	FEDERATION EUROPEENNE DE LA MANUTENTION **Product Group Cranes and Lifting Equipment**	**FEM** **5.016** **(2nd Edition)** **28.02.2013**

- Guideline -

"Safety Issues in Wind Turbine Installation and Transportation"

- Leitfaden -

"Sicherheitsrisiken während der Erstellung und des Transportes von Windkraftanlagen"

- Guide -

"Risques relatifs à la sécurité lors de l'installation et le transport d'éoliennes"

Fédération Européenne de la Manutention - Product Group Cranes and Lifting Equipment

Sources see end of the document

Available in: English (EN), French (FR), German (DE), Italian (IT), Spanish (ES)

CONTENT

Legal Note: It neither addresses each and every imaginable scenario, nor is it a binding interpretation of the existing legal framework. It does not and cannot replace the study of the relevant directives, laws and regulations. In addition, the specific features of different products and their various applications have to be taken into account (see related operating instructions of the equipment used). This is why the assessments and procedures referred to in this paper may be impacted by a large variety of circumstances.

Corrigendum (2 Ed)

a) Figure 3 corrected

b) Chapter 4 "To enable an easy and quick … in the work flow diagram to determine the ~~minimum~~ allowed wind speed."

c) Figure 4 Key added

d) Page 17 in section Theoretical background, “p: Dynamic pressure” is replaced by “q: Quasi-static impact pressure”

1. Introduction

Lifting loads in strong wind conditions can present a potential danger that should not be underestimated. Wind forces acting on loads during lifting operations have led to a number of serious accidents especially in the wind mill industry. Therefore ESTA (the European Association of Heavy Haulage Transport and Mobile Cranes Group) and FEM (the European Association of Lifting Equipment Manufacturers, Product Group Cranes and Lifting Equipment, Mobile Cranes) already issued a safety alert in April 2010 in several magazines (N 0219 Document compiled by FEM/ESTA).

Before starting the lift the crane operator must ensure that the crane and the load is not exposed to any wind that could exceed the limits set by the crane manufacturer. It is therefore important to be informed about the expected wind situation well ahead of the lift. Especially dangerous however are localised gusts which can arise in conjunction with heavy showers and thunderstorms for example.

In addition many haulers and crane rental companies complain about time constraints (time pressure), as far as lead time (wind mill rigging) is concerned. Especially, but not only, towards the end of a calendar year, lead time is often reduced to an unacceptable level. Without the proper lead time the possibility of “cutting safety related corners” increases, especially risks of accidents due to operating the crane in stronger wind conditions than allowed by the crane manufacturers.

This document serves to inform crane operators, project planners and also crane companies about safety issues during rigging of wind mills, especially about wind influences on a mobile crane on the job site. The third chapter is an introduction to the basics of wind loads as e.g. covered by the European Standard for mobile cranes, EN13000. In the following it will be shown how wind loads and finally special load cases, such as when erecting wind-power turbines, can be calculated. Likewise it will be shown which information is required.

This document does not claim to be complete and is complementary to the operating instructions of the particular crane. As such it does not replace the operating instructions and the load chart book for the crane in question.

It is intended to create more sensitivity for the work with heavy plants by issuing this document. FEM herewith offers the experience of all manufacturers joined in the association.

2. Scope

This document applies to mobile cranes (e.g. telescopic cranes on tires, crawler cranes). It should serve only as a reference and overview: it is meant to provide guidance in the assessment of risks.

3. Basics

3.1 Crane capacity and capacity charts

The capacity of a mobile crane in a configuration is limited by influences of many different variables (e.g. structural resistance of components, stability of the whole crane). Therefore the permitted loading capacity per configuration is given in a so called capacity chart as a combination of permitted load at the related load radius (see example in Annex 5). This load/radius combination is monitored by the loading control of the crane (rated capacity limiter, RCL) and shall not be exceeded!

The permitted loads in the capacity chart may need further reduction when the assumptions made during design calculation are exceeded (see below in chapter 3.2). This job specific assessment is under the responsibility of the user of the crane.

⚠ Planning and executing a lift with loads exceeding the permitted capacities including e.g. foreseeable wind influence, as well as overriding the loading control of the crane, may lead to accidents with injuries or fatalities!

3.2 Wind declaration in capacity charts

Often wind and occurring gusts of winds are an underestimated factor during lifts with mobile cranes. When lifting loads with a large surface area exposed to wind such as rotor blades or complete rotor units of wind mills the conditions and assumptions for calculation of wind loads may differ significantly from the standard values provided by EN 13000. These standard values are the basis for the crane calculations; as such the theoretical wind loads can be significantly exceeded.

All mobile cranes, working in the European market, must fulfil the requirements of the European Machinery Directive 2006/42/EC. The relevant European standard for mobile cranes is EN 13000, which encloses load assumptions for calculating the load bearing structure of a mobile crane. Regarding the calculation of wind forces on the lifted load, the following assumptions are given:

1) A standard projected surface area of the lifted load of 1 m^2 per ton.

2) A standard drag factor of the lifted load of $c_w = 1.2$.

But

- Rotor blades or rotor assemblies usually have a significantly higher projected surface area than 1 m^2/ t, often 5 – 10 times higher,
- The typical c_w factor of a complete rotor assembly is often 1.5 – 1.8 and not the value of 1.2 as assumed by the EN 13000 Standard.

Therefore the permitted wind speeds in the crane's capacity charts are often not valid when lifting rotor blades, rotor assemblies or other structures with big sail areas. Lifting of these items will require lower wind speeds, compared to the wind speeds allowed when lifting tower sections, a nacelle or other heavy items.

Regarding EN 13000 the wind speed referred to in capacity charts is the so called “3-second gust” measured at the highest point of the boom system, and not the average wind speed measured at a 10 meter elevation over a time period of 10 minutes as given by most weather stations. The 3 second gust wind speed can easily be higher by a factor of 2 and more; i.e. taking into account the average wind speed at 10m elevation may significantly underestimate the real conditions!

These 3 factors

- wind surface area of the rotor / rotor assemblies,
- drag factor c_w and
- “3 second gust” wind speed measured at the highest point of the boom system

are amongst the reasons, why thorough planning is required, the weather conditions need to be observed and why waiting time should be expected/calculated when planning the lifting of rotor blades / rotor assemblies.

⚠ Delays in lifting operations should be expected, when lifting rotor blades or rotor assemblies, due to the often significantly lower allowable wind speeds compared with the max. allowable wind speeds in the load chart of the crane. The risk of such delays needs to be taken into account during planning.

3.3 Wind influence on the crane and the load

Wind speed and direction, shape and size of load have a major impact on the stability and the loading of mobile cranes.

Doubling of wind speed results in four times higher wind load and the wind speed increases with height above ground level (see chapter 3.3 below). The shape of load influences the wind resistance and impacts as such the wind load acting on the crane (see chapter 4 below).

Wind influence on crane and load will create outrigger loadings which significantly differ from values as published in manuals or calculated with operation planning tools supplied by the manufacturers (see also chapter 7).

When the wind hits the load, it may swing 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 wind speed, the area of the load exposed to the wind and the direction of the wind, the radius of the load may increase or, prohibited lateral forces may act on the crane boom.

⚠ If the loading created by the swinging is close to the max. permitted load for that configuration the RCL cut-off could be switching in and out constantly.

The wind can blow from the front, the rear and the side on the crane and the load. All 3 directions have to be considered for the crane and the load and will have different influences on the crane:

The **wind from the front** does not reduce the loading of the hook, hoisting cable, sheaves and hoisting winch because the load continues to act with its gravitational force.

With wind from the front the boom system is relieved of load as the wind acts on the sail area of the boom reducing dead weight of the boom. The load indication of the rated capacity limiter (RCL) is lower than the real payload.

The corresponding RCL cut-off limit will be at a larger radius than given in the load chart book. Therefore the crane will be overloaded at the cut-off point.

Wind from the side acting on the crane boom and the load is particularly critical for the mobile crane.

The additional loading due to the wind from the side is not detected and indicated by the rated capacity limiter (RCL). The load indication is similar to the display when operating without wind. This can result in overloading the crane in its strength and stability.

With **wind from the rear** the boom system is additionally loaded. The load indication of the RCL is greater than the actual payload. The RCL cut-off actuates at a load that is less than the maximum permissible load given in the load chart.

A lift (especially when lifting loads with a large surface area exposed to wind) should never be planned too close to the limits of the load chart.

With the load being slewed during a lift all wind directions discussed may influence the loading status even if the wind direction itself is not changing.

Improved quality and technology in mobile cranes state of the art and a crane operator with many years of professional experience and education regarding the wind influences, as well as professional planning of the lift well in advance will significantly reduce the risk of an accident.

3.4 Wind basics

Wind speeds are generally classified with the so-called **"Beaufort scale"** in bft (see Annex 4). This is a phenomenological scale from 0-12 (through observing natural phenomena). The wind strengths can be determined by means of typical visible effects and natural observations of the landscape. The Beaufort strength refers in practical terms to the average wind speed value within a time period of **10 minutes** at a height of 10 meters. Beaufort values are varying from 0 (calm) to 12 (hurricane).

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 report speaks 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 lies significantly below this (in the example 33 km/h).

The speed of a gust is the average value of the wind speed measured for duration of **3 seconds**. The gust speed is higher than the average wind speed, which is measured over a period of 10 minutes. Furthermore the wind direction during a gust may vary by approximately 30 degrees which may cause additional unintended side effects.

High above the ground, at an altitude of approx. 1 kilometer, the wind is not any longer 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. Roughness classes are known between 0 (water surface) and 4 (cities with very high buildings).

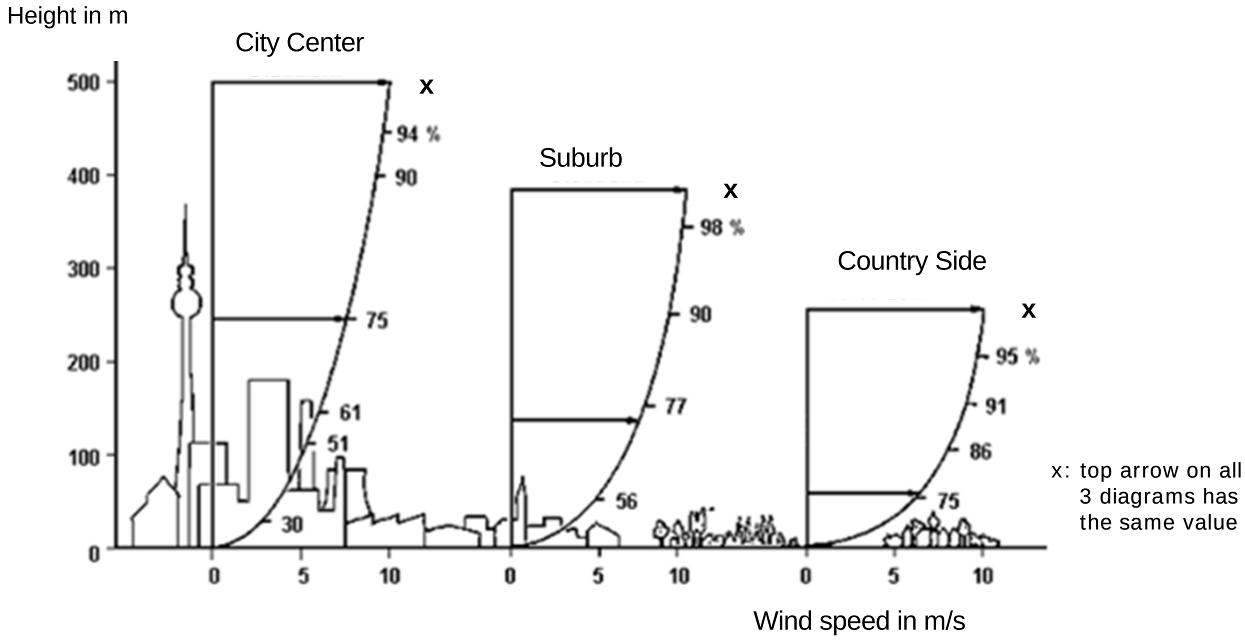


Figure 1 — Influence of the wind speed by the roughness of the ground

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 characterized 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. **Values from the weather office and calculations regarding the wind speed relate to roughness class 2**. In case of smaller roughness classes it is necessary to consider that the wind speed will be higher at the work site (see figure above) than the figures provided by the weather station!

Height-dependent wind speed

In order to calculate the wind speed expected for the highest point of the boom, the table in Annex 1 applies.

Example:

You receive notification (e.g. from the nearest weather station) of a wind speed of 6.2 m⁄s at 10 meters above ground level, calculated over 10 minutes. According to the Beaufort table (see Annex 4) this represents a wind speed with a Beaufort value of 4. You have a max. lifting height of e.g. 50 meters. Now the 3s gust wind speed at a height of 50 meters can be read out with the help of the table in Annex 1. It amounts to 13 m⁄s. As it exceeds the maximum permissible gust wind speed of 9 m⁄s according to the load chart, the load lifting operation shall not be carried out.

4. Lift planning and determination of permissible wind speed

The following values must be known or requested prior to the lift:

• The **mass of the working load** (m)

• The **maximum projected surface area** (A_P) of the load (see below)

• The **drag factor** (c_W)

• The forecasted 3s **gust wind speed** (v_{act}) at the highest point of the boom system

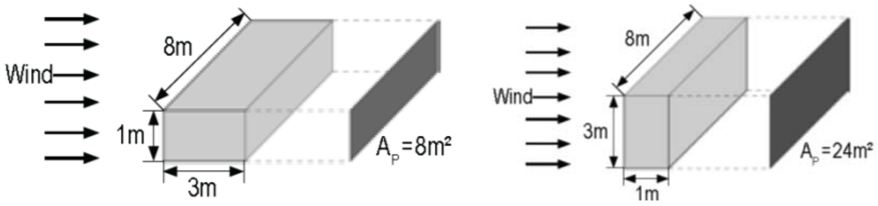


Figure 2 — Calculation of A_p

Procedures and safety information regarding wind conditions given in the manufacturers capacity charts and operating manuals have to be strictly observed and followed to prevent accidents. Planning as well as operation may only be done by skilled and qualified personnel.

Each lift shall be planned taking into account environmental conditions (e.g. meteorological data including weather forecasts, relevant environmental conditions).

- The determination of the wind speed shall be based on the expected wind gust (3-second wind gust) at the highest point of the boom system.
- During this planning, the lifted load, its geometric form and its air drag factor have to be taken into account as well.

A simplified calculation method (see flowchart below) covers all individual cases and is therefore conservative. Exact calculations may allow higher wind speeds; the manufacturer may be contacted for exact calculation.

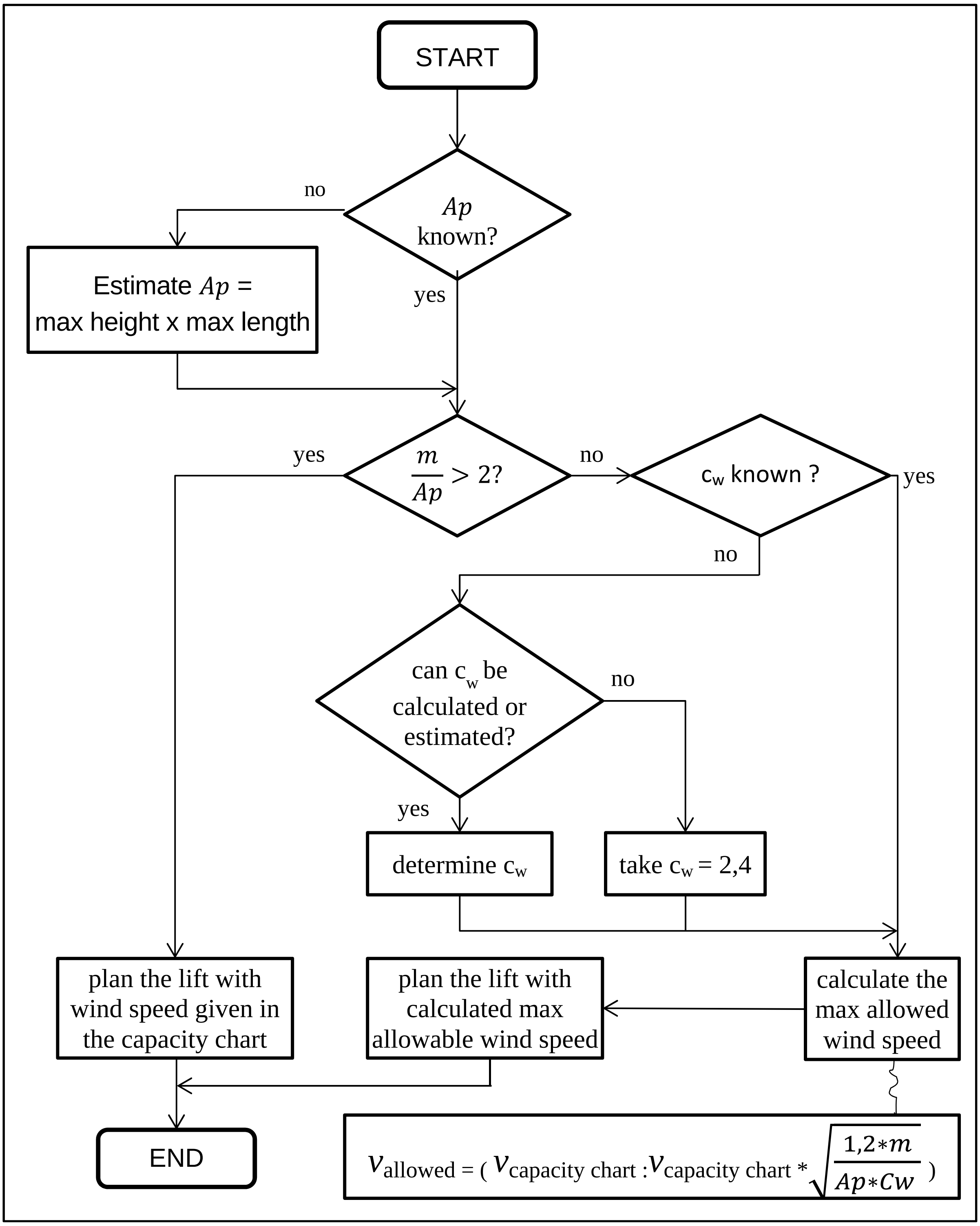


Figure 3 — Work flow to determine the allowed wind speed

Key

- m – Working load [t]
- Ap – projected surface area [m2]
- c_w – drag factor ; example of shapes and corresponding drag factors can be found in annex 3
- $v_{allowed}$ – maximum allowed wind speed of a 3-second gust wind at the highest point of the boom system [m/s]
  The allowed wind speed shall not be higher than the wind speed of the load chart. [m/s]
- $v_{capacity\ chart}$ – wind speed of capacity chart [m/s]

The factor 2 mentioned in the formula $\frac{m}{Ap} > 2$ corresponds to the ratio between max drag factor 2.4 and the standard drag factor 1.2 taken for the load assumption.

To enable an easy and quick determination of the maximum allowed wind speed (large formula in the flow chart above), a wind speed reduction diagram may be provided (see example below). The following two examples show the usage of such diagrams. The same results can be obtained by using the formula in the work flow diagram to determine the allowed wind speed.

Example 1 for determining the maximum permissible wind speed (dotted line in the wind speed reduction diagram, see below):

A load with a mass of 85 t has a c_W-value of 1.2 and a projected surface area of 50 m². A drag factor c_W of 1.2 and a projected surface area of 50 m² result in an area exposed to wind of 60 m² (A_{W1}). In this example the load chart permits a maximum wind speed of 9 m⁄s. For this reason the wind speed reduction diagram with 9 m⁄s must be used. Now a line must be drawn vertically upwards at the area exposed to wind value 60 m² on the wind speed reduction diagram 9.0 m⁄s. Draw a line horizontally to the right at the load to be lifted of 85 t. Both lines intersect in front of the 9 m⁄s gradient.

- ⇨ The maximum permissible wind speed for this load case remains to 9 m/s as shown in the load chart.

Example 2 for determining the maximum permissible wind speed (full line in the wind speed reduction diagram, see below):

The load to be lifted has a mass of 50 t, has a c_W-value of 1.3 and a projected surface area of 77 m^2 which results in an area exposed to wind of 77*1,3 = 100 m^2 (A_{w2}). If the area exposed to wind is divided by the load then it results in a value of 2 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 again a maximum wind speed of 9 m⁄s is permissible (for a related area exposed to wind of 1.2 m^2 per t). Now the maximum permissible wind speed must be determined by means of the wind speed reduction diagram to 7 m⁄s.

- ⇨ The maximum permissible wind speed for lifting this load must be reduced to 7 m⁄s in comparison to the 9 m/s shown in the load chart.

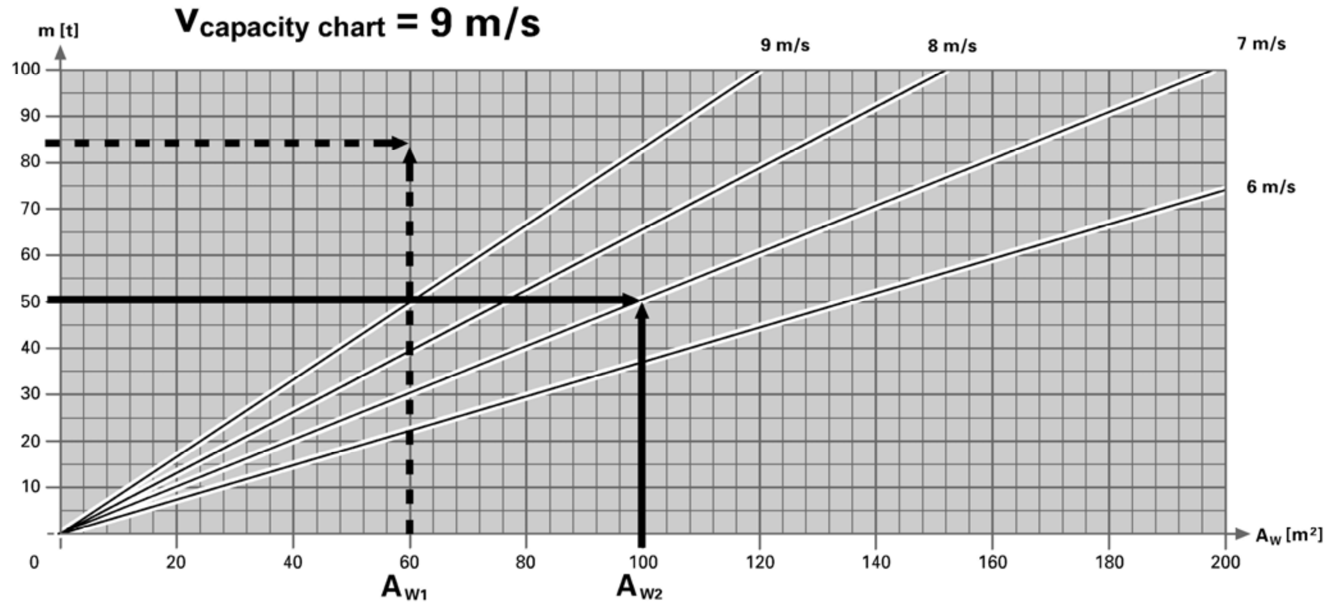


Figure 4 — Wind speed reduction diagram

Key

$A_w = A_p * c_w$ A_w - surface area exposed to wind (m²)

⚠ The determined maximum permissible wind speed of 7 m⁄s in example 2 is not programmed in the computer system of a mobile crane. There is no warning if the determined maximum permissible wind speed of 7 m⁄s is exceeded. For that reason, the crane operator himself must monitor the wind speed value in the computer system.

⚠ If the determined maximum permissible wind speed is reached or exceeded, the load must be brought to the ground as quick as possible. As it is often very difficult or even not possible to place the already hanging load back to the ground, it is essential for a safe lift to know the wind conditions during the whole duration of the lifting procedure in advance (including the rigging and de-rigging (see chapter 5)), e.g. by obtaining a detailed weather forecast.

Before starting a lift, turn the unloaded crane by 360° and watch the wind speed measured by the anemometer and displayed in the cab of the mobile crane. As the anemometer can be shaded by the wind mill or the crane's structure, the max wind speed may differ while slewing the crane.

Such wind speed reduction diagrams may be provided by the mobile crane manufacturer for each wind speed given in the capacity charts; without such diagram the calculation according to the work flow diagram as presented above will lead to the same results.

5. Influence of wind during rigging / de-rigging and parking of crane

The operator shall consider the manufacturer's instruction and information about influence of wind during rigging/de-rigging and parking of the crane. The information given in the manual contains at least the following facts:

- Wind speed, crane configuration and positioning of boom/jib; these facts have a major impact on the stability of mobile cranes during rigging/de-rigging and parking.

- Each crane erection shall be planned taking into account environmental conditions (e.g. meteorological data including weather forecasts, relevant environmental conditions) for the duration of all phases, including rigging, operation, parking and de-rigging.

6. Wind out of service

A mobile crane shall only be operated with load, within the allowable wind speeds (3-second gust) given in the load chards (for related area exposed to wind less or equal 1.2 m^2 per t) or determined with another calculation (for related area exposed to wind greater 1.2 m^2 per t – see chapter 4.). When wind speed increases, the crane has to be brought into a safe position by either laying down the boom or moving it into a parking position. The parking position given by the manufacturer is an optimized position in which the machine can withstand high wind speeds. The allowable wind speeds for crane out of service is given by the manufacturer.

While laying down the boom or moving it into the parking position, the crane may move through positions in which it is more affected by wind; therefore, the boom needs to be laid down or moved into parking position early enough, so that the allowed wind speed for rigging/de-rigging given by the manufacturer is not exceeded.

7. Outrigger loadings and surface pressures

- The outrigger loadings and surface pressures of crawlers of mobile cranes, given by the manufacturers, do not take into account the elastic deformation of the crane (regarding theory 2nd order),
- permissible inclination of the crane,
- wind loads on boom and load,
- additional load due to dynamics (crane movements),
- interaction between crane load on outrigger pads or crawlers and ground.

Further development of the cranes and the increased requirements during operation on the job sites in the past few years such as

- use of high strength steel with greater elasticity
- larger system length
- lightweight design
- more frequent lifts with larger surface areas exposed to wind and larger c_w values
- use in locations with higher wind speeds

lead to larger elastic deformation of the crane. This results in higher outrigger loads/surface pressures under crawlers.

As a rule of thumb following factors for mobile cranes with outriggers must be taken:

When lifting tower sections or the nacelle, an additional 20 % shall be added to the outrigger pressures given by the manufacturer for this configuration.

When lifting a rotor blade or a complete rotor assembly, an additional 35 % shall be added to the outrigger pad loads for this particular kind of lifting.

This should be remembered, when selecting the adequate support plates under the cranes outriggers.

When using crawler cranes the increase of the surface pressures depends on the ground under the crawlers/mats and the size of the mats. In this case special calculations are required. Always remember to add the additional outrigger loadings or surface pressures under crawlers created by the wind acting on the crane and its load. Make sure, that the hard stands are designed accordingly and support plates can take these added loadings.

8. Risks for Mobile Cranes during repair work of wind mills

For repair work e. g. exchange of the rotor blades or the complete rotor a smaller crane is normally used compared to the erection of the wind mill, where the size of the crane was dimensioned by the weight of the heavy nacelle. Therefore the crane used for maintenance may be lifting close to its rated capacity, and additional wind loading, not taken into account in the planning may overload the crane.

When lifting down components of the wind mill, make sure that the hoist cable is winded tough on the hoist drum while lifting up the empty hook block to avoid cutting in of the hoist rope in the loose rope package on the winch. This can be avoided by using a heavier hook block or an extra load.

9. Access roads

9.1 Preparation

Due to time constraints, mobile cranes are very often moved from one hard stand to the next on the job site in a semi-assembled configuration. This requires a number of additional safety precautions e.g.:

Load bearing capacity

The access roads must be able to bear the axle loads/crawler surface pressures from the crane in its semi- assembled configuration. When travelling on access roads with super lift attachment and/or the base section for the luffing jib and/or part of the counterweight, the axle load/ could increase to 25 tons or more. The civil contractor responsible for the construction of the access roads must have full knowledge of this increased axle load/crawler surface pressure.

Access roads must be designed to accommodate the crane in the particular configuration, in which it is moved on the site, and not according to the on-road configuration or to a generic axle load or crawler surface pressure.

⚠ Access roads for all-terrain cranes and truck cranes: Please have in mind that normally loaded tire of a crane with 12t axle load with nominal tire pressure of 10 bars equals to a local loading under the tire of 100t/m^2!

Cross fall or chamber of access roads, inclination of access roads

The chamber (or cross fall) of the road and the inclination of the road must be within the limits outlined by the crane manufacturer.

⚠ The road must be designed to accommodate the crane in that particular configuration in which it is moved on the site.

⚠ According to the cross fall of the road and the elasticity of the tires, the wheel loads from right to left side of the mobile crane will differ! Make sure that the road can take this load.

⚠ Access roads for crawler cranes: If the outside width of the crawler is bigger than the bearing width of the access road, the ground may be overloaded due to only the inner parts of each track are taking the load causing the track pads to incline. This may lead to tipping over the side. In addition the track rollers have only point contact to the track pads which will result in increased wear. Same happens if the cross section of the access road is built in a convex shape for water drainage.

9.2 Travelling the crane in partially assembled configuration

When moving mobile cranes in a semi assembled configuration, the centre of gravity is moving up to a higher level. Therefore each side inclination will lead to a rapid movement of the centre of gravity out of the centre line of the crane. This will lead to an increase in tire or crawler loadings, the ground can give way, or/and the mobile crane can tilt to the side. Moving mobile cranes on access roads or any other roads in a semi assembled configuration should only be done according to the operator's manual or/and after consultations with the crane manufacturer.

The instructions of the manufacturer need to be followed closely as the higher centre of gravity of the partially assembled crane presents an additional risk.

As a general backup (e.g. in case of a tire failure or if the ground gives way) the outriggers of telescopic cranes or truck/crawler mounted lattice boom cranes shall be always extended when travelling partially assembled. The outrigger pads shall be kept just above ground and the area under the moving pads shall be levelled to avoid sticking of pads over ditches and this area shall be able to take the loading if needed.

10. Conclusion

During crane operation in windy conditions 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 the site by contacting the appropriate weather station. Lifting is prohibited when the expected wind speeds are exceeding the max. wind speeds calculated for the relevant load during operation planning. When the wind speed is gusting just before the lift, there is a high probability that unexpected strong gusts will occur in near future. The forecasted **weather** data can be found on the internet (e.g. www.windfinder.com under the heading "Super Forecast"). Note that the given gust speed is based on a height of 10 meters above ground only.

Especially during lifting of loads with relative small masses but large sail areas, the wind load has a considerable impact on the load carrying performance of the crane. The effective surface area exposed to wind of the load which needs to be taken into account is the result of the projected area multiplied with the c_w factor (drag factor - shape coefficient for the load). The sail area and c_w factor must be known to all parties planning the lifting operation.

⚠ **Performing a lift without taking into account the expected wind forces and the actual surface area of the load exposed to wind can lead to a failure of components and/or tipping over of the crane!**

⚠ **Not taking into account wind effects on the job site, risk for life exists.**

Theoretical background

(For more information see EN 13000:2010)

<u>Definitions</u>

N	Newton (unit for the force)
c_W	wind resistance factor (drag factor)
A_P	projected surface area of a body (m²)
A_W	surface area exposed to wind (m²)
v_{max}	maximum permissible 3 second gust speed (m/s) at the highest point of the boom system.
$\bar{v}$	wind speed determined over 10 min *v* [m/s] at 10 m above ground or sea level
$v(z)$	the average value for the wind speed over a period of 3 seconds at a height of z above the ground (m/s).
z	height above ground
q	Quasi-static impact 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.

Wind speeds and pressures:

To calculate the wind loads it is assumed that the wind is blowing horizontally from the most unfavorable direction, but at an elevation-related speed (10m above ground). The speed of a 3-second wind gust $v(z)$ [m/s] acting on an elevated point z [m] and decisive for calculations is based on a mean wind speed determined over 10 min $\bar{v}$ [m/s] at 10 m above ground or sea level.

$$v(z) = \left[(z/10)^{0,14} + 0,4\right] \cdot \bar{v}$$

for $z = 10[m] \Rightarrow v(z) = 1,4 \cdot \bar{v}$ **see Annex 1**

The quasi-static impact pressure *q* [N/m2] is as a result of:

$$q = 0,625 \cdot v(z)^2$$

for $z = 10[m] \Rightarrow q(z) = 1,225 \cdot \bar{v}^2$ **see Annex 2**

The admissible wind speed for the crane in-service and out-of-service is derived from the wind gust speed *v*(z) acting on the highest elevated point taken in account for the verifications.

In service wind loads (during operation)

To calculate the wind load during crane operation conservatively, the wind gust speed determined at the highest elevated point v_i (max. *z*) can be assumed to act all over the height of the crane and its boom. Precise elevation-related calculations of the wind forces acting on the boom are permissible, e.g. in 10 m elevation intervals.

The wind forces acting on the crane and its components as well as the pertaining impact pressures determined shall be combined with the other in-service loads. The permissible wind speed v_i (max. *z*) shall be indicated in the rated capacity charts and in the instruction manual.

The reference values of the sail area and drag coefficient used to determine the wind effect on the load shall be indicated; the following minimum values shall be taken:

- Sail area per ton of lifted load: A=1,0 m²/t
- Drag coefficient: c_w=1,2

Thus the effective sail area becomes 1,2 m^2/t.

The wind loads acting on the suspended load shall be calculated with the effective sail area at the maximum lifting height of the suspended load. Special verification is required from case to case for lifting loads with a large "effective sail area" (A*c_w> 1,2 m²/t). If the manufacturer provides capacity charts based on other assumptions than the standard ones, this shall be mentioned in the provided capacity charts.

Safe crane use is only possible within the range of the permissible wind speed v_i (max. z) while the crane is in service, the speed at the highest elevation can be monitored by means of an anemometer. To prevent any danger, in particular, due to sudden changes in wind speed or direction during the passing of weather fronts, weather reports should be taken into account when lifting operations are being scheduled. Instructions should be laid down in the instruction manual providing suitable measures for lowering the crane to a safe position.

Mobile cranes are normally equipped with jib systems which can be lowered quickly and readily. As a result, the hazards due to sudden changes in wind speeds and increases in gust speed at elevated points can be reduced in a short time, e.g. within 5 min.

Out-of-service wind loads (when the crane is not in operation)

a) Out-of-service storm winds

To calculate the wind loads when the crane is not in operation, an average, regionally varying, reference wind speed can be assumed. The reference wind speed v_{ref} is determined over 10 min at 10 m above ground or sea level.

The design is considered safe when all the required verifications including the effect of 3-second elevation-related wind gusts are calculated based on a reference wind speed (see formulas in capital Wind speeds and pressures above and Annexes 1 and 2).

b) Out-of-service limiting wind speed

To calculate the wind load effect when the crane is not in operation, the wind gust speed at the highest elevated point v_a (max. z) shall be considered (see Annexes 1 and 2). The required safety shall be verified for all permitted configurations and/or positions of the crane. Precise elevation-related calculations of the wind forces acting on the jib in such a configuration and/or position are permissible, e.g. in 10 m elevation intervals, for the relevant gust speeds (3-second gust speed).

The forces on the crane and its components resulting from the impact pressure shall be combined with the dead weights and, if required, with other geometric influences (e.g. out of level surfaces).

A crane which is safe with respect to the effect of the wind speeds v_a (max. z) based on crane-specific limits, should only remain in this configuration and/or position up to the derived wind gust speed.

Information shall be provided in the instruction manual as to which measures shall be taken by the crane operator in order to maintain the crane in safe condition, e.g. by lowering or telescoping in the boom in the event that v_a (max. z) is exceeded. Instructions shall be laid down in the instruction manual providing suitable measures for securing the crane out-of-service.

The safety of a crane is only maintained within the range of the permissible wind speed v_a (max. z) while the crane is in- or out-of-service. Therefore exceeding of the limiting wind speed out-of-service should be prevented by planning a lift including the weather forecast.

Annex 1: Wind speed as a function of elevation

Table 1 — 3 second wind gust speed as a function of mean wind speed as per Beaufort Scale and as per elevation

Beaufort Grade	**3**	**4**	**5** [a]	**5** [b]	**6**	**7** [a]	**7** [b]	**8**	**9**	**10**
$\bar{v}$ [m/s] [b]	5,4	7,9	10,1	10,7	13,8	14,3	17,1	20,7	24,4	28,4
z [m]	$v(z)$ [m/s]									
10	8	11	14	15	19	20	24	29	34	40
20	8	12	15	16	21	22	26	31	37	43
30	9	12	16	17	22	22	27	32	38	45
40	9	13	16	17	22	23	28	33	39	46
50	9	13	17	18	23	24	28	34	40	47
60	9	13	17	18	23	24	29	35	41	48
70	9	14	17	18	24	25	29	36	42	49
80	9	14	18	19	24	25	30	36	42	49
90	10	14	18	19	24	25	30	36	43	50
100	10	14	18	19	25	25	30	37	43	51
110	10	14	18	19	25	26	31	37	44	51
120	10	14	18	19	25	26	31	38	44	52
130	10	15	19	20	25	26	31	38	45	52
140	10	15	19	20	26	26	32	38	45	53
150	10	15	19	20	26	27	32	39	45	53
160	10	15	19	20	26	27	32	39	46	53
170	10	15	19	20	26	27	32	39	46	54
180	10	15	19	20	26	27	33	39	46	54
190	10	15	19	20	26	27	33	40	47	54
200	10	15	19	21	27	27	33	340	47	55

[a] In-service wind:

1 light $\bar{v}$ = 10 [m/s] => for z = 10 [m] => $q(z)$ = 125 [N/m²]

2 normal $\bar{v}$ = 14 [m/s] => for z = 10 [m] => $q(z)$ = 250 [N/m²]

[b] Upper Beaufort Limit

Key

$\bar{v}$ [m/s]: Mean wind speed at 10 m elevation (upper limit of Beaufort grade) over a period of 10 min.

z [m]: Elevation above even ground.

$v(z)$ [m/s]: 3-second wind gust speed acting at elevation z and decisive for calculations.

$q(z)$ [N/m²]: quasi-static impact pressure acting at elevation z and calculated based on $v(z)$, see Annex 2.

Annex 2: Impact pressure as a function of elevation

Table 2 — Quasistatic impact pressure as a function of mean wind speed as per the Beaufort scale and as a function of elevation

Beaufort Grade	**3**	**4**	**5** [a]	**5** [b]	**6**	**7** [a]	**7** [b]	**8**	**9**	**10**
$\bar{v}$ [m/s] [b]	5,4	7,9	10,1	10,7	13,8	14,3	17,1	20,7	24,4	28,4
z [m]	$q(z)$ [N/m²]									
10	36	77	125	140	233	250	358	525	729	988
20	41	88	144	161	269	288	412	604	839	1137
30	45	96	156	176	292	313	448	657	913	1237
40	46	102	166	186	310	332	476	698	970	1314
50	50	107	174	196	325	348	499	732	1016	1377
60	52	111	181	203	338	362	519	761	1057	1431
70	54	115	187	210	349	374	536	786	1092	1480
80	55	117	193	216	360	385	552	809	1124	1523
90	57	121	198	222	369	395	566	830	1153	1562
100	58	124	202	227	377	404	579	849	1180	1598
110	59	126	206	232	385	413	591	867	1204	1632
120	60	129	210	236	393	421	603	883	1227	1663
130	61	131	214	240	400	428	613	899	1249	1692
140	62	133	218	244	406	435	623	914	1269	1720
150	63	135	221	248	412	442	633	928	1289	1746
160	64	137	224	251	418	448	642	941	1307	1771
170	65	139	227	255	424	454	651	953	1325	1795
180	66	141	230	258	429	460	659	966	1342	1818
190	67	142	233	261	434	465	667	977	1358	1839
200	67	144	235	264	439	471	675	988	1373	1860

[a] In-service wind:

1 light $\bar{v}$ = 10,1 [m/s] => for z = 10 [m] => $q(z)$ = 125 [N/m²]

2 normal $\bar{v}$ = 14,3 [m/s] => for z = 10 [m] => $q(z)$ = 250 [N/m²]

[b] Upper Beaufort Limit

Key

$\bar{v}$ [m/s]: Mean wind speed at 10 m elevation (upper limit of Beaufort grade) over a period of 10 min.

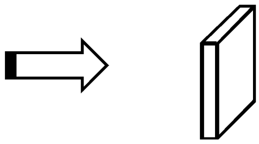
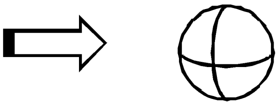
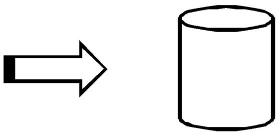
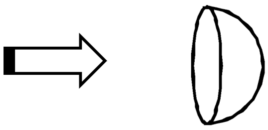
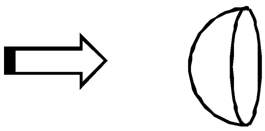
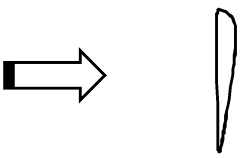
z [m]: Elevation above even ground.

$v(z)$ [m/s]: 3-second wind gust speed acting at elevation z and decisive for calculations, see Annex 1.

$q(z)$ [N/m²]: quasi static impact pressure acting at elevation z and calculated based on $v(z)$.

Annex 3: Typical shapes

Table 3 — Table with typical shapes and corresponding C_w values

Shape	Drag Coefficient C_w	Comment
	1,1 to 2,0	
	0,3 to 0,4	
	0,6 to 1,0	
	0,8 to 1,2	
	0,2 to 0,3	
	0,05 to 0,1	Wind mill blade
	Approx. 1,6	Wind mill blade

Annex 4: Beaufort values

Table 4 — Beaufort scale

Wind speed		Wind speed (average of 10 minutes)		Effect of wind inland
Beaufort scale	Designation	m/s	km/h	
0	Calm	0 to 0.2	1	Calm, smoke rises vertically.
1	Light draught	0.3 to 1.5	1 to 5	Direction of wind shown by smoke but not by weather vanes.
2	Light breeze	1.6 to 3.3	6 to 11	Wind felt on face, leaves rustle, weather vane moved by wind.
3	Gentle breeze	3.4 to 5.4	12 to 19	Leaves and twigs in constant motion, wind extends light flag.
4	Moderate breeze	5.5 to 7.9	20 to 28	Wind raises dust and loose paper, moves twigs and small branches.
5	Fresh breeze	8.0 to 10.7	29 to 38	Small trees begin to sway. Crested wavelets form on lakes.
6	Strong wind	10.8 to 13.8	39 to 49	Large branches in motion, telegraph lines whistle, umbrellas used with difficulty.
7	Moderate gale	13.9 to 17.1	50 to 61	Whole trees in motion, re-strictions when walking against wind.
8	Severe gale	17.2 to 20.7	62 to 74	Breaks branches off trees, considerably impedes when walking outside.
9	Storm	20.8 to 24.4	75 to 88	Slight structural damage (chimney pots and slates removed).
10	Severe storm	24.5 to 28.4	89 to 102	Trees uprooted, considerable structural damage occurs.
11	Violent storm	28.5 to 32.6	103 to 117	Widespread damage
12	Hurricane	32.7 and above	118 and above	Significant devastation

Annex 5: Capacity chart

Table 5 — Example of a capacity chart

	Crane with 56 t counterweight **Outrigger base – length 18,000 m – width 18,000 m**								
	Main Boom – fixed length in m								
	35.33	35 33	35.33	40.15	40.15	40.15	44.98	44.98	44.98
Tel. sec. 1	0.44	0.00	0.00	0.88	0.44	0.00	0.88	0.44	0.00
Tel. sec. II	0.44	0.44	0.00	0.44	0.44	0.44	0.88	0.44	0.88
Tel. sec. Ill	0.44	0.44	0.88	0.44	0.44	0.88	0.44	0.88	0.88
Tel. sec. IV	0.44	0.88	0.88	0.44	0.88	0.88	0.44	0.88	0.88
Slewing range	360°								
Radius in m	Lifting capacaties in t								
6.0	112.0	106.0	88.5						
7.0	112.0	100.0	81.5	90.0	92.0	82.5			
8.0	112.0	94.0	76.0	90.0	92.0	77.5	74.0	74.0	72.0
9.0	112.0	87.5	70.5	90.0	90.0	73.0	74.0	73.5	69.0
10.0	112.0	81.5	65.0	89.0	85.5	69.0	74.0	70.0	65.0
11.0	112.0	77.5	61.0	84.0	81.5	64.5	73.5	67.0	61.0
12.0	112.0	73.5	57.5	79.0	77.0	60.5	70.5	64.0	57.5
13.0	112.0	69.0	54.0	74.5	73.5	57 5	67.0	61.0	54.5
14.0	107.0	65.0	50.0	70.5	70.5	54.5	63.5	58.0	51.5
15.0	102.0	62.0	48.0	67.0	67.0	51.5	60.5	55.5	48.5
16.0	94.0	59.5	45.5	63.5	63.5	49.0	57.5	52 5	45.5
18.0	81.5	54.0	41.0	57.0	59.0	45.0	51.5	48.5	41.5
20.0	71.5	49.5	37.0	52.0	54.5	41.0	47.0	44.5	37.5
22.0	63.5	46.0	34.5	47.0	49.5	37.0	42.5	41.0	34.5
24.0	57.0	42.5	31.5	43.5	47.0	35.0	39.0	38.5	32.0
26.0	51.5	39.0	28.5	40.0	44.0	32.5	35.5	35.5	29.5
28.0	46.5	37.0	27.0	37.0	41.5	30.5	33.0	33.0	27.0
30.0	42.5	35.0	25.0	34.0	38.5	28.0	30.5	31.5	25.5
32.0	34.0	33.Q	23.5	31.5	37.0	26 5	28.5	29.5	23.5
34.0				29.5	35.0	25.0	27.0	28.0	22.0
36.0				27.5	33.5	23 5	25.0	26 0	20.5
38.0							23.5	25 0	19.2
40.0							21.5	23.5	18.2
RCL Code	1350								
Max. permitted windspeed	**12 m/s**								
	9 m/s	**11 m/s**	**12 m/s**	**10 m/s**	**8 m/s**	**12 m/s**	**10 m/s**		**11 m/s**

Bibliography

[1] N0129 FEM/ ESTA Press Release – Mobile Cranes – Influence of wind forces during crane operation – Frankfurt 12th April 2010

[2] Influence of wind on crane operation, 2nd release 2011, Liebherr Werk Ehingen GmbH

[3] European Standard EN 13000:2010 Cranes – Mobile Cranes, including preliminary work of CEN TC 147 WG11 for the next amendment.

[4] 2006/42/EC – Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast)
OJ No L 157, 9 June 2006

References

Established by the Technical Committee of Product Group Cranes and Lifting Equipment of the Fédération Européenne de la Manutention (FEM)

Secretariat: **Secretariat of FEM Product Group Cranes and Lifting Equipment**
c/o VDMA
Materials Handling and Logistic Technology Association
Lyoner Str. 18
D-60528 Frankfurt

Available from web server of FEM (Publishing House): http://fem.vdma-verlag.de

---

FEM Member Associations:

Belgium, AGORIA

Finland, Technology Industries of Finland

France, CISMA

Germany, VDMA

Italy, AISEM

Luxembourg, Industrie Luxembourgeois de la Technologie du Métalp. a. FEDIL

Netherlands, ME-CWM

Portugal, ANEMM

Spain, FEM-AEM - E.T.S.E.I.B

Switzerland, SWISSMEM

Sweden, TEKNIKFÖRETAGEN

Turkey, ISDER

United Kingdom, BMHF

For more information regarding FEM, please visit the FEM Website:

http://www.fem-eur.com