

BEST PRACTICE GUIDE

for

Transport and Installation of Onshore WTG Systems



Power Systems



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This Best Practice Guide was prepared with the advice and direction of Industry Subject Matter Experts retained to assist in the development and review of the Best Practice Guide content:

Kai Borchers

Project Engineer Logistics and Installation – Enercon

Ralf Lackner

Technical Engineering and Support – Enercon

David Collett

President, ESTA

Ton Klijn

Director, ESTA

Andre Gruendel

– Nordex

Martin Reuschell

– Nordex

Marcus Pecksen

Team Lead Transport Execution – Siemens-Gamesa

Will Jeffrey

Site engineer Tender and Construction – Siemens-Gamesa

Andre Kreimer

EMEA Leader, Business Development Field Services – GE Renewable Energy

Steffen Ripke

OTR Logistics Manager Europe, Onshore Wind – GE Renewable Energy

Jens Christian Dalgard

Heavy Transport Specialist – Vestas Wind Systems A/S

Louise Schmidt Nielsen

QSE Business Partner – SCP and Transport – Vestas Wind Systems A/S

Hauke Braasch

Logistics Engineer – Outbound Logistics – Servion

Wilke Wiech

Senior HSE advisor – Servion

Marcus Wuebbelmann

Managing Director – Crane & Logistics Partner

Paul Zepf

Product Group Cranes and Lifting Equipment Secretary – VDMA

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LEGAL NOTE: This Best Practice Guide 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.

The information in this document is for guidance only. The authors accept no liability for any actions taken as a result.

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1. PURPOSE

The purpose of this Best Practice Guide is to establish minimum requirements for transport and lifting operations of wind turbine installations by collecting existing and relevant industry guidance.

This document considers various aspects of transport and lifting operations, such as planning, inspection, maintenance and competency of personnel in order to minimize associated risks and with the aim of improving health and safety relating to transport and lifting operations during the construction of Wind Turbine Generators (WTG) plants.

2. SCOPE

The scope of this guideline is to provide stakeholders within the onshore wind industry with requirements and guidance for planning and undertaking transport and lifting operations related to WTG components.

Local legal requirements must always be considered and should any contradictions occur between this best practice guideline and the applicable local regulations, then local legislation shall take precedence. If, however, this guideline requires a higher standard than local legal requirements, then the guideline should be applied thereby positively contributing to the local requirements.

3. ABBREVIATIONS AND DEFINITIONS

COA	Certificate of Approval
CoG	Centre of Gravity
ECOL	European Crane Operators Licence
ESTA	European association of abnormal road transport and mobile cranes
GWO	Global Wind Organization
ISO	International Standards Organization
LiDAR	Light Detection and Ranging
MEWP	Mobile Elevated Working Platform
PPE	Personal Protective Equipment
RA	Risk Assessment
SWL	Safe Working Load
VDMA	Mechanical Engineering Industry Association
WAH	Working at Height
WLL	Working Load Limit
WTG	Wind Turbine Generator

Capacity Charts / Load Chart	A set of charts or tables provided by the manufacturer of the lifting appliance / crane detailing lifting capacities in all possible configurations.
CE markings	The CE marking is a mandatory European marking for certain product groups to indicate conformity with the essential health and safety requirements set out in European Directives
Class one (routine) Lift	This classification includes lifting operations where load characteristics are recognizable and there are no significant hazards within the working area or on the access route for the crane to the working area.
Class two (complex) Lift	Lifting operation where significant hazards have been identified with the load or with the working area or access route of the crane, and the crane is used to lift complex loads or persons, or where two or more cranes are used to lift the load, or where the lifting operation is carried out at a location with exceptional hazards.
Competent Person	Person who plans and manages transport or lifting operations and has training, practical, theoretical knowledge and experience required to plan a transport or lifting operation safely and establish a safe system of work.
Complex Lift	Lifting operation which requires more than one crane to lift the load, or cranes using load enhancement equipment, or the lifting of persons or when the lifting operation is deemed to entail exceptional hazards.

Contractor	Individual, organization or business, that signed a contract to perform a transport or lifting operation.	Lifting Point	The connection between the rigging and the load to be lifted.
Danger Zone	A potentially hazardous area, for example under a suspended load or in the swept path area of a transport.	Lifting Zone	The area around a lifting operation where if the load fell, shifted, rotated or otherwise moved in an unexpected manner could result in an injury or damage to individuals, equipment or materials in the area.
Davit Crane	A lifting device consisting of an angled beam which pivots over a vertical axis for example, on a pedestal on the WTG foundations.	Load	Any item being transported, lifted or lowered.
Grommet	An endless sling	Luffing jib	A hinged extension of the main boom that can be moved up and down (luff) to increase or decrease the radius of the lifting hook
Gross Weight (component)	The calculated or measured weight of the item to be lifted including a weight contingency factor.	Main Component	Rotor blade, hub, nacelle, drive train tower sections of a WTG.
Hazard	A potential source of harm or adverse health effect on a person or persons.	Man Basket	A cage for the lifting of personnel in places where no other method of safe access can be provided.
Hook Load	Weight of the suspended load plus weight of rigging.	Mobile Cranes	Wheeled or crawler cranes, equipped with a telescopic- or lattice boom, which can be moved around the site (partly) dismantled.
Knuckle Boom Crane	Also called a truck loader crane which features hydraulically or electrically powered articulated arm.	Mobile Work Equipment	Any work equipment which carries out work while it is traveling or which travels between different locations to carry out work.
Lashing point	A fixed point on the load intended for the attachment of lashing gear during transport.	Pad Eye	A certified lift point consisting essentially of a plate, reinforced by cheek plates if necessary, with a hole through which a shackle may be connected.
Lattice Boom	Crane boom comprising of a sectional frame work construction made from struts and main beams.	Periodic Examination	All transport and lifting equipment must be subject to regular periodic thorough examinations during the service life of the equipment. The frequency of the periodic examinations shall be determined by local legislation & manufacturer's recommendations. All lifting equipment must be inspected by a competent person at least annually.
Lifting / Transport Supervisor	Person who controls the lifting or Transport operation, and ensures it is carried out in accordance with the Lift- or Transport Plan.	Permit to Work	A formal written permit system used to control certain types of work that are potentially hazardous. A Permit to Work is a document which specifies the work to be done and the precautions to be taken.
Lifting Accessory	Any component that is not part of the Lifting Appliance, but forms part of the lift, i.e. placed between the Lifting Appliance and the load, also referred to as rigging.	Pre- and post-use Inspection	Visual and functional assessment of the lifting equipment's condition before and after use.
Lifting Appliance / Crane operator	The person responsible for ensuring the Lifting Appliance / Crane is operated safely and in accordance with the manufacturer's instructions and recommendations.	Pre- lift check	Reference document used for controlling the lifting operations completed by the Competent Person in Class 2 lifting operations.
Lifting Appliance	The primary plant used for lifting purposes, for example crane, winch, davit or forklift.	Pre- task Briefing	Briefing meetings between all associated personnel prior to commencing the lifting operation to ensure everyone is aware of their operational responsibilities. Must be documented and recorded.
Lifting Equipment	Work equipment for lifting or lowering loads and includes attachments used for supporting, anchoring or fixing it. Lifting Equipment includes both Lifting Accessories and Lifting Appliances.		
Lifting Operation	Any operation concerned with lifting or lowering of a load.		
Lifting Team	The lifting team described in this document.		
Lifting Plan	Written procedure establishing a safe system of work for a lifting operation.		

Responsible person	A responsible person is appointed to control transport operations or basic lifting operations as defined in Class One.	Slinger (aka Rigger)	Person responsible for attaching and detaching the load and identifying and use of lifting accessories in accordance with the specifications of the Lift plan. Referred to as Slinger in this document.
Rigging Weight	The total weight of rigging, slings, shackles etc. and other devices or items used to connect the load to the crane hook.	Steersman	A person responsible for steering the trailer and / or directing the driver (aka Banksman)
Rigging	Same as lifting accessory	Suspended Load	A load hanging from a lifting appliance.
Risk Assessment	A systematic process of evaluating the potential risks that may be involved in a projected activity or undertaking. For lifting and / or transport operations this is normally carried out by the competent person during the planning phase. In some countries this is a legal requirement.	Tagline	A rope of various materials used to control the load during lifting operations.
Risk	The combination of the likelihood and severity of an incident occurring.	Task Risk analysis (TRA)	TRA is a documented risk assessment developed for workplace hazard identification and an assessment of those hazards that may occur while performing a specific task or job.
Route survey report	Written capture of the findings of the route survey, containing proposals to mitigate any potential problems encountered on the intended route.	Telescopic Crane	Type of Mobile Cranes
Route survey	Investigation of the route to be travelled by a transport with certain dimensions and weights.	Toolbox talk	Same as pre-task briefing
Safe System of Work	A defined procedure resulting from risk assessment and designed in order to eliminate or reduce risks.	Transport equipment	Work equipment for transport and fixture of loads; includes attachments used for supporting, anchoring or fixing the load.
Safe Working Load	The maximum load that can be safely applied to a Lifting Appliance or Accessory in accordance with the manufacturer's instructions.	Transport operation	Any operation concerned with the transport of a load.
Safe Zone	An area that has been risk assessed and in which a safe system of work is established to minimize the risk to personnel.	Transport organisation	The transport team described in this document.
Signaller	Person responsible for giving directions and ensuring safe movement of the lifting appliance. Referred to as Signaller in this document.	Transport plan	Written procedure establishing a safe system of work for a transport operation.
		Traverse system	A (remotely operated) load control system and type of work equipment, used for orienting the load horizontally during lifting. Referred to as traverse system in this document.
		Weather Window	Time frame as per weather forecasts when a transport or lifting operation can be performed within the pre-defined maximum environmental limits.

4. MANAGEMENT OF LIFTING OPERATIONS

4.1 Safe Systems of Work (SSOW)

A large percentage of accidents occur due to lack of or failure in systems of work. Implementing safe systems of work is an important part of safety and lifting operations.

The EU Directive 89/391 (OSH Framework directive) requires employers to provide systems of work that are planned, organised, performed, maintained and revised as appropriate so as to be, so far as is reasonably practicable, safe and without risk to health.

A system of work is a set of procedures according to which work must be carried out. Safe systems of work are required where hazards cannot be eliminated and some risk still exists. When developing your safe systems of work, consider how the work is carried out and the difficulties that might arise and expose you or your workers to risk. Then develop a set of procedures detailing how the work must be carried out to minimise or eliminate the risk of accident or injury.

Systems of work must be communicated and understood by the employees concerned. The detail of the system of work, for example, whether it is oral or written will depend on the level of risk and the complexity of the work involved. For example, high risk activities where there is a risk of serious injury or death, will need to have documented systems of work which are strictly supervised and enforced.

Systems of work should be reviewed regularly to ensure that they still reduce or minimise risk and they should be revised as necessary.

Safe systems of work can reduce or eliminate exposure to hazards but they must be strictly followed.

On this basis, a safe system of work shall be established and maintained by a Competent Person. The system shall be followed for every lifting operation, whether it is a complex individual lift or repetitive routine operations.

The main principle of the safe system of work is that any lifting operation shall be:

- Properly planned;
- Well organised;
- Appropriately supervised;
- Carried out in a controlled and safe manner;
- Closed and 'lessons learned' documented and reviewed.

The objective of the safe system of work is that all hazards associated with and all factors affecting lifting operations are duly considered, communicated, well understood and controlled by the personnel involved in the vertical transport operations.

4.2 Introduction to work preparation and planning of lifting operations

Before the lifting operation is carried out, an exhaustive preparatory process takes place, culminating in the 'lift plan'. In this regard, Directive 2009/104/EC on the use of work equipment [<https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32009L0104>] states the following in article 3.2.5 of Appendix 2:

"All lifting operations must be properly planned, appropriately supervised and carried out in such a way as to protect the safety of workers."

The development of a lift plan is a central part of the methodical preparations for a lifting operation. The lift plan consists of agreements and documents detailing how the lifting activities are to be executed. Depending on the complexity of the lifting activities, the plan can be rather simple and straightforward, only including a work order with instructions. Or it can be made up of multiple elements, including a lift drawing and a Task Risk Analysis (TRA). For more information about the lift plan see paragraph 6.4.

Responsibility for compiling the lifting plan and ensuring that the lifting operation is properly supervised lies with the party in charge of directing the works, represented by the Competent Person. The agreement between the crane hire company and client specifies whether a 'crane hire contract' or a 'contract lift' applies to the services. It follows from the form of contract chosen which of the two is responsible for the lift planning and arranging the supervision. For more information about the types of contracts see paragraph 15.2.

Part of lift planning is the building of a lifting team. The safe execution of a lifting operation requires fulfilment of at least three roles:

- **Signaller.** The signaller is responsible for directing the crane operator by relaying the right instructions.
- **Slinger.** The slinger is responsible for safely attaching or detaching the load. If necessary, the slinger must be capable of guiding the load (on the instructions of the signaller), for example, using taglines. For some lifting activities, the slinger can also play the role of signaller.
- **Crane Operator.** The crane operator is the person responsible for operating the mobile crane.

Implementation of the lifting plan and assembly of the lifting team will vary depending on the complexity of the works and the expertise of the people involved. The same applies to the way supervision is organized. However, establishing a lifting team, organising supervision and agreeing on the means and ways of communication are key success factors for any lift. A grasp of the complexity of the lifting operation can be obtained using a risk analysis. For more information about the classification of lifting operations see chapter 5.

Adherence to the steps set out in these documents will assist in the safe execution of the lifting operation.

5. CLASSIFICATION OF LIFTING OPERATIONS

5.1 Class one – routine lifts

This classification includes lifting operations where the load characteristics are considered straightforward and there are no significant hazards within the working area or on the access route for the crane to the working area. All personnel involved with repetitive lifting operations should ensure that complacency is not allowed to develop.

Examples of class one lifting operations are:

- Lifting of standardized goods; intended and suitable for safe lift (e.g. pallets, containers)
- Lifting of loads with CoG and Gross weight known or easily estimated
- Operations where standard rigging and slinging practices can be applied
- WTG Foundation or Nacelle Davit crane lifts

The Competent Person must:

- Ensure appropriate information for lift planning is available.
- Assess supervision requirements and include supervision role.
- Ensure a clear definition of roles and responsibilities.
- Clarify if dynamic factors will influence the lifting operations.
- Identify hazards and conduct a risk assessment.
- Prepare the Lift Plan.
- Ensure a properly managed inspection and maintenance regime for lifting appliances and lifting accessories.
- Issue a Pre-Task Plan in case of variations or changes. Review and correct regularly the Lift Plan.
- Ensure a complacent attitude towards repetitive lifting operations is not allowed to develop.

In the case of repetitive or routine operations, assessment and planning may only be necessary in the first instance, with periodic reviews to ensure that no critical factors have been changed.



Figure 1: Tandem lift of a nacelle

5.2 Class two - complex lifts

Lifting operations where significant potential hazards have been identified either with the load or with the working area or access route of the crane, and the crane is used to lift complex loads or persons, or where two or more cranes are used to lift a load, or where the lifting operation is carried out at a location with exceptional hazards. In order to classify a lift the table below should be used.

Examples of complex lifts:

- Lifting of rotor blade (tandem lift) and rotor or nacelle installation (figure 1)
- Upending of tower sections
- Lifting of a nacelle (caused by height)
- Lifting of a man basket

In case of a complex lift, the Competent Person must:

- Ensure appropriate information for lift planning is available.
- Nominate the Lifting and / or Transport Supervisor for the task
- Clarify if and what dynamic factors will influence the lift.
- Identify hazards and conduct risk assessment.
- Prepare the Lift and / or Transport Plan and produce detailed planning lifting drawings
- Ensure properly managed inspection and maintenance regime for lifting appliances and lifting accessories.
- Seek out engineering support and specialist knowledge, where necessary.
- Ensure rigging instructions are in place.
- Produce appropriate documentation for briefings. Carry out audit and review of lifting operations.
- Review and correct the Lift Plan.
- Support the Lifting team when requested

Number	Decision table for complex lifts	YES	NO	If any of these questions is answered with YES, the lift is regarded as complex. A specific lifting plan should be made.
1	Will more than 1 crane be connected simultaneously to the same object to be lifted?			
2	Will a lattice boom crane be used with a capacity > 100 ton?			
3	Will a hydraulic crane be used equipped with a luffing jib?			
4	Is the load > 20 ton or is the lift radius > 50 m ?			
5	Is the lift to be performed in a live plant, a working installation or over a building?			
6	Is the centre of gravity of the load eccentric and not equilibrated by means of the lifting points?			
7	Does the lift involve the lifting of persons with the crane or by alternative means within the slewing range of the crane ?			
8	Is there any doubt about the equipment used or the method of execution?	NO LIFTING		

6. PLANNING OF LIFTING OPERATIONS

6.1 Lifting Equipment and Cranes

All lifting operations shall be planned and risk assessed prior to commencement to ensure safe execution. The planning and assessment shall be performed by the Competent Person.

Lifting operation objectives will define the amount of planning required, so lifting operations with objectives of turbine component installation will normally require more thorough planning compared to lifting of a pallet for offloading a truck for example.

Characteristics of the load to be lifted, such as weight, shape, position of CoG, availability of lifting points, etc. play an important role in the planning of lifting operations. Based on this information the correct selection of lifting equipment by the Competent Person will ensure that the equipment is suitable with regards to the objectives of lifting operations, characteristics of the load to be lifted, load travel path, frequency of use and the operational environment. The employing company is responsible for a timely supply of the correct information (usually drawings) containing those relevant characteristics.

Selection of a crane – loads and specifics

Introduction

The selection of a suitable crane is mainly determined by the dimensions and weights of the WTG components. Furthermore, it depends on a variety of different factors, e. g. the project duration, the overall size of the wind farm combined with the turbine quantity and the availability of cranes.

Additionally, the ground pressure that arises at the crane assembly site and during lifting heavily depends on the chosen type of crane.

The first section of this chapter provides an overview, and the advantages and disadvantages of different types of cranes and their associated supporting systems. This general information is used as a basis of the main points clarified in the following chapters. This guide is focused on mobile cranes and will not explain other types of cranes in detail.

The guideline will then consider the transportation of the cranes to the site and within the wind farm. Using that as a basis the explanation of the transport routes to the construction site, the construction space and the crane deployment site itself follows.

A second focus is the assembly of cranes and the characteristics during the operating mode. Insights are given into the ground pressures that arise underneath the crane based on the results of various load cases. The resulting indicative numbers are intended to create awareness of magnitude.

Finally, the topics maintenance and disassembly are taken into account.

The large variety of the given values makes it obvious that it is impossible to give unequivocal and binding advice based on the specified load cases. Each project situation therefore demands a separate observation, in close consultation with the crane supplier.

Crane categories, types and configurations

A huge variety of cranes, can be used for the assembly of a wind turbine. In addition to the common mobile cranes and tower cranes, other crane types like narrow track' crawler cranes or tower mounted telescopic boom cranes may be used for erecting wind turbines. The crawler crane might be equipped with a very narrow track base allowing the crane to be moved over the transport routes between the different turbine locations when (partially) assembled. In order to compensate for the narrow track base, these cranes are equipped with outriggers for the operating mode. The tower mounted telescopic is a type of crane specifically designed by a single manufacturer provided with a vertical telescopic boom on which an upper carriage is mounted that comes with a standard telescopic boom.

In Europe, mobile cranes are most commonly used for erecting wind turbines. With this in mind, this guideline is focused on the use of mobile cranes. Unlike mobile cranes, tower cranes are equipped with the turntable all the way at the top of the crane which is why they are also referred to as 'top-slewing cranes' refer to figure 1. The use of tower cranes requires a custom made concrete foundation for anchoring the machine and in many cases the option to connect the tower of the crane to the tower of the wind turbine at one or several points.

Mobile cranes are divided into two types:

- Mobile cranes with a telescopic boom, also called 'telescopic cranes';
- Mobile cranes with a lattice boom, also called 'lattice boom cranes'.

In the highest capacity classes only lattice boom cranes are available. However, if the lifting operations fall within the capabilities of the telescopic cranes, the following considerations must be made when choosing the right crane. Supplying and erecting telescopic cranes generally requires less time and less auxiliary equipment (assist cranes, trucks) compared to lattice boom cranes. This decreases the costs of mobilization and demobilization and increases the flexibility (moving the crane). A lattice boom crane however has lower daily rental costs compared to a telescopic crane with a similar capacity. Hence the project duration plays an important part in addition to the lifting capacity.

The choice for a suitable crane type and its configuration is also determined by:

- The required crane capacity and sail area effects to the configuration;
- The available space for the setup;
- The size of the wind farm or the number of wind turbines that must be erected;
- The availability of cranes ('supply and demand').

Advantages and disadvantages of various undercarriages

There are three common types of undercarriages for the telescopic cranes and lattice boom cranes: on tyres, on tracks, on four outriggers (pedestal).

- **Undercarriage on tyres;** in this case the crane is always provided with outriggers for stabilizing and levelling the machine for the operating mode (refer to figure 3)
- **Undercarriage equipped with tracks;** cranes that come with tracks are usually not equipped with outriggers, therefore the tracks determine the crane's tipping lines. Most crawler cranes are provided with lattice booms.
- **Undercarriage that is provided with four outriggers,** also called pedestal crane (figure 2).



Figure 2: 650 ton Pedestal Crane

Cranes equipped with tracks have the advantage of independent movement when fully assembled. In most cases the crawler crane may even be moved while the hoist is carrying a load. However, due to the sharp increase in the risks involving instability and possible damage to the crane assembly site, moving the crane (with or without load) is to be avoided as much as possible, or at least requires special consideration.

The cranes equipped with outriggers cannot be moved in the operating mode. However, they can level themselves, which is why these cranes have less requirements for providing a horizontal crane assembly site or crane pad (often referred to as 'hardstand').



Figure 3. 750 ton lattice boom crane on outriggers with an undercarriage on tyres.

Telescopic cranes may therefore have an undercarriage provided with tracks, but in most cases undercarriages with tyres and outriggers are used. To make this guide easier to read, the term 'telescopic crane' hereinafter refers to the latter type.

Auxiliary cranes

The auxiliary cranes are often telescopic cranes, sometimes provided with a crawler undercarriage. In case of the assembly of a lattice boom crane, the auxiliary crane deployment sites should be prepared directly next to and/or behind the main crane as well as at several locations in parallel with the boom assembly area. The crane supplier should provide its client with an exploded view indicating the deployment sites for the auxiliary cranes, including dimensions and the ground pressures that will arise. Auxiliary cranes are not always required for assembling a telescopic crane. A telescopic crane can fully erect itself in a main boom configuration without additional auxiliary systems.

In many cases wind turbine components are already supplied and must be stored at the construction site before the building process starts. Unloading the components is usually handled by telescopic cranes and in case of unloading the wind turbine blades it is common to use two cranes (called tandem lift). The locations of these cranes should be determined by the crane supplier beforehand, in consultation with the client.

Finally, it should be noted that in addition to sufficient room for the auxiliary cranes and storage of components, space must be created for tool containers, support equipment and lunch and sanitary facilities. When positioning this equipment, containers and cabins, again it is important to pay attention to the option of laying down the boom and setting down the superlift tray that might be required, e.g. when strong winds come up.

Often an auxiliary crane is required to safely turn a load from a horizontal to a vertical position ('tailing') in an operating mode (refer to figure 4). For tailing operations, a distinction is made between the main crane and the tail crane.



Figure 4: A tailing operation of a tower section

Crane capacities

The capacity of a crane is indicated by the maximum load expressed in tonnes. Lattice boom cranes are available in capacity classes that are similar to those of telescopic cranes, but also in classes far exceeding those. In the current market telescopic cranes are available in classes between 30 and 1200 tonnes.

The lattice boom cranes spectrum (available on the market) ranges from approximately 100 to 3500 tonnes. Comparing the capabilities of a telescopic crane and a lattice boom crane based on the maximum tonnage is not reasonable. When having an identical capacity indication both types can lift an equal maximum tonnage on the minimum radius.

However, over larger distances from the crane the maximum loads to be lifted differ significantly. Hence the capabilities of a '500-tonnes' telescopic crane can in no way be compared to those of a '500-tonnes' lattice boom crane. It may be said that a lattice boom crane of the same indication usually has a higher capacity than a telescopic crane.

Assist systems

Jib

The telescopic booms of most cranes can be extended using an attachment, the 'jib'. With one exception, the jib components may be recognized from their framework structure. The jib may be rigidly (sometimes at an angle) mounted on top of the boom and is in this case referred to as a 'fixed jib' (or 'boom extension'). In case of larger telescopic cranes (starting from a tonnage of approximately 300 tonnes) the jib may also be mounted on the boom in an articulated manner.

This often requires additional structural components such as winches, A-frames and / or back masts. The articulated jib is called the 'luffing jib'.

The terms 'boom', 'main boom', 'mast' and 'main mast' are not unequivocal and are often used interchangeably. In this document 'boom' or 'main boom' is used.

Telescopic- or lattice boom cranes may also be equipped with a 'luffing jib' or a 'boom extension' (refer to figure 5). Additionally, many lattice boom cranes may also be provided with a 'wind kit' (refer to figure 6). This consists of an extra jib with a length of approximately 6 to 14 m that is mounted on top of the boom extension at a fixed angle. This creates a small kink at the top of the boom allowing for placement of the nacelles with sufficient clearance.

Figure 5: Two 500 tons hydraulic cranes equipped with luffing jib





Figure 6: The wind kits (jib parts Y and Z) of a typical 750 ton lattice boom crane.

Superlift installation

The lattice boom cranes in the 300 tonnes class and higher may be equipped with a 'superlift installation'. In this case an extra boom is mounted on the crane, also called the 'derrick boom', aimed backwards at an angle (the orange boom part in the figure 6 above). By connecting this boom to the corresponding extra ballast (the 'superlift ballast') a sharp increase in capacity is realized.

In most cases the superlift ballast is stacked on a support frame, called 'the tray' (refer to figure 7). The tray can only be freely lifted from the bottom with sufficient balance in the crane (read: sufficient load in the hook), allowing for the slewing of the crane. When putting down a lifted load, the superlift tray must be brought back to the ground simultaneously. Less common (and also less available on the market) is the deployment of the ballast wagon. In this case the superlift tray is equipped with steerable sets of tyres, allowing for the slewing of the crane without the mentioned balance situation.



Figure 7: The superlift tray of a 600 tonnes crawler crane.

The superlift tray can be found on lattice boom cranes in the classes up to 750 tonnes up to 22 m behind the core of the crane (the turntable). The total weight of the superlift ballast on the tray can then be as high as 400 tonnes and even more. If the crane is equipped with a superlift installation, the crane deployment site must be made wider and heavier to accommodate the larger slewing range.

Outrigger plates

Another important assist system that can be mounted on crawler cranes is the 'mechanical outrigger plates' (refer to figure 8). The following applies in order to erect the boom of a lattice boom crane. For short boom configurations the boom can be erected without additional elements. The normal amount of ballast on the crane creates sufficient stability. For medium boom configurations the standard ballast is insufficient for guaranteeing the stability: additional elements are required. In this case outriggers can be mounted on the tracks of most crawler cranes. The longer moment arm allows the erection of the boom. In most cases where very long boom configurations are needed the superlift installation must be built. The superlift ballast then insures sufficient stability. Afterwards, it is quite possible that the superlift installation is not used for hoisting activities. The tray is then detached and remains at its position so it can be attached again quickly in order to lay down the boom when the weather deteriorates. It is therefore imperative that the superlift ballast is always relocated next to the lifting



Figure 8: The up righting outriggers on a 600 tons crawler crane.

location together with the crane.

In many cases the superlift installation may be used for erecting booms of average length. However, supplying all of the components and superlift ballast requires various extra shipments while it takes much longer to setup the crane.

Guying system

A further assist system is only available on telescopic cranes with a capacity from approximately 300 tonnes. This is called the 'guying system' or the 'boom guying' or the 'super lift'.

The guying system ensures the tensioning and consequently reinforcement of the main boom which results in an increased crane capacity. The guying systems consist of two rearward facing arms mounted on the main boom. The arms can be mounted to each other in parallel but can also be mutually standing at an angle (the 'V-position'). In the V-position the boom is not only reinforced in the forward bending direction, but also stabilized sideways. Often long booms are used for building wind turbines to able to place the loads at high altitudes. Side loads have an increased effect on longer booms, which is why the guying system arms are always mounted in the V-position when building wind turbines.



Figure 9: Rear view of a guying system on a telescopic crane

6.2 Site preparation / hard stands

The hard stand should always be level ($0^\circ \pm 0,1^\circ$) and have an adequate load bearing capability. For crawler cranes the requirements for the slope of the crane assembly site are very strict. According to the instruction manual of the machines it's a maximum of $\pm 0,3^\circ$ (this corresponds to approx. 0.52%). Mobile cranes equipped with outriggers may compensate for any irregularities.

However, large differences in level (> 10 cm) should be avoided due to the often limited stroke of the outrigger cylinders. In a properly made (that is to say, level) hard stand, problems may arise with regards to drainage. Drainage systems must be installed to guarantee the quality of the hard stand over longer periods of time or for e.g. any WTG maintenance works. The deployment of cranes with a superlift installation makes additional demands to the hard stand. More space is needed around the crane and the surface should be tested, possibly in several places, according to the pressure load due to the superlift ballast. The crane supplier should specify the exact weight of the superlift ballast and on which places it will be put onto the ground while erecting the boom and during the operating mode. For details of commonly used cranes please refer to Appendix 2: Typical Drawing examples Cranes.

Elevated platform

A hard stand that sits on a much higher level than the supply route of the crane should be avoided. The undercarriage ('the body') of a crawler crane is usually transported on a flatbed lorry and generally unloaded directly at the final assembly spot. The body unloads itself at that location by extending four assist outriggers that are mounted on the frame. An elevated platform may prevent the transport combination from driving onto the platform. If that is the case, a properly installed access ramp may be a solution. As a rule of thumb the maximum angle of an access ramp should be 4° (approx. 7%).

It is strongly recommended to not fully assemble the crane first and move it onto the platform afterwards. This creates huge safety risks, not only caused by the tilt of the crane, but also due to the large peak pressures underneath the tracks that arise due to the differences in height.

Crane assembly - the boom assembly area

When designing the crane assembly site the importance of the 'boom assembly area' is often understated. The area for erecting the boom and/or jib (including the airspace above it) should be completely free of obstacles and level preferably constructed without negative gradient. In case of a negative boom angle during erection, supports should be added to correct the boom position to the horizontal or a positive angle.

The length of the assembly field is determined by the chosen type of crane and the chosen crane configuration and method of assembly and erection. The following can be stated for a lattice boom crane to obtain an indication of the length of the assembly field: the total of the required boom plus any jib length amounts to the hub height of the wind turbine increased by 10 to 15 m. Additionally, the point of coupling of the boom is approx. 1.5 to 2.0 m from the core of the crane's turntable. For telescopic cranes this is harder to predict based on the hub height of the turbine. Only after having determined up to which length the main boom should be extended the type and length of the jib can be determined. Subsequently the length of the assembly field amounts to the total length of the jib increased by approx. 15 m (the length of the retracted telescopic boom), calculated from the core of the turntable. The

booms of the crawler cranes in the 400 to 750 tonnes classes are 3.0 to 3.5 m wide. To be able to work on both sides of the boom a total width of 5.0 m is required. Additionally, an access road for the crane components must be created with a width of 4.0 m. This road is also used for the manoeuvring with auxiliary equipment such as telescopic handlers. It should be possible for the assist cranes to be placed in parallel with the boom assembly area and they require an assembly surface of roughly 10.0 x 15.0 m (please refer to figure 13).

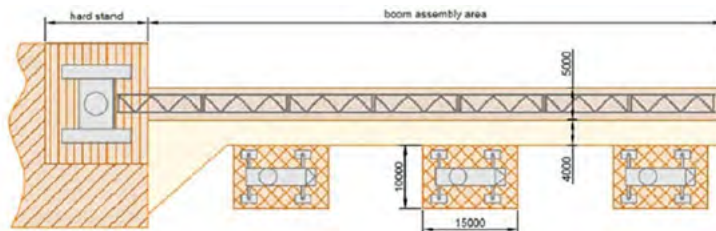


Figure 13: The specifications of the boom assembly area.

The 5.0 m wide stretch must be a level terrain and easy to be walked on by the personnel working on the crane. The construction terrain is often farmland and in this case modifications are required. Flattening and the use of road / steel plates may be a solution. Special attention should be paid to the locations for the boom supports that must be placed underneath the boom while erecting the crane.

The force on a support mat for cranes in the 600/750-tonnes class can increase to as much as approx. 65 -100 tonnes. That is why it is important to ensure pressure distribution. Most of the crane suppliers can also supply this, usually in the form of bog crane mats. This issue must be coordinated in a timely manner, for example during the work preparation phase.

The assist cranes and the trucks supplying the crane components must be able to easily and safely drive on the 4.0 m stretch. For the compaction of the support road the same specifications should be maintained as for the other transport routes.

For erecting the boom often the space next to the access road to the wind turbine location is used. Although this is a logical choice, it must be determined whether the construction site remains accessible to emergency services during the crane assembling activities in case of any calamities.

The orientation of the boom assembly area

Besides the fact that permanent obstacles determine the orientation of the boom assembly area, the limitations of the crane should be taken into account (refer to figure 14). For crawler cranes the boom must be erected perpendicular or parallel to the direction of the tracks. If the mechanical outriggers must be used for erecting the boom, the orientation is always perpendicular to the tracks.

A crawler crane may be moved after erecting the boom. On the one hand this provides flexibility regarding the orientation of the boom assembly area. On the other hand it must be ensured that the arising ground pressures will be checked at two crane locations. Additionally, there is a risk of damaging the crane assembly site during moving operations and the risk of tilting the crawler crane.



Figure 14: The boom assembly area'

When erecting the boom or jib of cranes equipped with an undercarriage with outriggers, it is preferred to have the orientation perpendicular to the undercarriage or over the rear of the undercarriage (compare fig. 8). The assembling orientation over the driver's cab of a wheeled mobile crane should be avoided. For some crane types the orientation may deviate from the described preferred orientations. If this happens the crane supplier should be consulted.

Additional requirements for the boom assembly area

Because the boom of most lattice boom cranes is erected in horizontal position, the boom assembly area should preferably be a flat terrain. If this does not seem feasible, a sloping terrain may be compensated for by placing elevated boom supports. This usually requires extra resources such as hydraulic MEWP's platforms (refer to figure 15).

It is important for the boom assembly area to remain clear during the assembly and disassembly phases of the crane as well as during lifting



Figure 15: An elevated boom support on a sharply sloping terrain

activities in order to quickly strike the boom in case of a sudden spell of bad weather. This is also why the used boom supports and extra ballast should remain in their position during lifting activities to ensure that the eventual required lay down operation can be carried out in a safe, controlled manner. The requirement that the boom assembly area needs to be clear also implies that the "airspace" needs to be free of any obstacles.

Pressure loads arising during the crane assembly

When erecting the mast, extremely high pressures arise underneath the outriggers or tracks, in some cases even higher than in the operating mode. When raising the mast of a crawler crane perpendicular to the tracks, almost the full weight of the machine will be distributed over a single track or extra outriggers (situation without superlift ballast). When raising the mast in parallel with the tracks, very high peak pressures arise underneath the front rollers of both tracks.

The ground loadings table in Appendix 2 indicates the distribution of ground pressures of the cranes that arise while lifting a load or erecting the mast. The outrigger forces for cranes with outriggers are usually expressed in [tonne] per outrigger and for crawler cranes in a pressure under the crawlers per square meter expressed in [kN/sqm].

For crawler cranes it is assumed in the ground loadings table that the boom is erected lengthwise to the tracks (refer to figure 16). In some cases the ground pressures may be decreased by increasing the amount of superlift ballast. Raising the boom perpendicular to the direction of the tracks also results in lower ground pressures.

For lattice boom cranes up to the 750-tonnes class most telescopic assist crane types that are deployed are of the class 90 to 200 tonnes. The larger variants are used for lifting the upper carriages of the cranes and/or the crawlers. For lifting the boom and jib components generally a lighter assist crane suffices, but sometimes it is decided to use the large assist crane also for the remaining assembly work. Please refer to Table 1 below.



Figure 16: Raising the mast of a 650 ton crawler crane.

Table 1: Loads acting onto the ground of assist cranes

Crane type	Crane configuration	Total Weight of the crane excl. load [in ton]	Load case	Max. ground bearing force and pressure
90 ton telescopic crane	36.2 m main boom 21 tonnes ballast ground bearing base 8.5 x 7.0 m	66.0	lifting a boom component G = 13 tonnes on radius 14.0 m	50.0 tonnes crane mat: LxW = approx. 2.5 x 1.3m → 15.4 ton/sqm
200 ton telescopic crane	26.7 m main boom 72.0 tonnes ballast ground bearing base 8.9 x 8.3 m	140.0	Lifting an upper carriage G = 66.0 tonnes on radius 9.0 m	103.0 tonnes crane mat: LxW = approx. 3.3 x 2.0m → 15.6 ton/sqm

The specified values in Table 1 serve solely as an indication; the ground loadings that arise are largely determined by the possible assist crane positions and the accompanying lifting radii.

Ground loadings arising with a crane in operation

The table A in appendix 2 shows the ground loadings of the cranes that arise in the operating mode. The specified pressures apply in the heaviest load case: the upper carriage of the crane sits slewed in diagonal position. Namely the moment in the crane is largely absorbed by an outrigger or by the end of a track. In case of a fully erected (topped-up) main mast without load in the hook, the contra ballast of a crane generates a large backwards acting moment. In some cases greater ground pressures arise in this situation compared to the operating mode in which the maximum load is being lifted. In its preparation the crane supplier must therefore consider the lifting situation as well as the ‘empty hook’ situation. Some manufacturers state that the values indicated by LMI’s include a load factor of 3% - 5%. This covers small dynamic effects due to the crane movements. However it is pointed out that this factor excludes the dynamic effects that occur due to wind. Not all crane manufacturers are transparent about whether they include load factors in their support software or not. It is therefore recommended to always assume that the values generated by the crane software are excluding load factors.

The ground bearing or track pressures that arise should be specified by the crane supplier in a lift drawing, usually in tabular format. In most cases an engineer already knows how heavy a load is and on which radius and height it must be lifted, but not the exact slewing range and slewing direction of the crane. For these reasons engineers often choose to indicate peak pressures for telescopic cranes that arise when the crane with load is slewed 360°. This results in four values that do not represent a load situation and can neither be adopted one on one in a ground loadings calculation. Hence consultation between the crane supplier and client is very important.

Pressure loads that arise during crane movements

Crawler cranes and pedestal cranes are often fully disassembled when moving them between two turbine locations. Cranes with an undercarriage on tyres can be driven independently and in most of these cases it is permitted to leave part of the support systems and/or crane ballast mounted on or to the crane. Below in Table 2 are several examples of machine configurations that, in accordance with the user instructions, may be moved self-propelled together with their resulting axle loads.

The following applies to these three cases:

- The average slope may be a maximum of 1% (0.6°). Peaks up to 5.2% (3.0°) are permissible;
- The minimum driving speed must be maintained (approximately 1 to 2 km/hour);
- The maximum 3-second wind speed amounts to 9 m/s;
- The outriggers must be partially or fully extended, depending on the configuration. The outrigger cylinders are extended to approximately 5 to 10 cm above the ground.

Before starting a project there must be clarity about the capacity of the roads between the turbine locations. Axle loads increase considerably when driving cranes in partly assembled mode with the outriggers pads just above ground; the road surface should be capable of taking the loads exerted by the wheels and pads. If the roads are unsuitable for the increased axle or outrigger pad loads the cranes must of course be fully disassembled for transport and reassembled again. Naturally this highly affects the required assembly and disassembly times of the crane per location.

Load distribution

The responsibility of the crane supplier basically ends upon delivering the crane mats underneath the crane. For cranes with outriggers these are always standard steel mats that belong to the crane. Telescopic cranes in construction work are usually provided with mats that reduce the ground pressures that arise up to approximately 100 to 200 kN/sqm. A crane mat under load contains often sagging positions. Therefore, the ground must be elastic, in order to allow the ground bearing pressure to be distributed over the full surface of the crane mat.

Crawler cranes are generally provided without standard crane mats. In practice these machines (up to the 750-tonnes class) are usually placed onto a platform of wooden mats. These mats are often 20 cm thick and made of hardwood (azobé) with a width of 1 m and a length of 5 or 6 m.

These mats lay transverse to the drive direction of the crawler crane, in two rows, under the core of both tracks. In case of uncertainty about the suitability of the ground, it is common to use a double layer of mats, preferably laid crosswise. Additionally, the effective width over which a wooden mat distributes the track pressures, strongly depends on the ground’s characteristics. It is good practice for the crane supplier to provide the civil surveyor with information about the arising track pressures and the specifications of the crane mats.

Table 2: **Axle loads during crane movements**

Crane type	Crane configuration	Total Weight of the crane	Maximum axle load
750 ton telescopic crane	Main mast with guying system 66.5 m luffing jib 84 tonnes ballast	approximately 260 tonnes	Axles 1 through 6: 32 tons Axles 7 through 9: 23 tons
1200 ton telescopic crane	7-Part main mast with guying system and 6.0+6.5m luffing jib 52 tonnes ballast	approximately 280 tonnes	Axles 1 through 4: 31 tonnes Axles 5 through 9: 31 tonnes
750 ton lattice boom crane on wheels	21 m main mast 145 tonnes ballast	approximately 370 tonnes	Axles 1 through 4: 49 tons Axles 5 through 8: 43 tons

6.3 Load control and clearances (power lines)

Load control

During lifting operations the crew should at all times have control over movements of the load. A load can turn as result of the swivel bearing connection of the crane hook that suspends the load. The swivel is required because the position of the load while being picked up can be different from the position required for installation.

During lifting operations ‘taglines’ can be used to steer a load in the required position. For a safe use of so-called taglines the following points should be considered:

- A tagline is meant to turn a load and not to tilt it or pull it sideways;
- The area where the person guiding the load has to walk, should be free of obstacles and if at height the area should be equipped with fall protection barriers.
- The operator should have clear vision of the person guiding the load.
- The tagline should have the correct length, taking into consideration the height of the lifted load and the preferable pulling angle (between 30° and 60°).
- The person guiding the load should always walk behind the load and be aware of the danger of the tagline getting caught. He should also be aware of the risk of stepping into a loop of the excess tagline lying on the ground.
- Trying to control the load by wrapping the tagline around something is not allowed; the tagline should be held in such a way that the person holding the line can let go at any moment. (See figure 17).
- A proper knot should be used to connect the tagline to the load. It is advisable to pull the tagline end through the connection point an extra time before securing it with two sheet bends. This prevents the line getting stuck during the lifting operation.

(See figure 18).

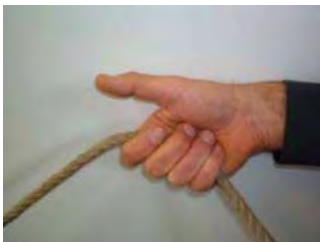


Figure 17: Holding tagline



Figure 18: Connecting a Tagline

Power lines

Power lines may require additional clearance for safety, depending on the voltage of the lines. Any site roads leading under power lines need to have warning signs to be installed from both directions. The installation of the required warning signs is the customer’s responsibility.

Regarding the warning signs to be installed for overhead power lines the following precautions and practices must be followed:

- Gateways to the passageway should be set up at both sides of the entrance by erecting goal posts. Similar to the barriers, the route of the passageway should be clearly fenced.
- The goal posts and crossbars should be rigid and of non-electrically conductive materials and be marked with distinctive colour stripes. If metallic goal posts or crossbars are used, they must be adequately earthed.
- Clearly marked warning notices should be placed at both gateways of the passageway indicating the potential electrical danger and ground clearance of the cross bar and advising that no part of the plant or equipment shall exceed this ground clearance when passing the fenced passageway.
- Adequate lighting for the notices, signs, passageway and its gateways should be provided if movement of plant or equipment is to take place after dark. Light fittings for illumination of the O/H line conductors immediately above the passageway should be sited at ground level projecting light upwards towards the conductors.
- Warning notices should be erected on all approaches to the crossing.

A guideline for safety distances is shown in the following table:

Voltage	Safety distance to overhead power lines
Up to 1 kV	1 m in all directions
1 kV – 110 kV	3 m in all directions
110 kV – 220 kV	4 m in all directions
220 kV – 380 kV	5 m in all directions

For information on safe distances from power lines refer to Appendix 4 ESNB Code of Practice



Figure 19: Overhead lines can present a danger to man and machine

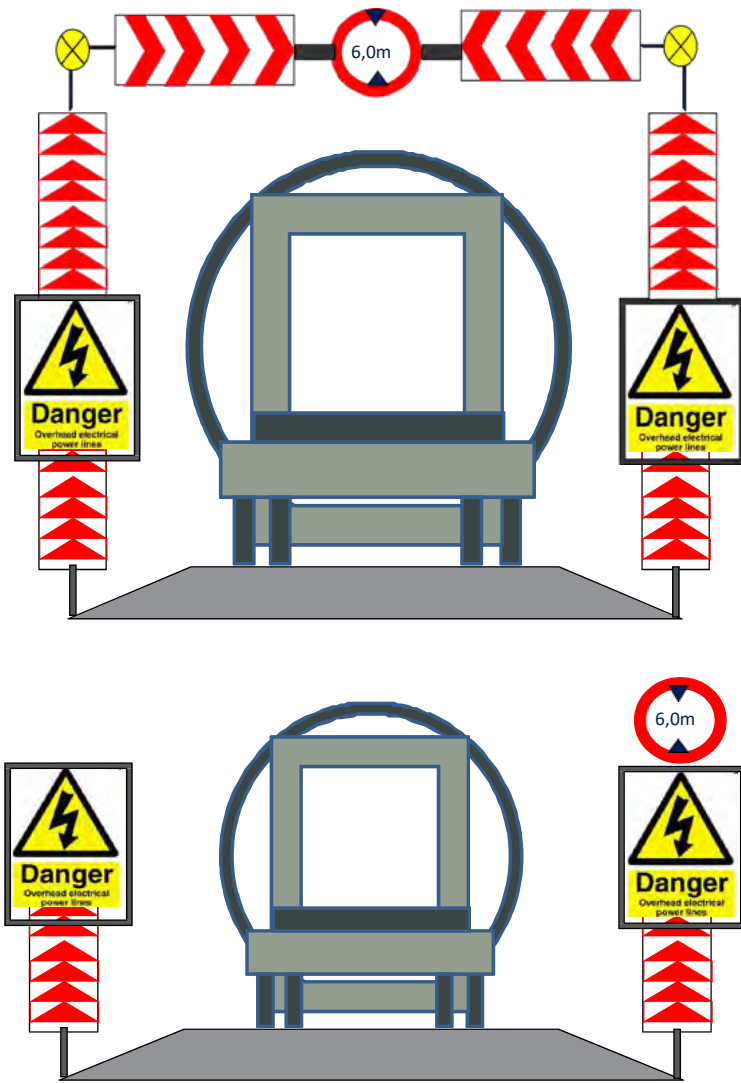


Figure 20: A sample of power line warning signs/ notices

6.4 Lift plan

The Lift Plan or Lifting Procedure are written method statements of an individual or repetitive lifting operation. The content of the Lift Plan will depend on the complexity of the lifting operations, (see classification of lifts above in 5.1 and 5.2). The Lift Plan must detail the requirements. The crane contractor should provide its client with an assembled view indicating the length of the boom assembly area and the positions of assist cranes, if required for the assembly of the crane.

The Lift Plan shall include the details of the lift, with as a minimum the following:

- Description of the operations.
- Organisation and responsibilities
- Communication
- Characteristics of the load.
- Brand, type, configuration and load charts of the lifting appliances / cranes
- Lifting accessories details
- Rigging instructions
- Limiting environmental criteria for each lift
- Lift plan drawings (if required)
- Parallel work procedure
- Check lists
- Contingency plan

The Lift Plan drawing shall show, as a minimum, the following details:

	Required items to be shown on a lift plan drawing	Addition
1	Crane type and crane capacity	indicate % of rated load
2	The lay out of the crane(s) and crane position(s)	
3	The load to be lifted (dimensions – weight – CoG)	
4	The lifting radius with the load	show all critical positions
5	Boom and ballast configuration	
6	Capacity at maximum radius	
7	Rigging attachment for the load	
8	Lifting height and clearances	
9	Outrigger loads and loads under crawlers, as well as load spreading under outriggers or crawlers.	show ground loadings calculation outcome
10	Maximum allowable windspeeds while lifting in the designed configuration	If applicable during raising / lowering of the boom

7. EXECUTION OF LIFTING OPERATIONS

7.1 Good practice prior to lifting

Prior to commencement of a lifting operation, the personnel in charge shall identify and clarify what dynamic or static factors will influence the lifting operation. Where appropriate, the WLL of lifting appliances should be reduced to consider the environment and mode in which it is being used, termed “derating”. Examples include using sling protection and the way a sling is attached to a load, i.e. the angle of legs and bend radii of the sling type.

When multiple lifting operations occur within the same area, the coordination of these lifting operations must be agreed prior to commencement by the Crane/Lift Supervisors and the operations shall be carried out in line with the Lift Plan.

All preparatory work at the location where the lifting operation takes place is to be completed. The safety of personnel not involved in the lifting operation must be ensured. A pre-task briefing must occur prior to the commencement of any lifting operation. The content of the briefing will be dependent on the lift categorization and must cover the details of the lifting operation, responsibilities, site and operational risks control measures.

The limitations of the lifting equipment shall be communicated and well understood by all personnel participating in the execution of the lifting operation. Lifting zones shall be defined by the Lift supervisor prior to commencement of the lifting operation, as these can vary depending on the load, lifting equipment, other objects, walkways, etc. The responsible person or Lifting Supervisor shall ensure that all unauthorized persons are kept out of the lifting zone, e.g. by means of barriers, fences, warning tape, signs and/or signaller. This also includes removal and prevention of access of non-essential vehicles or plant, both parked and travelling, inside the lifting zones.

7.2 Pre task briefing

Typical information that should be delivered to the lifting team during a pre-task briefing will include, but should not be limited to:

- Ensuring the lifting team is briefed on the operation and aware of the Lift Plan content.
- Applicable planning drawings for the operation.
- Pick up and lay down positions, travel path and elevation of the load from ground, vessel or structure.
- Rigging arrangement.
- Rigging drawings (if applicable) for the load.
- Lifting accessories to be used in the operation.
- Pre- and post-use check of lifting accessories and appliances.
- Permit to Work, Certificate of Approval and any conditions imposed by them.
- Lifting zones, areas to be closed off to personnel not associated with the operation.
- Hazards associated with the lifting operation.
- Method of communications during the operation.
- Radio channels to be used, agreed hand signals.
- Weather limits and weather window for the operation, lightning risk.
- Allocation of personnel to a particular task, i.e. Crane Supervisor, Crane

Operator, Signaller, Slings, PPE requirements.

- Information from previous shifts handover.
- Time out - has anything changed since the lift plan was developed?
- Any other business, i.e. “Does everyone understand the task?”

7.3 Communications

The common language to be used during the lifting operation will be established during the pre-task briefing. Where non-verbal communication is to be used, relevant hand signals should be clarified.

Where handheld radio communication will be used, the equipment must be checked prior to start of the lifting operation to ensure all equipment is functioning correctly (i.e. batteries, range, channel, frequency etc.) When directing the load, instructions shall be clear and precise.

Unnecessary interference or radio activity that could distract members of the lifting team must be avoided. Back up communications must be considered; spare radios and batteries should be available, and back up procedures identified for use in case of radio failure.

If visual signals are used, then hand signals as stated within the Lift Plan shall be observed. It is important that hand signals should be clarified and understood within the pre-task briefing. Video equipment such as CCTV is only to be used as an auxiliary device, and shall not be used as replacement for adequate communication and is not regarded as visual contact between the Signaller and the Lifting Appliance/Crane Operator.

Where directing blind lifts, there shall be a designated signaller to ensure that the lifted load will not strike anything or any person(s). The signaller must be in a safe position with clear visibility of the load path and must be in view, or able to communicate effectively, with the Lifting Appliance/Crane Operator. The communication must be appropriate for the operation, either radio or hand signalling. If the signaller is unable to maintain a clear view of the path of the load, then the Crane/Lifting supervisor must appoint assistant(s) for the signalling. All personnel involved shall have the same means of communication that is agreed prior to commencing the lifting operation. While the lift is travelling into blind zones then constant confirmatory communication is required and if contact is lost, then the lifting operation must cease immediately. There shall be an agreed handover call sign between the crane operator and signallers when control of lifting operation is relayed from one signaller to another.

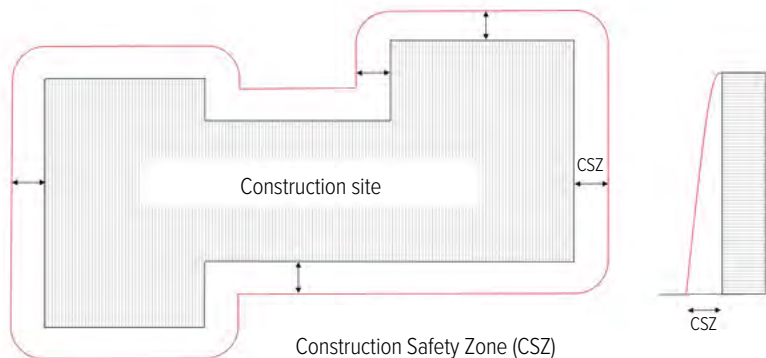
When performing lifting operations in noisy environments that restrict effective communication, a headset with integrated radio communication or visual signalling must be used. In case of disruption, poor visibility, unclear or failing communication, the lifting operation shall STOP immediately until the communication has been restored and the proper signal is given and understood. The operator shall obey a STOP signal at all times regardless of whoever gives the signal.

The Crane/Lifting Supervisor is obliged to monitor commands given by the Signaller during lifting operations at all times (verbal and/or visual).

7.4 Safety zones

The lifting of materials is often a complex and dangerous activity with hazards concerning the movement of loads and machines. Within the construction area there are different safety zones in places, these are:

Construction Safety Zone (CSZ); the area directly adjacent to the construction site where measures are taken to minimize the risks and dangers in relation to the construction activities (such as falling equipment or objects etc.). The width of the CSZ depends on the height of the lifting activities or the construction site.

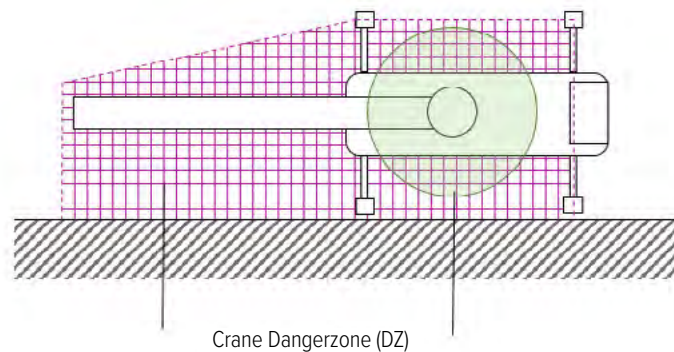


Crane Safety Zone / Danger zone (DZ); the area around the crane in which no unauthorized personnel is allowed. The area is equal to, or sometimes greater than the turning range of the top carriage of the machine.

Example of situations in which the danger zone is greater than the turning range are:

- The crane is located near a building, machine or obstacle, it is recommended to prohibit the space between these obstacles;
- The crane is equipped with a superlift installation;
- The crane is on tracks and is moved around the construction site.

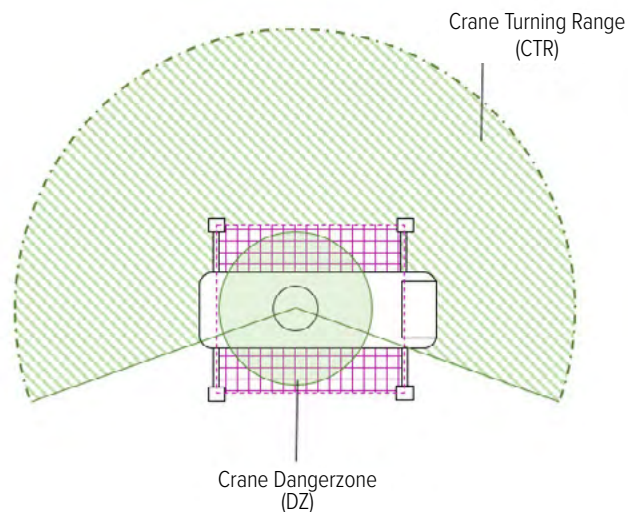
The crane and boom assembly area are part of the danger zone.



Construction / Lifting height (m)	CSZ (m)	Construction / Lifting height (m)	CSZ (m)
10	3	160	19
20	4	170	20
30	5	180	21
40	6	190	22
50	7	200	23
60	8	210	24
70	9	220	25
80	10	230	26
90	11	240	27
100	12	250	28
110	13	260	30
120	14	270	31
130	15	280	32
140	16	290	33
150	17	300	34

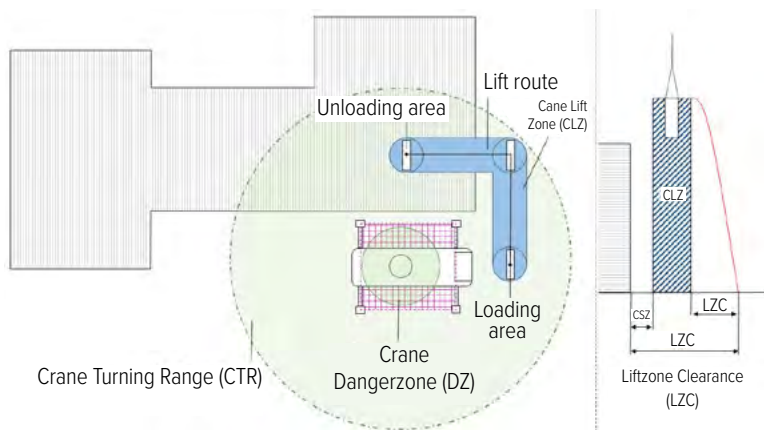
Crane Turning Range (CTR): the area within the 360 degrees radius distance from the centre of the slewing ring to the head of the boom.

With mobile cranes the turning range is dependent of the position and configuration of the crane and boom. It is of the utmost importance to determine the range when multiple cranes are being used or when other constructions / objects are near. It is often necessary to limit the range to less than 360 degrees to reduce the risk of colliding with other constructions, obstacles or cranes.



Crane Lift Zone (CLZ); the area underneath the loads during the transportation from the loading area to the construction area. It is prohibited to all persons to be directly underneath the loads at all times. It is recommended to prohibit the Crane Lift Zone for this reasons to all personnel, however the lifting team may be allowed to enter the lifting zone to guide the load (e.g. to guide the nacelle from the top of the tower). People in the tower of a WTG can safely guide a load from the top of the tower even when being underneath, as the tower will create a non-deflective volume

Lift Zone Clearance (LZC); The area adjacent to the crane lift zone in regards to the height of the lift. The width of the LZC is determined in the same manner as the construction safety zone in regards to the lifting height.



Necessary care shall be taken to consider the direction of wind and whether the wind is gusting, as this could place additional loads on the lifting equipment and could potentially cause the lifted load to travel into the lifting appliance or other structures. A decision to lower a large crane on account of predicted winds should be taken at an appropriate point in time as the lowering operation itself will take several hours to complete.

In poor visibility including fog and night work, suitable means of communication must be established and applied. Whenever lifting operations are carried out at night, the Crane Supervisor shall ensure that adequate lighting levels can be maintained for the planned lift (i.e. high powered flood lighting). However, in extreme conditions where visibility is reduced significantly and has the potential to cause an incident, the lifting operation shall be stopped until there is sufficient improvement in visibility to enable operations to be resumed safely. As a minimum, the Crane Supervisor must ensure that clear visibility of the load being lifted during the lifting operation is maintained at all times.

Lifting operations shall not be performed should there be a significant risk of personnel injury or equipment damage resulting from ice or large amount of snow falling from high or rotating structures; or a significant amount of rain that could affect the stability of the load or ground conditions.

The Lifting Supervisor must assess the associated control measures as stated within the Lift Plan, against the risks in real time because of weather conditions. Under no circumstances shall any external lifting operations be performed in the vicinity of electrical storms (lightning).

The Crane/Lifting Supervisor has the authority to call off a lift if he or she deems the conditions to be unsafe. However, any person involved in the lift can at any point express their concerns to the Crane/Lifting Supervisor if conditions are thought to be unsafe. No lifting operations are to be carried out in wind speeds exceeding those stated in the Lift Plan.

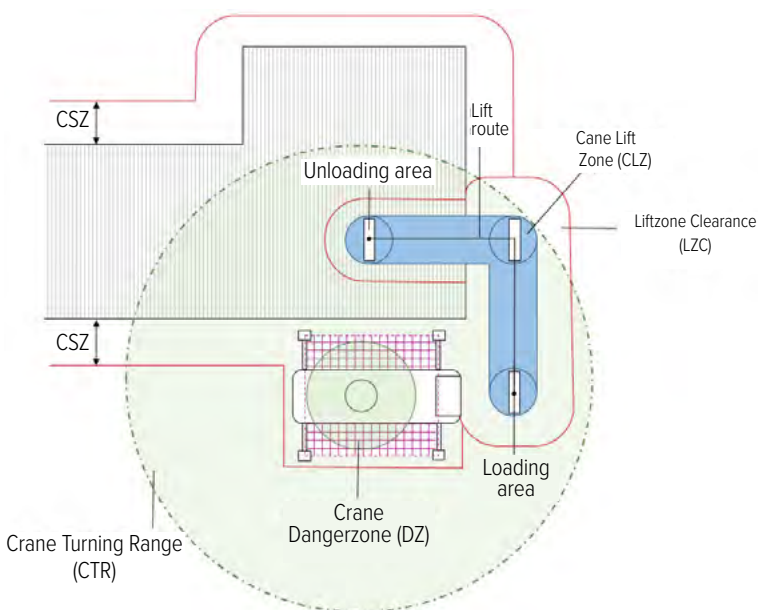
Where there is risk of loss of control of the load due to sudden gusts of wind, the operator must not operate the lifting equipment unless he is confident that he can handle the load safely. This may apply more to light loads with a large sailing area. A reliable anemometer should be available to those involved in the lifting operation and wind conditions should be closely monitored. The preferred height for measuring wind speeds for the component is at the ultimate lifting height. The operator should be aware that the anemometer on the crane may indicate windspeeds other than the one acting on the load due to its position close to the crane boom (shaded by the boom system).

The identification of the weather window must be based on 10-minute mean in the forecast. The monitoring of the wind speed on site must be based on 3 second gust value.

Actual wind conditions as well as predictions for every location, can be found at:

www.windfinder.com

For more extensive guidelines on monitoring weather (wind) conditions please refer to the document FEM 5.016-10/2012 in Appendix 4: Reference documents.



7.5 Environmental (weather) conditions

The execution of lifting operations must take into account the environmental / weather conditions. The execution of lifting operations in adverse weather conditions must be avoided as these can impose loads on the crane and load and adversely affect the safety of lifting operations. Careful consideration should be taken of the coefficient factors of the load and suitable limits put in place by the crane manufacturer.

In any lifting operation, the Crane Operator and/or the Crane Supervisor shall have the final decision about whether to perform the intended operation due to environmental conditions, regardless of the maximum limits stated in the Lift Plan.

When lifting equipment is positioned where it could be adversely affected by wind speed, it shall never be operated in wind speeds that are in excess of those specified in the manufacturers' operating instruction for the lifting equipment. Where wind factors have the potential for adverse effects on the lifting operation, the wind speed shall be monitored with an anemometer or LiDAR at a suitable high point throughout the lifting operation and weather forecast (e.g. wind speed, direction, lightening risk etc.) should be available.

8. MANAGEMENT OF TRANSPORT OPERATIONS

8.1 Safe Systems of Work (SSOW)

A large percentage of accidents occur due to lack of or failure in systems of work. Implementing safe systems of work is an important part of safety and transport operations.

The EU 'use of work equipment' directive (2009/104/EC) requires employers to provide systems of work that are planned, organised, performed, maintained and revised as appropriate so as to be, so far as is reasonably practicable, safe and without risk to health.

A system of work is a set of procedures according to which work must be carried out. Safe systems of work are required where hazards cannot be eliminated and some risk still exists. When developing your safe systems of work, consider how the work is carried out and the difficulties that might arise and expose you or your workers to risk. Then develop a set of procedures detailing how the work must be carried out to minimise or reduce the risk of accident or injury.

Systems of work must be communicated and understood by the relevant employees. The detail of the system of work, for example, whether it is oral or written will depend on the level of risk and the complexity of the work involved. For example, high risk activities where there is a risk of serious injury or death, will need to have documented systems of work which are strictly supervised and enforced.

Regularly review your systems of work to ensure that they still reduce or minimise risk and revise as necessary.

Safe Systems of Work can reduce or eliminate exposure to hazards but they must be strictly followed.

On this basis, a safe system of work shall be established and maintained by a Competent Person. The system shall be followed for every transport operation, whether it is a complex individual transport or repetitive routine operations.

The main principle of the safe system of work is that any transport operation shall be:

- Properly planned;
- Well organised;
- Appropriately supervised;
- Carried out in a controlled and safe manner;
- Closed and reviewed

The objective of the safe system of work is that all hazards associated with and all factors affecting transport operations are duly considered, communicated, well understood and controlled by the personnel involved in the transport operations.

9. PLANNING OF TRANSPORT OPERATIONS

9.1 Transport Equipment

Based on the dimensions and weights of the wind turbine components to be transported, the requirements of the transport route and the site conditions, the transport contractor will select the most suitable vehicle for the road transport.

In some cases, there are unique specialist trailer types and designs that have been specifically manufactured to handle or contain specific wind turbine components. This has been achieved by collaboration between the turbine manufacturers, the trailer manufacturers and the transport operators. In these cases, standards have been set and equipment is operated accordingly.

Each country has their own unique regulations with regards to vehicle and trailer dimensions and weights, when transporting abnormal loads.

For this reason it is important that the local regulations with regards to loaded vehicle dimensions, length, width, height and weight are adhered to. Furthermore local and domestic regulations for 'Gross Vehicle Weights' (GVW), group axle loadings and individual axle loadings and axle spacing must also be taken in to account when assessing the vehicle and trailer combinations required to affect delivery of the wind turbine components.

9.2 Abnormal load transport permits, authorisations and escorts

Although the focus of this document is based on the site transport and activities for Crane and transport on the actual wind farm site, it should also be noted that in order to get to the site, most of the components will require some arrangement of 'abnormal load permit', which is generally issued by local and government agencies as well as police authorities.

The timescale required to obtain authorisation and permits can vary dramatically between EU member states from 2 weeks to over 6 months. Furthermore, depending on the size of components and route involved, may also require the need for Temporary Traffic Removal Orders (TTRO) to be obtained to allow transit of the loads.

In most countries, abnormal loads also require the designation of escort or pilot cars as a matter of safety to raise awareness of the presence of the abnormal load on the highways. Some countries demand a Police presence or escort and some countries allow a private escort, given local regulations on lighting and marking of pilot cars and the training, qualifications and authority of the Pilot car drivers.

It should be noted that the cost of these services in part or in combination with the issue of the permits can vary dramatically from country to country, from being relatively cost effective to being very expensive.

It is normal practice that the appointed transport contractor will provide pilot cars and/or organise Police escort duties, seek authorisation of the permits and be governed by the results of the permits that are issued. The transport

contractor should therefore be involved in the delivery scheduling for the components.

For ‘best practice’ reasons, considerations for the provision of these permits should be made well in advance of the arrival of the turbine components and, due to the dimensions of the components and the alterations required to gain access en-route, these permits should be considered at the planning and development stage of the wind farm itself.

It should be noted that local restrictions on transport permits will affect the flow and delivery of components from the port to the site. This will have an impact on the on-site considerations and logistics, and ultimately impact the usage of the mobile cranes and the erection program for the entire wind farm.

9.3 Route survey and site preparation and maintenance of roads

It is imperative that a route survey should be carried out before delivery of the components is planned. The correct turbine component sizes and loaded vehicle profiles must be considered at this point, in case a specific trailer type is highlighted as being inappropriate and therefore an alternative can be considered.

The route survey should commence at the point of loading, continue along the proposed highways to the site and also include the site access track and the site roads.

See Appendix 6: Sample Route Survey
<http://www.estaeurope.eu/SRSurvey>

As a minimum, the dimensions of the site access tracks and site roads should comply to the standard specification included in this ‘Best Practice Guide’ see Appendix 1: Road Design Parameters.



Figure 21
Example of an insufficient site road, due to:

- **Bad compaction**
- **Steep inclination**
- **Insufficient width**

Adopting this standard will reduce risk and the accidents that are often attributable to unsuitable site road conditions, and improve the safety record of wind farms and the wider industry.

Additionally, where appropriate and at critical points, reflective delineation of the usable road width should be provided as part of the site road design and mounted along dangerous and complicated road stretches.

Markers should be spaced a maximum of 60m apart on main line sections and should be spaced a maximum of 30m apart on ramp or curved sections. For curved sections, a pair of markers should be used to mark the start and finish of the curved section as well as the apex of the bend.

Delineators may need to be removed for certain component deliveries, to allow for oversail of the components.

The point of delineation is to serve as an approved surface for which to drive on and eliminate the significant risk of vehicles running on soft ground and becoming stranded or worst, overturning and damaging vehicles, trailers, turbine components or personnel.

The road surfaces and hardstands should be maintained to ensure suitable surface for operations throughout the performance of the works.

- Site and access road should be regularly rolled to prevent large stones causing damage to trucks, trailers, cranes and other vehicles.
- Pot holes can cause damage to delivery vehicles, cranes and other vehicles and in extreme cases also present a hazard for vehicle operatives. Therefore the roads must be maintained as per the original design at all times.
- The road surface should provide suitable traction to allow a single tractor unit on the component trailer to transport all components up to a gradient of 10%. If suitable traction cannot be gained due to surface quality or weather conditions prevalent at the time, additional traction will be required to assist. (See ‘towing of vehicles / multiple tractors’)
- For gradients uphill/downhill greater than 10% a Risk Assessment and Method Statement (RAMS) must be carried out at each individual point to ascertain a Safe System of Work (SSOW) under the needs of ‘Special Measures’

Where public highways, site roads, access routes, loading and offloading points, turning heads and crane pad locations fall below the recommended design specification, the route survey report should highlight these points and issues to enable upgrading works to be carried out before the delivery of the components are made. It is usually the responsibility of the developer to provide the infrastructure of site roads and crane hard stands and make the necessary amendments required, to facilitate the transport of the components.

A digital model and drawing of the vehicle, trailer and load combination and accurate steering geometry can be produced. This is known as a Swept Path Analysis (SPA) and should be carried out for areas where it is difficult to determine the exact requirements of the transport turning circles.

Please refer to figure 22 for an example of a Swept Path analysis

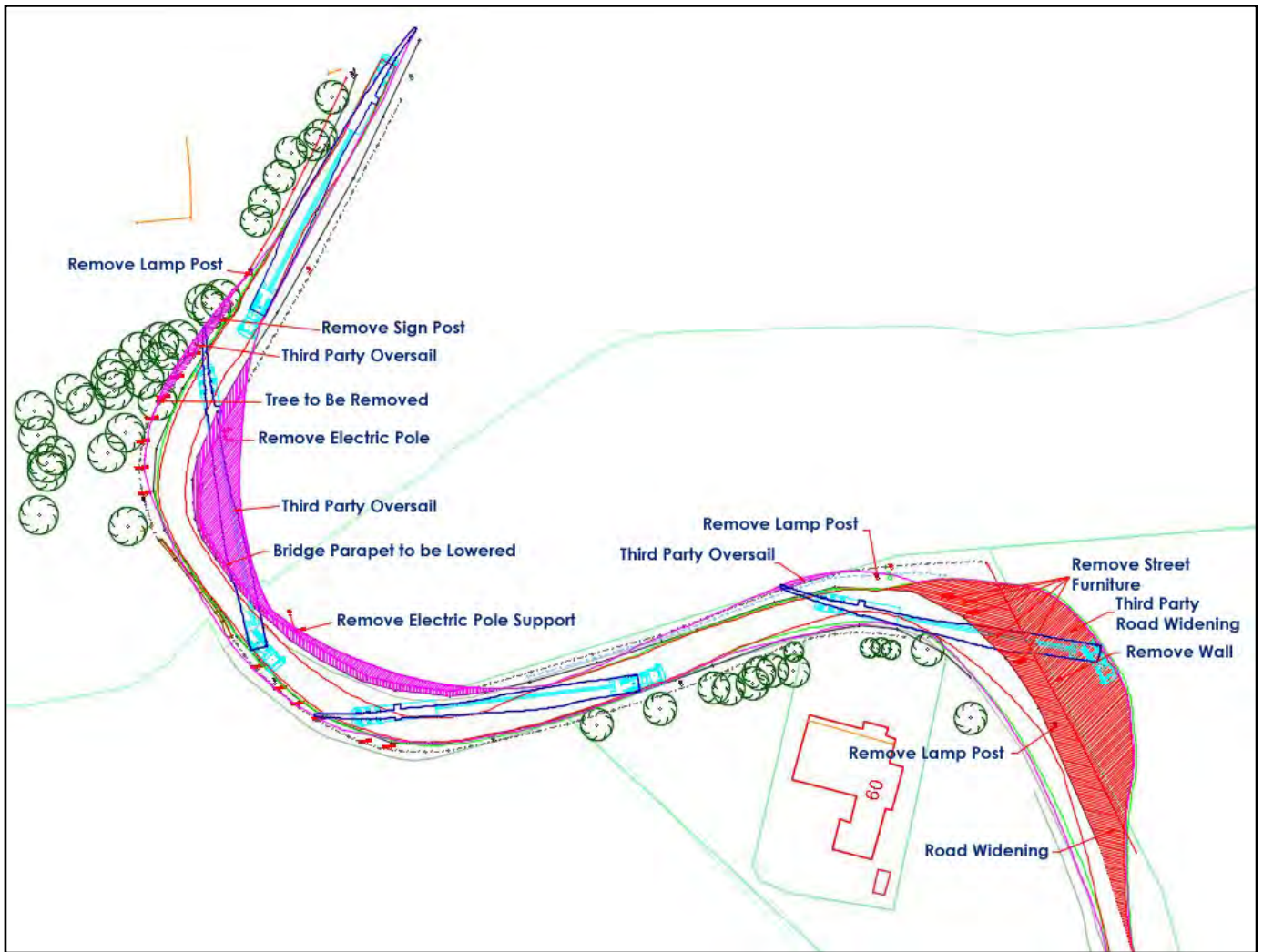


Figure 22 - Example of 2D Swept Path Analysis

The document Appendix 1: Road Design Parameters considers the loaded components of a variety of dimensions to illustrate some of the variances in component dimensions. This document does not list all possibilities but the attached ‘track design’ swept path drawings offer dimensions of roads and curves within the variance of 30°, 60° and 90° and should be used as a minimum dimensional requirement for road design.

Furthermore the document nominates if the dimensions given are based on ‘automatic steering’ or ‘manual steering’ principles for the trailer equipment.

It is important to recognise the difference between these two steering types and the very important issue of when to allow or nominate ‘manual steering’ operations (see §10.3 Manual Steering of Trailer Equipment)

With regards to turbine delivery vehicles, it is often the case that only the blade components have been assessed or considered for route access, as these are more often the longest component and are the obvious choice for a route access study.

However there are other components that also require careful considerations because, even though they are shorter, have dimensions exceeding the blades and can impact on the route and access.

Therefore it is of utmost importance that all components are considered when preparing road and site infrastructure for delivery of these components. For examples of different component dimensions and the relative road infrastructure required, see Appendix 1 – Road design parameters

Component characteristics

Towers - Can be up to 6.0 m diameter. Additionally the various tower sections vary in length and weight by each section and by the different turbine manufacturers. Tower sections also have a great influence on the ‘Gross Vehicle Weight’ (GVW) and individual axle load weight of the loaded combination.

In certain given circumstance, due to a combination of the size or weight of the tower section and the nature of the trailer that is required to transport the section size, the towers could be longer than the blade transport. Nevertheless, a combination of the width, height, length and weight carry different considerations to the blade transport when assessing route access.

Nacelles - Nacelles are generally smaller by dimension than the larger tower sections, although some nacelle types can be up to 5.0m wide. However nacelles represent some of the heaviest loads that are required to be transported.

They have a large impact on the GVW and maximum axle loading of any of the wind turbine components.

Foundations - These are normally delivered before the other components are due to arrive on site. However due to the large diameter of these sections, they should be considered in good time, as infrastructure is sometimes not altered until the moment before delivery of the main components is due to arrive.

Quick check for considerations of components on route surveys

	Blades	Towers	Nacelles	Hubs	Foundations
Length	X	X			
Width		X	X	X	X
Height	X	X	X		
Weight		X	X		

Route surveys can be commissioned at different stages of the planning and development of a wind farm project and therefore can offer different levels of output depending on what level of detail is required.

Initial studies can consist of analysis of a number of routes to establish which is the most viable in terms of access and egress for the delivery of the turbine components and may consider routes from one or more points of loading or port of import if sea shipping is being used.

Indeed a ‘multi-point of loading’ or ‘multi-port’ strategy may be required due to restrictions in port availability, storage capacity, highway viability relating to different turbine components or different manufacturing points and the type of shipping plans and strategy adopted.

For the purpose of this Best Practice Guideline, we are to assume that all preliminary and necessary route analysis has been carried out and a definitive route or routes has been established.

The typical output and results that a route survey can contain are:

- Contractor, client names and file reference number to identify the site and route
- Dates and times that the route survey was undertaken
- Weather conditions prevalent at the time of the route survey
- Candidate turbine with individual dimension and weights of the turbine components being assessed
- Profile drawings of the loaded vehicles dimensions showing axle spacing and weights
- Summary, caveats and conclusions of what is included and excluded from the survey and the expectations of the outcomes
- Addresses and co-ordinates of the starting points and the finishing points of the survey
- A map showing the overall route and distances to be taken and a list that identifies the road classification and street names.
- Route analysis should also be included to highlight any waypoints, turning points or overnight parking areas including dimensional requirements that will be required. This should also consider if multiple loads or convoys are anticipated. Overnight stopping points must also consider availability of the welfare facilities for the drivers.

- Assessment of the speed of the different loaded vehicles should be made and of the use of the EU Drivers hours regulations and working time directive to anticipate the total journey time and the required stopping and parking points.
- Analysis of the route and highways taken must identify areas of concern, pinch points, street furniture and vegetation that require removal or alterations.
- Identification of any points where 'land take' or highway or track alterations are required to allow axle loadings of vehicles outside of the normal highway boundary
- Identification of where any 'oversail' points are required outside of the normal highway boundary to facilitate access
- Identification of areas where manoeuvring of the loaded vehicles will be required and where manual steering of equipment will be required over and above the 'automatic' steering of trailer equipment
- Identification of areas where steep uphill or downhill gradients are involved and where additional towing or braking vehicles will be required to assist.
- Photographic evidence of the points of interest with map reference and co-ordinates to identify each specific issue, and where necessary, indication of direction of travel.
- Swept Path Analysis (SPA) drawings of known issues and areas where the pinch points are being mitigated, justified or quantified.
- Identification of areas where further SPA analysis is required
- Identification and highlighting of any impact on other road users of the loaded vehicles in day time or night time operation.
- Identification and highlighting of any other impacts on the viability of the route or third parties due to seasonal or weather conditions
- Pertinent copies of any communications and results of dealings with any third parties, such as highway authorities, Police, permit authorities, bridge and structure owners.

9.4 Load control, 'test drives' and clearances

As part of the delivery program, a Transport Management Plan (TMP) should be prepared in order to offer to the site the proposed flow and frequency of abnormal loads across the site (see 9.6).

The TMP will consider the complete route from the point of loading to the site and also account for driving on the site roads. It must take account of EU Drivers Hours and Working Time regulations (EC 2006/561), rest breaks, stop over points and possible overnight parking areas and restrictions, which in turn will impact on the site operations for transport that this Best Practice Guideline is considering. During this stage the TMP will also consider the possibility of forming convoys of vehicles, as this may be advantageous to the transport lead time.

In many cases it is appropriate for a 'test drive' to be carried out prior to the commencement of the delivery of the components.

A 'test drive' is performed by using an empty trailer that is extended to the appropriate length and include temporary frames to replicate rear and side projections. The vehicle is then driven along the proposed route and where possible along the site tracks and site roads in order to verify the facts contained in the route survey report and proof test the requirements for road alterations including horizontal and vertical elevations. The test drive should be completed with an empty trailer, so that in an emergency or at the points where land take has been recommended, but not progressed, or in the case of vertical alignment issues where there is insufficient ground clearance, the trailer can be 'retracted' until it is past the hazard. The test drive should be attended by turbine manufacturers, project managers, police, highways and authorities representatives and other interested parties. It is also advisable to video the event to use as evidence if required at a later date.

The type of delivery plan required (see Transport Management Plan) will dictate the expected volume of traffic across the site infrastructure.

In some cases it may be appropriate to engage the pilot cars that escort the vehicles on the highway, to also pilot the vehicles on the site to act as warning to other site traffic of the presence of the abnormal loads.

It is normal practice to have a check point or gatehouse at the entrance of wind farm sites. The TMP should also be issued to these points so that site entrances may be kept clear in readiness for the arrival of the components. This TMP will also assist with 'lone worker' regulations in so far that the security personnel at the gatehouse can check personnel on and off the site.

9.5 Lashing and securing

Details of the lashing points for securing of the components to the trailers should be provided by the turbine manufacturer to the contractor. The contractor must ensure that sufficient lashing and securing of the components is carried out to allow a safe delivery of the components. There are European guidelines on cargo securing based on physical laws of friction, gravity, dynamics and strength of materials. However the daily application of such laws can be complex.

To aid the design and the check of cargo securing arrangements, specific standards related to the strength and performance of a superstructure, securing arrangements, materials used for securing etc. can be found in the latest version of the following international standards

Standard	Subject
EN 12195-1	Calculation of lashing forces
EN 12195-2	Web lashing made from man-made fibres
EN 12195-3	Lashing chains
EN 12195-4	Lashing steel wire ropes
EN 12640	Lashing points
EN12642	Strength of body structure
EUMOS 40509	Transport packaging

It is important to bear in mind that different countries and EU member states might have specific or contradictory requirements related to cargo securing describing further limitations which are not covered in these international standards or these best practice guidelines. It is therefore recommended to consult the relevant authorities to enquire about the specific requirements of the countries the transport is being carried out in, or passing through.

Inevitably, as a result of further experience and the continuous development of cargo securing systems and techniques, these guidelines will need to be periodically reviewed and amended as necessary.

Considerations for braking and accelerating should be made for both normal road transport and also the additional values that are required for the site conditions. For example, if there are steep gradients on site, additional lashing may be required to be added once on site.

9.6 Transport Management Plan (TMP)

The Transport Management Plan is a written method statement of an individual or repetitive transport operation. The contents of the TMP can consist of many documents and will depend on the complexity of the transport operations. The TMP must detail the requirements needed to execute the transport. As part of the TMP the transport contractor should provide its client with a transport drawing indicating the dimensions, axle loads and steering characteristics of the loaded transport vehicle, required for the assessment of suitable road conditions on site.

The TMP shall include the details of the transport(s), with the following as a minimum:

- Description of the operations.
- Checklists
- Route survey
- Outcome and requirements of the route survey
- Organisation and responsibilities
- Communication
- Characteristics of the loads
- Configuration drawing of the vehicles
- Loading, transport and delivery routines (see Execution of Transport Operations)
- Routing and permit restrictions
- Lashing and securing details
- Limiting environmental criteria for transport operations
- Areas where 'Special measures' are required (see towing of vehicles/ multiple tractors. See 9.7)
- Lift plan drawings for knuckle boom cranes (if required)
- Contingency plans

Furthermore the TMP should assess and account for the different types of logistics routines that could be adopted.

Generally there are two types of logistics routine to consider:

1. Just in Time Delivery (JIT)

This is where each component is brought to the side of the crane in the correct sequence, where it is offloaded and erected directly by the installation crew

2. Pre-delivery

This is where the crane pad is built to a size and design where the components can be delivered and laid down before the arrival of the main erection crane.

In some cases a combination and variation of these two methods can be adopted, depending on the site layout, topography of each of the turbine locations, time constraints and land availability.

For large wind farm projects the site infrastructure may consist of many kilometres of site road. The transit time alone from one side of the site to the other may take some number of hours for loaded components travelling slowly, and the same for empty vehicles to return. Therefore it should be considered for one or more consolidation points for multiple loads and components to be stockpiled in order to feed to the crane pads and assist with the site logistics. It is recommended to prepare a site road map for truck / crane drivers and include marking signs at road junctions.

In many cases, it is more productive to have two teams working on the TMP. The first team delivering from the port to the site, and a second team delivering the components across the site.

Some of the advantages and disadvantages for each methodology are noted in the table below.

Type	Advantage	Disadvantage
Just in Time	<ul style="list-style-type: none"> • Minimal crane pad dimension required • No storage area on site required for auxiliary components. 	<ul style="list-style-type: none"> • If the transport is delayed, the crane and erection crew will incur downtime and cost • If the erection process is halted due to wind or crane breakdown this incurs demurrage charges for the transport • If the erection process is halted due to wind or crane breakdown this possibly incurs extra costs in police escort cancellation, additional permit costs, availability of the transport route to site • If the erection process is halted due to wind or crane breakdown, this has an increase effect of the loading and storage costs at the port area. This may also impact on the shipping routine and associated costs.
Pre-delivery	<ul style="list-style-type: none"> • Reduced risk of injury to personnel as there is less activity and fewer people on the crane pad at any one time • Increase productivity of the transport equipment and delivery timescale due to 'known' offloading time/ plan. • Reduced transport costs as no 'waiting time' incurred waiting for wind or crane and erection crew • Increased productivity of the crane and erection crew as all components are available at the crane pad • Reduced third party (e.g. police escorts) and cancellation costs due to a robust TMP • Delivery routines can usually continue even when high winds are present • Flexible delivery routine of types of components. E.g.: doesn't have to be in a specific order. • Allows flexibility in the shipping of components to the port. Port storage arrangements and handling of components and can minimise the area required for storage at the port. • More room on the pad as no main crane there, so the transport can turn around and eliminate the need for turning heads. 	<ul style="list-style-type: none"> • Larger Crane pad size required for storage arrangement of components

9.7 Towing of vehicles / multiple tractors

Where site road conditions and site gradients dictate, additional traction may be required.



Figure 23: Towing of vehicles requires special attention and work preparation to reduce risks

There are several issues to consider when providing additional traction on site.

- The road conditions and design must be suitable for the tractive and braking forces imposed by the tractor, trailer and towing units.
- Traffic control for the rest of the site and other site traffic whilst towing is being undertaken.
- Passing places and laybys for the adding and subtraction of the additional pulling vehicle will be required.
- Emergency routines and rescue scenarios should be considered, in case an issue occurs on a gradient.
- Fatigue of drivers and steersmen where there is a large amount of towing and steering of equipment required
- Type of coupling used for both the rear of the pulling vehicle and the nose of the tractor being pulled should be in accordance with Annex 7 of Directive of ECE R 55-01 (e.g.: Rockinger or register type coupling that is certified)
- The type of connection to be used between the tractor and the pulling vehicle. A draw bar is recommended rather than using a strop type connection. The use of a chains for the connection of vehicles should be avoided at all times.
- Direct radio communication between the pulling vehicle, the tractor unit and the steersman of the trailer or pilot car is required.
- One person should be assigned as responsible for the transport convoy.
- Insurance implications should anything go wrong. Who is ultimately in charge of the convoy and who is insuring the vehicles, trailers and load?
- One of the vehicles should have a torque converter to assist with the power transfer between the two vehicles.
- On downhill gradients, the braking vehicles should have engine retarders and the tractor unit should have an independent trailer brake system.
- On downhill gradients, front towing should be removed and additional braking vehicle attached to the rear of the trailer (depending on gross weight)
- On downhill gradients, the rear of the trailer and connections should be suitable to withstand the stresses imposed by the braking action of the rear braking vehicle.

- Type of pulling vehicle to be used which ideally should be a rubber tyred vehicle compatible for:
 - The gear ratio and horse power of the tractor unit being towed
 - The gradients that are being negotiated
 - The length of the gradient (short slopes are easier to negotiate than long slopes)

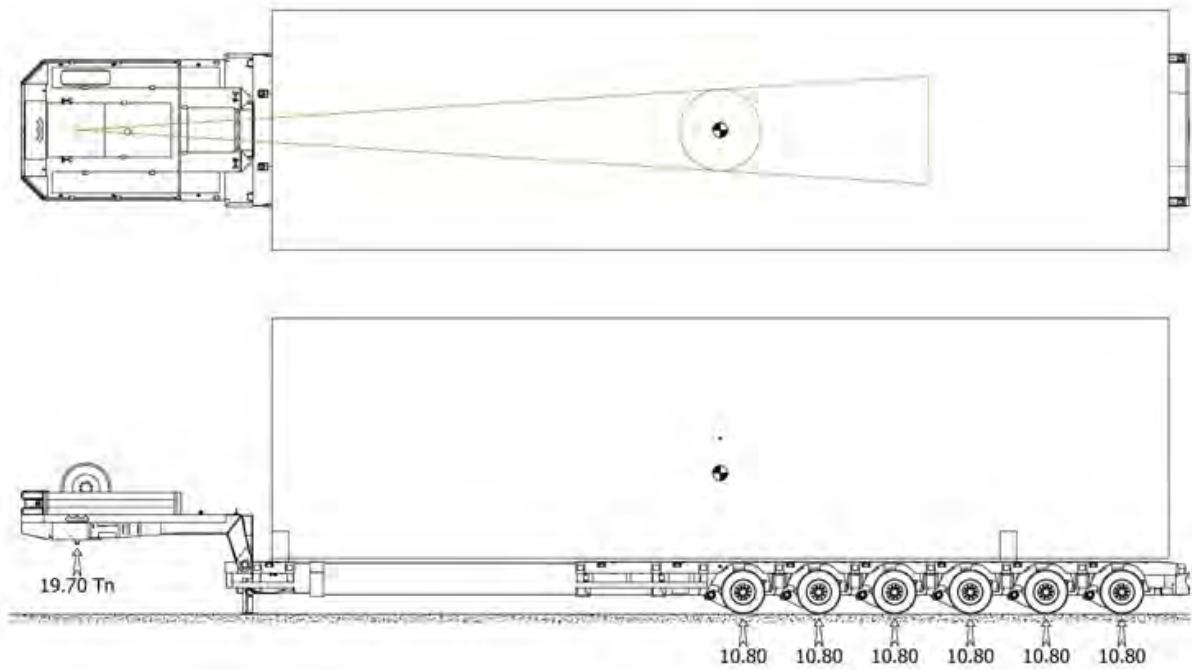
Uphill gradients are a different consideration from downhill gradients. Whereby traction is the prime consideration for uphill gradients, braking and vehicle control is the prime consideration for downhill gradients. The severity of the uphill and downhill gradients will have a large impact on the centre of gravity (CoG) of the load. This will influence the axle loadings of the trailers and the drive axles of the tractor units and thus the traction and braking performance. As an example below, we have taken a nominal tower section weighing 60 Tonnes on a 6 axle stepframe trailer. We see an increase in the axle load of the trailer and a reduction on the 5th wheel pin loading and drive axles of the tractor unit on an uphill gradient and vice versa on a downhill gradient.

Angle	Weight on 5 th wheel pin	Axle load of trailer
Horizontal	19.7 Tonnes	10.8 Tonnes per axle
20% uphill gradient	Reduce to 12.3 Tonnes This removes weight imposed on the drive axles of the tractor unit, where it is actually preferable to have more weight to increase adhesion to navigate uphill gradients	Increase to 12.0 Tonnes per axle This adds weight to the trailer axles and increases drag. Depending on the weight of component, could overload the design capacity of the axle
20% downhill gradient	Increase to 32.6 Tonnes This increases the weight impact and overloads the design weight of the neck of the trailer. Furthermore it is dangerous more so on bends and curves due to gravitational influences.	Reduce to 8.6 Tonnes per axle This reduces the axle load and can lead to ineffective braking by wheels locking up and sliding

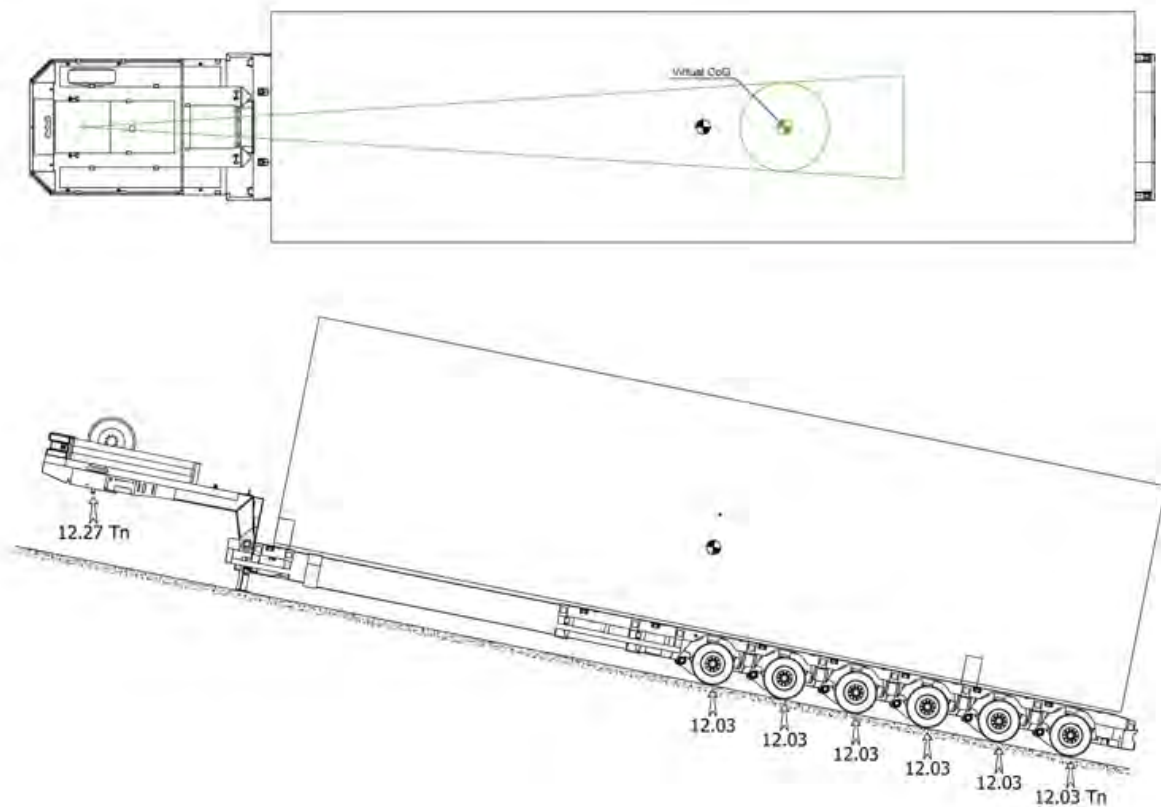
The figures in the above table are factual engineered calculations, offered purely from an illustrative perspective. They do NOT advocate the use of 20% gradients as this has dangerous operational implications. See fig. 24 on page 30.

Figure 24: Load distribution based on gradients

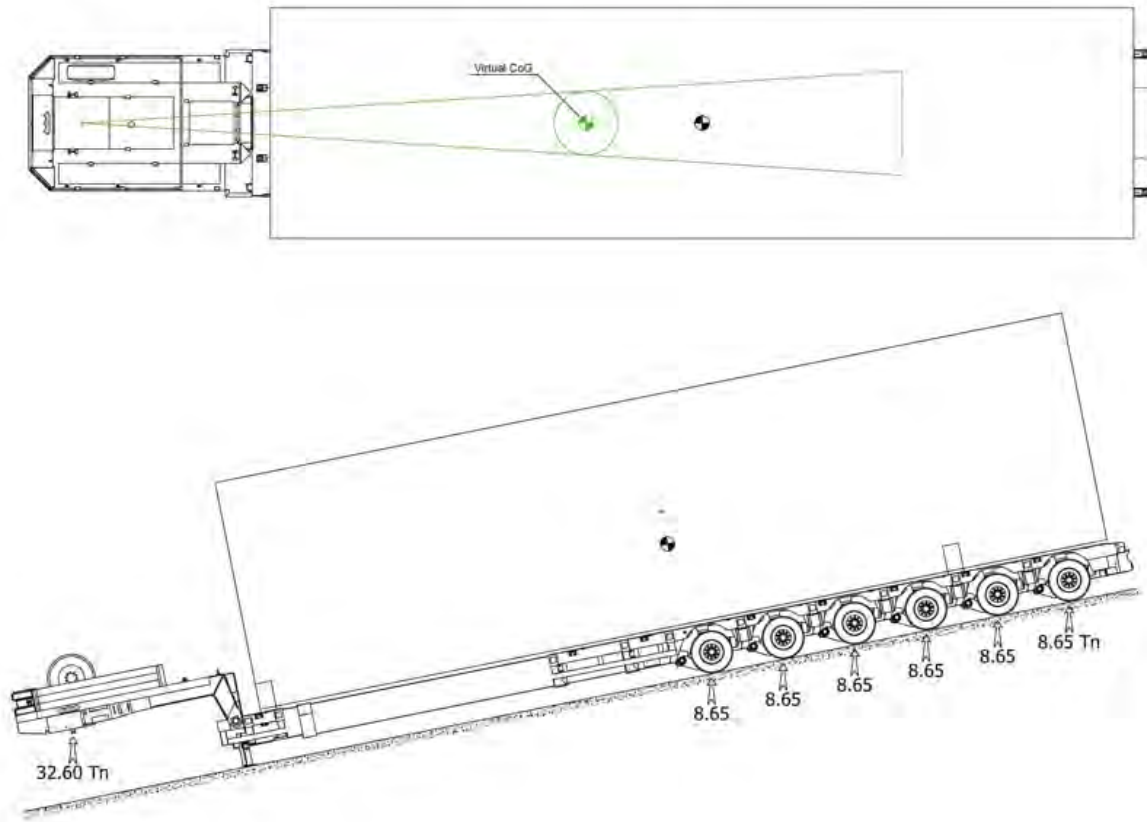
Horizontal



20 % uphill gradient



20 % downhill gradient



More detailed information on the calculation of gradeability of vehicles and vehicle combinations can be found in **Appendix 5 – Calculating the Gradeability.**

10. EXECUTION OF TRANSPORT OPERATIONS

10.1 Good practices prior to transport

There are several key points to consider when planning the execution of transport operations, all of which can be covered by the saying 'fail to plan is a plan to fail'.



Figure 25: Typical wind turbine transport convoy

Pre-planning: Best practice prior to the transport taking place requires early engagement by the turbine manufacturer with the transport contractor. This will allow sufficient time for the necessary route surveys, permit applications, port arrangements, highway amendments, site requirements and a TMP to be produced. Additionally, it is important that the transport contractor is involved and engaged with site meetings and discussions along with the Crane operator at an early stage, so that a complete picture of the process and requirements can be shared between all parties involved.

10.2 Pre-task briefing and communications

Execution of transport operations requires a solid team effort from all involved and the team should engage with each other on a daily basis. This includes providing safe systems of work through Pre-Task Briefings (aka tool box talks), the issuing of Risk Assessments and Method Statements (RAMS), the correct use of communications tools such as hand held radios, personal protective equipment (PPE) and accident and 'near miss' reporting.

Information from the client and site contractor will also be required in order to produce a comprehensive plan, including:

- Site layout map
- Project programme
- Contact details for site and client staff including 'out of hours' information
- Emergency evacuation accident plan
- Any pertinent site rules and restrictions that affect the delivery schedule
- Other activities that may be ongoing or adjacent to the site
- Clients safety rules
- Security arrangements, welfare facilities and first aid stations
- On site storage or consolidation points and hazardous materials
- Identification of water courses and structures on site
- Identification of known wildlife on site and areas of access open to the public
- Significant design and construction hazards, including overhead power lines
- General topography of the site and areas requiring 'special measures'

All vehicles, trailers and equipment should be tested in compliance with EU Directive 2014/45 EU and fit for purpose, and truck and escort drivers and steersmen should be trained, qualified and competent.

Importantly, the transport operations will require the TMP to also consider:

- Orientation of the components loaded on to the trailers
- The direction of travel and approach to the Crane pad/offloading position
- Time of day of arrival on site and transit time across site to offloading position
- Frequency of transport including convoys and combinations
- Available working time and shift patterns, including the EU drivers' hours and Working Time Directive regulations
- The size and position of 'turning heads' for loaded or empty vehicles
- Where manual steering of trailers are required, the length of road, the time spent engaging/de-engaging the steering operation, the distance that steersmen have to walk and the impact of fatigue.
- Removal of equipment from site such as blade and nacelle frames, tower cradles and tools containers.

Part of a proper briefing and communication set-up should also include a post-delivery debrief/lessons learned session at the end of the transport cycle. This requires the transport operator's project manager to engage with the client and the site agent, to discuss any outstanding issues, review problems that occurred and areas where improvements can be made for the future.

10.3 Manual steering of trailer equipment

The document **Appendix 1: Road Design Parameters** nominates which road parameter has considered automatic trailer steering and which parameter has considered manual steering of trailer equipment.

For the use of manual steering of trailer equipment there are points to consider regarding where, when and how this should be conducted as this carries a high degree of risk for the transport operation.

Do's

- Areas where manual steering is required must be identified and assessed before the transport takes place. The location of these areas should be communicated to the driver and steersman beforehand. Ideally they should have knowledge of these locations and the expected alignment that they have to take.
- Permanent radio contact must be maintained between the driver to the truck and the steersman of the trailer. If communication is lost, the convoy must halt immediately.
- Backup communications (i.e.: spare battery or mobile phone) must be readily available
- A common language or signals must be understood between driver and steersman before operations are undertaken.
- The steersman's only task should be to navigate the trailer when manual steering is in operation
- Clear visibility must be available for manual steering operations to take place.
- If manual steering in hours of darkness, temporary lighting must be provided at the points where manual steering is being performed.
- When on wind farm sites, manual steering should be carried out on level ground that provides a safe walking area.
- Trailers that have a manual steering option and have no operating platform, must also be fitted with a safety device that automatically makes the trailer disengage the manual option and revert to automatic steering when operating above 15kph.
- The steersman must have access to both sides of the vehicle whilst operating the manual steering in order to maintain visual assessment of the alignment of the trailer, load and projections with the road surface and various obstacles that need to be navigated or avoided.
- When reversing in manual steer mode, the steersman must take a safe position from which they have good visibility of the trailer axles and load and if possible within direct view of the driver. They must also be in permanent radio contact with the driver.

Don'ts

- The steersman must not be allowed to multi-task, for instance is used as a pilot car driver at the same time as steering the trailer. This can lead to loss of concentration on the important job of navigating the trailer at critical points.
- The steersman should not be allowed to continuously steer the trailer equipment for long distances or long periods of time, due to fatigue and levels of concentration required.
- Areas where repeat performance of manual steering takes place requires continuous assessment of the truck driver and steersman's behaviour. Complacency must not be allowed to develop. For example, they only had to do a very small amount of steering last time, so next time they will try without. Or last time they did it slowly, but next time they will go quicker.

- The point of manual steering should only be considered at restricted pinch points on the route. It must not be considered as normal practice or allowed to be used on a continuous basis. This can lead to mechanical failure.
- Trailers must not be operated on manual steering mode above walking speed
- Unless the trailer has a designed safe ride-on position provided, the steersman must not ride on the trailer whilst manual steering is in operation.
- Manual steering must not be operated on steep gradients (uphill or downhill) as the steersman's speed is impaired and fatigue/exhaustion can affect the steersman's dexterity to operate.

Where road modifications have not been progressed or are insufficient, or any obstacles have not been removed, then manual steering must not be attempted. The convoy must stop and alert management of the situation.



Figure 26: Tower transport using “clamps”

10.4 Environmental (weather) conditions

Operational matters should take account of environmental (weather) conditions and daily and weekly reports should be used in decision making, allowing for the transport plan to be flexible and changed where appropriate. The three main influences are wind and fog on a daily basis and snow and ice on a seasonal basis.

Example of equivalent forms of wind conditions can be found in **Appendix 4: Reference Documents**.

11. GENERAL CONSIDERATIONS

As a general rule, the following items should be taken into consideration when planning the involvement of horizontal and vertical transport activities during the construction of a wind turbine generator installation:

- **Contractual considerations**

Parties involved should realize that a successful installation of wind turbine generators requires close cooperation and good communication between the site owner, the wind turbine manufacturer and transportation and installation companies. A well-designed contract will have provisions that address these issues and define the responsibilities of the various parties during the construction phase of the project. For easy reference on the site we recommend a site responsibility schedule should be agreed on and made known to site staff. A sample document can be found in **Appendix 4 – Reference Documents.**

- **Statutory compliance with all health and safety regulations**

Construction site management should be aware of the local health and safety regulations that apply at the construction site and with which they will have to comply. They should also realise that contractors coming to site may not be aware of the specific health and safety regulations pertinent to the country the site is in. Hence site management should have a program in place that will ensure contractors from other nations are checked for compliance and if necessary instructed about local requirements in the phase in which contracts and subcontracts are drawn up.

- **Site layout issues,**

On every construction site the site layout is often the starting point for discussions about safety and efficiency. All site layouts are ultimately the result of a compromise between geographical conditions, economic viability and accessibility for heavy equipment. In view of this there are a number of topics that require specific attention.

Those making a site layout design should:

- Construct loops rather than spurs (see Figures 27 and 28);
- Construct sufficient passing lanes;
- Allow for emergency access roads to remain unblocked when transport and construction equipment is working at site;
- Make sure local emergency services are aware of the construction site location and entrance roads and site routes during the different construction phases.
- Allow budget for the delineation of roads, and sufficient lighting of work areas.

The creation of loops in a site design can increase efficiency and safety, whilst at the same time reduce problems and risk.

The specific benefits of loops are as follows:

- Two way traffic and congestion can be avoided thus increasing the efficiency of the delivery program and the navigation of other site traffic.
- If other site work is on-going such as cable laying which sever the 'artery' of the site, delivery vehicles can be diverted around the obstruction to continue the delivery process.
- Creating loops reduces the requirement and cost of construction for 'passing places' which are required at critical points
- A reduction in the requirement and cost of construction of 'turning heads' will be created as vehicles can enter and exit in one direction.
- A reduction in the risks involved in reversing vehicles on site and the accidents that can be caused by this.
- The ability of loaded vehicles to approach the crane pads from both sides or different angles may avoid the necessity to perform crane 'cross lifts' of the components and reduce the risks attached to this.
- Loops may simplify the handling procedure of some components at a site storage area or crane pad making it easier to sequence the order they are delivered in and then loaded out.
- Loops may help to avoid excessive uphill/downhill gradients by following more sympathetic topographical lines on the site terrain.
- The design of a storage/stockpile area on large sites allows a consistent feed from the port to the site and thereafter from the store at the site to the pad location. Loops may allow an efficient delivery plan for on-site logistics team to feed from store to crane side on a 'just in time' basis, so avoiding port to site delivery vehicles.
- Where a storage area doesn't exist, an increase in the size of pads to allow pre-delivery of all components could be adopted. By using loops in the site design, this allows an improved efficiency of the delivery routine and the service and crane vehicles required.
- Including loops in the site design offers better or alternative access for emergency service vehicles, should loaded components be on the site, blocking roads or access at any time.

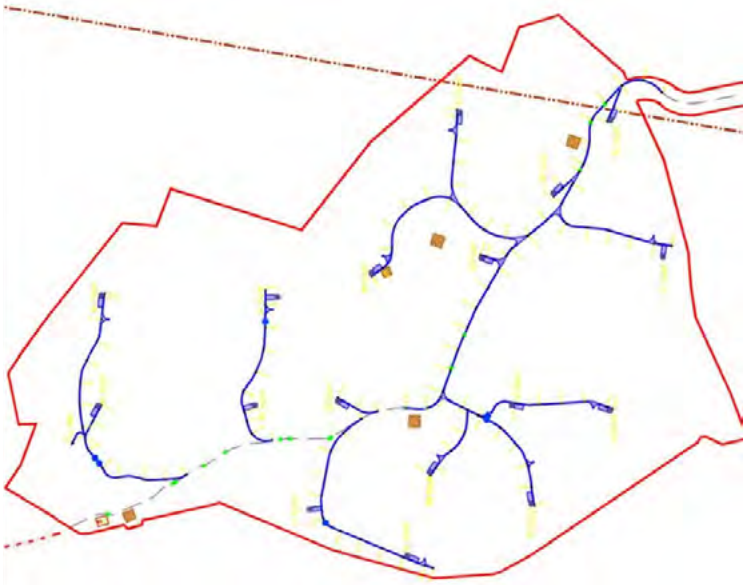


Figure 27: Example of wind farm site layout without loops



Figure 28: Example of same wind farm site layout with loops



Figure 29: Typical WTG tower base section transport

12. IDENTIFICATION OF HAZARDS AND RISK ASSESSMENTS

A transport operation may have many hazards associated with it, either due to the load, the direction or path of the load, the truck, trailer or appliances and accessories used, the environment in which the transport operation is being carried out or its proximity to other components, objects or other items or hazards.

12.1 Template risk assessments

Table 1 Lists examples of hazards which can be encountered during WTG lifting operations

Load	Environment	Proximity to
Position of CoG, incl. unknown Position; Location and type of lifting points; Complex slinging arrangements; Use of load control systems; Uncertainty in weight of load; Two crane lifting operations; Integrity of load; Load dynamics, floating, in port or in field; High surface area and drag coefficient; weight transfer; Aerial load transfer; Orientation of the load; Access to lifting points; Sharp edges; Protruding load parts;	Snow; Ice; Hail; Rain; Wind; Lightning; Sea state; Fog; Uneven ground; Poor ground conditions; Poor sea bed conditions;	WTG components; Adjacent vessels; Site structures (masts, accommodation); Roads; Railtrack; Passing traffic; Adjacent cranes, MEWPS or other plant and equipment; Temporary works (e.g. scaffolding); Permanent and temporary lighting; Power lines; Personnel;

For reference a number of Template Risk Assessments is inserted in

Appendix 4: Reference documents

13. SELECTION AND TRAINING REQUIREMENTS OF PERSONNEL

Safe transport and lifting operations depend upon the selection of suitable personnel who are competent to carry out the required duties. Records of training and experience can assist in the selection of suitable personnel as responsible person, lifting supervisor, crane / lifting appliance operator, slinger and signaller. All personnel who are involved in transport and lifting operations, or in the maintenance of transport or lifting equipment, shall be trained and competent to safely carry out their tasks within their area of responsibilities.

Transport equipment should preferably be operated by qualified personnel with an EU licence, if required for the equipment in question.

Cranes should only be operated by personnel with an ECOL operator's licence.

Power operated lifting appliances such as davit cranes, nacelle mounted cranes, key side cranes, winches etc. shall only be operated by personnel with an operator's licence and trained in accordance with the relevant manufacturer's recommendation.

All personnel who are involved in lifting operations, shall be certified to meet local legal requirements and if applicable ECOL standards. For more information please refer to: www.ecol-esta.eu

Qualifications for signaller and slinger shall be in accordance with relevant defined standards, the requirements of the employing organization and the internal requirements of the contractor (their employing company). The signaller and slinger shall as a minimum be trained in inspection, safe use and storage of lifting accessories and operation of signalling systems (visual and radio communications). Proficiency shall be demonstrated by a certificate and their competency periodically assessed.

Relevant training can be performed internally or under the direction of an external training provider. The purpose of the training is that requirements defined by the organization are fulfilled, and any applicable local legislative requirements are covered.

The method of teaching should be decided by the training organisation. Methods may include for example, classroom training, simulated practical training or hands-on training.

Where practical training is performed, this shall be performed on a lifting appliance that is either the same or of a similar type (e.g. mobile, crawler, davit, knuckle boom crane, etc.) to generally used or planned lifting appliance on projects and sites.

Records of competence (e.g. certification) for all personnel, including contracted employees, who have a role in the lifting operation - i.e. lifting appliance / crane operator, slinger, signaller - shall be readily accessible on request to the lifting supervisor at the location where the lifting operation is to be performed.

Personnel under training should only undertake duties within their current level of assessment by the Competent Person and then only under supervision of a qualified person.

Periodic assessment and refresher training shall be conducted at intervals not exceeding periods stated by the training organization course requirements, to ensure the necessary level and standard of training is maintained.

14. DRUG AND ALCOHOL POLICY

Drug and alcohol abuse is not acceptable in the workplace. Every responsible employer should acknowledge his obligation to take all reasonable steps to ensure the health and safety of its workers.

Legal regulation in relation to the testing of personnel on the use of alcohol or drugs might vary throughout the European Union. However a sensible drugs and alcohol policy as a minimum provides for the testing of employees for drug/alcohol abuse, assisting employees who voluntarily seek help for problems relating to alcohol and/or drugs, and educating employees on the dangers of drug and alcohol abuse.

A drug and alcohol policy should apply to all employees of a company. This policy may also be extended to subcontractors.

For the purposes of this policy, the following should be prohibited:

1. Being impaired by alcohol/drugs while at work.
2. The possession or use of illicit drugs on company premises, at company worksites, or in company vehicles.
3. The presence in the body of illicit drugs (or their metabolites) while at work.

For a sample Drugs and Alcohol Policy document please refer to **Appendix 4: Reference Documents**.

15. CONTRACTUAL CONSIDERATIONS (SITE RESPONSIBILITIES)

A successful installation of wind turbine generators requires a close cooperation and good communication between the site owner, the wind turbine manufacturer and transportation and installation companies. A well-designed contract will have provisions that address these issues and define the responsibilities of the various parties during the construction phase of the project.

For easy reference on the site we recommend a site responsibility schedule should be agreed on and made known to site staff. A sample document can be found in **Appendix 4: Reference Documents**.

The employing organization must determine whether a contractor has the necessary competence to carry out transport or lifting operations in accordance with the statutory requirements and the recommendations of this guideline. Appointment of the Competent Person and responsible person shall be carried out as agreed in the contract between the employing organization and contractor.

15.1 Transport contracts

There are several ways to contract transport operations but for the sake of this document we are specifying the normal transport industry practice and including terminology as detailed and accepted with normal domestic and international transport operations. In order for the transport contractor to understand the full scope of his supply, the client should first be clear as to their own scope of supply of the transport and shipping services of their products.

Incoterms are a set of rules which define the responsibilities of sellers and buyers for the delivery of goods under sales contracts. Shippers worldwide use standard trade definitions, called Incoterms (International Commercial Terms) to spell out who's responsible for the shipping, insurance, and tariffs on an item. They are commonly used in international contracts and are protected by International Chamber of Commerce copyright. Incoterms significantly reduce misunderstandings among traders and thereby minimize trade disputes and litigation.

In 2010, the two main categories of Incoterms were updated and are organized by modes of transport. Used in international as well as in domestic contracts for the first time, the new groups aimed to simplify the drafting of contracts and more clearly stipulate the obligations of buyers and sellers. These rules are due to be updated once again in 2020:

Group 1. The main Incoterms that apply to any mode of transport are:

- EXW = Ex Works
- FCA = Free Carrier
- CPT = Carriage Paid To
- CIP = Carriage and Insurance Paid To
- DAT = Delivered at Terminal
- DAP = Delivered at Place
- DDP = Delivered Duty Paid

Group 2. Incoterms that apply to sea and inland waterway transport only:

- FAS = Free Alongside Ship
- FOB = Free on Board
- CFR = Cost and Freight
- CIF = Cost, Insurance, and Freight

On this basis, the incoterm FOT (Free on Truck) is usually the defined starting point for most road transport contracts and operations as the transport operator is then responsible for the cargo at this point. From FOT to FOT means that the loading and offloading of the cargo is the responsibility of others.

Once the cargo is loaded to the truck, there are specific national and international 'Conditions of Carriage' that can be automatically imposed on the transport of goods.

For cross border traffic and international journeys by road in Europe, the 'Convention on the Contract for the International Carriage of Goods by Road (CMR) - (Geneva, 19 May 1956)' is a mandatory condition of carriage.

CMR conditions of carriage stipulate the responsibilities, performance, liabilities and provisions for the cargo whilst on a continuous international journey by road, including roll on/roll off ferry journeys by sea. However, if the cargo is unloaded from the vehicle and carried separately on another mode of transport, for example a ship, then CMR will not apply to the movement in accordance with Article 2 of the convention.

If a transport is deemed to be subject to CMR conditions of carriage, a specific document should be used for the transport, being a CMR consignment note.

If turbine components are not subject to CMR conditions of carriage, then the 'domestic rules' and conditions of carriage of the transport contractor are usually adopted. This could mean that two different conditions of carriage are present - first, conditions pertinent to the country of origin from the factory door to the port of export; second, conditions pertinent to the country of destination from the port of import to the delivery address.

Specifically, there are differences in the liabilities and insurance cover values between the various conditions of carriage, therefore some attention should be paid to defining the terms and conditions for which turbine manufacturers and transport operators contract the movement of the components.

Furthermore, it should be considered that once the components are 'grounded' on site, should they need to be reloaded or moved internally within the site, the handling, loading, and transporting of the components will fall under a separate or different set of terms and conditions.

15.2 Lifting contracts

When a lifting operation is contracted as a **Contracted Lift**, the contractor provides the Competent Person, lifting equipment and personnel. The contractor is responsible for operation of a safe system to work – planning, organization and control of the lifting operation.

When the contract is signed for a **Hired Lift Service**, the contractor provides a crane that is properly certified and tested and a competent and certified crane driver. The employing organization provides the Competent Person and lifting team personnel. The employing organization plans the lifting operation and operates a safe system of work.

In all contractual relations relating to the construction of wind power generating plants, an efficient and flawless interaction between employer and contractor is of the utmost importance. Exchange of data between employer and contractor with regard to soil conditions, access and site roads, hard stands and the various local (site) requirements and site regulations should be in a timely and organised fashion. Also attention should be given to make unequivocally clear between parties, who is responsible for which of the various interacting contractual obligations.

As a guideline a sample of a “Site Responsibilities” schedule is inserted.

Item	Site owner	Plant construction	Lifting / transport Contractor
Access road preparation	X		
Local Site specific regulations	X	X	
Site roads preparation		X	
Lighting & Marking of site roads		X	
Emergency services	X	X	
Supply of component details		X	
Route survey			X
Transport Management Plan			X
Transport Drawings			X
Risk assessment preparation		X	X
National HSE legislation		X	X
Mobilisation of lifting equipment			X
Crane stand preparation		X	
Lift Plan preparation			X
Lift execution			X
Assembly of Tower parts		X	
Demobilisation of lifting equipment			X
Cleaning of site construction area		X	

For both horizontal as well as vertical transport movements on site usually a Construction All-risk Insurance (CAR) will be in place which covers the associated risks. Contract parties should be aware these CAR policies can carry a high deductible and should be clear about policy conditions during the contracting stage.

16. APPENDIX 1 - ROAD DESIGN PARAMETERS, TRANSPORT CONFIGURATIONS AND ROAD LAYOUT DRAWINGS.

Transport and crane manual recommendations

Column A	Component Size	Common vehicle type	Results based on Manual Steering	Usable road Width	At 30 Degrees				Min. Inside Radii
					Min. Inside Radii	Min. Outside Radii	Usable road width	Oversail area required	
Blades									
B40.1 & track	up to 40m long Blade	Double/Triple teletrailer	No	4.5m	130m	40m	7.5m	-	32m r + 25m
B55.1 & Track	up to 55m long Blade	Triple teletrailer semi-step	No	4.5m	250m r + 25m	40m	9.5m	-	45m r + 50m
B70.1 & Track	up to 70m long Blade	Superwing trailer	No	4.5m	40m	55m	15.0m	-	40m
B74.1 & Track	74m long Blade Horizontal at 0°	**Blade Adapter SPT	Yes	4.5m	35.5m	40m	4.5m	See Dwg	35.5m
B74.2 & Track	74m long Blade Vertical at 60°	**Blade Adapter SPT	Yes	4.5m	35.5m	40m	4.5m	See Dwg	35.5m
B85.1 & Track	up to 85m long Blade	Clamp and Dolly system	Yes	4.5m	35m	40m	5.0m	See Dwg	32m r + 25m
Towers									
T40.1 & Track	up to 3.0m dia x 30m lg - 40 Te	Platform	No	4.5m	150m	40m	6.5m	-	70m r + 20m
T40.2 & Track	up to 3.0m dia x 30m lg - 40 Te	Stepframe semi trailer	No	4.5m	130m	40m	7.0m	-	45m r + 20m
T55.1 & Track	up to 4.0m dia x 20m lg - 55 Te	Vesselbridge / Low Loader	No	4.5m	120m	40m	7.5m	See Dwg	40m r + 25m
T70.1 & Track	up to 4.5m dia x 25m lg - 70 Te	Clamp system	Yes	4.5m	35m r + 15m	40m	5.0m	See Dwg	35m r + 10m
T90.1 & Track	up to 4.8m dia x 36m lg - 90 Te	HD Clamp and modular dollies	Yes	4.5m	35m r + 15m	40m	5.0m	See Dwg	35m r + 10m
T100.1 & Track	up to 5.6m dia x 25m lg - 100 Te	HD Clamp and modular dollies	Yes	4.5m	35m r + 15m	40m	5.0m	See Dwg	35m r + 10m
T100.2 & Track	up to 5.6m dia x 25m lg - 100 Te	**SPT	Yes	4.5m	34m r + 10m	40m	6.0m	See Dwg	34m r + 15m
Nacelle									
N30.1 & Track	3.0 Wi x 3.0 Hi - 30 Te	Stepframe semitrailer	No	4.5m	35.5m	40m	4.5m	-	35.5m
N70.1 & Track	4.0 Wi x 4.0 Hi - 70 Te	Stepframe semitrailer	No	4.5m	35.5m	40m	4.5m	-	35.5m
N70.2 & Track	4.0 Wi x 4.0 Hi - 70 Te	Low Loader	No	4.5m	120m	40m	7.0m	-	32m r + 25m
N90.1 & Track	4.5 Wi x 4.2 Hi - 90 Te	Stepframe semitrailer	No	4.5m	35m r + 15m	40m	5.0m	See Dwg	35m r + 10m
N90.2 & Track	4.5 Wi x 4.2 Hi - 90 Te	Low Loader	No	4.5m	150m	40m	8.0m	See Dwg	40m r + 25m
N90.3 & Track	4.5 Wi x 4.2 Hi - 90 Te	Clamp System	Yes	4.5m	35.5m	40m	4.5m	See Dwg	35.5m
N110.1 & Track	5.0 Wi x 4.5 Hi - 110 Te	Low Loader	No	4.5m	170m	40m	8.5m	See Dwg	40m r + 35m
N110.2 & Track	5.0 Wi x 4.5 Hi - 110 Te	Clamp System	Yes	4.5m	35m r + 15m	40m	5.0m	See Dwg	35m r + 10m
N110.3 & Track	5.0 Wi x 4.5 Hi - 110 Te	**SPT	Yes	4.5m	35m	40m	5.0m	See Dwg	35m

Remarks

- Sufficient oversail area should be available to accommodate overhang following from a swept path analyses
- The full bend radii should be on a horizontal plane surface
- In case of reversing 50 cm extra roadwidth should be considered.
- Blade transports on site should always be executed by a driver and a steersman using radio communication
- Manual steering of trailer equipment must be kept to a minimum due to risk of accidents and steersman fatigue
- Manual steering of trailer equipment must only be operated at walking speed

In the spreadsheet above the worst case scenario is indicated

Further information about typical transport configurations with the related track requirements are contained in a series of PDF documents held in a special section of the ESTA website at www.estaurope.eu/BPGApp1 The PDF file names on the website refer to Column A in the spreadsheet below.

At 60 Degrees			At 90 Degrees										
Min. Outside Radii	Usable road width	Oversail area required	Min. Inside Radii	Min. Outside Radii	Usable road width	Oversail area required	Vertical curve (pos/neg)	Vertical curve Radii	Cross fall	Uphill and downhill Max Gradient / Slope	Maximum weight per axle	Gross weight	Window (width x height)
40m	8.0m	-	40m	48m	8.0m	-	90cm over 30m	130m	2%	10% compacted surface	12 Te	40 Te	5.0 x 4.5
40m	12.0m	-	40m	53m	13.0m	-	85cm over 45m	300m	2%	10% compacted surface	12 Te	40 Te	5.0 x 5.0
55m	15.0m	-	40m	55m	15.0m	-	100cm over 60m	450m	2%	10% compacted surface	12 Te	60 Te	5.5 x 5.0
40m	4.5m	See Dwg	40m	44.5m	4.5m	See Dwg	62cm over 13.5m	37m	2%	10% compacted surface	13 Te	124 Te	See Dwg
40m	4.5m	See Dwg	40m	44.5m	4.5m	See Dwg	62cm over 13.5m	37m	2%	10% compacted surface	16 Te	124 Te	See Dwg
40m	8.0m	See Dwg	40m	48m	8.0m	See Dwg	200cm over 70m	310m	2%	10% compacted surface	12 Te	80 Te	6.5 x 6.0
40m	7.0m	-	40m	47m	7.0m	-	48cm over 25m	160m	2%	10% compacted surface	12 Te	60 Te	4.5 x 5.0
40m	8.0m	-	40m	48m	8.0m	-	35cm over 30m	300m	2%	10% compacted surface	12 Te	70 Te	4.5 x 4.5
40m	9.0m	See Dwg	40m	50m	10.0m	See Dwg	55cm over 35m	265m	2%	10% compacted surface	12 Te	105 Te	5.0 x 5.0
40m	5.0m	See Dwg	40m	45m	5.0m	See Dwg	120cm over 37m	145m	2%	10% compacted surface	12 Te	125 Te	5.5 x 5.0
40m	5.0m	See Dwg	40m	45m	5.0m	See Dwg	80cm over 42m	250m	2%	10% compacted surface	12 Te	133 Te	6.0 x 6.0
40m	5.0m	See Dwg	40m	45m	5.0m	See Dwg	70cm over 39m	265m	2%	10% compacted surface	12 Te	160 Te	7.0 x 6.5
40m	6.0m	See Dwg	40m	46m	6.0m	See Dwg	62cm over 25.5m	132m	2%	10% compacted surface	14 Te	168 Te	7.0 x 7.5
40m	4.5m	-	40m	44.5m	4.5m	-	20cm over 8m	45m	2%	10% compacted surface	12 Te	52 Te	4.5 x 4.5
40m	4.5m	-	40m	44.5m	4.5m	-	12cm over 9m	80m	2%	10% compacted surface	12 Te	110 Te	5.0 x 5.0
40m	8.0m	-	40m	48m	8.0m	-	55cm over 27m	160m	2%	10% compacted surface	12 Te	135 Te	5.0 x 5.5
40m	5.0m	See Dwg	40m	45m	5.0m	See Dwg	40cm over 18m	105m	2%	10% compacted surface	12 Te	145 Te	5.5 x 5.5
40m	9.0m	See Dwg	40m	49m	9.0m	See Dwg	55cm over 34m	260m	2%	10% compacted surface	12 Te	165 Te	5.5 x 5.5
40m	4.5m	See Dwg	40m	44.5m	4.5m	See Dwg	60cm over 23m	100m	2%	10% compacted surface	12 Te	145 Te	5.5 x 5.0
40m	10.0m	See Dwg	40m	51m	11.0m	See Dwg	55cm over 38m	320m	2%	10% compacted surface	12 Te	200 Te	6.0 x 6.0
40m	5.0m	See Dwg	40m	45m	5.0m	See Dwg	74cm over 24m	100m	2%	10% compacted surface	12 Te	190 Te	6.0 x 5.0
40m	5.0m	See Dwg	40m	45m	5.0m	See Dwg	62cm over 16.5m	55m	2%	10% compacted surface	14 Te	165 Te	6.0 x 6.0

- The negotiation of curves with a greater bend than 90 degrees requires a swept path analysis
- Window dimensions are based on a straight horizontal road

** Steering geometry is set for centre point turning circle

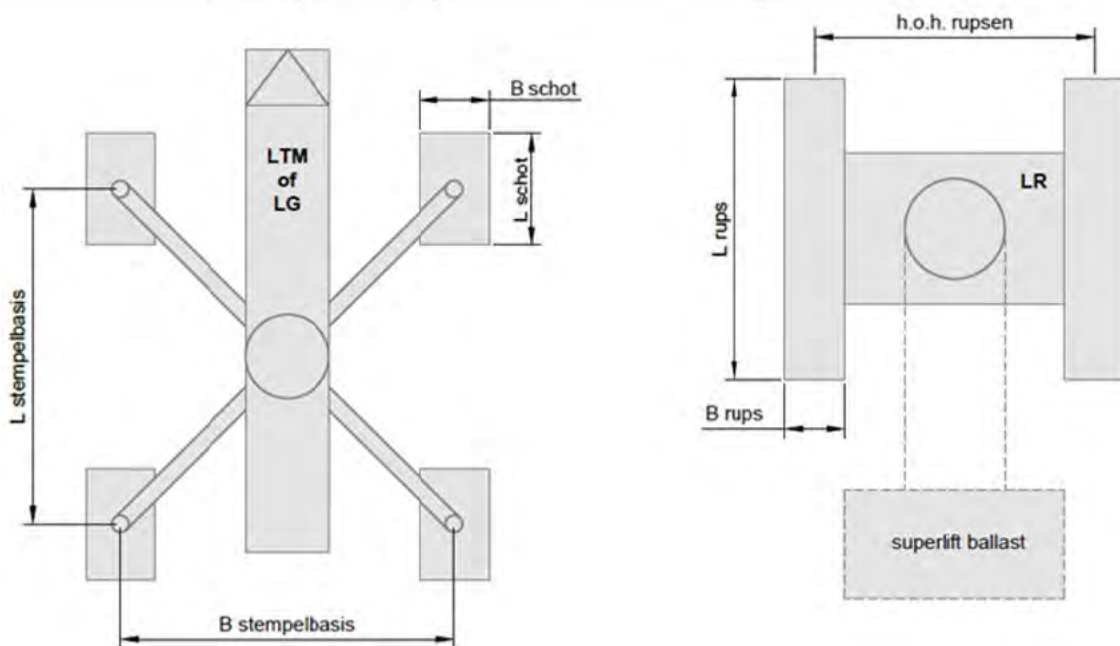
17. APPENDIX 2 - GROUND LOADING DETAILS AND DRAWING EXAMPLES OF TYPICAL CRANES.

The values in this table are indicative and only intended to create awareness. Alternative crane types and / or configurations are available for each load case, with deviating outrigger forces and / or crawlertrack pressures. The crane supplier must confirm the occurring pressures for each new project by means of the hoisting plan.

Nr.	Load Case				Crane basics				Boom erection				Operational situation, lifting nacelle					
	Kraan type	Con-figuration	Nacelle weight (ton)	Hub height (m)	Mass basic crane ^{*1} (ton)	Outriggerbase LxB / centre line crawlers (m)	Crane mat size ^{*2} LxB (m)	Crawler size ^{*3} LxB (m)	Required SL ballast (ton)	Total crane mass (ton)	Max. outrigger force (kN)	Max. crawler pressure (kN/m ²)	Hook height (m)	Crane radius (m)	Required SL ballast (ton)	Total mass crane (ton)	Max. outrigger force (kN)	Max. crawler pressure (kN/m ²)
1	LTM 1500-8.1	TY3SN	70	60	290	10,0 x 9,6	4,0x2,4	-	nvt	290	942	-	75	18	nvt	290	1472	-
2	LTM 1750-9.1	TYV2EN	80	80	395	12,0 x 12,0	4,5x2,4	-	nvt	395	1236	-	90	20	nvt	395	1815 ^{*5}	-
3	LTM 11200-9.1	T3YV2VEN	80	105	430	13,0 x 13,0	5,8x2,4	-	nvt	430	1432	-	115	24	nvt	430	2129 ^{*5}	-
4	LR 1600/2	SL3F	80	105	485	8,4	-	8,7x1,34	nvt	485	1550 ^{*4}	315 ^{*4}	120	18	nvt	485	-	473
5	LG 1750	SL8HS	80	105	495	16,0 x 16,0	6,0x2,5	-	nvt	495	2276	-	125	18	nvt	495	1864 ^{*5}	-
6	LR 1600/2	HSL4DF	80	120	560	8,4	-	8,7x1,34	250	810	-	942	135	20	0-70	560-630	-	545
7	LG 1750	SL8HDS	80	120	460	12,0 x 12,0	6,0x2,5	-	200	660	2276	-	140	20	-	460	1991	-
8	LR 1600/2	SL13DFB	80	140	565	8,4	-	8,7x1,34	300	865	-	816	155	24	45-90	610-655	-	498
9	LG 1750	SL7DHS	80	140	520	12,0 x 12,0	6,0x2,5	-	250	770	2766	-	150	24	-	520	2325	-
10	LR 1750/2	HSL7DHS	80	140	630	8,8	-	9,1x1,34	290	920	-	904	155	24	-	630	-	739
11	LR1750/2	SX3D4F2B	105	165	830	8,8	-	9,1x1,8	400	1230	-	587	180	28	105-175	935-1005	-	421
12	LG 1750	SX3D4F2B	110	165	725	12,0 x 12,0	6,0x2,5	-	400	1125	2943	-	180	28	110-180	835-905	2560	-
13	LG 1750	SL12D2FB	140	130	750	12,0 x 12,0	6,0x2,5	-	340	1090	2502	-	145	28	130-190	880-940	2609	-

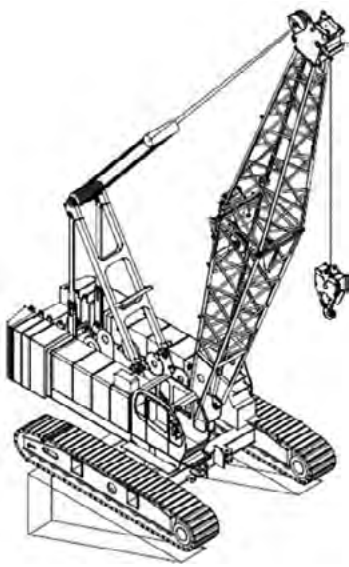
^{*1} Excluding any necessary Superlift Ballast for erecting the boom or operational situation
^{*2} Indicative (generally differs per crane operating company), the crane mats may be used in the turned position.
^{*3} Most crawler cranes in this class can be equipped with tracks with a width of 1.5 m or 2.0 m (the effective working width on hard surfaces is 1.34 or 1.84 m)
^{*4} The boom is erected with the help of uprighting outriggers, the entire crane mass is distributed over the two outriggers (max. 1550 kN tons on one leg) and one crawler track (max 315 kN / m2)
^{*5} In the operational situation, the largest pressures sometimes occur without a load in the hook, with a fully elevated boom (concerns a backward moment caused by the crane ballast).

No rights can be derived from this table.

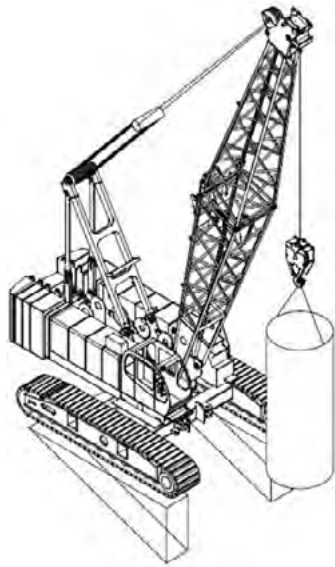


Further information and data sheets from Liebherr, Manitowoc and Tadano-Demag are available in the special section of the ESTA website at www.estaurope.eu/BPGApp2

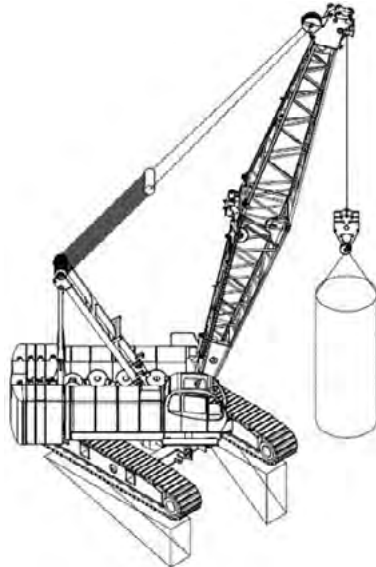
Figure 30: ground load distribution in different load cases



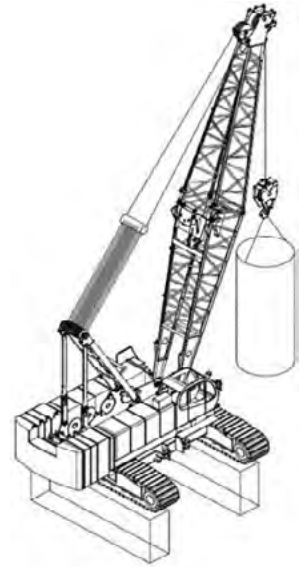
With no load on the hook the pressure is at highest under the rear of the tracks due to the counterweight.



With the jib in line with the tracks and a load on the hook there will be an equal, triangular or trapezoidal loading under each track.



As the jib is slewed around until it is over the end of one track, the pressure increases under that track.



If the jib is slewed until it is at a right angle to the tracks the pressure becomes a rectangular distribution with the track nearest the load usually having the greatest pressure.



Figure 31: Site transport of a 750 tons Telescopic crane



Figure 32: Example of a “tailing operation” with a main crane and a tailing crane

18. APPENDIX 3 – TYPICAL DRAWING EXAMPLES OF TRANSPORT EQUIPMENT AND TRANSPORT PHOTOGRAPHS



3 D view of a 4-axle double extendible step trailer



4-axle double extendible step trailer



8 axle extendible semi lowloader



Figure 33: 4-axle tractor with 3-7 extendible semi lowloader loaded with tower section



Figure 34: 4-axle tractor with 3 bed 5 lowloader loaded with Nacelle



Figure 35: 3 axle tractor with superwingcarrier loaded with a WTG wing



Figure 36: 4 axle tractor with 8 axle semi lowloader loaded with a nacelle

19. APPENDIX 4 – REFERENCE DOCUMENTS

Further reference documents on FEM5016, ESNB, ICSA Sample TRA's and Sample drugs and alcohol policy are available in the special section of the ESTA website at www.estaeurope.eu/BPGApp4

ISO 12480-1

Link: <https://www.iso.org/standard/2534.html>

Example of equivalent forms of Wind conditions

Beaufort number	Description	Wind speed			
		km/h	mph	kts	m/s
0	Calm	<1	<1	<1	< 0.3
1	Light air	1.1 – 5.5	1 – 3	1 – 2	0.3 – 1.5
2	Light breeze	5.6 – 11	4 – 7	3 – 6	1.6 – 3.4
3	Gentle breeze	12 – 19	8 – 12	7 – 10	3.4 – 5.4
4	Moderate breeze	20 – 28	13 – 17	11 – 15	5.5 – 7.9
5	Fresh breeze	29 – 38	18 – 24	16 – 20	8.0 – 10.7
6	Strong breeze	39 – 49	25 – 30	21 – 26	10.8 – 13.8
7	High wind, Moderate gale	50 – 61	31 – 38	27 – 33	13.9 – 17.1
8	Gale, Fresh gale	62 – 74	39 – 46	34 – 40	17.2 – 20.7
9	Strong gale	75 – 88	47 – 54	41 – 47	20.8 – 24.4
10	Storm, Whole gale	89 – 102	55 – 63	48 – 55	24.5 – 28.4
11	Violent storm	103 – 117	64 – 72	56 – 63	28.5 – 32.6
12	Hurricane-force	≥ 118	≥ 73	≥ 64	≥ 32.7

20. APPENDIX 5 – CALCULATING THE GRADEABILITY

Gradeability is dependent on:

- Tractive force (see Formula 1)
- Overall combined mass, including overall mass of the trailer or semi-trailer
- Rolling resistance
- Adhesion (friction)

Formula 1: Tractive force

$$F_z = \frac{2 \cdot \pi \cdot M_{MOT} \cdot \eta \cdot i_G \cdot i_V \cdot i_A}{U}$$

F_z : Tractive force in N

i_G : Transmission ratio

i_A : Driven axle ratio

i_V : Transfer case ratio

M_{MOT} : Engine torque, in Nm

U : Tyre rolling circumference, in m

η : Overall efficiency in the drive train, see Table 2

The following applies for gradeability:

Formula 2: Gradeability

$$\rho = 100 \cdot \left[\frac{F_z}{9.81 \cdot G_z} - f_R \right]$$

Where:

ρ = Gradeability, in %

F_z = Tractive force in N
(calculated in accordance with Formula 1)

G_z = Overall combined mass, in kg

f_R = Coefficient of rolling resistance, see Table 1

i_G = Transmission ratio

i_A = Driven axle ratio

i_V = Transfer case ratio

M_{MOT} = Engine torque, in Nm

U = Tyre rolling circumference, in m

η = Overall efficiency in the drive train, see Table 2

The gradeability determined using Formula 2 calculates the vehicle's gradeability based on its

- Engine torque
- Transmission, transfer case, final drive and tyre ratio and
- Overall combined mass properties.

Here only the vehicle's ability to tackle a specific gradient based on its properties is considered. Not taken into consideration is the actual adhesion between wheels and road which, in poor conditions (e.g. wet roads) can reduce propulsion so that hill-climbing performance is far below the value calculated here. Calculation of the actual conditions based on adhesion is addressed in Formula 3.

Table 1: Coefficients of rolling resistance

Road Surface	Coefficient f_R
Good Asphalt Road	0.007
Wet Asphalt Road	0.015
Good Concrete Road	0.008
Rough Concrete Road	0.011
Block Paving	0.017
Poor Road	0.032
Dirt Track	0.15...0.94
Loose Sand	0.15...0.30

Table 2: Overall efficiency in the drive train

Number of Driven Axles	η
One driven axle	0.95
Two driven axles	0.9
Three driven axles	0.85
Four driven axles	0.8

Example of calculation:

Vehicle Model	T42, 27.414 DFAK
Max. engine torque	$M_{MOT} = 1850 \text{ Nm}$
Efficiency with three driven axles	$\eta = 0.85$
Transmission ratio in lowest gear	$i_G = 13.80$
Transfer case ratio in on-road applications	$i_V = 1.007$
in off-road applications	$i_V = 1.652$
Final drive ratio	$i_A = 4.77$
Tyre 295/80 R 22.5 with rolling circumference	$U = 3.185 \text{ m}$
Overall combined mass	$G_Z = 100000 \text{ kg}$
Coefficient of rolling resistance smooth asphalt road	$f_R = 0.007$
poor, rutted road	$f_R = 0.032$

Desired feature:

Maximum gradeability pf in on-road and off-road conditions.

Solution:

1. Maximum tractive force (for definition, see Formula 1) in on-road conditions:

$$F_Z = \frac{2\pi \cdot M_{MOT} \cdot \eta \cdot i_G \cdot i_V \cdot i_A}{u}$$

$$F_Z = \frac{2 \cdot 3.14 \cdot 1850 \cdot 0.85 \cdot 13.8 \cdot 1.007 \cdot 4.77}{3.185}$$

$$F_Z = 205,526 \text{ N} = 205.5 \text{ kN}$$

2. Maximum tractive force (for definition, see Formula 1) in off-road conditions:

$$F_Z = \frac{2\pi \cdot M_{MOT} \cdot \eta \cdot i_G \cdot i_V \cdot i_A}{u}$$

$$F_Z = \frac{2 \cdot 3.14 \cdot 1850 \cdot 0.85 \cdot 13.8 \cdot 1.652 \cdot 4.77}{3.185}$$

$$F_Z = 337,170 \text{ N} = 337.2 \text{ kN}$$

3. Maximum gradeability in on-road conditions on good asphalt road:

$$\rho = 100 \left[\frac{F_Z}{9.81 \cdot G_Z} - f_R \right]$$

$$\rho = 100 \left[\frac{205,526}{9.81 \cdot 100,000} - 0.007 \right]$$

$$\rho = 20.25\%$$

4. Maximum gradeability in on-road conditions on poor, rutted road:

$$\rho = 100 \left[\frac{F_Z}{9.81 \cdot G_Z} - f_R \right]$$

$$\rho = 100 \left[\frac{205,526}{9.81 \cdot 100,000} - 0.032 \right]$$

$$\rho = 17.75\%$$

5. Maximum gradeability in off-road conditions on good asphalt road:

$$\rho = 100 \left[\frac{F_Z}{9.81 \cdot G_Z} - f_R \right]$$

$$\rho = 100 \left[\frac{337,170}{9.81 \cdot 100,000} - 0.007 \right]$$

$$\rho = 33.67\%$$

6. Maximum gradeability in off-road conditions on poor, rutted road:

$$\rho = 100 \left[\frac{F_Z}{9.81 \cdot G_Z} - f_R \right]$$

$$\rho = 100 \left[\frac{337,170}{9.81 \cdot 100,000} - 0.032 \right]$$

$$\rho = 31.17\%$$

Note:

The examples shown do not take into consideration whether adhesion between road and driven wheels (friction) will allow the tractive force required for tackling the gradient to be transmitted. The following formula is applied for this:

Formula 3: Gradeability taking into account road/tyre adhesion

$$\rho_R = 100 \cdot \left[\frac{\mu \cdot G_{an}}{G_Z} - f_R \right]$$

Where:

- ρ_R = Hill-climbing performance taking friction into account, in %
- μ = Tyre/road surface coefficient of friction, on wet asphalt surface ~ 0.5
- f_R = Coefficient of rolling resistance, on wet asphalt road surface ~ 0.015
- G_{an} = Sum of the axle loads of the driven axles as mass, in kg
- G_Z = Overall combined mass, in kg

Example of calculation:

Above vehicle Model	Type T42, 27.414 DFAK
Friction coefficient, wet asphalt road	$\mu = 0,5$
Coefficient of rolling resistance, wet asphalt	$f_R = 0,015$
Overall combined mass	$G_Z = 100,000$ kg
Sum of the axle loads of all driven axles	$G_{an} = 26,000$ kg

$$\rho_R = 100 \left[\frac{\mu \cdot G_{an}}{G_Z} - f_R \right]$$

$$\rho_R = 100 \left[\frac{0.5 \cdot 26,000}{100,000} - 0.015 \right]$$

$$\rho_R = 11.15\%$$

5 Torque

If force and distance from line of action are known:

Formula 4: Torque with force and distance from line of action

$$M = F \cdot I$$

If power output and rotational speed are known:

Formula 5: Torque with power output and rotational speed

$$M = \frac{9,550 \cdot P}{n \cdot \eta}$$

In hydraulic systems, if delivery rate (volume flow rate), pressure and rotational speed are known:

Formula 6: Torque with delivery rate, pressure and rotational speed

$$M = \frac{15.9 \cdot Q \cdot P}{n \cdot \eta}$$

Where:

- M = Torque, in Nm
- F = Force, in N
- I = Distance from the line of action on the force to the centre of rotation, in m
- P = Power output, in kW
- n = Rotational speed, in 1/min
- η = Efficiency
- Q = Volume flow rate, in l/min
- p = Pressure, in bar

Example of calculation when force and distance from line of action are known:
A cable winch with a pulling force F of 50,000 N has a drum diameter d = 0.3 m. Without taking efficiency into account, what is the torque?

Solution:

$$M = F \cdot I = F \cdot 0.5d \text{ (the drum radius is the leverage)}$$

$$M = 50,000 \cdot 0.5 \cdot 0.3 = 7,500 \text{ N.m}$$

Example when power output and rotational speed are known:
A power take-off is to transmit a power P of 100 kW at $n = 1500$ /min. Without taking efficiency into account, what torque must the power take-off be able to transmit?

Solution:

$$M = \frac{9,550 \cdot P}{n \cdot \eta}$$

$$M = \frac{9,550 \cdot 100}{1,500}$$

$$M = 637 \text{ N.m}$$

Example if delivery rate (volume flow rate), pressure and rotational speed are known for a hydraulic pump:

A hydraulic pump delivers a volume flow rate Q of 80 l/min at a pressure p of 170 bar and a pump rotational speed n of 1000/min. Without taking efficiency into account, what torque is required?

Solution:

$$M = \frac{15.9 \cdot Q \cdot P}{n \cdot \eta}$$

$$M = \frac{15.9 \cdot 80 \cdot 170}{1,000}$$

$$M = 216 \text{ N.m}$$

If efficiency is to be taken into account, the torques calculated in each case must be divided by the overall efficiency.



Europäische Schwertransport-Automobilkranunion
European association for abnormal road transport and mobile cranes
Federation Europeene pour les transport exceptionnels et les grues mobiles

ESTA Office

Lotte Beesestraat 4
2331 KJ Leiden
The Netherlands
T: +31 71 572 4705
F: +31 71 572 4968
info@estaeurope.eu

www.estaeurope.eu