High Wind Damage to Buildings Caused by Typhoon in 2004

by

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ABSTRACT

In 2004, Japan experienced noticeable damage by 10 typhoons, especially in western part. Severe damage to various buildings and structures occurred due to high wind during the passing of typhoons. The damage to roofing material or roof system of large-scale buildings was remarkable. Investigation on such damage in buildings is considered to be useful to prevent and to mitigate from similar damage.

KEYWORDS: Repeated Temperature Fluctuation, Roofing Material, Roof System, Typhoon

1. INTRODUCTION

In 2004, 29 typhoons were bone on the South Pacific Ocean and 10 typhoons struck Japan, which holds the annual record for the number of typhoons striking Japan. Fig.1 shows tracks of the typhoons in 2004.

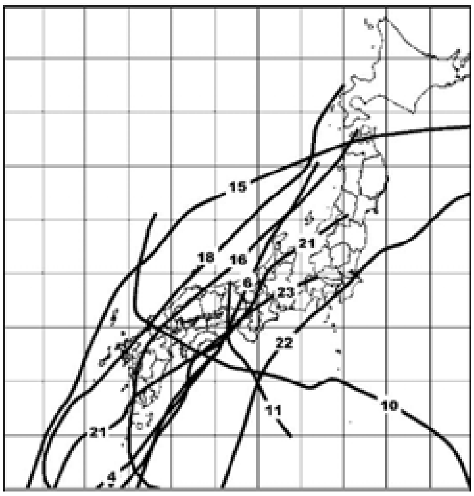

Fig.1 Tracks of Typhoons Striking Japan in 2004

In Japan, 214 people were killed and more than 2,000 people were injured by these typhoons. Houses more than 200,000 were collapsed or damaged by high wind and flooding. Serious financial losses exceeded $5 billion. Furthermore, lots of large-scale public or commercial buildings were damaged, which were remarkable for damage to roofing materials and system.

2. EXAMPLES OF HIGH WIND DAMAGE[1),2)]

2.1 Public Facility

Public facility named Yamaguchi Center for Arts and Media (YCAM) at Yamaguchi Prefecture in the southwestern part of Japan is a new building constructed in March, 2003. The main structure is steel frame with metal roof system which has a unique shape expressing three big waves. The roofing materials cover the roof with the length of 170m and the width of 30m. About half of the whole roofing materials were blown off due to high wind of Typhoon 0418 in September 7, 2004. Maximum 10 minutes mean wind speed of 24.4m/s and maximum instantaneous wind speed of 50.5m/s were observed at the local meteorological observatory. Fig.1 shows the failure observed in YCAM.

As a typical failure, lots of screws were observed to be pulled off from wood-wool cement board located on the edge of roof. On the other hand, screws attached to mortal slab at the center part of roof were tone. It is considered that the failure of roofing materials started from the edge of roof, and then they were subjected to increasing wind force and peeled from the roof one after another. A team of storm investigators concluded that the main cause of the failure is inadequate estimation of the design wind loads and the use of fasten materials whose strength is inadequate. The design wind load was evaluated using a wind force coefficient for a typical

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semi-cylindrical roof such as sports gymnasiums. Furthermore, it is found that the wind force could be increased by backpressure of roofing materials through under machinery space.

Fig.1 Failure of Roofing Materials of YCAM due to Typhoon 0418

Based on a number of tests to certify the strength of fastener as shown in Fig.2, it was found that the dispersion of the strength of fastener is larger than we expected. Some of them have the value less than the permitted strength of the fastener. It is also found, furthermore, that a remarkable strength reduction in the fastener may be appeared by the stretch of metal roof for daily heat fluctuation suffered by sunshine. Subsequently, the renovation of roof just after damage was assured to satisfy the wind design load considering a sufficient safety margin based on the research results including the wind tunnel experimental result.

Fig.2 Tensile Test for the Fastener of YCAM

2.2 Large-scale Experimental Facility

The roof of a large-scale experimental facility named SPring-8 was damaged by two Typhoons 0416 (August 30, 2004) and 0418 (September 7, 2004). Fig.3 shows the damage of its roof. The plan of the building is donut-shaped. It is approximately 1,500m in circumference and 30m in width and was constructed in 1997. The roof system consists of two-layer folded steel plates and with thermal insulating materials between them, and the gorge and ridge lines of the folded plates are in the radial direction. The southern part of the roofing material was damaged over an area 270m long-by-10m wide by typhoon 0416, and the eastern part of the roofing material was damaged over an area 100m long-by-10m wide by typhoon 0418.

According to the precise post-disaster investigations, the main cause of the damage was attributed to the fatigue effect on the bolts connecting the roof system to the tight frames due to daily solar heating effects on the upper layer. Fig.4 shows the fracture surface of damaged bolt. Striations and dimples are both observed in the fracture surface of it. Striations are basically observed in fatigue fracture surfaces caused by repeated loads, and dimples are generally observed in the normal fracture surfaces caused by tensile loads. Dimples also took place on the center with striations on both sides.

Fig.3 Failure of the roof of SPring 8

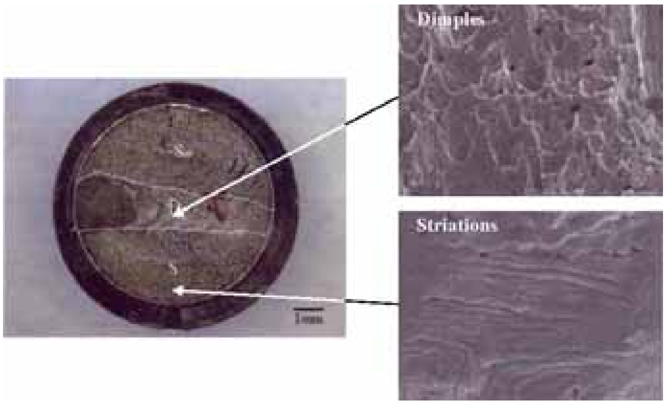

Fig.4 Fracture Surface of Damaged Bolt after Takeuchi, *et al*. [3)]

2.3 Warehouse

A large-scale commercial warehouse at Kobe was damaged due to high wind by Typhoon 0423 in September 27, 2004. The size of this building is 70m in width, 40m in depth and 30m in height. The wall was caved in and the roof was severely damaged due to strong wind pressures as shown in Fig.5. Many stocked goods resulted in suffering heavy losses by water intrusion.

The wall made of ALC (Autoclaved Light-weight Concrete) board, which was supported by light steel frame, was connected to solid rack in the building. The buckling of the connecting steel pipe which seems to have insufficient strength caused this failure. The roof system of a double metal roof deck filled with insulation glass wool was adopted. On this roof system, remarkable differences in temperature arise between the upper and the lower deck by incident sunshine on the roof. The repeated occurrence of significant difference in stretch of decks affected by fluctuation of temperature may cause the metal fatigue in bolts fastened between the upper and the lower deck.

Fig.5 Failure of Large-scale Warehouse at Kobe

2.4 Public Gymnasium

Okawa Taiikukan is a public gymnasium with ridged roof covered by metal roofing material located at Shikoku in southwestern part of Japan. This building was damaged three times in a year by Typhoons 0406, 0410 and 0423. At first, a quarter of roofing materials were blown off during Typhoon 0406. Subsequently, a few and a half cladding got blown off when Typhoon 0410 and 0423 were passing, respectively. Observed wind speeds were relatively small, i.e. the maximum instantaneous speed of 28.4m/s in Typhoon 0406 and 26.9m/s in Typhoon 0423, respectively. Fig.6 shows the failure of the gymnasium by Typhoon 0423.

Metal roofing materials were fixed to ALC board by using an aluminum anchor that spreads itself two wards inside the ALC board to resist against pulling force. The roofing materials, however, were damaged when high wind attacked to the building. It was observed that lots of anchors were broken without pulled off from the board. It suggests that somewhat substantial trouble in anchors occurred, which may be affected by an influence of temperature fluctuation. As described above, the effect of temperature causes metal fatigue, since a stretch of roofing material raises shear stresses in the anchor. Considering that this type of public building is generally used as a public shelter for local people, it is important to meet wind resistant performance not only in the structural elements but also in claddings such as roof coverings.

Fig.6 Failure of Public Gymnasium

2.5 Dome with Membrane Roof

Izumo Dome was constructed in 1992 at Shimane Prefecture in northwestern part of Japan. This building has a wooden-arch dome supported membrane structure of 148m in diameter at base and 48m in height. The membrane with the thickness of 0.8mm is made of glass fiber coated with Teflon, and the suspended cable with the diameter of 52mm is also finished with Teflon coating in order to reduce the friction to each other.

When the membranes were severely vibrated induced by high wind during Typhoon 0418, one of 36 sheets of membrane was suddenly punctured as shown in Fig.7. The maximum instantaneous wind speed was observed 38.8m/s at a nearby fire station. Since the punctured membrane was subjected to nearly normal to wind and the breakage started from a point under the cable near the top of the dome, it can be estimated that any flying debris did not attack the punctured area. Fragments of punctured membrane scattered outside and inside of the building and some parallel lines were observed on the surface of them. It implies that severe friction between the cable and the membrane apparently occurred.

In a long time, sand and dust ridden with wind had been stuck in a gap between the cable and the membrane. Those accumulations may act such as a sandpaper to tear the Teflon coating from the surface of the membrane when the building is vibrated by high wind. When high wind due to Typhoon 0418 hardly shook the building, significant reduction of the strength of the membrane might occur.

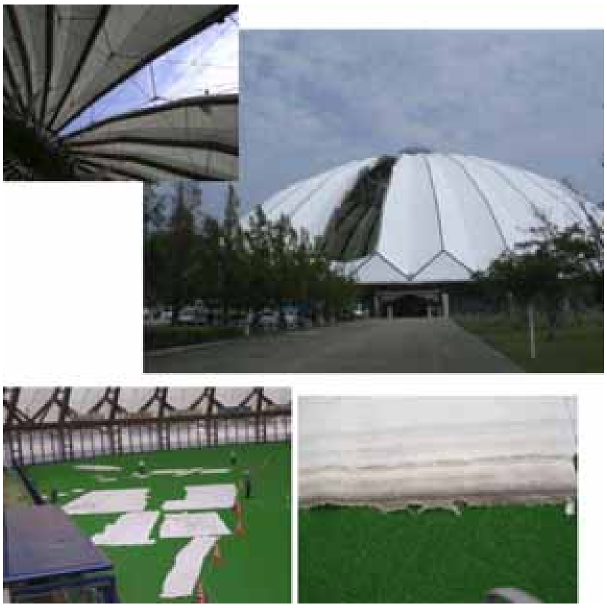

Fig.7 Punctured Membrane Roof of Izumo Dome

2.6 Inn

Typhoon 0406 struck Kinki area of Japan in June 21, 2004. A metal roofing covered on a motor inn at Shiga Prefecture was blown off from the building due to high wind and flew on to neighboring railway track of the Shinkansen super express as shown in Fig.8.

Fig.8 Blown Roofing Material from the Motor Inn

The size of the roofing material is 9 meter-by-41 meter and its weight is 7 ton. The Shinkansen service was suspended during 7 hours. The maximum 10 minutes mean wind speed of 16.0m/s and the maximum instantaneous speed of 36.4m/s were observed at the local meteorological observatory. The roof jumped upward and surprisingly passed over the signboard and the antenna on board apart and 10m in height 4m from the roof. Matsui *et al.*[4] carried out wind tunnel experiment to confirm the phenomenon as shown in Fig.9.

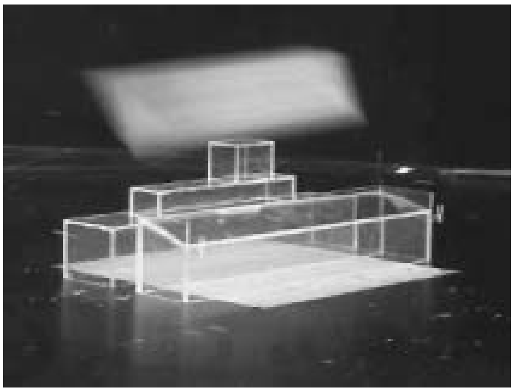

Fig.9 Experiment of Flying Roof Model by Matsui *et al*[4]

The blown roofing material was constructed on the original roof a few months before the damage in order to repair the rain leakage remaining the original one. The new roofing material was fixed to the original roof by using small fasteners and screws as shown in Fig.8. It was observed that the original roof was corroded and the number of fasteners was too small, and moreover a few screws did not reach to the beam in the existing roof system. Thus obviously, the strength of holding the roof was insufficient to resist wind pressure. The mean wind speed to start the flight of the roofing material is estimated to be 13.5m/s to 23.5m/s.

3. CONCLUSIONS

The investigation of wind damage to various buildings due to typhoons in 2004 indicates that actual wind speed on each site did not exceed the design wind speed based on the Building Standard Law of Japan. In many cases, the causes of the damage attribute to some reasons on buildings, e.g. the design of structure, the strength of materials, the consideration of effects on repeated temperature fluctuation on the roofing materials, and so on. Some of them are common problems to be solved for many other buildings.

4. REFERENCES

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5. ACKNOWLEDGEMENTS

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Table A.1 Lists of Typhoons Striking Japan in 2004

No (Name)	Date	Struck Site	Minimum Pressure [hPa]	Maximum Instantaneous Wind Speed [m/s] (Observed Site)
0404 (Conson)	June 11	Kochi	994	40.4 (Tanegashima)
0406 (Dianmu)	June 21	Kochi	965	57.1 (Muroto)
0410 (Namtheum)	August 1	Kochi	980	60.9 (Muroto)
0411 (Malou)	August 4	Tokushima	996	30.3 (Muroto)
0415 (Megi)	August 20	Aomori	980	48.7 (Izuhara)
0416 (Chaba)	August 30	Kagoshima	950	58.3 (Muroto)
0418 (Songda)	September 7	Nagasaki	945	60.2 (Hiroshima)
0421 (Meari)	September 29	Kagoshima	970	52.7 (Kagoshima)
0422 (Ma-on)	October 9	Shizuoka	950	67.6 (Ishirozaki)
0423 (Tokage)	October 20	Kochi	955	63.7 (Unzendake)