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Tower crane stability

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sharing knowledge ■ building best practice

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Summary

The document is intended to promote the safe design of foundations for, and use of, tower cranes through an improved understanding of temporary works design and health and safety issues. The initial sections of the report are aimed at those groups who need to understand the issues related to the safe use of tower cranes – planners, architects, permanent works engineers and site supervisors. The report highlights some key situations in which a specialist should be consulted. It covers specific guidance for designers of temporary works involving tower cranes. Issues include the understanding of wind effects, other loading and support considerations, and particularly factors of safety and design of foundations. Readers of this document may wish to refer to BS 7121-5:1997 *Code of practice for safe use of cranes. Tower cranes* and CIRIA publication C703 *Crane stability on site* for detailed guidance, and this is highlighted in the text.

Tower cranes are a vital element in the construction process. There are around 1500 cranes in the UK and at any time around 1000 are in use. Tower cranes are often in use on construction sites in urban areas and, although rare in the UK, any collapse of the crane is likely to result in injury to members of the public outside the boundaries of the site as well as personnel working inside the site. Collapse of tower cranes also presents a risk to adjacent railways and roads. This guidance aims to bring together important practical and design issues that impact on health and safety and to present a current understanding of best practice based on the experience of a wide cross-section of the industry.

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Bob Dunkley spent 31 years with John Laing in its temporary works department, and developed a specialism in tower crane bases. He was responsible for the design of many foundations, of all types, for tower cranes and wrote the firm's in-house design manual for tower crane bases. He has previously been involved in the preparation of the CIRIA site guide *Crane stability on site* (C703).

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Paul Blackmore is head of the wind engineering group at BRE. As a specialist in fluid mechanics – wind engineering and wind tunnel testing – he has 20 years of expertise in wind tunnel testing, wind loading and weathertightness and the analysis of wind damage and development of wind damage assessment methods. He has acted as an expert witness in cases of wind effects and damage including tower cranes. He is a member of a number of BSI and CEN committees related to wind loading and temporary structures.

The project was initially managed by Natalya Brodie-Hubbard, project manager, with Andrew Pitchford, project director, and subsequently led by Das Mootanah, project manager.

Steering group Following CIRIA's tradition of collaboration, the study was guided by a steering group of experts involved, or with an interest in the planning and management of tower crane use, and related health and safety issues and mitigation. CIRIA would like to express its thanks and appreciation to all members of the project steering group for their helpful and valued comments and advice throughout the project. The steering group comprised:

Chair	Mr Paul Phillips	HTC Plant Ltd
Members	Mr Mark Blundy	RB Wilbrey (Consultants) Limited
	Mr David J Butterworth	Health & Safety Executive
	Mr Robert Cameron	Sir Robert McAlpine Ltd
	Mr David Carter	George Wimpey UK Ltd
	Mr Charles S Dye	Lewis & Hickey Safety Management Ltd
	Mr Paul Forrester	Royal & Sun Alliance Engineering Business (Representing Safety Assessment Federation Limited)
	Mr Bernard Holman	HTC Plant Ltd
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	Mr Alan J Miles	Interserve Project Services Limited
	Mr Andy Newell	National Construction College, CITB-Construction Skills
	Mr Peter Oram	Peter Oram Consulting
	Mr David Rathbone	Alan Baxter & Associates (Representing the Department of Trade and Industry)
	Mr Ian Simpson	Health & Safety Executive
	Mr Haydn Steele	Construction Plant-hire Association
	Mr Rob Sweeney	CITB-Construction Skills
	Mr Andrew Thomsett	Taylor Woodrow Developments Limited
	Mr Kanji Vekaria	Bovis Lend Lease
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anemometer	device that measures and wind speed and direction
anemograph	device that measures and records wind speed and direction
appointed person	person with the training, practical and theoretical knowledge and experience required to comply with Clause 3.3 of BS 7121-1:1989
competent person	person who has such practical and theoretical knowledge and such experience of the crane and the equipment used in the lifting operation as is necessary to carry out the function to which the term relates in each particular context
crane coordinator	person who plans the sequence of operations of tower cranes on sites having more than one crane, to ensure that cranes, components and loads do not collide
crane operator	person who is operating the crane for the purpose of positioning loads or erection of the crane NOTE Sometimes referred to as "crane driver"
crane supervisor	person who controls the lifting operation, and ensures that it is carried out in accordance with the appointed person's safe system of work
DIN	German standards body (Deutsches Institut für Normung)
dead loads	weights of the tower crane components
EN	standard issued by **CEN** (Comité Européen de Normalisation) the European committee for standardisation.
EQU	equilibrium, or "overall stability" limit state in BS EN 1997: geotechnical design.
FEM 1.001	standards for crane design
FEM	(Fédération Européenne de la Manutention) is the European organisation of material handling suppliers.
imposed loads	weight of the load being lifted
live loads	wind loading
prEN	draft CEN standard.
reconfiguration	a change in the crane configuration when the crane has been installed (for example raising the crane height or altering the jib length)
signaller	person responsible for directing the crane operator to ensure safe movement of the crane and load
slinger	person responsible for attaching and detaching the load to and from the crane and for correct selection and use of lifting accessories.

1 Introduction

This best practice guide is intended to:

- provide basic information to all those involved in the planning and management of tower crane use
- enable temporary works design for tower cranes to be standardised and experience shared.

This report recognises that the standards relating to the design of cranes and the design of temporary works are changing. It is anticipated that within the next five years information routinely available from crane owners for the purposes of structural and geotechnical design will be more detailed, and will align with the design philosophy of the Eurocodes for structural design that are due within the next 10 years. Foundation design examples that relate to the current approach and to the Eurocode design are included.

While it articulates best practice based on the experience of a wide cross-section of the industry, this report does not deal with day-to-day lifting operations, rather with temporary works design, planning, communication and management of tower cranes.

Throughout the report, the "owner" is generally defined as "the company, firm or person owning and/or letting the plant on hire". The "user" is generally defined as "the company, firm, person, corporation or public authority taking the owner's plant on hire."

1.1 CAUSES OF FAILURE

While the collapse of tower cranes is rare, accidents and near misses do occur. Generally these result from events, either singly or in combination, that are not anticipated, events or actions that cause unexpected loads or from errors during erection, use or dismantling. Failures of any part of the crane or load carrying systems are likely to cause serious accidents – which generally involve both the crane operators, other site personnel or the general public.

1.1.1 Hazards

Operations that involve erection, reconfiguring and dismantling cranes are particularly hazardous. When a crane is in use, poor operation or failure of warning devices or structural members are most likely to result in a serious incident.

All personnel involved in specifying, procuring, planning, erecting and operating tower cranes, as well as those on site around it, should understand the major hazards associated with their safe use and stability.

> *It is vital that the personnel carrying out the erection, reconfiguration, use and dismantling of tower cranes are trained and competent.*

Some safety critical devices may require a tower crane to have an uninterrupted power source and this must be taken into account early in the planning.

The following list of hazards is not exhaustive. Further hazards may be identified by a site specific risk assessment.

Erection, climbing or dismantling

Failure of cranes during these critical operations is the most common cause of fatal accidents involving tower cranes in the UK. The weather conditions under which these operations can be carried out, in particular relating to maximum wind speed, must be adhered to (and for this the wind speed should be assessed at a suitable location). During these operations, the crane cannot be used for lifting!

Crane components may be lifted by a second crane (Figure 1.1) and may be in an inherently unstable condition until properly bolted together or when unbolted and disassembled. The correct sequence of component assembly or dismantling is vital to ensure that the part-completed crane remains stable.

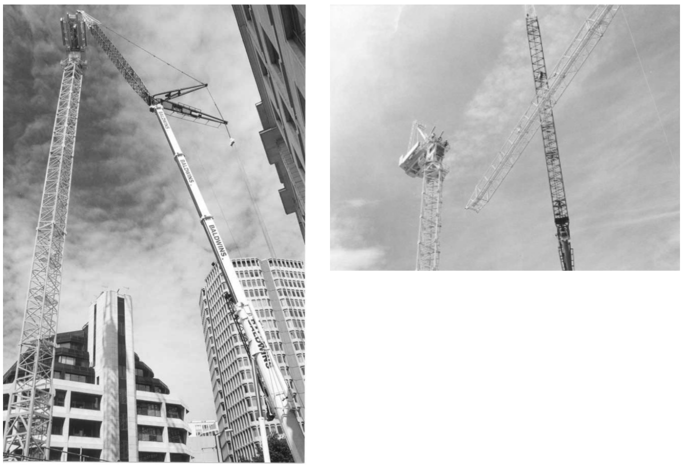


Figure 1.1 *Tower crane erection*

Climbing a tower (increasing its height) by means of an external frame involves particular hazards relating to the carrying of an unbalanced load during the operation. The HSE discussion paper published in 2003, *Safe use of external climbing frames* discusses the particular hazards that arise from the disconnection of the slewing section and jib assembly from the rest of the crane, its support and jacking upwards via a climbing frame before the insertion of additional mast sections.

Overload

The use of rated capacity indicators or limiters has reduced cases of overload, but the structure of the crane and its stability can be impaired when loads are lifted that are in excess of the rated capacity at the given radius, or are inappropriate in the wind conditions or for the crane configuration. It is, therefore, vital that all lifts are covered by a lifting plan and that such activities are controlled by an appointed person.

High wind loads

The crane structure and any load are both subject to wind forces. Loads in excess of design can impair the stability of the crane. Advertising banners etc, fixed to cranes, can add significantly to the wind loading.

Structural failure

Tower crane collapse could be caused by the failure of elements of the structure and its foundations that have either not been correctly assembled, or fail due to overload or fatigue.

Load failures or impact

Although not related to tower crane stability, a significant number of injuries have been caused by loads either slipping or lifting accessories failing, resulting in the load falling to the ground or into the structures under construction. Other hazards are related to poor control of the load during lifting and moving such that it may hit workers or structures. The sudden release of load, or impact of falling loads, can also damage the crane and impair stability.

Proximity hazards

Tower crane collapses or failures have been caused by crane impacts with other cranes, plant or buildings. It is critical that the crane's operational procedures take into account the proximity of hazards and that a safe choice of crane and system of work has been developed. It is important not to rely on anti-collision systems alone to warn of proximity to other structures. Zoning systems are a useful aid in preventing the load and/or parts of a tower crane from entering a prohibited space (Figure 1.2).

Overhead power lines

While not a stability issue, collision with power lines is reported in a recent worldwide survey – Occupational Safety and Health Administration (OSHA) – census to be the cause of the greatest number of electrocution fatalities (outside the UK) and merits a mention. This is not a common cause of accidents involving tower cranes in the UK, but it is critically important to site a crane such that it and its loads avoid power lines, or to ensure that, where possible, lines are powered down when lifting. There should be protection against electrocution for the crane operator, slinger, signaller and other site personnel.

Devices are available that are designed to be fitted on cranes to determine the presence and give warning of overhead electric lines and cables. Such devices are not recommended and should not be considered as a substitute for a safe system of work and safe clearances as set out in HSE Guidance Note GS 6.

Figure 1.2 *Proximity hazards*
(Photo courtesy HTC Plant Ltd)

1.2 REGULATIONS AND STANDARDS

Tower cranes are designed to current standards and must be supplied and used according to key health and safety and other relevant legislation. The standards related to tower crane design, published by FEM, DIN, CEN and the British Standards Institution (BSI), are in the process of re-drafting. The current standards and anticipated timetable for change are summarised in the table in Appendix 3.

The designer of foundations or other temporary works generally will not have to calculate loading applied by tower cranes, but it is useful to understand which standards have been applied in the calculation of loads supplied by the manufacturer. This is particularly pertinent when assessing whether the standards applied in the calculation of wind loads are appropriate to the particular site. If in doubt, the temporary works designer should consult the crane owner or hirer.

Standards relevant to the design of temporary or permanent works and the use of tower cranes are shown in Table 1.1.

Table 1.1 *Standards relating to tower crane temporary works design and operation*[1]

Standard	Comment
BS 7121-1:1989 *Code of practice for the safe use of cranes. General* BS 7121-2:2003 *Code of practice for the safe use of cranes. Inspection, testing and examination* BS 7121-5:1997 *Code of practice for the safe use of cranes. Tower cranes*	Part 2 revised 2003. Under revision. Replacing 1997 edition. Significant overhaul of all clauses relating to operation (only applies to Part 5).
BS 8110-1–4:1997 *Structural use of concrete. Code of practice for design and construction* BS 5950-1–6: *Code of practice for the use of structural steelwork in building*	
BS 8004:1986 *Code of practice for foundations* BS 5930:1999 *Code of practice for site investigation* BS 1377-1–9 *Method of tests for soils for engineering purposes*	Currently cover site investigation and foundation design in the UK. Codes of practice giving guidance rather than standards, little coverage of temporary works design.
BS EN 1990:2002 *Basis of structural design* BS EN 1991 *Actions on structures* BS EN 1992 *Design of concrete structures* BS EN 1993 *Design of steel structures* BS EN 1997-1:2004 *Geotechnical design.* General rules.	Expected to be in period of "co-existence" with equivalent BS until at least 2008. Will govern structural and foundation design. BS EN 1997 is supported by a suite of testing and execution standards covering site practice that become requirements when they are published.

1.3 HEALTH AND SAFETY REGULATIONS

The hiring, erection, use and dismantling of tower cranes must be carried out with due regard to the requirements of UK health and safety legislation. The responsibilities outlined in the **Health and Safety at Work Act** and the **Construction (Design and Management) Regulations** provide the framework under which cranes on construction sites must be operated. There are particular issues in crane use relating to the use of machinery and the regulations governing lifting. Detailed guidance on tower crane use is given in BS 7121-5:1997.

[1] ISO standards have not been included in this document.

Table 1.2 *Health and safety legislation and guidance*

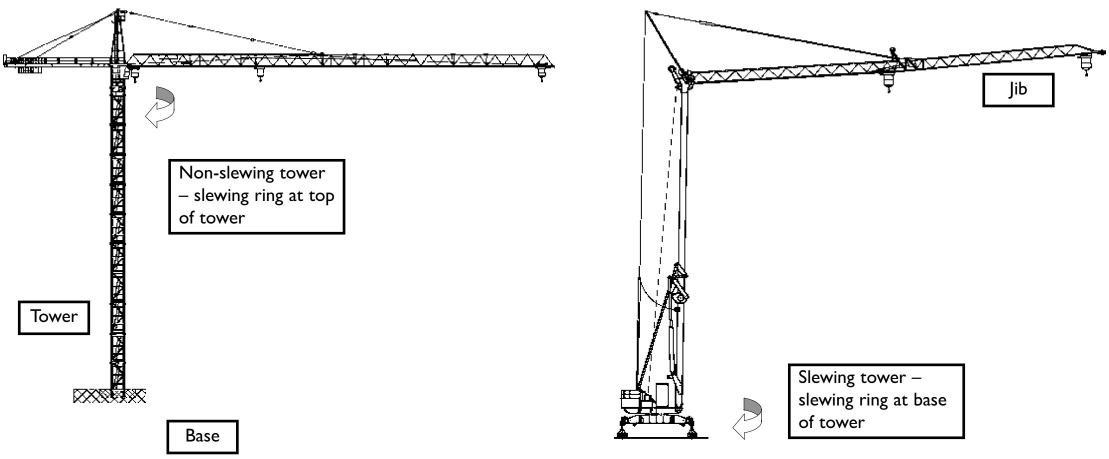
The Health and Safety at Work etc. Act 1974
Management of Health and Safety at Work Regulations. 1999
The Construction (Design and Management) Regulations 1994 (As amended)
The Work at Height Regulations 2005
The Lifting Operations and Lifting Equipment Regulations 1998 (LOLER)
The Provision and Use of Work Equipment Regulations 1998 (PUWER)
The Supply of Machinery (Safety) Regulations 1992 (As amended)
The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 (RIDDOR)
The Construction (Head Protection) Regulations, 1989.
HSE Guidance Note HS (G) 141, *Electrical safety on construction sites*. HSE Books.
CIC CDM Guidance Note I002 *Provisions for the safe use of cranes on construction sites* (2004)

Other standards, such as those applied by the rail network and operating companies, airports, ports, underground or tram owners and operators, must also be adhered to where relevant.

1.4 TOWER CRANE TYPES AND FEATURES

Tower cranes have a number of different features, which may vary in their construction. The tower or mast provides the height required for the crane operation. The tower supports the operator's cab, the main or load-carrying jib and the counter jib on which the crane motors, winches and counterweights are located.

Figure 1.3 *Parts of a tower crane*[2]



[2] Note slewing towers cannot be tied to adjacent structures and therefore rated capacity is only in the configurations supplied.

1.4.1 Common types of crane (issues for safety and selection)

Figure 1.4 *"A" frame tower crane*

(a) Horizontal trolley or saddle jib ("A" frame type, Figure 1.4)

- the jib is held in a horizontal or slightly raised position by tie bars or ropes connected to an "A" frame on the top of the crane tower
- fixed length horizontal jib – the hook is suspended from a trolley which moves along the jib to alter the hook radius
- high capacity available
- can be erected with the tower inside building
- but, needs access for erection and dismantling; semi-permanent structure; jib radius unalterable for out-of-service condition. Consequently fitting in multiple cranes on a congested site may be a problem.

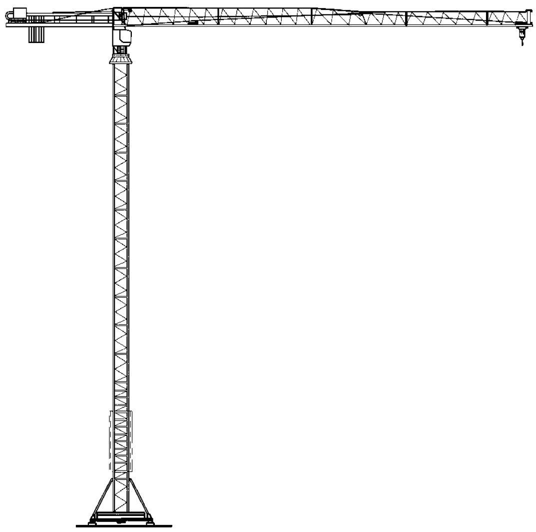


Figure 1.5 *Flat top crane*

(b) Horizontal trolley or saddle jib (Flat top type, Figure 1.5)

- the horizontal cantilever jib is connected directly to the tower top and does not require tie bars or ropes connected to an "A" frame
- reduced overall height of the crane which can be important on congested sites, near airports and where adjacent cranes oversail
- the hook is suspended from a trolley which moves along the jib to alter the hook radius
- higher weight for a given capacity because of jib being a pure cantilever
- can be erected with the tower inside building
- but, needs access for erection and dismantling; semi-permanent structure, jib radius unalterable for out of service condition. Consequently fitting in multiple cranes on a congested site may be a problem.

(c) Luffing jib (Figure 1.6)

- the jib angle can be changed to reposition the load at various radii. The jib may be single- or multi-component, and if multi-component, may be articulated (goose necked)
- lower capacity than trolley jib cranes for a given tower size but may be lower tower height
- radius can be altered to avoid obstructions which can be useful on congested sites (higher crane density likely to be possible) or to avoid oversailing other sites/buildings
- care is needed with out-of service position and high wind speeds as the jib can be blown over backwards if the radius is too small, and there may be insufficient wind area to allow the crane to weathervane – check manufacturers' instructions
- can be erected within building
- slow relative to trolley jib cranes
- generally require a bigger power supply than trolley jib cranes of equivalent capacity as additional motor power is needed to alter the angle of the jib.

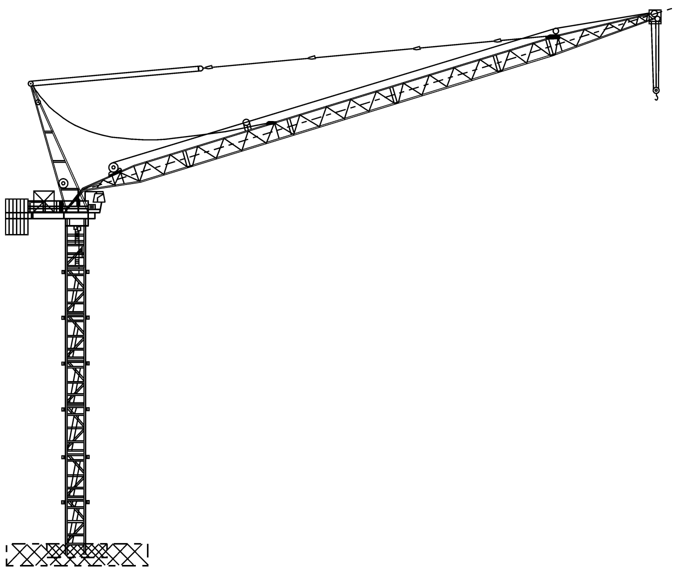


Figure 1.6 *Luffing jib cranes*

(d) Self-erector (Figure 1.7)

- alternative to smaller top slew tower cranes or mobile cranes or tele-handlers (forklifts with telescopic booms)
- space for access, erection and dismantling still required
- lower capacity
- normally mounted on wheeled chassis to facilitate transport to and movement around site (although not while carrying loads!)
- can also be mounted on rail-going or crawler chassis to enable a greater area to be covered on site
- generally outside the scope of this report.

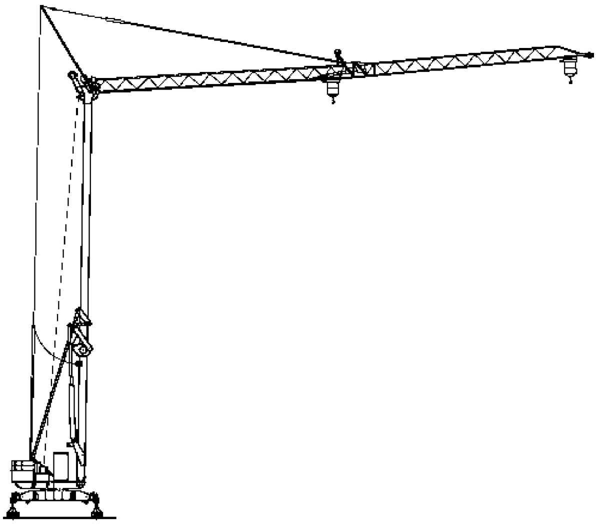


Figure 1.7 *Self erector*

1.5 SELECTION

It can be seen that tower cranes are available in a number of forms and the characteristics of the various cranes should be considered in relation to the job requirements. Having decided upon the type(s) of crane and knowing the overall requirements involved, cranes that will safely meet all the requirements of the planned lifts should be selected. The following section should be read in conjunction with BS 7121-5:1997, which gives further guidance on crane selection.

Raising and lowering people by equipment that is not specifically designed for this purpose should be carried out only in exceptional circumstances and when it is not practicable to do so by other, less hazardous means. Details of specific requirements are given in BS 7121-5. Careful planning should be carried out before each raising and lowering operation.

Points to be considered in making the selection include the following:

a) ***weights, dimensions and characteristics of loads***
The dimensions and characteristics of the load, as well as any potential for abnormal loading (eg additional wind loads), will determine the requirements for rated capacity of the crane. While cranes have rated capacity indicator/limiters, preventing the lifting of items heavier than the crane and equipment can carry, these must not be used to routinely limit the loads. Loads close to the capacity of the crane at the required radius should be identified before lifting is attempted. Some loads may cause non-vertical loading on the crane if lifted incorrectly.

b) operational speeds, radii, heights of lifts and areas of movement

The operational rate and area covered by the crane needs to be checked against the construction schedule and plans. Check for proximity hazards, numbers of cranes needed and oversailing. The freestanding height of the crane may be important.

c) number, frequency and types of lifting operations

The number and frequency of lifts need to be evaluated to ensure that the requirements of the construction programme can be met. Will the loads need to be held for a period of time while being fixed, as with steel work, which restricts availability of the crane? Or will the crane be required to operate with high load cycles as with skipping concrete? The rate of usage should be discussed with the crane supplier.

d) length of time for which the crane will be required or anticipated life expectancy for a permanently installed crane

Short durations may be best served by a tower crane that can be moved across site, such as rail mounted crane or a self-erector.

e) site, ground and environmental conditions, or restrictions arising from the use of existing buildings

The ground conditions may determine the type of crane base that can be constructed and may restrict the crane capacity. The loads that must be carried by the ground, whether during erection, use or dismantling, need to be considered. The designer of the tower crane support should take into account any additional loading applied to the ground and whether this may affect the foundations of existing buildings or other construction. The ground conditions should also be considered if a mobile crane is needed for erection or dismantling – these cranes need support beneath their wheels and outriggers (refer to *Crane stability on site* CIRIA C703). Figure 1.8 shows cranes on site – requirements for access, ground support and other structures should all be considered in crane selection. Where existing buildings are to be used to support the crane tower using ties, the load capacity of the existing structure must be assessed. The location of existing structures, and the location and any requirements for continued operation of overhead power cables will also need to be established.

Figure 1.8 *Tower cranes on site*

f) space available for crane access, erection, travelling, operation and dismantling

Tower crane components may be carried to site on articulated trucks, or may be towed as a complete unit in the case of a self-erector. In either case, suitable access to the crane location is needed. In some cases space will be needed for parts of the crane before erection. Space around the crane location is required for erection, raising and dismantling operations. This may need a mobile crane and the working area for this should be identified. Self-erecting cranes will also need space for the erection process. Where a crane is required to travel with a load, for example on a rail base, the space on site needed for the rails may be an issue within the construction schedule.

Figure 1.9 *Tower crane erection requires careful planning to ensure that access is available*

g) any special operational requirements or limitations imposed

The use of a tower crane near airports, railways, highways, or over other buildings that are not part of the construction site, requires particular care. The airports' code of practice (Airport Operators Association, 2003), can be followed to ensure that an appropriate height of crane is selected. Particular guidelines also apply to the use of cranes near railways and the rail operators' safety requirements must be taken into account. Agreement with local councils, and other property or land owners, is required to oversail either a public highway or other buildings.

h) prevailing wind-speeds, which can restrict the use of tower cranes in certain locations

The location of the site, if positioned on an escarpment or other area of high wind speeds, may reduce the physical dimensions of loads that can be carried. The likelihood of high in-service wind speeds may reduce the availability of the crane. High out-of-service wind speeds may require the crane to be designed against additional wind loading.