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A CRITICAL ESTIMATION OF DATA ON EXTREME WINDS IN LITHUANIA

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Abstract. An assessment of data on wind storms recorded in Lithuania during the past 48 years is presented. Records of storms with the average wind speeds of at least 30 m/s are compiled into one data set and presented in the paper. Reliability and meteorological homogeneity of wind storm data is assessed. The extreme wind data is estimated in relation to an assessment of damage to the built environment. An exceedance of basic reference wind speeds and design wind speeds specified in Lithuanian loading code by extreme winds (large cyclonic storms) is detected. The annual exceedance frequency was found to be considerably higher than the frequency of once per fifty years declared in the code. The exceedance was also found to be relatively dangerous in terms of magnitude. It is suggested to analyze wind data by a separate treatment of fastest annual winds and hurricane winds. Two hurricane wind regions are proposed for the Lithuanian territory. Basic reference wind speeds for these regions are calculated by applying the approach of partial duration series of extreme wind records. The regionalisation of hurricane-prone parts of Lithuania led to a compilation of two small-size statistical samples of hurricane wind speeds, which can be applied to an assessment of risk posed by hurricanes.

Keywords: wind data, wind storm, wind damage, hurricane, partial duration series, wind loading, wind region.

1. Introduction

Damage to environment by extreme winds is a fact of life in many countries. Although Lithuanian wind climate is considered to be moderate, strong cyclonic storms and local windstorms occur in Lithuania almost every year (Korkutis 1996, 2000; Galvonaitė 2007). Wind storms are well-known for their substantial damage to natural environment of Lithuania, especially, marine coast of the country (Žilinskas *et al*. 2000, 2005; Bukantis *et al*. 2007; Jaskelevičius and Užpelkienė 2008). However, they were also capable of causing damage to built environment. For instance, two large cyclonic storms in January 1993 and December 1999 resulted in serious damage, mainly, to Lithuanian infrastructure of communications and power supply (Korkutis 2000; Lietuvos hidrometeorologijos tarnyba 2008).

There are two principal approaches to the assessment of wind-induced damage to a specific structure, probabilistic and deterministic. The first is based on the use of probabilistic models of wind characteristics and developing a fragility function for a specific damage event (Minciarelli *et al*. 2001; Vaidogas 2002; Li and Ellingwood 2006, 2007; Pagnini 2010; Juocevičius and Vaidogas 2010). The probabilistic approach has been integrated into a formal quantitative risk analysis (e.g., Twisdale and Vickery 1995). The deterministic approach is prevailing in the structural design. The key element of this approach is nominal (basic) wind speeds specified in national wind loading codes and standards. A review of these documents is given by Holmes (2007). The codes and standards are developed, revised, and renewed using country-specific wind data and this process seems not to be finished in many countries (Żurański 2002; Holmes 2007; Kasperski 2009).

Lithuanian national code covering wind loading, STR 2.05.04:2003, is used since 2003. It was preceded by several additions of Russian loading SNiPs, the last of which, SNiP 2.01.07-85, was used in Lithuania in the period 1987 to 2002. Both STR and SNiP codes are consistent with the methodological limit states format of the European standard prEN 1991-1-4.6 (the final draft of Eurocode 1 on wind loads issued in 2004).

Over many decades, specifications of wind loading codes were based on the so-called “Gumbel analyses” of annual fastest wind series, although alternative methods have been proposed for an estimation of extreme wind speeds (e.g., Pandey 2002; Cook and Harris 2004; An and Pandey 2005). The specifications of wind loading codes have been challenged when wind speeds prescribed in them were exceeded during severe windstorms in some countries. This highlighted the need to separate wind data originating from different storm types (Gomes and Vickery 1977; Choi and Tanurdaja 2002; Cook *et al*. 2003; Lombardo *et al*. 2009).

Lithuania has several types of extreme winds, both local and covering relatively large parts of its territory. The dominant storm type is cyclones approaching Lithuania from the directions of 180 to 337.5 degrees (compass directions S to N-NW). As in many countries around the Baltic See, the highest extreme wind risk in Lithuania is related to the coastal region (Kristensen *et al.* 2000; Perrin *et al.* 2001; Pryor and Barthelmie 2003; Millington *et al.* 2009). However, the south-western part of Lithuania is also prone to extreme winds belonging to the category of hurricanes.

The annual fastest wind data in hurricane prone regions of Lithuania is a mixture of hurricane winds, cyclonic winds below the hurricane category, and thunderstorm winds. The present paper provides a critical appraisal of Lithuanian data on extreme cyclonic winds including data on a relatively small number of hurricanes. The analysis of extreme winds attempts to form statistical samples of extreme wind speed records, which could be used for an assessment of potential wind-induced damage. This task led to a division of Lithuanian territory into hurricane wind regions suggested in the paper. We think that the samples of the extreme wind speeds will be amenable to the analysis by applying methods suggested, among others, by An and Pandey (2005). However, the focus of this paper is presentation, estimation, and classification of extreme wind data recorded in Lithuanian weather stations in the past 48 years.

2. Data on extreme winds in Lithuania

Lithuanian classification of extreme winds corresponds to the international classification based on the Beaufort scale (e.g., Liu 1991; Allaby 2007). The two most severe categories of the wind speed v in the Beaufort scale are violent storm (28 m/s $< v <$ 32 m/s or 64 mph $< v <$ 73 mph) and hurricane ($v \geq$ 33 m/s or $v \geq$ 73 mph). These two categories of winds are used in the Lithuanian classification of extreme natural and man-made phenomena (Lietuvos Vyriausybė 2006).

A further Lithuanian categorisation of extreme winds distinguishes between "elemental" or strong wind (30 m/s $\leq v <$ 35 m/s) and "catastrophic" wind ($v \geq$ 35 m/s) (Korkutis 2000). Although the term "elemental" is a more precise translation of Lithuanian "*stichinis*", the term "strong wind" is more natural and will be used in the subsequent text. The categorisation of extreme winds into strong and catastrophic ones does not agree strictly with the Beaufort scale (see, e.g., the definitions of the scale presented by Liu (1991) and Allaby (2007)).

A reliable recording of wind speeds in Lithuania began in early 1960s when weather stations started using adequate instrumentation for obtaining and recording wind data. The data on extreme winds recorded in the period 1962 to 2005 is summarised in Table 1. In the subsequent years 2006 to 2009, no mean wind speeds exceeding 30 m/s were recorded. The data given in Table 1 are either 10-min means recorded at 10 m elevation of rotating cups anemometers or records adjusted to these instrumentation parameters. The network of Lithuanian weather stations with the records of strong and catastrophic winds is shown in Fig. 1.

In the period 1962 to 2009, a total of 33 wind storms reached the level of extreme winds. This results in the annual frequency of occurrence equal to 0.688 per annum. Four storms (18 Oct 1967, 23 Nov 1973, 14 Jan 1993, and 4 Dec 1999) covered more than one-third of the Lithuanian territory (recorded in at least seven weather stations). The largest storm recorded in 24 weather stations occurred on 14 Jan 1993.

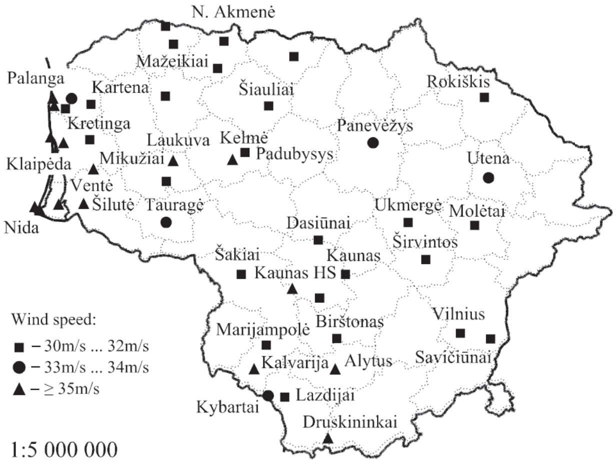

Fig. 1. Map showing the network of Lithuanian weather stations with 10-min wind speeds of at least 30 m/s recorded in 1962–2005 (the geographic coordinates of the stations were provided by Lithuanian Hydrometeorological Service, http://www.meteo.lt/)

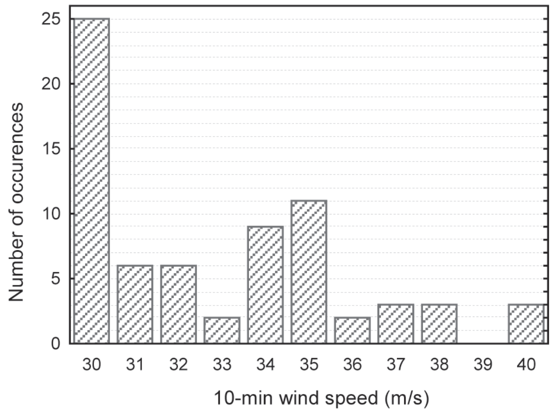

Fig. 2. Absolute frequencies of wind speeds recorded in 33 storms with the wind speed of at least 30 m/s in the 44 years period 1962 to 2005

The mean wind speeds of the extreme winds ranged between 30 m/s to 40 m/s. The frequencies of the wind speeds belonging to this range are shown in Fig. 2. These frequencies were calculated for a sample of wind speeds, which includes only one value of all speeds recorded in each individual storm, no matter how many whether stations measured this speed. Thus, 30 m/s wind speeds were recorded in 25 storms, 31 m/s wind speeds were recorded in 6 storms and so on. In counting the frequencies from the data given in Table 1, the values "over 30" and the like were replaced by a non-conservative "30" and the values "approx. 30" and similar by a fixed "30". The sample consists of 70 wind speeds.

The same sample of 70 winds speeds recorded in 33 storms was used to calculate annual frequencies of a non-strict exceedance of given wind speed values (Fig. 3). These frequencies are defined by

$$fr(v) = \frac{\text{Number of records greater or equal to } v}{\text{Period of record (years)}} . \quad (1)$$

The frequencies $fr(v)$ were calculated for the 48 year period 1962 to 2009.

Table 1. General data on storms with 10-min. wind speeds of at least 30 m/s recorded in Lithuania in the 44 year period of 1962–2005 (extracted from Korkutis (2000) and Lietuvos hidrometeorologijos tarnyba (2008))

Storm No.	Date	Weather station	10-min wind speed, m/s	Wind direction	Start of storm, hh:mm	Storm duration
1	2	3	4	5	6	7
			1960–1969			
1	1962 01 23	Klaipėda	34	SW	approx. 07:00	not recorded
2	1962 02 17	Klaipėda	30	NW	approx. 19:00	not recorded
3	1964 01 27	Kaunas AS(1)	30	NW	02:30	37 min
4	1965 12 06	Klaipėda AS	30	W	16:12	16 h 7 min
5	1967 10 18	Klaipėda	40	SW	00:25	12h 30 min
		Nida	40	SW	morning	not recorded
		Palanga AS	35	SW	02:00	12h 40 min
		Kybartai	34	W-SW	02:07	not recorded
		Laukuva	34	S	morning	not recorded
		Rokiškis	30	S-SW	morning	not recorded
		Šiauliai	30	S-SW	morning	not recorded
		Šilutė	30	SW	morning	not recorded
6	1967 11 12	Klaipėda	30	SW, S-SW/NW	21:00/02:40	2 h 45 min/4h 40 min
7	1969 03 09	Kaunas HS(1)	38	SW	08:00	12h 30 min
		Klaipėda AS	34	SW	13:20	10h 40 min
		Širvintos	approx. 31	SW	approx. 08:00	not recorded
		Padubisys	30	SW	10:35	8 h 25 min
8	1969 11 02	Klaipėda	36	W-NW	03:30	8h 40 min
		Klaipėda AS	35	W-NW	00:41	12h 19 min
	1969 11 01	Klaipėda	34	W	22:35	1 h 25 min
		Utena	30	W-SW, W-NW	02:30	1 h 35 min
	1969 11 03	Birštonas	approx. 31	not recorded	not recorded	not recorded
9	1969 11 20	Klaipėda	30	SW	03:55	1 h 20 min
	1969 11 21	Klaipėda AS	33	SW	23:05	5 h 55 min
			1970–1979			
10	1970 07 21	Klaipėda AS, Tubausiai	34	SW	13:05	3 h 55 min
11	1970 10 20	Klaipėda	35	SW	13:40	21 h 20 min
12	1970 10 31	Klaipėda	40	W	03:15	5 h 40 min
	1970 11 01	Klaipėda	30	W	18:10	8 h 10 min
	1970 11 02	Klaipėda	30	W	06:30	1 h 25 min
		Kaunas AS	30	NW	10:15	1 h
13	1970 11 10	Klaipėda	30	NW	14:10	41 min
14	1971 10 22	Šilutė	34	W	20:40	7 h 20 min
		Palanga AS	30	SW	approx. 17:05	not recorded
		Garliava	30	W	20:00	10 h 30 min
		Kybartai	30	SW	21:00	6 h 00 min
		Birštonas	30	NW	20:30	8 h 30 min
15	1971 12 08	Palanga AS	35	NW	11:00	19 h 45 min
16	1971 12 22	Palanga AS	30	NW	06:35	1 h 10 min
17	1972 03 23	Druskininkai	38	NW	approx. 20:00	not recorded
		Palanga AS	37	NW	16:25	20 min
		Kalvarija	35	W	approx. 19:00	not recorded
		Lazdijai	over 30	NW	approx. 20:00	not recorded
18	1973 11 23	Klaipėda	35	NW	approx. 15:00	not recorded
		Panevėžys	34	W-NW	afternoon	not recorded
		Utena	34	NW	approx. 18:00	not recorded
		Šilutė	34	NW	afternoon	not recorded
		Ventė	34	W-NW	afternoon	not recorded
		Kybartai	34	W-NW	11:00	9 h
		Birštonas	34	W	afternoon	not recorded
		Mikužiai	over 33	NW	approx. 15:00	not recorded
19	1975 01 06	Klaipėda	32	W	approx. 06:00	not recorded
20	1975 12 31	Klaipėda	30	W-PW	approx. 12:00	not recorded
21	1976 01 12	Alytus	35	W	approx. 21:00	not recorded
		Kalvarija	30	W	approx. 21:00	not recorded

Continued Table 1

Storm No.	Date	Weather station	10-min wind speed, m/s	Wind direction	Start of storm, hh:mm	Storm duration
1	2	3	4	5	6	7
			1980–1989			
22	1977 09 14	Klaipėda	30	SW	approx. 21:00	not recorded
		Šilutė	30	W-SW	approx. 00:00	not recorded
23	1981 11 21	Šilutė	30	W-SW	in the daytime	not recorded
		Klaipėda	30	SW	approx. 13:00	not recorded
24	1981 11 25	Kelmė	35	SW	night	not recorded
		Mikužiai	35	SW	night	not recorded
		Šilutė	35	S-SW	06:36	4h 54 min
		Nida	34	S-SW	morning	not recorded
		Kybartai	32	SW	morning	not recorded
		Klaipėda	30	SW	02:00	4 h
25	1982 12 16	Klaipėda	35	W	16:35	1h 40 min
		Šilutė	30	W-SW	afternoon	not recorded
		Nida	30	S	afternoon	not recorded
26	1983 01 18	Palanga	35	W	16:00	2h
		Šilutė	31	W-SW	in the daytime	not recorded
		Klaipėda	30	W	21:25	2 h 20 min
	1983 01 19	Šilutė	31	WNW	in the daytime	not recorded
		Nida	30	W	in the daytime	not recorded
27	1983 01 29	Šilutė	31	W-SW	in the daytime	not recorded
28	1984 01 02	Klaipėda	30	W	approx. 18:00	not recorded
29	1986 11 06	Nida	30	NW	20:05	55 min
			1990–1999			
30	1993 01 14	Nida, coastal station	36	SW	09:00	2 h
		Laukuva	35	W	09:05	2 h 55 min
		Telšiai	32	W-SW	07:25	6 h 35 min
		Ukmergė	31	W-SW	10:18	1 h 07 min
		Kybartai	31	W-SW	11:26	7 h 34 min
		Leckava	over 30	W-SW	morning	not recorded
		Mažeikiai	over 30	W-SW	morning	not recorded
		N. Akmenė	over 30	W-SW	09:45	9 h 15 min
		Joniškis	over 30	W-SW	morning	not recorded
		Papilė	over 30	W-SW	morning	not recorded
		Paakmenis	over 30	W	10:10	1 h 50 min
		Vilnius AS	30	W	approx. 11:00	not recorded
		Panevėžys	30	W-SW	09:35	3 h 50 min
		Vėžaičiai	30	SW	07:15	3 h 15 min
		Kelmė	30	W-SW	approx. 10:00	not recorded
		Molėtai	30	SW	morning	not recorded
		Dasiūnai	30	W-SW	11:00	7 h
		Šakiai	30	W-SW	11:00	3 h
		Savičiūnai	30	W	11:00	8 h
		Laukuva	30	W	night	not recorded
		Kartena	approx. 30	W-SW	morning	not recorded
		Mikužiai	approx. 30	SW	07:15	3 h 15 min
		Kretinga	approx. 30	W-SW	morning	not recorded
	1993 01 15	Marijampolė	31	W-SW	11:30	8 h
31	1999 12 04	Nida	40	S, SW[(3)]	06:33	10 h 20 min
		Ventė	40		08:00	8 h
		Mikužiai	38		03:30	5 h 30 min
		Klaipėda	38	S, SE[(2)]	04:30	11 h 45 min
		Šilutė	37	SW, W[(4)]	06:53	8 h 02 min
		Vėžaičiai	32		10:30	6 h 30 min
		Marijampolė	31		approx. 6:00	not recorded
		Birštonas	30		not recorded	not recorded

Continued Table 1

Storm No.	Date	Weather station	10-min wind speed, m/s	Wind direction	Start of storm, hh:mm	Storm duration
1	2	3	4	5	6	7
			2000–2005			
32	2002 01 29	Tauragė Klaipėda Mažeikiai	34 32 30	W-SW	8:15 16:20 17:30	15 min 10 h 25 min not recorded
33	2005 01 09	Klaipėda, seaport station Palanga	37 32	W W-SW	02:05 00:00	3 h 2 h

(1) AS = station at the airport; HS = hydrological station

(2) Prevailing direction in the evening of 1999 12 03, all stations

(3) Prevailing direction during the night and the 1st half of the day of 1999 12 04, all stations

(4) Prevailing direction during the night and the 2nd half of the day of 1999 12 04, all stations

The end of Table 1

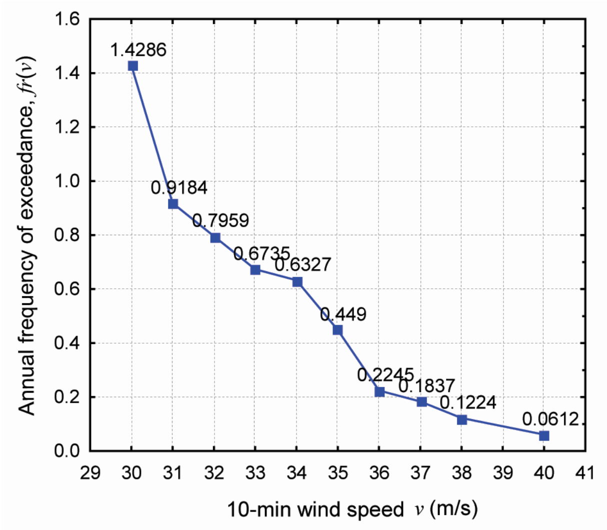

Fig. 3. Annual frequencies of a non-strict exceedance of the wind speed v calculated for the period 1962 to 2009

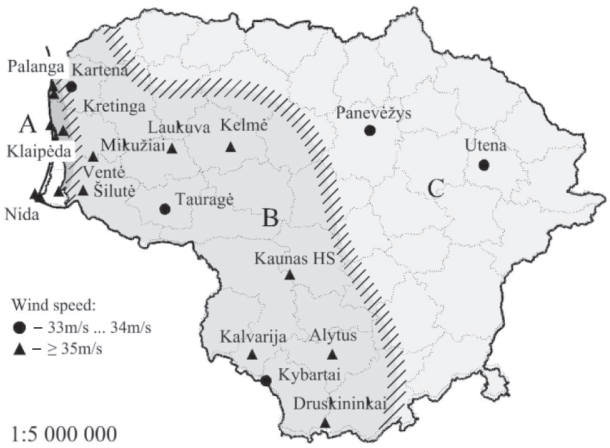

Fig. 4. Weather stations with the records of hurricane and catastrophic winds as well as proposed hurricane wind regions A, B, and C

The catastrophic winds with $v \geq 35$ m/s occurred in 15 storms in the period 1962–2005 (Table 1). During the storm, they were recorded in one weather station 9 times, in two stations 3 times, in three stations 2 times, and once the storm with catastrophic winds was observed in 5 stations. In total, the catastrophic winds were recorded in 16 weather stations (Fig. 4). The most severe storms with the mean wind speeds of 40 m/s were recorded three times, namely, on 18 Oct 1967, 31 Oct 1970, and 4 Dec 1999. All of these wind speeds were recorded in coastal wind stations.

3. Reliability and micrometeorological homogeneity of data on extreme winds

The instrumentation used for obtaining the wind data in Lithuania was of two types (Korkutis 1996):

- In the years 1961 to 1976, the wind speeds were measured by means of swinging-plate (pressure-plate) anemometers;
- Since 1976, the swinging-plate anemometers were replaced by windmill anemometers (the names of the devices were adopted from Allaby (2007)).

Information is available to adjust the wind records taken by swinging-plate anemometers to agree with the readings of the windmill anemometers (Korkutis 1996). The wind speeds recorded in Table 1 and covering the period 1960 to 1975 are adjusted readings of the swinging-plate anemometers. The set of wind speed data given in Table 1 may be considered to be relatively homogenous because all the data belonging to the set have been obtained under equivalent conditions. These conditions were determined by the following factors: averaging time, height of anemometers above ground, and roughness of terrain surrounding a weather station (e.g., Simiu and Scanlan 1996). As applied to the Lithuanian weather stations, the following statements can be made in favour of or against data homogeneity:

- The same averaging time of 10 minutes has been used in all weather stations during the period of record;
- The 10.2 m elevation of anemometers has been used in all weather stations since 1986; prior to

this year, elevations above 10.2 m have been used in a small number of stations (e.g., the costal station in Nida); all speeds from these stations included in Table 1 were corrected to agree with the readings at 10.2 m height;

– In some weather stations listed in Table 1, anemometer locations have been changed during the period of record; for instance, the stations in Laukuva, Šilutė and Panevėžys were relocated to more open areas and this had increased the quality of data recorded in these stations (Korkutis 1996); however, it doesn't seem that the records given in Table 1 have been adjusted to a common terrain roughness.

With one exception, the sensors of wind speed in all Lithuanian stations were exposed in such way that they were not influenced by local flow effects. In recent years, a land development around the Klaipėda costal weather station has changed the roughness of terrain surrounding its anemometer; however, these changes have not affected the terrain roughness in the prevailing directions of extreme winds. Consequently, there is no need to adjust wind speeds 38 m/s and 32 m/s recorded in this station during the storms 31 and 32 included in Table 1 (Galvonaitė 2009).

The maximum wind speeds of 40 m/s recorded in 1967 and 1970 by means of swinging-plate anemometers are of limited reliability. These instruments have the range of wind speeds limited by 40 m/s. It might be that the mean wind speeds of 40 m/s recorded in 1967 and 1970 have been exceeded, to say nothing about gust wind speeds. Another fact, which may also negatively influence the reliability of the data set given in Table 1 is a complete absence of the 39 m/s wind speed values (Fig. 2). It is difficult to explain what has caused such result, faulty observations or, simply, a pure coincidence.

One can conclude that the set of the wind speeds presented in Table 1 is not unquestionable in terms of reliability and meteorological homogeneity. On the other hand, this data set does not have grave and obvious faults, which could prevent it from being used for assessing the risks posed by extreme winds.

4. Estimation of data on extreme winds in relation to structural design

The set of wind speed data given in Table 1 can be estimated by comparing these data with the wind speeds specified in the loading codes STR 2.05.04:2003 and SNiP 2.01.07-85. They explicitly define serviceability and ultimate limit sates for structural design and provide either basic reference wind speeds (the case of STR) or characteristic wind pressures (the case of SNiP) for the regions of Lithuania shown in Figs 5 and 6.

The provisions of STR and SNiP are summarised in Tables 2 and 3, respectively. The basic reference wind speeds $v_{ref,0}$ specified in the STR code are 10-min mean velocities at 10 m height in open county terrain with an annual probability of exceedance of 0.02 (50-year return period) (Col. 2, Table 2). The characteristic wind pressures w_0 provided in the SNiP code were defined analogously

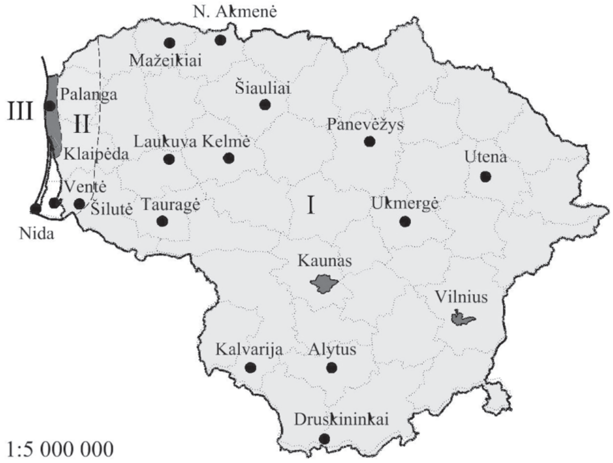

Fig. 5. The map of basic reference wind speeds $v_{ref,d}$ specified in the design code STR 2.05.04:2003 (see also Table 2)

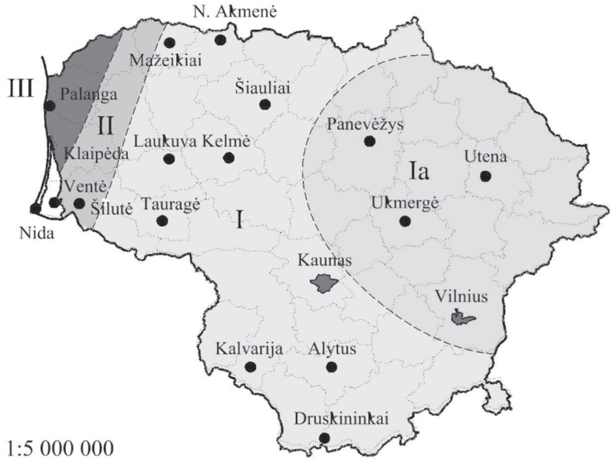

Fig. 6. The map of characteristic wind pressures w_0 specified in the design code SNiP 2.01.07-85 (see also Table 3)

with the exception of the return period. This period was set to be equal to 5 years although the code allowed specifying longer return periods (Col. 2, Table 3). The reason why such short basic return period was specified in the SNiP code is not known to us.

A natural approach to an estimation of the wind data given in Table 1 is a comparison of these data with the design wind speeds $v_{ref,d}$ and v_d, which were obtained by applying partial factors for the wind specified in STR and SNiP codes (Cols. 5 and 4 in Tables 2 and 3, respectively). As the basic reference wind speed $v_{ref,0}$ is defined using the annual exceedance probability of 0.02, one can expect that such probability for $v_{ref,d}$ will be much smaller.

The design wind speeds $v_{ref,d}$ and v_d (or corresponding dynamic wind pressures) have been applied in the years 1987 to 2009 to the design of structures for ultimate limit states. The frequency and magnitude of exceedance of these values by the mean wind speeds recorded during wind storms are obvious criteria for assessing the hazard to structural property posed by the storms listed in Table 1.

In this regard, one can say that the design wind speeds specified in the SNiP code, v_d, were exceeded during all 33 storms recorded in all regions shown in Fig. 6. After the

Table 2. Wind speed regions in Lithuania specified in the structural design code STR 2.05.04:2003 used since 2003

Wind speed region (see Fig. 6)	The basic reference wind speed $v_{ref,0}$, m/s$^{(1)}$	Characteristic wind pressure q_{ref}, kPa	Design wind pressure $\gamma_Q\, q_{ref}$, kPa$^{(2)}$	Basic design wind speed $v_{ref,d}$, m/s$^{(3)}$
1	2	3	4	5
I	24	0.36	0.468	27.4
II	28	0.49	0.637	31.9
III	32	0.64	0.832	36.5

(1) A 10-min mean velocity at 10 m height in open country terrain with 50-year return period

(2) The partial factor for the wind action $\gamma_Q = 1.3$

(3) Calculated by the standard formula $v_{ref,d} = (2\ \gamma_Q\, q_{ref}/\rho)^{1/2}$ with the air density $\rho = 1.25$ kg/m^3; q_{ref} in Pa

Table 3. Wind speed regions specified in the structural design code SNiP 2.01.07-85 used in Lithuania in the years 1987 to 2002

Wind speed region (see Fig. 7)	Characteristic wind pressure w_0, kPa$^{(1)}$	Design wind pressure $\gamma_f\, w_0$, kPa$^{(2)}$	Design wind speed v_d, m/s$^{(3)}$
1	2	3	4
Ia	0.17	0.238	19.5
I	0.23	0.322	22.7
II	0.30	0.420	25.9
III	0.38	0.532	29.2

(1) 5-year return pressures with a 10-min averaging time at 10 m height in open country terrain

(2) The partial factor for the wind action $\gamma_f = 1.4$

(3) Calculated by the standard formula $v_d = (2\ \gamma_f\, w_0/\rho)^{1/2}$ with the air density $\rho = 1.25$ kg/m^3; w_0 in Pa

Table 4. Numbers of exceeding of the design wind speeds $v_{ref,d}$ specified in STR 2.05.04:2003 and corresponding frequencies of exceedance calculated for the 48 years period 1962 to 2009

Wind speed region j (see Fig. 6)	Basic design wind speed $v_{ref,d}$, m/s	Numbers of exceeding N_j/ annual frequency N_j/48	Mean value of exceeding $v_{ij} - v_{ref,d}$, m/s$^{(1)}$	Maximum of exceeding $v_{ij} - v_{ref,d}$, m/s$^{(1)}$
1	2	3	4	5
I	27.4	47 / 0.98 per annum	4.17	10.6
II	31.9	15 / 0.31 per annum	3.83	8.10
III	36.5	5 / 0.10 per annum	1.90	3.50

(1) The symbol v_{ij} denotes the ith 10-min wind speed from Table 1 recorded in a weather station located in a respective wind speed region j ($i = 1, 2, \dots, N_j$)

introduction of the SNiP code in 1987 and until the last storm recorded in 2005, largest design value $v_d = 25.9$ m/s specified in SNiP for the coastal region III was exceeded four times by the winds ranging from 30 m/s to 40 m/s. This yields the annual exceedance frequency of 0.21 per annum. The 30 m/s to 40 m/s winds were 1.16 to 1.54 times faster than the wind with the speed v_d. The situation in the remaining wind speed regions I, Ia, and II is even more risky.

The design wind speeds provided in the STR code, $v_{ref,d}$, are more conservative that those specified in the SNiP code (compare Tables 2 and 3). Despite the fact that the "coastal" design wind speed $v_{ref,d} = 36.5$ m/s is relatively high, this speed was already reached and even slightly exceeded once after the introduction of the STR code in 2003 (the storm of 2005, Table 1). If we consider a long-term exceedance frequency related to the entire period of record in region III, 1962 to 2009, this frequency amounts to 0.10. Table 4 summarises numbers of exceeding and annual exceedance frequencies calculated for the three wind speed regions shown in Fig. 5 (see Col. 3). The annual frequencies given in Table 4 exceed by far the annual probability 0.02 used in the STR code to specify the basic reference wind speeds $v_{ref,0}$ for all regions. This difference is particularly grave in case of the largest region I. This region appears to be the most problematic also in terms on exceedance magnitude expressed by mean values and maxima of the differences between the winds speed given in Table 1, v_{ij}, and the design wind speed $v_{ref,d}$ calculated for all three regions (Cols 4 and 5, Table 4). Although the magnitude of exceedance of the design values $v_{ref,d}$ is not dramatic, it can be a cause of concern due to the following reasons:

– A relatively often exceedance of the design values (once every 1 to 10 years, depending on the region) can lead to an accumulation of wind-induced damage in a wind-sensitive structure;
– A gradual deterioration of structural resistance due to, say, corrosion may become dangerous during the wind loading peaks occurring as an exceedance of the design wind speeds, for which the structure was dimensioned;
– Older wind-sensitive structures designed and built in 1983 to 2002 in line with the SNiP code (or codes used in previous years) may be prone to the peak loading induced by the winds exceeding the design wind pressures specified in these codes.

The exceedance data shown in Table 4 lead to an obvious conclusion: the provisions of the STR design code are not sufficiently conservative, especially, with regard to the largest, inland wind speed region I. To the best of our knowledge, the basic reference wind speeds $v_{ref,0}$ were determined for all three regions by a standard extreme value procedure based on annual fastest wind series, although this was not documented in the open literature.

In our opinion, the exceedance of the design wind speeds $v_{ref,d}$ highlights the need to separate data expressed as the annual fastest wind series and data recorded during wind storms. The storm data can be grouped into the so-called partial duration series (e.g., Liu 1991; Ben-Zvi 2009). The need for such grouping arises from the fact that no storms were recorded in Lithuania during 27 years spread within the period 1962 to 2009, whereas the years 1967, 1969, 1971, and 1981 had more than one wind storm. The creation of the partial duration series evokes the question of dividing the territory of Lithuania into storm regions and combining storm data from several weather stations in each region.

5. Proposal of hurricane wind regions in Lithuania

The importance of the separation of data originating from different storm types and composing data on each type of storm from several stations into "super-stations" was recognised many times in the past decades (Gomes and Vickery 1977; Peterka and Shahid 1998; Holmes 2002; Cook 2004). The influence of individual storms on wind speed maps was investigated by Sacré (2002).

The Lithuanian wind climate is simple in the sense that the dominant type of wind storms affecting large parts of territory are cyclonic winds. The hurricane threshold of 33 m/s (75 mph) is the mostly known value related to cyclonic winds and the best candidate to separate fastest annual winds from extreme winds. In addition, this threshold exceeds the design wind speeds specified for the regions I and II (see Fig. 5 and Table 2).

A distribution of Lithuanian weather stations with records of hurricane winds (≥ 33 m/s) shown in Fig. 4 suggests an obvious conclusion that the southern and south-western parts of Lithuania, together with the coastal region, are much more prone to hurricanes than the north-eastern territory. In our opinion, this requires to introduce three hurricane wind regions:

- Region A as a narrow coastal strip covering the main coastal towns Klaipėda, Palanga, and Nida and the "inner" coastal station Ventė;
- Region B covering a near-coastal region and south-western part of Lithuania;
- Region C in the north-eastern part of Lithuania; this region can be considered to be not hurricane-prone one; hurricane winds of 34 m/s were recorded in two stations of this region only once during the storm of 1973 (Table 1).

We consider these regions to be preliminary and further investigation is necessary, to separate regions on a more detailed geographic level. However, such investigation is beyond the scope of the present work.

To allow a hurricane wind risk assessment, wind speed data for the regions A to B should be grouped into two partial duration series expressed as statistical samples, the components of which can be considered independent observations. We think that the basic property of independence can be assured by the following assumptions:

1. Occurrences of subsequent hurricanes in each region can be considered as independent events;
2. Each hurricane is represented in the sample by one wind speed;
3. In cases where hurricane wind speeds were recorded in more than one weather station within the region during the same storm, hurricane can be represented by the largest record.

Table 5. Statistical samples of hurricane wind speeds (m/s) in the hurricane wind regions A, and B (Fig. 4)

No of sample element	10-min 10 m wind speed (year of storm/storm no, Table 1)	
	Region A	Region B
1	34 (1962/1)	34 (1967/5)
2	40 (1967/5)	38 (1969/7)
3	34 (1969/7)	34 (1970/10)
4	36 (1969/8)	34 (1971/14)
5	33 (1969/9)	38 (1972/17)
6	34 (1970/10)	34 (1973/18)
7	35 (1970/11)	35 (1976/21)
8	40 (1970/12)	35 (1981/24)
9	35 (1971/15)	35 (1993/30)
10	37 (1972/17)	34 (2002/32)
11	35 (1973/18)	
12	34 (1981/24)	
13	35 (1982/25)	
14	35 (1983/26)	
15	36 (1993/30)	
16	40 (1999/31)	
17	37 (2005/33)	
Mean $\bar{v}$ (m/s)	35.9	35.1
Std.dev. s (m/s)	2.23	1.60
v_{50} (m/s)	43.3	40.4
v_{100} (m/s)	44.9	41.5
Period of record	44 years	36 years
Annual frequency	0.39 per year	0.28 per year

The latter assumption allowed creating statistical samples, the components of which are conservative in the sense of wind risk. The samples are presented in Table 5. The wind speeds were included into the samples without identifying a causal storm mechanism because the only type of large-area storms in Lithuania is cyclonic winds. The samples related to the Regions A and B contain 17 and 10 elements, respectively. The mean $\bar{v}$ and standard deviation s of these samples are presented at the bottom of Table 5. The latter values were applied to calculate the wind speeds v_{50} and v_{100} corresponding to 50-year and 100-year return periods, respectively. Liu (1991) recommends obtaining these values by the expression

$$v_T = \bar{v} + 0.78\,(\ln T' - 0.577)s \quad (T = 50 \text{ or } 100 \text{ years}), \qquad (2)$$

where T' is the return period for a partial duration series. The value of T' is calculated by the expression $-(\ln(1 - 1/T))^{-1}$. Eq. (2) is based on the use of a Type-I extreme value distribution for extreme wind analysis in hurricane regions. The values of v_{50} and v_{100} are given in Table 5. One can see from this table that the values $v_{50} = 43.3$ m/s (Region A) and $v_{50} = 40.4$ m/s (Region B) exceed considerably the basic reference wind speeds $v_{\mathrm{ref},0} = 24 \ldots 32$ m/s, which also correspond to a 50-year return period (compare Tables 2 and 5).

The statistical quality of the two samples presented in Table 5 is impaired by two facts. Firstly, the size of the samples is too small from the standpoint of the classical statistics. Secondly, the samples contain a relatively large number of repeated values. This makes a reliable fitting of a probability distribution to these samples problematic. However, we think that these samples are suitable to a probabilistic wind risk assessment by applying procedures of statistical (bootstrap) resampling suggested by Vaidogas (2003, 2007, 2009) as well as Vaidogas and Juocevičius (2007, 2009).

6. Conclusions

In this paper we presented an appraisal of data on extreme winds recorded during the past 48 years in Lithuanian weather stations. The data includes records of wind storms with the mean wind speeds of at least 30 m/s. It was found that coastline region and large south-western inner part of Lithuania are prone to strong cyclonic winds, the mean wind speed of which sometimes exceeds the hurricane threshold of 33 m/s.

The wind data was appraised in two respects: in terms of data quality (reliability and meteorological homogeneity) and in relation to a structural design for wind. It was noted that, whereas the data quality does not cast any considerable doubts, a "grey area" appears when this data is compared to the reference ("characteristic") wind speeds and design wind speeds specified in the current Lithuanian loading code and Russian loading codes, which preceded the former one. The design wind speeds were exceeded during wind storms much more often than once per 50 years as declared in the current loading code. The magnitude of exceedance is also a cause of concern, especially in the largest inland wind speed region of Lithuania.

The problem of exceeding of the design wind speeds can be solved by a separation of data represented as the fastest annual wind speed series and data originating from strong cyclonic winds. The paper suggested two hurricane wind zones for compiling the so-called partial duration series of hurricane wind speeds. These series were represented as two small-size statistical samples with independent components (hurricane wind speeds). The wind speeds with 50-year return periods determined with these samples can be used for the design of major infrastructure components for hurricane winds. It was also stated that there is a prospect of applying these small-size samples to a risk-based design for hurricanes of wind-sensitive components of major infrastructures, for instance, power supply lines or communication network.

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PAPER REVIEWS

VĖJO KELIAMA ŽALA APLINKAI: KRITINIS DUOMENŲ APIE EKSTREMALIUS VĖJUS LIETUVOJE VERTINIMAS

E. R. Vaidogas, V. Juocevičius

Santrauka

Nagrinėjami duomenys apie vėjo audras, kilusias Lietuvoje per pastaruosius 48 metus. Pateikiama duomenų apie vėjo audras, kurių vidutinis vėjo greitis buvo ne mažesnis kaip 30 m/s. Įvertinamas duomenų patikimumas ir meteorologinis homogeniškumas. Duomenys apie vėjo audras analizuojami vertinant tokių audrų galią sukelti užstatytos aplinkos pažeidimus. Nustatyta, kad ekstremalūs vėjai (didelės cikloninės audros) daugelį kartų viršijo bazinius atskaitinius ir projektinius vėjo greičius, apibrėžtus anksčiau Lietuvoje galiojusių ir dabar galiojančių projektavimo normų. Atskaitinių ir projektinių vėjo greičių viršijimai daug dažnesni nei normose nustatomas vieno karto per 50 metų dažnis. Atskaitinių ir projektinių vėjo greičių viršijimas taip pat yra gana pavojingas. Siūloma ekstremalius vėjo greičius analizuoti atskirai nagrinėjant metinius vėjo greičio maksimumus ir duomenis apie uraganinius vėjus. Lietuvos teritoriją siūloma dalyti į tris zonas, iš kurių dvi turėtų būti laikomos uraganinių vėjų zonomis. Baziniai atskaitiniai vėjo greičiai šiose zonose skaičiuojami taikant dalinės trukmės sekų metodiką. Uraganinių vėjų zonų įvedimas leido suformuoti dvi mažo dydžio statistines imtis, kurių elementai yra uraganinio vėjo greičio matavimų duomenys. Šias imtis siūloma taikyti vertinant uraganų sukeliamą riziką.

Reikšminiai žodžiai: vėjo parametrai, štormas, uraganas, dalinės trukmės seka, vėjo apkrova, vėjo zona.

ПОВРЕЖДЕНИЯ ОКРУЖАЮЩЕЙ СРЕДЫ, ВЫЗЫВАЕМЫЕ ВЕТРОМ: КРИТИЧЕСКАЯ ОЦЕНКА ДАННЫХ ПО ЭКСТРЕМАЛЬНЫМ ВЕТРАМ В ЛИТВЕ

Э. Р. Вайдогас, В. Юоцявичюс

Резюме

Рассматривается оценка повреждений, которые могут быть причинены природной и застроенной среде экстремальными ветрами. Внимание сосредотачивается на ветровых штормах, наблюдавшихся в Литве за последние 48 лет. В статье представлены данные о штормах со средней скоростью ветра не менее 30 м/с. Оценивается надежность и метеорологическая однородность данных по экстремальным ветрам. Данные анализируются в свете их применения к оценке потенциальных повреждений застроенной среды. Установлено, что экстремальные ветра, создаваемые большими циклонами, во много раз превышали нормативные и расчетные значения скоростей ветра, установленные нормами проектирования, применявшимися в предыдущие годы и применяемыми в Литве в настоящее время. Частота превышения нормативных и расчетных значений значительно превышает декларируемую настоящими нормами одноразовую частоту за 50 лет. Степень превышения нормативных и расчетных значений скорости ветра также является достаточно опасной. Предлагается раздельный анализ данных по годовым максимумам скоростей ветра и данных по ураганам. Вводятся три зоны территории Литвы, две из которых следует рассматривать как зоны возможных ураганов. Нормативные значения скорости ветра в этих зонах определяются при помощи метода последовательностей частичной продолжительности. Введение зон ураганных ветров позволило сформировать две статистические выборки, включающие в себя относительно небольшое количество ураганных скоростей ветра. Предлагается использовать эти выборки для оценки риска, создаваемого ураганами.

Ключевые слова: ветровые данные, шторм, ураган, последователъностъ частичной продолжителъности, ветровая нагрузка, ветровая зона.

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