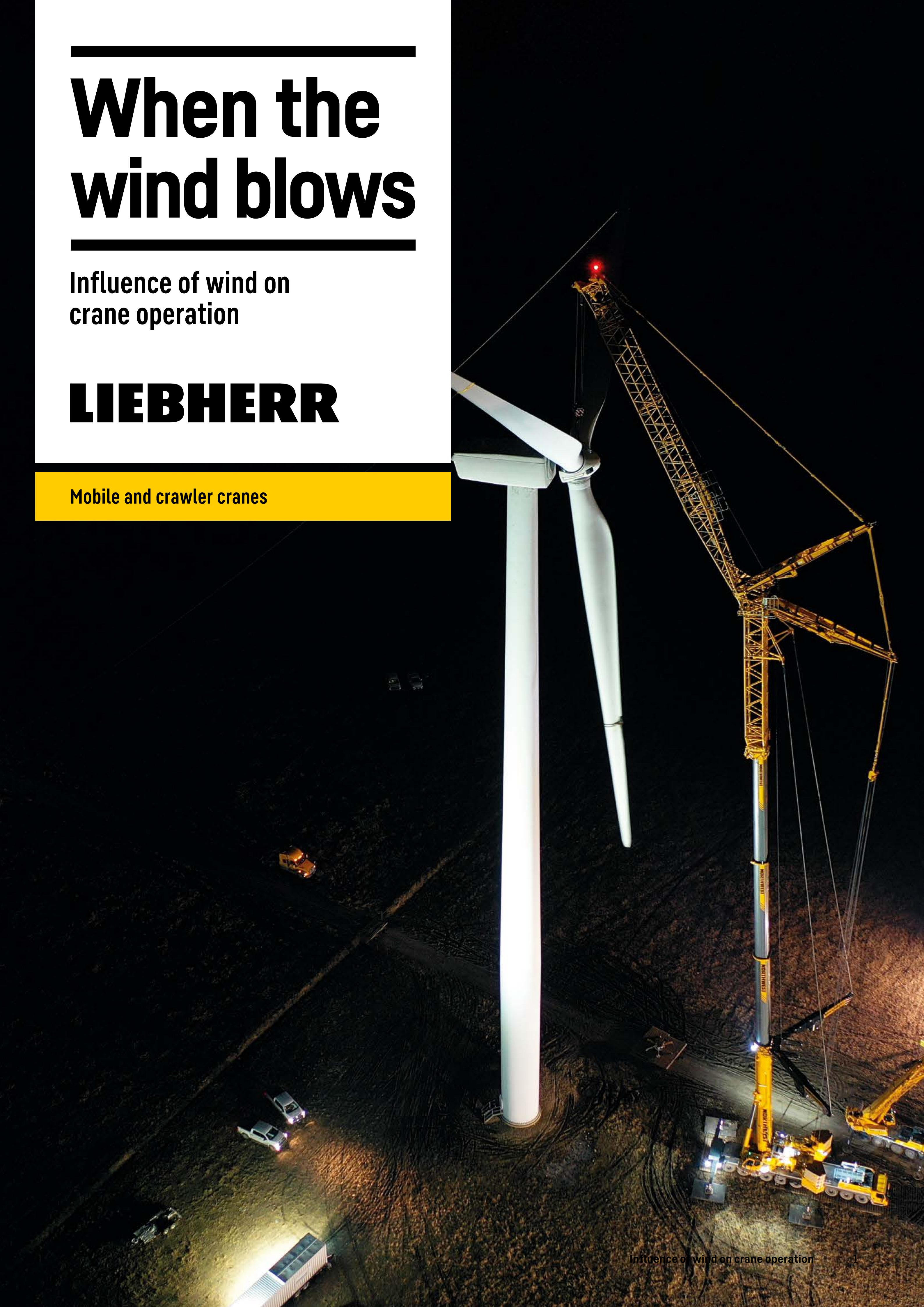
When the wind blows

Influence of wind on crane operation

LIEBHERR

Mobile and crawler cranes



When the wind blows

Wherever people are working, mistakes are made. With crane operation the wind conditions can present a potential danger that should not be underestimated. The crane driver must ensure that the crane is not exposed to any wind that could exceed the limits set by the crane manufacturer. It is also necessary to make the correct decisions and implement the correct measures at the right moment to ensure that the crane will never become unstable due to wind influences.
If there is a danger then the crane driver must implement the actions that have been defined by the contractor. Thus the crane driver decides in emergency situations on-site, whether the wind is too strong and the work must be halted. It is therefore important to be warned about prolonged and large-scale gathering storms in good time. Especially dangerous however are localised squalls, which can arise in conjunction with heavy showers and thunderstorms for example.

This training document serves to inform crane drivers, project planners and also crane companies and should provide examples of handling options for crane operation in windy conditions. To start we will introduce you to the basics of wind loads. As we proceed we will show how wind loads and finally special load cases, such as when erecting wind-power turbines, can be calculated. Likewise we will show you what information is required for this.

We have designed this documentation such that the reader can acquire the relevant information through self-study in accordance with their level of knowledge. Examples and problems serve as illustrations and provide the opportunity for practice. Furthermore, you can find useful advice and aids for day-to-day work with the crane. The training documentation does not claim to be complete and does not replace the operating instructions and the load chart book for the Liebherr crane in question. We can only urge caution here when working with mobile and crawler cranes and offer our fifty years plus experience as a leading manufacturer of cranes.

Liebherr-Werk Ehingen GmbH

Important

Every description of the wind speed in this document always refers to the wind gust speed, as this is always higher than the normal wind speed.
As a result, the wind gust speed must always be used as the basis for the calculation.

How to work with this document

Designates a dangerous situation about current topic.

Important note / information about current topic.

First read through the text of a chapter carefully. Reprise the content of the chapter. Answer the questions posed at the end of the chapter (without referring back if possible). The solutions to all questions can be found at the end of the document. If you are not able to answer the questions without referring back to the text then work though the chapter once again.
At the end of the document check to see if you have achieved the study goals listed here.

After having worked through this document you should:
- Know the various influences of the wind on crane operation
- Be able to name the terms for wind force calculation
- Be able to calculate the wind load for a standard load case and a special load case
- Be able to calculate the maximum permissible wind gust speed

Term definitions

N	**Newton (Unit of force)**
c_D	**Wind resistance factor (Drag coefficient)**
A_P	**Projected surface of a body (m²)**
A_W	**Surface area exposed to wind (m²)**
v_{max}	**Maximum permissible 3 second gust speed (m/s) at highest point on the crane**
v_{max_TAB}	**Maximum permissible 3 second gust speed (m/s) at highest point on the crane, which are specified for the load values in the load chart**
v_{act}	**Actual measured wind speed**
v(z)	**The average value for the wind speed over a period of 3 seconds at a height of z above the ground (m/s)**
p	**Dynamic pressure (pressure on a body as a result of wind exposure in N/m²)**
F_W	**Wind load (Influence of force on a body as a result of wind exposure)**
m_H	**Hoist load (t) (incl. fastening equipment and hook block and possible hoist rope section). The hoist load may reach no more than the maximum chart value of the load chart.**

Content

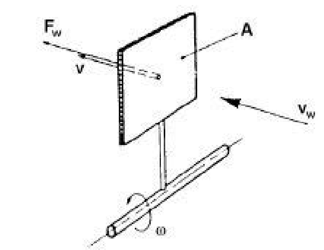
1. Introduction and presentation of problems

Wind influence on the load

Often wind and occurring gust of winds are an underestimated factor in accidents with mobile cranes or crawler cranes. When lifting loads with large surfaces exposed to wind such as rotor blades or complete propeller units for wind power plants (WPP) the standard values provided by EN 13000, which are the basis for the crane calculations, can be significantly exceeded.

Such standard values are the so-called **wind resistance factor** (c_D) for example or the value for calculation of the so-called **projected surface area** of a load. Both values together provide information about the force over the actual surface area exposed to wind of a load. In the case of large surface area loads (special load cases) in particular, the wind speeds given in the load charts can be inapplicable for the crane work. A new lower wind speed, compared with the original permissible wind speed, must be calculated for this special load case.

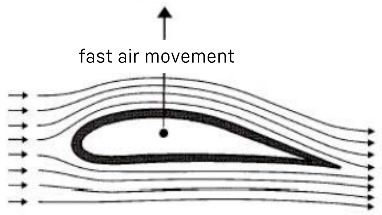
If



Resistance principle

What role does the wind play in the exceedance of these standard values?

Wind meets a surface then it exerts a force on this surface (**resistance**) that works in the wind direction.



Lift principle

So-called **lift additionally** applies in the case of an aerofoil or a rotor. The surface/length of the upper side of an aerofoil is larger than the underside. The air on the upper side must therefore move faster than the air on the underside. This causes under-pressure on the top side and over-pressure on the underside. As a result of the lift arising from this the aerofoil is pressed upwards.

The force of the wind thus creates a load. This can be an applied or relief load. The trigger for this is the so-called **resistance principle** and the **lift principle**.

Risk of accident!

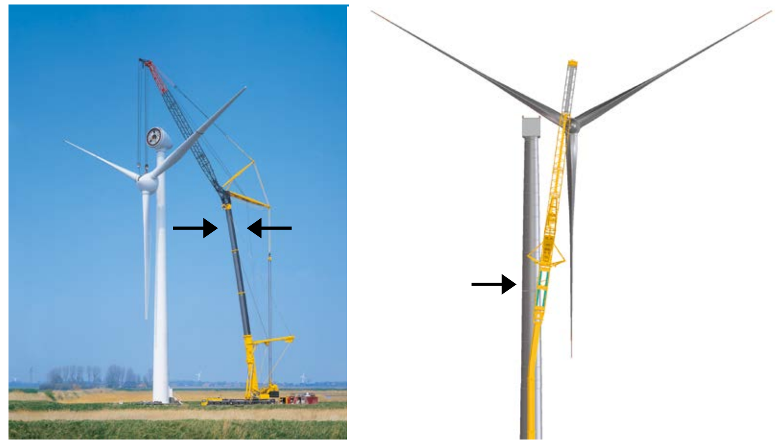
The wind from the front **does not** reduce the loading of the hook, hoisting cable, hoisting cable rollers and hoisting winch because the load continues to work with its gravitational force (see chapter 4.1.1). With wind from the front these assemblies can be overloaded through load lifting up to the load torque limiter (LMB) shut-off! The load reduction caused by the wind from the front can overload the complete crane with the boom guying, if it has been loaded up to the point of LMB shut-off beforehand!

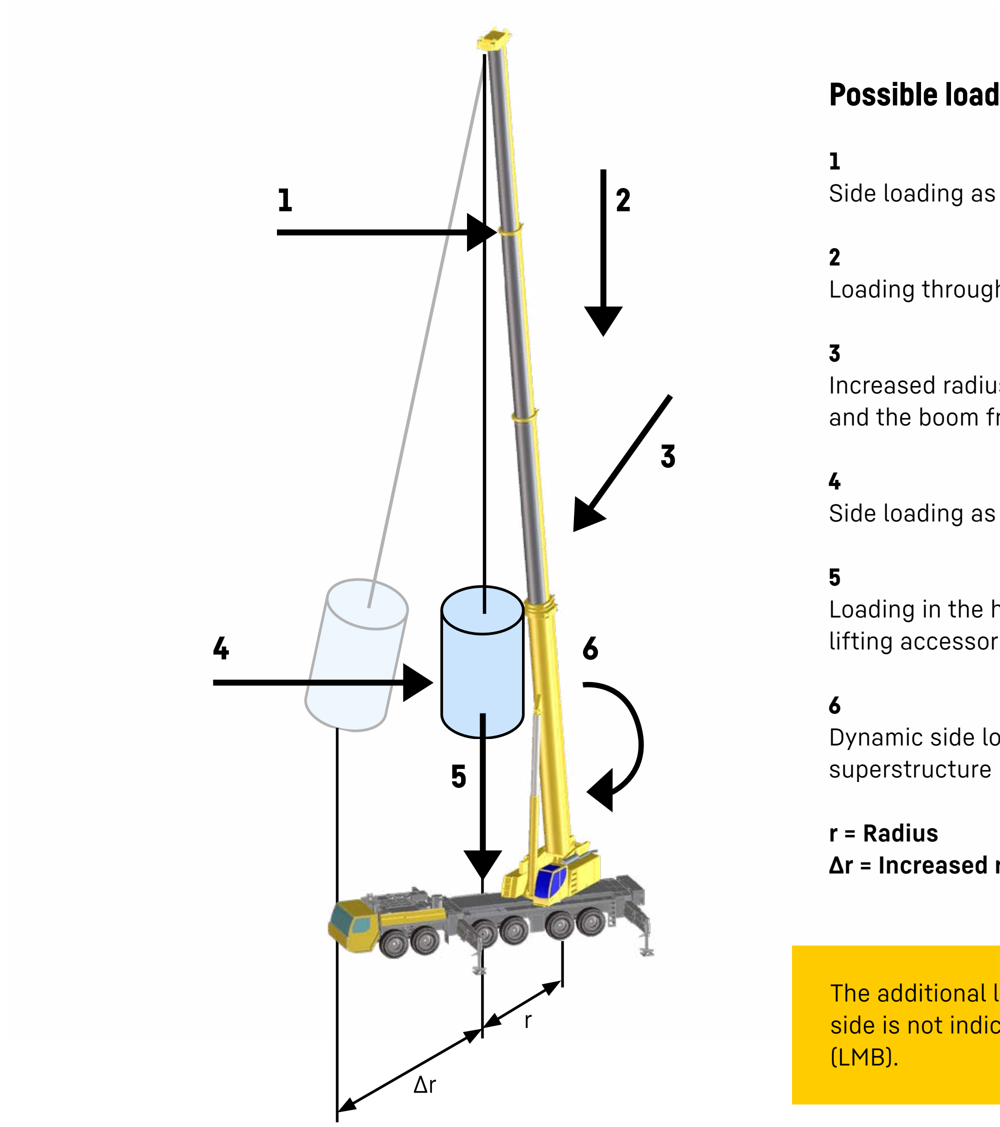
The crane driver must therefore know the weight of the load and must not exceed the max loading capacity!

1.1 Wind influence on the crane and the load

This has a similar effect on the crane.

Wind from the side is particularly dangerous for the crane boom and the load. This is not determined by the LMB. This can result in the crane being overloaded.





Possible loadings on the crane

1
Side loading as a result of wind on the crane boom

2
Loading through dead load

3
Increased radius loading as a result of wind on the load and the boom from the rear

4
Side loading as a result of wind on the load

5
Loading in the hoisting direction as a result of hoist load, lifting accessories and inertial forces

6
Dynamic side loading through turning of the superstructure

r = Radius
Δr = Increased radius through wind influence

The additional loading due to the wind from the side is not indicated by the load torque limiter (LMB).

If the wind hits the load then it swings in the direction of the wind. This means that the force of the load no longer acts vertically downwards on the boom. Depending on the strength of the wind, the surface area exposed to wind and the direction of the wind, the radius of the load may increase or impermissible lateral forces may act on the crane boom.

Overview of wind hazards

	Wind from the front	Wind from the rear	Wind from the side
Boom	With wind from the front the **boom system** is relieved of load. The load indication is too low. The LMB shut-off actuates only with a load that is greater than the maximum permissible load capacity.	With wind from the rear the **boom system** is additionally loaded. The load indication is too high. The LMB shut-off actuates at a load that is less than the maximum permissible load capacity according to the load chart.	With wind from the side the **boom system** is side-loaded. The load indication is similar to the display when operating without wind. The LMB **does not** take side winds into account.
Load	The form and the deadweight of the load plays a large role with the influence of wind. The wind causes the load to swing and this in turn causes the crane boom to swing. This swinging (dynamic) of the boom causes the crane's loading to increase. In the limit range the LMB shut-off could be switching in and out constantly. With special loads such as with a rotor for example, the wind can have the effect of reducing the load due to the shape of the rotor.		

Unpredictable factors

Superb crane quality and technology, many years of professional experience as well as good training of the crane driver and professional advance planning for the crane operation significantly reduce the risk of an industrial accident. However: Unforeseeable factors such as sudden gusts of wind are difficult and sometimes impossible to calculate accurately in advance. Terms such as surface area exposed to wind and wind projected surface area, c_D-value, gusts of wind, wind speed, wind load or roughness class will be discussed in the following.

What do these mean for crane operation in wind?

When planning activities, in particular in cases with large projected surfaces or high c_D-values, it is necessary to reduce the maximum permissible wind speed quoted in the load charts.
The person responsible for the crane operation must have basic knowledge in the field of wind influence on crane operations. Likewise, this person **must be able to calculate** the necessary reduction in permissible wind speeds for special load cases with large surface area loads.
The maximum permissible wind speed (v_{max}) and the maximum permissible wind speed in accordance with the load chart (v_{max_TAB}) relate at all times to the 3-second gust speed prevalent at highest point on the crane.

1.2 Exercises

Exercise 1

What types of wind can have an effect on the boom? (Multiple answers possible)

- ☐ Wind load
- ☐ Evaporation
- ☐ Wind from the front
- ☐ Wind energy
- ☐ Wind from the rear
- ☐ Wind from the side

Exercise 2

Which types of wind have an effect on the LMB?

__________________ The LMB shut-off actuates at a load that is less than the maximum permissible load capacity according to the load chart.

__________________ Shut-off actuates only after a load that is greater than the maximum permissible load capacity.

__________________ There is no LMB shut-off.

Exercise 3

What effect does the wind have on the crane load? (Multiple answers possible)

- ☐ None
- ☐ The load can swing
- ☐ The load turns on the cable
- ☐ The radius of the load can increase

2. Wind basics

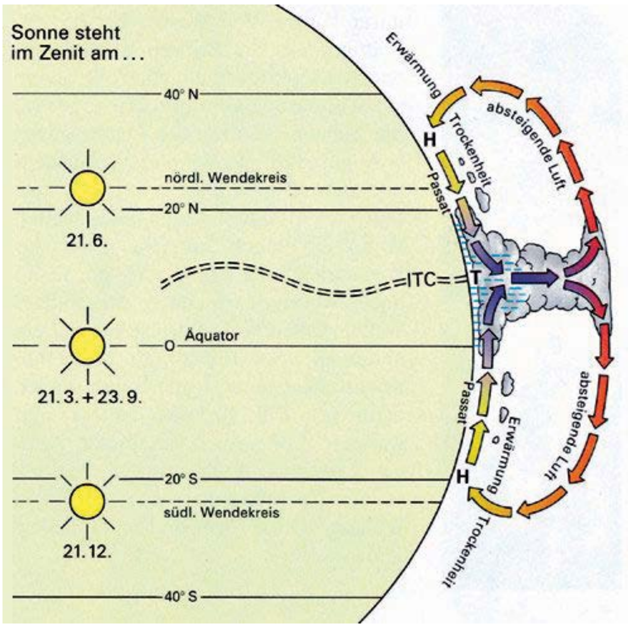
In this chapter you will learn the basics of how wind arises and you will obtain initial explanations for wind-specific terminology.

Wind is moving air. The movement arises through equalising flows resulting from different air temperatures and the pressure differences caused by this between high and low pressure areas.

How does wind arise?

The driving force of winds is solar radiation. It strikes the earth and its atmosphere with different intensities: Perpendicular at the equator and only tangentially at the poles. The earth and air masses at the equator heat up, the air becomes lighter and rises. Hot over the tropics, cold at the polar regions: It cannot remain like this as nature always seeks equilibrium. So the warm air - at the upper edge of the troposphere - flows to wherever it is colder.

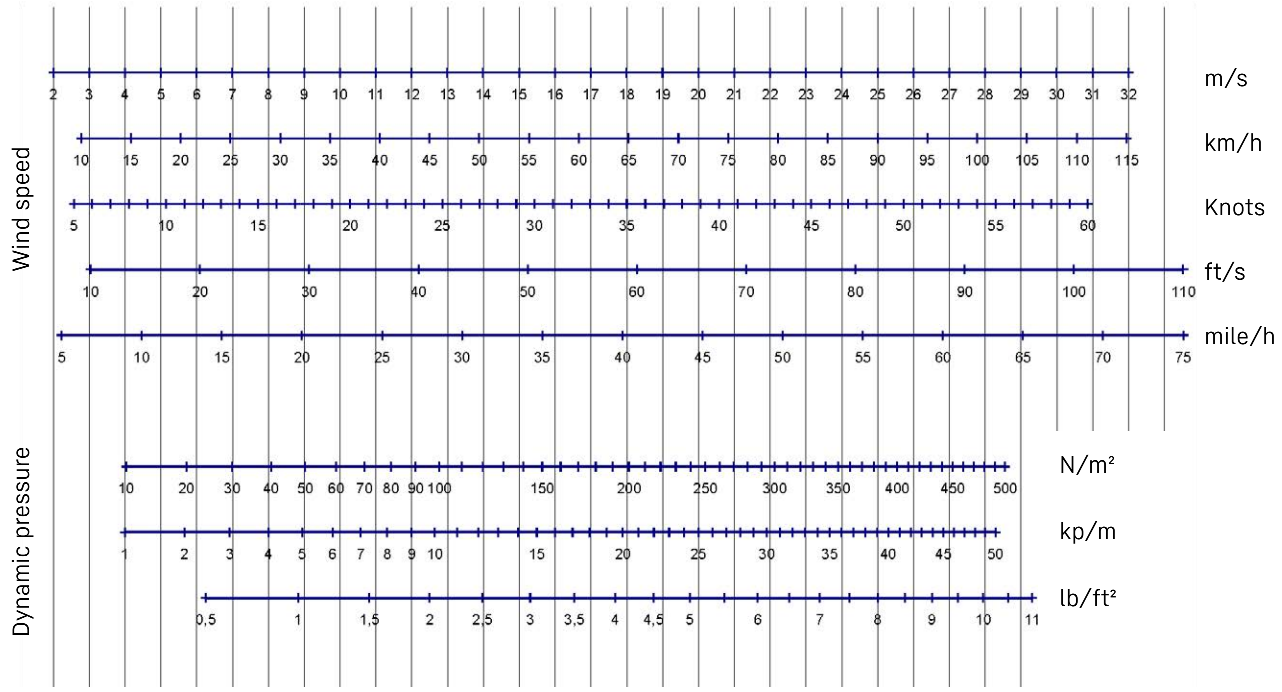
On the way north the air loses so much of its heat that it eventually becomes heavy and drops to the ground cold. A circuit is completed: In the upper atmosphere warm air pushes towards the polar region. On the ground cold air flows back to the tropics as through drawn from a vacuum cleaner. The air transportation from the equator never reaches the pole: The rotation of the earth diverts it far to the side. It also causes the high and low pressure areas to rotate.



The highest wind speed measured in Germany to date was 335 km/h recorded on the 12th June 1985 on Zugspitze. This represents a computed Beaufort value of 23.1.

Beaufort (bft) is an "arbitrary" unit. It expresses the discerned effects of the wind. Beaufort (bft) however is directly related to the physically measurable wind speed. The following diagram shows the interdependency of wind speed and wind strengths.

Wind strength diagram
Comparison of wind strength and wind speed



2.1 Gusts and roughness

What is a gust?

A strong flurry of wind that is active within a wind or storm system is known as a gust. People are surprised time and again when the weather reports speak of a wind of 33 km/h for example, as one has the impression that the wind is much stronger.

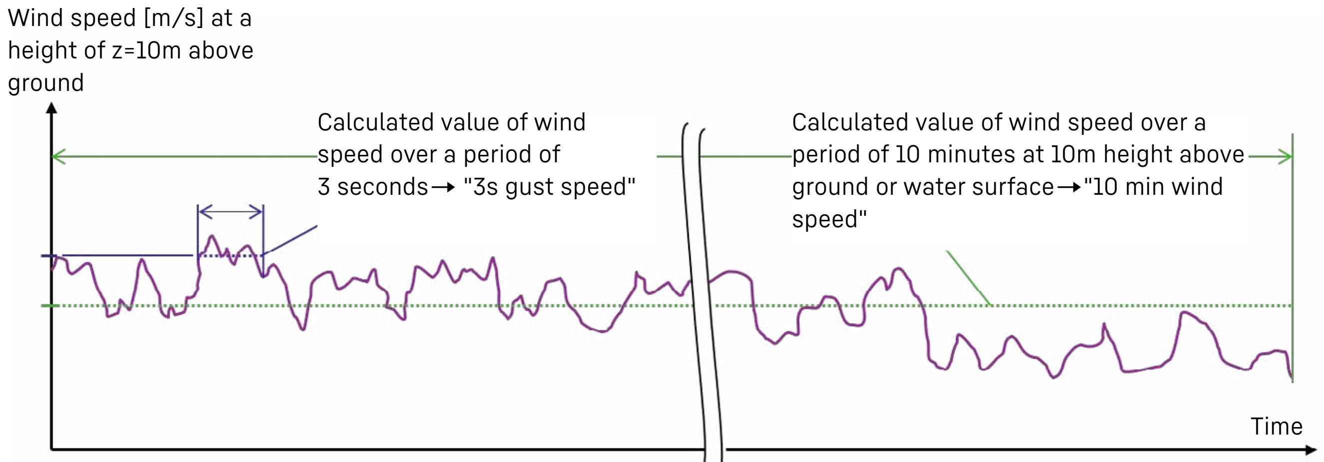
In reality with gusts we are dealing with a flurry of wind that is more powerful and independent of the average speed of the wind. So a gust of wind can reach 60 km/h or more whilst the average value (averaged value over 10 min) lies significantly below this.

Gusts can therefore also be **very dangerous** as they occur suddenly and do not last long. Here the duration is not the problem but rather the sudden appearance of a much stronger air movement than the rest of the wind leads one to expect. Thus gusts can lead to dangerous situations not only in road traffic.

Definition of a gust in accordance with EN 13000

The speed of a gust is the average value of the wind speed measured for a duration of **3 seconds.** The gust speed is higher than the average wind speed, which is measured over a period of 10 minutes.

Course of wind speed at a height of z [m] over time



There are external factors, which can increase or decrease the wind gust speed:

- Buildings
- Narrow valleys and gullies
- Smooth water surfaces
- Height above ground

Behaviour of the wind at high altitudes

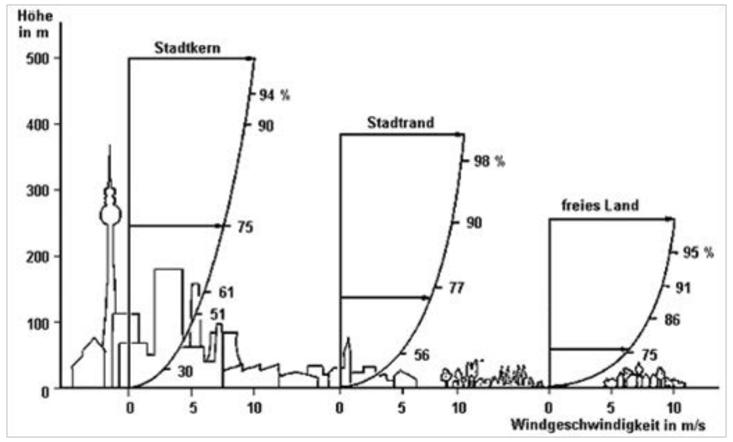
High above the ground, at an altitude of approx. 1 kilometre, the wind is hardly affected by the surface characteristics of the ground any more. The wind speeds in the lower atmospheric layers are reduced by ground friction. One differentiates between the **roughness** of the terrain, the influence of obstacles and the influence of the contours of the landscape, which is also known as the "orography" of the land.

The more pronounced the roughness of the terrain, the greater the reduction in the wind speed. Forests and cities naturally slow the wind appreciably, whereas across the concrete runways at airport the wind is only fractionally slowed. Smoother still are water surfaces, they have therefore an even lesser influence on the wind, whereas long grass, shrubs and bushes slow the wind considerably.

Wind speeds with different roughness classes

In the wind industry the technicians often speak of roughness classes when they are dealing with the evaluation of the wind characteristics of a landscape.

A high roughness class of 3 to 4 is characterised by many trees and buildings, whereas the surface of a lake falls into roughness class 0. Concrete runways at airports fall into roughness class 0.5.



Roughness classes in overview

Roughness class	Type of terrain surface
0	Water surfaces
0,5	Open terrain, smooth surfaces e.g. runways
1	Open terrain without fences and hedges, possibly with sparsely spread buildings and very gentle rolling hills
1,5	Terrain with a few houses and 8 m high hedges with at least 1 km clearance
2	Terrain with a few houses and 8 m high hedges with approx. 500 m clearance
2,5	Terrain with a few houses, bushes and plants, or 8 m high hedges with approx. 250 m clearance
3	Villages, small towns, terrain with many or high hedges, forests and very rugged and uneven terrain
3,5	Larger towns with high buildings
4	Cities with very high buildings

The "nozzle effect" phenomenon

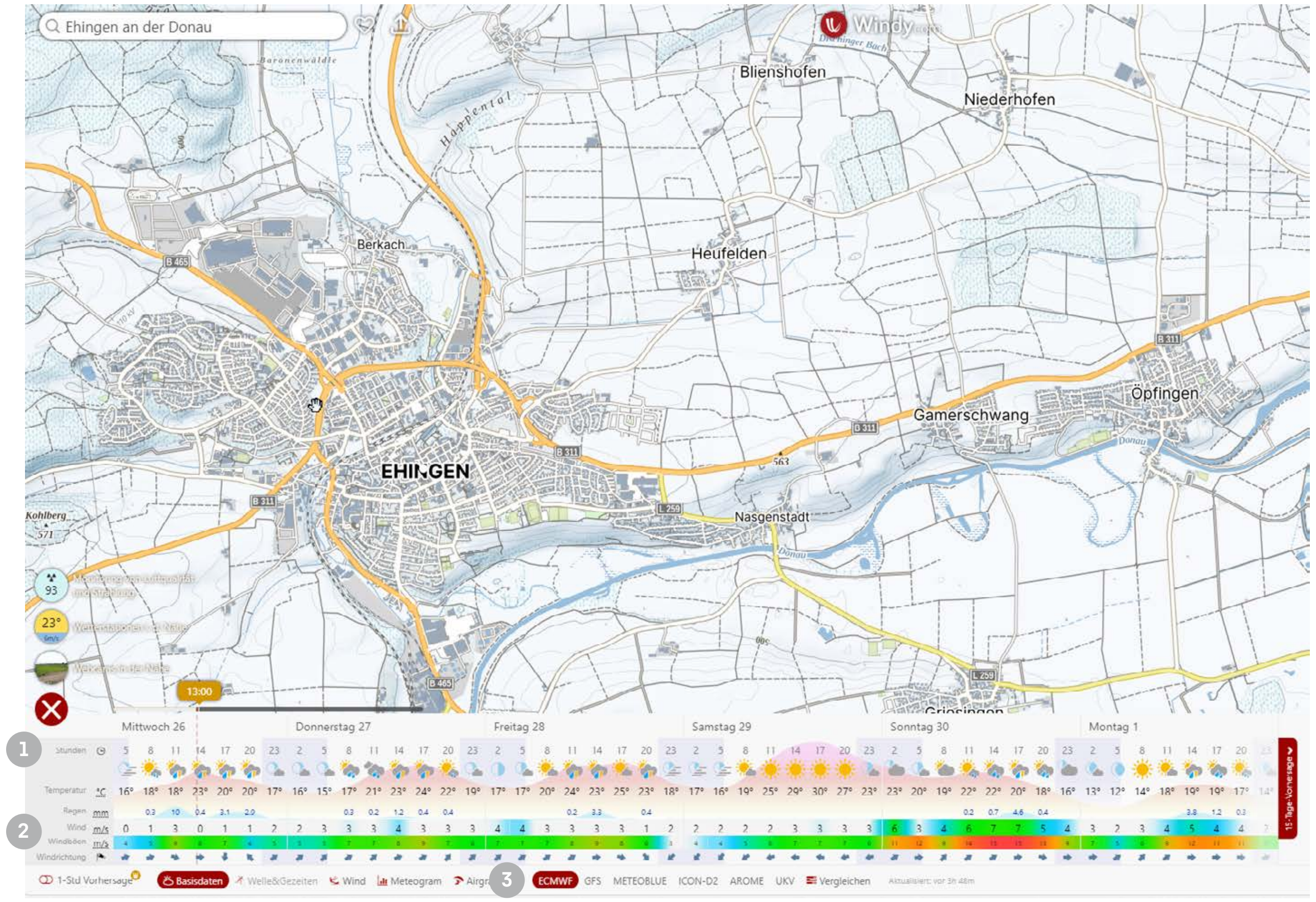
In cities with high buildings the roughness lies around 4 (see table 2). This creates the impression that the wind is not so strong there. However in large cities with high buildings there are also large urban canyons present. The air is compressed on the wind side of the houses and its speed rises considerably whilst it blows through the urban canyons. This phenomenon is known as the "nozzle effect".
If the normal wind speed in open terrain is 6 m/s for example, then in an urban canyon it can certainly reach 9 m/s and more.

2.2 Wind and weather information

With crane operation and especially when lifting loads with large surface areas the influence of the wind must certainly be observed.

Before starting work, the crane operator must determine the expected maximum wind speed at site by contacting the appropriate weather office. If impermissible wind speeds are expected, the load must not be lifted and the crane may not be erected.

Current weather data can be found on the internet (e.g. www.windy.com with ECMWF-tool). Note with this that the gust speed, as in this example, is based on a height of 10 metres above ground.



1. Day, date and time
2. Information on wind force, gusts and wind direction.
   The unit can be set to m/s, mph, km/h, kt and bft by clicking on it.
3. ECMWF = European Centre for Medium-Range Weather Forecasts

If the crane cannot be taken down at the job site when interrupting work, the occurring wind speeds must be obtained for the entire period of operation.

The occurring wind speeds may not exceed the permissible wind speeds from the wind charts.

2.2.1 Height dependant wind gust speed

The weather office normally provides the average wind speed for a period of 10 minutes and/or the corresponding wind gust speed, in each case in reference to a height of 10 m. Depending on which information is available, also other factors must be considered when determining the height-dependent wind gust speed. These are shown in the following chart.

If the weather office provides wind gust speeds for a height of 10 m, the factors in the blue column must be used to calculate the wind gust speed for the corresponding working height.

If however only wind speeds averaged over a period of 10 minutes are provided, use the yellow column. These factors can be used to calculate the wind gust speed at the available working height.

Working hight	Factors for available wind speed determined over a period of 10 minutes at a height of 10 m	Factors for available wind gust speed determined at a height of 10 m
10	1,400	1,000
20	1,502	1,073
30	1,566	1,119
20	1,614	1,153
50	1,653	1,181
60	1,685	1,204
70	1,713	1,224
80	1,738	1,241
90	1,760	1,257
100	1,780	1,272
110	1,799	1,285
120	1,816	1,297
130	1,832	1,309
140	1,847	1,319
150	1,861	1,329
160	1,874	1,339
170	1,887	1,348
180	1,899	1,356
190	1,910	1,364
200	1,921	1,372

Example

The weather office indicates a gust speed of 6.2 m⁄s at a height of 10 metres above the ground. You have, for example, a max. working height of 100 metres. According to the calculation (see left) the wind gust speed at a height of 100 m is 7.89 m⁄s. With a maximum permissible gust speed of 9 m⁄s, the load hoist can be performed according to the load chart.

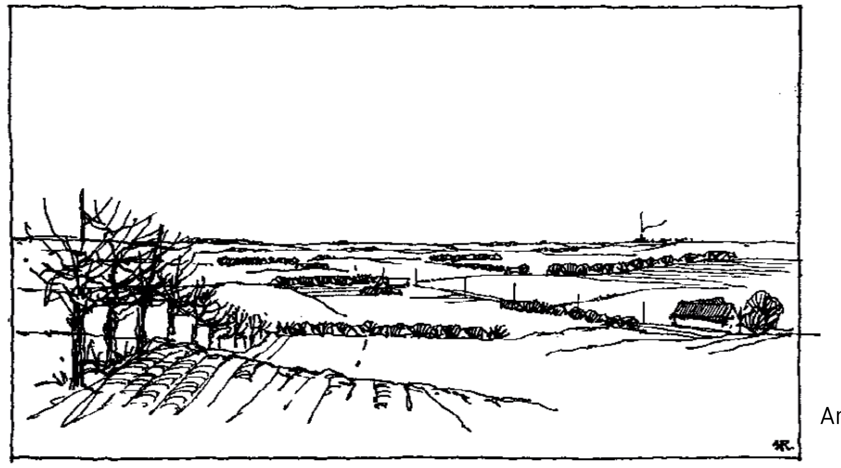
6,2 m/s x 1,272 = 7,89 m/s

2.3 Exercises

Exercise 4

Determine, with the help of table 1: Roughness classes that correspond to the roughness in the two pictures below.

Answer:________________________________



Answer:________________________________

Exercise 5

What do we understand by a "gust", per EN 13000?

- ☐ Weak wind caused by a difference in air pressure
- ☐ Short severe flurry of wind
- ☐ Severe flurry of wind higher than the average wind speed, over a period of 10 minutes

Exercise 6

Using the screenshot (Windy, page 13) and the table "Factors for determining the height-dependent wind gust speed (table, page 14) based on the wind/wind gust speed at a height of 10 m", determine which wind speed prevailing at Liebherr-Werk-Ehingen on Friday night 28.06.24 at 23:00 pm at a height of 160 m.

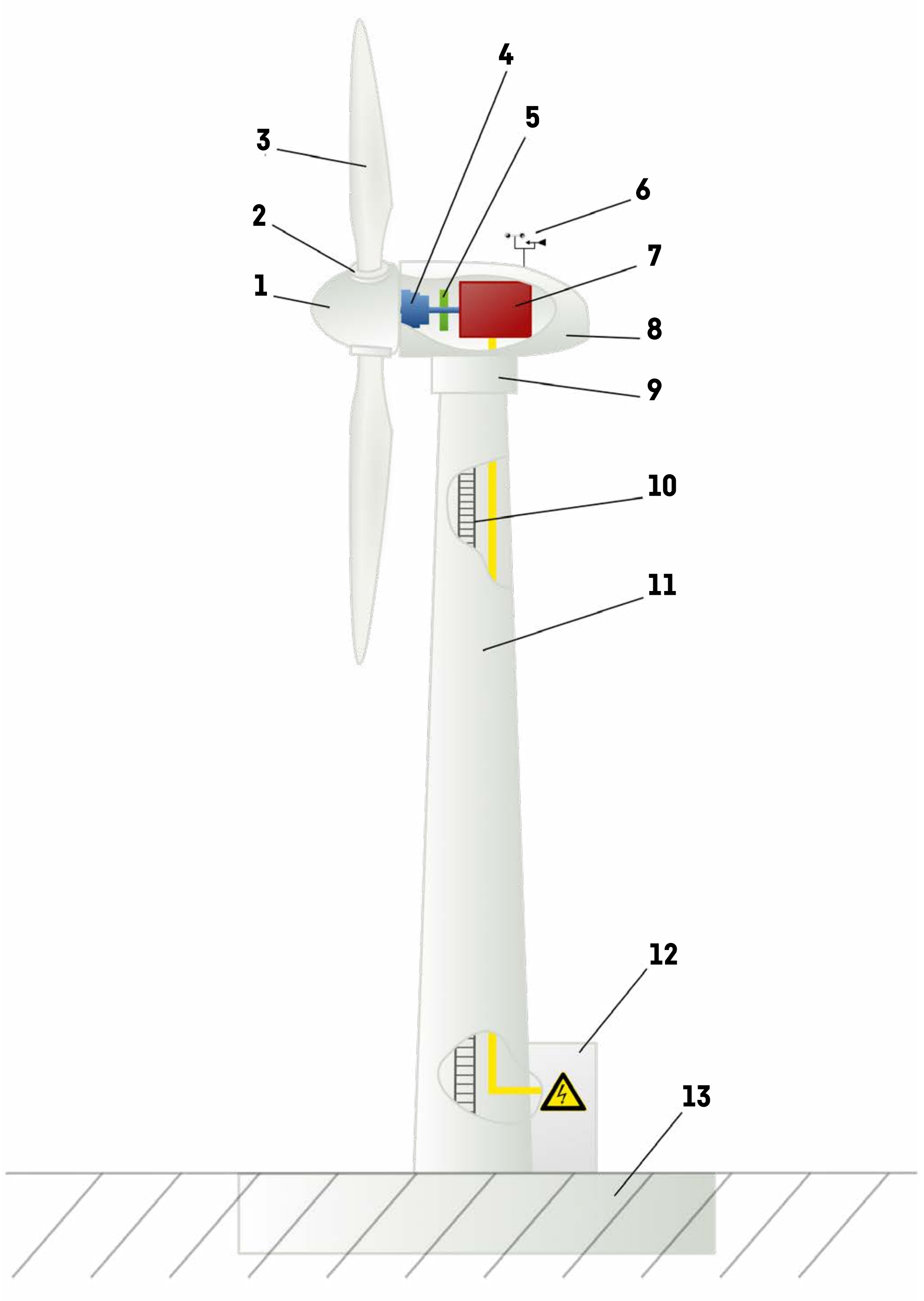
Answer:__________________________

3. Digression – Wind power turbine schematic

In this chapter you will learn about the schematic construction of a wind power turbine. Likewise we will show you how wind speeds behave at various different heights above ground.

The use of wind energy has been known for centuries. The development of increasingly powerful **wind power turbines** is being encouraged. The height of the towers upon which the turbine are being driven, is growing. New systems are breathtaking in their size. With a hub height of up to 135 metres the rotors turn with a diameter of 126 metres. By comparison: The wingspan of an Airbus A380 is just under 80 metres.

Component parts of a wind power plant



1
Rotor hub

2
Rotor blade adjustment (Pitch adjustment)

3
Rotor blade

4
Transmission

5
Brake

6
Measurement instruments

7
Generator

8
Nacelle

9
Wind direction tracking (azimuth adjustment)

10
Ladder

11
Tower

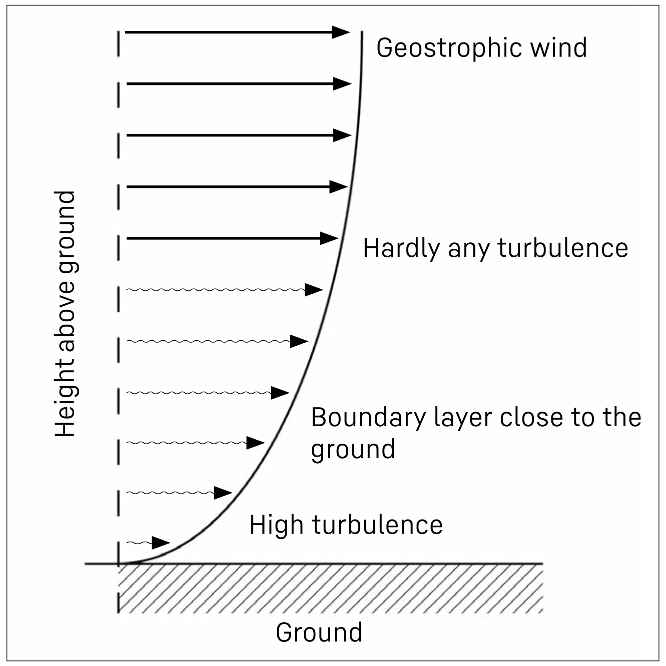
12
Grid connection

13
Foundation

Composition of air layers

Whether individual wind power plants or complete wind farms are erected, these are usually installed where the wind blows strongest. Every extra meter higher into the atmosphere that they can push is rewarded with better output. When considering the ertical **subdivision of the atmosphere** only its lower layer is suitable for exploitation of wind energy. This is due to the composition of the lowest air layers. With rising height the roughness of the ground has less influence on the wind speed. Therefore the wind blows more smoothly at high altitudes and is beset with significantly less turbulence. This fact is of great use to the manufacturers of wind power plants.

Where different types of turbulence occur



A further fact states that the wind speed drops the closer you get to the ground. Consider a system with a hub height of 40 metres and a rotor diameter of 40 metres, where the tips of the rotor blades are subjected to a flow of 9.3 m/s for example, when it is in the **highest position**. The wind speed in the **lowest position** on the rotor blade amounts to just 7.7 m/s. This means that the forces on the rotor blade (bearing load) are significantly higher in the highest position than in the lowest position.

4. Factors of wind force calculation

In this chapter you will learn the terms and basis of calculation required for determining the wind influence upon crane operations. Likewise you will learn to read the permissible wind speed from a diagram.

The following factors are of central importance to the calculation of the wind loads:
- Weight of the load
- Maximum projected surface area
- c_D-value
- Maximum wind speed
- Surface area exposed to wind
- Dynamic pressure

4.1 Request available values

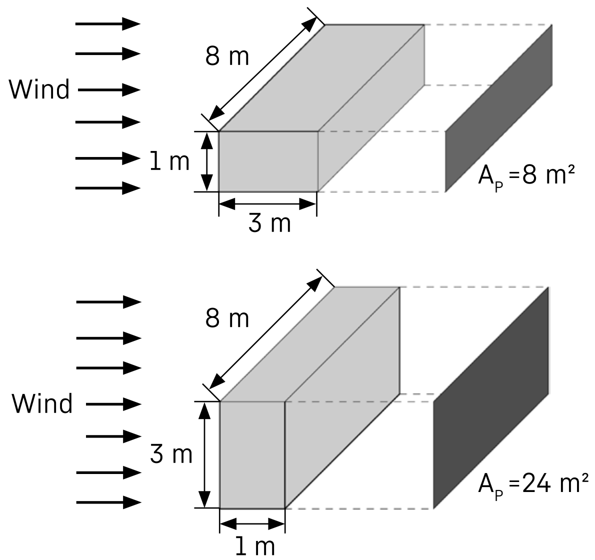
The following values must be requested in advance of the crane operation:
- The weight of the hoist load (m_H)
- The maximum projected surface area (A_P) of the load
- The coefficient of resistance (c_D-value)
- The current wind speed (v_{act})

4.1.1 Weight of the hoist load (m_H)

The weight of the hoist load (load and hook) to be lifted is measured in kilograms (kg) or tons (t). The crane driver can read the weight of the load from the delivery note or directly on the load or ask the manufacturer. A load for which the weight, the c_D-value and the projected surface area are not all known must not be lifted.

4.1.2 Maximum projected surface area (A_P)

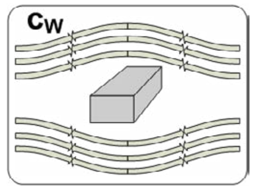
If a body is subjected to a light source then the body casts a shadow. This shadow is the projected surface area A_P of the body. If the body is subjected to a wind instead of light then the same shadow arises (projected surface). Depending on wind direction the shadow can be larger or smaller. The manufacturer of the load can supply you with the maximum projected surface area.



The example on the left side should make clear that an object can have different projected surface areas.
For this reason the maximum projected surface area of a load or body must be assumed.

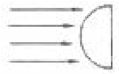
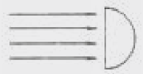
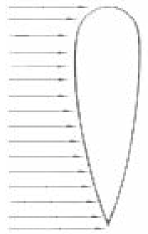
The larger the projected surface are the larger the area that can be exposed to the wind.

4.1.3 Definition of coefficient of resistance (c_D-Wert)



If a body is subjected to an air flow, either striking it or flowing through/past it, the air speed will be reduced by this. The body presents an obstacle for the air (flow resistance). The flow resistance changes depending on the shape of the body. In order to describe the shape of the body the **coefficient of resistance** is defined. The coefficient of resistance (c_D-value) of a body specifies how great the obstruction to the air flow the body presents. The manufacturer of the load can supply you with the coefficient of resistance c_D-value).

Some examples of common bodies

Body		Coefficient of resistance c_D
Plate / cube		**1,1 bis 2,0**
Cylinder		**0,6 bis 1,0**
Ball		**0,3 bis 0,4**
Hemisphere (front)		**0,2 bis 0,3**
Hemisphere (rear)		**0,8 bis 1,2**
Wind power plant rotor		**ca. 1,6**

4.1.4 Current wind speed (v_{act})

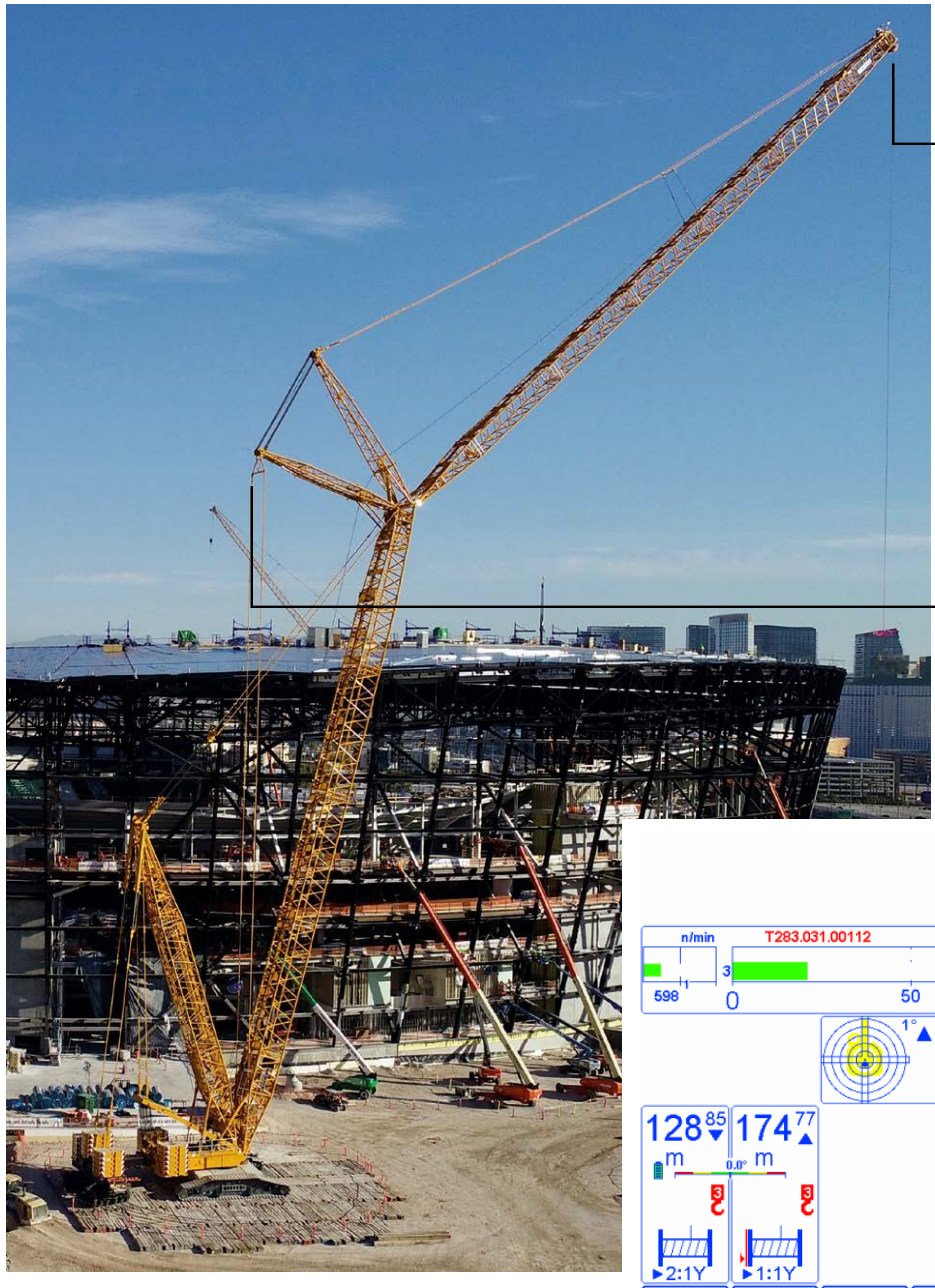
The current **wind speed** is given in [m/s] or [km/h]. Before starting work you must find out what wind speed is expected, from the weather office or the internet (e.g. www.windy.com). Lifting is prohibited if the expected wind speeds are impermissibly high!

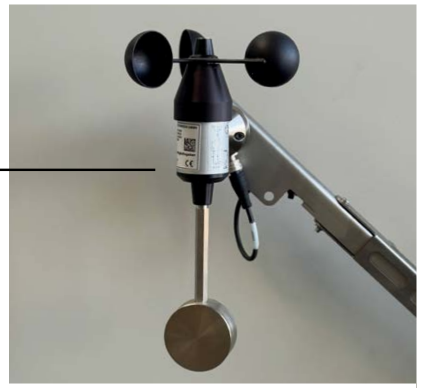
Likewise, you can read out the current wind speed with the help of the **wind sensor** on the LICCON computer system.

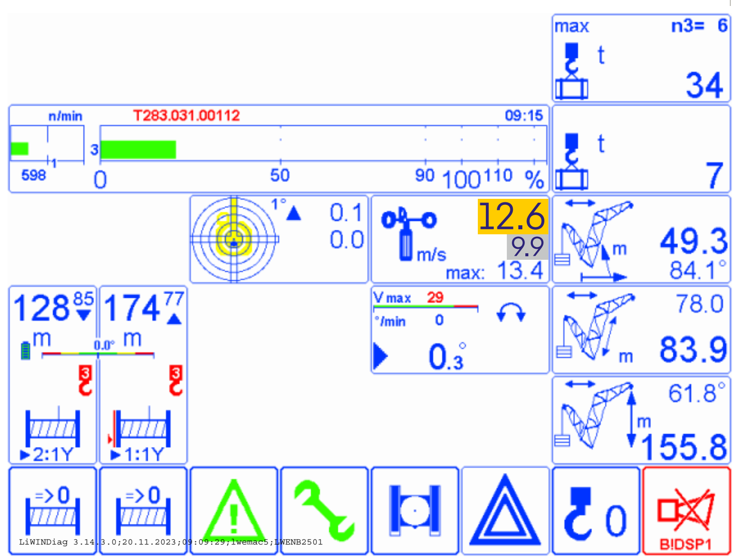
The current value from the wind sensor on the crane must not be used as the sole basis for calculating the load hoist.
Before starting the load hoist, contact the appropriate weather office or go online to find the expected/current wind gust/wind speed for the period of time of the load hoist.

Wind sensor (air speed indicator)

Up to **two wind sensors** can be installed on the crane. The wind warning appears on the operating screen of the LICCON computer system. If the current wind speed value exceeds the displayed maximum value, the “wind warning” icon starts to flash, and the acoustic alarm sounds. But the crane movements do not shut off. The load hoist must be ended as quickly as possible and the boom must be taken down if necessary. When doing so, observe the permissible wind speeds in the wind chart and the erection and take-down chart.







Since LICCON 2, the newly calculated maximum possible wind speed can be set in BSE 1.

The top value in the "wind warning" symbol on the operating screen shows the value from the wind sensor on the fixed jib. The bottom value in the "wind warning" symbol on the operating screen shows the value from the wind sensor on the main boom.

4.2 Determine or calculate missing values

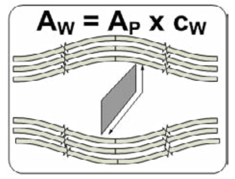
If possible, the following values should be determined or calculated with the known factors:
- The surface area exposed to wind
- The permissible wind speed from the load chart book
- The dynamic pressure
- The wind load

4.2.1 Surface area exposed to wind (A_W)

The **surface area exposed to wind A_W** specifies the surface area exposed to wind with consideration to the resistance presented by the body. It is composed of the projected surface area A_P and the c_D-value.

Surface area exposed to wind (A_W):

$$A_W = A_P \cdot c_D$$



4.2.2 Permissible wind speed from the load chart book

A calculated maximum permissible wind speed is given for every crane load chart in the **load chart book**. However, this is dependent on the length of the boom and the crane configuration. Standard values from EN 13000 have been used for the calculation (load reference value of 1.2 m² per ton).

If the **current wind speed** exceeds the **permissible wind speed** from the load chart then the crane operation must be halted and the boom set down if the permissible wind speed in accordance with the crane wind speed table is exceeded.

Example 1

t	300.0	350.0	400.0	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0
m	15.0	15.0	15.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
t	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0	170.0
EST1	18x2	18x2	18x2	18x	11x2	14x2	15x2	17x2	18x2	18x2	18x2	18x2
m/s	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0

Example 2

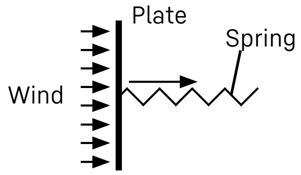
	t											
m	22.4	28.1	22.4	28.2	33.8	39.5	28.2	33.9	39.6	45.3	39.7	45.3
3.0												
3.5												
4.0												
4.5	116.5		122.5									
5.0	116.0		122.0									
6.0	115.2	87.4	121.1	111.0	102.0		91.2	108.9				
7.0	114.6	84.6	120.4	109.5	100.2		88.3	106.4	98.9		77.4	

4.2.3 Dynamic pressure (p)

Definition of dynamic pressure

If wind strikes a spring supported plate (see diagram on the right) then the air flows around this. At the same time a portion of the wind is backed up against the surface of the plate. This backing up results in an increase in pressure which presses the plate against the spring. This pressure is known as **dynamic pressure**.

If the wind speed (v) **doubles** then the dynamic pressure increases **four-fold**.



Formula for dynamic pressure (p):

$$p = F_W : A_W \qquad \text{oder} \qquad p = 0{,}5 \cdot \rho \times v^2$$

4.2.4 Wind load (F_W)

Definition of force

Strong wind is required to start up a propeller. That means that the dynamic pressure of the wind must be so large that the rotor starts to rotate. The larger the rotor's surface area exposed to wind the less the dynamic pressure needs to be in order to start it turning.

Formula wind load (F_W):

$$F_W = A_W \cdot p$$

4.3 Exercises

Exercise 7

You must replace a window pane in a glass facade with your crane. The window pane has a projected surface area of 2.6 m² and a c_D-value of 1.2. Calculate the surface area exposed to wind.

Answer: $A_w =$ m^2

Exercise 8

Fill in the missing words.

If the____________ wind speed exceeds the ____________ wind speed from the load chart then the crane operation must

be _____________ and the boom _____________ if the permissible wind speed in accordance with the crane wind speed

table is ______________ .

Exercise 9

1. Use the load capacity tables (4.2.2 page 21 / example 1) to determine the permissible wind speed for 170 t of rotating platform ballast and 200 t suspended ballast at 18 m with 17-fold reeving.

Answer:___________

2. Use the load capacity tables (4.2.2 page 21 / example 2) to determine the permissible wind speed at 39.6 m jib length.

Answer:___________

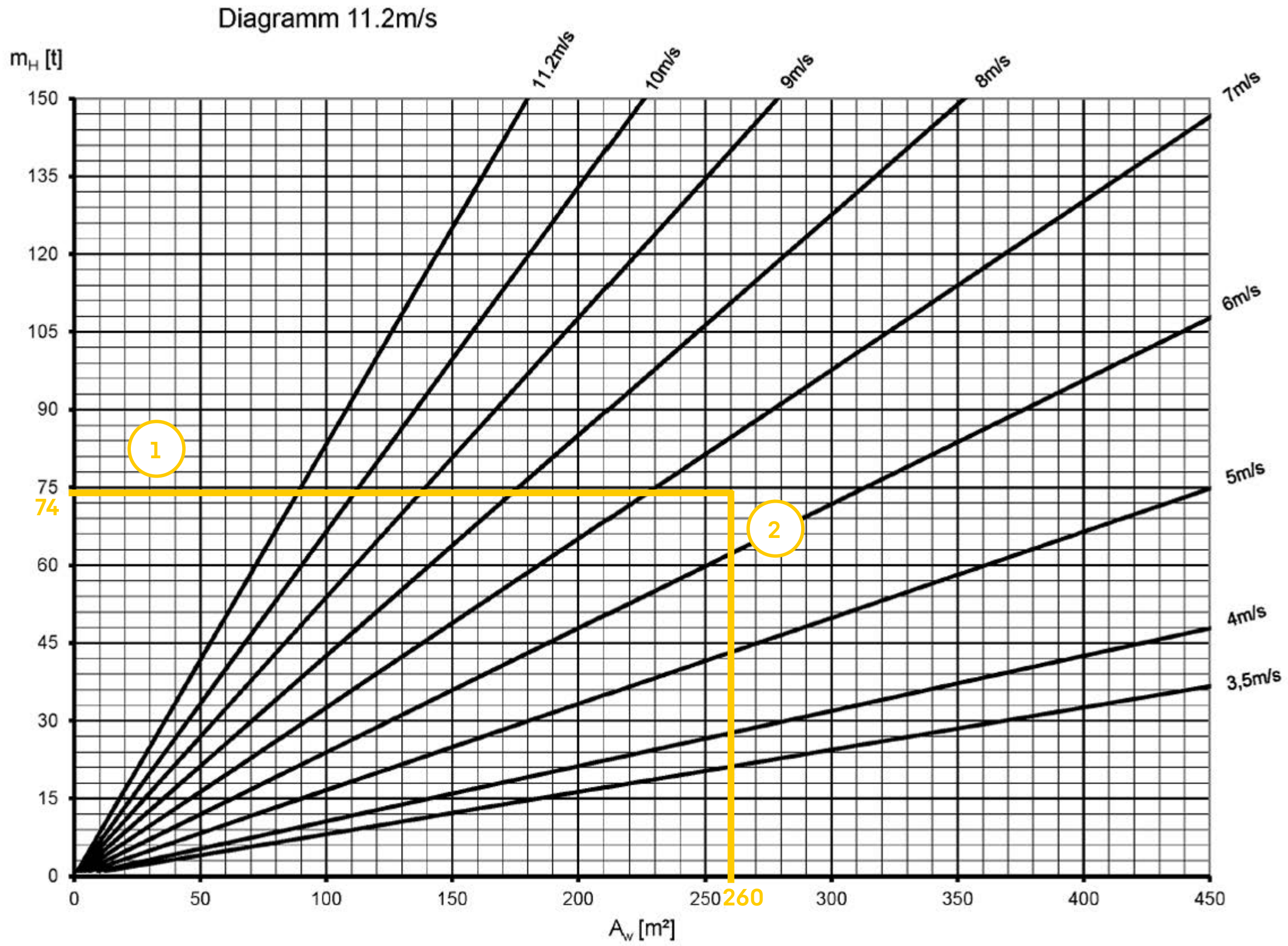
5. Determination of permissible wind speed

The following methods facilitate the determination of the maximum permissible wind speed:
- Method 1: Wind force diagram (see chapter 5.1)
- Method 2: Formula (see chapter 5.2)
- Method 3: Determining the maximum permissible wind speed using the work planner

5.1 Method 1: Wind force diagram

This form of determining the permissible wind speed is an inherent part of the load chart book.

If the **surface area** exposed to wind of the load is **greater than 1.2 m²** per t load then the maximum permissible wind speeds per the load table are **no** longer valid. In this case, compare the maximum permissible wind speed from the **load chart** with the wind speed in the wind force diagram. The two values must match with one another as otherwise you will read an incorrect wind speed from the wrong wind force diagram. This could cause an accident.



To determine the maximum permissible wind speed with the aid of a wind force diagram, the hoist load m_H (load + fastening equipment) must first be drawn in horizontally (see line 1).
In a further step, the wind-exposed surface A_W (projection surface x c_D-value) must be drawn in vertically (see line 2).
The maximum permissible wind speed can be read at the point in which the lines cross.

5.1.1 Example for determining the maximum permissible wind speed for a special load case

Example 1

The load to be lifted weighs **65 t**, has a c_D-value of **1.4** and a surface area exposed to wind of **280 m²** with a projected surface area of **200 m²**. If we divide the surface area exposed to wind by the load then we have a value of 4.31 m² per t. This value exceeds the permissible value for the load's surface area exposed to wind of 1.2 m² per t. According to the load chart a maximum wind speed of 11.2 m/s is permissible for the crane configuration required.
Now the maximum permissible wind speed must be determined by means of the wind force diagram 11.2 m/s.

The maximum permissible wind speed for the load amounts to 5.9 m/s.

The determined maximum permissible wind speed of 9.0 m/s is not accepted into the LICCON computer system. There is no warning if the determined maximum permissible wind speed of 9.0 m/s is exceeded. For that reason, the crane operator himself must monitor the wind speed value in the LICCON computer system. If the determined maximum permissible wind speed is reached, the load lift must be discontinued.

5.1.2 Example for determining the maximum permissible wind speed for a standard load case

Example 2

A load weighs **85 t**, has a c_D-value of **1.2** and a projected surface area of **50 m²**.
A c_D-value of 1.2 and a projected surface area of **50 m²** results in a surface area exposed to wind of 60 m². If you divide the surface area exposed to wind by the load then we have a value of 0.71 m² per t. In this example the load chart has a maximum wind speed of 9 m/s. For this reason the wind force diagram with 9 m/s must be used.

This means that the load can be lifted up to a maximum wind speed of 9 m/s, as given in the load chart.

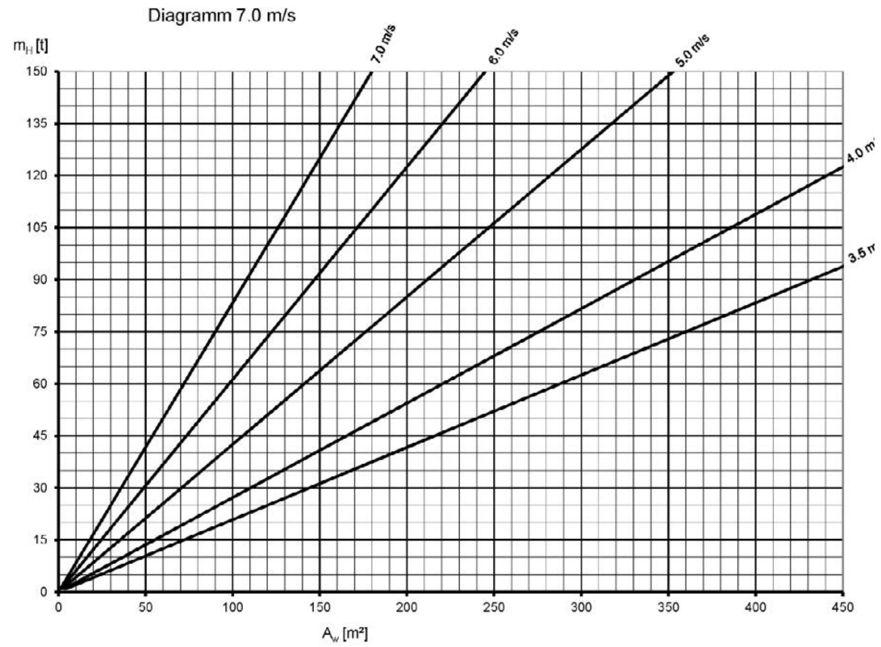
Exercises

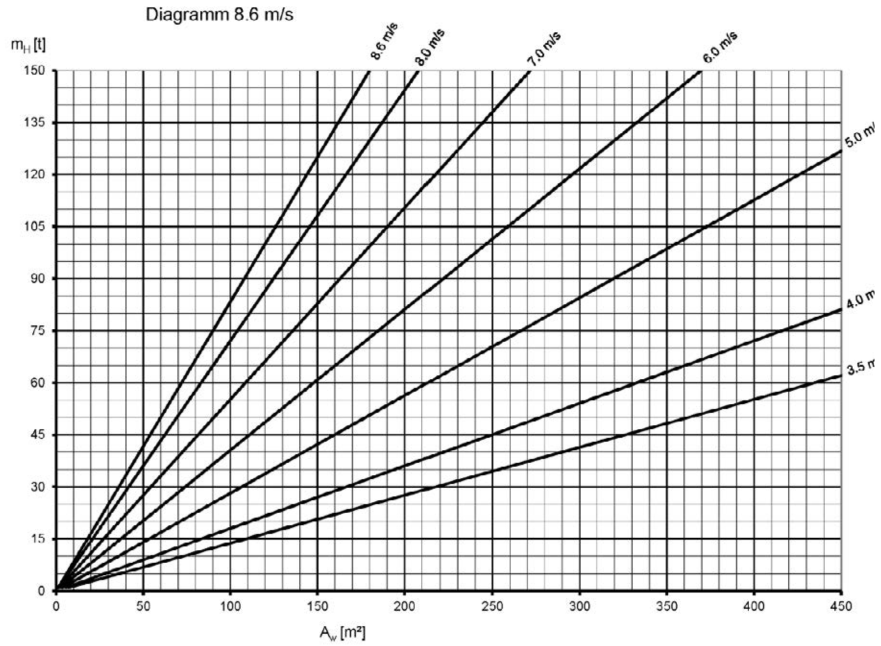
Exercise 10

Plot the values from example 5.1.1 on the corresponding wind force diagram on the following pages to determine the maximum permissible wind speed.

Exercise 11

Plot the values from example 5.1.2 on the corresponding wind force diagram on the following pages to determine the maximum permissible wind speed.





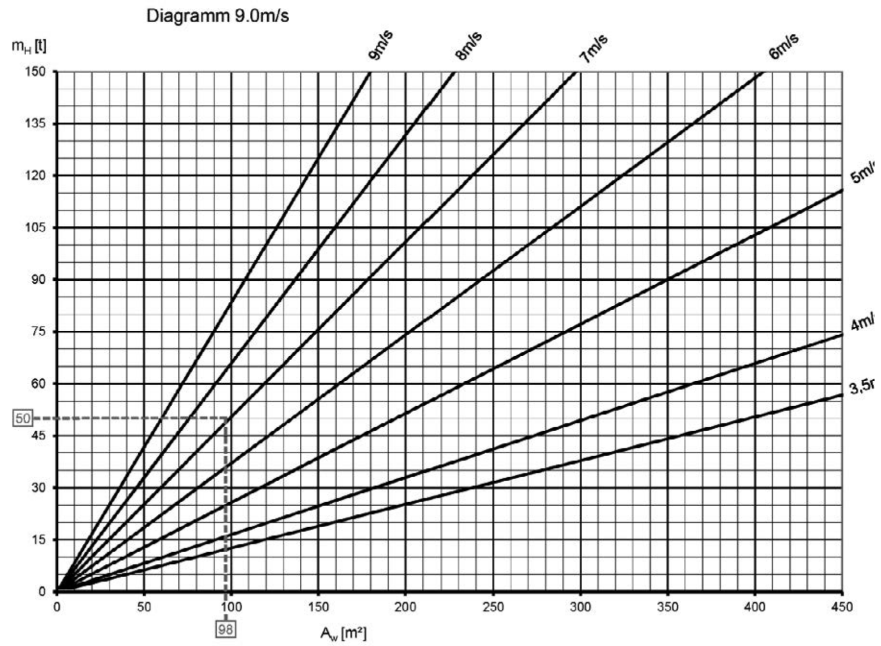


Diagramm 9.9 m/s

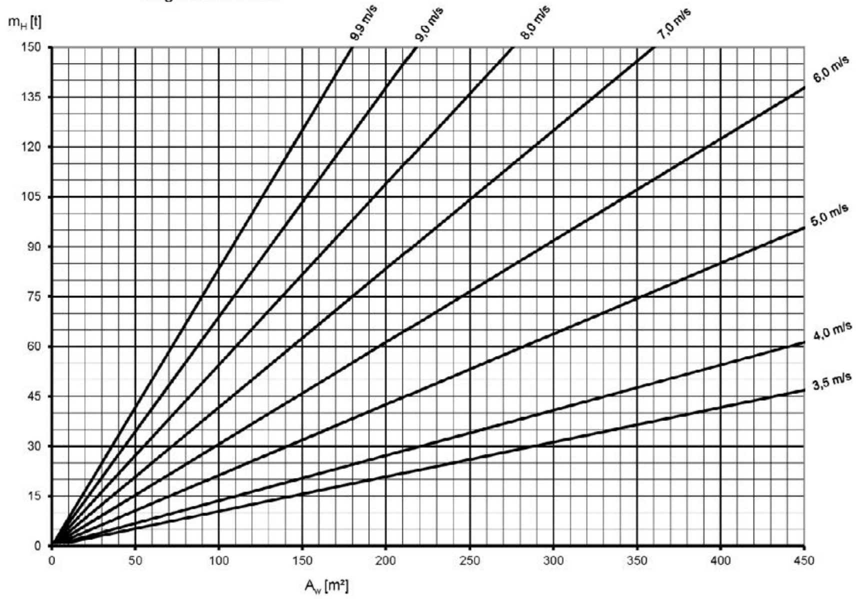


Diagramm 10.0 m/s

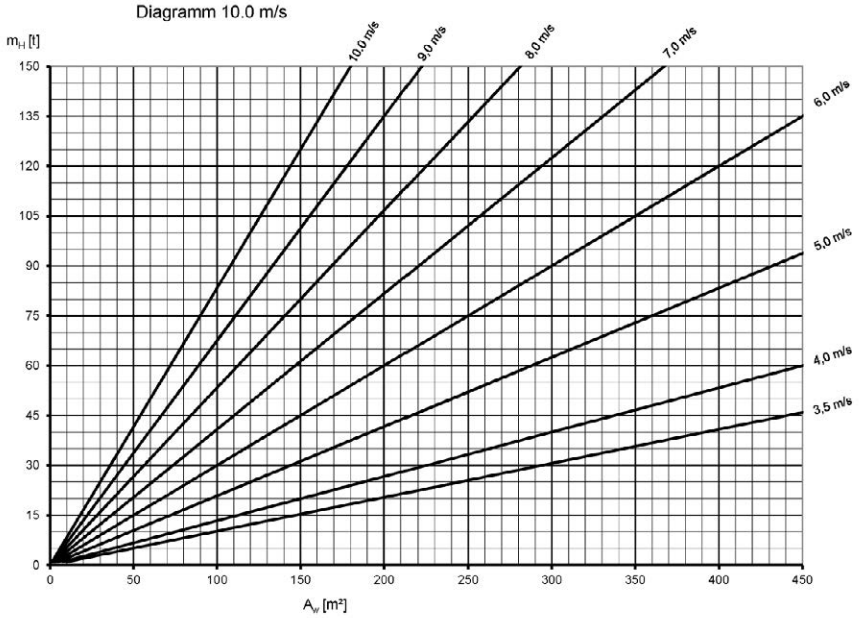


Diagramm 11.1m/s

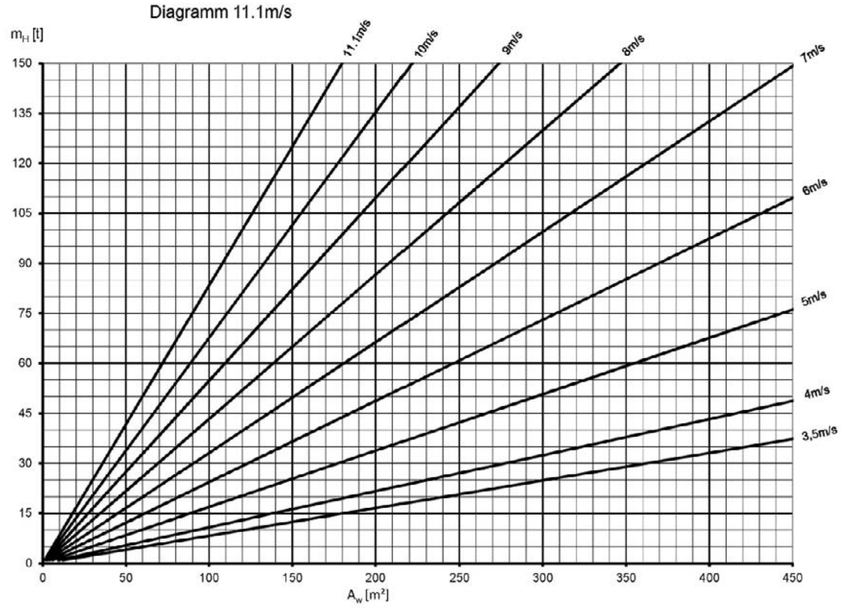


Diagramm 11.2m/s

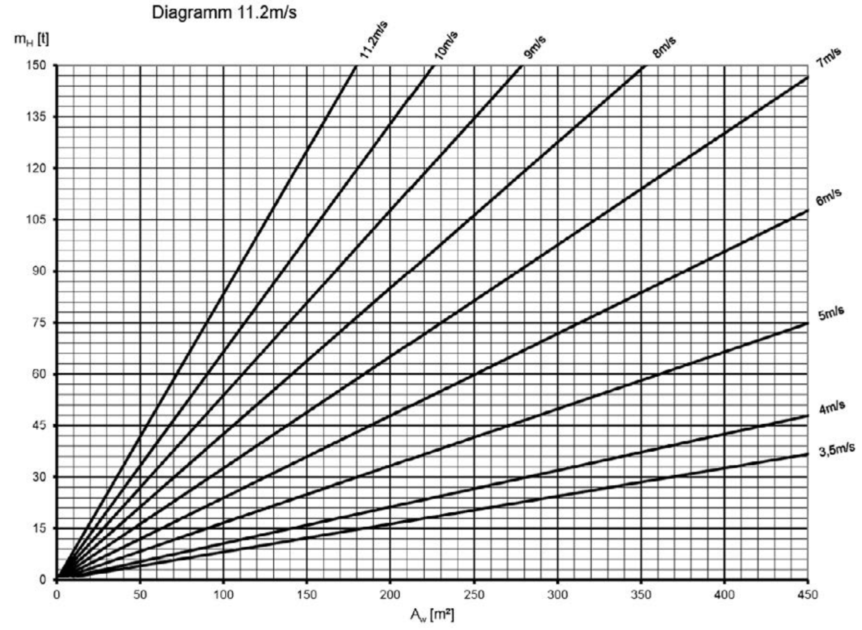


Diagramm 12.8m/s

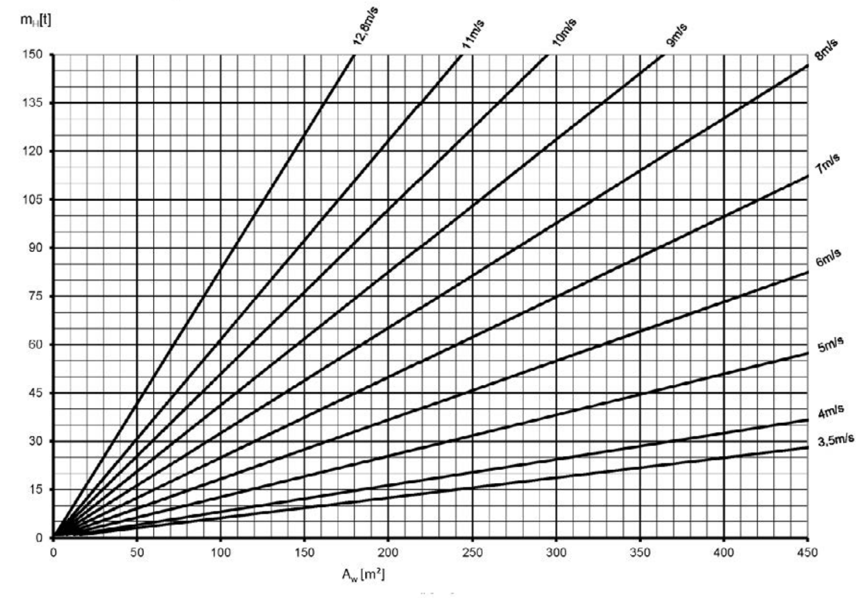
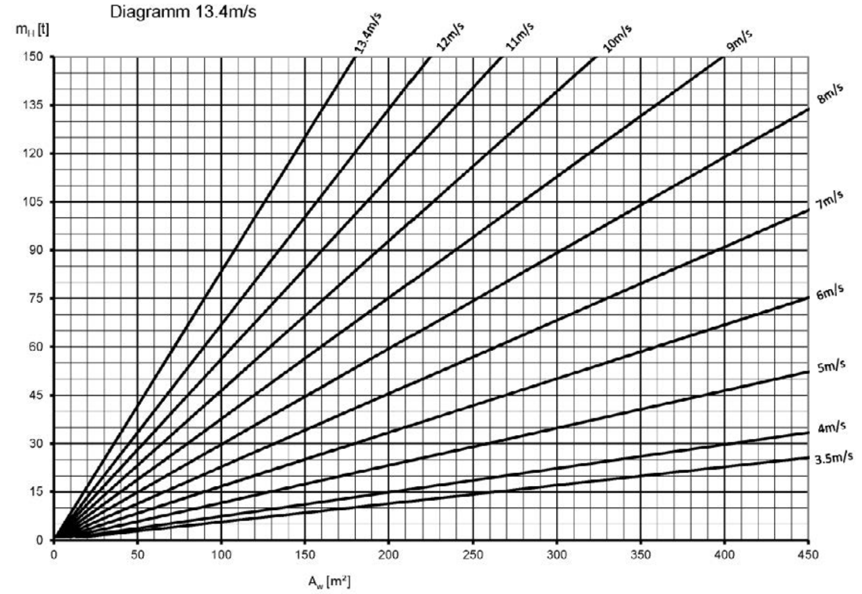
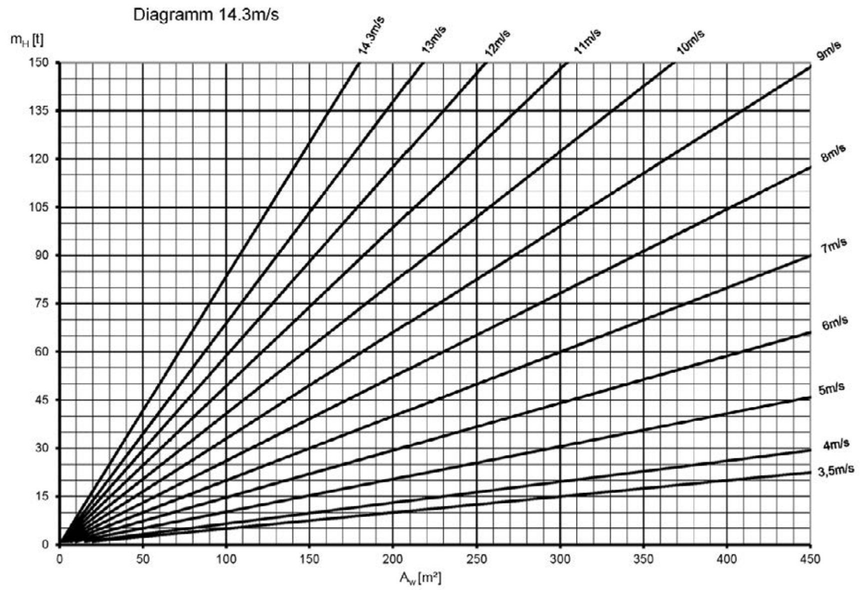
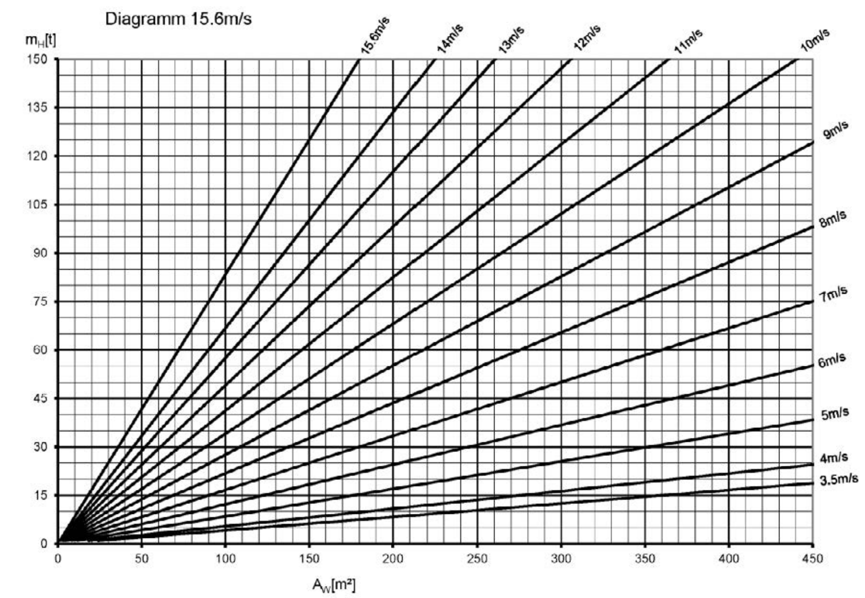


Diagramm 13.4m/s







5.2 Method 2: Formula

The permissible wind speed can be calculated with a single formula.
For this the following data must first be collected:

The hoist load (m_H) (incl. lifting accessories and hook block and any relevant portion of hoisting cable)
The surface area exposed to wind (A_W)
The maximum wind speed per the load chart

Formula for calculating the permissible wind speed:

$$V_{max} = V_{max\_TAB} \cdot \sqrt{\frac{1{,}2\ ^{m^2}/_{t} \cdot m_H}{A_W}}$$

The value 1.2 m²/t below the root corresponds to the constant according to EN 13000 and not the c_D-value! This value may not be changed!

5.2.1 Example for calculating the maximum permissible wind speed for a special load case

The load to be lifted weighs 65 t, has a c_D-value of 1.4 and a surface area exposed to wind of 280 m² with a projected surface area of 200 m². A maximum wind speed of 11.2 m/s is permissible for the crane configuration required according to the load chart.

Example 1

Surface area exposed to wind: 1,4 · 200 m² = 280 m²

$$V_{max} = 11{,}2\ ^{m}/_{s} \cdot \sqrt{\frac{1{,}2\ ^{m^2}/_{t} \cdot 65\ t}{200\ m^2}}$$

$$V_{max} = 5{,}9\ ^{m}/_{s}$$

The wind speed from the load chart drops from 11.2 m/s to 5.9 m/s.
The load may be lifted up to a maximum wind speed of 5.9 m/s.

The determined maximum permissible wind speed of 5.9 m/s is not accepted into the LICCON computer system. There is **no warning** if the determined maximum permissible wind speed of 5.9 m/s is exceeded. For that reason, the crane operator himself must monitor the wind speed value in the LICCON computer system. If the determined maximum permissible wind speed is reached, the load lift must be discontinued.

5.2.2 Example for calculating the maximum permissible wind speed for a standard load case

A load weighs 85 t, has a c_D-value of 1.2 and a projected surface area of 50 m². With a c_D-value of 1.2 and a projected surface area of 50 m² we have a surface area exposed to wind of 60 m². The maximum permissible wind speed from the load chart amounts to 9 m/s in this example.

Example 2

Surface area exposed to wind: 1,2 · 50 m² = 60 m²

$$V_{max} = 9\ ^{m}/_{s} \cdot \sqrt{\frac{1{,}2\ ^{m^2}/_{t} \cdot 85\ t}{60\ m^2}}$$

$$V_{max} = 11{,}73\ ^{m}/_{s}$$

If the result of the vmax is larger than v_{max_TAB}, the load can be lifted up to the maximum wind speed specified in the load chart, here 9 m/s.

5.3 Exercises

Exercise 12

You have to use a LTM 1300-6.3 (code 001.01112) to lift a load of 80 t and a wind load area of 235 m² to a height of 21 m high with an outreach of 6 m.

Determine the ideal teleconfiguration from the excerpt from the lifting capacity table book (see below).

Also determine the new maximum possible wind speed for this lift using the relevant wind force diagram (see section 5.1).

LTM 1300-6.3 T282.001.01112 EN 13000 / ASME B30.5

T: T

26.0 t	4.94 m	9.3m x 9.4V7.4m	360°	9.0m/s

m	14.7	19.6	19.6	19.6	19.6	19.6	24.5	24.5	24.5	24.6	24.6	24.6
3.0	155.7	116.7	114.5	84.9	72.4	73.0						
3.5	155.0	117.5	114.5	85.4	72.8	73.4	116.5	114.5	94.6	84.5	72.1	72.4
4.0	144.5	118.3	114.5	85.9	73.3	73.9	117.3	114.5	95.2	85.1	72.6	72.8
4.5	134.5	119.2	114.5	86.5	73.8	74.4	117.9	114.5	95.7	85.5	73.0	73.1
5.0	122.4	117.1	114.5	87.1	74.3	74.9	115.6	113.5	96.3	86.0	73.4	73.5
6.0	104.0	100.1	100.9	88.8	75.6	73.2	96.6	98.1	97.5	87.0	74.3	73.8
7.0	89.0	85.1	86.8	88.3	77.3	68.1	75.0	78.8	81.1	85.0	75.0	68.1
8.0	74.4	67.1	68.9	72.9	73.7	62.0	59.1	61.9	64.6	68.4	69.8	62.0
9.0	62.6	54.1	55.8	59.5	60.6	56.8	48.1	50.8	52.8	56.3	57.9	56.7
10.0	51.0	44.7	46.3	49.9	50.9	51.7	39.8	42.3	44.4	47.6	49.2	50.6
11.0	41.6	37.6	39.2	42.7	43.5	44.3	33.3	35.7	37.6	41.0	42.5	43.6
12.0	34.6	32.1	33.5	36.7	37.4	38.1	28.1	30.4	32.4	35.5	37.0	38.2
13.0	29.3	26.9	28.2	31.2	32.0	32.5	24.0	26.3	28.1	31.2	32.7	33.8
14.0		22.7	24.0	26.9	27.6	28.2	20.5	22.7	24.6	27.6	28.9	29.9
15.0		19.3	20.6	23.4	24.1	24.6	17.6	19.7	21.5	24.1	25.4	26.3
16.0		16.5	17.7	20.5	21.1	21.7	15.1	17.0	18.6	21.2	22.4	23.3
18.0		12.1	13.3	16.0	16.6	17.2	10.7	12.5	14.1	16.6	17.8	18.7
20.0							7.4	9.2	10.8	13.2	14.3	15.2
22.0							5.0	6.7	8.2	10.6	11.7	12.6
24.0												
26.0												
28.0												
30.0												
32.0												
34.0												
36.0												
38.0												
40.0												
42.0												
44.0												
46.0												
48.0												
50.0												
52.0												
% 1	0+	46+	0+	0+	0+	0+	92+	0+	0+	0+	0+	0+
% 2	0+	0+	46+	0+	0+	0+	0+	92+	0+	0+	0+	0+
% 3	0+	0+	0+	0+	0+	0+	0+	0+	92+	0+	0+	0+
% 4	0+	0+	0+	0+	0+	0+	0+	0+	0+	46+	0+	0+
% 5	0+	0+	0+	46+	0+	0+	0+	0+	0+	46+	46+	0+
% 6	0+	0+	0+	0+	46+	0+	0+	0+	0+	0+	46+	46+
% 7	0+	0+	0+	0+	0+	46+	0+	0+	0+	0+	0+	46+
EST1												

Exercise 13

You have to use a LTM 1650-8.1 (code 501.10213) to lift a load of 32 t and a wind load area of 112 m² to a height of 75 m with an outreach of 16 m.

Determine the ideal teleconfiguration from the excerpt from the lifting capacity table book (see below).

Also determine the new maximum possible wind speed for this lift using the relevant wind force diagram (see section 5.1).

LTM 1650-8.1 T275.501.10213 EN 13000

T5: T5

55 t	10.50 x 9.60m	360°	11.2m/s

m	69.3	73.3	75.0	77.0	79.0	80.0
3.0						
3.5						
4.0						
4.5						
5.0						
6.0						
7.0						
8.0						
9.0						
10.0						
11.0						
12.0	44.2	37.2				
14.0	41.6	35.3	38.4	35.6	32.7	32.1
16.0	38.4	33.5	34.4	33.6	31.2	30.7
18.0	32.4	31.2	28.9	28.8	27.9	27.4
20.0	27.5	26.8	24.6	24.4	23.8	23.3
22.0	23.7	22.9	20.9	21.0	20.3	19.9
24.0	20.3	19.9	17.9	17.9	17.5	17.1
26.0	17.5	17.2	15.4	15.4	15.1	14.6
28.0	15.2	14.9	13.0	13.2	12.9	12.6
30.0	13.2	12.9	11.2	11.3	10.9	10.6
32.0	11.3	11.1	9.5	9.6	9.3	9.1
34.0	9.7	9.6	7.9	8.1	7.8	7.6
36.0	8.3	8.3	6.5	6.7	6.5	6.3
38.0	7.1	7.0	5.3	5.6	5.3	5.1
40.0	5.9	5.9	4.2	4.5	4.3	4.0
42.0	4.9	4.9	3.1	3.4	3.2	2.8
44.0	3.9	4.0		2.3	2.0	
46.0	3.0	3.0				
48.0		2.0				
50.0						
52.0						
54.0						
56.0						
58.0						
59.0						
% 1	46+	46+	92+	92+	92+	100+
% 2	92+	100+	92+	92+	100+	100+
% 3	92+	100+	92+	92+	100+	100+
% 4	92+	100+	92+	100+	100+	100+
% 5	92+	100+	92+	100+	100+	100+
m	6.4	6.4	6.4	6.4	6.4	6.4
°	135.0	135.0	135.0	135.0	135.0	135.0
EST1	4x	3x	4x	3x	3x	3x

6. Wind influences for “Crane out of operation”

In addition to the danger of wind occurring during crane operation, there is also the danger of a crane accident due to the influence of wind on the crane when it is out of operation, or without a load. Mobile and crawler cranes have very large wind-exposed surfaces in spite of their filigree construction, also without a load. Even in the case of lattice booms, wind-exposed surfaces of multiple hundred square meters are possible. Very large boom lengths and a compact support base result in a great potential for danger when the maximum wind speed is exceeded.

The best image is that the entire crane could tip over. It is also possible, however, that wind from the front can cause the luffing lattice jibs and the main boom to tip over to the rear. Furthermore, a side wind can overload the slewing gear brake, which could cause the crane to turn inadvertently.

As described in the operating instructions from Liebherr-Werk Ehingen GmbH, the crane boom must always be taken down if the crane will not be supervised while the crane work is interrupted. If this is not possible due to limited space at the job site, the crane must be brought to the position specified by the manufacturer. This position is safe however only up to the specified wind speed. In order to determine the respective maximum wind speed, all Liebherr cranes with a lattice mast and all Liebherr telescopic cranes are equipped with wind charts. This information can be taken from the wind charts. If there are no wind speed charts available for the set up configuration, the value for the maximum permissible wind speed in the load chart must be used.

6.1 Procedure when interrupting crane work

Should the crane be taken down?

no | yes

Determine the position and permissible wind speed vwmax/vwabf for the set up configuration. When doing so, observe the weight of the installed hook block.

Obtain wind and weather information for the time period of the interruption. See chapter 2.3.

Convert the predicted wind gust speed for the highest point of the crane v(z). See chapter 2.3.1 (the highest point of the crane corresponds to the pulley height from the Liccon job planner or the total length of the installed boom system).

Does the wind speed that is predicted and converted for the highest point of the crane v(z) exceed the permissible wind speed vwmax/vwabf for the set up configuration and the specified position?

no | yes

Does the prevalent wind speed exceed the permissible wind speed for erection and take-down?

no | yes

Have authorized inspectors determine suitable measures. Evacuate the danger zone over a wide area around the crane.

Take down and secure the crane according to the erection / take-down charts. Observe and adhere to the permissible wind speeds when doing so.

Position the crane according to the wind chart. Establish the angle of the main boom and the jib according to the wind chart. The weight of the installed hook block may correspond maximum to the value in the selected wind chart.

6.2 Using the wind charts

6.2.1 Example with a telescopic crane

LTM 1750-9.1 – TYVEN

Support base:	12 m x 12 m
Counterweight:	184 t
Telescopic boom:	T-49.1 (92/92/92)
Luffing lattice jib:	N-59.5
Hook block weight:	1.5 t

Observe the operating mode, counterweight and support base in the chart description!
The hook block weight in the chart may not be exceeded.

TYVEN - 64.0 t bis 204.0 t Counterweight - Support base: 12.0 m x 12.0 m

Note
- TYVEN - Guyed telescopic boom with TY-guying, lattice extention and luffing lattice jib
- 5 m lattice extention
- Y-frame position 45°
- 64.0 t to 204.0 t counterweight
- Guy point of telescopic boom guying on eccentric
- The angle of the Y-frames is to be set according to the load chart
- The specified wind speeds are valid for the guyed status, if the boom may be guyed
- Extension conditions for which no load information is available in guyed condition may not be guyed
- For shortest telescopic boom T-16.3 and NA-frame 3 rods, the maximum angle of the luffing lattice jib is 58°
- Luffing lattice jibs from a length of 80.5 cm can not be telescoped and must be placed down
- Support base 12.0 m x 12.0 m

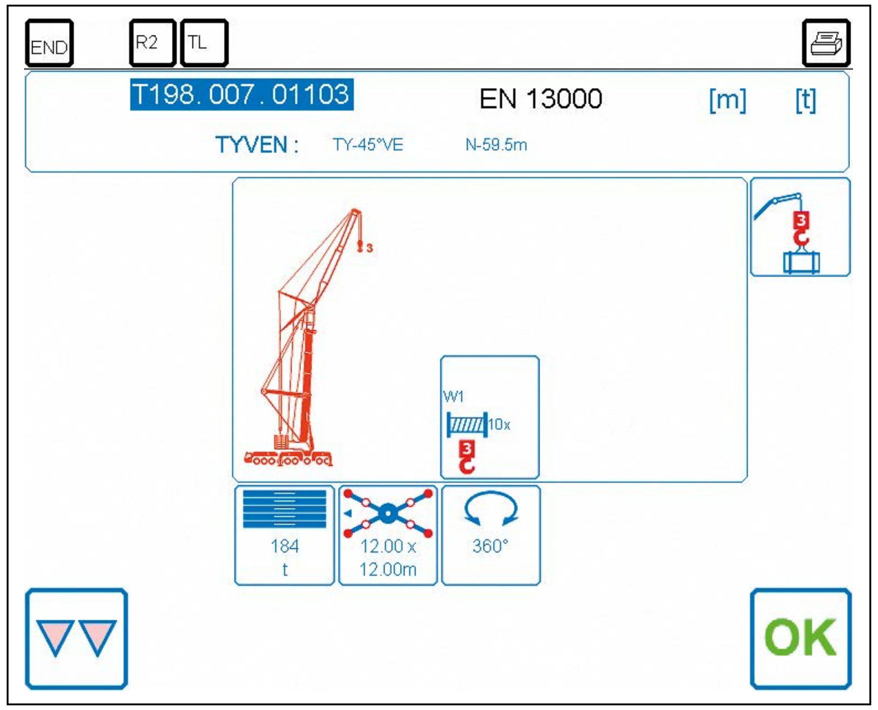
HA	Main boom
A	Adapter
HI	Lattice jib
WHA	Main boon angle
WHI	Lattice jib angle
RAD	Pulley head radius
HKFL	Maximum permissible hock block weight
OWB	Counter weight
VWMAX	Maximum permissible gust speed at the highest point of the crane

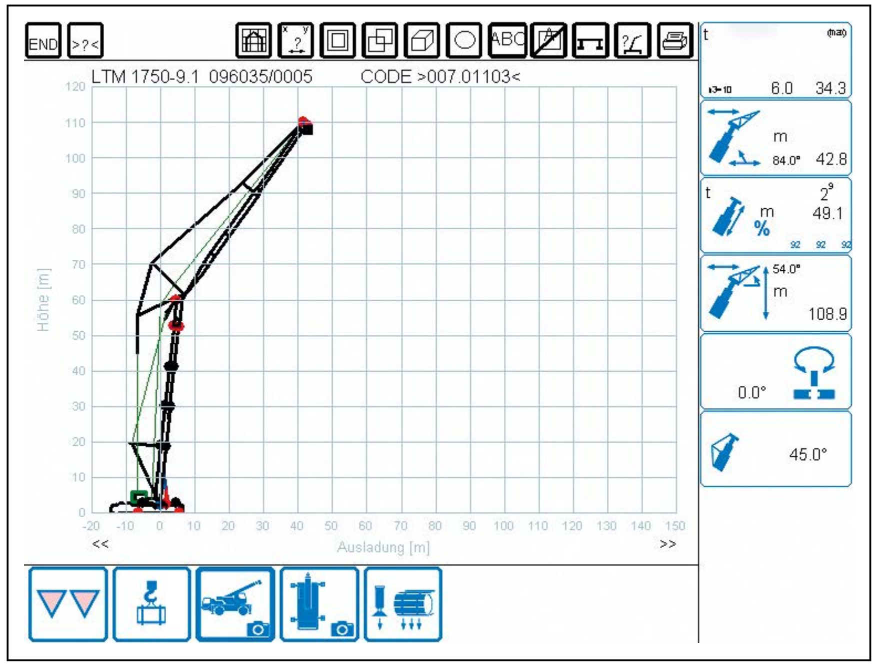
Permissible wind speeds — WAB-TAB198-007-001-00

HA [m]	A [m]	HI [m]	WHA [°]	WHI [°]	RAD [m]	HKFL [t]	OWB [t]	VWMAX [m/s]
T-16.3 (0/0/0)	A-9.0	N-21.0	84	7	24.5	4.0	var.	15.0
T-21.8 (0/46/0)	A-9.0	N-21.0	84	0	25.1	4.0	var.	15.0
T-21.8 (0/0/46)	A-9.0	N-21.0	84	7	25.1	4.0	var.	14.1
T-27.2 (46/46/0)	A-9.0	N-21.0	84	9	25.6	4.0	var.	14.1
T-32.7 (92/46/0)	A-9.0	N-21.0	84	8	26.2	4.0	var.	14.1
T-38.2 (92/92/0)	A-9.0	N-21.0	84	11	26.7	4.0	var.	14.1
T-43.7 (92/92/46)	A-9.0	N-21.0	84	0	27.4	4.0	var.	14.1
T-49.1 (92/92/92)	A-9.0	N-21.0	84	0	28.0	4.0	var.	14.1

Which gust speed is permissible at a height of 10 m for T-49.1 (92/92/92)?

Determining the pulley height using the work planner





Pulley height: 108.9 m
Determining the height using the total system length: 49.1 + 9 + 59.5 = 117.6 m

The predicted wind gust speed is 11 m/s at a height of 10 m
By making the conversion using chart 2.3.1, a gust speed of 14.2 m/s at a height of 120 m is determined, which means that the crane can be turned off as it is.
By telescoping in the boom the permissible wind gust speed increases to 16.8 m/s. This represents a clear increase in safety and must always be performed by longer interruptions.

6.2.2 Example with a lattice crane

LR 11000 - SDWB

Main boom	S-54 m	OW-ballast	210 t
Luffing lattice jib	W-114 m	Central ballast	50 t
Derrick boom	D-36 m	Hook block weight	14 t

If a chart with derrick ballast is not available, but an operating mode with derrick is set up, charts without derrick ballast should be used. The derrick ballast must be placed on the ground.

Example: Set up - charts to be used
SDB - SD
SDWB - SDW
SDWB2 - SDW - the ballast guide must be removed

SDWB-System

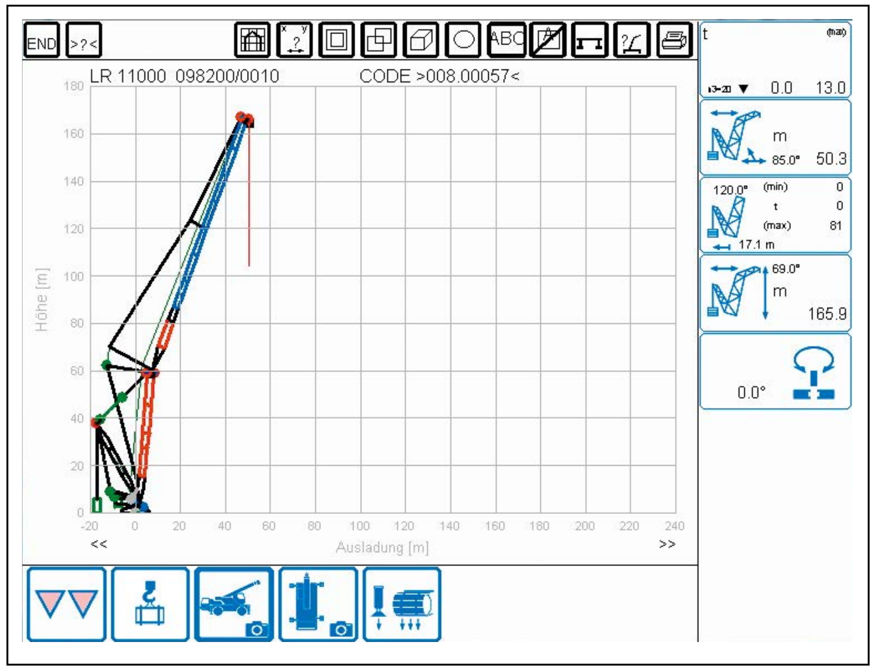
Hinweis
- Hook block weight 18 t
- Derrick ballast 0 t
- Turntable ballast 210 t
- Central ballast 50 t
- Derrick radius 12 m
- Number of slewing gears 3

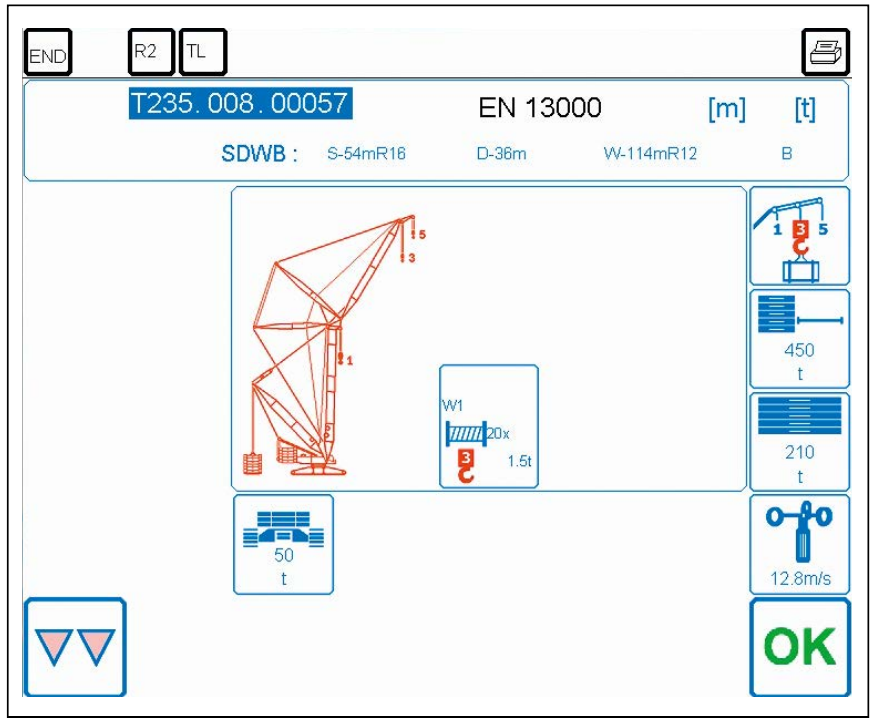
HA Main boom
D Derrick
HI Lattice jib
WHA Main boon angle
WHI Lattice jib angle
RAD Pulley head radius
HKFL Maximum permissible hock block weight
OWB Counter weight
ZBL Central ballast
DRAD Derrick radius
VWAB Maximum permissible gust speed at the highest point of the crane
VWABF Maximum permissible gust speed at the highest point for turning the crane
VWRST Maximum permissible gust speed for crane set up

Permissible wind speeds												wab_235_008_00001_00_000
HA [m]	D [m]	HI [m]	WHA [°]	WHI [°]	RAD [m]	HKFL [t]	OWB [t]	ZBL [t]	DRAD [m]	VWAB [m/s]	VWABF [m/s]	VWRST [m/s]
S-48	D-36	W-108	85	67	51.1	18.0	210	50	12	17.6	14.3	8.9
S-48	D-36	W-114	85	68	51.6	18.0	210	50	12	17.1	13.5	8.9
S-54	D-36	W-18	75	0	35.2	18.0	210	50	12	23.4	23.4	8.9
S-54	D-36	W-24	75	0	41.2	18.0	210	50	12	24.9	24.9	8.9
S-54	D-36	W-30	75	30	44.1	18.0	210	50	12	24.0	24.0	8.9
S-54	D-36	W-36	75	45	43.9	18.0	210	50	12	23.6	23.6	8.9
S-54	D-36	W-42	75	55	42.8	18.0	210	50	12	23.2	23.1	8.9
S-54	D-36	W-48	75	60	42.8	18.0	210	50	12	22.6	21.8	8.9
S-54	D-36	W-54	75	65	41.7	18.0	210	50	12	22.1	20.4	8.9
S-54	D-36	W-60	80	52	50.9	18.0	210	50	12	21.2	21.0	8.9
S-54	D-36	W-66	80	58	49.0	18.0	210	50	12	20.7	19.7	8.9
S-54	D-36	W-72	80	62	47.9	18.0	210	50	12	20.2	18.5	8.9
S-54	D-36	W-78	80	66	45.9	18.0	210	50	12	19.7	17.3	8.9
S-54	D-36	W-84	80	68	45.7	18.0	210	50	12	19.2	16.4	8.9
S-54	D-36	W-90	85	61	53.0	18.0	210	50	12	18.5	16.8	8.9
S-54	D-36	W-96	85	63	52.9	18.0	210	50	12	18.0	15.8	8.9
S-54	D-36	W-102	85	66	50.9	18.0	210	50	12	17.5	15.0	8.9
S-54	D-36	W-108	85	68	49.9	18.0	210	50	12	17.2	14.2	8.9
S-54	D-36	W-114	85	69	50.3	18.0	210	50	12	16.7	13.4	8.9

Which gust speed is permissible at a height of 10 m?

Determining the pulley height using the work planner





Pulley height: 165.9 m
Determining the height using the total system length: 54 m + 114 m = 168 m

The predicted wind gust speed is 11 m/s at a height of 10 m
By making the conversion using chart 2.3.1, a wind gust speed of 14.9 m/s at a height of 170 m is determined, which means that the crane can be turned off as it is. 16.7 m/s is permissible.

7. Final comments

The wind power boom of the last few years has given rise to many crane manufacturers' innovations. Never before have so many large machines been commissioned in order to meet the increasing demands of the new wind power plant technology as today.

When erecting a modern wind power plant care must always be taken to ensure that the size of the crane is suitable for the weight of the turbine house and the rotor's surface area exposed to wind in conjunction with the hub height. Likewise these must be considered when carrying out repair work or maintenance work. The influence of the wind on the crane and load is more heavily emphasised in the mind of the crane operator when installing wind power plant systems as the crane is deployed in locations where high winds must be taken into account.

The rule states that "double the wind speed means 4 times the wind loading on the boom and load".

In order to better evaluate the accident risk and thus to avoid industrial accidents when working with the crane, we have compiled this comprehensive document on the subject of "Wind influence on crane operation". Furthermore, competent colleagues from Liebherr-Werk Ehingen GmbH are available to answer any further questions that the reader may have.

You can find our current portfolio of cranes for wind power in the brochure of the same name as a download at www.liebherr.com.

8. Exercise solutions

Solution exercise 1

☒ Wind load	☐ Wind energy
☐ Evaporation	☒ Wind from the rear
☒ Wind from the front	☒ Wind from the side

Solution exercise 2

Wind from the rear	The LMB shut-off actuates at a load that is less than the maximum permissible load capacity according to the load chart.
Wind from the front	Shut-off actuates only after a load that is greater than the maximum permissible load capacity.
Wind from the side	There is no LMB shut-off.

Solution exercise 3

☐ none
☒ the load can swing
☒ the load turns on the cable
☒ the radius of the load can increasen

Solution exercise 4

- Forests and uneven land can be seen - this represents roughness class 3.
- A landscape with a few houses and trees and free spaces can be seen - this represents roughness class 2.

Solution exercise 5

- ☐ Weak wind caused by a difference in air pressure
- ☐ Short severe flurry of wind
- ☒ Severe flurry of wind higher than the average wind speed, over a period of 3 seconds

Solution exercise 6

Determined wind gust speed according to screenshot (Windy, page 13) = 3 m/s
Factor for 160 m working height with existing wind gust speed = 1.339
3 m/s x 1.339 = 4.017 m/s

Solution exercise 7

2,6 m² x 1,2 = 3,12 m²

Solution exercise 8

If the **current** wind speed exceeds the **permissible** wind speed from the load chart then the crane operation must be **halted** and the boom **set down** if the **permissible** wind speed in accordance with the crane wind speed table is **exceeded**.

Solution exercise 9

1. 9,0 m/s
2. 11,2 m/s

Solution exercise 10

5,9 m/s

Solution exercise 11

9,0 m/s

Solution exercise 12

The ideal teleconfiguration would be 0/92/0/0/0/0/0/0 (24.5 m).
According to the wind force diagram 9.0 m/s, the new maximum permissible wind speed is 5.75 m/s.

Solution exercise 13

The ideal teleconfiguration would be 92/92/92/100/100 (77 m).
According to the wind force diagram 11.2 m/s, the new maximum permissible wind speed is 6.55 m/s.

Notes

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