TOWARD MORE ACCURATE PREDICTION OF DAMAGE DUE TO STRONG WINDS

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ABSTRACT**:** The insured losses of structures due to strong winds have been always dominant and it will have significant contribution if such damage is effectively suppressed. In order to decrease the damage, it is useful to understand the mechanism of what kind of aerodynamic forces acts on the structure and how the structures are damaged. In this paper, recent studies in Japan are reviewed that were conducted to establish more accurate prediction procedure based on the mechanism of damage on typical three structures due to strong winds: houses, wind turbines, and long-span bridges.

Most of the insured loss due to strong winds is from damage of conventional houses. Typical damage in Japan is blown off of the roofing tiles. The blown off tiles often hit the nearby houses and thus cause the secondary damage. Therefore reducing the blown off of the roofing tiles is important, and recently some experimental studies are conducted to measure the force related the phenomenon using a full scale model house.

Utilization of the wind energy has recently become quite popular in Japan. High power wind turbines are often imported; however sometimes they suffer damage due to strong wind in Japan. This is probably because of the severe strong wind condition in Japan, caused by typhoons and complicated terrain. Vigorous studies have been conducted recently to establish the wind-resistant design procedures of wind turbines in Japan.

For long-span bridges, wind load determines the design of some structural members and the accurate prediction of the load is indispensable for an economical and safe design. Also the prevention of wind-induced vibration is important. Related recent studies are introduced.

KEYWORDS: roof tiles, wind turbines, damage reduction due to strong winds

1. INTRODUCTION

Wind disasters caused by strong wind are still serious in Japan; insurance loss became more than 9 hundred billion yen (although it includes the loss due to flood or landslides that is thought to be minor due to much less number of applications) in 2004 due to the record high number of 10 typhoons landed on Japan. The strong winds are often caused by typhoons and very strongly developed extratropical cyclones in Japan; but in some cases, tornadoes and downbursts cause damages on houses and other properties. The tornadoes in Japan are generally of F1~2 Fujita scale or at most F3, and their damage is usually limited in a very restricted area.

Wind engineers have been searching for the engineering countermeasures that can reduce the damage caused by the strong winds. In this paper, some of such Japanese current activities are summarized.

The most widely observed damage caused by strong wind is that of roof tiles of residential houses. Therefore, the wind effects on roof tiles have been studied for some time (for example, Okada, 1988). Recent development of such studies is introduced first.

The utilization of wind energy has become more and more popular in Japan. Most of wind turbines built in Japan are imported from European countries where wind condition is much calmer than in Japan. Probably because no detailed procedure for wind resistant design of wind turbines is established under such strong wind condition as in Japan, there are some incidents of wind damage of turbines. Current activities to prevent such damage are summarized next.

Wind effects often plays essential role in long-span bridge design, and studies in bridge aerodynamics reached a summit with the completion of the Akashi Kaikyo Bridge in 1998 and the Tatara Bridge in 1999. More attention has been paid for the economical design since then and related studies are introduced at the end.

2. WIND FORCES ON ROOF TILES

It is important to clarify the wind force characteristics on the roof tiles because it will lead to the prevention of the wind-induced damage. Okada(1988) conducted a wind tunnel test using 1/20 scale model that simulated the blown off of the tiles. However the direct measurement of the aerodynamic forces was not conducted and the similitude between the test and actual condition was difficult to be achieved. Recently, series of test have been conducted using 1:1 full scale models in actual natural wind and the results are introduced in the followings (Okada et al., 2005; Okada and Kikitsu, 2005).

2.1 Full scale measurement of the forces on roof tiles with lift

The full scale gable roof house used in the study is shown in Figure1. The height, width, length of the model house is 6.7, 6.3 and 5.7m, respectively. It was located in an industrial flat area facing a canal (Figure2). Wind forces acting on two Japanese style roof tiles, J type and F type (JIS A5208-1996), were measured (Figure3). The forces were measured with some lift, δ, of the tile, and the definition of δ is also shown in the figure. The effect of the lift was studied because the roof tiles are lifted and vibrate just before they are blown off in the strong wind and the

Figure1 the full scale model house (Okada et al., 2005)

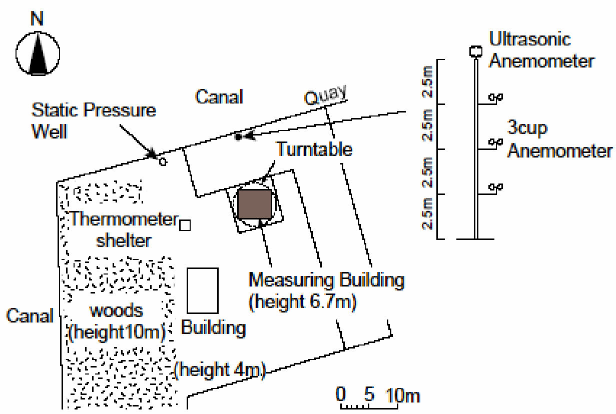
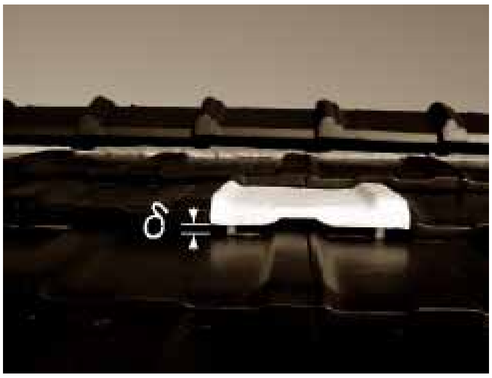


Figure2 the model house location (Okada et al., 2005)

(a) J type tile



(b) F type tile

Figure3 roof tiles used in the study (Okada et al., 2005)

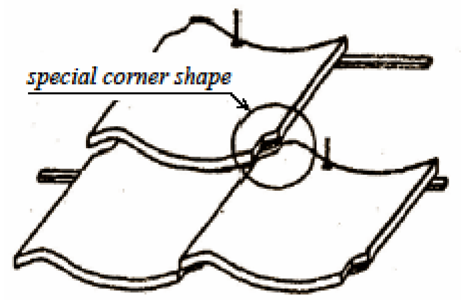


Figure4 disaster-preventing tile that engages with upper left and lower right adjacent roof tiles by special corner shape (Okada and Kikitsu, 2005)

Figure5 roof tile pulling-up test device (Okada and Kikitsu, 2005)

wind force characteristics under such condition was thought to play important role in the phenomenon.

Some of the obtained findings are:

1) The mean external and internal pressures on the tiles are affected by the lift of the tile, but the total mean wind force changes only a little with the lift for most cases.
2) In many cases, the maximum negative peak wind force increases with the lift of the tile.
3) Fluctuating internal pressure can be estimated by spatially averaging the fluctuating external pressure over the entire roof area.

2.2 Evaluation of wind resistance performance of roof tile

At first, information was collected from roof tile construction companies such as roof tile configuration (conventional and disaster-preventing type (Figure4)), pattern of fastening (all tiles, every 2nd or 3rd tiles fastening, or no fastening), and fastener details (nail configuration and so on). From the survey, regional difference in the popular construction methods became clear.

Then performance of the roof tiles was examined by a series of pulling-up tests and Figure5 shows the test device. Cases that correspond to various construction methods were tested for three times, and the average maximum pulling–up load was obtained.

From the result of the survey and pulling-up tests, regional wind resistance performance was estimated. Effects of recent construction method to reduce the damage were discussed for each region.

3. WIND RESISTANT DESIGN FOR WIND TURBINES IN JAPAN

In order to clarify the current situation of the wind resistant design of wind turbines in Japan, and to propose a guideline, Task Committee on Wind Resistant Design of Wind Turbine Generator System is actively conducting researches under Japan Society of Civil Engineers (Task Committee on Wind Resistant Design of Wind Turbine Generator System). In this section, their activities are introduced from their papers presented at a recent conference (Ishihara et al.. 2005a; Ishihara et al., 2005b; Noda et al., 2005).

3.1 Analysis of damaged wind turbines

Wind turbines on Miyakojima Island were seriously damaged by strong wind of Typhoon Maemi on September 11, 2003. Figure6 shows the location of the wind power plants on the island, and Figure7 shows the damaged wind turbines at Karimata wind power plant. First, the damage of each wind turbine was carefully examined to clarify the direction of collapse, blade position, entrance door direction and nacelle direction. Then the wind speed at the time of the damage was estimated from a hybrid method utilizing numerical simulation and wind tunnel test. The estimated wind speed seems to agree well with the observed data (Figure8), which was interrupted before the time of damage due to power failure.

FEM simulation and wind response analysis were conducted to evaluate the ultimate bending moment and maximum bending moment acting on the turbine towers and the foundation. The simulated result explained the observed damage.

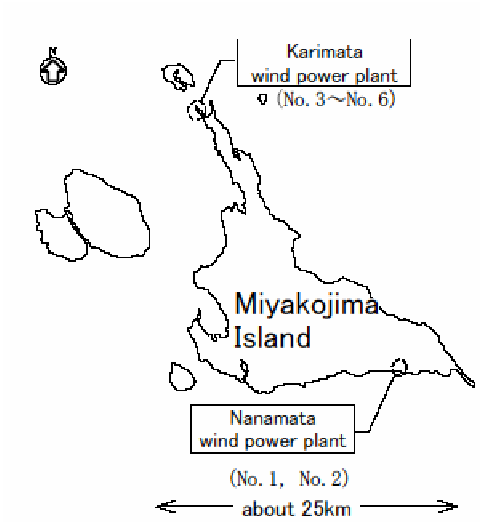


Figure6 the locations of wind power plants (Ishihara et al., 2005b)

Figure7 damaged wind turbines at Karimata plant (Ishihara et al., 2005a)

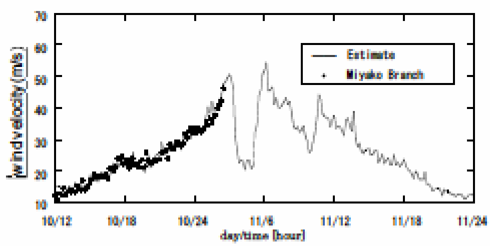


Figure8 comparison between estimated and actual average wind speed (Ishihara et al., 2005b)

3.2 A field test and dynamic simulation of a wind turbine

Related to the study described in the previous section, a field test of a wind turbine at Karimata, which was survived the typhoon's strong wind, was carried out to clarify the dynamic structural parameters such as natural frequencies and structural damping. The observed structural damping ratios of the tower were 1% for in the fore-aft direction and 0.6% in the side-side direction. A FEM code was developed to predict the natural frequencies and wind responses of the wind turbines. Using the full wind turbine model that model whole the turbine structure, i.e., the tower, blades, hub, and nacelle, was modeled with beam elements could reproduce the observed first two natural frequencies. The predicted tower bending moment response agreed well with the observation as shown in Figure9.

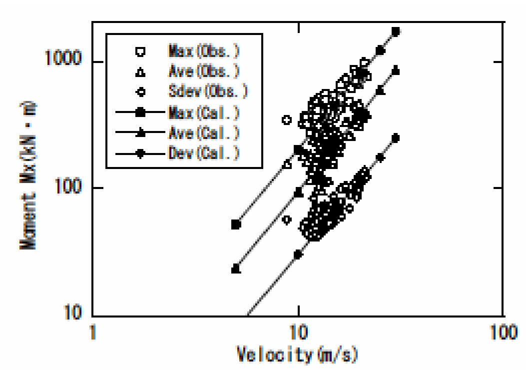


Figure9 comparison between predicted and observed tower bending moment in fore-aft direction (Ishihara et al., 2005a)

3.3 Wind forces on wind turbine nacelle

A wind turbine nacelle is a box containing gears and an electric generator which is usually located downward of the wind turbine blades for a large wind turbines. Total mean wind forces and local peak pressures on nacelles were measured with models with several configurations like shown in Figure10. Mean drag coefficient to estimate the total design wind load was proposed (Figure11) and its value is smaller than the other codes. On the other hand, the pressure coefficients recommended in GL2003 appear to be considerably underestimated. Also in some regions, negative peak pressure coefficients recommended in BSLJ and AIJ seem to be underestimated.

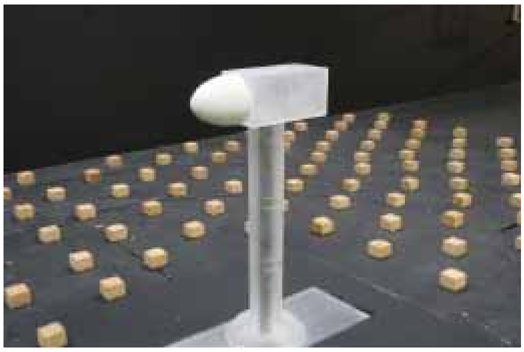


Figure10 example of wind force measurement model of a wind turbine nacelle (Noda et al., 2005)

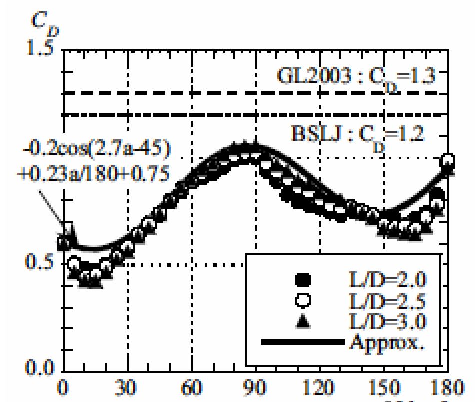


Figure11 proposed drag coefficient C_D vs wind direction taken from the front, compared with other codes: GL2003 (Germanischer Lloyd) and BSLJ (Building Standards Law in Japan) (Noda et al., 2005)

4. CURRENT TOPICS IN BRIDGE AERODYNAMICS AND HYDRODYNAMICS

For very long-span bridges, design of some structural members is determined by wind load. Therefore the accurate estimation of buffeting that is the random response caused by fluctuating natural wind is necessary for economical design. Studies aiming to clarify the fluctuating wind force characteristics and mechanism are currently undertaken in Japan. For relatively shorter span like a little less than 100m, application of a composite girder bridge with two main I girders is becoming popular in Japan. However the deck shape is similar to that of the Old Tacoma Narrows Bridge and it can be unstable even with such main span. Some studies have been conducted and design guidelines are under preparation. During a typhoon in 2004, the Ohmori Bridge was fallen down due to high wave hitting on the bridge. Together with much more extensive damage observed in USA by Hurricane Katrina with similar cause, probably some countermeasures will be sought and taken in the future.

5. CONCLUDING REMARKS

Some recent studies in Japan that aim to reduce the damage due to strong winds were briefly introduced in three main fields: roof tiles (architecture), wind turbines, and long-span bridges (civil engineering). Besides basic researches like mentioned in this article, activities such as Research Committee on Wind-induced Disasters in Japan Association for Wind Eng. (http://wwwsoc.nii.ac.jp/jawe/index-e.shtml) are probably worth mentioning. The committee was established for more active research and social contribution in order to decrease strong wind disasters. It organizes investigations of damage caused by strong winds and accumulates the information related to strong wind disasters. We hope such activities will lead to the reduction of wind disasters.

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