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Expert statement on the determination of the squall velocity pressure on the basis of the wind velocity

When photovoltaic plants are planned and realized, there are often discussions about the scale of the wind velocities that are assumed in the structural analysis for the determination of the wind load. The reason for that is the complex technical system of the calculation on the basis of architectural standards that considers different input parameters like the wind zone, unevenness of the terrain and the height above the ground of the component that has to be structurally analyzed, whereas the maximum wind velocities are usually indicated in km/h in the weather forecast or after storm events.
When it comes to photovoltaic plants, insurance companies, financing banks and investors rely on these striking top velocities that are published in the press and that are also available from weather information services. When the project-specific structural analysis is checked, it often turns out that considerably lower reference wind velocities were used for the calculation of the wind loads. This naturally leads to uncertainties and in the worst case even the correctness of the structural calculations is doubted. The following explanations are supposed to clarify the procedure of the architectural calculation of wind loads and to resolve misunderstandings.

Wind velocities are recorded by numerous representative weather stations with anemometers (also known as anemographs). Figure 1 shows the measurement plot of an anemograph over a period of 700 seconds. The blue curve shows an exact measuring signal, whereas the black curve represents a smoothing of the measuring series over a defined time interval by means of averaging. Among experts, the averaged black curve is called the stationary part of the wind velocity. The deviations of the blue curve from the black curve are called the inter-stationary part of the wind velocity that derives from wind velocity fluctuations and local turbulences. The reference wind velocity v_{ref} that is used in civil engineering represents the stationary part in the form of a 10-minute average value measured in an open area at a height of 10 meters above the ground.

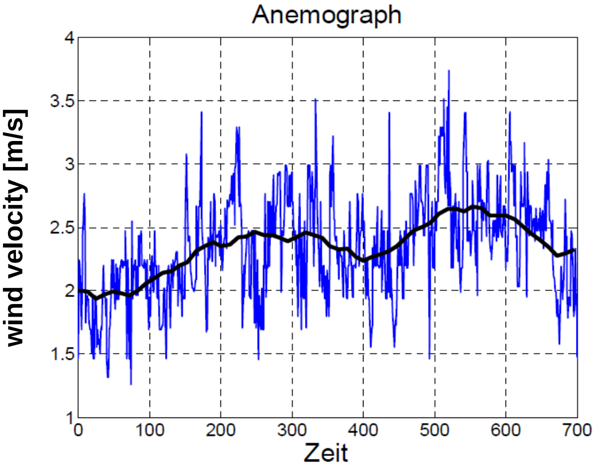


Figure 1: Exemplary display of the measurement plot of an anemograph

From a statistical point of view, this is the value that is only reached or exceeded once in an observation period of 50 years. The evaluation of the reference velocities is based on the series of measurements of numerous measuring stations (188), in some cases over a period of several decades. The reference wind velocity does not include any squall influences and applies exactly for the conditions of a measuring at a height of 10 meters above the ground.

On the basis of the evaluated results of the measuring stations, a wind zone map for Germany was created that is published in the engineering standards for the load assumptions DIN 1055-4 and Eurocode 1 (DIN EN 1991-1-4/NA) that will replace the national standard in the course of the European harmonization. Figure 2 shows the subdivision in 4 wind zones that are based on the basic values of the reference velocities v_{ref}.

Wind zone 1: 22.5 m/s (81 km/h)
Wind zone 2: 25.0 m/s (90 km/h)
Wind zone 3: 27.5 m/s (99 km/h)
Wind zone 4: 30.0 m/s (108 km/h)

The conversion of the unit "meters per second" into the unit "kilometers per hour" is carried out using the multiplication factor 3.6. The calculated values of 81-108 km/h show the seeming discrepancy to the peak velocities in storm events.

Figure 2: Wind zone map for Germany

However, the basis of support structure planning is not the wind velocity, but the impact pressure that is deducted from the wind velocity. The reference impact pressure q_{ref} is calculated using the basic value of the reference velocity v_{ref} according to the following equation:

$$q_{ref} = v_{ref}{}^2/1600 \text{ in kN/m}^2$$

Here it has to be pointed out that the wind velocity is squared. This means that a doubling of the wind velocity leads to a quadrupling of the impact pressure.

Only in a further step, the influences of the environment of the building and the height of the element above the ground are considered. Figure 3 illustrates this relation for open areas, village surroundings and big-city building density.

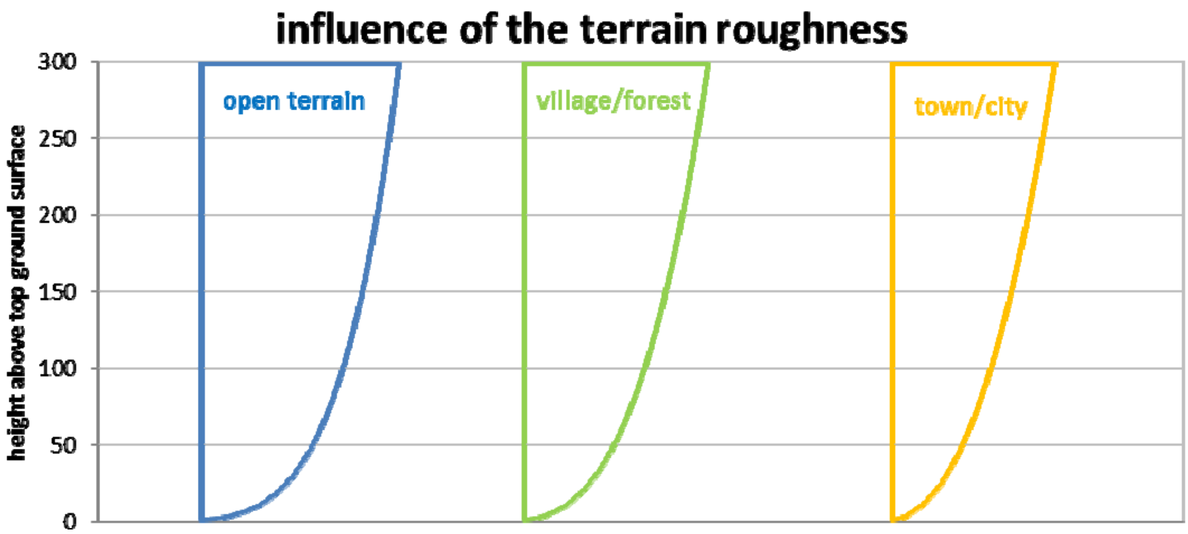
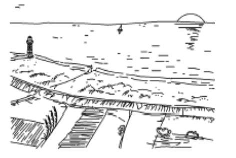
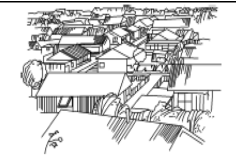
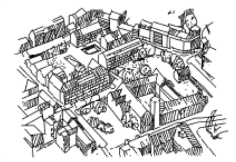


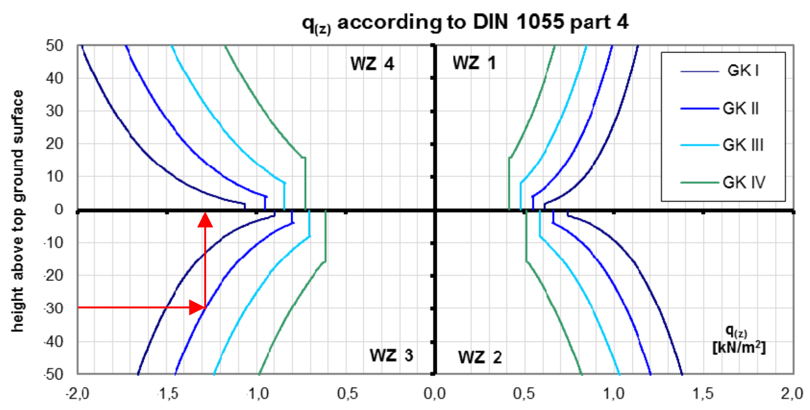
Figure 3: Influence of the terrain roughness on the wind velocity

Buildings and vegetation hamper the wind flow close to the ground and thus have a slowing-down effect caused by frictional resistance. This effect is called terrain roughness and is considered in the standardization by a categorization of the installation location in a so-called terrain category. According to chart 1, the regulations provide the terrain categories I-IV in Germany. In transitional areas between two terrain categories, mixed categories have to be considered.

Chart 1: Classification in terrain categories according to DIN 1055 part 4

Terrain category I: flat, even terrain without obstacles	
Terrain category II: terrain with hedges, single granges, houses or trees, for example farming area	
Terrain category III: suburbs, industrial or commercial areas, forests	
Terrain category IV: Urban areas in which at least 15% of the surface is covered with buildings whose average height exceeds 15 m	

In figure 4, a graphic evaluation of the calculated squall velocity pressures is displayed as a function of the wind zone, the terrain category and the height above top ground surface. In the 4 quadrants, the wind pressure profiles for the 4 terrain categories in the wind zones 1 - 4 are displayed. On the vertical axis, the height above the ground is shown, on the horizontal axis, the squall velocity pressure can be read off. In order to clarify the procedure, figure 4 shows an accordant example. For an object in wind zone 3, terrain category II and a height of 20 m above the ground, a squall velocity pressure $q_{(z)}$ = 1.3 kN/m^2 can be observed. This value can be hypothetically converted into an equivalent wind velocity of v = 164 km/h ($v = 144 \cdot q^{1/2}$). For reasons of demonstration, the reference wind velocity is increased with a squall reaction factor. In relation to the wind velocity, this factor can be quantified with 1.29 for this specific example.



Example:

Wind zone 3:
Terrain category II:
Height z = 30 m

$q_{(z)}$ = 1.3 kN/m^2

Equivalent wind velocity

v = 164 km/h

Figure 4: Graphic evaluation of the squall velocity pressures

Figure 5 shows the calculational evaluation of the equivalent wind velocities for the different wind zones and terrain categories. Depending on the input parameters, these values range from 93km/h und 200 km/h. Thus, the equivalent wind velocities are definitely within the range of wind velocities measured in storm events. In addition to that, it has to be pointed out that the wind loads for structural calculations are increased by a safety factor of 1.5.

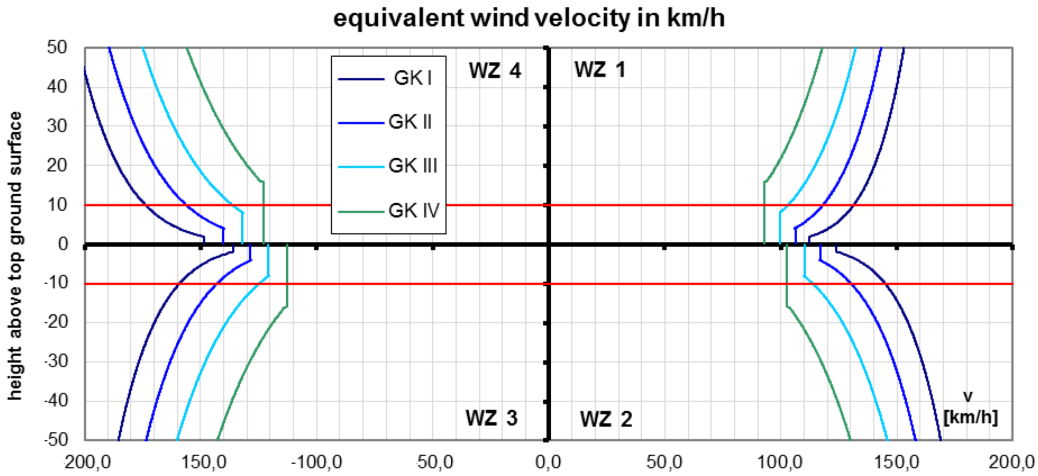


Figure 5: Conversion of the squall velocity pressures into equivalent wind velocities

A closer look at the illustration in picture 4 shows that lower squall velocity pressures respectively lower wind velocities are applied for near-ground constructions like open area photovoltaic plants than the peak velocities mentioned above. But these peak velocities are usually measured by official weather stations that by definition are installed at locations in open areas at a height of 10 m above the ground. From a mechanical point of view, the reduction of the impact pressures close to the ground is comprehensible.

For the sake of completeness it has to be mentioned that an increase of the wind velocity can arise at exposed locations on isolated hills and terraces due to a constriction of the flow profile. According to the normative regulations, such effects can be covered by considering a so-called topography factor. In unfavorable conditions, this can cause an increase of the wind velocity of up to 50%. This does not only apply for normal hilly terrain, but also for exposed locations. A landfill site in a flat environment can be taken as an illustrative example, as landfill sites become ever more popular as installation sites for photovoltaic plants in open areas.

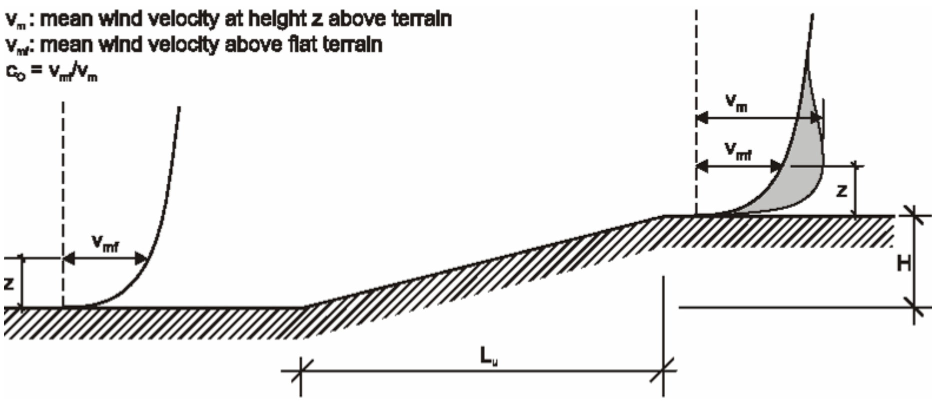


Figure 6: Influence of topographic changes on the wind velocity

In summary, it can be stated that the peak velocities measured in storm events correlate to the load assumptions according to DIN 1055 part 4, even if the normative classification as medium wind velocity on the basis of the stationary part and a squall reaction factor is not easily comprehensible to non-experts.

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