are wound. In the centrifugal casting process, the liquid resin is poured into a rapidly spinning cylindrical mould, where it is spread by the centrifugal force, and the glass fibre is added in the form of short strands. The hardening, or curing, of the resin requires careful control of chemical constituents, and of temperature.

A particular development of the filament winding method, is the "Drostholm" process, in which the surface of the mandrel is formed by a helically wound steel band. As this endless band comes off one end of the mandrel it is returned, via the inside of the mandrel cylinder, to the other end. In this way, not only does the mandrel surface rotate, but it also moves, continuously, in an axial direction. It is thus possible to produce pipes of theoretically unlimited length.

### C6.3 Sizes and Pressure Ratings

Centrifugally cast pipes are normally made in sizes up to 2 500 millimetres diameter, and with pressure ratings up to 16 bar. There is more variation in the case of filament wound pipes. Numerous manufacturers produce pipes of 2 000 millimetres diameter, several of 2 500 and a few of 3 000 millimetres or more. The maximum pressure ratings offered by the major manufacturers are in the range 13.5 to 16 bar, although even higher pressures can sometimes be obtained with small diameter pipes.

### C6.4 Joints and Fittings

GRTR pipes normally employ rubber ring sealed joints. Some manufacturers use detachable collar types, with two rubber sealing rings, and others integral socket joints sealed by a single ring.

Detachables mechanical joints, particularly those of the Straub or Tee Kay type, are sometimes used with GRTR pipes, and resin bonded socket and spigot joints are also occasionally used.

Fittings of standard types are sometimes produced on purpose made moulds, but the ability to cut and bond GRTR enables purpose made fittings to be fabricated in a manner comparable to that used for steel pipe fittings. Where very high operating pressures are required, resort is sometimes made to steel fittings for use with GRTR pipes.

### C6.5 Corrosion Resistance

The corrosion resistance of thermosetting resins is normally excellent, and corrosion of GRTR pipes in practice can normally only occur if glass fibres are exposed to attack, as a result of poor manufacture, or subsequent damage. It is therefore important to ensure that all the fibres are well covered by resin.

Consideration of the two types of manufacturing process shows that centrifugal casting tends to force the glass fibres outwards through the resin, if it is liquid, whilst filament winding tends to pull the glass fibres towards the inside surface of the pipe. These effects are normally avoided by partially curing the outer layer of resin, in centrifugally cast pipes, and inner layer of resin, in filament wound pipes, prior to applying the glass. The partially cured, or pre-gelled, resin then has sufficient strength to prevent the fibres moving through it.

Because of the manner in which the 'Drostholm' process operates, it is often very difficult to pre-gel the inner lining of the pipes, and this could reduce their resistance to internal attack. This problem can, however be reduced by using reinforcing glass of high chemical resistance (ECR glass). In any event, the problem is less likely to be a serious consideration in water transmission pipes, than in sewer pipes.

### C6.6 Handling and Laying

The extremely low weight of GRTR pipes makes them very easy to handle, and also permits considerable savings of space during transport, because pipes can easily be "nested". That is the smaller diameter pipes can be threaded inside the larger pipes.

The pipes are vulnerable, however, to cracking of the resin as a result of impacts. Since cracks can expose the glass reinforcement to attack, great care has to be taken to avoid damage.

#### **C6.7 Pipe Bedding Requirements**

GRTR pipes together with thin-walled steel pipes are normally amongst the most flexible pipes available, and therefore are particularly demanding in respect of their bedding. If the pipes are embedded in material other than gravel, there is a considerable risk that they may be severely distorted during the placing and compaction of the bedding material, and this can result in dangerously high levels of strain being locked into the pipe walls. Nevertheless, the bedding material must be at a high relative density, in order to prevent excessive deflections from developing as the backfill settles and consolidates. As explained in the case of thin walled steel pipes, in Section C4.7, the application of internal pressure helps to restore the circularity of the pipes, provided that the period between pipelaying and pressurisation is not too long, and that the depth of the pipeline is not large. Consequently pressure pipelines may not always require such a high standard of bedding as would similar non-pressure pipelines.

### **C7. THERMOPLASTIC PIPES**

#### **C7.1 General Description**

Poly-vinyl chloride (PVC) pipes were first introduced in the late 1930's, and became widely used from the mid 1950's. The other thermoplastic which has been used in significant quantities in water supply pipes is polyethylene, again from the 1950's onwards.

Lack of understanding, in the past, of the ductile-brittle transformation and slow crack growth phenomena in PVC pipes led to many apparently unaccountable pipe failures, and brought this pipe into disrepute in many quarters. Now that these processes are understood, it is possible to design and construct PVC pipelines with confidence. Account must always be taken, however, of the fact that thermoplastics, by definition, soften as they are heated. They are therefore less strong when used in hot climates than in colder climates.

Polyethylene, though much less vulnerable to premature failure by cracking, is often even more sensitive to temperature than is PVC. The related polyolefin plastics, such as polypropylene and polybutylene, have better performance at high temperatures, and have been successfully used for water conveyance in the Middle East. They are, however, expensive.

PVC pipes have been particularly developed in the UK, the USA, Holland and Germany, and polyethylene pipes in Germany and Scandinavia.

#### **C7.2 Methods of Manufacture**

Thermoplastic pressure pipes are invariably manufactured by extrusion. In these process, the basic feedstock, which will have been produced at a petrochemical factory, often in granular form, is heated to a temperature sufficient to permit it to flow, but below that at which oxidation will occur, and forced through an annular die under pressure. In this way, a hollow cylinder, or pipe, is produced in a single operation.

### **C7.3 Sizes and Pressure Ratings**

The maximum diameter to which PVC pipes are normally made is about 700 millimetres, and the thickest walled pipes offer pressure ratings of 16 bar, at 20°C ambient temperature, or 11 bar at 35°C.

Polyethylene pipes are widely made in diameters up to 600 millimetres, in which range the available pressure ratings are up to 16 bar, at 20°C, and 9 bar at 35°C. A few manufacturers make pipes up to 1 200 millimetres diameter, and one produces pipes of 1 600 millimetres diameter. In these larger sizes, the maximum available pressure ratings are 4 bar, at 20°C, and 2.4 bar, at 35°C.

### **C7.4 Joints and Fittings**

PVC pipes are best jointed by the use of rubber ring sealed socket and spigot joints. Solvent welded joints can be used, but are difficult to produce consistently well, and tend to be used only for very small diameter, plumbing pipes.

Polyethylene pipes are best jointed by heat fusion (welding) processes, in which the mating surfaces of adjacent pipes are heated above their softening temperature, pressed together so as to fuse, and allowed to cool. Either butt joints or socket and spigot joints can be made in this way.

The suitability of polyethylene for joining in this way facilitates the fabrication of beds and junctions. Fittings for PVC pipes, however, are difficult to produce. Large radius bends can be extruded, and some fittings can be injection moulded. Nevertheless, resort is sometimes made to plastic coated metal fittings.

### **C7.5 Corrosion Resistance**

Both PVC and polyethylene have excellent resistance to attack by any environment likely to be encountered in normal water supply practice.

### **C7.6 Handling and Laying**

The light weight of thermoplastics pipes makes them very easy to handle. They can, however, be weakened by exposure to direct sunlight, and it is therefore good practice to store them under cover until required for pipelaying, and to backfill as soon as possible after laying.

The propensity of PVC for slow crack growth means that these pipes should be handled with special care, to avoid causing scratches which could provide sites for subsequent crack growth. Polyethylene pipes are not likely to be affected by occasional scratches, however.

### **C7.7 Pipe Bedding Requirements**

Thermoplastics pipes are usually very flexible, even more so when used under high ambient temperatures. The bedding requirements for these pipes, therefore, are similar to those for GRTR pipes, as described in Section C7.7.

## **C8 ASBESTOS CEMENT PIPES**

### **C8.1 General Description**

Asbestos cement pipes have been very widely produced over a period of some 70 years, for use in both pressure and non-pressure applications. They are basically manufactured from cement mortar, reinforced so as to obtain tensile strength, by the inclusion of asbestos fibres.

In recent years, increasing awareness of the health risks associated with asbestos fibres has led to extensive investigations of asbestos cement pipes. Although it has been shown that fibres are leached out of the pipe walls into the water in the pipes, no evidence has yet been found to suggest that fibres ingested into the body with water cause disease. The serious health risks which have been proven to exist, occur when fibres in the air are ingested into the body by breathing. Stringent regulations are therefore required at asbestos cement pipe factories, and, because there remains some possibility of a risk with water borne fibres, it is recommended that asbestos cement pipes are not used for the conveyance of waters whose chemistry is likely particularly to promote the leaching out of fibres.

Asbestos cement pipes tend to be fragile, and therefore to crack easily. Unfortunately, impact or other cracks in asbestos cement pipes are very difficult to detect, and may therefore only come to light when they cause pipes to burst in pressure tests or in service.

Standard specifications covering asbestos cement pipes have been produced in virtually all of the numerous countries where they are made. Usually the national specifications are similar to the International Specification ISO 160 (and European Standard EN 512) which would be appropriate for international tendering.

### **C8.2 Methods of Manufacture**

Asbestos fibres are thoroughly mixed into a cement mortar slurry to produce a mixture of sufficient cohesion to adhere to the rotating mandrel onto which it is fed.

The material is consolidated by the application of pressure, externally, and removal of excess water is sometimes assisted by the application of a vacuum within the mandrel, which is perforated to permit the passage of water.

### **C8.3 Sizes and Pressure Ratings**

The maximum size in which asbestos cement pipes are made varies considerably from one manufacturer to another, and from one country to another. Frequently the maximum size is around 36 inches or 900 millimetres diameter. Sometimes it is rather smaller, whilst occasionally pipes up to 2 000 or 2 500 millimetres diameter are produced.

Operating pressures up to 15 bar are allowed for in the International Standard, but again, some manufacturers produce pipes with ratings up to 32 bar. Very high pressure ratings are not available, however, in the larger pipe sizes.

#### **C8.4 Joints and Fittings**

Jointing is normally by means of loose collars, with two rubber rings, sealing against the two pipe ends. Jointing tends to be time consuming, and, because the pipes are relatively short, a large number are required, further lengthening the pipe-laying operation. Although a few fittings manufactured from asbestos cement are sometimes produced, they are difficult to make, particularly for high pressures, and the more usual practice is to use cast iron fittings.

#### **C8.5 Corrosion Resistance**

For pressure applications, asbestos cement pipes, for many years, competed only with iron, and occasionally steel, pipes. In this context, and because they are not normally affected by high chloride levels or by electrochemical corrosion, they can be regarded as having good corrosion resistance. There are, however, other conditions in which asbestos cement will corrode, for example in water with high sulphate or free carbon dioxide levels. Some protection against these sources of corrosion can be obtained by coating and lining the pipes with bitumen, and in some countries this is standard practice. A higher degree of protection is possible with epoxy resin coatings.

#### **C8.6 Handling and Laying**

Asbestos cement pipes, particularly those of higher pressure ratings, are very heavy, making handling difficult. Coupled with the susceptibility to cracking, see Section C9.1, and possible problems of jointing, see Section C9.4, asbestos cement pipes represent one of the more difficult types for handling and laying.

#### **C8.7 Pipe Bedding Requirements**

Being rigid pipes, asbestos cement pipes are not subject to the sometimes stringent bedding requirements of flexible pipes. Because they have relatively low beam strengths, however, particularly careful attention is required to be given to ensuring even bedding support along the length of the pipes. This will normally involve excavating well below the bottom of the pipe, and often the use of imported bedding material.