

# Wasting Fresh Water: Stopping Systemic Failures





## About ISSF

The International Stainless Steel Forum (ISSF) is a nonprofit association, based in Brussels, which seeks, among other things to develop new markets for stainless steel and to promote the image of stainless steel as a sustainable and responsible product. The ISSF works with the Stainless Steel Development Associations (SSDAs), which are present in most markets towards end-users, the media, the general public and regulatory authorities.

The association has 56 members from all over the world and currently represents approximately 90% of the total production of stainless steel.



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## More information

For more information about ISSF, please consult our website [worldstainless.org](http://worldstainless.org).

For more information about stainless steel and sustainability, please consult the [sustainablestainless.org](http://sustainablestainless.org) website.



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## Foreword



TIM COLLINS  
Secretary-General

The story about the use of stainless steel in the water pipe network of the Tokyo Water Board came to us from a brief market report introduced by the Japan Stainless Steel Association (JSSA). And what an interesting story it turned out to be! In a period of 32 years, Tokyo had completely

transformed the city's service pipe network from an existing variety of materials including iron, lead and plastics to stainless steel, and had reduced their level of water losses from 17% per year to 2%. In a world where water is a precious resource, this was truly astonishing and we set ourselves the task of researching and preparing a Case Study to show exactly how it was done.

In the process we discovered very quickly that the Tokyo transformation is also underway in the cities of Seoul and Taipei, using the same techniques, and those two examples have given us access directly to the decision makers. This was an important

development, because the original decision makers for the Tokyo case have long since retired.

Over the last two years the Case Studies for Tokyo and Seoul have been developed into a very concise, but complete, information base. The Taipei project is still a work in progress and we are studying it very carefully in case additional information should emerge from it.

We are now ready to move on to the important next phase, which is communicating the success of these projects to other cities around the world. Many of them are experiencing high levels of treated water losses. We acknowledge the kind assistance of the OECD, which provided us with a list of cities with water losses in excess of 10%, and in some cases up to 40%.

This problem requires a solution, and stainless steel water pipes provide a workable, lasting solution. They are strong enough to withstand knocks and even seismic activity; they are clean and hygienic and thus help to improve the quality of the water; they are resistant to corrosion; and, in the flexible

"corrugated" form which has been used in the three Asian cities, they are light enough to be manhandled, can be easily bent into awkward shapes on site; and they will last for up to 100 years without undue maintenance interventions, thus reducing the biggest cost of repairing water leak damage, which is the cost of digging up road works and interfering with the movement of traffic. Cities need a system that can be set in place and stay there for generations.

This story has the serendipitous value of presenting the stainless steel industry with two direct benefits: an increase in demand for its products and an easy-to-understand environmental good news story. I commend it to you, Dear Reader, and also to the citizens of the world. Tell this story to your city councillors and your government representatives. The change will benefit you by saving the use of water, and therefore the cost of water.

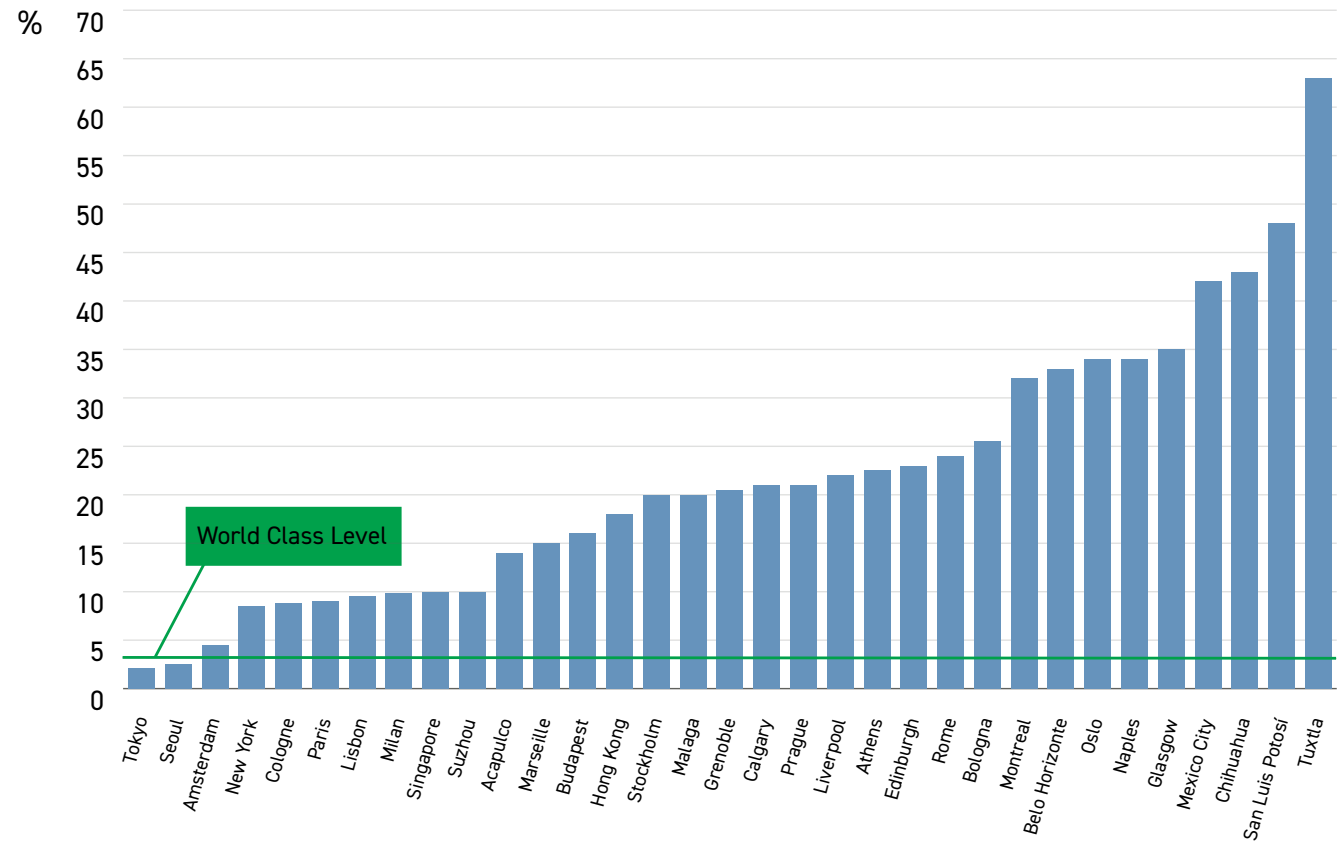
Tim Collins  
Secretary-General  
International Stainless Steel Forum  
Brussels



## Introduction

### Water Loss through Leaking Water Pipes in a selection of Cities

Water loss through leaking water pipes is a problem for cities all over the world. Some of them are losing water at upwards 40% per year, and this is all water which has already been treated. A recent study by the OECD has shown that it is not only the under developed or even the developing cities that are so affected – even the capital cities of major economies are losing far more water than is sustainable or even viable, as the table on this page illustrates.



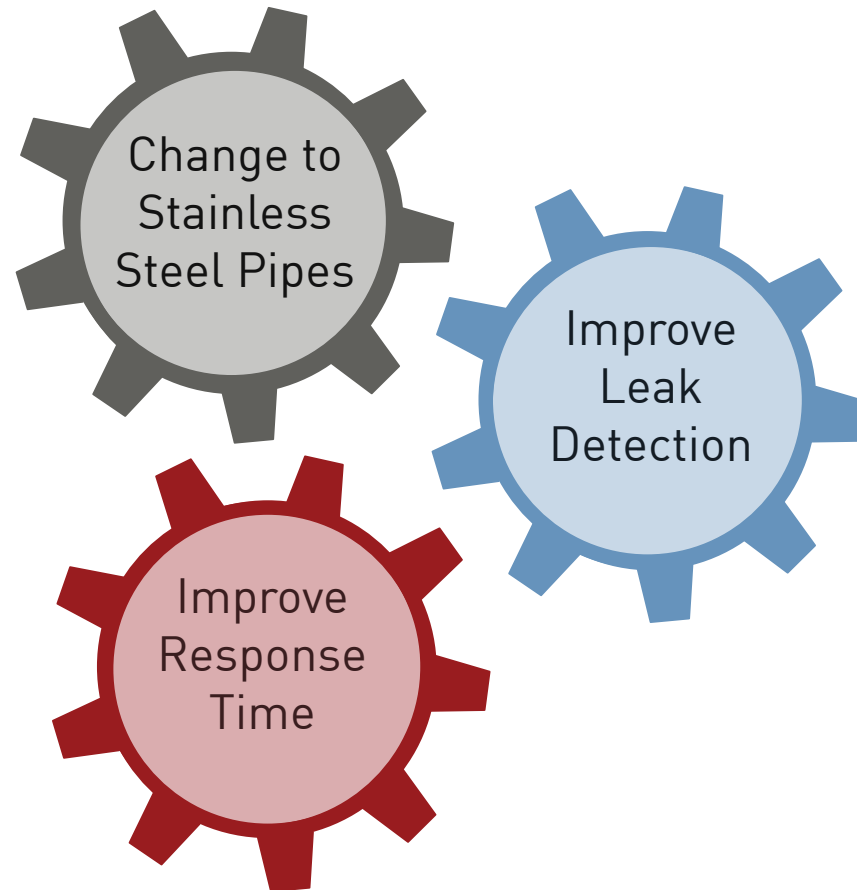
Leakage rate in major cities

Source: OECD (Water Governance in Cities, 2016)



## Managing Leaking Pipes

- ISSF, Nickel Institute and International Molybdenum Association studies have shown that the first and most important step is to replace service pipework with all stainless pipes and fittings.
- Stainless steels are highly corrosion resistant, have a higher strength to weight ratio, are strong enough to withstand shocks including seismic activity and do not encourage bacterial growth.
- The maintenance needs are exceedingly low, however no material can withstand severe damage and/or extreme shocks
- A secondary management system is always needed to detect any occurring leaks, even with stainless steels
- One advantage of using metal pipework is that leaks create sound which makes detection much easier
- It is also critical to have a rapid response team to deal with any leaks immediately and effectively before the situation deteriorates
- All three components (stainless steel pipework, sound leak detection systems and fast response) are critical to delivering a robust final solution





## Stainless Steel Corrugated Water Pipes

### Material Benefits

Stainless steel has high strength and is a very durable material. It is also less susceptible to cracking than competing materials. It is corrosion resistant, thus obviating the need for painting or other protective layers.

Stainless steel is exceptionally wear resistant. It has a hard, smooth surface, making it more difficult for bacteria to adhere and grow, thus making it very hygienic. Stainless steel has played a key role in the production, preparation and transport of food and drink for 100 years. It is chemically inert, meaning that it does not react with the food or drinks with which it comes into contact. For the purpose of transporting water, the ideal solution is to use stainless steel in corrugated pipe form. The introduction of corrugated pipes minimises the risk of leaks by reducing the number of joints that would otherwise be necessary. A secondary benefit is that the corrugations make the pipes easier to bend on site, thus making bending in inaccessible places easier. These pipes improve productivity and are also resistant to seismic shocks.

### Environmental Benefits

Over its entire lifecycle, stainless steel has one of the lightest environmental impacts of all known engineering materials. At the end of its long life, it is capable of being 100% recycled to create new stainless that will be as strong and long-lasting as the original product.



*Corrugated stainless steel pipes.  
Source: Korea Water Works Association (kwwa.or.kr)*

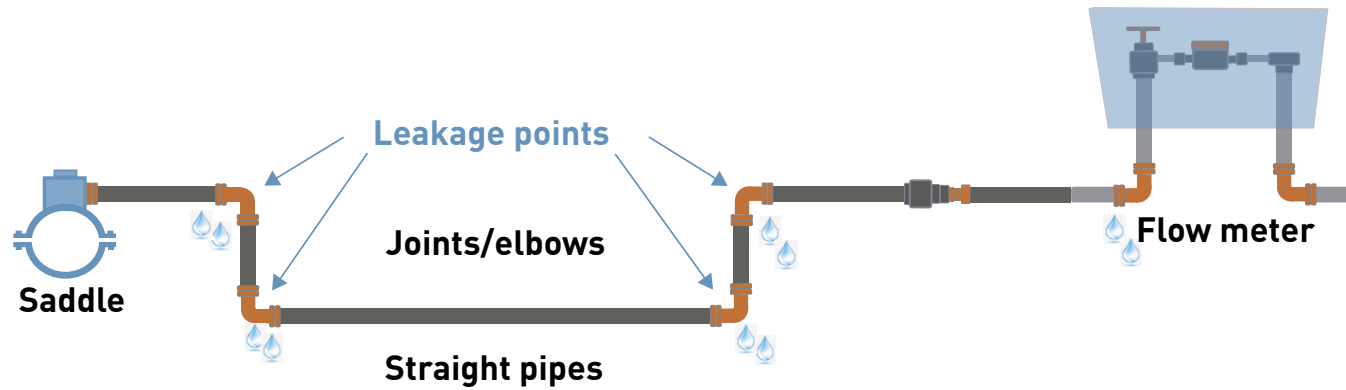
### Life Cycle Costing

Stainless Steel has a higher initial investment cost than many of its competing materials. However, when viewed across the full extent of its projected useful life, and noting that it requires very little maintenance and repairs, it is a less expensive option.

Assuming a useful life of 100 years at current real interest rates, the costs of using other materials will be significantly higher.



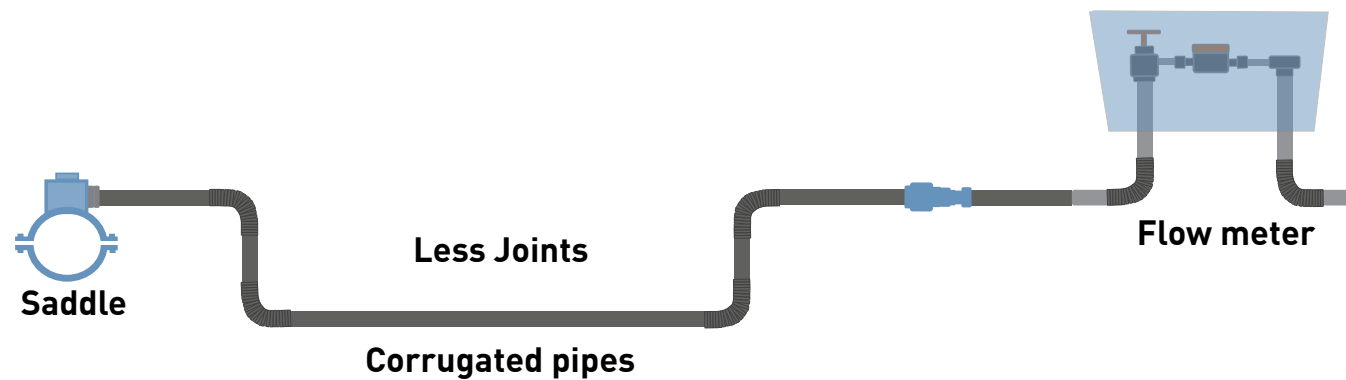
## Traditional Piping System



A flexible stainless steel corrugated piping system:

- avoids leaking at joints
- reduces the number of joints
- resists seismic shocks

## Stainless Steel Corrugated Pipes

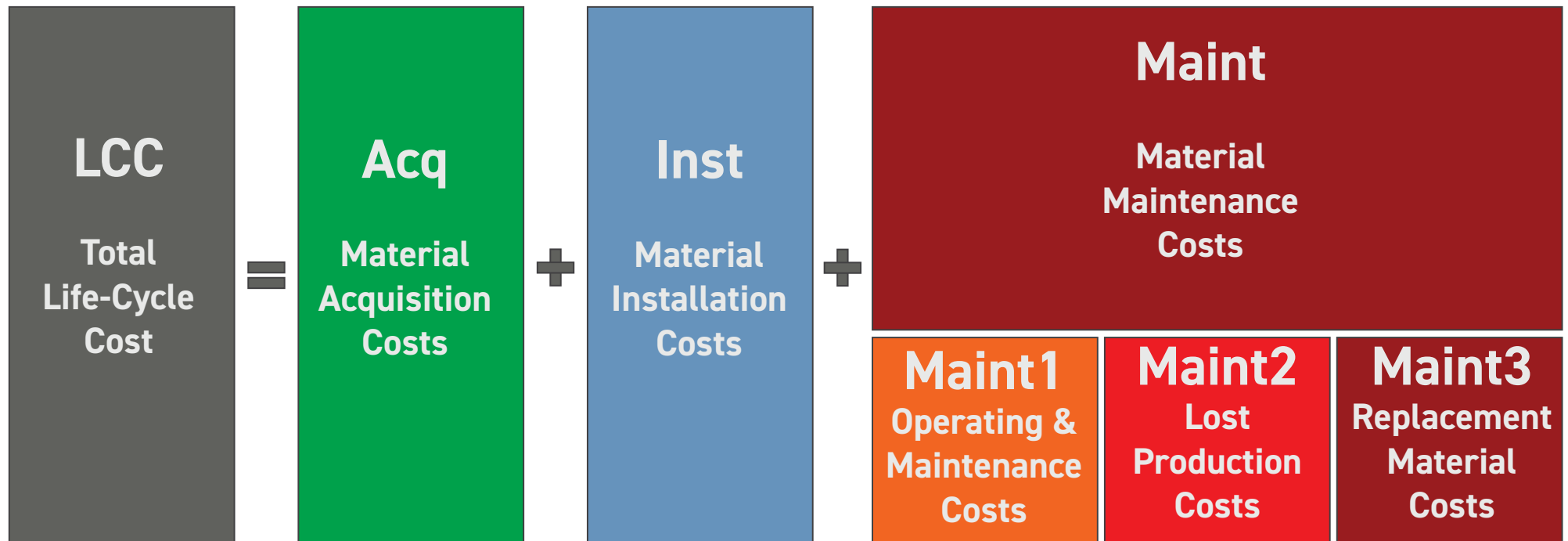






## Life Cycle Cost

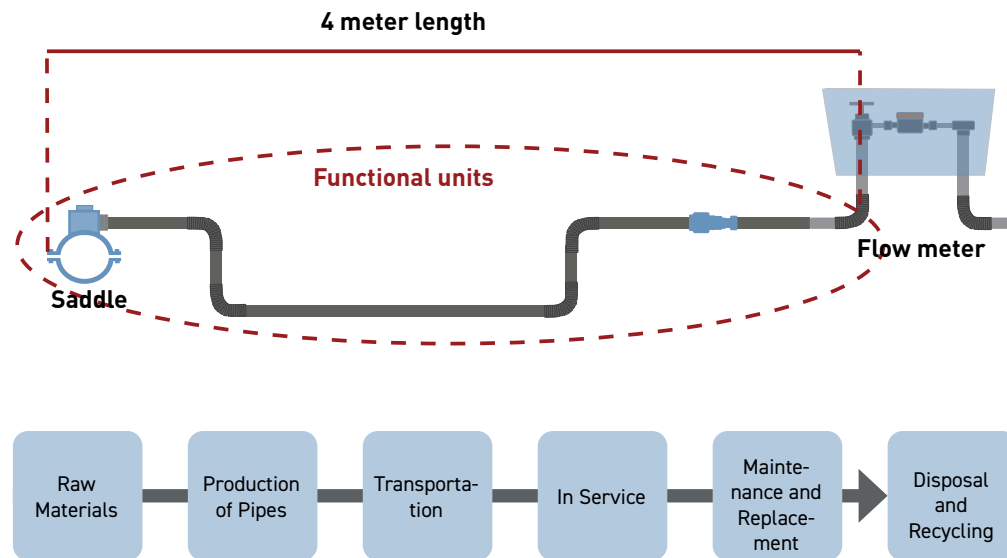
### Life Cycle Cost Formula





## Definition of the System

4 meter lengths (20 mm diameter) of service pipes with a service life of 100 years. Service pipes extend from the water mains to the household water meter and are inclusive of joints, elbow, T-joints and valves.



The LCC analysis was calculated from cradle to grave.

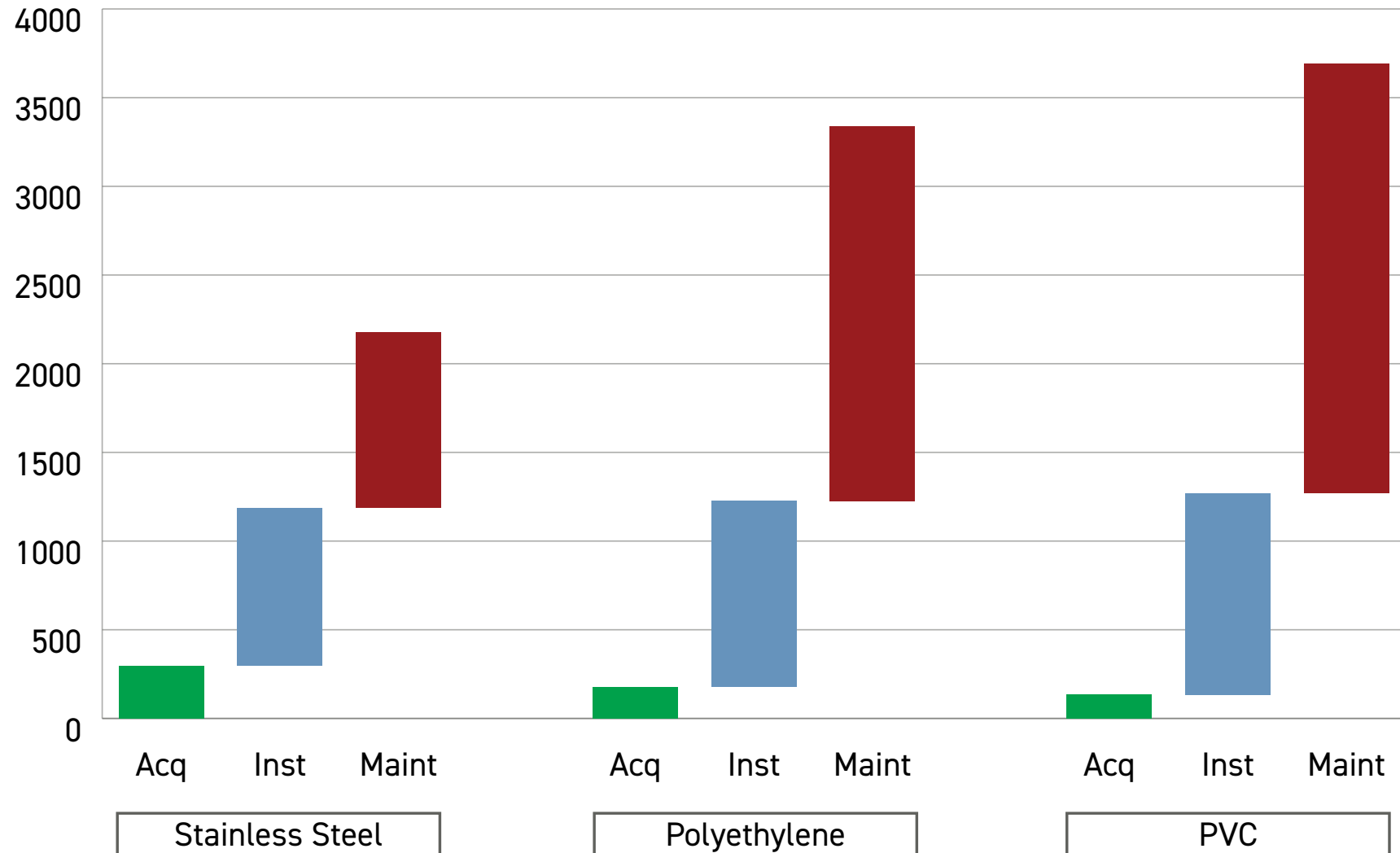
Assumptions	Stainless Steel (316)	PVC	PE
1. Service life	100 years	50 years	50 years
2. Real interest rate	0.27% <sup>1</sup>		
3. Initial material cost for a 4-meter corrugated pipe (including parts)	\$297 <sup>2</sup>	\$89 <sup>2</sup>	\$67 <sup>2</sup>
4. Initial installation (incl. labour costs) <sup>3</sup>	\$1,683 (assumed to be the same for each case)		
5. Operating and maintenance costs	Assumed to be zero (but maintenance and downtime costs exist in practice. Minimising that disruption is important)		
6. Lost production costs during downtime			
7. Replacement costs <sup>3</sup>	\$1,980/100 years	\$1,772/50 years	\$1,750/50 years
8. Residual value (Recycled scrap) <sup>4</sup>	\$100/100 years	\$0	\$0
<b>Total for service life of 100 years</b>	<b>\$2175</b>	<b>\$3,690</b>	<b>\$3,340</b>

1. Real interest rate forecast from IHS Markit
2. Pipe cost taken from Incheon (South Korea) example
3. Replacement cost taken from Incheon (South Korea) example
4. Stainless steel is capable of 100% recycling

The analysis of the Life Cycle Cost for grade 316 stainless steel illustrates that it is a less expensive product when viewed over its useful life. Alternatives which were tested by the Tokyo Water Board are shown to have a shorter life cycle and therefore a higher cost. Our assumptions have been based on a life span of 100 years and on current interest rates.



## Life Cycle Costing Comparison



## Corrugated Stainless Steel Water Pipes

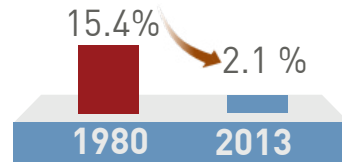




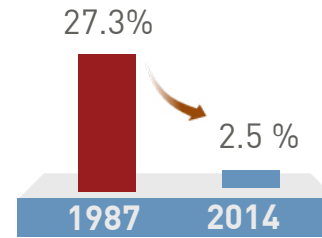
## Results of the projects in Tokyo, Seoul and Taipei

Leakage rate

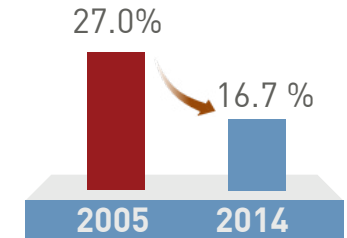
Tokyo



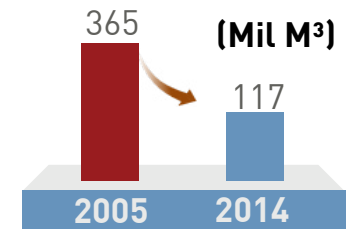
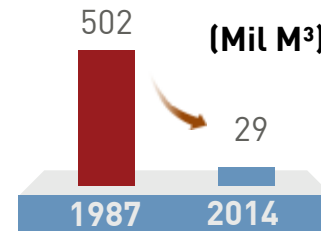
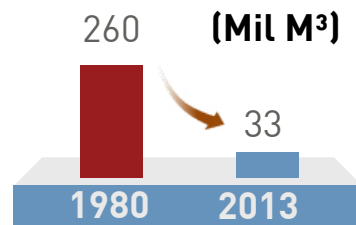
Seoul



Taipei



Leakage volume





## User Experiences

### Tokyo Water Board



The material change to stainless steel was carried out based on a thorough examination and it turns out to be the right decision. We found there was a considerable effect in the stainless steel application on both leakage and water quality.

Okabe Takeshi, Manager of the Water Supply Division

### Seoul Water Works



As we expected, stainless steel pipes have contributed to cleaner water quality and longer service life than other materials as well. The corrugated section contributed to an improved workability and a decrease in leakage.

Kim HyenTon, Director of the Water Distribution Department



*Flow meter and stopcock with the stainless steel corrugated pipe system  
Photographer: Philippe De Putter*



## Stainless Steel Water Pipes in Tokyo

### Tokyo Water Works in Figures (2013)

	1980	2013
Population (Mil)	11.6	13.3
Distributed volume (million m <sup>3</sup> )	1,692	1,523
Leakage volume (million m <sup>3</sup> )	260	33
Leakage rate (%)	15.4	2.2

### Major Challenges

- Critical water shortages
- Leaking water pipes
- High chloride ion content in the soil
- Concerns about maintaining a good water quality
- Susceptible to severe seismic shocks
- Severe localised flooding around the area of leaks, even causing some roads to collapse

### Why was 316 chosen over 304?

The Tokyo Water Board chose the higher alloyed grade 316 stainless steel for its improved corrosion resistance following extensive ground testing. They said that it was selected because they wanted the best available material. The cost of the material was less important than strength and durability because security of water supplies was the most important consideration.

### Underground burial tests

To check the corrosion behaviour of the pipes and to collect data on their corrosion resistance, the Tokyo Water Board commissioned tests using pipes made from a number of competing products, by burying them underground at 10 different sites, for a period of 10 years.

The tests showed that stainless steel had performed better in terms of strength and corrosion resistance with grade 316 performing better than 304. The Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup> concentrations in the soil were very high. The tests showed no evidence of pitting corrosion on the 316 samples.

316 is a higher alloyed grade and therefore more expensive than 304, but the Tokyo Water Board decided that the greater cost is the cost of laying the pipes and that the risk of failure could not be tolerated because of a potential water shortage. As a result, the decision to specify the stronger of the two grades of stainless steel irrespective of the initial costs difference, was economically justifiable.

### Corrugated Stainless Steel Pipes

The Tokyo Water Board discovered that many of their leaks had occurred at joints. The use of corrugated pipes allowed the installers to bend the pipes to the required shapes, thus reducing the need for joints and elbows, but it also allowed the



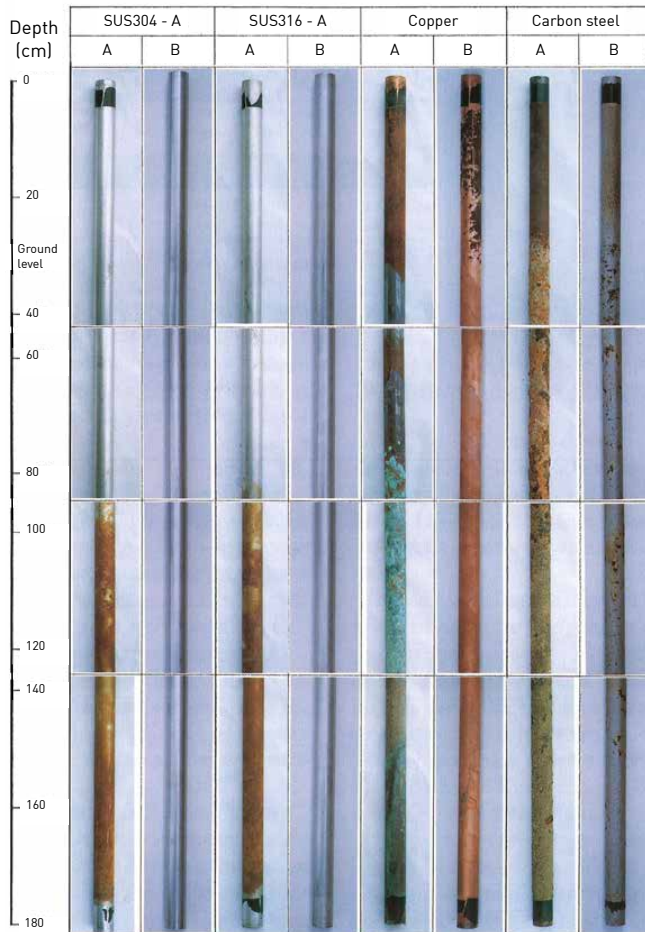
1. Kushiro city, test No. H; after acid pickling



2. Kuwana city, test No. P; after acid pickling

*Photos of the burial test results after 10 years of burial in Kushiro (North-East Japan) and Kuwana (Central Japan).*

pipes to remain more flexible after installation, and therefore more capable of resisting seismic shocks.



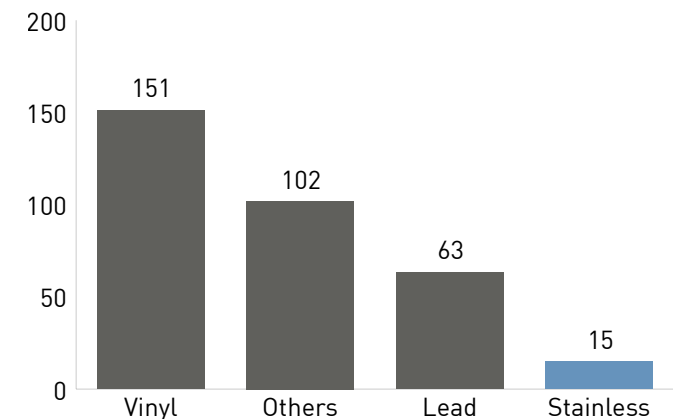
Burial test result from Okinawa.  
 A: After water cleaning  
 B: After pickling

This point was well proven after the Great Sendai Earthquake which struck the Northeast Coast of Honshu Island on 11 March 2011, with a magnitude of 9.0, which made it one of the strongest earthquakes ever recorded. Tokyo City lies on the boundary between the areas demarcated as having a strong to very strong impact (the earthquake was felt as far away as Beijing). After this incident inspections revealed that only 5% of the stainless steel pipes which had been installed were damaged.



Stainless Steel Corrugated Pipe  
 Photographer: Philippe De Putter

Tokyo tested corrugated stainless steel pipes from 1991 to 1998, before introducing them for all installations from 1998. In the early stages of testing, they used bronze fittings and discovered a risk of corrosion in the area of the joints. They therefore



Number of damages after the Great Earthquake of 2011 per pipe material.

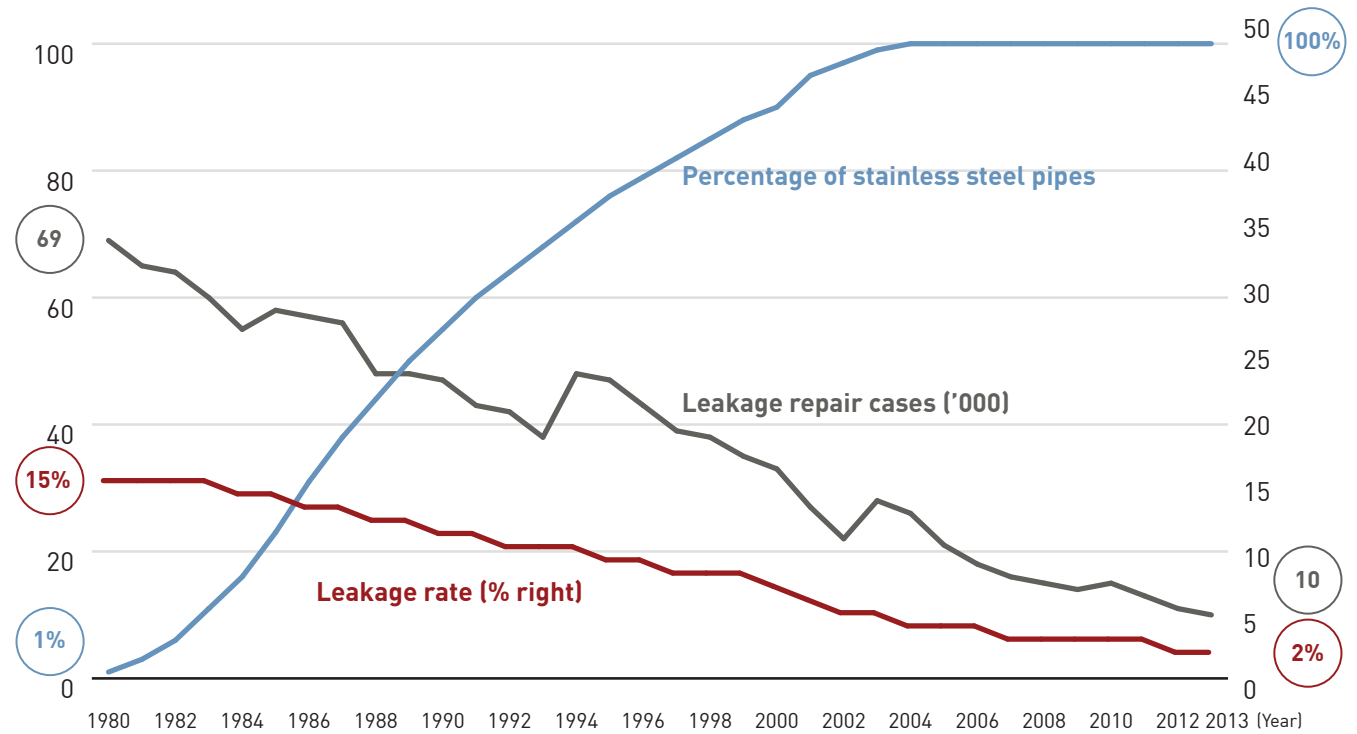
specified stainless steel for all joints, elbows, T-sections, valves and other fittings. The advantages provided by the use of stainless steel pipes were a reduction in the number of leaks; reduced maintenance; improved water quality; and a proven resistance to seismic activity.





The Tokyo Water Board has found no evidence of chemical residue deposits inside the pipes they have inspected.

### Reduction of leakage





## Stainless Steel Water Pipes in Seoul

### Seoul Waterworks in Figures (2014)

Service population: 10.3 million  
 Annual distribution volume: 1,169 million m<sup>3</sup> Water  
 leakage rate: 2.5%

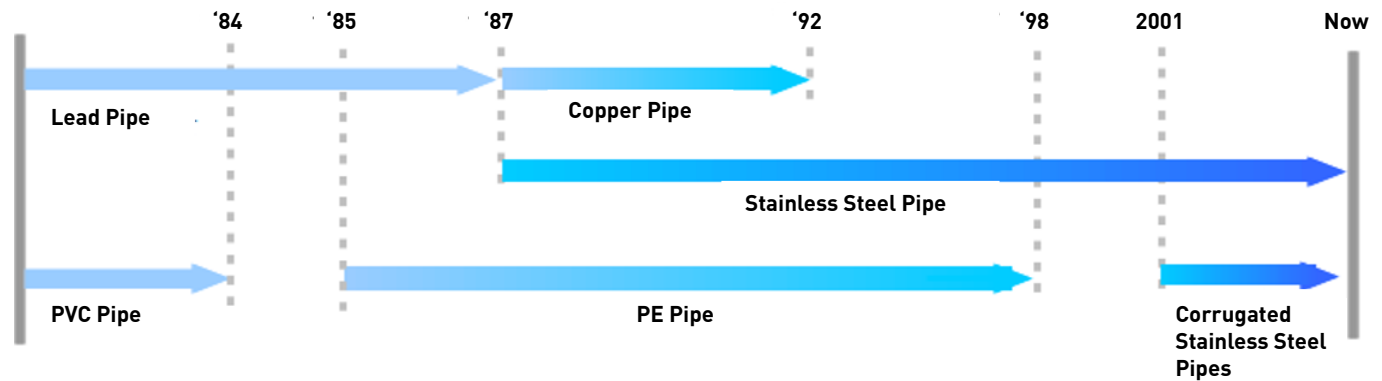
### Stainless Steel Service Pipes in Seoul

Seoul began to replace its water pipe lines in 1984. 95.6% of the pipes have been replaced so far. The total replacement will be finished by 2018.

- Total length of pipe lines: 13,720 km
- Total length of pipe line replaced so far: 13,192 km (95.6%)

	1984-1993	1994-2003	2004-2013	2014-2018
Replaced pipes (in km)	5,518	5,668	2,006	536

Stainless steel was used to reduce corrosion and improve water quality. It was also used to reduce water losses through leakage because of its superior strength. From 1987 to 1993 stainless steel and copper pipes were used together, but from 1993 only stainless steel has been used. From 2001 corrugated pipes were introduced to reduce joints and to make assembly easier on site. Seoul discovered that the reduction of water losses, together with the



improvement in water quality meant they could reduce the number of water treatment plants

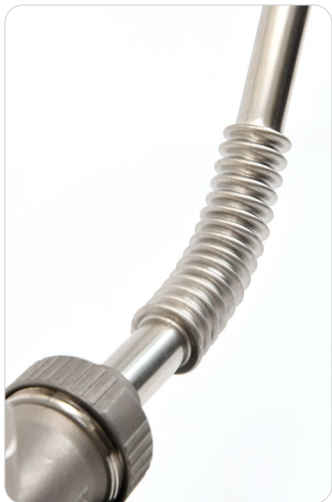


from ten to six, after this project. They found an improvement in the water leaks from 27% to 2.5%, even though the project still has one year left to run. This has enabled the city to reduce the number of repairs from 60,000 to 10,000 cases per year. It has also allowed the city to reduce its total water production (because there was less water wasted) from 7.3 million cubic meters per day to 4.5 million cubic meters, which is an excellent indicator of the water resource protection available from this project. Seoul considered alternative materials, but their tests demonstrated that stainless steel was the preferred option. Contrary to the experience of their mentors, the Tokyo Water Board, Seoul decided to specify grade 304 stainless steel, First, because their soils were shown to be less aggressive than those



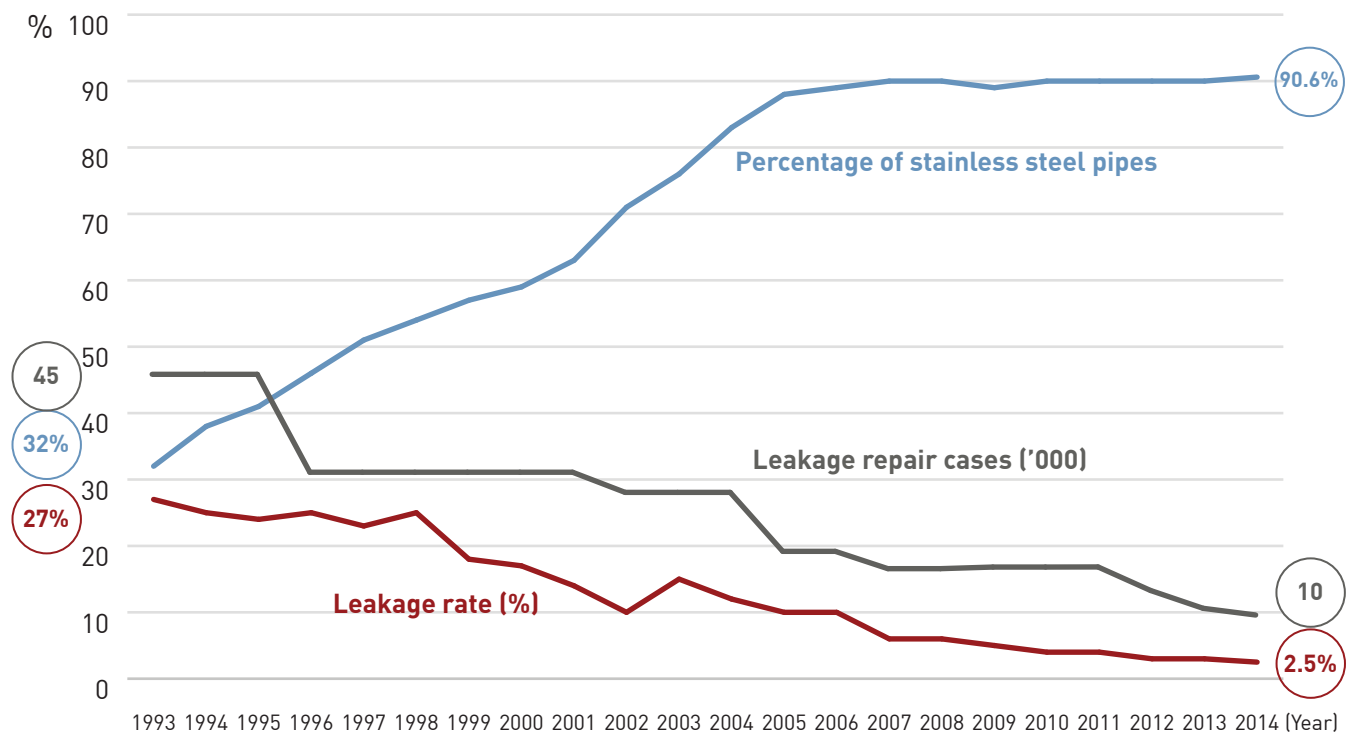
in Tokyo and second because 304 is a less expensive material.

Following the example of the capital, other Korean cities like Daegu, Incheon, Daejeon and Ulsan have also started to use stainless steel for their service pipes.



Stainless Steel Corrugated Pipe  
Photographer: Philippe De Putter

## Reduction of leakage





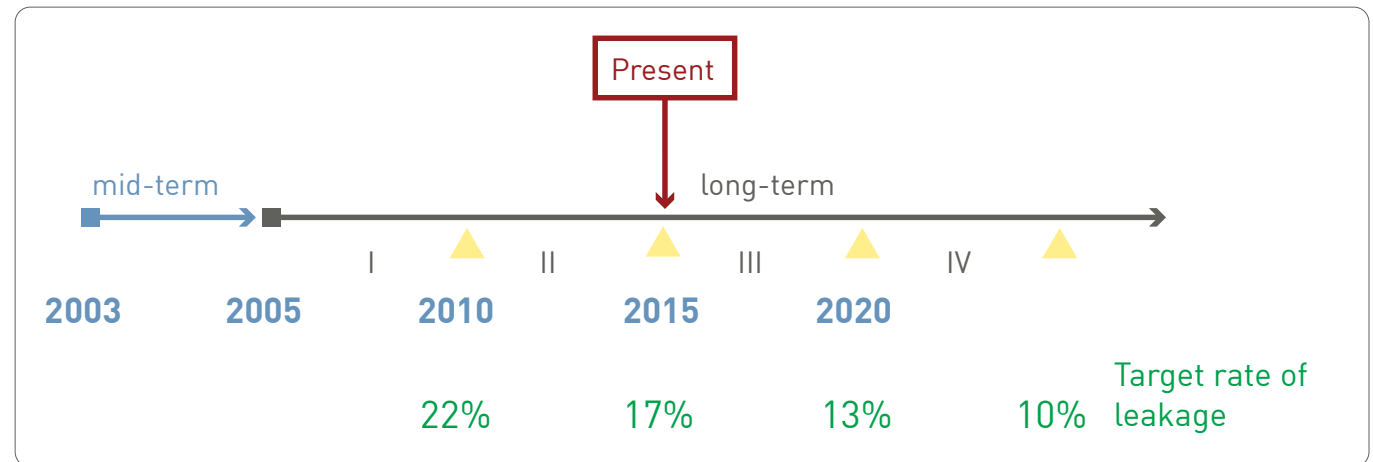
## Stainless Steel Water Pipes in Taipei

### Taipei Water Works in Figures

Service Population: 3.88 million  
 Daily Distribution Volume: 2.26 million m<sup>3</sup>  
 Daily Supply to Service Area: 1.97 million m<sup>3</sup>

### Background

In 2002 the level of water supplies to Taipei became dangerously low. With a 28.4% leakage rate in the pipelines, plus only half of the average rainfall, it resulted in a 49-day intermittent water supply. Taipei originally wanted only to expand the water supply, instead of controlling the water losses. This resulted in a complicated pipeline system, which had aged and was leaking. A leakage management project was planned to be finished in 4 phases within 20 years. This should improve the performance of the pipelines, reduce the water loss and prevent water shortages like the one in 2002.



### Implementation

Every year nearly 3% of the pipe network is being replaced. The last lead pipe was replaced in October 2017 which is 15 months ahead of schedule. So far 35% of the service piping of various materials has been replaced with stainless steel pipes. The

districts of the city that had the highest water loss (some more than 40%) were the first ones to have their pipes replaced with stainless steel ones. The last pipes that were taken out were investigated and revealed that 80% of the leaks originated from plastic pipes.



Year	Rain fall over Feitsui Reservoir (in mm)	Fetsui Reservoir Storage (%)	Leakage rate of TWD's* network	Annual Water Supply to TWD* (x 100 Mil m <sup>3</sup> )	Annual Water Supply to TWC* (x 100 Mil m <sup>3</sup> )
2002	1377	58%	28.44%	8.78	0.74
2014	1201	92%	16.70%	6.99	1.23
Difference	-176 mm	+34%	-11.74%	-1.79	+0.49

Intermittent water supply →

Less rainfall, end of 2014

Leakage reduction 11.74%

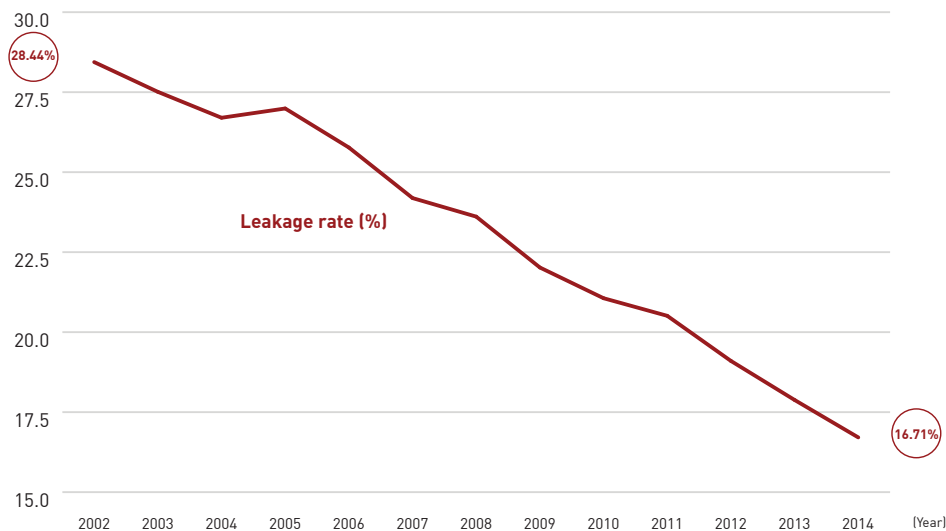
Water saved:  
1.23 supplied to TWC  
0.56 in reservoir

## Results

Even though only 35% of the pipes have been replaced so far, an excellent result already became apparent during the 2014 drought. That year had 13% less rainfall than during the previous drought in 2002, but there was no interruption to the water supply, thanks to the vast improvement in the leakage rates.

With the leakage rates reduced by more than 10% already, the water savings have been 1.79 billion m<sup>3</sup> per year. Water losses were at 365 million m<sup>3</sup> in 2005 and were down to 219 million m<sup>3</sup> in 2014. The target leakage rate of 10% should be reached by 2025.

## Reduction of leakage



\*TWD : Taipei Water Department  
\*TWC : Taipei Water Corporation



## Sources

1. International Molybdenum Association
2. Japan Stainless Steel Association
3. Ministry of Environment, Republic of Korea
4. Nickel Institute
5. Nisshin Stainless Steel Tubing Co. Ltd.
6. Seoul Water Works
7. Taipei Water Department
8. Tokyo Water Board
9. Histen ([histen.co.kr](http://histen.co.kr))



# Annexes



## What is Stainless Steel?

The material we know as stainless steel is an important feature of modern living and there can be very few people who have not come into contact with it at some stage of their lives. It was discovered in 1912 by a metallurgical engineer who found that an addition of not less than 10.5% chrome imparts significant corrosion resistance to steel. The chrome forms a protective layer on the surface of the steel which is capable of constantly renewing itself, thus protecting the surface against corrosion even when scratched or otherwise damaged. It is this important corrosion resistant property which sets stainless steels apart from other forms of steel – indeed the internationally accepted definition of stainless steel is steel containing not less than 10.5% chrome.

### 304

Grade 304 is the most commonly used form of stainless steel. This grade typically contains 18 % chromium and 8 % nickel. This is an austenitic steel. It is not a good conductor of electricity or thermal units and it is non-magnetic. The addition of nickel gives the material an even higher corrosion resistance and makes it much more malleable. It is considered ideal for potable water with up to 200 mg/L chlorides at ambient temperatures and 150 mg/L at 60 °C.

### 316

In addition to chrome and nickel, grade 316 stainless steel contains molybdenum, which further strengthens its corrosion resistance particularly against pitting and crevice corrosion in chloride environments. It has excellent forming and welding

characteristics and is easily formable into a variety of parts for different applications.

Grade 316 also has outstanding welding characteristics.

## Equivalent grade numbers of stainless steels

USA: UNS	USA: AISI	EU: EN	Japan: JIS	UK: BSI
S30400	304	1.4301	SUS 304	304S15, 304S16
S31600	316	1.4401	SUS 316	316S31

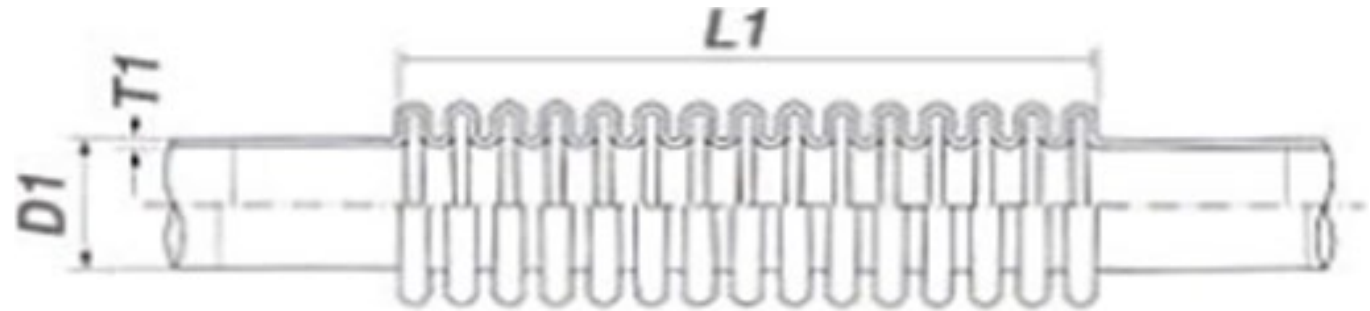




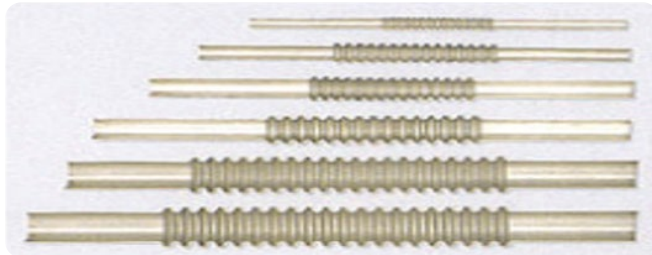
## Corrugated Stainless Steel Pipes

### Specification

Standard length: 4 meter  
 Maximum length: 5 meter  
 Diameter: 15~50 mm for service pipes  
 Thickness: 0.8~1.2 mm  
 Steel grade: SUS 304 or 316



Drawing of a corrugated pipe.  $D1$  is the diameter,  $T1$  the thickness and  $L1$  the length of the corrugation. Specifications for the different diameter pipes can be found in the table.



Corrugated stainless steel pipes in different diameters

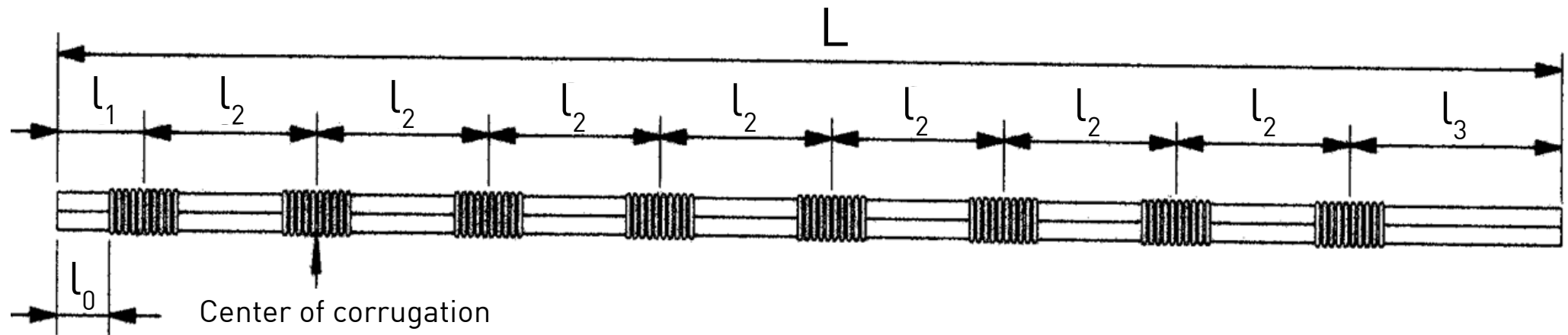
### [JWWA G119, KWWA D118]

Name	Outer diameter ( $D1$ )		Thickness ( $T1$ )		Length ( $L1$ )		# of thread	
	Standard	Tolerance	Standard	Tolerance	Standard	Tolerance		
13 Su	15.88	0~0.37	0.8	± 0.08	80	± 10	15	
20 Su	22.22		1	± 0.1	120			
25 Su	28.58							
30 Su	34	± 0.34	1.2	± 0.12	153	± 20	20	
40 Su	42.7	± 0.43			225			
50 Su	48.6	± 0.49						

Unit: mm



### Size of corrugated stainless steel pipes



Name	L		l <sub>1</sub>		l <sub>2</sub>		l <sub>3</sub>		l <sub>0</sub>
	Standard	Tolerance	Standard	Tolerance	Standard	Tolerance	Standard	Tolerance	Standard
13 Su	4,000	±0	190	+10 -0	475	±20	485	±0	150
20 Su			210		475		465		150
25 Su			210		475		465		150
30 Su			230		470		480		153.5
40 Su			265		460		515		152.5
50 Su			265		460		515		152.5

Unit: mm

The total length (L), number of corrugations and the length of the corrugation can be altered upon request to the supplier.



## Classification

Classification	Code	Application
Corrugated pipe A	CSST-ST304	General Water Distribution Pipes
Corrugated pipe B	CSST-ST316	Distribution pipes requiring more corrosion resistance

## Manufacturing process

- A. Straight pipes should be processed by arc welding or electric resistance welding
- B. For corrugated pipes, corrugations should be processed by hydro forming and finished by solution treatment

## Properties

- A. Pressure resistance: no leakage or damage when applying 2.5MPa pressure for two minutes on one end while closing the other end of the pipe

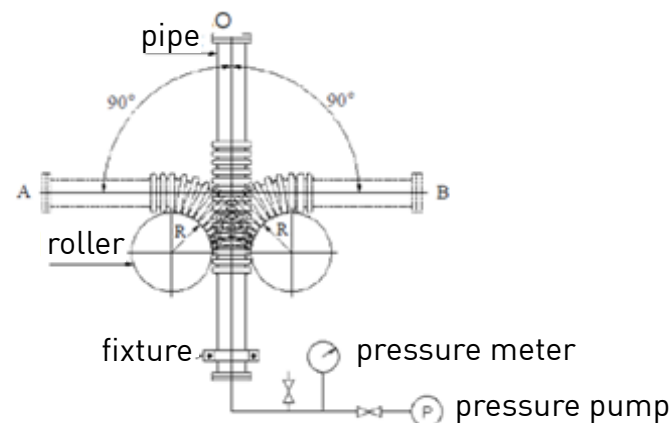
- B. Elongation and residual elongation: should conform to the table below.

Diameter	Elongation when 1.0 Mpa	Residual elongation when pressure change from 1 Mpa to 0 Mpa	Elongation when 2.5 Mpa
15~30	≤ 1.0	≤ 0.5	≤ 5.0
40, 50	≤ 2.0	≤ 1.0	≤ 10.0

- C. Bendability: no leakage or no malfunction after 10~20 times bending test in 0.1 Mpa.

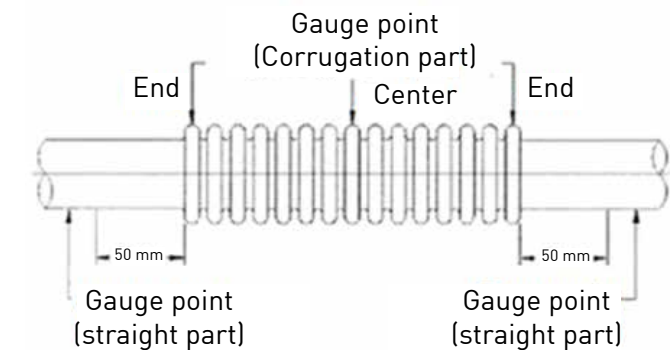
Diameter	# of bends
15/20/25/30	20
40/50	10

- D. Flatness: no scratch or crack on the surface after the pipe was forced to 2/3 of the diameter



- E. Hardness: equal or lower than HV200 on the corrugation section
- F. Shock resistance: no leakage or malfunction after 2 kg steel ball drop test from 1 meter high
- G. Thickness reduction ratio (r): equal or less than 20%  $r = (1 - t_1/t_2) \times 100$ , where r is the reduction ratio,  $t_1$  is the lowest thickness of corrugation,  $t_2$  is the lowest thickness of straight pipe
- H. Bio-elution: must confirm with the national regulations

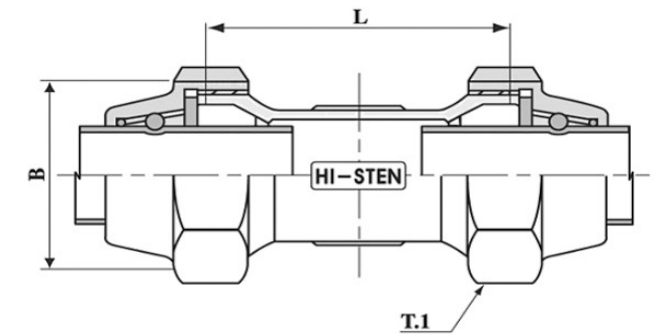
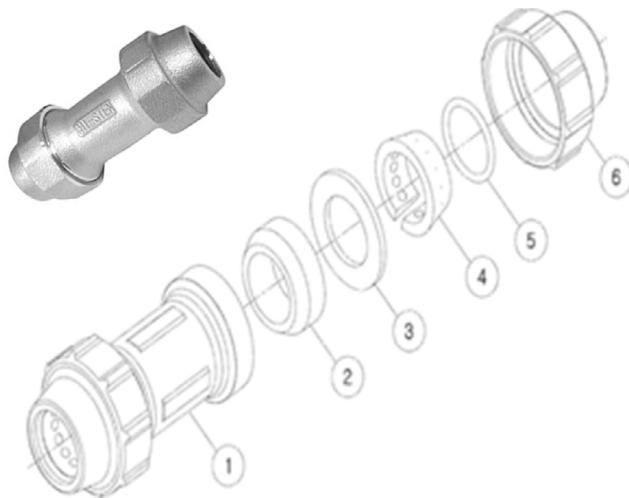
Source: Korean Standard of Corrugated Stainless Steel Pipe (SPS KWWA D 118-2058)





## Stainless Steel Joints and Fittings

Specification (Joint) - made of cast stainless steel



Item	Description	Material
1	Body	SSC13/14
2	Packing	EPDM
3	Washer	STS304/316
4	Ball Guide	STS304/NYLON6
5	O-Ring	EPDM
6	Nut	SSC13/14

*\*SSC: Stainless Steel Cast*

*\*EPDM: Ethylene Propylene Diene Monomer (It will last more than 100 years at room temperature water and more than 40 years at 70-80 degree in Celsius)*

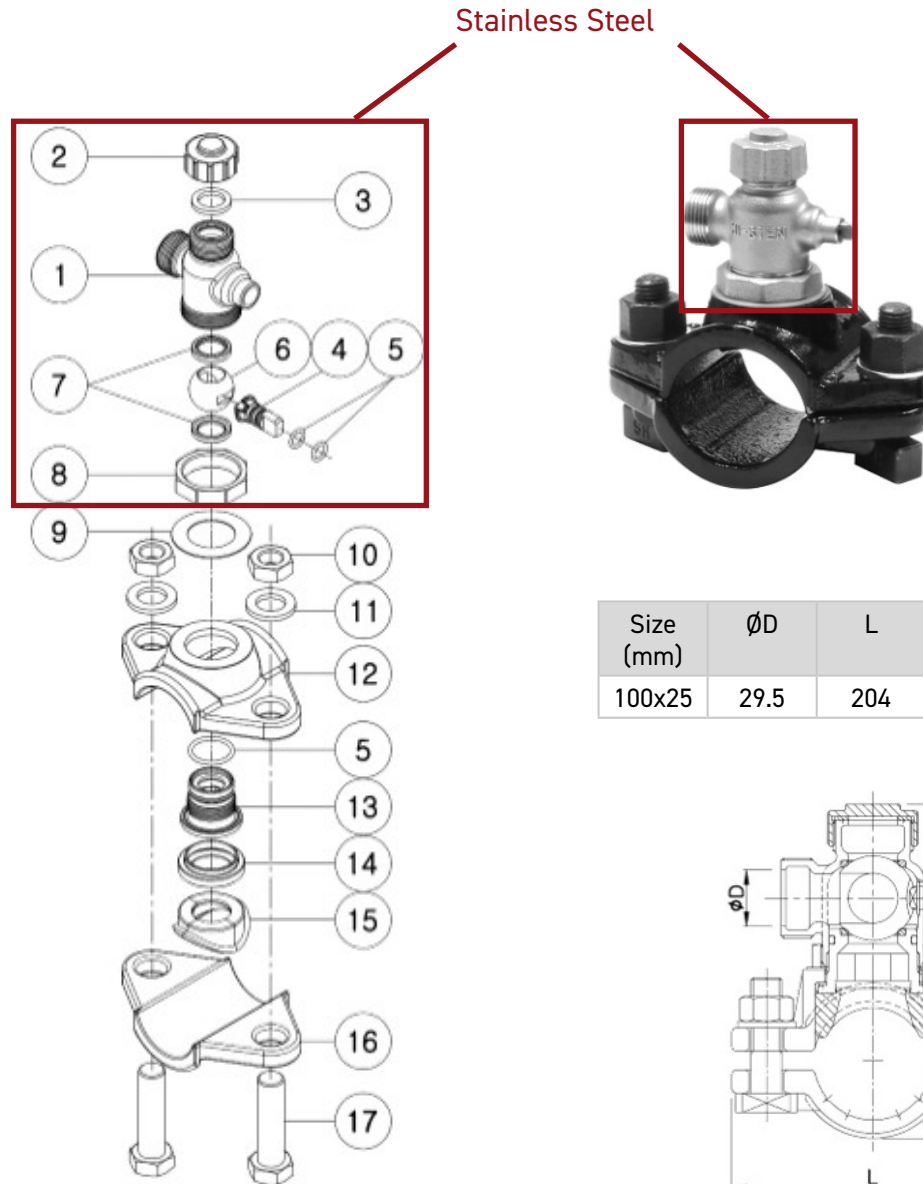
(mm)	L	B	T.1
13 Su	80	41.0	Hexagonal
20 Su	80	47.0	Hexagonal
25 Su	80	55.5	Hexagonal
30 Su	90	61.5	Octagonal
40 Su	90	71.0	Octagonal
50 Su	90	78.0	Octagonal
60 Su	90	90	Octagonal



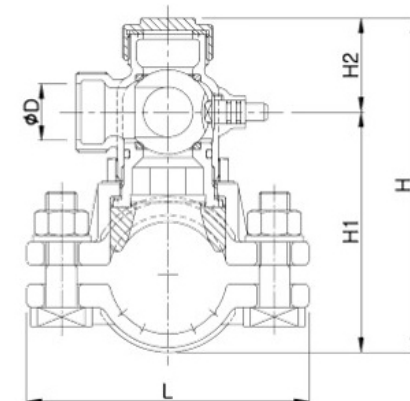
**Specification (Snap Tap with Saddle)**  
 - made of cast stainless steel and carbon steel (ductile)

Item	Description	Material
1	Body	SSC13/14
2	Cap	SSC13/14
3	Cap Packing	EPDM
4	Stem	STS304/316
5	O-ring	EPDM
6	Ball	STS304/316
7	Seat	PTFE
8	Lock Nut	SSC13/14
9	Insulation Pad	PE
10	Nut	FCD450
11	Washer	SS400
12	Saddle	FCD450
13	Insert	SSC13/14
14	Insulation Guide	PE/EPDM
15	Upper Packing	EPDM
16	Band	FCD450
17	Bolt	FCD450

- \* SSC: Stainless Steel Casting
- \* EPDM: Ethylene Propylene Diene Monomer
- \* PTFE: Polytetrafluoroethylene
- \* FCD: Ductile Cast Iron



Size (mm)	ØD	L	H	H1	H2
100x25	29.5	204	231.8	182.8	49



[worldstainless.org](http://worldstainless.org)



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