



Technical Report

ISO/TR 7035-2

Design and asset management of DIP for water application —

Part 2: Design, installation and operation

*Conception et gestion des actifs des tuyaux en fonte ductile pour
l'alimentation en eau potable —*

Partie 2: Conception, installation et exploitation

**First edition
2024-09**

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Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 5, *Ferrous metal pipes and metallic fittings*, Subcommittee SC 2, *Cast iron pipes, fittings and their joints*.

A list of all parts in the ISO/TR 7035 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

According to the World Health Organization, since 2010, the majority of the world's population lives in cities. By 2030, six out of every 10 people will live in cities and, by 2050, this proportion will have increased to seven out of 10 people. The water and wastewater infrastructure of distribution and collection pipes may have between 5 000 km and 10 000 km of underground piping for water distribution, and a similar network for wastewater collection, for a city of 100 000 to 500 000 people.

In introducing the practices or known acknowledges of this document due regard has been taken of the possibility to use ductile iron pipe easily and quickly, as well as the importance of a reliable and safe supply of water for human consumption and the purpose of trade, industry, agriculture and fire-fighting.

Renovation and repair of pipelines is usually complicated, administratively and technically. In many cases damage and service interruptions are created to other infrastructure networks (not knowing where these services run). Along with deterioration of roads and sidewalks the perceived image of the city worsens, increasing the great list of indirect costs, which is why the long lasting and reliable pipelines like ductile iron pipes (offering the best cost-effectiveness results), when taken all performances are into account by the asset management tools, explained in ISO/TR 7035-1.

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Design and asset management of DIP for water application —

Part 2: Design, installation and operation

1 Scope

The objective of this document is to assist conceptors, engineering offices, water companies or project owners in the design, installation and operation of the ductile iron pipeline systems for water supply:

- introduce practices for design, installation and operation of new ductile iron pipe water supply systems, rehabilitation or renovation;
- refers to existing standards that specify products' design, installation and site testing, materials and coatings.

This document gives efficient support to ISO/TR 7035-1 which indicates chapters here for readers' reference.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2531, *Ductile iron pipes, fittings, accessories and their joints for water applications*

ISO 16631, *Ductile iron pipes, fittings, accessories and their joints compatible with plastic (PVC or PE) piping systems, for water applications and for plastic pipeline connections, repair and replacement*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2531 and ISO 16631, and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

local main

water main which connects *principal main(s)* (3.2) with service pipes

3.2

principal main

water main serving as a principal distributor within the supply area, normally without direct consumer connections

3.3

service pipe

water pipe which supplies water from the *local main* (3.1) to the consumer

3.4

water distribution system

part of the water supply system comprising pipelines, service reservoirs, pumping stations and other assets by which water is distributed to the consumers

Note 1 to entry: Note to entry 1: It begins at the outlet from the water treatment works (or source, if there is no treatment) and ends at the point of connection to the consumer's installation.

3.5

carrier pipe

pipe inside a *casing* (3.6), which carries a product such as a gas or liquid

3.6

casing

metal pipe (as well as concrete pipe) used to protect the *carrier pipe* (3.5)

4 General

Due to its excellent characteristics, the designs and the applications of ductile iron pipe networks for potable water purpose are quite simple. High mechanical performance (i.e. the robustness) of ductile iron pipe systems allows energy saving from the reduced mechanisation required during the installation (no specialized equipment or on-site welding). Similarly, the need for the imported material for bed and surround is avoided or minimized, with the subsequent saving associated with the unnecessary use of natural resources and transport costs. Ductile iron pipes do not have the factor of time-dependent material creep deformation expressed as apparent stiffness as polymeric material pipes do.

Design processes normally start with the design/service objectives, which are related to the characteristics of the water supply systems in order to meet the targets outlined in [Clause 5](#) and the defined levels of service (see ISO/TR 7035 -1) over the range of operating conditions, having regards to all relevant economic considerations and environment and ecology consideration.

5 Practices to set targets for water supplying system

5.1 Water quality

5.1.1 Materials

Almost all the countries or areas have their rules to make all parts of water supply systems in contact with potable water to be designed and constructed by using components and materials which meet the national or area stands and regulations, such that there is no unacceptable deterioration on water quality. If that's not existing, a practical method is to refer to WHO's rules.

5.1.2 Prevention of back flow

Potable water supply systems are normally designed, equipped and installed to prevent the back flow. The air valves and washouts (with their operation and location) are usually used to avoid water entering the systems. In circumstances of particularly high risk of unacceptable deterioration of water quality, non-return valves would not be an effective method to prevent the back flow.

5.1.3 Stagnation

Potable water supply systems are principally designed installed and operated to minimize water stagnation (zones or points) which would lead to unacceptable deterioration of water quality.

The following arrangements are the main points or locations leading to stagnation:

- main with dead ends;

- branch with dead ends;
- spurs serving hydrants;
- un-isolated pipes laid in advance of development;
- sections with permanently low flow rates;
- enhanced pipe diameters required for fire-fighting or other non-permanent purposes.

In practice, facilities (for example, the level invert tees) are usually provided for main flushing.

5.1.4 Cross-connection with other systems

The interconnection of potable water supply systems is possible when the chemical and physical properties are compatible for blending and there is no unacceptable deterioration of water quality. Normally the potable water supply systems do not directly connect with the systems containing non-potable water, except a plan for the blending.

Closed valves or non-return valves, except for air valves, washout and hydrant, normally do not constitute an effective means of separation for the purpose of the design.

5.2 Design life

Design life follows the requests and needs from the end users or authorities. For ductile iron pipes (buried) a service life of 100 years is commonly recognized in usual conditions because of the excellent mechanical properties and good internally and externally anti-corrosion solutions. Normally the design life of ductile iron pipeline systems is at least 50 years or is based on local national building codes.

Some components such as pumps and certain metering and control equipment are usually replaced earlier based on the replace time from national regulations.

5.3 Demand for water

5.3.1 General

The total demand of water depends on the elements the pipe systems service for. That includes volume for resident, factories & plants, municipal use, firefighting. The leakage volume of the pipelines is practically taken into account also, that depends on the experienced data of leakage ratio.

5.3.2 Water demand estimate

The demand for water depends very much on local circumstances. The real measurement of consumption makes the estimate results accurate.

In the absence of detail flow measurements or historical data the average daily of demand is practically obtained by estimating the domestic consumption per person per day (the per capita allowance) and multiplying it by the number of persons to be supplied. Some local criteria (such as GB 50013) give quota data helping designing jobs.

Where no better information exists, the overall allowance is usually taken as being between 150 and 250 l per person per day depending on social and climate conditions excluding specific industrial demands. In some areas consumption is up to 450 l per person per day.

The demand normally covers other use e.g., street cleaning and supplies to premises such as schools and hospitals which, added to the per capita allowance, give the overall allowance.

Regarding the peak flow factors, where water use is estimated on an average day basis, suitable factors are usually applied to give estimates of the expected demand in the peak week, peak day or hour. If no better information available, the multiplying factor for the peak day usually varies from 1,5 for populations above

10 000, to over two times (the average day demand) for population below 2 000. The peak hour rate in any day ranges from twice the average hour rate in that day for over 10 000 people to more than 5 times the average for less than 2 000. Where consumer storage is provided, the peak hour flow factors is usually significantly lower than those experienced data above.

5.3.3 Water for fire-fighting

The potential demand for water for fire-fighting purposes to be provided by the water supply system is very large in relation with rules from authorities. In these circumstances the authorities responsible for fire-fighting usually incline to seek alternative sources of emergency supply.

5.4 System security

System security of water supply systems usually includes prevention of acts of vandalism, terrorism or other unlawful activity.

In general, the underground system will be secure, particular attention is given to above-ground pipework. Special designs are normally given to pumping station, service reservoirs and other above-ground structures, to deter unauthorized entry or interference with operation systems, as well as the possibility of contamination of potable water. Security fencing and monitoring systems are the practical ways for the places where risks are higher.

6 Design

6.1 Hydraulic design

6.1.1 Sizing

Mains and service ductile iron pipes are principally sized to meet the maximum specified flow rate having regard to the defined levels of service. Normally the capacity and flow requirements of the various system components depends much on the interaction of main, service reservoirs, pumping installations, optimum hydraulic and economic parameters like pumping cost and asset depreciation. In general, it is the local mains and principal mains used for direct supply which offer the capacity of sustaining peak flow rates or a subdivision thereof. Mains that supply reservoir is possible not to meet fully peak flow rates. National rules usually give the maximum and minimum flow rates. ISO 23991 also gives the experienced data.

In determining the capacity of a reservoir, a practical method is to take the balance between supply and demand into account. In addition, other aspects are usually considered as following (not limited):

- estimated time to repair burst main upstream;
- effect of pump or power failure;
- existence of alternative sources of supply;
- single or duplicate supply mains to storage;
- degree of telemetry monitoring;
- ratio of peak hour to average flow rate;
- demands with respect to water for industrial supplies, fire-fighting or other special circumstances.

6.1.2 Mains

6.1.2.1 General

Hydraulic calculations are the common jobs for designers to demonstrate that the system will

- satisfy the estimated demand,
- operate at acceptable velocity, and
- operate within the required pressure range.

The designed diameters to satisfy the flow requirements for the hydraulic gradient are calculated by widely known calculation methods as follow in this clause.

The inner diameter of the pipe has a major influence on the pressure loss and therefor on the pumping energy consumptions. The greater internal diameter of the ductile iron pipe in comparison to the equivalent nominal diameter provides better economic results.

6.1.2.2 Head loss

It's widely known that the total head loss of a pipeline is as following ([Formula 1](#)):

$$H_t = H_f + H_l \quad (1)$$

where

H_t is the total head loss, in meters;

H_f is the friction head loss, in meters;

H_l is the local head loss, in meters.

The H_f is calculated by different methods known as Hazen-William's formula, Darcy-Wisbach formula and Chezy formula. These formulae are well known by designers globally, and ISO 23991 gives some of them.

6.1.2.3 Local head loss

Local head loss mainly occurs at bends, tees, valves and other service connections, as well as the irregularities in the ductile iron pipeline profile. It is usually taken into account in two ways:

- using experimental results which demonstrate the head losses are approximately proportional to the square of flow velocity, as the [Formula 2](#) shows. Coefficients are available for various types of fittings;
- using an 'equivalent length' of straight pipe to give the same loss of head as the fittings. Some local criteria define k the hydraulic roughness to be 0,1 mm as a reasonable value for distribution mains instead of being 0,03 for straight ductile iron pipelines.

$$H_l = \sum \xi \times \frac{V^2}{2g} \quad (2)$$

Where

H_l is the local head loss in metres;

ξ is the coefficient for local head loss, which depends on the shape of fittings, flowing direction;

V is the flow velocity in metres per second;

g is the gravity acceleration in metres per square second.

Some experienced local head loss coefficients for different type fittings or points are available in published documents (such as *'Handbook of Hydraulic Calculation'*).

6.1.2.4 Flow velocities

Following aspects practically affect the acceptable flow velocities:

- stagnation;
- turbidity;
- pressure;
- surge;
- pumping facilities.

In practice, it is desirable to avoid unduly high or low velocities. The range from 0,5 m/s to 2,0 m/s is considered appropriate. For pumping mains, a financial appraisal is usually undertaken to determine the most economic diameter to minimize the capital and discount pumping cost. The resulting velocity normally lies in range of 0,8 m/s to 1,4 m/s.

6.1.3 Local main

Local mains are designed to meet estimated peak flow rates. That means the capacity of local main is adequate to convey additional flows for fire-fighting in accordance with national or local requirements.

6.1.4 Service pipes

6.1.4.1 Domestic consumers

The diameter of service pipes for domestic purpose is usually determined on the basis of the level of service requirements' including service pressure and flow rate. Head losses through all components including fittings and meters is normally taken into consideration.

6.1.4.2 Non domestic consumers

The service pipe diameter is determined on the basis of the requirements of the consumer as agreed with the water supplier.

6.1.4.3 Fire - fighting

The diameters of pipes for fire-fighting normally refer to the local regulations or rules from authorities.

6.2 Structural design

ISO 10803 gives the structural design of buried ductile iron pipelines.

6.3 System layout design

6.3.1 Mains

The layout of ductile iron mains depends much on the local circumstances. The consideration practically includes:

- reliability of supply;
- good access for maintenance;
- provision and location of line valves, air valves, washout and hydrants;

- adverse ground conditions and difficult terrain;
- risk of damage to and from plants/trees and their roots;
- corrosion protection systems in aggressive or contaminated soils;
- minimum gradient (minimum gradient normally is 1/500);
- crossing roads, rivers, railways, existing constructions;
- adoption of shortest practical route;
- location of other services, buildings and structures;
- telemetry, control and metering;
- all design pressures;
- earth loads and traffic loads;
- ease of operation;
- national and local planning, environmental protection;
- depth of frost penetration;
- risk of damage to and from utilities, works and apparatus;
- the minimum distance between existing/planned service, to follow the local criteria;
- minimum depth of cover for buried pipes;
- maximum depth of cover for ease of repair.

Whenever possible mains are normally located to allow easy vehicular access for repair and maintenance. Mains running parallel to or cross foul of combination sewers are normally located at higher levels. If this is not possible, adequate precautions are taken to preclude ingress of contaminated water to the main.

6.3.2 Service pipes

The location and depth of service pipes normally follows the same practice as for the mains.

The service pipes are normally planned to be as straight as possible following the shortest route from the local main to the buildings.

6.3.3 Valves

Valves including air valve, drain valve, isolation valve, hydrant and surging limitation equipment are integral components of a pipeline systems. ISO 21051 gives the detail instruction about layout and installation of them, some local criteria also offer similar information.

6.3.4 Reservoirs

Some reservoirs for example water towers are usually designed in the ductile iron pipeline systems. They are designed, constructed and tested to provide the required security to supplies, at same time not to make any unacceptable deterioration in the quality of the stored water.

6.3.5 Pump stations

Design of plant arrangements and pump duties for complex systems are usually based on detailed studies using simulation and optimization techniques. Control systems, actuated by pressure, flow, level or time, depend on local conditions and can be manual or fully automatic with telemetry monitoring. Safeguards are usually taken to incorporate in pump controls to stop units in the event of loss of suction pressure, or

unacceptable flow conditions. The major function of control systems is to ensure that unnecessary repeated stopping/starting or speed changes are prevented.

Practically, pumping units are designed to prevent the following conditions:

- cavitation;
- instability (abnormal fluctuation between different rates of flow);
- overloading (abnormal increase in power consumption).

6.4 Protection against aggressive environment

6.4.1 General

Ductile iron pipes are normally delivered externally and internally coated. These coatings (external) and linings (internal) make them to pass through in a wide range of external and internal environments. Evaluation of the different corrosion risks (corrosivity of the soil, stray currents, aggressive waters, etc.) into which the proposed pipeline to be installed is a major step to select the appropriate protection for the pipes.

6.4.2 External protection

Ductile iron pipeline systems are normally buried in contact with the majority of soils. Followings are the main factors to evaluate the aggressivity of external operating environments:

- resistivity;
- pH;
- water table level;
- stray currents;
- corrosion cells;
- soil contamination (industrial effluents, wastes, etc).

Metallic zinc-based coatings are suitable for the majority of the soils. Alternative coatings are available for highly corrosive soils or specific environments. Detailed lists of the different existing coatings, with their field of use, are given in ISO 2531, ISO 8179-1 and ISO 8179-2. Some local criteria (such as EN 545) also give similar indications.

Repairs to the pipe coatings at faults are usually specified by the designer in accordance with the product standards or ISO 21051, taking into account the manufacturer's instructions.

6.4.3 Internal protection

Ductile iron pipeline systems are used to convey a wide range of potable waters. The followings are main the factors to evaluate the aggressivity of potable waters:

- pH;
- sulfates;
- magnesium;
- ammonium;
- aggressive CO₂.

Cement linings according to ISO 4179 are suitable for the majorities of potable waters. Alternative linings for pipes or fittings are given in ISO 2531 and ISO 24131 series or local criteria (such as EN 545). An evaluation method of water aggressiveness and optimal choices for internal linings is given in ISO TR 4340.

7 Hydraulic thrust restraint design

7.1 Hydraulic thrust force and restraint principles

ISO 21052 gives details of hydraulic thrust forces and restraint principles. Practically there are two methods to restrain the thrust: blocks solution and restrained joints solution.

7.2 Thrust blocks solutions

Use of concrete thrust/anchor blocks is the most common applied technique for containing the hydraulic thrust of socket and spigot mains under pressure. But its use is now sharply decline.

Various type of concrete thrust/anchor blocks are designed for this solution, depending on the configuration of the main, the strength and type of soil, the presence or absence of ground water. The block contains the hydraulic thrust forces by friction on the soil or/and by bearing against the ground. In practice, thrust / anchor blocks are designed by taking into account both the friction forces and the soil reaction against their bearing surface. Bearing surface of concrete block is normally placed against undisturbed soil where possible.

Where it is not possible, the fill between the bearing surface and undisturbed soil is compacted to at least 90 % Standard Proctor density. Block height is usually designed to be equal to or less than one-half the total depth to the bottom of the block, and not less than the pipe diameter. The width of block is usually designed to be between one and two times the height of the block. The volume & dimensions of blocks can be calculated following national standards and/or the catalogues of ductile iron pipe suppliers.

[Figure 1](#) is the diagram of a thrust block combining with a bend.

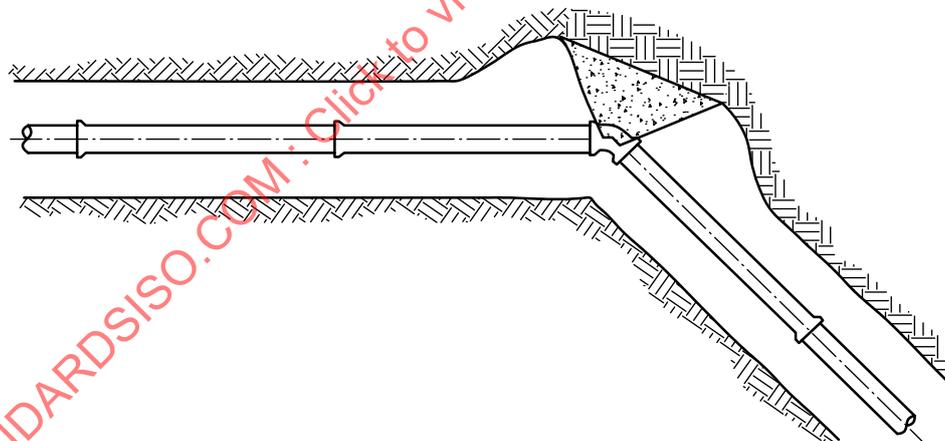


Figure 1 — Diagram of a thrust block combining with a bend

7.3 Restrained joints solution

7.3.1 General

Anchoring technologies (e.g., restrained joints or anchored joints) are increasingly taking the place of concrete anchor blocks which have some shortages including their weight and size. For example, the space demands on work sites for large diameter of pipelines, the time spent on trench opening and hardening, as well as the risk of long-term destabilization.

The utilization of restraint/anchoring joint is growing fast in most countries all over the world. These solutions offer significant advantages:

- limiting space requirement underground;
- reducing logistic constrains;
- quick installation and setting into service, no longer any need to wait for concrete to set;
- proven stability and durability.

7.3.2 Restrained joint systems

A restrained joint use means in it to prevent longitudinal separation of the assembled joint. Most of the restrained joints were developed from push-in flexible joints of ductile iron pipe, and still offer flexibility (e.g., angle deviation). A restrained joint mainly has two systems, sealing system by rubber gasket and locking system for restraint. The design rules and type testing of restrained joint system for ductile iron pipelines are defined in ISO 10804.

The object of the restrained joint system is to design a system to transmit the unbalanced forces to the surrounding soil without overstressing the pipe wall and without subjecting the pipeline to joints separation. Transmission the unbalanced forces principally relies upon the friction and passive resistance.

The technology is based on the principle of restrained joints over a sufficient length on both sides of a region of hydraulic thrust, such as a bend, in order to harness soil/pipe friction forces to counteract the thrust force. Seldom combination between restrained joints and thrust blocks or anchor blocks is used.

ISO 21052 gives the calculation processes and methods of the anchored length.

8 Design of trenchless method

Benefits from the technology breakthroughs (e.g., anchored joints, directional drilling, excellent protection layers, etc.), trenchless methods for ductile iron pipelines laying become popular. By its nature, ductile iron pipe possesses tremendous columnar and tensile strength, which makes it a superior material for trenchless applications. Followings are the main trenchless technologies for ductile iron pipelines which are introduced in ISO 13470:

- pipe jacking;
- horizontal direction drilling;
- casing method;
- pipe bursting

These types of ductile iron pipe laying are suitable for crossing under obstacle, rivers, motorways, railways or repair existing pipelines without recourse to open trenches and without disrupting the activity on the surface.

ISO 13470 defines the requirements of products and joints of ductile iron pipes and fittings, test methods and laying procedures.

The following subclauses introduce main job before the installation that's usually done by designers.

8.1 Pipe jacking

8.1.1 Survey

After the final route has been selected, the designer and the owner normally proceed a survey of the planned horizontal and vertical alignment, to provides plans and profile sheets that offer comprehensive details of the crossing, may including:

- site topography;
- existing utilities;
- right-of-way/easement;
- waterway, high/low;
- site size and access;
- street-traffic counts;
- boring locations;
- soil characteristic and underground water:
 - general properties of soil, e.g., density, grain diameter consistency;
 - properties concerning strength of soil, e.g., internal friction angle, cohesion;
 - properties about deformation of soil, e.g., coefficient of consolidation;
- water table.

Practically, the minimum depth for jacked ductile iron pipelines is bigger than 1,5 D (outside diameter of pipes) and 1,5 meters at least. For the project through a river, the depth is about more than 1,5 D and 2,5 meters at least.

Based on the survey, jobs such as calculation of jacking force, required strength of the thrust wall, countermeasures for underground water and ground improvement, selection of lead pipes will be made then by civil engineers.

8.1.2 Pipe protection

- Protection sheath

The ductile iron pipes used for pipe jacking are normally surrounded and protected by a sheath. The requests of the sheath are defined in ISO 13470.

- Lubrication

During the jacking processes, the increase of jacking force usually affects not only on thrust wall in launch shaft but also on ductile iron pipe body. In many cases, lubricant injection methods were applied in order to decrease the jacking force. Lubricant (normally the liquid with bentonite) was injected on the external surface of ductile iron pipes. And it's applied through grout holes which were provided on the pipe wall. Pipes with grout holes are normally produced in manufacturers' plants. After jacking processes finished, the grout hole will be sealed by a seal cap (e.g., a stainlessness steel plug).

8.1.3 Jacking procedure

Pipe jacking is considered to be unable to reconstruct generally.

Normally the jacking procedures include low and set the pipes, drill or cut the whole through which the pipes are to be jacked, start and control the lead pipe, joint assembling for ductile iron pipes, jacking, lubrication,

checking and pressure test. The more information of pushing methods is introduced in ISO 13470, or/and in some local criteria.

8.2 Horizontal directional drilling

8.2.1 General

The horizontal directional drilling technique (HDD) which is referred to below simply as the directional drilling technique, is the most widely used technique for installation small diameter pressure pipelines for water supply and for drainage application. This type of pipe laying is suitable for crossing under obstacles, rivers, motorways, railways, without recourse to an open trench without disrupting the activity on the surface.

The sequence of operations in the horizontal directional drilling technique is generally divide into 4 steps as following (not always):

- sub-soil survey;
- drilling a pilot bore
- upsizing the bore
- pulling in the assembled string of ductile iron pipes

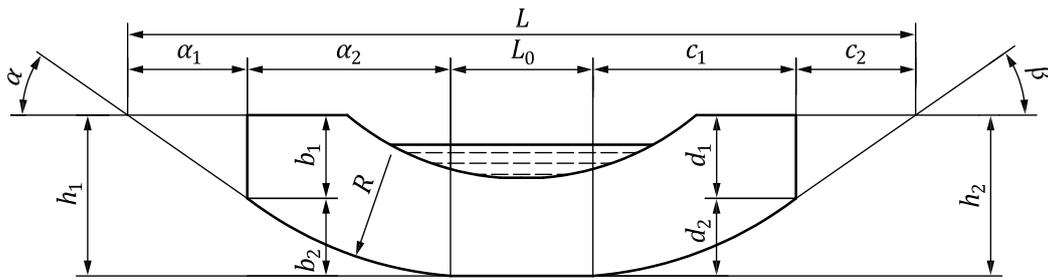
8.2.2 Site investigation

Normally for an HDD project, such as that associated with a river crossing, extensive and thorough surface and subsurface investigation is a crucial step. Qualified geotechnical engineers usually perform the work. The investigations include surface investigations and subsurface investigation. The performance normally follows the national standards and/or the catalogues of ductile iron pipe suppliers. Some local standards (like ASTM F1962-20) indicate the suitability of horizontal directional drilling with the characteristics of soil conditions and the depths.

8.2.3 Pilot bore design

The pilot bore path is principally designed and selected to place the ductile iron pipeline within stable ground and isolated from river activities (when crossing a river) based on the preliminary surface and subsurface investigation. The path is normally defined in an integrated reports summarizing the results of the surface and subsurface investigations.

The planned path is usually consistent with the required depth blow the obstacles, the steering capability of the drill string and the allowable radius of curvature from the steel drill rods and ductile iron pipelines (relate to single pipe length and the allowable deflection of joints, which manufacturers usually give in their catalogues). It's an integral step to double check the radius of curvature, R (see [Figure 2](#)), calculated from steel drill rod by the values from ductile iron pipes. The bigger value is practically selected as the final radius of curvature. The experience datum of steel drill rod's radius of curvature is about 1 200-1 500 D_{rod} , where D_{rod} is the nominal diameter of steel drill rod.

**Key**

- α pipe entry angle;
- β pipe exit angle;
- R radius of curvature.

Figure 2 — Typical profile of pilot bore

Normally the bore entry (pipe exit) point and entry angle β (see [figure 2](#)) are the crucial output of design works, consistent with the pipe route, equipment requirements and preliminary topographical investigation. Practically bore entry angle is in the range of 8 to 20° from the ground surface. For the bore exit (pipe entry) exit angle α (see [figure 2](#)), normally is less than 10°.

8.2.4 Upsize the bore

The pilot bore is practically enlarged by pulling back increasingly larger reamers, or reaming heads, from the pipe entry point. To achieve the appropriate bore path size, it's possible to perform several reaming operations.

The size and design of this step are mainly based on the soil conditions in each case and the dimension of the ductile iron pipe to be pulled through subsequently. The final diameter of the bore is approximately 1,2~1,5 times the largest outside diameter of the ductile iron pipe. May some local criteria also give the data of the size.

8.2.5 Pulling in

The analyses of operational and installation loads on pipe are important part of design output. The loads mainly include operational pressure loads, external hydraulic and earth loads, axial tensile stress, thermal stress. Due to the excellent mechanical properties of ductile iron material and flexible joint(retrained) characteristics, ductile iron pipe is the priority selection for horizontal directional drilling project. With the flexibility of restrained joints, ductile iron pipes deal with the thermal movement quite well during the service time.

a) Pulling force

The actual tensile force at the leading end of the ductile iron pipe varies during the operation and is, general, less than that experienced at the drill rig due to the additional load on the balance of the drill string still within the bore hole and that due to any simultaneous reaming operation. The tensile forces on the pipe result from the friction drag forces action on the sides of the pipe due to weight or buoyancy forces as it is pulled into and along the hole, and the force amplifications due to pulling the pipe around the curve. The resultant forces usually depend upon whether the pipe is empty or deliberately weighted to reduce the buoyancy.

The overall installation stresses due to the combination of loads which possibly present simultaneously is the major part of the final consider to designers. If the combined stresses are not within the desired overall design margin, a practical action is to select a thicker wall ductile iron pipe, or to modify the installation parameters to relieve the resultant stresses. Manufacturers of ductile iron pipe usually offer the calculation methods of pulling force in their catalogue as well as some local criteria do.

b) Bore path friction and pulling force capability

Case histories have given indications 'that pulling loads were less for ductile iron pipe than they typically were for similar size HDPE pipe. One reason for this is that the bulk density of empty ductile iron pipe is normally closer to that of the soil/fluid slurry than it is with lighter pipe materials. Therefore, there is very little normal force from gravity or buoyancy to result in increased friction against the walls of the bore hole as the pipe is pulled back.

In HDD installation, restrained joint of ductile iron pipe bells functionally to minimize friction of the bell in pulling through the bore hole. This allows the drilling fluid and excavated material to flow easily over the smooth contour of the bells.

HDD machines offer tremendous pulling forces, which are transmitted to pipes and their joints. Ductile iron pipe manufacturers have proprietary restrained joints to be used for HDD application with substantial strength. Requirements for this type joint of ductile iron pipe are given in ISO 13470.

8.2.6 Drilling fluid usage

Drilling fluid serves a critical role in HDD operations. The fluid provides lubrication during the pilot boring, reaming, and pullback operation to reduce the required torque or pullback loads. In addition, the drilling fluid stabilizes the bore hole, cools the drill head, and removes cuttings and spoils.

The drilling fluid usually consists of a mixture of fresh water and bentonite clay; other materials-such as polymers are sometimes used. Drilling fluid are characterized by their viscosity, gel strength, filtration, pH and lubricity. Local criteria or/and catalogue of suppliers usually give detail proportion of each ingredient.

The volume of drilling fluid is usually 3 to 5 times of the volume of the upsized bore. The crew are usually trained in the proper use of drilling fluids and the appropriate types for various ground conditions before the performance. Excessive drilling pressure or volumes usually result in greater disposal problems or appearance at undesired surface locations as the fluid penetrates through fissures.

8.3 Design of casing method

8.3.1 General

Water mains are frequently installed under highways and railroads. Because of its inherent toughness and high impact resistance, ductile iron is an excellent pipe material for this application. In many cases, ductile iron pipe eliminates the need for a protective steel or concrete casing pipe. However, existing conditions some time dictate the use of a casing and some local authorities including local highway departments and railroads continue to require casings.

8.3.2 Casing design

- a) Practically, the casing is designed as short in length as possible.
- b) Steel shells or concrete shells are the most popular casings to be used. They are designed strong enough to bear loads from soil and those from trucks or trains, as well as to meet the requests from local rules or authorities' instructions such as the anti-corrosion solutions, etc.
- c) The casing internal diameter is selected based on the nominal diameter of the carrier pipe, especially the external diameter of joint (socket face diameter, diameter of anchored joint with or without bolts), and the thickness of any extra abrasion resistant coating, such as concrete, or other materials. It's also based on the installation methods and the backfilling. The parameters of isolators/skids between carrier pipe and casing, the way to put ductile iron pipe into the casing are also factors to be considered by designers.
- d) For individual carrier pipeline with a nominal diameter of 200 mm or greater, the internal diameter of the casing is about minimum of 100 mm larger than that of the carrier ductile iron pipe (the lager value of its' joint, and extra abrasion resistant coating such as concrete). If installing parallel cable or conduits, the casing is about minimum 300 mm larger than that of the carrier pipes.

- e) For individual carrier pipeline with a nominal diameter less than 200 mm, the diameter of the casing is about minimum of 50 mm larger than that of carrier ductile iron pipe (the larger value of its joint and the extra abrasion resistance coating such as concrete).

8.3.3 Carrier design

The ductile iron pipes complying with ISO 2513 or ISO 16631 are frequently used as carrier pipe. The joints technologies depend on the methods to introduce ductile iron pipes into the casing pipe and how to connect with the existing pipelines. Restrained joints are used when pull the pipeline segments into the casing. Performance requests of the joints are defined in ISO 13470.

The carrier pipes are normally designed to be properly supported inside and outside the casing. Some local criteria may don't want metallic contact between carrier pipe and the case with steel shell. For these concerns, isolators or skids are designed as dielectric device. Though either push-on joint or mechanical joint has the ability to withstand vibrations, it's not to be designed for reciprocating that possibly be caused by unstable pressure or air stagnant in pipelines during the service terms. To find the solutions of fixing ductile iron pipelines in casing, either by backfill materials, or by suitable dimensions of isolators and spacers is one of the main jobs for designers.

8.3.4 Installation

ISO 13470 gives the installation procedures of casing pipe and carrier pipe (as well as service pipe).

8.4 Pipe bursting

8.4.1 General

Pipe bursting is used for the trenchless replacement of pipelines along the same route. In the processes, the existing old pipeline is destroyed by means of bursting head while simultaneously being pushed into the surrounding soil by an upsizing element and the new ductile iron pipe string is drawn in. The old pipe materials remain in the ground, that inclines to make some harmfulness on new pipes (point loading and destruction on coating). ISO 13470 gives detail technical descriptions including static variant and dynamic variant processes.

8.4.2 Parameters

a) Ground conditions

For most soil conditions, parameters including the potential effect of the ground movement and vibration on adjacent utilities and structures, and how to provide the required power to affect the burst, to displace the soil and to pull the replacement pipe in over the length of the burst are the main contents for designers to consider. The most favourable ground conditions for pipe bursting projects are where the ground surrounding the pipeline suitable to be compacted readily by the bursting operation as it is displaced. That intends to limit the outward ground displacement to a zone close to the pipe alignment. Less favourable ground conditions for pipe bursting involve densely compacted soils and backfills, soils below the water table and dilatant soil. Special soils such as highly expansive soils or collapsible soils usually cause problems.

In some ground conditions, problems time to time to be happened by the wrong selection of the pipe bursting system. For example, sands and crawfish type soil below groundwater table intend to cause a problem for pneumatic pipe bursting, and static pipe bursting usually to be a choice to eliminate this problem.

When the soil provides a high friction drag on the pipe and the length of run is long enough to generate high tensile forces on the replacement ductile iron pipe, bentonite or polymer lubrication muds are practically used and injected into the annular space behind the bursting head to help keep the hole open and to reduce the frictional drag on the replacement ductile iron pipe.

The base soil is another important concern to designers. That gives the fair and consistent support to the weight of the pipe bursting unit and the product pipe along the length of the pipeline.

b) Groundwater conditions

Pipe bursting below the groundwater table intends to increase the difficulty of bursting operations. Bursting in the saturated soil usually causes the water pressure to rise around the bursting head. The rise in water pressure causes the effective stress in the soil to drop and may cause the soil to behave more like a viscous fluid. In certain soil conditions, groundwater has a buoyant and lubrication effect on the bursting operation. During pipe bursting, insertion and receiving pits are normally preferably kept dry. Sometimes, if the groundwater is removed to a large degree (e.g. by well pointing), consolidation/densification of the soil surrounding the existing pipe possibly result, significantly increasing bursting forces.

c) Host pipe

Most brittle pipe materials make good candidates for pipe bursting. That may include:

- clay pipes are the good candidates for bursting. The fragments of clay pipe are likely to be sharp and there are some levels of concerns about the gouging or scoring of the replacement pipe and eventual point loading on the replacement pipe.
- plain concrete pipes are good candidates for bursting. But the thick plain concrete or reinforced encasements or repair (by metal components) to the pipe possibly cause difficulty in bursting.
- cast iron pipes are good candidates for bursting. The fragments of cast iron pipe are likely to be sharp and there are some levels of concerns about the gouging or scoring of the replacement pipe and eventual point loading on the replacement pipe. Ductile repair clamps, service saddles and fittings possibly cause problems for the bursting operation and hardened cutting blades possibly are incorporated to cut through such clamps.

Ductile pipes possibly are scored and then slit as in the pipe splitting operations. That may include:

- steel and ductile iron pipes are not good candidates for pipe bursting. In smaller diameters, they are possibly replaced by using pipe splitting techniques.
- PVC and other plastic pipes are usually replaced by using an appropriate combination of bursting and splitting techniques according to the strength and ductility of the pipe.

Pipes made of non-ductile abrasive material but with ductile reinforcing are the most difficult to replace using most pipe replacement techniques. That possibly includes:

- reinforced concrete pipes present difficulty unless the concrete and reinforcing steel is deteriorated. They are possibly burst with powerful enough equipment. Careful evaluations are usually made if the pipes are more than lightly reinforced and are not significantly deteriorated.
- asbestos cement pipes are generally good candidates for bursting. Thicker, higher tensile strength pipes tend to 'ball up', increasing required bursting forces. Combination of standard bursting heads and cutter blades is usually applied.

d) Surrounding utilities

Surrounding utilities time to time affect the location of insertion and reception pits. Utilities that interfere with or likely to be damaged by the burst are usually located and exposed prior to the burst. For typical pipe bursting operations, underground utilities in moderate condition are unlikely to be damaged by vibration at distance of greater than about 760 mm from the bursting head and ground displacements are unlikely to cause problems at distance greater than 2-3 diameters from the pipe alignment.

e) Upsizing

The selection of bursting machine is normally based on the host pipe diameter and the required upsize of the new pipe. To date, upsizing by up to 30 % of the original pipe diameter is common. Some documents

show to enlarge the nominal size by up to three stages is possible. Greater upsizing has been successfully completed in many projects.

f) Ground displacement

Normally each bursting step is associated with ground displacement. The ground displacements depend primarily on degree of upsizing, type and compaction level of the existing soil around the pipe and the depth of bursting.

In a relatively homogeneous soil with no close rigid boundaries, the displacements are likely to be directed upwards at small depth (shallow pipe). While at increased depths they are expected to have more uniform direction. In relatively loose soils and for small diameter pipes, a uniform expansion is expected at a depth of 610 mm, whereas in relatively dense soil the expansion at this depth would still be predominately upwards.

The soil conditions in a trench are usually non-homogeneous. The backfill material is often weaker than the original surrounding soil and the displacements are likely to be mostly confined within the existing trench.

Whether the surface will heave or settle depends on combination of many factors. If the existing soil is loose sand or relatively new trench backfill which is still settling, the bursting process likely act to further settle the existing soil. Otherwise, if the soil is well compacted and the pipe not very deep, the bursting process is likely to create a surface heave, especially when significantly upsizing the existing pipe.

8.4.3 Replacement pipe

Critical parameters are practically taken into consideration when select replacement pipes. That includes the pressure class, diameter, restraint technique, internal lining, external coating that may face the sharp fragment from the old pipe, pulling strength and so on. Because of its excellent mechanical properties, joint design and optional protection methods, ductile iron pipe is the ideal replacement pipe for projects.

9 Design of pipelines on supports

9.1 Pipelines on land

In some situations, it is desirable to use supports at designated intervals along ductile iron pipelines. Aboveground, supported pipe is designed to transport water and other fluid within treatment plants and buildings. Also, pipe on piers is utilized to cross natural or man-made objects. Bridge-crossing installations, which are not specifically addressed, may have special attention to their unique situations.

Sometimes, pipes are installed on piers or pilings underground when facing the unstable soil conditions or other factors. And that condition is not covered in this technical report.

The common joints used with ductile iron pipe are the push-on joints and the mechanical joints. Both of these rubber-gasketed joints allow a certain amount of deflection and longitudinal displacement while maintaining their hydrostatic seal. This makes these joints ideally suited for normal underground installation. The flexibility of the joints reduces the chance of excessive beam stresses occurring. Practically, at least one support is designed and placed under each length of ductile iron pipe with flexible joint for stability. So, the designs presented in this technical report is based on one support per length of a pipe.

9.1.1 Support design

Pipe supports are practically designed to cradle the pipe in a saddle. ISO 21051 demonstrates some charts for reference. This type of cradle, which will follow the contour of the pipe, minimizes stress concentrations at the supports. ISO 2531 and ISO 16631 give the detail external diameters of the ductile iron pipe. Normally the saddle angle of the support is between 90° and 120°. Little or no benefit is gained by increasing the saddle angle more than 120°. With angles smaller than 90°, the maximum stress tends to increase rapidly with decreasing saddle angle.

Some test data show a decrease in measured stresses with an increase in saddle width. There is little effect on the maximum stress when saddle support width is increased more than the value calculated by [Formula 3](#) as following. Practically that's the minimum width to be considered by designer.

$$b = \sqrt{2DE \cdot e} \quad (3)$$

Where

- b is minimum (axial) saddle width, in mm;
- DE is actual external diameter of the ductile iron pipe, in mm;
- e is nominal pipe wall thickness, in mm.

Supports, piles, piers are designed adequately from a structural and soil-engineering stand point to safely handle any loads transferred from the pipe. Supports are normally constructed accurately aligned with capacity of carrying the designed load and cradling the pipe over at least 90°.

9.1.2 Loading and forces

Supports are practically designed with a minimum of lateral and vertical stability for aboveground pipeline. Deflected pipe joints usually result in thrust forces of hydrostatic or hydrodynamic origin (see [6.1.2](#) to get the calculation methods). And if not laterally and vertically restrained, unbalanced forces possibly result in additional joint deflection and possible failure of the pipeline.

For aboveground, the total load transferred from the pipe includes the weight of the pipe and contents. If the designer expects greater loads (snow, wind, sleet...) to occur, she/he normally incorporates these loads into the design and that is not in the scope of this technical report.

9.2 Other cases of supporting pipe

For the installation about river cross, and in hilly terrain, ISO 21051 gives detail information.

10 Installation and hydrostatic test

10.1 Installation

Installation and assembling ductile iron pipes are very simple due to the pipes' mechanical properties, anti-corrosion solutions and push-in joint design which allows simple action to finish the assembly.

Installation of ductile iron pipelines is a systemic job that usually includes pipeline components transport, handling, input control, storage, site preparation and trench, necessary pipeline protection, pipe laying, joints assembling, thrust block construction, when necessary, vales installation, cleaning, hydraulic test and backfill. ISO 21051 gives relative requests about these processes.

10.2 Hydrostatic test

10.2.1 General

Ductile iron pipeline systems are made up of many different components and jointing solutions to deliver a reliable service under the worst situations (high pressure variations, earthquakes, etc.) hence the secure hydrostatic pressure test is designed and performed after having taken into account possible movements of the components.

The purpose of a water pressure test on every pipeline which has been constructed is to check the integrity of pipes, joints, fittings and other components such as anchor blocks.