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Wind as a natural hazard in Poland

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Abstract. The paper deals with the wind speed of strong and extreme wind events in Poland and their descriptions of their effects. Two recent estimation developed by the Institute of Meteorology and Water Management in Warsaw [4] and by Lorenc [3] are presented. Their strong and weak points are briefly described. The 37 annual maximum gusts of wind speeds measured at all meteorological stations between 1971 and 2007 are analysed with extremal probability paper. Based on the measured and estimated wind speeds (taken from existing literature), the authors suggest new estimations for strong and extreme wind that may occur in Poland. In the near future, Poland is going to construct some important structures, such as a central air terminal and some nuclear power plants, so knowledge about strong and extreme winds in our country is very important for engineers who will design these types of structures. In this case, the information given in Section 6 of the ISO 1382 standard for identifying hazards, estimating, evaluating, and treating risk may be applied.

1 Introduction

The wind is the dominating environmental loading affecting structural design in the world and is responsible for damage to structures in many countries as well as in Poland. Moreover, hurricanes and tornadoes can cause economic losses and have negative impact on society (Fricker, 2020; Kafi et al., 2021). Also in Poland, wind storms such as synoptics, thunderstorms, and downslope winds in the Tatry and Karkonosze mountain regions, tornadoes, downbursts, and derechos are leading causes of economic loss. It is also one of the main load types considered during the process of structural design. To design a critical infrastructure, it may be important to consider rare, extreme events. The proper estimation of these extreme events and analysis of their effects on the structures and infrastructure are still a current research issues. The recent estimation of the wind speed for all types of wind events was developed by Lorenc (2012). For the gust wind speeds in the range from 11 to 32 m/s at 10 m above ground, five names were proposed as follows: violent wind, storm, strong wind, and hurricane wind. It is not used in everyday life, and the authors of this paper are opposed to this proposal (for example, we do not have tropical storms in Poland, i.e., no hurricanes). The authors' study of maximum wind speeds in Poland is based on a set of annual maximum gust wind speeds measured at 39 meteorological stations from 1971 to 2010 (40 years), tornado reports collected from 1899 to 2019 (120 years), and estimation of wind speeds of derechos and recent tornadoes in Poland (Polish Government Centre for Security, 2013; Chmielewski et al., 2013; Taszarek and Brooks, 2015; Chmielewski et al., 2020). The authors' proposals for maximum wind speeds in Poland are given in Tables 1 and 2.

The case study of the estimation of strong and extreme wind speeds in Poland based on the measured and estimated wind speeds, is analysed in Section 4. In section 5 new extreme wind estimation is proposed. As in the near future, Poland is going to construct some important structures, such as a central air terminal and some nuclear power plants, in section 6 procedure for the application of this new wind classification is briefly described.

2 Poland and types of wind events

Poland is located in the center of Europe between the Baltic See in the north and the mountain ranges of the Carpathians and Sudetes in the south. So, the two types of climatic prevail, i.e. the continental and coastal. The most of the country is flat situated two or three hundred meters above sea level. Five different types of strong wind events may be distinguished in Poland. They are western or northern–western extratropical cyclones; downslope winds in the Tatra and Karkonosze mountain regions (foehn winds); thunderstorms; tornadoes which belong to the most devastating wind events, as described in (Chmielewski et al., 2013); derechos, an example of such event is described in the paper (Chmielewski et al., 2020).

3 Existing estimation of wind speeds in Poland

Two classifications of weak and strong winds exist in Poland. The first is done by the Institute of Meteorology and Water Management (IMWM) (only for weak and strong winds, not for extreme winds like tornadoes or derechos) (Polish Government Centre for Security, 2013). It considers three threats for three different wind speeds with a description of the effects of the wind action as follows 1st threat degree, $V_{av} > 15$ or $V > 20$, damage to buildings, roofs, damage to trees, breaking branches and trees, traffic difficulties, 2nd threat degree, $V_{av} > 20$ or $V > 25$, damage to buildings, roofs, breaking and uprooting trees, difficulties in communication, damage to overhead lines; 3rd threat degree, $V_{av} > 25$ or $V > 35$, destroying buildings, tearing off roofs, destroying overhead lines, large damage to trees, significant difficulties in communication, life-threatening.

The second classification was proposed by Lorenc (2012) who was a co-worker at the Institute of Meteorology and Water Management. This proposal consists of eight classes in the range of wind speeds from 11 to more than 251 m/s with a damage description for each class. These classes are as follows: gusty wind; violent wind; storm; strong wind; hurricane wind; hurricane/tornado 1st degree, very strong hurricane/tornado 2nd degree, destructive hurricane/ tornado 3rd degree. As it is written in the introduction, this proposal is not used in everyday life. And the authors of this paper are opposed to this proposal. We do not have tropical storms in Poland, so the name hurricane should be not used.

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4 Wind speed measured and estimated in Poland

4.1 Yearly maximum wind speeds measured at the meteorological stations

Wind speed records in gusts (measured in the years 1971-2007) were in the range of 25 – 40 m/s, extreme values were also recorded: 6.11.1986 Bielsko Biała 48 m/s, 1.12.1975 Zakopane 47 m/s, 21.10. 1986 Kalisz 46 m/s, 8.02.1990, Łeba 44 m/s, 4.12. 1999 Hel 41 m/s.

4.2 The Extremal Probability Paper

In Fig. 1, 37 annual maximum gust wind speeds measured in all meteorological stations in the years 1971- 2007 (Lorenc, 2012) are plotted on the Gumbel probability paper. The red line indicates the regression line fitted to the data with the following coefficients: $u_n = 32.4$ and $1/a_n = 5.14$. As can be noticed regression line fits well measured data which means that the random phenomenon of extremal wind speed described in this point can be modeled with a log-normal distribution, known also as the Gumbel distribution, one of the extreme-value distributions.

From the straight line graph, the probability associated with annual wind speeds in Poland of a given value may be read off directly. For example, the annual probability of gust wind speeds exceeding magnitudes 30 and 40 are as follows: $P(v_n > 30) = 1 - F_{Vn}(30) = 1 – 0{,}21 = 0{,}79$; $P(v_n > 40) = 1 - F_{Vn}(40) = 1 – 0{,}80 = 0{,}20$. The return period for wind speeds bigger than 45 m/s can be also easily estimated. For example, the 50 years return period corresponds to $s = -\log(-\log(0.98)) = 3.90$ and wind speed $v_n = 32.4 + 5.14 \cdot 3.90 = 52.4$ m/s.

4.3 Estimated wind speeds of tornadoes and derechos

The paper (Taszarek and Brooks, 2015) describes an updated climatology of tornadoes in Poland and the major problems related to the database. A total of 269 tornado cases derived from the European Severe Weather Data are used in the analysis, and the tornadoes are divided according to their strengths. On average, 8–14 tornadoes (including 2-3 waterspouts) with two strong tornadoes occur each year, and one violent one occurs every 12–19 years. Cases of strong and even violent tornadoes that cause death indicate that the possibility of a large-fatality tornado in Poland cannot be ignored.

The estimated extreme wind speeds of tornadoes and derechos were based on recent papers on these phenomena, which happened in Poland in the past and recently (Chmielewski et al., 2013, 2020, 2022). In the first case, i.e., on the 15th of August, 2008, a tornado caused severe damage in the three provinces of Poland: Opole, Katowice, and Łódź. Along the 105 km path, 1624 buildings were damaged, 4 people were killed, 60 people were injured, and some livestock was killed. Two approaches were used to estimate the wind speeds of the tornado. The first one was based on a comparison of the examined damage caused by the tornado in the affected area with the TORRO (tornado intensity scale). The second approach was based on the structural analysis of destroyed free-standing structures. The three road signs, which were bent while the tornado was passing, were examined during these studies. In the first approach, the wind speeds were estimated in the range of 52–72 m/s at a reference height of 10 m. In the second approach, the wind speed was estimated at around 71 m/s at 2.3 m above ground.

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In the second case, a strong thunderstorm happened on August 11–12, 2017, which resulted in catastrophic damage in three provinces in Poland: Wielkopolskie, Kujawsko-Pomorskie, and Pomorskie. This disaster has resulted in the deaths of six people, the injuries of several dozen others, and enormous property losses. It is described and analyzed in the paper (Chmielewski et al., 2020). A house with its roof blown off was thought to be an excellent example of wind speed for this derecho (Chmielewski et al., 2022). Based on the rafter framing of the house, the weight of the roof was calculated. With the estimation of connection strength between rafter plates and knee walls, it was possible to calculate the total force required to blow off the roof of the house. Next, the pressure coefficients were taken from the Tokyo Polytechnic University aerodynamic database. The aerodynamic force acting on the blown-off roof was calculated for the low-rise building with a gable roof because of similar ratios for length, width, and height. By comparing the aerodynamic force with the total force required to blow off the roof of the house, it was possible to calculate the critical wind speed needed for the roof blow-off. This critical wind speed was around 60 m/s. It was much bigger than wind speeds measured by meteorological stations on the path of the derecho in Chojnice (31,2 m/s), Gniezno (34,8 m/s), Chrząstowo (36 m/s), and Elbląg (42 m/s).

5 Development of estimation of maximum wind speeds in Poland

The authors suggest a new estimation for strong and extreme winds that may occur in Poland in the future based on old and recent works (e.g. Chmielewski and Nowak, n.d.) and the EF-Scale for Tornado Intensity (Mehta, 2013). This proposal is published first in the paper [9] and the authors of this paper confirm this proposal. This is done in recognition of the limitations of the current estimation for maximum wind speeds. Strong and intense winds are the two types of winds into which it is classified, as seen in Tables 4 and 5. The author's estimation is based on a distinction between strong wind speeds and extreme wind speeds. Based on the authors' observations over several years, Table 4 provides an explanation of the impacts of significant wind action.

Table 1. Classification of the levels of threats caused by strong wind [IMWM + Authors]

Degree threats	Wind speed criteria [m/s]	Description of the effects of wind action
1	Vav > 15 or V> 20	It moves tree branches, billboards, and road signs. Some of them can be knocked over. Breaks weaker tree branches that can block communication routes. It tears off individual roof tiles, scatters garden furniture, and damages local power lines, tents and awnings. Wind speed is felt by vehicle drivers. Light objects float in the air. During snowfall the wind causes blizzards.
2	Vav > 20 or V> 25	It breaks tree limbs, breaks or tears up shallow-rooted trees, broken branches and trees block roads, trams and railway lines. It is possible that tree branches fall on vehicles. Broken power cables (tens of thousands of people are deprived of

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		electricity), Wind significantly damages roofing, damages old farm and residential buildings. During gusts of wind, cars are pushed to the side of the road. It overturns billboards, road signs, and fences, individual items are floating in the air, after an intense storm, and cellars and apartments are flooded.
3	Vav > 25 or V≤ 30	Such synoptic wind velocities rarely occur in Poland - once every few years, their effects are similar to those described in the case of hazard level 2, but in larger dimensions, e.g., there are significantly damaged or completely broken roofs, damaged farm buildings and residential buildings, broken power poles and cables, roofs with reinforced concrete and steel structures are damaged. The described nature of the damage is typical of weaker tornadoes and squalls.

V_{av} – mean wind speed, V- gust wind speed

Table 2. Classification of extreme wind speeds

EF0	EF1	EF2	EF3	EF4	EF5	Wind speed
105-137	138-178	179-218	219-266	267-322	>322	km/h
29.2-38.1	38.6-49.4	49.7-60.6	60.8-73.9	74.2-89.4	>89.4	m/s
P0	**P1**	**P2**	**P3**	**P4**	**P5**	
108 - 120	**121-170**	**171-220**	**221-270**	**271-324**	**>324**	**km/h**
30,0 - 33.3	**33.6-47.2**	**47.5-61.1**	**61.4-75**	**75-90**	**>90**	**m/s**

6 Application of estimation of maximum wind speeds in Poland in engineering practice

The question arises as to how the estimations of wind speed in Poland presented in this paper may be used in engineering practice. The answer to this question gives the ISO 1382 standard (ISO, 2020). This standard provides a procedure for identifying hazards, estimating, evaluating, and treating risk through communication, consultation, and review. This procedure may be applied for important existing or new design structures and for systems involving structures.

7 Conclusions

a) The proposed wind speed estimation has been developed using data available in Poland, as described in Section 3. It estimates wind speed for strong winds (Table 1) and extreme winds (Table 2) ~~such~~ as tornadoes, derechos, etc.

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b) The authors propose: for synoptic, downslope winds in the Tatra and Karkonosze mountain regions, the estimation of strong winds proposed by IMWM with an improved description of the effects of wind action (Table 1), and adaptation of the EF tornado intensity scale with some modifications to extreme winds presented in Table 2 (the "P" scale).

c) To identify hazards and treat risks for important existing or new design structures in Poland, the information given in the ISO 1382 standard (ISO, 2020) may be applied.

Author contribution

TCh: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft preparation, Writing – review & editing. PB: Formal analysis, Visualization, Writing – review & editing.

Competing interests

The authors declare that they have no conflict of interest.

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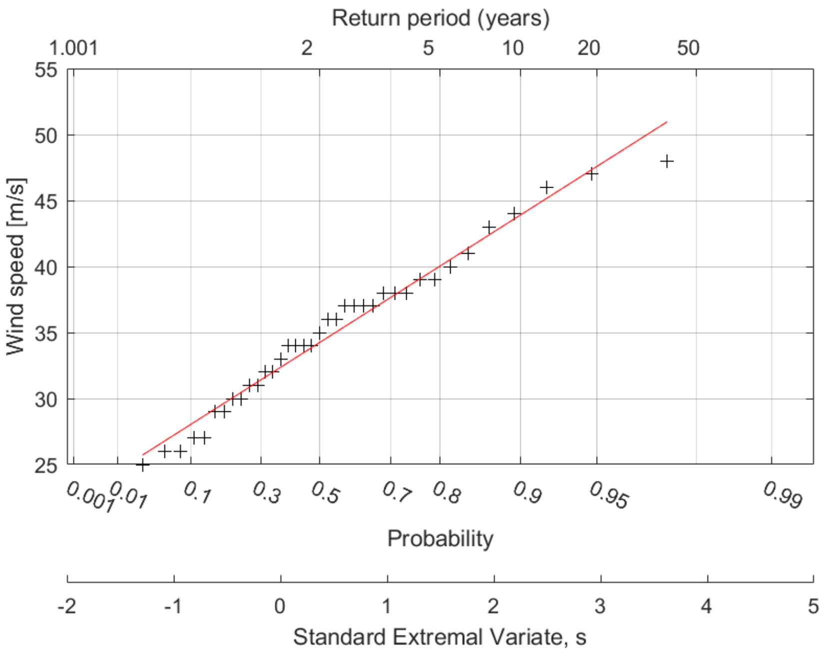

Fig. 1. Plot of wind speed from [1] against standard extremal variate *s*.