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DEVELOPMENT OF PROTECTIVE SHEETING FOR PE PIPES

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ABSTRACT

Polyethylene (PE) pipes for gas supply, which have been widely used in recent years, have superiority in installability, seismic performance and corrosion resistance, while their resistivity against external force such as from strikes by excavator bucket edges is inferior to metal pipes. Under some installation conditions, it is necessary to take appropriate protection measures for PE pipes. Use of protective steel sheets or concrete plates that are laid directly on pipes is commonly applied. However, their poor installability due to their heavy weight, as well as a high total cost including installation expense, remains a challenge.

To resolve this issue, the authors developed a unique PE pipe protective sheeting, which is superior compared to conventional protectors. It is characterized by decreasing the damage to a buried PE pipe surface within the rated value against assumed external force, for instance, due to being struck by an excavator bucket edge. It also contributes to an improvement in installability and workability as well as reduction in total cost including installation expense. This protective sheeting is comprised of two types of materials with different properties: reinforcing fiber and nonwoven material. The reinforcing fiber, which has a superior failure-bearing effect, protects against damage attributable to direct strike by an excavator bucket edge to a PE pipe surface. Nonwoven material is effective in mitigating external force and impact absorption.

To verify protection ability, we conducted performance testing by simulating two types of load: an impact load and a pressing load, which may be applied by an excavator bucket edge, by using both testing apparatus and an actual excavator used on site. As a result, we successfully attained the required protection ability using three-layered sheet wrapping around a PE pipe with a nominal diameter of ⌀100 bore, as well as two-layered sheet wrapping around PE pipes with ⌀150 and ⌀200. It was also validated that installation expense can be cut by up to 30%, since this product features flexibility and light weight materials, and can be installed quickly. This product has been applied company-wide since 2007, and has been available in the Japanese market. As of March 2011, about 13,000m^2 of this protective sheeting had been installed in Japan.

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1. INTRODUCTION

Polyethylene (PE) pipes and joints for gas supply were officially designated as conforming to Japanese Industrial Standards (JIS) in 1979. And in 1982, technical criteria for low pressure (LP) gas piping materials were prescribed by a related ordinance of the Gas Business Act. Subsequently, electrofusion joints with their superiority in installability, which appeared in the 1990's, gained rapid acceptance nationwide, since their excellent seismic performance was well demonstrated at the time of the South Hyogo Prefecture Earthquake that occurred in January 1995. Currently, PE pipes are being used for most newly-installed LP gas pipes. Against a background of prevailing public acceptance of PE pipes, because of their corrosion resistance and seismic performance, application of PE pipes for not only LP but also for medium pressure (MP) ranging from 0.1MPa up to 0.3MPa were demanded by gas suppliers[1]. As a result of safety examinations and compatibility screening, the applicable range of PE pipes was officially extended up to 0.3MPa in March, 2003.

PE pipes, which have been widely used in recent years, have superiority in installability, seismic performance and corrosion resistance, while their resistivity against external force such as from strikes by excavator bucket edges is inferior to metal pipes. Under some installation conditions, it is necessary to take appropriate protection measures for PE pipes. Use of protective steel sheets or concrete plates that are laid directly on pipes is commonly applied. However, their poor installability due to their heavy weight, as well as a high total cost including installation expense, remains a challenge. To resolve this issue, a unique PE pipe protective sheeting, which is installed by wrapping it around a PE pipe has been developed. This product is characterized by decreasing the damage to a buried PE pipe surface within the rated value against assumed external force, for instance, due to being struck by an excavator bucket edge. It also contributes to an improvement in installability and workability as well as reduction in total cost including installation expense, compared to conventional protectors.

2. DEVELOPMENTAL CONCEPTS

The authors originally developed the unique PE pipe protective sheeting focusing on the following developmental concepts: 1) high protection efficiency, 2) ease of installation, and 3) low-cost.

2.1 High protection efficiency

PE pipe damage attributable to mechanical shock or external force, for instance, due to being struck by an excavator bucket edge during road excavation work, is assumed.

- The sheeting must reduce damage to a pipe surface to within the rated value against assumed mechanical shock.
- The sheeting must provide enough protection performance for buried PE pipes against external force not only from above but from every direction.
- Long-term protection performance in buried condition must also be maintained.

2.2 Ease of installation

Materials, which have superiority in installbility, compared to conventional installations such as protective steel sheets or concrete plates, is to be used.

- The sheeting must be light-weight.
- The sheeting must provide flexible workability, capable of following the shapes of joints such as bending and branched sections.
- The sheeting made from the same materials must be suitable for use over a range of available bores (i.e. ⌀100, ⌀150, ⌀200).

2.3 Low-cost

Protective sheeting is to be lower in cost than conventional installations such as protective steel sheets or concrete plates.

- Using commercially-available materials, material sourcing cost must be cut.
- Through improvement in installability, total cost including installation expense must be cut.

3. FEATURES OF PROTECTIVE SHEETING

3.1 Protective sheeting materials

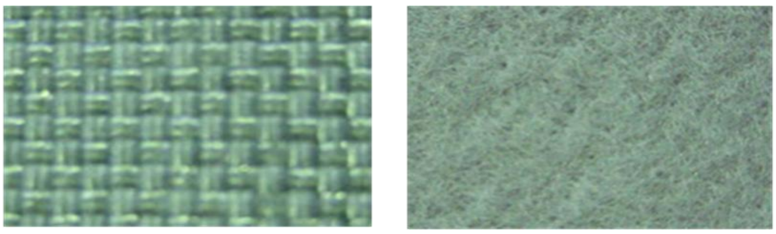
To protect PE pipes from mechanical shock or external force such as that received when being struck by an excavator bucket edge, protective sheeting is required to have a mechanism capable of dispersing or mitigating such damage so that applied external force is not directly transmitted to PE pipe surface. In light of this, we decided to create a unique protective sheeting which is comprised of two types of materials that have different properties: reinforcing fiber and nonwoven material, as shown in Photos 1 and 2, and Fig. 1. With a focus on light weight for easy handling, and flexible workability to allow all-round wrapping around a PE pipe, we selected optimal fiber materials.

3.1.1 Reinforcing fiber

Reinforcing fiber must be capable of dispersing external force and protect against damage attributable to direct strike by an excavator bucket edge to a PE pipe surface, functioning to provide a superior failure-bearing effect. The fiber selected is made of polypropylene (PP), or synthetic resin, which is characterized by its light-weight, and heat and chemical resistance. In particular, fiber sheeting made from this material using spread tows, has a rigid, high-tensile strength, and high-flexing performance; and it is widely used for industrial sheeting and soil reinforcing material for bank protection work since it can easily be purchased at low-cost.

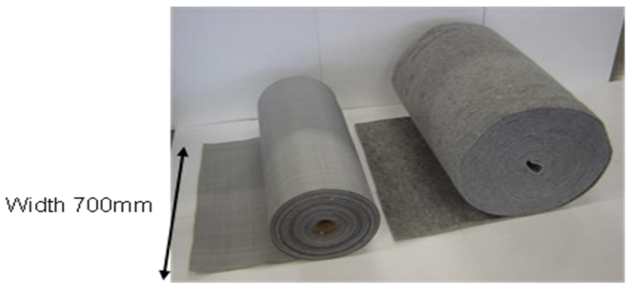
3.1.2 Nonwoven material

Nonwoven material, which is characterized by leno-weaving, must be capable of mitigating external force attributable to strike by an excavator bucket edge on a PE pipe, functioning to provide a high impact absorbing effect. Application of nonwoven sheeting is prevalent in soundproofing, vibration-proofing and filters for dust-proofing. In particular, we have employed eco-friendly, low-cost recycled material made from 100% polyethylene terephthalate (PET).



Reinforcing fiber　　Nonwoven material

Photo 1: Protective sheeting materials



Left：Reinforcing fiber
Right　Nonwoven material

Photo 2: Appearance of protective sheeting

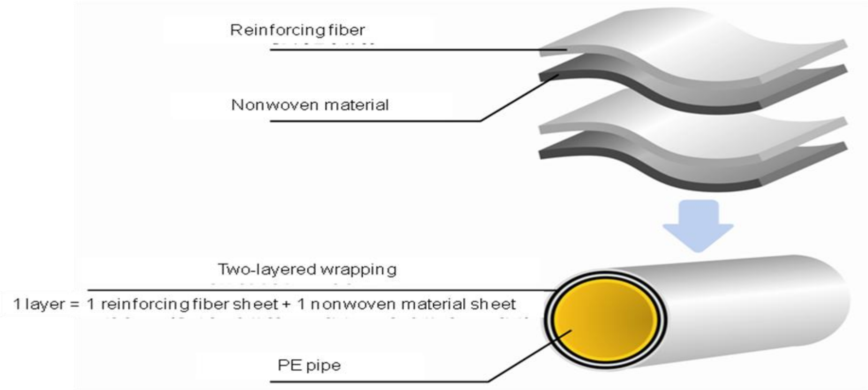


Fig. 1: Protective sheeting installation

3.2 Protection performance requirements

It is considered that there are two categories of external force, i.e. impact load and pressing load, either of which may be applied by excavator bucket edge during road excavation work. Impact load is applied when a bucket edge is driven into a road surface to be excavated, while pressing load is applied when an excavator bucket scoops sand or soil. Under general road working conditions, it is thought that pressing load is applied more frequently than impact load. With this background information, required values for pressing load and impact load were determined by varying testing conditions in performance testing, while our criterion of protection performance was placed mainly on pressing load.

3.2.1 Protection performance against pressing load

From technical guidelines, it is known that for a PE pipe with V-shape flaw depth equivalent to 20% or less of pipe wall thickness, there is little decrease in pipe strength.[2)] With this understanding, we pursued development of sheeting with performance against pressing load such that a PE pipe wall thickness reduction rate of 20% or less could be maintained as a rated value, in which case replacement of dented/flawed sections is unnecessary. This reduction rate can be calculated by the following equation:

Wall thickness reduction rate =

$$\frac{\text{Wall thickness before pressing load is applied (mm)} - \text{Wall thickness after pressing load is applied (mm)}}{\text{Wall thickness before pressing load is applied (mm)}} \times 100$$

3.2.2 Protection performance against impact load

When an excavator bucket is driven into a road surface to be excavated, and its edge directly contacts a PE pipe, considerable damage will be sustained by the pipe, compared to the impact of soil scooping. However, this kind of strike rarely happens in road excavation work. From the viewpoint of economic efficiency, we ensured protection performance against impact load, aimed at prevention of PE piping penetration. Although there may be need to repair damaged sections, our ultimate target was on prevention of gas leakage and secondary disaster.

3.3 Pressing load estimation

To examine protection performance required for protective sheeting, we measured the intensity of pressing load which would be applied on a PE pipe wrapped with protective sheeting by using a large excavator (bucket capacity: $0.4m^3$) of a type commonly employed during road excavation work at locations close to buried gas piping. We measured bucket edge load when the equipment operator was excavating a road surface and got a response as the bucket edge struck an underground gas pipe, as shown in Photo 3. As a result of measurement, pressing load was evaluated to be 15kN.

Then, we fabricated withstand load testing apparatus to reproduce a pressing load (15kN) indoors, in order to practice quantitative evaluation by implementing withstand load testing and perform quality control after commercialization, as shown in Fig. 2. Using this testing apparatus, pressing load equivalent to that generated by an excavator could easily be reproduced within a limited, indoor space.

PE pipes with protective sheeting installed

Taking measurements

Photo 3 : Pressing load measurement

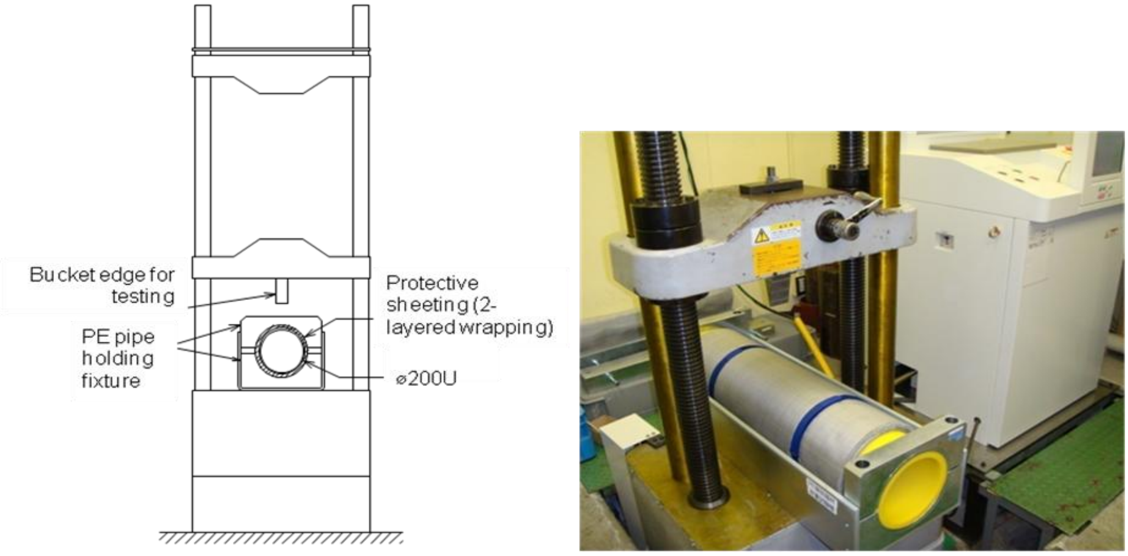


Fig. 2: Withstand load test

3.4 Optimized specifications of protective sheeting materials

Work was done to optimize the specifications of the reinforcing fiber and nonwoven material, which comprise the protective sheeting.

Reinforcing fiber:

We fabricated three kinds of reinforcing fiber sheet prototypes, to examine individual failure-bearing effects by varying fiber size, weaving density, and weaving pattern. Table1 shows major specifications of reinforcing fiber sheet prototypes. Each of the prototypes was wrapped around a PE pipe to compare its wall thickness reduction rate under pressing load. As a result of testing, it was found that prototype #1, which has an extremely fine weave, but which has no twisted warp or woof, had a high failure-bearing capacity against both pressing and impact loads. Figure 3 shows the result of failure-bearing capacity testing.

Nonwoven material:

For selection of nonwoven material, our focus was on low-cost recycled admixture materials comprised of polyethylene, polypropylene, polyethylene terephthalate (PET) etc. It was found that there was lot-to-lot variation in the proportions of each admixture constituent, resulting in instability in performance. After this finding, material made from 100% PET, which has optimum nonwoven material density to maximize impact absorbing effect, was finally selected.

Prototype	Fiber size (Tex*)	Weaving density (number of fibers per 25.4mm)	Weaving pattern
#1	256	15	Warp: not twisted Woof: not twisted
#2	278	14	Warp: twisted Woof: not twisted
#3	278	14	Warp: twisted Woof: twisted

*1 Tex = Fiber of 1g in weight with a length of 1,000m

Table 1: Major specs of reinforcing fiber sheet prototypes

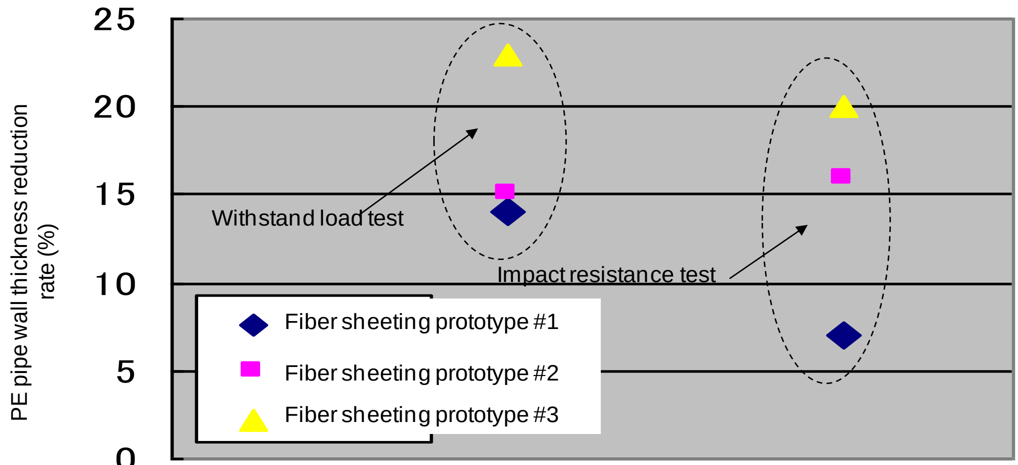


Fig. 3: Failure-bearing capacity test result

3.5 Determination of optimum number of layers of protective sheeting to apply around PE pipe

Since PE pipe wall thickness varies according to bore size, as shown in Table 2, wall thickness reduction rate also varies accordingly even if identical external forces are applied on PE pipes of different bores. Therefore, we examined the optimum number of protective sheet layers to apply to meet required performance.

Test method:
A PE pipe wrapped with protective sheeting was set on a withstand load testing apparatus. Pressing load of 15kN was applied in a vertical direction perpendicular to the pipe axis. 30 minutes after applied load was released, wall thickness was measured.

Test result:
Table 3 shows PE pipe wall reduction rate under pressing load according to number of layers of protective sheeting. For a pipe with a bore of ⌀100, the wall thickness reduction rate in the case of 2-layered wrapping exceeded 20%. That in the case of 3-layered wrapping was reduced to 15%, meeting the required performance against pressing load. For a pipe with a bore of ⌀150, the rate in the case of 2-layered wrapping was 11.5%. And for a pipe with a bore of ⌀200, the rate in the case of 2-layered wrapping was 2.7%, a high performance.

As a result of measurements, we standardized the wrapping of protective sheeting around pipes with both ⌀150 and ⌀200 at two times (i.e. 2-layered wrapping), and wrapping for ⌀100 pipe at three times (i.e. 3-layered wrapping). Further, in an impact test using heavy construction equipment, we also confirmed that the protective sheeting met the required performance against impact load, by applying the optimal number of layers of protective sheeting wrapping around PE pipes demonstrated in the case of pressing load. Prevention of gas leakage due to pipe penetration was successfully demonstrated.

PE pipe bore	Min. wall thickness (mm)
⌀100 #1 U pipe	8.5
⌀150 #1 U pipe	12.3
⌀200 #1 U pipe	16.0

Table 2: PE pipe wall thickness and bore

PE pipe bore	2-layered wrapping		3-layered wrapping	
	Wall thickness reduction (mm)	Wall thickness reduction rate (%)	Wall thickness reduction (mm)	Wall thickness reduction rate (%)
⌀100 #1 U pipe	Over 1.7	Over 20.0	1.37	15.0
⌀150 #1 U pipe	1.5	11.5	1,01	7.7
⌀200 #1 U pipe	0.45	2.7	—	—

Table 3: PE pipe wall thickness reduction rate under pressing load according to number of layers of protective sheeting

4. PROTECTIVE SHEETING EVALUATION TESTING

The final developmental stage was validation of this newly-developed protective sheeting through evaluation testing to verify performance degradation due to moisture, chemical-resistance, and influence of the protective sheeting being buried under road underground.

4.1 Performance degradation due to moisture

Under actual underground environments in which pipes are buried, moisture from rainfall or ground water may be contained in nonwoven material of protective sheeting. We examined whether the sheeting cushioning material and impact absorbing effect would degrade due to moisture content. In testing, we measured the wall thickness reduction rate under both pressing load and impact load of protective sheeting in which water was contained, and compared these with results under dry conditions. As a result, it was shown that wall thickness reduction rate under pressing load was 20% or less and that no penetration under impact load appeared in the case of normally-wrapped protective sheeting. There was no specific difference compared to wall thickness reduction rate under dry conditions. Table 4 shows the result of performance degradation due to moisture in the case of a ⌀200 pipe.

4.2 Chemical-resistance

We examined whether any soil components would influence reinforcing fiber or nonwoven material negatively. In the test, reinforcing fiber and nonwoven material were soaked in different test fluids containing acid, alkali, saline water, bacteria, and other soil components over a certain period, and evaluated material chemical-resistance performance [3) 4)]. As a result, it was found that there were no specific differences in external appearance, nor was there any degradation in either tensile strength or elongation. It was confirmed that there were no changes in material properties of either reinforcing fiber or nonwoven material as a result of extended exposure to an underground environment. Table 5 shows the results of chemical-resistance testing.

4.3 Influence on roads of buried PE pipe with protective sheeting

When a PE pipe onto which protective sheeting has been wrapped is buried, it is plausible that nonwoven material would be gradually compressed due to soil load after road surface recovery is completed, which might result in ground subsidence. In a laboratory test, soil load calculated from the burial depth of a PE pipe was applied on 2-layered protective sheeting comprising reinforcing fiber and nonwoven material, for one week. Then, sheet thickness after soil load had been applied was compared to initial thickness. In addition, we implemented a field density test[5)] to examine ground conditions of road bed and road surface, by burying pipes wrapped with the sheeting under actual road and pedestrian areas. The results of both laboratory test and field density test showed that there were no indications of road subsidence. Therefore, if surface compaction can be properly conducted after road surface recovery is completed, it is considered that no road subsidence attributable to protective sheeting will occur. Photo 4 shows the conditions of the field density test.

Test item	PE pipe wall thickness reduction rate (%)	
	Dry conditions	With moisture content
Under pressing load	3.5	4.5
Under impact load	3.7	4.4

Table 4: Performance degradation due to moisture: ⌀200 #1 U pipe

Reinforcing fiber		Initial value	Sulfuric acid aqueous solution	Aqueous sodium hydroxide	Sodium chloride solution	Hydrogen sulfide solution	Tap water
			PH4	PH10	5W/W%	Saturation	–
Tensile strength (N)	1	862.8	910.7	944.3	938.5	895.4	927.5
	2	953.8	913.1	906.6	894	903.1	894.9
	3	907.8	906.4	953.4	919.3	953.4	936.6
	Average	908.1	910.1	934.8	917.3	917.3	919.7
	Rate-of-change %	–	0.2	2.9	1.0	1.0	1.3
Elongation (%)	1	10.1	9.3	9.6	9.8	9.6	10
	2	9.6	9.6	9.2	9.2	9	9.6
	3	9.2	9.2	8.7	9.4	9.1	10.2
	Average	9.6	9.4	9.2	9.5	9.2	9.9
	Rate-of-change %	–	-2.8	-4.8	-1.7	-4.2	3.1
External appearance			No change	No change	No change	No change	No change

Nonwoven material (100% recycled PET)		Initial value	Sulfuric acid aqueous solution	Aqueous sodium hydroxide	Sodium chloride solution	Hydrogen sulfide solution	Tap water
			PH4	PH10	5W/W%	Saturation	–
Tensile strength (N)	1	59.2	72.3	47.1	70.3	51.6	73.3
	2	50.2	70.5	60	67.1	66.4	59
	3	63.4	64.4	68.5	65.9	58.8	65.2
	Average	57.6	69.1	58.5	67.8	58.9	65.8
	Rate-of-change %	–	19.9	1.6	17.7	2.3	14.3
Elongation (%)	1	8.7	9	7.9	10.7	9.4	12.6
	2	9.5	12.4	8.3	10.3	11.4	14.1
	3	9.7	8.9	12.9	12.8	11	12.3
	Average	9.3	10.1	9.7	11.3	10.6	13.0
	Rate-of-change %	–	8.6	4.3	21.1	14.0	39.8
External appearance		–	No change	No change	No change	No change	No change

Table 5: Results of chemical-resistance testing

Soil filling | Road surface | Road bed

Photo 4: Field density test

5. ESTABLISHMENT OF CRITERION

At the stage when this protective sheeting was commercialized and distributed in the Japanese market, it was important to establish and maintain quality control criterion prior to shipping. We therefore established a specific quality inspection method to examine whether the product would meet the required level of quality.

<u>Quality inspection relating to pressing load</u>:

Using withstand load testing apparatus, we conducted a laboratory test to examine protective sheeting performance against a pressing load applied by heavy construction equipment. A PE pipe wrapped with protective sheeting (⌀200 #1 U pipe, 2-layered wrapping) was held in place using a holding fixture mounted on the testing apparatus. A pressing load of 15kN was applied in a vertical direction perpendicular to the pipe axis by means of thrusting a simulated bucket edge onto the pipe. 30 minutes after applied load was released, the wall thickness of the section to which pressing load had been applied was measured.

<u>Quality inspection relating to impact load</u>:

Since there was no testing apparatus capable of quantitatively reproducing the impact of a strike by an actual excavator bucket, we fabricated original impact testing apparatus, as shown in Fig. 4. A PE pipe wrapped with protective sheeting (⌀200 #1 U pipe, 2-layered wrapping) was held in place on the testing apparatus. A simulated, unguiform bucket edge with a weight of 25 kg was allowed to swing down from an angle of 90 degrees. 30 minutes after applied load was released, the wall thickness of the section to which impact load had been applied was measured.

Based on the results of the above tests, we established a criterion for protective sheeting performance quality such that the rated value of PE pipe wall thickness reduction rate should be less than 20% in the cases of application of both pressing and impact loads, since it is known from technical guidelines as noted above that with this degree of damage, that is with dent/flaw depth of 20% or less of pipe wall thickness, there is little reduction in pipe strength.

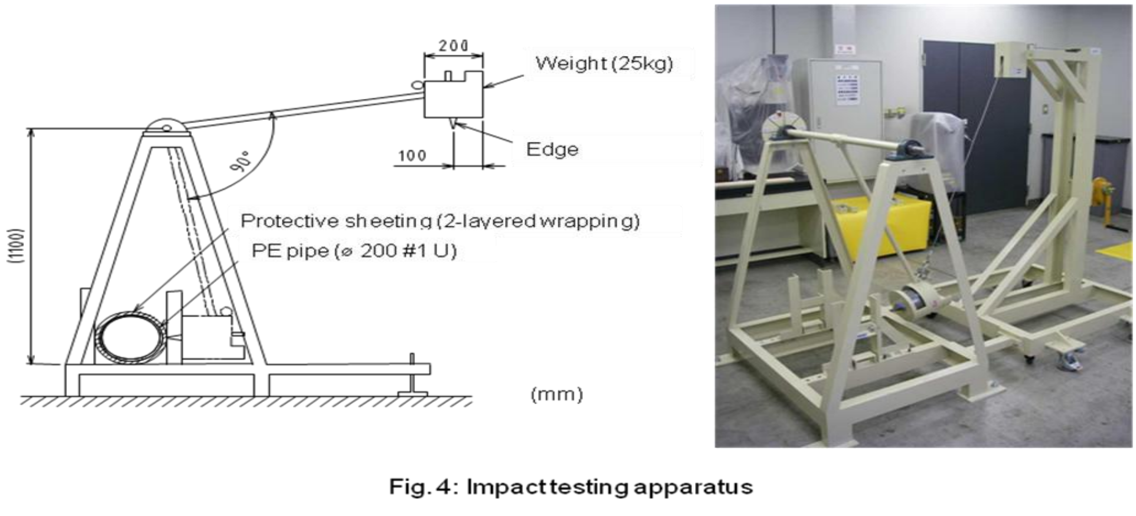


Fig. 4: Impact testing apparatus

6. BENEFITS THROUGH INTRODUCTION AND INSTALLATION ACHIEVEMENTS

Through introduction of this newly-developed protective sheeting, several benefits have been demonstrated as follows:

Improvement in installability:
Due to its light weight and high flexibility, it could be confirmed that the protective sheeting has superior installability, with insertion into culverts and/or conduits as well as rapid, streamlined fitting being achieved in a short period of time. Using only general-use cutting tools, the sheeting can be freely cut in a simple manner, thus, sheeting installation is flexible and sheeting can be fitted to special joints for bent or branched pipes of different shapes and dimensions, as shown in Photo 5.

High cost-performance:
In general, total installation cost including material cost, transportation cost, and fitting cost is estimated at about 4,500 yen per meter of pipe in the case of conventional protection using steel plates (thickness: 6mm). However, in the case of this newly-developed protective sheeting, the total cost can be reduced to about 3,000 yen per meter of pipe (⌀200), equivalent to a cost reduction of about 30%.

This product has been applied company-wide since February 2007, and has been available in the Japanese market since March 2008. As of March 2011, 29 companies in total have installed the sheeting, accounting for accumulated installation of about 13,000m of pipe in total (incl. installation by Saibu Gas), as shown in Table 6.

For bent pipe

For branched pipe

Photo 5: Protective sheeting installation

Year	Number of companies which introduced protective sheeting	Amount introduced (m of pipe)	
		Reinforcing fiber	Nonwoven material
2007	1	100	100
2008	7	2,000	1,780
2009	10	3,300	3,000
2010	9	3,100	3,120
2011	2	5,300	5,200
Total	29	13,800	13,200

Table 6: Installation record (from 2007 to March 2011)

7. CONCLUSION

Japan is prone to earthquakes. Measures to counteract seismic activity in the gas supply industry, aimed at stable supply and safety improvement, are crucial. During the massive earthquake off the Pacific coast of northeastern Japan that occurred in March 2011, and other earthquakes that occurred in 2004 and 2007, this PE piping demonstrated its potential to withstand earthquakes. During the last 10 years, accumulated installation of PE piping has exceeded 70,000km, equivalent to 2.5 times compared to the accumulated installation 10 years ago, in Japan. We believe that this protective sheeting will greatly contribute to improvement of the integrity of the gas pipe network and lead to the further expansion of PE pipe installation in the future.

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