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Wind-resistant performance of spiral protuberance cable

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ABSTRACT

A new aerodynamically stable cable with spiral protuberances was developed. It was confirmed that the cable showed a low drag force coefficient and it also prevented the formation of water rivulet on the cable surface. In this study, rain-wind-induced vibration which had not been tested for this cable was investigated with various flow angles and protuberance dimensions in a wind tunnel test. It was found that the spiral protuberance cable is stable against rain-wind-induced vibration as well as dry galloping for all test angles. It also clarified effects of protuberance dimensions.

1. INTRODUCTION

Stay cables of cable-stayed bridges are subject to aerodynamic excitation forces due to its oblique attitude against wind. They sometimes exhibit large amplitude vibration in not only a rain condition but also a dry (no rain) condition. The former is called “rain-wind-induced vibration (RWIV)” (Hikami et al. 1988) and the latter “dry galloping (DG)”. There are many studies (Zuo et al. 2010 and Matsumoto 2011) on their mechanism. It is understood that both vibrations are related to the inherent instability of inclined cables, and in particular RWIV is caused by water rivulet running down on the cable surface and DG is caused by the suppression of Karman vortices in the critical Reynolds number region together with an axial flow behind the cable. Considering their vibration mechanism, a couple of surface modification cable (spiral protuberances (Flamand 1995), longitudinally parallel protuberances (Saito et al. 1994), indented (Miyata et al. 1994), etc.) were developed. In order to further improve their performance, a new type of surface modification cable with prefabricated spiral protuberances was recently developed (Yagi et al. 2011). In this study, using a renovated wind-tunnel with a rain simulator system, performance of a couple of surface modification cables including the spiral protuberance cable was investigated.

2. RAIN-WIND SIMULATOR

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[2] Manager

RWIV was reproduced in the wind-tunnel facility with a rain simulator in the Yokohama National University. An old wind tunnel was renovated by replacing a working section and equipping water spray nozzles as shown in Fig. 1. The working section with the rain simulator is placed just at the wind-tunnel exit of 1.3m (W) $\times$ 1.3m (H). Water is sprayed from water nozzles on the ceiling of the working section as shown in Fig. 2. Maximum wind speed is about 20m/s.

A cable model of 1.5m effective length was placed in the working section by using a pipe frame as shown in Fig. 3. The model was supported by coil springs with vertical 1 DOF. The coil springs were attached in the direction normal to the cable axis. Flow yaw angle and vertical angle can be adjusted by rotating and lifting/lowering an one side of the pipe frame, respectively.

Response of the model was measured by accelerometers put on model both ends. Model vibration was measured with a sampling frequency of 100Hz. Natural frequency of the model is 0.8 – 1.0Hz depending on test cases.

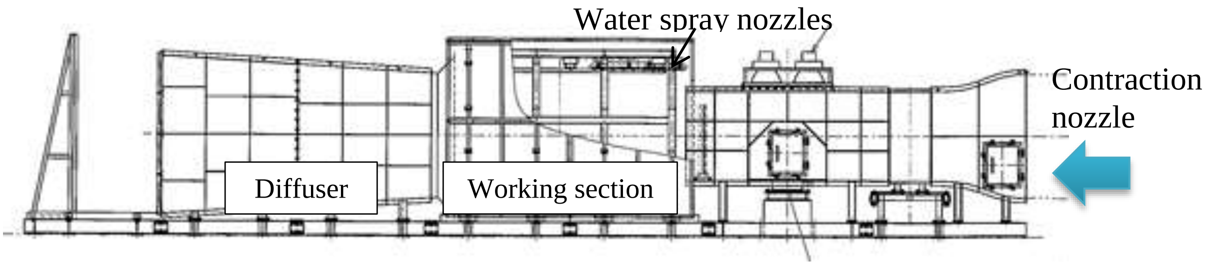


Fig. 1 Rain and wind simulator

Fig. 2 Working section and rain simulator

Fig. 3 Cable model set up

3. REPRODUCTION OF RWIV

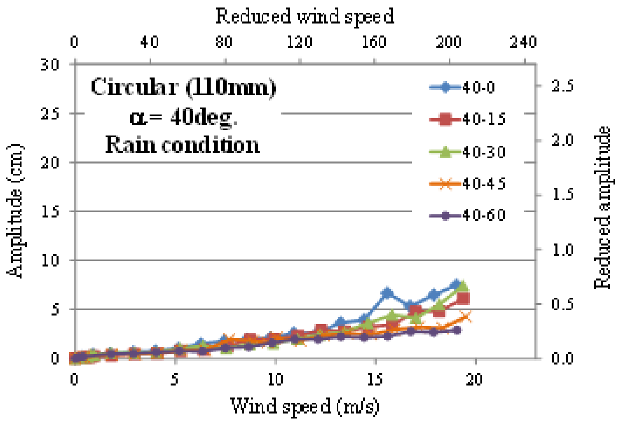
In order to check the performance of the wind tunnel and rain simulator, a circular cable model of a 1.5m long polyethylene pipe was tested to reproduce RWIV. Two different diameter models of 110mm and 158mm were tested.

Figs. 4 and 5 show response amplitude versus wind speed for D110mm and D158mm cases, respectively. Scruton number (Sc) was set to small from 3 to 11 in order to generate RWIV easily. Scruton number in this study is defined as follows:

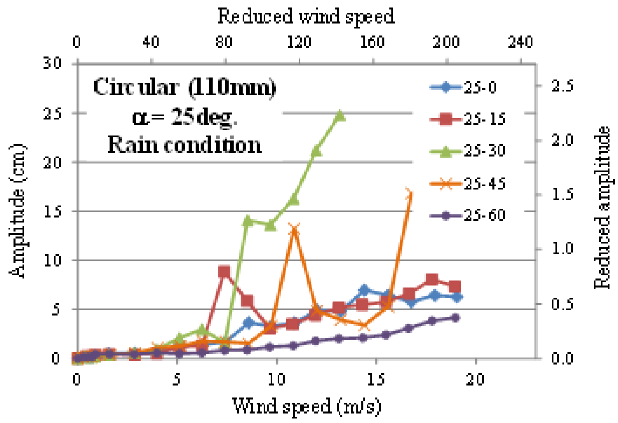
$$S_c = \frac{2m\delta}{\rho D^2} \tag{1}$$

where *m*: mass per unit length, δ: structural damping of logarithmic decrement, ρ: air density and *D*: model diameter. More detailed conditions are shown in each figure. Vertical angle (α) was changed to 40 and 25 degrees for D110mm case, and 40, 25 and 9 degrees for D158mm case. Flow yaw angle (β) was changed to 0, 15, 30, 45 and 60 degrees.

Large amplitude RWIV took place only at α = 25 degrees with β = 15, 30 and 45 degrees as shown in Figs. 4 and 5. It did not take place at α = 40 and 9 degrees. During RWIV, a thin-film like water rivulet was formed on the cable surface. The rivulet vibrated in the circumferential direction synchronously with the cable vibration. Those characteristics of RWIV and rivulet are quite similar to those observed in past studies (Gu et al. 2005). Rain intensity during RWIV was 40-60 mm/h which was heavy. The rain intensity was adjusted such that RWIV took place in this study. It must depend on cable length, too. However, detailed discussion is not made here.

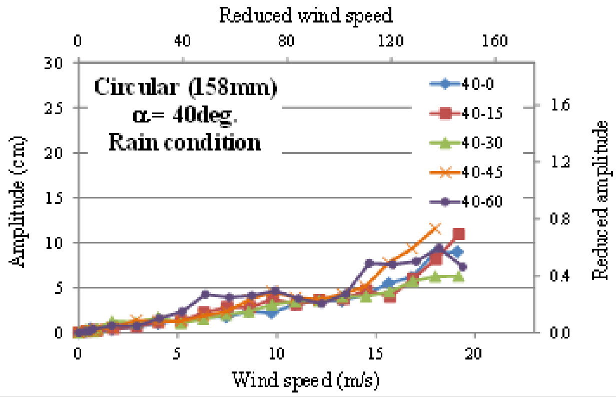


(1) α = 40 deg. (S_c = 10-11)

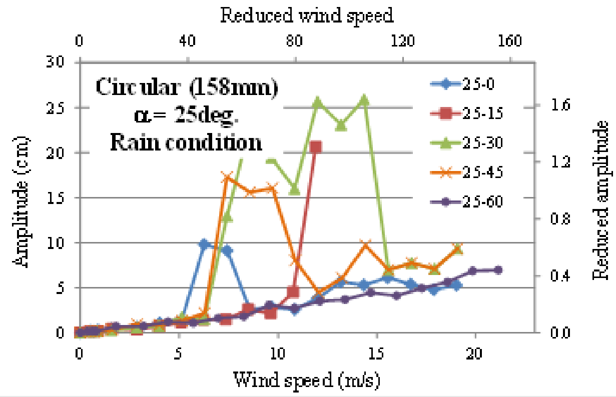


(2) α = 25 deg. (S_c = 9-11)

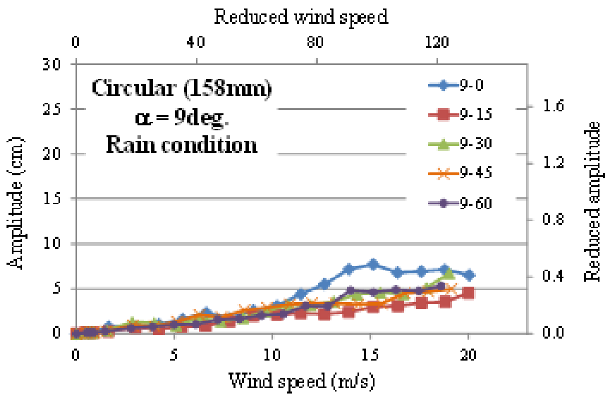
Fig. 4 Response amplitude of circular vs. wind speed in rain condition (D110mm)



(1) α = 40 deg. (S_c = 7-9)



(2) α = 25 deg. (S_c = 6-9)

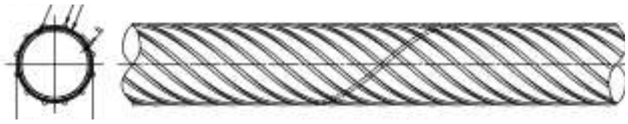


(3) α = 9 deg. (S_c = 3-4)

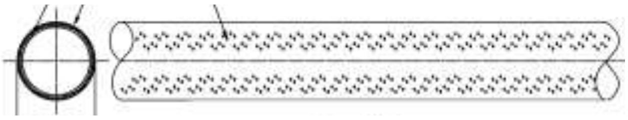
Fig. 5 Response amplitude of circular vs. wind speed in rain condition (D158mm)

4. RESPONSE OF SURFACE MODIFICATION CABLES UNDER RAIN CONDITION

As already described, some surface modification cables were developed for RWIV countermeasures. In this study, two types of surface modification cables; spiral protuberances (Yagi et. 2011) and indented (Miyata et al. 1994) were tested for RWIV. In addition, some parameter tests for the spiral protuberance were conducted. The models were supported in the same manner as in the circular model case. Scruton number condition is also nearly same as that of the circular model case which is shown in each case figure.



(1) Spiral protuberance cable



(2) Indented cable

Fig. 6 Surface modification cables

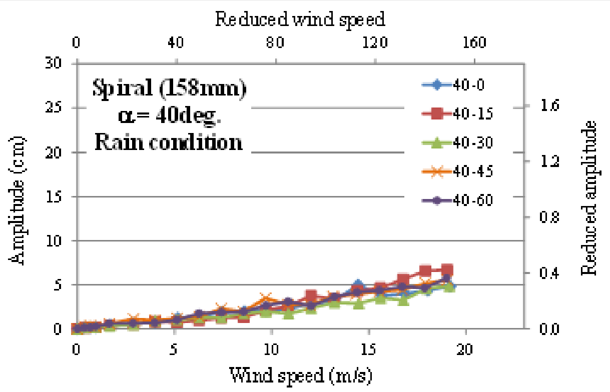
(1) Spiral protuberance

(2) Indented

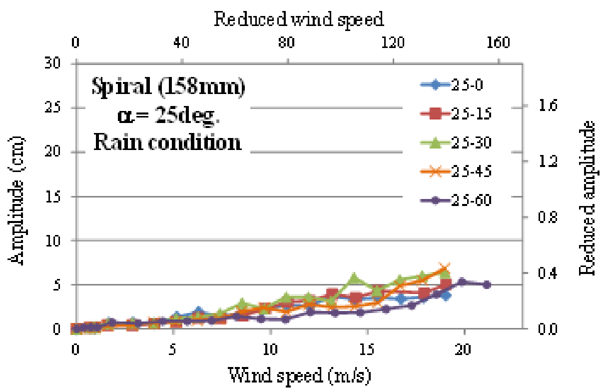
Fig. 7 Set up of surface modification cable models

4.1 Response Characteristics of Spiral Protuberance and Indented Cables

Figs. 8 and 9 show response amplitude of the spiral protuberance and indented cables with the diameter of 158mm in a rain condition, respectively. RWIV took place in the case of the indented cable at some angles. It was observed that water rivulet passed over indentations during RWIV. However it is understood that RWIV observed in this study was due to a small Scruton number condition. On the other hand, the spiral protuberance cable did not exhibit RWIV for all cases but only small amplitude buffeting like random vibration.

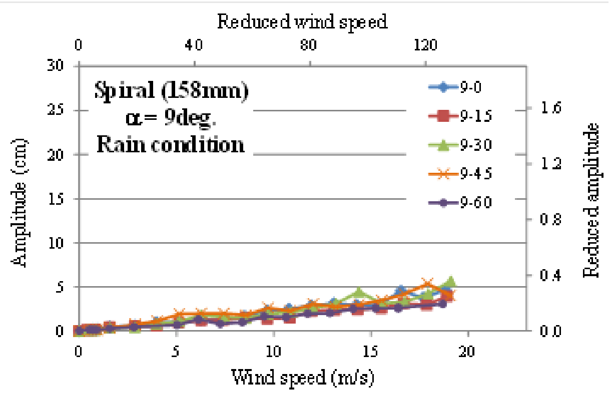


(1) α = 40 deg. (S_c = 9)



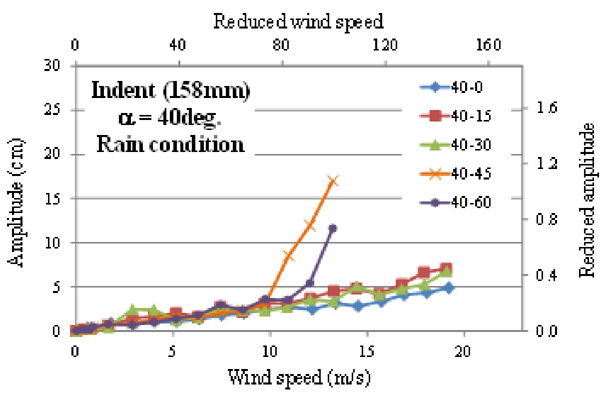
(2) α = 25 deg. (S_c = 5-12)

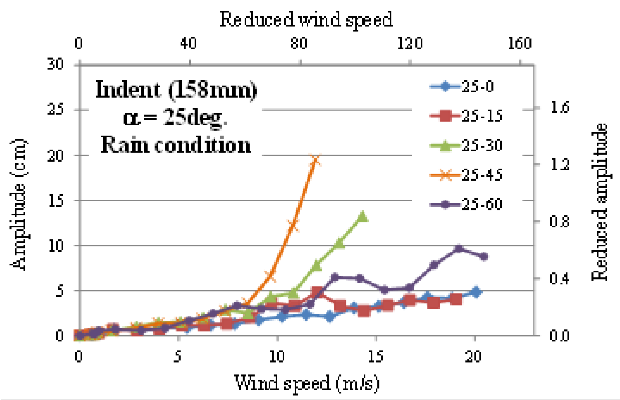
Fig. 8 Response amplitude of spiral protuberance vs. wind speed in rain condition (D158mm)



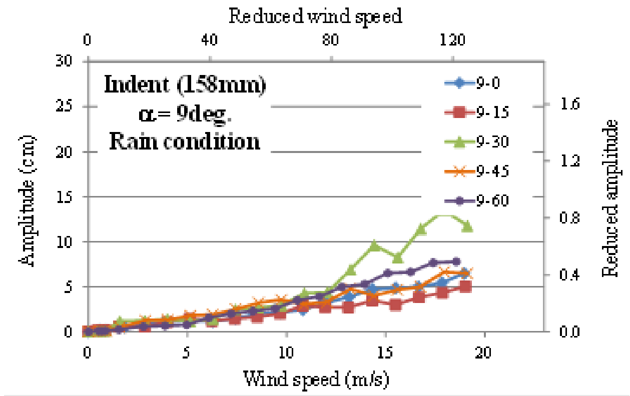
(3) α = 9 deg. (S_c = 4)

Fig. 8 Response amplitude of spiral protuberance vs. wind speed in rain condition (D158mm) (cont.)





(1) α = 40 deg. (S_c = 8-9) (2) α = 25 deg. (S_c = 5-8)



(3) α = 9 deg. (S_c = 3-4)

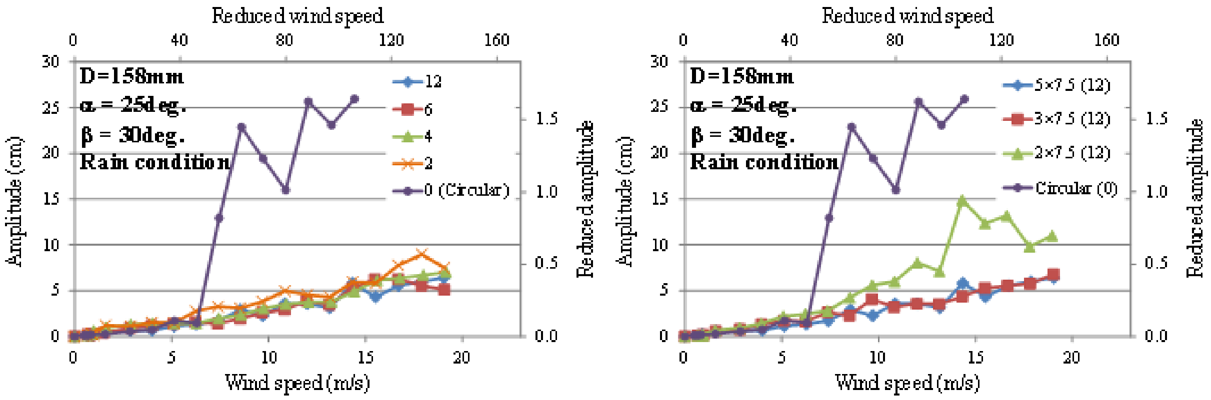
Fig. 9 Response amplitude of indented model vs. wind speed in rain condition (D158mm)

4.2 Effects of Protuberance Dimensions on Response

Dimensions of the spiral protuberance were decided based on the past study (Yagi et al. 2011). It considered that the drag force coefficient is kept low and rivulet formation is prevented. Basic dimensions are circumferential 12 protuberances of 5mm height and 7.5mm width with the spiral angle of 27 degrees. However those effects were only confirmed in a wind tunnel in a no rain condition (DG). Therefore, it is desired that effects of protuberance dimensions should be confirmed in a rain condition.

There is not significant effect of the number of protuberances (Fig. 10(1)) as long as the 5mm height is kept. However slight increase in the amplitude is found for the two protuberance case. In order to investigate the minimum height of protuberance, 2mm and 3mm height keeping twelve protuberances and 7.5mm width were tested. It is found that the 2mm height case increased the vibration amplitude significantly (Fig. 10(2)).

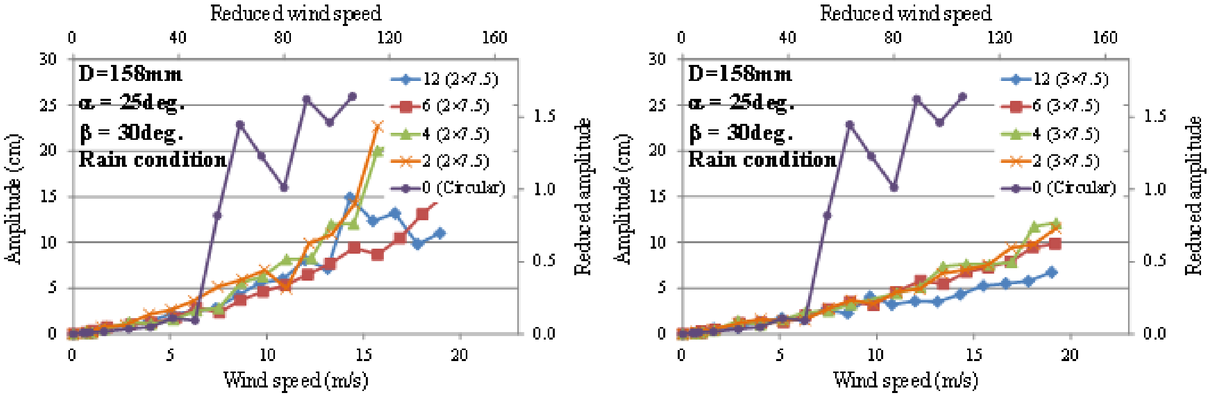
Further investigation on effects of the height and the number was conducted. The 2mm height increased RWIV amplitude even with twelve protuberances more than the basic 5mm height case as shown in Fig. 10(3). In the case of 3mm height, the decrease of protuberance number affects the vibration amplitude as shown in Fig. 10(4). Even the six protuberance case increased the amplitude. Based on those results, it is understood that the protuberance height needs at least 5mm to prevent rivulet and RWIV.



(1) Number of protuberance
(5mm height)

(2) Size of protuberance
(height x width)

Fig. 10 Response amplitude of spiral protuberances vs. wind speed for different protuberance dimensions (D158mm, α = 25 degrees, β = 30 degrees)



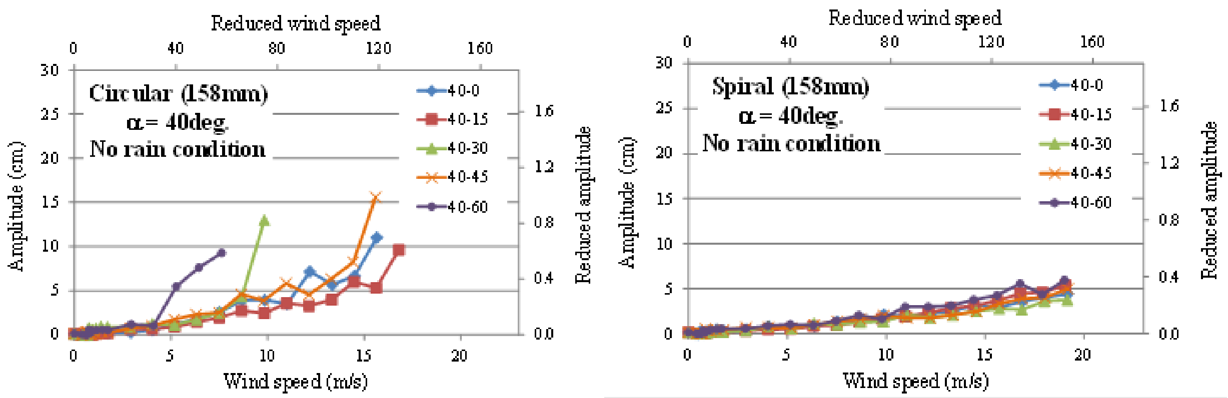
(3) Number of protuberance (2mm height) (4) Number of protuberance (3mm height)

Fig. 10 Response amplitude of spiral protuberances vs. wind speed for different protuberance dimensions (D158mm, α = 25 degrees, β = 30 degrees) (cont.)

5. DG OF SURFACE MODIFICATION CABLES

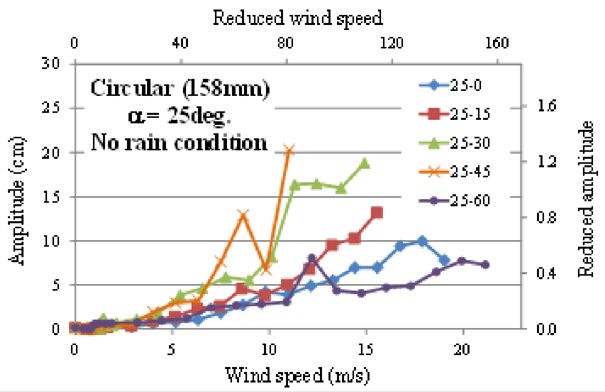
In addition to RWIV, DG was also tested for the surface modification cable model. Fig. 11 shows response amplitude of the spiral protuberance model in a dry (no rain) condition compared with the circular model.

The circular model exhibited large amplitude DG particularly with the flow angle β = 30 and 45 degrees. However these vibrations occurred with a low Scruton number of around 10. It was confirmed that large amplitude DG was suppressed below 0.5D reduced amplitude with the increase of Scruton number to around 60. On the other hand, the spiral protuberance model was completely stable and exhibited only small amplitude buffeting like random vibration.

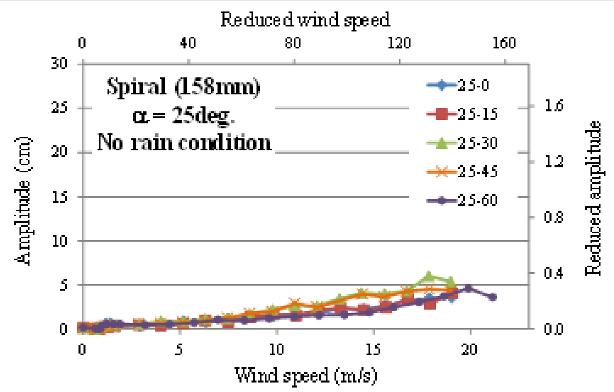


(1) Circular, α = 40 deg. (S_c = 7-9) (2) Spiral, α = 40 deg. (S_c = 9)

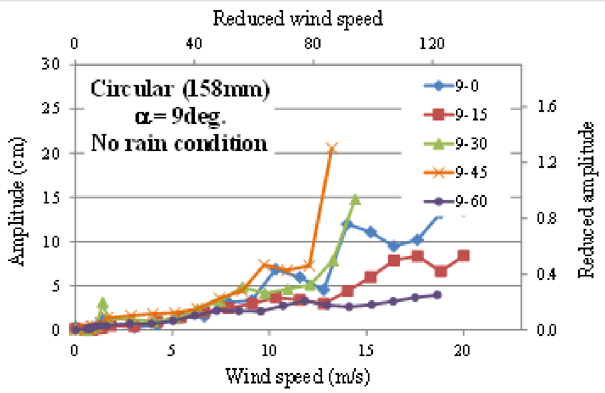
Fig. 11 Response amplitude vs. wind speed in dry condition (D158mm)



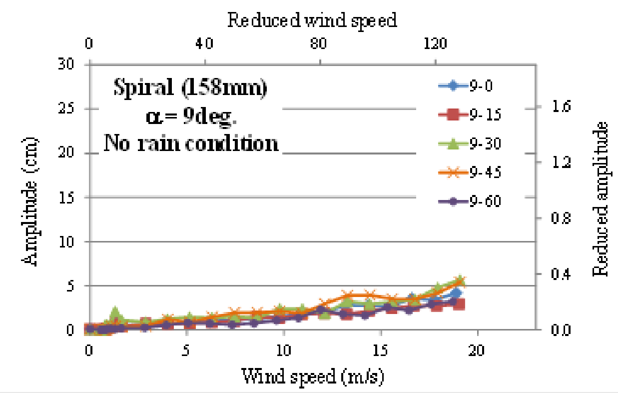
(3) Circular, α = 25 deg. (S_c = 6-9)



(4) Spiral, α = 25 deg. (S_c = 5-12)



(5) Circular, α = 9 deg. (S_c = 3-4)



(6) Spiral, α = 9 deg. (S_c = 4)

Fig. 11 Response amplitude vs. wind speed in dry condition (D158mm) (cont.)

6. CONCLUSIONS

In this study, using a renovated wind-tunnel with a rain simulator system, performance of a couple of surface modification cables was investigated. Results obtained as follows:

RWIV was successfully reproduced in the wind tunnel. It was also observed that rivulet on the cable surface vibrated in the circumferential direction synchronously with the cable vibration. Those characteristics were well coincide with past reports.

Surface modification cable of indented showed good performance for both RWIV and DG, except for some particular conditions. However the increase in Scruton number can suppress vibrations. Spiral protuberance cable showed completely good performance for both RWIV and DG.

Finally effects of protuberance dimensions were clarified. There is a certain limit of dimensions such as the height and number to suppress RWIV.

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