The International Fujita (IF) Scale

Tornado and Wind Damage Assessment Guide

Draft version 0.1 of 15 October 2018

Authored by the IF Scale Steering Group

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Preface

Draft Version 0.1:

This document is a description of the IF-scale, which was first presented at the ESSL workshop on tornado and wind damage 4—7 September 2018 in Wiener Neustadt. It includes a number of additions and revisions based on input from the Steering Group members in the weeks after that workshop.

In its current form, it is a draft document that ESSL will seek to turn into a first mature version 1.0 in 2019 or 2020. In order to arrive at this first complete version of the document, additional experts will be invited to join the steering group. Contributions from engineers are most urgently needed in order to provide a stronger basis for comparing the sturdiness of structures out of various building materials. With that knowledge, the building DI can be improved and a DI for free-standing walls can be added.

Altogether, the DI's for which not sufficient information was yet available to include them, and that are planned to be included in the next version are: crop fields, shrubs and bushes, noise barrier walls, jersey barriers, wind turbines, free standing masonry walls. Other DI's may be included as well.

Besides adding DI's, the present DI's need to be better illustrated by providing more examples of damage.

Pieter Groenemeijer, Wessling, 15 October 2018

1 Introduction

1.1 History of wind speed scales for tornadoes

Those who study severe local wind phenomena such as tornadoes and microbursts have an interest in comparing the intensity of such events. The biggest difficulty in estimating an event's intensity is that direct measurements of the wind speed are typically absent. Instead, the only information available is the resulting damage.

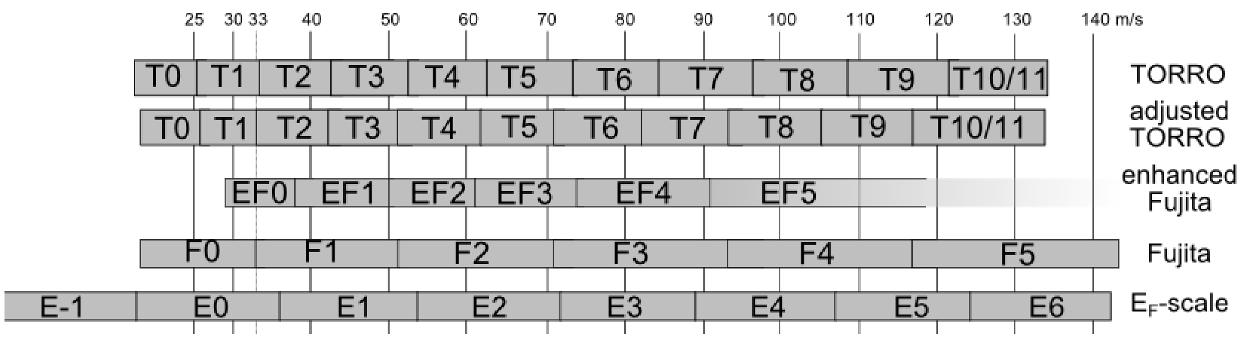


Figure 1. Various wind speed scales used for tornado damage assessment.

To be able to compare events by means of the inflicted damage, several methods and scales have been developed (Figure 1). Most prominently, Dr. Ted Fujita developed what has become known as the Fujita scale (Fujita, 1981). Other wind speed scales include the TORRO- or T-scale (Meaden, 1976) and the newer Enhanced Fujita or EF-scale (McDonald and Mehta, 2006), discussed below.

The Fujita and T-scales are numbered series of descriptions of increasingly serious wind effects on various objects, along with ranges of wind speeds thought to be responsible for causing the respective damage. No justification for the wind speed estimates of these scales are provided. The Fujita and T-scales have been used in the United States until 2007, and are still used in Europe and other regions.

1.2 Refinements and revisions

Fujita's revisions

In the 1990's and 2000's doubts arose in the USA about the accuracy of the wind speed estimates of the Fujita-scale and the scale was revised and its description refined. In his 1992 memoirs (Fujita, 1992), Fujita suggested that his scale be refined by taking the sturdiness of buildings into account when assessing damages (Fig. 2).

THE FUJITA TORNADO SCALE

Damage f scale		Little Damage	Minor Damage	Roof Gone	Walls Collapse	Blown Down	Blown Away
		f0	f1	f2	f3	f4	f5
Windspeed F scale (m/s)		17 m/s – 32	32 – 50	50 – 70	70 – 92	92 – 116	116 – 142
		F0	F1	F2	F3	F4	F5
Windspeed F scale (mph)		40 mph – 73	73 – 113	113 – 158	158 – 207	207 – 261	261 – 319
To convert f scale into F scale, add the appropriate number							
Weak Outbuilding	-3	f3	f4	f5	f5	f5	f5
Strong Outbuilding	-2	f2	f3	f4	f5	f5	f5
Weak Framehouse	-1	f1	f2	f3	f4	f5	f5
Strong Framehouse	0	F0	F1	F2	F3	F4	F5
Brick Structure	+1	-	f0	f1	f2	f3	f4
Concrete Building	+2	-	-	f0	f1	f2	f3

Figure 2. The Fujita (F-) scale allowing for various building types with varying sturdiness. The extent of damages expressed various with both windspeed and sturdiness of structures. From: Fujita (1992).

In Europe, the European Severe Storms Laboratory has used an adapted version of the Fujita (1992) approach, which was documented by Feuerstein et al (2012; see Figure 3). This implementation includes an analogous approach to assess vegetation damage (not shown) and allows for a distinction between the upper- and lower- ends of each intensity step.

	Fujita damage class	f0	f1	f2	f3	f4	f5
	loss ratio (%)	0.1	1	10	50	90	100
	degree of damage → / ↓ damage indicator	light roof damage	significant roof damage	roof gone	walls partly collapsed	largely blown down	blown away
A	weakest outbuilding	F0+	F0+	F1-	F1-	F1+	F2-
B	outbuilding	F0+	F1-	F1+	F2-	F2+	F3-
C	strong outbuilding/ weak framehouse	F0+	F1+	F2-	F3-	F3+	F4-
D	weak brick structure/ strong framehouse	F1-	F1+	F2+	F3+	F4-	F5
E	strong brick structure	F1-	F2-	F3-	F4-	F5	F5
F	concrete building	F1-	F2+	F3+	F4+	F5	F5

Figure 3. F-scale ratings as a function of building sturdiness (A-F), and of loss ratio and Fujita damage class (f0-f5), as used by ESSL. Adapted from: Feuerstein et al (2012).

The Enhanced Fujita (EF-) scale

In 2007, an effort by Texas Tech University lead to refinements and revisions of the wind speed estimates for particular damages leading to the Enhanced Fujita scale (McDonald and Mehta, 2006). A framework for the assessment of tornado damage was introduced by systematically categorizing the effects of severe winds using the concepts 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 damaged. The new wind speed estimates of particular DoD of a particular DI were obtained by the method of *expert elicitation*. A small number of 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.

Advantages of the EF-scale approach are (i) that the concepts of Damage Indicators and Degrees of Damage were explicitly introduced, and (ii) that a high number of Damage Indicators were defined. Drawbacks of the Enhanced Fujita are that the scale cannot be applied globally since the range of Damage Indicators is clearly incomplete or even inapplicable in other countries. For instance, the sturdiness of the Damage Indicator "Elementary School" in the USA may differ greatly from that in another country. Furthermore, some obvious DI's are missing, including many that are not buildings, such as vehicles and vegetation. Another drawback is that the wind speeds in the EF-scale have little scientific support in that they are typically not backed-up by experiments or calculations.

International additions to the Enhanced Fujita (EF-) scale

In response to these limitations, adaptations and additions have been made in several areas around the world, since the adoption of the Enhanced Fujita scale in 2007 by the U.S. National Weather Service. Most prominently by scholars in Canada (Environment Canada, 2015; Sills et al, 2014), and Japan (JMA, 2015), who have officially adopted an adapted version of the EF-scale. Several additional proposals have been made to include multiple new Damage Indicators such as by Mahieu and Wesolek (2016), and by Hubrig (2015) who proposed extensions reflecting damage to wooden trees. These additions were primarily motivated by the need for additional Damage Indicators, beyond or replacing those used in the United States. In 2015, an international workgroup convened to inventarize the various approaches used in practice in various regions of the world to categorize tornado damage, which resulted in a report entitled "International Approaches to Tornado Damage and Intensity Classification" (IAWE, 2017).

1.3 Principles of the IF-scale

The IF-scale has been developed based on the following three requirements stated by Doswell et al (2009). First, it should be *broadly applicable*, covering a wide range of observed wind effects and all possible wind speeds. Second, it should be *accurate*, or as accurate as possible given the available data. Last, it should be *consistent* in the sense that it can be applied consistently over time and across many regions, preferably globally.

Broad applicability

In order to guarantee broad applicability, the IF-scale foresees in dealing with wind effects to a wide range of objects and structures, many more than have been covered in the EF-scale, including trees. The concepts of DoD's and DI's are kept.

An important difference with the EF-scale is that built-up structures are not categorized based on their function (cf. EF-scale: small retail building, one-family residence, ground school, etc.), but on their sturdiness. On a national level, building codes for a buildings having a particular function may exist, but this approach will not work internationally as these codes will differ from one country to another.

Broad applicability also means also necessary that the scale can be applied to the entire range of observed wind speeds. Since accurate Doppler radar measurements of wind speeds up 135 m/s (Wurman et al, 2007), the scale should, although this is a challenging task, be able to address the potential effects of such wind speeds on objects.

Finally, in this document broad applicability is taken to mean that the scale should be applicable to many kinds of wind events, rather than exclusively to tornadoes. Although the type damage caused by tornadoes may differ from that of downbursts, for instance by greater pressure differences or more sudden changes in wind speed and direction, no scientific description of how the type and intensity of damage typically differs is presently available. Therefore the working hypothesis of the approach presented here is that those effects do not dominate the damage intensity.

Accuracy

In order to ensure high accuracy, wind speed estimates should preferentially be based on scientific research, e.g. engineering calculations andwind tunnel experiments, rather than subjective assessments, wherever this is possible. Where this is not possible, subjective estimates can be used. This approach has been taken with the EF-scale (McDonald and Mehta, 2006), the Japanese EF-scale (JMA, 2015), the Canadian EF-scale (Environment Canada, 2015; Sills et al, 2014), etc. Especially in the case of estimated speeds, is thinkable that particular wind speed estimates will require revision in the future as research evidence for better wind speed estimates become available.

In contrast to other scales, the IF-scale does not use specified ranges of wind speed values for each step of the scale, which might imply a higher accuracy than the scale can deliver, but instead provides a central value and an associated error. In order to express lower wind speeds with a higher precision, the IF-scale splits the lower steps of the scale into multiple steps using the suffixes + or -, following Feuerstein et al. (2012), e.g. IF2+.

Consistency

In order to ensure that the scale can be applied consistently in areas where the Fujita- or T-scale have been used in the past, the IF-scale has wind speeds that are compatible with those scales. In other words, the IF3 wind speed value corresponds to the centre of the F3 wind speed range.

The aim of IF-scale is to present an approach that is fundamentally applicable around the globe. It specifies the common denominator, to which further regional refinements can be made for specific regions.

2 The International Fujita Scale

2.1 The wind speeds of the IF-scale

These are the steps and respective wind speeds of the IF-scale.

Table 1. The IF-scale.

Class	speed m/s	error m/s	speed km/h	error km/h	Speed mph	error mph	speed knots	error knots
IF0-	20	± 6	72	± 22	45	± 14	39	± 12
IF0	25	± 7	90	± 27	56	± 17	48	± 15
IF0+	30	± 9	108	± 32	67	± 20	58	± 18
IF1-	36	± 11	128	± 38	70	± 24	69	± 21
IF1	41	± 12	149	± 45	92	± 28	80	± 24
IF1+	47	± 14	170	± 51	106	± 32	92	± 28
IF2-	54	± 16	193	± 58	120	± 36	104	± 31
IF2	60	± 18	217	± 65	135	± 40	117	± 35
IF2+	67	± 20	241	± 72	150	± 45	130	± 39
IF3	81	± 24	293	± 88	182	± 55	158	± 47
IF4	105	± 31	376	± 113	234	± 70	203	± 61
IF5	130	± 39	466	± 140	290	± 87	252	± 76

The IF-scale steps are defined by a central value and an error. The errors have been estimated to be 30% of the central value, resulting in overlapping speed ranges. The distances between the central values of the steps have been so chosen that the upper bound exceeds the central value of the next step, ensuring a balance between the resolution of the scale and the expected errors.

Since we required that the steps be consistent with the original Fujita scale, we introduced steps with – and + suffixes indicating steps one third higher or lower than the central value of the original scale, e.g. F1- equals “F⅔” and F2+ equals “F2⅓”.

Above F2, such a subdivision was not introduced and only full steps are used. The formula for the wind speed as a function of step is identical to that of the Fujita-scale, i.e.:

$IF(x) = 6.30\,(x + 2)^{1.5}$ m/s $IF(x) = 22.7(x + 2)^{1.5}$ km/h

$IF(x) = 14.1\,(x + 2)^{1.5}$ mph $IF(x) = 12.3\,(x + 2)^{1.5}$ knots

2.2 Future adjustments in the light of new findings

The Fujita scale has been adjusted to the Enhanced Fuita scale because of the feeling that the wind speeds associated with a particular step on the scale was not current. This may, of course, happen with the IF-scale too when new findings become available. For instance, it may become known that the winds speeds of the higher steps – speeds of which very few accurate measurements are available – need adjusting. This will require a revision of the original wind speed function posed by Fujita. This ought to be done only in light of a solid body of support resulting from scientific research. It may also be that it is found that a particular DI/DoD combination is associated with another step on the IF-scale than described in the original manual. This should be a smaller change. All changes should be communicated to the owner of the scale, which is presently the IF-scale Steering Group.

2.3 Conducting a damage survey

In order to conduct a damage survey, we have formulated the following reocmmendations. First, a survey is done as early as possible, but obviously after any emergency services have left the site. Second, all individual Damage Indicators and Degrees of Damage should be recorded and geo-referenced, as well as the resulting IF-rating. Optimally, references to photos of the damage are stored as well, and optionally a description. Since, it is of interest to identify a damaging wind event as a tornado or a straight-line wind event, the direction of falling of trees, or transportation of debris is to be recorded as well. The convention is to indicate the origination direction of the object, i.e. 180° is correct for a tree fallen towards the north, or an object displace from the south to the north.

The process of recording this data can be streamlined using an application (app) on a mobile device. Such software should result in a csv formatted table, as in Table 1. If an app cannot be used, the table can also be filled manually. In order to allow a concise description of any type of damage, all Damage Indicators have a short acronym.

Table 1. Example of a table with damage survey data.

#	Lat.	Lon.	DI	DoD	IF	Direction of falling/ transport	Distance	Trunk Thickness	Description	Link to photos
1	45.4461	12.0393	BSB	1	2-				Old Shed	http://....
2	45.4482	12.0471	BNT-	2	≥1	160°	10 m		Tiles of shed	http://....
3	45.4478	12.0476	TR2	1	1	180°		30 cm	Uprooted olive tree, rotten 1/3	http://....
4	45.4484	12.0482	PL	2	2-	40°			Light pole	http://....

Acronyms

A particular type of damage is unambiguously defined by writing down the Damage Indicator and the Degree of Damage. The Degree of Damage is a number, while the Damage Indicator is a combination of characters indicating the DI type, and the subclass or vulnerability where applicable.

The generic format is:

[DI type][DI subclass][DI vulnerability]/[DoD], or

[DI type][DI subclass][DI vulnerability]/[DoD]:[IF-rating]

Examples are:

BC/1:2+
A building [B] with sturdiness [C] has sustained a Degree of Damage 1 ('partially destroyed'), resulting in a rating of IF2+.

TR3/1:1+

A tree [T] with rooting strength [R] 3 was uprooted [1], resulting in a rating IF1+

BNT+/1:1-
A building [B] having as non structural elements [N] strongly attached roof tiles [T+] lost a few roof tiles, i.e. DoD1, [1], resulting in IF1-.

3 Damage Indicator Inventory

For the IF-scale, the following Damage Indicators have been defined. This list wil likely be expanded in the future.

Damage Indicator		DI Sub-class		DI Vulnerability class		DoDs
B	Buildings	**.**	Structure	**A - F**		**1 - 3**
		R	Roof structure	**A - F**		**0 - 2**
		.	Non-structural elements	**S+/-**	sheathing	**1 - 3**
				T+/-	roof tiles	
				H+/-	thatched roof	
		M	Anchoring	**1 - 3**		**1**
V	Road Vehicles	**C**	Car			**1, 2**
		E	Empty trucks			
		H	Large heavy vehicles			
		T	Caravan (towed trailer)			
T	Trees	**S**	Tree structure damage	**0 - 6**		**1 - 6**
		R	Uprooting	**0 - 6**		
R	Train cars				**S** (stationary/slow) **F** (operating speed)	**1**
M	Mobile homes					**1 - 5**
P	Poles & towers	**U**	Utility poles			**1, 2**
		L	Light poles			
		T	Power transmission towers			
F	Fences	**M**	Metal wire fences			**1**
S	Signs	**T**	Traffic signs			**1, 2**
		M	Metal frame billboards			
D	Scaffolding					**1**
SS	Service station canopies					**1**
G	Carports / garages					**1**
SC	Shipping containers					**1**
C	Cranes	**C**	Container (gantry) crane			**1, 2**
		T	Tower crane			
O	Outdoor furniture	**L**	Light			**1, 2**
		O	Other			

3.1 Damage Indicator: Buildings - B

Definition: 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 of any kind.

A building consists of a number of components. Each of these components is to be assessed individually, when possible.

These components are:

1. the building's structural elements, i.e. its frame or its walls
2. its roof structure
3. non-structural elements of the roof and/or walls

Additionally, a frame building may have been moved off its foundation.

In order ontain a rating of damage to a building, the individual ratings of the building components 1, 2 and 3 and the observation if the object has moved in its entirity have to be combined (Figure 4).

These components are considered to be individual Damage Indicators:

- **B.** ("building structure")
- **BR** ("building/roof")
- **BN** ("building/non-structural elements"),
- **BM** ("building/moved").

Note that ratings for these individual components may not be a particular IF-scale class, but can also be a range (e.g. ≥IF1+).

The logical result of a B rating of IF2+ and a BR rating of ≥IF1+ a would be IF2+.

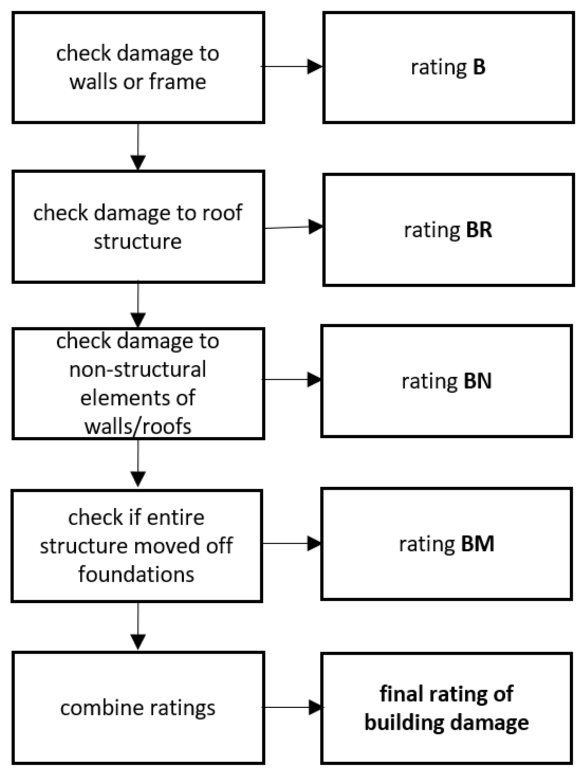


Figure 4. Flowchart for building damage assessment.

Damage to structural elements (walls or frame) – DI: B

If structural elements of a building fail, the sturdiness of the structure needs to be estimated in order to know the minimal wind speed responsible for the damage. Buildings are constructed in two fundamentally different ways: using a **frame** or using **mass walls**.

In frame structures, the frame gives the building its structural stability. The walls are made from panels of wood, metal, glass or other materials that contribute relatively little to the strength of the building. Frames are typically made of wood or metal.

In the case of mass walls, building material is stacked, and often connected by mortar or a similar material, to form walls that carry the weight of the structure. Examples of mass wall construction are brick masonry walls, walls of concrete blocks or wood log building. On average, mass wall structures are somewhat more wind resistant than frame structures.

Frame structures

Following Fujita (1992), six classes of sturdiness are distinguished.

Class	Description	Comparable description by Fujita (1992)
A	exceptionally weak or faulty frames	weak outbuilding
B	very weak frames	strong outbuilding
C	weak frames	weak framehouse
D	strong frames	strong framehouse
E	very strong frames	brick structure
F	exceptionally strong frames	concrete building

Table. Sturdiness classes for frame structures.

The sturdiness of a frame structure can be difficult to assess and depends both on the thickness of the frame's elements, the material, the strength connections between frame elements and its geometry.

Mass wall structures

The sturdiness of mass wall buildings can be estimated by the thickness and quality of the wall:

		Wall Thickness		
Wall Quality		7 – 15 cm	15 – 30 cm	> 30 cm
	stacked bricks or stones	**B**	**C**	**D**
	weakened brick masonry	**C**	**D**	**E**
	brick masonry, logs	**D**	**E**	**F**
	cast concrete	**E**	**F**	**F**

Table. Sturdiness classes for mass wall structures.

Based on the sturdiness and observed Degree of Damage an IF rating can be determined. The following table lists the IF-scale, along with their central values in m/s and km/h:

		Sturdiness						
		A	**B**	**C**	**D**	**E**	**F**	
Degree of Damage (DoD) to walls or frame*	**DoD 0** *No damage* *except possibly to gables above highest ceiling*	**≤IF0+** 30 108	**≤IF1+** 47 170	**≤IF2** 60 217	**≤IF2+** 67 241	**≤IF3** 81 293	**≤IF5** 130 466	m/s km/h
	DoD 1 *Partial destruction* *but not more than 2/3*	**IF1-** 36 128	**IF2-** 54 193	**IF2+** 67 241	**IF3** 81 293	**IF4** 105 376	**IF5** 130 466	m/s km/h
	DoD 2 *Near complete destruction* *more than 2/3*	**≥IF1** 41 149	**≥IF2** 60 217	**≥IF3** 81 293	**≥IF4** 105 376	**IF5** 130 466	**IF5** 130 466	m/s km/h

Table. IF ratings for building structural elements, i.e. the walls or the frame, as a function of sturdiness and DoD.

**Damage to mass walls above the highest ceiling and damage directly caused by failure of the roof construction are excluded.*

*** A motivation for the ratings for each DI/DoD combination, and a comparison with other ratings is given in the Appendix.*

**** For sturdiness classes A-C, an interpolation betwene classes is allowed.*

Example

One example is presented here. For more examples, see the Appendix.

Figure 5 shows a wooden shed in Germany used to store a farmer's equipment. The frame has sufficient sturdiness to sustain common windstorm gust, but was partially destroyed (DoD 1) by exceptionally strong tornado winds. The sturdiness is that of a typical outbuilding, between A and B. This yields a rating of IF1+.

Shorthand: **BAB/1:1+**

Figure 5. Damage to a shed in Barenthin, Germany on 10 November 2017. Photo: Thilo Kühne.

Damage to roof structure – DI: BR

The roof structure of a building is often more vulnerable to wind effects than the remainder of the building, due to a lower strength or lower strength of its connection to the rest of the structure. If a roof structure exists, as in gable or mansard roofs, it is to be rated separately. As a first guess, the sturdiness class of the roof structure can be assumed to be identical to that of the entire building, but a lower or higher category may be chosen if appropriate.

Table 2. IF-ratings for roof structure as a function of sturdiness and DoD.

		Sturdiness						
		A	**B**	**C**	**D**	**E**	**F**	
Degree of Damage (DoD) to roof structure	**DoD 0** *No visible damage*	**≤IF0** 25 90	**≤IF1** 41 149	**≤IF1+** 47 170	**≤IF2-** 54 193	**≤IF2** 60 217	**≤IF2+** 67 241	m/s km/h
	DoD 1 *Damaged* *But less than 2/3 destroyed.*	**IF0** 25 90	**IF1** 41 149	**IF1+** 47 170	**IF2-** 54 193	**IF2** 60 217	**IF2+** 67 241	m/s km/h
	DoD 2 *Roof destroyed or blown away* *Any destruction of walls limited to gables of top floor.*	**≥IF0+** 30 108	**≥IF1+** 47 170	**≥IF2-** 54 193	**≥IF2** 60 217	**≥IF2+** 67 241	**≥IF3** 81 293	m/s km/h

Example

One example is presented here. For more examples, see the Appendix.

Figure 6 shows a house that has lost its roof and one of the gables in a tornado. The house is a sturdy class E house, and it is assumed the roof structure was accordingly strong. The resulting rating is ≥IF2+.

Shorthand: **BRE/2:≥2+**

Figure 6. House deroofed by a tornado in Affing, Germany on 13 May 2015. Photo: Pieter Groenemeijer (ESSL).

Non-structural elements (tiles, shingles, sheathing, etc.) – DI: BN

Table 3 gives IF-scale ratings for damage to various types of non-structural elements of buildings. A distinction is made between sheathing, roof tiles and thached roofs, and within these classes between weak and strong attachment.

The weak category should be chosen where tiles or sheathing are not physically attached but kept in place by their own weight and are light. When tiles or sheathing are well-attached, or when roof tiles are exceptionally heavy, the strong category applies. For thatched roofs, whenever the roof has small eaves and is smooth, the strong caetgory applies; otherwise the weak category must be used.

Table 3. IF-rating for a number of non-structural elements of a buildng as a function of DoD.

	S sheathing (metal, cement, wood or other)		**T** tiles		**H** thatched (straw, reed, ...)	
	S- weak	**S+** strong	**T-** weak	**T+** strong	**H-** weak	**H+** strong
DoD 1 *Some lost elements (< 25%)*	**≥IF0+**	**≥IF1**	**IF0+**	**IF1-**	**≥IF1**	**≥IF2-**
DoD 2: *Many lost elements (25-50%)*	**≥IF1-**	**≥IF1+**	**IF1-**	**IF1**	**≥IF1+**	**≥IF2**
DoD 3: *Most elements lost (>50%)*	**≥IF1-**	**≥IF1+**	**≥IF1**	**≥IF1+**	**≥IF1+**	**≥IF2+**

Example

One example is presented here. For more examples, see the Appendix.

The images shows a house with a clay tile roof, where heavy tiles are kept in place by nails and their own weight (T+). Some tiles, but less than 25% have been blown off (DoD1), leading to a rating of IF1-.

Shorthand: **BNT+/1:1-**

Figure 7. A roof with a number of tiles having blown off in Bützow, Germany. Photo: Thilo Kühne (ESSL).

Failing anchoring: Structure moved off foundation (DI: BM)

This failure can occur with frame structures, e.g. wooden houses that moved off their foundation. It can occur only when the anchoring was less wind-resistant than the frame structure of the building, which typically means the anchoring was weak or faulty.

	Category		
	0 small shed or outbuilding	**1** one-storey building	**2** two-storey or higher building
DoD 1 *Building moved off foundations or overturned*	**≥IF0+** 30 108	**≥IF1** 41 149	**≥IF2-** 54 193

**In accordance with EF-scale (DI FR12 / DoD 5) and JEF-scale (DI 4 / DoD 2-3 and DI 10 / DoD 1,2)*

3.2 Road Vehicles – DI: V

Degrees of Damage	Category			
	C cars, vans	**E** empty trucks/lorries, similar vehicles with large surface area	**L** large heavy vehicles: buses, loaded trucks/lorries	**T** towed trailers
DoD 1 *Sliding*	**IF1+** 47 170	**IF1** 41 149	**IF1+** 47 170	**IF1-** 36 128
DoD 2 *Overturning*	**IF2-** 54 193	**IF1+** 47 170	**≥IF2** 60 217	**IF1** 41 149
DoD 3 *Displacement over large distance while overturning and/or being lofted (> 10 m)*	**≥IF2+** 67 241	**≥IF2** 60 217	**≥IF3** 81 293	**≥IF2-** 54 193

Estimates based on combining JMA(2015), Schmidlin et al. (2002), Haan et al (2017).

3.3 Trees - DI: T, TR

Introduction

In case of damage to trees, either (i) structural failure to parts of the tree occurred (branches or trunk broken), or (ii) the root system was too weak (uprooting). The wind speed needed to uproot or snap a tree depends strongly on the strength of the root system and soil conditions, and on the strength of the trunk, respectively.

If the anchoring of the root system in the ground is stronger than the strength of the trunk, the trunk breaks before the root system fails. Trunk snapping is comparatively more likely in quickly varying winds, such as tornadoes, but this a a too complex factor to account for. Compression failure occurs in trunks with a high flexural strength, but lower pressure resistance, ans is most likely during the vegetation period.

The ability of trees to withstand wind damage depends on many factors. They include

- the strength of the wood
- the shape and dimension of the trunk and crown, which can be characterized by
    - the typical ratio between tree height and trunk diameter, the “h/d ratio”
    - adaptation to higher wind speeds in solitary trees and trees at forest edges
- whether the tree is bearing leaves
- the size and geometry of the root system
- soil type and soil condition, in particular its the water content

Assessment

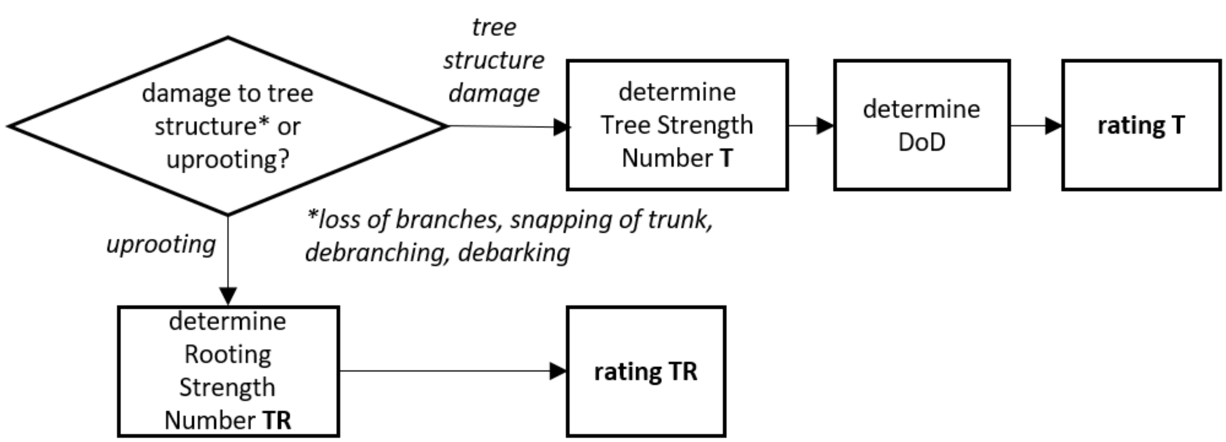


Figure 8. Flowchart to assess wind damage to trees.

Tree damage assessment begins by first determining if the tree was uprooted, or if the tree's structure was damaged (Figure 8). These two cases represent two different damage indicators, **TR** for uprooting and **T** for damage to the tree.

In case of structural damage, the Tree Strength Number is to be determined, in case of uprooting the Rooting Strength Number. In combination with a Degree of Damage, these numbers result in a rating. For uprooting, there is only Degree of Damage, i.e. "uprooted".

Determination of Tree strength number T

Low firmness species: **Softwood or soft hardwood trees**	**High firmness species:** **Hardwood trees**
Spruce (Picea sp.) Pine (Pinus sp.) Larch (Larix sp.) Douglas (Pseudotsuga sp.) Cedar (Cedrus sp.) Poplar, Aspen (Populus sp.), Willow (Salix sp.), Birch (Betula sp.), Eucalyptus (Eucalyptus sp.)	Oak (Quercus sp.) Beech (Fagus sp.) Maple (Acer sp.), Ash (Fraxinus sp.), Elder Alnus sp), Elm (Ulmus sp.), Walnut (Juglans sp.) Locust (Robinia sp.). Pine (Pinus sp.) Larch (Larix sp.) Douglas (Pseudotsuga sp.) Cedar (Cedrus sp.) Olive (Olea sp.) Palm (Arecaceae)

The tree strength number (**T**) is determined as follows.

- Start with 2, if the tree species is listed as a "Low Firmness" tree species, or start with 3 if the tree is listed as a "High Firmness" tree species.
- Add 1, if the tree is at the edge of a tree stand, or is solitary
- Add 1, if the tree has a very low height/diameter ratio such as a shrub, is an extraordinarily stable tree in a hostile zone, such as high mountains, deserts or other especially exposed places, or if the tree or the tree stand is very exposed, such as a free-standing or suspended survey (Hill or mountain) or isolated in a cleared-out area
- Add a "+" to the number in case the tree is a broadleaf tree without leaves
- Subtract 1 if the tree has a very high height/depth ratio

The resulting Tree Strength Number **T** ranges from T0 to T5+.

Damage to the tree structure – DI: T

Note: To get the correct DoD in forest stands, choose the most prevalent DoD.

<table>
<tr><th>Tree strength number:</th><th>T1</th><th>T1+</th><th>T2</th><th>T2+</th><th>T3</th><th>T3+</th><th>T4</th><th>T4+</th><th>T5</th><th>T5+</th></tr>
<tr><td>DoD 1
Twigs, dead branches and some small green branches broken off</td><td colspan="2">IF0-</td><td colspan="2">IF0-</td><td colspan="2">IF0</td><td colspan="2">IF0</td><td colspan="2">IF0+</td></tr>
<tr><td>DoD 2
Some large green branches or part of crown broken off</td><td colspan="2">IF0</td><td colspan="2">IF0+</td><td colspan="2">IF1-</td><td colspan="2">IF1</td><td colspan="2">IF1+</td></tr>
<tr><td>DoD 3
Compression failure</td><td>IF1-</td><td colspan="2">IF1</td><td colspan="2">IF1+</td><td colspan="2">IF2-</td><td>IF2</td><td>IF2+</td><td>IF3</td></tr>
<tr><td>DoD 4
Trunk snapped</td><td>IF1</td><td>IF1+</td><td>IF2-</td><td colspan="2">IF2</td><td colspan="2">IF2+</td><td colspan="3">IF 3</td></tr>
<tr><td>DoD 5
Strong debranching
(> 60% of estimated crown volume ripped off)</td><td>IF2-</td><td>IF2</td><td>IF2+</td><td colspan="7">IF3</td></tr>
<tr><td>DoD 6*
Isolated debarking of remaining tree parts due to impacts of small-sized debris</td><td colspan="10">≥IF3</td></tr>
<tr><td>DoD 7*
Extensive debarking (>60%) of remaining tree parts due to impacts of small-sized debris</td><td colspan="10">≥IF4</td></tr>
</table>

***Debarking:** Depending on the amount of debris and the thickness of the bark, debarking may only begin at higher windspeeds, therefore, only lower bounds are specified in DoDs 6 and 7.

Uprooting – DI: TR*

To obtain the Rooting Strength number (TR), take the Tree firmness number (T)and make these corrections:

- If the Tree firmness number has a "+", remove the "+" and add 1
- If the stand is unstable, subtract 1.
- If the tree is rooted in fragile, wet ground, subtract 1.
- If the trunk is rotten until 1/3 of the trunk cross-section, subtract 1.
- If the trunk is rotten until 2/3 of the trunk cross-section*, subtract 2.
- If the tree is rooted in firm, rocky ground, add 1.
- If TR negative, set TR to 0

* Note: If the tree rot is worse or there are any other significant defects, no TR number can be determined, and the damage is unratable.

Rooting strength number TR	**TR0**	**TR1**	**TR2**	**TR3**	**TR4**	**TR5**	**≥TR6**
DoD 1 *Uprooting*	**IF0+**	**IF1-**	**IF 1**	**IF 1+**	**IF 2-**	**IF2**	**IF2+**

Example

One example is presented here. For more examples, see the Appendix.

The image shows an oak tree that was uprooted. This means the Rooting strength number TR should be determined. The TR number depends on the T number.

The T number calculation starts with 3, because oak is in the list of high firmness species. No other additions or subtractions apply, so that T=3.

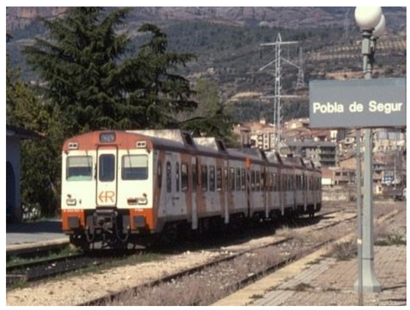
Figure 9. Uprooted oak tree. Photo: Martin Hubrig.

To compute TR, we start with 3, and need to subtract 1 because the soil is unstable, and subtract 1, because the rooting is unusually shallow for an oak. This results in TR=1. An uprooted tree with TR leads to a rating of **IF1-**. The shorthand for this rating is **TR1/1.**

3.4 Train cars – DI: R

	S Stationary or operating at < 25 m/s	**F** Operating at normal speed	
DoD 1 *Flipping or derailment*	**IF2-** 54 193	**IF1+** 47 170	 m/s km/h

** Estimates based on JMA(2015), rounded upward.*



3.5 Mobile Homes / Static Caravans – M*

Degree of Damage	Rating	
DoD 1 *Light damage to roof or siding*	**IF1-** 36 128	 m/s km/h
DoD 2 *Unit slides*	**IF1** 41 149	 m/s km/h
DoD 3 *Roof gone*	**IF1** 41 149	 m/s km/h
DoD 4 *Overturning*	**IF1+** 47 170	 m/s km/h
DoD 5 *Complete destruction*	**IF2-** 54 193	 m/s km/h

**Estimates based on EF-scale (McDonald and Mehta, 2006)*

3.6 Poles and Towers – P

Degree of Damage	**U** utility pole*	**L** light pole**	**T** power transmission tower*	
DoD 1 *Deformed, bent or leaning*	**IF1-** 36 128	**IF1-** 36 128	**IF2** 60 217	 m/s km/h
DoD 2 *Collapsed*	**IF1** 41 149	**IF1** 41 149	**IF2** 60 217	 m/s km/h

** Estimate based on Canadian EF-scale (Sills et al., 2014)*

*** Estimate based on EF-scale (McDonald and Mehta, 2006)*

3.7 Fences - F

Degree of Damage	**M** metal wire fences*	
DoD 1 *Partial or complete collapse*	**IF1-** 36 128	m/s km/h

** Estimate based on JMA (2015).*

3.8 Signs and billboards – S

Degree of Damage	**T** traffic signs*	**M** metal frame billboards*	
DoD 1 *Inclination or buckling of pillar(s)*	**IF1+** 47 170	**IF1+** 47 170	m/s km/h
DoD 1 *Collapse of pillar(s)*	**IF2-** 54 193	**IF2-** 54 193	m/s km/h

**Estimates based on JMA(2015).*

*** Estimates based on JMA(2015). Billboards with a wooden frame have greatly varying degrees of sturdiness, because of their design or inadequate maintenance. This makes them poor damage indicators.*

Figure 10. Traffic signs. Left: Pete Chapman, CC BY-SA 2.0 https://commons.wikimedia.org/w/index.php?curid=9178891
Centre: Rijksdienst voor het Cultureel Erfgoed, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=24252957
Right: Grzegorz W. Tężycki - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=53070922

Figure 11. Metal frame billboards. **By Kolforn (Kolforn) https://commons.wikimedia.org/w/index.php?curid=43306855**
By Jean Housen - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=20163037
By Lišiak - Own work, CC BY-SA 4.0, *https://commons.wikimedia.org/w/index.php?curid=39072776*

3.9 Scaffolding connected to walls – D

Degree of Damage		
DoD 1 *Breakage of connections to walls*	**IF0+** 30 108	 m/s km/h

Note: Estimate based on JMA(2015).

Figure 12. Scaffolding. **Left: by Plaats - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=17360293**
Centre: by TheRunnerUp - Own work, CC BY-SA 3.0 at, https://commons.wikimedia.org/w/index.php?curid=28131152
Right: by Globetrotter19 - Own work, CC BY-SA 3.0, *https://commons.wikimedia.org/w/index.php?curid=44053732*

3.10 Carports / Garages – G

Degree of Damage		
DoD 1 *Collapse*	**IF1+** 47 170	 m/s km/h

Figure 13. Carports / garages. By Aarp65 - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=30872535
By Ra Boe / Wikipedia, CC BY-SA 3.0 de, https://commons.wikimedia.org/w/index.php?curid=18177883
By Dr.Ing.S.Wetzel, de:Benutzer: Analemma - Own work (Original text: Eigenfoto), CC BY-SA 3.0 de, *https://commons.wikimedia.org/w/index.php?curid=47928444*

3.11 Service station canopies – SS

Degree of Damage		
DoD 1 *Collapse*	**IF2-** 54 193	 m/s km/h

Note: Estimate based on EF-Scale (McDonald and Mehta, 2006).

Figure 14. Service stations. Left: By Kulja - Own work, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=837123 5
Right: By Tiia Monto - Own work, CC BY-SA 4.0, *https://commons.wikimedia.org/w/index.php?curid=47617270*

3.12 Shipping containers – SC

Degree of Damage	**L** light* (contents < 300 kg)	**H** heavy* (contents > 300 kg)	
DoD 1 *Shifting / sliding*	**IF1-** 36 128	**IF1+** 47 170	m/s km/h

Estimates based on JEF-scale (JMA, 2015).

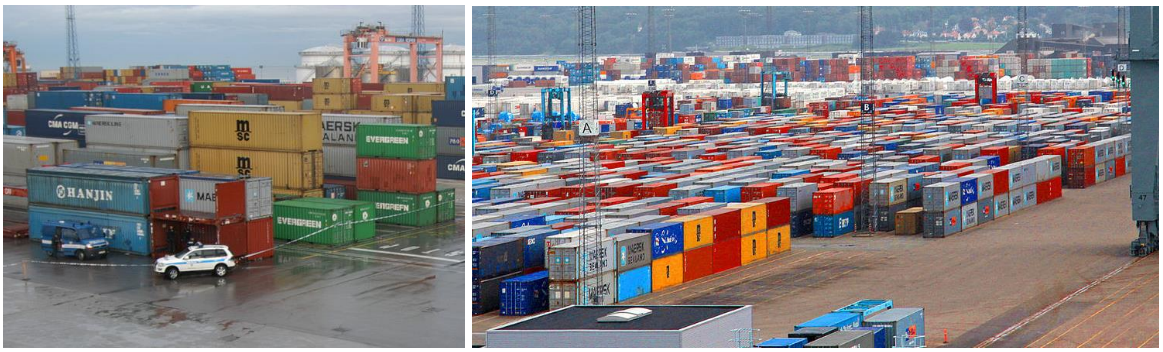


Figure 15. Shipping containers. Left: By IAEA Imagebank - 02510199, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=36209242
Right: By Guillaume Baviere, Flickr - https://www.flickr.com/photos/84554176@N00/6133222589, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=37188939

3.13 Cranes – C

Degree of Damage	**C** gantry/ container crane*	**TO** tower crane	
DoD 1 *Collapse when in operation*	**IF1-** 36 128	**IF1-** 36 128	m/s km/h
DoD 2 *Collapse when not in operation*	**IF2-** 54 193	**IF1+** 47 170	m/s km/h

Estimate based on JEF-scale (JMA, 2015).

Figure 16. Container / gantry cranes. By Alf van Beem - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=51959144
By Alf van Beem - Own work, CC0, https://commons.wikimedia.org/w/index.php?curid=26869428
By Polska Zielona Sieć from Kraków, Poland - Ostatni dzwonek dla Klimatu, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=17899828

3.14 Outdoor furniture – O*

Degree of Damage	**L** light unanchored objects such as plastic chairs or tables, unanchored trampolines	**O** other, heavier, objects	
DoD 1 *Overturned or shifted*	**IF0** 25 90	**IF0+** 30 108	m/s km/h
DoD 1 *Carrier through the air for several metres*	**IF0+** 30 108	**IF1** 41 149	m/s km/h

**Comparable to Canadian DI C-SFOF “Sheds fences or outdoor furniture” (Sills et al.)*

Figure 17. Outdoor furniture (left: light; right: heavier) .By Johann Jaritz - Own work, CC BY-SA 3.0 at, https://commons.wikimedia.org/w/index.php?curid=28977889

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Appendix I:

Photos and descriptions of undamaged buildings of various sturdiness classes

Class A

Characteristics:

- Thin wooden or metal panels, glass or mud walls
- Unanchored
- Lightweight

Typical examples: sheds, doghouses, or weak greenhouses

very weak frame with metal panels

Class B

Characteristics:

- Wood or metal frame with wood, metal panel, or glass siding
- Weak anchoring

Typical examples: structures typically not intended for permanent inhabitation such as sheds, barns, stables, garages or stronger greenhouses

weak wooden frame with wooden panels

By Renelibrary - Own work, CC BY-SA 3.0 https://commons.wikimedia.org/w/index.php?curid=31366017

metal frame structure with wooden panels

By Micov - Own work, CC BY 3.0,

https://commons.wikimedia.org/w/index.php?curid=4324950

metal frame with glass panels

By National Rural Knowledge Exchange - Flickr, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=3713996

Class C

Characteristics:

- Wood or metal frame with wood or metal panels, with or without brick veneer, stucco, external insulation layers
- CMU block masonry without any reinforcement

Typical examples: Frame houses with comparatively weak frame as well as strong outbuildings, such are sturdy stables

weak wooden frame structure with brick veneer

By 25or6to4 - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=66166439

weak wooden frame structure

By Remisc at English Wikipedia - Remisc (talk), CC0, https://commons.wikimedia.org/w/index.php?curid=15371546

wooden frame structure with wooden panels

By Johann Jaritz - Own work, CC BY-SA 3.0 at, https://commons.wikimedia.org/w/index.php?curid=38506826

Class D

- Weaker mass wall contruction of brick masonry, stone, concrete blocks, logs
- Strong frame structures, or brick/concrete block masonry structures with thin or degraded walls

Typical: one family residences, small commercial buildings

strong wooden frame structure

By User: (WT-shared) Aiko99ann at wts wikivoyage, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=22848045

strong wooden frame structure brick veneer

Adapted from ProfReader - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=70432812

strong wooden frame structure

By Werner Popken - taken by author, Panasonic FZ1, CC BY-SA 2.5, https://commons.wikimedia.org/w/index.php?curid=497074

weakened brick wall structure

Adapted from Kate Jewell, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=13466471

strong wooden frame structure with brick veneer

By MelvinMelvinMelvin - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=21180700

Class E

- Strong mass wall contruction of brick masonry, stone, concrete blocks, logs
- Very strong frame structures

Typical: one family residences, commercial buildings

brick masonry mass wall structure

By Evelyn Simak, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=13523321

wood log (load carrying) building structure

Adapted from Pudelek - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=40665727

concrete block mass wall structure

By Pavel Hrdlička, Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=34234877

brick masonry mass wall structure

By Vincent van Zeijst - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=23414912

wood log (load carrying) building structure

By Daniel Schwen - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=7743664

brick masonry mass wall structure

By Basotxerri - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=57525194

Class F

concrete structure

By Antoine - Own work, gemaakt met digitalecamera Olympus X-720, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=25895474

concrete structure

By Ddogas - Own work, CC BY-SA 3.0 https://commons.wikimedia.org/w/index.php?curid=5763609

Appendix II:

Examples of building damage

Photo	Description	DI/DoD:IF Shorthand	Resulting Rating
 *Photo: Pieter Groenemeijer (ESSL)*	Strong brick outbuilding of sturdiness C has partially collapsed walls (DoD=2). Roof BRC mostly destroyed (DoD=2). Affing, Germany, 15 May 2015	**BC/1:2+** **BRC/2:≥2-**	**IF2+**
 *Photo: Pieter Groenemeijer (ESSL)*	Strong brick masonry home class E has lost its roof (BRE; DoD=2), but all walls below highest floor still standing (BE; DoD=0). Affing, Germany, 15 May 2015	**BE/0:≤3** **BRE/2:≥2+**	**IF2+**
 *Photo: Alois M. Holzer (ESSL)*	Villa with thick brick walls, but with degraded mortar (class D), has most walls destroyed (DoD=2). Dolo, Italy 8 July 2015	**BD/2:≥4**	**IF4**

 Photo: Alois M. Holzer (ESSL)	Concrete masonry house (Class E) has partial destruction of walls (DoD=1) Dolo, Italy, 8 July 2015	**BE/1:≥4**	**IF4**
 Photo: Delia Gutierrez-Rubio & Juan de Dios Soriano (AEMET)	House with roof of heavy tiles (T+), has lost a few tiles (DoD=1). La Parilla, Spain, 21 February 2013	**BT+/1**	**IF1-**
 Photo: Alois M. Holzer (ESSL)	Single-layer concrete block masonry builging (Class C) has partial destruction of walls (DoD=1) Dolo, Italy, 8 July 2015	**BC/1:≥2+**	**IF2+**

Appendix III:

Notes on values in matrices of Damage indicator B “structure” and BR “roof”

BRA/2 is estimated based on the fact that sub-hurricane-force wind speeds often produce such kind of damage in European wind storms at such measured gust speeds. IF-value: 30 m/s.

BRB/2 The IF value (47 m/s) is slightly higher than EF DI=SBO DoD 5 (roof lift up of small barns and farm outbuildings @ 41 m/s), because these are “strong outbuildings”, and fits well with JMA DI 7 DoD 3--4 (major loss of roofing materials, and loss/destruction of roof frame for small non-residential wooden buildings @ 40--50 m/s). IF-value: 47 m/s.

BRC/2: JMA has Destruction/detachment of roof frames of its DI=9 (wooden livestock sheds) at 55 m/s, which probably are sturdy enough to fit into B-C2. B-C2 corresponds well to EF DI=FR12 DoD6 (roof gone for one/two family residences @ 54 m/s) and EF SRB DoD 7 (roof uplift or collapse of small retail building @ 53 m/s). IF-value: 54 m/s.

BRD/2 corresponds to EF DI=ACT DoD 4 (Uplift or collapse of roof structure for apartments, condominiums and townhouses @ 61 m/s). B-D2 is similar to JMA DI=2 prefabricated industrialized steel-framed houses DoD’s 4 and 5 (destruction of roof frames/components, and destruction of sheathing roof boards) @ 65 and 75 m/s, respectively. It may be argued that these frames are so strong, that this DI fits typically in sturdiness class E. For wooden houses and stores (JMA DI=1), loss of roofing structure is at 65 m/s. IF-value: 67 m/s.

BRE/2 is similar to DoD’s 8-10 of EF DI=IB (institutional building @ 63—68 m/s) and EF DI=ES, JSHS (elementary, junior/senior high school) DoD’s 7 and 8, resp. (uplift/collapse of roof), at 56 m/s. Our estimate is 67 m/s, which is still lower than Feuerstein et al (2012) (F3-; 76 m/s) and Fujita (1992) with 81—105 m/s (central values). Sills gives 63 m/s for heritage churches (C-HC DoD 5) having > 80% of their roof removed and 54 m/s for solid masonry buildings having half (but not all) of their roof removed. IF-value: 67 m/s.

BRF/2 was estimated to be F4 (105 m/s; central value) by Fujita. EF DI=LRB DoD5, MRB DoD8 and HRB DoD 9 have estimates of 59, 61, and 71 m/s; central values for roof collapse or uplifting. IF-value: 81 m/s.

--

BA/1. IF-value: 36 m/s.

BB1 IF-value: 54 m/s for “strong outbuildings” is a little higher than EF DI=SBO DoD6 (collapse of structure of small barns and farm outbuildings @ 43 m/s) which is the value for all (weak and strong) outbuildings.

BC/1 JMA DI=9 (wooden livestock sheds) major deformation/collapse of upper structures occurs at 60 m/s. Arguably, for weak framw hosues the value is a little higher. IF-value: 67 m/s.

BD/1 EF DI=FR12 (one to two family residences) DoD 8 (Most interior walls of top story collapsed) occurs at 66 m/s. EF DI=ACT (apartments, condominiums, townhouses) has DoD 6 (most top story walls collapsed) at 70 m/s. EF DI=MAM (masonry apartments) has DoD 5(Collapse of top story walls) at 59 m/s. JMA DI=1 (wooden houses or stores) has no intermediate DoD between some walls being damaged and the entire structure being destroyed/collapsed, which it puts at 75 m/s. Fujita (1992) originally put this at 81 m/s, Feuerstein et al (2012) at 87 m/s. IF-value: 81 m/s.

BE/1 EF DI's for sturdy buildings DI=15—21, have top floor walls collapsing between 62 and 70 m/s, which seems very low. Sills DI=C-SMH (solid masonry house) DoD 6 (Exterior walls collapsed) is consistent with 68 m/s. JMA DI=2 (Industrialized steel-framed houses - prefabricated) has DoD 6 (Major destruction/collapse of main frames – story collapse) at 100 m/s. Fujita (1992) put this at 105. IF-value: 105 m/s.

BF/1. JMA has no DoD's for DI=3 (reinforced concrete apartment buildings) representing damage to the structural integrity, i.e. it is > 100 m/s. Fujita (1992) has 130 m/s. IF-value: 130 m/s.

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BA/2: Weak outbuilding blown down is F1 per Fujita (1992), i.e. 41 m/s. This is typically observed in European wind storms with such gusts. IF-value: 41 m/s.

BB/2: Strong outbuilding blown down is F2 per Fujita (1992), i.e. 60 m/s, while EF DI=SBO DoD6 (total destruction of small barns and farm outbuildings) = 50 m/s, but this includes class A structures. IF-value: 60 m/s.

BC/2: Weak framehouse blown down is F3 per Fujita (1992), i.e. 81 m/s. EF DI=SRB (small retail building) DoD8 Total destruction of entire building @ 75 m/s. EF DI=FR12 DoD10 (Total destruction of one- or two-family residences) @ 76 m/s. JEF DI1 "Wooden houses and stores" DoD 8 "Major destruction/collapse of main structures and frames" is @ 75 m/s. IF-value: 81 m/s, i.e. is only more-or-less consistent with (J)EF-scales if these buildings fall can be considered "weak framehouses".

BD/2: Strong framehouse blown down is F4 per Fujita (1992), i.e. 105 m/s. The IF-scale values follow this, and are not consistent with the lower EF-scale estimates.

BE/2: Brick structure blown down is F5 per Fujita (1992), i.e. 130 m/s. The IF-scale values follow this, and are not consistent with the lower EF-scale estimates. The Canadian EF DI=C-SMH (Solid Masonry houses) has complete destruction at only 88 m/s.

BF/2: Concrete structure blown down is F5 per Fujita (1992), i.e. 130 m/s. The IF-scale values follow this, and are not consistent with the lower EF-scale estimates.

Appendix IV:
Examples of tree damage

Photo	Description	DI/DoD:IF Shorthand	Resulting Rating
 Photo: Martin Hubrig	An oak (high firmness tree 3) without leaves (T3+), and a typical rooting, (TR4), was uprooted (DoD=1)	**TR4/1**	**IF2-**
 Photo: Martin Hubrig	An oak (high firmness 3) located at a forest edge (+1) at a very exposed location (+1) (T5) lost some large green branches (DoD=2)	**T5/2**	**IF1+**
 Photo: Martin Hubrig	An oak (high firmness 3) located at a forest edge (+1) (T4) lost most of its branches (DoD=5)	**T4/5**	**IF3**

 Photo: Martin Hubrig	A pine with low firmness (T2), poorly rooted (-1), on wet (-1) soil (TR0) was uprooted (DoD=1)	**TR0/1**	**IF0+**
 Photo: Martin Hubrig	A spruce (low firmness 2), standing on an exposed hill (+1 = T3), was very well rooted (+1 = TR4), but still uprooted (DoD=1).	**TR4/1**	**IF2-**
 Photo: Martin Hubrig	Spruces (low firmness 2), with an unstable H/D ratio (-1 = T1), sustained compression failure (DoD=3)	**T1/3**	**IF1-**

 *Photo: Martin Hubrig*	Spruces (low firmness 2), with an unstable H/D ratio (-1 = T1) had their trunks snapped (DoD=4)	**T1/4**	**IF1+**
 *Photo: Hartmut Höller*	Spruces (low firmness 2), edge tree (+1=T3) had trunks snapped (DoD=4).	**T3/4**	**IF2+**
 *Photo: Martin Hubrig*	An oak (high firmness 3), that was solitary (+1) had a 2/3 rotten trunk (not visible; -2 = T2) that snapped (DoD=4)	**T2/4**	**IF2**

 *Photo: Rainer Kaltenberger*	A solitary tree (T unimportant), sustained beginning debarking by sandblasting (DoD=6)	**T/6**	**IF3**
 *Photo: Martin Hubrig*	An oak with very bad wood rot (> 2/3 of the trunk section), that cannot be rated.	**T/?**	**?**
 *Photo: Martin Hubrig*	A birch with low firmness (T2), poorly rooted (-1), on wet (-1) soil (TR0) was uprooted (DoD=1)	**TR0/1**	**IF0+**