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Experimental Study on Vibration Control of Steel Poles Using Chloroprene Rubber

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Synopsis

Recently, it is pointed out that the bridge vibration caused by the traffic causes damage to a pole type steel structures such as lighting poles or marker poles on elevated bridges. Some damages induce collapse in the severe case and its collapse may cause secondary accidents. Therefore, vibration problem of the pole type steel structures should be solved as soon as possible. As the number of such steel poles which should be maintain sufficiently is very large, it is important to avoid resonance and to improve damping performance of them economically. The presented herein are discussed a proposed vibration controlling technique for steel poles by using chloroprene rubber base and the effectiveness of this method based on the experimental results. .

KEYWORDS: Pole Type Steel Structure, Vibration Control, Resonance, Damping Performance,
Chloroprene Rubber

1. Introduction

Vibration of pole type steel structures becomes serious problem in these days[1] because vehicles weight is getting heavier, the number of them is increasing significantly, and rubber supports are adapted to many bridge structures due to improving seismic performance.

To avoid resonance and to improve damping performance of the steel poles, which are set onto the superstructures with various setting conditions and natural frequencies, becomes very important. For example, IMD (Impact Mass Damper)[2] or TMD (Tuned Mass Damper)[3] may be attached to the steel pole in order to improve damping performance. IMD does not have enough damping performance to control such traffic vibration. On the other hand, TMD is effective except for economical aspect. Accordingly, some other economical and practical methods for vibration control of steel pole structures will be strongly needed.

It is known that the rigidity of the base of a steel pole affects the vibration characteristic significantly. It is possible to change the base rigidity by installing the rubber sheet under the base plate of the steel pole structures. Proposed are seismic isolation rubbers and damping rubbers made from various materials. In this study, the chloroprene rubber, which is a general material and not expensive, is applied to the basement rubber.

Effectiveness of the rubber sheets for vibration control is investigated experimentally by using scaled specimens of an actual steel pole structure.

2. Vibration Test

2.1 Specimens and Experimental Cases

The specimens used in this study are shown in Fig. 1. The size of the specimens is almost 1/2 of actual lighting poles. The height of the specimens is 5000mm. 200N weight is set on the edge of the arm section as shown in Fig. 1. This weight is corresponding to that of an illuminator. Prepared are the chloroprene rubber sheets varying the thickness (3mm, 6mm, 15mm) and hardness (45Hs, 65Hs, 80Hs) of the sheet. The geometrical configurations of the rubbers are shown in Fig. 2. The size of the chloroprene rubber sheets is almost same as that of the base plate. The rubber is separated into two parts so that to replace. Summary of experimental cases are shown in Table 1. The case without the rubber sheet is named as in-n(in-plane) and out_n(out-plane).

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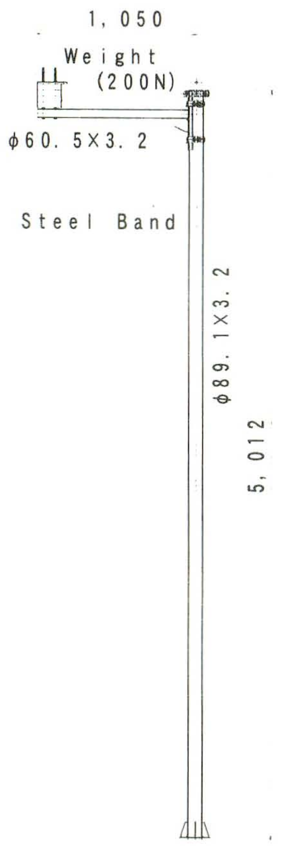


Fig. 1 Geometrical configurations of the specimen (unit: mm)

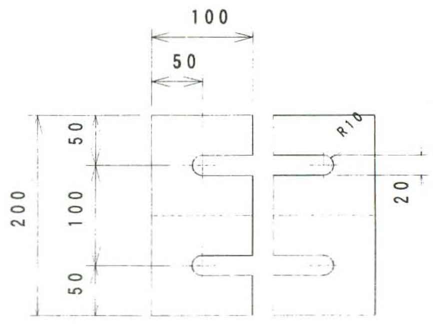


Fig. 2 Dimensions of chloroprene rubber sheet (unit: mm)

Table 1 Summary of experimental cases

Case name	vibration direction	Hardness(Hs)	Thickness(mm)
in_n	in-plane	---	---
in_r_45_3		45	3
in_r_45_9			9
in_r_45_15			15
in_r_65_3		65	3
in_r_65_9			9
in_r_65_15			15
in_r_80_3		80	3
in_r_80_9			9
in_r_80_15			15
out_n	out-plane	---	---
out_r_45_3		45	3
out_r_45_9			9
out_r_45_15			15
out_r_65_9		65	9
out_r_80_9		80	9

2.2 Loading and measurements

The plane view of the loading frame for the vibration test is shown in Fig. 3. Main beams made of the H-shape steel as shown in Photo 1 correspond to the main girder of the bridge. Detail of the support points is shown in Photo 2. The pins covered with rubber are used to realize simple supported condition at each support points.

The hydrofluoric actuator with the capacity of 1000kN is jointed to the center of the loading beam and applies the idealized bridge vibration as shown in Fig. 3. In case of applying in-plane vibration, the specimen is set at the center part of the main beam. In case of applying out-plane vibration, the specimen is set at vicinity of the support point.

In this study, free vibration and forced vibration test are executed. All experimental cases are tabulated in Table 1. In free vibration test, 16 cases as shown in Table 1 are executed. Case in n(normal case of in-plane) and out_n(normal case of out-plane) are prepared for comparison focusing on the hardness and thickness of the chloroprene rubber and the direction of the pole's vibration.

The initial displacement for free vibration is given at the top of the pole by human power. As for the forced vibration test, the same 16 cases as tabulated in Table 1 are also carried out. The harmonic force is given as the displacement, whose amplitude is ±5mm. Its frequency is set to be in a range of ±10% for the natural frequency of the pole.

In this experiment, the displacement of the beams, the accelerations at the top of the pole along in-plane and out-plane direction and the strains at the vicinity of the top of the welded rib plate are measured by digital strain meter with 100Hz sampling rate.

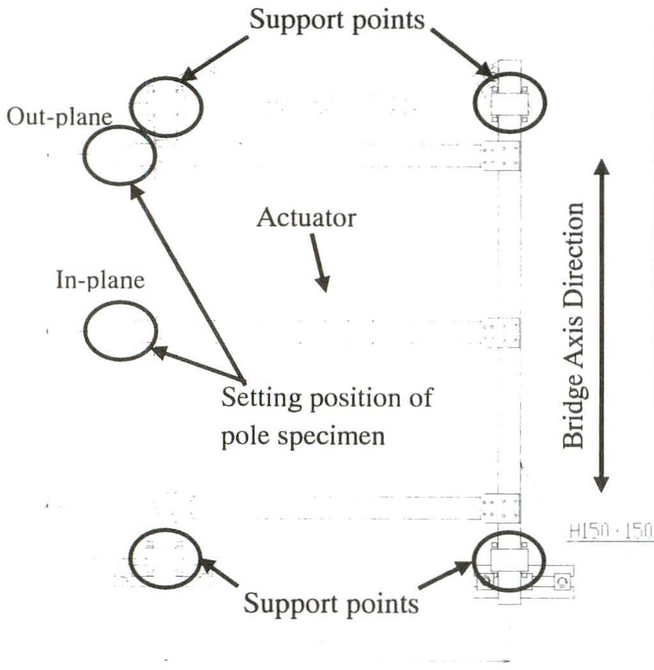


Fig. 3 Plane view of loading frame (unit: mm)

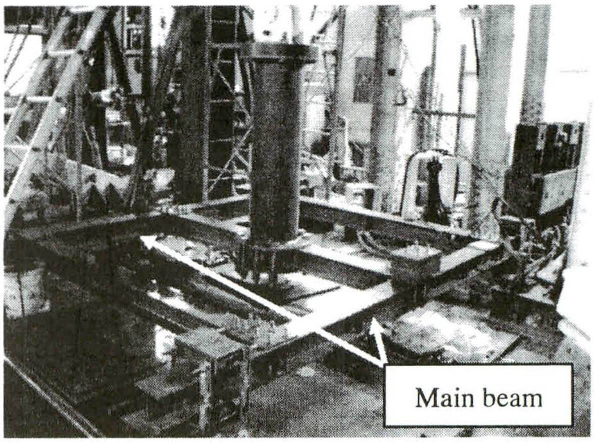


Photo 1 Loading frame

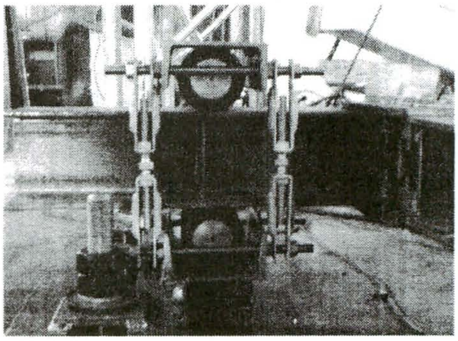


Photo 2 Details of support point

3. Test Results and Discussions

The results of the free vibration tests are summarized in Table 2.

It is found that first natural frequencies have been changed slightly by using rubber for both directions. The change of them is limited to almost 5%.

Logarithmical damping coefficients have been improved up to almost twice of them for each original case. But, there is little influence on change of logarithmical damping coefficient by varying thickness or hardness of the rubber.

The power spectrums obtained from the free vibration tests, in_n and in_r_45_9 are plotted in Fig. 5. It is considered from these results that the shapes of the spectrum have not be changed significantly by installing the rubber. In fact, there is little difference of the shape of the spectrum between the original case and other cases with rubber.

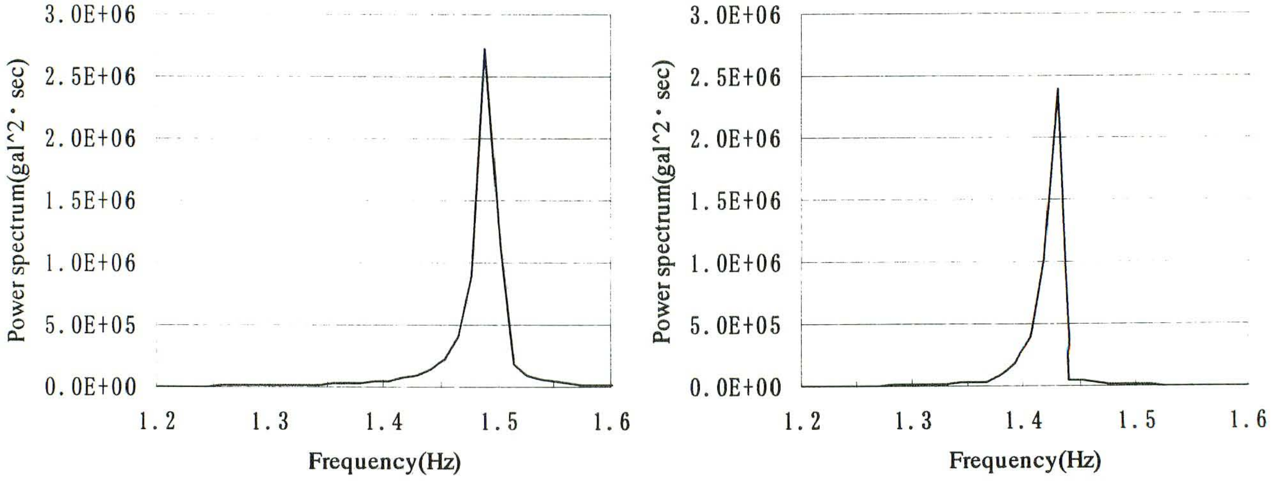
Table 2 Results of the free vibration test

(a) in-plane

Case name	First natural frequency(Hz)	Logarithmical damping coefficient
in_n	1.477	0.016
in_r_45_3	1.477	0.024
in_r_45_9	1.440	0.025
in_r_45_15	1.440	0.022
in_r_65_3	1.465	0.025
in_r_65_9	1.453	0.030
in_r_65_15	1.428	0.027
in_r_80_3	1.465	0.020
in_r_80_9	1.465	0.030
in_r_80_15	1.440	0.033

(b) out-plane

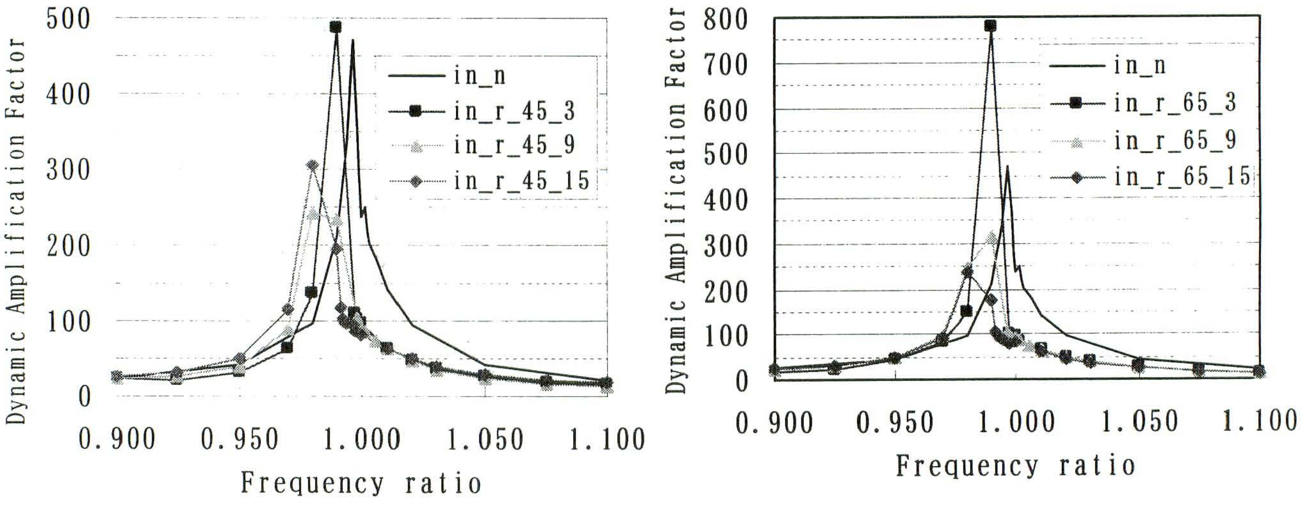
Case name	First natural frequency(Hz)	Logarithmical damping coefficient
out_n	1.428	0.018
out_r_45_3	1.392	0.041
out_r_45_9	1.361	0.050
out_r_45_15	1.367	0.032
out_r_65_9	1.398	0.032
out_r_80_9	1.416	0.032



(a) in_n

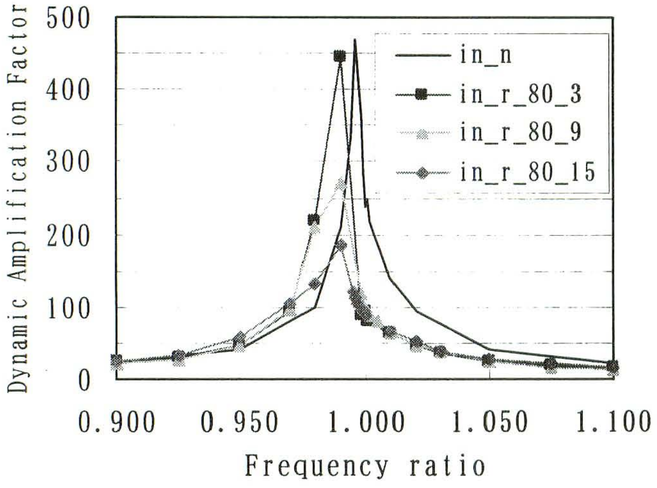
(b) in_r_45_9

Fig. 5 Power spectrums in free vibration test



(a)Hardness 45Hs

(b)Hardness 65Hs



(c) Hardness 80Hs

Fig. 6 Resonance curve in forced vibration test (in-plane)

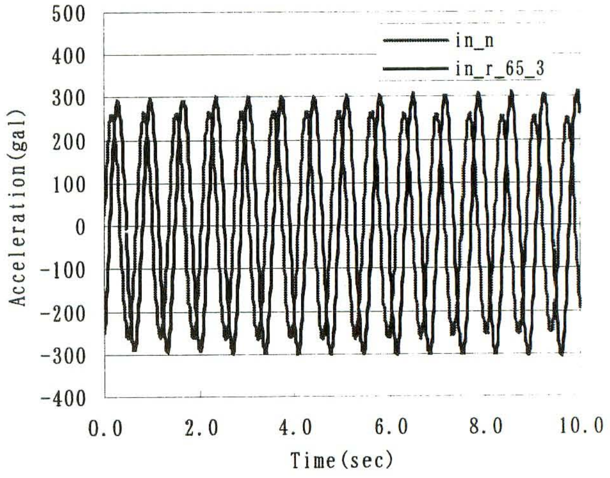
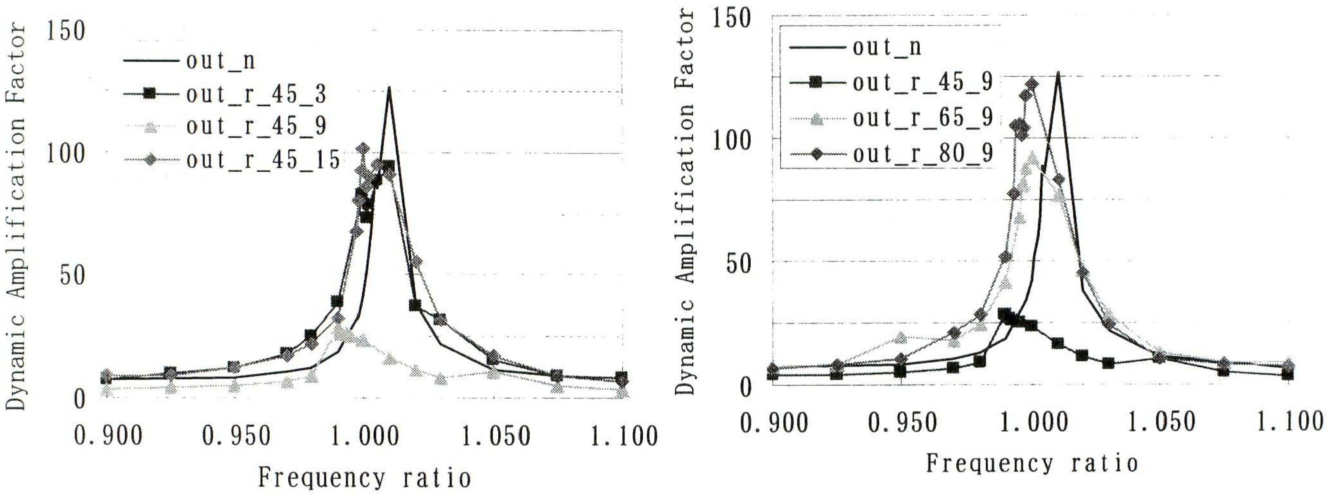


Fig. 7 Time history of acceleration at the top of the pole

The resonance curves of in-plane direction obtained through the forced vibration tests are shown in Fig. 6.

It is found that the response of the cases with the 9 mm rubber and 15mm rubber decrease greatly in the cases with any hardness of the rubber.

As shown in Fig. 6(b), the response of in_r_65_3 is larger than that of the original case(in_n) . It might be caused by the phase difference between the pole and the beam. Because it is observed that the phase of the specimen is changed greatly at vicinity of resonance point, and that the displacement of the beam is mitigated in high frequency ratio range . In addition, the acceleration at the top of the pole in the case in_65_3 isn't so different from that of the case in_n (normal case) as shown in Fig. 7.



(a)Hardness 45Hs

(b)Thickness 9mm

Fig. 8 Resonance curve in forced vibration test (out-plane)

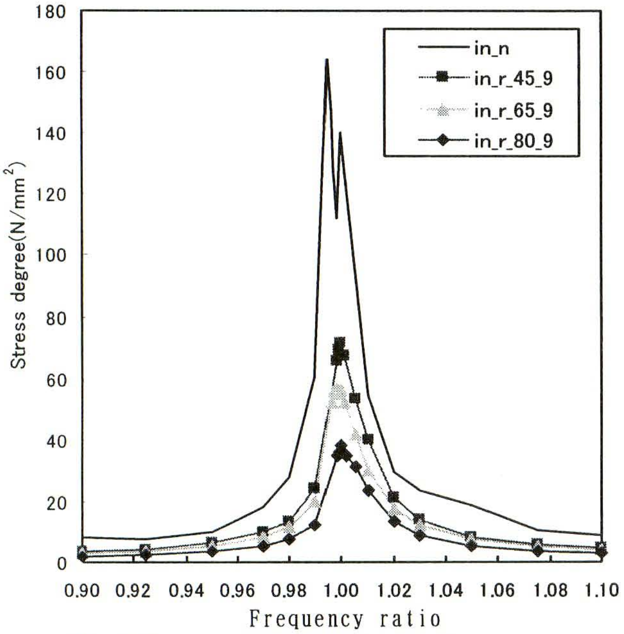


Fig. 9 Resonance curve of stress degree in forced vibration test (in-plane)

The resonance curves of out-plane direction of forced vibration tests are shown in Fig. 8. The effect of installing the rubber can be also confirmed, but this effect is less than that of in-plane direction. This is caused by the reason the response of case out_n is smaller than that of case in_n. It is considered that the method of installing the rubber sheet is effective in case of large response.

For the same reason, there is little effect in the case of out_r_80_9(Fig. 8(b)). It relates that the fixed condition doesn't change. On the other hand the result of the case, out_r_45_9 is quite different from other results. It is considered to be caused by the appearance of shearing mode.

The resonance curves of the stress at the welding of the rib plates obtained from the forced vibration test are shown in Fig. 9. The effect on the stress is larger than amplification of the displacement. This is because that the impact power might be softened by the rubber sheet.

4. Concluding remarks

As an economical vibration control method, the method installing the chloroprene rubber sheet to the basement of the pole type steel structures is proposed. The effectiveness of this method is investigated experimentally through the free/forced vibration test assuming the bridge vibration. Concluding remarks of this study are summarized as follows.

(1) At the resonance frequency, dynamic amplification factor of the pole installed the rubber sheet can be reduced to about half that of the pole without the rubber sheet. But it is necessary to use the rubber that thickness is more than 9mm in order to obtain the effect.
(2) This method is more effective in stress reduction than dynamic amplification factor reduction, because of softening of the impact power.
(3) The larger response brings the larger change of dynamic rigidity and can getthe larger effect.
(4) Decrease of frequency isn't so much (about 5% in large).

5. References

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