Unraveling the Mystery of Wind Damage to Buildings

In our last issue, we looked at the research activities of Japan's Building Research Institute concerning earthquakes and buildings. In this issue, we focus on the Institute's research into the impact on buildings of wind.

Wind that damages buildings in Japan can be linked to typhoons and tornadoes. A typhoon is a tropical cyclone generated in the Pacific Ocean or the South China Sea with wind speeds of 17.2 m/s or greater. Typhoons are huge vortexes that may exceed 1,000 km in diameter. Every year, twenty-seven typhoons are generated on average, eleven of which typically approach Japan, with an average of three making landfall. In 2004, ten typhoons reached the Japanese coast, causing record-breaking rainstorms in a number of areas. According to data from the Cabinet Office, these typhoons caused great damage, killing 214 people, injuring 2,542, fully destroying or causing more than 50% loss to about 1,200 dwellings, half-destroying or causing 20–50% loss to another 9,300, and partially destroying or causing less than 20% loss to 67,000. Tornadoes, meanwhile, are violent, rotating columns of air involving an ascending air current, which may occur under a cumulonimbus cloud, for instance. Tornadoes range from tens of meters to hundreds of meters in diameter (**photo 1**). The wind at the center of a tornado is extremely violent, and houses directly in its path are destroyed immediately. Approximately 1,000 tornadoes occur in the United States every year. Japan itself is not entirely free of tornadoes, with around twenty-seven in a typical year. Per unit of area, the incidence of tornadoes in Japan is actually quite significant, about half that of the United States. Areas where tornadoes occur are mostly coastal areas and open and flat land, which can be found throughout the country (**figure 1**).

As a consequence, many parts of Japan are subject to strong winds each year. It seems, however, that the damage that wind can cause buildings still remains something of a mystery.

TOYOHASHI CENTRAL FIRE STATION

Photo 1. A tornado on the horizon in Toyohashi, Aichi Prefecture, September 24, 1999

Damage Characteristics

Earthquake forces are first transmitted to the foundations of a building, then to its structural framework, such as columns and beams, and finally reach the ceiling, internal walls, exterior walls and roofing. On the other hand, wind forces first hit the cladding, such as roofing, exterior walls and windows, before their impact reaches the structural framework. Thus, the load paths of earthquake and wind within a building are the opposite to each other. And unlike earthquakes, strong winds such as typhoons buffet buildings continuously over an extended period, and place extreme pressure on ridges and the corners of roofs.

Earthquake forces are transmitted

from the ground to a building, causing damage to every part of the building. In contrast, strong winds mostly damage the cladding such as roofs, exterior walls and windows, which are directly hit. Generally, damage to the cladding lets rainwater into the building, which may soak furniture, goods stored in warehouses and equipment in factories, for example. Financial damage from the immersion of indoor goods may be much greater than the damage from the loss of roofing itself.

It is also pointed out that strong winds may cause serious secondary damage to adjacent buildings because they cause roofing to break away, becoming flying debris. **Photo 2** shows the flying debris caused by a tornado that occurred in Hokkaido on November 7, 2006. It was one of the largest tornadoes ever to occur in Japan, and the debris around the store includes structural frameworks that look like lattice beams, cladding such as roofing, interior materials and fittings, and even an object that looks like a refrigerator. Flying debris like this damages the cladding of other buildings, including walls, roofs, and windows, and this in turn causes other damage. This sort of chain reaction has frequently been cited.

On September 17, 2006, Typhoon Shanshan made a landfall on Nagasaki Prefecture and caused damage to buildings and other structures, along with high wind flooding, mainly on Kyushu. Major examples of damage from the typhoon include the broken roof of the Iizuka Cosmoscommon, the culture hall of Iizuka City, Fukuoka Prefecture (**photo 3**). This building had a hemispherical roof made of waterproof stainless steel sheets. More than half of the sheets were peeled off by the strong wind and fell to the surrounding ground and the roofs of adjacent buildings. Damage to the surrounding buildings was minor, so it is believed that the stainless steel roof had already been damaged, and that this became obvious when the roof was peeled off by the strong wind. Consequently, the damage to the roof was not seen as caused by a wind that was stronger than had been assumed.

Figure 1. Areas where occurrences of gusts including tornadoes were confirmed in 1961-2009

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Wind Resistant Designs

Buildings are designed to be wind resistant to prevent damage from strong winds. Skyscrapers and large-span structures are considered to be susceptible to wind. Therefore, structural designers carefully design structural frameworks of such buildings to be not only earthquake-resistant but also wind-resistant. However, structural designers were not very interested in wind resistant designs for cladding, although the majority of damage from strong wind involves cladding. In 2007, it became mandatory for structural designers to submit to the local governments structural calculation sheets proving the wind resistant designs of building cladding, in addition to evidence of the wind resistant designs of the structural frameworks, before buildings are constructed. This is likely to lead to wider recognition and application of wind resistant cladding designs by structural designers. Creative measures will be needed, such as indications of the wind-resistant performance of cladding that are easy for structural designers to recognize.

As in the example given in the pre-

HOKKAIDO REGIONAL DEVELOPMENT BUREAU, MINISTRY OF LAND, INFRASTRUCTURE, TRANSPORT AND TOURISM

Photo 2. The many objects that turned into flying debris in a major tornado in Hokkaido, November 2006 vious section, strong winds also cause flying debris to hit and damage cladding. This requires the development and proposals of methods for testing and assessing the crashworthiness of cladding in Japan.

Photo 3. The roof of the Iizuka Cosmoscommon in Fukuoka Prefecture damaged by Typhoon Shanshan in September 2006

Measures taken by the Building Research Institute for Reducing Damage from Strong Winds

The Building Research Institute conducts onsite investigations of areas hit by strong winds, as well as buildings damaged by earthquakes, to determine the degree of damage. The Institute conducts extensive surveys and research on measures to minimize damage to buildings from strong winds. Examples are as follows.

1) The Institute has been advancing research aimed at proposing a standard format of structural calculation sheets proving wind resistant cladding designs for buildings, which now must be submitted to the local government, as mentioned in the previous section. This format will make it easier to judge the wind-resistant performance of cladding, which will help reduce damage from strong winds.

2) As in the case of Iizuka Cosmoscommon, the roofs of particular buildings may be damaged even when the strength of the wind is within the scope assumed by the designers. To reduce damage to cladding in these instances, the Institute has studied causes and responses, and the results of the research are reflected in the manuals intended for people who work on construction sites.

3) Methods of understanding the damage from disasters are specified in Japan (Criterion for Judging Levels of Damage to Dwelling Houses Concerning Disasters). The results of the Institute's studies were reflected in the revision of these Standards, which were made in 2009, and methods for determining the degree of damage from strong winds were added to the Standards.

4) Tornadoes are extremely violent gusts of wind. It is extremely costly to make a building that is strong enough to withstand tornadoes. Moreover, because the probability of damage to a building caused by a gust such as a tornado is extremely low, the current Building Standard Law of Japan (BSL) only assumes strong winds such as typhoons and winter storms, with gusts such as tornadoes outside the scope of the BSL. However, some buildings (such as disaster-prevention facilities, hospitals, nuclear power plants and chemical plants) are required to be fully resistant to gusts such as tornadoes, even though the probability of such phenomena is extremely low. For this reason, recent years have seen growing research into the wind effects of gusts like tornadoes on these buildings both in Japan and overseas.

The Building Research Institute has also begun researching gusts, such as tornadoes. For instance, it has installed a tornado simulator (**photo 4**; developed with reference to the tornado simulator of Iowa State University in the United States) and has agreed to conduct joint research into damage from tornadoes with other research institutes in Japan.

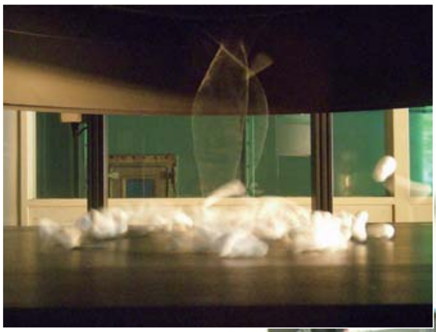

Photo 4. The BRI's tornado simulator