資料4－2

6B.5 DEVELOPMENT AND IMPLEMENTATION OF JAPANESE ENHANCED FUJITA SCALE

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1 . INTRODUCTION

Japan experiences about 20 tornadoes per year (Niino et al., 1997), which is about 60 times less than the US. Even if frequency per unit area are compared, Japan is about 2.4 times less. Furthermore, annual tornado fatality in Japan is about 120 times less. Thus, tornadoes are not significant weather disaster in Japan.

In the year of 2006, however, Japan experienced two significant tornadoes that caused 12 fatalities. One is Nobeoka F2 tornado (Mashiko et al., 2009) and the other is Saroma F3 tornado. After these tornadoes, Japan Meteorological Agency (JMA) enhanced their operations related to tornadoes: For example, they started to upgrade 20 conventional radars to Doppler radars and completed the upgrade in 2012. They also started in 2008 to issue tornado advisories based on potential prediction of environmental parameters and radar observations such as detection of a mesocyclone and certain reflectivity distribution. Two years later they started to make one hour forecast of tornado probability for every 10 km mesh. Furthermore, they enhanced damage survey of hazardous winds to determine their cause and strength.

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In Japan, no systematic rating of tornado intensity was done before 1990, although a small fraction of tornadoes were occasionally rated by individual researchers. However, after two significant tornadoes in 1990, which are Mibu F2 tornado (Suzuki et al., 2000) and Mobara F3 tornado (Niino et al., 1993), JMA started to rate intensity of every tornado based on Fujita-scale (Fujita, 1971).

In February 2007, the Enhanced Fujita scale (EF-scale; McDonald and Mehta, 2006) was implemented by the National Weather Service in the US. It uses 28 Damage Indicators (DIs) and Degree of Damage (DOD). In April 2013, Environment Canada implemented Canadian EF-scale with 31 DIs (Sills et al., 2014). In order to enhance damage surveys, it was necessary for JMA to develop a Japanese EF-scale which is based on DIs commonly found in Japan, and is easily used by staff of local meteorological observatories.

In July 2013, JMA organized the Advisory Committee for Rating Intensity of Tornadoes which consisted of 9 experts in wind engineering and meteorology. The chairman and vice-chairman of the committee were Prof. Yukio Tamura, who is an expert of wind engineering, and Prof. Hiroshi Niino, who is an expert of meteorology. After two and a half years' efforts of the Advisory Committee, the guideline for the Japanese EF-scale (JMA, 2015) was compiled and was published online from JMA in December 2015. JMA started to use it operationally for rat-

ing tornado intensities from April in 2016.

2 . DEVELOPMENT OF JEF-SCALE

There were three steps for developing the Japanese EF(JEF)-scale: First, DIs and DODs were selected. Second, wind speeds corresponding to DODs for each DI were determined based on the state-of-art knowledge of wind engineering. Third, the relation between the wind speeds and JEF classes were determined. In the following, each step is explained in order.

2.1 *SELECTION OF DIS AND DODS, AND ESTIMATED WIND SPEEDS*

Thirty DIs were selected (Table 1). These include 9 DIs from houses and buildings. The DI No. 1 is wooden residential houses or stores which are most common in Japan. 21 DIs were also selected from other structures.

Wind speeds corresponding to DODs of each DI were estimated based on the latest knowledge of wind engineering, which was obtained from wind tunnel experiments, computer simulations and so on.

The detailed description of DODs for each DI may be found in the guideline (JMA, 2015; in Japanese; an English version is under preparation). Table 2 shows the three kinds of the estimated wind speeds for DODs for DI No.1 (wooden residential houses or stores) as an example: a representative value, lower bound and upper bound. Each wind speed is rounded to multiples of 5m/s. The range of estimated wind speed reflects difference in building and construction methods and so on. Figure 1 shows the typical damage corresponding to each DOD.

2.2 *RELATIONSHIP BETWEEN THE WIND SPEEDS AND JEF-SCALE CLASSES*

In order to have a continuity with the previous database based on F-scale, it is necessary to establish a relationship between the wind speeds and JEF-scale classes. To this end, we have decided to examine correlation between the wind speeds estimated by F-scale and JEF-scale. A total of 215 photos of damage due to tornadoes during 2007-2013 and F3 tornadoes after 1999 are used.

No.	DIs
1	Wooden residential houses or stores
2	Industrialized steel-framed houses (prefabricated)
3	RC apartment buildings
4	Temporary buildings
5	Large eaves
6	Steel-framed warehouses
7	Small non-residential wooden buildings
8	Greenhouses, gardening facilities
9	Wooden livestock sheds
10	Small sheds
11	Shipping containers
12	Vending machines
13	Light vehicles
14	Ordinary vehicles
15	Large vehicles
16	Railway vehicles
17	RC utility poles
18	Ground-based billboards
19	Traffic signs
20	Carports
21	Hollow concrete block (HCB) walls
22	Wooden, plastic, aluminum or mesh fences
23	Windbreak or snowbreak fences for roads
24	Net fences
25	Broad - leaved trees
26	Coniferous trees
27	Gravestones
28	Road surface
29	Temporary scaffolding (with wall ties)
30	Gantry cranes

Table 1: DIs for JEF scale

To obtain estimates of wind speed based on F-scale, five JMA experts examined each photo, determined the F-scale by subdividing F*n*-class into three sub-classes F*n*+, F*n*, and F*n*-, and the corresponding wind speeds converted to 3-second gusts with Durst's (1960) method were averaged.

To obtain estimates of wind speeds based on JEF-scale, on the other hand, five experts in

DOD	Damage		Wind Speed (m/s)		
			Rep.	LB	UB
1	Visible minor damage (breakage of glass)		30	25	35
2	Minor loss (detachment)/ displacement of roofing materials	Clay tile roofing	35	25	50
		Metal sheet roofing	40	30	55
3	Major loss (detachment) of roofing materials	Clay tile roofing	45	30	60
		Metal sheet roofing	50	40	65
4	Destruction/detachment of eaves or sheathing roof boards		50	40	65
5	Damage (deformation, cracking, etc.) to walls from deformation of main frames		55	40	65
6	Loss of metal wall cladding		60	45	70
7	Destruction/detachment of roof frames/components		65	50	75
8	Major destruction/collapse of main structures and frames		75	55	85

Table 2: DODs for DI No.1 (wooden residential houses or stores)

Fig.1: Examples of damage corresponding to each DOD for DI No.1 (wooden residential houses or stores). No photo with copyright permission is available for DOD5.

wind engineering estimated the wind speeds based on the DIs and DODs and the resulting wind speeds were averaged. The resulting scatter plot between wind speeds estimated by F-scale and JEF-scale is shown in Fig. 2. We decided to use a least square fitting to a power law, which is similar to the Canadian EF-scale (Sills et al., 2014). The best fit turns out to be

$$V_{\text{JEF-scale}} = 2.8 \times V_{\text{F-scale}}^{0.74}. \quad (1)$$

Table 3 shows the wind speed ranges corresponding to F-, EF- and JEF-scales. The wind speed range for JEF-scale n turns out to be given by $14n+25$ and $14n+38$ (m/s), which are linear with respect to n and are easy to remember. The wind speeds of JEF-scale are slightly larger than those of EF-scale.

The JEF-scale was first applied to Ohshu City, Iwate Prefecture, tornado on 20 June 2016. It was rated as JEF1 with estimated maximum wind speed of about 45m/s. So far 15 tornadoes were rated by JEF-scale with estimated maximum wind speed except that one tornado was categorized to "unknown" due to lack of DIs.

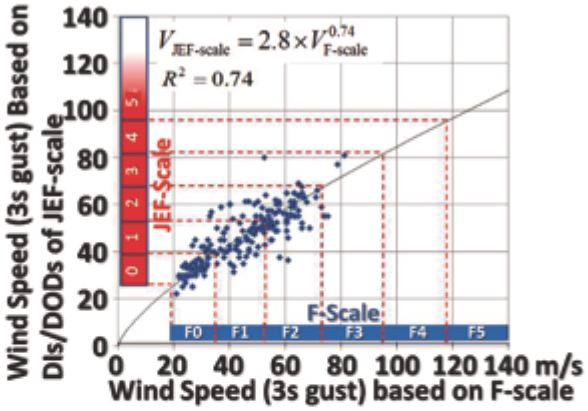

Fig.2: Relation between F-Scale and JEF-Scale

3. SUMMARY

The development of JEF-scale for two and a half years was completed in December 2015 and was implemented in April 2016 by JMA. The tornado database of JMA now records both the estimated maximum wind speed and JEF-scale class. The Advisory Committee for Rating Intensity of Tornadoes plans to review the performance of JEF-scale at least once a year.

We need to accumulate tornado data based on JEF-scale rating for long time to have a reliable statistics, since Japan experiences only 20 tornadoes per year (Niino et al., 1997) and have not experienced F4 and F5 tornadoes. The latter can be a weakness in the extrapolation of the power law during the development of the JEF-scale.

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F-scale		EF-scale		JEF-scale	
F	3s gust(m/s)	EF	3s gust	JEF	3s gust
0	19-35	0	29-38	0	25-38
1	35-52	1	38-49	1	39-52
2	52-72	2	50-60	2	53-66
3	72-94	3	61-74	3	67-80
4	94-117	4	74-89	4	81-94
5	117-142	5	89-	5	95-

Table 3: Comparison of E-,EF- and JEF scales

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