Proceedings of the 19th Plastic Pipes Conference
PPXIX
September 24-26, 2018, Las Vegas, Nevada

POLYETHYLENE PIPELINE PERFORMANCE AGAINST EARTHQUAKE

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Keywords: Polyethylene, earthquake, monolithic pipeline, flexibility

Abstract

In Japan, polyethylene (PE) pipe have been used for a long time, but its usage is limited for water service (low density PE / PE 50) and gas service (medium density PE / PE 80). However, after Hyogoken Nanbu Earthquake in 1995, it started to sell PE pipes for water distribution applications, because no damage on PE pipes at the earthquake was highly evaluated. In addition, long-term durability was also evaluated, and 31,700 km PE pipes for water distribution have been installed until 2015.

The main futures of PE pipe are two points, 1) pipes and fittings using a high-performance polyethylene material "PE 100", 2) pipes and fittings are formed by an integral structural by electro-fusion (EF) joints.

The "PE100" material developed in the late 1980s has many advantages for underground pressure pipeline, e.g. flexibility, impact resistance, anti-crack propagation performance and long-term durability. With respect to flexibility, in particular, the tensile yield strain is 8% or more, which is much larger than that of a metal material, and almost no deterioration in strength is caused by tension and compression until yield. In addition, both pipes and fittings can be provided of the same polyethylene material. We think that the characteristics of monolithic pipeline and the flexibility can absorb the ground distortion due to the earthquake.

We have verified the characteristics of PE pipeline from the viewpoint of seismic performance. 1) Basic characteristics (tensile, compression and repeated elongation), 2) Real scale simulated test, 3) Evaluating pipeline after actual earthquake. We measured strain distribution of pipe deformation by actual scale experiment simulating ground crack and unequal settlement. We selected hydrostatic pressure performance for the evaluating pipe and fittings through the real earthquake. As the result, we found that it has high earthquake resistance performance.

Also, we were investigating PE pipeline damages after actual earthquakes, e.g. 2007 Niigata Chuetsu-oki Earthquake, 2011 the Great East Japan Great Earthquake, 2016 Kumamoto earthquake. There is no damage by ground deformation, seismic motions and liquefaction, except for extreme cases like tsunami and ground collapse.

From the above, we can confirm that polyethylene pipe has high earthquake resistance. Furthermore, it has a superiority of long life and economic efficiency.

1. Introduction

It has been reported that there was no damage to gas polyethylene (PE) pipelines and water service PE pipelines during major earthquakes - including the 1995 Hyogoken Nanbu Earthquake. Also, PE pipe has been examined as JWWA (Japan Water Works Association) standard regarding water distribution pipeline. However, since its material characteristics are different from those of gas PE and water service PE pipes, we have conducted several experiments to evaluate the earthquake resistance of the PE pipeline.

First, the stress-strain characteristics of PE pipe were obtained by axial stretch and compression experiments for short pipe segments.

Next, full-scale experiments simulating fissure and uneven ground settlement along the pipeline's axis were carried out to obtain pipeline deformation and strain distribution.

Furthermore, evaluating pipeline after actual earthquake

In this study, the earthquake resistance of PE pipeline for water distribution was attempted through both experiments and investigations.

2. Material property of Polyethylene

Figure 1. shows the outline of the longitudinal stretch experiment.

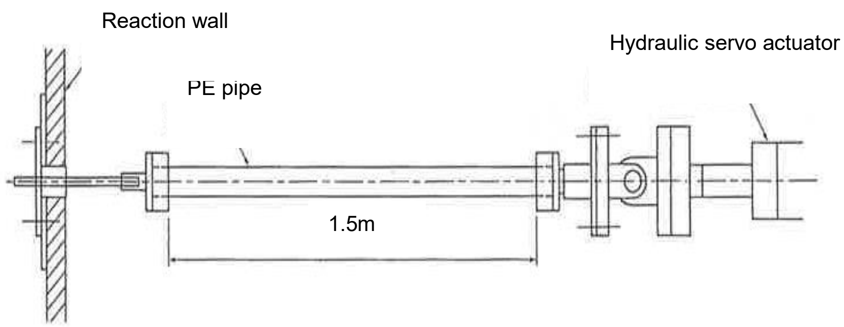


Figure1. Outline of the longitudinal stretch experiment

One end of PE pipe segment of OD90mm (SDR11) and a 1.5m pipe length was connected to reaction wall and the other end was connected to hydraulic servo actuator. By pulling the end of the pipe segment at a constant velocity, a longitudinal stretch was placed upon it.

And in the similar way to the stretch experiment, a longitudinal compression experiment was carried out to obtain the bucking behavior of the PE pipe. The nominal diameter of the pipe segment was OD180mm, SDR11 and its length was 50cm.

Both of tensile yield strain and compressive yield strain were about 8%.

In the Japan Water Work Association Design Code, it is mentioned that the tensile ground strain in perpendicular direction to normal line of the abutment may be set as 1.2% to 2%.

Therefore it can be considered that PE pipe has a sufficient ground strain absorbing capacity.

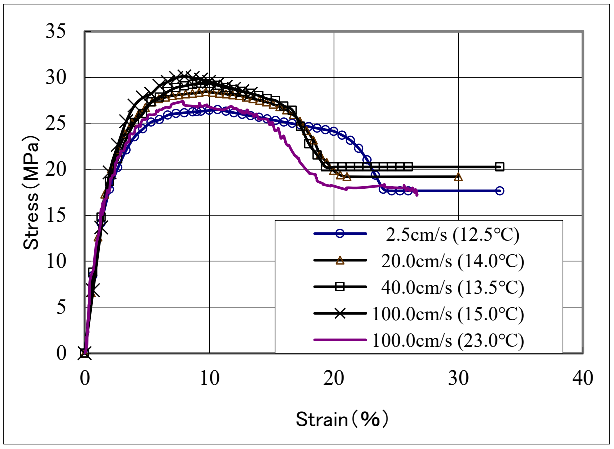


Figure.2. Tensile stress-strain curve

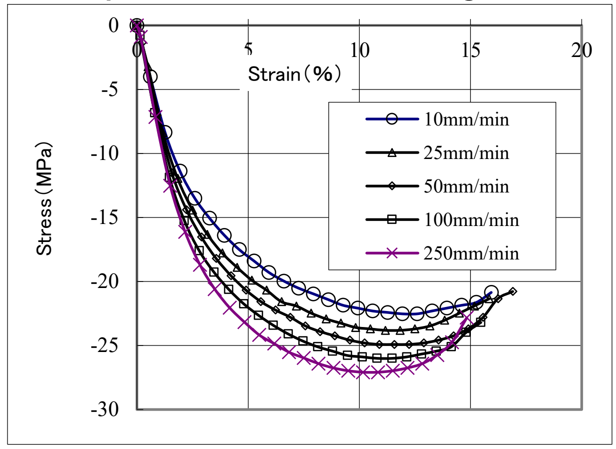


Figure.3. Compressive stress-strain curve

3.Polyethylene pipeline performance against earthquake

3.1 Seismic calculation

PE pipeline performance against earthquake is evaluated by comparing the allowable strain and sum of strain by seismic motion and stationary load.

Figure4. shows the outline of the ground model and pipeline location.

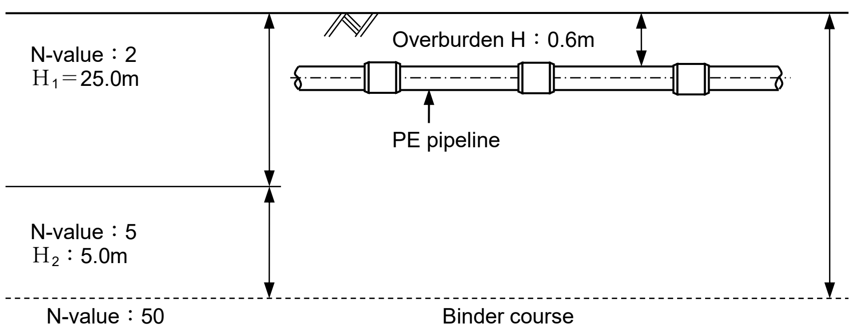


Figure4. Outline of the ground model and pipeline location

Ground distortion which is calculated by the seismic deformation method and is not decided by pipe material but by ground conditions, are 0.060% to level-1 earthquake motion and 0.502％ to level-2 earthquake motion.

Strain of PE pipeline is calculated with hard condition which is slip reduction factor = 1.0 (there is no slip between ground and pipeline).

And in view of poor ground, it is multiplied by η＝2 (Non-uniformity coefficient of ground)

Following above calculation, the strain by the level-2 earthquake motion is 1.01％ and strain by stationary load is 0.62％, sum of them is 1.63％.

In the Japan Water Work Association Design Code, It is mentioned that the allowable strain is 3.0%, so strain of seismic calculation is acceptable.

3.2 Seismic test（Repetitive expansion and contraction test）

Figure5. shows the procedure of repetitive expansion and contraction test.OD180mm , SDR11(t=11.4mm) , L=250mm）

Figure6. shows the result of the test which the cycles to failure after repetitive expansion and contraction with varying strain.2)

In the Japan Gas Association Design Code, It is mentioned that the equivalent to the number of repetitions to level-2 earthquake motion is as 5.6 cycles/ Average(12cycle/Maximum).
(Include 2011 The Great East Japan Earthquake)

It is confirmed that more than 600 cycles to failure have 50 times safety margin to maximum specified equivalent to the number of repetitions / 12 cycles.

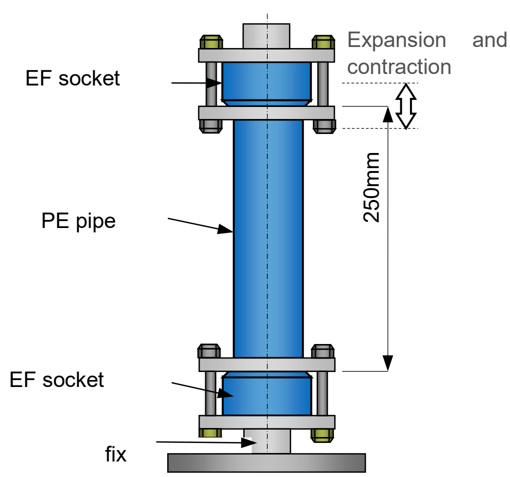


Figure5. Repetitive expansion and contraction test

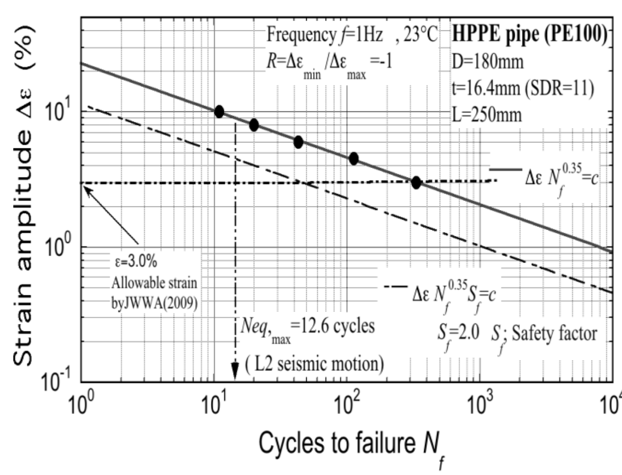


Figure6. Cycle of failure –strain curve

4.Real scale simulated test

4.1 Fissure Experiment

Figure 7. shows an outline of the fissure experiment.

A model pipeline with a 180mm nominal diameter was buried in a 50m-length of test enclosure. By separating the enclosure at the central portion using hydraulic jacks , one installed on each side , up to 50cm of relative movement was produced between the two 25m-length enclosures to simulate large fissure occurring during an earthquake. Then the pipeline strain distribution related to the fissure width was measured.

Figure 8. shows longitudinal strain.

As seen in this figure , there are little jumps at the jointsportions due to higher ground resistant force on the electro-fusion(EF)sockets. However,the maximum strain was about 3.2% ,which is smaller than the yield strain and no pipe breakage or cross-sectional shrinking were found at the central portion of the test enclosure.

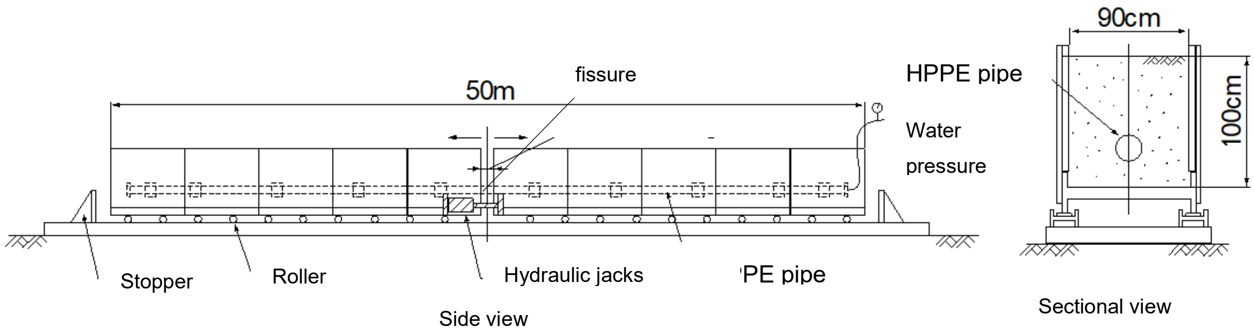


Figure7. Outline of fissure experiment

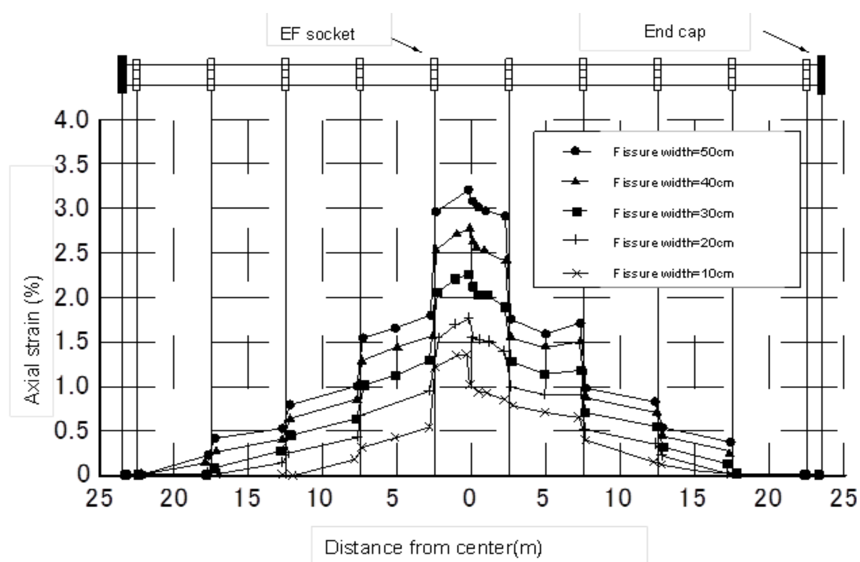


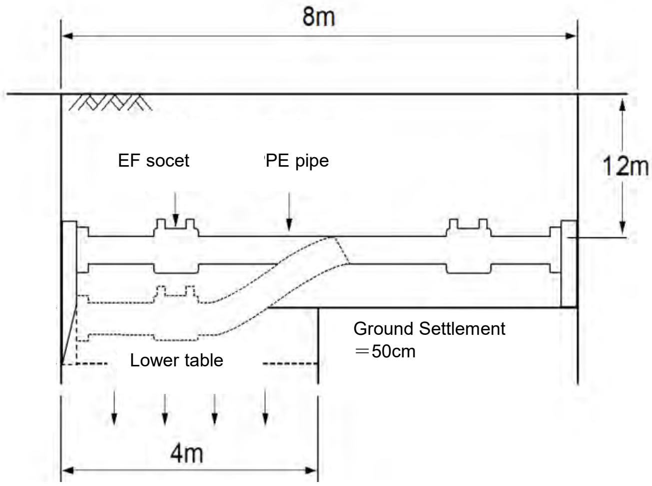
Figure8. Longitudinal strain distribution

4.2 Ground Settlement Experiment

Figure9. shows the outline of ground settlement experiment.

A model pipeline of OD125mm was buried the test pit eith 8m length and 2m width. By lowering the table on one side, uneven ground settlement (jumping) was produced. Ground settlement speed is 2cm/min. And max settlement is 50cm.

Figure10. shows the distribution of longitudinal pipe strain on the bottom surface of the pipe which was greater than that on the upper surface. The maximum strain appeared 1m from pipe center on the settlement side. However, the strain value was about 3%(this was less than yield strain),there was only minute deformation of PE pipeline and no local bending or leakage were found.



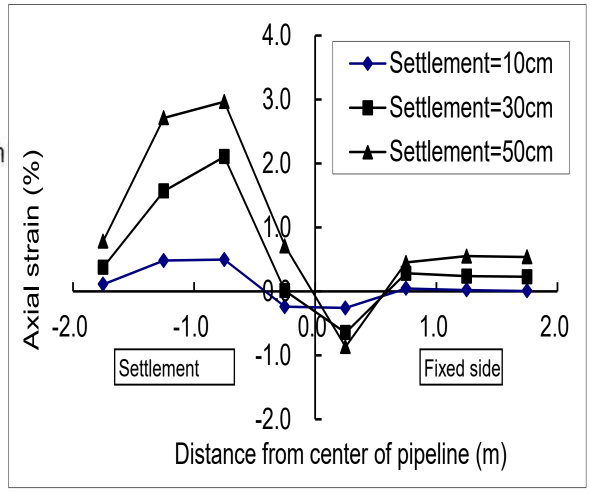


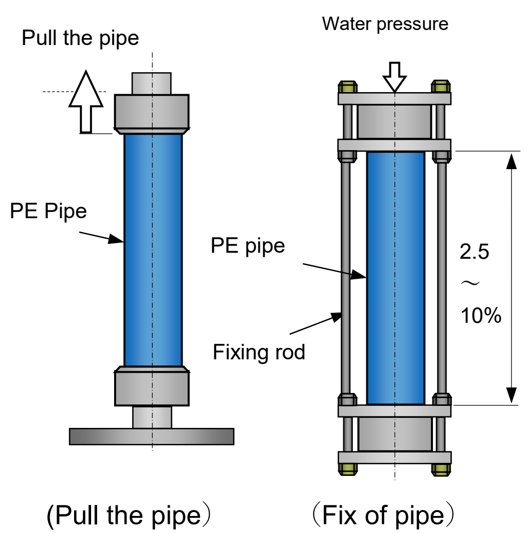
*Figure 9.*Outline of settlement experiment *Figure10.* Longitudinal strain distribution

4.3 Hydrostatic strength of strained pipe

To evaluate long term hydrostatic strength of strained pipe by earth quake, we did hydrostatic strength (creep) test with longitudinal strained pipe.

In the test, PE pipe(OD=90mm SDR11) was pulled to apply a strain of 2.5% to 10% in advance, then the creep test (under water at 20 ° C.) prescribed by ISO9080.

Figure11. shows the fabrication method of strained pipe.



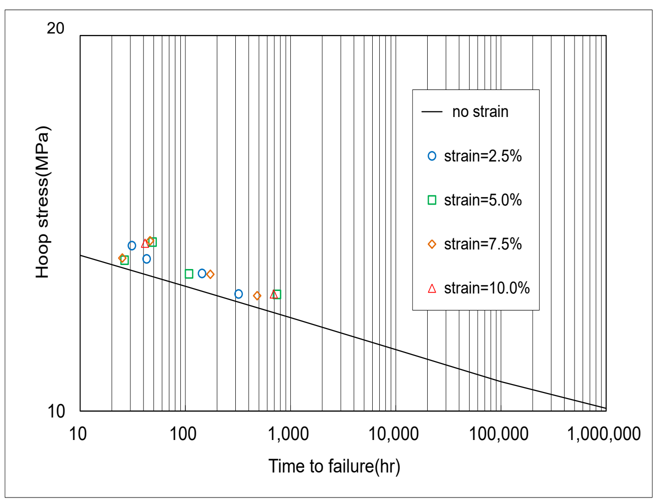


Figure 11. Fabrication method of strained pipe *Figure12.* Result of creep test

Figure12. shows the result of the creep test.

Performance of the strained pipe was better than unstrained pipe's one, therefore the PE pipe strained by ground displacement has same strength as new one.

5.Investigation of damaged by earthquake

In Japan, Polyethylene Piping System Integrated Technology and Engineering Center (POLITEC) have investigated the damage of the PE pipeline by the earthquake.

Table1. shows the investigated of damage by earthquake.
There were no damage by seismic motion.

Table1. Investigation of damage by earthquake

Name of earthquake	Magnitude	Total length of PE	Damage
2003 Miyagiken Hokubu Earthquake	6.4	10km	None
2003 Tokachi-oki Earthquake	8.0	2.6km	None
2004 Mid Niigata Prefecture Earthquake	6.8	11.4km	None
2004 Noto Hanto Earthquake	6.9	2km	None
2007 Niigataken Chuetsu-oki Earthquake	6.8	13km	None
2008 Iwate-Miyagi Nairiku Earthquake	7.2	47.4km	None
2011The Great East Japan Earthquake	9.0	996km	None
2016 Kumamoto Earthquake	7.3	147.7km	None

※Investigated by Polyethylene Piping System Integrated Technology ＆ Engineering Center (POLITEC：Japan)

Furthermore, there were no damage by the ground deformation and the liquefaction. But ‘tsunami’ of 2011 The Great East Japan Earthquake broke the seawall (levee) and some of PE pipeline at Shinchi -machi and Minamisouma city in Fukushima prefecture, other.

Picture1.and 2. show the PE pipeline where the seawall broken in Shinchi-machi.

Pic1. Damage example (1)

Pic2. Damage example (2)

However, where the seawall has not been destroyed by the tsunami, PE pipeline has been scouring was not destroyed.

Picture3.and 4. show the PE pipeline that not damaged by tsunami.

Pic3. PE pipeline example (1)

Pic4. PE pipeline example (2)

In order to investigate the HPPE pipe scoured by tsunami, took out the PE Pipe (*Pic3.*) used in Minamisouma city and evaluated them.
The PE pipe had been used from 1999 to 2011 The great East Japan Earthquake and suffered seismic motion by earthquake and deformation by tsunami. Furthermore, it was left at the site for more than half a year, it was also affected by UV.
Table2. shows the test result.

Table2. Test result

No.	Characteristic	Requirement	Result	standard
1	Elongation at break	≧350%	613%	ISO 4427-2
2	Yield stress	≧20MPa	28MPa	JWWA K 144[3)]
3	Hydrostatic strength at 20℃	No failure 12.4MPa 100h	No failure	ISO 4427-2
4	Hydrostatic strength at 80℃	No failure 5.4MPa 165h	No failure	ISO 4427-2
5	Destroying water pressure	≧4.0MPa	5.5MPa	JWWA K 144

It was confirmed that the performance of PE pipe which has been scouring by tsunami is same level as them of new pipe.

6. Conclusions

1. The yield strain of the PE pipe for both longitudinal tensile and compressive was about 8% and, until reaching the yield point ,the pipe evenly. In the JWWA Design Code, it is mentioned that the tensile ground strain in perpendicular direction to the normal line of the abutment may be set as 1.2 to 2%. Therefore, PE pipe can be considered to have a sufficient ground strain absorbing capacity.
2. Two type of full-scale experiments simurating a 50cm fissure and a 50cm of uneven ground settlement were conducted. The maximum pipe strain obtained was almost 3%

for both cases, so the PE pipeline can be considered to perform adequately against large ground deformation.
3. Evaluating pipeline after actual earthquake. We measured strain distribution of pipe deformation by actual scale experiment simulating ground crack and unequal settlement. We selected hydrostatic pressure performance for the evaluating pipe and fittings through the real earthquake. As the result, we found that it has high earthquake resistance performance.
Also, we were investigating PE pipeline damages after actual earthquakes, e.g. 2007 Niigata Chuetsu-oki Earthquake, 2011 the Great East Japan Great Earthquake, 2016 Kumamoto earthquake. There is no damage by ground deformation, seismic motions and liquefaction, except for extreme cases like tsunami and ground collapse.
From the above, we can confirm that polyethylene pipe has high earthquake resistance. Furthermore, it has a superiority of long life and economic efficiency.

Acknowledgments

I would like to offer my special thanks to professor Takashi Kuriyama (Yamagata University).

References

1) Japan Waterworks Association (JWWA), Investigation Report of the Higher performance polyethylene pipe and fitting for water supply, 1998
2) Seismic Performance Evaluation of Polyethylene Pipe for Water Distribution , 2018 Yuichi Shiohama , Hideki Omuro ,Takashi Kuriyama , Joji Ejiri , Michiyo Soejima
3) Japan Water Works Association (JWWA) Standard JWWA K 144 Higher performance polyethylene (PE) pipes for water supply

