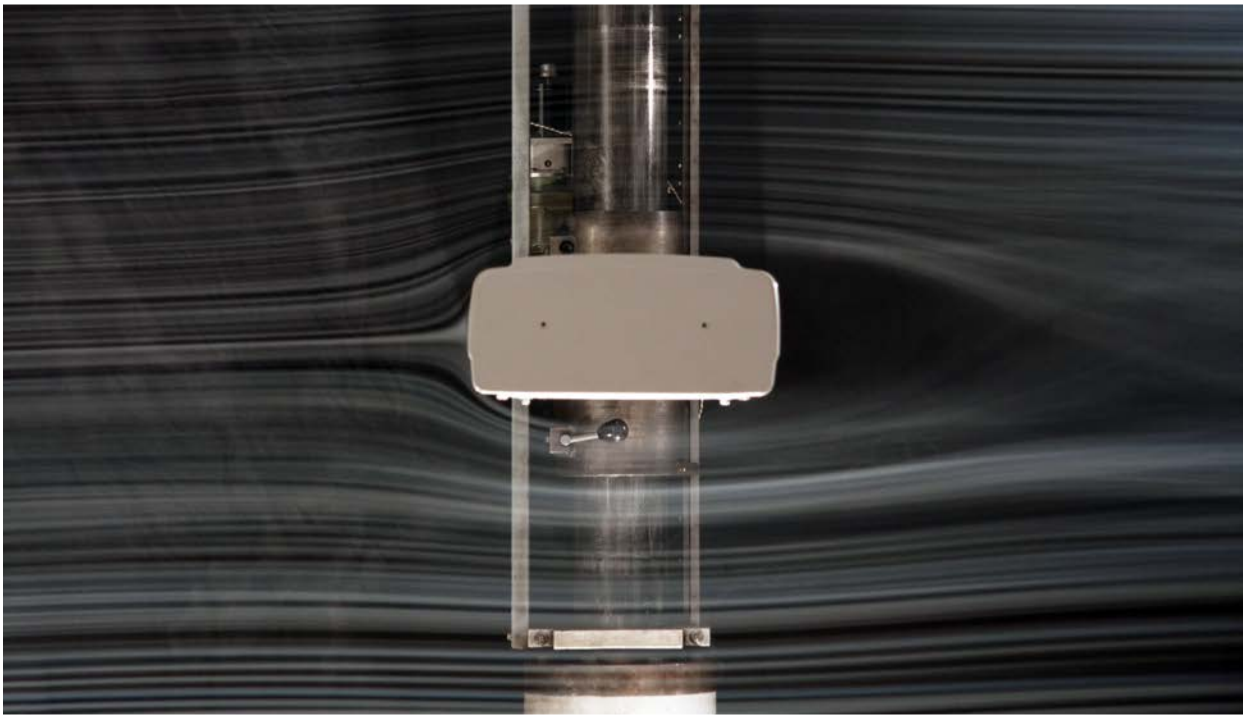
White Paper

BASE STATION ANTENNAS – RELIABLE WIND LOAD CALCULATION



CONTENTS

ABSTRACT

One of the most important mechanical characteristics stated in the data sheets of base station antennas is the wind load. This white paper describes how this parameter is determined and its values are obtained. The technically oriented user can find a detailed overview of the various calculation steps according to standards at the end of this document.

This report will also go into detail concerning the reasons why Kathrein emphasises the frontal and maximum wind loads. It clearly defines wind load characteristics and explains the background to the calculations and tests conducted by Kathrein.

THE IMPORTANCE OF THE WIND LOAD

The market for base station antennas is developing very dynamically. To ensure that the demand for growing data transmission capacities is well met, antennas are developed to be more efficient and complex. This has an impact on the outside dimensions of antennas, even though these are designed with an increasing integration density.

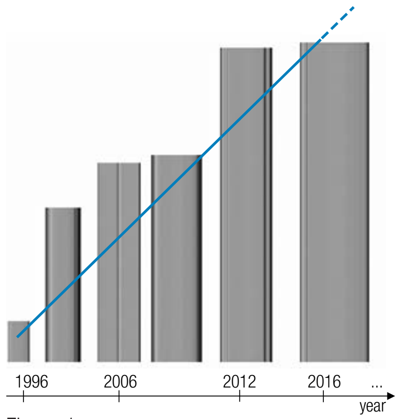


Figure 1:
Antenna sizes over the years

With this development, the strength of the existing antenna masts may no longer be ensured, especially when antennas in the field are replaced or additional ones are mounted. Antenna site operators implementing modernisations are, therefore, facing additional costs. Furthermore, high wind loads at high wind speeds, for example during storms or hurricanes, are a particular challenge. The MNOs (mobile network operators) or their contractors are always legally responsible for designing and dimensioning antenna sites. Depending on the region and the location of the antenna site, these influences have to be taken into account when considering the site safety from a structural analysis point of view.

This white paper on wind loading gives a detailed explanation of these facts and circumstances. It provides a clear understanding of the values stated in data sheets and reveals their limits of use.

METHODS OF DETERMINING THE WIND LOAD

There are three recognised methods for determining the wind load of base station antennas:

1. Numerical simulation of the wind flow
2. Wind tunnel testing
3. Calculation according to standards

From the time when the first base station antennas were developed in the 1980s until today's solutions, Kathrein has conducted studies to ascertain the best suitable method for determining the wind load. This has resulted in Kathrein using a combination of all the three methods.

1. Numerical simulation of the wind flow

The numerical simulation is used for the qualitative development of flow-optimised profiles. At Kathrein, this method is not used as the only basis for determining the wind load values stated in data sheets.

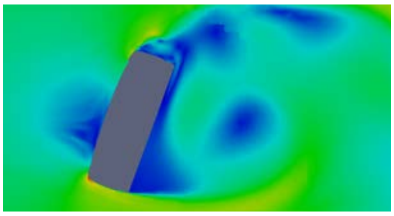


Figure 2:
Numerical simulation of an antenna profile

2. Wind tunnel testing

The values obtained in wind tunnel tests are dependent on the characteristics of the wind tunnel and the test set-up. In order to obtain comparable results, the antennas are tested with the same test set-up in the same wind tunnel. Kathrein uses the wind tunnel to ascertain flow characteristics, to validate mathematical methods and to quantitatively determine the wind load of specific profiles in a 360° scan.

Figure 3:
Test set-up in the wind tunnel

3. Calculation according to standards

Kathrein calculates the wind load of antennas according to recognised and internationally valid standards. This ensures that the method used is clearly defined and universally comprehensible. The calculation according to standards is an accepted and reliable method. However, subsequent tests in the wind tunnel have shown that the calculated results are conservative rather than precise. This explains why a combination of computation according to standards and wind tunnel testing is used for the data sheets. The complete procedure is described in detail in Section “Determining the wind load”, p. 3.

Kathrein uses the EN 1991-1-4 standard in combination with the results from the wind tunnel tests. This standard approximates the general forms of antennas.

DETERMINING THE WIND LOAD

With regard to the wind load determination, it is necessary to point out that the established values are only applicable to a standard case, i.e. an antenna with its original brackets and accessories which is mounted directly on one continuous mast. This is considered the standard case of how antennas are mounted. All other objects that may be within the antenna’s sphere of flow influence are not considered. These may include additional antennas, filters, cables, supplementary mounting equipment and many other items which would increase the number of possible combinations enormously. For this reason, only one antenna per mast is examined.

Figure 4:
Standard configuration

The principle of the wind load determination

Due to the radiation-optimised shape of Kathrein's base station antennas, the wind load is calculated in compliance with the standard on the basis of a body with a rectangular cross section with rounded-off corners. All the variables which appear in the calculation are defined in detail below.

$$F_w = c_f \cdot A_{ref} \cdot q_p$$

F_w	c_f	A_{ref}	q_p
N	-	m²	N/m²

Formula 1

The wind load F_w of base station antennas in the form of a rectangular body with rounded-off corners is the product of the force coefficient c_f, the projected area A_{ref} and the dynamic pressure q_p.

The force coefficient c_f represents the aerodynamic properties of objects: the more favourable the shape for the airflow, the smaller this value. The force coefficient can be determined by means of wind tunnel tests, taken from published literature or calculated using the standards.

The projected area A_{ref} is the product of the length and the depth or width of the antenna, depending on the airflow direction.

The dynamic pressure q_p is the square function of the wind velocity: if the wind velocity doubles, the dynamic pressure quadruplicates.

$$q_p = \frac{1}{2} \rho \cdot v^2$$

q_p	ρ	v
N/m²	kg/m³	m/s

Formula 2

The air density ρ depends on the temperature and the air pressure (at height above sea level). The EN 1991-1-4 standard recommends a value of 1.25 kg/m³.

The detailed deduction of the individual values can be found in the appendix on pages 13ff.

It is customary to calculate the wind load according to Formula 1 by multiplying the area by the force coefficient A·c and using a site-specific dynamic pressure.

The value A·c of Kathrein's antennas can be calculated using the wind load at 150 km/h given in the data sheet as follows:

$A \cdot c = F_{150\ km/h}\ /\ 1085\ N/m^2$	$F_{150km/h}$	A·c
	N	m^2

Formula 3

The calculation according to the standard gives results for a specific wind direction, e.g. frontal or lateral airflow. For flow angles between these calculated points, the wind load is interpolated and has, therefore, only limited significance. Moreover, the calculated results are far higher than the values obtained from the wind tunnel tests. Due to these facts, Kathrein uses a combination of measured results and standard calculations for the data sheet values. As a further consequence, the wind loads are now uniquely indicated as the frontal and the maximum wind load. This results in a realistic representation of the standard case antennas.

The force coefficient determined in the wind tunnel is used as a basis for the wind load calculation of an antenna with a specified length. In combination with the reduction factor Ψ_λ for the peripheral flow taken from the EN 1991-1-4 standard, the wind loads for other antenna lengths are determined analogously, as shown in the appendix.

The calculation of the wind load by means of the wind tunnel test results gives detailed information for each wind direction, including those which would only be available as calculated interpolation values otherwise. The results from the wind tunnel tests show that the frontal and the maximum wind loads are the most important ones for describing the behaviour of the antenna in the wind flow. This is also the reason why they are both specified for a flow sector of ±45°. This approach is further explained on the following pages.

Due to the fact that positive fluid mechanical effects occur for the frontal flow, the maximum wind load is obtained by multiplying the frontal load by a correction factor of 1.1 if the mathematical approach is used, see Table 1. This value was also confirmed by the wind tunnel tests.

If test results are available, these values are used to specify the wind load of all the antennas with the same profile. For all other cases, the calculation is carried out according to the procedure explained above.

Therefore, Kathrein uses the following procedure for determining the force coefficient:

	Calculation	**Measurement**
Frontal	According to adapted standard	Frontal measurement
Maximum	Calculated frontal wind load x 1.1	Measurement of the maximum in ±45°sector

Table 1:
Overview of c_f determination

THE ANTENNA IN THE WIND TUNNEL

On the one hand, the calculation according to the standard is claimed to be conservative, on the other hand, it can only give values for a limited number of geometries.

As the market has become much more sensitive with regard to wind loads, their values have been revised in 2016. The calculation algorithm has been refined but it is still based on the EN 1991-1-4 standard. To confirm the adapted values from a technical point of view, new tests were carried out in the wind tunnel at the Technische Universität Dresden. For calculations, Kathrein has up to now interpreted the EN 1991-1-4 standard conservatively. This resulted in the wind load values being higher than the ones obtained in wind tunnel tests.

Aerodynamic properties

The force coefficient determined in the wind tunnel is complex, as can be seen in Figure 5, p. 7 which shows the measurement for an antenna without a mast.

Figure 5 shows the airflow angle plotted in a circle and the respective c_f value of the antenna plotted radially. This figure shows the properties of an antenna with relatively large rounded longitudinal edges. The following effects can be seen:

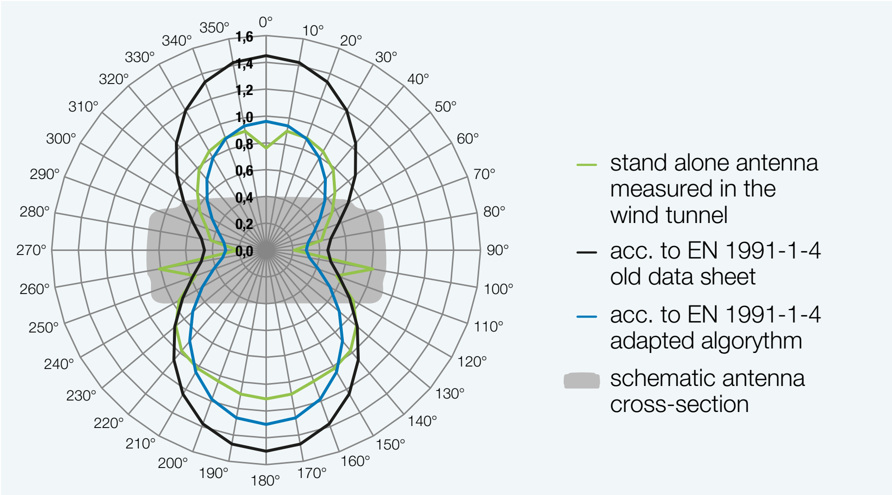


Figure 5:
Calculated force coefficient and measured total force coefficient with the same reference area

1. Calculating the wind load with the actual calculation method and fitted radii (blue line) results in considerably reduced wind load values when compared to the old calculation method (black line). The fitted radii are shown in the appendix in Figure 10. The radii used for the calculations according to the current method are larger than those of the old method. This has a significant influence on the load reduction. The wind load measured in the wind tunnel (green line) confirms this reduction.

2. The wind load measured in the wind tunnel in the 0° direction, i.e. the frontal direction, is much lower than the maximum wind load in the sector of ± 45°. All wind load maxima of different antenna profiles lie within this range; it is for this reason that this sector was chosen. Figure 6 compares two antenna types with different depth-to-width ratios.
    - The force coefficient of the antenna with the higher depth-to-width ratio is shown in yellow.
    - At the 0° flow direction, a concavity typical for rounded profiles emerges. The higher the depth-to-width ratio of the antenna, the larger the concavity.
    - Approximately 20° away from the frontal wind direction, the wind load rises compared to the measured frontal wind load. The calculated wind load does not show concavity

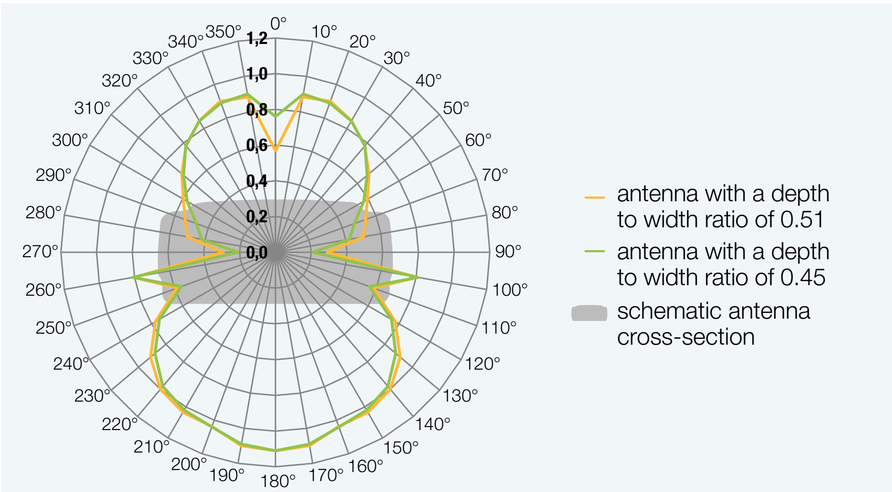


Figure 6:
Total force coefficient for two different antennas measured in the wind tunnel

effects. Compared to the frontal wind load calculated according to the standard, the calculated maximum wind load can be up to 10% higher.
This explains why a factor of 1.1 is used for determining c_f, compare Table 1, p. 6.

The sole specification of the frontal wind load would thus be misleading for the customer when designing and dimensioning the mast. This is the reason why Kathrein also indicates the maximum wind load.

3. For the rear flow at about 180°, a convexity emerges which represents a maximum in this sector. This is characteristic of antennas with a small longitudinal edge radius. The ideal antenna would have no minima and maxima in the wind load curve and a maximum wind load as low as possible.

4. The lift and drag forces due to the lateral flow acting on the antenna are responsible for the characteristic spikes at around 100° and 260°. This effect is even more pronounced when the corner radii of the antenna are larger, in particular on the downwind side. An antenna with sharp longitudinal edges causes an early stall and, therefore, results in a considerably reduced lift. The more rounded the antenna is, the more pronounced the lift and drag forces become.

Influence of the mast

Figure 7 shows the impact of the mast on the wind load properties of the overall system consisting of both antenna and mast, as described in the standard case.

1. The mast has virtually no impact on the frontal airflow.

2. With regard to the rearside airflow, the mast causes a considerable reduction of the wind load of approximately 60%.

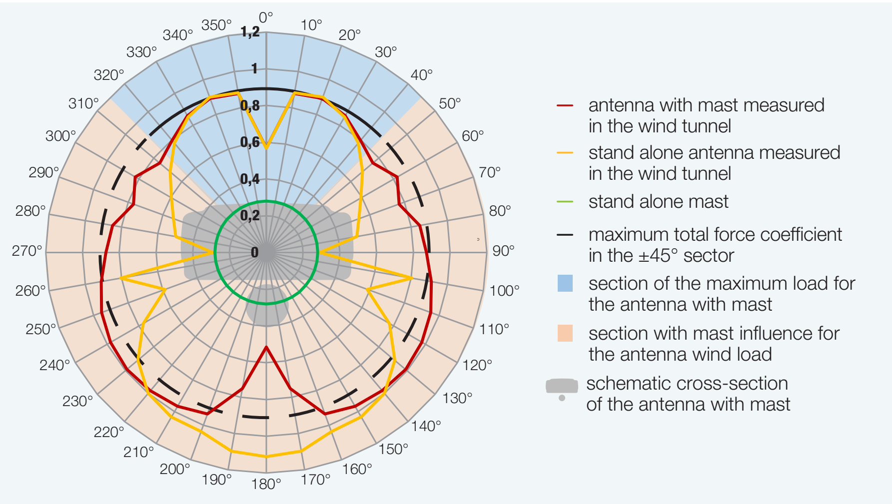


Figure 7:
Force coefficient of an antenna with mast

3. With regard to the lateral airflow in the sectors between 45° to 140° and 220° to 315°, the mast is no longer in the slipstream of the antenna and considerably increases the cross-sectional area exposed to the airflow. This results in the formation of complex interference phenomena, which can lead to an elimination of the lift effects on the antenna. Thus, it is impossible to separate the wind loads of mast and antenna and the measured force coefficient diagram is, therefore, not significant for examining the force coefficient for lateral flow.

Kathrein defines the wind loads for mast-mounted antennas, a condition common to most applications. The values for the frontal wind load and the maximum wind load stated in the data sheet make it possible to design a mast for the purpose mentioned above without having a specific value for the airflow from the rear.

For antennas that are mounted on stub masts on the upper and lower mounting clamps, which means they do not have one continuous mast, it is recommended to increase the value of the maximum load by 20%. Compared to the standard case, this higher value arises because there is no positive effect from the mast.

Conclusion
The adapted data sheet values are determined by applying the valid standards and were additionally confirmed by wind tunnel testing.

THE WIND LOAD AT ANTENNA SITES

The wind loads stated in data sheets always refer to a reference wind speed of 150 km/h. This enables a direct comparison of the antennas with regard to their wind load.

As all sites have site-specific wind speeds, it is necessary to calculate the load so that these wind speeds are taken into account:

$$F_{Location} = F_{150\ km/h} \cdot (v_{Location}/v_{150\ km/h})^2$$

F_w	v
N	km/h

Formula 4

The site-specific load acting on an antenna depends on its geographic location, the location-specific factors, the orthometric height and the way the antenna is mounted on a mast.

When configuring and dimensioning structures that are slim and can sway with the loads that are acting on them – as masts in general are – the dynamic reaction of the overall structure to the gustiness of wind is taken into account by using the following factor as an additional factor to Formula 1, p. 4 "structural factor $c_s \cdot c_d$" (EN 1991-1-4) or "gust effect factor" (TIA 222). Loads acting on antennas are also increased by this factor.

When configuring antennas and their direct mounting equipment, these factors can generally be multiplied by 1 because antennas are usually more rigid than masts and, therefore, less prone to vibrations.

It should be noted that it is the site structural engineer who is responsible for the correct calculation and interpretation of the wind load at the respective antenna site. The wind load values were determined under the test conditions described in this paper and serve as a basis for the values stated in the data sheets. It is strongly advised to refrain from using these values for the respective site without further verification.

FAQ

How can I work with these wind load values?

The adapted values are technically verified values and can be used as before. The values are determined by means of a combination of calculation according to the EN 1991-1-4 standard and results obtained from wind tunnel testing.

Can the wind load from the rear side be supplied as additional information?

The wind load data relating to the rear side of the antenna does not need to be considered for setting up a mast-mounted antenna because this value is smaller than the frontal value. If a stand-alone antenna is set up, the latest antenna profiles are expected to have a load that is 20% above the maximum wind load.

Why are the wind load values suddenly so much lower?

The calculation method was adapted so that it corresponds to the real values from the wind tunnel tests. However, the wind load values are still based on the calculation according to the EN 1991-1-4 standard and are scientifically confirmed.

Two other changes have also been incorporated:

- Up to now, the load at 150 km/h was calculated according to the VDE 0855 standard (which has meanwhile been withdrawn) with a dynamic pressure of 1100 N/m². Applying an air density of 1.25 kg/m³ as recommended in EN 1991-1-4 results in a lower dynamic pressure of 1085 N/m².
- Connectors and fixtures are only considered for short antennas. TIA 222 permits plugs and fixtures to be disregarded as long as their wind load fraction is less than 10% of the one of the whole antenna. Besides the integration of RET in the antenna, with more compact plugs, and new fixture concepts for the new antenna series, the impact of these components has become negligible.

Why have the wind loads been changed at this particular point of time?

Up to now, Kathrein has used a conservative interpretation of the calculation according to the EN 1991-1-4 standard for data sheet values. Market demand and the fact that antennas are becoming ever larger have made it necessary to run wind tunnel tests and work on a better fitting method to determine the wind load values.

APPENDIX

Different standards give different possibilities and approaches to calculate the wind load of antennas.
Some examples:

- TIA 222 permits the load calculated for any direction, if the normal and lateral loads are given (based on $\sin^2+\cos^2$)
- TIA 222 permits neglection of small irregularities, such as connectors or RCUs
- EN 1993-3-1 permits load reduction of the stand-alone antenna (shielding)
- The German national annex to EN 1993-3-1 recommends to apply the normal load at the same time in the lateral direction if lift forces are not known or specified

standards for wind loading	year	region	method	covered shapes	slenderness	forces	moment	diversity of load and wind direction	shielding
TIA-329	2003	USA	calculation	round / flat	no	maximum	no	no	no
TIA-222	2005	USA	calculation in absence of specific data	round / flat	yes	every direction	no	no	yes
EN 1993-3-1	2007	EU	wind tunnel	all	no	every direction	yes	yes	yes
EN 1991-1-4	2005	EU	calculation	round/flat/flat with curved edges	yes	orthogonal	no	no	yes

Table 2:
Comparison of the standards for the wind load of base station antennas

	calculation			measurement	
	$c_{f,0}$	ψ_r	ψ_λ	c_f	ψ_λ
frontal	according to EN 1991-1-4	adapted to EN 1991-1-4	according to EN 1991-1-4	frontal measurement	according to EN 1991-1-4
maximum	calculated frontal wind load x 1.1			measurement of the maximum in the ±45° sector	

Table 3:
Detailed determination of the values for wind load calculations

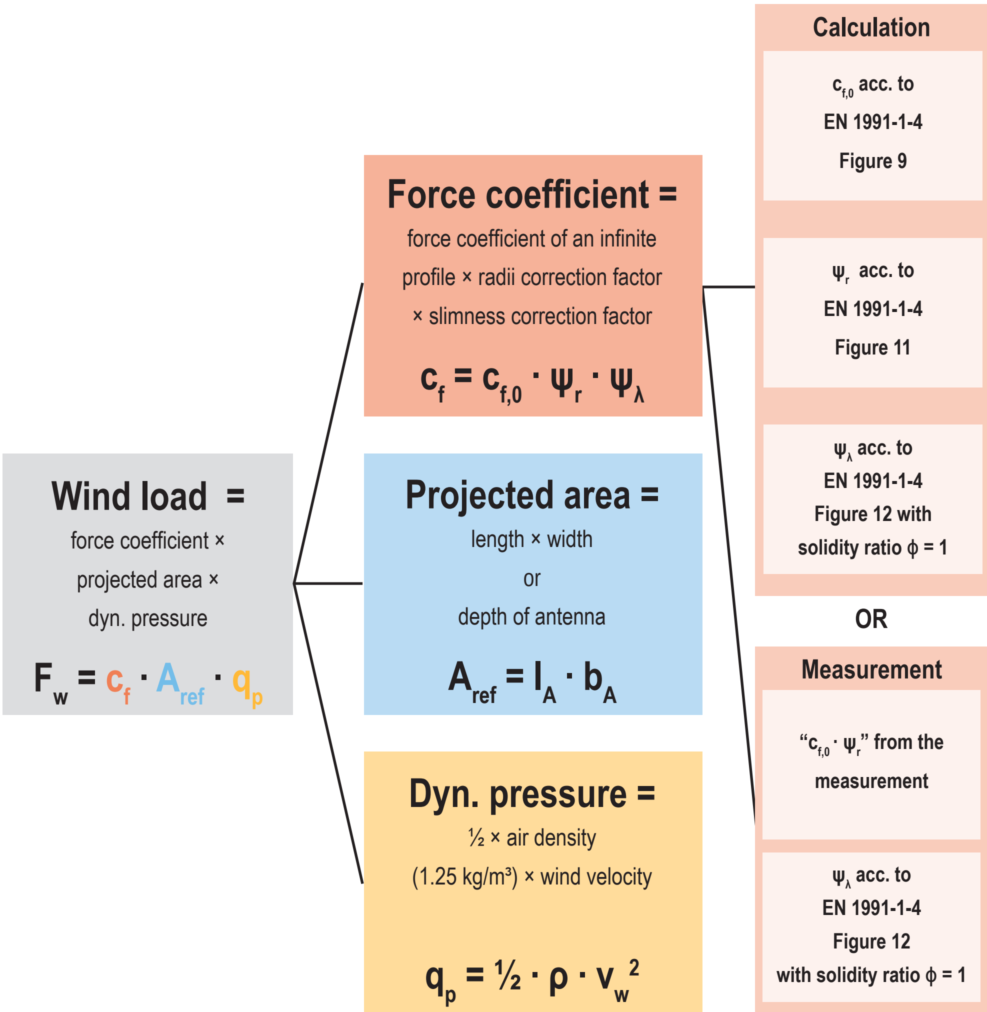


Figure 8:
Calculation of the wind load according to EN 1991-1-4

Determination of the force coefficient

When determining the force coefficient c_f, there is a difference between
1. values and parameters from the EN 1991-1-4 standard and
2. measurement values obtained from wind tunnel tests.

The force coefficient determined according to the standard uses the basis $c_{f,0}$ ($c_{f,0}$ of rectangular sections with rounded corners and without free end flow) in combination with the reduction factors Ψ_r and Ψ_λ. Ψ_r considers the longitudinal edge radius of the antenna, Ψ_λ the length-to-width ratio:

$c_f = c_{f,0} \cdot \Psi_r \cdot \Psi_\lambda$	c_f	$c_{f,0}$	Ψ_r	Ψ_λ
	-	-	-	-

Formula 5

The determination of the force coefficient and the reduction factors is explained in Figure 8.

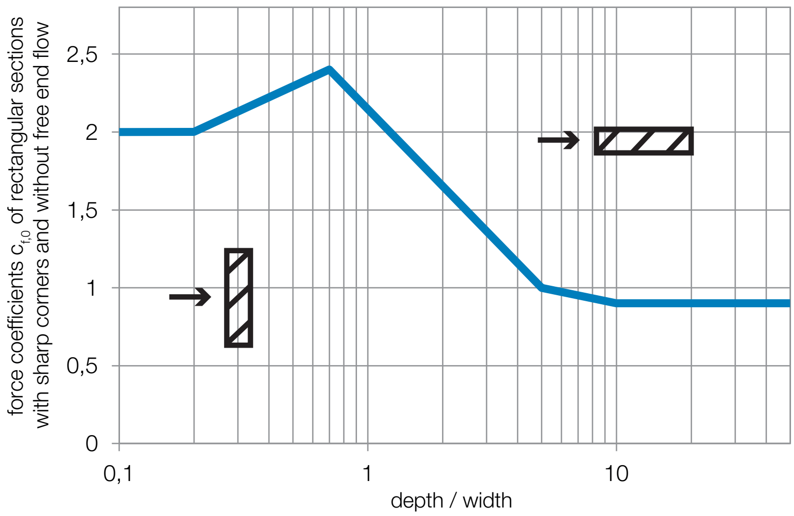


Figure 9:
Force coefficient $c_{f,0}$ of rectangular sections with sharp corners without free end flow according to EN 1991-1-4

Determining the reduction factor Ψ_r for cross sections with rounded edges

Wind tunnel tests have shown that the results obtained from the calculations according to the standard with the actual edge radii of the profiles are actually considerably higher than the real wind loads. In order to compensate for this, an effective radius is fitted into the surrounding rectangle. This radius is defined by the two tangential contact points with the surrounding rectangle and the first contact point with the profile.

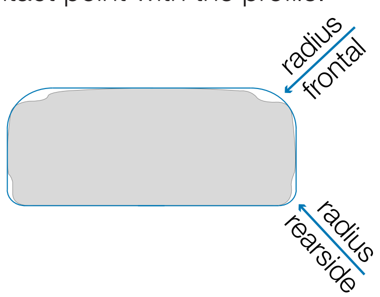


Figure 10:
Improved radii for the calculation according to EN 1991-1-4

The dependence of the reduction factor Ψ_r on the radius-to-width ratio is defined in EN 1991-1-4 as follows:

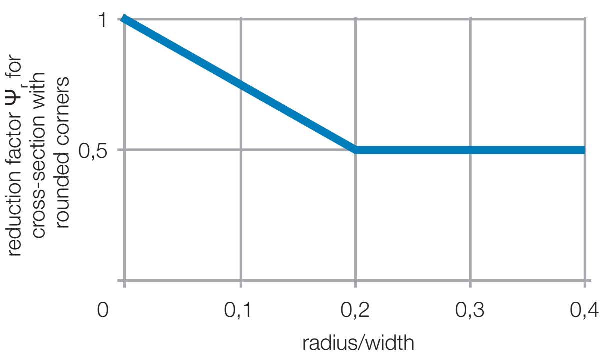


Figure 11:
Reduction factor Ψ_r for a square cross section with rounded corners according to EN 1991-1-4

Determination of the reduction factor Ψ_λ for the free end airflow

This slenderness curve describes the wind load as a function of the length-to-width ratio of the antenna. For wind loads based on wind tunnel tests, this curve is extrapolated for other antenna lengths.

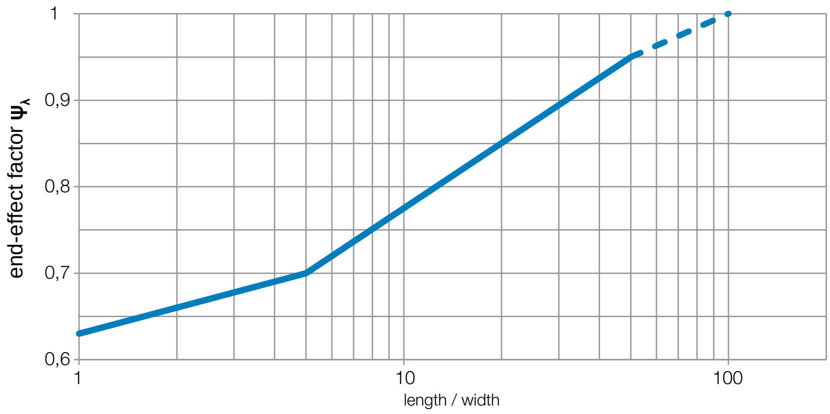


Figure 12:
Reduction factor for the end-effect factor Ψ_λ acc. to EN 1991-1-4

SOURCES

DIN EN 1991-1-4:2010-12 Eurocode 1: Einwirkungen auf Tragwerke - Teil 1-4 (Actions on Structures - Part 1-4): Allgemeine Einwirkungen – Windlasten (General Actions - Wind Actions)

DIN EN 1993-3-1:2010-12 Eurocode 3: Bemessung und Konstruktion von Stahlbauten - Teil 3-1 (Design of steel structures - Part 3-1): Türme, Maste und Schornsteine - Türme und Maste (Towers, masts and chimneys - Towers and masts)

EIA/TIA-222-G:2005-08-02 Structural Standard for Antenna Supporting Structures and Antennas

NGMN-P-BASTA White Paper Version 9.6 Recommendation on Base Station Antenna Standards by NGMN Alliance

ABOUT KATHREIN

Kathrein is a leading international specialist for reliable, high-quality communication technologies.

We are an innovation and technology leader in today's connected world. Our ability to provide solutions and systems enables people all over the world to communicate, access information and use media, whether at home, at the office or on the road.

We cover a broad spectrum: from mobile communication and RFID solutions, to satellite reception, broadband and broadcast technology, to transmission and reception systems in vehicles.

As a hidden champion and family-owned enterprise, we have been working on the technologies of tomorrow since 1919. We take pride in our dedicated employees and our passion for customers and quality.

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