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The Japanese Enhanced Fujita Scale:

Its Development and Implementation

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1. Introduction

1-1. Tornadoes in Japan

Annual frequency of confirmed tornadoes in Japan: **25**
(2007-2015 average)

↑ Tornado in Nobeoka [F2] (17 SEP, 2006)
3 fatalities, 143 injuries, 427 houses destroyed or severely damaged

← Tornado in Saroma [F3] (7 NOV, 2006)
9 fatalities, 33 injuries

After these hazardous tornadoes, enhanced damage investigation started in 2007.

1-2. Necessity of a new set of guidelines for tornado rating in Japan

■ **F Scale / EF Scale** → based on **damage to buildings and trees in the United States and Canada**
→ It was recommended that Japan Meteorological Agency (JMA) formulate **a new set of guidelines to be applied to buildings and structures in Japan**.

■ **In formulating a new set of guidelines:**

- **Organization of an advisory committee**
- **Consideration of expertise in wind engineering**
- **Ensurance of statistical continuity with F Scale**

2. Development of the Japanese Enhanced Fujita (JEF) Scale

2-1. Issues for F Scale and EF Scale

■ **F Scale rating**

Correspondence NOT adequately verified

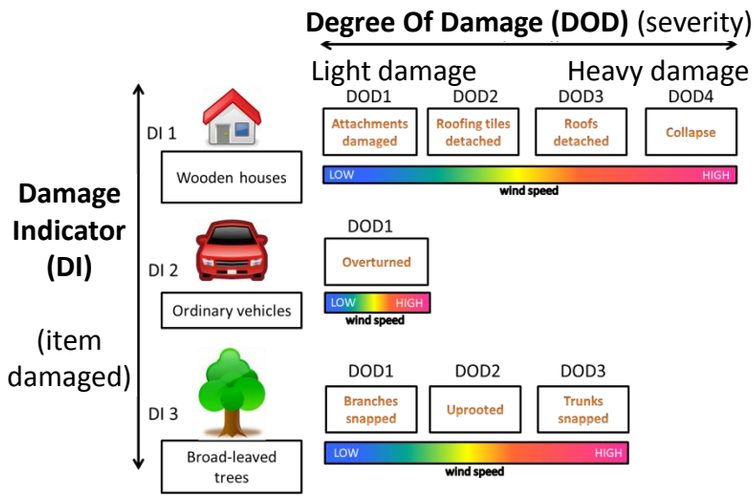
Individual damage cases → **Application to damage descriptions** → **Class (F Scale)** / **Range of wind speed**

Only 9 damage indicators

■ **EF Scale rating**

Individual damage cases → **Application to DIs and DODs** → **wind speed** → **Class (EF Scale)**

defined for buildings and structures in the US and Canada



2-2. Formulation of the Japanese Enhanced Fujita (JEF) Scale

- Members of the Advisory Committee of Tornado Intensity Rating -

ITO, Masaru	Nihon Sekkei, Inc. [**architecture**]
KIKITSU, Hitomitsu	Building Research Institute [**wind engineering**]
MAEDA, Junji	Kyushu University [**wind engineering**]
NIINO, Hiroshi**	The University of Tokyo [**meteorology**]
OKUDA, Yasuo	National Institute for Land and Infrastructure Management [**wind engineering**]
SAKATA, Hiroyasu	Tokyo Institute of Technology [**architecture**]
SHOJI, Yoshinori	Meteorological Research Institute [**JMA/meteorology**]
SUZUKI, Satoru	Forestry and Forest Products Research Institute [**dendrology**]
TAMURA, Yukio*	Tokyo Polytechnic University [**wind engineering**]

*Chair **Vice-Chair

Note: Members listed above and other 16 researchers cooperated to establish DIs/DODs and corresponding wind speeds.

3. Details of the JEF Scale

3-1. Characteristics of the JEF Scale

■ DIs/DODs
→ **buildings and structures commonly found in Japan**

■ Tornado intensity is estimated by **wind speed rounded to multiples of 5m/s (3-sec. average)** from engineering expertise.

▼List of DIs

1	Wooden houses or stores	16	Railway vehicles
2	Industrialized steel-framed houses (prefabricated)	17	RC utility poles
3	RC apartment buildings	18	Ground-based billboards
4	Temporary buildings	19	Traffic signs
5	Large eaves	20	Carports
6	Steel-framed warehouses	21	Hollow concrete block (HCB) walls
7	Small non-residential wooden buildings	22	Wooden, plastic, aluminum or mesh fences
8	Greenhouses, gardening facilities	23	Windbreak or snowbreak fences for roads
9	Wooden livestock sheds	24	Net fences
10	Small sheds	25	Broad-leaved trees
11	Shipping containers	26	Coniferous trees
12	Vending machines	27	Gravestones
13	Light vehicles	28	Road surfaces
14	Ordinary vehicles	29	Temporary scaffolding (with wall ties)
15	Large vehicles	30	Gantry cranes

3-2. DOD example

DI=1: "Wooden houses or stores"

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

3-3. Wind speed estimation example

DI=1: "Wooden houses and stores"
DOD=8: "Major destruction/collapse of main structures and frames"

Wind load against buildings w (N/m²)

$$w = \frac{1}{2}\rho V^2 C_f$$

Horizontal resistant strength R (N/m²)

$$R = C_0 \frac{W}{A_w}$$

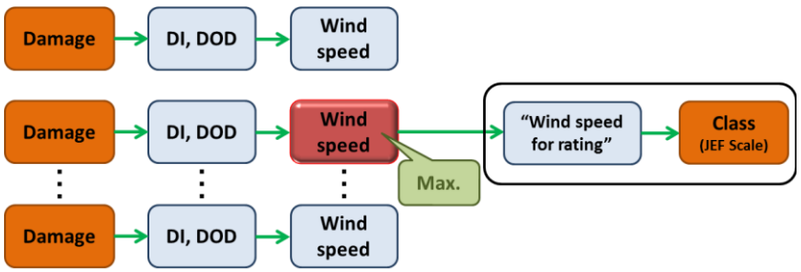
Wind speed for DOD is the minimum instantaneous wind speed V that satisfies:

$$R \leq w$$

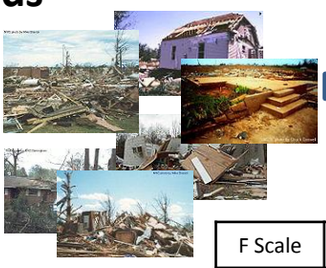
ρ	air density (1.2 kg/m³)
V	instantaneous wind speed (m/s)
C_f	wind force coefficient (1.2) *from engineering estimation
W	building weight (N)
A_w	wind receiving area (m²)
C_0	story shear coefficient *depends on **construction period**

Construction period	Before 1981 ↓	1981-2000 ↓	After 2000 ↓
Wind speeds (m/s)	LB (Lower Bound wind speed)	Rep. (Representative wind speed)	UB (Upper Bound wind speed)
	55	75	85

3-4. Rating procedure for the JEF Scale



4. Determination of correspondence between JEF Scale classes and wind speeds



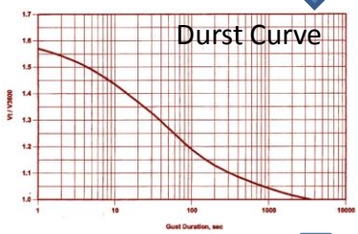
rating using DIs/DODs

rating using F Scale

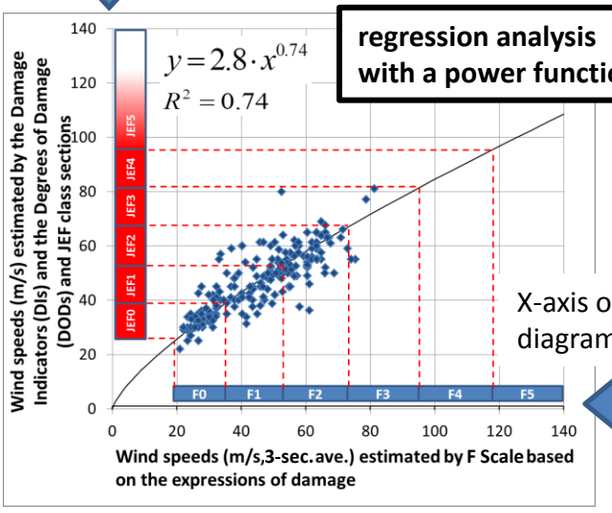
DOD	Damage	Wind speed (m/s) Rep.	LB	UB
1	Visible minor damage	30	25	35
…	…	…	…	…
7	Destruction of roof frames…	65	50	75
8	Major destruction…	75	55	85

F Scale	Wind speed range
F0	17-32 (15-sec. ave.)
F1	33-49 (10-sec. ave.)
F2	50-69 (7-sec. ave.)
F3	70-92 (5-sec. ave.)
F4	93-116 (4-sec. ave.)
F5	117-141(3-sec. ave.)

converting wind speed ranges into 3-sec. averaged wind speeds using Durst Curve



Y-axis of scatter diagram



Class	Wind speed range (m/s) (3-sec. ave.)	Primary damage (instances of damage cases for reference)
JEF0	25 to 38	 
JEF1	39 to 52	 
JEF2	53 to 66	 
JEF3	67 to 80	
JEF4	81 to 94	Roofing materials of large eaves of factories or warehouses overturned or blown away over relatively large areas
JEF5	Over 95	Main frames of steel-framed prefabricated houses or warehouses severely deformed or destroyed Banisters on balconies of reinforced-concrete apartment buildings severely deformed or destroyed

5. Operational use of the JEF Scale rating in 2016

JEF Scale rating was started by JMA in **1 April, 2016**.

5-1. Primary rating cases

DI=6: →
"Steel-framed warehouses"

DOD=3: "Loss (removal, detachment)/ distortion of roofing materials"
[With openings at windward wall] (UB, 60m/s)

(Kochi City, 5 OCT, 2016)

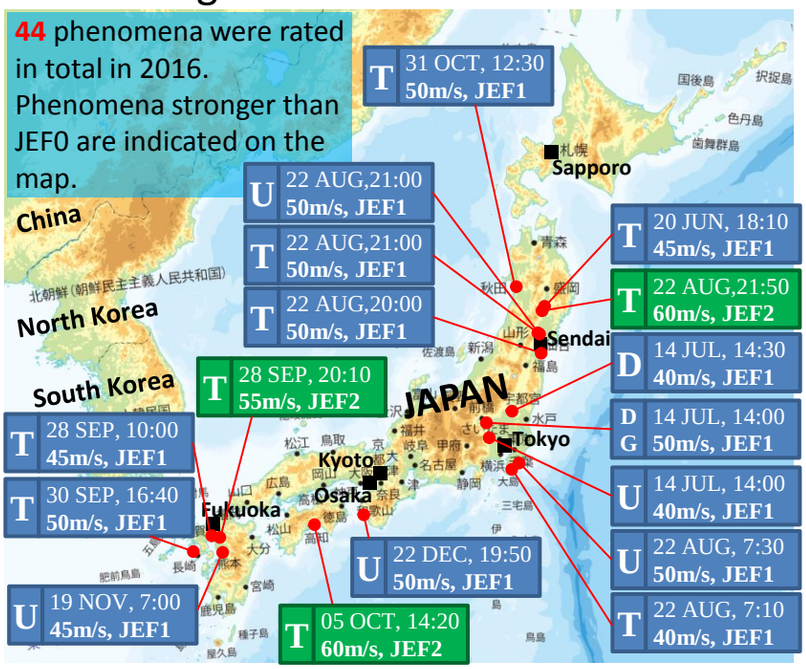
←
DI=13: "Light vehicles"
[Vans, lightweight trucks with hoods]

DOD=1: "Overturning"
(Rep., 40m/s)

(Akita City, 31 OCT, 2016)

5-2. Rating results

44 phenomena were rated in total in 2016.
Phenomena stronger than JEF0 are indicated on the map.



* T: Tornado, D: Downburst, DG: Downburst or Gust front, U: Unknown

JEF2: JEF1:

6. English version of the guidelines for the JEF Scale

English version is under preparation and will be uploaded on JMA web site (http://www.jma.go.jp/jma/en/Publications/publications.html) in due course.

Contents of "Guidelines for the Japanese Enhanced Fujita Scale"

7. Conclusions

- Japanese Enhanced Fujita (JEF) Scale, which can rate the intensity of tornadoes in Japan more accurately than the conventional F Scale, was developed.
- JEF Scale includes **DIs and DODs corresponding to buildings and structures commonly found in Japan**. Wind speeds corresponding to DODs were determined by **expertise in wind engineering**.
- **The Advisory Committee plans to revise JEF Scale continuously**, by adding new DIs and/or re-evaluating wind speeds corresponding to DODs as wind resistance of buildings improves in the future.
- **Unmanned Aerial Vehicles (UAVs) are being considered as a useful tool** for a more detailed investigation of buildings from various angles in determining DI and DOD.