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Life cycle analysis and recycling of ductile iron pipes for water applications

Coût du cycle de vie et recyclage des tuyaux en fonte ductile pour l'eau

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Foreword

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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*.

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.

Life cycle analysis and recycling of ductile iron pipes for water applications

1 Scope

This document specifies the evaluation method of life cycle analysis of ductile iron pipes used for water applications as specified in ISO 2531 and ISO 16631.

Studies on economic and environmental impacts are important for utility decision-makers as they seek to balance budget concerns over immediate and long-term needs across acquisition, operations and maintenance, and planned end of life. For authorities and engineers designing pipeline systems, the life cycle cost analysis serves as a tool to study various scenarios to determine the right solution for site-specific conditions and community values, as well as to provide the necessary data to support those decisions.

Informative annexes are included in this document as a compilation of reference and consensual factors (pumping cost, leakage incident rate, etc.).

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*

3 Terms and definitions

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

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
life cycle cost
LCC
cost of an asset throughout its life cycle, while fulfilling the performance requirements

3.2
acquisition cost
all costs included in acquiring an asset by purchase/lease or construction procurement route, excluding costs during the occupation and use or end-of-life phases of the life cycle of the constructed asset

[SOURCE: ISO 15686-5:2017, 3.1.1]

3.3
operation cost
total running costs for water conveyance, including the pumping cost

Note 1 to entry: Operation costs could include rent, rates, insurances, energy and other environmental/regulatory inspection.

3.4
maintenance cost
total labour, material and other related costs incurred to maintain pipelines

3.5
end of life cost or revenue
total of costs or fee for disposing of an asset at the end of its *service life* (3.7) or interest period, including costs resulting from pipeline dismantling, waste disposal and revenue from material recovery

3.6
period of analysis
period of time over which *life cycle costs* (3.1) or whole-life costs are analysed

Note 1 to entry: The period of analysis is determined by the client.

[SOURCE: ISO 15686-5:2017, 3.3.6, modified — "life-cycle" has been replaced with "life cycle".]

3.7
service life
total life of pipelines in use from the point of construction to the end of life

3.8
residual value
value assigned to an asset at the end of the *period of analysis* (3.6)

[SOURCE: ISO 15686-5:2017, 3.3.8]

3.9
discount rate
factor or rate reflecting the time value of money that is used to convert cash flows occurring at different times to a common time

Note 1 to entry: This can be used to convert future values to present-day values and vice versa.

[SOURCE: ISO 15686-5:2017, 3.3.1]

3.10
leakage incident rate
number of pipe bodies' damages or water leak per unit length of pipeline

3.11
nominal diameter
DN
alphanumeric designation of size for components of a pipework system, which is used for reference purposes

[SOURCE: ISO 2531:2009, 3.20, modified — The term has been changed from "nominal size" to "nominal diameter"; Notes 1 and 2 to entry have been removed.]

4 Basic concept of life cycle cost

4.1 Definition of life cycle cost

The life cycle cost is calculated using Formula (1) as a sum of not only the acquisition cost but also total costs including the operation cost such as the electric power usage cost of the pump operation, the maintenance cost such as the leakage cost, and the end of life cost or revenue. Annex B shows scenarios of LCC with two different pipelines.

$$C_L = C_A + C_O + C_M + C_E \quad (1)$$

C_L is the life cycle cost;

C_A is the acquisition cost; it includes the pipe material cost, construction cost and designing/survey cost;

C_O is the operation cost; it includes the pumping cost;

C_M is the maintenance cost; it includes the leakage cost, repair cost, etc.;

C_E is the end of life cost or revenue; it includes the disposal cost and benefit of recycling.

4.2 Calculation method

The life cycle cost is calculated using Formula (2) to (4) by totalizing all the costs in a period of analysis. Cost in the future is converted into a current value using a discount rate. In a case where the evaluation period is not just the same as multiples of the service life, the residual value is deducted from the life cycle cost.

Case 1 $t_n < t_m$

$$C_L = C_A + \sum_{t=1}^{t_n} \left(\frac{C_{O,t} + C_{M,t}}{(1+r)^t} \right) - \frac{C_A \times (t_m - t_n)/t_m}{(1+r)^{t_n}} \quad (2)$$

Case 2 $t_n = t_m$

$$C_L = C_A + \sum_{t=1}^{t_m} \left(\frac{C_{O,t} + C_{M,t}}{(1+r)^t} \right) + \frac{C_E}{(1+r)^{t_m}} \quad (3)$$

Case 3 $t_m < t_n < 2 \times t_m$

$$C_L = C_A + \frac{C_A}{(1+r)^{t_m}} + \sum_{t=1}^{t_n} \left(\frac{C_{O,t} + C_{M,t}}{(1+r)^t} \right) + \frac{C_E}{(1+r)^{t_m}} - \frac{C_A \times (2 \times t_m - t_n)/t_m}{(1+r)^{t_n}} \quad (4)$$

where

C_L is the life cycle cost;

t is the time in year;

t_n is the period of analysis;

t_m is the service life;

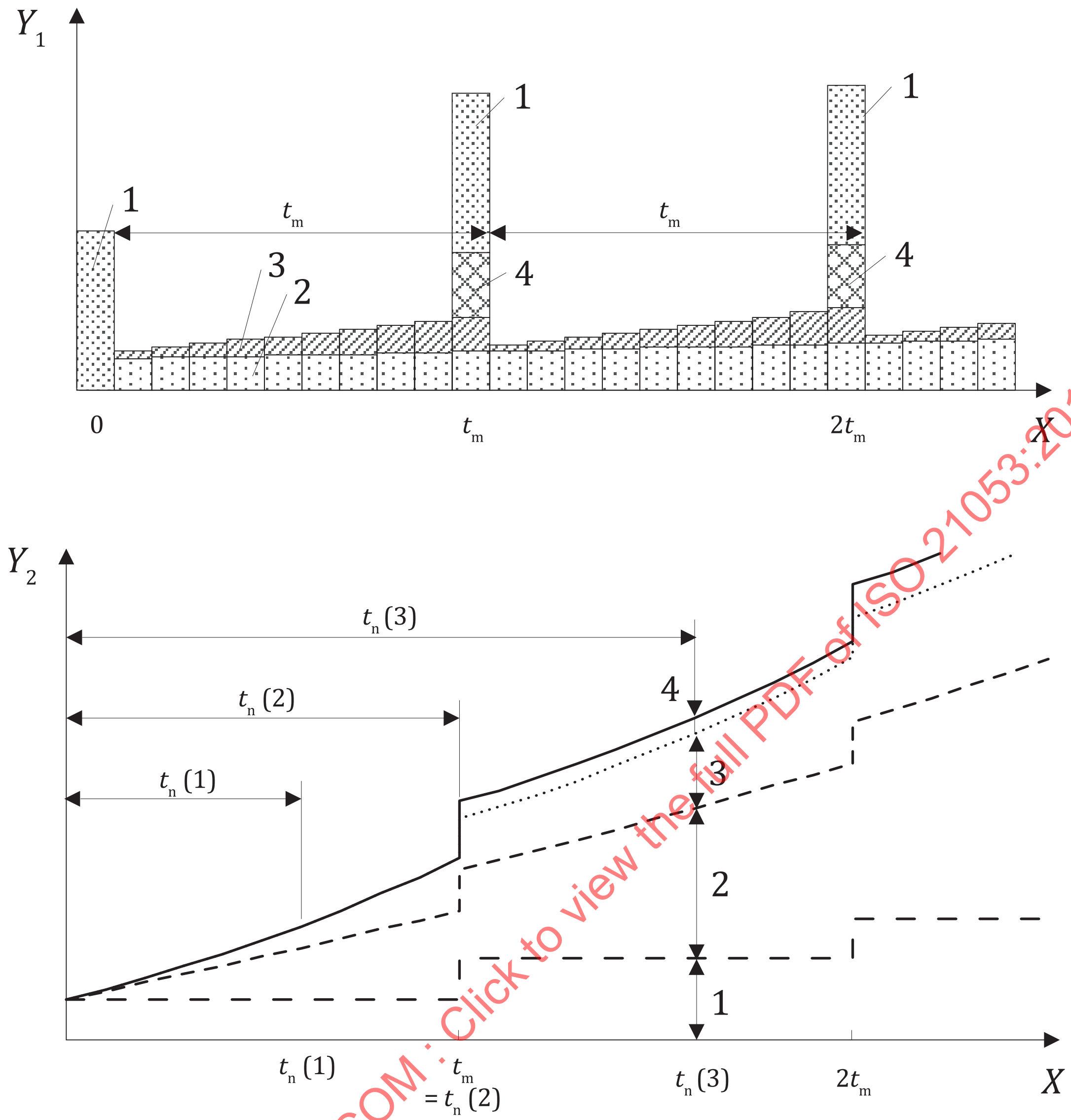
C_A is the acquisition cost;

$C_{O,t}$ is the operation cost in the t^{th} year;

$C_{M,t}$ is the maintenance cost in the t^{th} year;

C_E is the end of life cost or revenue;

r is the discount rate.



Key

1 acquisition cost
2 operation cost
3 maintenance cost
4 end of life cost or revenue
X time in year
Y_1 cost
Y_2 LCC

Figure 1 — Image of life cycle cost

5 Breakdown of life cycle cost

5.1 Acquisition cost

The acquisition cost is calculated using Formula (5) as a total of the pipe material cost, construction cost, and designing/survey cost.

$$C_A = A_P + A_C + A_D \tag{5}$$

where

C_A is the acquisition cost;

A_P is the pipe material cost;

A_C is the construction cost (pipe laying cost, trenching cost, backfilling cost etc.);

A_D is the designing/survey cost (all the studies useful for the project).

5.2 Operation cost

The yearly operation cost is calculated using Formula (6) as the pumping cost such as the electric power usage cost of the pump operation. Details of the computation about the pumping cost are shown in Annex A.

$$C_{O,t} = O_{P,t} \tag{6}$$

where

$C_{O,t}$ is the operation cost in the t^{th} year;

$O_{P,t}$ is the pumping cost in the t^{th} year.

5.3 Maintenance cost

The yearly maintenance cost is calculated using Formula (7) as a total of the leakage cost, leak detection cost, repair cost, and others maintenance cost.

$$C_{M,t} = M_{L,t} + M_{D,t} + M_{R,t} + M_{O,t} \tag{7}$$

where

$C_{M,t}$ is the maintenance cost in the t^{th} year;

$M_{L,t}$ is the leakage cost (cost of water losses) in the t^{th} year;

$M_{D,t}$ is the leak detection cost in the t^{th} year;

$M_{R,t}$ is the repair cost in the t^{th} year;

$M_{O,t}$ is other maintenance cost in the t^{th} year.

The yearly leakage cost is calculated using Formula (8) as a total of water loss costs due to leakage and pipeline cleaning during damage.

$$M_{L,t} = D_R \times P_L \times (L_V + V_C) \times U_P \tag{8}$$

where

D_R is the damage ratio, in incident numbers per kilometre per year;

P_L is the total pipeline length, in km;

L_V is the water leakage volume, in cubic metres per incident;

V_C is the water volume for cleaning, in cubic metres per incident;

U_P is the unit price of water supply, in currency per cubic metre.

5.4 End of life cost or revenue

The end of life cost or revenue is calculated using Formula (9) as a total of the pipeline dismantling cost and the waste disposal cost, deducting the revenue from material recovery.

$$C_E = E_P + E_W - E_R \tag{9}$$

where

C_E is the end of life cost or revenue;

E_P is the pipeline dismantling cost;

E_W is the waste disposal cost;

E_R is the revenue from material recovery.

Material recovery is considered to be applicable only to ductile iron pipes.

6 Key drivers for life cycle cost reduction

The following key drivers can be highlighted:

— **Leakage:** Strong material properties and flexibility of joints contribute to prevent the leakage incident on buried ductile iron pipes. Annex C proposes examples of statistical values of incident rate per kilometre.

— **Durability:** A service life of 100 years is commonly recognized for ductile iron pipes buried in usual conditions. However, the service life can be reduced or increased considering the nature of the pipe coating and the local soil conditions.

— **Conveyance capacity:** For a given nominal diameter, ductile iron pipes are duly designed with a larger internal diameter in order to reduce the head loss on energy pumping and the operation cost such as the electric power usage cost. Annex A shows that the internal diameter is a more influent factor on the head loss than the surface roughness coefficient.

— **Recyclability:** Excavated iron pipes can be reused as a raw material to manufacture new ductile iron pipes. Benefits of lower-cost production can be expected in a case where natural resources are used, allowing the disposal cost to be reduced.

The development of new methods of laying (re-use of excavated soils for backfilling, narrow trench, etc.) can also contribute to reducing the construction cost.

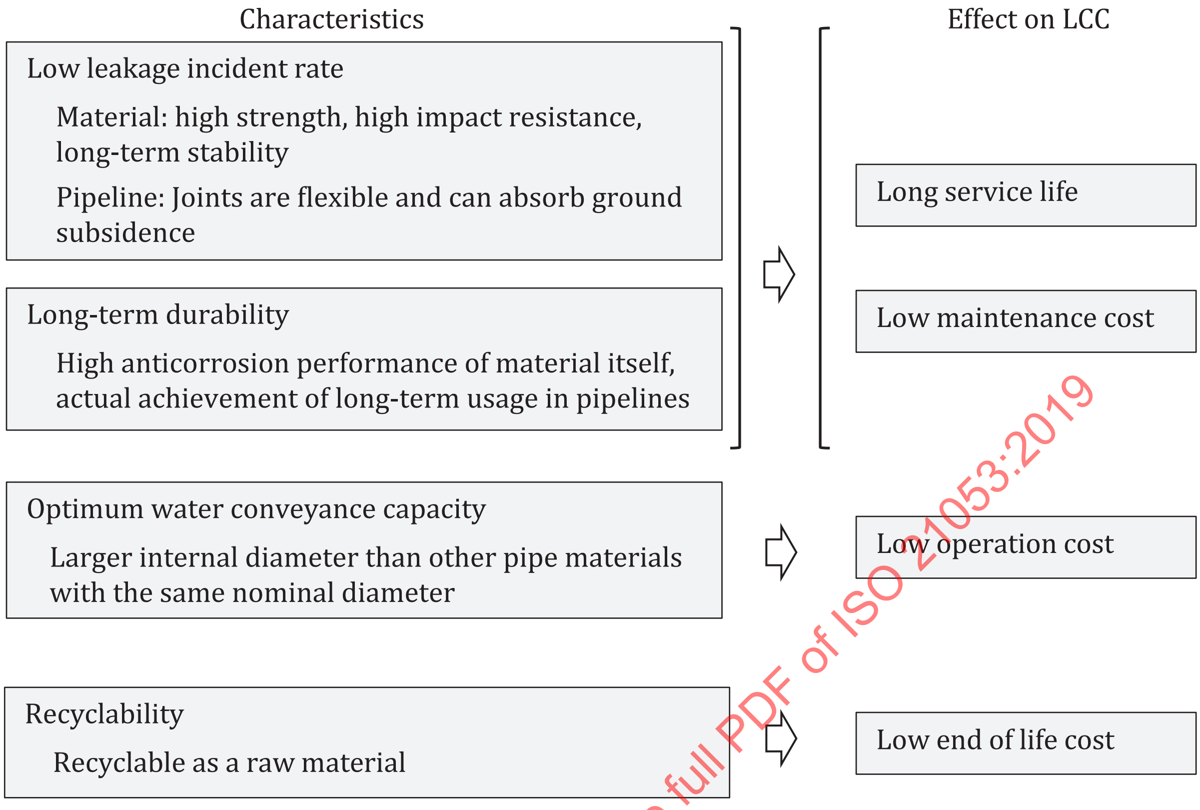


Figure 2 — Key drivers for LCC reduction

Annex A
(informative)

Pumping cost

A.1 Pumping cost

Pumping costs increase with the electricity price and pipe aging (dependent on pipe service life). The pumping cost is calculated using Formula (A.1).

$$O_{P,t} = (E \times 365{,}25 \times Y_e) \times (1 + y_e)^t \quad \text{(A.1)}$$

where

$O_{P,t}$ is the pumping cost in the t^{th} year;

E is the daily pumping energy, in kilowatt hours per day;

Y_e is the price of electricity, in currency per kilowatt hour;

y_e is the pumping energy increase, in percentages per year;

t is the time in year.

A.2 Daily pumping energy

The energy daily required for pumping is calculated using Formula (A.2).

$$E = \frac{\gamma \times Q \times H}{h_{eff} \times e_{eff}} \times d \quad \text{(A.2)}$$

where

γ is the unit weight of pumping liquid, in kN/m^3, defined as γ=9,81;

Q is the flow rate, in m^3/s;

H is the total head, in m;

h_{eff} is the hydraulic efficiency (set as default 70 %);

e_{eff} is the electricity efficiency (set as default 70 %);

d is the daily pumping duration, in hours per day.

A.3 Total head (H)

The required pump head, called total head, is calculated using Formula (A.3).

$$H = H_a + H_t + \frac{V_d^2}{2 \times g} + \frac{1\,000 \times (P_d - P_s)}{\gamma} \quad \text{(A.3)}$$

where

H_a is the actual head, in m;

H_t is the total head loss, in m;

V_d is the flow velocity, in m/s;

g is the gravitational acceleration, in m/s^2, defined as g = 9,81;

P_d is the pressure exerted on the discharge water surface, in MPa;

P_s is the pressure exerted on the suction water surface, in MPa.

The total head loss is calculated using Formula (A.4). The head loss is the hydraulic energy loss essentially caused by the water viscosity and its friction against the pipe walls. The effect is an increase in the energy consumption in a pipeline.

The Darcy formula is the general formula for the calculation of the friction head loss of the pipeline H_p.

$$H_t = H_p + H_o = j \times L + H_o = \frac{8 \times \lambda \times Q^2}{\pi^2 \times g \times I_D{}^5} \times L + H_o \quad (A.4)$$

where

H_p is the friction head loss of the pipeline, in m;

H_o is the head loss of the pipeline except for friction head loss, such as due to bend, valve, flowing into pipe, etc., in m;

j is the hydraulic gradient, in m/m;

L is the pipeline length, in m;

λ is the head loss coefficient determined using the Colebrook-White formula (dimensionless);

Q is the flow rate, in m^3/s;

I_D is the internal pipe diameter, in m.

The internal diameter is a more influent factor on the head loss than the head loss coefficient λ.

The Colebrook-White formula [see Formulae (A.5) and (A.6)] is used for determining the head loss coefficient λ.

$$\frac{1}{\sqrt{\lambda}} = -2 \times \log\left[\frac{2,51}{Re \times \sqrt{\lambda}} + \frac{k}{3,71 \times I_D}\right] \quad (A.5)$$

$$Re = \frac{4 \times Q}{\pi \times I_D \times \mu} \quad (A.6)$$

where

Re is the Reynolds number (dimensionless);

k is the equivalent pipe surface roughness, in m (see Table A.1);

Q is the flow rate, in m^3/s;

μ is Kinematic viscosity of the fluid at the operating temperature, in m^2/s — here the fluid considered is water and the kinematic viscosity is set to $1{,}01 \times 10^{-6}$ m^2/s.

In the Colebrook-White formula, the first term in the logarithmic function corresponds to the portion of the head loss due to the liquid's own internal friction acting upon itself. The second term corresponds to the portion of the head loss caused by the friction of the liquid against the pipe wall ($k = 0$ for an ideally smooth pipe).

Table A.1 — Equivalent pipe surface roughness of ductile iron pipe

Pipe material	Type of lining	Equivalent pipe surface roughness *k* (mm)
Ductile iron	Blast furnace slag cement mortar	0,03
	Portland cement mortar	0,03
	Polymeric lining (polyurethane, epoxy, polyethylene)	0,005

NOTE 1 See Reference [6].

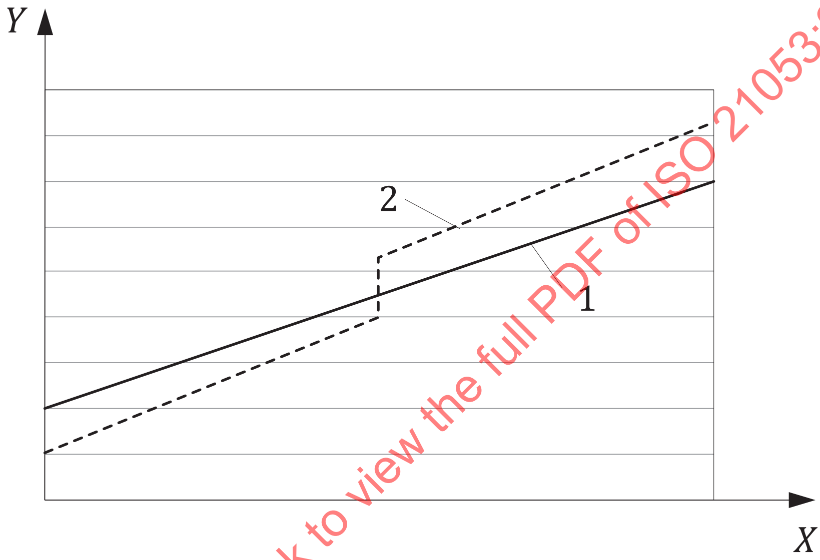
NOTE 2 *k* is not equal to the height of the surface imperfections; it is a theoretical concept relating to the surface roughness.

Annex B
(informative)

Scenario of LCC with different pipelines

Figure B.1 shows scenarios of LCC with two different pipelines.

Although the initial cost of pipeline A is higher, its LCC can become lower than that for pipeline B because of the low operation/maintenance cost and long service life.



Key

1 pipeline A

2 pipeline B

X time in year

Y LCC

NOTE See Table B.1.

Figure B.1 — Scenarios of LCC with different pipelines

Table B.1 — Comparison of the two pipelines

Pipeline	A	B
Pipe material cost	High	Low
Operation cost and maintenance cost	Low	High
Service life	Long	Short
Cost of recycling	Low	High

Annex C
(informative)

Leakage incident rate of ductile iron pipes

C.1 Water leakage evaluation

Water leaks are, in most cases, one of the main focus points of the total cost of ownership (TCO) and environmental life cycle assessment (LCA) for water pipes. However, very few models for the calculation of water leaks exist today, this parameter is highly variable and depends on the pipe material, the installation process, the age and length of the pipeline, among others.

Traditionally water leak for a given year (N) is calculated using Formula (C.1) and (C.2).

$$W_{\mathrm{L},N} = Q_{\mathrm{in}} \times \tau_N \tag{C.1}$$

where

$W_{\mathrm{L},N}$ is the water leak for a given year (N);

Q_{in} is the flow rate entering the pipe system, in m^3/s;

τ_N is the leak rate for a given year (N) and it is calculated as follows.

$$\tau_N = \left(Q_{\mathrm{in}} - Q_{\mathrm{out}}\right) / Q_{\mathrm{in}} \tag{C.2}$$

where Q_{out} is the flow rate at the end of the pipe system, in m^3/s.

It is generally accepted that the leak rate increases over time; the leak increase rate can therefore be defined and the following Formula (C.3) can be established.

$$\tau_N = \tau_{N-1} \times \left(1 + r_{\mathrm{L}}\right) \tag{C.3}$$

where r_{L} is the leak increase rate, in %.

We can therefore assume that water leaks increase exponentially each year depending on the leak increase rate. The doctoral thesis of Thomas Hendrickson[7] gives several possible values for the leak increase rate depending on the type of materials used to build the water pipe system. An average value of r_{L} of 0,5 % should be used by default.

C.2 Example of leakage incident rate of ductile iron pipe network

C.2.1 General

Studies on water network reliability and durability of pipe materials have developed very significantly in the recent years worldwide. However, it is difficult to give universal values of reliability of the water networks. It is therefore chosen to present some examples published in the literature highlighting the actual performance of ductile iron networks.

Ductile iron pipes have strong material properties and flexibility of joints, and it has been verified that the leakage incident rates caused by pipe bodies' damages or water leak from joints are extremely low.