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Development of a new type of GRP pole guard

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Abstract—Many roadside utility poles are covered with steel guards to protect them from car collision damage and to make them more visible at night. But steel has its disadvantages in this application: It is difficult to handle during installation, and rust causes poor appearance and, ultimately, failure of the part.

A new GRP pole guard has been developed and is already in use in Japan. This new pole guard takes advantage of GRP's elasticity to offer better durability and easier handling. The new GRP pole guard is self-attaching; thus it can be installed and removed without bolts or belts. In addition, posters and fliers will not adhere to the GRP's textured surface. We studied the optimum design to capitalize on GRP's properties. We used curved beam theory and finite element analysis to design the shape, and studied fiber structures to improve strength and rigidity. This specially shaped GRP pole guard is made using the pultrusion molding method.

Keywords: Fiber reinforced composite; pultrusion; self-holding force; pole guard.

1. INTRODUCTION

GRP has many advantages: low density and high strength, corrosion resistance, productivity and freedom of design. It is used for products with corrosion resistance, in automotive and power/electric parts, and so on. New features and a new design method for GRP have been developed. As a result, a product with a self-holding force was created by optimizing the elastic transformation and elasticity of the GRP material. The product was developed for a guard to protect utility poles.

In Japan, most utility poles are made of steel-reinforced concrete. Automobile collisions with such poles lead the steel reinforcements in the concrete to rust from exposure to the atmosphere. This reduces the strength of the utility pole. Consequently, roadside utility poles are covered with guards to protect them from collision damage.

Traditionally, steel guards are attached to utility poles using metal belts with bolts. These are difficult to handle during installation, and sometimes pedestrians are scratched by the bolts.

The new GRP pole guard was developed using the self-holding force of the material. The new guard grips the pole by itself without bands and bolts. In addition, posters and fliers will not adhere to its surface, it is visible to drivers at night, and it harmonizes with the urban scenery.

2. PRODUCT DESIGN

2.1. The concept of self-holding force

Load (stress)–displacement (strain) relationships for GRP, steel and plastics are shown in Fig. 1. Unreinforced plastics have low strength but high strain; steel has high strength and low strain. GRP has the same strength as steel and medium strain, between steel and plastic, giving greater toughness. Depending on the kind and form of reinforcement, GRP can have a wide range of properties; it is 'tailor-made material.'

Traditionally, a GRP product is designed based on applied stress. Then the product shape and reinforcement structure are selected so that the maximum stress is within the permitted range.

We established a new design method for GRP products using a quite contrary idea. We deflected the product within its elastic limit and determined the elastic force and elastic strain energies caused by the deflection. We incorporated the elastic force and elastic strain energies into the design for the pole guard; thus, we designed the new pole guard to grip the pole by itself without bands and bolts.

This new concept is shown in Fig. 2. The diameter of the cylindrical pole guard, with about a three-quarter-circle cross-section, is less than that of the utility pole. The pole guard is installed on the utility pole by opening a slit and snapping the guard around the pole. It is very important that the pole guard be strong enough to bear the deformation during the installation; after installation, its elasticity must give it enough holding force to firmly grip the pole. Steel and conventional plastics do not have enough holding force.

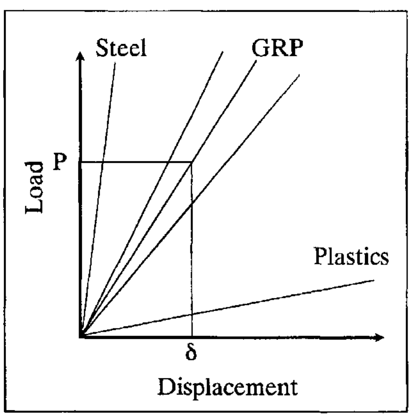

Figure 1. Load–displacement relatioship.

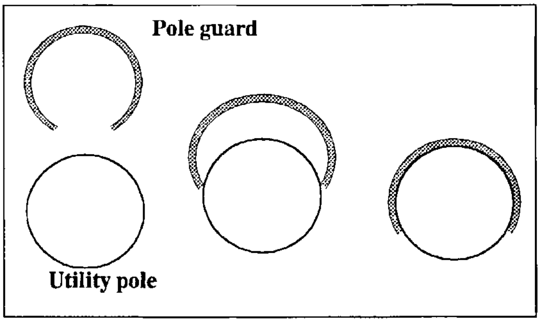

Figure 2. Self-holding force.

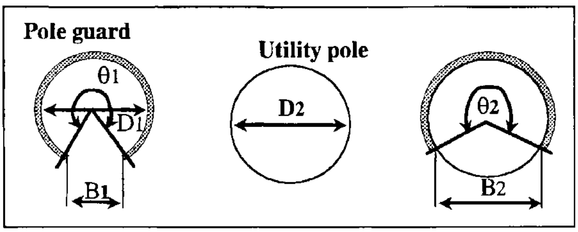

Figure 3. Pole guard dimensions.

2.2. Optimization of self-holding force

The pole guard was developed to fit a standard 15 m high concrete utility pole. To design the best self-holding force, both the force for installation and removal had to be evaluated. The curved beam theory and finite element analysis were used for the design. The design approach and results follow. The critical dimensions of the pole guard are shown in Fig. 3.

2.3. Installation force

To make the installation of the pole guard easy, the force for installation should be less than 590 N. The force for installation (F_I) was calculated with the following equation:

$$F_\mathrm{I} = P_\mathrm{I}\mu \leqslant 590\ \mathrm{N},$$

where P_I is the spring slit closing force when the slit width (B_I) is equal to the utility pole diameter; and μ is the coefficient of friction between the pole guard and utility pole.

The force to expand the slit for installation (P_I) was calculated using the curved beam theory:

$$P_\mathrm{I} = 2ELt^4/9D_\mathrm{I}^3,$$

where E is Young's modulus; and t, L and D_I are respectively the thickness, length and diameter of the pole guard.

The stress distribution on the installed pole guard was calculated using finite element analysis. Three-dimensional 8-node structural shell elements were used. The pole guard was divided into 225 elements and 744 nodes, then analyzed as a non-linear model.

Results were obtained for two cases: one is for when the installation is with uniform expansion of the slit longitudinally, and the other is for when the slit at the top of the pole guard is expanded and it is installed on the utility pole from the top. These results are shown in Figs 4a and 4b.

2.4. *Removal force*

To protect the pole guard from removal by vandals, the removal force should be more than 1470 N. The removal force (F_2) was calculated from the same values as the installation force. In order to increase the force needed for removal, adhesive tape was attached to the inside of the pole guard. The adhesive force (F_3) is calculated from the adhesive strength (α) times area of adhesive tape (A):

$$F_2 = F_1 + F_3 = F_1 + \alpha A \geqslant 1470 \text{ N}.$$

Because the installation force F_1 is less than 590 N, adhesive force F_3 becomes:

$$F_3 \leqslant 880 \text{ N}.$$

The type of adhesive tape and its area were selected to meet this equation.

2.5. *Holding force*

The holding force is the most important property after installation. The holding force is the force on the surface of the utility pole (P_2) when the pole guard's internal diameter (D_1) is the same as the utility pole's diameter (D_2).

$$P_2 = C(B_2 - B_1)LEt^3/D_1^3, \qquad B_2 = D_2 \sin(\pi/2 - \theta_2/2),$$

where C is a constant.

Finite element analysis was used for calculating the holding force distribution. This distribution is shown in Fig. 5.

2.6. *Installation angle*

The design criteria are: (1) arc length of the pole guard (W) should be longer than the length of the half-arc of the utility pole, and (2) the installation angle should harmonize with urban scenery. An installation angle of 205° was chosen.

To make a product that met the above design criteria, trial products were made based on the calculated results and evaluated repeatedly. The shape of the pole guard (thickness, slit width, internal diameter, length for longitudinal direction and circumference angle) and reinforcement (kind, shape, stacking sequence and glass content) were selected from these results.

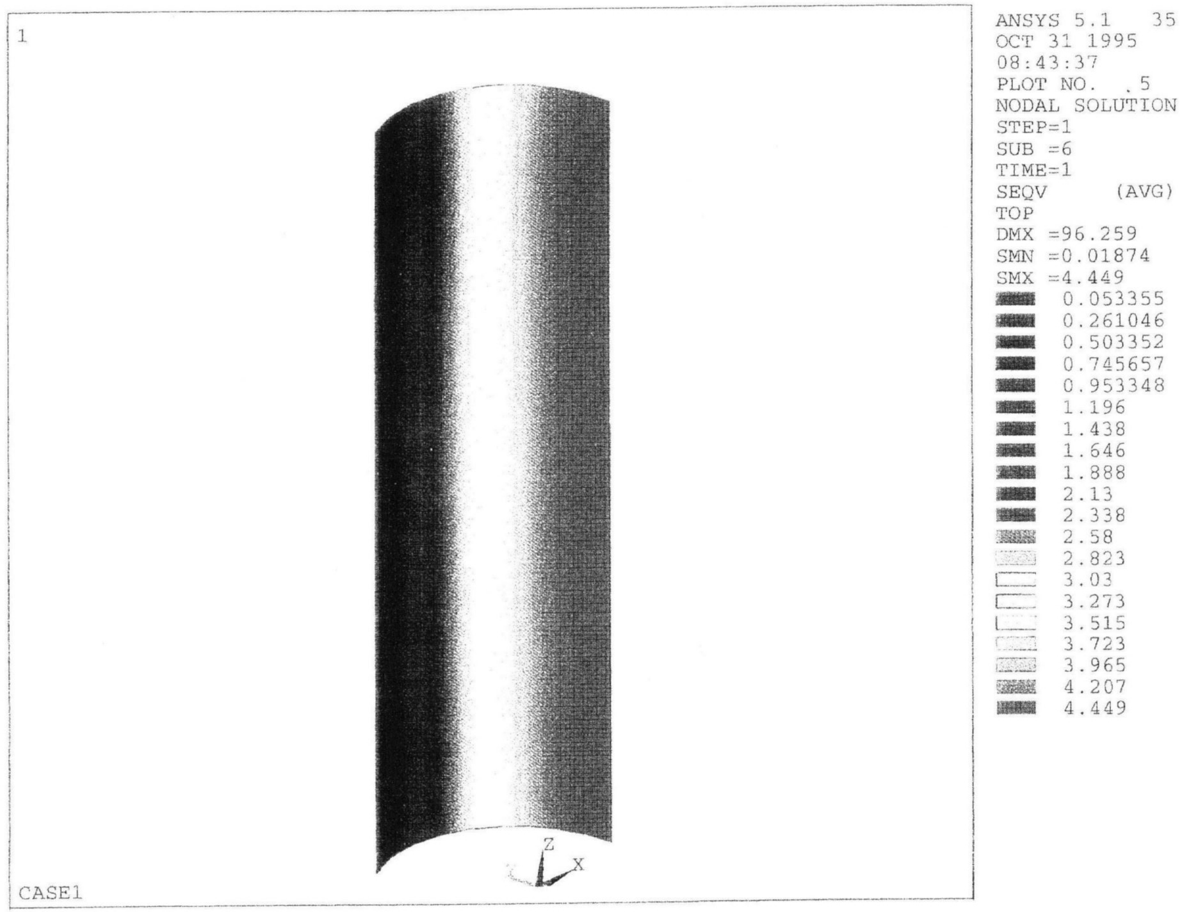

Figure 4a. Simulation of stress distribution.

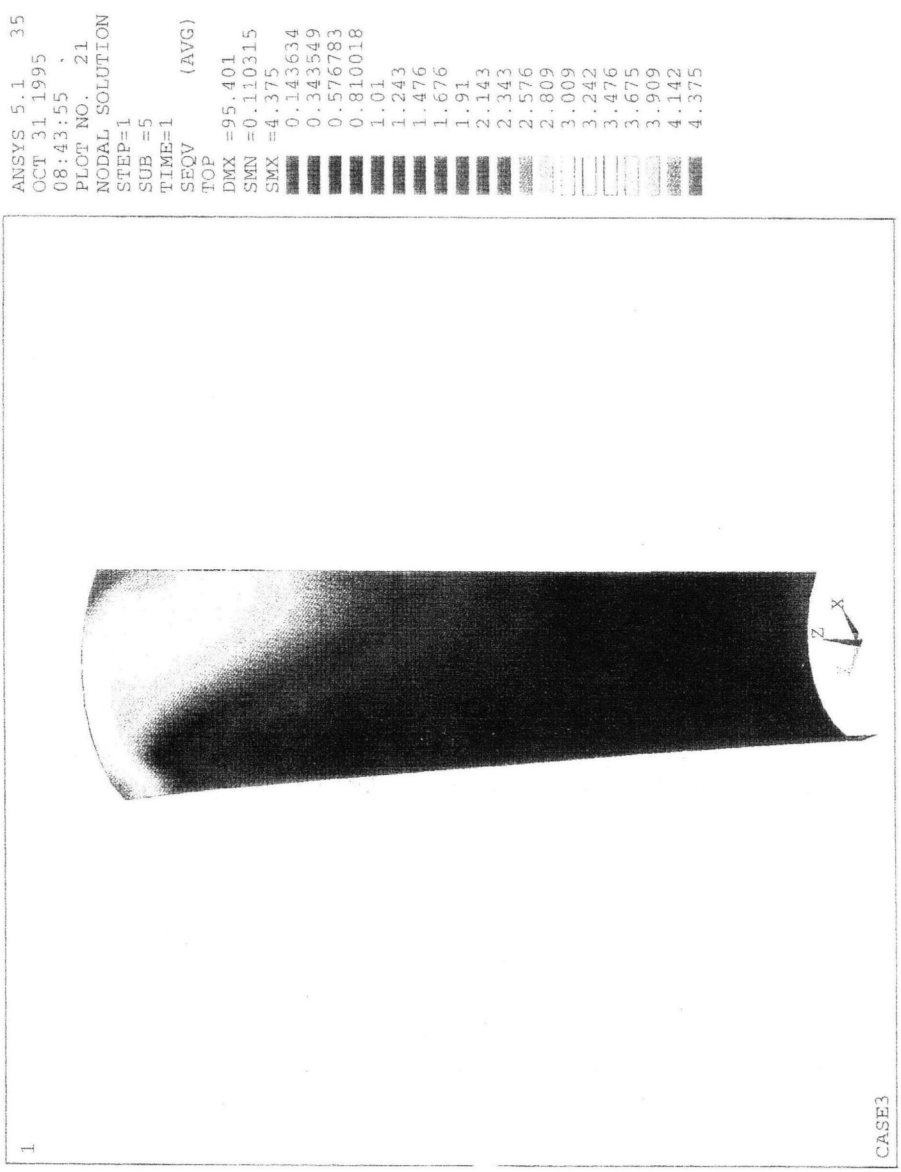

Figure 4b. Simulation of stress distribution.

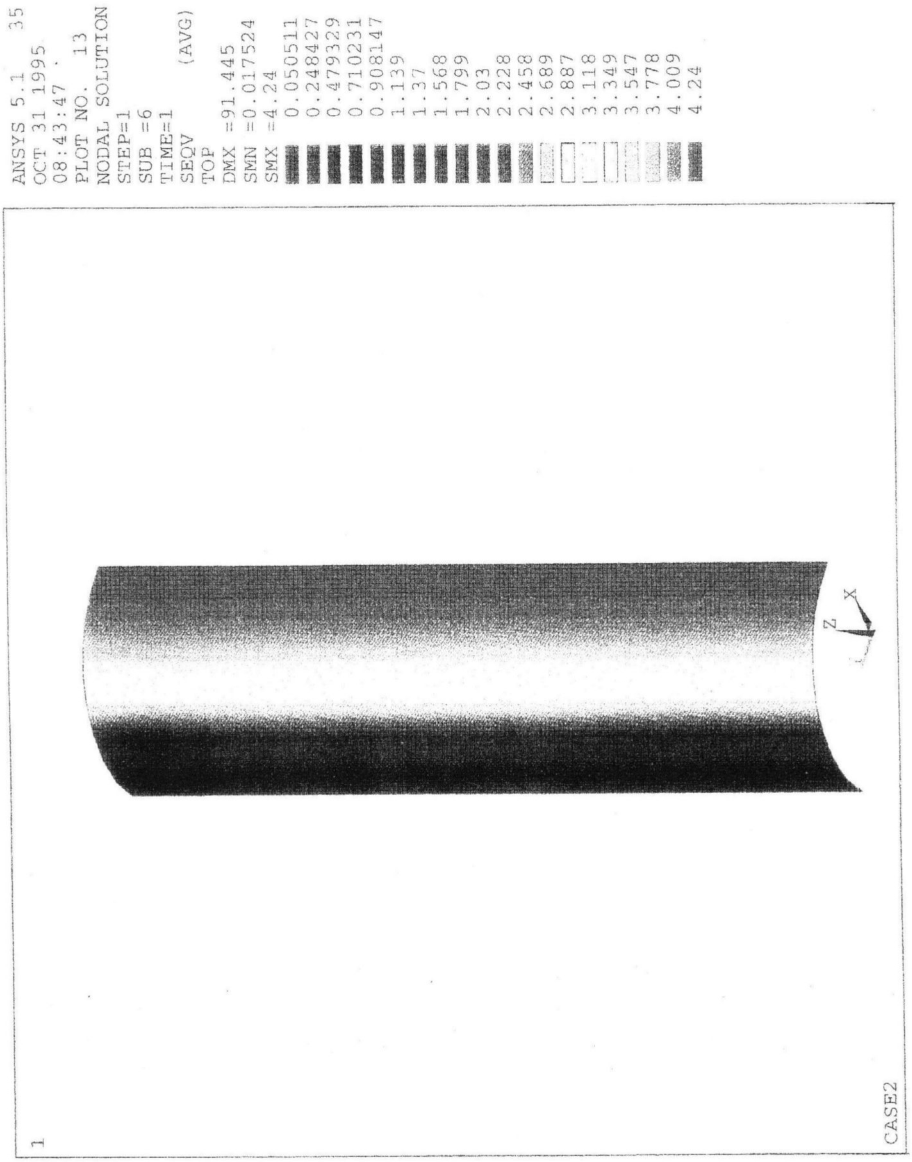

Figure 5. Holding force distribution.

2.7. Additional functions

To fully use the advantages of GRP products, additional functions were developed:

Reducing car collisions: There are two ways to protect utility poles from collision damage. One is direct protection by the pole guards, and the other is to prevent collisions. To prevent collisions, utility poles are made to be noticeable, especially at night. Wide-angle light-reflecting tape is used to make the pole guards more noticeable in the dark.

Protection from posters and fliers: Unauthorized posters on utility poles detract from their appearance. Traditionally, plastic sheets are installed on the utility poles with the steel pole guards to prevent posters and fliers from sticking to them. This function has been incorporated into the GRP pole guards.

To minimize 'stickable' area for posters and fliers and to make their removal easy, various surface shapes were designed and tested. Projections aligned in the longitudinal direction every 4 mm with 2-mm radius semicircular cross-sections are effective for this function.

3. SELECTION OF FINAL SPECIFICATIONS

The final specifications were determined from the results of the above items. It is important for the pole guards to harmonize with the urban environment, so the appearance of the pole guards was designed with the advice of a professional designer.

The final specifications of the pole guard are shown in Table 1 and depicted in Fig. 6. The structure of the reinforcement is shown in Table 2.

Table 1.
Pole guard specifications

	Pole guard type		
	Large	Medium	Small
Internal diameter (mm)	260	235	190
Thickness (mm)	3.0	3.0	3.0
Length (mm)		900 or 1200	
Angle of arc (°)	280	280	280
Color		Rose-gray and yellow	
Weigth (kg/900mm)	4.0	3.5	3.0

Table 2.
Reinforcement construction

Internal	Roving cloth Roving	Composite mat
	Continuous strand mat	
External	Roving cloth Roving	Composite mat
Projections	Vinylon roving	

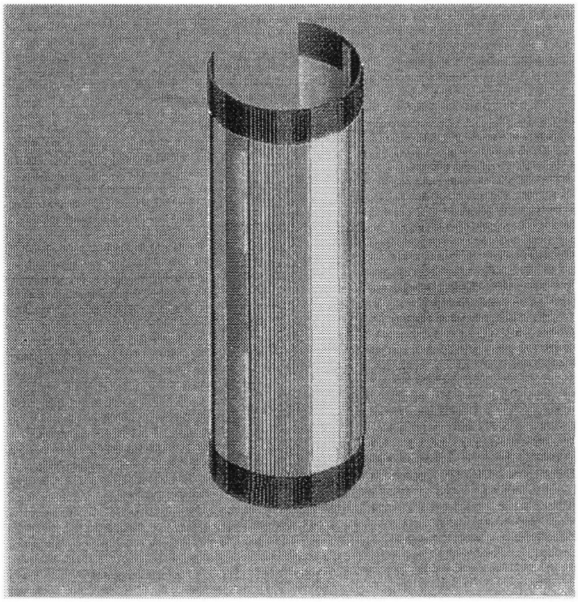

Figure 6. Pole guard.

4. MOLDING TECHNOLOGY

The pultrusion molding method is appropriate for making the pole guards. To establish a molding technology for the pole guard using pultrusion, die shape, preform of reinforcement and resin cure properties were examined. To stabilize the holding force of the pole guard, the design calls for uniform placement of longitudinal and transversal glass fibers. However, it was found that using 400 glass fibers uniformly in a longitudinal direction was very difficult. Solving this problem required a special composite mat made of an appropriate ratio of glass roving and glass cloth united into the mat. The composite mat is shown in Fig. 7.

5. EVALUATION

Pultruded pole guards were evaluated for both physical properties and practical properties. Typical tests were:

Static tests. Mechanical properties (bending and tensile, distribution of glass content and flame resistance), installation force, removal force, falling weight, impact test, removal of stuck posters, paint adhesion, night visibility (reflective property of light-reflecting tape).

Durability tests. Stress relaxation (reduction of clutching force) and weatherability.

Handling test. Ease of handling during installation.

The stress relaxation was measured as the change of the holding force with time using the pole guard installed on a steel pipe with the same diameter as a utility pole. Results of this test are shown in Fig. 8.

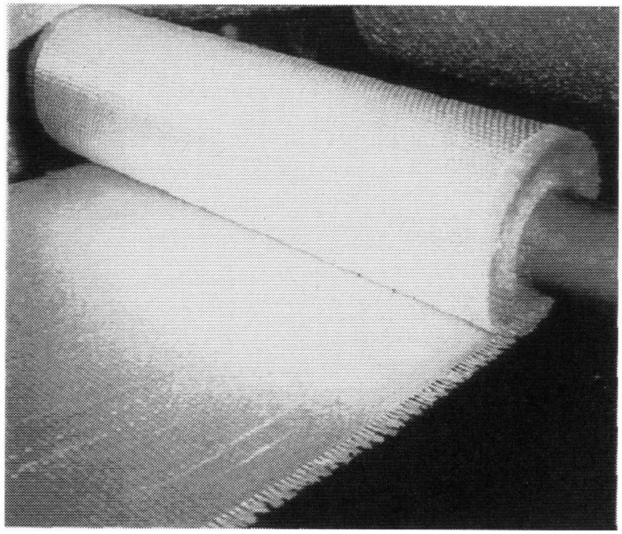

Figure 7. Composite mat.

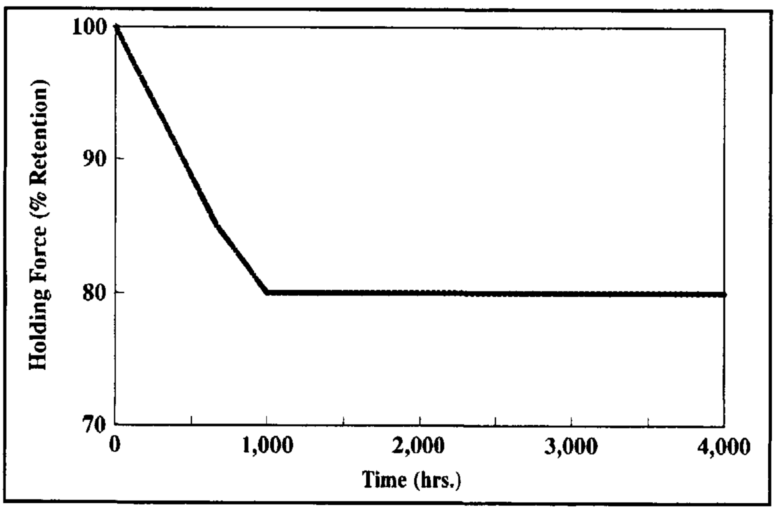

Figure 8. Stress relaxation.

Table 3.
Results of impact test

Type of pole guard	Depth of scratch (mm)
GRP	2.4
Steel	3.1
No guard	8.0

A picture and results of the impact test are shown in Fig. 9 and Table 3, respectively. Pictures of the installation force test and the removal force test are shown in Fig. 10 and Fig. 11, respectively, and results of these tests are shown in Table 4. From these results, we confirmed that the holding force was retained over time, and the installation force and removal force met the design criteria. The results showed that the pole guard met all requirements for use. We have started to produce the pole guards.

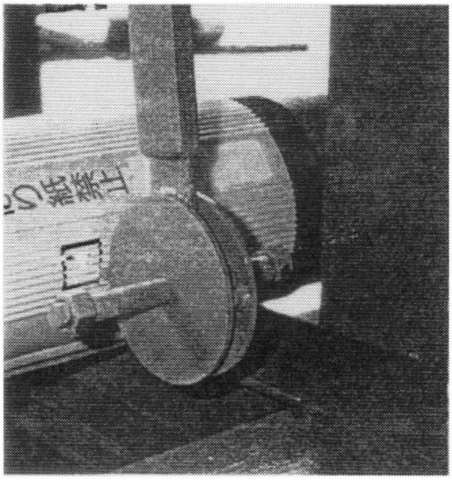

Figure 9. Impact test.

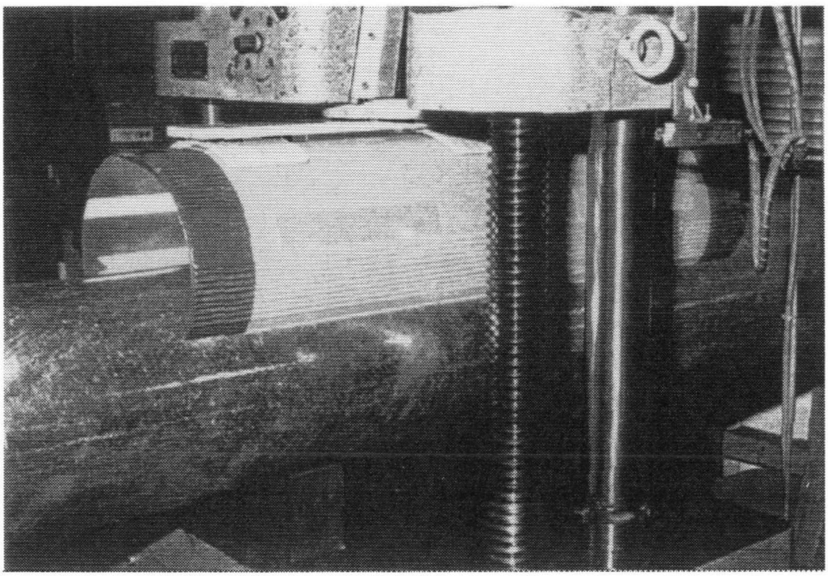

Figure 10. Installation force test.

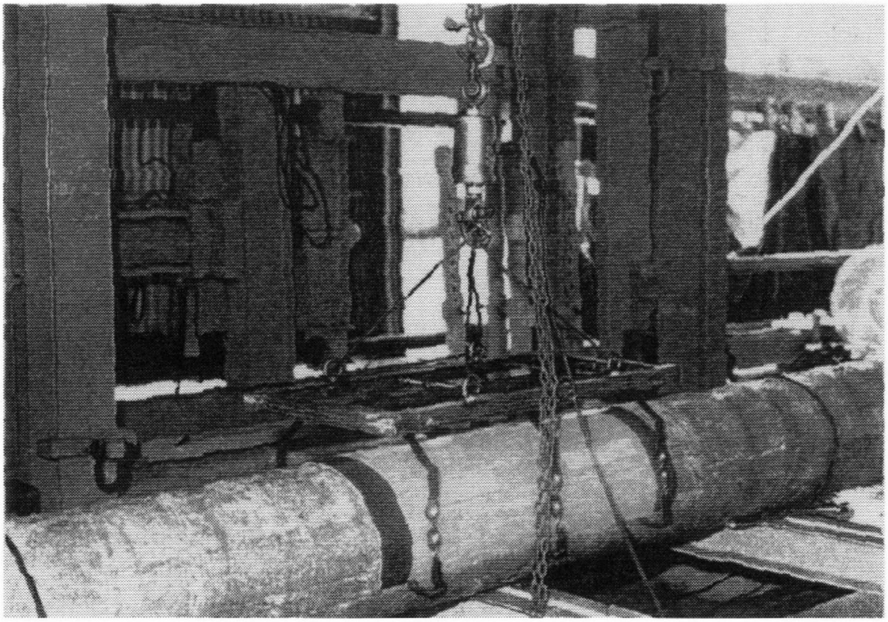

Figure 11. Removal force test.

Table 4.
Force for installation and removal of GRP pole guard

Criterion	Type	1	2	3
Force for installation (N)	Large	470	441	460
	Medium	509	470	539
	Small	558	470	539
Force for removal (N)	Large	2646	2548	2744
	Medium	2891	2940	2842
	Small	2940	2940	2940

6. CONCLUSIONS

New functions for GRP and a new design method for GRP products have been developed. A new product with self-holding force was created by optimizing GRP's elasticity. A utility pole guard with the following new advantages was developed using this design method:

- The pole guard grips the utility pole by itself without bolts or belts; therefore, handling during installation improved dramatically. The elimination of belts and bolts also makes it safer for passers-by.
- To prevent car collisions, the pole guard is noticeable, especially in the dark.
- The pole guard hinders posters and fliers from sticking to it.
- The pole guard was designed to harmonize with urban scenery.

Utility companies favor the pole guards and are already installing them.