7

ORNL/SUB-79/7672/1

ASSESSMENT OF EXISTING
AND PROSPECTIVE PIPING TECHNOLOGY
FOR DISTRICT HEATING APPLICATIONS

By

MASTER

I. OLIKER

BURNS AND ROE, INC.
ORADELL, NEW JERSEY 07649

For

ENGINEERING TECHNOLOGY DIVISION
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE 37830

SEPTEMBER, 1979

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

LEGAL NOTICE

ORNL/SUB-79/7672/1

ASSESSMENT OF EXISTING AND PROSPECTIVE PIPING TECHNOLOGY FOR DISTRICT-HEATING APPLICATIONS

By

I. OLIKER

BURNS AND ROE, INC.
POWER TECHNOLOGY DIVISION

For

ENGINEERING TECHNOLOGY DIVISION
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE 37830

Operated by
UNION CARBIDE CORPORATION

For the
UNITED STATES DEPARTMENT OF ENERGY

SEPTEMBER, 1979

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

ACKNOWLEDGEMENTS

This study was prepared under the direction of the Advanced Nuclear Systems and Projects Division of DOE and Oak Ridge National Laboratory with Dr. A. M. Rubin and Dr. M. A. Karnitz as Project Officers.

Dr. I. Oliker was the project manager and principal investigator of the study. Messrs. P. Goldbrunner and K. Lee of Burns and Roe Power Technology Division performed special tasks for the study. The study report has been reviewed and approved by Mr. J. Philipp, Deputy Director, Power Technology Division and Dr. S. Baron, Senior Corporate Vice President and Director Power Technology Division.

Many district heating utilities and associations from the United States, Europe and Japan provided invaluable operational experience information. Their support is very much appreciated.

A large number of district heating piping manufacturers supplied helpful information and comments regarding the objectives of this study.

Special thanks are due to H. Jaehne, H. Nyman (Saint Paul District Heating Development Company), P. A. Johnson and R. B. Anderson (Northern States Power), R. D. Visness and R. E. Sundberg (Minnesota Energy Agency), L. E. Tuck (Boston Edison Co.), M. A. Buffa (Con. Edison Co.), Neil Childress (Wisconsin Electric Power), H. Neuffer and I. A. Klopsch (W. German District Heating Association), D. H. Stolte and K. Mielke (Hamburgische Electricitats-Werke, W. Germany), Ernest Haseler (United Kingdom District Heating Association), B. Osterling (Stockholms Energiverk, Sweden), W. Kilpinen and I. Pirvola (Finnish District Heating Association), Renzo Capra (Brescia District Heating System, Italy), Shunzo Wada (Hokkaido Heating Co., Japan), Jens Christiansen (i. c. møller a/s, Denmark), A. Tautz (Niederrhein Research Center, W. Germany), G. G. Robertson (Ameron), R. O. Couch (Ric-Wil) and M. Neishloss (Superior Steam).

The draft report has been presented and discussed with the Department of Energy, Oak Ridge National Laboratory, Northern States Power and St. Paul District Heating Development Company. Acknowledgements for the critical review of the report are due to W. F. Savage, Dr. A. Rubin, I. Helms and J. Rodousakis of the Department of Energy, Dr. M. A. Karnitz and J. Meador of the Oak Ridge National Laboratory, H. Jaehne, H. Nyman of the St. Paul District Heating Development Company and C. Aas and P. A. Johnson of the Northern States Power.

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

SUMMARY AND CONCLUSIONS

A. Data on design features and operational experience of forty hot water and steam district heating networks with an overall heat capacity of 18,000 MWt have been collected, systematized and analysed. Piping networks located in Canada, Denmark, Finland, France, Italy, Japan, Netherlands, Sweden, U.S.A., U.S.S.R. and West Germany have been analyzed. The analyses resulted in the following general conclusions:

1. Four installation methods are in use for district heating installations as follows: concrete culvert, conduit, directly buried pipes insulated with powder backfill and rigid concrete envelope. Based on reliability and cost considerations, two of these methods dominate in hot water networks. Conduit design is typically used for pipe sizes up to 8 inches and concrete culvert designs for larger piping. The rigid concrete envelope design is the most widely used in steam systems in the United States.

   Carbon steel is almost exclusively used as a heat carrier pipe for both hot water and steam networks.

2. Most of the hot water systems in West European countries are designed for maximum temperatures of between 230° and 266°F in the supply line and 122° to 158° in the return line. Typical maximum temperatures in the supply and return lines in East European countries are 300° and 160°F, respectively.

   The pressure in the piping network varies between 130 to 250 psig during the winter and between 60 and 150 psig during the summer.

   The central temperature control system is used mostly in Europe while the variable flow control method is employed in Japan.

3. Polyurethane foam is widely used as an insulating material for conduit installations for water temperatures not higher than 250°F, while calcium silicate is used for higher temperatures.

4. Novel methods for accommodation of piping thermal expansion were recently developed and utilized, such as sinusoidal curve pattern designs and piping prestressing techniques under hot and cold conditions. In these systems, expansion devices and loops are eliminated from the network resulting in the reduction of installation costs.

5. The reliability of an underground hot water system is determined by the following factors: quality of anti-corrosion protection, average annual water temperature in the piping network, age of the network, type of installation, (especially the provision of an air gap between the insulation and the culvert during service life of the pipe), site hydrological and soil conditions, and the condition of adjoining utility systems. It is of major importance, if not mandatory, that the contractor be highly qualified and capable of closely implementing the requirements of the installation specification. It is equally important to provide stringent supervision of the contractor's work.

   Major network components, subject to failure, are the supply carrier pipes, expansion bellows and piping joints. The major causes of the failures are as follows: external corrosion as a result of periodic contact of an unprotected external piping surface with ground water, insulation failure, failure of co-located utility systems, and mechanical and structural damage of the piping installation.

   The corrosion rate of steam supply piping is lower than that of hot water networks.

6. The average repair cost per pipe failure is $8,400 for hot water networks and $3,800 for steam networks. The average annual maintenance cost is $9,100 per mile for hot water networks (varying between one and six percent of the piping installation cost) and $22,500 per mile for steam network (1978 dollars).

   The higher repair cost for hot water networks is explained by the nature of the failures in this type of installation. The failure character (usually pipe rupture) is more complicated in hot water systems. This results in higher repair costs as compared with steam networks. The higher maintenance cost for steam systems is mostly related to the loss of condensate. In addition, the steam systems reviewed are much older than the hot water networks which also contributes to the higher maintenance cost.

7. Based on statistical information on piping failures presently available, it could be stated that the most reliable installation method is the concrete culvert design followed by the conduit, rigid concrete envelope and ductless types of installation.

8. To increase the reliability of networks already in operation, the preventative maintenance measures should be performed as follows: detection of all weak, corroded sections of pipeline and their prompt removal (by testing in summer); systematic excavation of inspection pits (exploratory excavation) in places where there is a danger of corrosion and where the replacement of the damaged sections is anticipated to be difficult; drainage of the pipe runs in every possible way (water removal, laying associated drains, etc.); altering the operating temperatures of networks, especially in summer.

9. Based on the data reported, the average heat loss figure has been estimated at 8.8 percent of the annual heat consumption for hot water systems and 15 percent for steam systems.

B. Analysis of recent European network piping technology, including discussions and visits to a number of installations indicated, that their experience with large district heating systems has resulted in a substantial reduction in piping costs compared with the U.S. This has been achieved by means of a number of relatively small improvements, which in summation, have resulted in the piping cost reductions.

1. The major factors which have substantially contributed to the reduction in the piping installation cost are as follows:

    a. Utilization of low temperature hot water systems (maximum temperature of 240° to 250°F permitting the use of conduits, with polyurethane insulation and plastic casings). This resulted in a substantial reduction in piping installation cost when compared to conduits with carbon steel casings.

    b. Use of minimum trench depth in order to reduce the volume of excavated and backfilled soil, and elimination of shoring requirements.

    c. Installation of district heating networks beneath sidewalks instead of streets, wherever possible, with associated reduction in excavation, backfill and concrete culvert costs.

    d. Optimization of the concrete culvert design.

    e. Reduction in the carbon steel carrier pipe wall thickness when compared to typical U.S. piping installations.

f. Removal of insulation from the return pipe with associated reduction in the insulation and concrete culvert costs. In this case, the heat losses from the return lines are increased, and consequently the temperature of the return water is decreased. This may result in an increase of electrical generation based on heat supply because lower pressure steam is extracted from the turbine for heating the return water. Therefore, an economic comparison has to be performed taking into consideration the reduced capital cost of piping installation, and the increase in electrical generation, versus increased heat losses during the service life of the piping installation.

g. Reduction in the number of expansion devices and manholes installed in the network.

h. Development of an extensive, very competitive industry, which specializes in the mass production of components and equipment for district heating networks.

2. Cost estimates for a concrete culvert and a conduit installed under the city street and sidewalk have been developed for Minneapolis/St. Paul, Boston, Baltimore, Philadelphia and Washington, D.C. utilizing a majority of the above means for cost reduction.

   The results of the estimates have demonstrated that the application of the above listed design features can result in a cost reduction of the piping installation of up to 50 percent when compared with typical U.S. practices.

   Generally, the conduit design results in lower installation cost for pipe sizes up to 8 inches as compared with concrete culvert method. For larger piping, installation of a concrete culvert is more economical.

3. From the estimates developed, it is evident that the highest cost item is the mechanical material, with the next highest being mechanical craft labor. Cost reduction efforts therefore should be concentrated on the piping materials and labor to have the greatest effect. Other major items of expenses included street excavation, formwork, insulation and concrete.

   Sidewalk installation reduces the cost from 10 to 19 percent of the street installation depending on the street arrangement and pipe size. The larger the pipe size the lower the cost reduction since the civil work forms a lower overall percentage of the total cost.

   Typical savings for concrete culvert installation, if the return pipe insulation is removed, would be in the range of $10 to $20 per foot for pipe sizes between 10 inches and 24 inches.

4. Cost estimates for several alternate piping system designs and materials have been performed. A comparison of costs indicates that about 50 percent savings are available when installing a system with polyurethane foam insulation and polyethylene casing as opposed to calcium silicate and a steel casing.

5. As a practical example, the cost estimate for a district heating main for Jackson Street, St. Paul, Minnesota was developed using the concrete culvert design applied beneath a sidewalk. This estimate includes provisions for specific interference problems which were investigated by direct contact with many of the local utilities and by on-site investigation. The interference cost contributed about 40% to the specific piping cost per foot.

C. The status of fiberglass reinforced plastic, cross-linked polyethylene, polybutylene, prestressed concrete, polymer concrete and asbestos-cement piping has been assessed as the most promising non-corrosive materials for future district heating network applications. The specific physical and design features of the above piping materials have been discussed. Piping installation costs have been developed where possible and compared with present typical installations. The assessment analyses resulted in the following conclusions:

1. The major advantages in the utilization of FRP for district heating compared to the carbon steel piping are as follows: elimination of electrochemical corrosion problems, reduction of pressure drop and pumping power, reduction in the heat insulation thickness required, and reduction in the installation cost. The major disadvantage of FRP piping is the possibility of the strength decrease under stress as a function of time and during cycling pressure and temperature conditions.

   Fiberglass pipes using epoxy resins can withstand a maximum operating pressure of 150 psi and a maximum operating temperature of 250°F. For such temperature and pressure, the standard pipe sizes that are available range from 2 to 13 inches. The cost of a conduit design with the fiberglass carrier pipe, polyurethane insulation and polyethylene casing is about 35 percent more expensive per foot than comparable carbon steel carrier pipe with the same insulation and casing.

2. The advantages of the cross-linked polyethylene piping are as follows: high corrosion resistance, high piping strength, substantial reduction in piping joints, low friction losses and subsequent reduction in pumping power, elimination of expansion devices, reduction in piping weight, easy to handle and install. The major disadvantages of the cross-linked

polyethylene piping are as follows: operating temperature limitation up to 203°F; low ultraviolet stability, the pipes must not be exposed to direct sunlight; there are indications that oxygen diffusion in the pipe causes corrosion of the attached fittings.

Cross-linked polyethylene piping in sizes up to 1 in. can be utilized for temperatures up to 203°F and pressures up to 145 psi. Pipes with sizes up to 4 inches may be used in systems with temperatures up to 203°F and pressures up to 85 psi. The pipe is manufactured in lengths of both 150 and 300 ft. The pipes up to 2 in. in diameter are rolled up in bundles which can usually be carried by two men. Mineral wool and polyurethane materials are used for pipe insulation.

Utilization of cross-linked polyethylene pipe in low temperature district heating systems promises cost reductions of up to 50 percent over conventional carbon steel conduits.

3. The major problems in utilization of prestressed concrete piping for hot water applications are as follows: concrete pipes have to be provided with an internal non-corrosive lining in order to prevent leaching of calcium and silicate materials, deposit accumulation, and the rubber sealed joint has to withstand relatively high temperatures over the service life of the pipe.

   Tests are underway to utilize the concrete pipes with an inner, adherent layer of sand-filled epoxy resin for district heating applications with temperatures of between 200 and 230°F.

   Utilization of conduits with a polymer concrete carrier and casing pipe results in installation cost savings of 27 percent over a conduit design with carbon steel carrier pipe and fiberglass casing.

4. In spite of encouraging results achieved to date, further technical development and long-term testing is required before the non-metallic piping materials will be widely utilized in district heating networks.

5. The specific problem areas for the prospective piping materials have been discussed, in addition to the ongoing research and development programs.

6. It is evident that the development of non-corrosive, cost-effective piping materials for network applications would greatly benefit from the establishment of a district heating test facility in the United States.

1. INTRODUCTION

1.1 PURPOSE AND SCOPE OF WORK

This study is a part of the Department of Energy program to assess the existing and prospective technologies for District Heating applications in the United States. In 1978 an assessment of the turbine technology was performed by Burns and Roe, Inc. for the DOE.[1] The purpose of the present study was to analyze the operational experience of district heating systems and to assess the existing and prospective piping materials for heating networks. The major goals and the scope of the study were as follows:

1. Perform a data search and analyze available information concerning operational experience gained in large district heating networks.
2. Perform cost estimates for typical piping transmission and distribution systems with emphasis on reduction on the piping installation cost.
3. Assess the status of prospective non-metallic piping materials under development for hot water district heating applications.

1.2 GENERAL CONSIDERATIONS

Utilization of the rejected heat from power plants for district heating purposes is now under extensive consideration in the U.S. as one of the prime energy conservation measures. A number of the U.S. studies have demonstrated that the cost of heat generation at the cogeneration power plant is relatively low (between \$1.00 to \$1.50 per 10^6 BTU of heat).[2,3] However, to transmit the heat from the power plant to the heat load area and distribute the heat to the customers, substantial capital investment in the piping system is required. This factor is especially important when the power plant cannot be located close to the city. Power plant citing remote from the heat load centers substantially increases the cost of the heat transport system. Practical experience has demonstrated that the district heating piping network can constitute between one-third and one-half of the overall cogeneration system cost.

The United States was the pioneer in the practical applications of district heating in 1877, and to date about 40 district heating systems are in operation in this country, supplying approximately one percent of the total U.S. heating demand. Historically, district heating systems in the U.S. have utilized steam as the heating medium, while hot water systems are more commonly used in Europe.

The main advantages of using hot water as a heating medium in comparison to steam are:

- Cogeneration of heat and power at the power plant is achieved with a higher thermal efficiency. In a hot water system, low-pressure steam from turbine bleeds is used for heating the water which is supplied to the customers. In the steam system, the steam has to be extracted from the higher pressure bleeds of the turbine to allow for required pressure drop in the piping network.
- Hot water provides the capability of heat transmission over long distances with relatively low heat losses.
- A more economical central control system for the heat supply from the power plant can be used. For example, the relationship between supplied hot water temperature and ambient conditions can be maintained more easily.

- The connection of most of the customers to the district network is simplified.

- The condensate from the extraction steam can be saved at the power plants. In many steam district heating systems, the condensate is not returned to the power plant for a number of reasons (corrosion problems, collection problems, etc.). To replace the lost condensate in a steam system, a high quality make-up for the boilers is required, thus imposing a high cost penalty against steam systems.

- Lower surface temperatures on the water radiators in the residential buildings provide better sanitary and safety conditions for the inhabitants. In steam heating systems, organic dust is partially decomposed on high-temperature steam radiators, and as a result harmful substances are released in the living space. Therefore, in some countries steam heating systems are not permitted for use in residential buildings.

- The hot water network inherently constitutes a large storage capacity. The heat storage capacity of the network is directly proportional to the additional temperature increase above the water temperature required by the customers. The temperature increase can be achieved during periods of low-load demand at the power station. Usually, the temperature of the water in the return line is increased by bypassing water from the supply line. Such a possibility does not exist in steam networks.

Because of the above advantages, hot water is more widely used than steam in large district heating systems in Europe.

The district heating piping network constitutes a substantial part of the overall district heating system cost. The district heating pipes in a city are usually installed underground. However, the operation of a district heating system differs substantially from other utility systems. District heating networks are in operation all year-round with varying flow and temperature. During operation the pipes are subjected to thermal expansion and undergo thermal stresses. Piping installations in cities can be complicated by such factors as, soil condition variations and interferences with other underground facilities.

The reliability of a district heating network is very important in view of the large number of customers who, in addition to receiving space heating and possibly cooling, are also provided with domestic hot water throughout the year. The radius of the heating networks often extends up to 20 miles and tens of thousands of consumers are supplied with heat. As a rule, the main transmission lines, 32 to 40 in. in diameter, carry heat loads of between 600 to 1000 MWt.

The reliability factor is particularly important in a large system where the breakdown of a large diameter main can cause interruption of heat supply to hundreds of buildings for long periods. Experience with the world's largest hot water district heating system in Moscow, demonstrates that it takes a minimum of 30 to 50 hours to bring pipes of 24 to 28 in. in diameter back into service after a failure has occurred.

The existing operational experience of district heating systems provides sufficient material for a detailed analysis of the reliability of the networks to ensure uninterrupted heat supply to consumers. In order to assess the operational experience in district heating networks, a special questionnaire was developed and distributed to about one hundred district heating utilities in the U.S., Europe and Japan. Both hot water and steam heat supply networks have been investigated, which has permitted a direct comparison between these two systems.

The questionnaire covered three major aspects of the district heating networks: design parameters and features, operational conditions, and network failure analysis.

Forty district utilities with a total heat load of 18,000 MWt returned the questionnaire providing variable completeness of information. The utility replies to the questionnaire can be broken down by the different countries:

Hot Water District Heating Networks (total 14)

Sweden - 3, overall heat load - 3641 MWt
West Germany - 3, overall heat load - 2944 "
Japan - 6, overall heat load - 312 "
Italy - 1, heat load - 182 "
Netherlands - 1

Steam District Heating Networks (total 26)

U.S.A. - 21, overall heat load - 8109 MWt
France - 1, heat load - 2180 "
Canada - 2, overall heat load - 293 "
Japan - 2, overall heat load - 62 "

In addition to this data, the extensive West German and USSR district heating network experience has been analyzed based on a survey of technical literature and the author's experience with district heating systems.

In spite of a substantial amount of information assessed, conclusions very often could not be generalized since the information is related to a particular manufacturer and site. The data bank and analysis of the operational experience, and design features of hot water and steam district heating networks are provided in Sections 2 and 3.

Some recent investigations of large hot water district heating systems in the U.S. have estimated the cost of underground piping networks as twice as high compared to equivalent European piping installations. In Section 4 of this report, the piping installation design was optimized in order to reduce costs wherever possible, without jeopardizing overall system efficiency, reliability or service life, and employing a mixture of typical U.S. and European district heating practices. Vendor and Burns and Roe cost data have been utilized in developing piping costs for five U.S. cities as well as and specific cost for Jackson Street in St. Paul, Minnesota.

The status of prospective non-metallic piping materials is presented in Section 5. This section is based mostly on information from U.S. and European manufacturers, and research institutions. The following materials have been investigated: fiberglass reinforced plastic, cross-linked polyethylene, polybutylene, prestressed concrete, polymer concrete and asbestos-cement piping. It was concluded that further extensive testing and research is required before the new piping materials will be acceptable for wide utilization in hot water networks.

2. DESIGN FEATURES AND OPERATIONAL EXPERIENCE OF HOT WATER NETWORKS

2.1 DESIGN PARAMETERS AND FEATURES

2.1.1 Temperature and Pressure

The district heating piping size is determined by the heat load and the water temperature drop in the system, which depends in turn on the type of heat supply control. Different methods of controlling the heat supply in district heating systems have been developed. The simplest and most widely used is the central temperature control system. In this case, the required amount of heat is provided to the customer by varying the temperature in the supply network line at the power station as a function of the outdoor ambient temperature. This means that the flow rate of water circulated in the district heating system is almost constant during the heating period. The central temperature control system is used mostly in Europe, while variable flow control method is employed in Japan.

For a given heat load, every effort is made to increase the temperature drop between delivery and return lines, thus reducing the flow rate of the circulating water and as a result the piping size and the pumping power. An increase in the delivery temperature provided at the cogeneration power plant reduces the electrical generation. Therefore, the optimal delivery temperature is established as a result of optimization studies, considering the economics of both the cogeneration power plant and the piping system.

Most of the hot water systems in West European countries are designed for maximum temperatures of between 230° and 266°F in the supply line and 122° to 158°F in the return line (EXHIBIT I). Typical maximum design temperatures in the supply and return lines in East European countries, including the USSR are 300° and 160°F, respectively.

The major reasons for the use of the lower temperatures are the smaller system sizes and utilization in many cases of polyurethane insulation which has a temperature limitation of about 250°F. Some of the Japanese systems and one system in the Netherlands have supply temperatures up to 356° or 419°F, which is explained by the fact that those systems are not of the cogeneration type and therefore the high temperature does not affect the economics of the power plant.

The pressure in the piping network which depends on the system size and operating temperature varies between 130 to 250 psig during the winter and between 60 and 150 psig during the summer. Only for district heating systems with high supply temperature does the pressure in the network increase to 450 psig.

The optimal pipe diameter and water velocity in the network is usually determined by an optimization study, which takes into account the piping cost, the pumping power, and the heat loss in the network, to provide the minimum annual cost of the system. Based on the data reported, the water velocities range from 1.6 up to 13 fps, with an average of 7 fps.

2.1.2 District Heating Standards

Countries utilizing hot water district heating have developed special piping standards to which the networks are manufactured and tested. Special consideration is given to preinsulated, prefabricated, pipe-in-pipe type conduits.

In the United States, the Federal Construction Council of the National Academy of Sciences has developed a set of special recommendations for the design and installation of underground heat distribution systems.[4]

Finland, Denmark, Sweden, West Germany and the United Kingdom have established special working groups within the National District Heating Associations which are responsible for developing, improving and updating the existing heating network standards.

Efforts are under way to develop a European district heating standard. On May 17, 1979 during the International District Heating Congress (UNICHAL) in Stockholm, a meeting of the European standards committee, with representatives of most European countries involved in district heating, took place.

2.1.3 Heat Carrier Pipe Materials

Metallic pipes commonly available for district heating systems are usually made of steel, iron, copper or copper alloys. Some steel and cast iron pipes are available at standard sizes up to 30".[5] Copper pipe because of its high cost, is available at smaller standard sizes up to 6".[6] Pipes larger than standard sizes are still available, but involve a longer delivery period. Large systems use pipe sizes up to 40" in West Europe and up to 56" in the USSR.

Low-carbon steel pipes are the most extensively used among the ferrous materials. Seamless, longitudinally welded and spirally welded pipes are utilized. According to pipe manufacturers' information, spirally welded pipes have mechanical and physical properties equal at least to those pipes manufactured from similar steel by other processes. The manufacturer further indicates that a spiral welded pipe is subject to less stress from internal overpressure than a longitudinal welded pipe. However, the major problem with low-carbon steel pipe is its poor resistance to corrosion.

When the carrier pipe is made of steel, American district heating systems usually utilize a higher schedule than that of their

European counterparts. Some American pipe manufacturers produce schedule 40 or 80 pipes for high temperature hot water applications as their standard preinsulated pipes. In contrast, thinner-walled pipes are used in European district heating networks. Usually a wall thickness equivalent to schedule 10 or between schedules 10 and 20 is utilized. Typical dimensions of carrier steel piping utilized in West Europe[7] are presented in Table 2-1. Following the trend in reduction of pipe thickness, there is a Swedish company that manufactures pipes of schedule 10 (for pipes with diameters of 20" and 24") and below (for pipes with diameters below 20") as standard pipes for hot water applications.[8]

The difference in schedules of the steel pipe allows the European district heating enterprises to incur a lower capital cost in piping than that of their American counterparts. The reduction in piping schedule requires, of course, special attention to the network design and maintenance practices in order to prevent groundwater penetration to the external piping surface.

Most of the steel carrier pipes in West European district heating systems do not have any protective anti-corrosion coating except for some cases where rust inhibiting paint is used. In the USSR different protective coatings are used for corrosion protection of the pipe including heat resistant glass enamel, which should be noted, increases the piping installation cost.

The piping joints are welded and prefabricated bends are often utilized. Japanese utilities are using argon welding for piping joints. Practically all utilities have reported that the prefabricated piping is tested at the factory, and the piping system at the site is hydrostatically tested and the welds are x-ray examined (usually about 10 percent of the welded joints are x-ray inspected).

Table 2-1

PIPING USED IN EUROPEAN DISTRICT HEATING NETWORKS

1. WELDED STEEL PIPING

1.1 DIMENSIONS: DIN 2458

Nominal Pipe Size, in.	Outer Diameter in.	Wall Thickness, in.
28	28.00	0.346
24	24.00	0.280
20	20.00	0.248
16	16.00	0.248
14	14.00	0.220
12	12.75	0.220
10	10.75	0.197
8	8.63	0.177
6	6.63	0.157

1.2 Material: St 37-2, DIN 17100/66

1.3 Other technical terms of delivery: DIN 1626/65, sheet 3

1.4 Receipt: DIN 50049/60, point 2

1.5 Welding seam:
- The seam can be either longitudinally or spirally welded
- In the event of spirally welded tubes, the weld must be 100 percent x-rayed
- The welding seams must meet at least the x-ray classification 4 according to IIW
- The external welding bead should not exceed 20 percent of the wall thickness of the pipe

1.6 Length: 33 to 46 ft.

1.7 Ends of tubes: Calibrated and bevelled according to DIN 2559/62, form 2

1.8 Straightness of tubes: Straightness tolerance 0.59/33 ft.

1.9 Pressure test: Every tube must be hydraulically tested to at least 25 kp/cm^2 cold water at the factory

1.10 Surface treatment: Outer surface treatment of tubes must be done at the factory after fabrication with such rust preventer which protects the tubes in transit and during a short stocking at the customer.

2. SEAMLESS STEEL TUBES

2.1 DIMENSIONS: DIN 2448/61

Nominal Pipe Size, in.	Outer Diameter in.	Wall Thickness, in.
6	6.63	0.177
5	5.50	0.157
4	4.50	0.142
3	3.50	0.126
2-1/2	3.00	0.114
2	2.37	0.114
1-1/2	1.90	0.102
1-1/4	1.67	0.102
1	1.33	0.102
3/4	1.06	0.091
1/2	0.84	0.079

2.2 Material: St 35

2.3 Other technical terms of delivery: DIN 1629/61, sheet 3

2.4 Receipt: DIN 50049/60, point 2

2.5 Length: 20 to 40 ft.

2.6 Ends of tubes:
- nominal pipe size 6 in.: calibrated and bevelled according to DIN 2559/62 form 2
- nominal pipe size 5 in.: 15 straight, smooth

2.7 Pressure Test: Every tube must be hydraulically tested to at least 25 kp/cm^2 cold water at the factory

2.8 Surface treatment: Outer surface treatment of tubes must be done at the factory after fabrication with such rust preventer which protects the tubes in transit and during a short stocking at the customer.

Copper pipes are used extensively for district heating distribution systems in Europe and Japan. Utilization of copper piping in closed district heating networks carrying deaerated water increases substantially the corrosion resistance of the network. Copper pipes are generally used for temperatures up to 250°F and pressures up to 230 psi. Copper pipes are prefabricated in conduits and are delivered in large coils of about 80 ft. lengths depending on the pipe size. The pipe sizes range between 1/2 and 3 in. Larger sizes are supplied in straight lengths. Installation of long pipe sections reduces substantially the number of joints and provides a possiblity of bending the pipes in a sinusoidal pattern for thermal expansion purposes.

Depending on the operation temperature and pipe size, copper joints and fittings are usually connected by either brazing or with socket type fittings.

Stainless steel is used for small pipe sizes, and is available from West Germany in a conduit configuration. The pipes are flexible and can be buried directly in long continuous lengths, following curves and slopes similar to an electrical cable. Connections are made with standard fittings. The casing is corrugated steel with extruded polyethylene jacket. Corrugated copper in small pipe sizes is also utilized as a carrier pipe in the same "cable-pipe" fashion.

Cast iron, one of the earliest materials used in metal pipes, has a high resistance to atmospheric and soil corrosion and acceptable strength, but is brittle. Ductile cast iron pipes have reduced brittleness and are stronger than cast iron.

Recently a preinsulated conduit with a ductile cast iron carrier pipe has been developed in France.[9] The conduit has rigid polyurethane foam insulation and may be utilized for hot water temperatures up to 230°F. The pipes are connected with a bell/spigot type joint using a rubber gasket.

Wrought iron has high corrosion resistance and it is applicable for district heating installations but it is rather expensive, especially the pipe fittings.

2.1.4 Piping Installations

The district heating pipes in a city are usually installed underground. A buried pipe must be protected from groundwater and mechanical damage by enclosing it inside a conduit, culvert, etc. Insulation on the pipe is needed to minimize the amount of heat loss from the water, especially if the pipe is buried above the frost line. Different piping installation designs are used to protect the insulation and the pipe from damage and groundwater which tends to degrade the insulating quality of the material. The piping installation requirements could be summarized as follows:

- Prevention of water penetration to the piping surface.
- Provision of efficient heat insulation.
- The network components which require high quality should be manufactured at the factory and must be transportable.
- Have reasonable installation cost.

Most of the European systems are utilizing concrete culverts for pipe installations (Exhibit I). This method, for example, is almost exclusively used in West Germany.[10] Concrete culverts are used for pipe sizes of 10 in. and larger, and conduit designs for smaller size pipe installations. Japanese district heating systems of relatively small size are using mostly steel cased conduits. One Japanese company is utilizing ductless installation with powder backfill insulation. Tunnels are used whenever possible, especially in the Stockholm district heating system.

From the reliability point of view, it is very important that the piping installation be drainable and dryable. Most of the utilities surveyed provide for this, however, some indicate that pre-insulated systems do not meet this criteria. Most of the systems provide an air gap between the insulation and the culvert, but some pre-insulated systems do not.

A majority of utilities consider their piping systems resistant to groundwater infiltration and the spread of water. The preferable type of installation which has a resistance to water damage, corrosion and mechanical or structural damage is considered to be the concrete culvert. One utility points out that in a concrete culvert, wool insulation can easily be dried out. Other piping installations meet the above criteria to some extent. One utility has reported that conduit design is not resistant to corrosion.

The existence of groundwater drainage along the piping network is an important factor in ensuring the reliability of the system. However, 70 percent of the networks surveyed have no drainage system. Some utilities rely on the culvert itself as a good means for water drainage. The concrete culvert design is considered by most utilities to be simple in installation and in repair.

Concrete Culvert Installations

The main advantages of concrete culverts are strength, durability and the prevention of water penetration to the insulation. Typically, concrete culverts are designed for a wheel load of 15,000 lb. plus a forty percent increase for dynamic load consideration.[7] In order to make the culvert installation watertight, the breaking strength of the concrete should be about 300 kp/cm^2.

Concrete culverts cast at the construction site (Figure 2-1) are the most expensive, but when properly constructed, provide the most

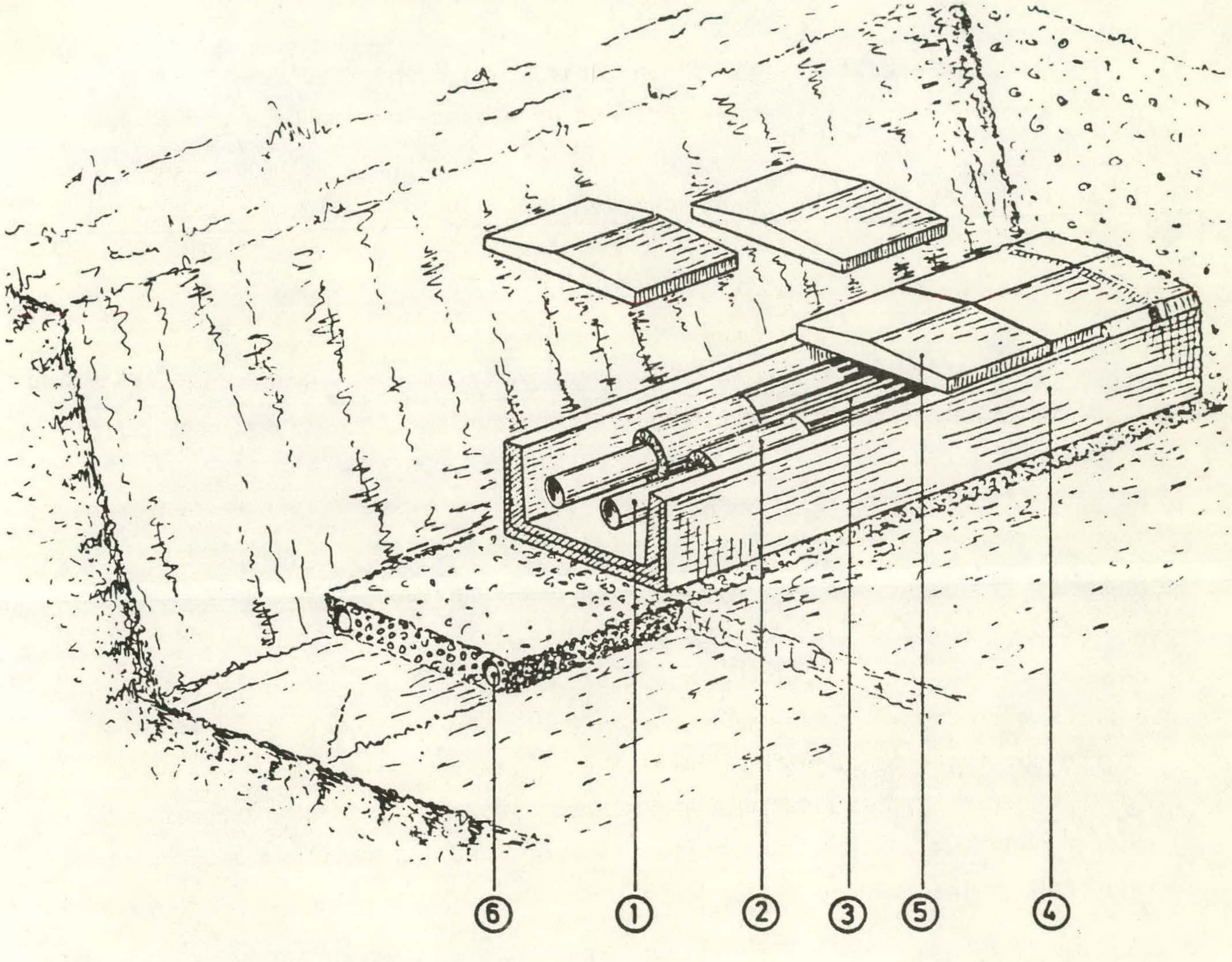


FIGURE 2-1 CONCRETE CULVERT CAST-IN-SITU

1 - Carbon steel pipe; 2 - Mineral wool insulation; 3 - Asphalt millboard; 4 - Concrete culvert; 5 - Concrete covers; 6 - Water drain pipe

watertight solution.[11] This installation is the best solution in exceptionally wet ground or in places where extreme strength is needed. The culvert should be waterproofed and usually a PVC band is used to seal the seams between the walls and the cover, and the joints between the culvert sections.

To reduce the installation cost, semi-fabricated culvert is often used. This installation consists of a cast-in-situ base and of a prefabricated cover. As an example, a Danish semi-prefabricated culvert installation is presented in Figure 2-2 and described below.[12]

The installation of the piping systems is provided as follows:

Prefabrication of the top cover. The concrete culvert is assembled from two components. The top cover, which requires the highest quality is prefabricated at the factory from reinforced concrete and it is waterproofed. If no in-leakage takes place, the culvert internal environment will be dry and non-corrosive with a temperature of about 100°F. Chemical resistance of the culvert should be provided if the soil components are acidic and road salt is used for snow melting. The cover element is usually 20 ft. long and weighs about 5700 lbs. These dimensions permit a truck with crane to transport and assemble the top cover. The length of the cover can be adjusted to local conditions, in lengths of about 20 to 25 ft. for hard foundations and shorter lengths of about 10 ft. for soft foundations. This reduces the risk of settling faults and of water penetration into the culvert.

Excavation and Drainage. A plastic sheet and steel forms are installed on top of the crushed stone (Figure 2-3a). The form includes slots for components, drainage grooves and rim demarcation. The concrete is then poured and smoothed. The culvert joints, even if properly sealed, may become loosened during the service which could result in water penetration into the culvert. Therefore, the design must have provisions to drain the water within the culvert to a manhole, and a 0.01 slope

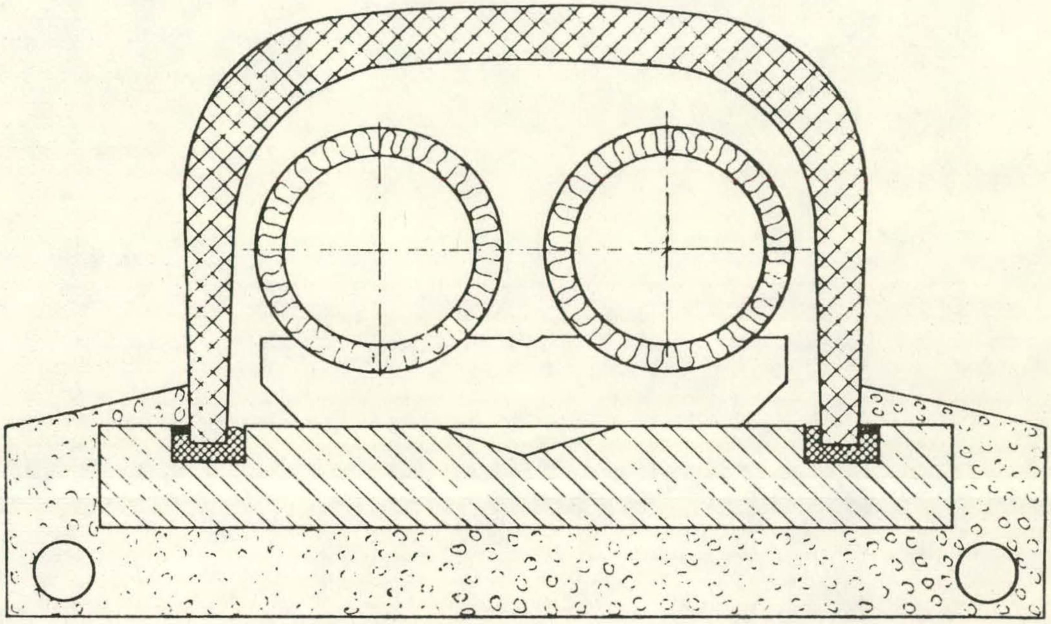


FIGURE 2-2 SEMI-PREFABRICATED CONCRETE CULVERT

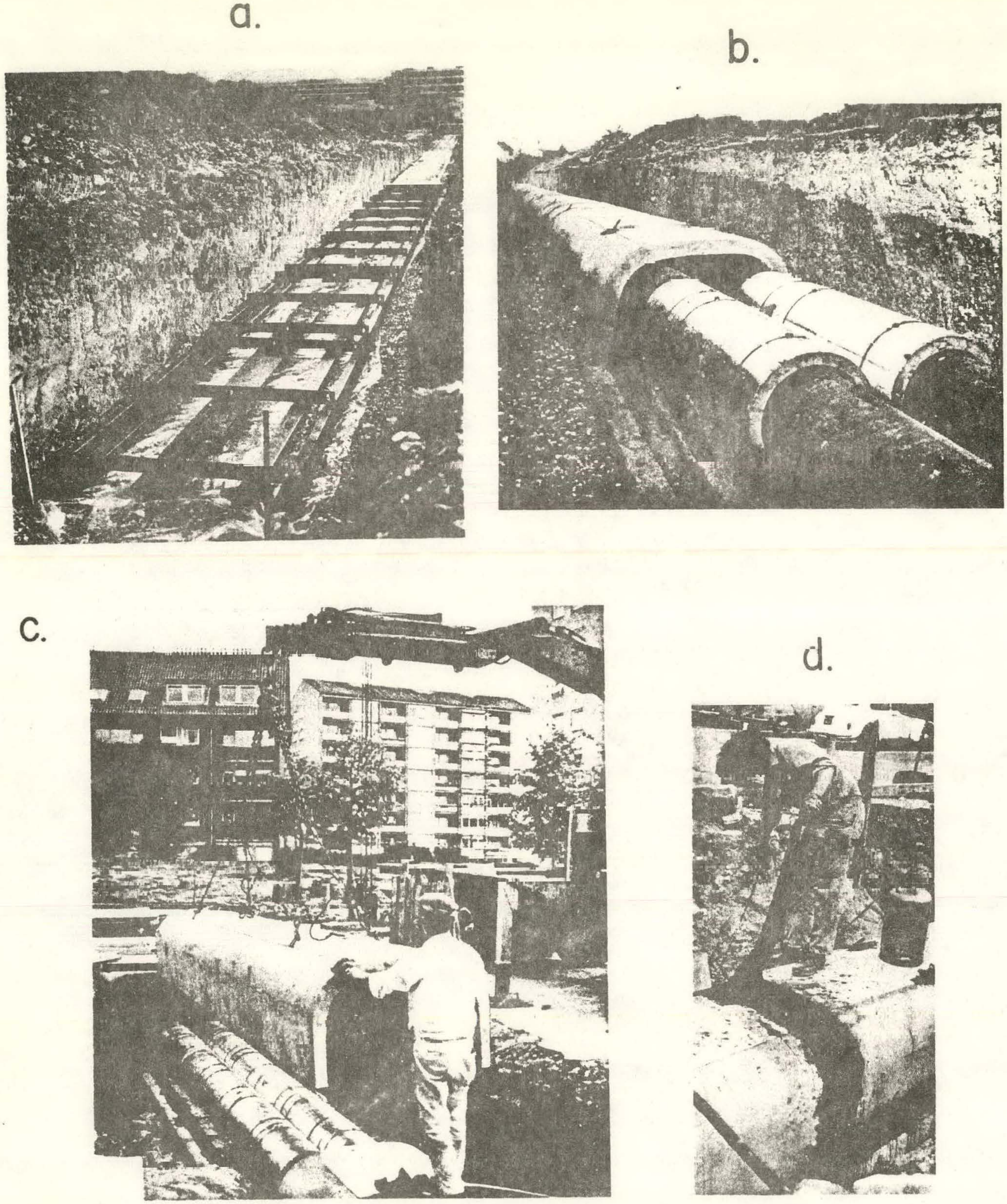


FIGURE 2-3 CONSTRUCTION OF A SEMI-PREFABRICATED CULVERT

should be provided. The drain grooves are connected to the sewage system through inspection wells.

Pipe Installation and Insulation. Polyurethane insulation can be used within suitable weight grades which has compressive strength enough for the insulation to support heating pipes on saddle-shaped concrete base plates.

Polyurethane liners are supplied grouted in a protective casing of either bituminous felt or aluminum foil in lengths of about 3 ft. (Figure 2-3b). The liner is split lengthwise like other insulating pipe covers, and can thus be hinged directly on the pipes. The opening in the liner is placed downwards so that a couple of bindings with tape per component is sufficient to keep the two halves of the liner closed. Glass wool or mineral wool insulation is used for temperatures above 250°F. An external jacket is usually not applied so that moisture can always evaporate. A plastic sheet, however, is often used to cover the top of the pipe insulation for protection against the possibility of water dripping on the pipes.

Placing the Covers. The covers are placed 4 to 8 inches apart (Figure 2-3c). Just before positioning, cement mortar is applied to the outermost grooves. The mortar is immediately removed from the outside, and, at the same time, an 8 in. deep groove is etched.

Joints. After the cement mortar hardens, hot asphalt is poured into the groove, thereby completing the longitudinal joints. The joints between the covers are also waterproofed. This is accomplished with a thick, 10 in. wide glass fiber reinforced band of bituminous material which seals the two components. To protect the bituminous band from stone damage during the backfilling, a 4 in. wide polyester liner is taped over the joint. A 20 in. wide bituminous felt band is placed over the pipe joints as further protection against any water penetration (Figure 2-3d).

Backfilling. The area along the base plate is cleaned out. The excess plastic sheet is scraped off and about 4 in. of crushed stone is placed over the base plate. The trench is then filled in with sand.

The culvert is designed to withstand an axial load of 22,000 lbs. and a cover pressure of about 100 psi. The strength of the concrete in the cover is 250 kp/cm^2 and in the base plate about 150 kp/cm^2. This corresponds to European Common Market regulations for road loads. The minimum earth cover required is 1.6 ft. The culvert, however, may be installed as deep as 30 to 50 ft. When exposed to earth pressure, the culvert is considered as a double joint arch for static forces. For wheel pressure, the culvert's spatial effect has been considered. In addition, the culvert is also designed to withstand a restraining force of 2 x 32,000 lbs., which represents the test pressure on the axial expansion devices in the heating pipes. This force is absorbed in the base plate through a cast vertical steel girder. The concrete base is reinforced at the points of attachment. No other reinforcing of the base plate is provided.

A prefabricated concrete culvert is presented in Figure 2-4. Dimensions of the culvert for pipe diameters between 6 and 28 in. are given[13,14] in Table 2-2. The length of the prefabricated elements vary according to pipe size from 7 to 15 ft. The cross and longitudinal joints of the culvert are sealed with a rubber bitumen band. The cross culvert joints are also protected with cement mortar.

Vent stacks are usually installed to permit humidity to escape from the culvert. They may be used also for forced drying, when necessary. For that purpose, compressed air is blown into one vent stack.

Conduit Installations

In the last 10 to 15 years, various types of conduit installations have been developed and extensively used for pipe sizes up to about 8 or 10 in. (Figure 2-5).

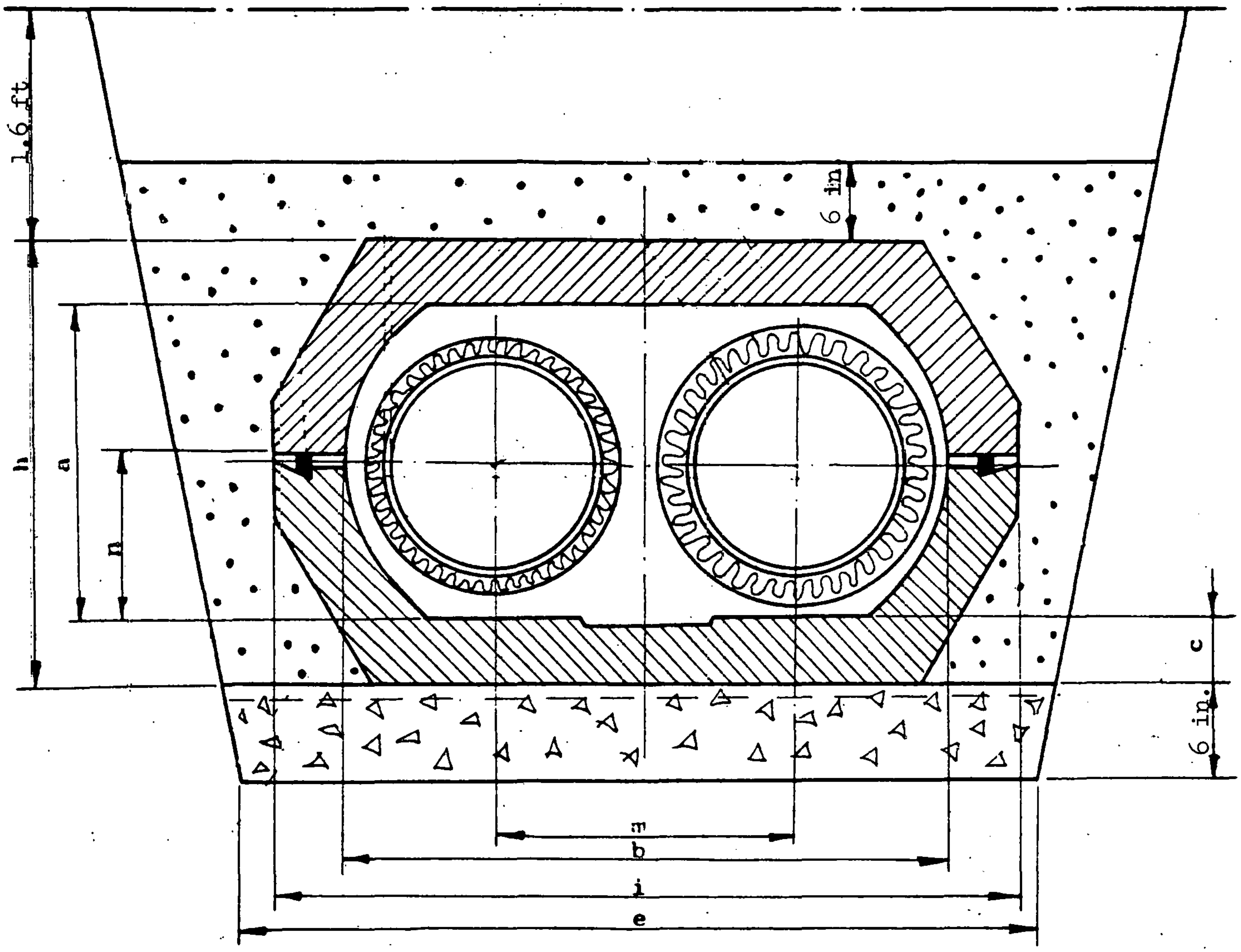


FIGURE 2-4 PREFABRICATED CONCRETE CULVERT

Table 2-2

DIMENSIONS OF A TYPICAL PREFABRICATED
CONCRETE CULVERT (FINNISH STANDARD)
CARRIER PIPE DIAMETERS OF BETWEEN 6 AND 28 IN.

Nominal Pipe Diameter	Dimensions, in.							
	e	h	i	a	b	n	m	c
28	85	50	84	37	71	20	37	6
24	73	44	72	34	62	18	31	5
20	67	38	64	29	54	15	27	5
16	55	32	52	24	43	12	22	4
12	49	27	45	20	37	10	19	4
10	43	24	39	17	31	9	15	3
8	40	21	34	15	27	8	13	3
6	36	18	29	12	22	6	11	3

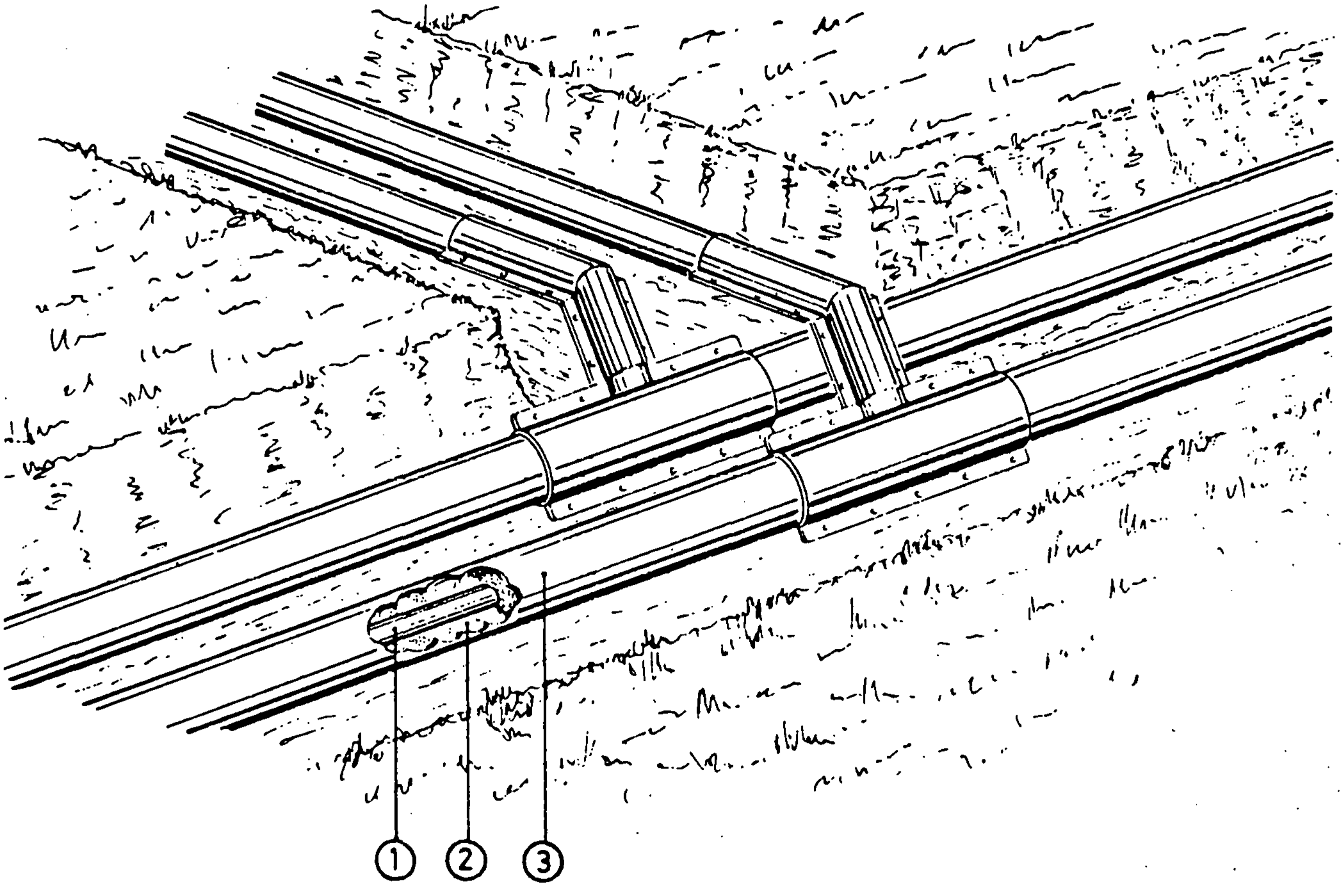


FIGURE 2-5. TYPICAL PREFABRICATED CONDUIT

1 - Carbon steel carrier pipe; 2 - Polyurethane insulation; 3 - Polyethylene casing

A conduit comprises a jacket or casing enclosing the heat carrier pipe which may or may not be insulated. The conduits are completely prefabricated and tested at the factory and only jointing is performed at the installation site. This allows quicker installation of the pipes, making it cheaper than insulating the pipes in the field.

The selection of the proper casing material is essential if the pipeline insulation system is to perform its specified function over the projected life of the line. In the absence of a casing, electrochemical corrosion of the metallic carrier pipe arises from the seepage of ground-water through an absorbent insulation, thus shortening the line life.

Current technology encompasses a wide range of casing materials. At present, the following materials[15] are used to protect the insulation and to prevent water penetration:

Tubes

Extruded HDPE (high density polyetheylene); extruded LDPE (low density polyethylene); extruded PVC (polyvinylchloride); extruded polypropylene; aluminum; carbon steel; corrosion coated carbon steel; stainless steel; asbestos cement; fiber reinforced epoxy or polyester.

Wraps and Films

Polyethylene film and tape; polyvinylchloride film and tape; bitumastic impregnated paper; polybutylene film and tape.

Coatings

Bitumastic blends; fiber reinforced polyesters (FRP); fiber reinforced epoxy (FRE); flexible urethane elastomer.

With the exception of carbon steel, all of the above-mentioned casing materials have excellent resistance to electrochemical corrosion. However, with a coating of epoxy-type resin, reinforced with fiberglass cloth or an outer wrapping of asphalt impregnated, fiberglass reinforced, asbestos pipe line felt, carbon steel exhibits improved corrosion resistance. It is generally good practice to provide coating and cathodic protection for carbon steel pipes. Coating alone does not provide adequate protection since accelerated failures often occur at coating flaws. An appraisal of the effectiveness of outer casing materials for insulated pipes is provided in Table 2-3. It should be noted that although wraps and films are anti-corrosive, they do not provide sufficient corrosion protection for the piping. Asbestos cement conduit is not recommended where soil pH is below 5.0. Utilization of asbestos cement is prohibited now in some countries because of reports that show it may be carcinogenic.

Casings are manufactured as smooth-walled (Figure 2-6)[16] or corrugated (Figure 2-7).[17,18] Corrugated casings are flexible as a result of the inherent action of the corrugations.

Some manufacturers produce conduits that allow an air space between the insulation and the casing. This is a desirable feature because if there is any water in the insulation layer, it is evaporated into the air gap. However, conduits without an air gap are also extensively used.

As an example, a conduit without air gap is widely utilized in West Europe and described as follows.[19,20] The prefabricated conduit consists of a carbon steel carrier pipe and a polyetheylene casing moulded together with the insulation. The conduits are installed directly into trenches with a minimum cover of about 1.3 ft. surrounded by homogeneous stone-free sand. A minimum 4 in. sand bed is also required.

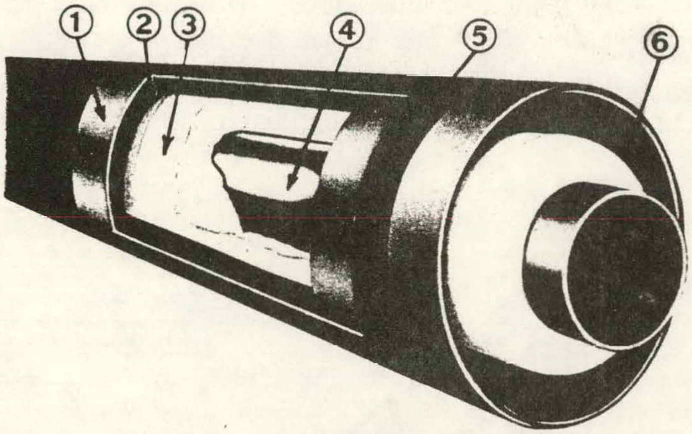
After butt-welding the pipe sections together, the joints are completed with a steel fitting, which is coated with a thick ductile layer of polyethylene. Prior to installation at the steel fitting, an elastic sealing compound is applied to all joint surfaces as an added safeguard against the ingress of water (Figure 2-8). For large pipe

Table 2-3

AN APPRAISAL OF THE EFFECTIVENESS OF CASING MATERIALS FOR INSULATED CONDUITS

	DESIRED CHARACTERISTICS								
	Leak Proof	Permeability	Impact Resistance	U.V. Resistance	Abrasion Resistance	Chemical Resistance	Corrosion Resistance	Bendability	Repairability
TUBES									
HDPE	E	E	E	E	E	G	E	E	G
LDPE	E	E	E	G	G	G	E	G	G
Polypropylene	E	E	E	F	G	E	E	P	E
PVC	E	E	G	F	G	E	E	P	E
FRP	G	E	F	F	G	G	E	P	G
FRE	E-F*	E	F	F	G	G	E	P	G
Aluminum	E-F*	E	G	E	G	G	E	P	F
Carbon Steel	E-F*	E	E	E	E	F	P	P	F
Corrosion Coated Steel	E-F*	E	E	E	E	G	E	P	F
Stainless Steel	E-F*	E	E	E	E	E	E	P	F
Cement	F	E	F	E	G	E	E	P	P
WRAPS AND FILMS									
P.E. Film	P	P	P	P	P	G	E	P	P
PVC Film	F	P	P	P	P	G	E	P	P
Bitumastic Paper	F	P	P	G	P	P	E	P	P
Polybutylene	F	P	P	P	P	G	E	P	F
COATINGS									
Bitumastic	P	P	P	G	P	P	G	P	G
FRP	G	G	F	F	G	G	E	P	E
FRE	G	G	F	F	G	G	E	P	E

E = excellent
G = good
F = fair
P = poor
* - depending on type of manufacture



1. 10 gauge (min.) steel conduit.
2. Air space.
3. Insulation, as specified.
4. Pipe, as specified.
5. 20 mil (min.) cold-setting epoxy coating reinforced with fiberglass cloth.
6. 6 mil (min.) epoxy coating on inside of conduit surfaces.

FIGURE 2-6 SMOOTHWALL EPOXY COATED CONDUIT

Courtesy of Ric-Wil, Inc.

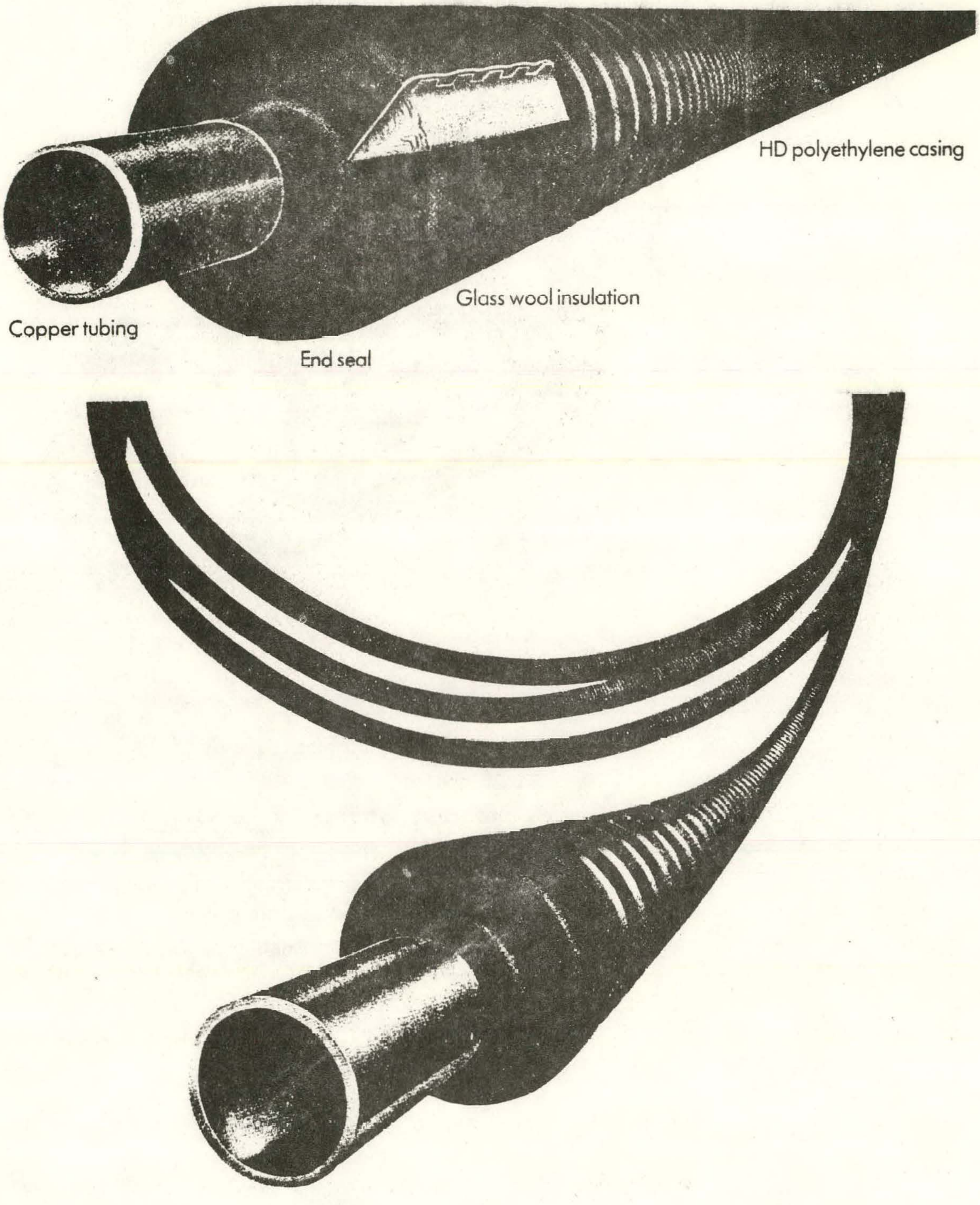


FIGURE 2-7 CONDUIT WITH A CORRUGATED CASING

Courtesy of Aquawarm, Sweden

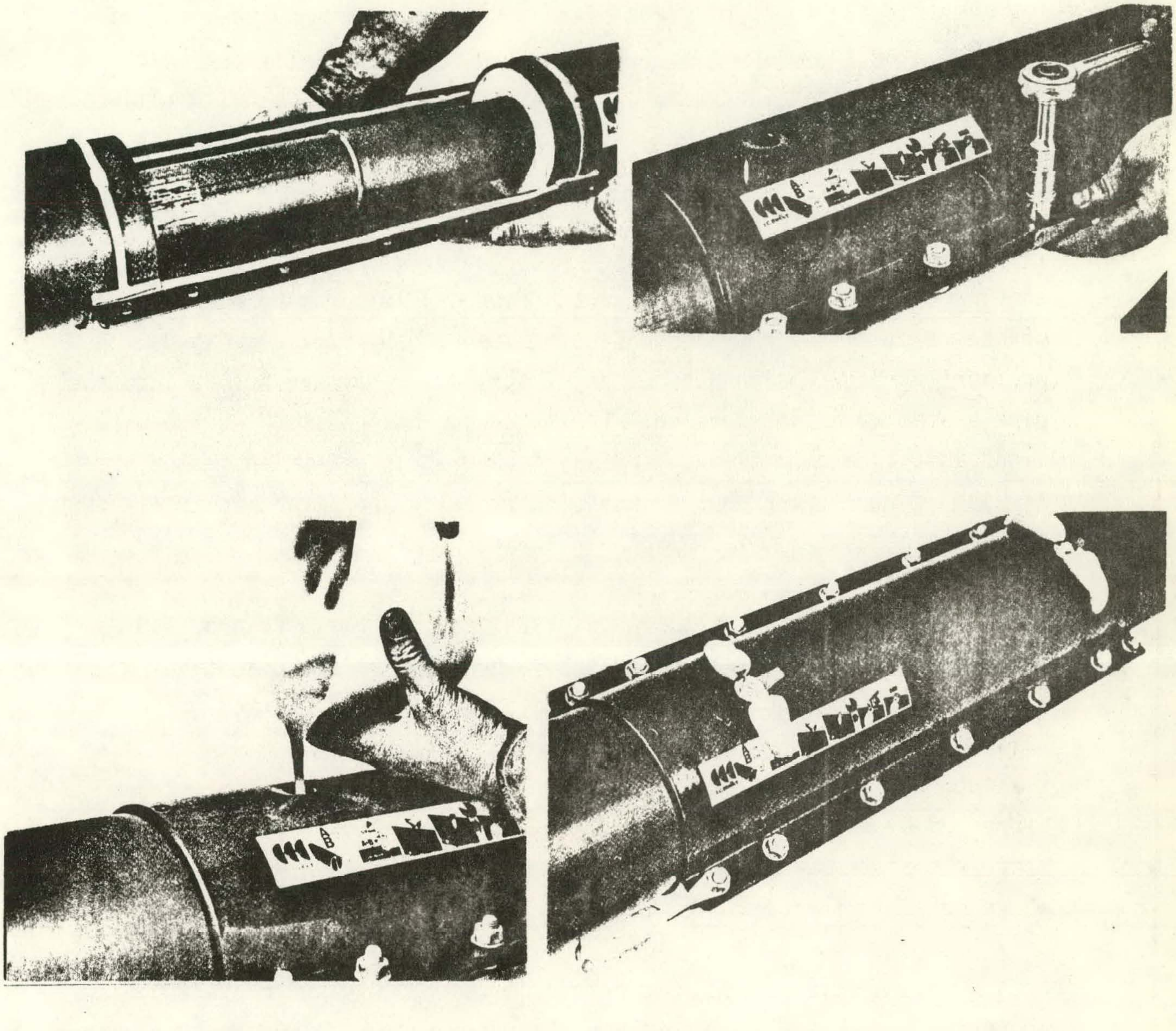


FIGURE 2-8 INSTALLATION PROCEDURE FOR SMALL SIZE CONDUITS

Courtesy of i.c. møller

sizes the joints are sealed by the application of a robust shrink sheet. An aluminum sheet with filling holes is placed around the pipe ends. The sheet is tightened by means of a steel-strapping machine and then riveted. The foam liquid is poured through one of the filling holes. Afterward the shrink sheet is placed around the insulated joint (Figure 2-9).

For larger pipe sizes, preinsulated bend fittings and branch fittings are supplied. The branch fittings are manufactured with a combination of main and branch pipes (Figure 2-10). Where expansion movements of the pipe system cannot be absorbed by expansion loops, prefabricated expansion devices are installed. They are welded into the pipe system as a pipe section. The expansion bellows is a sealed watertight unit in a robust insulated jacket and it is delivered in the prestressed form. The expansion unit is typically installed midway between anchor points.

Preinsulated ball type isolation valves are also provided which are installed directly in the ground. The valve consists of an all-welded casing and a polished stainless steel ball, fitted with spring loaded teflon seats which make the valve watertight. When backfilling, the spindle of the isolation valve must be led up to surface protected by a polyethylene-pipe. When making roads or pavements the spindle must be terminated in a cover of suitable dimensions with space where possible for operation of one or more valves.

Anchoring of the pipes is achieved by welding in preinsulated anchors (Figure 2-10). The anchor flange is welded to the steel carrier pipe.

A different type of conduit utilized in West Europe[21] is presented in Figure 2-11. The culverts are manufactured for one, two or

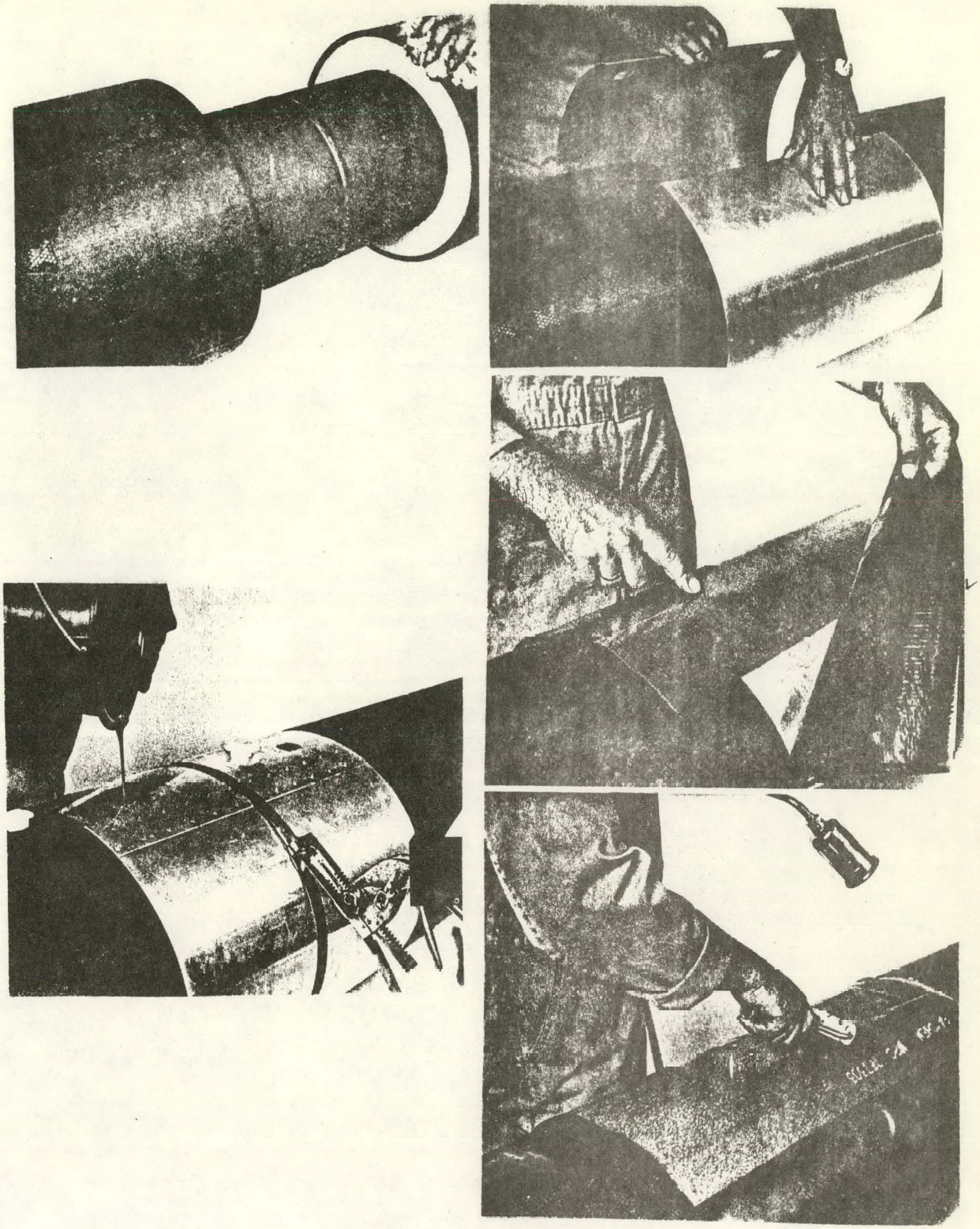


FIGURE 2-9 INSTALLATION PROCEDURE FOR LARGE SIZE CONDUITS

Courtesy of i.c. møller

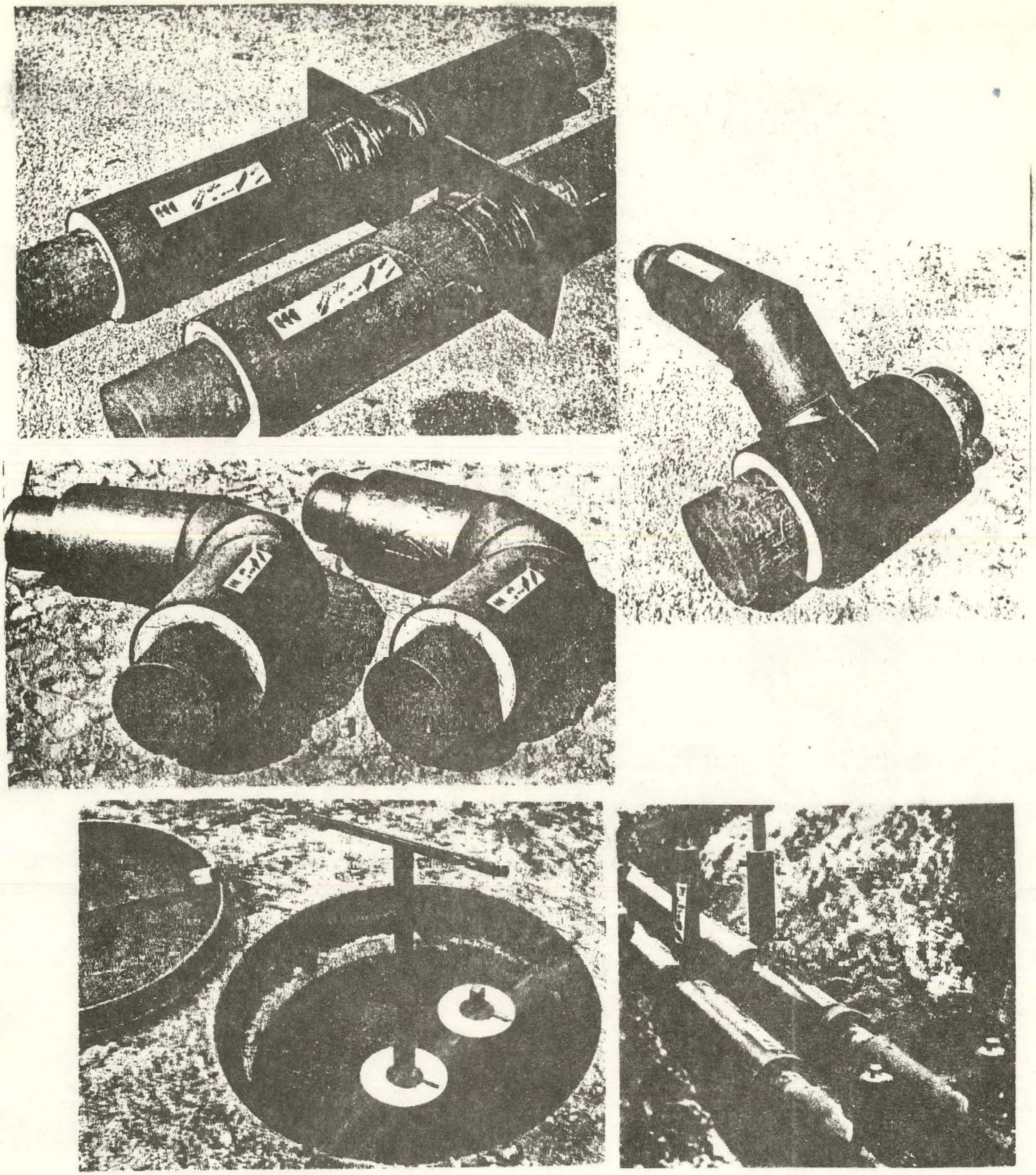


FIGURE 2-10 PREINSULATED ELEMENTS OF THE CONDUIT SYSTEM

Courtesy of i.c. møller

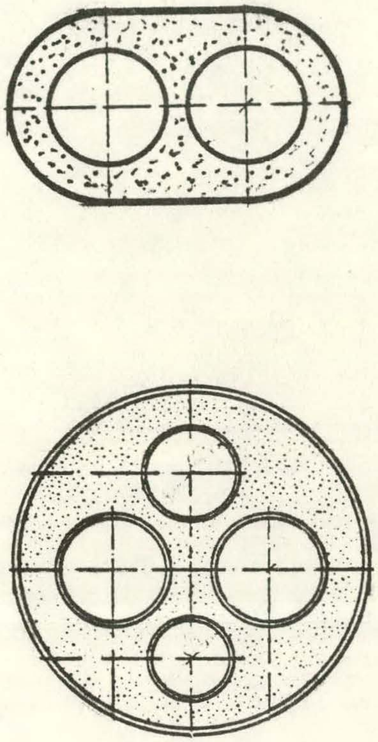


FIGURE 2-11 DOUBLE CASING CONDUIT

Courtesy of OY Fiskars AB,
Finland

four pipes with dimensions from 1 x 5 in. up to 1 x 10 in., 2 x 1 in. up to 2 x 8 in. and 2 x 1.5 x 1 in. up to 2 x 4 x 2.5 x 1.5 in. Polyester tubes with a high percent of glass reinforcement are used as internal casing to protect the insulation material from mechanical and thermal strain caused by the steel tubes. The insulating material is a hard polyurethane foam. The outer casing is made of LD-polyethylene, which is resistant against stress cracking and chemical corrosion. The culvert has a built-in pipe for water drainage. Problems have occurred in the past in which the casing did not withstand handling at temperatures down to -4°F. For this reason, the glassfibre casing was changed to HDPE and in turn to LDPE.

The conduit elements are fitted on the carrier pipe as the welding proceeds. The prefabricated conduits are about 30 ft. long and they are jointed with rubber bitumen felt. The joint is protected with reinforced concrete or with shrink sleeves of polyethylene. The advantages of this system are the small space requirement and relatively long prefabrication length. It has proved satisfactory in branch piping between the main line and buildings.

Proper backfilling of the conduit is a very important procedure. The manufacturer's specifications have to be followed with care in order to achieve the required protection for the pipe. For example, a sand bed may be required before laying the conduit. Then another layer of sand is poured over the piping line and compacted to whatever relative density is specified by the manufacturer. The remainder of the trench is then backfilled with topsoil and compacted. While some manufacturers do not recommend vibratory or tamping equipment for fear that the equipment may drive small stones into the pipe wall, other manufacturers do not restrict the use of such equipment. This usually depends on the conduit design.

Directly Buried Pipeline Insulated with Powder Backfill

The insulating materials existing in granular form may be hydrocarbon (asphaltic material of high resin content) or inorganic in nature. Both types of insulating material are used as part of the backfill of the trench holding a buried pipe.

A necessary condition in using asphaltic material is the detection in their composition of aggressive impurities (sulphates and others), carbenes, and carboids. An indication of purity is the solubility in benzene, which should not be less than 90 percent, and ash concentration on calcination, which should not be higher than 5 percent by mass. When utilizing asphaltic material, curing is required, which is provided by maintaining a controlled temperature in the carrier pipe. Curing allow the formation of a consolidated anti-corrosive coating on the pipe, surrounded by a semi-porous intermediate zone that has some insulating value, and an external zone or loose aggregate. This external zone guarantees retaining most of the heat-insulating and load-bearing capabilities of the structure (Figure 2-12). This method can produce the required three-zone condition only if the curing temperatures are carefully controlled. A major problem is that the melting point of asphaltic materials can vary by more than $100^{\circ}F$. So even with carefully graded material, the desired curing may not be uniform.[22]

A similar method utilizing the homogenous mixture of bitumen and cork as a backfill insulation is widely used in Europe (Figure 2-13).[23]

The inorganic insulating material does not require any curing. It is poured into the trench into a form built around the carrier pipe to establish the configuration of the insulating envelope. The form is filled to whatever level is recommended by the manufacturer for a certain size pipe. The system depends on the inherent water resistance of the insulating material to keep water out. Since the resistance of the material to water infiltration can break down under water pressure, such systems will not perform satisfactorily if the groundwater level is of such a height that an excessive head of water is imposed. Even if the system is not below groundwater level, a drain pipe should be installed to take away any water that may otherwise accumulate.

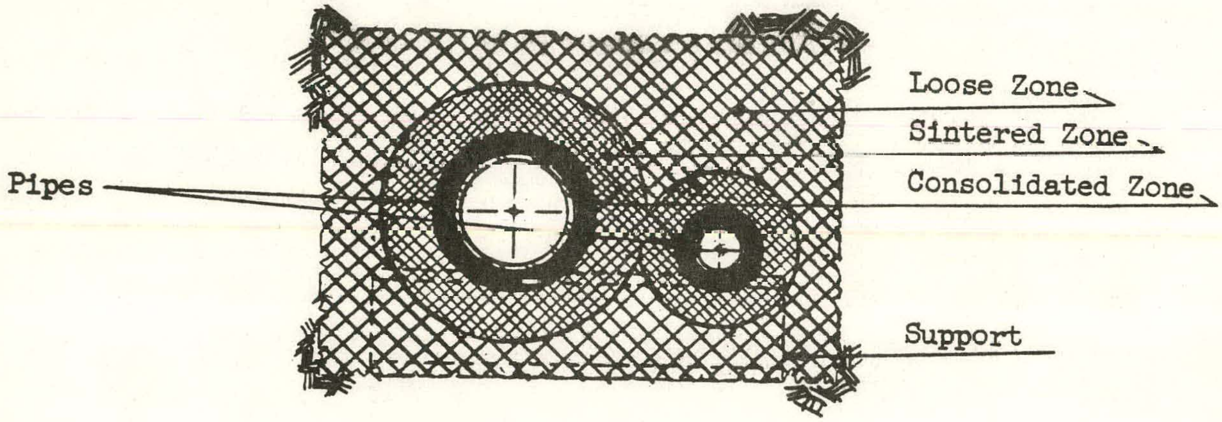


FIGURE 2-12 DIRECTLY BURIED PIPELINE INSULATED WITH HYDROCARBON BACKFILL

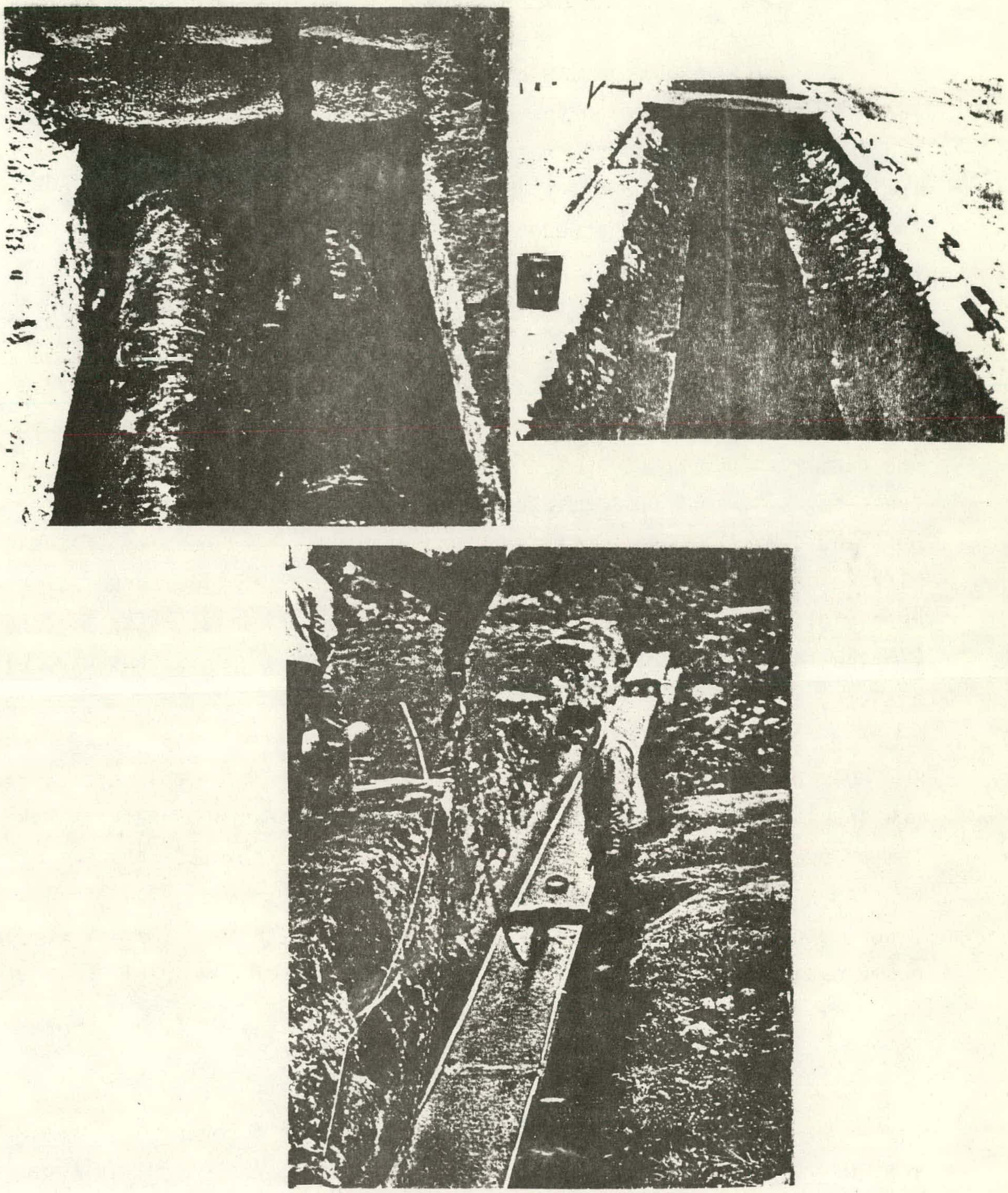


FIGURE 2-13 DIRECTLY BURIED PIPELINE INSULATED WITH BITUMEN AND CORK

Courtesy of Lebit A/S

Rigid Concrete Envelope

The poured concrete envelope provides a physical barrier against water contact with the piping (Figure 2-14). Reinforcing bars are included in the structure to prevent cracking of the concrete resulting from the thermal gradient imposed between the piping and the ground. An air gap is provided between the insulation and the concrete to permit thermal expansion of the pipe. Pipe supports and anchors are also provided to control movement of the pipe towards the expansion joints.

In this type of installation, concrete may also be utilized as an insulating material. This design has a concrete slab base to support the carrier pipe, which is surrounded by an envelope of insulating concrete. The most common insulating concrete used is a mixture of portland cement and vermiculite (expanded mica). The density of the mixture can be varied to be either firmer for better pipe support, or more yielding, to absorb thermal expansion. To minimize water penetration, either the carrier pipe or the concrete envelope is protected with a cover, such as asphalt-impregnated felt.

One attempt at constructing a watertight system of this type is a new insulating concrete employing a polystyrene bead aggregate. This new product is highly water resistant.[24] Another attempt consists of pouring insulating concrete into an elliptically shaped shell of fiberglass-reinforced epoxy to which a fitted cover with seal forms a complete outer casing. Drains are provided at the bottom of the shell.

Leakage Detection System

A leakage detection system installed with the piping system is most useful. It saves time in identifying the source of the leakage. The sooner a leakage is detected, the lesser the damage to the piping system. Moreover, it also reduces the disruption in service time.

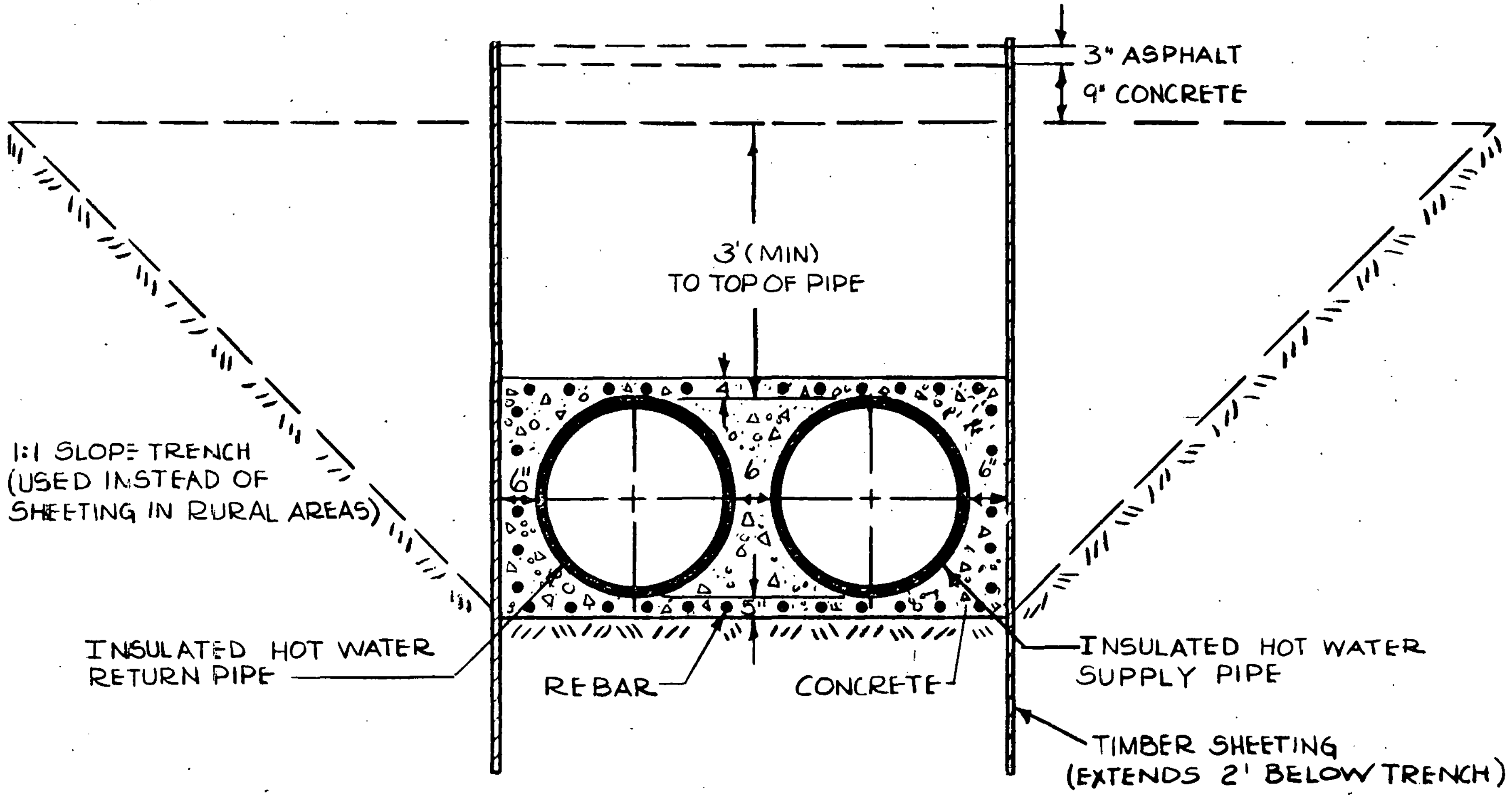


FIGURE 2-14 RIGID CONCRETE ENVELOPE

One type of leakage alarm system used by several manufacturers[19,25] utilizes two copper wires. They are centered in the insulation on opposite sides of the steel tube (Figure 2-15). The leakage detection system uses an electronic digital fault locator, which is the heart of an integrated alarm system. It monitors the complete piping system and at the same time combines the fault indication with an immediate localization of the fault.[19,26]

2.1.5 Current Excavation Practices

The depth of soil cover for underground piping very much affects the overall piping cost and is therefore of great importance. The depth of a trench depends on the size of the pipe, thickness of the conduit or culvert, the frost line of the particular area, and the type of traffic involved in the area. The force acting on a buried pipe is the summation of the live load (e.g., axle load of a vehi-cle) and the dead load (e.g., the weight due to backfill). The live load acting on a buried pipe decreases as the earth cover increases. Conversely the dead load on the pipe increases with depth of earth cover. For example, for a pipe buried under highways traversed by trucks, the force acting on the pipe is mainly due to the live load for the first 2 to 3 feet of earth cover. From 3 to 10 feet of earth cover, both the live load and the dead load due to backfill are of equal concern in determining the structural integrity of the pipe to withstand the two loads. With this range of earth cover, the live load acting on the pipe decreases, but the dead load increases, such that the summation of both loads may be almost constant. However, when the earth cover increases beyond 10 to 12 feet, the pipe experiences mainly the dead load acting on it. The live load has a negligent affect on the pipe at this depth.

If a conduit or culvert is used to protect the buried pipe, the depth of earth cover can be varied according to the strength of the conduit or culvert. An economic analysis has to be done to determine

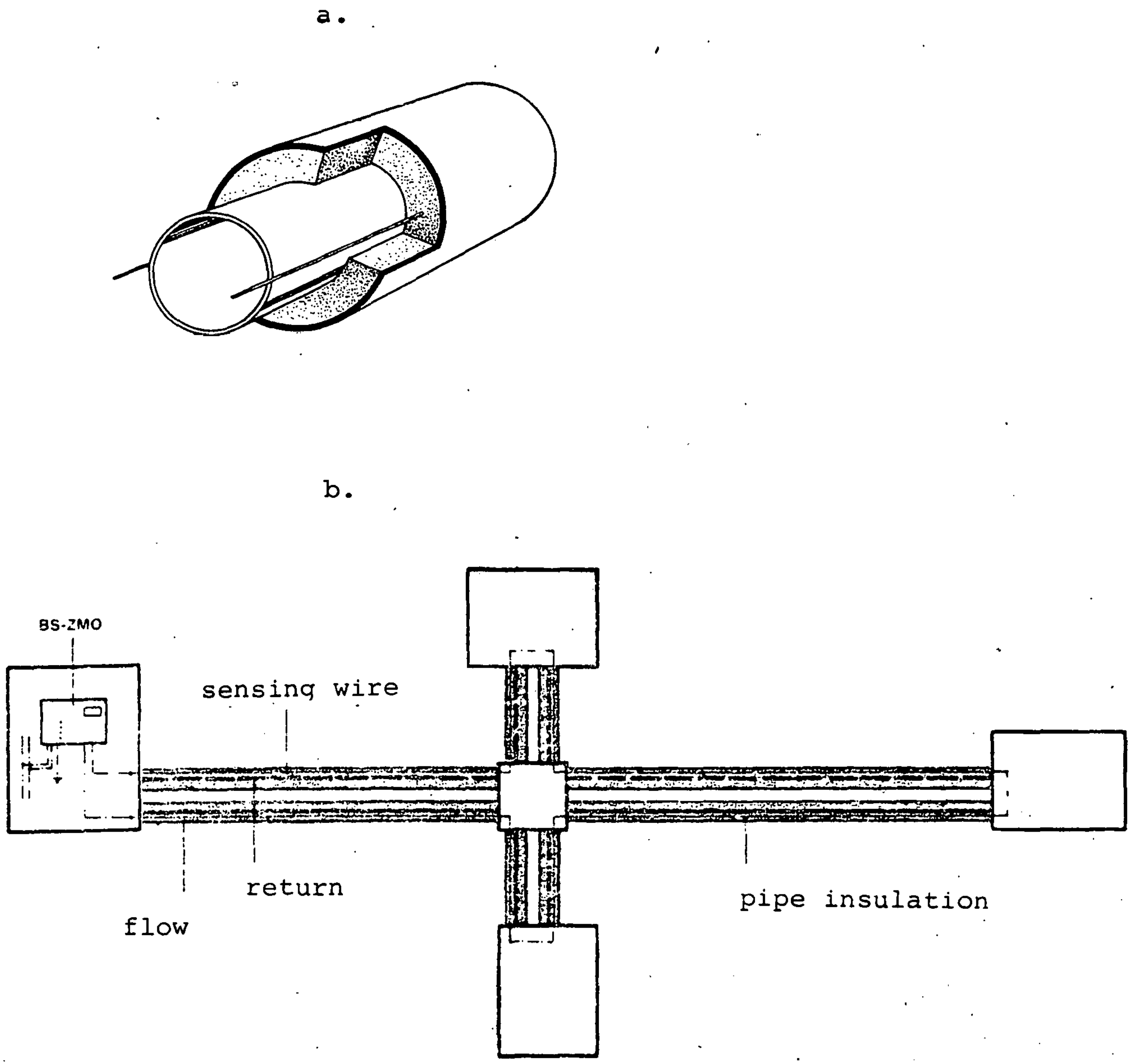


FIGURE 2-15 LEAKAGE DETECTION SYSTEM

a. Leakage Detection Wires
Courtesy of Lubonyl

b. Network Leakage Detection Example
Courtesy of Brandes Co.,
West Germany

the optimum depth of earth cover and the thickness of the conduit or culvert.

The current survey indicated that the depth of the cover varies for different systems from 1.6 to 10 ft. in the urban areas, and from 1.6 to 5 ft. in suburban areas. The average depth however is about 4 ft. based on data reported by 12 of the utilities. It should be mentioned that in many European systems the depth is even less.

Trenching. The major advantages of the trenching method are the ability to use specialized machines for rapid excavation and the low cost involved in this type of excavation. Speed in excavation would be reduced in congested areas where large numbers of underground utility lines may be installed already. In such a case, great care should be given during excavation to ensure that there are no damages to the utility lines, which would result in discontinuity of services.

In city streets, where they are paved, excavation commences after the paving material is cut. Where possible, any excavated earth will be piled on the street while trenching. Where street space is not available, the removed earth has to be hauled to some other location and then transported back to its original location when backfilling.

When the overall depth of a trench exceeds 5 ft., sheeting or alternate means to shore and brace the sides of the trench are necessary to meet OSHA requirements. In rural areas where a permanent street surface does not exist, the sides of the trench may be sloped at an angle of 45°. This approach is less costly than the use of sheeting,[27] but it is not practical in urban and suburban areas because of the excessive width of the trench required.

Plowing-in. A modification of the trenching method is the plowing-in technique. The beauty of this technique is that an open trench is not excavated. In this method, a plow is inserted into the earth to the desired depth. As the plow advances along its entire run, it separates the soil. The plow does not turn the soil though.

Two methods are used to place the pipe in the opening.[28] In the first method, called "pulling-in," the pipe is pulled through the entire length of the opening created by the plow. "Pulling-in" is usually used with large diameter pipes only. Such pipe sizes cannot be fed from reels as is used in "feeding-in", the second method. In "feeding-in," the pipe is fed into a "cable shoe." The pipe is laid along the bottom of the slit as the shoe moves through the earth. This is satisfactory for small size pipes which are delivered in coils, like copper,[29] polyethylene, and polybutylene. Such a technique can be used to install more than one pipe simultaneously.

An advantage in plowing-in is that as it does not eliminate surface disturbance, the total amount of earth moved is minimized. However, plowing-in can be used in streets only if the paving material is removed or cut beforehand.

Tunneling. Tunneling requires three essential steps to be undertaken. First, material at the face of the tunnel has to be excavated. Second, the excavated material from the face of the tunnel has to be removed and hauled to the surface. Third, the structural integrity of the opening of the tunnel has to be maintained for reasons of safety and operability.

Economic methods still have to be developed to produce long, small diameter tunnels.[28] Tunneling is more commonly used when the depth of the installation is too great for trenching.

2.1.6 Insulating Materials

Polyurethane

Polyurethane foam is commonly used as an insulating material by pipe manufacturers. The popular use of polyurethane in the United States and Europe is a result of its low thermal conductivity of 0.18 BTU/in/hr/ft^2/^{0}F that can generally be obtained.[5] However, the material age and operating temperature also significantly affect the resultant thermal conductivity. Consequently, polyurethane is used for pipes with operating temperatures not higher than 250^{0}F, in order to retain its insulating quality.

The polyurethane foam components must be properly weighed or metered, and thoroughly mixed at closely controlled temperatures, to produce a foam with optimum physical properties.

There are basically three methods for the machine manufacture of foams, i.e., froth, spray, and foamed-in-place. Froth foam is produced by mixing the liquid components with either a volatile liquid or a secondary blowing agent in the mixing head so that the foam is dispersed in a partially expanded state. A spray foam system, as with any other, requires the accurate metering of components, but the temperature control of the components is more critical than in the other processes. The mixing of the components is normally dependent on the viscosity of the streams, and therefore the temperature of the components (which controls their viscosity) also controls the mix. Foamed-in-place refers to a system where the liquid components are accurately metered and mixed in the mixing head, dispensed as a liquid and placed in the mold in the liquid state. This method is superior to the froth and spray methods only when properly installed. The liquid material must be evenly distributed to reduce the distance it must travel in order to fill a void. When this is done, a foamed-in-place system will produce an even, uniform foam with a minimum of voids.

To inspect the pre-insulated pipe for voids, an optical infra-red thermometer such as the Mikron 10 is used.[15]

Most pipe manufacturers use the foamed-in-place method. The foam is bonded between the carrier pipe and casing and capped at both ends with water and heat resistant seals to ensure complete encasement, thus maintaining the high thermal efficiency.

Polyurethane foam, while offering high thermal efficiency as an insulating material, has certain characteristics which require that it be adequately protected. Specifically, moisture penetration of foam will result in a significant increase in thermal conductivity. Although the polyurethane foam is not hygroscopic, due to its closed cells, it cannot stand the influence of water vapor. Proper casing also is a requirement to protect the foam from chemicals, vermin, mechanical abuse, ultraviolet degradation, erosion and other deleterious environmental hazards. Finally, unprotected foam is subject to mechanical damage from weathering, handling abuse, field bending, lay-barge tensions and bends, casing pressures, water pressure, saddle-bearing forces, ground movement, and damage in storage.

A comparison between requirements for polyurethane insulation in prefabricated conduits in West Germany, Denmark, and Sweden, as discussed at the 1979 International District Heating Congress, is presented in Table 2-4.

Calcium Silicate

Calcium silicate is widely used in the U.S. to insulate pipes conveying high temperature fluids because of its ability to retain its insulating quality at high temperatures. The thermal conductivity of calcium silicate ranges from 0.42 at 200^{o}F to 0.7 to 700^{o}F. According to one manufacturer, its asbestos free calcium silicate insulation is

TABLE 2-4

COMPARISONS BETWEEN PRESENT NATIONAL MINIMUM REQUIREMENTS FOR POLYURETHANE FOAM INSULATION IN FACTORY MADE, PRE-INSULATED PIPE-IN-PIPE SYSTEMS FOR DISTRICT HEATING

Art of the test	AGI Q 167 draft specification West Germany	Dutch draft specifications 1. draft	Swedish draft specifications, 2.draft
1. Visual evaluation	cell-diameter < 0,4, radially. Faults in cell structure only as a rare exception. Cavities < 2/3 of insulation thickness	No cavities	Regular, small cells, no discolouration. Cavities < 2/3 of insulation thickness in all directions only as a rare exception
2. Density	Core > 50 kg/m^3, > 40 kg/m^3 for foam insulation transmitting no forces Test specimen: 30 x 30 x 10 mm	80-100 kg/m^3 average, specimen 20 x 20 x 20 mm taken min. 3-5 mm from rims	close to service pipe 120-150 kg/m^3 average 80-90 kg/m^3, core 60-70 kg/m^3
3. Open cell	< 10%	< 10%	< 10%
4. Compressive stress with 10% deformation	> 0,2 MPa radially	0,2 MPa radially, 0,45 MPa axially, specimen 50x50x50 mm	> 0,5 MPa
5. Shear strength axially/ tangentially	> 0,2 MPa tangentially	0.2 MPa tangentially 0.4 MPa axially	> 0.2 MPa specimen: length = diameter
6. Heat transmission coefficient	< 0,027 W/mK at 50°C	0.030 W/mK at 80°C	< 0.03 W/mK at 50°C < 0.035 W/mK in joints
7. Form stability in the cold	less than 2 vol.%/20 h - 25°C specimen 30 x 30 x 30 mm	2%/3 h - 30°C	
8. Temperature resistance	4 weeks 130°C, 50% reduction of shear strength, > 0,1 MPa	2000 h, 140°C, min. requirements as in 1-8	BS 4508/part 4 section 5.2.3.2.
9. Water absorption	< 3 vol.% equal to 0,02 cm^3/cm^2		< 2%
10. Foam adhesion to steel/ polyethylene	fulfilled by 5		> 0,2 MPa specimen: length = diameter
11. Eccentricity			±3-8% outer jacket 90-800 mm

recommended for use on pipes conveying fluids with operating temperatures up to 1200°F.[30] It is further stated by this manufacturer that its product, Kaylo 10 (a registered trademark), will not initiate stress corrosion cracking of a stainless steel pipe. The insulation is available in single or double layer thicknesses from 1" to 6", depending upon the pipe size.

Cellular Glass

Cellular glass is another insulating material that can withstand high operating temperatures - about 800°F.[31] Its thermal conductivity is 0.44 $BTU/in/hr/ft^2/^oF$ at 200°F, somewhat higher than that for polyurethane. The insulation is impervious to common acids and their fumes, except hydrofluoric acid, and it is not combustible. However, it has a 0.2% absorption of moisture by volume when tested according to ASTM Designation C-240. A casing is required to ensure that the physical properties of the insulation are maintained.

Inorganic Granular Insulation

One inorganic granular insulation product (under the trade name of Gilsulate 500) can still maintain its insulating quality for operating temperatures up to 460°F. Its thermal conductivity is 0.64 $BTU/in/hr/ft^2/^oF$ at 260°F.

Gilsulate 500 is non-flammable and non-toxic according to the manufacturer.[32] It is further stated that the product does not require curing, mixing or special preparations for use. During installation, personnel face mask dust respirators are required since the granular nature of Gilsulate 500 creates a dust concentration which may exceed the threshold limit value allowed by OSHA.

When this granular material is packed to a density of 40 lb/ft^3, as would be the case during installation, there is no water penetration at a 48-inch hydrostatic head on a continuous 30-day test. It is important that the density of the insulation be carefully monitored during installation. No casing is used in this installation method. However, a drain pipe has to be installed since the insulation may be saturated with water whenever a high ground water table occurs. The insulation is capable of supporting pipes of all sizes, except at expansion loops or bends.

It is undesirable to insulate pipes with Gilsulate 500 inside concrete trenches or the equivalent, since soil water, or water from pipe leaks, is confined in the trench and occasionally causes long sections of insulation to be needlessly wetted. If there are no alternatives (for example, rehabilitation of a piping system already in a concrete trench), sub-drainage has to be provided inside the concrete trench.

Perlite

Perlite is the name given to a class of lavas described as siliceous glass, or pitchstones, know as rhyolitic perlites, dacitic perlites, andesitic perlites, perlitic obsidians and pitchstones.[33] They are all described as acidic volcanic glass, being essentially an amorphous aluminum silicate, containing dissolved water in sufficient amount to intumesce into bubbles when heated to a suitable point within the pyroplastic range.

Perlite can maintain its insulating quality up to very high temperatures, beyond 1300^{o}F. At 300^{o}F, the thermal conductivity of the insulation is 0.36 BTU/in/hr/ft^2/^{o}F.

Perlite is available in powder form. It is blown into the annular void between the carrier pipe and the casing through nozzles which are fed from storage bins (Figure 2-16). According to a manufacturer,[34] during the filling process, the Perlite or Pulvinsul (a British trade name) behaves almost like water, featuring a very low sagging factor. Creation of a vacuum of approximately 0.02 psia in the annular void ensures a thermal insulation factor comparable to that of a thermos bottle.

Other Forms of Insulation

Glass wool and mineral wool are also being used as insulation material. Glass wood can withstand operating temperatures up to about 730°F without aging. Although both types of wool can withstand high operating temperatures, their thermal conductivities are much higher than polyurethane.[29,35] As a result, the insulation has to be thicker than that for polyurethane. In addition, compared with polyurethane, the wool material is more expensive. However, their ability to withstand high temperature makes them most suitable for high temperature hot water piping insulation. To circumvent the cost problem, two different insulation materials are used. A layer of glass wool or mineral wool is used to cover the carrier pipe. Its thickness is such that the temperature at the outer surface of the wool is less than 260°F, thereby allowing a layer of polyurethane foam over the wool. Consequently, the cost and the overall thickness of the combined insulation are lower than using glass wool or mineral wool only for the same heat loss through the pipe. There is at least one European company that combines mineral wool with polyurethane foam[36] to insulate pipes used for district heating mains.

2.1.7 Thermal Expansion Devices and Manholes

Since the pipes are carrying hot water there is the expansion of the pipes to be taken into consideration. One of the ways of absorbing

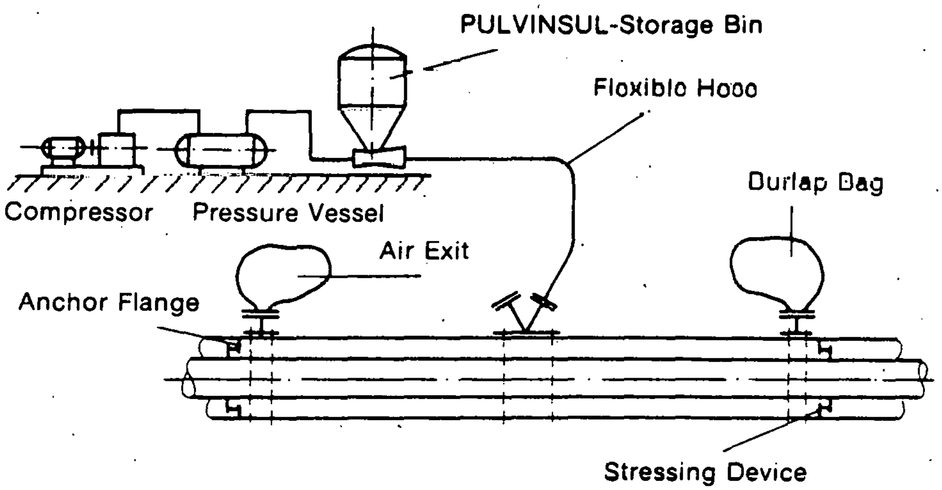


FIGURE 2-16 INSULATING PROCESS USING PERLITE

Courtesy of Preussag AG Bauwesen

the thermal expansion is by installing an expansion loop, elbow, or offset, where space permits. The great advantage of loops or elbows is that they do not require any maintanance during the life of the system and therefore are installed wherever possible.

Another thermal expansion device is the mechanical expansion joint, which is either of the slip type or the bellows type. The advantage of using such a joint is that straight lines of piping may be used in narrow access routes such as under streets, sidewalks, and between other utilities. However, the disadvantage is that expansion joints require replacement or periodic maintenance. They should be installed in accessible spaces, like manholes, to allow for maintenance.

The slip type joint consists of a cylinder that slides in a machined housing as the pipe moves (Figure 2-17). The joint accommodates axial and torsional movement of the pipe, but not lateral movement. The standard amount of expansion accommodated by a slip joint is 4", 8" or 12".[37] As sealing is a major problem, maintenance of this type of joint consists mainly of repacking or adding packing. However, for most joints, this can be done while the line is in operation.

The bellows type consists of convoluted bellows of corrosion resistant material that compress or flex with the pipe movement (Figure 2-18). When inner telescoping sleeves are used, it minimizes contact between the flowing fluid and the bellows.[37] To add additional hoop strength to the bellows and to equalize the expansion movement among all of the individual convolutions, reinforcing rings are added to the bellows. Bellows joints are generally designed to accommodate longitudinal movement of the pipe. Lateral movement is limited, but special bellows joints can be hinged or gimballed. The amount of expansion accommodation in a bellows joint is proportional to the number of convolutions. Bellows are used as far as possible in distribution systems. Alignment of the pipe ends at the bellows connection is critical. If this is not ensured, the bellows may fail prematurely.

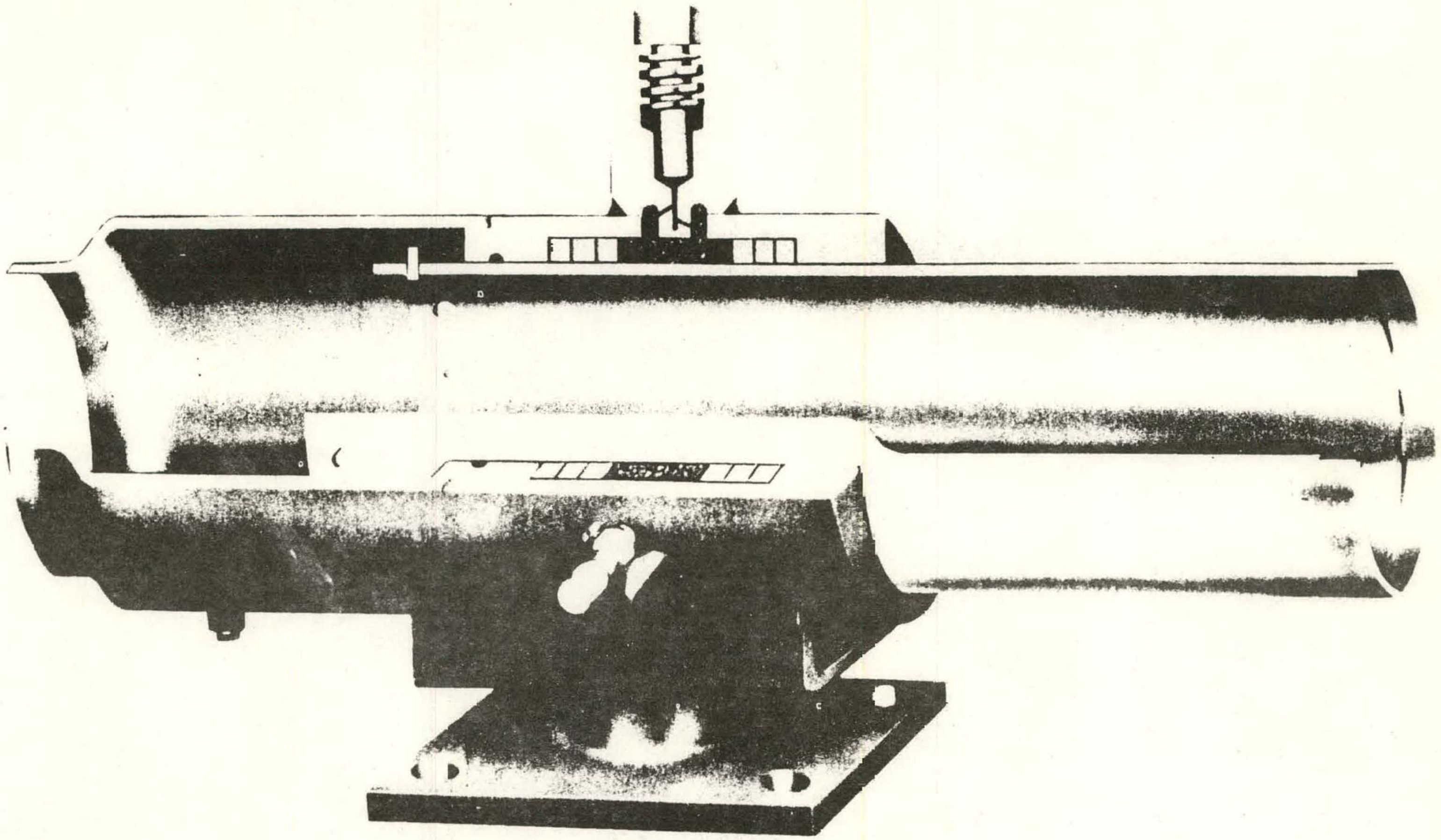
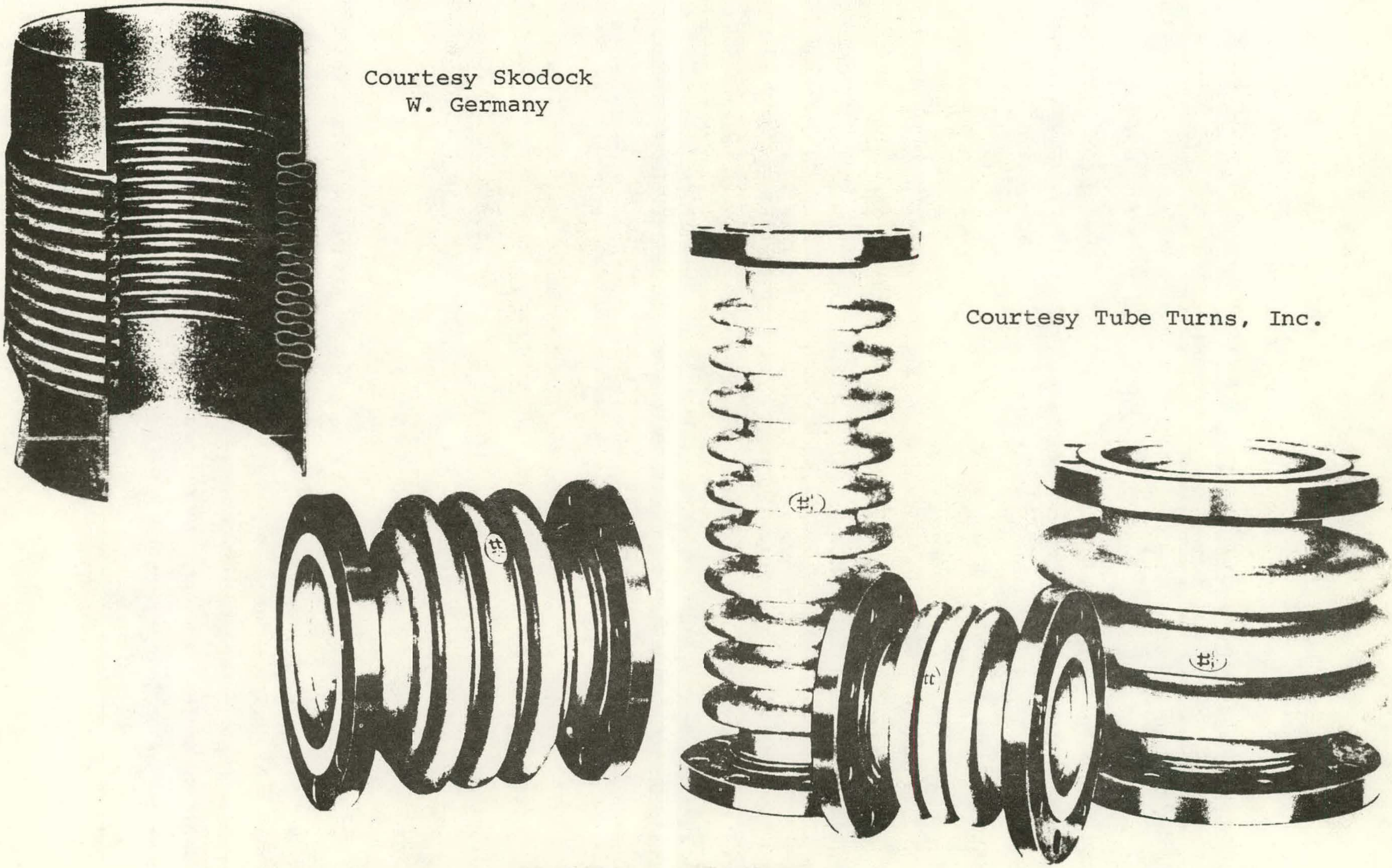


FIGURE 2-17 SLIP TYPE EXPANSION JOINT

Courtesy of Advanced Thermal Systems



Courtesy Skodock
W. Germany

Courtesy Tube Turns, Inc.

FIGURE 2-18 BELLOWS TYPE EXPANSION JOINTS

A ball or swivel joint can also be used as a thermal expansion device. It has four basic parts, i.e. a polished spherical ball, a machined casing, sealing gaskets, and a retaining flange or nut (Figure 2-19). Ball joints do not directly absorb axial movements, but they can accommodate torsional movement. Offsets are used to laterally accommodate the movement of the pipe. Because of the limited amount of angular flex, the amount of expansion that ball joints can accommodate is dependent upon the distance between the ball centers. Ball joints, like slip type joints and bellows type joints, should be installed in accessible spaces, like manholes, to allow for maintenance.[37]

Another method of absorbing the thermal expansion of a pipe is through the use of couplings. The couplings contain rubber rings which provide watertight seals when two pipe ends are joined. While performing their function of leak proofing, the rubber rings also allow expansion and contraction in the joints. Hence, no additional expansion joints are required. Furthermore, these couplings also accommodate pressure surges, shocks and vibration.[38] The ability of the couplings to continuously perform their functions depend on their ability to retain the elasticity of the rubber rings through aging.

A similar design is used to accommodate the expansion forces in ductile cast iron pipes. According to the manufacturer[9] the conventional expansion devices are eliminated from the system and expansion is taken by the rubber gasket sliding along the outside of the pipe barrel (Figure 2-20).

One novel method surveyed consists of absorbing thermal expansion without the use of any expansion elements. The copper pipe is laid in a sinusoidal curve pattern,[29] giving it a built-in expansion allowance (Figure 2-21). When the temperature of the carrier pipe rises, the amplitude of the curve will increase if the end points are fixed. The increase in amplitude is very small, since the expansion is uniformly

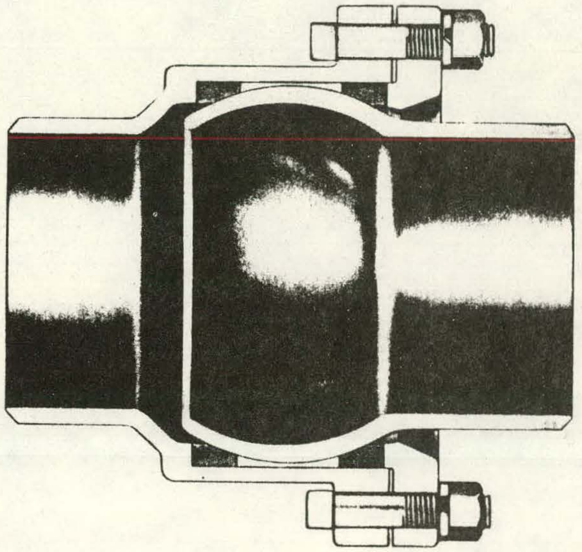


FIGURE 2-19 BALL TYPE EXPANSION JOINT

Courtesy of Aeroquip

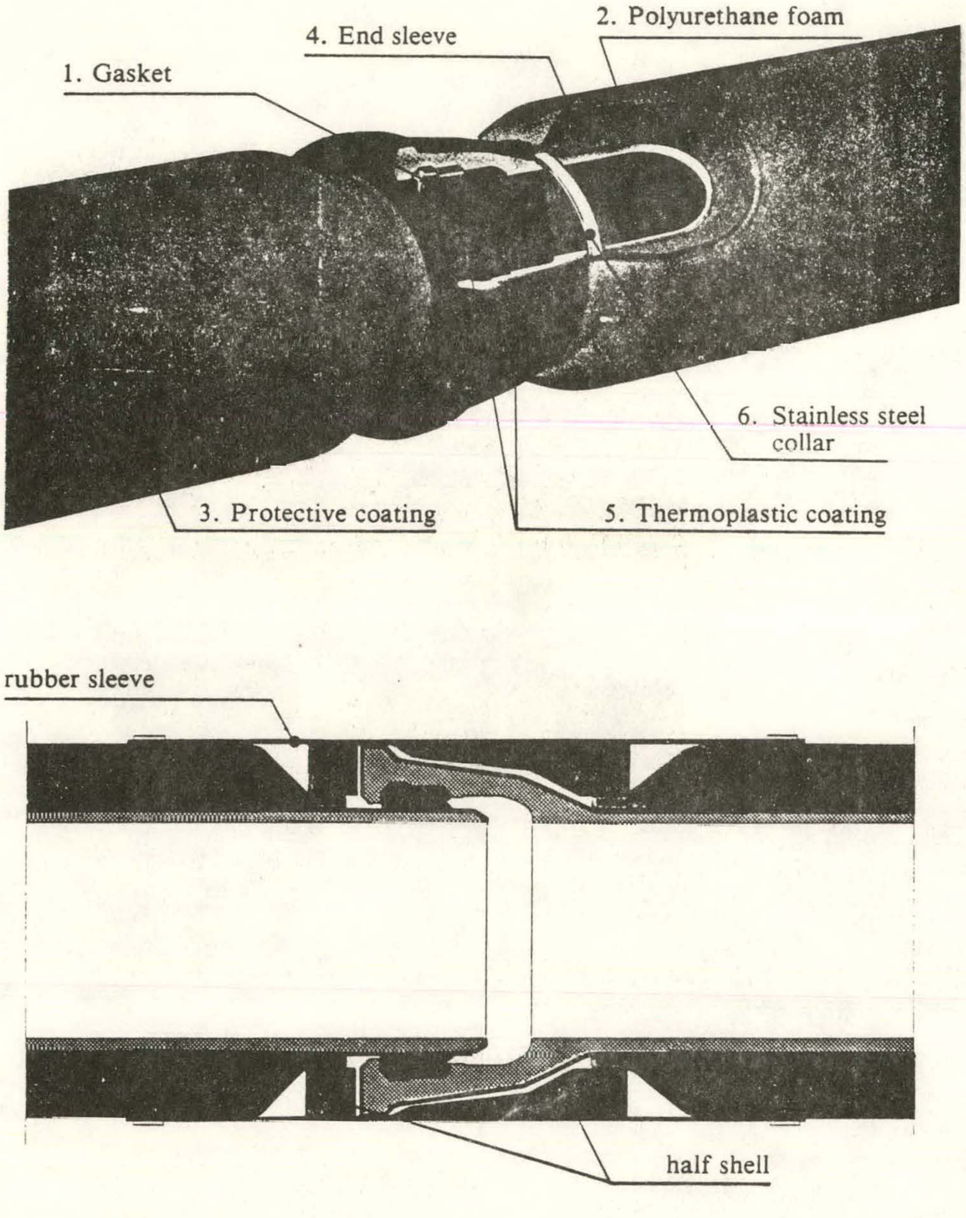


FIGURE 2-20 BELL/SPIGOT TYPE JOINT

Courtesy of Pont-A-Mousson S.A.

FIGURE 2-21 FOUR PIPE DISTRICT HEATING NETWORK LAID IN A SINUSOIDAL CURVE PATTERN

Courtesy of Aquawarm

distributed across the entire arc length. Owing to the wavy pattern in which the pipe must be laid, about 3% must be added to the length of pipe when this piping system is used.

Thermal stresses due to thermal expansion can be minimized by prestressing the pipe. This facilitates compensation-free laying and achieves an installation free from any fixed points without any concrete structures. The prestressed pipe lengths are, in accordance with the respective temperature differences, dimensioned such that the lines are kept free from thermal stresses during normal operating conditions. Prestressing is achieved when both the carrier and the casing pipes are each metallic. The prestressing of the conduit is performed by (1) stretching the carrier pipe, (2) upsetting the casing pipe and (3) anchoring the two pipes to each other.[34] Figure 2-22 shows what "stressing" and "upsetting" of the pipes mean. The movable bearing of an anchor flange, which is welded between the carrier and casing pipes at the end of a prestressed conduit section 1300 ft. long, prevents relative length expansions of the pipes. In addition, by constructing the anchor flange as a double flange, any transfer of heat and any electrical conduction between the two pipes are avoided. Such features are also offered by the various spacers, as shown in Figure 2-22. According to the manufacturer, the prestressing device needed is simple and the space requirement for the pipeline is modest.

A further method to accommodate thermal expansion has been developed in Denmark[39] for conduits with steel carrier pipe, polyurethane insulation and polyethylene casing. In this system expansion devices and loops are eliminated from the piping together with some concrete anchors. The technique utilizes the flexibility features of steel pipes at stress ranges up to the elastic limit.

When a detached steel pipe is anchored at one end, it will expand when heated from the installation temperature of about 65°F to

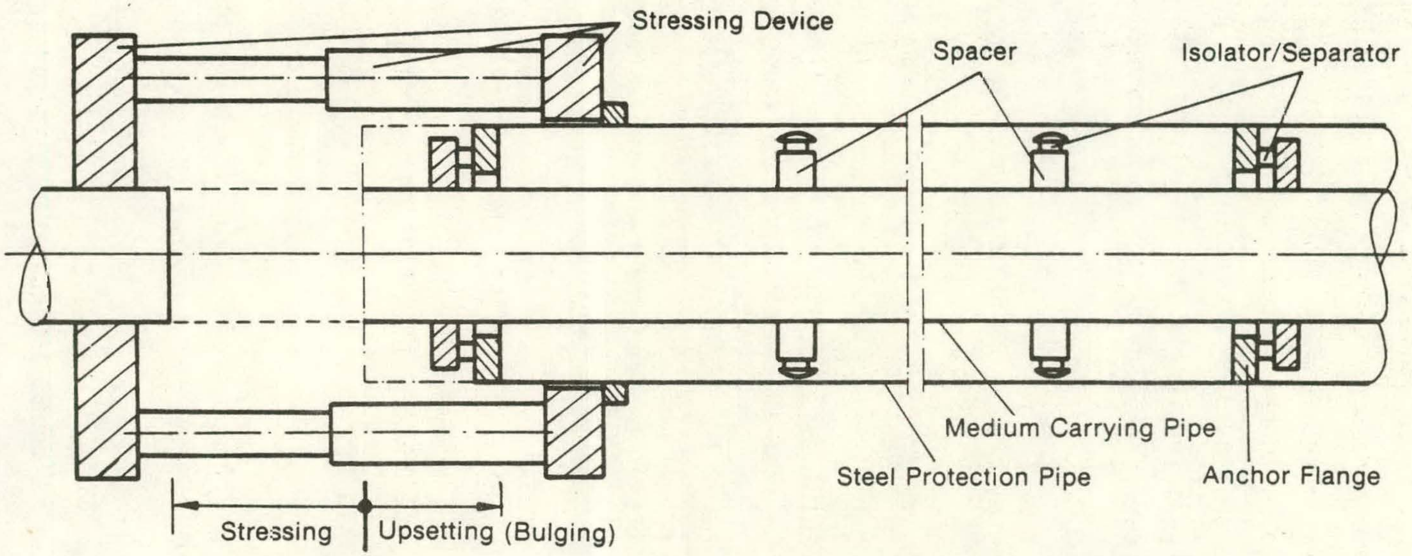


FIGURE 2-22 DIAGRAM OF CONDUIT PRESTRESSING

Courtesy of Preussag AG
Bauwesen, West Germany

an average temperature of 120°F. A subsequent anchoring at the opposite end at the average temperature does not change the physical state of the pipe, and the tension in the steel material will be zero. If the temperature of the pipe is increased to an operating temperature, e.g. 230°F, then a compressive stress will be generated in the steel pipe within the allowable limits. If the temperature is reduced to the installation temperature, the tensile stress of the same magnitude as the above compressive stress will be generated.

Pipe prestressing by cold drawing or by heating to a predetermined installation temperature before the pipes are backfilled requires large street areas to be open for long periods, because the prestressing can only be done with completely uncovered pipes in relatively large sections. With this method, the conduits are installed in the ground in the usual way, but with an E-muff element (Figure 2-23) welded into the system instead of the conventional expansion devices. Before the E-muffs are welded to the system, they are adjusted by prestressing according to the actual distance between the two E-muffs for the maximum operating temperature of the network. When starting up the system, the steel pipes expand, and the bellows of the E-muffs are pressed together until the internal pipe ends meet. Then the E-muff is locked by a pressure tight weld, and the function of the muff is complete. It now acts as a stiff piece of pipe and joint insulation by means of a long muff. Then the remaining joints with the fixed E-muffs are insulated and backfilled.

This technique has been tested in trial installations in pipe sizes up to 12 in. The manufacturer states that the technique provides the following advantages:

- Installation cost is reduced because of elimination of the typical expansion devices and most of the anchors resulting in a material cost reduction of between 10 to 15 percent.

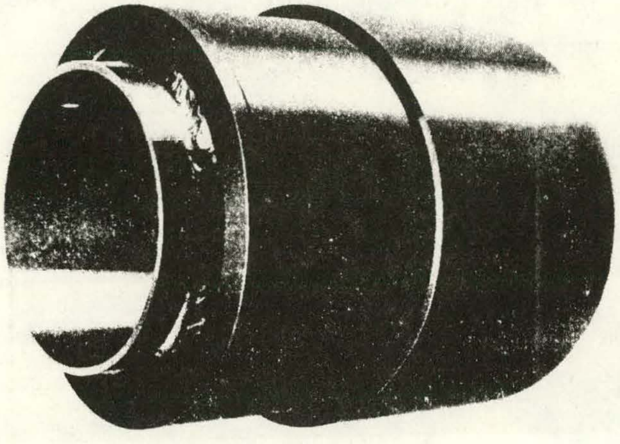


FIGURE 2-23 E - MUFF ELEMENT

Courtesy of i.c. møller, Denmark

- Site problems are reduced because the conduit can be backfilled immediately after the hydrotest.

- The carrier pipe is almost free of tension at operating temperatures of about 160°F which prevails most of the year

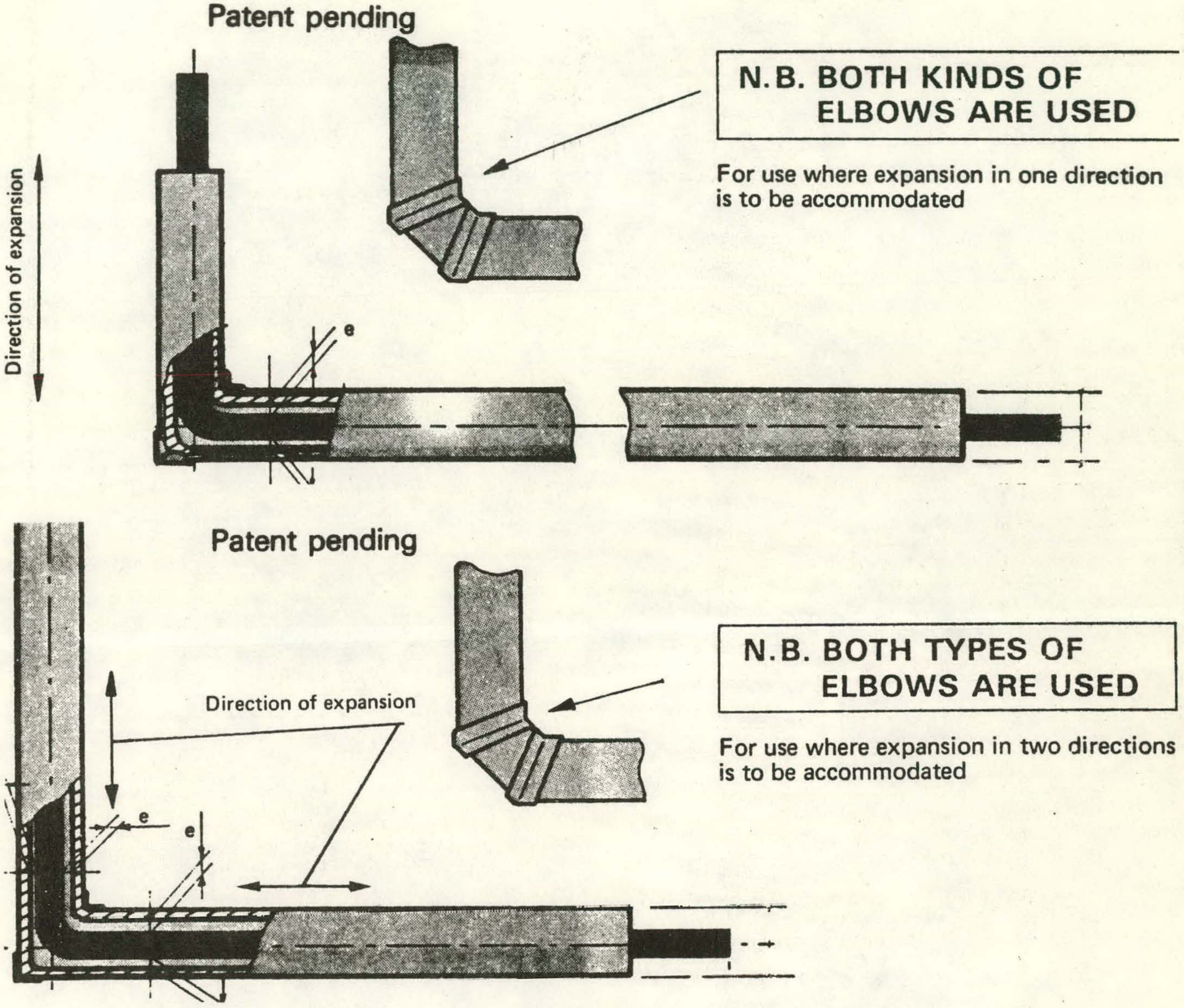
It seems, however, that the disadvantage of the system is the requirement for E-muff installation which may cause problems if not properly installed and adjusted.

One Danish pipe manufacturer utilizes a lubricating agent that permits the carrier pipe, insulation, and casing to expand and contract independently of each other, thereby reducing the friction among these elements.[40] The bends provide spaces for the thermal expansion of the carrier pipe, insulation, and casing (Figure 2-24). Although the lubricating agent reduces the shear stresses, due to less friction, thermal expansion devices still must be installed.

Manholes

Manholes are a very necessary part of an underground distribution system. They provide the housing for many miscellaneous pieces of equipment necessary for the control of the system and its proper operation. The equipment may be: (1) control valves for both lines and branches, (2) expansion devices, and (3) venting and draining points for high temperature hot water.

There are two types of manholes available. They are either built in-situ of concrete usually or prefabricated of steel or concrete (Figure 2-25). Although concrete manholes have the advantage that they can be built to any size in the field, they are difficult to make watertight.[37] Concrete manholes are usually built by contractors other than the mechanical



N.B. BOTH KINDS OF ELBOWS ARE USED

For use where expansion in one direction is to be accommodated

N.B. BOTH TYPES OF ELBOWS ARE USED

For use where expansion in two directions is to be accommodated

FIGURE 2-24 90 DEGREE BENDS WITH SPACE FOR THERMAL EXPANSION

Courtesy of Løgstør Rørindustri A/S

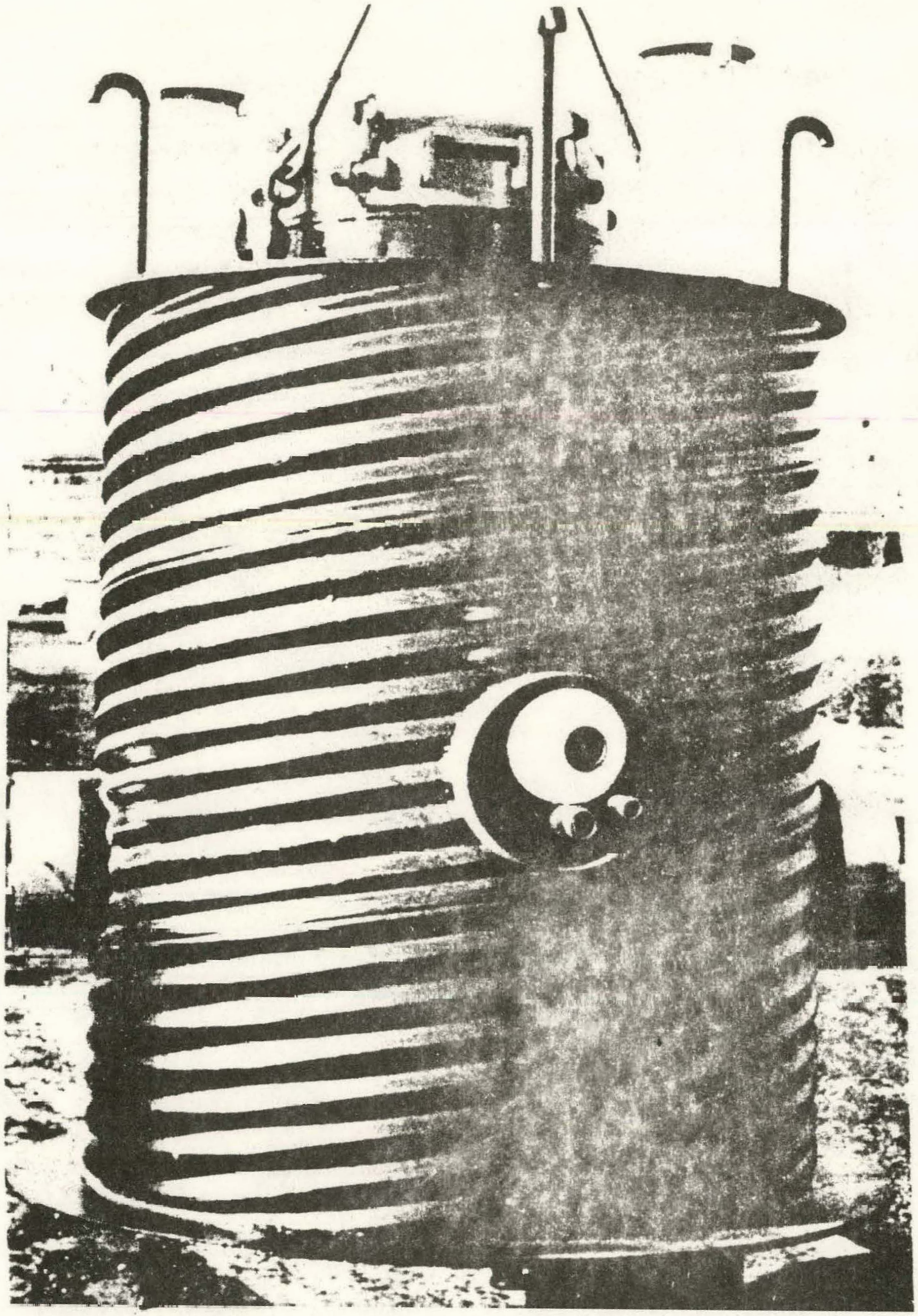


FIGURE 2-25 PREFABRICATED STEEL MANHOLE

Courtesy of Ric-Wil, Inc.

contractor. Therefore, close coordination between the two contractors is necessary.

On the other hand, prefabricated galvanized steel manholes do not require close coordination between two contractors. The prefabricated manholes arrive at the site completley piped with all specified equipment, insulated and ready for immediate installation. The contractor has only to connect the piping and conduit and pour a concrete anti-flotation pad at the bottom of the manhole. One other advantage is the ability to air test prefabricated manholes for watertightness. A disadvantage of the prefabricated galvanized steel manholes is a limitation in size up to 10 ft. in diameter, due to shipping restrictions. Internal and external corrosion resistant coatings have to be applied to steel manholes for protection.

2.2 OPERATIONAL EXPERIENCE AND NETWORK FAILURE ANALYSIS

Almost all district heating networks have experienced piping failure problems. Even in more recently constructed systems, corrosion failures and increased heat losses have been recorded. For example, investigations in Denmark have indicated that the heat loss in a number of networks is normally about 20 to 25 percent of the heat produced, and in some cases, as high as 45 percent.[41] Furthermore, it was found that of the total 9,300 miles of district heating piping in Denmark, about 10 percent is in poor condition and should be renovated at the earliest possible time. The cost of this work would be 200 to 300 million dollars. This number could be compared to about 100 million dollars of annual investment which is necessary for new district heating plants and networks. This example clearly demonstrates that the reliability of the district heating system is of prime importance.

2.2.1 Piping Installation Methods

In West Germany the operational results of 800 miles of 49 different types of underground piping installations have been analyzed.[42]

The results of this analysis, presented in Figure 2-26 and Table 2-5 are broken down into four major types of installation as follows: rigid concrete envelope (type 1), ductless directly buried pipeline insulated by powder backfill (type 2), conduit (type 3), and concrete culvert or concrete trench (type 4). The pipe failure rate is defined as actual corrosion damage per mile of two pipe network per year. The results of failure rate analysis of this and other operational data have demonstrated that the most reliable type is the concrete culvert installation (type 4). The external corrosion rate for other installations as compared to type 4 was higher by a factor of 20 for type 1, by 140 for type 2, and by a factor of 8 for type 3.[43] However, because the failure rate depends on a number of site specific factors, the results of this analysis cannot be generalized. For this point of view, it is interesting to review the experience obtained in the Moscow district heating network and compare it with the information reported during the present survey.[43,44,45]

The Moscow district heating network has been in existence for more than 40 years with considerable additional piping installations in the last 20 years. The total length of the major distribution lines only is more than 1100 miles. About 80 percent of the network is installed in concrete trenches or culverts. The pipes are insulated with mineral wool and covered with an asbestos-cement layer. Soil conditions vary and include clay (30%) and sand (50%). The depth of cover above the culvert is between 2 and 10 feet. Up to 1960 a type of stoving varnish was used for anti-corrosion coating of the piping. After 1960, hot bitumen applied strip type materials were used.

In the Moscow network external corrosion of the piping is the cause of 90% of the breakdowns. The failure rate of district heating systems is much higher than that of gas and electric installations, but somewhat lower than that of potable water systems.

Examination of the failures in the Moscow and West European heating networks indicated that in many cases the external corrosion

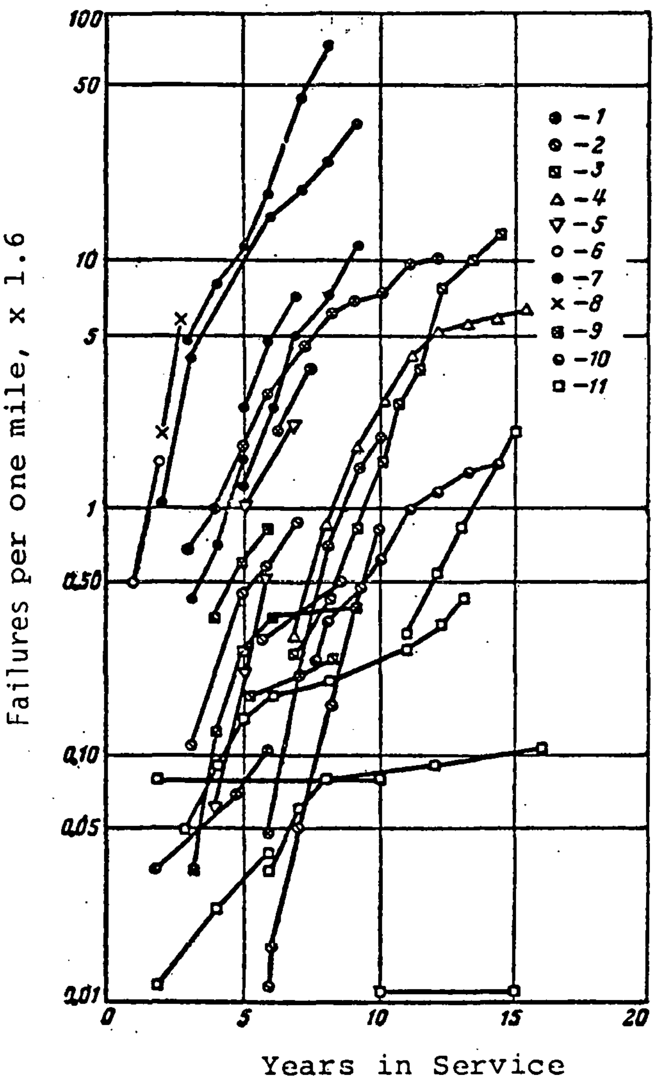


FIGURE 2-26 THE DEPENDENCE OF THE CORROSION FAILURE RATE ON THE SERVICE LIFE OF THE UNDERGROUND PIPING INSTALLATIONS

1 to 5 - Rigid concrete envelope; 6 to 8 - Ductless with powder insulation; 9 and 10 - Conduit; 11 - Concrete Culvert

Table 2-5

AVERAGE CORROSION FAILURE RATE FOR UNDERGROUND DISTRICT HEATING PIPING INSTALLATIONS (FAILURES PER MILE PER YEAR)

Type of Piping Installation	YEARS IN SERVICE 1	2	3	4	5	6	7	8	9	10	11	12	13	Average Increased Failure Rate Relative to Concrete Culvert
Concrete Culvert	0.078	0.083	0.106	0.136	0.131	0.176	0.194	0.246	0.179	0.266	0.397	0.590	0.622	
Conduit	-	-	-	-	0.272	0.329	0.320	0.583	0.985	1.862	3.32	5.84	8.40	
Increased failure rate relative to concrete culvert	-	-	-	-	2.08	1.87	1.65	2.37	5.50	7.00	8.36	9.90	13.5	8
Rigid Concrete Envelope	-	0.299	0.498	0.85	1.74	2.52	2.93	3.81	6.66	9.02	11.35	12.04	12.94	
Increased failure rate relative to concrete culvert	-	3.60	4.70	6.25	13.30	14.30	15.10	15.50	37.20	33.90	28.60	20.4	20.8	20
Ductless with Powder Backfill	2.43	6.06	7.98	8.84	11.79	29.92	59.56	-	-	-	-	-	-	
Increased failure rate relative to concrete culvert	31.1	73.0	75.3	65.0	90.0	170.0	307.0	-	-	-	-	-	-	140

took place in relatively small spots in sizes from 0.04 to 0.08 in., while the rest of the pipe had a uniform and lower corrosion rate. Pitting type of corrosion is also experienced. The corrosion spots are located on the bottom (60%) and on the top (40%) side of the pipe. In breakage cases the thickness of the pipe wall was observed to have been reduced to 0.004 to 0.28 in. As a result, the pipe ruptured under internal water pressure. Observations have shown that at the failure spot the coating is usually destroyed.

Based on the USSR heating network operational experience, the lowest number of failures due to corrosion occurs in concrete culvert networks.

Routine excavation and openings of pipes in concrete culverts carried out in 1956-1962 in Moscow[46] have shown that in the first five years of service emergency conditions of heating pipes (film of corrosion over 0.40 in. and through holes) were recorded only in 3% of cases, after service for five years in 2%, and after service for 10 years in 4% (Figure 2-27,A).

In subsequent periods (in Moscow in 1962-1971) a considerable increase in corrosion rate was indicated (Figure 2-27,B); in the first five years of service, emergency conditions were detected in 2% of routine openings; in the subsequent five years in 30% of openings, and after service for 10 years in 46%.

However, the conclusion based on the use of concrete culvert design in the Moscow network only should not be generalized. In particular, inspections in Kiev heating network (530 miles of piping) carried out in 1962-1971 have shown satisfactory corrosion conditions of concrete culvert networks. In the first 10 years of service emergency conditions were found in only 5% of cases and after 10 years, in 10% (Figure 2-27,C).

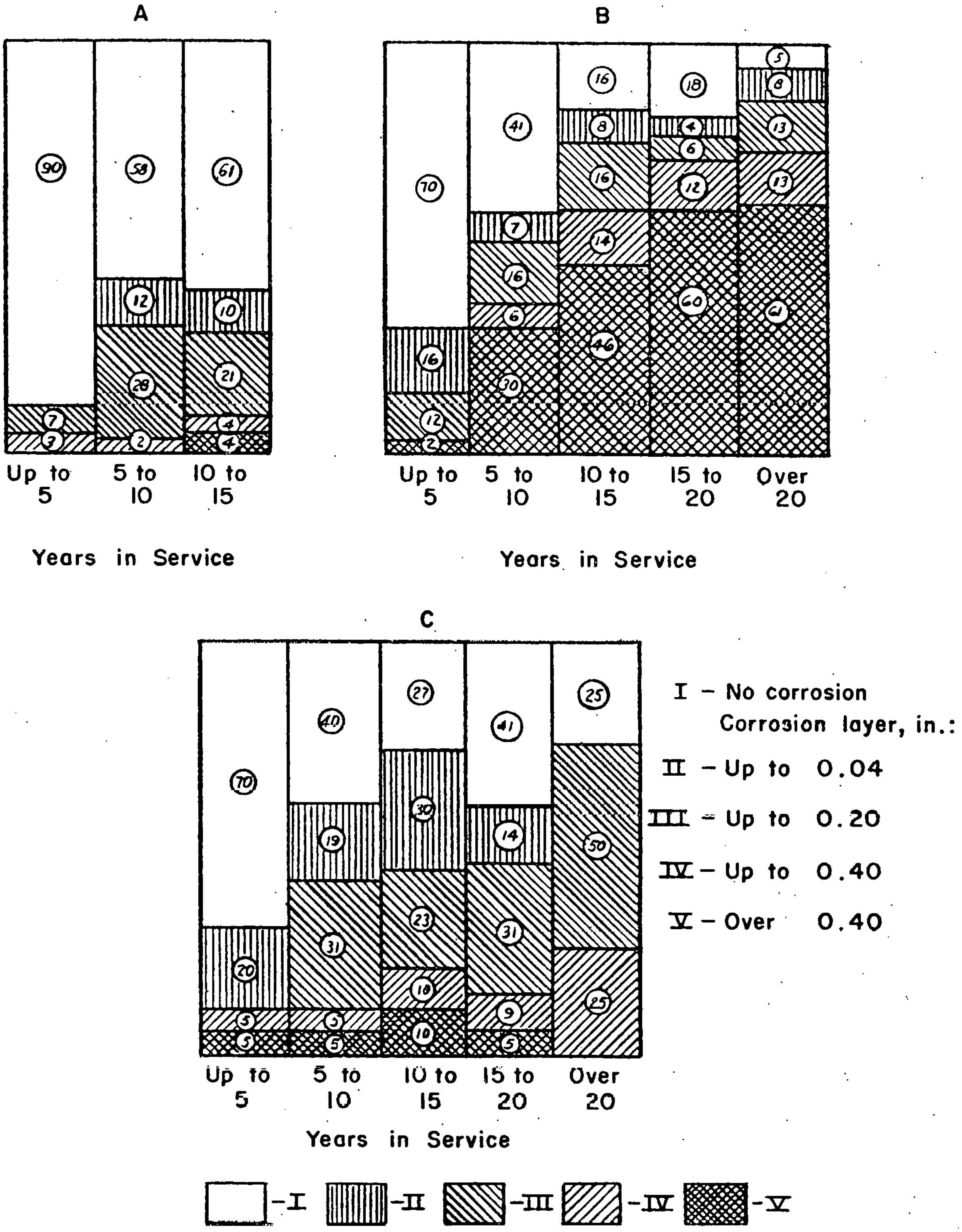


FIGURE 2-27 EXTERNAL CORROSION RATE (IN PERCENT) OF THE UNDERGROUND PIPING INSTALLED IN CONCRETE CULVERT.

A = Moscow, 1956 - 1962
B = Moscow, 1962 - 1971
C = Kiev, 1962 - 1971

The fastest increase in the corrosion damage is observed in ductless directly buried pipes with powder backfill (Figure 2-28) where after service for 4-6 years the failure rate reached up to 32 failures in some pipes per mile per year.

In rigid concrete envelope designs, the failure rate is considerably lower (up to 5-6) than in ductless installations. However, also in rigid concrete envelope designs after service for 5-7 years (Figure 2-29) a sharp failure rate increase takes place.

Thus, in rigid concrete insulation, in the first five years of service emergency conditions of piping were observed in 20% of routine openings (Figure 2-30) and in the subsequent 6-10 years in 62%, and after service for over 15 years in 82%. In bitumen-pearlite insulation an increase in damage is observed after operation for only 3 years, and the first traces of corrosion are noted after operation for 1-2 years.

2.2.2 Piping Network Service Life

The average failure rate depends on the duration of service of the system. As one can see from Figures 2-27, 2-30, and 2-31, the failure rate grows with the age of the system. This is particularly the case in the large diameter piping which has the greatest wall thickness.[43]

During the present survey, some utilities have also reported that the failure rate increases with the age of the system. Other utilities, however, have concluded that no relationship exists between the failure rate and piping age, or that the age has a small influence when the system is in good condition.

The number of failures in the Moscow network is related to the diameter of the pipe, therefore to the pipe wall thickness (Table 2-6).[44,45]

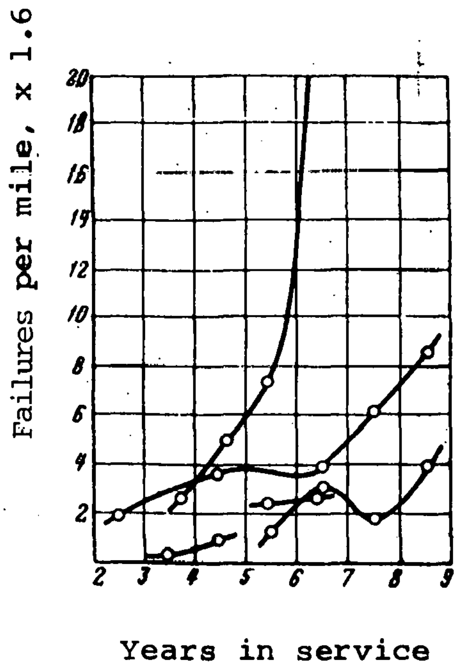


FIGURE 2-28 THE DEPENDENCE OF THE CORROSION FAILURE RATE ON THE SERVICE LIFE FOR DUCTLESS POWDER BACKFILL INSTALLATIONS

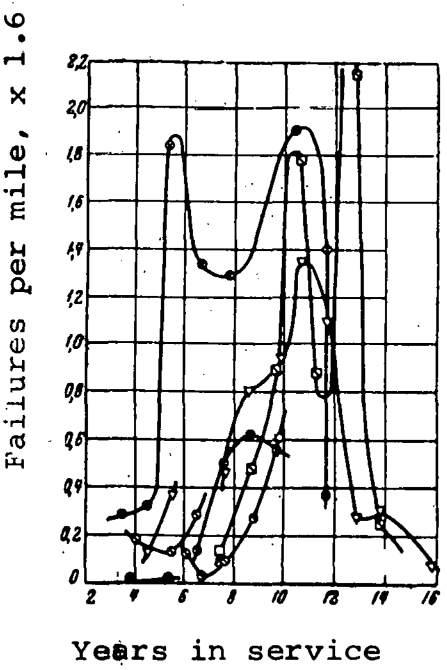


FIGURE 2-29 THE DEPENDENCE OF THE CORROSION FAILURE RATE ON SERVICE LIFE FOR RIGID CONCRETE ENVELOPE INSTALLATIONS

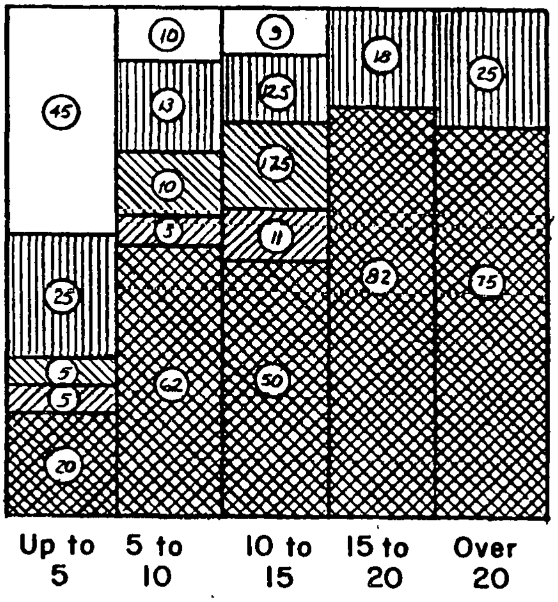


FIGURE 2-30 EXTERNAL CORROSION RATE (IN PERCENT) OF THE PIPING WITH RIGID CONCRETE INSULATION

Legend see Fig. 2-27

Table 2-6

Failure Rate in Moscow District Heating Network

Pipe Diameter (inches)	Pipe Wall Thickness (inches)	Failures per Mile	
		1970	1971
2 to 6	0.118 to 0.177	0.91	0.96
8 to 32	0.236 to 0.315	0.37	0.42
40 to 55	0.394 to 0.551	0.08	0.07

Based on West Germany and USSR network experience, the duration of stable service of different types of piping to the time of sharp increase in corrosion damage is 10 to 12 years for the concrete culvert designs, and 4 to 7 years for rigid concrete envelope and ductless powder backfill designs.

Dependence of the corrosion failure rate on duration of service is of a clearly pronounced cyclic nature (Figures 2-28, 2-29, and 2-31). After sharp increases the failure rate decreases due to repair and pipe replacement work. After 2 to 3 years of subsequent service, a sharp increase takes place again.

2.2.3 Causes of Piping Failures

The piping failure rate or the actual breaks of pipes reported during the present study is between 0.048 and 0.32 per mile per year. The average failure rate is 0.144 based on data reported by four utilities. The average annual failure rate for the district heating system in Moscow during 1968 and 1971 was 0.43. The failure rate for the Kiev

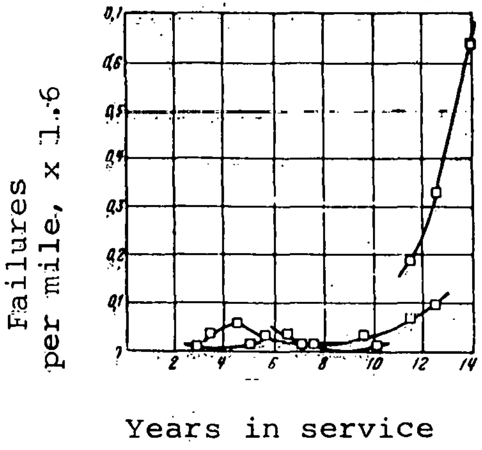


FIGURE 2-31 THE DEPENDENCE OF THE CORROSION FAILURE RATE ON THE SERVICE LIFE OF THE NETWORK FOR CONCRETE CULVERT INSTALLATIONS

district heating system was between 0.48 and 0.64. One European system reported 0.68 leaks per mile in 1978 as a result of external corrosion. One Japanese system has reported five pipe failures in four months in the fifth year of operation. The piping system installed at this location is of conduit type manufactured in Japan. Another Japanese system has also reported failures of conduit type installation after the second and fourth year of network operation. Other utilities reported no pipe breakages, but only corrosion resulting in leaks (up to 0.68 leaks per mile per year).

Major failure elements reported are carrier pipes, expansion bellows, and pipe connections to valves in manholes and piping joints.

The location of the pipe failure varies substantially for different utilities. Failures occur in straight piping, joints, expansion devices (bellows and ball type), manholes, valves, pipe anchors and supports, crossings with other utilities.

The major causes of the failures are as follows:

- external electrochemical corrosion; in conduits it is usually related to the casing coating failure and ground water infiltration into the conduit.
- insulation failure and damage of the insulation joints which finally causes pipe corrosion

- failure of co-located utility system

- mechanical and structural damage as a result of vibration from vehicles and leaky manhole covers under thermal stresses, and impingement of hot water from leaky valve gland packings.

The character of the failures leads to a conclusion that intensive local corrosion takes place because of periodic contact of an unprotected external piping surface with ground water. This process takes place in both directly buried and culvert type installations when they are flooded with water, and especially when they are covered with mud. The cyclic wetting and drying of the pipe insulation causes external corrosion. Another significant factor associated with wetting of insulation is the increase in heat losses from pipes due to increase in the coefficient of heat transfer of the insulation, and in a number of instances its rapid mechanical disintegration. The heat losses in the transmission and distribution piping reported range from 4 to 15 percent of the annual consumption. The average heat loss figure has been estimated as 8.8 percent based on data reported by 12 of the utilities in Europe and Japan.

The source of water could be as follows: penetration of water from above the pipe as a result of rain or snow melting, water dripping on the pipe from cold surfaces, failure of a co-located potable water, sewer or drainage system, ground water penetrating in the area of the pipe underside as a result of capillary action. When the district network is flooded with water, mud enters and afterwards remains in the trench. If the pipe in a culvert is installed in an area between buildings, it serves very often as a water drainage system for rain and ground water.

The culvert retains its function if an air gap exists along the pipe. In this case, the water from the insulation layer is easily evaporated into the air gap, and the dry insulation is a reliable means of ensuring that the pipe remains in good condition. In a concrete culvert the following favorable conditions are provided for drying of the insulation: existence of convection in the air gap, decrease in relative humidity of the air with sweeping of the hot surface of the insulating cover and considerable time intervals between successive wettings of the insulation. At the same time the insulation must not undergo destruction and aging with cyclic conditions of wetting and drying.

Therefore the extensive use of insulation materials such as calcium silicate which has a low coefficient of thermal conductivity and is resistant to aging during periodical wetting and drying[47-50] is very important for the reliable service life of the network.

Installations with such an air gap have a corrosion rate not higher than 0.004 in/year. However, to maintain the air gap in a concrete culvert and protect it from mud flow is very difficult and requires constant control of the trench conditions. This is especially difficult for a small diameter piping system where mud ingress occurs often and the culvert size does not allow for maintenance. Complete or even partial mud ingress into the culvert changes its operational condition to that of a directly buried installation. Therefore, utilization of concrete culverts makes sense only with properly organized landscaping and the installation of a reliable water drainage system.

Most of the utilities confirmed during the present survey an existence of an air gap between the insulation and the culvert during the service life, and stressed the importance of the air gap for the reliable long service life of the pipe.

Utilization of ductless piping designs with no air gap results in constant wetting of the insulation after being in contact with ground water.

In addition, with use of materials of high porosity for insulation, intense moisture penetration into the insulating layer takes place due to condensation of moisture vapor found in the dry part of the insulation when the district water temperature is low.[43,51-53]

Protection of the insulation against moisture with a waterproof cover is not sufficiently reliable because it is very difficult to ensure continuity of the cover in the majority of cases,[46,54] and even slight local damage to the waterproofing leads to intense wetting of large volumes of insulating material.[42,55]

The use of water-repellent powder backfill insulation does not prevent penetration of moisture to the surface of the piping surface. Under the conditions prevailing during long periods of operation under dynamic heat and moisture conditions, intense hydrophilisation of the walls of capillaries of water-repellent material takes place. This is mainly due to the precipitation of salts in heating and evaporation of the moisture penetrating the heat insulation[51,54] and the resulting formation of a film of adsorbed moisture on the capillary walls. Some influence on moisture penetration in the insulation results from the diffusion of vapor through the water-repellent film.[56]

At the same time, in ductless designs the process of drying the insulating layer considerably slows down. The reason for this is the absence of convection in the space between particles of the surrounding ground and also the short intervals between successive wettings of the ground and of the insulation, especially during the heating season.

With use of a waterproofing cover, the drying of moistened insulation is even more difficult (absence of evaporation surface). An egress of penetrating moisture to the peripheral layers of insulation and a spreading of water along the piping are observed.[42,47,54]

2.2.4 Operational Conditions

The major failure component in a network is the supply line; the return line does not experience such severe corrosion problems. The external operating conditions of both pipes are identical, but internally there is a significant difference in pressure and temperature. The internal pressure cannot substantially affect the external corrosion process; however, a pipe damaged by corrosion will rupture at this spot as a result of pressure. The statistics do not show a direct dependence between failure rate and the temperature level of the system. Since the failures occur at different supply line temperatures, this means that the duration of the development of the seat of failure depends on the corrosion process only. Practically all European and some Japanese systems are operating on continuous basis all year-round. The systems are out of service for short periods of time, from 2 to 24 hours. However, the major influence on the corrosion rate is the average temperature level in the supply pipe, which throughout the year operates at water temperatures of between 165°F and 180°F. For example, the water temperature in the Moscow system exceeded 212° for only about 70 days during the year.[44] The return line operates for about 70 percent of the year with a water temperature of about 115°F. In Moscow the operating time of the return line with temperatures of 140°F and higher is less than 30 days per year. The average annual temperature variations reported during the present survey by most utilities are between 158°F and 216°F in the supply line and 104°F and 149°F in the return line. Systems with no cogeneration have higher temperatures of between 230°F and 419°F in the supply line and 176°F to 266°F in the return pipeline.

It is well known from the theory of corrosion[59,60] that with free access of moisture and oxygen to the piping surface, a wall temperature of between 155°F and 185°F is the most dangerous with respect to intensity of corrosion (Figure 2-32). The supply line operates most of the time in these unfavorable temperature modes. The underground pipes operating at higher temperatures are less affected by external corrosion. For example, the corrosion rate of steam heating networks examined during the present study is substantially lower than that of hot water networks. The steam piping system in Moscow, with a length of about 40 miles, has been in service for more than 30 years. During this period no substantial failures caused by external corrosion have been recorded in steam pipes. Similar experience is recorded by other investigators.[61] In contrast, condensate return lines with fluid temperature below 200°F are subject to high corrosion rate.

2.2.5 Maintenance Requirements and Cost

From the data presented, it could be concluded that the failure rate and the resulting maintenance cost of district heating networks is relatively high. The reliability of an underground hot water piping system is determined by the following factors: quality of anti-corrosion protection; average annual water temperature in the piping network;

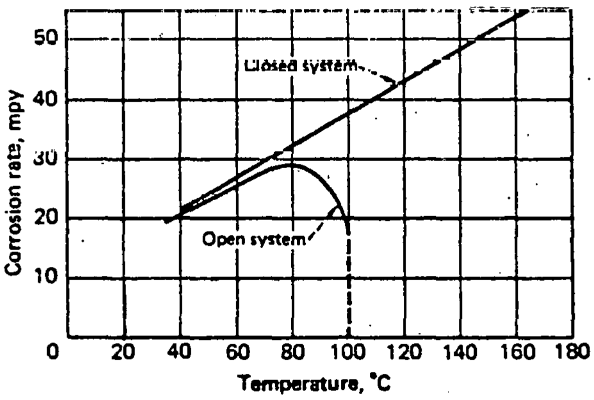


FIGURE 2-32 INFLUENCE OF TEMPERATURE ON CORROSION RATE OF STEEL IN WATER CONTAINING DISSOLVED OXYGEN

age of the network; thickness of the pipe walls; type of installation (especially the provision of an air gap during service life of the pipe); site hydrological conditions; and the condition of adjoining utility systems.

The construction of new underground heat supply lines is always associated with a large number of possible breakdowns, even with reliable anti-corrosion protection, therefore, it is not sufficient to design only for adequate reliability of the pipeline. It is difficult to maintain a high reliability over a long period of operation.

The results of the present survey have indicated that most of the district heating network utilities do not perform periodic hydro (pressure) and thermal (temperature) tests as a preventive maintenance measure. Only one Japanese company indicated that a hydro test is performed once per year. Manholes, including expansion devices and valves are visually inspected on a regular basis. However, the inspection period varies substantially between once per ten days to once per four months.

The methods of failure detection are usually as follows: visual detection, pressure test, utilization of an infrared scanner (thermographic method), substantial increase in the make-up water flowrate and regular inspection of manholes. Nine out of fourteen utilities have reported that they monitor the piping flowrate in regard to leakage detection. The make-up water requirements for different systems vary between 0.12 to 2 percent per day of the network water flowrate. The utilities do not usually monitor the external corrosion processes. The internal corrosion rate is controlled by treatment of the make-up and analysis of water samples.

Closed district heating networks have a relatively low internal corrosion rate and scaling problems. The small amount of make-up water for such systems is usually chemically treated. Practically, all systems surveyed have water treatment (mostly ion exchange resin) to prevent scaling problems in the heat exchangers and district heating equipment. To prevent internal corrosion direct contact atmospheric type deaerators are provided. Some systems use hydrazine to prevent oxygen induced corrosion. A word of caution should be stated regarding the use of hydrazine. Hydrazine is poisonous and should be used only in closed networks, where the possibility for taking the water out of the system for domestic use is not possible.

Internal corrosion and scaling problems are more important in open district heating networks; however, such systems are not used in West Europe. Internal corrosion problems in district heating networks are discussed in detail in Reference 62.

The average length of piping sections replaced after failure in European hot water systems ranged between 16 to 66 ft. One Japanese system replaced about 2000 ft. of piping conduit in the second year of operation and 1100 ft. in the fifth year of operation. The repair time per one failure varies from two hours up to two months, however, the system is usually out of service for only three or four days. The cost of repair per failure reported is between $2,800 and $20,000 with an average cost of about $8,400.

The maintenance cost varies for different utilities between one and six percent of the piping network installation cost or between $1,800 and $18,000 per mile per year. The average maintenance cost is about $9,100 per mile per year.

To increase the reliability of networks already in operation, the preventative maintenance measures should be performed as follows:

- Detection of all weak, corroded sections of pipeline and their prompt removal (by testing in summer).

- Systematic excavation of inspection pits (exploratory excavation) in places where there is a danger of corrosion and where the replacement of the damaged sections is anticipated to be difficult.

- Draining of the pipe runs in every possible way (water removal, laying associated drains, etc.).

- Installation of a leakage detection system to permit early detection of groundwater penetration through the outer casing into the insulation.

- Construction of active (cathodic) protection measures, especially for ductless networks.

- Altering the operating temperatures of networks, especially in summer.

3. DESIGN FEATURES AND OPERATIONAL EXPERIENCE OF STEAM NETWORKS

3.1 DESIGN PARAMETERS AND FEATURES

Most of the steam district heating systems in the U.S. and Europe were designed and constructed about 50 to 90 years ago. At the time of low fuel cost, the centralized steam supply systems were thought to be progressive and economic. However, with fuel price escalation and the requirement to transport the heat for long distances, hot water systems have been judged economic.

The steam pressure at the heat source in most heating networks surveyed is between 175 and 250 psig (Exhibit II). Some of the systems have lower (40 to 150 psig) and sometimes higher steam pressure (400 to 750 psig). For comparison purposes, it should be noted that in cogeneration hot water systems, the steam pressure extracted from the turbine is usually between 15 and 25 psia, which results in higher thermal efficiency.

The steam temperature is usually commensurate with properties of saturated steam at the given pressure and it is relatively high (in the range of between 300 and 750 F). It is common to control the pressure in the network by means of pressure control valves and desuperheating stations. The steam pressure after the main transmission lines is reduced to different values and is utilized by the customers at levels of usually between 7 to 15 psig. In all systems practically, the condensate is not returned to the power plant for a number of reasons (corrosion, collection problems, high cost for installing condensate lines in existing systems, etc.). To replace the lost condensate a high quality make-up for the boilers is required, thus imposing a high cost penalty.

The steam networks are designed according to the pressure power piping code ANSI B 31.1 and range in size between 2 to 30 in. for transmission and between 3/4 and 30 in. for distribution piping. Most of the piping has wall thicknesses equivalent to schedules 40 and 80. The piping length is relatively small, the largest systems having 90 miles in the USA and 153 miles in Europe. This is explained by the fact that the networks serve mostly the high density city core areas and the heat load per mile of piping network is very high (Figure 3-1).

The major steam piping installations in the U.S. and Canada use the rigid concrete envelope poured in place with some conduit type designs. The Paris heating system mostly uses prefabricated concrete culvert installations. Ductless installations have been tried in the Paris system, but they are no longer used. Expansion loops are used whenever possible in addition to slip, bellows and ball type expansion devices.

Carbon steel A53 Grade B typically used for carrier piping has mostly welded connections, along with some flange joints. The manholes are usually made of reinforced concrete poured in place or of combined brick and concrete construction.

The carrier pipe has external rust inhibiting paint except for two systems having asphalt and high temperature tar coating. All systems, particularly in the U.S. and Europe use calcium silicate for pipe insulation, while some systems utilize fiberglass.

Carbon steel is used as a casing material in conduits and it is protected against corrosion with different types of coatings (tar, asphalt). Some systems utilize cathodic protection to protect the carrier and the casing pipe from corrosion.

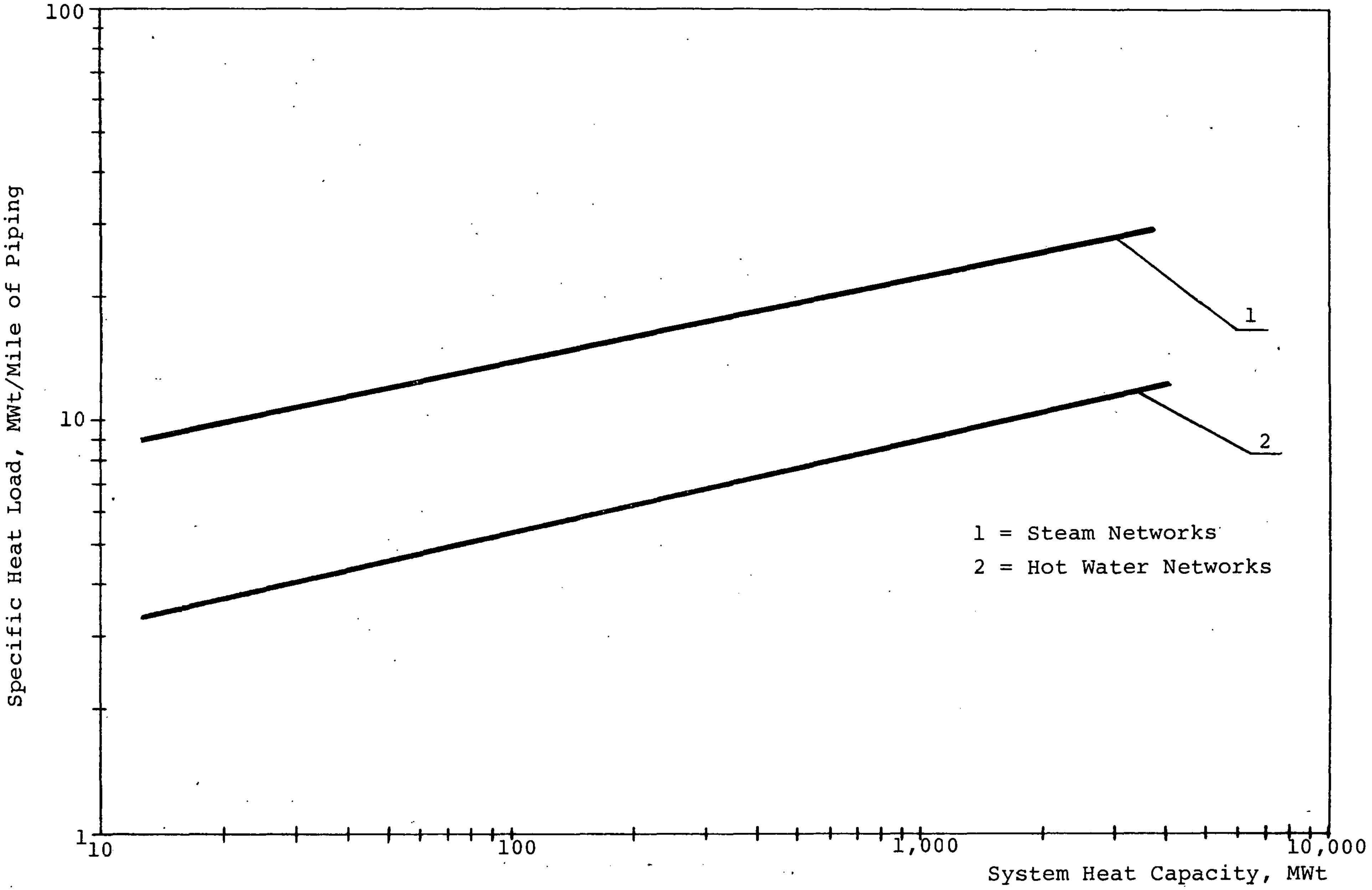


FIGURE 3-1

FIGURE 3-1 THE DEPENDENCE OF THE SPECIFIC HEAT LOAD ON THE SYSTEM HEAT CAPACITY

Most of the steam utilities have reported that their piping networks are drainable and dryable. However, a number of systems consider the rigid concrete envelope installation poured in place either not drainable, or not dryable.

Fifty percent of the networks examined indicated the existence of an air gap between the insulation and the culvert or the envelope with only 10 out of 26 systems having a ground water drainage system.

All networks are equipped with water treatment equipment including demineralizers and deaerators of the atmospheric type.

The depth of soil cover above the piping installation ranges from a minimum of 1.5 - 2.0 ft. to 18 ft. maximum depending on the site conditions.

The steam velocity in the piping network varies from system to system and is in the range of between 70 to 260 fps. Only the Paris system used an entry velocity of up to 550 fps for large mains.

Most of the utilities consider their network resistant to groundwater infiltration and spread of water in the event of water infiltration. However, six utilities gave a negative answer to the above question. It was evident in the design of all systems that every effort is made to keep the surface water and leakage from other utilities out of the heating network.

A majority of utilities consider their networks resistant to mechanical or structural damage. One utility has pointed out, however, that cracks in the concrete envelope did occur in the past which resulted in water penetration to the carrier pipe. Eighteen out of twenty-six utilities consider their systems resistant to corrosion. Year-round operation and keeping the ground water out of the network have been considered the most important factors in the prevention of corrosion failures.

A majority of utilities have reported that the piping networks are simple in installation and easy to repair, however, localization of the leak or damage is difficult. Some utilities consider rigid concrete envelope and conduit designs to be difficult to repair.

The quality control measures include usually x-ray of the welded joints and hydrostatic test at the site, per applicable ASME and local codes. Prefabricated conduit installations are usually tested at the factory. The Paris utility reported that in addition to a pressure test, a special corrosion test is provided at the factory.

3.2 OPERATIONAL EXPERIENCE

The conditions of the other utility systems adjoining the heating network (such as cold water, sewer, storm drainage, electrical) are very important from a reliability point of view. In most of the networks examined, the condition of adjoining systems are average; some of them have periodic leaks which saturate the earth around the piping with water. Some electrical and phone systems have been damaged by steam leaks. Some utilities do not have information on these systems.

Only a limited number of utilities have available information on soil corrosiveness, sulfate and sulfide contents, soil pH factor and presence of stray direct currents. These factors are of great importance and affect the design and maintenance operation of the district heating system. It should be noted that in urban areas the soil conditions very often do not remain constant. This is often because the adjoining utilities periodically maintain their facilities and use various foreign backfill material.

The design criteria and reliability of the piping system depends very much on the site water table. A majority of the utilities examined have a moderate site water table, which means that the ground water is never above the bottom of the piping system, but surface water remains for short periods in the soil surrounding the system. The control of water flooding conditions is performed by some utilities with installation of automatic pumps at low elevations and by inspecting the manholes on a regular basis.

Nineteen utilities indicated that a possibility exists in their systems for periodic contact of the external unprotected piping surface with ground water, or in other words of cyclic wetting and drying of the insulation. This condition is usually a result of a rain water run-off or water penetration from other utility leakages. This happens in some low areas or sites located close to the river flooded areas.

Practically no utility has effective measures to monitor the external corrosion rate of the piping system. Some utilities monitor periodically the piping equipped with cathodic protection. The internal corrosion rate is well controlled by effective water treatment, especially the deaeration process.

The other important problem is piping leakage detection. The steam leak areas are usually visible or are detected as follows: (1) inspection of manholes (hot manholes) to which the steam flows by following along the service pipe, (2) detection of warm spots on ground surfaces adjacent to steam lines with some settling of the wet soil, or (3) utilization of leak indicators located at expansion joints. Pressure and flow chart records may also help to indicate the pipe leakage area. Piping drawings with all joint locations are also helpful. However, to locate the exact leakage place, exploratory spot excavation is often required.

Practically all systems (except 4) operate on year-round basis, supplying heating, cooling and domestic hot water to the customers. The networks are out-of-service for only short periods of time from between 8 to 24 hours for repair.

The preventive maintenance of an underground network reduces substantially the failure rate and the repair cost. However, it was reported that no utility performs preventive hydro pressure or thermal (temperature) tests. The hydro test is performed only for new piping installations. Thermal test is performed when hydro test cannot be used.

Manholes are usually inspected on a regular basis. The frequency of inspection varies for different utilities from weekly or monthly to a yearly period. The manholes are cleaned up and the collected water pumped out. Special attention is given to expansion devices. Slip joints installed in manholes are inspected on a regular basis (weekly, monthly, yearly) and are repacked when necessary. Valves and traps are another important component that should be regularly inspected and properly maintained.

Fifteen utilities reported heat loss values in the piping system. The heat losses range between 5.4 and 37 percent. Even for systems with 70 to 75 percent of condensate return, the heat losses average about 15 percent. The breakdown of heat losses totalling 14% provided for example by Paris steam utility is as follows: condensate loss = 8.5 percent; steam heat loss = 2.5 percent; and the condensate heat loss = 3 percent. A majority of the utilities do not return the condensate and have therefore a 100% make-up supply. Only four utilities report that their make-up requirement is between 25 and 60%.

3.3 PIPING NETWORK FAILURE ANALYSIS

The location of the pipe failures experienced could be summarized as follows:

- o Straight Piping = 14 utilities (contributes approximately from 30 to 50 percent of the overall number of leaks)
- o Expansion Devices = 15 utilities (contributes from 25 to 35 percent of the leaks)

- Joints = 15 utilities
- Valves = 16 utilities (up to 35 percent)
- Manholes = 11 utilities
- Anchors = 10 utilities
- Traps = 4 utilities
- Condensate Return Lines = 3 utilities (out of 4)

The major reasons for the above failures are as follows:

- external corrosion aggravated by road salt and stress corrosion of piping, expansion devices, especially bellows of corrugated type, valves and bolts in flanged joints (15 utilities out of 26);
- internal corrosion of condensate return lines, especially at the high points where air venting is not provided and where stray currents are present; trap piping; and stress corrosion on bellows joints;
- internal corrosion of steam mains caused by non-deaerated water used for desuperheaters;
- internal erosion caused by the flow of condensate in the steam piping and service take-offs where the condensate drains into a main line;
- defective welding joints, flange connections, packing, and gasket failures.

Only one utility reports bacteriological corrosion as a failure reason. Five utilities report insulation failures, one of them specifically referring to powder or granular type of insulation (ductless piping installation).

Eleven utilities reported failures of co-located utility systems with water leaks as a contributing factor to the external corrosion problems in the district heating network.

One utility reported conduit pipe breaks resulting from two-phase flow conditions involving water hammer phenomena. Mechanical and structural damage of the piping installation caused by vehicle load and water hammer were also reported by some utilities.

In 14 out of 21 corrosion cases (representing 67%) the character of corrosion was of the pitting type (the pitting varying from pinholes to 0.5 in. diameter holes). Four cases (19%) had uniform corrosion and three (14%) had small spot type corrosion. In 15 cases (out of 23) the corrosion spots were located as being at the bottom of the pipe and in eight cases on the top side. When the pipe suffers a rupture as a result of corrosion, the wall thickness has been found to be reduced to almost zero (in eight cases). In six cases no ruptures were reported, but leaks were identified which usually started with a pinhole and then propagated.

In approximately 50 percent of the failures, the insulation was wet, saturated with condensate, damaged or blown away by the leaking steam. In the other 50 percent, utilities reported that the insulation was found to be in a fair or good condition.

The utilities split almost equally in assessing the dependence of the failure rate on the piping system age. About 50 percent of the utilities considered age and the failure rate unrelated. Some indicated that the failure rate is more dependent on the type of installation than on age. The average age of the steam heating network in service is reported to be between 25 to 30 years. It is after this period that most failures are experienced. One utility for example had little trouble from 1924 to 1961. After 1961 most of the failures are related to road salt induced corrosion problems.

Nine utilities reported an existence of an air gap between the insulation and the culvert during the service life of the pipe. One utility stated that the air gap was maintained as nearly as possible to the original condition. No utility has provided data on external corrosion rate.

Installation of adequate vents in concrete manholes is very important in order to reduce the corrosion rate of the enclosed components.[64]

The length of the piping section replaced after failure varied from 2 to 200 ft. for different utilities, it being 6 to 8 ft. per leak on the average. Based on data reported by 15 utilities, the repair time per failure varied from six hours to six weeks, being eight days on the average.

Repair cost per pipe failure depends on a number of factors, such as location of the pipe and interference with other utilities, pipe size, etc. The range of costs reported is between $1,000 to $7,900. The average cost based on data provided by eleven utilities is about $3,800 in 1978 dollars.

The maintenance cost varies substantially for different systems being between $2,700 to $37,000 per mile per year (1978 dollars). The average cost based on data reported by 13 utilities is about $22,500.

4. PIPING COST ESTIMATES

During recent investigations of large scale hot water district heating systems in the United States the cost of underground piping networks have been estimated as excessively high. Previous estimates based on typical U.S. technology, which has relied mainly on steam district heating experience have, as a result, tended to be overly conservative.

These costs have been in good agreement with piping replacement costs experienced by a number of steam heating networks in the U.S., but were almost twice as high when compared to the equivalent piping installation in Europe. Analysis of recent European network piping technology, including discussions and visits to a number of network installations indicates that their experience with extensive systems has resulted in a substantial reduction in piping costs compared with the U.S. This has been achieved by means of a number of relatively small improvements which in summation have resulted in the aforementioned piping cost reductions.

The purpose the present study was to optimize the piping installation design in order to reduce costs wherever possible, without jeopardizing overall system efficiency, reliability or service life, employing a mixture of typical U.S. and European district heating practices.

The cost estimates developed include a variety of piping materials, and installation designs for comparison purposes. The form in which the estimates are presented allows for easy analysis to determine the areas of highest cost, enabling future efforts of cost reduction to be properly directed.

A typical city street was selected for a specific detailed cost analysis. The street chosen for this purpose, Jackson Street, is located in St. Paul, Minnesota and is a typical urban street. This estimate included costs for intersection interferences which is fairly typical of urban areas such as St. Paul.

4.1 METHODOLOGY

The piping network typically comprises three subsystems: transmission, distribution, and interconnections to end users.

The transmission piping subsystem represents the long distance large diameter piping which transports the hot water from the power plant to the urban area. The transmission piping is installed in relatively long straight runs, with allowances for expansion loops. The distribution piping subsystem represents the large and medium diameter piping which is used to distribute the hot water within the service area. This distribution piping will be arranged in a network to serve those areas deemed economically attractive.

The interconnection service includes the piping and accessories which connect the distribution piping in the city street to a service valve located inside the end user's property line or building wall.

The costs developed for this report cover all ranges of the above described piping subsystems except very large transmission mains. The cost estimates are based on a two-pipe installation, one supply and return. As is clear from Section 2, two installation methods dominate the European district heating market, based on reliability and cost considerations. Conduit design is used for pipe sizes up to 10 in. and concrete culvert design for carrier piping larger than 10 in. in diameter. Therefore, the majority of cost estimates are performed for these two installation methods. For comparison purposes, cost of a ductless installation with powder backfill is also developed. Different conduit modifications have also been analyzed. Carbon steel piping has been assumed as the carrier pipe for all analyses performed. Cost estimates developed for non-metallic carrier piping are presented in Section 5.

The major design assumptions, including the number of fittings and valves are presented in Table 4-1. Expansion joints were included for temperatures up to 300°F.

Cost estimates for the piping installation are developed by individually estimating the cost of each component and installation step. The cost estimate is comprised of the following items:

- Removal of existing street or sidewalk surface
- Excavation of trench
- Hauling of excavated and backfill material
- Concrete culvert and manhole construction
- Piping installation, welding, x-ray and hydro testing
- Installation of isolation valves, fittings and expansion joints
- Pipe and joint insulation
- Concrete placement
- Spreading and compaction of backfill material
- Replacement of street or sidewalk surface

Some of the above items are not applicable to each piping installation method evaluated, as for example, to conduit installation. However, the cost components were modified for each design accordingly.

Pavement and sidewalk breaking are considered as a separate operation prior to excavation, however, depending on site conditions, contractors and equipment, this operation could be reduced or even eliminated. No

Table 4-1

DESIGN ASSUMPTIONS FOR COST ESTIMATES

1. Excavation is 50% machine, 50% hand. Medium dry soil conditions prevail.

2. Excavated material not reused. Select structural fill or sand used for backfill.

3. Excavated and backfill material hauled five miles.

4. Compaction of backfill required.

5. Pipe joint every 20 ft., all welded joints are radiographed.

6. Pro-rated cost of accessories based on the following number of fittings per 1000 ft. of piping system: 40 elbows, 5 tees, 20 flanges, 2 valves (butterfly type), 5 expansion joints (bellows type); a prefabricated concrete manhole every 400 ft.

7. Average manhour cost $15.45.

shoring has been included in these cost estimates except for the specific case of Jackson Street. The shoring requirements vary greatly with area conditions. To impose a requirement for shoring in a general cost estimate might very well overestimate one area of the country or city while under-estimating others. Shoring requirements can and do vary regularly within the confines of one city.

Previous studies have used schedule 40 carbon steel as the main carrier piping in almost all sizes. In typical European district heating networks lower pipe schedules are employed. Therefore, for this study all carbon steel piping is assumed to be schedule 10 in 14" sizes and above, 10" and 12" piping is schedule 20, piping smaller than 10" is schedule 40. The reduction in piping wall thickness requires, of course, special attention to the network design and maintenance practices in order to prevent groundwater penetration to the external piping surface. The costs for welding of schedule 10 pipe are developed from analysis of the costs of welding heavier wall pipes and applying appropriate factors. Costs for joining conduit piping are also factored in from analysis of joining carbon steel and also from a review of costs presented in Reference 65.

Manholes are required for expansion joints in street application. Sidewalk applications may not require manholes, however they are included in the sidewalk estimate. Costs for precast manholes are obtained from Reference 66.

All excavation work was assumed to be 50 percent hand, 50 percent machine. This provides for squaring the trench and excavating around other utilities. To be conservative, the same ratio is used for sidewalk excavation, however, a higher machine utilization factor could most likely be applied. Sidewalk installations assume that the undisturbed sidewalk and curb can be reused following installation of the district heating network.

The development of piping system cost estimates using the approach described does not take into account the special and costly problems associated with underground construction in major urban areas. The major problem encountered is that of interference with foreign utilities already in place under the city streets. Gas, water, sewer, telephone, electrical lines, and subways represent significant congestion problems, particularly in downtown areas. The interferences must be resolved by routing the hot water piping around or under existing utilities, or by relocating the existing utilities with the agreement of the specific utility involved. In either case, the cost would be borne by the hot water piping system.

Disruption of city traffic is another contributor to increased costs. The permit issued to the contractor installing the hot water piping will limit the working hours to minimize disruption of traffic. Typically, no work will be done during morning and evening rush hours, and in some cases work may only be permitted at night and on weekends. These restrictions result in the payment of premium labor rates. Other added costs include the use of bridging and plating at major intersections to permit the continued flow of traffic. The previous studies demonstrated that the piping cost may be doubled when interferences are considered and factored in.[27] However, in this study, with the exception of Jackson Street, no figures were included for interferences within urban areas. As can be seen in the discussion on Jackson Street, later in this report, many different variables apply to make up interference costs. To assume a factor to provide for these costs is unrealistic and may penalize one urban area, indeed a single street heavily, while not penalizing another correctly. The interference cost, therefore, should not be generalized and must be estimated on a site-by-site basis.

Costs for piping and other materials are based on budget estimates provided by vendors.[66-79] Costs for earthwork, labor, equipment and materials for different cities were developed using accepted reference sources for the construction industry.[65,66] The cost estimates are in 1979 dollars and include the overhead and profit for the installation contractor. Overhead and profit are estimated as 45 percent on labor and 10 percent on material. In addition, 18 percent of labor costs fo workmen's compensation and public liability insurance is included. However, engineering costs for the piping system and interest during construction cost have not been included.

The cost estimates developed do not specifically include a margin for contingencies. However, the budget type estimates provided by vendors undoubtedly included some margin for uncertainty. Also, the extensive scope of a district heating project would lead to competitive bidding tending to lower the total installation cost.

Right-of-way and permit costs have not been included in the cost estimates. Discussions with utility personnel have indicated that these costs are insignificant when compared to the piping system costs.

4.2 COST ESTIMATE RESULTS

4.2.1 Concrete Culvert Installation

Cost estimates for a concrete culvert installed under the city street and sidewalk are developed separately for Minneapolis/St. Paul, Boston, Baltimore, Philadelphia and Washington, D.C. using labor rates applicable to each city.

Concrete Culvert, City Street Installation

This design consists of two pipes in a single concrete culvert installed beneath a city street. The culvert protects the pipe and insulation from water submersion and the accompanying corrosion and degradation of thermal and structural properties. Additionally, the culvert design protects the pipe from stones, street loads, inadvertent interference from street work on other utilities.

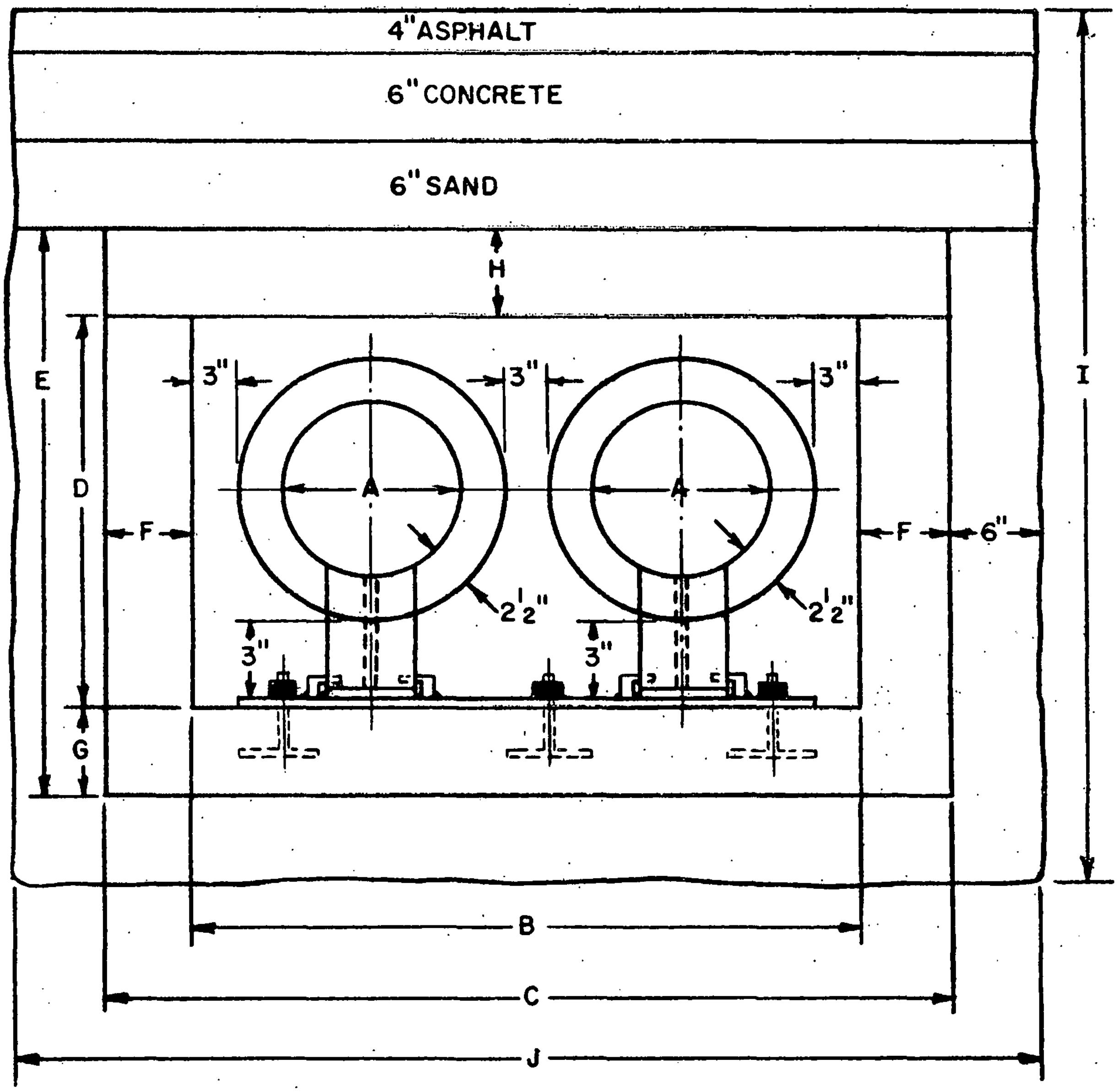
The culvert itself must be designed for the appropriate loads. Under typical U.S. city streets, the design load includes provision for an HS-20 truck load.[78,79] If the culvert has less than two feet of cover with flexible pavement, the walls, bottom and top slab will be of considerably heavier construction than if the earth cover is greater than two feet. The design under consideration here has attempted to minimize the trench depth to avoid the requirements for shoring. In so doing, a cover of less than two feet has been imposed. Also, the wider the trench, the thicker the walls and the more costly the installation. Three inches of space between pipes and walls has been provided for in the estimates, however, European practice provides almost zero clearance, which will effect some additional small cost savings. The concrete culvert dimensions developed for street installation and utilized for estimates are presented in Figure 4-1.

A six-inch sand bed has been included to provide for drainage of occasional water infiltration. If water appears to be a constant problem, then a drain line made of plastic piping can be placed at the bottom of the trench and covered with several inches of gravel and sand to provide for drainage. A 3-inch drainage pipe can be installed for about $4 to $5 per foot of trench. This concrete culvert is designed to drain the water to the manholes required for expansion joints and valving. The manholes are then either periodically emptied by work crews or an automatic means of pumping could be provided at additional cost.

Calcium-silicate is used for piping insulation.

The cost estimates developed for the five U.S. cities are presented in Tables 4-2 through 4-6 and the average cost in Figure 4-2. It should be mentioned that the costs developed are in general agreement with the data based on practical installations in the Twin Cities.[80]

CONCRETE CULVERT DIMENSIONS FOR STREET INSTALLATION



A*	B	C	D	E	F	G	H	I	J
10	39	47	19	32	4	6	7	52	59
12	43	53	21	34.5	5	6	7.5	54.5	65
14	47	57	23	36.5	5	6	7.5	56.5	69
16	51	61	25	38.5	5	6	7.5	58.5	73
18	55	67	27	42	6	7	8	62	79
20	59	71	29	44	6	7	8	64	83
24	67	81	33	48	7	7	8	68	93
30	79	95	39	55	8	8	8	75	107

*Nominal Pipe Diameter
All dimensions in inches

FIGURE 4-1

TABLE 4-2

PIPING SYSTEM COST ESTIMATE

(Concrete Culvert Design, $/Ft of Piping System)

Minneapolis/St. Paul, Minn.

ITEM OR PROCESS	PIPE OD (IN) 10		12		14		16		18		20		24	
	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street
Civil Work														
Excavation & Pavement Breaking:														
Labor	4.05	11.44	4.54	12.92	5.09	14.03	5.97	15.03	6.66	16.71	7.11	18.04	9.22	20.72
Material	1.50	8.71	1.67	9.66	1.86	10.50	2.17	11.07	2.40	12.09	2.55	12.99	3.28	14.56
Formwork: Labor	15.82	16.97	17.37	18.52	18.99	20.07	20.84	21.60	22.39	23.55	23.92	25.07	27.39	28.18
Material	5.21	5.59	5.72	6.10	6.25	6.61	6.86	7.11	7.37	7.75	7.87	8.26	9.02	9.28
Concrete (Inc. Manholes):														
Labor	2.79	4.69	2.79	4.69	2.79	4.69	3.74	6.59	3.74	6.59	3.74	6.59	3.74	6.59
Material	13.12	17.09	13.75	19.23	14.62	20.05	20.09	24.05	21.12	26.78	21.77	28.06	28.39	33.13
Backfill & Repavement														
Labor	2.59	8.56	2.87	9.32	3.10	9.96	3.36	10.61	3.58	11.36	3.79	12.01	4.32	13.40
Material	.47	5.46	.50	5.99	.54	6.37	.59	6.75	.68	7.28	.67	7.67	.76	8.58
Civil Work Overhead & Profit	18.01	29.93	19.54	32.73	21.22	35.06	24.34	38.83	26.08	42.08	27.60	44.59	32.30	49.98
Total Civil Work	63.56	108.44	63.75	119.16	74.46	127.34	87.96	141.64	94.02	154.19	99.02	163.28	118.42	184.42
Mechanical Work														
Pipe, Fittings, Supports:														
Labor	19.58	19.58	21.66	21.66	25.10	25.10	27.49	27.49	30.04	30.04	32.04	32.04	37.20	37.20
Material	38.37	38.37	50.35	50.35	70.04	70.04	81.12	81.12	97.27	97.27	116.59	116.59	139.88	139.88
Valves: Labor	.10	.10	.12	.12	.14	.14	.15	.15	.18	.18	.20	.20	.24	.24
Material	2.62	2.62	3.46	3.46	5.40	5.40	6.87	6.87	9.29	9.29	11.71	11.71	16.61	16.61
Expansion Joints:														
Labor	.30	.30	.35	.35	.41	.41	.45	.45	.55	.55	.61	.61	.71	.71
Material	4.19	4.19	5.17	5.17	6.47	6.47	7.39	7.39	8.84	8.84	9.88	9.88	13.60	13.60
Insulation: Labor	6.17	6.17	6.74	6.74	7.57	7.57	8.14	8.14	9.83	9.83	9.83	9.83	11.22	11.22
Material	14.37	14.37	16.07	16.07	17.90	17.90	19.78	19.78	21.67	21.67	23.57	23.57	27.08	27.08
Mechanical Overheads & Profits	22.44	22.44	25.70	25.70	30.91	30.91	34.35	34.35	39.29	39.29	43.07	43.07	50.83	50.83
Total Mechanical Work	108.14	108.14	129.62	129.62	163.94	163.94	185.74	185.74	216.96	216.96	247.50	247.50	297.37	297.37
Total Civil & Mechanical	171.70	216.58	198.37	248.78	238.40	291.28	273.70	327.38	310.98	371.15	346.52	410.78	415.79	481.79

TABLE 4-2

TABLE 4-3

PIPING SYSTEM COST ESTIMATE

(Concrete Culvert Design, $/Ft of Piping System)

Boston, Mass.

ITEM OR PROCESS	PIPE OD (IN) 10		12		14		16		18		20		24	
	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street
Civil Work														
Excavation & Pavement Breaking:														
Labor	4.35	12.27	4.88	13.87	5.46	15.06	6.40	16.12	7.14	17.93	7.63	19.35	9.89	22.23
Material	1.00	5.81	1.11	6.44	1.24	7.00	1.45	7.38	1.60	8.06	1.70	8.66	2.18	9.70
Formwork: Labor	16.25	17.44	17.85	19.03	19.51	20.62	21.41	22.20	23.00	24.20	24.58	25.76	28.14	28.96
Material	4.91	5.27	5.39	5.75	5.90	6.23	6.47	6.71	6.95	7.31	7.43	7.78	8.50	8.75
Concrete (Inc. Manholes):														
Labor	3.09	5.15	3.09	5.15	3.09	5.15	4.12	7.21	4.12	7.21	4.12	7.21	4.12	7.21
Material	14.39	19.51	15.07	21.68	15.91	22.51	21.99	27.67	23.03	30.44	23.58	31.73	30.29	36.86
Backfill & Repavement:														
Labor	2.89	9.18	3.08	9.99	3.33	10.67	3.61	11.38	3.85	12.19	4.07	12.89	4.64	14.38
Material	.32	3.64	.33	3.99	.36	4.24	.40	4.50	.42	4.85	.45	5.11	.51	5.72
Civil Work Overhead & Profit	18.81	31.12	20.40	34.04	22.12	36.44	25.44	41.49	27.23	43.83	28.38	46.42	33.65	51.93
Total Civil Work	66.01	109.39	71.20	119.94	76.92	127.92	91.29	144.66	97.34	156.02	101.94	164.91	121.92	185.74
Mechanical Work														
Pipe. Fittings, Supports:														
Labor	21.39	21.39	23.66	23.66	27.42	27.42	30.02	30.02	32.82	32.82	35.00	35.00	40.64	40.64
Material	40.67	40.67	53.36	53.36	74.22	74.22	85.97	85.97	103.08	103.08	123.56	123.56	148.24	148.24
Valves: Labor	.11	.11	.13	.13	.15	.15	.17	.17	.20	.20	.22	.22	.26	.26
Material	2.77	2.77	3.66	3.66	5.72	5.72	7.28	7.28	9.84	9.84	12.41	12.41	17.60	17.60
Expansion Joints:														
Labor	.33	.33	.39	.39	.45	.45	.50	.50	.61	.61	.66	.66	.77	.77
Material	4.44	4.44	5.48	5.48	6.85	6.85	7.83	7.83	9.37	9.37	10.47	10.47	14.41	14.41
Insulation Labor	6.75	6.75	7.36	7.36	8.27	8.27	8.89	8.89	10.73	10.73	10.73	10.73	12.26	12.26
Material	15.23	15.23	17.03	17.03	18.97	18.97	20.96	20.96	22.97	22.97	24.98	24.98	28.70	28.70
Mechanical Overheads & Profits	24.32	24.32	25.82	25.82	33.45	33.45	37.14	37.14	42.48	42.48	46.51	46.51	54.88	54.88
Total Mechanical Work	116.01	116.01	136.89	136.89	175.50	175.50	198.76	198.76	232.10	232.10	264.54	264.54	317.76	317.76
Total Civil & Mechanical	182.02	225.40	208.09	256.83	252.42	303.42	290.05	343.42	329.44	388.12	366.48	429.45	439.68	503.50

PIPING SYSTEM COST ESTIMATE

(Concrete Culvert Design, $/Ft of Piping System)

Baltimore, Maryland

ITEM OR PROCESS	PIPE OD (IN) 10 Sidewalk	10 Street	12 Sidewalk	12 Street	14 Sidewalk	14 Street	16 Sidewalk	16 Street	18 Sidewalk	18 Street	20 Sidewalk	20 Street	24 Sidewalk	24 Street
Civil Work														
Excavation & Pavement Breaking:														
Labor	3.68	10.38	4.12	11.72	4.61	12.73	5.41	13.63	6.04	15.16	6.45	16.36	8.36	18.80
Material	.99	5.67	1.09	6.28	1.21	6.83	1.41	7.20	1.56	7.87	1.66	8.45	2.13	9.47
Formwork: Labor	14.73	15.81	16.17	17.25	17.68	18.69	19.40	20.12	20.85	21.93	22.27	23.35	25.50	26.24
Material	5.19	5.57	5.70	6.08	6.23	6.59	6.84	7.09	7.35	7.73	7.85	8.23	8.99	9.25
Concrete (Inc. Manholes):														
Labor	2.72	4.63	2.72	4.63	2.72	4.63	3.68	6.54	3.68	6.54	3.68	6.54	3.68	6.54
Material	14.23	18.92	14.93	21.15	15.80	22.01	21.77	26.72	22.85	29.57	23.54	30.91	30.44	36.20
Backfill: Labor	2.44	7.76	2.61	8.45	2.82	9.04	3.05	9.63	3.25	10.31	3.44	10.90	3.92	12.16
Material	.31	3.55	.33	3.89	.35	4.14	.39	4.39	.41	4.73	.44	4.99	.50	5.58
Civil Work Overhead & Profit	16.93	27.69	18.36	30.25	19.90	32.38	22.93	36.00	24.54	38.99	25.94	41.28	30.35	46.22
Total Civil Work	61.22	99.98	66.03	109.70	71.32	117.04	84.88	131.32	90.53	142.83	95.27	151.01	113.87	170.46
Mechanical Work														
Pipe, Fittings, Supports:														
Labor	18.41	18.41	20.37	20.37	23.60	23.60	25.85	25.85	28.25	28.25	30.14	30.14	34.99	34.99
Material	39.04	39.04	51.21	51.21	71.24	71.24	82.52	82.52	98.94	98.94	118.60	118.60	142.29	142.29
Valves: Labor	.09	.09	.11	.11	.13	.13	.15	.15	.17	.17	.19	.19	.22	.22
Material	2.66	2.66	3.51	3.51	5.49	5.49	6.99	6.99	9.45	9.45	11.91	11.91	16.90	16.90
Expansion Joints:														
Labor	.28	.28	.33	.33	.38	.38	.43	.43	.52	.52	.57	.57	.67	.67
Material	4.26	4.26	5.26	5.26	6.57	6.57	7.52	7.52	9.00	9.00	10.05	10.05	13.84	13.84
Insulation: Labor	5.80	5.80	6.34	6.34	7.12	7.12	7.65	7.65	9.24	9.24	9.24	9.24	10.55	10.55
Material	14.61	14.61	16.35	16.35	18.21	18.21	20.12	20.12	22.05	22.05	23.98	23.98	27.55	27.55
Mechanical Overheads & Profits	21.59	21.59	24.74	24.74	29.83	29.83	33.19	33.19	38.00	38.00	41.74	41.74	49.32	49.32
Total Mechanical Work	106.74	106.74	128.22	128.22	162.57	162.57	184.42	184.42	215.62	215.62	246.42	246.42	296.33	296.33
Total Civil & Mechanical	167.36	206.72	194.25	237.92	233.89	279.61	269.30	315.74	306.15	358.45	341.69	397.43	410.20	466.79

TABLE 4-5

PIPING SYSTEM COST ESTIMATE

(Concrete Culvert Design, $/Ft of Piping System)

Philadelphia, Pa.

ITEM OR PROCESS	PIPE OD (IN) 10		12		14		16		18		20		24	
	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street
Civil Work														
Excavation & Pavement Breaking: Labor	3.90	11.02	4.38	12.45	4.90	13.52	5.75	14.47	6.41	16.09	6.84	17.37	8.88	19.96
Material	1.07	6.19	1.19	6.86	1.32	7.46	1.54	7.86	1.70	8.59	1.81	9.23	2.33	10.34
Formwork: Labor	17.88	19.18	19.63	20.93	21.46	22.68	23.55	24.41	25.30	26.62	27.03	28.33	30.95	31.85
Material	4.75	5.10	5.22	5.57	5.71	6.03	6.26	6.49	6.73	7.08	7.19	7.53	8.23	8.47
Concrete (Inc. Manholes): Labor	2.98	5.01	2.98	5.01	2.98	5.01	4.00	7.04	4.00	7.04	4.00	7.04	4.00	7.04
Material	13.27	17.42	13.94	19.55	14.76	20.37	20.31	24.54	21.34	27.77	22.00	28.54	28.57	33.60
Backfill: Labor	2.59	8.24	2.77	8.98	2.99	9.59	3.24	10.22	3.45	10.94	3.65	11.57	4.17	12.91
Material	.34	3.88	.36	4.25	.38	4.53	.42	4.80	.45	5.17	.48	5.45	.54	6.10
Civil Work Overhead & Profit	19.19	30.64	20.79	33.47	22.59	35.72	25.87	39.73	27.69	43.04	29.30	45.59	34.62	51.05
Total Civil Work	65.97	106.68	71.26	115.07	77.09	124.91	90.94	139.56	97.07	152.34	102.30	160.65	122.29	181.32
Mechanical Work														
Pipe, Fittings, Supports: Labor	22.70	22.70	24.47	24.47	28.36	28.36	31.06	31.06	33.94	33.94	36.21	36.21	42.04	42.04
Material	38.69	38.69	50.76	50.76	70.61	70.61	81.78	81.78	98.06	98.06	117.54	117.54	141.01	141.01
Valves: Labor	.11	.11	.13	.13	.15	.15	.17	.17	.21	.21	.23	.23	.27	.27
Material	2.64	2.64	3.48	3.48	5.44	5.44	6.93	6.93	9.36	9.36	11.80	11.80	16.75	16.75
Expansion Joints: Labor	.34	.34	.40	.40	.46	.46	.51	.51	.63	.63	.69	.69	.80	.80
Material	4.22	4.22	5.21	5.21	6.52	6.52	7.45	7.45	8.92	8.92	9.96	9.96	13.71	13.71
Insulation Labor	6.98	6.98	7.61	7.61	8.56	8.56	9.19	9.19	11.10	11.10	11.10	11.10	12.68	12.68
Material	14.49	14.49	16.20	16.20	18.05	18.05	19.94	19.94	21.85	21.85	23.76	23.76	27.30	27.30
Mechanical Overheads & Profits	24.98	24.98	28.12	28.12	33.71	33.71	37.40	37.40	42.73	42.73	46.69	46.69	55.03	55.03
Total Mechanical Work	115.15	115.15	136.38	136.38	171.86	171.86	194.43	194.43	226.80	226.80	257.98	257.98	309.59	309.59
Total Civil & Mechanical	181.12	221.83	207.64	251.45	248.95	296.77	285.37	333.99	323.87	379.14	360.28	418.63	431.88	490.91

PIPING SYSTEM COST ESTIMATE

(Concrete Culvert Design, $/Ft of Piping System)
Washington, D. C.

ITEM OR PROCESS	PIPE OD (IN)													
	10		12		14		16		18		20		24	
Civil Work	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street
Excavation & Pavement Breaking:														
Labor	3.74	10.55	4.19	11.92	4.69	12.94	5.50	13.85	6.14	15.41	6.55	16.63	8.50	19.11
Material	1.23	7.13	1.37	7.90	1.52	8.59	1.78	9.06	1.96	9.90	2.09	10.63	2.68	11.91
Formwork: Labor	15.52	16.65	17.04	18.17	13.62	19.69	20.44	21.19	21.96	23.10	23.46	24.59	26.87	27.64
Material	5.22	5.60	5.73	6.10	5.26	6.62	6.87	7.12	7.39	7.77	7.89	8.27	9.03	9.30
Concrete (Inc. Manholes):														
Labor	2.76	4.60	2.76	4.60	2.76	4.60	3.68	6.44	3.68	6.44	3.68	6.44	3.68	6.44
Material	12.95	17.69	13.55	19.61	14.30	20.35	19.78	25.10	20.71	27.56	21.30	28.71	27.24	33.26
Backfill & Repavement:														
Labor	2.48	7.89	2.65	8.59	2.86	9.18	3.10	9.78	3.30	10.48	3.50	11.08	3.99	12.36
Material	.39	4.47	.41	4.90	.44	5.21	.48	5.53	.52	5.96	.55	6.28	.63	7.02
Civil Work Overhead & Profit	17.42	28.50	18.89	31.12	20.48	33.33	23.50	36.35	25.16	40.04	26.61	42.41	31.08	47.46
Total Civil Work	61.71	103.08	66.59	112.91	71.93	120.51	85.13	134.42	90.82	146.66	95.63	155.04	113.70	174.50
Mechanical Work														
Pipe, Fittings, Supports:														
Labor	20.46	20.46	22.63	22.63	25.23	26.23	28.73	28.73	31.39	31.39	33.49	33.49	38.88	38.88
Material	39.70	39.70	52.08	52.08	72.45	72.45	83.91	83.91	100.62	100.62	120.61	120.61	144.70	144.70
Valves: Labor	.10	.10	.12	.12	.14	.14	.16	.16	.19	.19	.21	.21	.25	.25
Material	2.71	2.71	3.57	3.57	5.59	5.59	7.11	7.11	9.60	9.60	12.11	12.11	17.18	17.18
Expansion Joints:														
Labor	.31	.31	.37	.37	.43	.43	.48	.48	.58	.58	.64	.64	.74	.74
Material	4.33	4.33	5.35	5.35	5.69	6.69	7.65	7.65	9.15	9.15	10.22	10.22	14.07	14.07
Insulation: Labor	6.45	6.45	7.04	7.04	7.92	7.92	8.50	8.50	10.27	10.27	10.27	10.27	11.73	11.73
Material	14.87	14.87	16.62	16.62	13.52	18.52	20.46	20.46	22.42	22.42	24.38	24.38	28.02	28.02
Mechanical Overheads & Profits	23.38	23.38	26.76	26.76	32.21	32.21	35.77	35.77	40.92	40.92	44.84	44.84	52.91	52.91
Total Mechanical Work	112.31	112.31	134.54	134.54	170.18	170.18	192.77	192.77	225.14	225.14	256.77	256.77	308.48	308.48
Total Civil & Mechanical Work	174.02	215.39	201.13	247.45	242.11	290.69	277.90	327.19	315.96	371.80	352.70	411.81	422.18	432.98

AVERAGE PIPING INSTALLATION COST FOR FIVE U. S. CITIES

CONCRETE CULVERT DESIGN

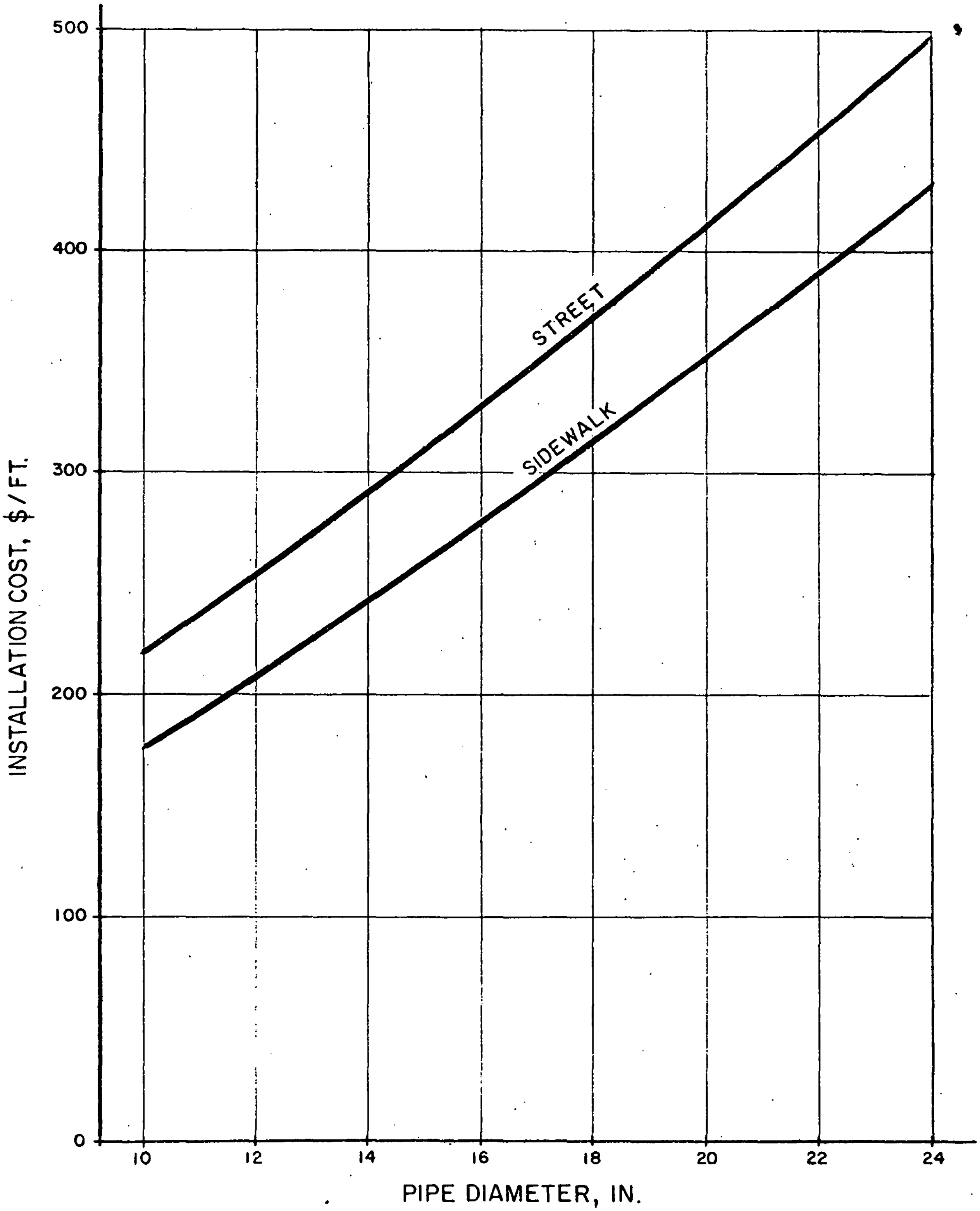


FIGURE 4-2

Concrete Culvert, Sidewalk Installation

This design is essentially similar to Figure 4-1 with the exception that the culvert is installed beneath the sidewalk. Sidewalk installation has several advantages over street installation which combine together to effect a considerably lower estimated cost.

The sidewalk design load is such that the structural characteristics of culvert walls, floor and cover can be greatly reduced. The culvert cover can, in fact, be the sidewalk, if so desired. This also allows for a shallower excavation which reduces the possibility of shoring. Another benefit of sidewalk installation is a reduction in the number of interferences. Most service lines are located beneath the street, only branch connections and possibly transformer vaults may cause interference problems.

Installing district heating lines beneath the sidewalk has the added benefit of providing for snow and ice melting. This feature is of benefit not only to pedestrian traffic, but building owners who would otherwise employ personnel to effect clearing of sidewalks. Maintenance benefits to a sidewalk installation are numerous. The entire system is not subjected to the loading of traffic which may cause eventual failures. It is not as subject to damage by contractors for other services. Since the culvert is not as deep, it is less subject to ingress of ground water, thereby lessening the possibility of corrosion to the pipe and destruction of the insulation. Access to the pipe and insulation for maintenance and inspection is also greatly simplified. Salt induced corrosion is also eliminated (when salt is used for snow melting).

Use of the sidewalk may be limited due to physical interferences and legal obstacles. These limitations will differ from city to city and should be investigated on a case-by-case basis.

The concrete culvert dimensions developed for sidewalk installation and utilized for estimates are presented in Figure 4-3, The cost estimates are presented in Tables 4-2 through 4-6 and the average cost in Figure 4-2.

4.2.2 Conduit Installation

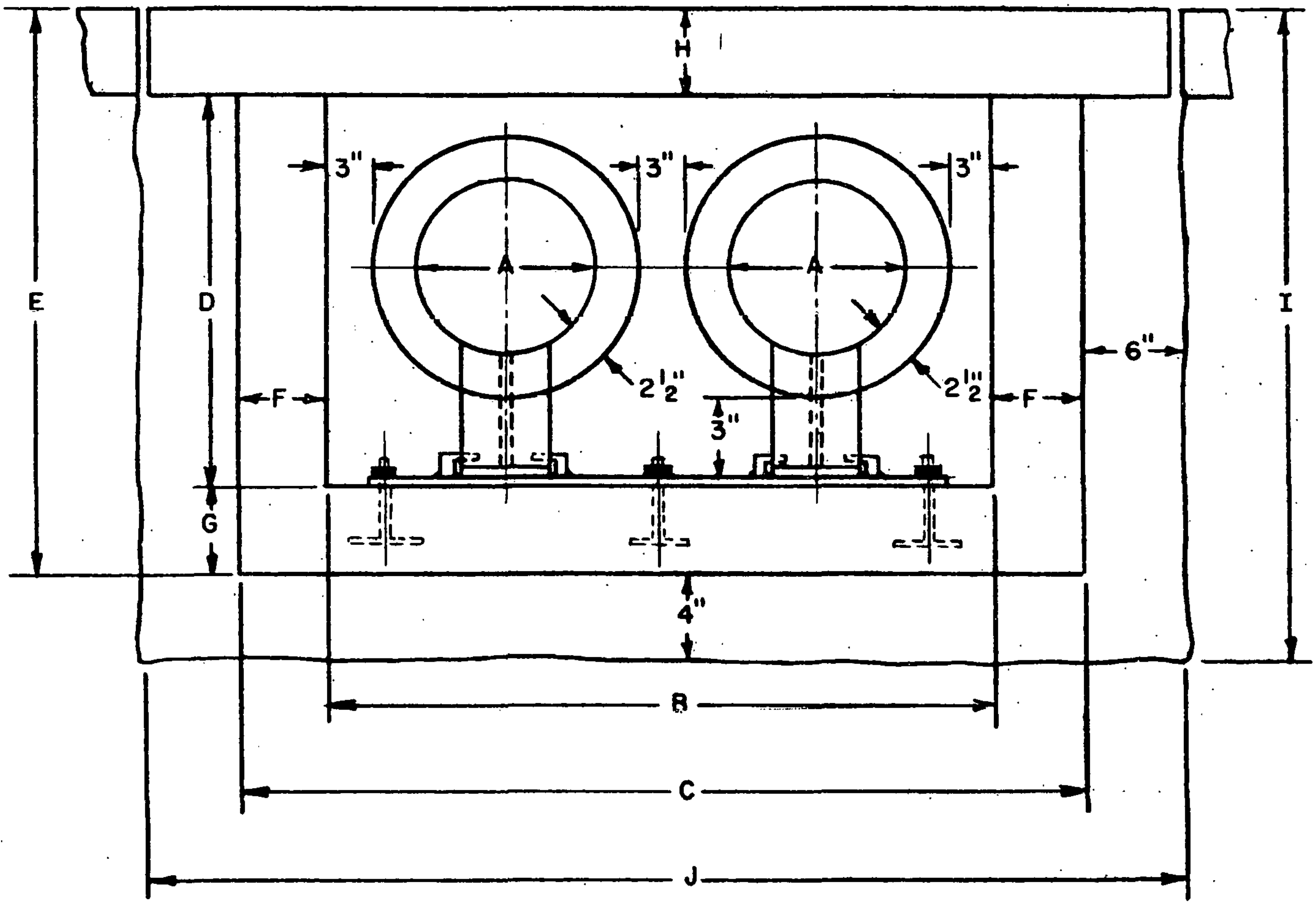
The design is for direct buried pipe using a conduit for each pipeline rather than a culvert for protection of the pipe and insulation material. The piping insulation and conduit material may vary for this design, however, the susceptibility to corrosion for carbon steel materials is quite high unless alternate means of protection are provided. Several means of protection are available and currently in use. The methods selected for our cost analysis were: carbon steel pipe with calcium silicate insulation encased in a welded steel pipe protected with an epoxy coating similar to RicWil's "Imperial" design, and, as alternates for cost comparison figures, carbon steel with polyurethane insulation and an outer polyethylene casing similar to RicWil "Terra Guard." Piping systems with polyurethane insulation and polyethylene casing are only useable for lower temperature installations, below 250°F.

The piping installation dimensions developed for conduit design and utilized for estimates are presented in Figure 4-4. The cost estimates are presented in Tables 4-7 and 4-8 and in Figure 4-5. As can be seen from the cost data, the advantages in initial installation costs are substantial for lower temperature systems when compared with the steel casing installations.

4.2.3 Ductless Installation with Powder Backfill

This design employs the use of an insulating powder backfill similar to that manufactured by the American Gilsonite Corp. or Protexulate, Incorporated. Essentially this design consists of installing pipe in a

CONCRETE CULVERT DIMENSIONS FOR SIDEWALK INSTALLATION

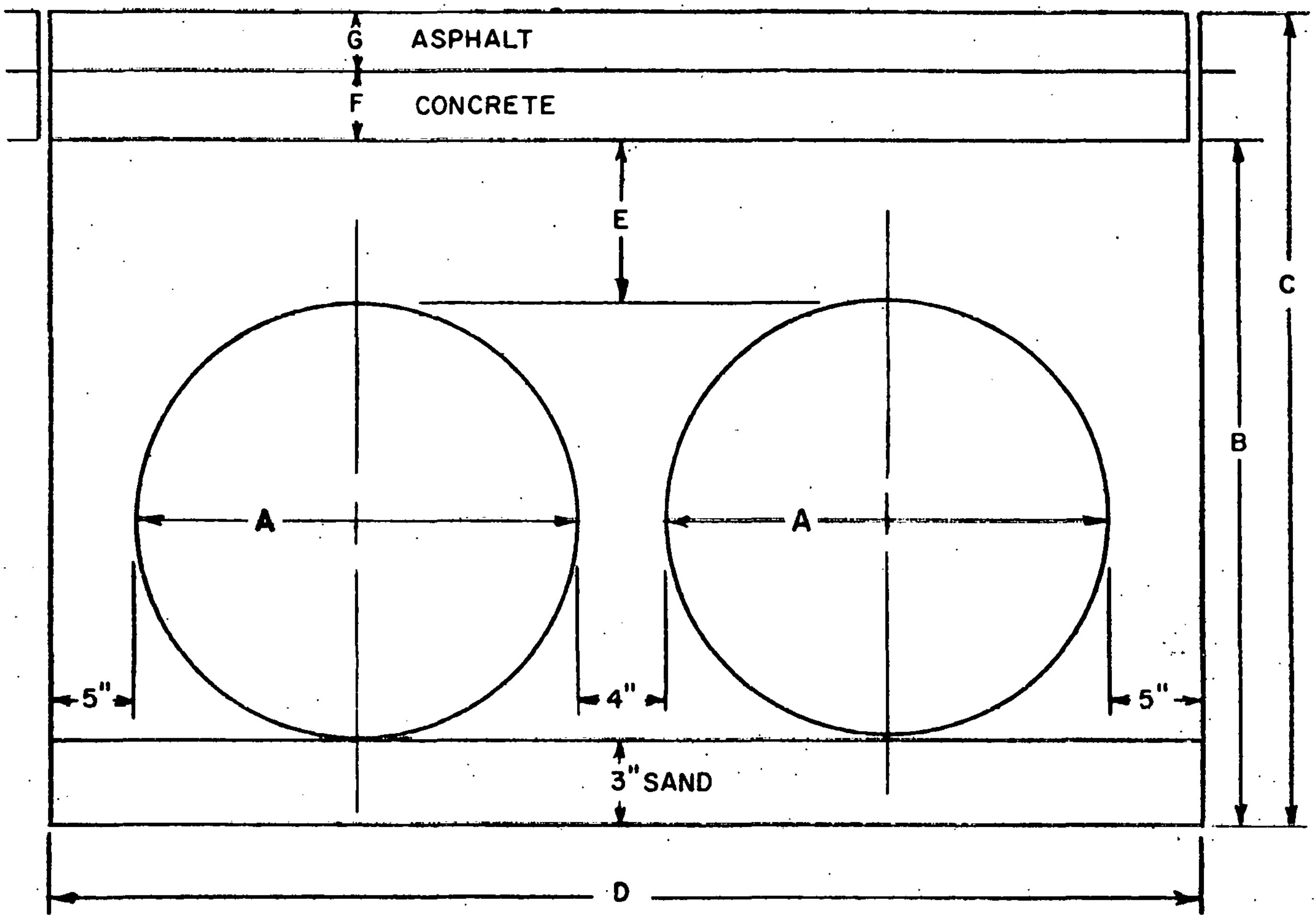


A*	B	C	D	E	F	G	H	I	J
10	39	45	19	26	3	3	4	30	57
12	43	49	21	28	3	3	4	32	61
14	47	53	23	30	3	3	4	34	65
16	51	59	25	34	4	4	5	38	71
18	55	63	27	36	4	4	5	40	75
20	59	65	29	38	4	4	5	42	77
24	67	77	33	44	5	5	6	48	89
30	79	89	39	50	5	5	6	54	101

*Nominal Pipe Diameter
All dimensions in inches

FIGURE 4-3

CONDUIT DIMENSIONS



CONDUIT DESIGN
STREET - SIDEWALK INSTALLATION

ITEMS				STREET INSTALLATION						SIDEWALK INSTALLATION					
Carrier pipe size	Insul. Type	Insul. Thickness	Casing Diam. A	B	C	D	E	F	G	B	C	D	E	F	G*
2	Cal Sil	1.5	8.75	36	46	32	24	6	4	15	19	32	3	4	-
2	PU Foam	1.5	5	32	42	24	24	6	4	11	15	24	3	4	-
4	Cal Sil	1.5	10.75	38	48	36	24	6	4	17	21	36	3	4	-
4	PU Foam	.7	6	33	43	26	24	6	4	12	16	26	3	4	-
6	Cal Sil	1.5	12	39	49	38	24	6	4	18	22	38	3	4	-
6	PU Foam	.7	8	35	45	30	24	6	4	14	18	30	3	4	-
8	Cal Sil	2	16	43	53	46	24	6	4	22	26	46	3	4	-
8	PU Foam	.7	10	37	47	34	24	6	4	16	20	34	3	4	-
12	PU Foam	.64	14	41	51	42	24	6	4	20	24	42	3	4	-
16	Cal Sil	2.5	24	51	61	62	24	6	4	30	34	62	3	4	-
16	PU Foam	1.9	20	47	57	54	25	6	4	26	30	54	3	4	-

*No Asphalt required
All dimensions in inches

FIGURE 4-4

TABLE 4-7

PIPING SYSTEM COST ESTIMATE

(Underground Conduit Design, $/Ft of Piping System)

Carbon Steel with Calcium Silicate Insulation and Steel Casing

ITEM OR PROCESS		PIPE OD (IN)							
		2		4		6		8	
		Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street
Civil Work									
Excavation & Pavement Breaking:	Labor	1.66	5.97	1.92	6.74	2.10	7.29	2.88	9.19
	Material	.49	3.65	.57	4.01	.61	4.33	.84	5.34
Formwork:	Labor	.16	.16	.21	.21	.23	.23	.34	.34
	Material	.05	.05	.06	.06	.07	.07	.10	.10
Concrete (Inc. Manholes):	Labor	.94	.94	.94	.94	.94	.94	.94	.94
	Material	2.00	2.08	2.05	2.05	2.09	2.09	2.18	2.18
Backfill:	Labor		8.99	4.68	10.32	5.04	10.85	6.41	13.75
	Material	1.87	2.82	2.01	3.21	2.14	3.37	2.63	4.20
Total Civil Work		11.44	24.58	12.44	27.54	13.22	29.17	16.32	36.04
Mechanical Work									
Pipe, Fittings, Supports:	Labor	10.14	10.14	16.28	16.28	22.52	22.52	26.17	26.17
	Material	60.29	60.29	83.35	83.35	102.52	102.52	145.62	145.62
Valves:	Labor	.13	.13	.07	.07	.08	.08	.13	.13
	Material	1.25	1.25	.86	.86	1.48	1.48	1.85	1.85
Expansion Joints:	Labor	.15	.15	.20	.20	.26	.26	.36	.36
	Material	1.10	1.10	1.80	1.80	2.71	2.71	3.39	3.39
Total Mechanical Work		73.06	73.06	102.56	102.56	129.57	129.57	177.52	177.52
Overheads & Profits		18.73	23.83	24.38	31.43	30.79	38.22	39.11	48.32
Total		103.23	121.47	139.38	161.53	173.58	196.96	232.95	261.88

TABLE 4-8

PIPING SYSTEM COST ESTIMATE

(Underground Conduit Design,$/Ft of Piping System)

Carbon Steel Pipe with Polyurethane Insulation and Polyethylene Casing

ITEM OR PROCESS	PIPE OD (IN) 2 Sidewalk	2 Street	4 Sidewalk	4 Street	6 Sidewalk	6 Street	8 Sidewalk	8 Street
Civil Work								
Excavation & Pavement Breaking:								
Labor	1.10	4.35	1.21	4.56	1.50	5.54	1.85	6.28
Material	.33	2.75	.36	2.75	.44	3.36	.54	3.71
Formwork:								
Labor	.07	.07	.11	.11	.14	.14	.19	.19
Material	.02	.02	.03	.03	.04	.04	.05	.05
Concrete (Inc. Manholes):								
Labor	.94	.94	.94	.94	.94	.94	.94	.94
Material	1.91	1.91	1.96	1.96	2.00	2.00	2.05	2.05
Backfill:								
Labor	2.83	6.36	3.09	7.12	3.64	8.46	4.34	9.58
Material	1.30	2.07	1.42	2.27	1.64	2.67	1.89	3.04
Total Civil Work	8.50	18.47	9.12	19.74	10.34	23.15	11.85	25.84
Mechanical Work								
Pipe, Fittings, Supports:								
Labor	8.20	8.20	13.66	13.66	19.62	19.62	25.64	25.64
Material	17.74	17.74	31.28	31.28	45.96	45.96	62.24	62.24
Valves:								
Labor	.04	.04	.07	.07	.09	.09	.13	.13
Material	1.25	1.25	.86	.86	1.48	1.48	1.85	1.85
Expansion Joints:								
Labor	.11	.11	.22	.22	.28	.28	.36	.36
Material	1.10	1.10	1.80	1.80	2.71	2.71	3.39	3.39
Total Mechanical Work	28.44	28.44	47.89	47.89	70.14	70.14	93.61	93.61
Overheads & Profit	10.74	19.32	15.92	20.90	21.94	27.91	28.27	34.80
Total	47.68	62.23	72.93	88.53	102.42	121.20	133.73	154.25

TABLE 4-6

AVERAGE PIPING INSTALLATION COST

CONDUIT DESIGN

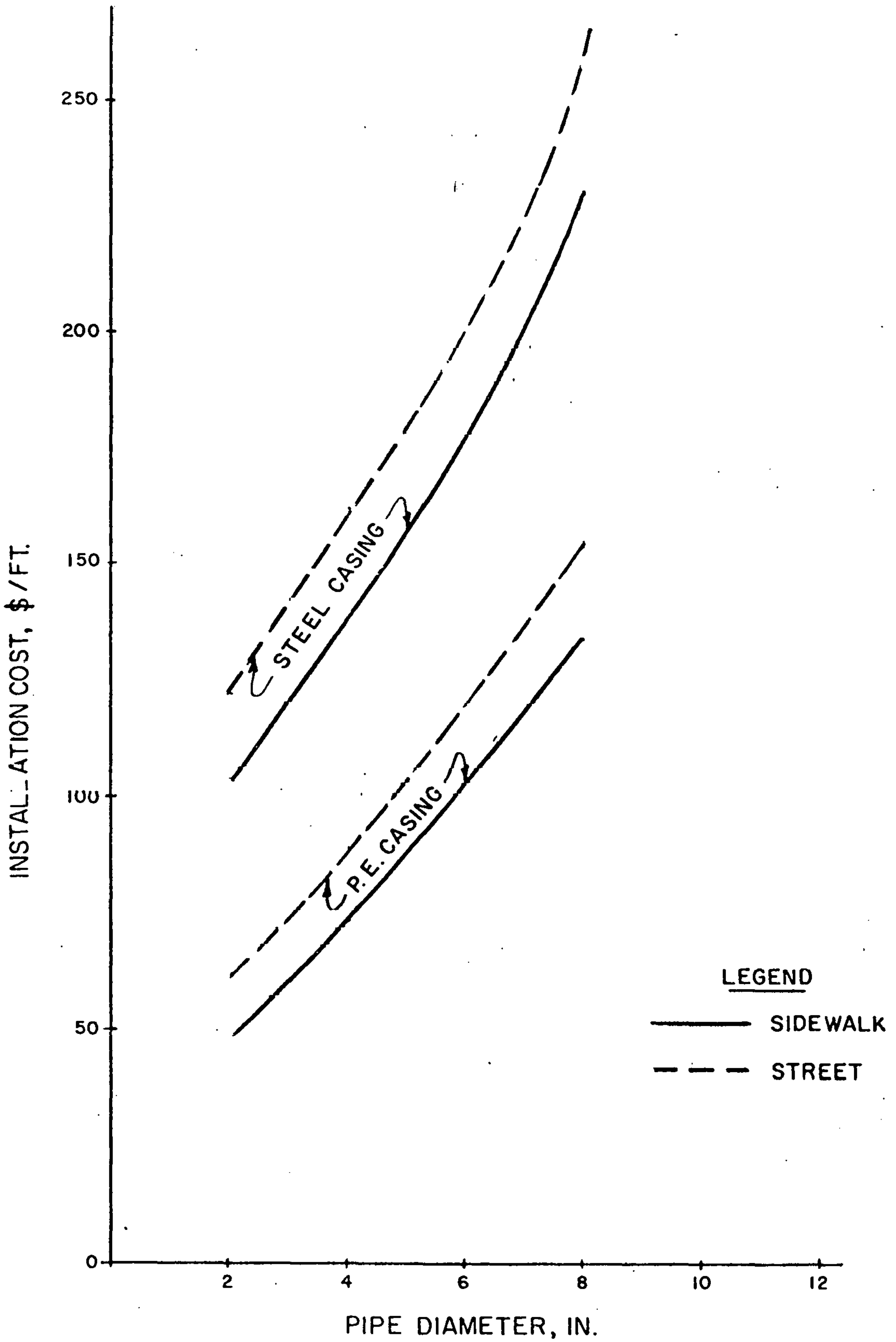


FIGURE 4-5

trench and backfilling with the insulation material. The insulating material is water repellent and when compacted properly should prevent water from migrating to the pipe surface by capillary action. To provide for drainage in the event of seasonal water problems, a layer of drainage material, such as sand and gravel or a concrete aggregate mix, should be installed with a porous drainage pipe to provide for water run off. These are manufacturer's recommendations and they have been included in the design.

The piping installation dimensions utilized for estimates are presented in Figure 4-6. The cost estimate developed for a 16 in. piping line is presented in Table 4-9.

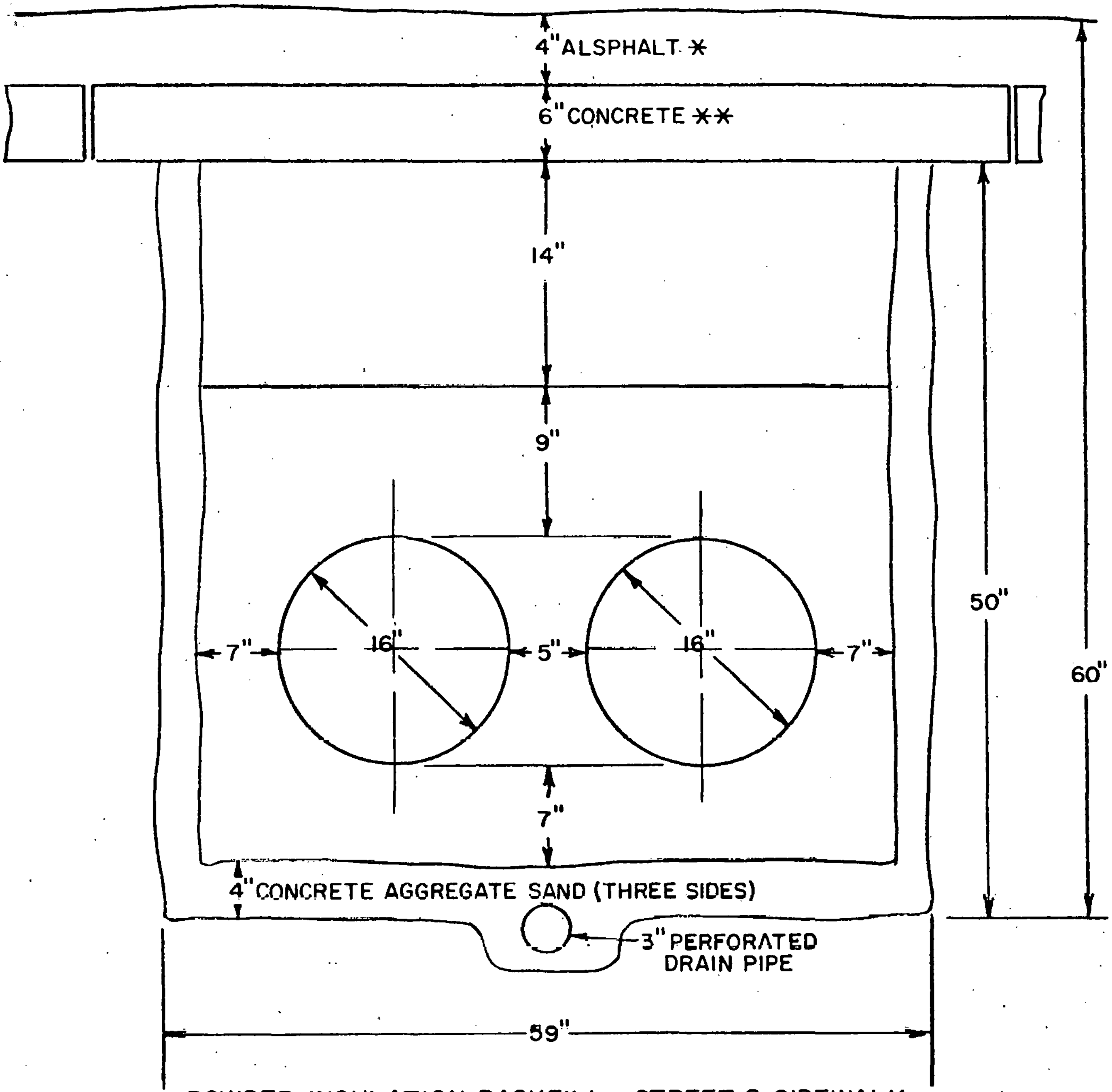
4.2.4 Piping Cost for Jackson St., St. Paul, Minnesota

Part of the scope of work for this report was to analyze a typical street in downtown St. Paul, Minnesota and perform a cost estimate for a 16 in. district heating line for the various designs as applied to this area. Northern States Power assigned a four block section of Jackson Street between Kellogg and Seventh Streets as a typical street.

A visit was made to St. Paul to review the area, and to discuss the design with Northern States Power. Photos were taken of the Jackson Street area and are shown in Appendix I. Discussions have been held with most of the major utilities responsible for the underground installation. Some utilities services piping were identified and located using existing drawings. The results are as shown in Figure 4-7 which plots the existing utilities for the four block area of Jackson Street.

Figure 4-7 gives some indication of the maze of utility services beneath Jackson Street. Attempts at locating the hot water district heating lines in the street were fraught with numerous interferences and associated high costs. Discussions with the phone company, power company,

DUCTLESS INSTALLATION DIMENSIONS



POWDER INSULATION BACKFILL - STREET & SIDEWALK

* EXCLUDE FOR SIDEWALK INSTALLATION.

** 4" CONCRETE FOR SIDEWALK INSTALLATION.

FIGURE 4 - 6

Table 4-9

PIPING INSTALLATION COST COMPARISON*

$/Ft of Piping System
16 Inch Carbon Steel Carrier Pipe

Item or Process	Installation Method			
	Concrete Culvert	Conduit, Steel Casing	Conduit, Polyethylene Casing	Ductless with Powder Backfill
Sidewalk Installation:				
Pavement Breaking & Excav.	7.61	6.17	4.93	7.86
Forms	28.35	.79	.63	12.15
Concrete	24.32	.68	.50	.45
Backfill & Repavement	3.81	13.06	10.93	21.68
Manholes	2.76	2.76	2.76	2.76
Pipe & Fittings	112.46	329.81	195.37	113.96
Butterfly Valves	7.13	7.19	7.18	7.13
Expansion Joints	7.99	8.15	8.11	7.99
Insulation	29.00	**	**	76.90
Overhead & Profit	59.51	65.65	49.08	60.28
Total For Sidewalk	282.94	434.26	279.49	311.16
Street Installation:				
Pavement Breaking & Excav.	23.42	20.05	16.99	15.94
Forms	29.39	.79	.63	12.15
Concrete	34.56	.68	.50	.45
Backfill & Repavement	15.73	25.18	21.30	21.67
Manholes	2.76	2.76	2.76	2.76
Pipe & Fittings	112.46	329.81	195.37	113.96
Butterfly Valves	7.13	7.19	7.18	7.13
Expansion Joints	7.99	8.15	8.11	7.99
Insulation	29.00	**	**	76.90
Overhead & Profit	71.38	77.83	59.57	63.08
Total	333.82	472.44	312.41	322.03

Footnotes

* Interference cost with other street utilities is not included.
** Insulation included with pipe & fittings.

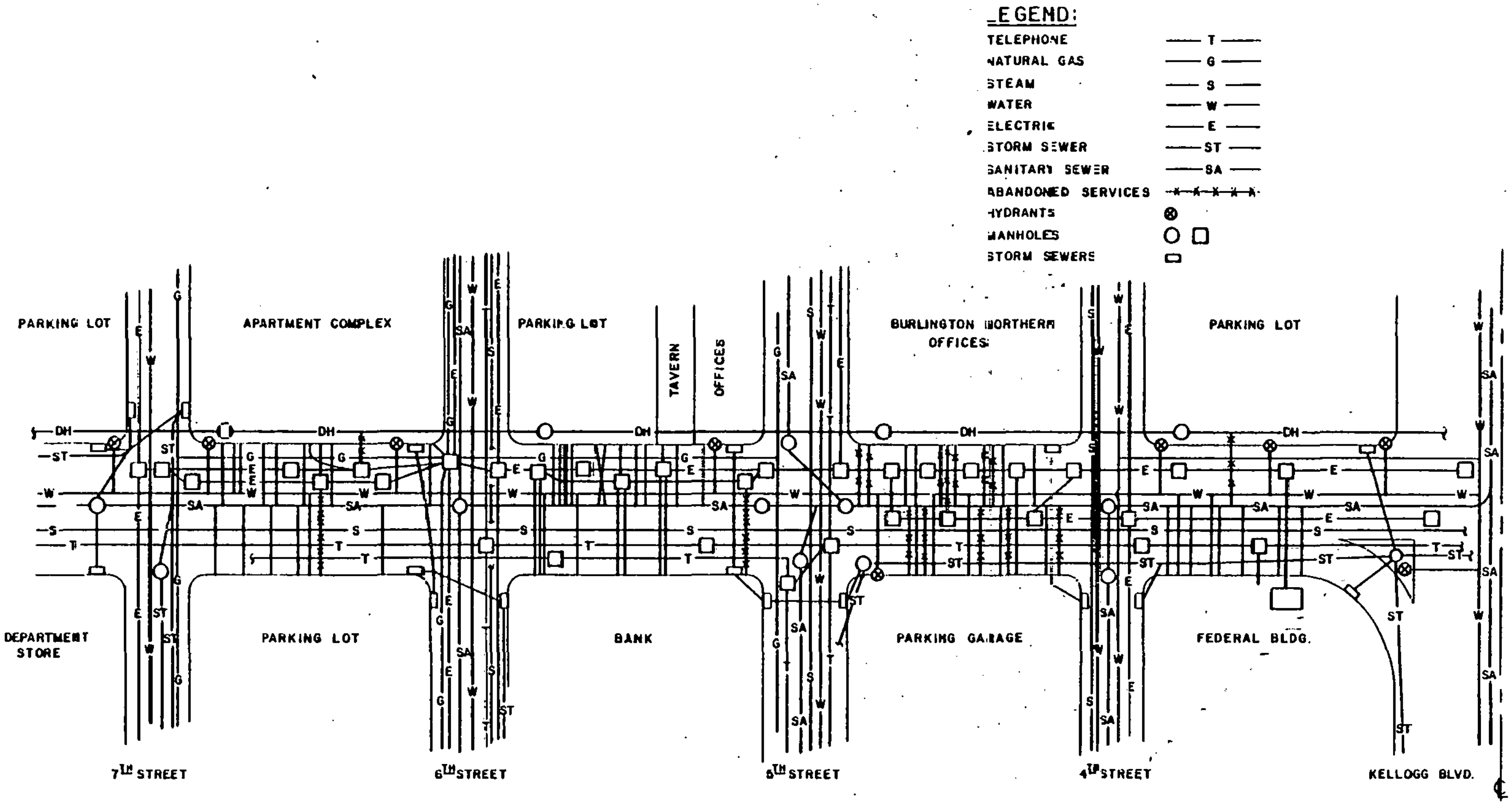


FIGURE 4-7 EXISTING SERVICES AND PROPOSED DISTRICT HEATING PIPELINE LOCATION JACKSON STREET, SAINT PAUL MINN.

FIGURE 4-7

sewer authority, gas company, and other utilities involved resulted in the following conclusions.

Relocation of phone company equipment is a lengthy and expensive process. Since no interruption of service can be tolerated, it was explained, a new service must be installed in its entirety prior to removal or relocation of existing equipment. In buildings such as the Federal Government Building at Kellogg and Jackson, this could be quite an expensive, time consuming operation. Phone company services are typically located between two and four feet below the street surface.

Northern States Power Company Electric Distribution personnel provided drawings and information indicating two main distribution networks under Jackson Street. Again relocation of facilities is not desirable and would be costly. Typical depth of the distribution system is three to four feet, although some are as deep as six feet. Manhole depths are four to six feet. Transformer vaults may be located beneath sidewalks.

The sewer Department provided drawings showing the mains, but not all the connections for both sanitary and storm sewers. They stated, however, that normally an 8 foot depth is maintained for both mains and building connections. Occasionally the storm sewer catch basis connections may be above this eight foot elevation.

Water Department drawings were also obtained which showed the location of their services. Water mains, except for the large tunnels are also generally below the frost elevation of eight feet. Tunnels are normally designed with a cover of two feet.

The gas company has very few service mains along Jackson Street. Gas lines, however, are normally between 2 to 4 feet below the surface. Relocation of gas mains is more readily accomplished than electric and telephone lines. Other utilities in the street include Western Union, traffic signal controls, street lighting, and existing steam lines for district heating.

The composite drawing was developed based on the material collected and shows the approximate locations of existing utilities (Figure 4-7). Site inspection (see photos in Appendix I) and discussions with utility personnel summarized above lead to the conclusion that installation under the sidewalk along the east side of Jackson Street would result in the least number of interferences. Only a question of access along the block between Fourth and Fifth exists since the building basement may extend to the curb line. The following discussion covers the construction of a hot water network on a block by block basis for a sidewalk installation.

Kellogg and Fourth Streets

Excavation of the sidewalk between Kellog Blvd. and Fourth Street is straightforward. Excavation is simplified since the property adjoining the sidewalk is a parking lot. At most, a small gas line will require relocation at nominal cost and some abandoned service lines will have to be removed in the excavation process.

As with all sidewalk excavation at the curbs, traffic control and street lighting cables will have to be identified, worked around, and possibly relocated. This first section of sidewalk is wide enough and should not present any problems.

Fourth-Fifth Streets

Between Fourth and Fifth Streets, the sidewalk is relatively narrow and adjoins the offices of Burlington Northern. Excavation to the curb line may be required, however, there are no street lights and only some parking meters may require relocation. For purposes of this study, it is assumed that there is no restriction on using this sidewalk.

If it turns out that the building basement does go to the curb line, two alternatives could be investigated. Either go into the street for this block or, and which may be less costly, go through the building basement if the owner permits.

Fifth-Sixth Streets

The block between Fifth and Sixth Streets has a small building with offices and a tavern. Here again the routing may require going either into the street or through the tavern basement. The majority of this block, however, is a parking lot, and sidewalk excavation should be straight-forward with only one street light and some parking meters to relocate and/or reinstall.

Sixth-Seventh Streets

Between Sixth and Seventh Streets is a recently completed apartment complex. The sidewalk here is wide enough for easy excavation. Utility services should pose no problem since they are fairly shallow and may only require slightly deeper excavation.

Seventh-Eighth Streets

This block contains another parking lot adjacent to the sidewalk and therefore presents no problem for the sidewalk installation of district heating pipes.

Interferences with Other Utilities

An attempt has been made to determine the effect on the cost of the piping system of the interferences with other utilities in Jackson Street. Reviewing the photos of the street one can see some small added costs using the sidewalk installation method, some of which were mentioned previously. A number of parking meters will require removal, and reinstallation of parking lot bumpers may also be required. These costs are minor and were not considered for the purpose of this report.

In this particular street containing a number of parking lots, the problem of interferences with other utilities is minimized. The services which could pose an interference problem at the elevations under consideration are electric, gas, steam, and telephone. Water, sanitary sewers, and storm sewers customarily exit or enter buildings below the eight foot frost elevation.

For the blocks being studied and the buildings involved, there do not appear to be many interferences when using the sidewalk. Telephone service enters the Burlington Northern (BN) and Tavern Buildings from Fifth Street. Electric does enter the Tavern Building from Jackson Street, however, this should be an easy service to relocate considering its size. Electric supply services apparently enter the BN Building from Fifth Street. The appartment complex may require the district heating system to go under these services.

The most difficult and therefore most expensive part of the piping system along this stretch of Jackson St. is the street intersection. At these points many of the other utilities are crossed and their elevations can and do interfere with the district heating system.

An additional obstacle is the large quantity of existing manholes in the intersection. For this study we are assuming an offset in the piping at the intersection to avoid these manholes.

From the data gathered to date, it appears that the majority of utility interferences are 4 ft. and above or 8 ft. and below. For 16 inch piping in a concrete culvert this just leaves the necessary 4 ft. of space for district heating lines, but at a deeper than desirable elevation.

For purposes of this report we have estimated the additional excavation and piping installation costs for crossing the intersection.

In addition to the deeper excavation, street crossings may require working during the off-hours to ease traffic congestion. Manhour cost estimates for this intersection work were figured on a double time basis. Additionally since working at night is more difficult, the manhours to complete the work were increased by 50% to provide for reduced productivity.

Manholes, although included in the cost estimates, are probably not required since removable sidewalk surface sections could probably be utilized. Manholes were assumed mainly for expansion joints and with the configuration of piping now under consideration, a great deal of expansion will probably be taken in the loops under the intersections. Manholes would therefore be reduced, eliminated or, if required, placed in the center of a block to minimize interferences.

Table 4-10 presents the interference costs estimated for the concrete culvert sidewalk installation of Jackson Street. As can readily be seen, this is more than three times the cost of a normal installation on a per foot basis. However, the interference cost contributed about 40% to the specific piping cost per foot (Table 4-11 and Table 4-12). This supports the previous statement that the interference cost is a function of a particular site and cannot be generalized.

To extend the piping from Jackson Street to the Third Street Station, a brief inspection of Kellogg Street was made during an on-site inspection, (see photos). There appears to be available, large open areas in the form of parks and road dividers which look promising for installation of district heat piping. From Third Street Station to High Bridge Station there are also large open areas, parking lots, high voltage tower rights-of-way, etc., which appear promising as avenues for installing mains for district heating purposes.

Table 4-10

PIPING SYSTEM COST ESTIMATE

Jackson Street Intersections

Concrete Culvert Design - Sidewalk Installation - 16 in. Carbon Steel

	Matl Cost $ per Unit	Labor Cost $ per Unit	Total Units	Total Matl $	Total Labor $	Total $
Pavement Breaking	8.56/ft	7.28/ft	40 ft	342	291	633
Excavation	.50/yd^3	5.81/yd^3	72 yd^3	36	418	454
Forms	7.11/ft	21.60/ft	40 ft	285	864	1149
Shoring	4.75/ft	43.56/ft	40 ft	190	1742	1932
Hauling	1.42/yd^3	.97/yd^3	90 yd^3	128	87	215
Concrete	24.05/ft	6.59/ft	40 ft	962	264	1226
Backfill	3.95/yd^3	1.65/yd^3	80 yd^3	316	132	448
Compact	-	20.76/yd^3	64 yd^3		1329	1329
Repavement	5.53/ft	3.65/ft	40 ft	221	146	367
Piping & Mechanical	115.16/ft	36.23/ft	40 ft	4606	1449	6055
Sub Total				7086	6722	13808
Premium Time for Labor					6722	6722
Labor loss of productivity					6722	6722
Overhead & Profit on Labor					12705	12705
Profit on Material				709		709
Total				7795	32871	40666
Dollar/Ft of Piping System @ Intersection						1017

Table 4-11

TOTAL PIPING MAIN COSTS

Concrete Culvert Design

Jackson Street-St Paul, Minnesota

Beneath East Sidewalk

Block	Length, ft	Cost, $
Kellogg - Fourth	280	77,000
Fourth - Fifth	311	85,000
Fifth - Sixth	316	86,000
Sixth - Seventh	315	86,000
Sub Total	1222	334,000
Intersection		
Half of Kellogg	35	36,000
Fourth	41	42,000
Fifth	40	41,000
Sixth	50	51,000
Seventh	40	41,000
Sub Total	206	211,000
TOTAL	1428	545,000
Piping Cost, $/ft		382

Table 4-12

COST COMPARISON OF CARBON STEEL PIPING HAVING DIFFERENT WALL THICKNESSES

Pipe Size (inches)	Schedule	Wall Thickness (Inches)	Piping Weight (cu.ft.)	Piping Cost ($/ft.)
10	20	.25	28.04	12.52
	30	.307	34.24	13.75
	40/Std	.365	40.48	15.51
12	20	.25	33.38	17.55
	30	.33	43.77	17.77
	Std	.375	49.56	19.25
	40	.406	53.52	20.90
14	10	.25	36.71	22.06
	20	.312	45.61	22.29
	30/Std	.375	54.57	22.49
	40	.438	63.44	26.53
16	10	.25	42.05	25.14
	20	.312	52.27	25.43
	30/Std	.375	62.58	25.63
	40/XS	.500	82.77	34.12
18	10	.25	47.39	29.32
	20	.312	58.94	29.61
	Std	.375	70.59	29.89
	30	.438	82.15	33.66
	XS	.500	93.45	38.29
	40	.562	104.67	-
20	10	.25	52.73	32.54
	20	.375	98.60	33.18
	30	.500	104.13	42.50
	40	.594	123.11	-
24	10	.25	63.41	38.59
	20/Std	.375	94.62	39.34
	XS	.500	125.49	50.44
	40	.688	171.29	-
26	Std	.375	102.63	44.85
	20/XS	.500	136.17	57.66

4.2.5 Piping Cost Analysis

The primary objective in all of the estimates performed was to reduce costs wherever possible, without sacrificing service life or reliability of the district heating network. From the estimates developed, it is evident that, regardless of location, the highest cost item is the mechanical material, with the next highest being mechanical labor. Cost reduction efforts therefore should be concentrated on the piping materials and labor to have the greatest effect. Other major items of expenses included street excavation, formwork, insulation and concrete.

One area of cost reduction which was investigated is the carbon steel carrier pipe wall thickness. Previously schedule 40 piping was used in cost estimates. These estimates use piping with 1/4 inch wall, which for the larger sizes is schedule 10. As an example, Table 4-12 presents the cost savings which can be accomplished by using schedule 10 versus schedule 40. These are material costs only. Substantial labor savings were also estimated due to reduced weight and welding times.

Sidewalk installation formwork and concrete costs remain relatively constant for any street installation. For estimating purposes the piping installation cost in the street and sidewalk is assumed to be the same. However, in practice, some savings should exist since the trench is shallower thereby making work easier. Premium labor payment for overtime construction could also be reduced compared with a street installation.

Two items which could probably be eliminated or reduced in a sidewalk installation include manholes and associated expansion joints. They were included for purposes of this report, however, close attention to detailed design and utilization of expansion loops at the intersections could reduce or eliminate the expansion joints and result in additional cost savings.

Sidewalk installation reduces the cost anywhere from 10 to 19 percent of the street installation depending on the street arrangement and pipe size. The larger the pipe size the lower the cost reduction since the civil work forms a lower overall percentage of the total cost.

Sidewalk costs might be further reduced by changing the excavation labor ratio of 50% manual/50% machine to a higher machine utilization factor. Fewer obstacles will be encountered and therefore a higher percentage of machine excavation is quite probable.

As mentioned previously, no shoring is included with these costs. Shoring costs have been estimated elsewhere at $2/sq. ft. of trench wall area upwards. Reduction of shoring requirements is a major consideration. Here again, the sidewalk installation method is advantageous. The trench is shallower, eliminating shoring in all but the most extreme cases.

Interference costs, as discussed earlier are very site specific. For this reason, they were not included in the estimate except for Jackson Street in St. Paul. Local conditions at the installation site must be individually assessed for accurate costs to be determined.

The comparative costs for conduit piping systems of differing materials are presented in Figure 4-5. A comparison of costs indicates that about 50 percent savings are available when installing a system with foam insulation and polyethylene casing as opposed to calcium silicate and a steel casing.

Removal of insulation from the return pipe is another possible means of installation cost reduction. This method is, for example, widely used in West Germany. Discussions and site visits to the Hamburg district heating system confirmed the validity of such a type of installation. The heat losses from the return lines are increased, and consequently the temperature of the return water is decreased. This may result in increase in electrical generation based on heat supply because lower pressure steam is extracted from the turbine for heating the return water. Therefore, an economic comparison has to be performed taking into consideration the reduced capital cost of piping installation, and the increase in electrical generation, versus increased heat losses during the service life of the piping installation.

The major cost saving items associated with the insulation are material and installation costs. Reduction in trenching and in the culvert dimensions due to elimination of insulation from the return pipe should also be considered. Typical savings for concrete culvert installations, if return pipe insulation is removed, would be in the range of $10 to $20 per foot for pipe sizes between 10 inches and 24 inches. However, these savings were not considered in the present piping cost estimates.

Comparative costs of various piping installation designs for 16 inch pipe size were developed and are presented in Table 4-9. From the data presented in this Table, it is apparent that culvert systems are indeed feasible and competitive in cost with conduit and powder backfill design.

The costs estimated in this report for various designs indicate the competitive nature of certain designs. Although there are certain apparent cost benefits of one installation concept over another, there are also other considerations such as corrosion resistance, temperature and pressure ratings, interferences, etc. which must be recognized before any one design can be selected as the most cost effective. It is evident, however, that small changes in design parameters, and engineering specifications, can substantially effect total installed costs.

5. PROSPECTIVE PIPING MATERIALS FOR DISTRICT HEATING NETWORKS

At the present time, carbon steel piping is almost exclusively used as a heat carrier for district heating network. However, in spite of costly protection measures, carbon steel can suffer severe corrosion problems. Therefore, development and utilization of a piping material with high corrosion resistance and low installation and maintenance cost is very important. Reduction in the piping cost will allow the extension of the heating network to the low heat load density areas and result in more efficient fuel utilization. This problem is especially important in the United States where about 70 percent of the population inhabits single-family homes.

Different types of non-metallic materials commercially available can be considered for district heating applications. Most of them are plastic materials. Non-plastics are also used like cement base materials. However, at the present time only a limited number of these piping materials are capable of meeting the operational conditions encountered in district heating networks. These are fiberglass reinforced plastics (FRP), cross-linked polyethylene, polybutylene and concrete pipes, which are discussed in more detail in the following sections. However, extensive testing and research is required before the new piping materials would be acceptable for wide utilization in hot water networks.

5.1 FIBERGLASS REINFORCED PLASTIC

5.1.1 Design Parameters and Features

Fiberglass reinforced plastic heat carrier pipes are made of chemically resistant resins, reinforced with fiberglass filament. Aromatic amine cured epoxy, heat cured vinyl ester-styrene, biphenol ester and biphenol acrylic resins are used.[81,82]

Most FRP pipes are constructed with a single angle fiberglass reinforcement. The filament may be wound at a helical angle of 35-1/4 degrees. One manufacturer constructs the FRP pipes with a dual angle fiberglass reinforcement.[83] The filaments are wound at 89 degress and cross-wound at 11 degrees. The manufacturer states that the high angle reinforcement resists external crush loads while the low angle reinforcement improves tensile and compressive strengths.

Some physical properties of FRP pipe using epoxy resins are provided in Table 5-1. A summary of tensile strengths and density properties for filament FRP and other structural materials is presented[85] in Table 5-2. As one can see from Table 5-2, considerable weight reduction can result when comparing FRP pipe with metal pipe of equal performance since the density of FRP is only one-quarter that of steel.

When compared with carbon steel, the FRP piping has the following important properties: lower Young's modules, lower heat conductivity and friction factor (water flow Hazen and Williams coefficient of C=150). The relatively low Young's modulus provides flexibility which is advantageous during installation. The coefficient of thermal expansion of the FRP pipe is of the same order as that of steel, but since the Young's modulus is about one-tenth that for steel, the stress for a given thermal strain is also less by a factor of 10. This makes it possible to minimize the number of expansion devices in the district heating system.[85]

Epoxy resin carrier pipes can withstand a maximum operating pressure of 150 psi and a maximum operating temperature of 250°F. For such temperature and pressure, the standard pipe sizes that are available range from 2 to 12 in.[86-88] Some manufacturers produce FRP pipes that can take, at an operating temperature of 250°F, operating pressures of 400 psi for small size pipes (2 in. diameter).[88] However, for a 12 in. pipe by the same manufacturer and for the same operating temperature, an operating pressure of only 130 psi is possible. Again, depending on the

Table 5-1

PHYSICAL PROPERTIES OF EPOXY PIPE
TYPICAL MODULI OF ELASTICITY AND
ALLOWABLE STRESS VALUES AT 70 F

	Modulus of Elasticity	Allowable Stress
Hoop Tensile ASTM D1599*	$4.6\mathrm{x}10^6$ psi	8600 psi
Axial Tensile ASTM D2105*	$1.6\mathrm{x}10^6$ psi	3025 psi
Beam Flexural Ameron	$2.0\mathrm{x}16^6$ psi	4000 psi
Axial Compression ASTM D685*	$2.3\mathrm{x}10^6$ psi	4000 psi

Coefficient of Thermal Expansion (Ameron) - 8.5×10^6 in./in.F

Thermal Conductivity (Ameron) - 2.3 x Btu/hr ft^{2}F/in.

*ASTM Test Methods were used to the extent applicable. Allowable stresses are based on a safety factor of 3.

Table 5-2

STRENGTH TO DENSITY RATIOS OF SOME STRUCTURAL MATERIALS

Material	Ultimate Tensile Strength (psi)	Density lbf/in^3	Ultimate Strength Density Ratio
Filament wound laminate (70% glass)	116,000	0.068	1.71
High tensile welded steel	300,000	0.283	1.07
Mild steel	70,000	0.283	.25
Aluminum	65,000	0.097	.67
Copper	58,000	0.322	.18
Stainless steel	45,000	0.290	.16

Note: The figures for the filament wound tube are uni-directional and correspond to a hoop stress at failure of 75,000 psi for a helically wound pipe at a helix angle of 55°.

manufacturer, pipe sizes ranging from 6 to 24 in. are available, but for a lower operating temperature of 200°F, where the carrier pipe is made of filament-wound epoxy resin with a ceramic liner. Larger pipe sizes are also available, being made of vinyl ester resin. The maximum operating temperature and pressure are 200°F and 150 psi, respectively. The pipe sizes range from 18 to 48 in.[81] However, the preferable diameter range of FRP applications in district heating network is between 1 and 6 in.

In summary, the major advantages in the utilizing of FRP for district heating compared to the carbon steel piping are as follows:

- elimination of electrochemical corrosion problems
- reduction of pressure drop and pumping power
- reduction in the heat insulation thickness required
- reduction in the number of expansion devices
- reduction in the installation cost

One of the major disadvantages of FRP piping and plastics in general is the possibility of the strength decrease under stress as a function of time, especially at elevated temperatures. Another problem is the reliable performance of the FRP pipe during cycling pressure and temperature. At these conditions there is a risk of pipe delamination due to different temperature expansion rates.

At the present time concrete thrust block installations at every change of pipe direction are recommended by pipe manufacturers. The blocks should encapsulate the fittings since after long-term exposure to the elevated temperatures, the FRP pipe will relax and when the temperature in the network is reduced the pipe will go into tension and the joint into shear.[84] It is also recommended not to use FRP piping for two-phase flow. Temperature and pressure of the superheated water inside the FRP should be such that steam flashing does not occur.

The above considerations are the subject of special investigations and testing of FRP in district heating systems. FRP pipes are now being seriously evaluated for use in district heating in Europe, especially by a FRP piping subcommittee of the German District Heating Association (AGFW). This committee comprises members of the German Association of Electricity Producers (VDEW), plus resin, glass fiber and FRP pipe manufacturers.[89]

Special tests of glass reinforced epoxy resin pipes with temperatures up to 300°F have been performed at Niederrhein GmbH's district heating plant at Moers, W. Germany.

These tests will provide information about the pipes' long-term performance and their suitability for use for long service in heating networks. The committee limited the study to fiberglass reinforced epoxy pipes with diameter up to 8 in. and pressure up to 230 psi.

Objective of the program is to investigate the aging process and creep behaviour of FRP pipes at elevated temperatures. The tests should give information on the life expectancy of FRP pipes in typical district heating networks. The tests have been performed by an independent institution, the T.U.V. - Bayern.

Some test results have been published recently [90-93] and require analysis. However, the preliminary information tends to demonstrate the feasibility of utilizing FRP piping in district heating networks.

A similar test program is being conducted in Sweden.[82] The stress testing is performed according to ASTM-D-2992, procedure B. Temperature and pressure cycling tests of the FRP piping and different joint techniques have also been performed.

There are a number of manufacturers in the U.S. and Europe who offer prefabricated, preinsulated FRP pipes. Typically the FRP carrier pipes are utilized in conduit installations similar to that described in Section 2. An FRP carrier pipe is enclosed in polyurethane insulation with a tight casing of FRP, PVC or PE. For temperatures up to 250°F, the pipe is a filament wound fiberglass with epoxy resin plastic. The pipe usually does not have any expansion devices. Elbows are located in poured concrete thrust blocks in order to hold the pipe in position and allow expansion in straight lengths.

In the U.S. and Europe, the FRP piping has been extensively used for condensate return lines. However, the use of FRP piping for hot water district heating seems to be most advanced in West Germany, where Deutsche Fibercast GmbH and Theodor Wuppermann GmbH have installed about 20 miles of experimental piping of this type. They have demonstrated the feasibility of using FRP pipes in district heating applications.[89] Wuppermann's Epogard system comprises a fiberglass reinforced epoxy pipe surrounded by layer of polyurethane insulation and an external PVC casing. The Epogard pipe is designed to be buried directly in the soil. As the pipes themselves absorb thermal forces, they are installed without expansion devices.

One of the U.S. manufacturers which has supplied the FRP piping for the German installations recently stated that the current test results showed that the FRP can be used for hot water installations with temperatures up to 275°F and maximum pressure combined with this temperature, of 150 psi.[89,93] The tests are being performed on 3 and 4 in. FRP piping. These results are from extensive testing of the pipes in European district heating systems.

In Scandinavia the FRP piping has also penetrated the district heating market.

5.1.2 Piping Cost Estimates

The cost of FRP carrier pipe is higher than the equivalent in carbon steel. However, during discussions with FRP manufacturers, they stated that on an installed-cost basis, the FRP installations are less costly for the following reasons:

- savings in labor for handling and assembling the FRP piping due to its light weight
- reduction in the insulation thickness required
- reduction in the number of expansion devices
- elimination of ground water drainage systems
- some reduction in trenching cost

It is also indicated in the technical literature that, based on the West German experience, the aforementioned savings may result in a cost reduction for FRP installation from 10 to 50 percent when compared to carbon steel.[89] Longer life and substantial reduction of the maintenance cost over carbon steel piping is also expected.

In order to compare the cost of FRP and carbon steel piping installations, a number of cost estimates have been performed during this study. Cost of a conduit installation, including FRP carrier pipe with a polyurethane foam insulation and a polyethylene casing have been estimated. The temperature limitation for such a conduit is 250°F maximum at the present time.

In order to develop comparable information, the cost estimates have been performed on the same design assumptions as stated in Section 4. However, the method of joining FRP is very different. End preparation, adhesive preparation, curing times, etc. are time consuming. It is of interest to note that the pricing received from vendors for straight prefabricated fiberglass pipe with foam insulation and polyethylene casing was more expensive per foot than comparable carbon steel piping with the same casing (by about 35 percent). The cost of prefabricated elbows, however, was significantly more for carbon steel than for fiberglass.

The results of the estimate developed for sidewalk and street installations are presented in Table 5-3. A review of the installation costs of fiberglass piping leads to the conclusion that it is comparable to the installation costs of carbon steel piping with a polyethylene casing. The cost comparison for these two installations is presented in Figure 5-1. These results are encouraging, and therefore, further testing of FRP installations under district heating operational conditions should continue. The object of such testing would be to ensure the reliable performance of this piping during the required service life.

5.2 CROSS-LINKED POLYETHYLENE

For about ten years, 25,000 miles of plastic pipes manufactured from cross-linked polyethylene have been utilized for internal heating applications. In West Germany, heating systems consisting of floor-laid 3/4" in. cross-linked pipe have been installed in 12,000 residences. In Scandinavia, approval for utilization of cross-linked pipe for domestic hot water has recently been obtained.

In recent years, the cross-linked piping has also been installed underground in district heating networks. Since 1973 about 30 miles of this piping has been used for underground district heating networks in Sweden (Figure 5-2).

This type of pipe is manufactured in a high pressure cross-linking and forging process giving a highly cross-linked (about 97%) end product. In this process, a dry blend of resin and cross-linking agent (organic peroxide) are forced, by means of a reciprocating ram, through a chamber

TABLE 5-3

PIPING SYSTEM COST ESTIMATE

(Underground Conduit Design, $/Ft of Piping System)

Filament Wound Fiberglass Pipe with Polyurethane Insulation and Polyethylene Casing

ITEM OR PROCESS	PIPE OD (IN) 2		4		6		8		12	
	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street	Sidewalk	Street
Civil Work										
Excavation & Pavement Breaking:										
Labor	1.10	4.35	1.21	4.56	1.50	5.54	1.85	6.28	2.53	8.07
Material	.33	2.75	.36	2.75	.44	3.36	.54	3.71	.73	4.71
Formwork:										
Labor	.07	.07	.11	.11	.14	.14	.19	.19	.29	.29
Material	.02	.02	.03	.03	.04	.04	.05	.05	.08	.08
Concrete (Inc. Manholes):										
Labor	.94	.94	.94	.94	.94	.94	.94	.94	.94	.94
Material	1.91	1.91	1.96	1.96	2.00	2.00	2.05	2.05	2.14	2.14
Backfill:										
Labor	2.83	6.36	3.09	7.12	3.64	8.46	4.34	9.58	6.40	12.18
Material	1.30	2.07	1.42	2.27	1.64	2.67	1.89	3.04	2.47	3.77
Total Civil Work	8.50	18.47	9.12	19.74	10.34	23.15	11.85	25.84	15.58	32.18
Mechanical Work										
Pipe, Fittings, Supports:										
Labor	8.20	8.20	13.66	13.66	19.62	19.62	25.64	25.64	29.92	29.92
Material	26.21	26.21	34.62	34.62	52.60	52.60	74.21	74.21	122.18	122.18
Valves:										
Labor	.04	.04	.07	.07	.09	.09	.13	.13	.13	.13
Material	1.25	1.25	.86	.86	1.48	1.48	1.85	1.85	3.50	3.50
Expansion Joints:										
Labor	.11	.11	.22	.22	.28	.28	.36	.36	.39	.39
Material	1.10	1.10	1.80	1.80	2.71	2.71	3.39	3.39	5.24	5.24
Total Mechanical Work	36.91	36.91	51.23	51.23	76.78	76.78	105.58	105.58	161.36	161.36
Overheads & Profit	11.58	16.17	16.26	21.21	22.60	28.58	28.47	35.99	39.21	46.87
Total	56.99	71.55	76.61	92.18	109.72	128.51	145.90	167.41	216.15	240.41

AVERAGE PIPING INSTALLATION COST

CONDUIT DESIGN

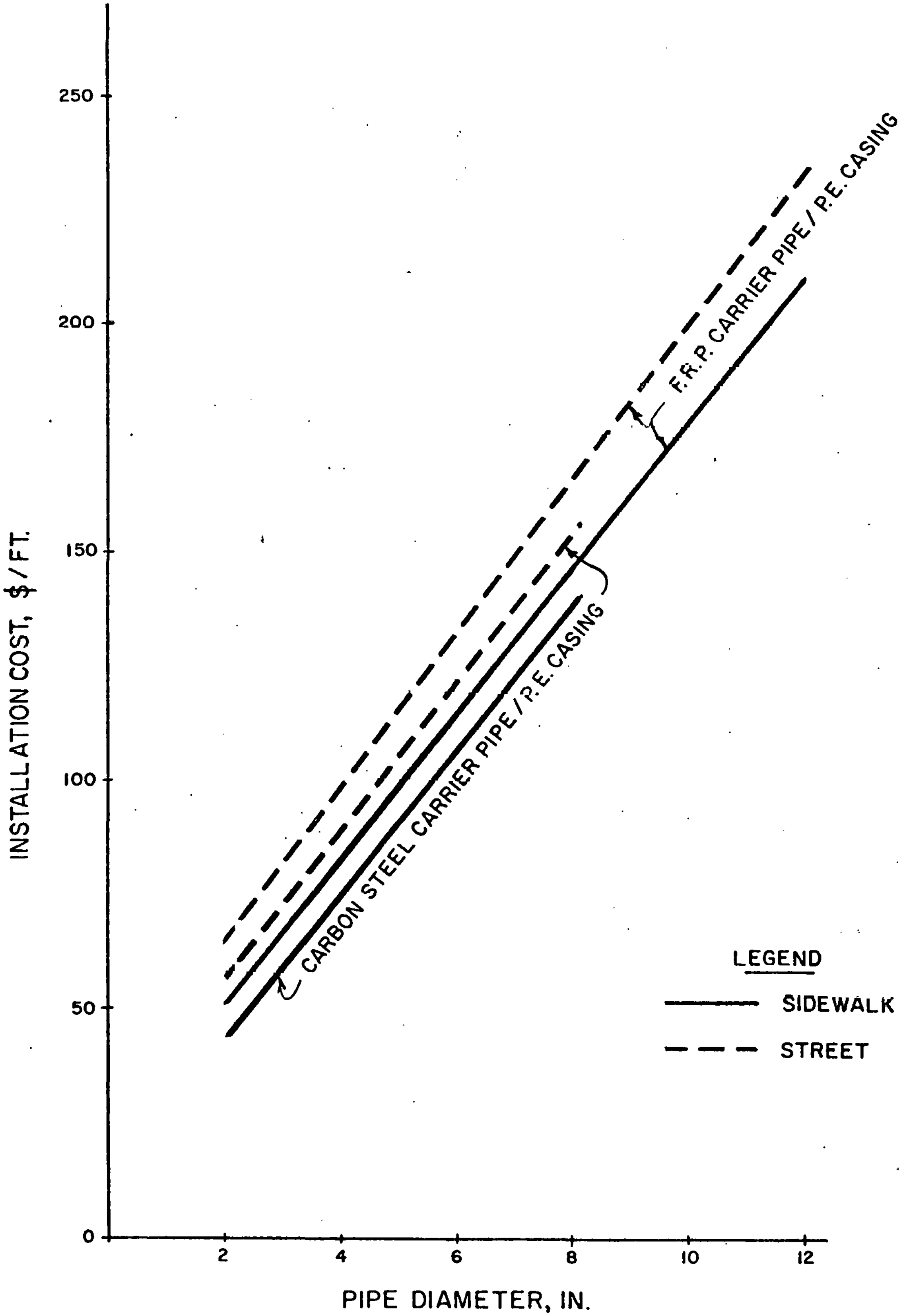


FIGURE 5 - I

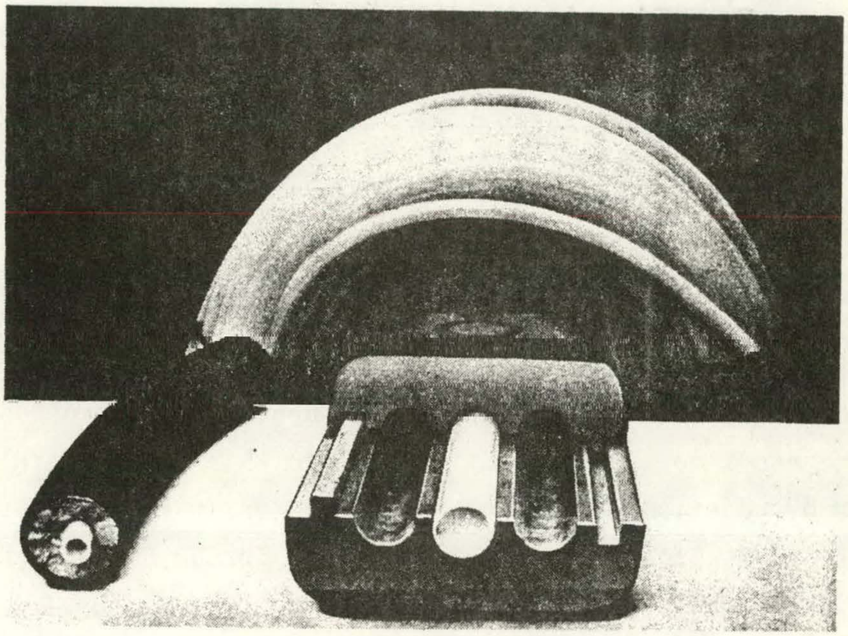


FIGURE 5-2 CROSSLINKED POLYETHYLENE PIPING
LEFT: PREFABRICATED CONDUIT WITH
CORRUGATED POLYETHYLENE CASING
(GRÄNGES ESSEM)
RIGHT: CROSSLINKED PIPING INSTALLED
INSIDE PREFABRICATED INSULATION BLOCKS
(WIRSBO BRUK)

system, where cross-linking occurs under controlled conditions of temperature and high pressure (about 150,000 psi), out of a pipe die.[89] The latest version of the equipment developed for this process incorporates a redesigned compression chamber said to have better flow characteristics, which gives more reliable cross-linking action. Operational flexibility has been improved by the wider availability of high density polyethylene resins with low catalyst residues, which in high concentrations interfere with cross-linking action. In a related process improvement a new quality control technique for quick checking of the degree of cross-linking has been developed.

The cross-linked polyethylene is manufactured by Wirsbo Pex (Gmbh), Heusenstamm, and Rehau Plastik, Rehau, in West Germany. Wirsbo Pex^{R} is the registered trademark of Wirsbo Bruk in Sweden. Another Swedish manufacturer, Granges Essem, utilizes a different manufacturing process. Granges Essem, utilizes a different manufacturing process. Granges uses silane and a conventional extruder. In this case cross-linking takes place by reaction with water, after processing.[82] In Japan similar pipes are manufactured by the Mitsubishi group and are currently used for geothermal applications.

One of the pipe manufacturers stated that cross-linked piping in sizes up to 1 in. can be utilized for temperatures up to 203°F and pressures up to 145 psi. Pipes with sizes up to 4 in. may be used in systems with temperatures up to 203°F and pressures up to 85 psi.[94] Such conditions may be provided in low temperature district heating systems and secondary network systems after the substations in the heating network. The pipe is manufactured in sections of both 150 and 300 ft. lengths. The pipes up to 2 in. in diameter are rolled up in bundles which can usually be carried by two men. The fittings for joining the pipes are made of red brass and the joining nuts and bolts from a type 316 stainless steel (Figure 5-3). It is stated by the manufacturer that the design of the coupling prevents torsional stresses

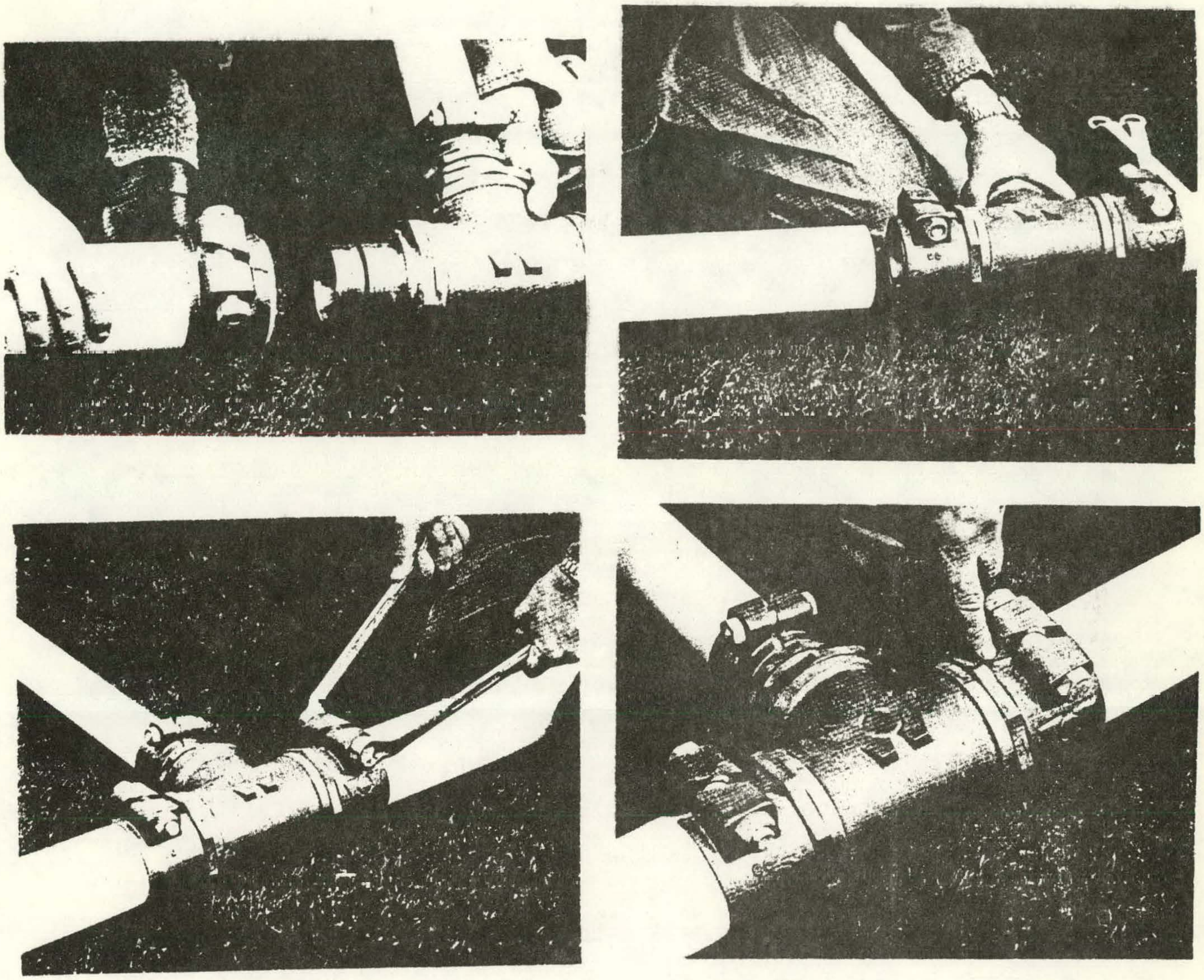


FIGURE 5-3 CROSSLINKED POLYETHYLENE FITTINGS

Courtesy of Wirsbo Bruk

in the pipe and that the fitting strength is higher than the tensile strength of the pipe.[95,96]

Mineral wool and polyurethane materials are used for pipe insulation. The mineral wool insulation consists of prefabricated rigid grooved blocks with associated covers (Figure 5-4). Differently shaped blocks to provide changes in pipe direction are supplied. The blocks are available with two and three grooves for both space heating and domestic hot water applications. Mineral wool insulation could be utilized in areas where no long-term water flooding is expected. However, the trenches should be provided with a drainage system. During the installation, the blocks are first placed in the trench. The tubes are then laid in the grooves and the covers fitted. Branches are installed last and are insulated with mineral wool.

The second type of insulating blocks are fabricated from foamed polyurethane. The elements are about 3 ft. long and have a watertight molded skin. In order to prevent water penetration, the internal surface of the blocks is covered with aluminum foil. Trench drainage is not required for this type of insulation. During installation the piping is first laid in the trench and the insulating blocks are then fitted around the pipe (Figure 5-5). This prevents the ingress of dirt between the tube and the insulation, and the risk of damaging the diffusion barrier. Thermal expansion is taken up by the insulation.

Lack of long-term operating experience with cross-linked piping limits its wide application in district heating networks. To obtain the required information special accelerated testing of this piping is being performed in Sweden as follows:

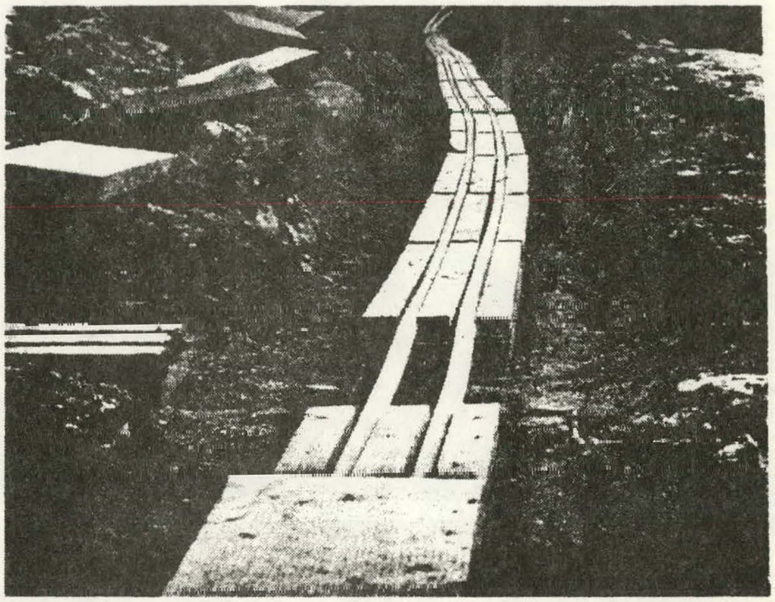


FIGURE 5-4 MINERAL WOOL INSULATING BLOCKS FOR PIPING INSTALLATION

FIGURE 5-5 MINERAL WOOL INSULATING BLOCKS FOR PIPING INSTALLATION

- long-term hydrostatic tests; pipes filled with hot water have been subjected to internal hydrostatic pressure. The tests at temperature of 203°F have shown no sign of sudden decrease of piping strength after two years operation. The results have indicated that the piping strength decrease should not occur until after 20 years at 176°F and 50 years at 140°F.

- influence of chemical factors; commercial polytheylene is always stabilized against thermal oxidation by addition of special oxidants. However, there is a risk that they will fail over the expected life of 50 years in a district heating network. The tests have to determine how the anti-oxidants in cross-linked piping are affected under typical temperature and pressure conditions.

- influence of detergents; it is known that stressed polyethylene may be affected by surface active ingredients. In the tests the cross-linked pipes have been immersed in detergents while under different pressure and temperature conditions. The results have demonstrated that there is only a minor strength reduction at 176°F which is not expected to influence the long-term service life of the piping.

- influence of the bending process on the long-term pipe strength; straight pipes and pipes bent with a radius of 5 pipe diameters at 176°F have been tested. It was concluded that bending at this condition does not reduce the piping strength.

In summary, the advantages of the cross-linked piping are as follows:

- high corrosion resistance
- high piping strength
- substantial reduction in piping joints

- low friction losses and subsequent reduction in pumping power
- elimination of expansion devices
- reduction in piping weight, easy to handle and install

The major disadvantages of the cross-linked polyethylene piping are as follows:

- operating temperature limitation up to 200°F
- low ultraviolet stability; the pipes must not be exposed to direct sunlight
- there are indications that oxygen diffusion in the pipe causes corrosion of the attached fittings

In spite of encouraging results achieved and indication that cost reduction up to 50 percent over conventional steel conduits may be expected, further technical development and testing is required before the cross-linked polyethylene piping will be widely utilized in the district heating networks.

5.3 POLYBUTYLENE

Polybutylene piping is a promising material for some district heating applications. Polybutylene piping is manufactured from polybutylene resins which are high-molecular-weight isotactic polymers synthesized from butene-1 monomer. They are flexible, crystalline thermoplastic pololefins having a density of about 0.91. They can be distinguished from polymers of isobutene, which are widely used as oil additives, and from amorphous atactic poly polymers, which range from viscous oils to rubbery polymers.

Polybutylene exists in two crystalline forms in melt processes. During cooling from the melt, polybutylene crystallizes initially in the tetragonal Form II, which transforms finally to the stable rhombohedral

Form I. Under normal conditions this transformation is completed in 5 to 7 days. Concurrent with transformation, the crystallinity increases up to approximately 50% with a corresponding increase in density, hardness, rigidity, and strength. Polybutylene films provide good impact, puncture resistance, and yield strength. Polybutylene pipe has received a 1000 psi design stress rating at 73 F and 500 psi at 180 F from the Plastics Pipe Institute.[97-100]

Other important characteristics include resistance to elevated temperatures, good barrier properties, and good electrical insulating characteristics. Polybutylene is resistant to most organic solvents, salts, acids and alkalines even at elevated temperatures. It is not affected by soil and will not rust or rot. It is not subject to electrolytic corrosion and is, therefore, suitable for underground use. However, it is partially soluble in aromatic and chlorinated hydrocarbon solvents above 140^oF.

Polybutylene piping is manufactured in the U.S. and utilized for cold water distribution, hot water plumbing and heating, gas distribution, and a variety of industrial uses including high-temperature and abrasive slurry piping, high temperature acid effluent lines, chemical process lines, and water mains.

An important feature of this piping material is its flexibility. According to information provided by the manufacturer, polybutylene pipe is twice as flexible as medium density polyethylene pipe and three times as flexible as high density polyethylene pipe designed for the same pressure service. It is very important to this application that pipes up to four inches in diameter can be easily coiled.

Polybutylene pipe weighs up to 90 percent less than steel, and approximately 30 percent less than other polyolefin pipes of the same diameter and pressure rating. This makes it easy to handle. The thermal conductivity of this type of piping is 1.5 $BTU\text{-}in/hr\text{-}ft^2\text{-}^oF$.

Butt fusion is used to join polybutylene pipes. The teflon-coated surfaces of a thermostatically controlled, electrical-induction heater are brought in contact with the ends of the two polybutylene pipes. The pipes are held together until a melt-bead appears around the circumference of each. The pipes are then retracted and the heater plate is quickly removed. Finally, the pipes are brought together under a pressure depending on the pipe cross-section. The machine automatically sets the required pressure, subjecting the pipe for about 30 seconds under pressure. The pipe is allowed to cool before removing the clamps. The resulting butt fusion joint should be as strong as the pipe itself. If the whole process is done correctly, leakage from the joint is not expected.[101]

Socket fusion is also used to join two polybutylene pipes. It involves the use of a male/female heating tool and hub-type fittings. This method of joining is restricted to the smaller diameters (up to 4") because of the availability of socket weld fittings.[102]

According to the manufacturer, polybutylene piping of type SDR 13.5* will serve in the temperature and pressure range of up to 200 F and 60 psi respectively (Figure 5-6).

The polybutylene may be used for some secondary low temperature district heating systems. However, intensive testing of this material under district heating operational conditions must be performed in order to ensure the reliable performance of this piping during the required service life.

---

* The wall thickness of pressure rate plastic pipes is based on the standard dimension ratio-pressure rated (SDR-PR) concept. This concept requires that the ratio of pipe diameter to minimum wall thickness be a constant value and that it complies with one of a series of standard ratios regardless of the actual pipe diameter.

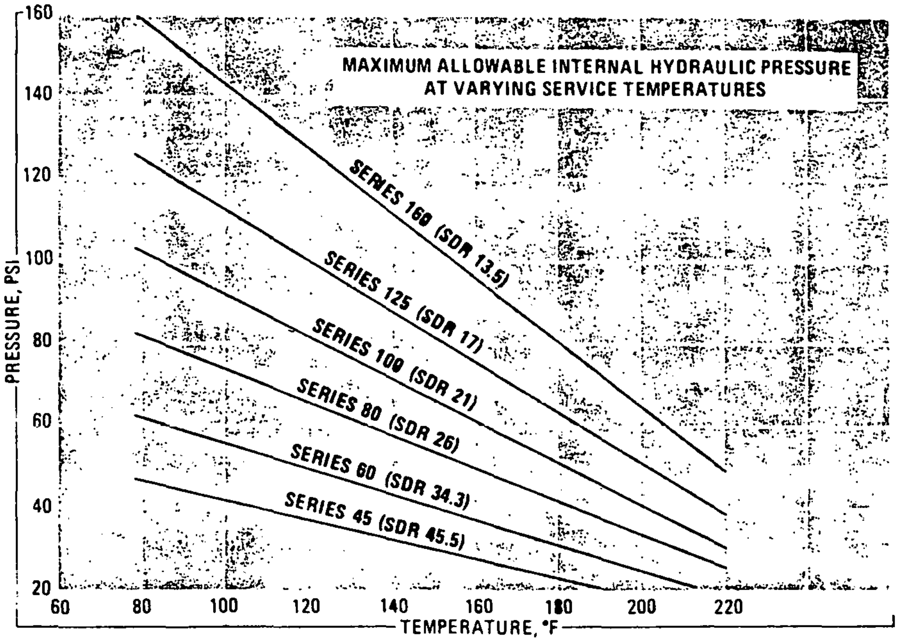


FIGURE 5-6 PRESSURE DERATING FACTORS OF POLYBUTHYLENE PIPING

(Clow Corporation, USA)

5.4 CONCRETE PIPES

5.4.1 Prestressed Concrete

Pipes fabricated of prestressed concrete have been used for many years in large cold water mains. The standard pipes are manufactured in lengths of about 15 ft. and are available in sizes 16 in. and above. Special rubber seals are used for the joints, permitting the pipes to absorb axial movements due to temperature fluctuations. The pipes are normally placed in direct contact with the earth. The concrete pipes have a number of advantageous features as follows: the material is non-corrosive, provided the soil pH is above 5.5, and can withstand significant external loads, the pipes are heat resistnat, have a high flow coefficient and reasonable cost.[22,103] However, the flow coefficient of the concrete pipes may actually decrease with use due to the accumulation of deposits in the initially rough concrete surface inside the pipe. The accumulation of such deposits can form a slick surface with lower flow resistance.

The major problems in utilization of concrete piping for hot water applications are as follows:

- concrete pipes have to be provided with an internal non-corrosive lining in order to prevent leaching of calcium and silicate materials and deposit accumulation
- the rubber sealed joint has to withstand relatively high temperatures over the service life of the pipe

Tests are underway in Sweden to utilize the concrete pipes with an inner, adherent layer of sand-filled epoxy resin for district heating applications with temperatures of between 200 and 230°F.[82] The test program and some results have been reported as follows:

- pipe tests at elevated temperature and pressure; short sections of pipe (Figure 5-7), each with a diameter of about 20 in. and a length of 4 ft. are connected, and hot water is circulated in them for prolonged periods. From time to time a section is taken out and a new one put in its place. The chosen section is inspected and the breaking strength measured by applying internal pressure and comparing the result with an untreated section. This test shows if there is a risk of relaxation in the concrete which would lead to loss of strength.

  To date a train of tubes has been tested for two months at 200 F and 75 psi. The test will continue at the same temperature and pressure of 120 psi for at least one year. No ill effects have been detected so far. A second loop will be tested at 230 F and 120 psi. This test will also continue for at least one year.

- resistance to temperature shock; concrete is known to be very sensitive to temperature shock. The actual shock limitations of prestressed concrete have to be checked experimentally. A loop containing full-size tubes is tested at a maximum of 220 psi and 250 F. The loop is designed to deliver repeated temperature shocks of differing severity, for instance changing the temperature from 230 F to 70 F within a minute. The tests will be followed by a careful inspection of the concrete and the inner plastic lining.

- test of internal lining; the tubes are internally lined with a plastic layer which has to adhere to the concrete and act as a corrosion-resistant lining for the life of the tubes. A sand-filled epoxy plastic has shown promising results. The adherence of the plastic layer is tested after repeated temperature cycling of the full-size tubes.

FIGURE 5-7 INSULATED PRESTRESSED CONCRETE PIPE WITH AN INTERNAL PLASTIC LINING

Pipe Diameter 20 in.

- relaxation of rubber seals; rubber O-rings permanently compressed are tested at high temperature for making accelerated tests and selection between the different materials available.
- relaxation of prestressing wire; a reinforcement cage, consisting of a helix of prestressing wire, is used for the manufacture of the prestressed concrete tubes. The quality of the wire is checked by measuring the stress relaxation of various brands at 210 and 250 F. There is, however, no reason to expect technical difficulties at this working temperature.
- field testing; testing of a full-size line under field conditions is performed. The pipeline is built parallel to an existing district heating pipe and will be operated at typical temperature and pressure conditions.

No detailed results from this program have yet been reported.

5.4.2 Polymer Concrete

Significant progress in construction of district heating networks is possible by utilization of non-corrosive piping manufactured from different polymer materials developed and manufactured in the U.S., USSR, and other countries.

One of these materials, polymer concrete, has been investigated for utilization in geothermal applications. Polymer concrete is a mixture of organic monomers with inorganic ingredients similar to those used in Portland cement concrete. These include sand, gravel and other fillers. For use in hydrothermal environments, reactive fillers, such as di- or tricalcium silicate that are generally added in the form of Portland cement, are included in the aggregate.[105] The resulting polymer concrete has many properties superior to those made with hydrated Portland cement. To date, monomer formulations such as 60 st % styrene-40 wt % trimethylolpropane trimethacrylate (TMPTMA), 55 wt % styrene-36 wt % acrylonitrile-9 wt % TMPTMA and 50 wt % styrene-34 wt % acrylonitrile-5 wt % acrylamide-10 wt % divinyl benzene have been shown to be highly durable to geothermal fluids. These systems can be polymerized using chemical initiators and heat or by chemical initiators and promotors. The properties of polymer concrete materials are presented in Table 5-4.

Laboratory and preliminary field tests have shown that several polymer concrete formulations are suitable for use in medium to hot saline water applications under widely varying pH conditions and elevated temperatures. Resistance to corrosion is a function of the monomer and the aggregates used in compounding, and further testing is continuing to determine the optimum composition.

Field testing of polymer concrete mixtures at potential sites for direct utilization of geothermal energy in the U.S. such as Klamath Falls, Raft River, Coso Hot Springs, and East Mesa has been in progress for more than a year. The maximum brine temperature in these tests is about 320 F. To date, no deterioration or scale buildup has been detected.

The possibility of utilizing polymer concrete piping for geothermal district heating for the City of Klamath Falls, Oregon, has been investigated and cost comparison with carbon steel piping performed.[106] The cost analysis has indicated that utilization of a conduit with a polymer concrete carrier and casing pipes results in capital cost savings of 27 percent over a conduit design with carbon steel carrier pipe and FRP casing. The installation of a polymer concrete insulated carrier pipe in a concrete culvert provided 13 percent savings over a concrete culbert installation with an insulated carbon steel carrier pipe. However, some increase in the maintenance costs for these installations has been anticipated.

Table 5-4

PROPERTIES OF POLYMER CONCRETE MATERIALS

Polymer-Impregnated Concrete

Density	150 pcf
Compressive strength	20,000 psi
Tensile strength	1,600 psi
Flexure strength	2,000 psi
Water absorption	$<0.5\%$
Thermal conductivity	1.3 BTU/hr ft°F

Lightweight Polymer-Impregnated Concrete

Density	60-70 pcf
Compressive strength	5,000 psi
Tensile strength	1,000 psi
Flexure strength	1,800 psi
Thermal conductivity	
Perlite cement	0.11 BTU/hr ft°F
Foamed glass concrete	0.16 BTU/hr ft°F

Polymer Concrete

Density	140 pcf
Compressive strength	12,000 psi
Tensile strength	1,000 psi
Flexure strength	2,000 psi
Water absorption	$<1\%$
Thermal conductivity	~ 1 BTU/hr ft°F

The study concluded that the potential economic advantages of polymer concrete piping warrant further development efforts to resolve the outstanding technical problems which are as follows:

- development of joint designs which are able to withstand the thermal and pressure stresses at a temperature of 325 F
- development of expansion joints for long piping sections
- development of a method to commercially produce polymer concrete pipes up to 24 in. in diameter which are suitable for pressures of 150 psi and temperatures of 325 F
- acquisition of data on the resistance of polymer concrete piping to damage from vibrations, water hammer, thermal cycling, thermal expansion, flashing fluids, and erosion
- investigation of the technical and economic potential of prestressed and reinforced polymer concrete pipe construction
- improvement of the tensile strength of polymer concrete for use in piping by inclusion of steel or glass reinforcing fibers.
- acquisition of a complete set of mechanical and thermal data for the range of conditions anticipated, such as thermal conductivity, expansion coefficients, tensile and compressive strengths, Poissons Ratio, Youngs Modulus, etc.

Work has already been started in some of these areas, and it is reasonable to expect that practical solutions can be found to the technical problems indicated above.

The polymer silicate concretes developed in the USSR are manufactured on the basis of soluble glass and synthetic resins and are considered for utilization in structures of underground heating networks.[58] The main advantages of this new material in replacing the normal cement concrete in underground structures of heating networks are as follows: high mechanical strength, which will make it possible to considerably lighten the structures by decreasing the thickness of precast elements: high chemical resistance to corrosive soils and waterproof qualities. Polymer concrete is also utilized for manhole construction, especially for sites with a high level of ground water.

5.4.3 Asbestos-Cement

Asbestos-cement is composed of a mixture of portland cement, silica and asbestos fiber. The material is completely free from organic or metallic substances. Depending on the manufacturer, the carrier pipe may be lined with epoxy. Epoxy lining is recommended when conveying extremely soft water.

The pipe is available in Classes 100, 150 or 200, thus allowing it a maximum operating pressure of 200 psi. The operating temperature range is between 40°F and 210°F.[107,108]

The smooth epoxy-lined bore of the carrier pipe allows a water-flow Hazen and Williams coefficient of $C = 140$ to $C = 150$, depending on manufacturer. The smooth bore eliminates encrustations, making possible a maintained high level of flow and low level of friction resistance. The result is a considerable reduction in the incidence of water leakage, pipe failure and costly maintenance.

Class 150 asbestos-cement pressure pipe is available in most sizes (with standard sizes ranging from 4" to 16"), to meet ASTM-C-296, AWWA-C-400-64.T and Federal SS-P-351a specifications. It is resistant to corrosion and chemical attack. Heat loss is minimum.

A disadvantage of asbestos-cement piping is the relative brittleness. As a result, the piping is susceptible to damage from crushing by heavy excavating equipment or heavy trucks. Asbestos-cement is also susceptible to corrosion in soils of less than 5.5pH.[61] Couplings are used to join asbestos-cement pipes.[38] Rubber gasket rings are channeled in the asbestos-cement couplings to provide seals. However, there is a possibility of leakage around the rubber rings due to aging of the rings.

Asbestos cement pipe has been extensively tested at the Raft River geothermal project. In 1975, 4000 ft. of this pipe was installed to transport 300°F geothermal fluids at 150 psi. The experience has been satisfactory and it was recommended that this pipe be used for connecting future wells. However, when this pipe was used for transportation of cool water resulting in rapid temperature changes, a number of pipe ruptures occurred because of the severe thermal shock. The test also revealed the need for some modifications in trench design, better seal inspection, and better installation supervision.[109]

Cost estimates have indicated that utilization of asbestos-cement conduit design for geothermal application can provide savings up to 24 percent over the carbon steel culvert design.[106] However, further technical development is required before asbestos-cement piping could be specified commercially for district heating applications.

REFERENCES

1. Oliker, I., "Assessment of Turbine Generator Technology for District Heating Applications," Study performed by Burns and Roe for the U.S. Department of Energy, 1978

2. Karnitz, M. A., Olszewski, M., Anderson, T. and Rubin, A. M., "Description of District Heating - History and Current Status," District Heating/ Cogeneration Symposium, April 2-3, 1979

3. Oliker, I., "Economic Feasibility of District Heat Supply from Fossil and Nuclear Cogeneration Power Plants in the U.S.A." International District Heating Congress - UNICHAL, Stockholm, Sweden, May 1979

4. National Academy of Sciences, Federal Construction Council Technical Report No. 66, Criteria for Underground Heat Distribution Systems, 1975

5. Johns-Manville Sales Corporation, "Temp-Tite" Pre-Insulated Pressure Pipe Catalog, 1976

6. Ric-Wil, Incorporated, "Ric-Wil Copper-Gard" Catalog, 1977

7. Risto Vartia, "Planning and Construction of District Heating Pipelines," First International District Convention, London, 1970

8. Starheat Co., Sweden, "Starpipe" Catalog, 1979

9. Pont-A-Mousson S.A., France, "Pre-insulated Ductile Cast Iron Pipes for Transporting Hot Water" Catalog, 1979

10. Private Communication, I. Oliker, Burns and Roe, Inc. to H. Neuffer, H. P. Winkens, and D. H. Stolte, West German District Heating Association, May 1979

11. Mikkelsen, W., "Planning of Distribution Network to New District Heating Plants," Bruun & Sørensen, Danish Board of District Heating, 1979

12. New Trench Construction in Aarhus, Facts About Danish District Heating Standberg Bogtryk SpS, Denmark, 1979

13. Kilpinen, U., "Development of District Heating in Finland," District Heating, No. 3, 1978

REFERENCES (Continued)

14. Private Communication, I. Oliker, Burns and Roe, Inc. to H. Kilpinen and I. Pirvola, Finnish District Heating Association, May 1979

15. TPCO, Inc., "X-50 Pre-Insulated Pipe" Catalog, 1976

16. Ric-Wil, Incorporated, "Imperial Smoothwall Epoxy Coated Conduit" Catalog, 1976

17. Aamot, H. W. C., "Utility Distribution Systems in Sweden, Finland, Norway and England," Corps of Engineers, U.S. Army, "Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, SR 76-16

18. Aquawarm, Teplo International AB, District Heating Pipe Catalog, 1979

19. i. c. møller A/S, Denmark, "Environmental Heating - District Heating," an i. c. møller Report, 1979

20. Private Communication, I. Oliker, Burns and Roe, Inc. to J. Christiansen, i. c. møller, Denmark, May, June, September 1979

21. Oy Fiskars AB, District Heating Catalog, 1979

22. Meador, J. T., "MIUS Technology Evaluation - Thermal Energy Conveyance," ORNL/HUD/MIUS-22, UC-38, May 1976

23. LEBIT A/S, "District Heating System" Catalog, 1979

24. Borger, H. A., "Available Types of Underground Heat Distribution System," Proceedings for the Symposium on Underground Heat and Chilled Water Distribution Systems, Tamami Kusuda, ed., National Bureau of Standards Building Science Series 66, Washington, D.C., 1973

25. Lubonyl (a Divison of AB Gustavsberg, Sweden), "Lubo District Heating Systems" Catalog, 1979

26. Brandes Co., West Germany, "Network Supervision for District Heating Lines" Catalog, 1979

27. Oliker, I., Edelman, R. A. and DeVito, L, "Urban Area District Energy System Study," Part of an ERDA Study by Burns and Roe, Inc. for Brookhaven National Laboratory, Nov. 1977

REFERENCES (Continued)

28. Boegly, W. J., Jr., Griffith, W. L., and Ulrich, W. C., "System Requirements for Underground Utility Installation," ORNL-HUD-19, UC-41 - Health and Safety, Feb. 1971

29. Jan Munck of Rosenschold, "A System of Piping for Economical Connection of Small Houses to the District Heating Network," Teplo International AB, Sweden, 1978

30. Owens/Corning Fiberglas Corp., "Kaylo 10 Asbestos Free Pipe Insulation", Catalog P4, Aug. 1977

31. Insta-Foam Products, Inc., "Hi Temp" Catalog, 1978

32. American Gilsonite Company, "Gilsulate 500" Catalog, 1978

33. Blattner, R. H., "What is Perlite? and Some of its Uses," Preussag AG, Bauwesen, West Germany, 1979

34. Preussag AG Bauwesen, West Germany, "Long Distance Heating - Contemporary, Environmentally Safe" Catalog, 1979

35. Engelhardt, W., "Prefabricated Flexible Low-Temperature Plastic Pipes for Mains and Services," Wirsbo Bruk, Sweden, 1978

36. Durotan RØr A/S, Denmark, "District Heating Pipes" Catalog, 1979

37. Couch, R. O., "Design Criteria for Auxiliary Equipment for Underground Heating and Cooling Distribution Systems," Proceedings for the Symposium on Underground Heat and Chilled Water Distribution Systems, Tamani Kusuda, ed., National Bureau of Standards Building Series 66, Washington, D.C., 1973

38. Insta-Foam Products, Inc., "Epoxy Lined Asbestos-Cement Pressure Pipe" Catalog, 1976

39. Thastrup, O., "New Installation Technique for District Heating Pipes," Facts about Danish District Heating, Strandberg Boytryk ApS, Denmark, 1979

40. LØGSTØR RØR industri a/s, Denmark, "Prefabricated District Heating Pipes" Catalog, 1978

REFERENCES (Continued)

41. Larsen, K., "District Heating in Energy Picture," Facts About Danish District Heating," Strandberg Boytryk ApS, 1979

42. Augenkorrosion and Fernwarmeleitungen, Fernwarme International - FWI, Jg. 1, H. 2, 1972

43. Balter, I. V., "Analysis of Corrosion Rate of The Underground Installation of District Heating Network," Teploenergetika, No. 7, 1976

44. Gromov, N. K., City District Heating Systems, Publishing House Energiya, Moscow, 1974

45. Oliker, I., "Problems of Piping Networks Supplied from Cogeneration Power Plants," National Pressure Vessels and Piping Conference, San Francisco, California, June 1979, ASME Paper No. 79-PVP-66

46. Vitaliev, V. P., Ductless Installation of District Heating Networks, Energia, 1971

47. Haseler, A. E., New Heat Mains Techniques for Telethermics, The Journal of the Institution of Heating and Ventilating Engineers, 1970 (38)

48. Prefabricated Insulated Pipeline System, The Steam and Heating Engineer, 1966 (414)

49. Prefabricated, Pre-insulated Pipes, Fuel Efficiency, 1965 (11)

50. Sutton, J. W., Underground Hot Water Mains, Pipes and Pipelines International, 1971 (9)

51. Bauer, H., Muller, H., Brennst-Warme-Kraft, 1970 (6)

52. Brachetti, H. E., Zur Problematik, der Erdverlegung warmefuhrender Leitungen, Elektrizitatswirtschaft, 1971 (5)

53. Brun, H. V., Zuc Problematik der Erdverlegung warmefuhrender Leitungen, Elektrizitatswirtschaft, 1971 (25)

54. Erfahrungsaustausch in der Fernwarmeversorgung. Eine Aussprachetaguing der Betriebsingenieure 1971 in Stuttgart, Elektrizitatswirtschaft, 1971 (5)

REFERENCES (Continued)

55. Strizhevskii, I. V., et al, Protection of Underground Heating Conduits Against Corrosion, Stroiizdat, 1972

56. Rybev, I. A., Asphalt Concretes, Vysshaya shkola, 1969

57. Haseler, A. E., "District Heating and Telethernics," Building Services Engineer, Feb. 1975

58. Skvortsov, A. A., "Improvement of District Heating Network Installations," Teploenergetika, 1976, No. 11

59. Uhlig, H. H., "Corrosion and Corrosion Control," 2nd Ed., John Wiley & Sons, New York, 1971

60. Speller, F. N., "Corrosion, Causes and Prevention," McGraw-Hill, New York, 1951

61. Fitzgerald, J. H. and Moody, K. J., "Design Criteria of Underground Heat and Chilled Water Distribution Systems for Corrosion Protection," Proceedings for the Symposium on Underground Heat and Chilled Water Distribution Systems, U.S. Department of Commerce, May 1975

62. Oliker, I., "Vacuum Deaeration of Water - An Effective Method for Preventing Corrosion," International Corrosion Forum, Toronto, Canada, 1975, Published in Corrosion, No. 3, 1977

63. Programmstudie Warmeverteilung, Battelle-Institut e. v. Frankfurt, 1977

64. Fletcher, P. "Design Consideration for Underground Steam Manholes," Proceedings of the International District Heating Association, 1977

65. Richardson Engineering Services, Process Plant Construction Estimating Standards, Volumes 1 and 3, 1979

66. Building Construction Cost Data, Labor Rates for the Construction Industry, Robert Snow Means Company, Inc., 1979

67. Telephone Conversations, P. Goldbrunner (B&R) to M. Neishloss (Superior Steam), Pricing of Conduit Piping, various dates, 1979

68. Telephone Conversation P. Goldbrunner (B&R) to E. Sigali (Concrete Products), Pricing of Precast Concrete Culverts, 6/22/79

REFERENCES (Continued)

69. Telephone Conversation, P. Goldbrunner (B&R) to Stirling Larsen (Gilsonite Corp.), Application of Gilsonite Products to District Heating, 6/28/79

70. Telephone Conversation, P. Goldbrunner (B&R) to D. Jacobs (Cretex Concrete Products), Prices of Precast Concrete Culvert, 7/11/79

71. Telephone Conversation, P. Goldbrunner (B&R) to P. Weghorn (Trenwa Products), Price of Precast Concrete Trench, 7/18/79

72. Telephone Conversation, P. Goldbrunner (B&R) to G. Robertson (Ameron), Fiberglass Pipe in District Heating Application, 9/11/79

73. Telephone Conversation, P. Goldbrunner (B&R) to S. Melcon (Piping Specialties, Inc.), Expansion Joint and Pipe Support Pricing, 7/22/79

74. Telephone Conversation, P. Goldbrunner (B&R) to J. Kellaher (Powell Valve), Pricing for Standard Gate Valves, 7/22/79

75. Telephone Conversation, P. Goldbrunner (B&R) to S. Dufton (Protexulate), Price of Protexulate Loose Fill Insulation, 8/3/79

76. Components & Controls, Inc. to P. Goldbrunner, Quotation #0779-20-B, Pricing for Posi Seal Wafer Trunnion Valves, 7/20/79

77. Albert Pipe Supply to Burns & Roe, Price of Carbon Steel Pipe Fittings, 7/12/79.

78. ANSI B31.1 Power Piping Code, ASTM C789-77 Precast Culverts, ASTM C780-77, "Precast Culverts with Less Than 2 Ft. of Cover"

79. AASHTO (American Association of State Highway and Transportation Officials) Standard Specification for Highway Bridges, Twelfth Edition, 1973

REFERENCES (Continued)

80. Anderson, R. B., "St. Paul District Heating Cost Study - Cut and Cover Piping Installation, Twin City Area," March 1979

81. A. O. Smith-Inland, Inc., "Fiberglass Reinforced Piping Systems" Catalog, 1977

82. Roseen, R., and Schmeling, P., "Development Work on New Hot Water Transport and Distribution Systems," Urban District Heating Using Nuclear Heat, Proceedings of an Advisory Group Meeting, IAEA, Vienna, 1977

83. Ciba-Geigy Corporation, "Pipe Systems" Catalog, 1978

84. McKeown, J. M., "Fiberglass Reinforced Plastic Pipe and the Heating Industry," Annual Proceedings of the IDHA, 1974

85. Ainsworth, L., and Harrison, G., "Reinforced Plastic Pipes for District Heating," Reinforced Plastics, October 1971

86. Insta-Foam Products, Inc., "Fiberglass Reinforced Plastic Pipe" Catalog, 1978

87. Ric-Wil, Incorporated, "Dual-Gard, 250" Catalog, 1978

88. Ameron Co., "Bondstrand (R) Series" Catalog, 1978

89. Sprecher, N., "New Urban Heating Plants in Europe, Present Massive Potential Applications for FRP," Owens-Corning Fiberglas Europe S.A., 1975

90. Schadel, O., and Mattern, A., "Long-Term Internal Pressure Tests of Industrial Pipe Made from Glassifiber Reinforced Plastic," TUV Bayern, West Germany, 1978

91. Tautz, A., "Undersuchung uber Kunstoffrohre," Fernwarmeversorgung Niederrhein, June 1978

92. Private communciation, I. Oliker, Burns and Roe, Inc., to A. Tautz, Niederrhein, West Germany, May 1979

93. Private communication, I. Oliker to G. Robertson, Ameron Co., June 1979

REFERENCES (Continued)

94. Wirsbo Bruk, Sweden, Catalog, 1979

95. Engelhardt, W., "Prefabricated Flexible Low-Temperature Plastic Pipes for Mains and Services," Swedish District Heating Workshops, USA, 1978

96. UNICHAL District Heating Exhibition, Stockholm, Sweden, May 1979

97. Modern Plastics Encyclopedia, 1977

98. Pannkoke, T., "Thermoplastic Piping: An Overview," Heating/Piping/Air Conditioning, April 1979

99. Mruk, S. A., "Plastic Piping: Growing Use Enchances Status," Specifying Engineer, May 1979

100. Shell Chemical Company, "Polybutylene in Depth" Catalog, 1978

101. Brown, M. A., "Polybutylene Eases Wastewater-Pipe Installation," Electrical World, pp. 32 & 33, Sept. 1, 1976

102. RAHN Metals & Plastics, Ltd., Canada, "Polybutylene Industrial Systems" Catalog, 1979

103. Private communication, I. Oliker to C. R. Lindegren, Shell Chemical Company, May 1979

104. Nilson, A. H., Design of Prestressed Concrete, Published by John Wiley and Sons, 1978

105. Sugama, T. and Kukacka, L. E., "The Effect of Dicalcium Silicate and Tricalcium Silicate on the Thermal Stability of Vinyl-Type Polymer Concrete," Cement and Concrete Research 3, pp. 69-76, 1979

106. Burns and Roe Industrial Services Corporation, "Economic Assessment of Using Non-Metallic Materials in the Direct Utilization of Geothermal Energy," for Brookhaven National Laboratory, February 1979

107. Johns-Manville Sales Corporation, "Transite" Pressure Pipe Catalog, 1977

REFERENCES (Continued)

108. Ric-Will, Incorporated, "Dual-Gard A.C." Catalog, 1976

109. Miller, L. G., Kunze, J. F., Sanders, R. D., "Asbestos Cement Pipeline Experience at the Raft River Geothermal Project," EG&G Idaho, Inc., 1979

EXHIBIT I

Hot Water District Heating Networks Operational Experience

EXHIBIT I
page 1

HOT WATER DISTRICT HEATING NETWORKS OPERATIONAL EXPERIENCE

Country	WEST GERMANY			SWEDEN			ITALY	NETHERLANDS
Name of the District Heating System	Berliner Kraft- und Light (Bewag) Berlin	Fernwärme Innenstadt, Dusseldorf	Stadwerke Bielefeld GmbH, Bielefeld	Gothenburg District Heating System	Uppsala Industriverk, Värmeverket	Stockholms Energiverk	Teleriscaldamento di Brescia	Free University Campus, Amsterdam
Identification Number	101	102	103	104	105	106	107	108
Heat Capacity of the System (MWt)	1924	580	440	1306	791	1544	182	
Years in Service	55	15	24	27	18	26	7	12
A. Design Parameters and Features								
1. Pressure (psig)	differential pressure: 232=design 145=winter 58=summer	248=winter 121=summer, 70% load	74=max	250=winter 147=summer	232 max	232 (max)	235	170
2. Temperature range (F)								
. Supply line	131 to 230	230 to 266	158 to 266	248=winter 185=summer	240 at outdoor temperature of -5.8F	176 to 248	302	356
. Return line	95 to 140	113 to 158	86 to 140	158=winter 140=summer	158	113 to 149	140	248
3. Type of control of heat supply	temperature and pressure	manual	by the customers: water flow, up to 80 KWt; heat meters	temperature control		temperature control	manual	flow control
4. Piping design standard or code	DIN 2440, 2441, 2448 and 2458	PN16, PN25	DIN 2448 and 2458	NT 16	Swedish Standard	SIS 142101 or SIS 1430, pressure vessel steel	ANSI	ND 25
5. Piping size range (in)								
. Transmission piping	12 to 32	28	12 to 18	12 to 35	12 to 28		10 to 28	6 to 10
. Distribution piping	1.5 to 10	4 to 8	4 to 10	2 to 10	3/4 to 8	up to 40	2 to 8	up to 6
6. Piping wall thickness (in) for different pipe sizes	0.144 to 0.394	28"=0.394 4"=0.197	follows DIN 2448 and 2458	0.11 to 0.31	sched. 10 approximately	sched. 10 approximately	below sched. 20	0.236 and below
7. Piping length (miles)								
. Transmission	3 x 169	14	15	101	83		9.5	one
. Distribution piping			42		72	168	17	several

EXHIBIT I
page 1

EXHIBIT I
page 2

Identification Number	101	102	103	104	105	106	107	108
8. Type of piping installation and manufacturer								
. Rigid concrete envelope		no		no				
. Conduit		no	yes, carbon steel carrier pipe and asbestos-cement casing	yes (Eternit)			yes	
. Concrete culvert or trench	U-profile different manufacturers	100%, several manufacturers	domed concrete culvert with insulated carrier pipe	yes	yes	yes	yes	
. Ductless directly buried in powder backfill		no		no	no			
. Others		no		preinsulated piping systems (steel pipes, PU-insulation, PE-casing)		tunnels		concrete walk-through tunnels
9. Type of thermal expansion devices								
. Slip type	yes	20%	yes, journal bearing type	no	English axial compensators, Teddington type			
. Bellows type	yes	50%	yes	yes, when no space for expansion loops		yes	yes	
. Expansion loops	yes	20%		yes, most common		yes	yes	yes
. Others	no			no-comb. (ground fixed piping system)	U- and Z-bends			
10. Type of piping joint and bend techniques	welding	welding, prefabricated bends	according to DIN 2605	welding, prefabricated bends	welding		butt welding joints	welding
11. Type of manholes		no manholes	prefabricated in 24" to 32" diameter				track resistant and can be inspected	

EXHIBIT I
page 2

Identification Number	101	102	103	104	105	106	107	108
12. Piping material (carrier pipe)	St. 35 (steel)	St. 35	St. 35, DIN 2448, and St. 37-2 DIN 2458	steel; small amounts of copper and plastic pipes	as per Swedish Standard Association No. 141232-05 and 06	carbon steel	steel, SL, Grade B	
13. Type of carrier pipe external protective coating		no coating	asbestos-cement	rust inhibiting paint		plastic materials and concrete	prefabricated reinforced cement covers	
14. Type of insulation	wadding of glass	mineral wool and bituminous coating	polyurethane foam or fiberglass	glass wool, PU-foam,	mineral wool, or PU	formed mats of mineral wool, polyurethane foam	mineral glass and rock wool covers	rock wool
15. Casing piping material (insulating envelope)	bitumen paper, aluminum cover	concrete	protective coating and bitumen	PE-casing, concrete culvert, asbestos concrete tubes	concrete culvert, asbestos cement pipes, PE-pipes	plastic materials or concrete	tarred vetroflex	aluminum plate
16. Means of corrosion protection (cathodic protection, etc.)		none	drainage and cathodic protection	none		none	none	
17. Is the piping system water drainable and dryable		yes	yes	yes, except for the pre-insulated systems		yes	yes	
18. Existence of an air gap between the insulation and the culvert or soil	yes	yes	yes	yes, except for the pre-insulated systems		no	yes	no
19. Existence of a ground water drainage system along the district heating piping	no	no	yes	yes, connected with the storm drainage system		yes		
20. Makeup water treatment								
. Type of softening	ion exchange resin	trinatrium-phosphite	NaH ion exchange	none	demineralization	demineralization	demineralization	demineralization
. Type of deaeration	direct contact	hydrazine	direct contact	direct contact 221 F and 3psig	yes	hydrazine		direct contact

EXHIBIT I
page 3

Identification Number	101	102	103	104	105	106	107	108
21. The depth of soil cover above the piping installation (ft)								
. Urban area	2.6 to 4.9	6.6 average	2 to 4.6	2.3	2 to 2.3	1.6 to 3.3	2.6	
. Suburban area	2.6 to 4.9	3.3 average		2.3		1.6 to 3.3	3.3	
22. Hot water veolocity at nominal conditions ft/sec	6.6 to 13	8.2	1.6 to 6.6	<10	3.3 to 4.9 for pipes < 6"; 6.6 to 9.3 for < 8" to 28"	up to 11.5 to 13 for large size piping	from 13 fps for 28" to 3.3 fps for 2"	less than 5
23. Does the piping installation meet the following performance criteria:								
. Resistance to groundwater infiltration and spread of water in the event of water infiltration.	yes	only in suburban areas	yes	yes	yes	yes	yes	
. Resistance to water damage	yes	concrete		yes	the mineral wool can be dried out		yes	
. Resistance to mechanical or structural damage	yes	concrete	no	yes=concrete; others to some extent	yes		no	
. Resistance to corrosion	culvert=yes, conduit=no	no	no	yes	close culvert the steel pipes are not coated		no	
. Resistance to other causes of deterioration		no						
. Simplicity of installation	yes	medium	yes	no, especially	yes		yes	boiler plant and 5 substations
. Ease in repair	yes	yes	yes	no			yes	yes
24. Quality control criteria								
. Testing of prefabricated piping component at the factory	yes	yes, welding	yes	yes	100% pressure test; 10%= x-rays		no	no
. Testing of both system components and the complete system at the site	yes	pressurized water	yes	yes		pressure test and x-ray inspection	yes	10% of the welded joints are x-ray inspected

EXHIBIT I
page 4

EXHIBIT I
page 5

Identification Number	101	102	103	104	105	106	107	108
B. Operational Conditions								
1. Average annual temperature of the hot water (F)								
. Supply line	165	194	194	216	185	185 to 203	203	356
. Return line	122	140	130	149	131 to 140	104 to 122	140	248 to 300
2. Condition of other adjoining utility systems								
. Cold water piping				103 psig	no other adjoining utility systems in culverts		good	good installed in tunnels
. Sewer system							not in good conditions (in part very old)	ditto
. Electrical system	220/380 V			220/380 V			fairly good	ditto
. Storm drainage system							fairly good	ditto
. Others							gas piping system in good condition	
3. Type of soil where the network is installed								
. Clay		no	yes	usually the soil contents both clay and sand	in park area	yes	yes	n/a
. Sand	yes	yes			in streets	yes		n/a
. Others		loam		15% to 20% of the system in rock		yes	earth embankment	
4. Soil corrosiveness								
. Corrosive (resistivity less than 10,000 ohm-cm)	unknown			yes			yes	
. Mildly (10,000 to 30,000 ohms-cm)		15,000					yes	
. Noncorrosive (over 30,000 ohms-cm)							yes	

EXHIBIT I
page 5

Identification Number	101	102	103	104	105	106	107	108
5. Presence of stray direct currents	unknown		yes, in the subway area	yes, the pipes are however electrically isolated which solves this problem		yes	yes	
6. Soil sulfate content	unknown	unknown						
7. Soil sulfide content	unknown							
8. Soil pH		7.0		6 to 7				
9. Site water table (the water is above the bottom of the piping system:								
. Severe (frequently)		no					no	tunnels are below ground water level
. Bad (occasionally)		no	10%			yes	no	
. Moderate (never, but surface water remains for short periods in the soil surrounding the system)	yes	one site	yes				yes	
. Mild (never)		no		yes	the manholes are regularly inspected and water is pumped out when necessary		no	
10. Types of control of the pipe condition during operation								
. External and internal corrosion monitoring	only external	external=no internal=water treatment		visual inspection six times per year in the manholes	no		no	
. Water flooding in the piping system	yes	no	visual control	in the concrete and asbestos concrete culverts			no	water samples analyzed daily
. Piping leakage detection	no	no	heat leak detection by infrared scanner	in the preinsulated culverts	are now being installed in PEH-culverts	yes	yes	
. Pressure in the conduit	no	yes	pressure loss	no		yes	yes	
. Others	no	temperature; leaking waterrefill						

EXHIBIT I
page 6

EXHIBIT I
page 7

Identification Number	101	102	103	104	105	106	107	108
11. How long is the system out of service during the year?	never	never	generally none; continious operation	about 24 hrs per year	for short periods from 2 to 24 hrs	never	at present the system has never been out of service	never
12. Possibility of periodic contact of the external unprotected piping surface with ground water (cyclic wetting and drying of the insulation)	none	does not happen	none	the casing is water tight, generally no problems with ground water	no	no	no	no
13. Frequency of preventive maintenance								
. Hydro test (pressure)	none	only by installation	daily	continious measuring of the pressure in carrier pipes				
. Thermal test (temperature)	none	none	daily	continious measuring				
. Manholes	none	none		visual inspection six times per year			yes, every four months	
. Expansion devices	none	every 3 months	every 6 months	visual inspection six times per year		—	yes, every four months	
. Joints	none	none		visual, six times per year				
. Valves	none	every 3 months	every 6 months	visual, six times per year			yes, every four months	
. Others					regular inspection of the manholes		fixed points, every four months	
14. Heat losses								
Transmission piping	5% of the annual consumption	15% of the capacity	10% of heat generated per year	7% (average) per year	5 to 8% annual		3%	
. Distribution piping					10 to 15% annual	7%	4%	
15. Water makeup requirement in percent from the network water flow rate	1.5% per day	0.5% of the network water content	9.1 to 14.7 gpm	1% per day	150%/year		2%	

EXHIBIT I
page 7

EXHIBIT I
page 8

Identification Number	101	102	103	104	105	106	107	108
C. Network Failure Analysis								
1. Piping failure rate for different pipe sizes (breaks of the pipe per mile per year) . Actual pipe breaks	0.048 (20 to 30 failures per year)	none	no pipe breaks, only corrosion 0.68 leaks per mile in 1978	very seldom, no statistics	0.16	0.048	none, some trouble from water dripping from valves	
. Damage caused by thermal and hydro tests	none	none		very seldom, no statistics				
2. Major failure element (s)	external corrosion	corrosion	carrier pipe	expansion bellows, pipe connections to valves in manholes (pipes ≤4")	outside corrosion	bellows		
3. Method of failure detection	regular control	water leakage	infrared scanner, pressure test	visual inspection, electronic leakage detection, telephone calls from public	regular inspection of manholes	locating the leaking water in drainage	visual detection	
4. Location of pipe failure								
. Supply line								
a) straight pipe		yes		seldom	mostly	yes		
b) joints		flanges		seldom				
c) expansion devices		none		more common		bellows		
d) manholes		none	yes	none				
e) valve		yes		seldom				
f) pipe anchors and supports		none	yes	none			yes	
g) others	crossings with other utilities			pipes and other equipment in manholes located in streets				
. Return line								
a) straight pipe		yes		the same as the supply line	mostly	yes		
b) joints		flanges						

EXHIBIT I
page 8

Identification Number	101	102	103	104	105	106	107	108
c) expansion devices		none						
d) manholes		none	yes					
e) valve		yes					yes	
f) pipe anchors and supports		none	yes					
g) others	crossing with other utilities							
5. Cause of pipe failure								
. External electrochemical corrosion	yes	yes		yes		yes		
. Internal electrochemical corrosion		no		no				
. Bacteriological corrosion		no		no				
. Erosion		no		no				
. Insulation failure		2 times	water infiltration	very seldom				
. Failure of co-located utility system		no		no				
. Failure of the culvert		no		no	the major cause is corrosion damage			
. Mechanical or structural damage under earth loads, vehicle loads, thermal stresses, etc.		no		sometimes	vibration from vehicles and leaky manholes covers			
. Others				the joints of the insulation has been damaged and caused corrosion of the pipes				
6. Character of corrosion								
. Uniform		no		occur, but seldom				
. Pitting		yes		none				
. Small spots	yes	no	yes	usually	yes	yes		

EXHIBIT I
page 9

EXHIBIT I
page 10

Identification Number	101	102	103	104	105	106	107	108
7. Corrosion spot location								
. Bottom side of the pipe	yes	yes	yes	seldom	yes	yes		
. Top side	yes	yes	yes	normally				
8. Wall thickness when the pipe ruptured	unknown	none		usually very thin, 0.004" to 0.008"	approximately 0.04" to 0.06"			
9. Condition of the coating, wrapping or insulating envelope	destroyed	none			leak in culverts			
10. Dependence of the failure rate on the piping system age		1/25 miles for 15 years	no relationship	age has small influence when the system is of good condition	yes, but the new construction methods are reducing the failure rate	yes	no specific experience yet	
11. Existence of an air gap between the insulation and the culvert or soil during the service life of the pipe	yes	all the time	yes	too short experience with the system without air gap to give an answer	air gap is important for the service life of the pipe	no	yes	
12. External corrosion rate per year (in per year)	unknown		39 failures in 1978	steel pipes from early 1950's still in good condition				
13. Average length of the piping section replaced after failure	16 to 33	no failure	16 per failure	can't be answered	33 to 66	16 to 32		
14. Average repair time per one failure (depending on pipe size)								
. Urban area	about 30 days	no failure	varies, for small size pipes it takes one day	can't be answered	2 to 24 hrs	total repair time: 1 month; pipe out of service for 3 to 4 days		
. Suburban area	including all auxiliary work	no failure						
15. Average cost of the repair per failure per pipe size								
. Urban area	$10,600 to		$2,800	can't be answered	for example, 33" of 8" pipe cost $6,100			
. Suburban area	$15,900							

EXHIBIT I
page 10

Identification Number	101	102	103	104	105	106	107	108
16. Maintenance cost per mile per year								
. Urban area	6% per year of the installation cost	2% per year of the installation cost	$1,800	$14,000	$3,100		two persons all year round=total $37,000/year	
. Suburban area						1% of reinvestment value		
D. Additional Comments or Information		the system is 15 years in operation; the experience is good; the maintenance cost is low; the installation cost is high				total operational cost $18,000/mile/year		

EXHIBIT I
page 11

HOT WATER DISTRICT HEATING NETWORKS OPERATIONAL EXPERIENCE

Country			JAPAN			
Name of the District Heating System	Hokkaido Heating Co., Sapporo	Senri Central Heating, Osaka	Chiba Seaside New-Town, Masago Chiba City	Fukuoka Heat Supply Co., Fukuoka	Nakita New Town District Heating System, Tokyo	Hakodate Netsu Kyokyu Co., Hokkaido
Identification Number	109	110	111	112	113	114
Heat Capacity of the System (MWt)	198	50	23	23=hot water 17=chilled water	11 (157 total proposed) hot water in winter, chilled water in summer	7.5
Years in Service	8	9	5	6	6	5
A. Design Parameters and Features						
1. Pressure (psig)	455	267	139	128=winter 100=summer	70 to 92 (140 max)	141 max winter season only
2. Temperature range (F) . Supply line	419	356	230 to 266	248=hot water 45=chilled water	158 (176 max)	248 ± 9
. Return line	261	248	176 and below	122=hot water 57=chilled water	122	158
3. Type of control of heat supply	variable flow	variable flow	variable flow by pressure difference regulating valve	variable flow	variable flow	
4. Piping design standard or code		Japan Industry Standard JIS G 3454		four pipe system	JIS and Japan Petrolium Institute (JPI)	
5. Piping size range (in) . Transmission piping	8 to 16	3 to 13		7=hot water 16=chilled water	6 to 22	3 to 6
. Distribution piping	2 to 10	3 to 8		1¼ for hot and chilled water	2 to 10	1 to 2½

EXHIBIT I
page 12

Identification Number	109	110	111	112	113	114
6. Piping wall thickness (in) for different pipe sizes	0.146 to 0.500	sched. 40	0.217" to 0.437 for RicWil steel; 0.047" to 0.083" for F-F Kabel (spiral corrugated copper)		carbon steel: 2"=sched. 40 8"=sched. 20 12"=sched. 20 22"=sched. 20 copper: 4"= 0.032" 5"=0.0472" 6"=0.0512	
8. Piping length (miles)						
. Transmission piping	11	2.5		6 x 4	3	2.5
. Distribution piping	16.5	0.2		2 x 4	0.5	1.3
8. Type of piping installation and manufacturer						
. Rigid concrete envelope			no	no		
. Conduit	metal-cased type	RicWil Japan Co.; Kubota Tekko Co. (permanent pipe)	yes, RicWil Japan Ltd.; Flexwell-Fernheiz Kabel manuf. by Nishi Nippon Elec. Wire & Cable Co., Ltd. under license of Kabel and Metall Werke W. Germany	no	steel pipe conduit	yes, Nishinihon Electric Wire Co.
. Concrete culvert or trench			concrete culvert for installation under railway only	1640 ft		
. Ductless directly buried in powder backfill			no	using this type except 1640 ft of conduit		
9. Type of thermal expansion devices						
. Slip type			no	no	yes, ball joint type	
. Bellows type			no	no	yes	
. Expansion loops	U-loops and L-bends	yes	yes, for installation in manholes and culvert for F-F Kable	partially	yes	
. Others		ball joints	BARCO Ball-joint made by Aeroquip. Co., U.S. for installation in manholes for RicWil pipes	sinusoidal type	snake type	

EXHIBIT I
page 13

Identification Number	109	110	111	112	113	114
10. Type of piping joint and bend techniques	all joints are arc-welded		argon-welding for RicWil pipes; no joints for F-F Kabel	welding and flanges	welded and flanged	flange, pipe flexible
11. Type of manholes	reinforced concrete	rigid concrete	reinforced concrete construction underground or road	no standard specification, depends on construction site	concrete and steel type	concrete manholes, steel lid
12. Piping material (carrier pipe)	carbon steel pipes for pressure service	carbon steel, JIS G 3455		steel and copper=hot water; steel=chilled water	carbon steel=SGP, SGPG 38, STPY 41; copper=DCuR-1 (JIS Standard)	corrugated copper
13. Type of carrier pipe external protective coating	rust inhibiting painting		no coating	carrier pipe enclosed in a conduit		
14. Type of insulation	calcium-silicate type		calcium silicate and air space for RicWil pipes; hardened polyurethane foams for F-F Kabel	polyurethane foam	calcium silicate or polyurethane	polyurethane
15. Casing piping material (insulating envelope)	electric arc-welded carbon steel pipe	carbon steel	spiral corrugated steel conduit or steel pipe for RicWil pipes; spiral corrugated steel conduit for F-F Kabel	steel	steel, SGP, SGPY 41, other FRV (JIS)	corrugated steel
16. Means of corrosion protection (cathodic protection, etc.)	cathodic protection and coated with coal-tar enamel	cathodic protection	asphalted glass fiber coating and cathodic protection for RicWil pipes; polyethylene sheath for F-F Kabel	no	external conduit is protected with coal tar coating	none
17. Is the piping system water drainable and dryable	dryable	yes	yes, for RicWil pipes	no	use of drain trap	dryable
18. Existence of an air gap between the insulation and the culvert or soil	air gap exists between insulation and casing pipe	none	yes	none	yes, in case of steel conduit	none

EXHIBIT I
page 14

Identification Number	109	110	111	112	113	114
19. Existence of a ground water drainage system along the district heating piping	none	none	none	none	none	none
20. Makeup water treatment						
. Type of softening	ion exchange resin	ion exchange resin	ion exchange resin	ion exchange resin		chemical
. Type of deaeration	deoxidation	direct contact	not installed			
21. The depth of soil cover above the piping installation (ft)						
. Urban area	over 4	4 to 9.8	4 to 9.8	over 4		2.6 to 9.2
. Suburban area		4 to 9.8		over 4	over 4	none
22. Hot water velocity at nominal conditions, ft/sec	less than 4	5.9	4.3 to 5.6	6.6	10.5	3 to 6
23. Does the piping installation meet the following performance criteria:						
. Resistance to groundwater infiltration and spread of water in the event of water infiltration.	yes			yes	yes	no examined
. Resistance to water damage	yes			yes	yes	ditto
. Resistance to mechanical or structural damage				yes	yes	ditto
. Resistance to corrosion	yes		yes	yes	yes, the casing pipe is coated with coal tar enamel	ditto
. Resistance to other causes of deterioration				none	no	
. Simplicity of installation				yes	no	
. Ease in repair				yes	yes, in manholes; difficult in streets	
24. Quality control criteria						
. Testing of prefabricated piping components at the factory	service pipe is hydrostatically tested at 850 psig and x-ray examined	yes	yes	presently performing such testing	yes, x-ray, pneumatic test, hydro test	yes
. Testing of both system components and the complete system at the site		yes	yes	presently performing such testing	yes	none

Identification Number	109	110	111	112	113	114
B. Operational Conditions						
1. Average annual temperature of the hot water (F)						
. Supply line	419	267	230 to 266	248=hot water 45=chilled water	158	248
. Return line	248 to 266	230	176 and below	122=hot water 57=chilled water	122	158
2. Condition of other adjoining utility systems						
. Cold water piping		good	12" min.apart for parallel run; 6" min.apart for crossing	no existence		
. Sewer system		good	ditto	no existence		town service system
. Electrical system	heat-proofing by insulating material	good	10' apart for parallel run; 5' for crossing	more than 6½' away		yes
. Storm drainage system		good		no existence		none
3. Type of soil where the network is installed						
. Clay		yes		yes	yes	yes
. Sand	yes			yes	yes	
. Others			silt and sand	no		
4. Soil corrosiveness						
. Corrosive (resistivity less than 10,000 ohm-cm)		yes	yes, but have no available data of resistivity	no	2350 to 35,000 ohm-cm	not examined
. Mildly (10,000 to 30,000 ohms-cm)	10,000 ohms-cm			yes		
. Noncorrosive (over 30,000 ohms-cm)				no		
5. Presence of stray direct currents	none	none	perhaps no presence	no	yes	not examined
6. Soil sulfate content	no data at present	unknown	unknown	low	no	ditto

EXHIBIT I
page 16

Identification Number	109	110	111	112	113	114
7. Soil sulfide content	no data at present	unknown	unknown	no	no	ditto
8. Soil pH	no data at present	5 to 7	7.2	6.5	6.75 to 7.9	ditto
9. Site water table (the water is above the bottom of the piping system:						
. Severe (frequently)			yes	partly		
. Bad (occasionally)				mostly	yes	
. Moderate (never, but surface water remains for short periods in the soil surrounding the system)				no	yes	
. Mild (never)	water is below the bottom of the piping system	yes		no		yes
10. Types of control of the pipe condition during operation						
. External and internal corrosion monitoring		none	none	none	none	
. Water flooding in the piping system		none	none	none		
. Piping leakage detection		none	yes, by system pressure and quantity of make-up water	make-up water volume	monitoring make-up water flow rate	sound detection, temperature detection
. Pressure in the conduit		none	none		none	
. Others	check for the existence of steam in manhole from conduit					
11. How long is the system out of service during the year?		none	never, in service all year round	hot water= seven months; cold water= eight months	30 days	5 months
12. Possibility of periodic contact of the external unprotected piping surface with ground water (cyclic wetting and drying of the insulation)	none	none	none	none		

EXHIBIT I
page 17

Identification Number	109	110	111	112	113	114
13. Frequency of preventive maintenance						
. Hydro test (pressure)		none	none	none	none	once/year
. Thermal test (temperature)			none	none	none	none
. Manholes	check once in 10 to 30 days	monthly	monthly inspection	inspection once a month	visual inspection every 10 days	2 to 3 times per month
. Expansion devices		monthly	monthly inspection	2 times/year	visual inspection every 10 days	not installed
. Joints		monthly		once a month	no	
. Valves	check once in 10 to 30 days	none	monthly inspection	2 times/year	visual inspection every 10 days	2 times per month
. Others				once/year		
14. Heat losses						
. Transmission piping	10% per year	.15%		0.04 MW/mile= hot water 0.023 MW/mile= chilled water	9%	5% estimate
. Distribution piping				0.003 MW/mile= hot and chilled water	9%	
15. Water makeup requirement in percent from the network water flow rate		0.12%			0.6%/day	7%=1978 3%=1977
C. Network Failure Analysis						
1. Piping failure rate for different pipe sizes (breaks of the pipe per mile per year)						
. Actual pipe breaks		none	once in 1975 and once in 1978, RicWil pipe	0.32	none	this year is the first occurrence, 6 times in 4 months
. Damage caused by thermal and hydro tests		none		none	none	
2. Major failure element (s)		expansion devices	errosion of carrier pipe by ground water infiltration in conduit	leakage from pipe joint	inspection by periodical patrol	joints on branch parts
3. Method of failure detection		routine inspection		thermoelectric couple, infrared scanner		abnormal amount of make-up water

EXHIBIT I
page 18

Identification Number	109	110	111	112	113	114
4. Location of pipe failure						
. Supply line						
a) straight pipe				few	none	
b) joints				many	none	5 cases
c) expansion devices				few	none	
d) manholes				many	none	
e) valve	yes			few	none	
f) pipe anchors and supports				few	none	
g) others					little corrosion on the external surface of small pipes	one case due to damage of the casing coating
Return line						
a) straight pipe			yes	few	none	none
b) joints		ball joints	yes, ball joints in manholes	many	none	none
c) expansion devices				few	none	none
d) manholes				many	none	none
e) valve				few	none	none
f) pipe anchors and supports					none	none
5. Cause of pipe failure						
. External electrochemical corrosion					very low corrosion rate	
. Erosion			yes, by ground water infiltration in conduit			now being studied
. Insulation failure			yes	yes		
. Failure of co-located utility system				yes		
. Failure of the culvert				yes		

EXHIBIT I
page 19

Identification Number	109	110	111	112	113	114
. Mechanical or structural damage under earth loads, vehicle loads, thermal stresses, etc.	gusting of hot water due to mis-handling when gland packing of bulb was exchanged		yes, cause of ground-water infiltration is the conduit damage due to construction works	mechanical or structural damage under thermal stresses		none
6. Character of corrosion						
. Pitting			yes			
. Small spots					yes, 0.04" to 0.08"	
7. Corrosion spot location						
. Bottom side of the pipe						yes
. Top side			yes			
8. Wall thickness when the pipe ruptured			0.28"			
9. Condition of the coating, wrapping or insulating envelope			crumbled out			
10. Dependence of the failure rate on the piping system age				failure rate decreases year after year		
11. Average length of the piping section replaced after failure			980' x 2 = 1975 560' x 2 = 1978	no data		
12. Average repair time per one failure (depending on pipe size) . Urban area			two months	2 days		3 to 4 days
13. Average cost of the repair per failure per pipe size . Urban area						$2,500 to $20,000 (estimate)
14. Maintenance cost per mile per year						
. Urban area	$15,000	$2,900				
. Suburban area				no data		

EXHIBIT I
page 20

<u>EXHIBIT II</u>

Steam District Heating Networks
Operational Experience

EXHIBIT II
page 1

STEAM DISTRICT HEATING NETWORKS OPERATIONAL EXPERIENCE

Country	UNITED STATES								
Name of the District Heating System	Con Edison	Boston Edison	Indianapolis Power & Light	Rochester Gas & Electric	Union Electric St. Louis, MO.	Wisconsin Electric Power	Baltimore Gas and Electric	Dayton Power and Light	Georgia Power, Atlanta, Ga
Identification Number	1	2	3	4	5	6	7	8	9
Heat Capacity of the System (million lb/hr of steam/MWt)	14/4100	2.34/686	1.72/504	1.57/460	1.2/352	1.1/322	.99/290	.96/281	0.80/234
Years of Service	80	93	80	59	79	74	63	72	new plant from 1973, retired from 1903
A. Design Parameters and Features									
1. Pressure (psig)	200 and 400	250,300,400= design; 150=operating	10=LPS 250=HPS	350=DPS 750=TPS	228=winter 200=summer	25=DPS 185=TPS	125=LPS 250=HPS	7=LPS 175=HPS	10 to 15=LPS 90=MPS 160=HPS 210=plant header
2. Temperature range (F) . Supply line	413 and 475	commensurate with properties of saturated steam	240 to 600	550=DPS 750=TPS	365 to 520	steam supplied to IHS at 405F	353=LPS 406=HPS	378=HPS	450 at plant to saturation temperature at above pressures
3. Type of control of heat supply		250 and 300 psig lines=pressure 400 psig=desuperheater		station dispatch, turbine back pressure, transmission pressure regulators and desuperheaters	spence reducing valve		pressure control	automatic master control of boilers	temperature operated control valves
4. Is condensate of the steam system being returned	no	no, only two customers	no	no	no	no	no	no	no
5. Piping design standard or code	ANSI B 31.1	ANSI B 31.1		ANSI B 31.1	ANSI B 31.1 250 psig	ANSI B 31.1	ANSI B 31.1	ANSI B 31.1	ANSI B 31.1=piping 150 & 300 psig=valves 300 psig/500F=expansion joints 250 psig=traps
6. Piping size range (in)									
. Transmission piping	24	2 to 24	20 to 30	10 to 12		12 to 30		2 1/2 to 20	11, 16 and 20
. Distribution piping	4 to 30	2 to 24	2 1/2 to 12	3/4 to 24	8 to 24	2 to 24	2 to 24	3/4 to 12	2,4,6,8,10,12
7. Piping wall thickness (in) for different pipe sizes	.237 to .50	STD except 24=XS	.375 min.	sched.40 seamless= DPS; sched. 80=TPS	STD	sched. 40	STD	STD	2 to 12=STD 16 and 20=XS
8. Piping length (miles)									
. Transmission piping	15	24		1.96	none	23	12.9=mains	13.2=mains	11.8
. Distribution piping	75		35	24	27		5.5=service	3.7=service	

EXHIBIT II
page 1

EXHIBIT II
page 2

Identification Number	1	2	3	4	5	6	7	8	9
9. Type of piping installation and manufacturer									
. Rigid concrete envelope		yes	30%		yes	owner's design	Perma-Pipe (Porter-Hayden)	around precast insulation with or without air space and concrete envelope around monolithic insulation	none
. Conduit	steel pipe conduit	yes				RicWil	RicWil; Ebco	RicWil prefabricated sections	Ebco, RicWil, clay tile, clay tile/conc. pad
. Concrete culvert or trench	reinforced concrete structure	no	50%				poured in place by company or contractor	walk through tunnel (2200 ft)	
. Ductless directly buried in powder backfill		no	20%	temporary use only			none	Gilsulate (only 200 ft)	Trisulite, Insulfil, Gilsulate
. Others		no		EBKO on RicWil with 4" concrete envelope and concrete expansion boxes			none	wood encased wrought iron pipe installed from 1907 thru 1929 inclusive	current use is EBKO and/or Trisulite
10. Type of thermal expansion devices									
. Slip type	yes	yes	yes	ATS only if necessary	yes	ADSCO	yes	yes, gland packed and gun packed	Yarway and ATS
. Bellows type	yes	yes	yes	no	yes	numerous manufacturers	yes	yes	Zallea and ADSCO
. Expansion loops	yes	no	yes	used whenever possible			no	yes	yes
. Others		ball joints, expansion bends					ball joints	yes, diaphragm type on older LP lines	
11. Type of piping joint and bend techniques	flanges, welds, forget fittings		welding	butt welds, manufactured bends 99% 1 ½" diameter	slip type, bends all welded	welding	butt weld joints, no bending allowed	welding joints and fittings; other lines have screwed fittings, flanges, flanges with wedges & some special angle fittings	
12. Type of manholes	reinforced concrete	concrete	precast; brick walls, concrete or roof & concrete build at site	reinforced concrete	9" wall thickness, concrete poured in place	poured or block concrete construction	reinforced concrete poured in place	all have concrete floor and ceiling; walls are either brick, block or concrete	brick and/or concrete

EXHIBIT II
page 2

Identification Number		1	2	3	4	5	6	7	8	9
13.	Piping material (carrier pipe)	carbon steel A53 Grade B seamless	carbon steel	carbon steel	carbon steel A53B & A106B			carbon steel, API Std. 5L	carbon steel; older lines are wrought iron	ASTM Grade B
14.	Type of carrier pipe external protective coating	none	none	witeolite #303-P-primer	none	none		none	none	none, except item 9
15.	Type of insulation	calcium silicate; closed cellular glass	sponge-felt; asbestos calcium silicate/ asbestos free	calcium silicate	calcium silicate, A fiber in wet areas	Garey temp. 2(layer) double thickness	calcium silicate after 1974; asbestos before 1974	calcium silicate	precast or monolithic	current type is calcium silicate
16.	Casing piping material (insulating envelope)	concrete, steel	concrete		12 gauge black iron with tar wrapping	none		carbon steel pipe	RicWil	
17.	Means of corrosion protection (cathodic protection, etc.)	hot coal tar enamel coating; cathodic protection	none	none, no problems	none	none	none	casing pipe-protective coatings and magnesium anodes	some cathodic protection	none present, but may be required
18.	Is the piping system water drainable and dryable	yes	box construction-yes; solid pour construction is not drainable but dryable	yes	yes	yes	yes	yes	yes	yes
19.	Existence of an air gap between the insulation and the culvert or soil	yes	none	50%	yes, 1" minimum	yes	yes	yes	yes, in our standard open duct	except for powder insulation
20.	Existence of a ground water drainage system along the district heating piping	none	none	30%	10% of system installed in 1920-1930	yes	none	none	none	where required
21.	Makeup water treatment . Type of softening		zeolite treatment with brine solution for regeneration		zeolite bed			zeolite	hot process lime and soda	sodium zeolite
	. Type of deaeration		yes		yes			thermal, acid feed and vacuum degasification to remove CO_2	direct contact deaeration	Chicago heaters

EXHIBIT II
page 3

Identification Number	1	2	3	4	5	6	7	8	9
22. The depth of soil cover above the piping installation (ft) . Urban area	2 to 10	ranges from 2' minimum to 12-14' maximum	3 to 9	3 to 4	4 to 7	1.5 to 8 or deeper	2.5 minimum	approximately 2 to 7	varies from 1.5 to 3
23. Steam velocity at nominal conditions, ft/sec	100	variable dependent upon load		30 to 90		250	200 max.	150	130 to 170
24. Does the piping installation meet the following performance criteria:									
. Resistance to groundwater infiltration and spread of water in the event of water infiltration.	yes	all construction is installed for resistance to ground water; however in solid pour construction the spread of water results in localized boiling at infiltration point	yes	80% excellent	yes	no	yes	we do not have a ground water problem	on new construction
. Resistance to water damage	yes		yes	fair		no	yes	we design to keep surface water and leakage from other utilities out of the system	same
. Resistance to mechanical or structural damage	yes	yes	yes	excellent		yes	yes	yes, concrete envelope	same
. Resistance to corrosion	yes		yes	excellent with year around operation		yes	yes	yes, by designing to keep water out of the system	same
. Resistance to other causes of deterioration				none				we have installed bonding cables around our slip expansion joints to help minimize pipe pitting due to electrolysis	
. Simplicity of installation	yes	yes	yes			no	yes	depends on the size, depth, and location (street bed vs. sidewalk bed, etc) of the line being installed and the number and location of other utilities encountered	yes

EXHIBIT II
page 4

EXHIBIT II
page 5

Identification Number	1	2	3	4	5	6	7	8	9
. Ease in repair	no	yes, contingent on location dictated by city grants of location	yes	difficult		yes	no	ditto	where possible
25 Quality control criteria									
. Testing of prefabricated piping component at the factory	no	no		yes		no	yes	yes, in regard to RicWil piping sections	yes
. Testing of both system components and the complete system at the site	welds are x-rayed	yes, weld testing by x-ray	yes	no	yes	100% x-ray of welds on piping	yes	hydrostatic test at 400 psig	yes
B. Operational Conditions									
1. Average annual temperature of the heating medium (F) . Supply line	365	commensurate with properties of saturated steam		420 to 670	365	saturated steam at pressure up to 25 psig=DPS; 410 F at 185 psig= TPS	274=LPS 350=HPS	233=LPS 338=MPS 378=HPS	230 to 450
2. Condition of other adjoining utility systems									
. Cold water piping	several leaks	average	fair	bad		unknown, but leaky	fair	some leakage which can saturate the earth around our lines	n/a
. Sewer system	below steam piping	average	fair	fair			good	some leakage but the sanitary sewer system is usually located below our lines	n/a
. Electrical system		average	good	good	ventilation manholes	unknown	good	generally good	n/a
. Storm drainage system		average	fair	fair		none	good	some leakage which can saturate the earth around our lines	n/a
. Others		average		telephone-poor			gas-good	gas and telephone generally good	
3. Type of soil where the network is installed									
. Clay		yes		25%	yes	yes	yes	20%	yes
. Sand	yes		yes	25%		no	yes	30%	no
. Others	rock, silt	compacted gravel (filled land) and natural gravel		50% rubble			combination of above	gravel 50%	

EXHIBIT II
page 5

Identification Number	1	2	3	4	5	6	7	8	9
4. Soil corrosiveness									
. Corrosive (resistivity less than 10,000 ohm-cm)	corrosive	n/a			n/a	n/a	varies with location	20%	
. Mildly (10,000 to 30,000 ohms-cm)		n/a		yes	n/a	n/a	generally mildly corrosive	30%	
. Noncorrosive (over 30,000 ohms-cm)		n/a			n/a	n/a		50%	
5. Presence of stray direct currents	yes	n/a		n/a	n/a	n/a	no	yes, some now, but they plan to eliminate these in the future	not at present
6. Soil sulfate content	varying	n/a		n/a	n/a	n/a	not measured	information not available	
7. Soil sulfide content	varying	n/a		n/a	n/a	n/a	not measured	n/a	
8. Soil pH	high to low	n/a		n/a	n/a	n/a	6.5	from 6.6 to 7.3 inclusive	
9. Site water table (the water is above the bottom of the piping system:									
. Severe (frequently)		average condition would be classed as bad						no	
. Bad (occasionally)	yes					yes	yes	no	
. Moderate (never, but surface water remains for short periods in the soil surrounding the system)			yes	yes	yes			yes	yes
. Mild (never)			fair					no	
10. Type of control of the pipe condition during operation									
. External and internal corrosion monitoring	periodic monitoring of mains controlled by cathodic protection	none		none			none	none	when possible
. Water flooding in the piping system	pumps are located throughout the system	trapping					no	no	rain storms

EXHIBIT II
page 6

Identification Number	1	2	3	4	5	6	7	8	9
. Piping leakage detection	leaks are visible, repaired on priority	visual, or exploratory excavation	manholes, warm spots, other conduits			yes	no	yes, audio-visual	visual, venting at manholes
. Pressure in the conduit	none	manholes inspection					no	yes	no
. Others		leak indicators at expansion joints			none	visual observation of leaks at the manholes		hot street, sidewalk or ground surface adjacent to steam lines	none
11. How long is the system out of service during the year?	only for short periods, say 8 hrs each time to do repair	never, except for localized maintenance	heating only, 3 months each year	never completely out of service	never	total system-never; partial areas 8 to 24 hrs	never	it operates year-round	
12. Possibility of periodic contact of the external unprotected piping surface with ground water (cyclic wetting and drying of the insulation)	possible contact during rain water runoff	yes, occasionally	none	yes	short periods	yes	occasionally	yes, with surface water percolation and other utility leakage; high on old wood encased lines	during rain storms in certain areas
13. Frequency of preventive maintenance									
. Hydro test (pressure)	none	none	new systems	n/a			none, except upon installation	400 psig, cold water at installation	new construction tested with steam
. Thermal test (temperature)	none	none	at some customer location	n/a			none	when hydrostatic test cannot be used, we use steam pressure	new construction tested with steam
. Manholes	none	ongoing		cleaned and inspected yearly	inspected once a month	annually	visual, annually	weekly, audio-visual inspection	monthly checks, more often in some cases
. Expansion devices	slip joints inspected 3 times per year	occasional packing of slip joints		n/a	inspected once a month	annually	visual, annually	weekly, audio-visual, inspection (slip joints in manholes)	varies with location
. Joints	none	none		packed twice yearly, except ATS joints	inspected once a month	annually	none	weekly audio-visual inspection (in manholes)	visual checks, monthly, repairs made when needed

EXHIBIT II
page 7

Identification Number	1	2	3	4	5	6	7	8	9
. Valves	none	continual		as required	inspected once a month	part of manhole inspection	visual annually	weekly, audio-visual inspection (in manholes)	trap inspection monthly or sooner when required
. Others			3 two men crews are out everyday				as required	steam traps-weekly, audio-visual inspection (in manholes)	
14. Heat losses									
. Transmission piping		10 to 12%		120 btu/hr per ft^2 of pipe area		averages	none	14,831 #/hr=steam maines;	250,000 #/day
. Distribution piping					information not available	10%	6% of output	1,436 #/hr=steam services	average
15. Water makeup requirement in percent from the network water or steam flow rate		100%		100%	100%	100%	100%	100%	

C. Network Failure Analysis

Identification Number	1	2	3	4	5	6	7	8	9
1. Piping failure rate for different pipe sizes (breaks of the pipe per mile per year)									
. Actual pipe breaks	none	minimal		none	not recorded	.177 average	no record negligible	0.30, since Jan 1, 1976. Our analysis only takes into consideration the replacement of LP & MP valves 6" and over, HP valves 2" and over, all pop-safety valves, all pressure regulating valves, all expansion joints, all complete service lines and 15 ft. or more main line.	only four in 15 years
. Damage caused by thermal and hydro tests	no testing done	none		none	not recorded	none	none	none	none
2. Major failure element (s)	leaks on flanges, valves, expansion joints	expansion joints and gaskets	age and water	LPS installed in 1950's operated seasonally	expansion joints	leak in	expansion joints, trap piping, manhole sump pumps	corrosion of pipe wall and expansion joint bellows	bellows joints, trap lines, anchors
3. Method of failure detection	visual	leak indicators at expansion joints, exploratory excavation		visual	isolation	visual observation	visible vapor	audio-visual and thermal	isolation and excavation, all welds are located on piping drawings

EXHIBIT II
page 8

EXHIBIT II
page 9

Identification Number	1	2	3	4	5	6	7	8	9
4. Location of pipe failure									
. Supply line a) straight pipe		none, rare weld leak	yes	none		yes	corrosion bottom	11	yes
b) joints	yes	bellows of corrugated expansion joints		none			welds, some with flange gaskets	no record	weld, flanges
c) expansion devices	yes		packing	none			stress cracking of bellows	7	yes
d) manholes	yes	gaskets and auxiliary piping		n/a	yes		deterioration of concrete	no record	seldom
e) valve	yes	gaskets	yes	none, only leakage			corrosion of operating mechanism	3	flanges
f) pipe anchors and supports	yes	extremely rare	yes	none		yes	deterioration	negligible	yes
g) others				small leaks on trap discharge lines	welds		corrosion of trap piping	no record	
5. Cause of pipe failure									
. External electrochemical corrosion	stress corrosion on bellows joints	none	yes	none	yes	yes	yes, valves	yes	
. Internal electrochemical corrosion	stress corrosion on bellows joints	none		none			pipe, expansion joints, trap piping	yes, very little	
. Bacteriological corrosion	none	none		none			none	none	
. Erosion	none	none		none			none	yes, internally caused by the flow of condensate	yes, mostly
. Insulation failure	none	none		none		yes	water infiltration via manholes	no	

EXHIBIT II
page 9

Identification Number	1	2	3	4	5	6	7	8	9
. Failure of co-located utility system	water main breaks may rupture cast iron fittings	occasional rupture of water mains	yes	water leaks appear to be a probably contributing factor			water main breaks	yes, water lines, storm sewers, and sanitary sewers	
. Failure of the culvert		no		no			none	yes, some spalling of the walls and ceilings in our tunnel	
. Mechanical or structural damage under earth loads, vehicle loads, thermal stresses, etc.	none	yes, thermal shock and settlement		no			anchor and support failure lead to thermal stress failure, vehicle loads accelerate manhole deterioration	little, if any	water hammer
. Others	valve packing gaskets							anchors concentrated on a small pipe area causing metal fatigue	
6. Character of corrosion									
. Uniform		n/a		yes				no	
. Pitting	conduit only	n/a			yes		usually	yes	from internal erosion
. Small spots		n/a	yes					pitting varies from pin holes to ½ in diameter or larger	
7. Corrosion spot location									
. Bottom side of the pipe		n/a			yes	yes	usually	yes, some; some at sides of pipe	yes
. Top side		n/a				yes		yes, mostly	
8. Wall thickness when the pipe ruptured	no pipe rupture	original		no major failure	thin around external corrosion	no records kept	reduced to 0	no rupture; leaks start with a pinhole and grow	

EXHIBIT II
page 10

Identification Number	1	2	3	4	5	6	7	8	9
9. Condition of the coating, wrapping or insulating envelope	none on pipe	average to very good	generally good		wet from failure		poor	insulation is saturated with condensate and damaged or blown away by the leaking steam	varies from excellent to poor, depending on age and type
10. Dependence of the failure rate on the piping system age	old systems have flanged joints, these fail more than welded joints	unrelated	no	n/a	not known	more breaks the older the system is	average age= 30 years	high	most failures occured in pipe over 25 years old
11. Existence of an air gap between the insulation and the culvert or soil during the service life of the pipe	system is constructed with an air gap	n/a			minimum 2"	yes	good	yes,in our open duct;no,in our solid-pour,monolithic-pour, RicWil,Gilsulate, and wood encased lines	except where powdered insulation is used
12. External corrosion rate per year (in. per year)		unknown, if any					no estimate	no record	
13. Average length of the piping section replaced after failure (ft)	6	approximately 4, which represent length of expansion joints	8		5	6	3 to 4	29 ft;this is taken from 17 repair jobs in the past 3-4 yrs; the lines repaired ranged from 4 to 20 in.	2 to 200
14. Average repair time per one failure (depending on pipe size) . Urban area	6 to 8 hrs	8 hrs	4 days		no record	6 days including digging and restoration	3 days	405 man hours	3 days to 6 weeks
15. Average cost of the repair per failure per pipe size . Urban area	$1,000	$3,000			no record	$2,200 and up depending on interference by other utilities	no record	$7,228	too variable to estimate, failure frequency low
16. Maintenance cost per mile per year . Urban area	$36,000	$30,000, labor and material	$37,600		no record	approximately $37,300,this includes maintenance of tunnel and manhole structures	$16,470 for main and service	$14,243	$5,254

EXHIBIT II
page 11

STEAM DISTRICT HEATING
NETWORKS OPERATIONAL EXPERIENCE

Country	UNITED STATES							
Name of the District Heating System	Harrisburg Steam Distribution System	Kansas City Power and Light	Northern States Power	Community Central Energy Corp.	The Washington Water Power Co., Spokane	Eugene Water & Electric Board, Oregon	Pennsylvania Electric Co., Erie, PA.	Austin Utilities Austin, MN.
Identification Number	10	11	12	13	14	15	16	17
Heat Capacity of the System (million lb/hr of steam/MWt)	0.60/176	0.60/176	0.50/146	0.44/129	actual peak in last 12 yrs = 0.27/79	0.265/78	0.20/59	0.07/21
Years in Service	92	over 80	over 50	90	64	17	70	52
A. Design Parameters and Features								
1. Pressure (psig)	150	15=LPS 105=MPS 185=TPS	8=LPS 75=HPS	40=winter 20=summer	12=LPS 150=HPS	15 and 150	15=LPS winter 5=LPS summer 250=HPS	21
2. Temperature range (F)	420	250 @ 15 psig 342 @ 105 " 380 @ 185 "	365	300	246=LPS 365=HPS	440=supply line 170=return line	400	270
3. Type of control of heat supply	pressure and temperature sensors in boiler outlet header	pressure reducing valves and desuperheating stations	pressure reducing stations	multi-stations	supply is controlled by maintaining 150 psig plant pressure	PRV		turbing topping (extraction)
4. Is condensate of the steam system being returned	no	no	no	no	no	50%	no	no
5. Piping design standard or code	ANSI B 31.1	ANSI B 31.1			none followed			ANSI B 31.1
6. Piping size range (in)								
. Transmission piping	4 to 20	4 to 20		6 to 22		8 to 14	6 to 20	
. Distribution piping	2 to 16	4 to 18	4 to 20	2 to 8	6 to 20=LPS 4 to 10=HPS	2 to 4	2 ½ to 6	2 to 10
7. Piping wall thickness (in) for different pipe sizes	4" and Larger= sched. 40; 2" and smaller= sched. 30	LPS=sched. 40 HPS & MPS=STD	sched. 80	.322 to .500	sched. 30 and 40	sched. 40	sched. 40	sched. 40
8. Piping length (miles)								
. Transmission piping	2.2	11.9		11.4		8	5.5	
. Distribution piping	6.6		6.1	6.8	4.09=LPS 2.46=HPS		1.9	1.2

Identification Number	10	11	12	13	14	15	16	17
9. Type of piping installation and manufacturer								
. Rigid concrete envelope		yes			direct burial of pipe with 2" insulation covered by 6" surrounding concrete	yes, zecrete	yes	
. Conduit		no				yes		
. Concrete culvert or trench		no	some	concrete square duct				yes
. Ductless directly buried in powder backfill		no						
. Others	reinforced concrete duct with precast concrete top slabs per owner specifications		wooden log, sewer tile, tunnels		direct burial of pipe with 6" surrounding insulating concrete (vermiculite concrete). Original (1915) direct burial with 4" wood log insulation		some RicWil	
10. Type of thermal expansion devices								
. Slip type			yes	yes	a few	yes	60%	ADSCO flanged
. Bellows type	mostly BOA or BADGER	yes	yes		mostly	yes	40%	
11. Type of piping joint and bend techniques	welded joints, flanged at components	welded and flanged			joints generally welded, flanged in plant	weld	butt weld joints	flanged
12. Type of manholes	concrete per company standard	cast in place	built up brick and block	concrete	brick	concrete	brick and block	concrete
13. Piping material (carrier pipe)	carbon steel, A 106 Grade B or A53 Grade B	ASTM A53 Grade B	carbon steel	ASTM A53 B	carbon steel	carbon steel	carbon steel and wrought iron	carbon steel
14. Type of carrier pipe external protective coating	Rust-sele 774 paint	roofing felt 20#		high temperature tar	none			none

EXHIBIT II
page 13

Identification Number	10	11	12	13	14	15	16	17
15. Type of insulation	mineral wool (older installations; now using calcium silicate	calcium silicate	1" formed fiber glass	2 ½" fiberglass	wood original; fiberglass and calcium silicate; presently use insulating concrete (vermiculite)	various	calcium silicate	calcium silicate covered with building paper
16. Casing piping material (insulating envelope)	15 LB asphalt roof felt			concrete	concrete as outer coat	zecrete	some cast iron	
17. Means of corrosion protection (cathodic protection, etc.)	none	none	none	cathodic=70% balance=no protection	none; rely on good insulation	none	cathodic protection	none, mainly try to eliminate electralyte by maintaining dry culvert
18. Is the piping system water drainable and dryable	drainable-yes	yes, traps	no	yes	no	partial	yes	pitched to manholes
19. Existence of an air gap between the insulation and the culvert or soil	yes, within concrete duct	no	some	yes	none	partial	partial	yes
20. Existence of a ground water drainage system along the district heating piping	yes	no	no	yes	none	yes	yes	yes, crushed rock and tile
21. Makeup water treatment . Type of softening	zeolite softener plus sodium sulfite	hot zeolite with cold zeolite @ peak	lime/zeolite, cation-acid		zeolite	demineralization		hot process lime and zeolite
. Type of deaeration	direct contact	yes			direct contact	direct contact		direct contact
22. The depth of soil cover above the piping installation (ft) . Urban area	3.5 min.	2.5 min	from 3 to 5	3 min.	most are from 4 to 7, some are 13	3 to 15	3.5 to 8	concrete
23. Steam velocity at nominal conditions, ft/sec	30	177 in 18" line at 1978 winter peak			142 to 157			80
24. Does the piping installation meet the following performance criteria; . Resistance to groundwater infiltration and spread of water in the event of water infiltration.	some resistance	yes	no	yes	no	yes		yes

EXHIBIT II
page 14

Identification Number	10	11	12	13	14	15	16	17
. Resistance to water damage	some resistance	yes	yes, asphalt coating	yes	no	partly		yes
. Resistance to mechanical or structural damage	yes	yes	yes, cement block casing or tunnel	yes	no	yes	yes	yes
. Resistance to corrosion	some resistance	yes	no	yes	no	no outside, yes inside		yes
. Resistance to other causes of deterioration					no			
. Simplicity of installation	field fabricated per owner specifications	no	yes, in tunnels	yes	yes	yes		no
. Ease in repair	yes	no	yes, in tunnels	yes	yes	questionable		no
25. Quality control criteria								
. Testing of prefabricated piping component at the factory	no prefabricated piping systems	yes	no		n/a	no		yes, refers to one very short section of RicWil
. Testing of both system components and the complete system at the site	yes, hydro and steam tests	yes	no	yes	yes	yes	yes	yes
B. Operational Conditions								
1. Average annual temperature of the heating medium (F) . Supply line	366	same as item A2 above	380	300	245 to 248=LPS 365=HPS	440=supply line 170=return line	400	270
2. Condition of other adjoining utility systems								
. Cold water piping	bad		generally in good condition	unknown	good	n/a		
. Sewer system	good		good	unknown	good	n/a		

EXHIBIT II
page 15

Identification Number	10	11	12	13	14	15	16	17
. Electrical system	good		good	unknown	damaged by steam leaks and heat loss in some cases	n/a		
. Storm drainage system	bad		good	unknown	none	n/a		
. Others	Bell telephone-good				phone, same comment as for electrical		telephone	
3. Type of soil where the network is installed								
. Clay	yes	yes	yes	yes		yes		
. Sand	yes		yes	yes		yes	mostly	
. Others	shale	shale, lime stone	shale-rock		gravelly sand	yes		
4. Soil corrosiveness								
. Corrosive (resistivity less than 10,000 ohm-cm)			not known			yes		
. Mildly (10,000 to 30,000 ohms-cm)				yes	yes	yes		
. Noncorrosive (over 30,000 ohms-cm)								
5. Presence of stray direct currents					some, because the steam system is not electrically isolated from other utilities	n/a	yes	
6. Soil sulfate content					unknown			
7. Soil sulfide content					unknown			
8. Soil pH					6 to 7.3			
9. Site water table (the water is above the bottom of the piping system:								
. Severe (frequently)			no			yes		
. Bad (occasionally)	yes		no				yes	

EXHIBIT II
page 16

Identification Number	10	11	12	13	14	15	16	17
. Moderate (never, but surface water remains for short periods in the soil surrounding the system)		yes	yes		sometimes due to leaks in water system			
. Mild (never)				yes				yes
10. Type of control of the pipe condition during operation								
. External and internal corrosion monitoring		no	no		no	none		
. Water flooding in the piping system		no problem	no		no	none		
. Piping leakage detection	visual	visual, pressure readings	visual	yes	visual	none	yes	yes
. Pressure in the conduit		recording pressure charts and flow charts	yes	yes	yes	none		
. Others				external monitoring				
11. How long is the system out of service during the year?	never	not down completely, customers were not delivered rated pressure for about 25 hrs due to PRV problems	LPS only for 3 months	never	never	never	never	never
12. Possibility of periodic contact of the external unprotected piping surface with ground water (cyclic wetting and drying of the insulation)	yes	with concrete envelope not a problem	in some low areas	very rare	moderate	constantly	some	none
13. Frequency of preventive maintenance								
. Hydro test (pressure)	only when new mains installed	initial installation			no	no		
. Thermal test (temperature)	always, whenever repairs are made or new mains tested	no			no			

EXHIBIT II
page 17

Identification Number	10	11	12	13	14	15	16	17
. Manholes	as required	constant inspection and maintenance of HPS, every service inspected twice per month	attempt to clean them once a year	annual	no	monthly	yes, when needed	annual
. Expansion devices	when installed	most sealed underground	grease them once a year	annual	no	monthly where available	yes, when needed	annual
. Joints			attempt to clean stem and oil once a year	annual	no			annual
. Valves	as required	monthly		annual		monthly	packing	annual
. Others					steam traps are checked annually or as required			monthly traps
14. Heat losses								
. Transmission piping	13%, estimated	1978=28% system unaccounted for@ customer meters; 1977=18%				very little	at times 37%	
. Distribution piping	unaccounted		5.4%		15% assumed			44,000#/day
15. Water makeup requirement in percent from the network water or steam flow rate	100%	100%	100%		100%	40 to 60%		100%
C. Network Failure Analysis								
1. Piping failure rate for different pipe sizes (breaks of the pipe per mile per year) . Actual pipe breaks	5	20 to 25 leaks repaired per year on LPS; HPS=no problem	no data	80	leaks: 25=1978 21=1977 26=1976 14=1975 3 to 4= 1968 to 1973	none		none
. Damage caused by thermal and hydro tests	none	none	none		none		none	none

EXHIBIT II
page 18

Identification Number	10	11	12	13	14	15	16	17
2. Major failure elements (s)	piping and expansion joints	piping and expansion joints	corrosion of piping		ground water or water system leak flashes to steam causing pitting and holes	corrosion		gaskets and packing
3. Method of failure detection	steam observed visual	visual	steam will come to manhole or follow service pipe		visual	loss of vacuum		visual
4. Location of pipe failure								
. Supply line								
a) straight pipe	50% of leaks (20)	1/3	yes		yes	yes		
b) joints		1/3	yes	yes			yes	yes
c) expansion devices	25% of leaks (10)	1/3	yes	yes		yes	yes	yes
d) manholes			yes	yes	yes		yes	
e) valve		rare	yes	yes			yes	packing and flange gaskets
f) pipe anchors and supports		rare	yes					
g) others	25% (10) service lines (lines from main to curb)					traps		
5. Cause of pipe failure								
. External electrochemical corrosion	steam main leaks caused by external corrosion	yes	yes	yes	yes	condensate lines	yes	yes
. Internal electrochemical corrosion		no problem	little					
. Bacteriological corrosion		no	no	yes				
. Erosion		no	no					yes, where condensate in steam service accelerates as it drains into main line
. Insulation failure	yes	no	n/a		yes		yes	

EXHIBIT II
page 19

Identification Number	10	11	12	13	14	15	16	17
. Failure of co-located utility system	service piping at curbline due to ground water	no	some	yes	yes		yes	
. Failure of the culvert		n/a	no					
. Mechanical or structural damage under earth loads, vehicle loads, thermal stresses, etc.		no problem	some	yes				
. Others	improper backfilling by contractors					main steam piping pitting from nondeaerated water used for desuperheaters		
6. Character of corrosion								
. Uniform	general corrosion	yes					yes	
. Pitting			yes	yes	yes	yes		yes
. Small spots			yes					
7. Corrosion spot location								
. Bottom side of the pipe	yes	yes	yes	yes	all around	condensate lines no particular location	yes	yes, at rollers
. Top side	yes		yes	yes		main steam lines		
8. Wall thickness when the pipe ruptured			zero at the rupture	1/8" or less	varying from original to zero	zero	zero	
9. Condition of the coating, wrapping or insulating envelope	poor		fair	good	non-existant normally; most leaks have occured in areas where the original (1915) wood log insulation has completely deteriorated	good		good

EXHIBIT II
page 20

Identification Number	10	11	12	13	14	15	16	17
10. Dependence of the failure rate on the piping system age	partially true	very dependent	fairly direct		almost 100% dependent on age			more dependent on installation condition than age; exception is service goose neck where erosion is a function of time
11. Existence of an air gap between the insulation and the culvert or soil during the service life of the pipe	n/a	no			none			maintained as nearly as possible to original condition
12. External corrosion rate per year (in. per year)	not known	not known	no data					do not test
13. Average length of the piping section replaced after failure(ft)	8 to 20 ft/ leak	15	8 to 10	5	10		6 to 10	patch
14. Average repair time per one failure (depending on pipe size) . Urban area	1 week	15 working days	2 weeks	45 man hours from concrete to finished work			2 days	1 day (steam off approx. 2 hrs.)
15. Average cost of the repair per failure per pipe size . Urban area	$6,000/leak average	$3,600	n/a		5 days		$2,000	$1,000 (patch repairing, size does not make a difference)
16. Maintenance cost per mile per year . Urban area	$25,000	$2,708; total maintenance cost of the piping system in 1978=$32,500	n/a	80¢ per ft for urban area and 120¢ for suburban area	$14,420 in 1978			$8,000

EXHIBIT II
page 21

EXHIBIT II
page 22

STEAM DISTRICT HEATING
NETWORKS OPERATIONAL EXPERIENCE

Country	UNITED STATES				CANADA		FRANCE	JAPAN	
Name of the District Heating System	Rice Lake Steam Corp., Rice Lake, Wisconsin	Alabama Power, Birmingham Steam heat System	Iowa Electric Light and Power	Chicago Union Station Co.	Toronto Hydro Electric System	Winnipeg Hydro Electric System	Compagnie Parisienne de Chauggage Urbain, Paris	Ikebukuro District Heating & Cooling Co.	Okazaki Energy Supply Co,Ltd.
Identification Number	18	19	20	21	22	23	24	25	26
Heat Capacity of the System (million lb/hr of steam/MWt)	0.05/15				.70/205	.30/88	6.5/2180	.185/54.3	.026/7.7
Years in Service	29		86	46	14	75	49	1	7
A. Design Parameters and Features									
1. Pressure (psig)	125	2 to 5=LPS 150=HPS	10 to 100	210	25=LPS 195=HPS	70	275=winter 174=summer 72=delivered to the client	128	100=winter 43=summer
2. Temperature range (F) . Supply line	400	216 to 225=LPS 366=HPS	240 to 375	389=supply line 150=return line		350	455,superheated=supply line at the plant; 130=return line	354=supply line 176=return line	338=supply line winter 290=supply line summer 185=return line
3. Type of control of heat supply		PRV	manual	PRV	pressure control		pressure control, central dispatch and telephone	automatic control by pressure	pressure control using air
4. Is condensate of the steam system being returned	no	no	no	yes	no		yes, 75%	yes	yes
5. Piping design standard or code		ANSI B 31.1		250 psig design	ANSI B 31.1 Canadian code UW51	125 psig	steam=NF 49 112 and NF 49 250 condensate=API	subject to technical standard regulations and DH industry's law	standard STPG 38

EXHIBIT II
page 22

Identification Number	18	19	20	21	22	23	24	25	26
6. Piping size range (in)									
. Transmission piping	4, 5, and 6	6 to 18	6 to 24	10 to 12		6 to 14 (main loops)	steam=1½ to 28"; condensate-1½ to 14	8 to 14	2½ to 10
. Distribution piping		6 to 20	6 to 24	2 to 8	2 to 20	2½ to 6 (services)		3 to 8	
7. Piping wall thickness (in) for different pipe sizes	sched. 80	sched. 40	sched. 40 and 80	XS	2"=sched. 80 2½" to 10=sched. 40 12" to 20"=STD	STD	up to 4"=0.157 on 28"=0.669 max	sched. 20 and below for steam and sched. 40 for condensate	sched. 40
8. Piping length (miles)									
. Transmission piping	1.7	6.34	3	2.3		6.3 (mains)	132 (mains)	1.4	
. Distribution piping			5		6 (4 miles 200 psig, 2 miles 25 psig)	2.4 (services)	21 (services)	0.2	
9. Type of piping installation and manufacturer									
. Rigid concrete envelope	yes		majority-self design		yes, solid pour	concrete box approx. 2'x 2' O.D. 4" walls			
. Conduit		yes, EB Kaiser Co.	some RicWil				steel conduit only at certain crossections, but not used now		yes
. Concrete culvert or trench		field fabrication with half round clay pipe cover	some-self design				yes, mostly prefabricated	yes	
. Ductless directly buried in powder backfill							tried, but not used anymore		
. Others				on hangers					
10. Type of thermal expansion devices									
. Slip type		yes	some	yes	exclusively in HPS	packed and gum packed expansion joints	yes, old large diameters		

EXHIBIT II
page 23

Identification Number	18	19	20	21	22	23	24	25	26
. Bellows type	yes	yes	majority	yes	only in LPS		Zallea and Teddington type	yes	
. Expansion loops			some	yes	where possible		yes	yes	yes
. Others							compensators		
11. Type of piping joint and bend techniques		welded	fabricated in field	weld	welded	screwed construction 1924-1950; from 1950 on welded	welded	weld or flange connection	
12. Type of manholes	concrete	concrete, poured in place	poured concrete	none	concrete	concrete		water and electrical resistance	concrete
13. Piping material (carrier pipe)	carbon steel	carbon steel A53 Grade B	carbon steel	carbon steel	carbon steel	genuine wrought iron	pipes are installed in the culvert on structural steel, guided and fixed at every 200 ft	carbon steel	carbon steel
14. Type of carrier pipe external protective coating		none	concrete			none	only painting	rust inhibiting paint	asphalt coating
15. Type of insulation	fiberglass	calcium silicate		asbestos	calcium silicate	1½" rock wool or laminated asbestos and insulating concrete	glass wool	calcium silicate	3" calcium silicate
16. Casing piping material (insulating envelope)		steel	none or steel	roofing paper and aluminum	concrete		bituminous wrapping		STK 41 6" to 22"
17. Means of corrosion protection (cathodic protection, etc.)	none	fiberglass or tar coating	none		none, pipes grounded	none	two layers of heat resistant painting	painted to prevent corrosion	galvanic anode method
18. Is the piping system water drainable and dryable	yes	yes	no	yes	theoretically yes, designed to be drainable and dryable	yes	drainable	no	yes
19. Existence of an air gap between the insulation and the culvert or soil	none	yes	no	none	average 1½"	yes, approximately 4"	yes	yes	yes

Identification Number	18	19	20	21	22	23	24	25	26
20. Existence of a ground water drainage system along the district heating piping	no	no	no		yes, 3" weeper pipe	yes	yes, inside the concrete culvert	yes	
21. Makeup water treatment . Type of softening	hot lime and soda ash	sodium zeolite	demineralizer	Cochrane hot process, continius softener using caustic soda and sodium alumina	H_2Na blend system	hot lime softener	demineralization	yes	softening
. Type of deaeration	mechanical	direct contact	direct contact	Cochrane direct contact	cold degasifier and 5 psig direct contact deaerator	direct contact	direct contact at 217F, plus hydrazine and neutralization by ammonia	yes	
22. The depth of soil cover above the piping installation (ft) . Urban area	3 to 5	3 to 10 (100% of main under paved street area)	3		2 min. 18 max.	urban=n/a; 5.5 average in suburban area	mostly less 1.6 ft, sometimes one ft, generally not more than 3.3 ft	5 to 16	1.9 to 7.5
23. Steam velocity at nominal conditions, ft/sec		varies		66	100, design		max entering velocities: 550=28" piping; 260=8" piping; 72=1½" piping; steam pressure drop 0.0133 psi/ft	90 to 130	
24. Does the piping installation meet the following performance criteria:									
. Resistance to groundwater infiltration and spread of water in the event of water infiltration.	yes	some, and no	yes	yes	to some degree	limited amount	yes	the ground water is collected in a reserve tank	yes
. Resistance to water damage	yes	some	yes	yes	to some degree	limited	yes, except when river conduit breaks and the water floods the area	yes	yes

Identification Number	18	19	20	21	22	23	24	25	26
. Resistance to mechanical or structural damage	yes	yes	yes	yes	yes	cracks in concrete envelope allow water access	yes	yes	none
. Resistance to corrosion	yes	yes	no	yes	yes		yes	yes	yes
. Resistance to other causes of deterioration					as any other burried concrete	salt spread for winter snow has caused extensive corrosion in last 16 years		painted to prevent corrosion, all welds are x-ray inspected	none
. Simplicity of installation	yes		yes		yes		yes, by means of careful attention	yes	yes
. Ease in repair	yes		yes		difficult to pinpoint leak		repair is no problem, localization of the leak is difficult	yes	difficult
25. Quality control criteria									
. Testing of prefabricated piping component at the factory		no	no			no	yes	pressure test and corrosion test	yes
. Testing of both system components and the complete system at the site		yes	yes	yes	x-raying all welds plus hydrostatic test of piping as per applicable ASME and local Government codes	pressure testing	hydro test for steam= 435 psig and x-ray, for condensate 218 psig	yes	yes
B. Operational Conditions									
1. Average annual temperature of the heating medium (F)									
. Supply line	400	216 to 225=LPS 366=HPS	240 and 375		390	330 to 350	356=supply line 140=return line	354=supply line 140=return line	338=supply line 185=return line
2. Condition of other adjoining utility systems									
. Cold water piping	not known	veries	excellent			in service for number of years and subject to frost action		exists	
. Sewer system	not known	varies	excellent			good		none	

Identification Number	18	19	20	21	22	23	24	25	26
. Electrical system	not known	good	excellent			good		exists	
. Storm drainage system	good	varies	good					exists	
3. Type of soil where the network is installed									
. Clay	yes	yes	yes		yes	silt beds			
. Sand	yes		yes		yes				yes
. Others							the soil used for the construction of the sewer system	loam layer	
4. Soil corrosiveness									
. Corrosive (resistivity less than 10,000 ohm-cm)		unknown			unknown				yes
. Mildly (10,000 to 30,000 ohms-cm)			yes			yes		yes	5,000 to 19,000 ohms-cm
. Noncorrosive (over 30,000 ohms-cm)	no problem						probably		
5. Presence of stray direct currents	not known	not known	yes		unknown	very little	yes, in certain areas close to subway and railroad	none	none
6. Soil sulfate content	nile						unknown	none	
7. Soil sulfide content			due to system being in urban area where other utilities periodically maintaining their facilities using various foreignbackfill it was not felt soil conditions would remain constant. For this reason no testing has been performed		unknown		unknown	none	
8. Soil pH					unknown	over 7		not known	

EXHIBIT II
page 27

Identification Number	18	19	20	21	22	23	24	25	26
9. Site water table (the water is above the bottom of the piping system:									
. Severe (frequency)			never					depends on the site	
. Bad (occasionally)							when it is flooded by the river, few miles		
. Moderate (never, but surface water remains for short periods in the soil surrounding the system)	yes	yes	yes		yes	watermain breaks and spring flooding			
. Mild (never)							yes	yes	yes
10. Type of control of the pipe condition during operation									
. External and internal corrosion monitoring	internal pipe water treatment used	none	no			none			yes
. Water flooding in the piping system	none	automatic pumps at low elevation	yes			daily patrol			yes
. Piping leakage detection	visual		no		visual in manholes	daily patrol	yes	yes	yes
. Pressure in the conduit	no		no					yes	
11. How long is the system out of service during the year?	never	downtown not energized 5½ summer months	never	never	operates all year round	2½ months from June 10, to Sept. 1 for annual overhaul	never, but some sections for 8 to 12 hrs.	never	never
12. Possibility of periodic contact of the external unprotected piping surface with ground water (cyclic wetting and drying of the insulation)	nile	yes	occasionally		unlikely, but possible		yes, located close the river flooded area	none	no
13. Frequency of preventive maintenance									
. Hydro test (pressure)	never	no			no			no	once a week
. Thermal test (temperature)		no			no			no	once a week

EXHIBIT II
page 28

Identification Number	18	19	20	21	22	23	24	25	26
. Manholes		annual inspection and cleaning	yearly		visual inspection of manhole piping every 6 months	daily to weekly, inspection during in-service		n/a	once a week
. Expansion devices			yearly	annual	same as above as all expansion joints located in manholes		replacement of the bellows joints between 10 to 20 years; packing slip joints every four years	twice per month	once a week
. Joints		annual inspection of slip type joints	yearly			adjusted as required; repacked every 3 yrs.		twice per month	once a week
. Valves	once a year	repacking after leaks start, some valves packed each year	yearly	annual	in steam lines, cast steel 300 lbs welded ends, gate type; valves located in manholes	annual	maintenance every 4 years	twice per month	once a week
14. Heat losses . Transmission piping		unknown	unknown	15%		estimated .5#/sq.ft/ season	Total loss 14% as follows: 1. condensate loss=8.5% 2. steam heat loss=2.5% 3. condensate heat loss= 3%	5 to 10% from the heat sold	
. Distribution piping			unknown					3 to 5 % from the heat sold	
15. Water makeup requirement in percent from the network water or steam flow rate		100%	100%	30%	100%	95%	25%	30%	
C. Network Failure Analysis									
1. Piping failure rate for different pipe sizes (breaks of the pipe per mile per year)									
. Actual pipe breaks	none	none	none	none	there were no pipe breaks, only leaks to which the following comments refer	average two to three/year	11 leaks in 4 years; 0.112/mile,yr	none	
. Damage caused by thermal and hydro tests		none	none		none		none	none	
2. Major failure elements (s)	expansion joints				bad welds, external corrosion	threaded joints, external corrosion			

EXHIBIT II
page 29

Identification Number	18	19	20	21	22	23	24	25	26
3. Method of failure detection	visual	spot excavation	none		steam escaping from manholes after travelling along the buried pipe to the outside; locating the leak by trial excavations	leaking steam (hot manholes)	detection of leaks by observation of steam which penetrated to the manholes; sometimes settling of the wet soil		
4. Location of pipe failure									
. Supply line									
a) straight pipe		yes	yes		no	external corrosion, aggravated by road salt	yes, on the return line		
b) joints	yes		yes		yes	threaded flanges and couplings	sometimes, but always in manholes		on the supply and return lines
c) expansion devices	yes	yes		yes	no		yes, many accidents before applying preventive maintenance program		
d) manholes			yes		yes	flanged joints-bolt corrosion	--		
e) valve			yes		through packings or corroded body	flanges	yes, leakages and valve seat problems		on the supply and return lines
f) pipe anchors and supports		yes	yes		yes	corrosion of braces and anchors	very rare corrosion at the anchors, where stray currents exist		
g) others		threads on condensate drain piping			at branch connections				
5. Cause of pipe failure									
. External electrochemical corrosion		yes	yes			yes	condensate line, specially where there are stray currents; supply line=stress corrosion at the expansion joints(bellows)		
. Internal electrochemical corrosion			yes		yes		sometimes at the high points when air venting is not provided		

Identification Number	18	19	20	21	22	23	24	25	26
. Bacteriological corrosion					no				
. Erosion					no				
. Insulation failure					no		not very often, except for piping systems with Gilsulate insulation		
. Failure of co-located utility system			no		no				
. Failure of the culvert			no		no		not very often, except of pipe breaks under hummering condition		
. Mechanical or structural damage under earth loads, vehicle loads, thermal stresses, etc.									yes, thermal stresses
. Others			floods		faulty welds at time of construction			failure of joint welding	
6. Character of corrosion									
. Uniform					no		no		
. Pitting		yes	yes		yes	yes	yes		
. Small spots					no				
7. Corrosion spot location									
. Bottom side of the pipe		varies, no set pattern	yes		yes	mainly bottom of pipe	external corrosion, variable		
. Top side			yes		no		external corrosion, variable		
8. Wall thickness when the pipe ruptured			no ruptures, leaks only		no rupture of pipe experienced	in thousands of an inch	no rupture only sometimes small holes		
9. Condition of the coating, wrapping or insulating envelope			good		destroyed	blown clear		good	good

EXHIBIT II
page 31

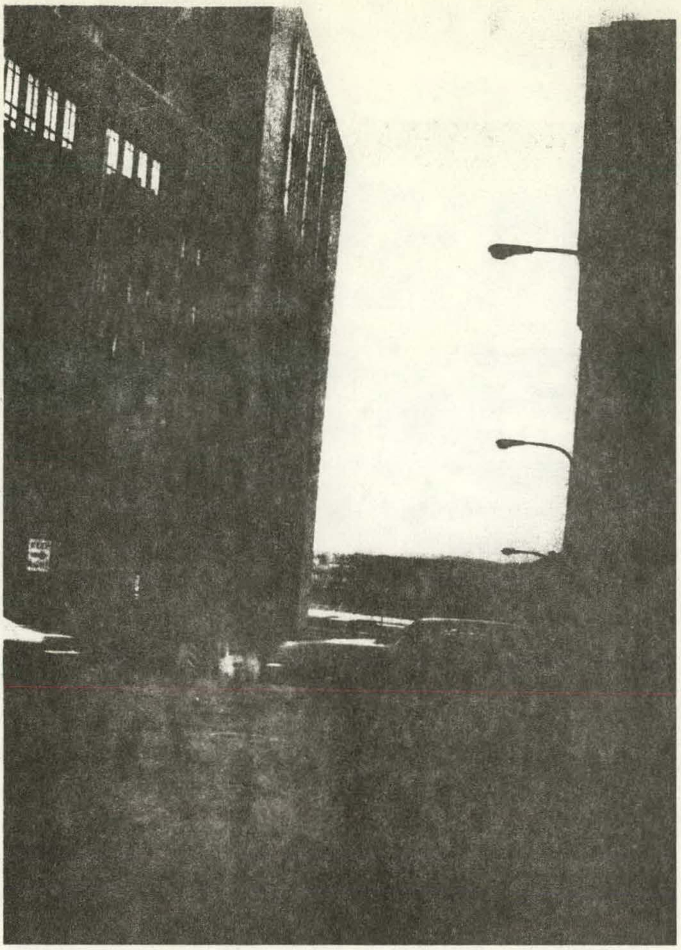
Identification Number	18	19	20	21	22	23	24	25	26
10. Dependence of the failure rate on the piping system age		none, age varies	none		could not be assessed in our system which is 14 years old	1924-1961=very little trouble; 1961 to date excess salt induced corrosion	no correlation with age on the frequency of the pipe deterioration	none	
11. Existence of an air gap between the insulation and the culvert or soil during the service life of the pipe		yes	none		no gap designed, nor constructed		yes		
12. External corrosion rate per year (in. per year)		not known			not known		no, except at some locations	no data	
13. Average length of the piping section replaced after failure (ft)		varies			25	from a few feet to 100 feet	100	no failure yet	
14. Average repair time per one failure (depending on pipe size) . Urban area		2 to 3 days on mains as a result of excavation and location time requirement	6 hours		5 days to locate leak in underground pipe	2 to 7 days in suburban area	the service interruption is always less than 12 hrs; none, if it only affects the condensate line, whose failure rate however is very frequent	none	
15. Average cost of the repair per failure per pipe size . Urban area		varies	$1,800		$7,000 in 1978		$7,100 the cost is independent of pipe size		
16. Maintenance cost per mile per year . Urban area		not available			$22,000 in 1978	$26,000 to $30,000 in suburban area	close to one percent per year of the cumulative investment	approximately $29,200	

EXHIBIT II
page 32

APPENDIX I

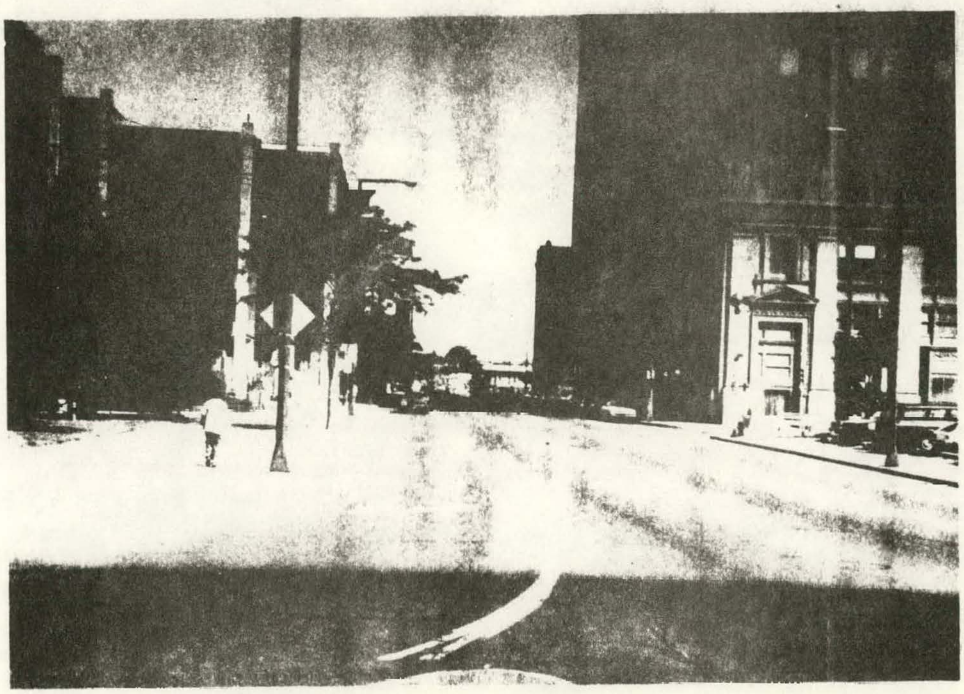
Proposed District Heating Pipeline
Location, Jackson Street
St. Paul, Minnesota

1.



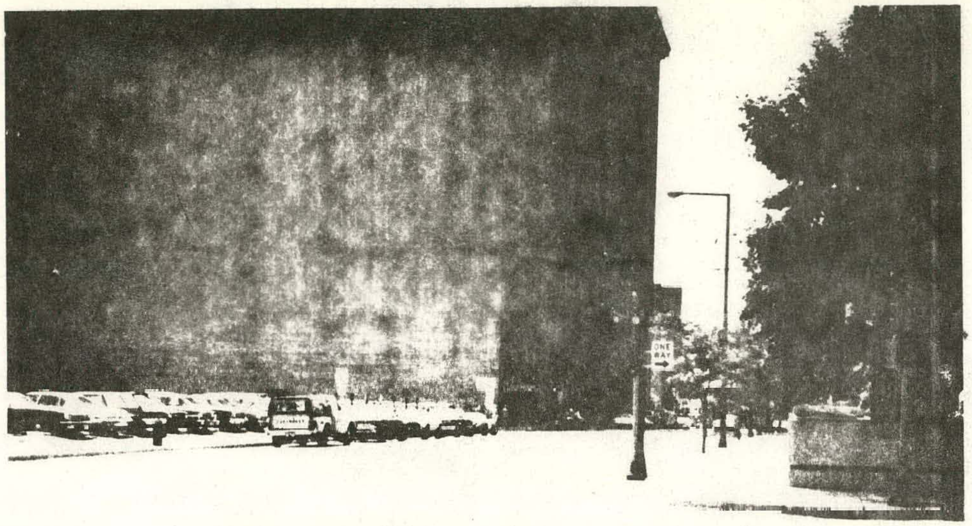
Kellogg and Jackson - looking South
(Post Office on Left, State Building on Right)

2.



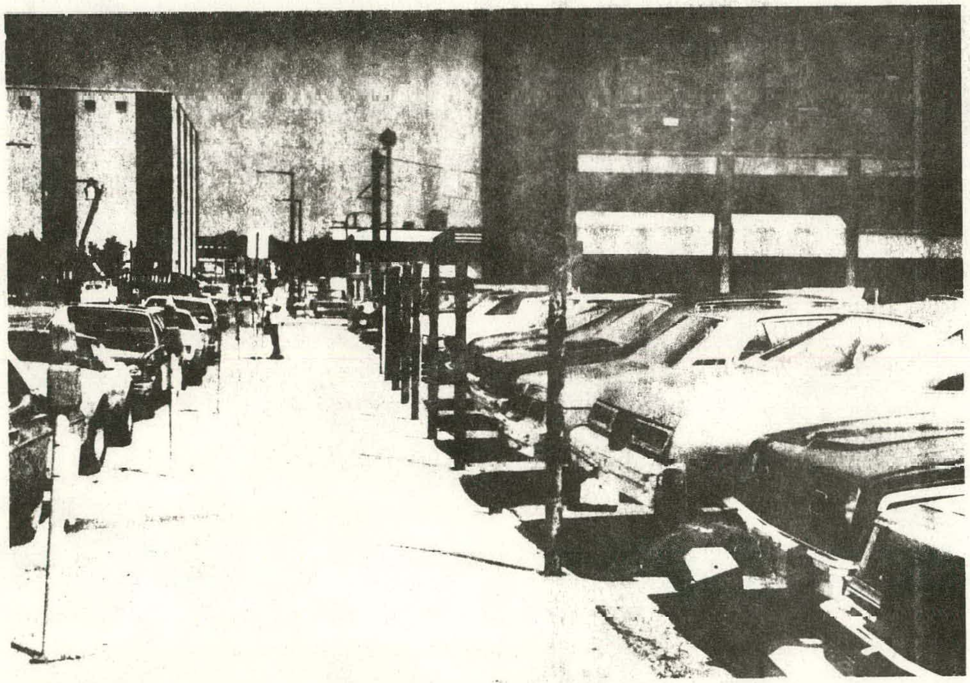
Kellogg and Jackson - looking North
(Federal Building on Left, Parking Lot on Right)

3.



Sixth and Jackson - looking South
(Note Parking Lot, Tavern and B.N. Office
on East Side of Street)

4.



Jackson Street looking North to Sixth
(Note New Apartments on East Side)

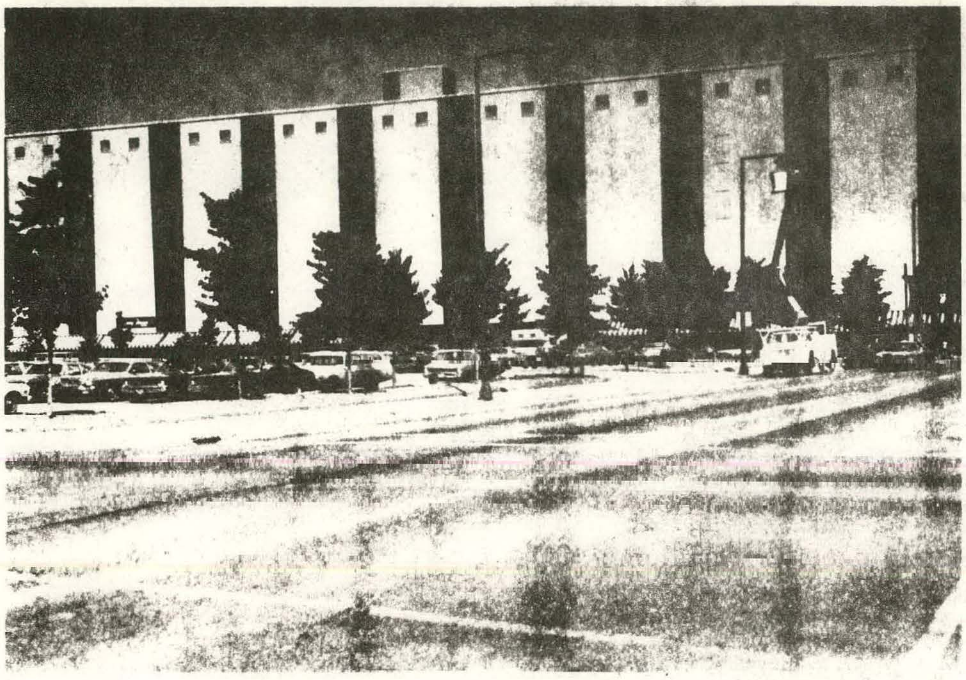
5.

Jackson Street looking South to Fifth

6.

Jackson Street and Sixth looking South

7.



Jackson and Sixth looking North

8.

Jackson and Seventh looking South

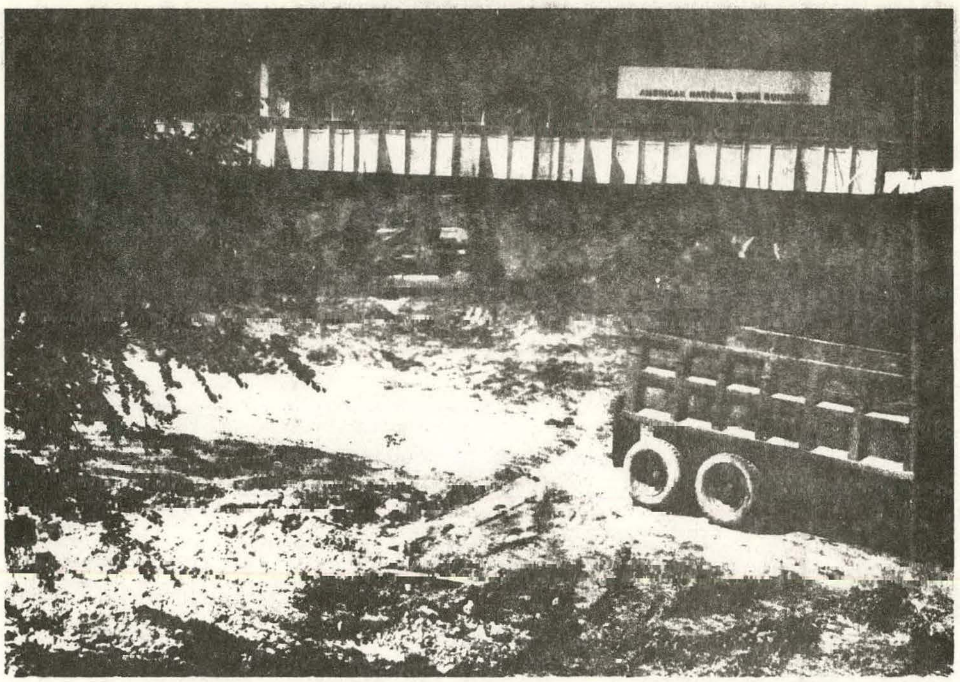
9.

Jackson Street and Seventh looking North
(Note Parking Lot on East Side)

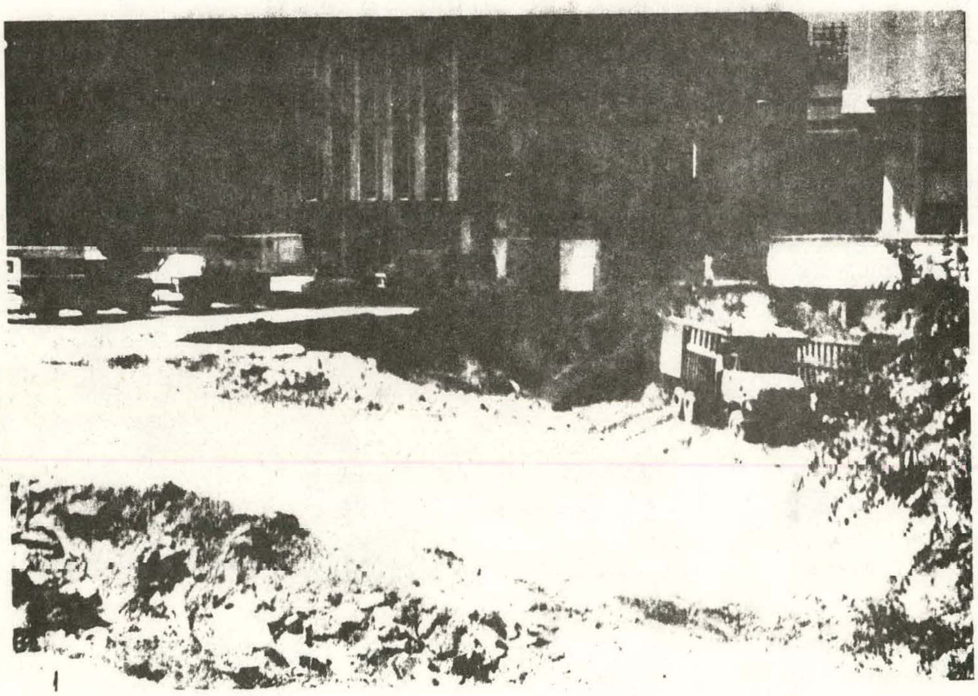
10.

Jackson Street and Seventh looking Northeast
toward Parking Lot

11.

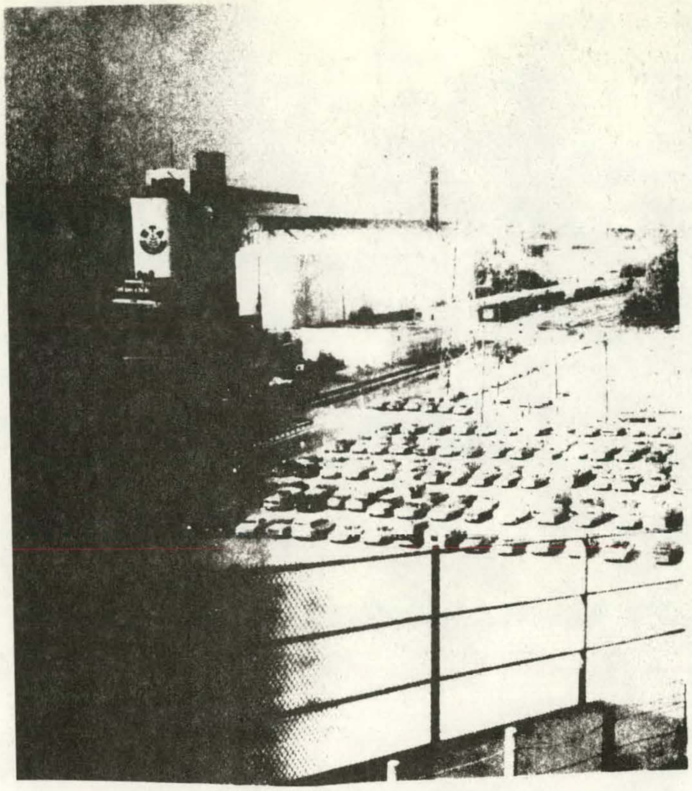


12.



Construction Site on Fifth between Jackson and Robert
(Note Soil Conditions)

13.

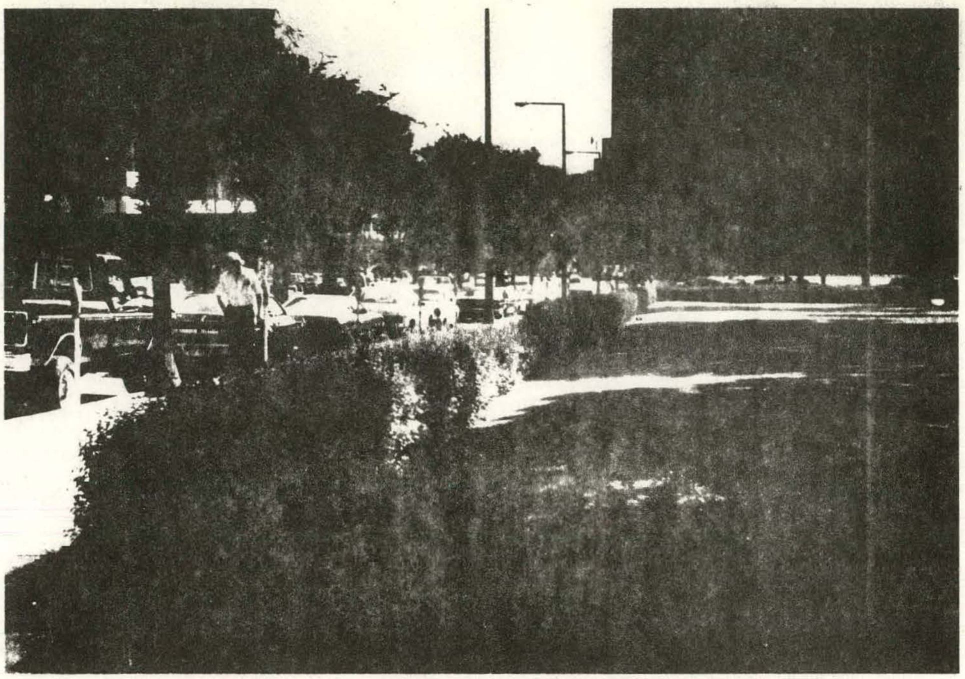


Third Street Station looking Southwest to
High Bridge Station
(Note High Voltage Line Row)

14.

Kellogg at Cedar looking West
toward Third Street Station

15.



Kellogg and Cedar looking East
(Note Post Office on Jackson - right center)