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VARIABILITY OF ANEMOMETRIC CONDITIONS IN A SELECTED REGION OF THE CRACOW METROPOLITAN AREA

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Abstract

The article describes the effect of substrate roughness on the generation of air flow resistance and the occurrence of kinetic friction. These are the two main factors influencing reduction in wind speed, lack of ventilation in built-up areas, and stagnation of pollution over areas with high substrate roughness. The work presents the results of the authors' own measurements in the field, carried out using WindLog and CHY 361 anemometers, in two different types of atmospheric conditions – sunny and rainy weather. The measurements were taken on a stretch of the Rudawa River, located on the Cracow city limits. Wind speed was measured at all established measurement points. The immediate surroundings of the points varied in terms of how densely the areas were built up. The effect of changes in the shape and equivalent diameter of the measurement profile on the magnitude of flow resistance and friction was also tested. The results of the study indicate that the best type of arrangement for buildings around the valley of the Rudawa River is a latitudinal configuration. The lack of buildings on the path along which the airstream flows creates suitable conditions for ventilation of the city, and thus for clearing the air of pollution. In the event of construction on a north-south axis it is important to avoid erecting tall and very tall buildings in the area.

Key words: wind, airflow resistance, kinetic friction

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INTRODUCTION

Anemometric conditions are understood as horizontal air movement caused by a difference in pressure or as air movement with a predominant horizontal component with respect to the Earth's surface (Kopacz-Lembowicz *et al.* 2000). Observations of wind mainly involve determination of its direction and speed, which we express in metres per second. This speed is the ratio of the distance travelled by air molecules to the time duration of the movement over this distance. Instruments used to measure wind direction and speed include Wild anemometers, cup anemometers, and Robinson or Rosenmüller anemometers (Kopacz-Lembowicz et al. 2000).

Both wind characteristics mentioned above are determined by the spatial distribution of the atmospheric pressure field over a given macroregion, the distribution of highs and lows, and the size of flowing air masses (Terpińska and Kowanetz 2000, Angrecka 2014). These may be subject to deviations depending on local factors. The most important of these are terrain shape and varied substrate roughness, resulting from diversified land cover. The configuration of the terrain determines change in wind direction, while roughness affects the degree of friction, leading to changes in wind speed. Wind speed decreases as it approaches the surface of the land (Rojek and Bac 2012). This has been confirmed in a study by Bednorz and Kolendowicz (2010) of the Adam Mickiewicz University in Poznań. The results were published in the paper: Local variation in wind parameters on the Łeba Spit (Słowiński National Park).

The spatial organization characteristic of cities has a strong reducing effect on wind speed and modifies its initial direction. Due to substrate roughness, defined by the density, distribution and height of buildings, light winds with a speed of under 3.0 $m \cdot s^{-1}$ predominate in urban areas. This means that wind speed decreases by about 20% in comparison with the surrounding areas (Bokwa and Walczak 2004, Swianiewicz and Kalimska 2005, Bondar-Nowakowska *et al.* 2012). Dense, tall buildings force the wind to flow along transport routes, along the axes of the main streets, and increase its strength on the corners of narrow side streets. On crossroads, squares and car parks (especially large ones), local vortexes arise due to an influx of air from several different directions (Czarnecka and Koźmiński 2006). Negative effects of strong winds over a city include the spread of pollution, while positive effects include cooling of the air in the city, where high temperatures are linked to increased evaporation from impervious surfaces in the summer, an influx of clean air from non-urban areas, and ventilation of the city (Bokwa and Walczak 2005, Janka 2014).

MATERIALS AND METHODS

The methods used in the study consisted of two elements, i.e. field measurements and analytical work, which are described in this section. To maintain uniform conditions in terms of the height at which the measurements were taken and to avoid distortion of the results by external factors (road traffic), the Rudawa River valley was chosen as the study site. Wind speed and direction were measured parallelly by the point method in three selected profiles on river embankments. Profiles I and II consisted of two measurement points each, while profile III was one measuring point. The distance between profiles I and II was 950 m, and the distance between profiles II and III was 1,310 m. The measurements were taken at a height of 5.5 m using WindLog anemometers (profiles I and III) and CHY 361 anemometers (profile II). On the Fig. 1 was shown the dominant land usage in measurement profiles.

Meteorological data were obtained from the Cracow weather station in Balice (www.pogoda.net). Cloud cover, humidity and sunshine duration were determined on the basis of our own field observations during the study. To compare the cross section of the valley to several basic geometric figures, the profile was simplified to the shape of an ellipse, a rectangle, and a trapezium. The area between flood embankments was defined as the river bed and valley. Information and instantaneous data collected during the field work (one measuring day) were subjected to a calculation average sequence aimed at determining the air flow resistance in each profile (Wyszkowski 1979, Boecker and Grondelle 2002).

a)

b)

c)

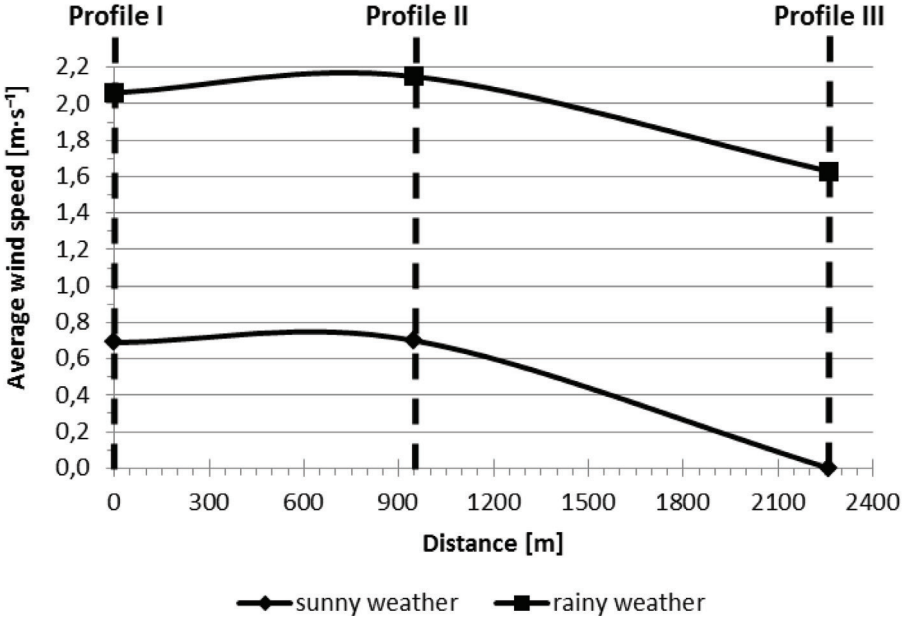
Source: Own photo

Figure 1. The dominant land usage surrounded Rudawa River valley:
a) profile I, b) profile II, c) profile III

RESULTS

According to the scale adopted by the World Meteorological Organization (2010), the wind at the time of the measurements in sunny weather can be classi-

fied as 'light air' (0.3–1.5 $m \cdot s^{-1}$). When atmospheric conditions changed the wind speed increased; this wind can be described as a 'light breeze' (1.6–3.3 $m \cdot s^{-1}$). On the basis of the calculations made, Fig. 1 presents modifications in airflow speed on a path with varied substrate roughness.



Source: Own study

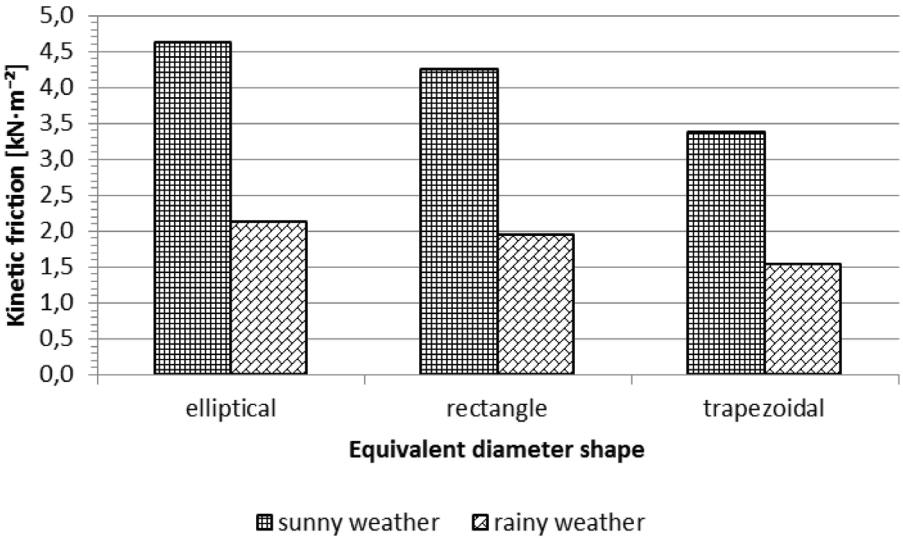
Figure 2. Changes in wind speed as the wind progresses along the flow path

During sunny weather the wind speed increases in grassland areas (profile I) and attains its maximum value when it reaches the point where the built-up area begins (profile II). When it reaches the end of this stretch, the wind is decelerated (profile III) by the flow resistance caused by the considerable substrate roughness between profiles II and III. During rainy weather the phenomenon of reduced air speed is also observed between profiles I and III (there are no data for profile II), but because of its increased average speed, the wind does not die down (Fig. 2). Changes in wind speed are affected by resistance caused by the substrate over which it flows.

In the sunny weather the ratio of average wind speed to the flow resistance caused by the substrate is considerable. In the case of stronger wind the flow resistance decreases. The difference in the ratio of these resistances to the wind speed is smaller as well. There are similar trends for friction against the substrate caused by wind flow. Flow resistance and friction change proportionally to one

another. Their values are influenced by the transverse surface area and wetted perimeter of the profile, as illustrated in Fig. 3.

As the length of the equivalent diameter of the valley increases, the friction of the airflow against the substrate decreases. It is 15.86 m in the case of the valley considered in the shape of an ellipse, 17.25 m for the rectangular valley, and 21.76 m for the trapezium. The mean friction values for the three shapes, respectively, are 4.62 kN·m^{-2} (sunny weather) and 2.12 kN·m^{-2} (rainy weather); 4.25 kN·m^{-2} (sunny weather) and 1.95 kN·m^{-2} (rainy weather); and 3.37 kN·m^{-2} (sunny weather) and 1.54 kN·m^{-2} (rainy weather). In rainy weather, when the mean wind speed increases, friction decreases. This trend persists in sunny weather, but the friction is lower than in the case of rainy conditions by one order of magnitude – on average by 37.14%.

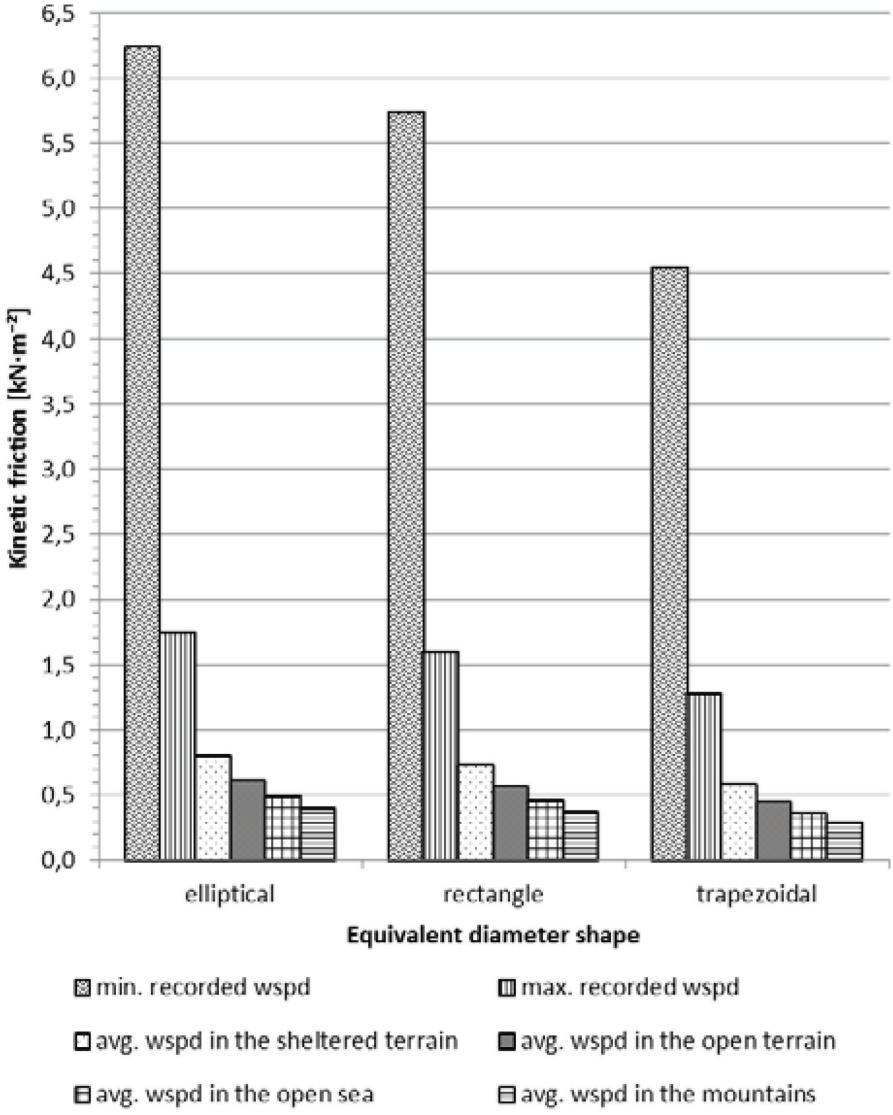


Source: Own study

Figure 3. Comparison of the degree of friction during sunny and rainy weather in relation to the shape and equivalent diameter

To illustrate the results obtained for the friction calculations, Fig. 4 shows a comparison of the friction at the lowest and highest wind speed recorded during the study with the friction occurring at average wind speed for other areas of Poland (Kusto 2016). The friction occurring at the lowest wind speed considered in the figure above, i.e. 0.64 m·s^{-2}, is about 15 times greater than the friction occurring at the average maximum wind speed on elevations and mountain ridges – 10.0 m·s^{-2}. The friction occurring at the highest wind speed

recorded during the measurements, i.e. 2.28 $m \cdot s^{-2}$, is about 4 times greater than the friction at a wind speed of 10.0 $m \cdot s^{-2}$. These trends occur in all cases of equivalent diameters.



Source: Own study

Figure 4. Comparison of friction at different wind speeds (wspd)

CONCLUSIONS

1. The magnitude of flow resistance and friction are directly proportional and depend on the shape and equivalent diameter of the profile cross section, decreasing as the length of the diameter increases.
2. The magnitude of the resistance and friction also depend on the speed of the airflow; they decrease as its speed increases.
3. An increase in substrate roughness causes a decrease in wind speed; even low-rise buildings are able to completely minimize (<0.3 $m \cdot s^{-1}$ – calm) wind speed in certain weather conditions, thereby causing stagnation of atmospheric pollution.
4. Over the metropolitan area there is an influx of air from the northwest and southwest.
5. A latitudinal configuration of natural and artificial corridors and tunnels causes an increase in the contribution of winds from the west; the Rudawa River valley significantly modifies the initial direction.

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