資料３－１

# Guidelines for the Japanese Enhanced Fujita Scale

**December 2015**

**Japan Meteorological Agency**

# Introduction

Tornadoes are infrequent, small-scale brief phenomena whose development is difficult to identify with ordinary weather observation network resources, and their exact mechanism remains unclear. It is important to determine the status of tornadoes in order to support research and investigation on the related genesis mechanism and improve prediction accuracy. Against such a background, the Japan Meteorological Agency (JMA) dispatches the JMA Mobile Observation Team (JMA-MOT) to tornado disaster sites in order to investigate damage, collect information on the phenomenon and rate its intensity.

The Fujita scale, which is used to estimate wind speed ranges based on tornado damage (e.g., the state of buildings), has conventionally been used to rate tornado intensity. It is used for such classification in the United States, Japan and a variety of other countries for its simplicity. However, a number of factors limit the scale's effectiveness for accurate intensity rating in Japan, including its development in consideration of damage to buildings and structures in the United States rather than in Japan and the limited number of indicators used in its intensity rating standards.

To address these issues, the Advisory Committee for Tornado Intensity Rating (chair: Yukio Tamura, professor emeritus, Tokyo Polytechnic University) run by JMA from 2013 to 2015 formulated the Japanese Enhanced Fujita Scale, which builds on the conventional Fujita scale in consideration of damage to buildings and structures (including vehicles, trees and so on) in Japan based on updated expertise in wind engineering.

The new scale supports accuracy in wind speed evaluation based on recent results from related studies, including experiments and simulations on relations between wind speed and damage.

These guidelines outline the characteristics of the Japanese Enhanced Fujita Scale and its rating procedures, and provide technical standards for tornado intensity rating in Japan. They are expected to support more accurate evaluation and rating of tornadoes.

Content may be revised in line with progress in future related research.

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# Chapter 1
# The History of the Japanese Enhanced Fujita Scale's Formulation

### 1.1. Rating of tornadoes using the Fujita Scale

Tornadoes are horizontally small-scale phenomena whose wind speeds are difficult to determine with existing ground-based anemometers. Against such a background, Fujita (1971) developed the Fujita scale (Table 1; referred to here as the F Scale) to support wind speed estimation for strong-wind phenomena such as tornadoes and downbursts based on damage to buildings and structures.

F Scale rating is based on evaluation of a tornado's destructiveness (i.e., damage and its severity) and related matching to the damage descriptions indicated in Table 1. Classes are converted into corresponding wind speed ranges using the formula proposed by Fujita, whose scale is commonly adopted in the United States, Japan and other countries worldwide for its ease of use.

Figure 1 shows numbers of recent confirmed tornadoes in Japan by F Scale class. The country's largest-ever was an F3.

Table 1. The Fujita Scale (Fujita 1971)

| Class | Wind speed | Damage descriptions |
|---|---|---|
| F0 | 40 – 72 mph | Some damage to chimneys and TV antennae; breaks twigs off trees; pushes over shallow rooted trees. |
| F1 | 73 – 112 mph | Peels surface off roofs; windows broken; light trailer houses pushed or overturned; some trees uprooted or snapped; moving automobiles pushed off the road. 73 mph is the beginning of hurricane wind speed. |
| F2 | 113 – 157 mph | Roof torn off frame houses leaving strong upright walls; weak buildings in rural areas demolished; trailer houses destroyed; large trees snapped or uprooted; railroad boxcars pushed over; light object missiles generated; cars blown off highway. |
| F3 | 158 – 206 mph | Roofs and some walls torn off frame houses; some rural buildings completely demolished; trains overturned; steel-framed hangar-warehouse type structures torn; cars lifted off the ground; most trees in a forest uprooted, snapped, or leveled. |
| F4 | 207 – 260 mph | Whole frame houses leveled, leaving piles of debris; steel structures badly damaged; trees debarked by small flying debris; cars and trains thrown some distances or rolled considerable distances; large missiles generated. |
| F5 | 261 – 318 mph | Whole frame houses tossed off foundations; steel-reinforced concrete structures badly damaged; automobile-sized missiles generated; incredible phenomena can occur. |

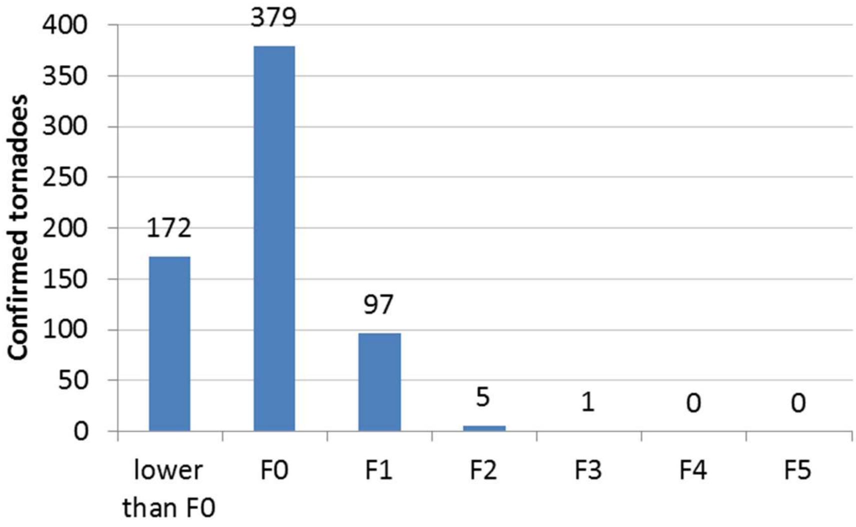



Fig. 1. Numbers of confirmed tornadoes in Japan by F Scale class (2007 – 2014).
Waterspouts and other phenomena for which F Scale rating is not possible are excluded.

### 1.2. Issues of the Fujita Scale and the Enhanced Fujita Scale

The F Scale is commonly used worldwide, but is characterized by a number of issues as outlined below.

1) Correspondence between damage descriptions and wind speeds has not been adequately verified. Based on related studies, Minor et al. (1977) and Phan and Simiu (1998) proposed that wind speeds corresponding to F4 and F5 were overestimated.

2) The only indicators that can be used for rating are residences, non-residences, greenhouses, chimneys, antennas, automobiles, trains, objects weighing several tons, and trees. This makes it difficult to establish ratings corresponding to multiple damage types of a greater extent.

In response to these issues, the Enhanced Fujita scale (referred to here as the EF Scale) was developed in the United States in 2006 (McDonald and Mehta, 2006), and was adopted by the National Weather Service in 2007. In the EF Scale, the verbose damage descriptions of the F Scale are replaced with 28 Damage Indicators (i.e., damaged items, referred to here as DIs) and several Degrees of Damage (i.e., damage severity, referred to here as DODs) for each DI (Fig. 2 shows DIs and DODs). Wind speeds corresponding to each DI and DOD are also defined in consideration of previous research and experience. This enables more quantitative evaluation than with the previous F Scale rating as well as more accurate evaluation of wind speeds.

A Canadian version of the EF scale developed by adding more items to the DIs of the conventional EF Scale and modifying related classifications has also been implemented (Sills, 2013 a).

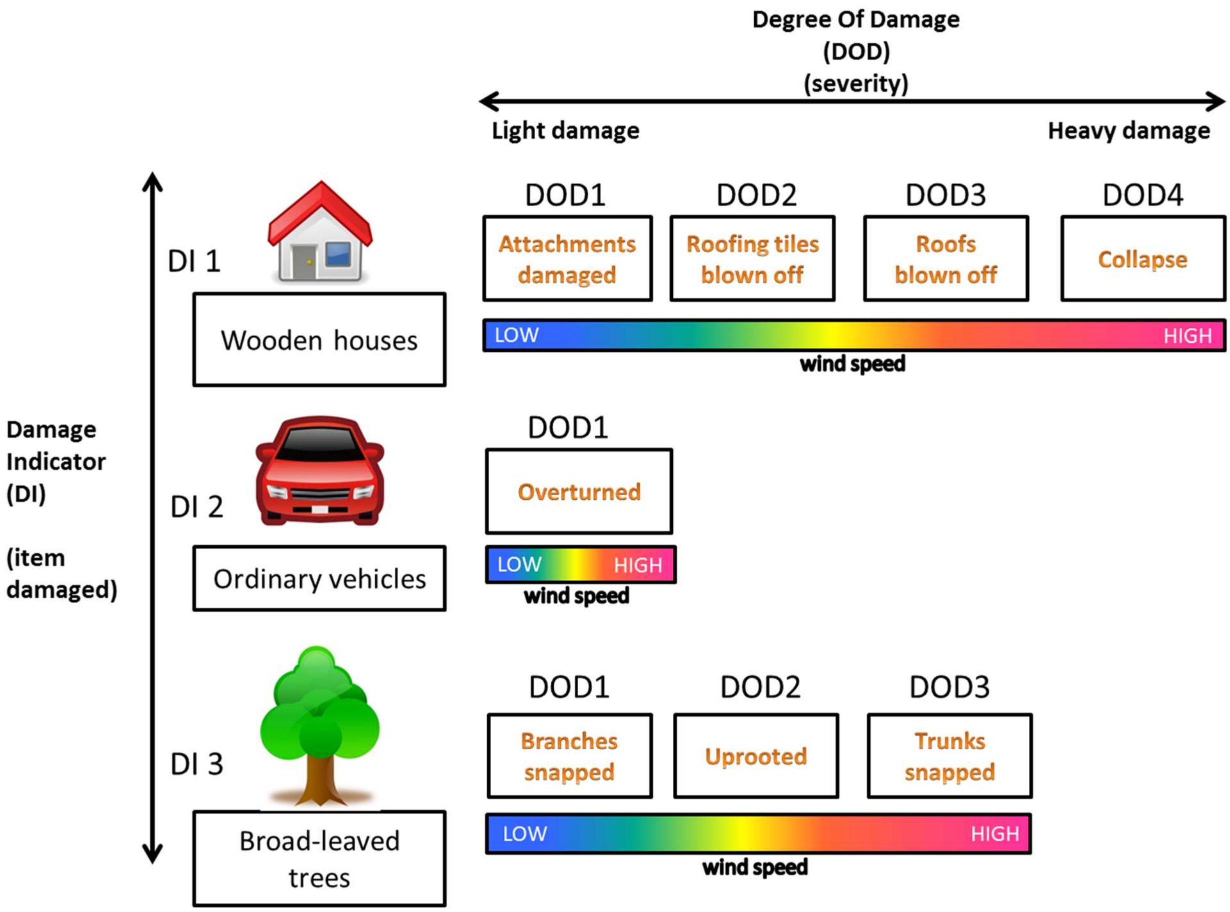



Fig. 2. Damage Indicators (DIs) and Degrees of Damage (DODs)

More accurate wind speed evaluation in other countries requires consideration of local architectural characteristics, as damage to buildings and structures in the damage descriptions of the F Scale and the EF Scale are for the United States and Canada. As the types and characteristics of buildings and structures in Japan differ significantly from those of the United States, large errors in wind speed evaluation may arise from the adoption of these scales in Japan.

### 1.3. Efforts to develop the Japanese Enhanced Fujita Scale

On 6 May 2012, multiple tornadoes caused serious damage in the Japanese prefectures of Ibaraki, Tochigi and Fukushima. In response, JMA formed the Committee for Improved Tornado Prediction consisting of academic experts and journalists. The committee composed a proposal titled *Improvement of Information on Tornadoes* in July of the same year. The Director-level Conference for Measures against Tornadoes attended by representatives of relevant Japanese government ministries and agencies was also held in 2012. At the conference, measures on which government ministries and agencies should work together (including technological enhancement in observation and forecasting) were proposed.

In accordance with the proposals and reports resulting from the conference, it was recommended that

JMA formulate a new set of guidelines to be applied to buildings and structures in Japan in consideration of the F Scale issues outlined above. It was also noted that the new guidelines should ensure statistical continuity with the conventional F Scale in order to facilitate comparison with past statistics and international data.

As the US EF Scale is not compatible with buildings and structures in Japan, JMA developed the Japanese Enhanced Fujita Scale (referred to here as the JEF Scale) as an improvement on the conventional F Scale for correspondence to buildings and structures in Japan with reference to the US EF Scale.

Between 2013 and 2015, JMA hosted six meetings of the Advisory Committee for Tornado Intensity Rating (chair: Yukio Tamura, professor emeritus, Tokyo Polytechnic University) consisting of wind engineering and meteorology experts toward examination and formulation of the Japanese Enhanced Fujita Scale (Appendix A).

# Chapter 2
# The Japanese Enhanced Fujita Scale and its Characteristics

The Japanese Enhanced Fujita scale was formulated on the basis of cutting-edge expertise in wind engineering with reference to the US EF Scale in order to enable more accurate estimation of tornado intensity in Japan. Its characteristics are outlined in Sections 2.1 – 2.3.

While each class in the F Scale corresponds to a wind speed range, each combination of DIs and DODs in the JEF Scale corresponds to wind speed values. Accordingly, the rating procedures of the two scales differ.

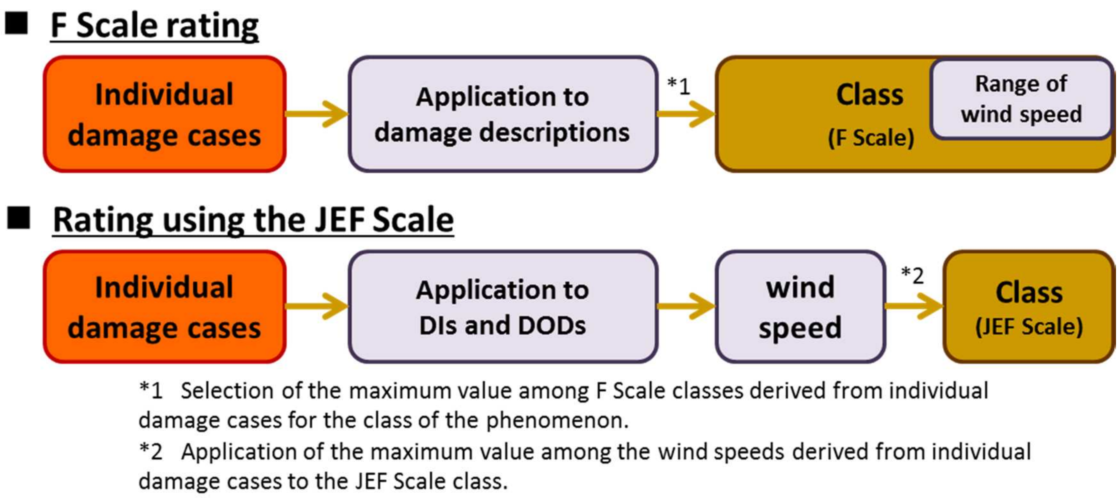



Fig. 3. Differences in F Scale and JEF Scale rating procedures

### 2.1. Introduction of damage indicators and degrees of damage corresponding to buildings and structures in Japan

On the JEF Scale, damage situations (i.e., damage and its severity) used for rating are described using two factors (DIs and DODs) as with the US EF Scale. Thirty types of buildings and structures (including vehicles, trees and so on) in Japan are used as DIs (Table 2) based on expertise in wind engineering, and multiple DODs are defined for each DI (Appendix B).

Table 2. Damage Indicators (DIs) in the JEF Scale

| No. | Damage Indicators (DIs) | No. | Damage Indicators (DIs) |
|---|---|---|---|
| 1 | Wooden houses and 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 |

### 2.2. Wind speeds corresponding to damage indicators and degrees of damage

Wind speed distribution corresponding to each DI and DOD was determined from the results of research involving large-scale wind tunnel equipment, computer simulation and experiments on tornado-related damage to buildings and structures (Appendix B). Based on the integration of these results, a special research project titled *Cooperative Study on a New Scale for Rating Tornadoes in Japan (2013 – 2015)* conducted by the Wind Engineering Joint Usage/Research Center with funding from the Ministry of Education, Culture, Sports, Science and Technology made a significant contribution to the establishment of correspondence between DIs/DODs and wind speeds.

If the wind resistance of buildings and structures is increased in the future, the degree of tornado-related damage will be reduced. Accordingly, wind speeds corresponding to DODs will need to be re-evaluated so that estimated wind speeds for tornadoes with the same intensity remain the same (Fig. 4) with no change in the criteria for the relationships between JEF Scale classes and wind speeds (Table 3).

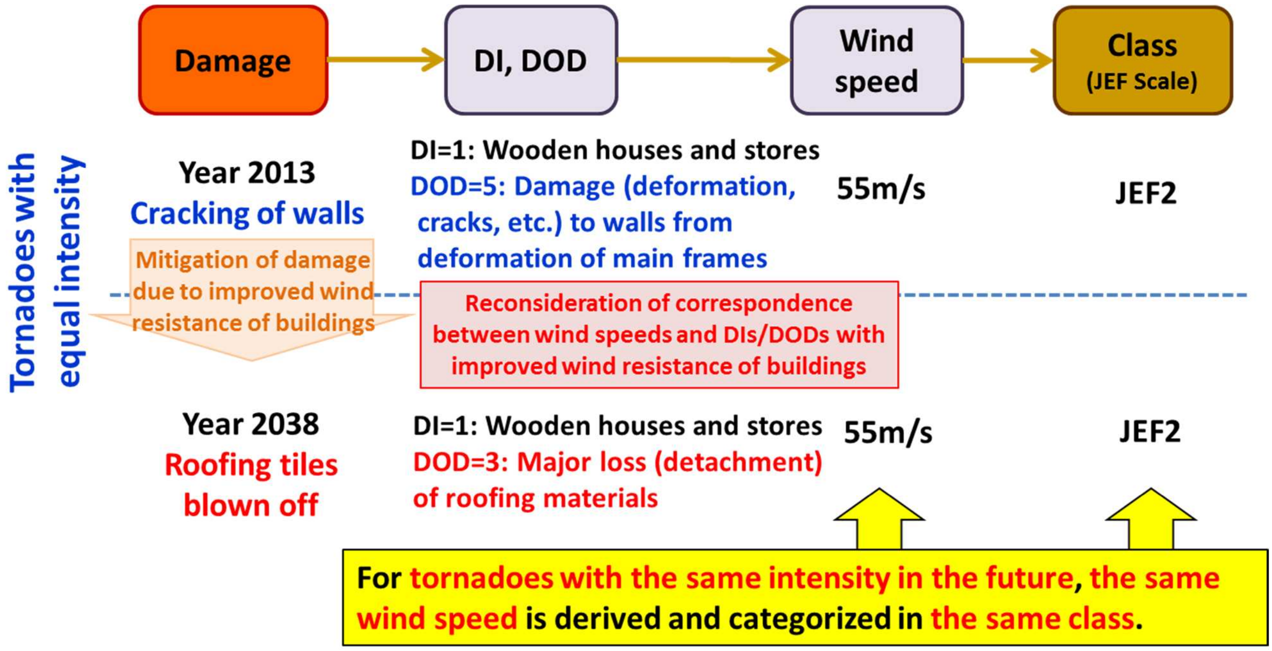



Fig. 4. Re-evaluation in relation to changes in building wind resistance

**2.3. Correspondence of wind speed ranges to classes in consideration of statistical continuity**

The JEF Scale class corresponding to wind speed was determined to allow the categorization of phenomenon rating results in the same class for both the F Scale and the JEF Scale wherever possible in order to maintain statistical continuity (e.g., phenomena rated as F2 on the F Scale would generally be rated as JEF2 on the JEF Scale). This concept is also adopted in the development of the US EF Scale.

Specifically, for multiple cases of tornado-related damage, the correlation between wind speeds rated on the F Scale and those rated on the basis of DIs and DODs were calculated to determine the correspondence of wind speeds to the JEF Scale class as shown in Table 3 (Appendix C). As a result, the lower and upper boundaries of the wind speed range for each JEF Scale class are given as 14 × JEF + 25 m/s and 14 × JEF + 38 m/s (up to JEF4), respectively.

Table 3. Correspondence of wind speeds to JEF Scale classes

| Class | Wind speed range (m/s) (3-sec average) | Primary damage (instances of damage cases for reference) |
|---|---|---|
| JEF0 | 25 to 38 | Wooden houses visibly damaged (windows broken by wind-borne debris) Roofing materials on wooden houses detached or displaced over limited areas<br>Horticultural facility coverings (vinyl, etc.) displaced<br>Greenhouse steel framing damaged or broken<br>Small sheds moved or overturned<br>Vending machines overturned<br>Unreinforced hollow concrete block walls damaged or largely destroyed<br>Branches with diameters of 2 – 8 cm or decayed broad-leaved tree trunks snapped |
| JEF1 | 39 to 52 | Roofing materials on wooden houses detached or displaced over relatively large areas<br>Eaves or sheathing roofing boards on wooden houses damaged or blown away<br>Plastic greenhouses damaged or destroyed over relatively wide region<br>Light vehicles or ordinary vehicles (compact cars) overturned<br>Train cars under ordinary operation overturned<br>Pillars of ground-based standing billboards inclined or deformed<br>Pillars of traffic signs inclined or blown over<br>Reinforced hollow concrete block walls damaged or largely destroyed<br>Trees uprooted or coniferous tree trunks snapped |
| JEF2 | 53 to 66 | Main frames of wooden houses deformed and walls damaged (distorted or cracked)<br>Structural members of roof frames on wooden houses damaged or blown away<br>Roofing materials of steel-framed warehouses detached or blown away<br>Ordinary vehicles (minivans) or large vehicles overturned<br>Reinforced-concrete utility poles collapsed<br>Carport frames inclined or destroyed<br>Reinforced hollow concrete block walls with buttresses largely destroyed<br>Broad-leaved tree trunks snapped<br>Gravestones overturned or shifted |
| JEF3 | 67 to 80 | Main frames of wooden houses severely deformed or destroyed<br>Eaves or sheathing roof boards of steel-framed prefabricated houses damaged or blown away, or wall claddings deformed or blown away<br>Banisters on balconies of reinforced-concrete apartment buildings deformed over relatively large areas<br>Roofing materials of large eaves of factories or warehouses overturned or blown away |

| | | |
|---|---|---|
| | | over limited areas<br>Wall claddings of steel-framed warehouses detached or blown away<br>Asphalt pavement displaced or blown away |
| 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<br>Banisters on balconies of reinforced-concrete apartment buildings severely deformed or destroyed |

# Chapter 3
# Rating Procedure for the Japanese Enhanced Fujita Scale

The procedure for tornado intensity rating with the JEF Scale is as follows (Fig. 5):

1) Determination of DI and DOD for each case of tornado-related damage with reference to Appendix B
2) Establishment of wind speed corresponding to each combination of DI and DOD determined in 1)
3) Selection of the maximum wind speed obtained from 2) to represent the phenomenon (referred to as the *wind speed for rating*)
4) Application of the *wind speed for rating* to the wind speed ranges in Table 3 and subsequent determination of the JEF Scale class

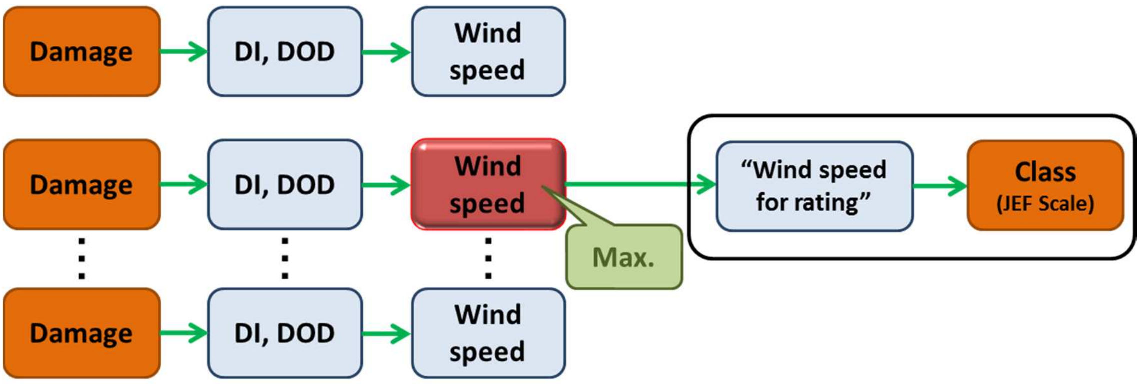
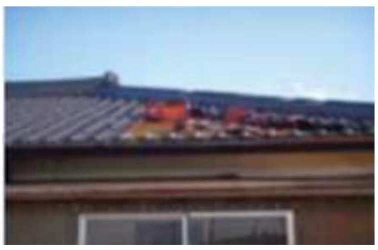



Fig. 5. Rating procedure for the Japanese Enhanced Fujita Scale

**Sample Rating**



| Damage Case A | Damage Case B | Damage Case C |
|---|---|---|
| Roofing tiles dislodged over a small area | Roof blown off | Roofing tiles dislodged over a large area |

1) Determination of DI and DOD for each damage case

In this scenario, it is assumed that a tornado caused three instances of damage referred to as A, B and C. As this damage was sustained exclusively by wooden houses, it can be determined as the DI of No. 1, *Wooden houses and stores*. The DOD for each damage case is then determined with reference to Appendix B, *DI: Wooden houses and stores*.

As Damage Case A meets the criteria for *Minor loss (detachment)/displacement of roofing materials*, its DOD is 2. Damage Case B meets the description *Destruction/detachment of roof frames/components*, hence its DOD is 7. Damage Case C meets the description *Major loss (detachment) of roofing materials*, making its DOD 3.

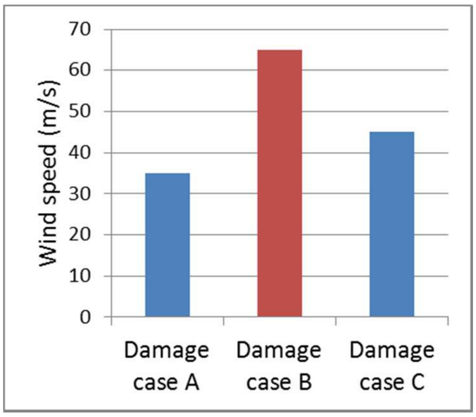
2) Determination of wind speeds corresponding to each damage case

With reference to the table of wind speeds for the DI *Wooden houses and stores* in Appendix B, the representative value for each DOD is selected as the wind speed for each Damage Case A, B or C.

*Note: For some DIs, numbers other than representative values may be chosen. Refer to Appendix B for details.*

Chosen DODs and wind speeds (representative values)

| | DOD | Wind speed (m/s) |
|---|---|---|
| Damage case A | 2 | 35 |
| Damage case B | 7 | 65 |
| Damage case C | 3 | 45 |




3) Determination of wind speed for ratings

The maximum value of 65 m/s for Damage Case B is chosen based on comparison of these three wind speed values. This is therefore chosen as the wind speed used for rating.

4) Determination of JEF Scale class

The 65 m/s wind speed used for rating is categorized as JEF2 with reference to Table 3. Accordingly, the phenomenon is rated as JEF2.

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## Appendix A
## Members of the Advisory Committee for Tornado Intensity Rating

| | |
|---|---|
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*Chair
**Vice-Chair

# Appendix B
# Relationships between Damage Indicators (DIs)/Degrees of Damage (DODs) and Wind Speeds

This appendix details relationships between DODs and corresponding wind speeds, the rating procedure (with commentary for operational use) and methods of wind speed calculation (rounded to multiples of 5 m/s) for each DI. These are based on the findings of a special research project titled *A Study of the Japanese Tornado Scale and Related Rating Methods* conducted by the Wind Engineering Joint Usage/Research Center with funding from the Ministry of Education, Culture, Sports, Science and Technology.

In these descriptions, three wind speed values (representative (Rep.), upper boundary (UB) and lower boundary (LB)) are defined as corresponding to DIs and DODs. Representative values are typical wind speeds that can cause each DOD level, and are generally used for rating. Upper- and lower-boundary values indicate the range of wind speeds for each DOD in consideration of structural and material differences.

< DI List >


1 Wooden houses and stores...... 18
2 Industrialized steel-framed houses (prefabricated)...... 25
3 RC apartment buildings...... 28
4 Temporary buildings...... 31
5 Large eaves...... 34
6 Steel-framed warehouses...... 38
7 Small non-residential wooden buildings...... 40
8 Greenhouses, gardening facilities...... 43
9 Wooden livestock sheds...... 46
10 Small sheds...... 49
11 Shipping containers...... 51
12 Vending machines...... 53
13 Light vehicles...... 55
14 Ordinary vehicles...... 57
15 Large vehicles...... 60
16 Railway vehicles...... 62
17 RC utility poles...... 66
18 Ground-based billboards...... 70
19 Traffic signs...... 73
20 Carports...... 75
21 Hollow concrete block (HCB) walls...... 78
22 Wooden, plastic, aluminum or mesh fences...... 81
23 Windbreak or snowbreak fences for roads...... 83

24 Net fences………..…………………………………………………………………………………….. 85

25 Broad-leaved trees……………………………………………………………………………….. 88

26 Coniferous trees………………………………………………………………………………… 95

27 Gravestones……………………………………………………………………………….............. 101

28 Road surfaces…………………………………………………………………………….......... 104

29 Temporary scaffolding (with wall ties)………………………………………………….............. 106

30 Gantry cranes…………………………………………………………………………………….. 108

# DI = 1: Wooden houses and stores

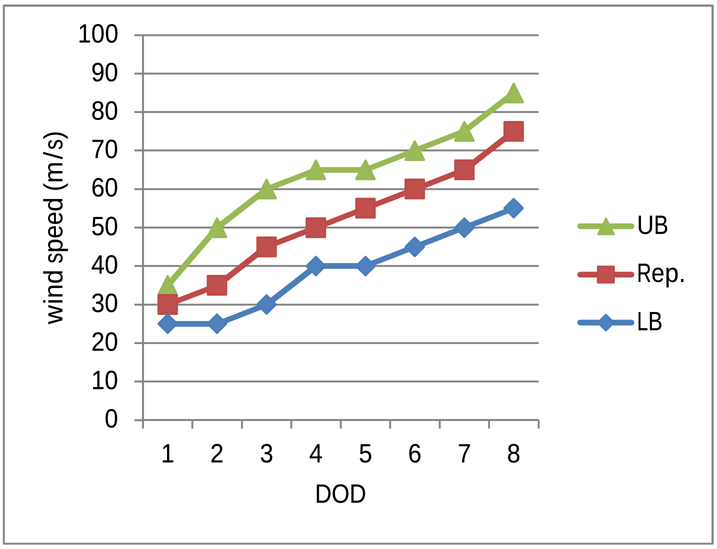
**[Indicators]**

1 or 2-story conventional wooden houses (including dwellings combined with stores)

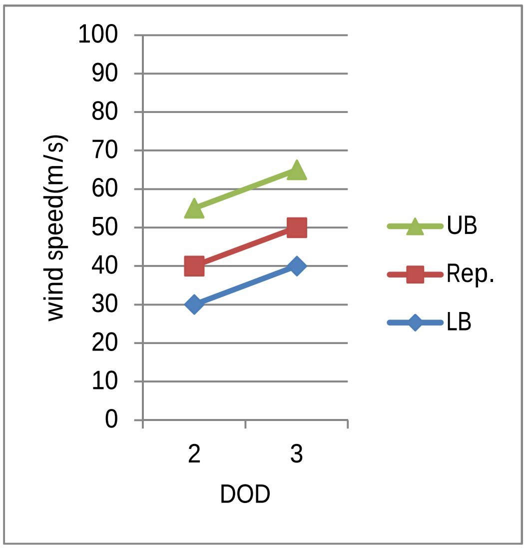
2-story wooden multiple dwellings

**[DOD and wind speed]**

| 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** |
| | | Sheet-metal roofing | **40** | **30** | **55** |
| 3 | Major loss (detachment) of roofing materials | Clay tile roofing | **45** | **30** | **60** |
| | | Sheet-metal 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** |




Clay tile roofing




Sheet metal roofing (DOD = 2, 3)

**[DOD example]**

| | |
|---|---|
|  |  |
| DOD = 1 Visible minor damage (breakage of glass)<br>Courtesy of the National Institute for Land and Infrastructure Management (NILIM), Building Research Institute (BRI) | DOD = 2 Minor loss (detachment)/displacement of roofing materials (clay tile roofing)<br>Courtesy of NILIM, BRI |
|  |  |
| DOD = 3 Major loss (detachment) of roofing materials (clay tile roofing)<br>Courtesy of NILIM, BRI | DOD = 4 Destruction/detachment of eaves or sheathing roof boards<br>Courtesy of NILIM, BRI |

| | |
|---|---|
|  |  |
| DOD = 6 Loss of metal wall cladding<br>(Example of LB adoption due to a lack of connection resistance against pull-out force in surrounding damaged sections)<br>Courtesy of NILIM, BRI | DOD = 7 Destruction/detachment of roof frames/components<br>Courtesy of NILIM, BRI |
| <br>DOD = 8 Major destruction/collapse of main structures and frames<br>(Example of LB adoption because the house was built before 1981.)<br>Courtesy of NILIM, BRI | |

**[Operational guidance]**

(1) For DOD = 2 (minor loss of roofing materials), it is assumed that the damaged roof area is less than around 25% of the whole and more for DOD = 3 (major loss of roofing materials).

For DOD = 2, 3, 4, 6, and 7, rate wind speeds via the following procedure:

Step 1) Adopt the value in column (c) with reference to columns (a) and (b) in the table below:

| (a) Detailed investigation of damaged parts | (b) Connection method for damaged parts | (c) Wind speed |
|---|---|---|
| Not executed | — | Rep. |
| Executed | Simplified connection method: No signs of connection resistance against pull-out force are observed at damaged sections around connections. | LB |
| | Normal connection method: Separation or damage around connections is often observed. | Rep. |
| | Reinforced connection method with joint metal: Separation or damage around connections is often observed. | UB |

Step 2) If damaged parts are obviously in a state of significant aging deterioration, select the wind speed one level lower than the value selected in step 1):

- UB → Rep.
- Rep. → LB
- LB → LB (one DOD lower) (If the one-DOD-lower LB is the same as the LB selected in step 1), replace it with the two-DOD-lower LB.)

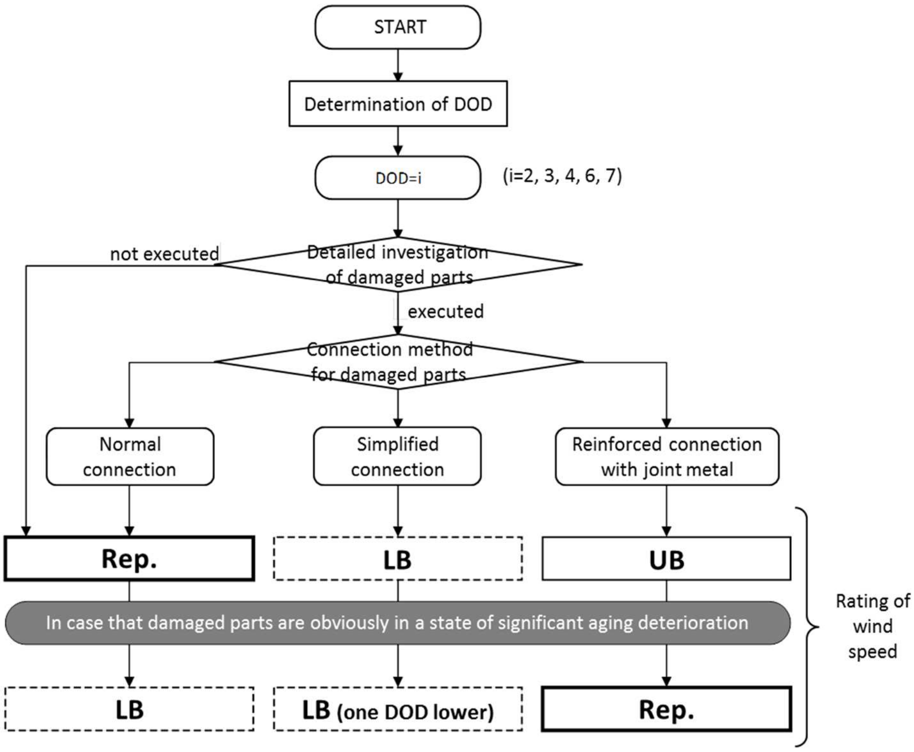



Fig. Wind speed rating procedure for DOD = 2, 3, 4, 6 and 7

(2) For DOD = 5 and 8, rate wind speeds via the following procedure.

Step 1) Adopt the value in column (c) with reference to columns (a) and (b) in the table below.

| (a) In-situ investigation for residents | (b) Year of construction | (c) Wind speed |
|---|---|---|
| Not executed | — | Rep. |
| Executed | 1959 – 1981 | LB |
| | 1981 – 2000 | Rep. |
| | 2000 – | UB |

Step 2) If damaged parts are obviously in a state of significant aging deterioration, select the wind speed one level lower than the value selected in step 1):

- UB → Rep.
- Rep. → LB.
- LB. → LB (one DOD lower) (If the one-DOD-lower LB is the same as the LB selected in step 1), replace it with the two-DOD-lower LB.)

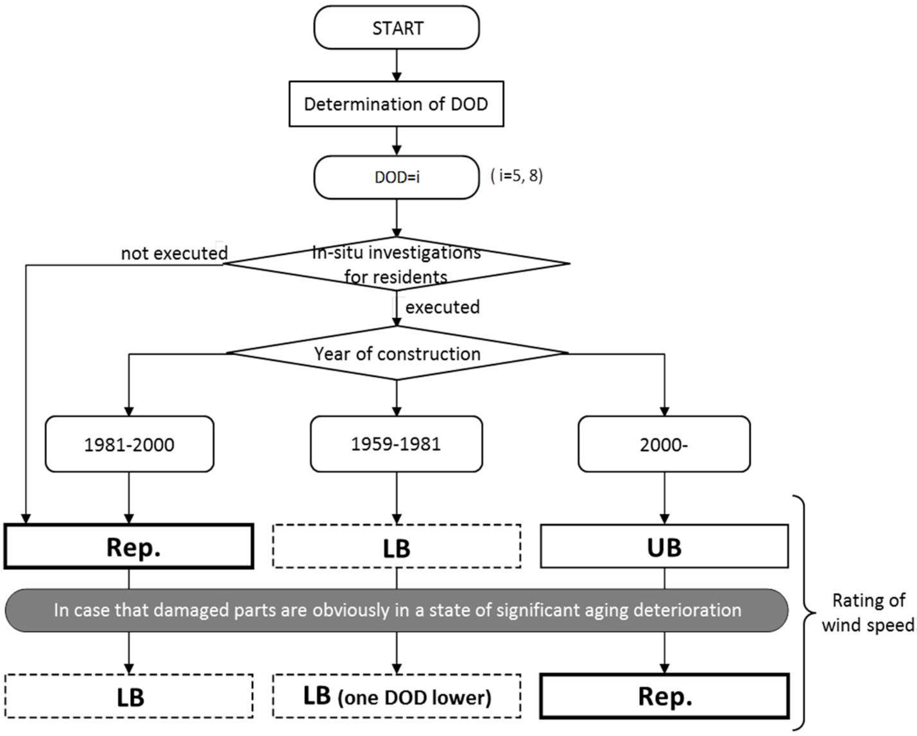



Fig. Wind speed rating procedure for DOD = 5 and 8

**[Outline of wind speed estimation]**

Wind speeds for this DI were estimated on the assumption of the following:

- One or two-story conventional wooden houses (including dwellings combined with stores) with clay tile or sheet-metal roofing built on a total floor area exceeding around 70 $m^2$.
- Two-story conventional wooden multiple dwellings with clay tile or sheet-metal roofing built on a total floor area not exceeding 300 $m^2$.

Wind speed estimation summary:

1) Maximum wind resistances of roofing materials and components for DOD = 2, 3, 4, 6 and 7 were estimated with reference to related data from loading tests (Okada and Kikitsu 2005; Kikitsu and Kawai 2009) and design standards (JMRA and JSSC 2009). The difference between minor and major loss of roofing materials was estimated from past results of experimentation using a boundary-layer wind tunnel (Okada 1988).
2) Maximum wind resistances of upper structures for DOD = 5 and 8 were estimated with reference to the story shear coefficient model (Sakata 2014), which is based on a revision of related building regulations.
3) Wind force acting on wooden buildings was calculated using instantaneous wind speed and wind force coefficients as specified in related building regulations and recommendations.
4) It was assumed that damage occurred when wind force calculated as described in 3) surpassed maximum wind resistance as described in 1) or 2), and that instantaneous wind speed under such conditions was applied to the wind speed of the corresponding DOD. As maximum wind resistance depends largely on how roofing components are attached and the year of construction, the estimated wind speed for each DOD varies in a range

from LB to UB.

**[References]**


Japan Metal Roofing Association, and Japanese Society of Steel Construction, 2008: Standard of Steel Roofing SSR2007. (in Japanese)

Kikitsu, H., and N. Kawai, 2009: Evaluation on wind resistance performance of roof frame in timber structure based on load tests, *J. Structural and Construction Engineering (Transactions of Architectural Institute of Japan (AIJ))*, **74** (646), 2181-2188. (in Japanese)

Kikitsu, H., T. Nakagawa, Y. Okuda, and H. Sakata, 2015: Development of Japanese Enhanced Fujita Scale, Outline of Degree of Damage and Corresponding Wind Velocity Estimation for Timber Residences, *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **40** (2), 119-120. (in Japanese)

Okada, H., 1988: Wind tunnel test on behavior of roof tiles under strong wind, *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **35**, 1-15. (in Japanese)

Okada, H., and H. Kikitsu, 2005: Evaluation of wind resistance performance of clay tile roof based on survey of construction method and pulling-up tests, *J. Structural and Construction Engineering (Transactions of AIJ)*, (596), 9-16. (in Japanese)

Okuda, Y., J. Kabeyasawa, T. Tsuchimoto, H. Kikitsu, Y. Araki, Y. Ishii, and T. Nakagawa, 2013: Report on field surveys and subsequent investigations of building damage following the May 6, 2012 tornado in Tsukuba city, Ibaraki prefecture, Japan, *Building Research Data*, (141). (in Japanese)

Sakata, H., 2014: Wind resistance of timber buildings, Proceedings of the research on development of Japanese tornado scale and related evaluation method, Tokyo Polytechnic University, 48-55. (in Japanese)

## DI = 2: Industrialized steel-framed houses (prefabricated)

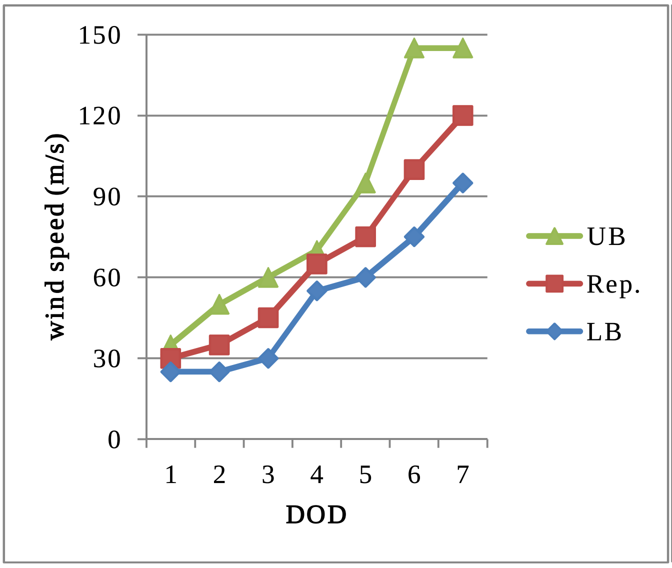
**[Indicators]**

2 story, light-gauge steel-framed, low-rise prefabricated houses and prefabricated multiple dwellings

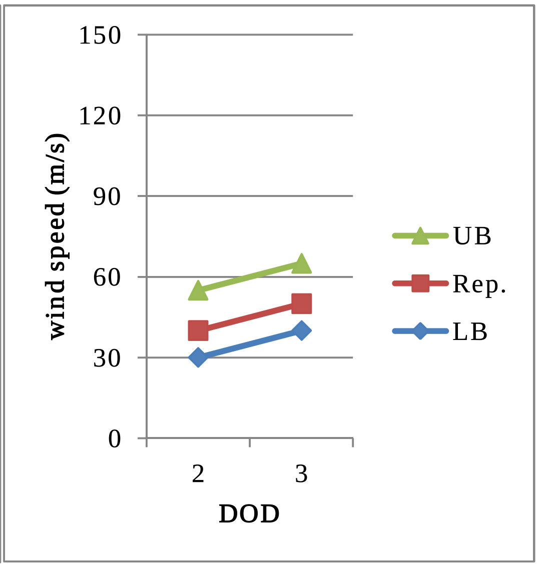
Convenience stores, gas stations, fast food restaurants

**[DOD and wind speed]**

| 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 |
| | | Sheet-metal roofing | 40 | 30 | 55 |
| 3 | Major loss (detachment) of roofing materials | Clay tile roofing | 45 | 30 | 60 |
| | | Sheet-metal roofing | 50 | 40 | 65 |
| 4 | Destruction of roof frames/components | | 65 | 55 | 70 |
| 5 | Destruction/detachment of eaves or sheathing roof boards<br>Deformation/loss of wall cladding | | 75 | 60 | 95 |
| 6 | Major destruction/collapse of main frames (story collapse) | | 100 | 75 | 145 |
| 7 | Overturning of upper structures (breakage of anchor bolts embedded in foundations) | | 120 | 95 | 145 |




clay tile roofing




sheet-metal roofing (DOD = 2 and 3)

**[DOD example]**

DOD = 5: Destruction/detachment of the eaves or the sheathing roof boards, deformation/loss of wall cladding
Courtesy of Building Research Institute (BRI)

**[Operational guidance]**

(1) This DI should be applied when steel columns are exposed due to separation or loss of cladding on dwellings. Otherwise, regard the building as a wooden residence and apply DI = 1. Even if steel beams are exposed in a damaged dwelling, it is necessary to determine DI based on column materials because beams may consist of steel-reinforced wood.

(2) For DOD = 2 (minor loss of roofing materials), it is assumed that the damaged roof area is less than around 25% of the whole and more for DOD = 3 (major loss of roofing materials).

(3) For DOD = 2 or 3, rate wind speeds via the following procedure:

Step 1) Adopt the value in column (c) according to columns (a) and (b) in the following table.

| (a) Detailed investigation of damaged parts | (b) Connection method for damaged parts | (c) wind speed |
|---|---|---|
| Not executed | ――― | Rep. |
| Executed | Simplified connection method: No signs of connection resistance against pull-out force are observed at damaged section around connections | LB |
| | Normal connection method: Separation or damage around connections is often observed | Rep. |

| | | |
|---|---|---|
| | Reinforced connection method with joint metal: Separation or damage around connections is often observed | UB |

Step 2) In case that the damaged part is obviously in a state of significant aging deterioration, select the one level lower wind speed than the value selected in the step 1) as below:

- UB → Rep.
- Rep. → LB.
- LB. → LB (one DOD lower) (When the one-DOD-lower LB is the same value as the LB selected in the step 1), replace it with the two-DOD-lower LB.)

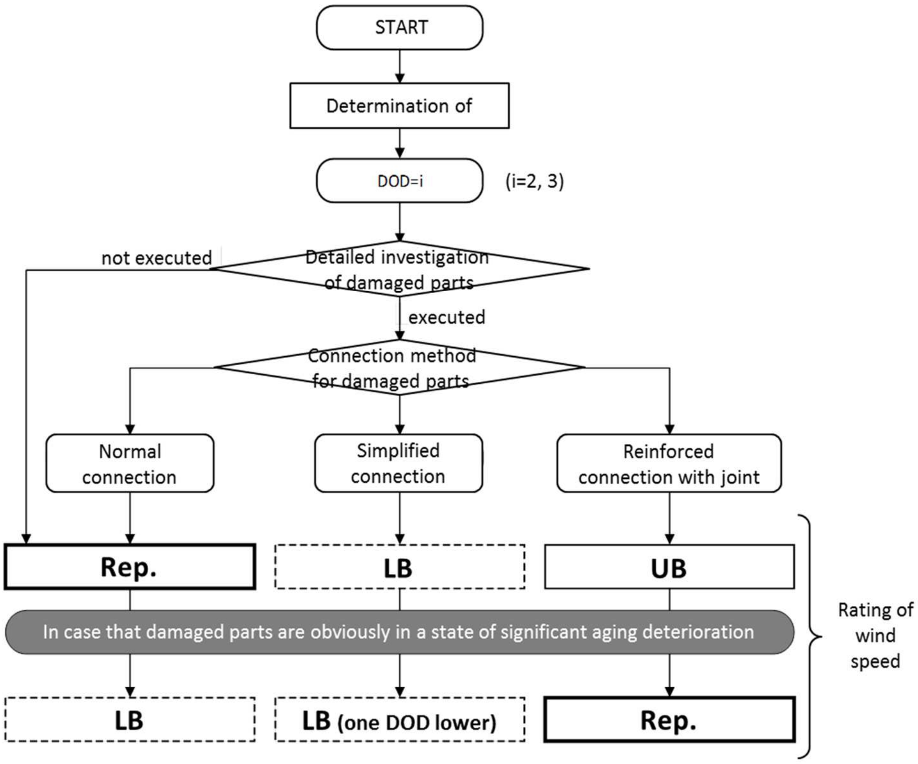



Fig. Wind speed rating procedure for DOD = 2 and 3

**[Outline of wind speed estimation]**

- Roof covering materials are assumed to be clay tiles and sheet-metal roofing, and external wall is assumed to be ALC panels in this DI.
- Wind speed estimations for DOD = 1 to 3 are the same as those for DI = 1.
- Wind speed estimations for DOD = 4 to 7 are based on maximum element intensity calculated using structural experimental data from manufacturers.

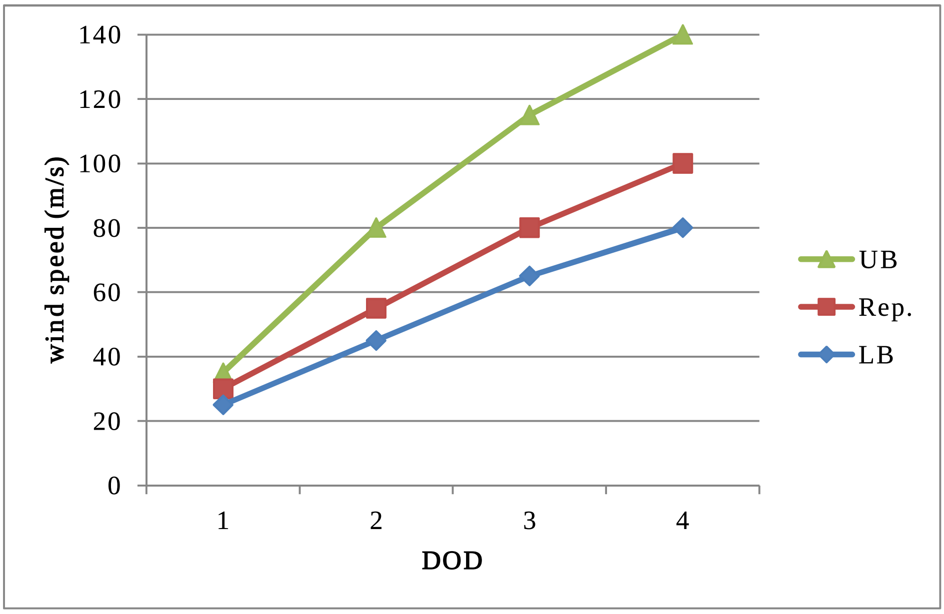
## DI = 3: RC apartment buildings

**[Indicators]**

Glass and aluminum handrails along corridors or balconies of RC apartment buildings up to five stories

**[DOD and wind speed]**

| DOD | Damage | Wind (m/s) | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Visible minor damage (breakage of glass) by wind-borne debris | **30** | **25** | **35** |
| 2 | Partial deformation of handrails/pillars, balusters | **55** | **45** | **80** |
| 3 | Major deformation of handrails/pillars, balusters | **80** | **65** | **115** |
| 4 | Significant deformation/detachment of handrails/pillars, balusters<br>Major destruction of panels | **100** | **80** | **140** |



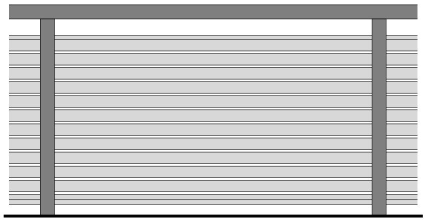
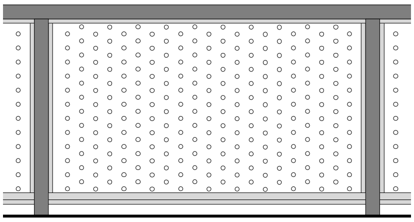
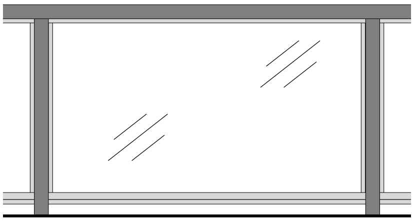
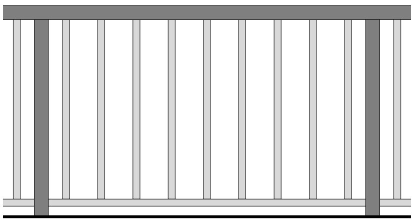

**[DOD example]**

| DOD = 4 Significant deformation/detachment of handrails/pillars, balusters<br>Major destruction of panels<br>(Example of LB adoption in consideration of panel-type handrails) |
|---|
| Courtesy of National Institute for Land and Infrastructure Management (NILIM), Building Research Institute (BRI) |

**[Operational guidance]**

(1) Apply DOD = 1 for minor damage from wind-borne debris to windows or aluminum handrail components.

(2) Apply DOD = 2 to 4 for wind-induced damage to aluminum handrails on balconies. Adopt Rep., LB or UB as detailed in the table below.

| Wind-affected structure | Example | Wind speed |
|---|---|---|
| Handrail with intermittent gaps | <br>Louver type<br><br>Punched-metal type | Rep. |
| Handrail with panels made of glass or other materials | <br>Panel type | LB. |
| Handrail with railings | <br>Railing type | UB. |

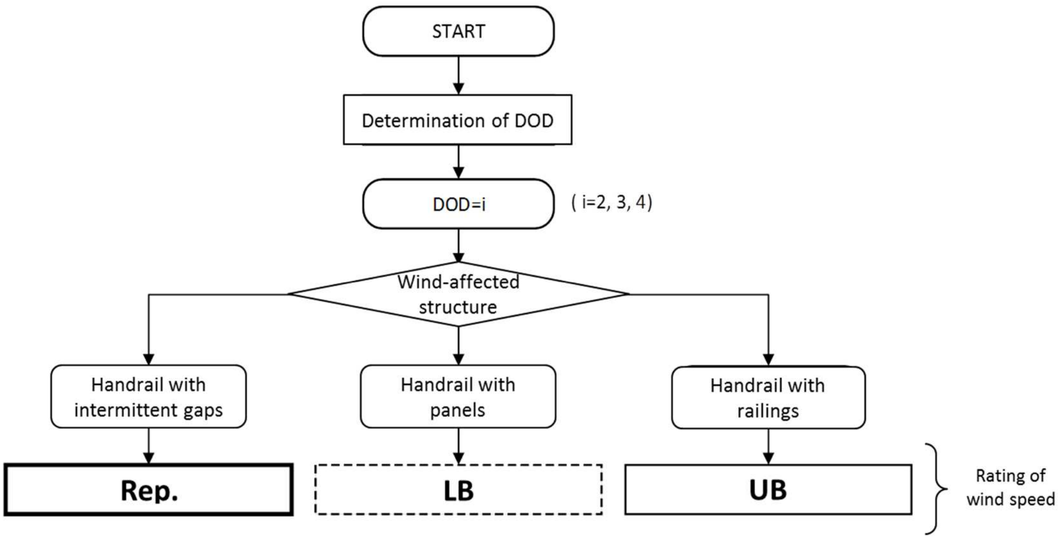



Fig. Wind speed rating procedure for DOD = 2 to 4

**[Outline of wind speed estimation]**

- The wind speeds for DOD = 1 are set with reference to those of DI = 1 (Wooden houses or stores).
- In calculation of wind speeds for DOD = 2 to 4, values of peak wind force coefficient, wind resistance and the solidity ratio of the handrail area are assumed.
- Peak wind force coefficients are calculated with reference to past experimental results (Ohtake et al. 2011). The wind resistance of an aluminum handrail is estimated from the nominal concentrated load of 100-type and 150-type handrails, where the interval and height of balusters are set as 1.2 m.
- The range of estimated wind speed was evaluated in consideration of the difference in a product of the peak wind force coefficient and the solidity ratio corresponding to the size of wind-affected area in the formulas.

**[References]**

Ohtake, K., O. Nakamura, and Y. Okuda, 2011: Peak wind force coefficients for balcony handrail, *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **36** (4), 376-381. (in Japanese)

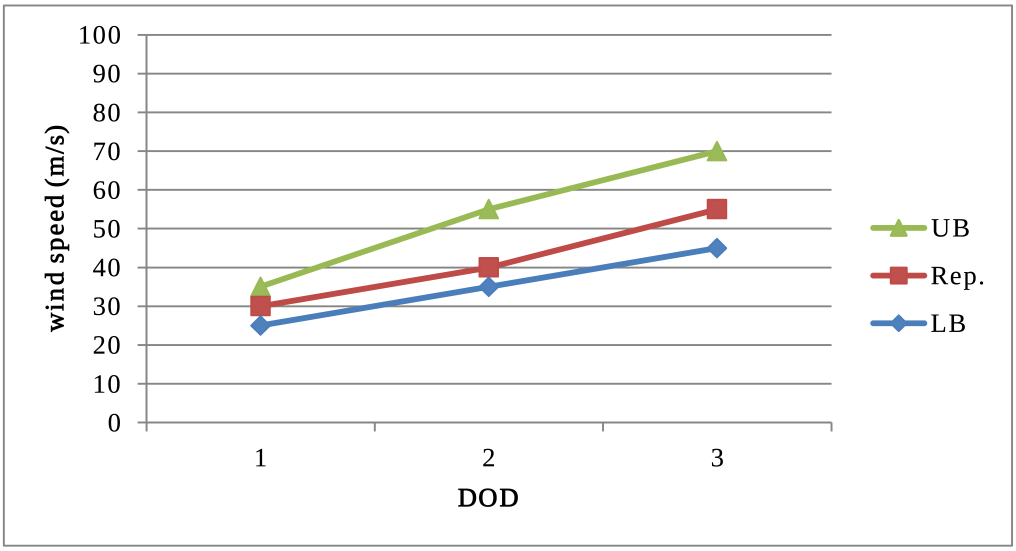
## DI = 4: Temporary buildings

**[Indicators]**

1- 3 story light-gauge steel-framed temporary offices/stores or prefabricated huts with limited connection to the ground/foundations

**[DOD and wind speed]**

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Visible minor damage (breakage of glass) | **30** | **25** | **35** |
| 2 | Overturning of one-story buildings | **40** | **35** | **55** |
| 3 | Overturning of multi-story buildings | **55** | **45** | **70** |




**[DOD example]**

DOD = 2: Overturning of a one-story building (example of LB adoption for single unit)

Courtesy of Miyako City, Okinawa Pref.

DOD = 3: Overturning of multi-story buildings

Two steel-framed temporary offices as marked by the dashed red frames in the photo on the left (identical to the remaining one) were blown away. The photo on the right shows the ground and wooden piles left under the structures. No sign of the wooden piles having resistance against lift force is observed. (Example of Rep. adoption for multi-story, multi-unit damage to structures measuring more than 10 m from front to back).

Courtesy of Tokyo Polytechnic University (TPU) and Building Research Institute (BRI)

**[Operational guidance]**

(1) This DI is applicable to steel-framed temporary buildings (e.g., 1 – 3 story light-gauge offices/stores or prefabricated huts). One unit is defined as a single temporary building measuring 3 m in height, 5 to 7 m in width and 2 m in depth. Several such units are occasionally combined and used as multi-unit and/or multi-story buildings. Prefabricated huts are regarded as single-unit, single-story temporary buildings. Apply DI = 10 (small sheds) for temporary buildings considerably smaller than one unit.

(2) This DI is applicable when anchors fixed between substructures and superstructures are minor and not resistant to external force or there is no anchor.

(3) For DOD = 2, adopt LB for single-unit temporary buildings (or prefabricated huts) and UB for multi-unit

buildings more than 10 m broad. Otherwise, adopt Rep.

(4) For DOD = 3, adopt LB for two-story and two-unit temporary buildings, and UB for multi-story, multi-unit buildings more than 10 m broad. Otherwise, adopt Rep.

**[Outline of wind speed estimation]**

- For DOD = 2 and 3, wind speeds are estimated from the balance of wind force and overturning moments calculated from the weight of the building, with the base of the building's downwind side taken as the center of rotation.
- The weight of a temporary building consists of its empty weight and a typical superimposed load (one person + objects) of 700 $N/m^2$. The drag coefficient of a building is 1.2, and the wind pressure coefficient of the roof is -1.0.

**[References]**

Architectural Institute of Japan, 2015: Recommendations for Building Stress and its Commentary (2015), Chapter 4, *Sekisai Kaju (Loading stress)*, 151. (in Japanese)

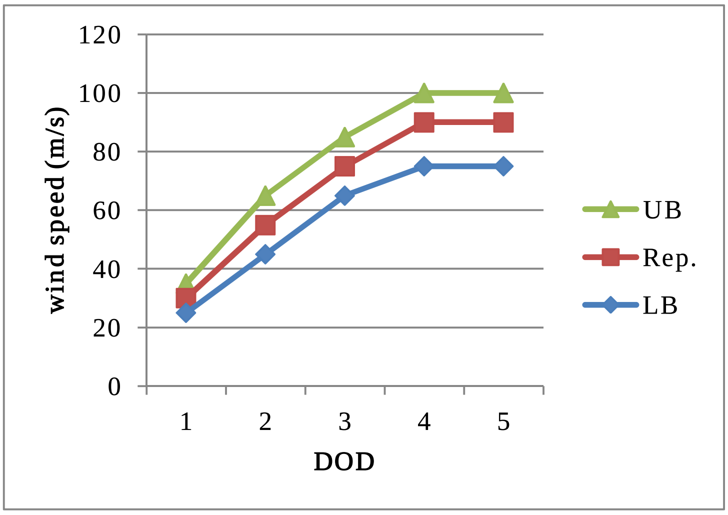
## DI = 5: Large eaves

**[Indicators]**

Large eaves on single-floor non-residential buildings (warehouses, factories, hardware stores) with folded steel-plate roofs

**[DOD and wind speed]**

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | Rep. | LB | UB |
| 1 | Visible minor damage | 30 | 25 | 35 |
| 2 | Destruction of beams | 55 | 45 | 65 |
| 3 | Minor loss (removal, detachment) of roofing materials | 75 | 65 | 85 |
| 4 | Destruction of beams (suspending members with larger diameters) | 90 | 75 | 100 |
| 5 | Major loss (removal, detachment) of roofing materials | 90 | 75 | 100 |




**[DOD example]**

| |
|---|
| DOD = 5 Major loss (removal, detachment) of roofing materials<br>(Example of two-DOD-lower LB adoption because the support length of the folded steel plate roofing is more than around 2.5 m and the damaged part is obviously in a remarkable state of aging deterioration)<br>Courtesy of National Institute for Land and Infrastructure Management (NILIM), Building Research Institute (BRI) |

**[Operational guidance]**

(1) For DOD = 3 (minor loss of roofing materials), it is assumed that the damaged roof area is less than around 25% of the whole. With DOD = 5 (major loss of roofing materials), it is assumed that the damaged roof area is more than around 25% of the whole.

(2) For DOD = 3 and 5, rate wind speeds via the following procedure:

Step 1) Adopt the value in column (c) with reference to columns (a) and (b) in the table below.

| (a) Detailed investigation of damaged parts | (b) Support length of folded steel plate roofing | (c) Wind speed |
|---|---|---|
| Not executed | — | Rep. |
| Executed | More than approx. 2.5 m | LB |
| | Approx. 2.5 m | Rep. |
| | Less than approx. 2.5 m | UB |

Step 2) If damaged parts or parts connected to them are obviously in a state of aging deterioration, select the wind speed one level lower than the value selected in step 1):

- UB → Rep.
- Rep. → LB.
- LB. → LB (one DOD lower) (If the one-DOD-lower LB is the same as the LB selected in step 1), replace it with the two-DOD-lower LB.)

(3) For DOD = 2 and 4, rate wind speeds via the procedure outlined below. Apply DOD = 4 if the diameter of hanging members is large and buckling strength is high.

Step 1) Adopt the value in column (c) with reference to columns (a) and (b) in the table below.

| (a) Detailed investigation of damaged parts | (b) Eave length | (c) Wind speed |
|---|---|---|
| Not executed | — | Rep. |
| Executed | More than approx. 7 m | LB |
| | Approx. 7 m | Rep. |
| | Less than approx. 7 m | UB |

Step 2) If damaged parts or parts connected to them are obviously in a state of aging deterioration, select a wind speed one level lower than that selected in step 1):

- UB → Rep.
- Rep. → LB.
- LB. → LB (one DOD lower) (If the one-DOD-lower LB is the same as the LB selected in step 1), replace it with the two-DOD-lower LB.)

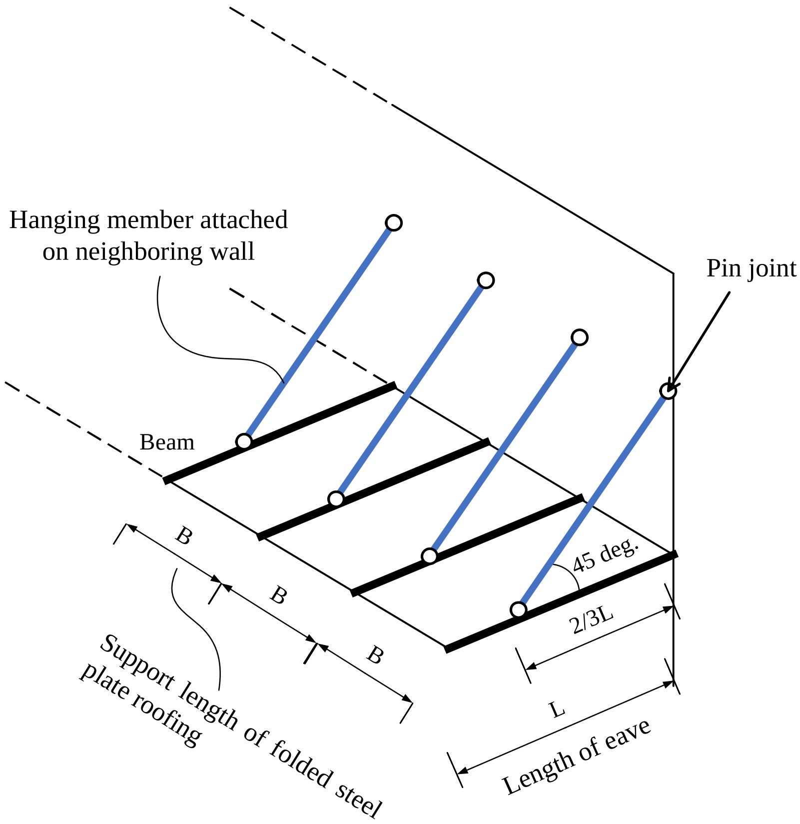
**[Outline of wind speed estimation]**

In wind speed estimation, large steel-framed eaves with folded steel plate roofs are assumed. The estimation method is outlined below.

1) Roof fastening strengths for DOD = 3 and 5 are estimated with reference to past load test data (JMRA and JSSC 2008; JMRA 2015), and the horizontal pitch of metal sheet is set as 0.4 m. For peak wind force coefficients, the values listed in building regulations are used. As estimated wind speed depends on the support span of folded plate roofs, UB and LB for DOD = 3 and 5 are set in consideration of this estimated range.

2) Wind speeds for DOD = 2 and 4, which correspond to beam destruction, are estimated from the bending moment at the beam end $M$ and the critical moment for beam destruction $M_r$. An eave length of 7 m and a beam span of 5 m are assumed in this estimation.

   Generally, large-scale eaves are structurally supported by hanging members attached to a neighboring wall. Accordingly, the moment $M_r$ above is set as the sum of the maximum beam moment and the moment determined from the strength of the hanging member with both ends pin-jointed and a 45-degree angle of support. Rep. values were calculated with the diameter of hanging members at around 100 mm for DOD = 2 and 150 mm for DOD = 4. UB and LB were calculated in consideration of the assumed eave length range.




**[References]**

Japan Metal Roofing Association (JMRA), and Japanese Society of Steel Construction, 2008: Standard of Steel Roofing SSR2007. (in Japanese)

JMRA, 2015: Load tests of connections of steel roofing, Newsletter of JMRA. (in Japanese)

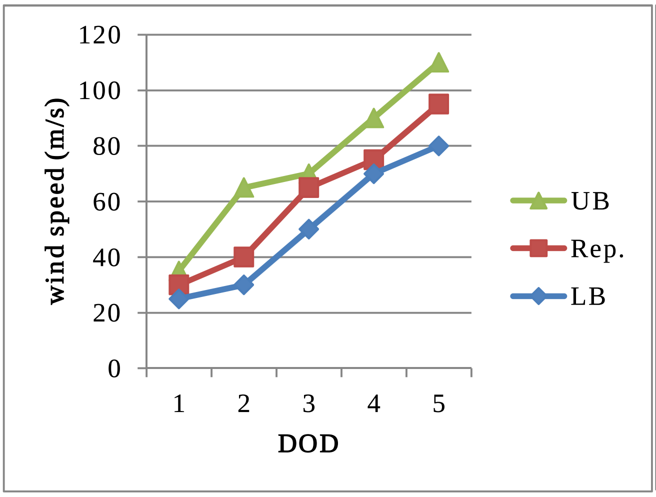
## DI = 6: Steel-framed warehouses

**[Indicators]**

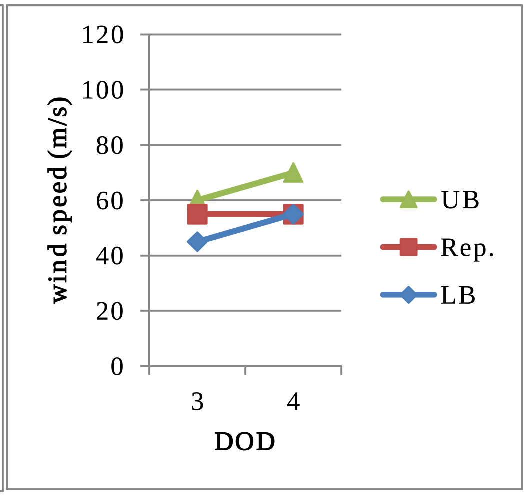
Steel-framed factories or warehouses

**[DOD and wind speed]**

| DOD | Damage | | Wind speed (m/s) | | |
|---|---|---|---|---|---|
| | | | **Rep.** | **LB** | **UB** |
| 1 | Visible minor damage | | **30** | **25** | **35** |
| 2 | Damage to eave soffits | | **40** | **30** | **65** |
| 3 | Loss (removal, detachment)/distortion of roofing materials | With openings at windward wall | **55** | **45** | **60** |
| | | Without openings at windward wall | **65** | **50** | **70** |
| 4 | Loss (removal, detachment)/distortion of cladding | With openings at windward wall | **55** | **55** | **70** |
| | | Without openings at windward wall | **75** | **70** | **90** |
| 5 | Major deformation or collapse of main frames | | **95** | **80** | **110** |




Without openings at windward wall




With openings at windward wall (DOD = 3 and 4)

**[Operational guidance]**

(1) For DOD = 3, adopt LB for slate roofing, UB for sheet-metal roofing and Rep. for unknown roof materials.

(2) DOD = 4 is applicable to ALC panels, ECP panels, sheet-metal walls and slate walls. Warehouses with tin corrugated sheets cannot be used as damage indicators because the estimated critical wind speed drastically depends on the degree of related deterioration.

(3) For DOD = 4, adopt LB for slate walls, UB for sheet-metal walls and Rep. for unknown wall materials.

(4) For DOD = 5, adopt UB for buildings with significant depth ((height) / (depth) ≥ 3.0) and LB for low-depth buildings, ((height) / (depth) ≤ 1.5). Otherwise, adopt Rep.

**[Outline of wind speed estimation method]**

- DOD = 1: The estimation method is the same as DOD = 1 for DI = 1 (Wooden houses or stores).
- DOD = 2: Wind speed is calculated from bolt buckling or clip tripping in eave ceilings. Rep. is set in cases where bolts buckle and penetrate ceilings due to positive wind pressure; LB is set for cases where negative wind pressure acts in ceiling spaces due to cladding damage; and UB is set for ceiling collapse.
- DOD = 3: Wind speed is calculated from the relationship between the strength of each connection and the negative wind pressure on each piece of roofing for the metal sheets or slate roofing generally used with steel-framed warehouses. When cladding damage occurs on windward walls due to wind pressure or impact from wind-borne debris, the wind speed value is multiplied by 0.85.
- DOD = 4: Wind speed is calculated from the relationship between the strength of each connection and the negative wind pressure on each piece of roofing for ALC panels, ECP panels, sheet-metal walls and slate walls as generally used for steel-framed warehouses. When cladding damage occurs on windward walls due to wind pressure or impact from wind-borne debris, the wind speed value is multiplied by 0.85.
- DOD = 5: The horizontal strength of regular buildings is determined on the basis of seismic loads in Japan. Horizontal strength is calculated in consideration of building weight as 2.5 $kN/m^2$ with reference to the weight per unit floor area of a steel-framed gymnasium and the base shear coefficient as 1.0. Wind pressure is calculated using the drag equation [(drag force) = (velocity pressure) x (drag coefficient) x (cross sectional area)], and wind speed is estimated from the balance of strength and wind force on buildings in a condition of non-cladding detachment.

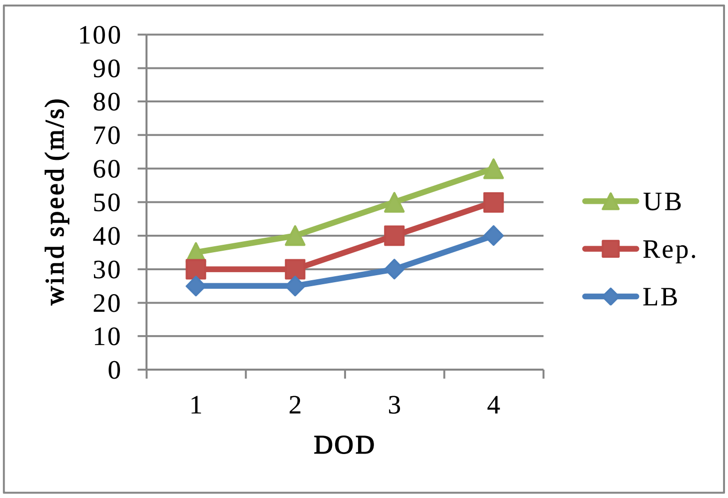
## DI = 7: Small non-residential wooden buildings

**[Indicators]**

Single-story non-residential wooden buildings (work sheds)

**[DOD and wind speed]**

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | Rep. | LB | UB |
| 1 | Visible minor damage (breakage of glass) | 30 | 25 | 35 |
| 2 | Minor loss (removal, detachment)/distortion of roofing materials | 30 | 25 | 40 |
| 3 | Major loss (removal, detachment) of roofing materials, collapse/major deformation of main frames | 40 | 30 | 50 |
| 4 | Destruction/loss of roof frames, displacement of upper structures | 50 | 40 | 60 |




**[DOD example]**

DOD = 4 Destruction/loss of roof frames, displacement of upper structures

(Example of Rep. adoption due to upper-structure displacement)

Courtesy of National Institute for Land and Infrastructure Management (NILIM), Building Research Institute (BRI)

**[Operational guidance]**

(1) For DOD = 2 (minor loss of roofing materials), it is assumed that the damaged roof area is less than about 25% of the whole, and for DOD = 3 (major loss of roofing materials), it is assumed that the damaged roof area is more than about 25% of the whole.

(2) For DOD = 3 (collapse/major deformation of main frames), adopt Rep. for normal damage states, LB for buildings with a large dominant opening such as an overhead door on a wall, and UB for buildings with a relatively small opening area.

(3) For DOD = 4 (loss of roof frames), adopt LB for buildings with minor forms of damage such as breakage of eave edges and UB for buildings with significant forms of damage such as extensive displacement of roof frames. If it is difficult to determine the degree of damage, adopt Rep. For states corresponding to displacement of upper structures, adopt Rep.

(4) If damaged parts or parts connected to them are obviously in a state of aging deterioration, select the wind speed one level lower than the value specified above:

- UB → Rep.
- Rep. → LB
- LB → LB (one DOD lower) (If the one-DOD-lower LB is the same as the LB specified above, replace it with the two-DOD-lower LB.)

**[Outline of wind speed estimation]**

Wind speeds for this DI were estimated assuming non-residential buildings such as work sheds with conventional one-story wooden structures over a total floor area of around 45 $m^2$ with metal sheet roofing.

Methods of wind speed estimation are outlined below:

1) Maximum wind resistances of roofing materials and components for DOD = 2, 3, and 4 were estimated with reference to related past data from load tests (Kikitsu and Kawai 2009) and design standards (JMRA and JSSC 2008). The differences between minor and major loss of roofing materials were estimated from past results of experimentation using boundary-layer wind tunnel (Okada 1988).
2) Maximum wind resistance of upper structures for DOD = 3 was estimated with reference to the story shear coefficient model (Sakata 2014), which is based on a revision of related building regulations. For the state corresponding to displacement of upper structures in DOD = 4, the friction coefficient was assumed to be 0.4 to 0.5.
3) Wind force acting on wooden buildings was calculated using instantaneous wind speed and wind force coefficients regulated according to related building regulations and recommendations.
4) It was assumed that damage occurs when wind force specified in 3) surpasses the maximum wind resistance specified in 1) or 2), and the instantaneous wind speed for this condition was applied to the wind speed of the corresponding DOD.

**[References]**

Japan Metal Roofing Association, and Japanese Society of Steel Construction, 2008: Standard of Steel Roofing

SSR2007. (in Japanese)

Kikitsu, H., and N. Kawai, 2009: Evaluation on wind resistance performance of roof frame in timber structure based on load tests, *J. Structural and Construction Engineering (Transactions of Architectural Institute of Japan (AIJ))*, **74** (646), 2181-2188. (in Japanese)

Kikitsu, H., T. Nakagawa, Y. Okuda, and H. Sakata, 2015: Development of Japanese Enhanced Fujita Scale, Outline of Degree of Damage and Corresponding Wind Velocity Estimation for Timber Residences, *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **40** (2), 119-120. (in Japanese)

Okada, H., 1988: Wind tunnel test on behavior of roof tiles under strong wind, *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **35,** 1-15. (in Japanese)

Sakata, H., 2014: Wind resistance of timber buildings, Proceedings of the research on development of Japanese tornado scale and related evaluation method, 48-55. (in Japanese)

## DI = 8: Greenhouses, gardening facilities

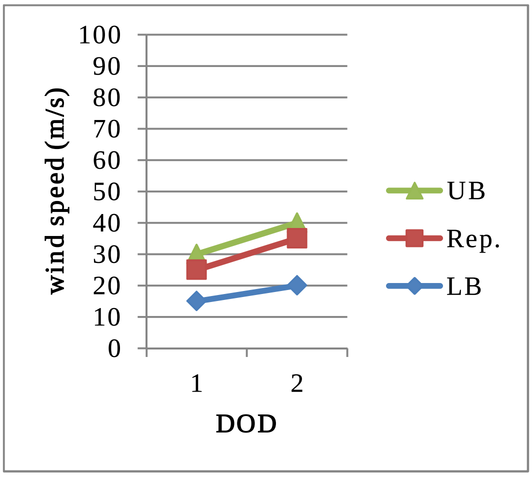
**[Indicators]**

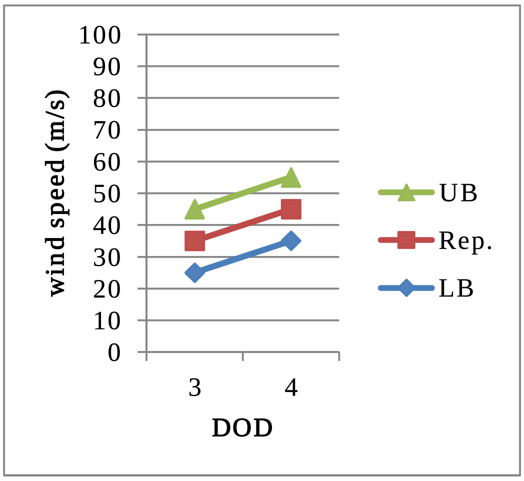
Pipe-framed greenhouses

Film-plastic-clad greenhouses

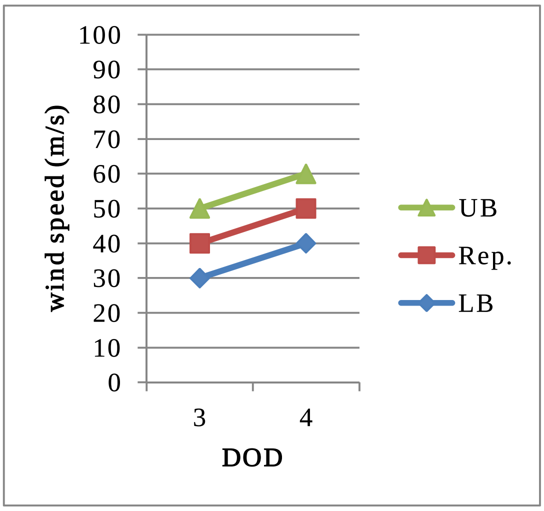
**[DOD and wind speed]**

| **DOD** | **Damage** | | **Wind Speed（m/s）** | | |
|---|---|---|---|---|---|
| | | | **Rep.** | **LB** | **UB** |
| 1 | Loss of cladding sheets (peeling, detachment) | | **25** | **15** | **30** |
| 2 | Deformation of pipes or collapse of pipe-framed greenhouses | | **35** | **20** | **40** |
| 3 | Deformation of frames or other damage to film-plastic-clad greenhouse | Tohoku, Kou-Shin-Etsu or Hokuriku districts | **35** | **25** | **45** |
| | | Other areas | **40** | **30** | **50** |
| | | Kochi, Kagoshima or Okinawa prefectures | **45** | **35** | **55** |
| 4 | Collapse of film-plastic-clad greenhouses | Tohoku, Kou-Shin-Etsu or Hokuriku districts | **45** | **35** | **55** |
| | | Other areas | **50** | **40** | **60** |
| | | Kochi, Kagoshima or Okinawa prefectures | **60** | **50** | **70** |

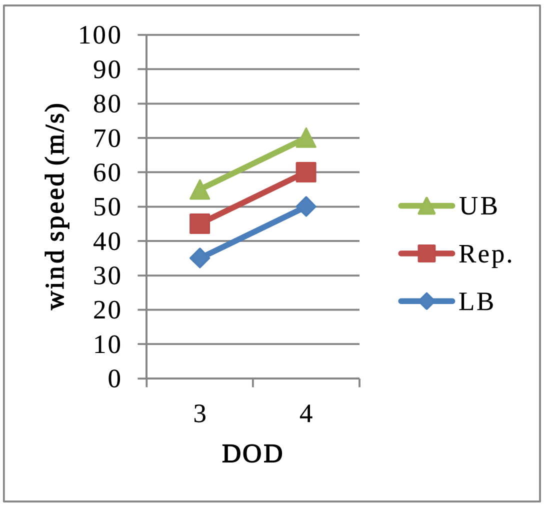



Tohoku, Kou-Shin-Etsu or Hokuriku districts




Other areas




Kochi, Kagoshima or Okinawa prefectures

**[Operational guidance]**

(1) For DOD = 1, adopt LB for damaged cladding sheets where the ratio of the damaged area to the total area is around 25% or less, and UB for ratios of around 50% or more. Otherwise, adopt Rep. If the damaged cladding sheets are obviously in a state of significant aging deterioration, adopt LB.

(2) DOD = 2 is applicable to pipe-framed greenhouses. Adopt Rep. for normal damage states. If the construction method is observed to be relatively simple with thin steel pipes (e.g., those with a diameter of less than 20 mm), adopt LB; if the frame and foundation are well constructed with thick steel pipes (e.g., those with a diameter of 30 mm or more), adopt UB.

(3) DOD = 3 and 4 are applicable to film-plastic clad greenhouses. The wind speed to be applied differs for three areas in Japan. Adopt Rep. in each DOD for normal damage states. If the construction method is observed to be relatively simple, adopt LB; if construction is solid and the in-service period is shorter than the normal lifespan, adopt UB.

(4) If damaged parts or parts connected to them are obviously in a state of aging deterioration, select the wind speed one level lower than the value specified in (2) or (3):

- UB → Rep.
- Rep. → LB.
- LB. → LB (one DOD lower) (If the one-DOD-lower LB is the same as the LB specified above, replace it with the two-DOD-lower LB.)

The normal lifespan of film-plastic-clad greenhouses is 10 – 15 years according to the Japan Greenhouse Horticulture Association. Interaction with greenhouse owners regarding actual states of operation and maintenance supports rating in consideration of degradation.

(5) If the ground of film-plastic-clad greenhouses with DOD = 3 or 4 is flooded with rainwater, this DI cannot be used because whole structures may float and be damaged by relatively weak wind under such conditions.

**[Outline of wind speed estimation]**

- Wind speeds for DOD = 1 were estimated on the basis of a proposal by the Japan Association of Wind Engineering (JAWE) (2008) and experience of past field investigation.
- Wind speeds for DOD = 2 were estimated on the basis of a JAWE proposal (2008) and verification involving past damage to pipe-framed greenhouses (Moriyama et al. 2003).
- Wind speeds for DOD = 3 were estimated on the basis of the design standard of the Japan Greenhouse Horticulture Association (1997), which provides design wind speeds in consideration of regional differences in Japan. Wind speeds for DOD = 4 were estimated by multiplying wind speeds for DOD = 3 by a factor of approximately 1.3.

**[References]**


Japan Association of Wind Engineering, 2008: Relation between instantaneous wind velocity and related situation of human and town. (http://www.jawe.jp/images/gust/gusttable.pdf) (in Japanese)

Japan Greenhouse Horticulture Association, 1997: Tentative standard of structural safety of greenhouse. (in Japanese)

Moriyama, H., S. Sase, H. Kowata, and M. Ishii, 2003: Engineering Analysis of the Greenhouse Structures Damaged by Tyhoon 0221 in Chiba and Ibaraki, *J. the Society of Agricultural Structures*, **34** (3), 199-212. (in Japanese)

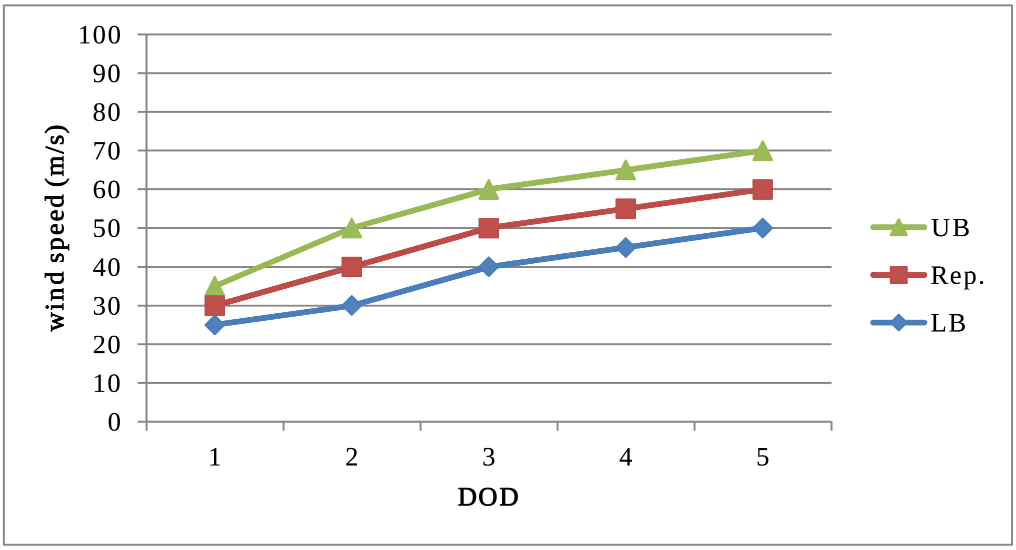
## DI = 9: Wooden livestock sheds

**[Indicators]**

Single-story wooden livestock sheds, barns

**[DOD and wind speed]**

| 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 | **40** | **30** | **50** |
| 3 | Major loss (detachment) of roofing materials | **50** | **40** | **60** |
| 4 | Destruction/detachment of roof frames | **55** | **45** | **65** |
| 5 | Major deformation/collapse of upper structures | **60** | **50** | **70** |




**[DOD example]**

DOD = 5 Major deformation/collapse of upper structures

Courtesy of National Institute for Land and Infrastructure Management (NILIM), Building Research Institute (BRI)

**[Operational guidance]**

(1) For DOD = 2 (minor loss of roofing materials), it is assumed that the damaged roof area is less than about 25% of the whole. For DOD = 3 (major loss of roofing materials), it is assumed that the damaged roof area is more than about 25% of the whole.

(2) For DOD = 4, adopt Rep. for normal damage states. Adopt LB when minor forms of damage such as breakage of beam edges are observed in damage surveying. Adopt UB when significant damage such as extensive displacement of roof frames is observed.

(3) For DOD = 5, adopt Rep. for normal damage states. Adopt LB for sheds with a large dominant opening such as an overhead door and/or inadequate load-bearing walls. Adopt UB for sheds with adequate load-bearing walls.

(4) If damaged parts or parts connected to them are obviously in a state of aging deterioration, select the wind speed one level lower than the value specified above:

- UB → Rep.
- Rep. → LB.
- LB. → LB (one DOD lower) (If the one-DOD-lower LB is the same as the LB specified above, replace it with the two-DOD-lower LB.)

**[Outline of wind speed estimation]**

Wind speeds for this DI were estimated assuming livestock sheds and barns with one-story wooden structures over a total floor area of about 90 $m^2$ with metal sheet roofing.

Methods of wind speed estimation are outlined below:

1) Maximum wind resistances of roofing materials and components for DOD = 2, 3, and 4 were estimated with reference to related past data from load tests (Kikitsu and Kawai 2009) and design standards (JMRA and JSSC 2008). The difference between minor and major loss of roofing materials was estimated from past results of experimentation using a boundary-layer wind tunnel (Okada 1988).

2) Maximum wind resistance of upper structures for DOD = 5 was estimated with reference to the story shear coefficient model (Sakata 2014), which is based on a revision of related building regulations.

3) Wind force acting on wooden buildings was calculated using instantaneous wind speed and wind force coefficients as specified in related building regulations and recommendations.

4) It was assumed that damage occurs when the wind force specified in 3) surpasses the maximum wind resistance specified in 1) or 2), and that instantaneous wind speed under such conditions was applied to the wind speed of the corresponding DOD.

**[References]**

Japan Livestock Industry Association, 2007: Guidebook for the notification and related structural design of livestock barns. (in Japanese)

Japan Metal Roofing Association, and Japanese Society of Steel Construction, 2008: Standard of Steel Roofing SSR2007. (in Japanese)

Kikitsu, H., and N. Kawai, 2009: Evaluation on wind resistance performance of roof frame in timber structure based on load tests, *J. Structural and Construction Engineering (Transactions of Architectural Institute of Japan (AIJ))*, **74** (646), 2181-2188. (in Japanese)

Kikitsu, H., T. Nakagawa, Y. Okuda, and H. Sakata, 2015: Development of Japanese Enhanced Fujita Scale, Outline of Degree of Damage and Corresponding Wind Velocity Estimation for Timber Residences, *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **40** (2), 119-120. (in Japanese)

Okada, H., 1988: Wind tunnel test on behavior of roof tiles under strong wind, *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **35**, 1-15. (in Japanese)

Sakata, H., 2014: Wind resistance of timber buildings, Proceedings of the research on development of Japanese tornado scale and related evaluation method, Tokyo Polytechnic University, 48-55. (in Japanese)

The Ministry of Land, Infrastructure, Transport and tourism (MLIT), 2002: Establishment of technical criteria necessary for ensuring safety of the structural method of specific livestock barns, Notification No.474 of MLIT. (in Japanese)

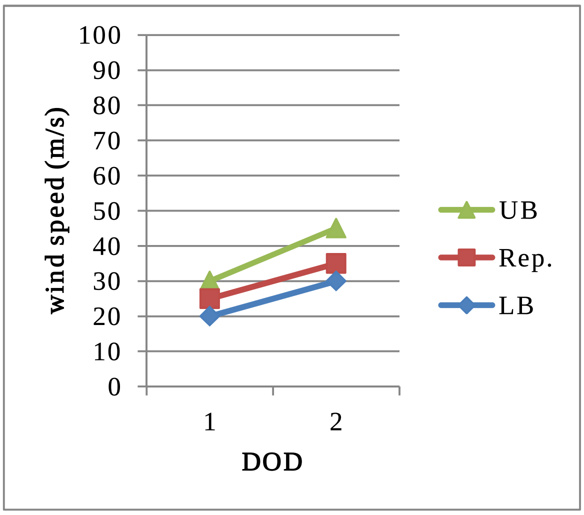
## DI = 10: Small sheds

**[Indicators]**

Prefabricated small sheds with limited connection to substructures

**[DOD and wind speed]**

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Slippage/overturning with content of 0 – 300 kg | **25** | **20** | **30** |
| 2 | Slippage/overturning with content exceeding 300 kg | **35** | **30** | **45** |




**[DOD example]**

DOD = 1 Slippage/overturning with content of 0 – 300 kg

Courtesy of Wind Engineering Research Center, Tokyo Polytechnic University

**[Operational guidance]**

(1) This DI cannot be used for prefabricated small sheds fixed with anchors, restraining cables or similar.

(2) Adopt LB for DOD = 1 if the shed is empty or close to empty, UB for DOD = 1 for contents totaling around 300 kg, and Rep. for other cases.

(3) Adopt UB for DOD = 2 if the shed is close to maximum loading capacity, and Rep. for other cases.

**[Outline of wind speed estimation]**

- Small sheds with light content [0 – 300 kg]
  Wind speeds are calculated assuming small sheds with no content or relatively light content (below 300 kg).
- Small sheds with content of medium weight or more [300 kg and above]
  Wind speeds are calculated assuming small sheds with content of 300 kg or more.

- Wind speed calculation conditions and methods are as follows:

  Based on Yoshida et al. (2015), the aerodynamic coefficients of different wind directions were examined in wind tunnel tests using a wind-force model with the geometry of a typical prefabricated small shed to determine the critical wind speed for overturning.

  Critical wind speeds for overturning and slippage were calculated based on the geometry and weight of three types of prefabricated small sheds. The minimum and maximum values among these speeds were set as LB and UB, respectively. Rep. was set from the average of all the speeds.

  The critical wind speed for slippage is the minimum value satisfying [horizontal wind speed] > [friction power] (the product of the static friction coefficient (presumed to be 0.6) and the shed weight).

  The critical wind speed for overturning is the minimum value satisfying [wind-related overturning moment at the base on the leeward side of the shed] > [remainder of resistance moment from total weight at the base on the leeward side of the shed reduced by vertical wind force].

**[References]**

Yoshida, A., et al., 2015: Development of Japanese Enhanced Fujita Scale -DOD of non-residential structure- [vehicle, container and vending machine]. *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **40** (2), 123-124. (in Japanese)

## DI = 11: Shipping containers

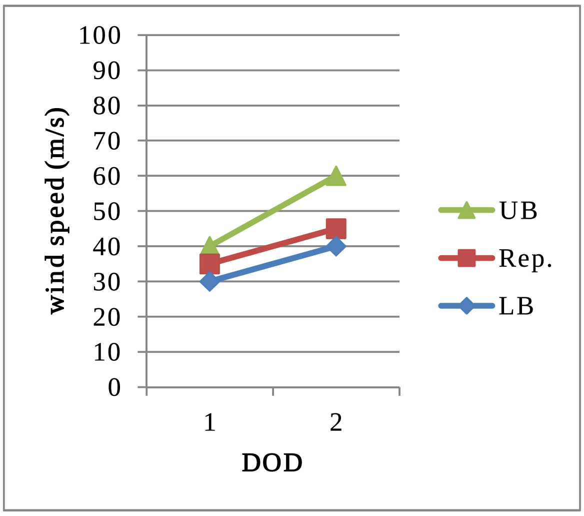
**[Indicators]**

20-foot containers for domestic use

Containers for freight trains

**[DOD and wind speed]**

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Slippage/overturning with content of 0 – 300 kg | **35** | **30** | **40** |
| 2 | Slippage/overturning with content exceeding 300 kg | **45** | **40** | **60** |




**[DOD example]**

DOD = 1 Slippage/overturning with content of 0 – 300 kg

Container slippage (left) and overturning (right)

Courtesy of Wind Engineering Research Center, Tokyo Polytechnic University

**[Operational guidance]**

(1) This DI cannot be used for containers fixed to the ground surface with anchors, restraining cables or similar.

(2) Adopt LB for each DOD for damaged 40-foot containers.

(3) Adopt LB for DOD = 1 if the container is empty or close to empty, UB for DOD = 1 for contents totaling around 300 kg, and Rep. for other cases.

(4) Adopt UB for DOD = 2 for containers with heavy contents (e.g., farm equipment such as cultivators) and Rep. for other cases

**[Outline of wind speed estimation]**

- Containers with light content [0 – 300 kg]

  Wind speeds are calculated assuming containers with no content or relatively light content (below 300 kg).

- Containers with content of medium weight or more [300 kg and above]

  Wind speeds are calculated assuming containers with content of 300 kg or more. Assumed medium-weight contents include farm equipment such as cultivators.

- Wind speed calculation conditions and methods are as follows:

  Based on Yoshida et al. (2015), the aerodynamic coefficients of different wind directions were examined in wind tunnel tests using a wind-force model with the geometry of a typical distribution container (20-foot units and freight train units) to determine the critical wind speed for overturning.

  Critical wind speeds for overturning and slippage were calculated based on total weight (i.e., empty weight and load weight). The minimum and maximum values among these speeds were set as LB and UB, respectively. Rep. was set from the average of all the speeds.

  The critical wind speed for slippage is the minimum value satisfying [horizontal wind speed] > [friction power] (the product of the static friction coefficient (presumed to be 0.6) and the container weight).

  The critical wind speed for overturning is the minimum value satisfying [wind-related overturning moment at the base on the leeward side of the container] > [remainder of resistance moment by total weight at the base on the leeward side of the container reduced by vertical wind force].

**[References]**

Yoshida, A., et al., 2015: Development of Japanese Enhanced Fujita Scale -DOD of non-residential structure- [vehicle, container and vending machine]. *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **40** (2), 123-124. (in Japanese)

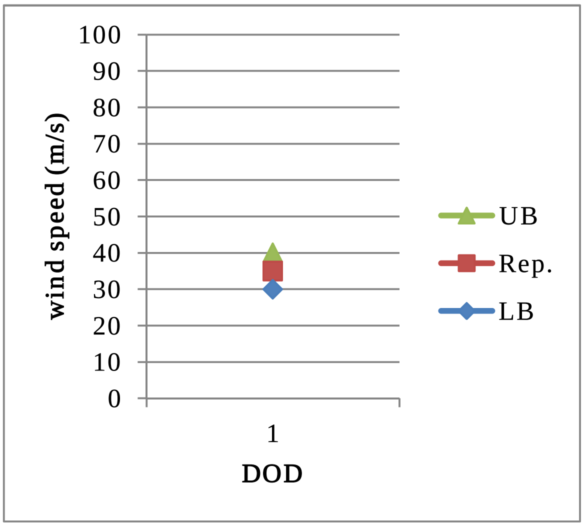
## DI = 12: Vending machines

**[Indicators]**

Non-anchored vending machines

**[DOD and wind speed]**

| DOD | Damage | Wind speed（m/s） | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Overturning | **35** | **30** | **40** |




**[DOD example]**

DOD = 1　Overturning

Courtesy of Wind Engineering Research Center, Tokyo Polytechnic University

**[Operational guidance]**

(1) This DI is applicable to vending machines not fixed to the ground surface. It cannot be used for vending machines fixed with anchor bolts.

(2) Wind speeds vary with content volume; adopt Rep. if content volume is unknown. Adopt LB if content volume is near zero and UB for fully loaded units.

**[Outline of wind speed estimation]**

- Based on Yoshida et al. (2015), the aerodynamic coefficients of different wind directions were examined in wind tunnel tests using three wind-force models with the geometry of a typical vending machine to determine the critical wind speed for overturning.
- Critical wind speeds for overturning were calculated based on the total weight (i.e., empty weight and full load weight). The minimum and maximum values among these speeds were set as LB and UB, respectively. Rep. was set from the average of all the speeds.
- The critical wind speed for overturning is the minimum value satisfying [wind-related overturning moment at the base on the leeward side of the vending machine (if there are concrete blocks, the moment at its tip)] > [remainder of resistance moment by total weight at the base on the leeward side of the vending machine reduced by vertical wind force].

**[References]**

Yoshida, A., et al., 2015: Development of Japanese Enhanced Fujita Scale -DOD of non-residential structure- [vehicle, container and vending machine]. *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **40** (2), 123-124. (in Japanese)

## DI = 13: Light vehicles

**[Indicators]**

Lightweight trucks or light minivans

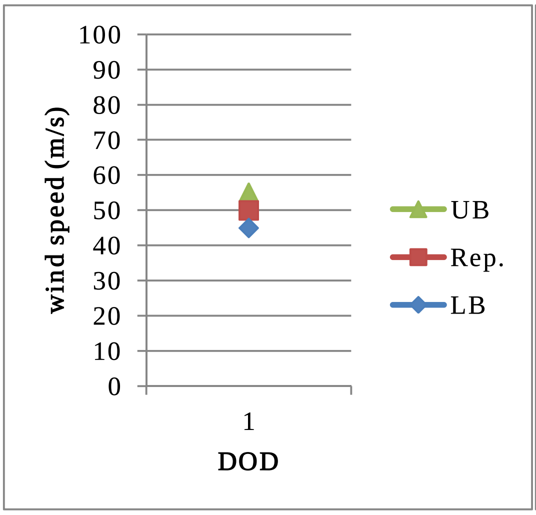
**[DOD and wind speed]**

Lightweight trucks without hoods

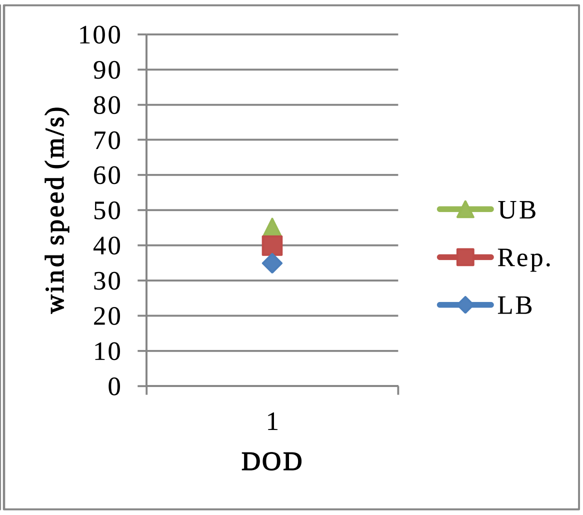
| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Overturning | **50** | **45** | **55** |

Light minivans, lightweight trucks with hoods

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Overturning | **40** | **35** | **45** |




Lightweight trucks without hoods




Light minivans, lightweight trucks with hoods

**[Operational guidance]**

(1) Adopt LB in cases of overturning with no load or almost no load while the vehicle is stationary, and in cases where it is being driven. Load weight includes occupants' weight.

(2) Adopt Rep. in cases where the vehicle is stationary and has a typical load (approx. 60 kg).

(3) Adopt UB in cases where the vehicle is stationary and has a heavy load (more than approx. 60 kg).

(4) Adopt Rep. in cases where it is difficult to determine the above conditions.

**[Outline of wind speed estimation]**

- Based on Yoshida et al. (2015), the aerodynamic coefficients of a stationary vehicle from different wind directions were examined in wind tunnel tests using a vehicle wind-force model. The critical wind speed for overturning was calculated from the balance of overturning moment and resistance moment.
- Wind speeds were calculated for a vehicle with no load and one with a passenger (60 kg load).
- For lightweight trucks, critical wind speeds for overturning were calculated using specifications such as full length/width/height and the weight of an eight-car series as basic data. The critical wind speed calculated for the typical weight was set as Rep. LB and UB were set in consideration of load differences in the eight-car series.
- The calculation method using the specifications of the eight-car series was also applied for vans.
- As the critical wind speed for overturning while being driven is lower than that for a stationary state, adopt LB for overturning during operation.

**[References]**

Yoshida, A., et al., 2015: Development of Japanese Enhanced Fujita Scale -DOD of non-residential structure- [vehicle, container and vending machine]. *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **40** (2), 123-124. (in Japanese)

# DI = 14: Ordinary vehicles

**[Indicators]**

Ordinary cars (sedans, station wagons or SUVs)

Minivans or minibuses

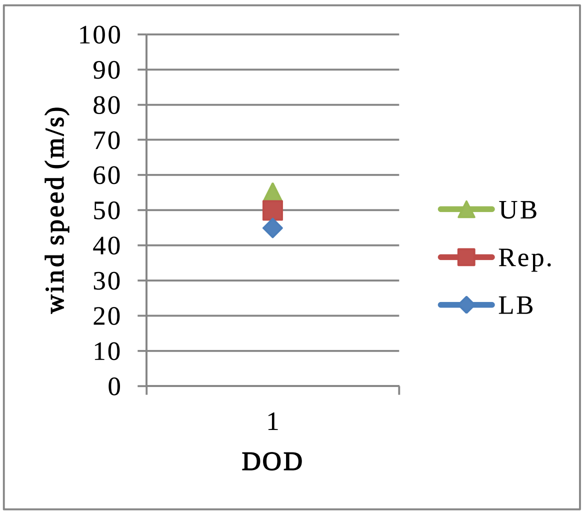
**[DOD and wind speed]**

Ordinary cars

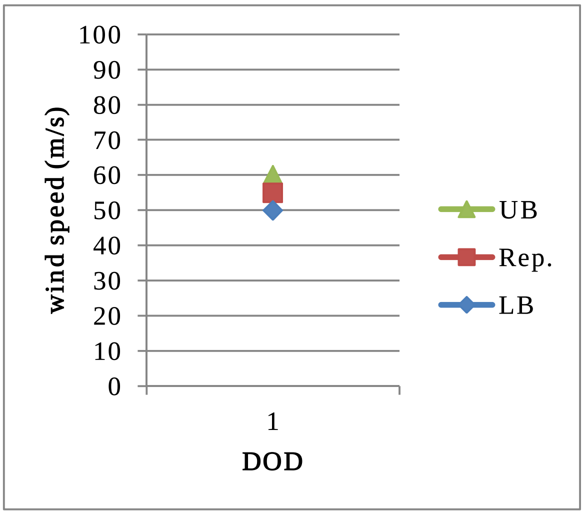
| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | Rep. | LB | UB |
| 1 | Overturning | 50 | 45 | 55 |

Minivans, minibuses

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | Rep. | LB | UB |
| 1 | Overturning | 55 | 50 | 60 |




Ordinary cars




Minivans, minibuses

**[DOD example]**

DOD = 1 Overturning (Vans)

Courtesy of Ishigaki City Office

**[Operational guidance]**

(1) Adopt LB in cases of overturning with no load or almost no load while the vehicle is stationary and in cases where it is being driven, but Rep. for sedans. Load weight includes occupants' weight.

(2) Adopt Rep. in cases where the vehicle is stationary and has a typical load (approx. 60 kg), but UB for sedans.

(3) Adopt UB in cases where the vehicle is stationary and has a heavy load (more than approx. 60 kg).

(4) Adopt Rep. in cases where it is difficult to determine the above conditions.

**[Outline of wind speed estimation]**

- Based on Yoshida et al. (2015), the aerodynamic coefficients of a stationary vehicle from different wind directions were examined in wind tunnel tests using a vehicle wind-force model. The critical wind speed for overturning was calculated from the balance of overturning moment and resistance moment.
- Wind speeds were calculated for a vehicle with no load and one with a passenger (60 kg load).
- For ordinary cars, critical wind speeds for overturning were calculated using specifications such as full length/width/height and the vehicle weight of an eight-car series as basic data. The critical wind speed calculated for the typical weight was set as Rep. LB and UB were set in consideration of load differences in the eight-car series.
- The calculation method using the specifications of a three-car series was also applied for minivans and minibuses.
- Since the critical wind speed for overturning while being driven is lower than that for a stationary state, adopt LB for overturning during operation.

**[References]**

Yoshida, A., et al., 2015: Development of Japanese Enhanced Fujita Scale -DOD of non-residential structure- [vehicle, container and vending machine]. *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **40** (2), 123-124. (in Japanese)

## DI = 15: Large vehicles

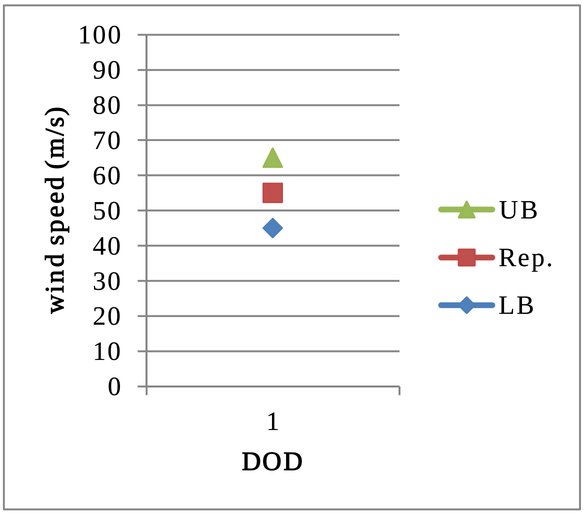
**[Indicators]**

Truck with hood

Buses

**[DOD and wind speed]**

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | Rep. | LB | UB |
| 1 | Overturning | **55** | **45** | **65** |




**[Operational guidance]**

(1) Adopt LB in cases of overturning with no load, almost no load or while being driven.

(2) Adopt UB in cases where the positional relationship between the wind direction and the car body is clear, and the wind direction is significantly off (more than 45°) from the orthogonal direction of the axle (cross wind).

(3) Adopt UB in cases where the vehicle is stationary and has a heavy load (more than approx. 1 t).

(4) Adopt Rep. for other cases and when it is difficult to determine the above conditions.

**[Outline of wind speed estimation]**

- Based on Yoshida et al. (2015), the aerodynamic coefficients of a stationary vehicle from different wind directions were examined in wind tunnel tests using a vehicle wind-force model. The critical wind speed for overturning was calculated from the balance of overturning moment and resistance moment.
- Wind speeds were calculated for a vehicle with no load and one with a passenger (1 t load).
- For trucks, critical wind speeds for overturning were calculated using specifications such as full length/width/height and the weight of a four-car series as basic data. The critical wind speeds calculated for vehicles with no load and a 1 t load were set as LB and UB, respectively. Assuming typical conditions, the

average of the critical wind speeds for the four-car series was set as Rep.

- The calculation method using the specifications of three-car series was also applied for buses.
- Since the critical wind speed for overturning while being driven is lower than that for a stationary state, adopt LB for overturning during operation.

**[References]**

Yoshida, A., et al., 2015: Development of Japanese Enhanced Fujita Scale -DOD of non-residential structure- [vehicle, container and vending machine]. *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **40** (2), 123-124. (in Japanese)

## DI = 16: Railway vehicles

**[Indicators]**

Railway vehicles under normal or restricted operation

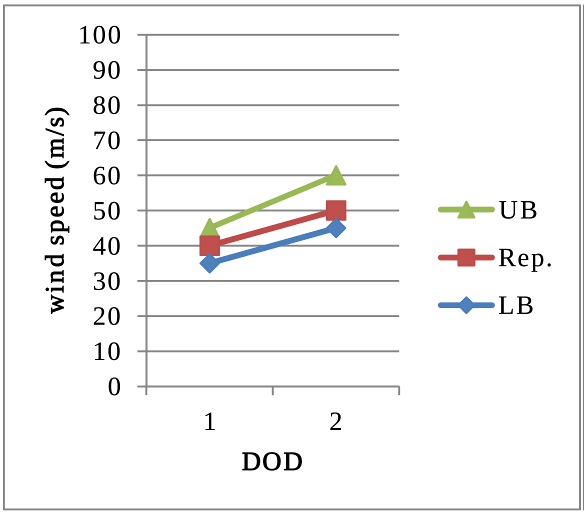
**[DOD and wind speed]**

Normal operation

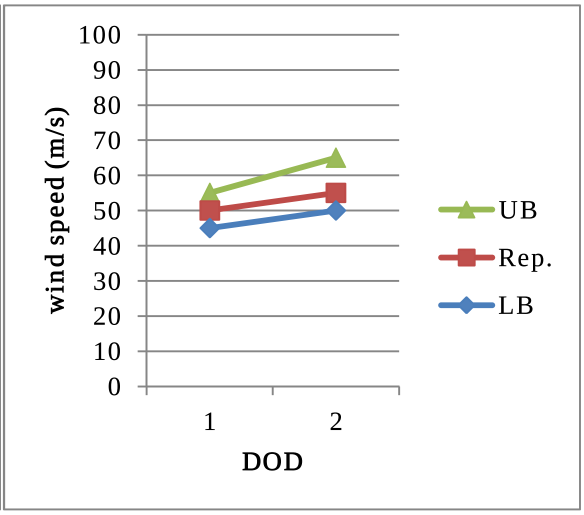
| DOD | Damage | Wind Speed (m/s) | | |
|---|---|---|---|---|
| | | Rep. | LB | UB |
| 1 | Overturning from lead vehicle | **40** | **35** | **45** |
| 2 | Overturning from non-end vehicle | **50** | **45** | **60** |

Restricted operation (less than 25 km/h)

| DOD | Damage | Wind Speed (m/s) | | |
|---|---|---|---|---|
| | | Rep. | LB | UB |
| 1 | Overturning from lead vehicle | **50** | **45** | **55** |
| 2 | Overturning from non-end vehicle | **55** | **50** | **65** |




Normal operation




Restricted operation

**[DOD example]**


DOD = 1: Overturning from lead vehicle (Restricted operation (less than 25 km/h))

Courtesy of Wind Engineering Research Center, Tokyo Polytechnic University

On September 17 2006, The Nichirin No. 9 Ltd. Exp. overturned due to a tornado in Nobeoka. While the train was running at 25 km/h, wind-borne debris was observed and the emergency brake was applied. However, just before stopping, the first and second vehicles derailed and overturned, and the front bogie of the third vehicle derailed. The wind speed was estimated as close to UB.

[**Operational guidance]**

Estimated wind speed varies with running speed, wind direction, topographic conditions and other variables.

(1) Adopt LB if the train is running on an embankment under normal operational conditions, or if it is evident that the running speed greatly exceeds 100 km/h. If the running speed is considerably less than 100 km/h (approx. 60 km/h), adopt UB. In all other cases, adopt Rep.

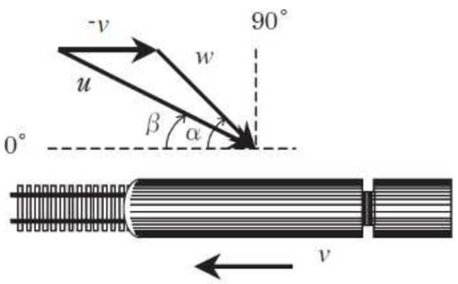
(2) For an almost stationary state, adopt UB for trains under restricted operation.

(3) Apply DOD = 2 if only a non-end vehicle overturns, or such a vehicle obviously overturns prior to the lead vehicle.

[**Outline of wind speed estimation]**

- The wind speed when a train car's wheel load on the upwind side reaches zero is called the critical overturning wind speed. The RTRI Detailed Method is proposed for calculation of this speed. This approach reflects expertise and information from train overturn accidents (ARAIC 2008 a; ARAIC 2008 b) and recent research based on wind tunnel experiments (Hibino and Ishida 2003; Hibino et al. 2009; Hibino et al. 2011; Moriyama 2011; Moriyama 2012; Kurihara et al. 2013).

- Critical overturning wind speed is affected by (1) vehicle shape, (2) vehicle weight, (3) vehicle gravity center height, (4) lead vehicle or middle vehicle, (5) shapes of ground structures such as windbreak fences, embankments, (6) running speed, (7) wind direction, and other variables. These factors should be considered in estimation.
- Estimations of the above wind speeds corresponding to DODs for normal and restricted operation at running speeds of less than 25 km/h were based on the RTRI Detailed Method under the conditions of a common vehicle shape, running on flatland at various speeds, and assumption of the most unfavorable wind direction (the relative wind direction $\beta$ to the running vehicle is 70 – 90 degrees for the lead vehicle and 90 degrees for middle vehicles).




$v$: running speed
$w$: wind speed
$\alpha$: wind direction
$u$: relative wind speed
$\beta$: relative wind direction

Wind acting on a running vehicle (Hibino and Ishida 2003)

[**References]**

ARAIC, 2008a: Railway accident investigation report on overturning accident between Sagoshi Station and Kita Amarume Station on Uetsu Line of East Japan Railway Company. *Aircraft and Railway Accidents Investigation Commission, RA2008-4, April 2, 2008* (Accident date: December 25, 2005, Shonai-cho, Yamagata Pref.). (in Japanese)

ARAIC, 2008b: Railway accident investigation report on overturning accident in Minami Nobeoka Station on Nippo Line of Kyushu Railway Company. *Aircraft and Railway Accidents Investigation Commission, RA2008-6-1, April 2, 2008* (Accident date: September 17, 2006, Nobeoka City, Miyazaki Pref.). (in Japanese)

Hibino, Y., and H. Ishida, 2003: Static analysis on railway vehicle overturning under crosswind. *Railway Technical Research Institute (RTRI) Report*, **17** (4), Special Features, 39-44. (in Japanese)

Hibino, Y., T. Shimomura, and K. Tanifuji, 2009: Verification of static analysis on railway vehicle overturning under crosswind. *Transactions of the Japanese Society of Mechanical Engineers (JSME)*, **75** (758), 1-8 (2605-2612). (in Japanese)

Hibino, Y., Y. Misu, T. Kurihara, A. Moriyama, and M. Shimamura, 2011: Examination of new operation control method for strong wind events. *Japan Railway (JR) East Technical Review*, **35**, Special Edition Paper, 36-41. (in Japanese)

Kurihara, Y., A. Oyama, K. Doi, and Y. Yasuda, 2013: Introduction of new train operation control method for strong wind events. *JR East Technical Review*, **45**, Special Edition Paper, 17-22. (in Japanese)

Moriyama, A., 2011: Verification of railway vehicle overturning under crosswind by field data (Measurement results at the Japan Sea coast main line in winter). *Transagtion of JSME. (Ser. C)*, **77** (778), 221-231 (2389-2399). (in Japanese)

Moriyama, A., 2012: Verification of railway vehicle overturning under crosswind by field data (An effect of the cross-sectional shape of vehicles). *Transaction of JSME (Ser. C)*, **78** (791), 182-194 (2536-2548). (in Japanese)

## DI = 17: RC utility poles

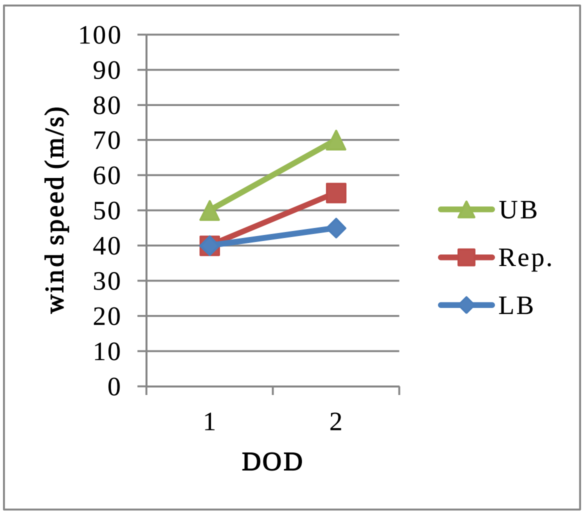
**[Indicators]**

RC utility power poles

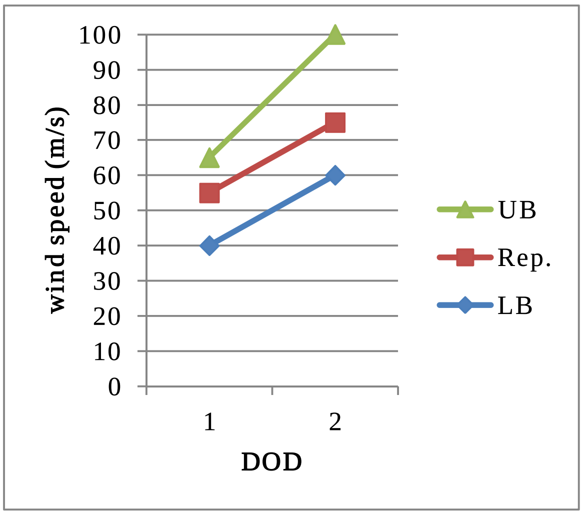
**[DOD and wind speed]**

| DOD | Damage | | Wind speed (m/s) | | |
|---|---|---|---|---|---|
| | | | **Rep.** | **LB** | **UB** |
| 1 | Cracking at base part | AA × CC ≤ 100 | **40** | **40** | **50** |
| | | AA × CC > 100 | **55** | **40** | **65** |
| 2 | Breakage at base part | AA × CC ≤ 100 | **55** | **45** | **70** |
| | | AA × CC > 100 | **75** | **60** | **100** |

AA: length (m); CC: cracking load (kN)




AA×CC≦100




AA×CC＞100

**[DOD example]**

DOD = 2 Breakage at base part

Courtesy of Institute of Technology and Science, Tokushima University

**[Operational guidance]**

1) The length AA (m), top diameter BB (cm) and cracking load CC (kN) are indicated with a form such as AA-BB-CC on circular tags on RC utility power poles. If the CC is larger than 100, divide the value by 98 for conversion from kgf to kN.

2) This DI cannot be used when the pole is not damaged at the base part or is damaged by wind-borne debris.

3) At the damage site, record the parameters AA and CC of the damaged pole from the circular tag and the form of destruction (such as cracking or breakage) at the base part to rate wind speed based on the corresponding DOD. If the tag indication is illegible, apply AA × CC ≤ 100.

4) Adopt Rep. for the typical condition of poles with one or two groups of three horizontally parallel transmission lines and a communication line. Adopt UB for poles with one or a few lines around their top. Adopt LB for poles with multiple lines (more than three columns) or additional equipment such as power transformers.

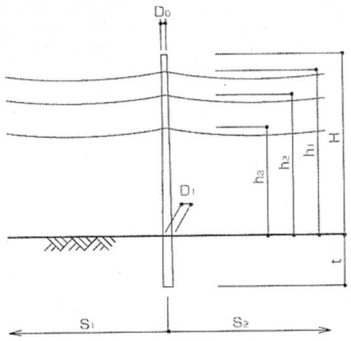
**[Outline of wind speed estimation]**

- It is assumed that poles with one or two columns for three horizontally parallel transmission lines and a communication line are affected by wind normal to the lines.
- Rep. was estimated with the assumption of no additional equipment such as transformers.

**[Calculation of strength for the wind load normal to the transmission lines against an RC utility power pole]**

Poles on straight lines are assumed.

$$\frac{(H-0.25)P}{f} \geq K_1 \frac{(2D_0+D_1)H^2}{6} + K_2 S\left(\sum d_n h_n\right)$$




where

$P$: breakage strength (cracking load x 2) (kN)

$K_1$: wind load acting on pole for unit projection area (Pa)

$K_2$: wind load acting on transmission lines for unit projection area (Pa)

$D_0$: top diameter of RC utility pole (m)

$D_1$: bottom diameter of RC utility pole (m)

$H$: length of RC utility pole (m)

$S$: half sum of span of both sides

$d_n$: diameter of transmission lines (m) (approx. 20 mm including cover)

$h_n$: height of transmission line array (m)

$f$: safety factor (1.0 for RC utility poles)

Wind load $K$ for *ko-shu* type

| Types affected by wind load | | $K$ (Pa) | Corresponding $C_D$ |
|---|---|---|---|
| RC poles | Circular type | 780 | 0.81 |
| Transmission and other lines | Multiple conductor | 880 | 0.92 |
| | Others | 980 | 1.02 |

- The critical cracking wind speeds for poles with one groups of three horizontally parallel transmission lines (at $h = H - 0.25\,(\mathrm{m})$) and a communication line (at $h = 5.5\,(\mathrm{m})$ with a diameter of 30 mm) are determined using

$$U_{crack} > \sqrt{\frac{2M_{crack}}{\rho\left(C_{D,pipe}\frac{(2D_0+D_1)H^2}{6} + 3C_{D,cable}d_1 S(H-0.25) + C_{D,cable}d_2 S \times 5.5\right)}}$$

- The critical cracking wind speeds for poles with two groups of three horizontally parallel transmission lines (the first and second columns at $h_1 = H - 0.25\,(\mathrm{m})$ and $h_2 = 0.5h_1 + 2.75\,(\mathrm{m})$, respectively) and a communication line (at $h = 5.5\,(\mathrm{m})$ with a diameter of 30 mm) are determined using

$$U_{crack} > \sqrt{\frac{2M_{crack}}{\rho\left(C_{D,pipe}\frac{(2D_0+D_1)H^2}{6} + 3C_{D,cable}d_1 S\{1.5(H-0.25)+2.75\} + C_{D,cable}d_2 S \times 5.5\right)}}$$

The standard deviations of these critical wind speeds from differences of typical standards for RC utility poles are determined for AA × CC $\leq$ 100 and AA × CC > 100, respectively.

The critical wind speed for breakage at the base part is $\sqrt{2}$ times of that for cracking at the base part because breakage strength is defined as twice the cracking load.

**[References]**

Japan Electro-technical Standards and Codes Committee, 2000: JEAC7001-1999Power Distribution Code. The Japan Electric Association. (in Japanese)

Ministry of Economy, Trade and Industry, 2012: Ministry of International Trade and Industry Ordinance No.52. (in Japanese)

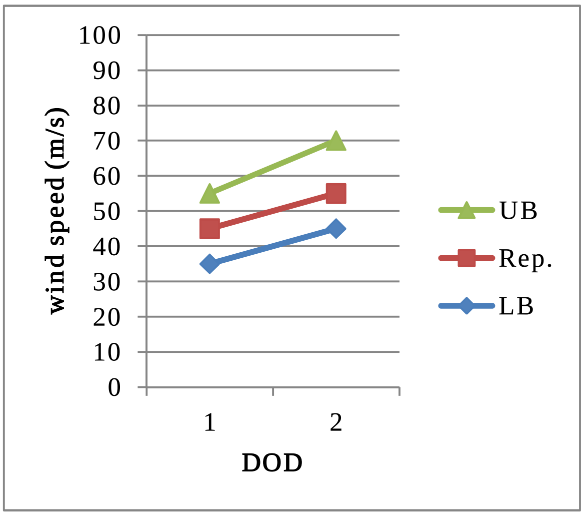
## DI = 18: Ground-based billboards

**[Indicators]**

Billboards are defined as ground-based structures with two pillars, a width of approx. 3 m and a height of approx. 2 m.

**[DOD and wind speed]**

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Inclination, local buckling of pillars | **45** | **35** | **55** |
| 2 | Collapse | **55** | **45** | **70** |




**[DOD example]**

DOD = 2 Collapse

Courtesy of Tokyo Polytechnic University

[**Operational guidance]**

(1) This DI is applicable to ground-based billboards with two steel pillars.

(2) This DI cannot be used for billboards overturning from the foundation because wind speed cannot be evaluated accurately.

(3) Only billboards with square sectional steel pillars can be considered.

(4) Adopt LB for pillars with peeling paint and rusting at the base.

[**Outline of wind speed estimation]**

1 Calculation conditions

The calculation conditions are as proposed by Okada et. al (2005). The basic configuration is shown in the figure on the right. The critical wind speeds for both inclination and collapse are calculated in assumption of standard-size billboards with reference to sample field measurement:

Billboard width = 3 m

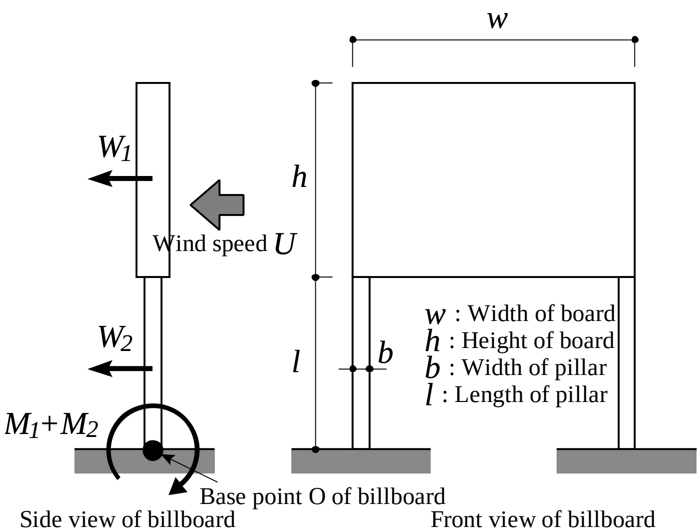
Billboard height = 2 m

Pillar width = 0.1 m

Pillar length = 2 m

Pillar count = 2

The pillar width *t* is set as 3.2 mm with reference to square sectional steel specifications.




2 Calculation of overturning moment at the billboard base and wind speed corresponding to typical steel strength

The wind load and overturning moment at the base point O of the billboard are estimated via procedures (1) to (4) in Okada et al. (2015). Instantaneous wind speed for billboard inclination can be estimated if the steel yield strength is given. Instantaneous wind speed for billboard collapse can be estimated if the steel tensile strength is given.

3 Estimation of wind speeds for each DOD

- DOD = 1: inclination, local buckling of pillars

  The variation in steel yield strength is around 1 to 1.45 times higher and the mean value of the variation is about 1.2 times higher. As the critical wind speed for inclination is proportional to the square root of steel yield strength, Rep. was calculated as 1.1 times higher than $\hat{U}_{cr}$ (Aoki and Murata 1984; Aoki and Masuda 1985; Toyama et al. 2012; AIJ 2009).

  Adopt LB when the strength of the pillar base is reduced due to rust. LB is 15% less than Rep. in assumption of partial loss caused by rust approx. 0.5 mm deep from the surface of the steel pillar.

UB is set as 10 to 25% higher than Rep. in assumption of pillar specifications such as depth or width as one rank higher. Wind speed values determined as above are rounded to multiples of 5 m/s as speeds for DOD = 1.

- DOD = 2: collapse

  The mean tensile strength variation of steel is 1.1 times higher than the standard strength, and the standard deviation of the variation is around 5 to 10%. Although the critical wind speed for collapse is proportional to the square root of steel tensile strength, Rep. was calculated as 1.05 times higher than the critical wind speed $\hat{U}_{cr}$ in consideration of estimation accuracy. LB and UB were estimated in the same way as DOD = 1.

[**References]**


AIJ, 2009: Recommendations for stability design of steel structure. (in Japanese)

Aoki, H., and K. Murata, 1984: Statistical study on yield point, tensile strength and yield ratio of structural steel, *J. Structural and Construction Engineering (Transactions of Architectural Institute of Japan (AIJ))*, **335**, 157-168. (in Japanese)

Aoki, H., and M. Masuda, 1985: Statistical investigation on mechanical properties of structural steel based on coupon tests, *J. Structural and Construction Engineering (Transactions of AIJ)*, **358**, 94-105. (in Japanese)

Okada, R., et. al., 2015: Development of Japanese Enhanced Fujita Scale -DOD of non-residential structure**-** [sign board and grave stone], *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **40** (2), 125-126. (in Japanese)

Toyama, K., M. Matsuda, and T. Yamada, 2012: Statistical research on mechanical properties of steel by tensile tests results, *Summary paper for AIJ annual meeting*, 1087-1088. (in Japanese)

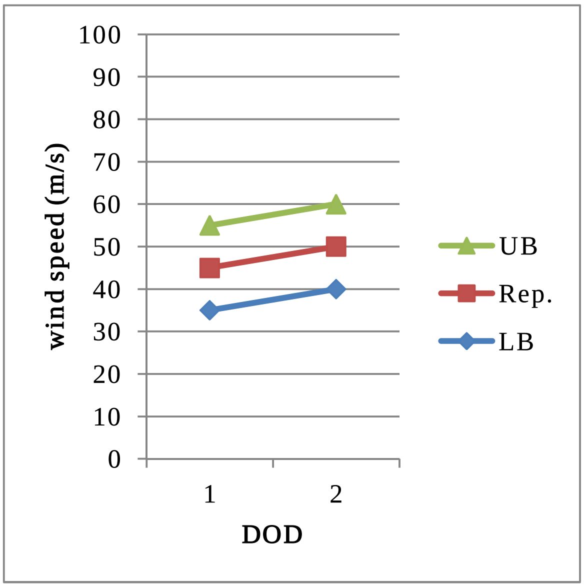
# DI = 19: Traffic signs

**[Indicators]**

Roadside traffic signs

**[DOD and wind speed]**

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | Rep. | LB | UB |
| 1 | Pillar inclination | 45 | 35 | 55 |
| 2 | Pillar collapse | 50 | 40 | 60 |




**[DOD example]**


| DOD = 1 Pillar inclination | DOD = 2 Pillar collapse |
|---|---|
| Courtesy of Wind Engineering Research Center, Tokyo Polytechnic University | Apply DOD = 2 when the breaking point is partially buckled, even if inclination is slighter than in this example.<br>Courtesy of Wind Engineering Research Center, Tokyo Polytechnic University |

**[Operational guidance]**

(1) If damage is obviously due to impact from wind-borne debris, pillar damage cannot be used as a damage indicator.

(2) This DI is applicable to roadside traffic signs. Other types such as cantilever/overhang models and road information delivery devices cannot be used as damage indicators.

(3) Adopt LB for pillars with rust at the base in consideration of cross-section reduction.

(4) Adopt UB when the positional relationship between the wind direction and the sign is clear and the wind direction is significantly off (more than 45°) from the direction perpendicular to the sign.

(5) Adopt Rep. for conditions other than (3) and (4).

**[Outline of wind speed estimation]**

- Roadside traffic signs with heights of 1.8 – 2.6 m are assumed for wind speed calculation.
- The critical collapse wind speed was calculated based on the conditions and assumptions indicated by Yoshida et al. (2007). Wind speeds in this DI are calculated from 20 typical sign types with several heights, shapes, numbers and pillar diameters.
- DOD is classified as 1 for pillar inclination with visible residual deformation and 2 for pillar collapse with pole bases partially buckled. Corresponding wind speeds for each DOD are calculated from the balance between wind-related stress applied to the pillar base and the pillar's yield strength (DOD = 1) or tensile strength (DOD = 2) . These speeds are calculated in consideration of variations in yield strength and tensile strength.

**[References]**


AIJ, 2009: Recommendations for Stability Design of Steel Structures. (in Japanese)

Aoki, H., and M. Masuda, 1985: Statistical Investigation on Mechanical Properties of Structural Steel Based on Coupon Tests. *Transactions of the Architectural Institute of Japan (AIJ)*, **358**, 94-105. (in Japanese)

Aoki, H., and K. Murata, 1984: Statistical Study on Yield Point, Tensile Strength and Yield Ratio of Structural Steel. *Transactions of the Architectural Institute of Japan*, **335**, 157-168. (in Japanese)

Toyama T., M. Matsuda, and T. Yamada, 2012: Statistical Research on Mechanical Properties of Steel by Tensile Tests Results. *Summaries of technical papers of annual meeting AIJ*, 1087-1088. (in Japanese)

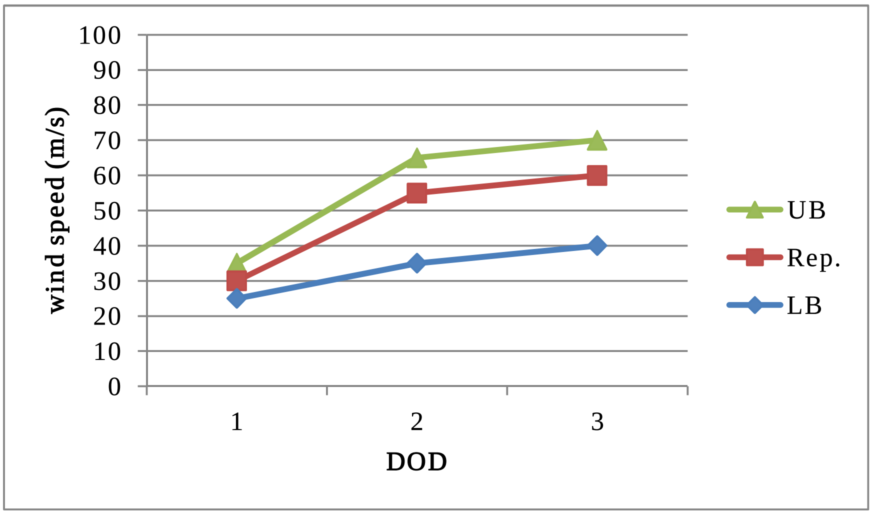
Yoshida, A., and Y. Tamura, 2007: Basic study for wind speed estimation based on damaged road sign. *Japan Association for Wind Engineering*, **32** (2), 147-148. (in Japanese)

# DI = 20: Carports

**[Indicators]**

Cantilevered carports made of cast aluminum

| DOD | Damage | Wind Speed (m/s) | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Debris-related destruction of roofing panels | **30** | **25** | **35** |
| 2 | Wind-related inclination of frames | **55** | **35** | **65** |
| 3 | Wind-related destruction of frames | **60** | **40** | **70** |




**[DOD example]**

DOD = 1 Debris-related destruction of roofing panels

Courtesy of Wind Engineering Research Center, Tokyo Polytechnic University

DOD = 2 Wind-related inclination of frames

(Application of UB to a three-column cantilevered carport without walls)

Courtesy of Institute of Technology and Science, Tokushima University

**[Operational guidance]**

(1) For DOD = 2 and 3, only cantilevered carports are applicable, and carports supported from both sides cannot be used as damage indicators. The wind speed value depends on the carport constitution as listed below. For carports whose shape cannot be classified, adopt Rep.

LB: two-column cantilevered carports with walls

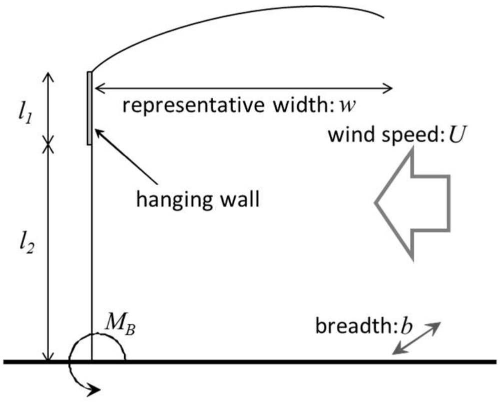
Rep.: three-column cantilevered carports with walls or two-column cantilevered carports without walls

UB: three-column cantilevered carports without walls

(2) When it is unclear whether damage was caused by wind or by wind-borne debris, assume damage from wind-borne debris and apply DOD = 1.

**[Outline of wind speed estimation]**

- DOD = 1 (debris-related destruction of roofing panels) is based on DOD = 1 (visible minor damage; breakage of glass) for DI = 3 RC apartment buildings.
- Bending stress at column bases, which generally deform prior to other parts, was considered in wind speed estimation. Wind speeds producing representative bending stresses for inclination and destruction are for DOD = 2 and DOD = 3, respectively (see "Estimation of wind speeds for DOD = 2 and 3" below). Carports with roof only, roof + hanging wall, and roof + total wall were assumed for comprehensive evaluation of wind speeds for DODs.




- Based on wind tunnel tests, wind for estimation is considered to blow in the direction that generally produces the most effective load against the carport (see the figure on the right).
- The Japan Exterior Industrial Association published its Technical Standards for Aluminum Carports , and these have been applied since 2006 to ensure correspondence between JIS-compliant carports and related laws. Force coefficients were determined by applying fundamental data from the Technical Standards for Aluminum Carport to Uematsu (2001).

**[Estimation of wind speeds for DOD = 2 and 3]**

Wind speeds were calculated as outlined below. Carport dimensions of 3 m in width, 5.7 m from front to back, and 2.7 m in total wall height $l_1 + l_2$ with 0.5 m of hanging wall are assumed.

1. Moment caused by wind load

Based on the results of wind tunnel tests, the equivalent roof force coefficients were assumed to be within $C_{fr} = -0.6$ to $-1.8$ for calculation of the corresponding moments $M_B$, which give the wind speed range (UB and LB), because the estimated wind speed depends on the roof shape. The equivalent force coefficients for hanging walls ($C_{fw1}$) and total walls ($C_{wf2}$) were assumed to be $C_{fw1} = C_{fw2} = -1.4$

2. Strength of column base (section modulus)

The plastic section modulus $Z_p$ was calculated to allow estimation of critical wind speeds for support inclination and carport destruction. Supports are assumed to be aluminum pipes.

3. Calculation of critical wind speed

Using the moment from step 1, the plastic section modulus from step 2, offset yield stress (corresponding to 0.2% plastic strain) $\sigma_{0.2}$ and tensile strength $\sigma_u$, critical wind speeds for inclination and destruction were calculated. In the calculation, supports were assumed to have an extruded section made of high-strength aluminum.

**[References]**

Japanese Industrial Standards, 2006: Aluminium and aluminium alloy extruded profiles, JIS H 4100:2006. (in Japanese)

Uematsu, Y., 2001: Report of wind tunnel experiment on design wind stress of aluminum carports, New Industry Creation Hatchery Center, Tohoku University. (in Japanese)

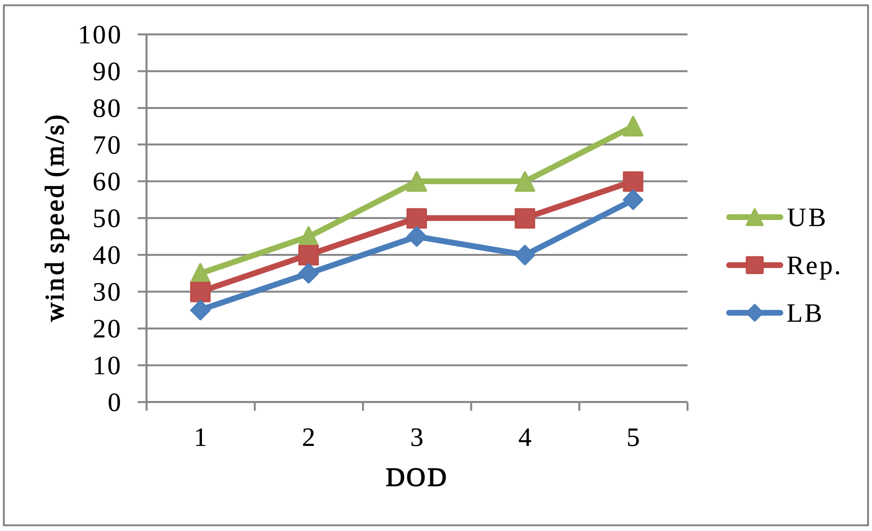
## DI = 21: Hollow concrete block (HCB) walls

**[Indicators]**

Reinforced or unreinforced hollow concrete block (HCB) walls with/without buttresses

**[DOD and wind speed]**

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Unreinforced: partial or complete destruction | **30** | **25** | **35** |
| 2 | Reinforced without buttresses or side walls: minor collapse | **40** | **35** | **45** |
| 3 | Reinforced without buttresses or side walls: major collapse | **50** | **45** | **60** |
| 4 | Reinforced with buttresses or side walls: minor collapse | **50** | **40** | **60** |
| 5 | Reinforced with buttresses or side walls: major collapse | **60** | **55** | **75** |




**[DOD example]**

| |
|---|
| DOD = 1 Unreinforced: partial or complete destruction<br>(As the block was type-C and less than 150 mm thick, LB was adopted.)<br>Courtesy of National Institute for Land and Infrastructure Management, The Building Research Institute |

**[Operational guidance]**

(1) Check whether the block wall has reinforcing bars, buttresses and fall directions (to the buttress side or the other side).

(2) The recommendations require buttresses at intervals of less than 3.4 if the wall is higher than 1.2 m. If this requirement is not satisfied, adopt DOD = 2 or DOD = 3.

(3) Check the concrete block type. If this cannot be determined, assume type C.

(4) When DOD = 1:

- If the block type is A or B, adopt LB.
- If the block type is C and its thickness is less than 150 mm, adopt LB.
- If the block type is C and its thickness is 150 mm, adopt Rep.
- If the block type is C and its thickness is more than 150 mm, adopt UB.

(5) When DOD = 2 to 5:

- If the block type is A or B, or if degradation such as rust is found in blocks or reinforcing bars, adopt LB.
- If the block type is C, there is no degradation in blocks or reinforcing bars, and the block thickness is less than 150 mm, adopt LB.
- If the block type is C, there is no degradation in blocks or reinforcing bars, and the block thickness is 150 mm, adopt Rep.
- If the block type is C, there is no degradation in blocks or reinforcing bars, and the block thickness is more than 150 mm, adopt UB.

(6) Blocks damaged by wind-borne debris cannot be used as damage indicators.

(7) Walls with damage at the base cannot be used as damage indicators due to the uncertainty of the ground condition near the surface.

- Concrete block types

The three types of hollow concrete blocks (HCB) in Japan are referred to as A, B and C. Their compositions show differences in density, water absorption rate, compressive strength and other variables. The nominal design compressive strengths for the three types are 8, 12 and 16 N/mm2, respectively. Hollow concrete block walls are generally made of type-C blocks.

**[Outline of wind speed estimation]**

- Wind speeds for each DOD are evaluated as the minimum values satisfying [Wind load] > [Allowable strength].
- The upper-limit value of allowable strength is estimated by methods such as evaluation for the plastic

moments of components. If such evaluation is impractical, the upper value is determined on the assumption that the actual strength is 110% of the nominal value.

- Directional wind force coefficients are evaluated. The maximum directional value is adopted for wind speed evaluation.
- The strength of reinforced hollow concrete block walls is evaluated with reference to the procedure proposed in Structural Design Notes for Various Reinforced Masonry Buildings (AIJ 2009) and experimental results reported by Shiga and Komura (1964). This evaluation was based on walls with reinforcing bars set vertically at intervals of less than 800 mm.
- It is assumed that wind loads are uniformly distributed near the ground and that ground roughness is category III as stipulated in the AIJ Recommendations for Loads on Buildings. Stress distribution is considered to be that observed in a rectangular flat plate with three clamped edges and one free edge. LB wind speeds were evaluated from specifications of wall height = 1.8 m, block type = C, thickness = 120 mm and buttress interval = 3.4 m; UB wind speeds were evaluated from specifications of wall height = 1.8 m, block type = C, thickness = 190 mm and buttress interval 3.4 m; and Rep. wind speeds were evaluated from specifications of wall height = 1.8 m, block type = C, thickness = 150 mm and buttress interval = 3.4 m.
- Unreinforced block wall strength was calculated with reference to Shiga (1964).

**[References]**

Architectural Institute of Japan (AIJ), 2009: Structural Design Notes for Various Reinforced Masonry Buildings. (in Japanese)

Shiga, T., and S. Komura, 1964: Seismic strength of concrete block walls, Part 2, Proceedings of AIJ Tohoku Chapter, *Architectural Research Meeting*, **3**, 21-24. (in Japanese)

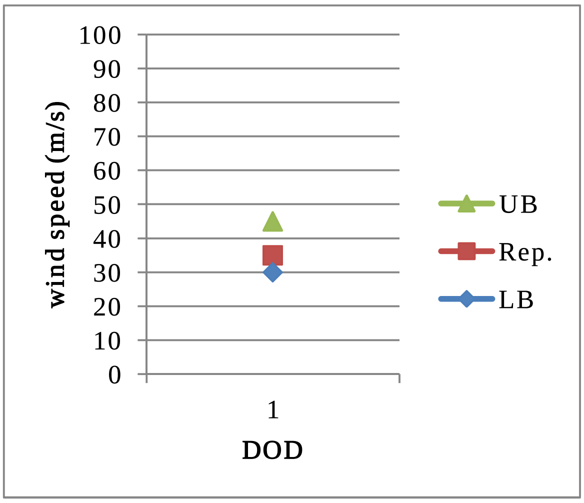
## DI = 22: Wooden, plastic, aluminum or mesh fences

**[Indicators]**

Wooden, plastic, aluminum or fences up to 2m high at lot borders

**[DOD and wind speed]**

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Partial destruction or overturning | **35** | **30** | **45** |




**[DOD example]**

DOD = 1 Partial destruction or overturning

UB was adopted, as there were no apparent deposits on the fence.

Courtesy of Wind Engineering Research Center, Tokyo Polytechnic University

**[Operational guidance]**

(1) As wooden fences may contain invisible degradation, adopt LB. Fences with visible deterioration cannot be used as damage indicators.

(2) Fences damaged by wind-borne debris cannot be used as damage indicators.

(3) If there are no apparent deposits on the fence, adopt UB. If significant deposits block mesh openings, adopt Rep.

(4) Fences with damage at the base cannot be used as damage indicators due to the uncertainty of ground conditions near the surface.

**[Outline of wind speed estimation]**

- Wind speeds for each DOD are evaluated as the minimum values satisfying [Wind load] > [Allowable strength].
- The upper limit of allowable strength is estimated from evaluation of the plastic moments of components and other considerations. If plastic moment evaluation is impractical, the upper limit is based on the assumption that actual strength is 110% of the nominal value.
- Directional wind force coefficients are evaluated. The maximum directional value is adopted for wind speed evaluation.
- For this DI, it is assumed that fences are provided by exterior manufacturers, who often design structural components with wind speed compression of 33 to 42 m/s. Due to the complexity of the combination of components/materials and their load-deformation relationships, estimation of UB and LB is based on the assumption that strengths calculated from these design wind speeds vary by 100 – 120%. As wooden fences may be affected by invisible degradation, LB is estimated as 30 m/s.
- When the solidity ratio of the mesh is 0.1, wind speed calculated from manufacturer specifications is estimated at around 45 m/s (approx. UB). Significant deposits on meshes can block openings, resulting in an increased apparent solidity ratio. In such cases, wind speed is evaluated at around 35 m/s (approx. Rep) with the solidity ratio assumed to be 50% larger.

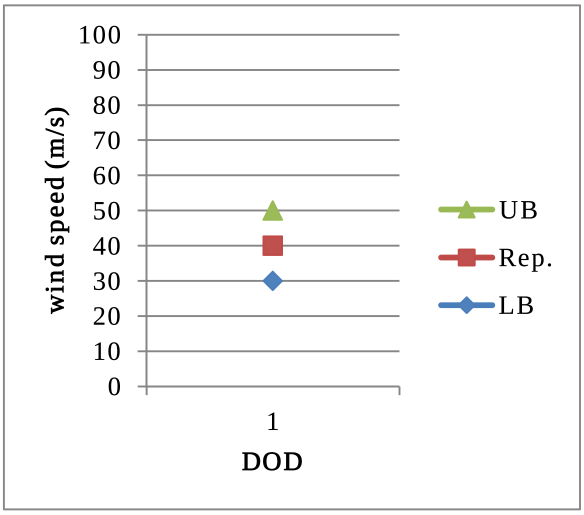
## DI = 23: Windbreak or snowbreak fences for roads

**[Indicators]**

Windbreak or snowbreak fences for roads

**[DOD and wind speed]**

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Partial destruction or overturning | **40** | **30** | **50** |




**[DOD example]**

DOD = 1 Partial destruction or overturning

Courtesy of Wind Engineering Research Center, Tokyo Polytechnic University

**[Operational guidance]**

(1) For components and bolts at joints that have rusted and lost parts, adopt LB. For sound components, adopt UB. For components whose rusting does not result in partial loss and in situations where joint status is unclear, adopt Rep.

(2) Fences damaged by wind-borne debris cannot be used as damage indicators.

(3) Fences with damage at the base cannot be used as damage indicators due to the uncertainty of ground conditions near the surface.

(4) For damage at supporting columns, adopt UB.

**[Outline of wind speed estimation]**

- Wind speeds for each DOD are evaluated as the minimum wind speed satisfying [Wind load] > [Allowable strength].
- The upper limit of allowable strength is estimated from evaluation of the plastic moments of components and other considerations. If plastic moment evaluation is impractical, the upper limit is based on the assumption that actual strength is 110% of the nominal value.
- Directional wind force coefficients are evaluated. The maximum directional value is adopted for wind speed evaluation.
- In damage to wind/snow break fences along roads, panels detachment is common. As wind loads against supporting columns differ significantly with panel condition, estimation of the critical collapse wind speed is challenging regardless of panel condition. For this DI, wind speeds are evaluated on the assumption that panels are affected by wind before supporting columns. If columns are damaged, wind speed is evaluated as more than UB. In wind speed calculation, columns are assumed to support a fence fully enclosed by panels with sound conditions.

**[References]**

Matsui, M., Y. Tamura, and S. Cao, 2007: Wind damage at Ogata-mura and Koto-oka-machi, Akita Prefecture on November 8, 2005. *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **111**, 179-180. (in Japanese)

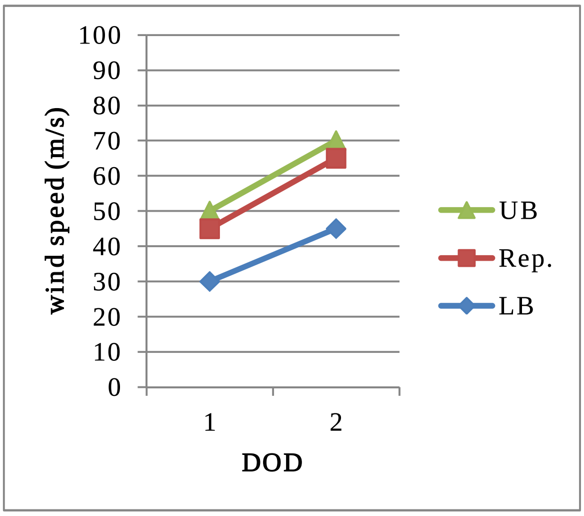
# DI = 24: Net fences

**[Indicators]**

Net fences at baseball grounds or golf courses

**[DOD and wind speed]**

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Inclination of posts | **45** | **30** | **50** |
| 2 | Collapse of posts | **65** | **45** | **70** |




**[DOD example]**

DOD = 2 Collapse of posts

Rep. was adopted, as wind loads were estimated in a direction perpendicular to the net surface.

Courtesy of Wind Engineering Research Center, Tokyo Polytechnic University

**[Operational guidance]**

(1) Check for deposits on the net and take photos where present. If deposits cover over 10% of the net surface, adopt LB.

(2) Posts with significant damage from wind-borne debris cannot be used as damage indicators.

(3) In consideration of post fall directions, if wind direction is estimated to be off more than 45 degrees from the direction perpendicular to the net surface, adopt UB.

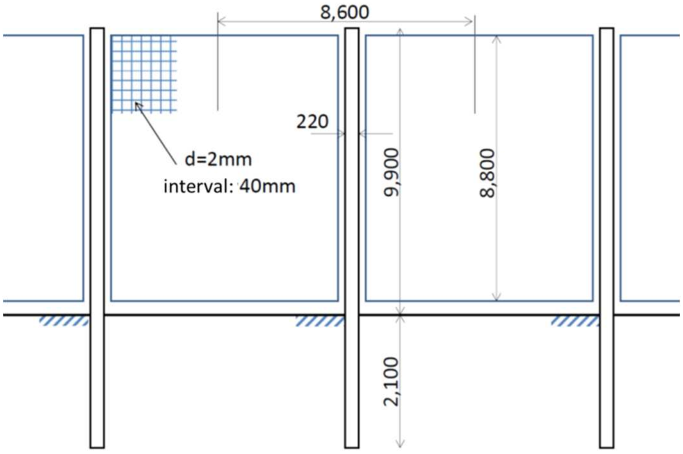
(4) Net fences for golf practice areas are sometimes designed for relatively lower wind loads intended for fences considered vulnerable to damage in high wind conditions. Such facilities cannot be used as damage indicators.

**[Outline of wind speed estimation]**

- Assumed shape of net and posts

1) The thickness and intervals of net meshes of nets are 2 and 40 mm, respectively. The solidity ratio is around 0.1.

2) To evaluate LB, cases with significant net deposits and solidity ratios increased by a factor of 1.5 to 2 are considered.




Assumed example of net and posts

- Elastic deformation, collapse limit wind speed

1) The limit wind speed for elastic deformation is evaluated as the minimum wind speed satisfying [Bending moment of supporting posts under wind loading] > [Elastic limit strength (nominal value provided by manufacturers or the calculated value from the allowable stress for temporary loading and sectional secondary moment)].

2) The limit wind speed for collapse is evaluated as the minimum wind speed satisfying [Bending moment of supporting posts under wind loads] > [Plastic limit strength (nominal value provided by manufacturers or fully plastic moment)].

3) Directional wind force coefficients are evaluated. The maximum directional value is adopted for wind speed evaluation.

- Strength of supporting posts

The strength of concrete poles used for utility poles or used in athletic fields is specified in JIS A5373. The related breaking load must be more than twice the allowable strength. For DOD = 1, the elastic limit stress is assumed to be 1.1 times the allowable stress and cross section in an elastic condition. For DOD = 2, the allowable stress is assumed to be the same as DOD = 1 with the cross section in a full plastic condition.

- Evaluation of wind load and wind speed

The thickness and intervals of meshes of typical nets are 2 and 40 mm, respectively. The solidity ratio *S* is around 0.1 (Murota 1974, Ueda 1999). The empirical relations proposed by these authors are used to calculate the drag coefficient $C_D$ from the solidity ratio. It is also assumed that the drag coefficient is 1.2 (for circular cylinders), that the distribution of wind load is vertically uniform and that air density is 1.2 kg/m$^3$.

The bending moment *M* at the basement of posts is evaluated using

$$M = \frac{1}{2}\rho U^2 \left\{ C_{DN} W_N H_N H_{EN} + C_{DP} D H_P H_{EP} \right\} < M_y, M_P \qquad (1)$$

where $\rho$ is air density, *U* is the limit wind speed, $C_{DN}$ is the drag coefficient of the net, $W_N$ is the width of the net, $H_N$ is the height of the pillar, $H_{EN}$ is the height of the wind load acting on the net, $C_{DP}$ is the drag coefficient of the pillar, *D* is the diameter (width) of the pillar, $H_P$ is height of the pillar, $H_{EP}$ is the height of the wind load acting on the pillar, $M_y$ is the critical cracking moment (allowable strength), and $M_P$ is the destructive moment (maximum strength).

$M_y$ = 48.25 kNm (nominal value from the manufacturer), $M_P$ = 96.6 kNm, $W_N$ = 8,600 mm, $H_N$ = 8,800 mm (= 2 $H_{EN}$), *D* = 220 mm, $H_P$ = 9,900 mm (= 2 $H_{EP}$), and $C_{DN}$ = 0.092 – 0.14 are used for calculation. For nets with significant mesh deposits, the solidity ratio is increased by a factor of 1.5 to 2. Strength dispersion is also assumed to be around 10%, and the actual strength of the post is assumed to be 1.1 times the nominal value. The corresponding Rep. and UB values for each DOD are 1.05 and 1.1 times the calculated values, respectively.

**[References]**

Architectural Institute of Japan (AIJ), 2009: Buckling design for steel structures, Section 6.6, 214-226. (in Japanese)

Murota, T., 1974: An experimental study on the drag coefficient of screens used for buildings. *The Building Research Institute (BRI) Annual Report*, 290-297. (in Japanese)

Ueda, H., E. Maruta, and T. Hongo, 1999: A study on drag coefficient of reticulated structures: Drag coefficient of 2-D reticulated plates. *J. Structure and Construction AIJ*, **524**, 51-56. (in Japanese)

## DI = 25: Broad-leaved trees

**[Indicators]**

Without decay: broad-leaved trees without trunk/branch decay exceeding reference values

With decay: broad-leaved trees with trunk/branch decay exceeding reference values

If the tree contains a visible root decay or has grown in a tree pit, it cannot be used as a damage indicator.

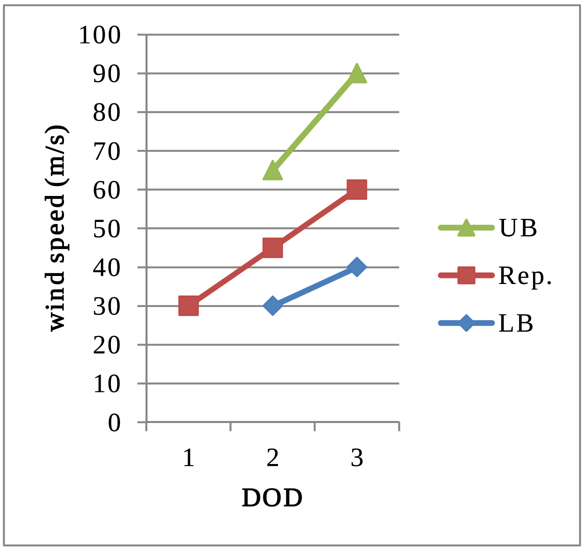
**[DOD and wind speed]**

Without decay

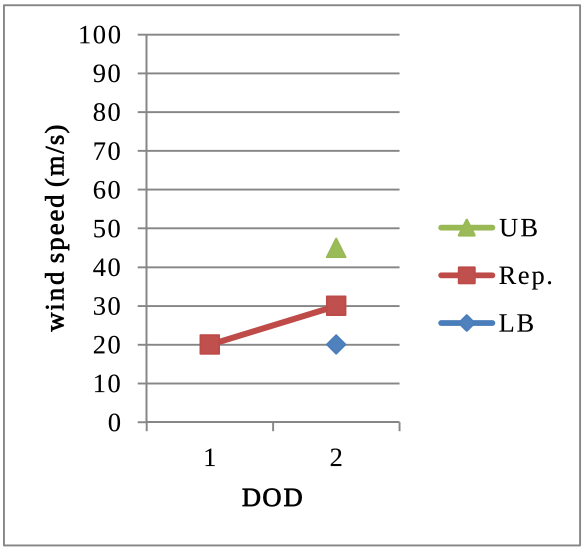
| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | Rep. | LB | UB |
| 1 | Branch breakage (2 – 8 cm in diameter) | **30** | **-** | **-** |
| 2 | Uprooting without root decay | **45** | **30** | **65** |
| 3 | Trunk snapping | **60** | **40** | **90** |

With decay

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | Rep. | LB | UB |
| 1 | Branch breakage (2 – 8 cm in diameter) | **20** | **-** | **-** |
| 2 | Trunk snapping except at the base | **30** | **20** | **45** |




Without decay




With decay

**[DOD example]**

Without decay

| | |
|---|---|
|  |  |
| DOD = 1 Branch breakage (2-8cm in diameter)<br>Courtesy of Forestry and Forest Products Research Institute | DOD = 2 Uprooting without root decay<br>Courtesy of Forestry and Forest Products Research Institute |
|  | |
| DOD = 3 Trunk snapping<br>Courtesy of Forestry and Forest Products Research Institute | |

With decay

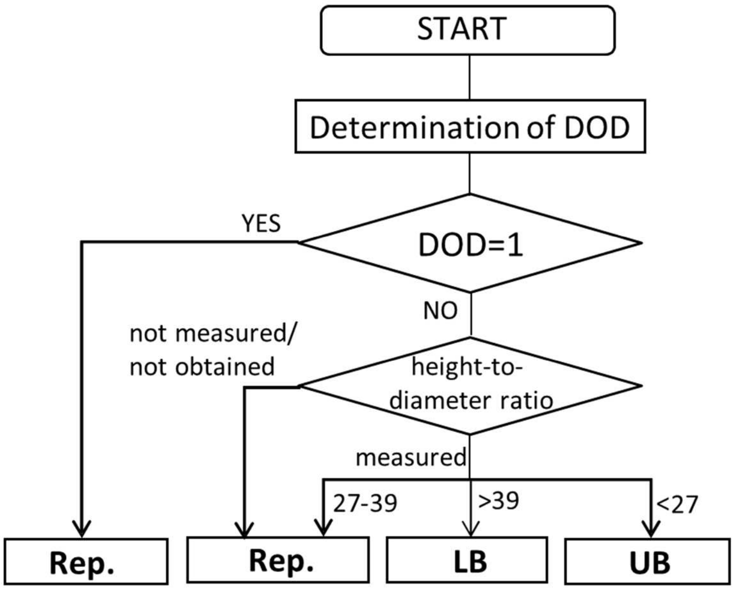
| | |
|---|---|
|  |  |
| DOD = 1 Branch breakage (2-8 cm in diameter)<br>Courtesy of Forestry and Forest Products Research Institute | DOD = 2 Trunk snapping except at the base<br>Courtesy of Forestry and Forest Products Research Institute |

**[Operational guidance]**

(1) When decay is found in trunks and branches, refer to “Decay reference” for applicable DOD table information (with or without decay).

(2) For DOD = 2 or 3 (DOD = 2 with decay), calculate the height-to-diameter ratio to determine applicable wind speed, Rep., LB or UB. If this ratio is not determined, adopt Rep.

(3) Adopt DOD = 3 for trunk breakage at heights between the base of the trunk and the lowest branch.

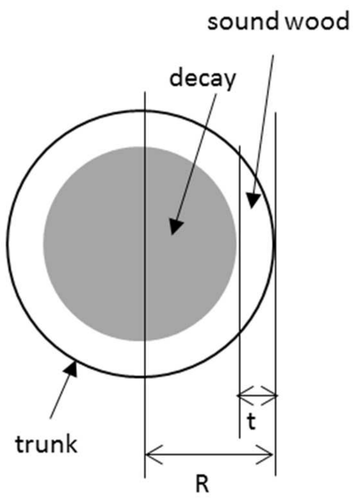



Wind speed evaluation based on height-to-diameter ratio

**[Decay reference]**

Use the "With decay" table if t/R is less than 0.3 for trunk snapping (refer to the figure on the lower right).

The criterion for branch decay is 2 or more (see the list below). Wood with black or dark-brown discoloration, worm consumption, cavities, weakening, sponge-like softening and mushroom growth is typically observed in decayed trunks and branches.

| Branch decay reference | Trunk decay reference |
|---|---|
| Degree of decay (Amemiya, 1963)<br>0: Sound wood<br>1: Partial mild insect damage or decay<br>2: Overall mild insect damage or decay<br>3: Partial severe insect damage or decay in addition to the conditions of 2<br>4: Overall severe insect damage or decay<br>5: Collapse due to insect damage or decay |  |

**[Outline of wind speed estimation]**

- The critical wind speeds *U* for uprooting, trunk snapping and trunk breakage were estimated from wind loads and resistive moments. Rep., LB and UB were calculated from the frequency distribution of *U*. Formula for critical wind speed calculation:

  Uprooting

$$U_{uproot} = \sqrt{\frac{2M_{\max}}{\rho C_d AL}}$$

  $M_{max}$: resistive moment (Nm); $L$: center of pressure (m); $\rho$: air density (kg/m$^3$);
  $C_d$: drag coefficient; $A$: vertical projection area of tree crown (m$^2$); $U$: critical wind speed (m/s)

  Trunk snapping

$$U_{break} = \sqrt{\frac{MOR\pi D^3}{16\rho C_d AL}}$$

  *MOR*: modulus of rupture (Pa); $L$: center of pressure (m); $\rho$: air density (g/m$^3$);
  $C_d$: drag coefficient; $A$: vertical projection area of tree crown (m$^2$); $U$: critical wind speed (m/s);
  $D$: stem diameter (m)

Branch breakage

$$U_{break\_branch} = \sqrt{\frac{MOR\pi D_0^{\ 3}}{16\rho AL_w C_d}}$$

$D_0$: branch base diameter (m); $A$: leaf area ($m^2$); $L_w$: center of pressure (m); $C_d$: drag coefficient

- Data for calculation

Critical wind speeds were estimated for 118 trees growing in forests, parks and gardens. (Ginkgo were treated as broad-leaved trees from a practical viewpoint).

- Determination of variable values

1) Vertical projection area of tree crown (areas subject to wind loads)

Photographs were used for estimation. The center of pressure was assumed to be at ½ of the crown length.

2) Trunk diameter/tree height

Trunk diameters were estimated for every 0.1 m between 0.2 and 1.5 m from the ground based on photographs.

3) Drag coefficient

The following formula was derived from values for red maples presented by Kane (2006):

$$C_d = 0.3379 + 0.2821\exp\left(\frac{-(U-11)}{7.2916}\right)$$ $U$: critical wind speed (m/s)

4) MOR of green wood

The MOR of green wood was estimated as 57 Mpa, which is the average of five species of maple, nine species of oak and three species of elm (USDA 2010).

5) Resistive moment

A formula (Suzuki 2012) was obtained in consideration of *Betula* (Nakabayashi et al. 2011), *Quercus serrata* (Fukami et al. 2011) and *Betura grossa* (Fukami et al. 2011).

6) Areas subject to wind loads and center of pressure in the event of branch breakage

Critical wind speed was calculated from the branch base diameter using the relationship between the base diameter or its square and the projection area or center of pressure. The relationship was determined from 25 branches from *Liriodendron tulipifera*, *Cornus florida* and *Quercus serrata.*

- Rep., UB, LB

Rep., UB and LB were the mean, mean +1σ and mean -1σ, respectively, of the critical wind speed after logarithmic transformation.

Rep. had a 50% interval probability around the mean value. UB and LB were assumed to be representatives of 25% intervals above and below the Rep. range, respectively.

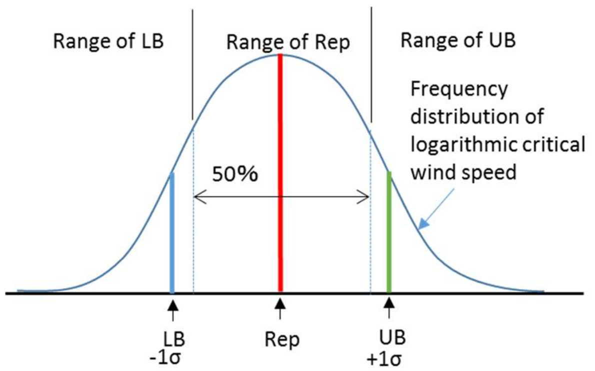
The ranges of Rep., UB, and LB corresponded to height-to-diameter ratios based on the relationship between critical wind speed and this ratio.

Use the height-to-diameter ratio of damaged trees to determine whether to adopt, Rep., UB or LB.

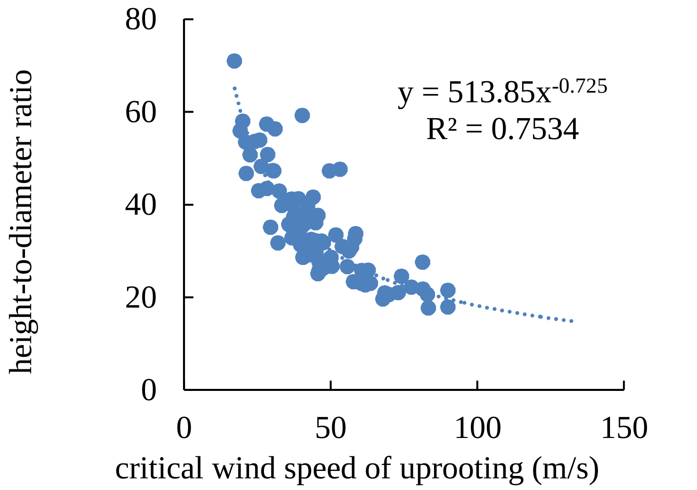
- Influences of decay

Branch breakage: bending strength reduced to 50% (Mori 2002)

Trunk snapping: stress increased by a factor of 3.6 (Mattheck *et al*. 2006)




Ranges for Rep., UB and LB




Relationship between critical wind speed and height-to-diameter ratio

| Height-to-diameter ratio | |
|---|---|
|  |  |
| Height-to-diameter ratio: 56 | Height-to-diameter ratio: 21 |
| Height-to-diameter ratios tend to be small for trees that are far from others or isolated. | |

**[References]**

Amemiya, S., 1963: Field examination of pile strength in Asakawa (1). *Bulletin of the Forestry and Forest Products Research Institute*, **150**, 143-156. (in Japanese)

Kane, B., and E. T. Smiley, 2006: Drag coefficients and crown area estimation of red maple. *Canadian J. Forest Research*, **36**, 1951-1958.

Mattheck, C., K. Bethge, and I. Tesari, 2006: Shear effects on failure of hollow trees. *Trees*, **20**, 329-333.

Mori, M., 2002: Prediction of the strength of wooden civil engineering structures for decaying. *Report of forest products research institute*, May, 1-3, ISSN 1349-3132. (in Japanese)

Nakabayashi, H., R. Inoue, K. Asano, and H. Torita, 2011: Tree pulling tests for establishing the debris flow buffer forest. *Proceedings of Japan society of erosion control engineering*, **59**, 354-355. (in Japanese)

Suzuki, S., 2012: Wind and tree. *J. tree health*, **16**, 15-22. (in Japanese)

Suzuki, S., J. Watai, T. Kato, H. Noguchi, and K. Nanko, 2015: Development of Japanese Enhanced Fujita Scale -suggestion of DI and DOD for tree-. *J. Wind Engineering (Japan Association for Wind Engineering (JAWE))*, **40** (2), 127-128. (in Japanese)

Takeuchi, I., T. Kawasaki, and S. Mori, 1997: Changes of stem height-to-diameter ratio in hinoki (Chamaecyparis obtuse) young man-made stands. *J. Japan Forest Society*, **79**, 137-142. (in Japanese)

USDA, 2010: Wood Handbook, 508.

## DI = 26: Coniferous trees

**[Indicators]**

Without decay: coniferous trees without trunk/branch decay exceeding reference values

With decay: coniferous trees with trunk/branch decay exceeding reference values

If the tree contains a visible root decay or has grown in a tree pit, it cannot be used as a damage indicator.

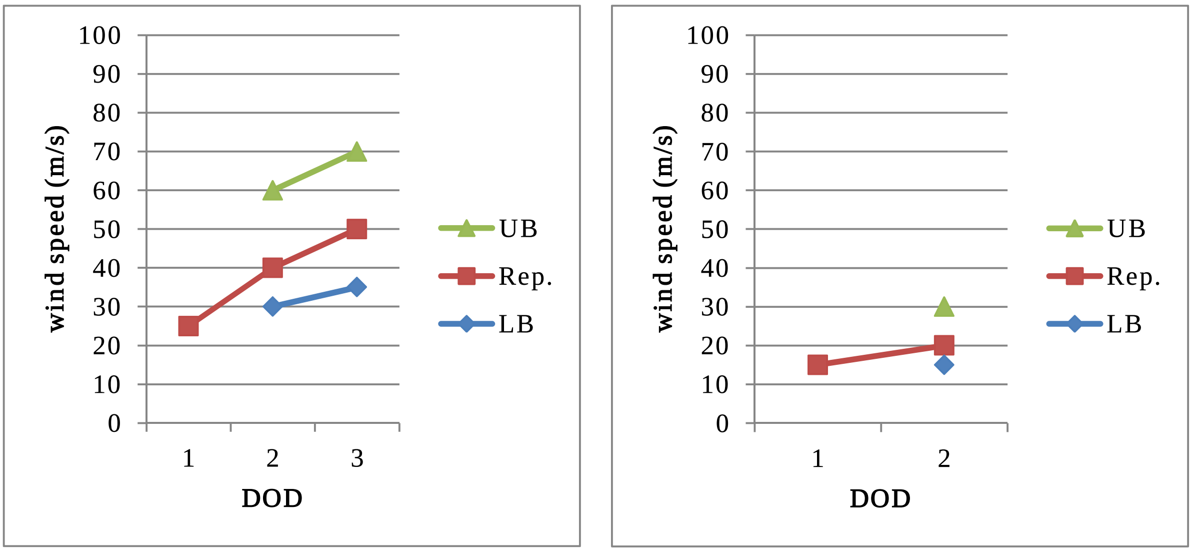
**[DOD and wind speed]**

Without decay

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | Rep. | LB | UB |
| 1 | Branch breakage (2 – 8 cm in diameter) | **25** | **-** | **-** |
| 2 | Uprooting without root decay | **40** | **30** | **60** |
| 3 | Trunk snapping | **50** | **35** | **70** |

With decay

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | Rep. | LB | UB |
| 1 | Branch breakage (2 – 8 cm in diameter) | **15** | **-** | **-** |
| 2 | Trunk snapping except at the base | **20** | **15** | **30** |




Without decay With decay

**[DOD example]**

Without decay

| | |
|---|---|
|  |  |
| DOD = 2　Uprooting without root decay<br>Courtesy of Forestry and Forest Products Research Institute | DOD = 3　Trunk snapping<br>Courtesy of Forestry and Forest Products Research Institute |

With decay

| |
|---|
|  |
| DOD = 2　Trunk snapping except at the base<br>Courtesy of Forestry and Forest Products Research Institute |

**[Operational guidance]**

(1) If decay is found in branches and trunks, refer to “Decay reference” in DI = 25 (Broad-leaved trees) and determine the applicable DOD table (with or without decay).

(2) For DOD = 2 or 3 (DOD = 2 with decay), calculate the height-to-diameter ratio to determine whether Rep., LB or UB is applicable. If this ratio is not determined, adopt Rep.

Adopt DOD = 3 for trunk breakage at heights between the trunk base and the lowest branch.

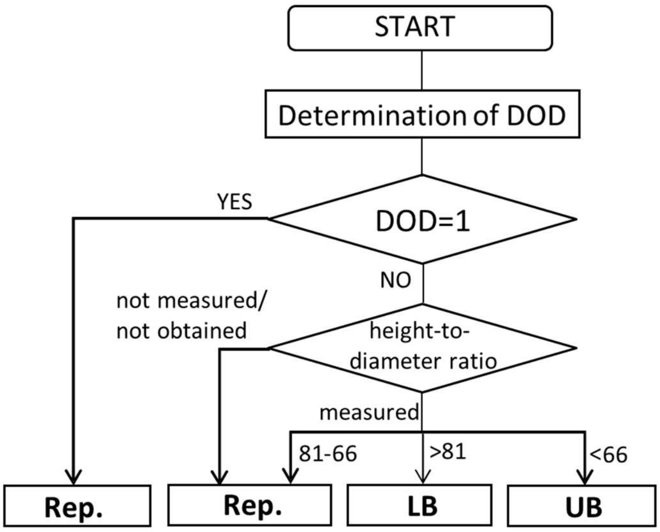



Fig. Rating procedure for wind speed based on height-to-diameter ratio

**[Outline of wind speed estimation]**

- The critical wind speeds *U* for uprooting, trunk snapping and trunk breakage were estimated from the wind loads and the resistive moments. Rep., LB and UB were calculated from the frequency distribution of *U*.

Formula for the calculation of critical wind speeds:

Uprooting

$$U_{uproot} = \sqrt{\frac{2M_{\max}}{\rho C_d AL}}$$

$M_{max}$: Resistive moment (Nm), *L*: center of pressure (m), $\rho$: air density (kg/m$^3$)

$C_d$: drag coefficient, *A*: vertical projection area of tree crown (m$^2$), *U*: critical wind speed (m/s)

Trunk snapping

$$U_{break} = \sqrt{\frac{MOR\pi D^3}{16\rho C_d AL}}$$

*MOR*: modulus of rupture (Pa), *L*: center of pressure (m), $\rho$: air density (g/m$^3$),

$C_d$: drag coefficient, *A*: vertical projection area of tree crown (m$^2$), *U*: critical wind speed (m/s)

*D*: stem diameter (m)

Branch breakage

$$U_{break\_branch} = \sqrt{\frac{MOR\ \pi D_0^{\ 3}}{16\ \rho A L_w C_d}}$$

$D_0$: Base diameter of a branch (m), $A$: leaf area (m$^2$), $L_w$: center of pressure (m), $C_d$: drag coefficient

- Data for calculation

Shape data on undamaged trees (309 Hinoki and 82 Sugi) obtained from research on wind damage caused by Typhoon T0423 in 2004 were used. (Shizuoka Prefecture Research Institute of Agriculture and Forestry, Forestry and Forest Products Research Center 2006)

- Determination of variable values

1) Vertical projection area of tree crown (area subject to wind loads)

The crown shape was estimated using the method proposed by Takeshita (1985). The center of pressure was assumed to be at 1/3 of the crown length from the crown base.

2) Trunk diameter/tree height

The trunk diameter was estimated using the trunk diameter distribution formula for Hinoki and Sugi trees as developed by Shizuoka Prefecture Research Institute of Agriculture and Forestry (Forestry and Forest Products Research Center).

3) Drag coefficient

The following formula was derived from values for coniferous trees presented by Mayhead (1973):

$$C_d = 0.188 + 0.752\exp(-0.068U)$$

$U$: critical wind speed (m/s)

4) MOR of green wood

Sugi (*Cryptomeria japonica*): 40.6 MPa; Hinoki (*Chamaecyparis obtuse*): 49.1 Mpa (Tokuda et al. 1988)

5) Resistive moment

A formula (Suzuki 2012) developed with reference to data on *Cryptomeria japonica* (Kayashima and Sasaki 2010; Nakabayashi et al. 2011) and *Larix kaempferi* (Torita 2009; Torita et al. 2010; Fukami et al. 2011) was used.

6) Areas subject to wind loads and center of pressure in the event of branch breakage

The critical wind speed was calculated from the branch base diameter using the relationship between this diameter and the projection area or the center of pressure. The relationship was determined from 17 *Cryptomeria japonica* branches.

- Rep., UB, LB

Rep., UB and LB were mean, mean +1σ and mean -1σ, respectively, of the critical wind speed after logarithmic transformation.

Rep. had 50% interval probability around the mean value. UB and LB were assumed to be the representatives of 25% upper and lower intervals than the Rep. range, respectively.

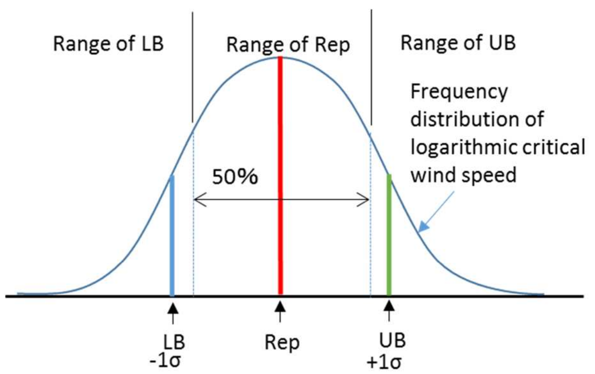
The ranges of Rep., UB, and LB were corresponded to the height-to-diameter ratios by the relationship between the critical wind speed and the height-to-diameter ratio.

Use the height-to-diameter ratio of the damaged trees to determine which wind speed to adopt, Rep., UB or LB.

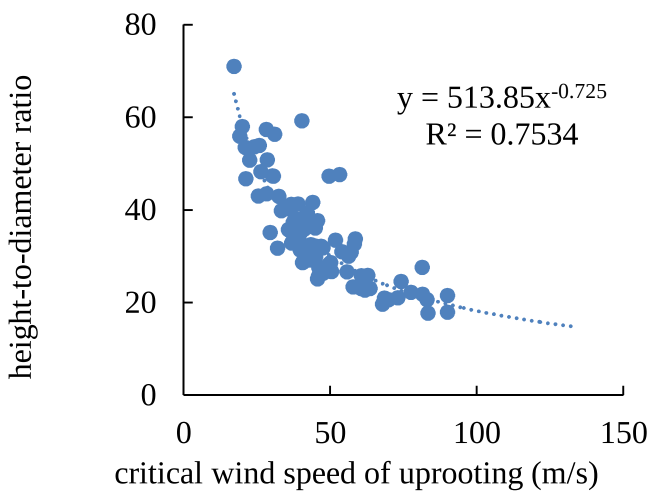
- Influences of decay

Branch breakage: bending strength was reduced to 50% (Mori 2002)

Trunk snapping: stress was increased by a factor of 3.6 (Mattheck et al.2006)




Schematic diagram of the ranges for Rep., UB and LB




Example of the relationship between the critical wind speed and height-to-diameter ratio.

| Example of height-to-diameter ratio | |
|---|---|
|  |  |
| height-to-diameter ratio: 86 | height-to-diameter ratio: 31 |
| Height-to-diameter ratios tend to be small in case that trees have long distance with others or are isolated. | |

**[References]**


Amemiya, S., 1963: Field examination of pile strength in Asakawa (1). *Bulletin of the Forestry and Forest Products Research Institute*, **150**, 143-156. (in Japanese)

Fukami, Y., H. Kitahara, and H. Ono, 2011: Standing tree pulling tests in several conditions of soil moisture. *J. Japan Forest Society*, **93**, 8-13. (in Japanese)

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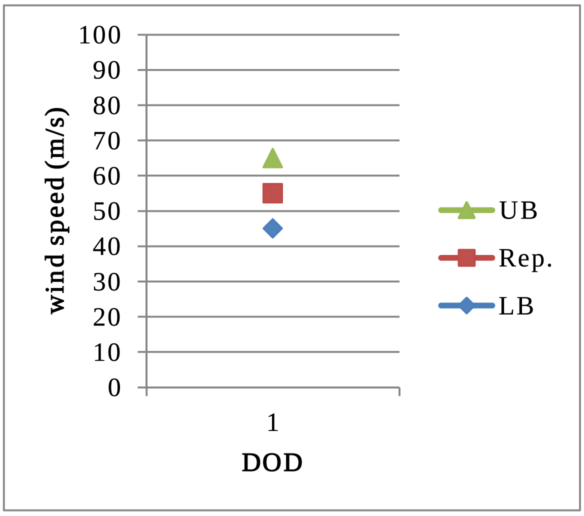
## DI = 27: Gravestones

**[Indicators]**

Standard Japanese gravestones (*sao-ishi*) with maximum widths/lengths of 20 – 40 cm

**[DOD and wind speed]**

| DOD | Damage | Wind Speed（m/s） | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Slippage or overturning | **55** | **45** | **65** |




**[DOD example]**

DOD = 1Slippage or overturning

Gravestones overturned in the direction of the arrows

Courtesy of Building Research Institute

**[Operational guidance]**

(1) This DI is applicable to gravestones on pedestals not held in place by plaster.

(2) Damage induced by wind-borne debris cannot be used as a damage indicator.

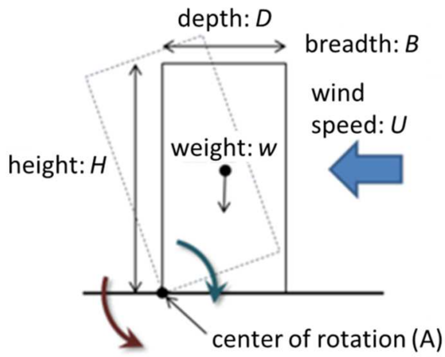
(3) Gravestones far from the traditional Japanese style and those with irregular shapes cannot be used as damage

indicators.

(4) Adopt LB, Rep. or UB when the longer of the depth and width is 20, 30 and 40 cm, respectively.

**[Outline of wind speed estimation]**

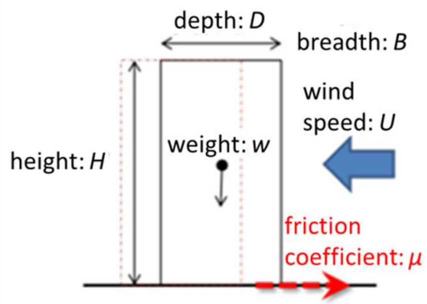
- Wind speeds were calculated statistically based on the standard size of Japanese-style gravestones (breadth x depth x height = 25 x 25 x 68 cm).
- Wind is assumed to blow against gravestones horizontally and uniformly (Vickery 1968; Kikitsu et al. 2002) and to have the minimum force necessary to induce slippage or overturning.
- The critical wind speed for overturning was calculated from the balance of the overturning moment assuming that gravestones overturn in the leeward direction (Architectural Institute of Japan, 1978). Considering the height, width, breadth and weight of the gravestone, the wind load acting on it is given as




$$\widehat{W} = \frac{1}{2}\rho\widehat{U}^2 HBC_f \qquad (1)$$

The critical wind speed for overturning is that at which the moment from the wind load exceeds the moment by weight at the center of rotation (A).

$$\frac{1}{2}H\left(\frac{1}{2}\rho {U_{cr}}^2 HBC_f\right) > \frac{D}{2}w \qquad (2)$$




- The critical wind speed for slippage was calculated from the balance between the friction of gravestones and lateral force caused by wind (Architectural Institute of Japan, 1978). Gravestones slip when the wind speed satisfies

$$\frac{1}{2}\rho {U_{cr}}^2 HBC_f > \mu w \qquad (3)$$

- A force coefficient of $C_f$ = 1.2 (Kikitsu et al. 2002; Nomura et al. 2008), an air density of $\rho$ = 1.2 kg/m$^3$ and a friction coefficient of $\mu$ = 0.3 between the gravestone and the pedestal were used in the above equations (1), (2) and (3). Gravestone density is assumed to be 2.6 g/cm$^3$.

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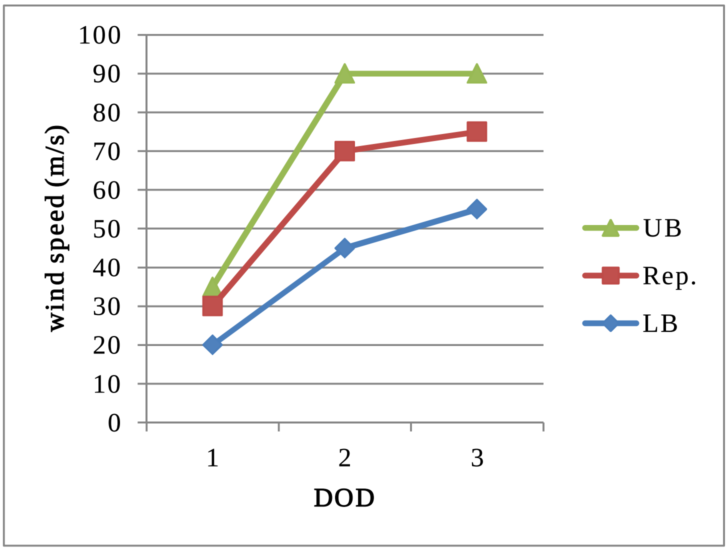
## DI = 28: Road surfaces

**[Indicators]**

Asphalt pavement

**[DOD and wind speed]**

| DOD | Damage | Wind speed (m/s) | | |
|---|---|---|---|---|
| | | Rep. | LB | UB |
| 1 | Displacement of degraded asphalt pavement | **30** | **20** | **35** |
| 2 | Displacement of normal asphalt pavement (on embankments) | **70** | **45** | **90** |
| 3 | Displacement of normal asphalt pavement (on flat ground) | **75** | **55** | **90** |




**[DOD example]**

DOD = 1 Displacement of degraded asphalt pavement

Courtesy of Institute of Technology and Science, Tokushima University

DOD = 2 Displacement of normal asphalt pavement (on embankments)

(The embankment angle exceeded 30 degrees.)

Courtesy of Institute of Technology and Science, Tokushima University

**[Operational guidance]**

1) Peeling or scattering of asphalt pavement is a unique phenomenon associated with tornadoes. Apply DOD = 1 when asphalt pavement around damaged parts cracks and no longer adheres to the road bed.

2) Apply DOD = 2 when the damaged asphalt pavement is normal and the slope of the embankment exceeds 30 degrees. Apply DOD = 3 when the damaged asphalt pavement is normal and the slope of the embankment does not exceed 30 degrees.

**[Outline of wind speed estimation]**

- This DI is applicable to the following conditions:
    1. Roads paved with a 5-cm-thick asphalt mixture on a roadbed with macadam or slag.
    2. Roads paved with a 5-cm-thick asphalt mixture covering 5-cm-thick roadbed asphalt pavement.
- Wind speeds for DOD = 1 were evaluated in consideration of the weight of asphalt pavement only. Wind speeds for DOD = 2 and 3 were determined in consideration of the weight of asphalt pavement and adherence strength.
- Wind speeds for DOD = 2 were evaluated in consideration of wind speed enhancement by embankments. Wind speeds for DOD = 3 were evaluated from a condition in which wind speed enhancement by embankments is negligible.
- Calculation of critical wind speeds for peeling and scattering was conducted with reference to Noda and Nagao (2015).

**[References]**

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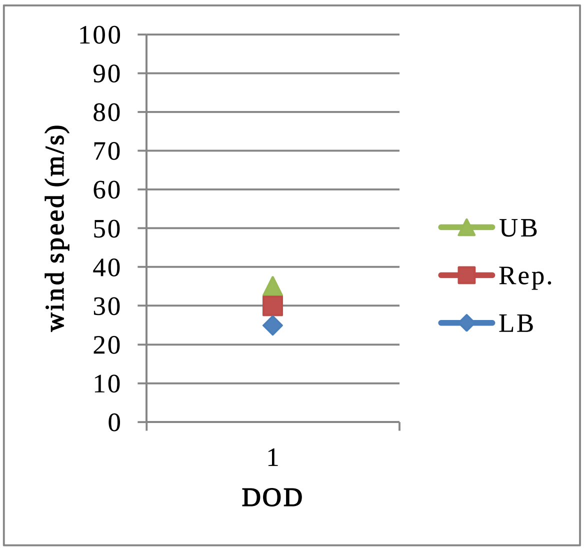
## DI = 29: Temporary scaffolding (with wall ties)

**[Indicators]**

Temporary scaffolding covered with nets or sheets

**[DOD and wind speed]**

| DOD | Damage | Wind Speed（m/s） | | |
|---|---|---|---|---|
| | | **Rep.** | **LB** | **UB** |
| 1 | Wall tie fracture | **30** | **25** | **35** |




**[DOD example]**

DOD = 1 Wall tie fracture

Application of LB for type-I temporary scaffolding

Courtesy of National Institute of Occupational Safety and Health, Japan

**[Operational guidance]**

(1) Wind speeds can be applied to all types of scaffolding (types installed on one side (type I), two sides (type L) and three sides (type U) of buildings).

(2) Nets are defined as materials with openings covering scaffolding, and sheets are materials without openings.

(3) Adopt LB for type-I scaffolding covered with sheets, Rep. for type-L or type-U scaffolding covered with sheets or nets, and UB for type-I scaffolding covered with nets.

**[Outline of wind speed estimation]**

- Damage is assumed to occur from fracturing of wall ties connecting temporary scaffolding and buildings under wind loads.
- Wind loads on temporary scaffolding are evaluated using the following equation (Wang *et al*. 2013):

$$\widehat{W} = \widehat{q_H} \cdot A \cdot C_f \cdot IF \cdot \varphi$$

where $\widehat{W}$ is the wind load acting on the scaffolding, $\widehat{q_H}$ is the velocity pressure at a representative height of the building, $A$ is the tributary area of one wall tie, $C_f$ is the force coefficient based on previous studies (the force vector is negative when a force acts in the desorption direction from the wall surface). $IF$ is an interaction factor indicating the influence from neighboring buildings on wind loads. According to Wang et al. (2014), IF varies from 0.9 to 1.4 depending on the arrangement of neighboring buildings, but is set as 1.0 for simplicity. The reduction factor of the force coefficient is also derived from the net blockage ratio.

- The strength of wall ties against wind loads is prescribed as exceeding 5.7 kN by the Scaffolding and Construction Equipment Association of Japan, and this value (5.7 kN) is used for wind estimation.
- Wind speeds corresponding to DODs were defined as values for which the wind load on temporary scaffolding is equivalent to wall tie strength.

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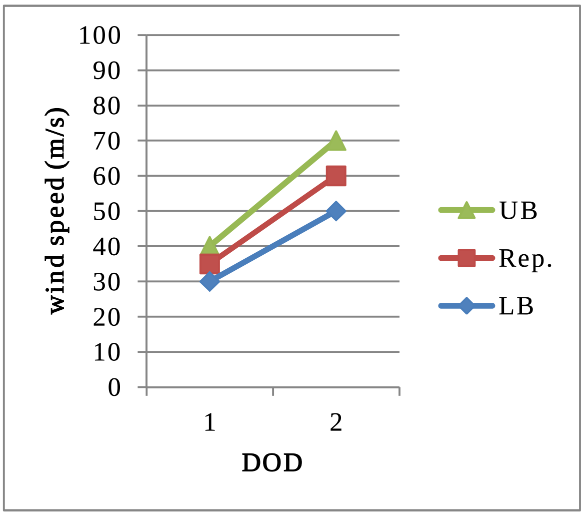
## DI = 30: Gantry cranes

**[Indicators]**

Gantry cranes under operation or at rest

**[DOD and wind speed]**

| DOD | Damage | Wind Speed (m/s) | | |
|---|---|---|---|---|
| | | Rep. | LB | UB |
| 1 | Overrun or overturning (under operation) | **35** | **30** | **40** |
| 2 | Overrun or overturning (at rest) | **60** | **50** | **70** |




**[DOD example]**

DOD = 1 Overrun or overturning (under operation)

Courtesy of Wind Engineering Center, Tokyo Polytechnic University

**[Operational guidance]**

(1) Gantry cranes moving on rails cannot be used as damage indicators.

(2) Apply DOD = 1 when clamped gantry cranes are at rest under operation.

(3) Apply DOD = 2 when gantry cranes are at rest and moored with anchors in specific positions.

**[Outline of wind speed estimation]**

- DOD = 1: According to Japanese Industrial Standards, rail clamping devices function while the wind speed is less than 35 m/s.
- DOD = 2: According to Japanese Industrial Standards, anchors function while the wind speed is less than 60 m/s.

**[References]**

Japanese Industrial Standards, 2013, Cranes-Anchoring devices for in-service and out-of-service conditions, JIS B8828:2013. (in Japanese)

Ports and Harbors Bureau of Ministry of Land, Infrastructure, Transport and Tourism, 2012: Model Operational Regulations for Crane Anchoring. (in Japanese)

# Appendix C
# Determination of Correspondence between Japanese Enhanced Fujita Scale Classes and Wind Speeds

To maintain statistical continuity between the F Scale and the EF Scale, the following procedures were implemented in the United States: 1) the correlation between wind speeds estimated using both the F Scale and the EF Scale for multiple cases of damage was examined; and 2) the wind speed ranges of EF Scale classes were determined based on the correlation between the two scales so that the degrees of damage for each EF Scale class would match the corresponding class number in the F Scale classas closely as possible. The correlation in 2) was examined using regression analysis with a linear function.

The Canadian EF Scale was developed by adding six DIs to those of the US EF Scale (Sills 2013a) and implementing the procedures detailed above, but a power function was used instead of a linear function for the regression analysis in 2) (Fig. C-1, right).

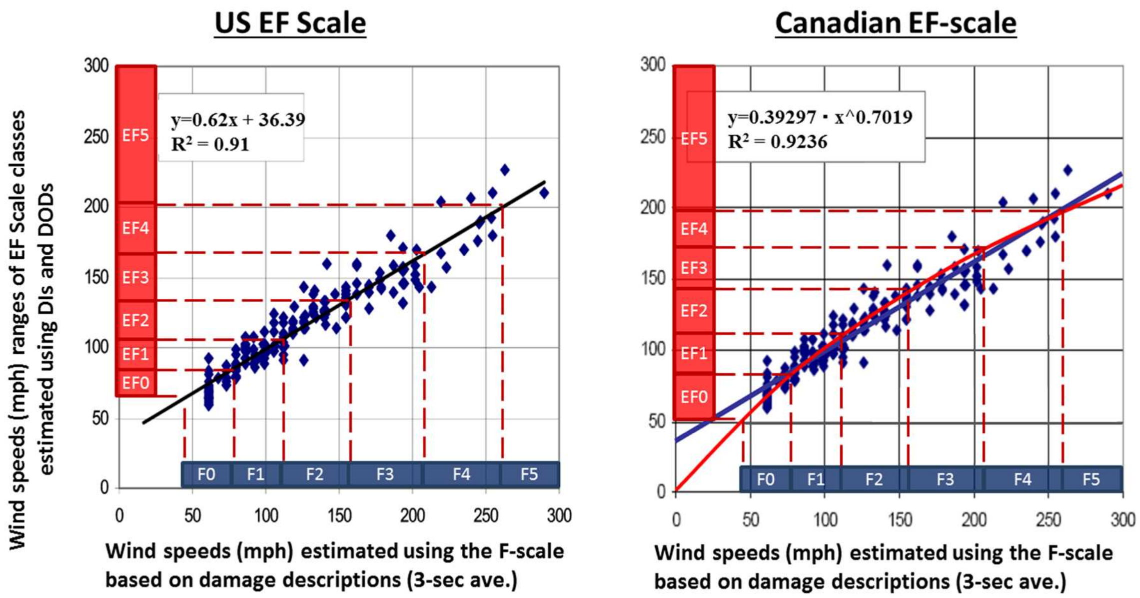



Fig. C-1. Correlations between wind speeds estimated using the F Scale and the EF Scale

Left: US EF Scale; right: Canadian EF Scale

Regarding wind speed correspondence to the classes of the JEF Scale, the following procedures were taken using the approach detailed above:

1) Selection of damage events for correlational examination

a) The following primary tornado damage events were chosen for correlational examination:

- Events in which tornadoes caused more than 30 cases of damage to buildings and structures from 2007 to 2013

- Other extreme events (rated as F3); tornadoes occurring in Saroma-cho, Hokkaido Pref. (2006), Mobara City, Chiba Pref. (1990) and Toyohashi City, Aichi Pref. (1999)

b) For the 215 damage events based on the criteria described in a), the correlation between wind speeds estimated using the F Scale and the JEF Scale was examined.

2) Wind speed estimation using the F Scale

a) Five F Scale rating experts at JMA derived wind speeds corresponding to individual damage events with reference to the table on the right, which shows categories of weak (W), medium (M) and strong (S) for each F Scale class (F0 to F5).

b) The average of the wind speeds calculated in a) was adopted as the wind speed value for each case of damage estimated using the F Scale.

Table on the right: F Scale and wind speeds corresponding to the different classes

*Wind speed value calculation: Using the Durst curve (Dregger, 2005; WMO, 2009; ANSI, 1996), which shows the ratio of wind speeds averaged over a number of seconds to one-hour averages, wind speed ranges corresponding to F Scale classes were converted into three-second average wind speeds. Each wind speed range in the F Scale classes was divided equally into weak (W), medium (M) and strong (S) categories, and the average of the maxima and minima in each section was adopted for rating purposes.*

| F Scale class | Wind speed (m/s) (3-sec. average) | |
|---|---|---|
| F0 | W | 21 |
| | M | 27 |
| | S | 32 |
| F1 | W | 38 |
| | M | 44 |
| | S | 49 |
| F2 | W | 55 |
| | M | 62 |
| | S | 69 |
| F3 | W | 75 |
| | M | 83 |
| | S | 90 |
| F4 | W | 98 |
| | M | 106 |
| | S | 113 |
| F5 | W | 121 |
| | M | 130 |
| | S | 138 |

3) Wind speed estimation using the DIs and DODs of the JEF Scale

a) Five wind engineering experts determined the DIs and DODs of each damage event and calculated the corresponding wind speeds with reference to Appendix B.

b) The average of these wind speeds was adopted as the value for each case of damage estimated using the DIs and DODs.

4) Examination of correlation between wind speeds estimated using the F Scale and JEF Scale DIs/DODs

a) Using a scatter diagram of wind speed values obtained from 2) and 3) (Fig C-2), the correlation between wind speeds estimated using the F Scale and the JEF Scale was examined using regression analysis ($R^2$ (coefficient of determination): 0.74). The regression methods of the linear function of the US EF Scale and the power function of the Canadian EF Scale were both considered. The latter was adopted for the JEF Scale, as it produced better correlations.

5) Determination of correspondence between JEF Scale classes and wind speeds

a) Based on the regression curve and the wind speed ranges of F Scale classes, the correspondence between JEF Scale classes and wind speeds was determined as shown in Fig C-2 (see Table 3 in the main part).

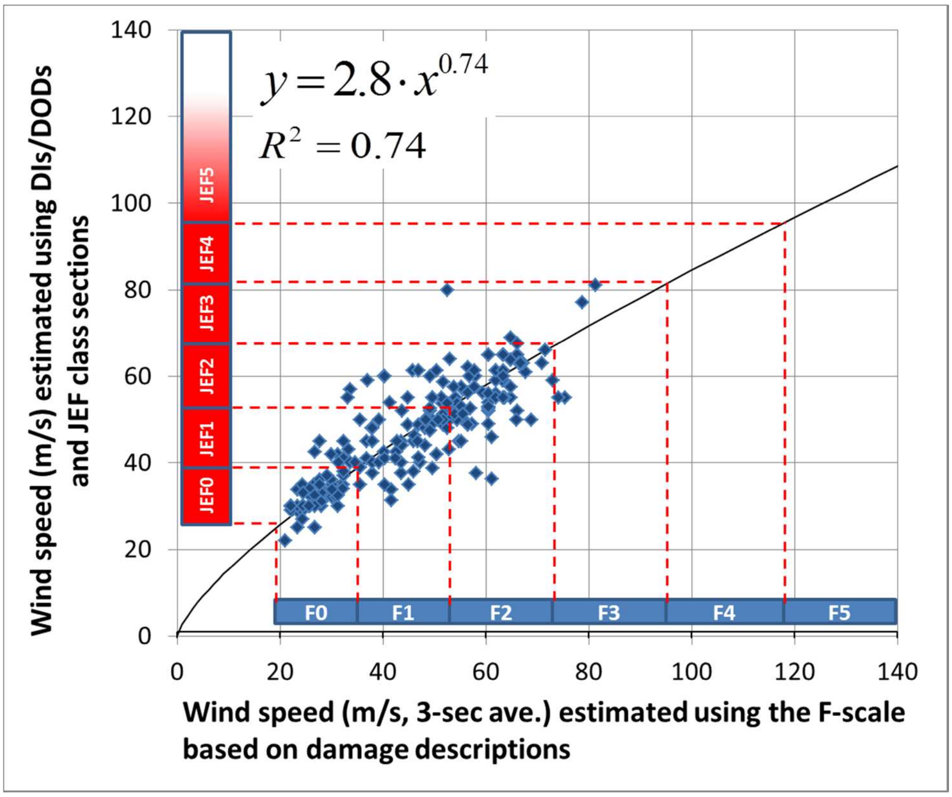



Fig. C-2. Correlation between wind speeds estimated using the F Scale and JEF Scale DIs/DODs