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Dams and Special Structures

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Abstract: *Rain vibration of cables is becoming a matter of great concern recently in Japan for design and construction of cables-stayed- bridges. The features of rain vibration are the strong influence of rain on wind-induced oscillation of cable. The cables in cable-stayed bridges, which are stable with respect to wind acting in dry condition, became very unstable with rain, and large amplitude oscillation of cable could be developed under low speed wind around10m/s. for the first time this phenomena have been seen in the bridge Meiko-Nishi (Japan) and after in the others cable-stayed bridges as: Aratsu, Higashi –Kobe (Japan), Dömitz (Germany), Erasmus (Holland) est.*

Many analytical and experimental investigations have been made for known the influence of different factors that produce this phenomenon in much country, especially in this country that is attacked by this phenomenon as: Japan, Germany, Holland, France EST. The reason of this seminar work is to make UN representation to this phenomenon, to represent same some analytical and experimental investigation made by different authors and conclusion yielding from this investigation.
Here are presented first the response of cables on the excitation by the wind and after are compared with the response under the couplet excitation « Rain-Wind »

The principal parameters that give a grate influence in this phenomenon can be classified in two groups. First the group of the situation of cable were included: the orientation of cable, wind speed, reins intensity. In second group named cables properties were are included natural periods, damping ratio and property of the surface of cables. We point here the fact that even many investigation are made this phenomenon is not well known, the reason for this is the fact that the excitation couplet Rain –Wind is very complex

INTRODUCTION

Rain vibration of cables is becoming a matter of great concern for design and construction of cables-stayed- bridges. The features of rain vibration are the strong influence of rain on wind-induced oscillation of cable. The cables in cable-stayed bridges, which are stable with respect to wind acting in dry condition, became very unstable with rain, and large amplitude oscillation of cable could be developed under low speed wind around 10m/s.
The name of these phenomena is made from Hikami in 1986 as « Rain - Wind » phenomenon.
Many analytical and experimental investigations have been made for known the influence of different factors that produce this phenomenon in much country.

Three important topics are :
- First is expressed the phenomenon,
- In second is given the influence of the different parameters ;
- In third is given some solution that can be used for elimination of vibrations produced from this phenomenon.

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First the group of the situation of cable were included: the orientation of cable, wind speed, rains intensity.
In second group named cables properties were are included natural periods, damping ratio and property of the surface of cables.

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1. PRINCIPLE OF EXCITING RAIN-WIND MECHANISMS

Many experimental investigation has been made in wind tunnel including also the rain.
Detailed observation of the interaction between the motion of acrylic tube during the model test and the motion of one ore two rivulet on the surface of the tube in the circumferential direction led to finding the new mechanism.
The response of cables subjected to the rain-wind excitation has been with big amplitudes.
The conclusion of this experimental investigation has been the mechanisms that create this instability.

1.1 General data for the experiment rain-wind

For the response of the model are used different deviation and inclination angles
The dimension of the wind tunnel is 2.7 m high and 1.8 m wide, the maximum speed is about 30 m/s.
The diameter of model is the same as the prototype for the reason to eliminate the scale effect of the water rivulet and cable diameter.
The cable is inserted inside an acrylic tube with a smooth surface.

The position of shower that stimulates the rain can be changed depending the model position. The moment that the response of the model have big amplitude is when on the model is created the water rivulet that move in circumferential direction.
For our study the rain intensity used corresponds to the intensity with the biggest amplitude in the model response.

1.2 Cross section cable modification

Interaction cable –rivulet is very difficult to be understood because of the complexity. The cross section is a function of the water rivulet on the surface of the cable. This position is depended on the wind speed rain intensity, dynamic property of cable, friction force cable-water rivulet.

1.3 Energy input

If the resulting wind force acting on the entire cross section is oscillating at the same frequency an with the same we sign as the oscillation velocity or with a little time lag positive work is done and the oscillation system gets an energy input , which is assessed according respectively formula.

1.4 Excitation mechanism

Essentially three types of mechanisms have been observed. They are characterized by the location of the rivulet on the cross section and the vibration direction of the cable.

MECHANISM 1
(Oscillation in wind direction)
The movement of rivulets is symmetric. The biggest amplitude for this mechanism is for the inclination angle $\alpha = 30^\circ$, deviation angle $\beta = +90^\circ$ and for win speed $V = 22 m/s$.
MECHANISM 2
(cross-wind vibration two rivulet)
Movements of rivulet are nonsymmetrical. This type of rain-wind-induced vibration can occur in cables inclined against the wind direction.
MECHANISM 3
(cross-wind vibration one rivulet)
This mechanism is presented for the cable with the angles $\beta = \pm 45^\circ$ and $\alpha = 30^\circ$.This mechanism is produced for low wind speed.

1.5 General findings

The vibration are produced for wind speed $V \in [5 \div 25] m/s$ and for the frequencies low than $8.9 Hz$. However, at these frequency only-rain-wind-induced amplitudes of the magnitude of the vortex excited amplitudes arose. At higher frequencies, increasing vibration acceleration makes the water, due to its masse of inertia unable to follow the motion of the cable. That could be the reason for low amplitude for high frequencies. For inclined cable the largest amplitudes occurred at the angles $\beta \pm 45^\circ$.

1.6 Conclusions

- Interaction between the rivulet in circumferential direction and the vibration of the cylinder is fundamental for the excitation rain-wind
- The instability can be for this condition $\beta = \pm 45^\circ$. The wind speed is around the interval $5 - 25 m/s$.

2.ANALITICAL STUDY OF THE RAIN- WIND INDUCET MECHANISM

The cables in cables stayed bridges which are stable with respect to wind action under dry condition, become very unstable with rain. Characteristics of the phenomenon have been presented in the previous chapter by wind tunnel test and field investigation. The object of the present investigation is to analyze the phenomenon based on a theoretical modeling and thereby to clarify the rain-wind mechanism.

The rain water rivulet formed along the upper part of the surface cable has been known from the previous investigation. Due to this experiment the analytical model used have a cross section shape on the form of 8, as indicated in the figure 1

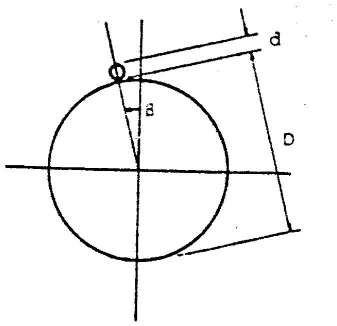

Fig.1 Analytical model

Natural frequency of circumferential motion of rivulet is proportional to the wind speed, while the natural frequency of plunge motion of cable is independent of the wind speed.

The aerodynamic damping change drastically as the wind speed change. Especially for the wind speed 10m/s, went the natural frequency of rotation coincide with natural frequency of plunge motion.

2.1 Influences of rivulet dimensions

In the previous section it was assumed that the position of the angle and thickness rivulet remain constant even the wind speed change, while the position and dimensions of the rivulet change with the increase of wind speed. This assumption may not be suitable for predicting the real phenomenon but has given a useful information on the qualitative characteristics of rain vibration.

The instability characteristic is very sensitive to any small change of rivulet and that is very important to clarify the position and configuration of rivulet under wind for investigating the real phenomenon of rain-wind induced vibration quantitatively.

2.2 Conclusions

- The rain water rivulet , which is formed along the upper surface of cable under rain and wind condition is able to oscillate in circumferential direction because of the aerodynamics stiffness.
- The aerodynamic damping coefficient for the cable oscillation became negative when the frequency of upper rivulet is close to the natural frequency of cable.

- The circumferential oscillation of the upper rivulet is coupled with the vertical oscillation of the cable and is indispensable to the growth of rain vibration.
- Response has a divergent nature. Consequently the cable models were more prone to vibration in this test than real bridge cables would have been in natural environment. This vibration can be present for $\alpha = 0^{\circ}$ and $\beta = 45^{\circ}$ also $\alpha = 60^{\circ}$ and $\beta = -90^{\circ}$.
- The vibration rain-wind has a convergent nature.
- The rain is an amplification of vibration.
- Cable response depend on the reduced wind velocity
- The wind velocity that induces the vibrations depends on the natural frequencies of cable.
- It appears that the air turbulence has the effect of stabilizing the rain/wind-induced vibration. The cable vibration was gone when the intensity of flow turbulence exceeded 10%.

3. INFLUENCE OF SURFACES INPROPERTY ON THE EXCITATION RAIN-WIND

This test is made during the construction of the cables stays bridge of Normandy with a main span 856 m long, the longest stays are 460 m and composed of 53 parallel stands.
By the test is shown the influence of improperly surface on the excitation rain-wind.

3.1 Test condition

The model is equipped with a polyethylene standard case which is 7m long and 160mm diameter smooth tube. A complete of series of test is conduced without and with rain. The fixation of the model is given in the figure 2. The model is on steel 7m long. The two tables give the test data and dynamic characteristic of the model.

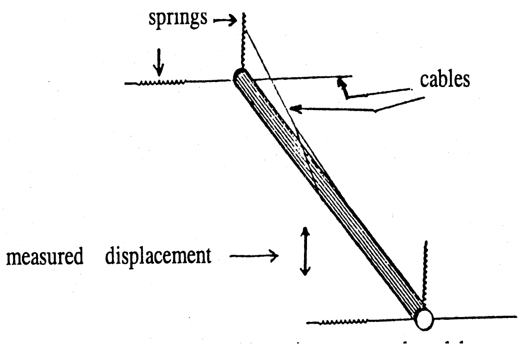

Fig. 2 Test scheme

wind tunnel section	7 x 6 m
wind mean speed	0 to 20 m/s
turbulence intensity	4 to 12%
rain intensity	0-300 mm/h

Table 1 Wind tunnel characteristics

3.2 Identification of rain-wind induced excitation

During the series of test 1,2 and 3 no regular excitation has been identified. On the contrary the series 4 test showed a regular excitation yielding after 20min, a stabilized sinusoidal movement with 150 mm amplitude. The amplitude decreased with increasing wind speed.

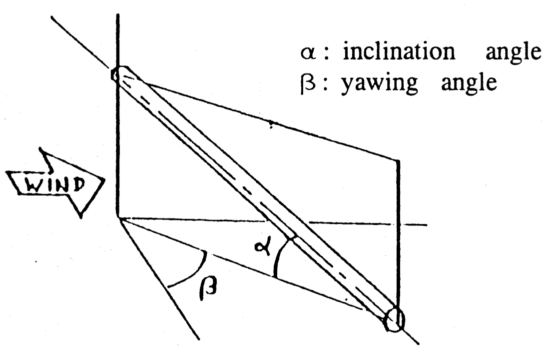

Fig. 2 Model fixation

Series	1	2	3	4
Case type	**clean PE**	**clean PE**	**PE+oil**	**PE+soot**
Rain	**no**	**yes**	**yes**	**yes**
Upper Rivulet	**no**	**no**	**no**	**yes**
β (degrees)	**30-45-60-90**	**30-45-60-90**	**30-45-60-90**	**30**
U(m/s)	**6 to 13**	**6 to 13**	**6 to 13**	**10**
Excitation	**no**	**no**	**no**	**yes**

Tab.2

The tests are made for two different materials surface PE (polyethylene) and PP (polypropylene), both smooth tubes.

When the case is clean, for both materials, there is not excitation.

When the case is coated with soot resulting from fuel-oil combustion, which is a like the atmospheric pollution, the upper rivulet appears and oscillates.

3.3 Conclusion

- Not cleaned cables are one reason more for generation of rain-wind excitation.

4. INFLUENCE OF SURFACE ROUGHNESS FOR ELEMINATION OF RAIN-WIND VIBRATION

4.1 Aerodynamic response of PE stay cables with different surface roughness

The tests are made for different pattern surface. The model $A_1 - A_6$ have a uniform pattern. For the models $B_1 - B_3$ and models C_2, C_3 is applied a pattern surface as given by the figure below. The characteristics of this model are given in the table. For the models A_i, B_j is used the wind tunnel with 2m height and 1m width. Wind speed $V = 25m/s$ that correspond to the Reynolds number $\mathrm{Re} = 2.2 \cdot 10^5$. Wile for the models C_k dimension tunnel are 3 m and 2 m and the maximum speed is used $V = 55m/s$.

Model	Diameter D (m)	Surface roughness (μm)	Relative surface roughness (k/D)
A_1	0.1315	3	2.3×10^{-5}
A_2	0.1220	30	2.5×10^{-4}
A_3	0.1315	100	7.6×10^{-4}
A_4	0.1235	200	1.6×10^{-3}
A_5	0.1240	600	4.8×10^{-3}
A_6	0.1275	1,500	1.2×10^{-2}
B_1	0.1465	200	1.6×10^{-3}
B_2	0.1465	600	4.1×10^{-3}
B_3	0.1490	1,200	8.1×10^{-3}
C_1	0.140	3	2.1×10^{-5}
C_2	0.140	1,500	1.1×10^{-2}
C_3	0.140	1,500	1.1×10^{-2}

Remarks
smooth
uniform distribution
“
“

grid-like pattern all over surface

smooth
discrete concave patterns
“

Tab. 3 Mode A_i, B_j, C_k

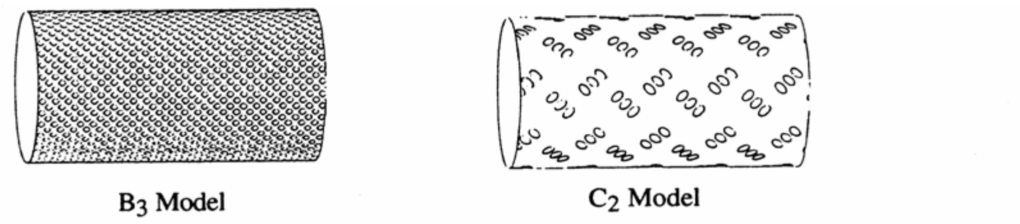

Fig. 3 Surface pattern for models

The drag coefficient of a body with a circular section and smooth surface in a uniform flow is a function of the Reynolds number, $\mathrm{Re} = \frac{V \cdot D}{\vartheta}$

$V \rightarrow$ wind speed
$D \rightarrow$ cable length
$\vartheta \rightarrow$ kinematics' viscosity

This means that the flow around the body changes with Reynolds number.
Surface roughness causes a shift in the separation point along the body were the section is circular and this accelerates the transition in top the turbulent flow region. Since changes in drag coefficient are dominated by the location of the separation point the surface roughness also has a great effect on the drag coefficient in the range of Reynolds number.

With increasing the relative surface roughness k/D, the drag coefficient at the critical Reynolds number exceeds the drag coefficient of the smooth round cable models by 0.5.
With increasing wind velocity, the drag coefficient increases and has a tendency to rapidly approach 1.2.

4.2 Influence of surface roughness for elimination of the vibration rain-wind

Figure 4 show the wind tunnel apparatus used. Models C_1 and C_3 with the length 3m are used for the test.
Table 4 show the experimental parameters for each cable with inclination angle $\alpha = 45^\circ$ and deviation angle $\beta = 45^\circ$.

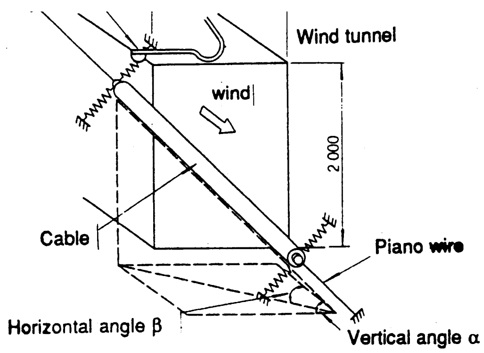

Fig.4 Model fixation

Model	Weight per length (N/m)	Fre-quency (Hz)	Log-arithmic decrement δ	Remarks
C1	64.7	1.8	0.0035	Smooth
C2	64.7	1.8	0.0039	Discrete concave pattern
C3	64.7	1.8	0.0032	Discrete convex pattern

Table 4 Model dimensions

4.3 Vibration response during rainfall

With simulated rainfall at water volume of 0.8, 1.4 and 2 l/min., for model C_1 vibration occurred at wind velocities of about 9÷12m/s.
Unstable vibration occurred when the reduced wind velocity V/fD exceeded about 40.

For models C_2 and C_3 with roughened surfaces no rain vibration occurred for these models the other intensity water is used but no vibration occurred.

5. ELEMINATION RAIN-WIND VIBRATION SOLUTION USED

We have shown the principal vibration that influence in the response of the cables subjected to this excitation.
This are : wind speed, cable orientation, rain intensity, cable characteristics as natural frequency, damping, cable roughness etc. Based in the result of many analytical and experimental investigation we are giving here same example that are used in al cables stay bridges. Some of this bridges have been firstly subjected to this type of excitation.

5.1 Surface modification

The experiment shows that is very important to destroyed the water rivulet running on the surface cable. The way of destroyed this water rivulet is presented by the Fig. 5.

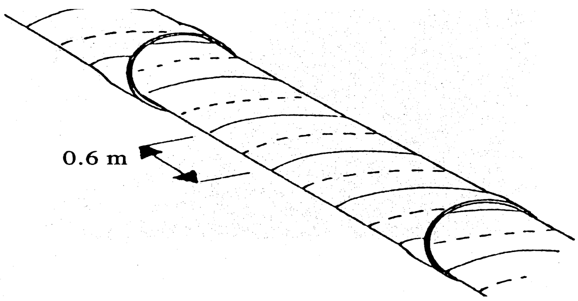

Fig.5 Solution used for the bridge of Normandie

Filets with dimensions 1.3 mm high and 2 mm large are fixed in a helicoidally way on the surface of the cable.

5.2 Aerodynamics method of cable vibration control

By the resultants of the experiment that show as the influence of the turbulence, (this investigation is made during the study for solving the rain-wind vibration subjected to the cables-stayed bridge of HIGASHI-KOBE, Japan. One solution is found. This is given in fig 6 and consists in longitudinal parallel surface projection. These make the turbulence flow that makes the creation of water rivulet mechanism impossible. After made on place of this solution and investigation during 3 years not vibration occurred in the cables.

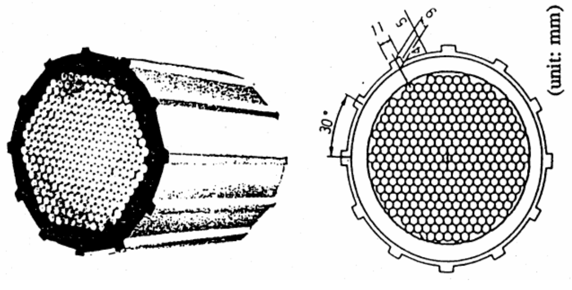

Fig.6 Higachi-Kobe cable stayed bridge aerodynamic solution

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