풍력에 대한 합리적인 접근

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A REASONABLE APPROACH FOR WIND FORCES.

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초록

모든 건설재료에는 치수의 한계가 있다. 현수선교나 사장교인 경우 강재를 사용하면 최대지간 거리 5000m~7000m 가 가능하나, 유리섬유 복합재료를 사용하면 이의 2 배, 탄소섬유 복합재료를 사용하면 이의 3 배가 가능하다. 지간 거리가 20,000m 가 되면 가장 중요한 하중은 바람하중이다. 복합재료의 여러 장점 때문에 거대한 규모의 건물, 교량등 구조물이 건설될 때 구조 기술자는 풍(바람)하중을 구하고 다룰 수 있어야 한다. 이 논문에서는 구조 기술자가 풍 하중을 구할 수 있게 기초 이론과 기본기술을 제공하고 있다.

1. Introduction

Whenever an engineer designs a structure, he must consider all the possible forces acting on the structure. Among these forces, the most uncertain one is the force caused by wind, that is, the wind forces. One may consider the effect of atomic blast, but it has the shock-wave front and the problem reduces to that of wind forces with different magnitude of the force and oscillation. Therefore, the analysis of wind forces and the structural responses against them are the most important and basic problems in design.

2. General Idea of Wind

The wind may be defined as the motion of the air caused by deflective forces due to earth's rotation, and by centrifugal forces due to the curvature of the wind path. Certainly, this motion is opposed by friction and viscosity. This flow of the air, or motion of the air possesses kinetic energy by virtue of the velocity and the mass of the air. Of course, the air never flows with streamline motion but always with fluctuations which has both vertical and horizontal components.

For our purposes, the wind forces acting on the structures are significant when they are strong and these occur only during storms. Thus, the study of wind forces becomes closely related with that of the storms.

The wind velocities are different according to geographical areas. Therefore it is necessary to determine the possible maximum wind velocities from the basis of recordings of storm observations at certain areas.

3. Velocity and Pressure

As it was pointed out previously, the flow of the air, which is the wind, has certain kinds of kinetic energies. Therefore, for any selected two points within the flow the Bernoulli equations can be written as

$$\frac{V^2}{2g}+\frac{P}{\gamma}+z=\frac{V_0^{\,2}}{2g}+\frac{P_0}{\gamma}+z_0+f$$

in which V,P,z are the velocity, the pressure, and the potential energy of approaching wind, V_0, P_0, z_0 are those of on the boundary of the objective, f is the energy loss caused by friction, g is the gravitational acceleration, and

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γ is the specific weight of the air or $g\rho$.

If gravity effect is absent, $z = z_0$. Moreover, the friction between the flow of the air and the surface of the structure can be neglected. Thus f = 0.

Hence,

$$\frac{V^2}{2g} + \frac{P}{\gamma} = \frac{P_0}{\gamma} + \frac{V_0^2}{2g}.$$

or $\frac{V^2\rho}{2} + P = \frac{V_0^2\rho}{2} + P_0.$

Thus, if the velocity at the stagnation point is assumed at zero,

$$P_{st} = P + \frac{V^2\rho}{2}.$$

If the atmospheric pressure is assumed as same at both approaching point and the structure,

$$P = \frac{V^2\rho}{2}.$$

This is the basic equation for calculating the wind pressures.

4. Basic Characteristics of Winds

Wind has vertical component as well as horizontal.

Then one can express as

horizontal force (drag) = $C_D qA$ and

vertical force (lift) = $C_L qA$

where C_D and C_L are the coefficients of drag and lift, A is the area of the surface, and $q = \frac{1}{2}\rho V^2$ is the wind pressure.

If the resultant force is eccentric, we have moment,

$M = C_m qA$

where C_m is the coefficient of turning moment.

There is no way to determine these values except by experiment. The magnitudes of drag and lift vary with

a) geometric form of the object,

b) position of the object in the wind stream,

c) friction effects, and

d) to a limited extent, the size of the object.

Den Hartog suggested that the intensity of the alternating force be witted as

$$F_k = C_k \rho \frac{V^2}{2} A$$

where F_k is Karman fore and C_k is a dimensionless coefficient which he suggested to call as Karman coefficients.

5. Shape Coefficients

Singell, T. (1958) suggested to use the velocity pressure, q. to be expressed as q = $0.001274V^2(Pa)$ using air density of $0.125058\,N/m^3(\gamma)$ corresponding to $15\,^{\circ}C$ at 760mm of mercury.

The basis of this equation is as follows.

$$q = \frac{1}{2}\rho V^2 = \frac{1}{2}\gamma V^2$$

$$= \frac{1}{2} \times \frac{0.125058\text{N/m}^3}{9.81456 m/\sec^2} \times [\frac{1609.34}{3600} \frac{m}{\sec}]^2 V^2$$

$$= 0.001274V^2 N/m^2(Pa)$$

The unit of V is miles per hour (MPH).

Of course, this may not be conservative, for the density increases according to the decrease of the temperature, thus increasing the value of q. Therefore, it is suggested to use the value of air density at the lowest temperature recorded at the specific area. Once this expression is obtained the effect of the shape of the structure must be considered.

As it was shown, the pressure can be expressed as the product of $\frac{1}{2}V_0^2\rho$ and a certain constant C, which may be called as the shape coefficient.

Thus,

$P = q \times C$

where, $q = \frac{1}{2}V_0^2\rho.$

If Singell's suggestion is used,

$P = C \times 0.001274V_0^2(Pa).$

The unit of V_0 is miles per hour, and that of P is pounds per square foot.

For the external forces on buildings with plane surfaces normal to the wind, the total pressure on the outside of the windward and leeward faces of an average buildings is 1.3q of which 0.88q is on windward and 0.5q is the suction on the leeward wall

Hence,

$P = q \times C = q \times 1.3 = 0.001656V^2(Pa).$

6. Variation of Velocities due to Height

As the air flows, there are ground friction, shear force due to viscosity, upward and downward movement caused by temperature changes, and many other factors which cause the changes in velocity. Moreover, the mountains and high buildings which lie on the pass of the winds will make great influence on the velocities and they will have almost completely different characteristics when they approach different cities or towns. One can conclude that it is very difficult to generalize characteristics of the wind. The best way may be to keep the weather observation recordings. But, at certain height, the influence of the ground friction, transmitted upward through eddy viscosity, has a negligible effect on the velocity of the wind. At this height, the pressure gradient is said to be dynamically balanced against two components arising from centrifugal force, one due to the rotation of the earth and the other due to the curvature of the wind path. The wind velocity computed on this basis is called the "gradient wind". But there must be a transition from the surface velocity to the gradient velocity and this is referred to as the variation of the wind velocity with the height.

There are many factors which cause the variation of the wind velocity with height, such as the pressure gradient, the mass density of the air (therefore, the temperature), the angular velocity of the earth's rotation, the geographical attitude at which observations are made, the curvature of the wind path, and the coefficient of the eddy viscosity of the air. The best way of determine the design velocity is the use of storm observation data.

7. Oscillation

Wind has the characteristics of oscillations.
These are caused by

a) vortex shedding,
b) negative slope on the lift or moment curve,
c) flutter, and
d) shockwave.

These oscillations will have critical effect when the structures respond dynamically to the imposed wind forces or (in other words) the natural frequency of the structure coincides with that of the external wind forces.

High tension transmission lines, tall stacks, suspended pipe lines, and girder stiffened suspension bridges are subject to the vortex shedding.

Ice-coated transmission lines, deep plate girder-stiffened suspension bridge (h/b>0.23) are subject to the vibration due to the negative slope on the lift or moment curve.

Any flexible type of structures involving large flat areas upon which the wind impinges at a relatively small angle of attack, such as large cantilever roof structures, certain types of suspension bridges, inadequately supported sign boards and various elements which, during erection, may be inadequately supported, are subject to flutter.

For design, it is preferred to make the structure so as to break the uniformity of the wind and to make it stiff enough to avoid oscillation. In general, a truss-stiffened section is more favorable than a girder stiffened section.

8. Conclusion

Civil and architectural structures built by composite materials may have very huge sized. Then the forces caused by the wind forces will be very great. In this paper, the general guide line to obtain such forces is briefly explcined.

Reference

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