

# Economical and technical evaluation of PE100 pipes used in natural gas distribution systems

IGRC 2014, Copenhagen  
Transmission & Distribution  
*Evaluation of Polyethylene and Polyamide gas pipes*

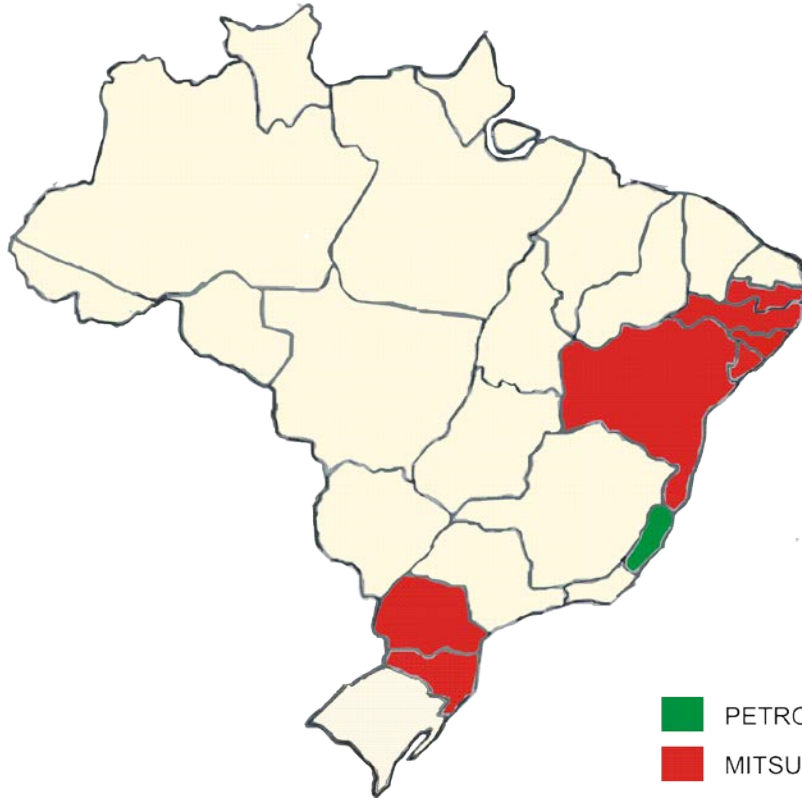
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# 1. Introduction





Petrobras Distribuidora (BR) and Mitsui Gas run natural gas distribution companies in Brazil.

(BR is an operating company, and Mitsui Gas is a holding company of 7 LDCs)

	<b>Number of Customers</b>	<b>Pipe network length (km)</b>	<b>Volume (x10<sup>3</sup> m<sup>3</sup>/day)</b>
<b>BR</b>	29,083	432	3,950
<b>Mitsui*</b>	128,804	3,927	13,010

As of July 2014, \* Total of 7 LDCs

-  PETROBRAS DISTRIBUIDORA
-  MITSUI GÁS

# 1. Introduction



## **Natural gas distribution in Brazil**

- A concession area is on an entire state bases (except for SP and Rio de Janeiro states)
- In most states, supply of natural gas has 20 years experiences.
- Development of residential market in recent years leads to a formation of PE pipe networks in urban areas.

## **Our philosophy in network formation**

- `Efficient and economical gas pipe network`
- It is one of key factors **to choose most suitable pipe material.**  
=> **Comparison of PE100 pipe and PE80 pipe**

## ***Terminology***

- *`PE100 pipe` = PE pipe composed of PE100 resins*
- *`PE80 pipe` = PE pipe composed of PE80 resins*

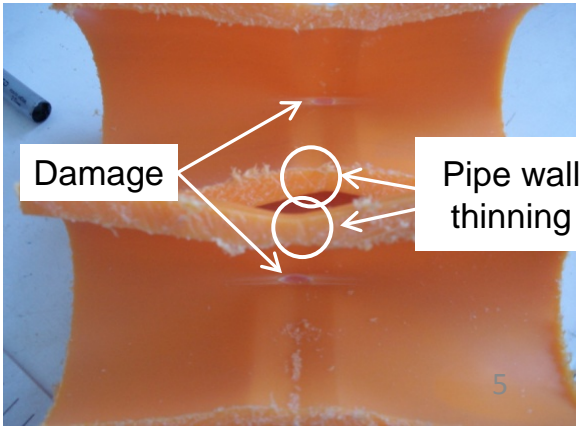
## 2. A business dilemma

### Squeeze-off

- Makes use of flexibility of PE pipe
- An effective flow-stopping measure in an emergency or even in ordinary operation
- Pipes are squeezed together thus preventing the flow of gas and isolating the pipe section.
- Uses specially designed tools
- Usually re-rounding is done after squeeze-off.



### Advantage, Disadvantage of PE100 pipe and Squeeze-off

Advantage in comparison with PE 80	Disadvantage in comparison with PE 80
<ul style="list-style-type: none"><li>• Realizes a higher tensile strength with greater resistance against slow and fast crack propagation</li><li>• Enables higher operational pressures, larger flow capacity in an economical manner</li></ul>	<p>PE100 material is <b>`harder`</b> =&gt; Concerns about damages and pipe wall thinning by squeeze-off</p>  <p>The image shows a close-up of a pipe joint with two overlapping circles highlighting areas of 'Damage' and 'Pipe wall thinning'.</p>

## 2. A business dilemma



### Application of Squeeze-off to PE 100 Pipes

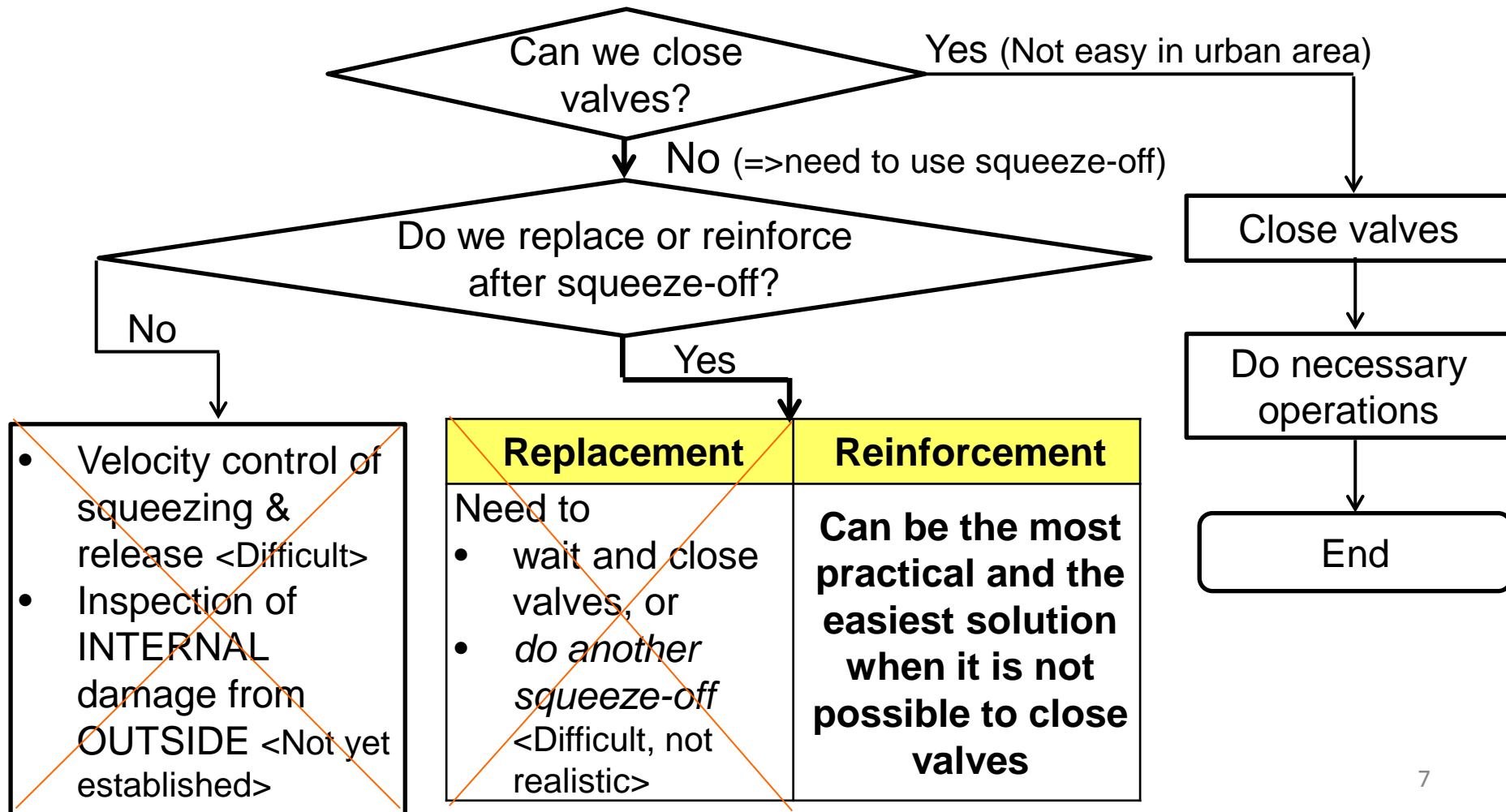
Examples of concerns and restrictions about application of squeeze-off to PE100

Concerns and Restrictions	Reference
"Equipment for squeeze-off of PE pipes is available on the market, but the effect of the squeezing on the long-term strength of PE 100 water pipes is still not fully studied"	The Nordic Plastic Pipe Association (Sweden), PE Pressure pipe system, 2012
"Reference should be made to the relevant pipe manufacture for specific advice regarding squeeze-off operations on PE 100 pipes (stress cracking could occur and mechanically-aided re-rounding would be required)"	Institute of Gas Engineers and Managers (UK), IGEM/TD/3 Edition 5, 2014
"After the squeeze-off procedure is complete the pipe must be: - Inspected and re-rounded if necessary; - Renewed if there are any signs that the pipe is damaged, i.e., splitting or cracking."	GPS PE Pipe Systems (USA), Installation and Technical Guidelines, 2011
"After squeeze-off of the pipe (PE100), the section should be reinforced with mechanical clamp" (Translation by the author)	Japan Polyethylene Pipes Association for Water Service (Website)

### 3. Technical issues related to squeeze-off of PE-100 pipes



#### How to cope with the problem when we need to stop gas flow?



## 4. Procedure of squeeze-off and reinforcement



### Target of the studies

**To establish a method and procedure of reinforcement which ensures long-term integrity of squeezed-off PE 100 pipes**

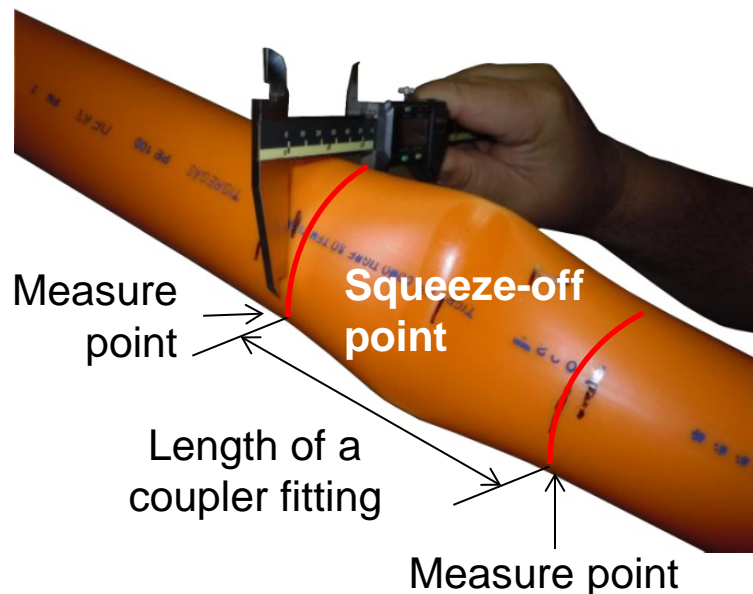
### Main points of studies

1. Taking `Viscoelasticity` and `Elastic rebounding` of PE material into consideration, we prepared 10 test pipes (PE100,  $\varnothing$  63mm, SDR11) to evaluate
  - 1) squeeze-off time effect,
  - 2) re-rounding time effect,
  - 3) re-rounding tool geometry\* effect, and
  - 4) effectiveness of coupler and saddle reinforcement fittings.10 pipes are different one another in duration of squeeze-off ( $T_{sq}$ ), duration of re-rounding ( $T_{rr}$ ), re-rounding tool geometry, and fitting type (coupler/saddle).  
\*: Circular and Elliptical (Flattening=9.5%)
2. Comparison of PE100 pipe and PE80 pipe based on actual projects in terms of
  - 1) Network flow capacity, and
  - 2) Installation costs



## 4. Procedure of squeeze-off and reinforcement

### Tests and Measurement of deformation



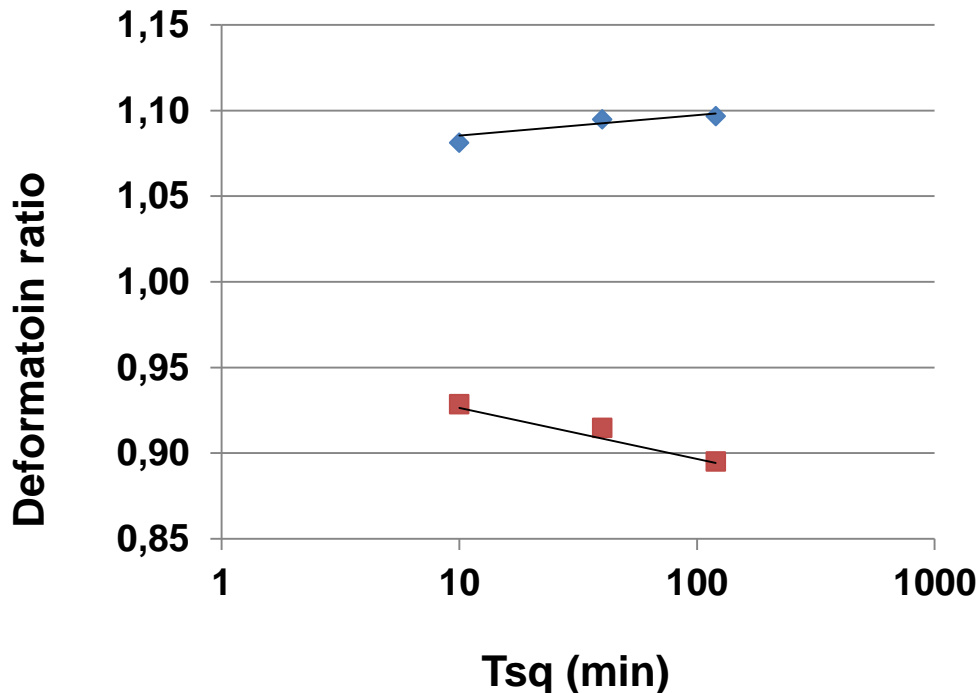
- Direction of squeezed-off : vertical;
- Measurements : vertical diameter ( $D_v$ ) and horizontal diameter ( $D_h$ ) at two points (See the left figure);
- Two measure points : distance of them = a length of reinforcement coupler, i.e., where electro-fusions are realized;
- Reason of the selection of the points: roundness after re-rounding is important to assure sound electro-fusion and mechanical integrity of reinforcement
- Timing of measurement:
  - 1) before squeeze-off, 2) after squeeze-off and 3) after re-rounding

#### ***Deformation ratio***

Ex. `A deformation ratio of 0.9` means that a pipe diameter has changed to 90% of its original diameter.

## 4. Procedure of squeeze-off and reinforcement

### Squeeze-off time effect



◆ Horizontal diameter    ■ Vertical diameter

- Relationship between squeeze-off duration and the resulting deformation
- Results - Deformation by squeeze-off increases proportionally to the logarithm of Tsq (Duration of squeeze-off).
- The ambient temperature was 26-28°C.
- The results conform to viscoelasticity of polymer material.

## 4. Procedure of squeeze-off and reinforcement



### Re-rounding time effect

- The objective - to find out the **optimum duration of re-rounding ( $T_{rr}$ )** in order to establish effective operations (*Should we keep re-rounding for 1 hour or 1 minute?*)
- **Re-rounding effect (A/B):** *How much does the re-rounding operation make the pipe recover its original shape?*

$$\text{Re-rounding effect} = \frac{\text{Deformation ratio after squeeze-off}}{\text{Deformation ratio after re-rounding}}$$

The table below shows an example of the calculation of the re-rounding effect:

Circular		$T_{rr}$ 20 min.	$T_{rr}$ 10 min.	(a/b)
Dv	After squeeze-off (A)	0.915	0.915	
	After re-rounding (B)	0.984	0.981	
	Re-rounding effect <b>(A/B)</b>	<b>0.930</b> (a)	<b>0.933</b> (b)	<b>0.997</b>

- The **ratio** of Re-rounding effects **(a/b)** shows **How are the re-rounding effect of duration 20 min and that of 10min close?** In the above case,  $a/b = 0.997$ . *Note that A/B and a/b are different. Now let's concentrate on a/b.*

## 4. Procedure of squeeze-off and reinforcement

### Re-rounding time effect (continuation)

- The table below summarizes all the values of a/b in four cases (Circular/Elliptical, Dh/Dv) (Duration of squeeze-off (Tsq) were 40 min in all cases).

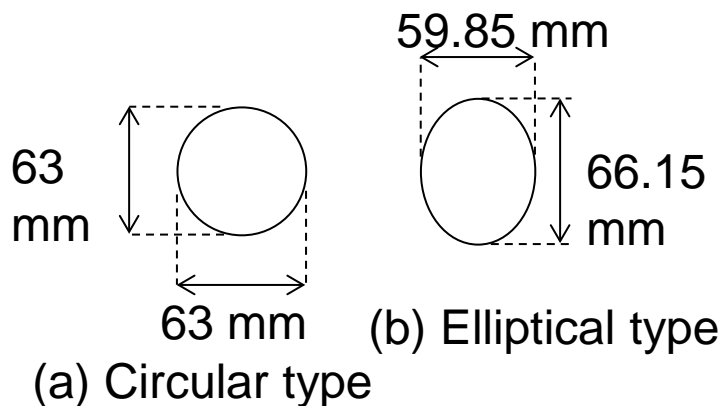
Re-rounding tool	Dh or Dv	a/b value (Ratio of re-rounding effects between 20 min and 10 min)
Circular	Dh	1.010
	Dv	0.997
Elliptical	Dh	0.990
	Dv	1.011

- Since the a/b values are very close to one (1) (actually they are all within  $1 \pm 1.01\%$ ), there is **little difference** of the effect of the duration of re-rounding between 10 min. and 20 min. at temperature 26-28°C.
- Therefore, most of the re-rounding deformation must have completed within 10 min. => Keeping re-rounding for 10 min can be sufficient to recover the roundness at above said temperature.
- The finding can help realize secured and effective re-rounding/reinforce work at site.

## 4. Procedure of squeeze-off and reinforcement

### Re-rounding tool geometry effect

- Considering the work procedure of reinforcement (to be described later), it is important to obtain high degree of roundness by re-rounding.
- Why?
  - 1) a reinforce coupler needs to pass the squeezed-off/re-rounded section;
  - 2) high degree of fusion of resin needs to be realized between the coupler and a pipe body to ensure mechanical integrity of the reinforcement.



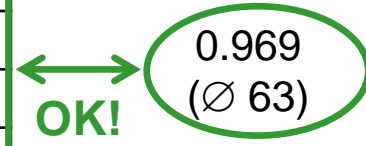
- Therefore, we conducted testes to see the effects of re-rounding tool geometry on the recovery of roundness.
- Two types of tools: (a) circular and (b) elliptical, as shown in the left side figure
- Note that the ratio between long axis and short axis of elliptical type is around 0.90 ( $=59.85/66.15$ ) (Flattening=9.5%).

## 4. Procedure of squeeze-off and reinforcement

### Re-rounding tool geometry effect (continuation)

- The results are summarized in terms of **Oval ratio** (=Dmin/Dmax) in the table below. (Trr = 20 min in all cases)

*Note that the closer to one (1) is an Oval ratio, the closer to circular is the shape.*

Re-rounding tool	Squeeze-off duration	Oval ratio after re-rounding	Minimum Oval ratio *
Circular	40 min.	<b>0.973</b>	 0.969 (∅ 63) <b>OK!</b>
Elliptical		<b>0.991</b>	
Circular	120 min.	<b>0.969</b>	
Elliptical		<b>0.998</b>	

\* Brazilian standard NBR 14462

- Result - **elliptical type is better than circular type**: the oval ratios of elliptical type are within 1% from 1.0, whereas the ratios are within 2-3% from 1.0 with circular type.

*The results can be related to `elastic re-bounding` of PE pipe when unloaded. To compensate the re-bounding, it is necessary to `over-compress` to the horizontal direction in re-rounding. The elliptical type can realized it, but the circular type cannot. All the results satisfy the Brazilian standard as shown in the table (∅ 63).*

- It is recommended to use an elliptical type** for re-rounding.

## 4. Procedure of squeeze-off and reinforcement

### Effectiveness of coupler and saddle reinforcement fittings



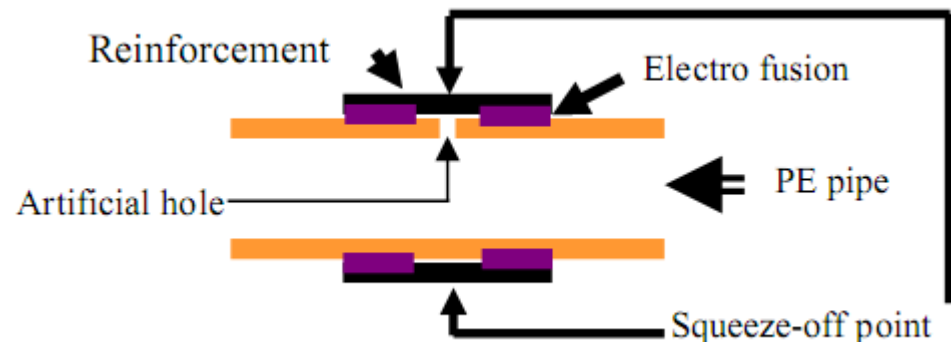
EF Reinforcement  
coupler joint



EF Reinforcement  
saddle joint

### Reinforced pipe submitted to hydrostatic test (Cross section)

A hole was made artificially to simulate the situation that Slow Crack Growth, initiated at damages by squeeze-off at inner surface, reaches the outer surface.



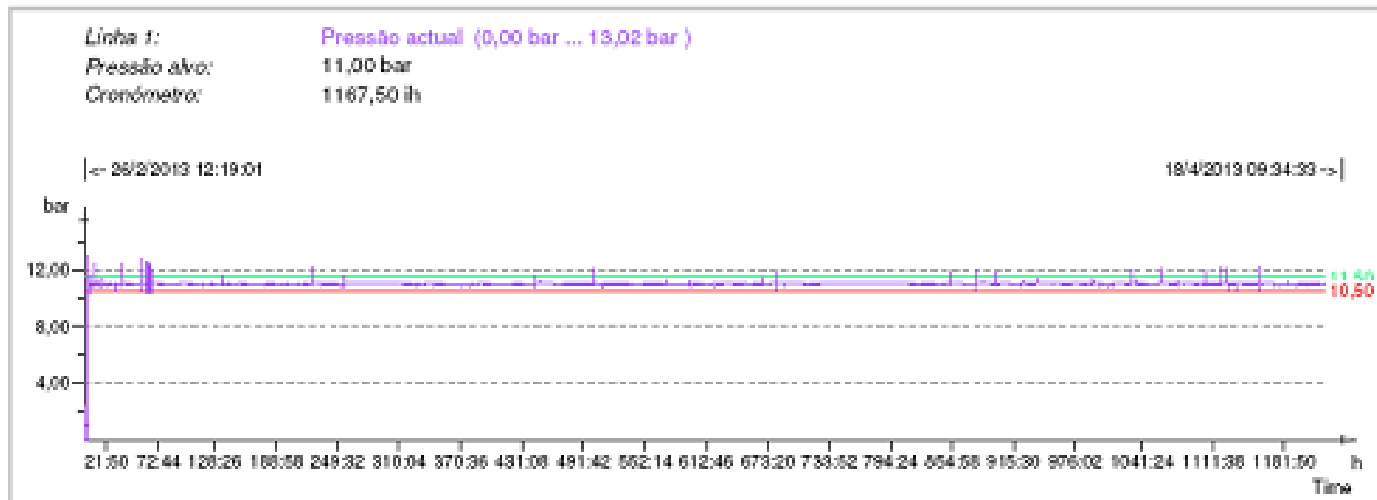
## 4. Procedure of squeeze-off and reinforcement



### Reinforcement fittings – Hydrostatic tests

- Short and long term accelerated hydrostatic tests (ISO 1167)
- 8 test pipes after squeeze-off, re-rounding, perforation and reinforcement
- All tests cleared short term and long term tests without any leakage

Test type	Circumferential stress $\sigma_c$	Required Min. Duration
Short term resistance to pressure at 80°C	5.5 MPa	165 hours
Long term resistance to pressure at 80°C	5.0 MPa	1,000 hours

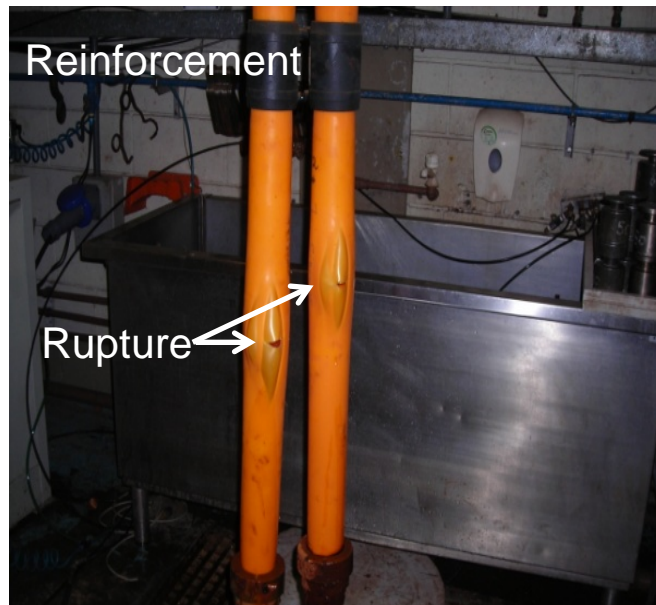




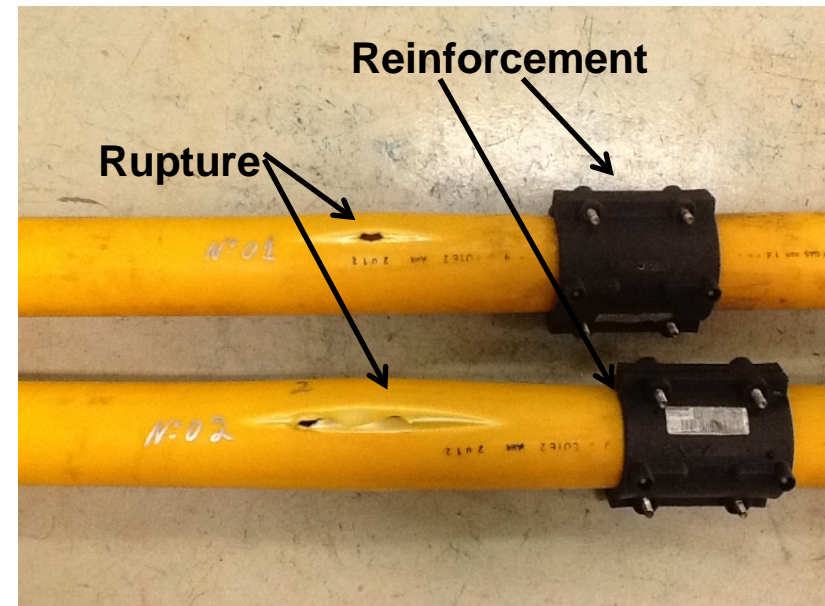
## 4. Procedure of squeeze-off and reinforcement

### Reinforcement fittings – Rupture tests

- 4 samples after the short and long term tests to compare the strength of reinforcement (coupler and saddle) in comparison to the pipe body
- In all cases, ductile rupture occurred in **pipe body**
- Results show that the reinforced part has more strength than pipe body after 1,000 hours hydrostatic pressure under accelerated condition.



Coupler reinforcement

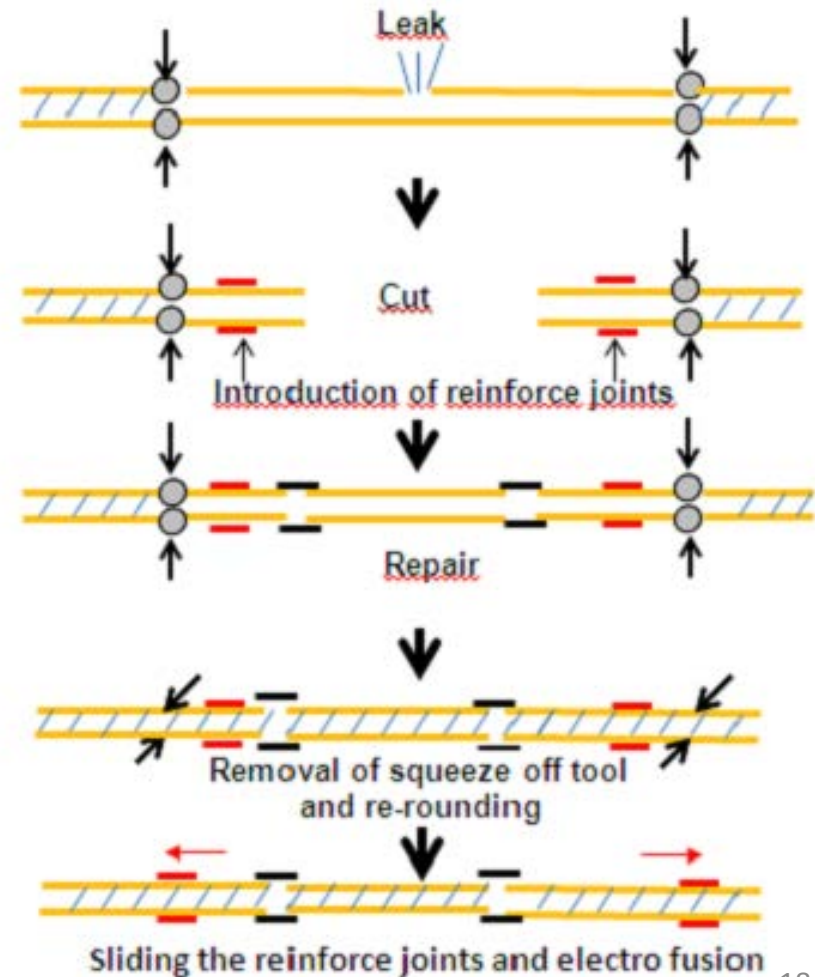


Saddle reinforcement

## 4. Procedure of squeeze-off and reinforcement

### Reinforcement method with coupler

- Tests showed that reinforcement fitting has more resistance than the pipe's body itself, and so it can assure long term integrity.
- A reinforcement method with coupler was proposed by SEKISUI, a Japanese polyethylene supplier, and is used in Japanese water industry.



## 4. Procedure of squeeze-off and reinforcement



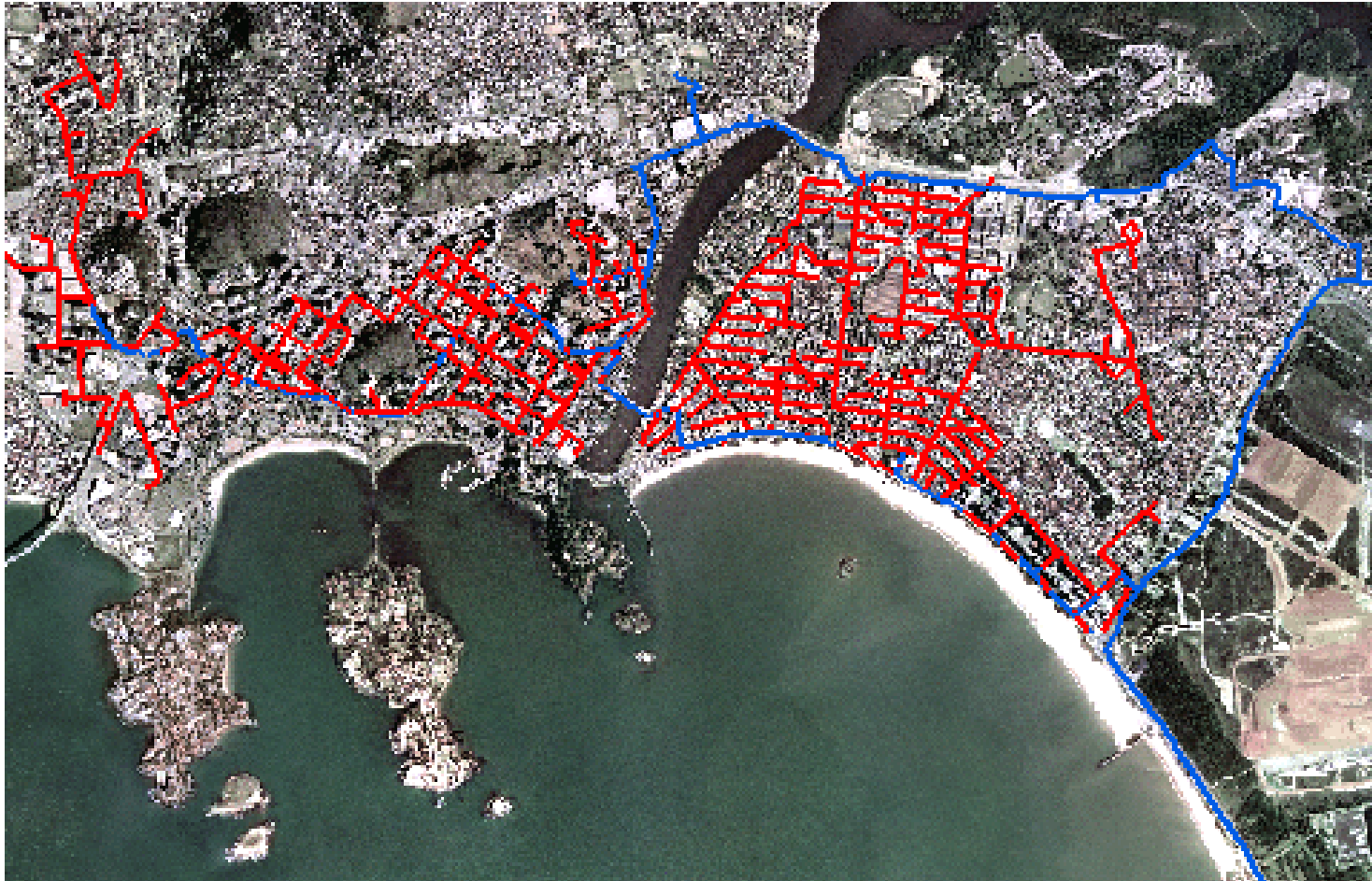
### **Suggested squeeze-off and reinforcement procedure**

- Always do reinforcement when squeeze-off is applied to PE 100 pipes (unless effective inspection and evaluation method of internal damage is established);
- Always do re-rounding with at least 10 minutes;
- An elliptical type is preferable for re-rounding;
- Try to use a coupler EF joint reinforcement which is full encirclement type. A saddle type is acceptable if there is difficulty to slide the coupler joint;
- Register the squeezed-off point in GIS and monitor in an Integrity Management Plan.

## 5. Comparisons between PE100 and PE 80

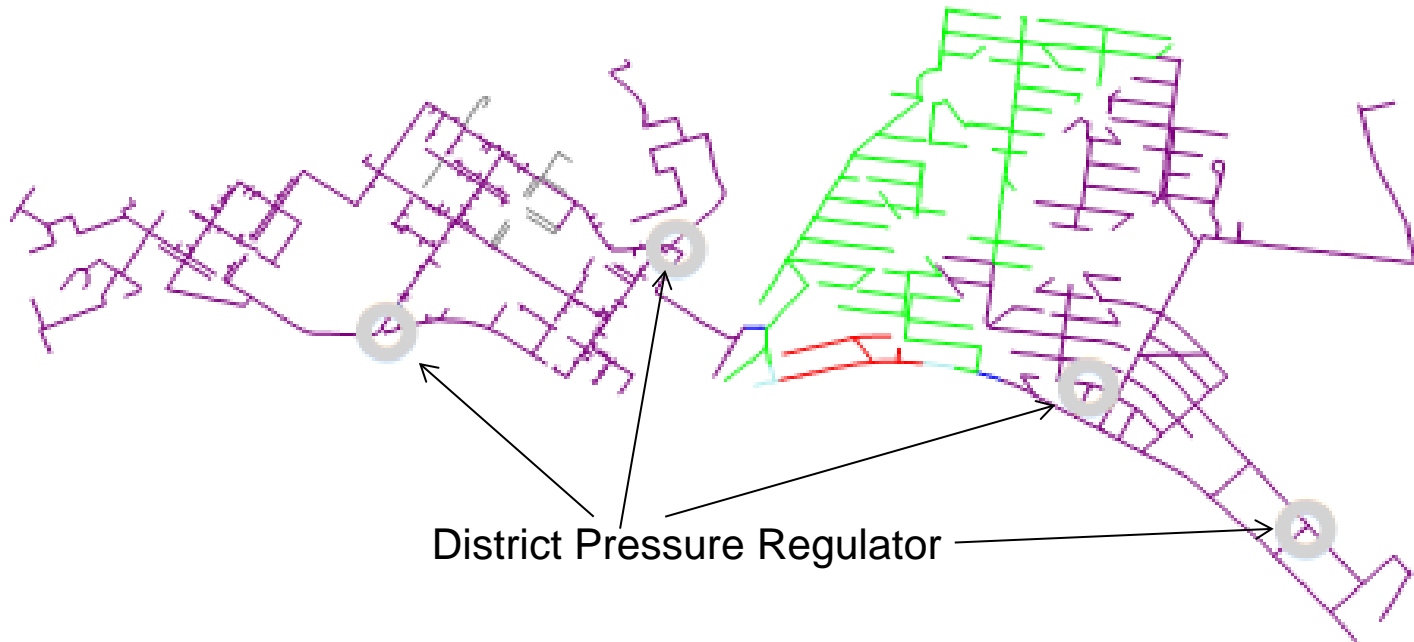


### City of Vitória – Espírito Santo



## 5. Comparisons between PE100 and PE 80

### Simulated grid – PE100 (Ø63)



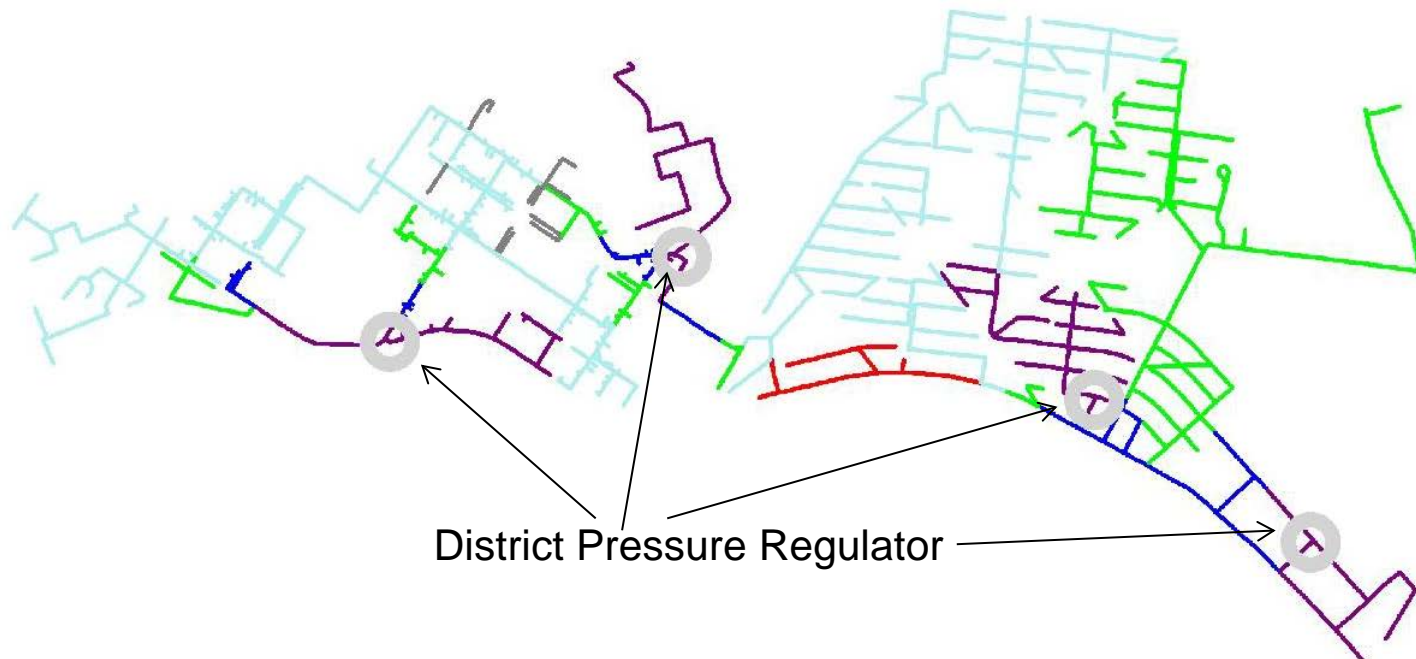
### Flow Capacity

Maximum Operational Pressure 0.7 MPa

Maximum flow capacity: **17,722 m<sup>3</sup>/hour**

## 5. Comparisons between PE100 and PE 80

### Simulated grid – PE80 (Ø63)



### Flow Capacity

Maximum Operational Pressure 0.4 MPa

Maximum flow capacity: **10,518 m<sup>3</sup>/hour**

## 5. Comparisons between PE100 and PE 80



### Installation Costs

In order to compare installation costs:

- Service costs were referenced to bid prices put forward by a contractor in 2013 to construct a network in the neighboring cities of Vila Velha and Serra.
- Material prices were checked with a national supplier. PE100 pipes were 12% more expensive than PE80 pipes.

#### PE100 (Ø63)

Service cost:	US\$ 3,685,665.65
Material cost:	US\$ 188,749.13
Total cost:	US\$ 3,874,414.78

#### PE80 (Ø63)

Service cost:	US\$ 3,685,665.65
Material cost:	US\$ 168,526.09
Total cost:	US\$ 3,854,191.74

## 5. Comparisons between PE100 and PE 80



### Flow capacity comparison

$$\text{PE100/PE80} = 17,722/10,518 = 1.68$$

**PE100 pipe has 1.68 times more flow capacity than PE80 pipe.**

### Installation cost comparison

$$\text{PE100/PE80} = 3,874,414.78/3,854,191.74 = 1.0052$$

### Summary of comparison

Flow capacity increase      **PE100 (Ø63)/PE80 (Ø63): +68%**

Installation cost increase      **PE100 (Ø63)/PE80 (Ø63): +0.52%**



## 6. Conclusions



- It is recommended to do reinforce to all PE 100 pipe section where squeeze-off is applied;
- The shape of roundness, which is obtained through re-rounding operation, is vital for secured reinforcement. Elliptical type re-rounding device has better re-rounding capacity than circular type and is recommendable;
- All reinforced PE100 pipes using EF coupler and EF saddle have passed accelerated 1,000 hours hydrostatic tests without any leakage;
- Reinforced part has more mechanical strength than the pipe body against internal pressure. Therefore, reinforcement can assure long term integrity of squeezed-off PE100 pipes;
- When comparing a PE100 with a PE80 pipe network, the first one may have a 1.68 times higher flow capacity with less than 1% increase in total installation costs.

# Thank you!

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