Case study of a derecho wind storm on August 11-12, 2017 in Poland: part one

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Abstract. Windstorms belong to the most costly natural threats in Poland. On August 11-12, 2017, a strong thunderstorm happened which resulted in a catastrophic damage in three provinces: Wielkopolskie, Kujawsko-Pomorskie, and Pomorskie. This disaster has resulted in the death of 6 people, injuries to several dozen people, and enormous property losses including approximately 16,000 residential, utility and public buildings, 80,000 hectares of forest area, 67,000 hectares of agricultural crops, in excess of 300 overhead power line poles, and over 200 cables were downed. The trees felled by the wind blocked and partially damaged local and municipal roads over a length of about 1100 km. Over 500,000 consumers were deprived of electricity at the peak of the disaster. The purpose of this paper is to describe, analyse, and learn from such a dangerous extreme weather event. In order to achieve this, a cause of the thunderstorm, its important meteorological data, the severity of damage to buildings, civil infrastructure and environment, processes of damage surveys, ideas for reconstruction and removing of all damage, financial assistance from the central government, local authorities, and public collections were studied for better preparation of all services and people for mitigation of the effects of a natural disaster which may happen in the future. An example of a building with improved stiffness as the solution for better resistance of wind forces is presented.

1 Introduction

Damage to buildings, civil infrastructure, and the environment by different kind of wind storms have been a fact of life for a human being from the past to the present day. On August 11-12, 2017, a mesoscale convection system containing the squall line was created on the border between the Czech Republic and Poland, passing through the Dolnośląskie, Opolskie, Wielkopolskie, Kujawsko-Pomorskie, and Pomorskie provinces. When the thunderstorm reached the border between the Dolnośląskie and Wielkopolskie, it grew stronger and caused catastrophic damage in three provinces: Wielkopolskie, Kujawsko-Pomorskie, and Pomorskie. The disaster has caused the death of 6 people, injuries to several dozen people and enormous property losses including approximately 16,000 residential, utility, and public buildings, 80,000 hectares of forest area, 67,000 hectares of agricultural crops, in excess

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of 300 overhead power line poles and over 200 cables were downed. The trees felled by the wind blocked and partially damaged local, and municipal roads over a length of about 1100 km. Over 500,000 consumers were deprived of electricity at the peak of the disaster. The objective of this paper is to describe, analyse, and learn from such a dangerous extreme weather event. Specifically, in order for better understanding the course of rescue operations in the first response and subsequent days after the natural disaster, documenting related structural damage, and later repair and reconstruction in order to mitigate the effects of this natural disaster.

This paper present only first finished part of post-disaster investigation results. The second part on the 65 Scientific Conference in Krynica-Zdrój 15-20.09.2019 is going be presenting.

2 Description of the cause of the thunderstorm

In Poland, the first days of August 2017 were sunny. From August 9, 2017 hot tropical air began to flow into Poland, carrying a huge amount of energy. At 00:00 (02:00 official time) on August 11, 2017, a wavy, almost stationary, cool polar-maritime atmospheric front approached western Poland, preceded by a line of convergence. The front was arranged parallel to the flow at the central troposphere, so it moved slowly deep into the country only departing on the morning of August 13, 2017. The meeting of these two different air masses - hot tropical and cold polar - generated a dangerous weather phenomenon. There was a strong thermal gradient, the difference between the temperature in the north-west and the temperature in the south-east, both near the surface of the Earth and at a level of 850 hPa (at a height of about 1500 m), was about 13°C. Amongst the hot and unstable mass of air, a squall line formed along the front. One of these lines was created on Friday (August 11, 2017). This thunderstorm line was extremely violent because it appeared at the junction of two extreme masses of air: a hot and damp air mass, which for several days laid over a much colder polar air mass over Poland. The cold denser air forced the warm moist air aloft, which resulted in the accelerated development of storm clouds. The whole storm covered a vast area about 540 km from Wrocław, through Poznan, Bydgoszcz, along Gdynia and Gdansk and part of the coast. Late in the evening of August 11, 2017, and at night from August 11/12, 2017, a squall line crossed the area from Wielkopolskie through Kujawsko-Pomorskie to Eastern Pomorskie (see Fig.1) [1, 2].

Fig. 1. The thunderstorm path (red colour) in Poland in August 11/12, 2017 over three provinces: Wielkopolskie, Kujawsko-Pomorskie, and Pomorskie [3].

This thunderstorm front moved very fast with high speed wind on August 11, 2017 at 18:00, it reached the borders of the Wielkopolskie province. At 1:00 on August 12, 2017 the storm front left the border of the Pomorskie province. Multiple storm cells formed in Pomorskie suddenly, on Friday (August 11, 2017) late in the evening between 21:00 and 22:00. The related storm cells created a mesoscale convective system, from which later a devastating meteorological phenomenon known as a bow echo developed as shown in Fig.2. This formation consists of closely related storm cells, which in the radar image have the shape of an arch, which created the so-called *bow echo*. Such phenomena were accompanied by strong air currents descending from the storm cloud, causing a straight-linear strong wind, impacting the ground cutting down trees like matches, breaking roofs and destroying buildings and power lines, destroying everything it its path. Wind speed reached 120 km/h and at some points (at Elbląg) even exceeded 150 km/h.

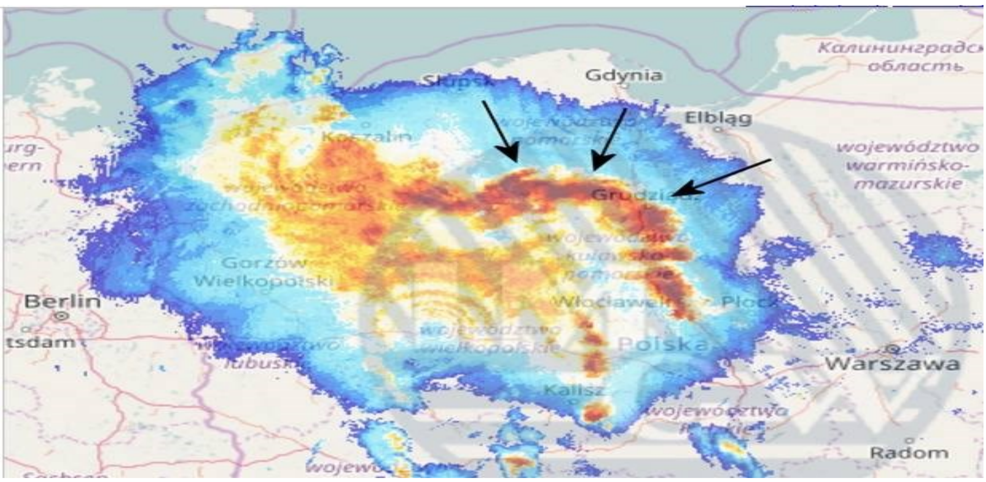

Fig. 2. Thunderstorm over Chojnice on the night of 11/12 August, 2017 on the radar picture. Bow echo marked with arrows, [3].

The sky was crisscrossed by lightning every few seconds as shown in Fig. 3. The thunderstorm caused much fear and despair for residents in its path. Based on the data collected in the European Severe Weather Database (ESWD) [1] and by authors of the paper [2], it appears that the storm meets the derecho criteria.

Fig. 3. Dark clouds in contact with the surface of the ground with strong atmospheric discharges – August 11/12, 2017, [3].

The derecho wind storm criteria are as follows:

a) The wind storm damage path must be at least 460 km long,

b) Wind speed greater than or equal to 26 m/s (94 km/h) in three places on the path of damage, at least separated from each other of 74 km.

3 Information about meteorological data measurements

A strong wind, which was highly gusty during this extreme event, was the cause of the catastrophic damage observed in the three provinces mentioned above. A compilation of meteorological data, presented below, provides important information about the short storm duration during its passage across a measurement station, non-stationarity of wind speed and intensity of rainfalls.

The Institute of Meteorology and Water Management (IMWM) presented a report on the thunderstorm, how it passed over Pomorze province from August 11/12, 2017. It presented a summary of meteorological data for the city of Chojnice and its neighbouring areas in the path of the storm. Compilation of meteorological data from the Chojnice station from 18:00 on August 11,2017 until 06:00 August 12, 2017 are shown in Table 1 and Table 2, [3].

Table 1. Measured wind speeds at the meteorological station at Chojnice from 18:00 on August 11, 2017 until 06:00 August 12, 2017, [3].

Time UTC	Gust wind speed [m/s]	Mean wind speed [m/s]	Wind direction	Rainfall 10 min [mm]	Rainfall 1 hour [mm]	Temperature [℃]
18:00	2.6	1.5	NNW	-	0.0	23.6
19:00	2.6	3.4	NNW	-	0.0	22.1
20:00	5.9	4.1	NNW	0.0	0.0	22.0
20:10	7.3	4.9	NNW	0.0	-	22.1
20:20	10.1	5.1	NNW	0.0	-	22.1
20:30	12.8	7.1	NNW	0.0	-	22.2
20:40	14.4	8.3	NNW	2.8	-	21.2
20:50	**31.2**	**18.4**	**SW**	**8.9**	**-**	**17.0**
21:00	**24.3**	**12.5**	**WSW**	**8.2**	**19.9**	**16.6**
21:10	13.5	8.2	WSW	1.9	-	16.7
21:20	9.8	6.1	WSW	0.9	-	17.0
21:30	6.4	3.9	WSW	0.2	-	17.1
21:40	6.1	3.7	WSW	1.1	-	17.1
21:50	5.9	3.3	W	0.9	-	17.0
22:00	7.0	4.5	NNW	0.5	5.5	17.0
23:00	7.3	4.8	NNW	-	0.4	16.7
00:00	4.3	3.0	N	-	0.0	17.0
01:00	7.0	4.8	SSW	-	0.0	16.5
02:00	5.9	4.0	SSW	-	0.0	16.7
03:00	5.0	3.0	ENE	-	0.3	16.6
04:00	3.6	2.4	SSW	-	0.0	17.0
05:00	5.5	3.5	WSW	-	0.0	17.2
06:00	4.3	2.9	WSW	-	0.0	17.2

Table 1 gives an example of non-stationary wind speed measured at a height of 10 m above ground. For this station the direction of the wind remained quite constant before, during, and after maximum wind speed. The measured wind speeds at others meteorological stations varied from 32 to 42 m/s. A maximum wind speed value of 42 m/s was measured at Elbląg. The moment of the passage of the atmospheric front over Chojnice from 18:00 on

August 11, 2017 until 06: 00 August 12, 2017 is shown in Fig. 4. The intensity of rainfalls in two stations Zapędowo and Czarna woda, located not far from Chojnice in Table 2 are presented.

Table 2. Rainfalls from Zapędowo and Czarna woda stations - from 18:00 UTC on 11/08/2017 until 06:00 UTC 12/08/2017; IMWM, [3].

Zapędowo			**Czarna Woda**		
Time UTC	**Rainfall 10 min [mm]**	**Rainfall 1 hour [mm]**	**Time UTC**	**Rainfall 10 min [mm]**	**Rainfall 1 hour [mm]**
18:00	-	0.0	18:00	-	3.1
19:00	-	0.0	19:00	-	0.0
20:00	0.0	0.0	20:00	0.0	0.0
20:10	0.0	-	20:10	0.0	-
20:20	0.0	-	20:20	0.0	-
20:30	0.0	-	20:30	0.0	-
20:40	9.3	-	20:40	0.0	-
20:50	**5.7**	**-**	**20:50**	**4.5**	**-**
21:00	**3.2**	**18.2**	**21:00**	**9.4**	**13.9**
21:10	0.6	-	21:10	0.5	-
21:20	1.1	-	21:20	0.7	-
21:30	1.1	-	21:30	0.6	-
21:40	0.8	-	21:40	0.5	-
21:50	0.6	-	21:50	0.6	-
22:00	0.5	4.7	22:00	0.6	3.5
23:00	-	0.5	23:00	-	1.2
00:00	-	0.0	00:00	-	0.1
01:00	-	0.1	01:00	-	0.0
02:00	-	0.5	02:00	-	0.2
03:00	-	0.1	03:00	-	0.1
04:00	-	0.0	04:00	-	0.1
05:00	-	0.1	05:00	-	0.0
06:00	-	0.0	06:00	-	0.0

4 Human victims and damage to buildings, forests, agriculture, power lines and biosphere

On August 11-12, 2017, the thunderstorm caused the death of 6 people, injuries to several dozen people, and enormous property losses. The details are given below:

a) the death of 6 people and 62 people were injured,
b) damage to 16091 residential, farm, commercial, and public buildings,
c) agricultural crops were destroyed in an area covering 66 717 hectares,
d) forests were destroyed in an area of approximately 80 000 hectares,
e) blocked and partially damaged commune, district and province roads over a length of about 1100 km,
f) damage to 25 high-voltage lines, 300 overhead power line poles, and over 200 cables were downed. Due to this damage, over 500,000 consumers were deprived of electricity at the peak of the disaster. The last recipients received electricity after 18 days (2.5 weeks),

g) the area of losses in valuable natural areas amounted to approximately 541 km^2. These include destruction affected numerous forms of nature protection, i.e. the World Biosphere Reserve "Bory Tucholskie" inscribed on the UNESCO list, nature reserves, areas Nature 2000 (areas of special protection of birds, areas of importance for the Community), landscape parks and protected landscape areas, as well as numerous nature monuments, ecological lands, nature and landscape complexes,
h) about 40,000 people were directly affected by the thunderstorm.

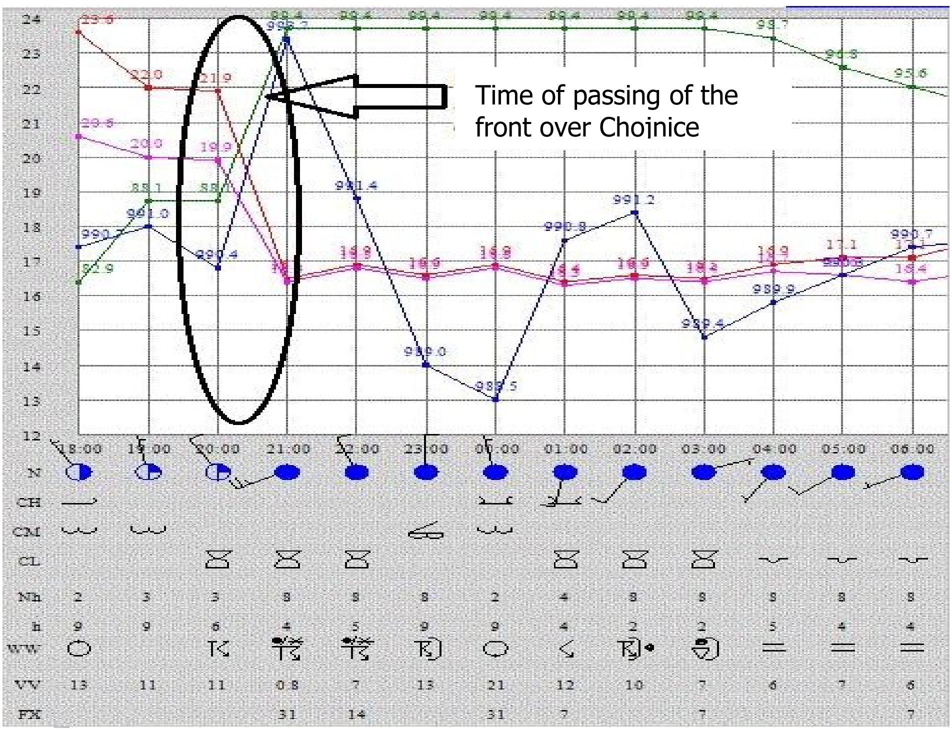

Fig. 4. The meteochart from the meteorological station in Chojnice illustrating the moment of the passage of the atmospheric front over Chojnice from 18:00 UTC on 11/08/2017 until 06:00 UTC 12/08/2017; IMWM, [3].

Some cases of damage to buildings, agricultural crops, forests, and power line poles are shown in Figs. 5 – 7. The details of enormous damage which are presented above have been the basis for the estimation of all costs for the reconstruction and repair of buildings, infrastructure, forests, natural, and tourist values on the communes, districts, provinces, and government level.

Fig. 5. Damage to buildings: entire roof blew off and part roof blew off from residential building.

Fig. 6. Damage to forests.

Fig. 7. Damage to a overhead power line pole and a commune road.

5 Data on buildings damage, their statistical analysis and proposals to reconstruct buildings

The damage survey and assessment of damaged buildings started on August 17, 2017. It was conducted by district building inspectors in the affected districts. After recognizing the scale of damage, the coordination was carried out by the Chief Inspector of Buildings Authorities, who posted his employees (on August 16, 2017) and obliged the building inspectors of the remaining 13 provinces (on August 18, 2017) to share damage survey and assessment of buildings. In approximately 3 weeks, 488 building inspectors have surveyed and assessed over 16,000 buildings [4]. Building inspector teams, consisting of two people, assessed first of all the safety of buildings from the point of view of returning people to them, i.e. they sought to eliminate the possible threat to human life and health. In the survey and assessment of the buildings, a special form was used called: "Assessment of damage to the building caused by atmospheric phenomena - August 2017", which streamlined and standardized work in three affected provinces.

The form allowed the assessment of a residential and farm and public building in three aspects of human health and life:

– whether the existing damage threatens the health and life of people,
– whether any damage can threaten the health and life of people,
– whether the damage does not threaten the health and life of people,

and the degree of damage to building elements was determined as a percentage, in relation to the whole building, in three ranges, i.e. up to 5 %, 5-20 % and above 20 %. Completed assessment forms were forwarded to the relevant municipality, which on this basis, without the need for a property expert, made decisions regarding the payment of compensation to building owners.

The number of surveyed and assessed buildings by September 15, 2017, in three provinces, is presented in Table 3.

Table 3. The number of surveyed and assessed buildings by September 15, 2017.

Province	Number of buildings	Percentage	Residential buildings	Number of affected districts
Kujawsko-Pomorskie	9668	60 %	3510	16
Wielkopolskie	4188	26 %	1875	11
Pomorskie	2235	14 %	887	17
Together	**16091**	**100 %**	**6272**	**44**

Table 3 shows that the majority of damage to buildings was in Kujawsko – Pomorskie, less in Wielkopolskie, and the least in Pomorskie province. This is shown in Fig. 8.

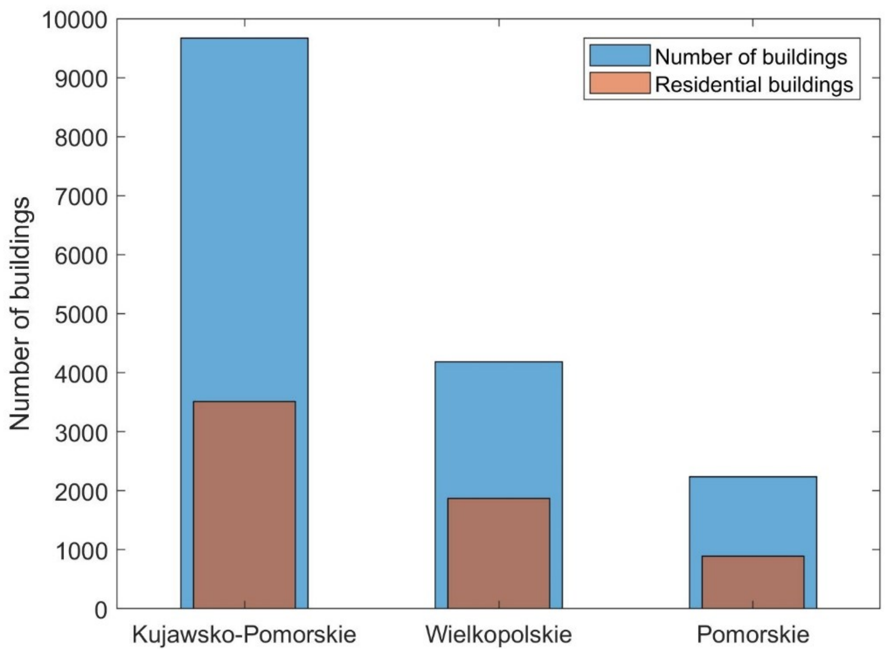

Fig. 8. Histogram of damage to buildings in in three provinces: Wielkopolskie, Kujawsko-Pomorskie, and Pomorskie.

Buildings inspectors teams have made a percentage classification of damage or destruction of building elements in relation to the whole building. The results of such an assessment in three ranges are presented in Table 4.

Table 4. Damage to buildings in three percentage ranges for different provinces.

Province	**Damage below 5 %**		**Damage in the range 5 – 20 %**		**Damage above 20 %**	
	All buildings	Residential buildings	All buildings	Residential buildings	All buildings	Residential buildings
Kujawsko-Pomorskie	5048	2056	3091	1132	1505	322
Wielkopolskie	2356	1118	1354	648	478	109
Pomorskie	890	709	821	173	524	154
Together	**8294**	**3586**	**5266**	**1132**	**2507**	**585**

This method of assessment (percentage of damage to a building) has a large practical aspect. The amounts of financial assistance to owners affected by the disaster were granted on the basis of the estimated percentage of damage to a residential, farm, commercial or public building.

Damage to roofs were found in all damage buildings. The majority of damage buildings, above 90 %, were low-rise structures, i.e. less than 14m in height. The degree of damage to the buildings was different. It was in the range from light damage, i.e. damage to gutters, several exposed tiles, through medium- including loss of roofing, battens, rafters, to total damage, i.e. loss of roof and loss of some walls. On the base of conducted control, 1116 buildings (i.e. 11.5 % of assessed), including 235 residential buildings, have been excluded from further use. Generally, buildings constructed in the early 2000s performed better than the buildings which were constructed earlier, e.g. in the years 1945-1990. Several of them have been built according to lower building codes, suffered a lack of maintenance, and some by an economic system that can be treated as non-engineering

The authors of the paper [5] with co-author of this paper have proposed three pieces of advice on how to construct law-rise buildings to be resistant for tornadoes. They may be recommended to any extreme wind. They are as follows:

a) to increase the stiffness of a part of all residential building against drag and uplift wind forces,
b) a stronger anchorage of roof elements down to the top of the building walls,
c) to apply stronger connections between construction elements.

Recently many people have been convinced to apply these proposals. Several victims of the described extreme weather event on August 11-12, 2017, whose buildings were totally damaged, applied above suggestions for rebuilding their residential, farm, and utility buildings as shown in Fig. 9.

Fig. 9. An example of a residential building with improved stiffness, i.e. with two concrete rim and selected concrete columns.

6 Conclusions

The investigation of the dangerous atmospheric phenomenon of August 11-12, 2017 and its effects on people and properties have provided a better understanding of the course of rescue operations immediately and during subsequent days after the natural disaster, documenting damage, and to mitigate the effects of a natural disaster. The major conclusions derived from this study are as follows:

1. The thunderstorm on August 11-12, 2017 moved fast over western part of Poland covering a length about 540 km, approximately in straight line, brought strong wind that caused the catastrophic damage mainly in three provinces (details given in Section 2) over an area several km wide. This kind of wind storm is called *derecho* in meteorology.
2. Measured peak wind speeds by meteorological stations of the Institute of Meteorology and Water Management were in the range 31-42 m/s (112-151 km/h) at the reference height of 10 m.
3. In the first days of responding to the effects of the distractive *derecho* on August 11-12, 2017, the emergency services undertook about 10,000 interventions. In the first week after the event, victims (per family) received direct financial assistance from the government and from a month up two month later financial support for the reconstruction of destroyed residential and utility buildings. This was possible thanks to an efficient assessment of the degree of damage to buildings by building inspectors.

We thank all of the individuals from the Communes Brusy, Chojnice, Czersk, the Chief Building Supervision Inspector in Warsaw, and groups from Kujawsko-Pomorskie, Wielkopolskie, and Pomorskie province governors who provided us with data.

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