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Quick Report on Damage to Buildings by the Tornado on May 6, 2012 in Tsukuba City, Ibaraki Prefecture, JAPAN

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1. Introduction

Buildings suffered damage from a tornado which occurred around 12:35 PM on May 6, 2012 centered in Hojo area, Osuna area and Tsukuba North Industrial Park in Tsukuba city, Ibaraki prefecture. NILIM and BRI jointly conducted quick field investigations to grasp outlines of damage to buildings and others in Tsukuba city. The Japan Meteorological Agency (JMA) recognized it was a tornado and originally rated it as Fujita Scale of F2 [1]. As of June 8th, JMA changed the scale from F2 to F3 [2]. (For the outline of Fujita Scale, see Appendix A.)

The followings illustrate outline of damage to buildings and others through the field investigation. Further surveys and analysis will be conducted based on this field survey information. In addition, Appendix B introduces past major damage by tornados after 1990, including a tornado that occurred in Tsuchiura city next to Tsukuba on October 8, 2009.

2. Outline of Investigation

2.1 Data and Areas of Investigation

May 6 (Sunday) PM	Hojo area, Tsukuba city
May 7 (Monday) AM	Hojo area, Tsukuba city
PM	Osuna area and Tsukuba North Industrial Park, Tsukuba city
May 8 (Tuesday) PM	Yamaki and Hojo areas, Tsukuba city

2.2 Investigators

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3. Areas of Investigation

Investigation was conducted in Hojo area, Osuna area and Tsukuba North Industrial Park of Tsukuba city as shown in Figure 1, in which the red circle indicates Hojo area, green circle does Osuna area, and the blue circle does Tsukuba North Industrial Park. Section 4 shows damage in Hojo and Osuna areas and Section 5 shows damage in Tsukuba North Industrial Park, respectively. The black circle shows NILIM and BRI located at about 5km from the estimated path of the tornado.

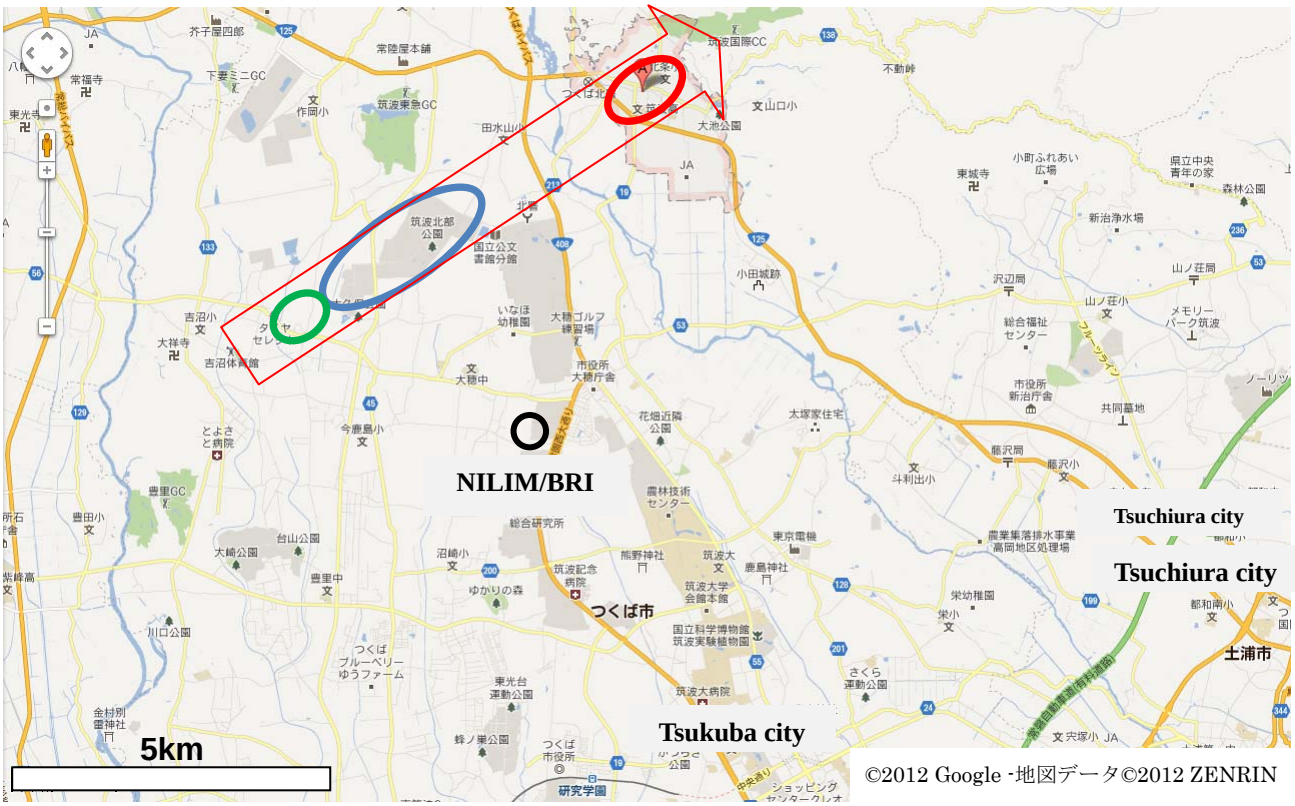

Figure 1 Areas of Damage Investigation (Arrow shows estimated direction of movement of the tornado)

4. Outline of Damage to Buildings etc. in Hojo and Other Areas in Tsukuba City

In this section, patterns of damage to buildings observed in Hojo and Osuna areas are illustrated.

4.1 Damage to Wooden Buildings

Damage cases are shown as below. (1) to (5) show structural damage, while (6) and (7) show damage of non-structural members.

(1) Turn-over of Wood House with Foundation

A wooden structure A (Photos 1, 2) completely turned over with mat foundation from ground.

Photo 1 Wood House A

Photo 2 Turned mat foundation of Wood House B

(2) Collapse of Wood Construction

Though the details of the collapsed structure cannot be grasped, wood construction B (this side, Photo 3) and C (Photo 4) completely collapsed because tornado-induced wind force was estimated to surpass the lateral shear strength of these structures.

Photo 3 Wood construction B (this side, collapsed one)

Photo 4 Wood construction C

(3) Scattering of Wood Construction

Whole wood construction without foundation (of wood houses D and E) were scattered. In the case of wood house D (Photo 5), the foundation remained (Photo 6) but most of wood construction were scattered. And, in the case of wood house E (Photo 7), sills, joists, and a part of floor board were remained.

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Photo 5 Wood House D

Photo 6 Remaining foundation of Wood House D

Photo 7 Wood House E

(4) Horizontal Movement of Wood House

A case of horizontal movement of wood house to the road was observed (Wood House F, Photo 8). Anchor bolts or connection of columns and foundation might be failed by the strong horizontal force of tornado.

Photo 8 Wood House F which moved horizontaly

(5) Failure and Scattering of Roof System

Many cases of damage on roof systems were observed. The damage cases are shown in Photo 9 of a gable roof (comparatively old house), Photo 10 of a gable roof (comparatively new house), Photo 11 of a hipped roof and Photo 12 of a shed roof, respectively.

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Photo 9 Wood House G whose gable roof was scattered.

Photo 10 Wood House H whose gable roof was scattered.

Photo 11 Wood House I whose hipped roof was scattered

Photo 12 Wood House J whose shed roof was scattered

(6) Damage on Openings

Openings are considered to have been broken due to out-of-plane wind pressure or collision of flying debris induced by the tornado.

The damage from out-of-plane wind pressure (Photos 13 and 14) caused failure of whole openings of outside in many cases, while partial damage of openings was seen in the case of collision of flying debris.

Photo 13 Wooden Building K

Photo 14 Wooden Building L

(7) Falling down and Scattering of Roofing and Exterior Materials

Substantial damage to roofing materials was observed (Photo 15). In addition, metal roofing materials were confirmed to have been scattered to considerable distances.

On the other hand, falling down of exterior materials was observed in exterior walls with mortar. In some cases, the wood laths of mortar wall were confirmed to be deteriorated. It is claimed that the mortared exterior walls will not collapse except the cases of structural shear deformation or out-of-plane forces, this cited failure is not determined to occur because of the reason of them.

Photo 15 Wooden Building M

Photo 16 Wooden Building N

4.2 Damage to Steel Building Structure

Major damage cases observed in steel buildings are shown in the following;

(1) Collapse and Scattering of Roof Truss and Breakage of Exterior Materials

The collapse and scattering of roof trusses with damage of exterior materials and windows were observed in a light-gauge steel framed house.

Photo17 Steel Framed Building A

(2) Residual Deformation of Structural Frame

Residual deformation of structural frame was observed in a warehouse building.

Photo 18 Steel Framed Building B

(3) Turn Sideways of Garage

A steel framed building used as a garage fell down and turned sideways.

Photo 19 Steel Framed Building C

Photo 20 Pull out of column base shown in Photo 19

4.3 Damage to Reinforced Concrete Building

Major damage to a reinforced concrete building was observed as introduced below;

(1) Damage to Openings and Fittings

Window glass, frames, handrails of verandah etc. of a five-story multifamily housing were

significantly damaged on the south side. Similar damage was observed on the north side although the openings were small.

Photo 21 South side of a public multifamily housing

Photo 22 Windows and handrails 1

Photo 23 Windows and handrails 2

Photo 24 North side of a public multifamily housing

4.4 Damage by Flying Debris

Much damage to exterior facials and openings by tornado-induced flying debris was confirmed.

Photos 25 and 26 show traces of collision at an entrance of a shopping center, Photos 27 and 28 show the collision of flying roof/roofing materials and Photo 29 shows a flying roofing material hung at electric cables.

Photo 25 Evidence of collision to window

Photo 26 Evidence of collision to exterior material

Photo 27 Scattered long steel roofing materials

Photo 28 Collision of flying roof frame

Photo 29 Roofing materials hung at electric cables

4.5 Other Damage

The followings are of additional cases to the previously introduced ones within sections 4.4. Photos 30 and 31 show collapse of a roof at gas station and heavy deformation of roofing materials at a bicycle station, Photo 32 shows collapsed stone fence, Photos 33 and 34 show broken electricity poles, Photo 35 indicates broken trees and Photos 36 and 37 indicate rolling cars etc. Photo 33 shows continuous broken electricity poles or inclined ones while Photo 34 shows the situation of broken electricity pole affecting a neighboring house. Turnover of not only light vehicles but also heavier vehicles and a truck was observed. (Photo 37)

Photo 30 Collapse of a gas station roof

Photo 31 Heavy deformation of roof of a bicycle park

Photo 32 Collapse of stone fence

Photo 33 Broken / inclined electricity poles 1

Photo 34 Broken / inclined electricity poles 2

Photo 35 Broken tree

Photo 36 Overturned cars

Photo 37 Rolling truck

5. Damage to Buildings in the Tsukuba North Industrial Park

The following damage was confirmed in the Tsukuba North Industrial Park.

(1) Damage to Glass

Window breakages were observed at exteriors and within roofed passages of reinforced concrete

or steel framed buildings.

Photo 38 Broken window of a roofed passage

(2) Damage to Exterior Materials, etc.

Damage to exterior materials and eave soffits was confirmed in steel framed buildings.

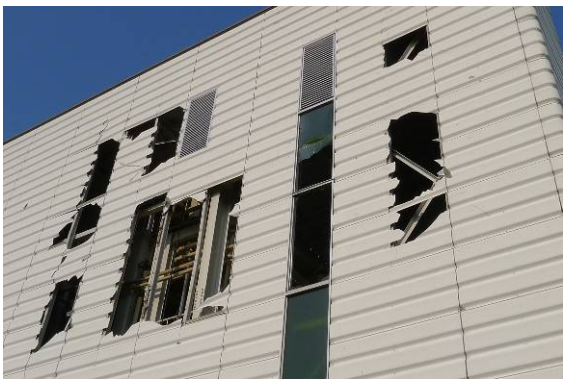

Photo 39 Breakage of exterior and windows

Photo 40 Breakage of eave soffits

(3) Damage to Roofing Materials

Damage to roofing materials of steel framed buildings was confirmed. Some roofing materials were scattered far to the next factory on the other side of the street more than several dozen meters.

Photo 41 Damage of roofing materials

Photo 42 Scattered roofing materials

(4) Other Damage

Some cases of broken trees and fallen trees pulled up by the roots were confirmed.

Photo 43 Fallen tree that was pulled up by the root

6. Summary

National Institute for Land and Infrastructure Management (NILIM) and Building Research Institute (BRI) jointly conducted field investigations on building damage caused by the tornado which occurred on May 6 in Tsukuba city Ibaraki prefecture, in order to understand the situation immediately after the disaster.

With respect to structural damage to buildings, collapse and movement of upper structures of wooden buildings and scattered roof trusses were observed. In addition, scattered roofing materials of wooden buildings, window breakage over roofing passages of steel framed buildings, window breakage and damage to handrails of verandah of a reinforced concrete building, and damage caused by the collision of tornado-induced flying debris were observed.

We sincerely express our condolences to a victim and his family and to the injured residents caused by the tornado. We have received cooperation for the field investigation by the affected persons and institutions, and express our gratitude for their cooperation.

Reference

1) Japan Meteorological Agency (JMA): Tornado occurred in Tsukuba city, Ibaraki prefecture on May 6th, 2012, May 7th ,2012 (in Japanese)
http://www.data.jma.go.jp/obd/stats/data/bosai/tornado/new/2012050601/2012050601.pdf

2) Japan Meteorological Agency (JMA): Report on the Tornado Outbreak on May 6th, 2012, June 8th, 2012 (in Japanese)
http://www.jma.go.jp/jma/press/1206/08b/toppuhoukoku120608.pdf

Appendix A

Fujita Scale

Source : NOAA's National Weather Service, Storm Prediction Center
http://www.spc.noaa.gov/faq/tornado/f-scale.html

Scale	Wind Estimate ***	Typical Damage
F0	< 73mph (< 32m/s)	Light damage. Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.
F1	73 – 112mph (33 – 49m/s)	Moderate damage. Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos blown off roads.
F2	113 – 157mph (50 – 69m/s)	Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
F3	158 – 206mph (70 – 92m/s)	Severe damage. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.
F4	207 – 260mph (93 – 116m/s)	Devastating damage. Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown and large missiles generated.
F5	261 – 318mph (117 – 142m/s)	Incredible damage. Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly through the air in excess of 100 meters (109 yds); trees debarked; incredible phenomena will occur.

*** IMPORTANT NOTE ABOUT F-SCALE WINDS: Do not use F-scale winds literally. These precise wind speed numbers are actually guesses and have never been scientifically verified. Different wind speeds may cause similar-looking damage from place to place -- even from building to building. *Without a thorough engineering analysis of tornado damage in any event, the actual wind speeds needed to cause that damage are unknown.*

Appendix B

This appendix contains a list of major damage by tornadoes from 1990 in Japan. URLs of related NILIM/BRI investigation reports are also introduced.

Feb. 1990
Mobara Tornado (Mobara city, Futtsu city etc., Chiba pref.) **F3 (70-92m/s)**
Damage area; length 5 km, width max. 1 km
Death 0, seriously injured 7, slightly injured 72 persons
Totally collapsed 85, half collapsed 176, partially damaged 1843 houses (Chiba pref.)
(BRI investigation report in Japanese)
http://www.kenken.go.jp/japanese/contents/publications/data/78.htm

Sept. 1999
Toyohashi Tornado (Toyohashi city, Toyokawa city etc., Aichi pref.) **F3 (70-92m/s)**
Damage area; length 19 km, width max. 550 m
Death 1, seriously injured 14, slightly injured 400 persons
Totally collapsed 40, half collapsed 309, partially damaged 1980 houses (Toyohashi city)

July 2002
Sakai Tornado (Sakai town, Gunma pref. and Fukaya city, Saitama pref.) **F2 (50-69m/s)**
Damage area; length 5 km, width max. 100 m
Death 0, seriously injured 1, slightly injured 11 persons
Totally collapsed 7, half collapsed 31 houses (Sakai town, Fukaya city)
(BRI investigation report in Japanese)
http://www.kenken.go.jp/japanese/research/str/list/topics/tatsumaki/index.pdf

June 2004
Saga Tornado (Saga city, Tosu city etc., Saga pref.) **F2 (50-69m/s)**
Damage area; length 8 km, width max. 300 m
Death 0, seriously injured 0, slightly injured 15 persons
Totally collapsed 13, half collapsed 34, partially damaged 322 houses (Saga, Tosu etc.)
(NILIM/BRI investigation report in Japanese)
http://www.kenken.go.jp/japanese/contents/activities/other/disaster/kaze/2005saga/index.pdf

Sept. 2006
Nobeoka Tornado (Nobeoka city, Miyazaki pref.) **F2 (50-69m/s)**
Damage area; length 7.5 km, width max. 250 m
Death 3, seriously injured 3, slightly injured 140 persons
Totally collapsed 71, half collapsed 317, partially damaged 599 houses
(BRI investigation report in Japanese)
http://www.kenken.go.jp/japanese/contents/activities/other/disaster/kaze/2006taifu13/2006taifu13.pdf
Nov. 2006

Saroma Tornado (Saroma town, Hokkaido) **F3 (70-92m/s)**
Damage area; length 1.4 km, width approx. 100m – 300m
Death 3, seriously injured 6, slightly injured 25 persons
Totally collapsed 7, half collapsed 7, partially damaged 25 houses
(BRI investigation report in Japanese)
http://www.kenken.go.jp/japanese/contents/activities/other/disaster/kaze/2006saroma/2006saroma.pdf

May 2008
U.S.A. Iowa Tornado (Parkersburg, Iowa, U.S.A.) **EF5 (89m/s-)** EF scale
Death 8, seriously and slightly injured more than 50 persons
Totally collapsed 394, half collapsed 65, partially damaged 162 houses
(BRI investigation report in Japanese)
http://www.kenken.go.jp./japanese/contents/activities/other/disaster/kaze/2008iowa/index.pdf

July 2009
Mimasaka Tornado (Mimasaka city, Okayama pref.) **F2 (50-69m/s)**
Damage area; length approx. 10 km
Slightly injured 2 persons
Totally collapsed 2, partially damaged 72 houses
(NILIM/BRI investigation report in Japanese)
http://www.kenken.go.jp./japanese/contents/activities/other/disaster/kaze/090719-okayama.pdf

July 2009
Tatebayashi Tornado (Tatebayashi city, Gunma pref.) **F1 or F2 (33-69m/s)**
Damage area; length approx. 6.5 km
Totally collapsed 25, half collapsed 33, partially damaged 361 houses
(NILIM/BRI investigation report in Japanese)
http://www.kenken.go.jp./japanese/contents/activities/other/disaster/kaze/090727-gunma.pdf

Oct. 2009
Tsuchiura Tornado (Tsuchiura city, Ibaraki pref.) **F1 (33-49m/s)**
Damage area; length approx. 2.8 km, width approx. 200m – 300m
Totally collapsed 1, half collapsed 11, partially damaged 94 houses
(NILIM/BRI investigation report in Japanese)
http://www.kenken.go.jp/japanese/contents/activities/other/disaster/kaze/091008-tuchiura.pdf

Feb. 2012
Izumo Tornado (Izumo city, Shimane pref.) **F0 (17-32m/s)**
Damage area; length approx. 7 km
(NILIM investigation report in Japanese)
http://www.nilim.go.jp/lab/bbg/saigai/h24shimane/h24shimane.pdf