IF-scale: Tornado and Wind Damage Assessment Guide

A globally applicable approach

Draft, work in progress, version 22 December 2016

Contents

1 Background

Those concerned with the physics and impacts of severe local wind phenomena, such as tornadoes and microbursts, have an interest in comparing the intensity of such events. For such a comparison, both a method of measuring the intensity and a unit of measurement are necessary. The biggest difficulty in establishing the intensity of an event is the typical absence of direct measurements of the wind speed. Instead, events can only be compared on the basis of the damage caused by the wind.

Several tornado intensity scales have been developed on the basis of after-the-fact assessments. Most prominently, Dr. Ted Fujita developed what has become known as the Fujita scale (reference). Other wind speed scales include the TORRO- or T-scale (reference) and the newer Enhanced Fujita or EF-scale (reference). The Fujita and TORRO scales are numbered series of descriptions of increasingly serious wind effects on various objects, along with estimates of the range of wind speeds responsible for causing the respective effects. No justification for the wind speed estimates of these scales was provided.

The F- and T-scales have been used, respectively in the United States, and in the United Kingdom and several places in Europe. In the USA in the late 1990's and early 2000's doubt about the accuracy of the wind speed estimates arose. Those were fed by incidental Doppler-radar measurements of actual tornado wind speeds and increased confidence of the engineering community in their ability to estimate such speeds. The measured wind speeds and the estimates of engineers were not consistent with the original estimated by Fujita. The problem was mitigated to some extent by developing the Enhanced Fujita scale. Besides providing updated wind speed estimates for particular wind effects, the Enhanced Fujita scale provided a conceptual framework for the assessment of tornado impacts. Wind effects were systematically categorized using the concept of Degrees of Damage, and Damage Indicators. A Damage Indicator (DI) is any specified object that may be affected by the wind, and a Degree of Damage (DoD) is the extent to which this object was affected, i.e. typically damaged. The new wind speed estimates of particular DoD of a particular DI were obtained by the method of *expert elicitation*. Essentially, multiple persons, experts in engineering and meteorology were asked to provide estimates for each DoD/DI combination, the results of which were all taken into account and used to provide a range of wind speeds likely responsible for having a particular damage effect.

Since the adoption of the Enhanced Fujita scale in 2007 by the U.S. National Weather Service adaptations and additions have been made in several areas around the world, most prominently Canada (reference) and Japan (reference). These additions were primarily motivated by the need for additional Damage Indicators. In addition, some Damage Indicators were found not to be applicable worldwide, as building codes differ from one location to another. The aim of the present document is to go a step further and present the basis of a scale that is fundamentally applicable around the globe. In this manual, ESSL takes into account the progress that has been made in developing a framework for wind damage assessments, but changes a number of components. The concepts of DoD's and DI's are retained. In contrast to the EF-scale, for buildings, a differentiation is made that is based on the sturdiness of a structure, rather than its function. Furthermore, the roof of a building is considered to be a separate DI. Additionally, the presented method puts more focus on assessing wind speeds from vegetation damage than any previous efforts.

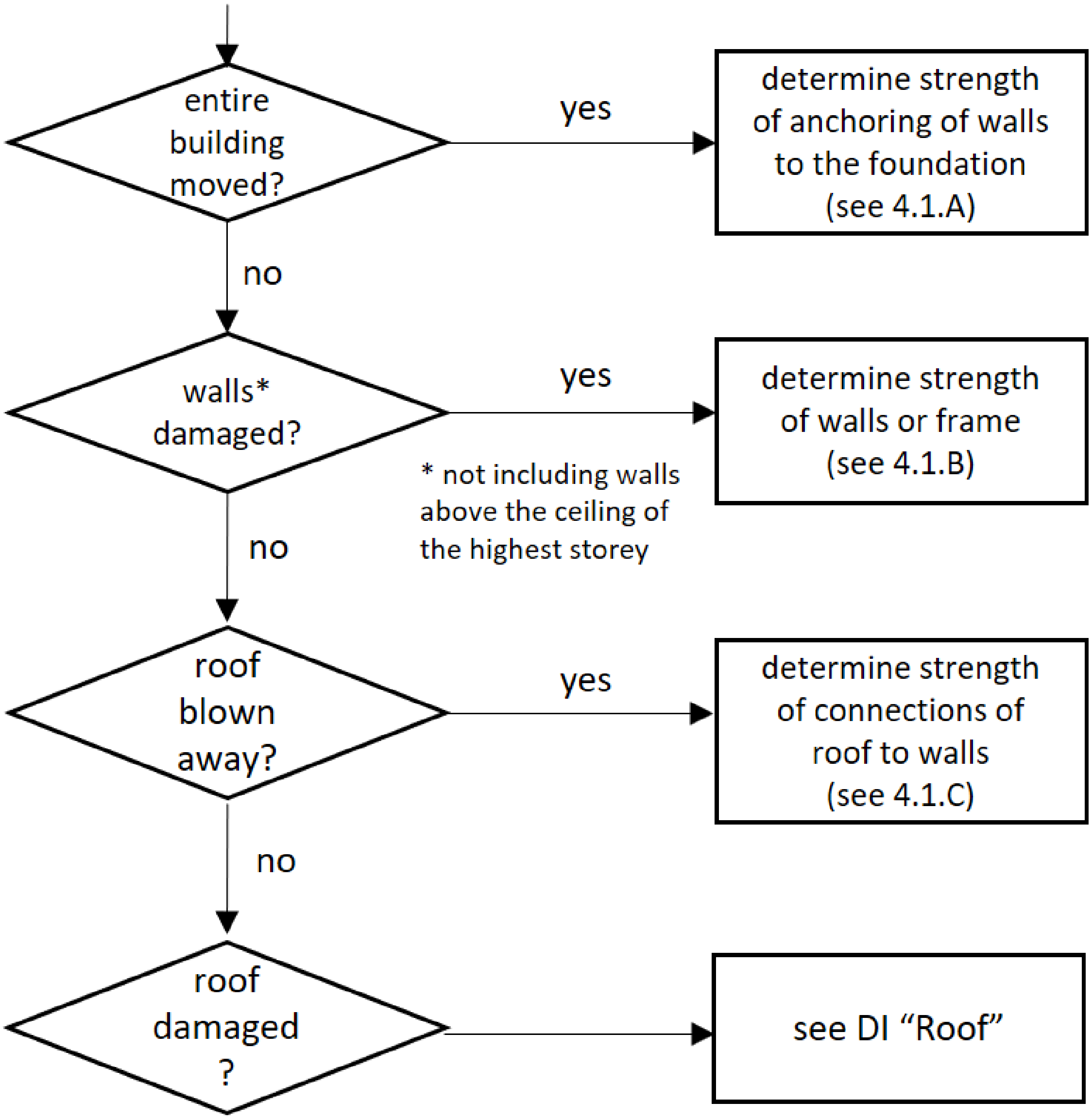
2 The International Fujita Scale

IF-class	speed m/s	error m/s	Speed km/h	error km/h	speed mph	error mph	speed knots	error knots
0↓	20	± 6	72	± 22	45	± 14	39	± 12
0	25	± 7	90	± 27	56	± 17	48	± 15
0↑	30	± 9	108	± 32	67	± 20	58	± 18
1↓	36	± 11	128	± 38	70	± 24	69	± 21
1	41	± 12	149	± 45	92	± 28	80	± 24
1↑	47	± 14	170	± 51	106	± 32	92	± 28
2↓	54	± 16	193	± 58	120	± 36	104	± 31
2	60	± 18	217	± 65	135	± 40	117	± 35
2↑	67	± 20	241	±72	150	± 45	130	± 39
3	81	± 24	293	± 88	182	± 55	158	± 47
4	105	± 31	376	± 113	234	± 70	203	± 61
5	130	± 29	466	± 140	290	± 87	252	± 76

3 DI and DoD Inventory

3.1 Buildings

Buildings are structures with a roof and walls standing more or less permanently in one place. They include all forms of residential, commercial and industrial buildings as well as outbuildings.



4.1.A Determine strength of anchoring of walls to foundation

4.1.B Determine strength of walls or frame

Based on the strength, determine IF rating:

	walls partly destroyed (5 - 80%)	(almost) all walls destroyed (80 – 100%)

B0	**IF 1**	**IF 2**
BI	**IF 2**	**IF 3**
BII	**IF 3**	**IF 4**
BIII	**IF 4**	**IF 5**
BIV	**IF 5**	**IF 5**

*not including walls above the ceiling of the highest storey

For masonry or stacked stone or brick walls:

	wall thickness ->			
quality of mortar		**< 15 cm**	**15 – 40 cm**	**> 40 cm**
	no mortar	**B0**	**BI**	**BII**
	bad mortar	**BI**	**BII**	**BIII**
	good mortar	**BII**	**BIII**	**BIV**

For walls of wood, metal sheets, glass, synthetic materials:

weak	**B0**
intermediate	**BI**
strong	**BII**
very strong	**BIII**
exceptional	**BIV**

Weak (B0)

Characteristics:

- Wood or metal frame
- Wood or metal panel, or glass siding
- Typical examples: weakly constructed or weakened sheds, barns or greenhouses

Moderate (BI)

Characteristics:

- Wood or metal frame
- Wood or metal panel, or glass siding
- Typical examples: sheds, barns, stables, garages or greenhouses, houses with defects

 *Rijksdienst voor het cultureel erfgoed* *CC BY-SA 4.0*	Add example
 *By Renelibrary - Own work, CC BY-SA 3.0* *https://commons.wikimedia.org/w/index.php?curid=31366017*	Add example

Strong (BII)

Characteristics:

- Typical examples: well-constructed wooden frame houses, add examples

<table>
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By National Rural Knowledge Exchange - Flickr, CC BY 2.0
https://commons.wikimedia.org/w/index.php?curid=3713996</td>
</tr>
<tr>
<td>
Arildv, CC BY-SA 3.0</td>
<td>Add example</td>
</tr>
</table>

Very strong, BIII

Exceptional, BIV

Characteristics:

- ?

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3.2 Roofs

Roofs with ceramic, concrete or asphalt roof tiles - **RT**

Assumption is that the frame supporting the roof is intact.

Degree of Damage	Wind speed	Class
1. Isolated roof tiles blown away	30 m/s	IF 0↑
2. Many tiles (20 - 50%) blown away	42 m/s	IF 1
3. Most tiles blown away	60 m/s	IF 2

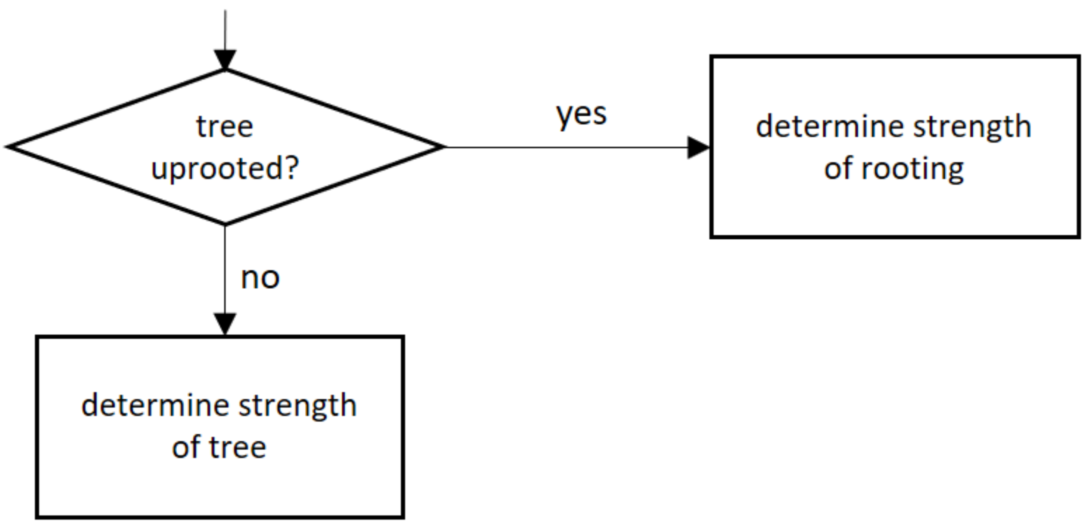
Checked for consistency with McDonald et al.

In case the roof collapsed or was blown away, please refer to DoD “Buildings”.

3.3 Trees, shrubs and hedges

Trees - **T**

In case of damage to trees, either i) structural failure to parts of the tree occurred (branches or trunk broken), or the root system was too weak (uprooting).



4.3.A Tree uprooted

Determine strength of root system.

4.3.A Tree snapped tree limbs broken

Determine strength of tree

Wood class W1

Modulus of rupture of green wood < 48 MPa

 Pine (Pinus sp.) *photo: HenKvD* *License: CC BY-SA*	 Spruce (Picea sp.) *photo: Crusier* *License: GFDL i CC-BY 3.0*	 Fir (Abies sp.) *Photo: Crusier* *License: CC BY-SA 3.0*
 Willow (Salix sp.) *photo: J. Sedols*	 Poplar (Populus sp.) *Photo: Rasbak* *License: CC BY-SA 3.0*	 Alder (Alnus sp.) *Photo: Chris.urs-o* *License: CC BY-SA 3.0*
Add picture Horse Chestnut (Aesculus Hippocastanum)		

Wood class W2

Modulus of rupture of green wood 48 - 65 MPa

Elm (Ulmus sp.)

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Beech (Fagus sp.)

Photo: Biggi185

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Maple (Acer sp.)

Photo: 4028mdk09

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Add picture

Cherry

Add picture

Birch

Wood class W3

Modulus of rupture of green wood > 65 MPa

Pedunculate Oak

(Quercus robur)

Photo: Jorchr

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Add picture

Walnut

(Juglans sp.)

Add picture

Locust

(Rubinia sp.)

European Ash

(Fraxinus excelsior)

Photo: Andy F

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1. Determine wood class.

2. In case of broadleaf tree, did the tree have leaves? If no, add 1 to the wood class.

3. Is the tree solitary, in a line or at the very edge of a stand? If yes, add 1.

The resulting number is the Firmness Class.

Determine IF-scale:

<table>
<tr><th></th><th colspan="5">Firmness Class of Damage Indicator</th></tr>
<tr><th>Degree of Damage</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td>1. Twigs or small branches broken off</td><td colspan="5">IF 0</td></tr>
<tr><td>2. Some large branches broken off</td><td colspan="5">IF ↑0</td></tr>
<tr><td>3. Compression damage</td><td>IF ↓1</td><td colspan="2">IF 1</td><td colspan="2">IF ↑1</td></tr>
<tr><td>4. Trunk snapped</td><td>IF 1</td><td>IF ↑1</td><td>IF ↓2</td><td>IF 2</td><td>IF ↑2</td></tr>
<tr><td>5. Extensive debranching, only tree stumps left</td><td colspan="2">IF 2</td><td>IF ↑2</td><td>IF ↓3</td><td>IF 3</td></tr>
</table>

Estimates more or less (but not completely) consistent with poster by Hubrig. IF-scale estimates assume that trees compensate a lower (higher) modulus of rupture for 50% by thicker (thinner) trunk and limbs.

3.4 Road Vehicles

All vehicles are assumed not to be driving.

Cars - **V**

Degree of Damage	Wind speed	Class
1. Overturning*	55 m/s	IF 2↓

Estimate based on consistency with Tamura and Schmidlin et al.

Large heavy vehicles: Buses, loaded trucks/lorries - **LV**

Degree of Damage	Wind speed	Class
2. Overturning*	55 m/s	IF 2↓

Estimate based on consistency with Tamura and Schmidlin et al.

Empty trucks/lorries, other vehicles with a large lateral surface area - **ET**

Degree of Damage	Wind speed	Class
1. Overturning*	45 m/s	IF 1↑

Overturning may be followed by flipping and lifting, which does not necessarily require higher wind speeds

Estimate based on consistency with Tamura and Schmidlin et al.

Caravans - **CV**

Degree of Damage	Wind speed	Class
1. Overturning	41 m/s	IF 1

3.5 Trains

Train cars, operating at normal speed – **TMov**

Degree of Damage	Wind speed	Class
1. Overturning	47 m/s	IF 1↑

Estimate based on consistency with Tamura, rounded slightly upward.

Train cars, operating at low speed (<25 m/s), or stationary **– TSlow**

Degree of Damage	Wind speed	Class
1. Overturning	54 m/s	IF 2↓

Estimate based on consistency with Tamura rounded slightly upward.

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3.6 Poles and towers

Utility poles - **UP**

Degree of Damage	Wind speed	Class
1. Poles leaning	45 m/s	IF 1↑
2. Complete collapse	55 m/s	IF 2↓

Estimate based on Sills et al.

Power transmission towers - **TT**

Degree of Damage	Wind speed	Class
1. Partial or complete collapse	55 m/s	IF 2↓

Estimate based on on Sills et al. and various design guidelines.

Light poles - **LP**

Degree of Damage	Wind speed	Class
1. Bent pole	45 m/s	IF 1↑
2. Pole collapsed	55 m/s	IF 2↓

Estimate based on EF-scale (McDonald et al).

Wind turbine – **WT**

Degree of Damage	Wind speed	Class
1. Collapse	?	?

3.7 Fences and barriers

Metal wire fences - **MF**

Degree of Damage	Wind speed	Class
1. Partial or complete collapse	37 m/s	IF 1↓

Estimate based on Tamura.

Noise barrier walls - **NW**

Degree of Damage	Wind speed	Class
1. Partial or complete collapse		

Jersey barrier - **JB**

Degree of Damage	Wind speed	Class
1. Moving		
2. Overturning		

3.8 Signs

Traffic signs - **TS**

Degree of Damage	Wind speed	Class
1. Inclination of pillar	45 m/s	IF 1↑
2. Collapse of pillar	55 m/s	IF 2↓

Estimate based on Tamura.

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Metal frame billboards – **MB**

These billboards are engineered structures.

Degree of Damage	Wind speed	Class
1. Inclination or buckling of pillars	45 m/s	IF 1↑
2. Collapse	55 m/s	IF 2↓

Estimate based on Tamura.

Billboards with a wooden frame have greatly varying degrees of sturdiness, because of their design or inadequate maintenance. This makes them poor Damage Indicators.


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3.9 Selected frame structures

Scaffolding connected to walls - **SF**

Degree of Damage	Wind speed	Class
1. Breakage of connections to walls	29 m/s	IF 0↑

Note: Estimate based on Tamura.

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Carports - **CP**

Degree of Damage	Wind speed	Class
1. Collapse	55 m/s	IF 2↓

Compared for consistency to Tamura.

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Filling station canopies - **FS**

Degree of Damage	Wind speed	Class
1. Collapse	55 m/s	IF 2↓

Compared for consistency with McDonald et al.


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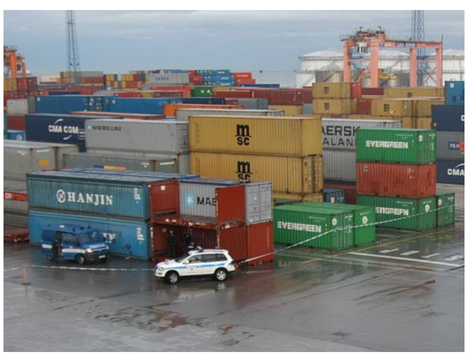
Right: By Tiia Monto - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=47617270

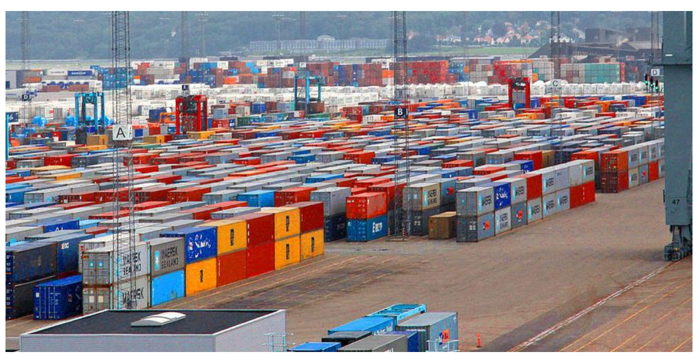
3.10 Shipping containers

Shipping containers - **SC**

Degree of Damage	Wind speed	Class
1. Overturning (contents <300kg)	37 m/s	IF 1↓
2. Overturning (contents >300kg)	45 m/s	IF 1↑

Estimate based on Tamura, numbers rounded.





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3.11 Gantry cranes

Gantry crane - **GC**

Degree of Damage	Wind speed	Class
1. Collapse when in operation	37 m/s	IF 1↓
2. Collapse when not in operation	55 m/s	IF 2↓

Estimate based on Tamura, numbers rounded.



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3.12 Outdoor furniture

Light outdoor furniture: plastic chairs or tables, unanchored trampolines – **OFL**

Degree of Damage	Wind speed	Class
1. Lifted up	24 m/s	IF 0↓

Estimate of ESSL.

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Other outdoor furniture: wooden chairs or tables – **OFH**

Degree of Damage	Wind speed	Class
2. Lifted up	29 m/s	IF 0↑

Estimate of ESSL.

3.13 Gravestones

Gravestones – **GS**

Degree of Damage	Wind speed	Class
1. Slipping or overturning	55 m/s	IF 2↓

Estimate from Tamura.

4 References

McDonald et al -> TTU EF-scale document

Sills -> Canadian EF-scale document

Tamura -> presentation of Japanese EF-scale at workshop

Hubrig -> Poster presented at ECSS conference