INTRODUCTION

Chimneys belong to building structures particularly exposed to wind actions. On their examples it is possible to see the evolution of wind loading provisions in the last century or even in longer time. A 100-year period is meant here as a conventional time. The paper deals with this evolution for each link of the Alan Davenport’s wind loading chain [1] [2] that are: wind climate and strong wind speed assumptions, terrain characteristics affecting wind speed and its profile and turbulence, aerodynamic coefficients of a chimney, dynamic response and safety factors. It must be remark that two first part of Davenport’s chain concern all kind of building structures.

WIND CLIMATE

Early approaches to wind loading of structures in the second part of XIX century were based on every day observations of wind speed recorded by meteorological stations. Maximal values of wind speed in different countries were noted as collected by Lang [3]. Practical view was represented by Thullie, who wrote: “In our countryside wind speed rather rarely exceeds 30m/s and we take this value for the calculations of roofs” [4]. However, the velocity pressure recommended for calculations was much higher than resulting from such a wind speed. At the beginning of XX century 1.5 kN/m² was used in Austro-Hungarian Kingdom and 1.25 kN/m² in Prussia [5]. It seems that only in 1920s a value of 0.50 kN/m² was commonly accepted in Central Europe as a recommended velocity pressure on the level of 10 m above terrain [6]. No averaging time and return period as well as no wind load zones were considered before the IIWW. These subjects appeared at the end of 1950s and beginning of 1960s. In those years wind speed was first time studied in the terms of probability. Several publications can be mentioned. Anapolskaya and Gandin used Weibull probability distribution as a parent one of wind speed [7]. Shellard examined extreme wind speeds [8] and Davenport presented a concept of statistical analysis of wind loading of structures [9]. Thom published the distribution of extreme winds in the United States [10] and van Koten elaborated data of wind speed in Western Europe [11]. On the base of his work a wind map of Europe was elaborated and included into the first edition of ECCS recommendations [12] [13]. It has been an unique European wind map for last several decades. During the last two decades of the XX century as well as at the beginning of XXI century many publications on wind speed analyses appeared. It is hardly to referred to all of them, but at least the publications of Cook [14] and Harris [15] should be mentioned. Finally, the paper by Holmes et al.
may be considered as an overview of up to date methods of works concerning wind speed prediction and zoning wind.

TERRAIN CHARACTERISTICS AFFECTING WIND SPEED

It is evident that wind speed increases with height above ground level and that this phenomenon should be taken into calculations of chimneys. A simple, linear equation for the velocity pressure was presented by Lang [3] with a basic pressure 1.25 kPa (here in SI units) and an increment 0.01z, where z is the height above ground level, m. It is interested that similar formulae were in use in German standards for brickwork and RC chimneys [17] and quite recently for steel chimneys [18].

In general standards for wind load two approaches were used. One approach preferred power law dependence of wind speed and velocity pressure on height above terrain, like in the Soviet early provisions of the 1936 [19], another used stepwise changes of wind pressure, like in the general German standard from 1938 [20].

It is interesting that an early proposal of the three categories of terrain was presented in former Soviet Union in 1936 [19]. Dependence of the velocity pressure on height above ground was given as the power law with a common exponent $\alpha = 0.5$ (for wind speed it was $\alpha = 0.25$) for all categories of terrain and reduction factor $k$ depending of the terrain. Three categories of terrain were proposed with different values of $k$: an open terrain A with $k = 1.0$, small villages and rare woods with $k = 0.8$ and large villages and towns with $k = 0.6$. Those wind profiles were valid up to 100 m height. Despite of the progressive approach (or due to it) this proposal was not accepted by the Soviet authority. Three categories of terrain were put into the Soviet standard in 1986, fifty years later [21].

A comprehensive study was done by Davenport, who proposed three wind profiles with following power law exponents [22]: open terrain $\alpha = 0.16$, suburbs $\alpha = 0.28$ and towns $\alpha = 0.40$. Next, three categories of terrain were adopted in several national standards; among them in Polish one [23].

Several years later, in ECCS Recommendations five categories of terrain appeared as logarithmic law [13]. These five categories are given now in Eurocode for wind action [24]. This way logarithmic law has been accepted not only as possessing equal rights but as a leading one. Thanks to this approach intensity and scales of turbulence were introduced into the Eurocode in a homogeneous notation.

Finally, it must be mentioned that high chimneys are not to be constructed in cities but rather at their outskirts so one wind profile may be suitable in their structural calculations.

AERODYNAMIC COEFFICIENTS

Chimneys usually have simple cross sections, most frequently they are circular. Brickwork chimneys were also of rectangular or polygonal cross sections. For such chimneys simple values of drag coefficient were in use even in XIX century. Lang specified [3]: $C_D = 0.67$ for circular cross section, $C_D = 0.71$ for octagonal and $C_D = 1.00$ for rectangular. Not only aspect ratio but also several main features of chimneys with circular cross section had to be investigated: Reynolds Number, surface roughness and turbulent flow influence on drag coefficient. Many investigations have been undertaken during the XX century. The pioneer investigations of Prandtl and his collaborators [25] should be mentioned as well as the works by Fage and Warsap [26] and others [27] [28] [29]. Finally, in the Eurocode [24] one can find dependence of the drag coefficient of circular cylinder on the Reynolds Number and surface roughness. Drag coefficients for polygonal cylinders have already been given in the French code of practice from the 1960s [30] and are in the present Eurocode [24].

DYNAMIC RESPONSE

Chimneys are especially susceptible to dynamic wind action. Probably all early constructors of chimneys were aware of this effects but they did not know how to take it into calculations. Fortunately, simple formulae for wind actions were safe enough to cover also dynamic effects. When
the more detailed calculation of wind loads was adopted it became necessary to take into account the
dynamic effects of wind gusts.
The first was a concept of a sudden increase of wind load in the form of one-fourth of the sinusoid,
presented by Rausch [31]. This concept was next modified into the form of two half sinusoidal
impacts [32] [33] and introduced to several standards for chimneys in Central Europe, e.g. [17].
A quite different concept of dynamic wind action on high structures was developed in the former
Soviet Union by Barstein [34] [35]. Wind action was considered as a stochastic process. He presented
a general solution of the problem of vibration of a system with many degrees of freedom in a turbulent
wind. A simplified formula was derived to be used in codes of practice. This method has been
introduced into wind codes of the East European countries and to the French code [30].
In the same decade Davenport presented his gust response method [36]. Next steps in the definition of
dynamic response of chimneys are methods given in the Eurocode [24] and ISO Standard [37].

FINAL REMARKS

In this paper a brief summary is presented of the wind loading provisions for chimneys. These
provisions have passed a long way from the simple formulae used in the second half of XIX century
to present day sophisticated methods. Result of the different methods of calculation can be shown on
the base of working examples. Concerning design criteria it may be said that instead of the rarely
exceeded wind speed a 50 year return period is now commonly accepted. Dynamic effects can be also
estimated in details. A partial safety factor, now 1.5 in Eurocode can be seen as giving safety enough
for structures exposed to wind actions.

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