



ONR GUIDE			
<b>NUCLEAR LIFTING OPERATIONS</b>			
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## 1. INTRODUCTION

- 1.1 ONR has established its Safety Assessment Principles (SAPs). The SAPs are applied by ONR specialist inspectors to the assessment of safety cases for nuclear facilities. These facilities may be operated by potential licensees, existing licensees, or other dutyholders.
- 1.2 The SAPs are supported by a suite of technical assessment guides (TAGs) to further assist ONR's inspectors in their technical assessment work in support of ONR's regulatory judgements and decisions. This document is one of these technical assessment guides.

## 2. PURPOSE AND SCOPE

- 2.1 This TAG is intended to support ONR's SAPs [1]. Providing guidance on the assessment of safety submissions relating to lifting operations and lifting equipment on or adjacent to nuclear licensed sites.
- 2.2 In this guide, "lifting equipment" means work equipment for lifting or lowering loads and includes the attachments used for anchoring, fixing or supporting the load. The integrity of the load affects the safety of the lifting operation and must also be considered.
- 2.3 The TAG applies to:
- New plant throughout the design, construction and commissioning phases.
  - Operating plant through to its use for post-operative clean out and eventual decommissioning.
- 2.4 The TAG considers the performance and behaviour of lifting components and systems in relation to the safety functional requirements of lifting equipment intended for use within a nuclear licensed site. It also considers the generic safety issues that may influence the performance of such systems.
- 2.5 The TAG does not extend to the detailed design, categorisation, qualification or specification of individual components or systems, particularly in relation to their ability to perform their safety function.
- 2.6 Further guidance is provided in:
- Appendix 1 identifies relevant statutory legislation and explains how it applies to the nuclear regulation of a licensed site.
  - Appendix 2 provides guidance on the mechanical engineering components and features that comprise a lifting system.
  - Appendix 3 provides guidance on electrical, control and instrumentation equipment and their interaction with mechanical structures and components.
  - Appendix 4 provides guidance on the use of mobile equipment
  - Appendix 5 provides guidance on relevant design codes and guidance that apply to the design of lifting equipment
- 2.7 As for all guidance, inspectors should use their judgement and discretion in the depth and scope to which they employ this guidance. Comments on this guide, and suggestions for future revisions, should be recorded on the appropriate registry file.

### 3. RELATIONSHIP TO LICENCE CONDITIONS AND OTHER RELEVANT LEGISLATION

3.1 There are no licence conditions dealing explicitly with lifting systems or its use. However, certain licence conditions are more likely to be used by inspectors when dealing with lifting operations and lifting equipment. The list below gives a summary of how each licence condition might apply specifically to lifting systems:

- **Licence Condition 7: Incidents on the Site** – Any incidents involving faults or mal-operation of lifting equipment which had or may have had a significant effect on nuclear safety should be recorded, investigated and notified to ONR. Where required by other legislation (e.g. RIDDOR), such incidents must also be reported to ONR.
- **Licence Condition 14: Safety Documentation** – The safety case for the plant, including the justification of lifting operations and lifting equipment, is produced and assessed by the licensee under this condition.
- **Licence Condition 15: Periodic Review** – The adequacy of the licensee's safety case, where it addresses lifting operations and lifting equipment, should be reviewed and assessed. Lifting equipment should be reviewed against the past, current and future operating conditions and current statutory requirements. Modern analysis techniques should be used to ensure that there have been no significant changes or deterioration (e.g. corrosion, wear, fatigue and damage) sufficient to invalidate the safety case.

Because of developments in national and international standards, existing plant may not comply in every respect with current standards. Where this is the case, other factors such as the age of the plant and projected lifetime may be taken into account in demonstrating that the risk is as low as reasonably practicable (ALARP).

- **Licence Condition 17: Management Systems** – Adequate quality assurance arrangements shall be implemented for all lifting operations and the supply and use of lifting equipment throughout its lifetime.
- **Licence Condition 19: Construction or Installation of New Plant** – The design of the lifting system should be considered at an early stage, and appropriate testing should be carried out to ensure that the systems meet the safety case requirements.
- **Licence Condition 20 and 22: Modification to Plant** – Modifications should be assessed to ensure that they do not impact adversely on the design and capability of the lifting system or the nuclear safety case.
- **Licence Condition 21: Commissioning** - Commissioning tests should be carried out so far as is reasonably practical (SFAIRP) to ensure that design criteria and the safety functional requirements claimed within the safety case have been met.
- **LC 23 and 24: Operating Rules and Instructions** – Safe limits of operation should be clearly defined. For example, working load limits, maximum operating speeds, lifting machinery and rigging configurations, location of lifting operations and transfer routes. Consideration should also be given to external factors and hazards that can affect the performance of the plant when setting such Operating Rules and Instructions. For example, extreme weather, temperature conditions, ice, snow, storm, and the availability of

external electrical power. The actions to be taken in the event of abnormal occurrences or loss of such services should be specified (e.g. Emergency Operating Procedures) and the appropriate recovery method.

- **LC 25: Operational Records** – Operational records of the key operating parameters affecting the safety of lifting systems should be maintained. For example, records of operating history (weights lifted and number of cycles) and number of hours in service for lifting systems. Consideration should be given to the automatic recording of measurements of any derived parameters that are important to safety.
- **LC 26: Control and Supervision of Operations** – The licensee should ensure that lifting operations are properly planned, supervised and carried out by suitably qualified and experienced persons (SQEP).
- **LC 27: Safety Mechanisms, Devices and Circuits** – The suitability and sufficiency of the lifting equipment protection systems should be assessed to comply with this condition. The licensee should ensure that the plant is not operated unless the necessary systems are properly connected and in good order.
- **LC 28: Examination, Inspection, Maintenance and Testing** – It is expected that lifting system assemblies and components such as structures, mechanisms, ropes, chains, etc. that could deteriorate or become damaged in service would form part of the licensee's site-wide arrangements under this licence condition. The licensee should ensure that a full and accurate report of every examination, inspection, maintenance or test is completed by a SQEP. Where this reveals any matter indicating that the safe operation or safe condition of the plant may be affected, appropriate action should be taken under LC 7.
- **LC 30: Periodic Shutdown** – This condition requires the periodic shutdown of the plant for the purpose of enabling any EIM&T of the plant or process to take place in accordance with the schedule referred to in LC 28. Lifting equipment may provide essential EIM&T support during such shutdown periods, which should be addressed by the safety case.

3.2 The following statutory instruments apply to the supply, provision and use of lifting machinery and equipment:

- Supply of Machinery (Safety) Regulations 2008
- Lifting Operations and Lifting Equipment Regulations 1998
- The Provision and Use of Work Equipment Regulations 1998

More detailed guidance for inspectors on the application of the Supply of Machinery (Safety) Regulations, LOLER and PUWER is given in Appendix 2 and the Guide to the Application of the Machinery Directive<sup>[6]</sup>.

3.3 The following statutory instrument applies to all work activities:

- Management of Health and Safety at Work Regulations 1999

It requires every employer to make a suitable and sufficient assessment of the risks to health and safety. It also deals with the principles of prevention and the arrangements

for the effective planning, organisation, control, monitoring and review of preventive and protective measures.

3.4 The following statutory instruments may be relevant and applicable for the supply, provision and use of certain lifting machinery and equipment:

- The Construction (Design and Management) Regulations 2015
- The Electromagnetic Compatibility Regulations 2006
- The Low Voltage Electrical Equipment (Safety) Regulations 1989
- The Work at Height Regulations 2005

#### 4. RELATIONSHIP TO SAPS, WENRA REFERENCE LEVELS AND IAEA SAFETY STANDARDS ADDRESSED

##### Safety Assessment Principles

4.1 There are no SAPs that specifically mention lifting operations or lifting equipment. The following SAPs may apply to the assessment of lifting operations and lifting equipment:

##### EKP – Key principles

- A suitable plant configuration and layout that takes account of the hazards presented by lifting operations can minimise risk, optimise defence in depth and stop the progression of fault sequences. This can reduce the demands (safety functional requirement) being placed on a lifting system and its interaction with related SSCs. EKP.1 to 5 (Key principles)

##### ECS – Safety classification and standards

- Safety Functions of lifting systems are generally related to: maintaining safe lifting, lowering and transport of loads within prescribed limits and avoiding a failure of a structure, system or component which could impair the safety function of other systems. (ECS.1 and ECS.2)
- Design codes and standards for lifting SSCs should be commensurate with their safety classification. (ECS.3 to ECS.5)

##### EQU – Equipment qualification

- Lifting equipment should perform its allocated safety functions in all normal operation, fault and accident conditions for the duration of its operational life. (EQU.1)

##### EDR – Design for reliability

- Lifting SSCs should be designed to fail to safety or in a safe manner, incorporating redundancy and diversity, wherever practicable. (EDR.1 and EDR.2)
- Appropriate segregation should be provided for electrical, control and instrumentation (EC&I) systems. (EDR.2)
- The load path for most lifting systems will be vulnerable to common cause failure, e.g. ropes and rope terminations. This will also apply to dual rope systems. (EDR.3)

- A lifting system alone may not be capable of meeting the single failure criterion. It is therefore expected that it would be achieved through combination with other SSCs, e.g. package withstand claims. (EDR.4)

#### ERL – Reliability claims

- Reliability claims for lifting systems may be based on generic data, e.g. a particular crane type. This data should be relevant and directly comparable. For example, rope construction and rope reeving arrangements can have a significant effect on reliability claims. (ERL.1)
- Reliability claims for lifting systems and the measures adopted to protect against faults should be justified. (ERL.2 to 5)

#### ECM – Commissioning

- Demonstration of a lifting system's safety features and mechanisms may be carried out during works testing or initial setting to work at site prior to the commissioning phase. Commissioning should demonstrate the capability of the lifting system to meet the operational demands of the facility and its satisfactory performance and interaction with other SSCs to meet the requirements of the safety case. Commissioning should also demonstrate the satisfactory performance of any recovery systems. (ECM.1)

#### EMT – Maintenance, inspection, and testing

- Adequate provision should be made to carry out all EIM&T that could occur throughout the plant lifetime. This should include provision for lifting heavy assemblies requiring replacement or repair (e.g. motors and gearboxes). Suitable strategies for safely demonstrating the performance of safety mechanisms, devices and circuits (SMDC) should be incorporated into the lifting system design. (EMT.1 to EMT.8)

#### EAD – Ageing and degradation

- The safe working life of SSCs that are important to safety should be evaluated and defined at the design stage. This is important for large lifting system structures that would be difficult or impracticable to replace during the plant lifetime. (EAD.1)
- Due allowance should be made in the design for degradation processes, including corrosion, erosion, creep, fatigue, and ageing, and for the effects of the local environmental conditions. (EAD.2)
- Lifting systems are likely to be required for the complete operating lifetime of a facility. For example, an overhead crane may be required to support construction/installation and final deconstruction activities. Provision should be made for replacement of systems and components that can carry out the same safety duty. (EAD.5)

#### ELO – Layout

- Lifting systems have a major influence on the layout of a facility. These principles should also be applied to the lifting system. (ELO.1 to ELO.4).

#### EHA – External and internal hazards

- Lifting systems (e.g. overhead cranes) can be a source of internal hazards resulting from structural collapse, collision or release of a load. These can be of

greater consequence than the initiating internal or external hazard. (EHA.1, 5, 6, 7, 10, and 13 to 18)

- Large lifting systems in particular can be subject to significant loadings from external hazards (e.g. seismic and wind) owing to their mass and physical size. They will also have a significant effect on how the overall building structure responds and can also generate significant reactions that must be resisted by both building and lifting system. Displacement and relative movement between lifting systems and the other SSCs they interact with should be addressed. (EHA.2 to 11, 15 18)

#### EMC – Integrity of metal components and structures

- Lifting machines comprise of metallic structures and mechanisms (e.g. ropes, gears, shafts and linkages). A demonstration of their integrity will be required. (EMC.1 to EMC.22 and EMC.24 to EMC.34)

#### ENC – Integrity of non-metallic components and structures

- For some applications, non-metallic slings may be more appropriate than chain or wire rope slings (e.g. as a means of securely slinging items with no engineered lifting features). (ENC.1 and 2)

#### ESS – Safety systems

- Lifting systems should be provided with protection systems to prevent entering an unsafe state. These may include mechanical (e.g. mechanical interlocks, torque limiters, braking systems, buffers and end stops) and electrical based devices (e.g. load cells, overspeed monitoring and end of travel limits). (ESS.1 to 27)

#### ESR – Control and instrumentation of safety-related systems

- Lifting systems will be provided with control systems that maintain the lifting system within its safe operating envelope, reducing the likelihood of a demand on a safety system. They also provide information to assist the operator (ESR.1 to 7 and ESR.9 to 10)

#### EHF – Human factors

- The potential for human interaction with lifting systems can be considerable. This can have a positive or negative contribution to safety. For example, the crane driver, the banksman to guide the load and the operator/rigger who attaches the load to the lifting device all have a safety role. (EHF.1 to 10)

#### ENM – Control of nuclear matter

- Arrangements for the storage of nuclear matter in a form and manner that allows it to be retrieved might include the provision of mechanical handling and lifting systems. (ENM.7)



## 5. ADVICE TO INSPECTORS

### Introduction

- 5.1 This guide supports the assessment of safety cases involving the use of lifting equipment and lifting operations on or adjacent to nuclear licensed sites. It covers all lifting operations whose failure could affect nuclear safety. The guidance is therefore not limited to the lifting and movement of nuclear material.
- 5.2 The principal objective for any lifting operation is to demonstrate that risk is reduced ALARP. SAP FP.6 (Prevention of accidents).
- 5.3 The safety case should:
- Demonstrate that the lifting operation reduces risk ALARP.
  - Identify the structures, systems and components (SSCs) of the lifting system that are important to safe operation.
  - Identify normal operating and potential fault conditions, including internal and external hazards that could affect the lifting system and other plant and equipment.
  - Consider human factor influences that affect the safety of lifting operations.
  - Demonstrate that the integrity of the lifting system SSCs important to safety is adequately managed. This applies throughout the projected life of the installation, through to the point at which it no longer has any nuclear safety consequence. This should take account of potential ageing and degradation mechanisms.
- 5.4 The Inspector should establish how the lifting system fits within the safety case. The assessment should be targeted and proportionate, relative to the nature and severity of the hazards associated with lifting operations. This includes the risks to other safety significant plant and equipment.
- 5.5 Lifting system reliability depends on a wide range of technical areas. For example: materials, fabrication, stress analysis and EC&I systems. Human factors, as well as statutory legislation must also be considered. It is unlikely that a lifting system safety case will be made on one feature alone.
- 5.6 The lifting and transport of a load introduces the potential to disrupt the safety of radiological processes, barriers, safety mechanisms and devices that are designed to protect such systems in normal or faulted process conditions.
- 5.7 An inspector may need to consider a different weighting of the safety case claims to that presented by the licensee. Where a balanced judgement is required, they should consult with other specialists.
- 5.8 IAEA Safety Requirements document NS-R-1[3] Section 4.6 defines three fundamental safety functions. These might be affected by a lifting system failure:
- control of the reactivity
  - removal of heat from the core
  - confinement of radioactive materials and control of operational discharges, as well as limitation of accidental releases
- 5.9 How a safety case addresses these fundamental safety functions will vary. For example:



- The catastrophic failure of a lifting system on to a Reactor Pressure Vessel (RPV) of a large power plant would likely lead to unacceptable radiological consequences. High levels of quality and conservative engineering would be required throughout the life of such a lifting system.
  - The radiological consequences of a dropped nuclear package (flask) may be less significant. The package might withstand the drop impact, maintaining adequate containment and shielding. Appropriate industrial, national or international standards may suffice.
- 5.10 Nuclear safety-related plant and equipment might be concealed (e.g. emergency feed pumps in turbine halls and electrical cables located under the ground). Their safety contribution may therefore not be visibly obvious. A comprehensive review of the vulnerability of nuclear safety-related systems that could be affected by lifting operations should be undertaken.
- 5.11 The assessment of lifting operations should consider the likely failure mechanisms of lifting equipment. The assessment of probability of failure and the consequences of failure should ensure that risks are tolerable and ALARP. SAP FA.14 (Probabilistic safety analysis).

### **Lifting safety case philosophy**

- 5.12 Conventional health and safety legislation (e.g. MHSWR, LOLER, PUWER and Supply of Machinery (Safety) Regulations and their Approved Codes of Practice (ACoP)) set out the dutyholders' legal responsibilities and the expectations of relevant good practice.
- 5.13 Eliminating lifting operations and adopting potentially safer methods of lifting or handling should be considered at an early stage of the design process. SAPs EKP.1 and 2 (Key principles). However, ONR recognises that lifting may be the only effective means of moving materials and equipment, e.g. maintenance operations.
- 5.14 Nuclear lifting safety cases generally fall into one of two strategies:
- 'Dropped load' safety case.
  - Low probability of lifting system failure safety case.

#### 'Dropped load' safety case

- 5.15 The 'dropped load' safety case offers a more robust safety case strategy as it provides defence in depth against the consequences of lifting system failures. SAP EKP.2 (Fault tolerance).
- 5.16 Lifting operation fault conditions should be robustly analysed to demonstrate that nuclear material remains adequately contained, heat removal is not compromised and criticality cannot occur. SAP ECV.2 (Minimisation of releases), SAPs EHT.1 to 5 (Heat transport systems) and ECR.1 (Safety measures). In these cases, the assessment should consider whether the fundamental principles have been met and that all reasonably practicable steps have been taken to prevent and mitigate accidents. SAP FP.6 (Prevention of accidents).
- 5.17 If the principal nuclear hazard has been addressed, the assessment of the lifting equipment may be limited to examining the internal faults in the lifting system. These faults should not give rise to any additional hazards e.g. structural collapse of the lifting system. Protection systems and enhancements might still be required for risk to be ALARP.

- 5.18 'Dropped load' safety cases may be argued on the basis of limited consequences. An example is the lifting of an IAEA licensed transport package, where there is a sound and detailed justification of its impact resistance. The safety case should justify the suitability of all nuclear transport packages used within the facility.
- 5.19 A dropped load can damage other plant and equipment. If the damage is not tolerable, the impacted structures (e.g. a reactor pile cap or containment structure) should be justified against such an impact.
- 5.20 'Double blocking' events (where the hook block makes contact with the underside of the crane) are a recognised cause of dropped loads. The safety case claim on the lifting system should demonstrate that it is not physically possible to lift the underside of the load (e.g. package) to a height greater than the justified impact withstand of the load and/or the plant and equipment below.
- 5.21 In some circumstances it may be reasonably practicable to avoid lifting loads above their drop withstand capability. A robust optioneering study should be undertaken to demonstrate that risk is ALARP and that it would be disproportionate to adopt an alternative solution.
- 5.22 Alternative solutions that might be considered are:
- Stepped transfer route  
This solution would not eliminate the potential for lifting the load above its drop withstand height. A suitable protection system may be required that limits the height of the load as it proceeds up and down the stepped transfer route.
  - Impact absorber  
The safety case should demonstrate that the load can only land on the impact absorber in a manner consistent with the impact analysis.

#### Low probability of lifting system failure safety case

- 5.23 In this type of safety case, the consequences of lifting system failure are not acceptable and it is not possible to provide defence in depth. These safety cases should be scrutinised in greater detail.
- 5.24 Demonstrating that a lifting system has a sufficiently low probability of failure is a significant challenge. Greater dependence will be claimed for the robustness, integrity and reliability of the lifting equipment.
- 5.25 A protection system that protects against one fault may introduce a fault condition that requires another protection system. Inspectors should also be aware that design enhancements that increase the mass and energy within a lifting system can increase the severity of other hazards (e.g. impacts and interactions with other plant and equipment).

#### Fault analysis

- 5.26 SAPs FA.1 to FA.24 (Fault analysis) and NT.1 and NT.2 (Numerical targets and legal limits) detail the requirements for safety analysis of plant. They cover normal operation to severe accidents where major plant damage may be sustained. A conventional lifting system may not satisfy the fault conditions identified.
- 5.27 Inspectors should use their experience and judgement to assess the extent of the design basis analysis (DBA) required for lifting operations based on the nature of the nuclear hazard. The mixture of passive design features, mitigation measures and engineering features will differ in each safety case.

- 5.28 The DBA should demonstrate that in combination, the proposed design and use of the equipment has been thoroughly examined, and shown to be acceptable and tolerable against a recognised range of criteria that reflect the potential nuclear hazard.
- 5.29 When assessing such nuclear lifting systems it is important to ensure that all the reasonably foreseeable fault sequences are considered. The collapse of the structure itself should also be included. Crane structures can be expected to have significantly greater potential energy, due to their greater mass and position (height), than the loads being lifted.
- 5.30 Principal load path failures of lifting equipment will have potentially major consequences. It is therefore important, when assessing lifting operations, that the sensitivity of the fault analysis (and the conclusions drawn from it) to the assumptions made in any supporting analysis are adequately validated. SAPs FA.19 and FA.22 (Fault analysis).
- 5.31 Assessments should identify the internal faults that can develop into overloads and uncontrolled motions. Such effects should be quantified and justified in detail. SAPs FA.7 and FA.8 (Fault analysis).
- 5.32 Appendix 6 identifies fault conditions that are common to most lifting systems together with the risk reduction measures that may be considered by licensees.

### **Strength and stability**

- 5.33 Adequate strength and stability is a requirement of LOLER (Regulation 4). For nuclear applications it is expected that there design codes and standards will be further supplemented or modified as necessary to a level commensurate with the importance of the relevant safety function(s). ONR SAPs Para 170.
- 5.34 Design codes for lifting systems are discussed in Appendix 5.
- 5.35 Lifting systems that lift loads within their supporting wheel base are generally stable as there is no overturning moment. For cranes that lift loads outside their supporting wheel base, overturning is more likely e.g. jib cranes and dockside cranes. In these cases, overturning may be the limiting state and sufficient counterbalance and/or anti-toppling features will be required to maintain stability in both normal and fault conditions (e.g. overload and seismic).
- 5.36 A likely consequence of enhancing design codes is increased mass, inertia and stiffness of the lifting system. This will increase the capability of lifting systems to damage other plant and equipment. For example, motors will be more powerful required and impact forces will be greater. It is therefore important that all plant and equipment associated with the lifting system faulted conditions is assessed for its ability to deliver the safety function requirement. SAPs FA.7 and FA.8 (Fault analysis).
- 5.37 Inspectors should be aware that de-rating will have a variable effect on the design margins throughout the system. For example, faulted loads are generated by the drive motor or application of a brake, not the load being lifted. It is therefore important, when assessing lifting systems, that the effects of the static and dynamic forces generated by faulted conditions are fully analysed.
- 5.38 For either option, increasing the power of the hoist motor may not improve safety. Although it might have greater reserve capacity for lifting the load, in a fault condition a greater force can be generated (e.g. restrained load fault).

## Proof testing

- 5.39 The requirement for proof load testing of lifting systems is derived from the Supply of Machinery (Safety) Regulations. Inspectors should not assume that a proof load test alone provides assurance against defects. It should be supported by suitable inspection and fracture mechanics assessment, as appropriate.
- 5.40 Inspectors should note that proof load testing is normally only carried out at the time of installation and setting to work. The effects of regular proof load testing should be analysed for any detrimental effects (e.g. potential damage and shortening the fatigue design life of the lifting system).
- 5.41 Where the safety case requires regular load testing of lifting systems (e.g. to support reliability claims), the rated capacity of the lifting system should be equal to or greater than the specified test load.
- 5.42 Conventional lifting machinery proof tests (typically 125% safe working load) are not sufficient to demonstrate that the lifting system can withstand worst case dynamic faulted conditions arising from the following:
- a. A failed rope in a dual reeved system, where an increase of 200 to 300% or greater in load may be developed in the remaining rope system.
  - b. Loads generated by the inertia of the hoisting system in a snagged or restrained load fault condition that cannot be limited by an overload detection trip.
  - c. Loads that are ledged and then drop suddenly (often described as a 'hangman's drop').
  - d. Seismic loadings where there may be significant horizontal accelerations and magnification of the vertical load.
- 5.43 Inspectors should note that catastrophic modes of failure could arise with such fault loadings. These may result in simple tensile failures, buckling or loss of stability. It is important therefore to consider the limitations of proof tests on lifting equipment, and recognise that it may be appropriate to justify a design solely on the basis of theoretical analysis, unless additional testing strategies are devised.

## Safety systems

- 5.44 The nuclear safety case may determine that the robustness and safety measures offered by a conventionally designed lifting system cannot provide adequate fault tolerance. SAP FA.4. Additional safety systems might be required as identified by the safety case.
- 5.45 To protect against uncontrolled lowering, additional hoist braking might be provided. In its basic form, this might take the form of an additional brake on the input side of the hoist gearbox. An emergency braking or retardation system that acts directly, or as close as possible, on the rope drum should also be considered as a means of protecting against mechanical failure of the hoist gearbox. It should be possible to demonstrate the required performance of such features throughout the operating life of the lifting equipment. SAP EQU.1 (Equipment qualification).
- 5.46 It is standard practice for all brakes to be applied on loss of power to the lifting machine or drive motors. However, this feature may not initiate emergency braking/restraint in response to a mechanical failure or electrical fault. Failure/fault

detection may therefore be required, which may take the form of over-speed detection and/or speed comparator (i.e. monitoring the output speed relative to input speed).

- 5.47 Although additional braking/restraint systems can enhance safety, they may impose greater dynamic loadings on the hoist drive components than normal design code requirements. Design analysis should therefore consider the faulted condition of spurious operations. Application of the emergency braking or retardation system (e.g. testing and spurious tripping) should also be considered when assessing the fatigue life of the drive components.
- 5.48 Another method of reducing the risk of uncontrolled lowering is the 'single failure proof' hoist system, see "Single Failure Proof Cranes for Nuclear Plants" NUREG-0554[9]. In these systems, load paths are duplicated with the intent that that no single failure will result in loss of capability of the system to support the load. Consideration should be given to the increased complexity of the 'single failure proof' system, which may introduce new fault modes that are not present in conventionally reeved hoist systems. The effects of these faulted conditions should be assessed to ensure that they do not compromise the 'single failure proof' principle.
- 5.49 It should be noted that whilst such arrangements may be acceptable in the short term, they do not remove the potential hazard of a dropped load. A protection system may be part of the recovery system so, for example, when the emergency brakes are released to make a recovery action there may be no defence in depth. SAP EKP.3 (Defence in depth). The operation of lifting systems in any foreseeable degraded state should be justified within the safety case.
- 5.50 The "one fault safe" approach has been developed in the US and incorporated in the US NRC ASME NOG-1 Standard[10]. It should be noted that such standards have been developed for specific types of reactor and lifting operations, namely shutdown and refuelling operations associated with civil PWR and BWR reactors. These may not bound all potential hazards, such as those created by on-load refuelling or lifting in less contained environments, see NUREG-0612 "Control of Heavy Loads at Nuclear Power Plants" [11].
- 5.51 The final approach used for developing lifting safety cases is to rely on some level of redundancy or diversity that goes beyond the "one fault safe" approach. That is, there is an independently operable load path capable of supporting the load (e.g. an independent load follower or similar device). Whilst such systems have advantages and comply with the nuclear safety principles in terms of redundancy and diversity, it is important that they are adequately assessed, including the dynamic loading effects of primary lifting system failures. Issues to be considered with respect to high reliability systems are covered by SAPs EDR.1 to EDR.4 (Design for reliability).
- 5.52 Whatever solution is adopted by the Licensee, it is important that the claimed engineering benefits are achieved in practice, SAPs SC.4 to SC.6 (Safety cases). Some of the detailed technical issues that need to be considered in the assessment of these systems are indicated in Appendix 6.

### **Recovery philosophy**

- 5.53 Inspectors should consider the hazard of a suspended load and the risks associated with the actions necessary in making them safe. Certain systems will lend themselves to emergency action to remove the main hazard (e.g. the reactor may be tripped, the process is stopped and made safe, or there may be a suitable evacuation, prior to recovery). In others the hazard will remain until the load is finally grounded. To avoid leaving a suspended load over safety critical plant, there should be an effective means of safely recovering a broken down crane to a safe position.

- 5.54 The consequences of rope failure in a 'single failure proof' system may affect the ability to raise or lower the load safely. Recovery of the suspended load may need to be carried out by an alternative lifting system.
- 5.55 There may be radiological constraints restricting access to the load and lifting equipment during recovery operations. Remotely operated lifting equipment will require remotely operated recovery systems that protect (e.g. shield) the operator. These systems should be proven during commissioning for all predictable recovery scenarios and the equipment subject to an in-service maintenance regime to ensure they will function on demand.
- 5.56 There may also be restrictions on the time that nuclear materials and packages can remain suspended (e.g. fuel cooling, hydrogen venting and weather conditions including wind, snow or lightning). It is important therefore to consider these aspects when assessing the adequacy of safety systems that may trip the crane during the lifting operation, and when considering the provision of any redundancy or means of recovery.

### **Reliability**

- 5.57 Failure rate data relating to cranes and lifting operations is difficult to establish due to the variety of cranes in use, the variability of usage, and a significant element of operator error in many of the failures. Crane failures can be caused by a wide range of different fault mechanisms such as operator error, loss of stability, insufficient mechanical strength, fatigue, wear and EC&I failures. Where failure rate data does exist, it should be relevant to the lifting system and how it is operated.
- 5.58 Inappropriate reliability data should not be used to justify short duration lifting operations. See ONR Fault Analysis SAPs particularly Paragraph 613.
- 5.59 Reliability studies may assist in studying specific aspects of the design where the data may be more robust (e.g. human factors aspects and control and instrumentation systems). This may indicate a requirement to remove operator action or improve control system reliability in more hazardous applications.
- 5.60 Reliability data for uniquely designed mechanical parts needs to be treated with caution. Inadequate design might be more likely than simple time dependant failure mechanisms.

### **Human factors**

- 5.61 Human error is often a contributory factor in a lifting accident. Its importance should not be overlooked either in the operation of the crane, planning the lifting operation or in attaching the load to the crane.
- 5.62 Where it is not possible to remove operator action from the design of a lifting system, claims might be made on operator action as part of a safety measure. A detailed assessment of the human factors aspects should be undertaken.
- 5.63 Particular attention should be given to training and instructions to operators and supervisors on the safe use of equipment. This should include recognition of faulty/damaged equipment, planning of lifting operations, management and control, and selection of equipment for lifting operations. See SAPs EHF.3 to EHF.10 (Human factors).
- 5.64 Whatever approach is used it is important to note that the requirements of SAP SC.6 (Safety case content and implementation) are achieved. The relevant limits of safe operation should be identified for any design basis fault sequence and the integrity of

the physical barriers to radioactive release maintained. SAPs FA.1 to FA.7 (Fault analysis).

- 5.65 In addition, no structure, system or component important to safety required to prevent or mitigate the fault sequence should be caused to operate outside the conditions for which it has been qualified.



## 6. REFERENCES

1. ONR Safety Assessment Principles for Nuclear Facilities, 2014 Edition, Revision 0.
2. Western European Nuclear Regulators Association (WENRA) Safety Reference Levels for Existing Reactors, September 2014
3. IAEA Safety Standard, Specific Safety Requirements No. SSR-2/1 (Rev.1), Safety of Nuclear Power Plants: Design, February 2016
4. IAEA Safety Guide Ref No. NS-G-1.4 – Design of Fuel Handling and Storage Systems in Nuclear Power Plants
5. IAEA Safety Guide Ref No. NS-G-2.5 - Core Management and Fuel Handling for Nuclear Power Plants
6. Guide to the Application of the Machinery Directive 2006/42/EC (Edition 2.1, July 2017)  
<http://ec.europa.eu/docsroom/documents/24722>
7. NS-TAST-GD-041 – Criticality Safety
8. Reducing Risks Protecting People – HSE’s Decision Making Process
9. NUREG-0554 – Single Failure Proof Cranes for Nuclear Plants US Nuclear Regulatory Commission
10. ASME NOG-1 – Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge Multiple Girder)
11. NUREG-0612 – Control of Heavy Loads at Nuclear Power Plants
12. BS7121 – Code of practice for safe use of cranes
13. NS-TAST-GD-006 – Deterministic safety analysis and the use of engineering principles in safety assessment
14. BS2573 – Rules for the design of cranes
15. BS EN 13001 – Cranes. General design
16. BS EN 13155 – Cranes. Safety. Non-fixed load lifting attachments
17. NS-TAST-GD-016 – Integrity of metal components and structures
18. NS-TAST-GD-003 – Safety Systems
19. NS-TAST-GD-046 – Computer based safety systems
20. NS-TAST-GD-011 – The single failure criterion
21. BS 7608 – Code of practice for fatigue design and assessment of steel structures
22. NS-TAST-GD-013 – External Hazards
23. BS466 – Power driven overhead travelling cranes, semi-goliath and goliath cranes for general use
24. BS EN 15011 – Cranes. Bridge and gantry cranes
25. BS ISO 4309 – Cranes – Wire ropes – Care and maintenance, inspection and discard
26. BS EN 13135 – Cranes – Safety – Design – Requirements for equipment

**7. GLOSSARY AND ABBREVIATIONS (EXAMPLE LIST)**

ACoP	Approved Code of Practice
ALARP	As low as reasonably practicable
BPEO	Best Practicable Environmental Option
BSL	Basic Safety Level
BSL(LL)	Basic Safety Level (legal limit)
BSO	Basic Safety Objective
CBA	Cost Benefit Analysis
CCF	Common Cause Failure
CNS	Civil Nuclear Security (Office for Nuclear Regulation)
DBA	Design Basis Analysis
DBE	Design Basis Earthquake
DEPZ	Detailed Emergency Planning Zone
HSE	Health and Safety Executive
HSWA74	The Health and Safety at Work etc Act 1974
IAEA	International Atomic Energy Agency
NDA	Nuclear Decommissioning Authority
NEPLG	Nuclear Emergency Planning Liaison Group
OBE	Operating Basis Earthquake
PSA	Probabilistic Safety Analysis
PSR	Periodic Safety Review
SAP	Safety Assessment Principle(s)
SFAIRP	So far as is reasonably practicable
SEPA	Scottish Environment Protection Agency
SMDC	Safety Mechanisms Devices and Circuits
SM(S)R	Supply of Machinery (Safety) Regulations
SSC	Structures, Systems and Components
TAG	Technical Assessment Guide(s)
WENRA	Western European Nuclear Regulators' Association

## 8. APPENDICES

### Appendix 1 – Guidance for ONR inspectors on the application of statutory legislation

The guidance provided in this appendix is intended to explain how statutory legislation applies to a nuclear licensed site and a nuclear safety case. Inspectors should consult the relevant HSE approved code of practice (ACoP) for more detailed guidance.

#### A1.1 Supply of Machinery (Safety) Regulations 1006

A1.1.1 The Supply of Machinery (Safety) Regulations SM(S)R is applicable to the supply of machinery and includes lifting equipment and lifting accessories (e.g. slings and shackles).

A2.1.4 SM(S)R define ‘lifting accessories’, as:  
 “a component or equipment not attached to the lifting machinery, allowing the load to be held, which is placed between the machinery and the load or on the load itself, or which is intended to constitute an integral part of the load and which is independently placed on the market; slings and their components are also regarded as lifting accessories”.

A1.1.2 Although not fitting the requirement for machinery to have a power source, manually operated lifting equipment is included as defined by:  
 “an assembly of linked parts or components, at least one of which moves and which are joined together, intended for lifting loads and whose only power source is directly applied human effort”.

A1.1.2 The SM(S)R do not apply to “machinery specially designed or put into service for nuclear purposes which, in the event of failure, may result in an emission of radioactivity”.

A1.1.3 The published “Guide to application of Directive 2006/42/EC” advises that “Machinery used in the nuclear power industry which does not give rise to a risk of emission of radioactivity is not excluded from the scope of the Machinery Directive”.  
<http://ec.europa.eu/docsroom/documents/24722>

A1.1.4 The failure of most nuclear lifting equipment would not directly result in an emission of radioactivity. It is therefore considered unlikely that nuclear lifting equipment would be excluded from the SM(S)R. Notable exceptions to this would be handling equipment (e.g. a shielded fuel carrier) that has a containment and/or shielding safety function.

#### A1.2 Lifting Operations and Lifting Equipment Regulations (LOLER) 1998

A1.2.1 In these regulations, "lifting operation" means an operation concerned with the lifting or lowering of a load. By implication, this also includes any other movement of a load e.g. travel, traverse, luffing and slewing. The following advice highlights specific issues associated with the use of lifting equipment on a nuclear licenced site.

LOLER Regulation 4 – Strength & Stability

A1.2.2 This requires the following:

- i. lifting equipment is of adequate strength and stability for each load, having regard in particular to the stress induced at its mounting or fixing point;
- ii. every part of a load and anything attached to it and used in lifting it is of adequate strength.

- A1.2.3 The term "adequate strength" will be open to interpretation, especially where proprietary equipment is used. Inspectors will therefore need to consider the requirements of NS-TAST-GD-016 [17] when considering significant claims being made on the structural integrity of lifting systems.
- A1.2.4 Due consideration should be given to the means of attaching the load to the lifting device (e.g. crane) to ensure it is attached correctly and cannot become detached during the lifting operation.
- A1.2.5 The stability of lifting equipment will need to be assessed by suitable analysis and testing if appropriate. Testing has the advantage that uncertainties in weight and weight distribution can be removed. Test conditions will also have to address any faulted loads and any dynamic effects imparted to the load, if they are to be truly representative and robustly support claims made in the safety case.
- A1.2.6 Where the conventional and nuclear safety risks associated are such that the test cannot be carried out on a nuclear licensed site, consideration should be given to the validity of off-site testing.

#### LOLER Regulation 6 – Positioning and installation

- A 1.2.10 Hazards and risks associated with lifting operations and lifting equipment can be eliminated or significantly reduced by the overall plant layout together with suitable positioning and installation of the lifting equipment. SAP ELO.4 (Minimisation of the effects of incidents).
- A1.2.11 The philosophy of low level lifting is recognised as relevant good practice by UK site licensees. This requires lift heights not to exceed the safe drop withstand of the load being lifted or the structural withstand of any SSCs below the load.
- A1.2.11 The physical presence of lifting equipment when it is not in use needs to be considered as it can pose a threat to other systems or operations. Consideration should be given to out of use, lifting equipment being parked in a position where the risk or consequence of collapse is reduced.
- A1.2.12 The potential collapse zone of a tower crane or mobile crane can extend over a considerable area. Cranes should be selected and positioned to minimise the effects of possible collapse.

#### LOLER Regulation 8 – Organisation of lifting operations

- A1.2.13 Inspectors should consider the requirements of LC12 in ensuring that those planning and supervising operations are SQEP with respect to both the lifting issues and the nuclear safety case. Operating instructions (LC24) should include the actions to be taken in the event of failure or other incident.
- A1.2.14 The ability to carry out lifting operations in a safe manner is intrinsically linked to plant layout. SAP ELO.4 (Minimisation of the effects of incidents) is therefore relevant.

## LOLER Regulation 9 – Thorough examination and inspection

A1.2.15 LOLER specifies the requirements for thorough examination, covering:

- putting equipment into service
- examination periods for equipment types
- exceptional circumstances that could jeopardise safety

A1.2.16 Lifting equipment should be thoroughly examined so that deterioration can be detected in sufficient time to allow remedial action to be taken. A competent person is required to determine the level of thorough examination required based on an assessment of the risks.

A1.2.16 The purpose of a thorough examination is therefore to reveal deterioration in areas where the competent person would reasonably expect to find it and judge it to be dangerous.

A1.2.17 Inspectors should be mindful that a thorough examination by a competent person is usually limited to finding deterioration and does not provide assurance of suitability for nuclear use. Inspectors should therefore seek assurance that the scope and extent of a thorough examination is proportionate to the nuclear safety risk.

A1.2.18 Independent competent persons are unlikely to have any detailed information, or knowledge of the nuclear safety significance of the equipment, or the nature of the operations performed. They should therefore be instructed and directed by a licensee's SQEP who is identified in the licensee's arrangements. Independent third parties will, however, usually have wide experience and knowledge of the inspection of similar lifting equipment in a range of other industries. They should therefore be a valuable independent source of practical and theoretical advice on lifting equipment and inspection processes and techniques.

A1.2.18 The nuclear safety case may need to specify additional design-informed in-service inspections to ensure that the condition of equipment remains consistent with the claims made of it. These design-informed inspections may be targeted at areas where there is no degradation expected, but where they may be highly stressed or safety critical.

A1.2.19 It is expected that the most sensitive nuclear equipment would have a detailed EIM&T regime developed from the design, through manufacture and operation, and this would reflect the requirements of NS-TAST-GD-016 to achieve an appropriate structural reliability.

A1.2.20 In addition to periodic statutory examinations, it is expected that licensees will appoint SQEPs to assess nuclear lifting operations and lifting equipment so that continued fitness for purpose can be confirmed within safety cases. Inspectors should therefore note that lifting equipment may need to be thoroughly examined more frequently than the statutory minimum periodicity. This may be due to concerns about the condition of the equipment (e.g. rate of deterioration, environment conditions, poor maintenance record, etc.). It may be also considered appropriate to carry out a thorough examination before a significant nuclear lift.

A1.2.21 LOLER identifies a complementary system to the specified period approach. The written examination scheme can be particularly relevant and proportionate for equipment used for nuclear lifting operations.

A1.2.22 Risk based inspection schemes may be considered for safety critical items. These can give greater control and focus to the examination process. They may also reduce exposure of 'competent person' surveyors to radiological hazards, particularly where lifting equipment failure does not present a hazard to personnel. The risk based examination scheme should address the nuclear and radiological hazards including any dose burden from potential recovery operations resulting from lifting equipment failure.

LOLER Regulation 10 – Reports and defects

A1.2.23 LOLER requires written reports to be provided for all thorough examinations.

A1.2.29 Where there is, in the opinion of the 'competent person', a defect in the lifting equipment involving an existing or imminent risk of serious personal injury, a copy of the report must be sent as soon as is practicable to the relevant enforcing authority. For nuclear licensed sites the authority is ONR. This is in addition to any reporting or other requirements required under LOLER, PUWER or any other regulation e.g. Reporting of Incidents Diseases and Dangerous Occurrences (RIDDOR).

A2.2.30 Thorough examination reports should be considered in any assessments performed to support the nuclear safety justification. Whilst the presence and nature of any defects may not affect the nuclear safety case, they could present a serious conventional hazard.

**A1.3 Provision and Use of Work Equipment Regulations (PUWER) 1998**

A1.3.1 PUWER applies to all work equipment, and therefore applies to the design of lifting equipment. PUWER and LOLER transpose the Amending Directive (95/63/EC) (AUWED) to the Use of Work Equipment Directive (89/655/EEC) into UK law. PUWER addresses all work equipment. LOLER addresses the specific aspects of lifting operations and lifting equipment.

A1.3.2 Equipment that is selected for nuclear lifting operations is 'work equipment' and must be suitably selected and designed for that purpose.

PUWER Regulation 4 – Suitability of Work Equipment

A1.3.3 PUWER contains significant regulations relating to the suitability, maintenance, guarding, training, emergency stops, control systems and other features of work equipment that are fundamental to the safe design of lifting equipment and lifting operations.

## Appendix 2: Guidance for mechanical engineering specialist inspectors

### Introduction

- A2.1 The following are a selection of issues that might arise when assessing the safety of nuclear lifting systems. Where there is any uncertainty or doubt, assessors should seek more detailed technical advice from topic specialists. This appendix indicates the importance of such issues and how they apply to the assessment of lifting systems.

### Load effects

- A2.2 The design analysis of lifting systems requires a detailed understanding of the engineering mechanics and dynamics of their drive systems and the fault conditions that can be generated by them.
- A2.3 A detailed knowledge of the applicable design codes is required to understand their inbuilt design margins and how the design factors can be applied and supplemented to address normal service and fault conditions.
- A2.4 The dynamic effects of faulted conditions should be examined separately to normal service conditions. The loads created by fault conditions, load path failure and emergency braking might be significantly greater than a controlled lifting operation.
- A2.5 The load effects and claimed benefits that the licensee is making for any protection system should be closely examined. The lifting system should be able to respond to a fault condition in a manner that transfers the load into the redundant system or senses the failure and arrests the load within safe limits. The effect on the load, the lifting system and any impacted structure should be considered.
- A2.6 It is recommended that inspectors carrying out design assessments obtain a stress schedule from the licensee. This schedule should identify and summarise the principal loads, stresses, deflections, design criteria and design margins of the key structures and mechanisms of the lifting system.

### Dual Load Path Systems

- A2.7 An effective dual load path system offers consistency with ONR SAPs EDR.1 (Failure to safety) and EDR.2 (Redundancy). These systems can be complex and need to be suitably engineered to ensure that the intended safety benefit is realised. The use of two hoisting ropes is an example of this. The potential for common cause failure should therefore be considered, SAP EDR.3 (Common cause failure).
- A2.8 There are broadly two approaches to designing such systems. Either, a diverse backup system which is normally unloaded, or there is some form of redundancy within the normal operating system, resulting in a sharing of load during normal operation and a shedding of load on to the parallel system in the event of failure.
- A2.9 Some of the issues that need to be considered in assessing such systems are as follows:
- a. Lifting systems with a duplicated load path introduce greater complexity and might be difficult to engineer successfully.



- b. It may not be technically feasible to incorporate a normally unloaded redundant system into a lifting system. For example, it is normal practice to incorporate a means of load equalisation into rope reeving systems.
  - c. Regardless of load sharing, the potential for either system to fail and disrupt the other needs to be considered in the fault analysis and the engineering design. Operating failures in either drive chain must not load the parallel system in a manner that leads to its catastrophic failure.
  - d. Both systems must be capable of responding to transient conditions during the full range of motion of the load. For example: starting, stopping, ledged loads, snagging, zero load, overload and the transient initial pickup of the load.
  - e. Both systems need to be reliably synchronised and controlled.
  - f. The redundant/diverse system must be capable of sustaining the maximum dynamic loads resulting from failure of the primary/first system.
  - g. The requirements for recovering the load need to be established.
  - h. The response of the system to internal faults must be consistent with achieving the overall reliability and operability required for the complete system.
  - i. Nuisance tripping. Fault diagnostic methods need to be available to ensure that control of the load is not lost during a trip, e.g. during power failure and hang up. Adequate information for fault diagnosis should be provided to ensure that the lifting system and its load can be recovered safely.
- A2.10 The requirements and arrangements to test such systems need to be established to demonstrate that claimed performance of safety function to a level commensurate with their classification. ONR SAP EQU.1 (Qualification procedures).

### **Ropes and reeving systems**

- A2.11 Steel ropes are complex structures that are designed and configured for particular applications. Selection of the wrong rope type may result in operational problems, an increased rate of deterioration and possible damage to the rope, reducing its strength and life. SQEP technical advice should always be sought when assessing the detailed behaviour of rope systems in complex reeving systems.
- A2.12 Whilst a rope may appear to have a large reserve margin, this will be based on a minimum tensile breaking strength (confirmed by the destructive testing of a sample length). This reserve margin will reduce over time. Suitable fleet angles, pulley and drum diameters, groove shapes and radii will reduce fatigue and wear. Reverse and transverse bends in rope systems should be avoided wherever practicable.
- A2.13 All ropes will rotate to some degree under tensile load. Torsional stability is their resistance to rotation. Ropes may lose their torsional stability over time and the amount of rotation will increase. The torsional stability of the rope system should be demonstrated for all modes of operation, especially where dual reeving is used and claims are made regarding its redundancy. The torsional stability of the rope is also affected by the type of rope termination used.
- A2.14 Certain types of ropes are constructed to resist rotation under an applied axial load. Pairs of ropes of opposite lay (twist) can be effective in balancing the rotation effect of a single rope to prevent load rotation as it is lifted and lowered.
- A2.15 Multi-layered drums should be avoided wherever possible. The rope layering mechanism is complex with greater potential for damage and reduced rope life. However, where there is a large range of lift and/or space limitations their use might be unavoidable. Knowledge and experience of these systems is critical and expert advice should be sought.

- A2.16 Ropes should be inspected regularly to ensure that they are replaced before there is an unacceptable loss of performance that could result in catastrophic failure. BS ISO 4309:2010[23] is a source of relevant good practice for care and maintenance, inspection and discard for wire ropes.
- A2.17 Inspectors should be aware that intrusive inspection of the internal core structure may damage the rope and is not recommended for certain types of rope construction, e.g. ropes with compacted strands ('dyform') or plastic inserts. Consideration should therefore be given to a programme of periodic replacement supported by destructive testing and surveillance of discarded ropes.
- A2.18 Corrosion can occur throughout the rope structure, affecting internal strands and wires. This is particularly relevant for exposed marine environments or where ropes enter and leave water (e.g. ponds with chemical additives). Although stainless steel ropes may be less susceptible to corrosion effects, they are vulnerable to internal abrasion (galling) that occurs between stainless steel surfaces. This damages the internal wires of the rope. Expert advice should be sought for critical applications to determine the most suitable rope material, inspection techniques and discard criteria.

### **Use of proprietary devices**

- A2.19 Inspectors should be aware that lifting devices are likely to incorporate proprietary equipment. For example gearboxes, brakes, couplings, bearings, load cells and rope terminations. The design justification of such equipment may not be readily available and reliance will be placed on commercial rated capacities, etc.
- A2.20 In some cases, the only available evidence is a type test certificate. This may not be adequate to demonstrate its reliability, design life or tolerance to the fault conditions identified by the safety case.
- A2.21 Licensees should demonstrate that the equipment selected adequately supports the safety case.

### **Gears, drive shafts and bearings**

- A2.22 Gearboxes invariably contain a large number of components that are subject to relatively complex forces, moments and torques. The failure of any one of these geometrically complex components may result in uncontrolled lowering of the load.
- A2.23 Gearboxes should be of rigid construction. They will generally consist of double helical (herringbone) spur gears mounted between bearings. Novel gearing arrangements introduce more complex loading conditions and failure modes. They will therefore require more extensive and technically challenging analysis to justify the design.
- A2.24 Fatigue failure of mechanical and structural components within a hoisting mechanism is a major concern. Changes in section and keyways introduce stress concentrations and should be suitably designed to minimise this effect.
- A2.25 Particular attention needs to be given to the design and set up of drive shafts. Poor alignment of equipment and lack of rigidity in the supporting structure might introduce additional load cycles. Design assumptions should therefore be suitably communicated (e.g. set up instructions) to ensure they are not compromised by construction/assembly and are maintained throughout the life of the equipment (e.g. maintenance instructions).

- A2.26 Gearboxes and shafts need to be suitably mounted so they are not inadvertently loaded due to structural movement in normal operation or faulted conditions
- A2.27 Ball and roller bearings that support such shafts may fail catastrophically. Shafts can be redundantly mounted on simple solid plain bearings to maintain gear engagement in the event of failure of the rolling element in critical applications.
- A2.28 The load carrying capacity of gears can be increased by heat treatment, surface treatment and surface finish. Process variations might affect mechanical properties. A high standard of quality control is therefore essential. For novel and complex heat treatments, parallel manufacture for destructive testing purposes should be considered.

### **Hooks, lifting features and lifting accessories**

- A2.29 Hooks, lifting features and 'below the hook' lifting accessories (e.g. lifting beams, shackles and slings) provide a means of attaching the load to the lifting device. It should not be possible to disconnect them unintentionally.
- A2.30 Inspectors should examine the attachment system to confirm that the load cannot be unintentionally released. The suspension of the load should provide a mechanical advantage to capture the load and not generate a reaction that opens the attachment mechanism.
- A2.31 Positive latching may not be practicable for remotely operated equipment as it may prevent remote disconnection of the load. In these circumstances, the engagement interface should be configured to reduce the risk of accidental disconnection.
- A2.32 Powered attachment mechanisms should be designed so that the load cannot be released if power is lost.
- A2.33 Magnetic or vacuum lifting systems should normally only be used where the consequence of a dropped load is tolerable. Where such systems cannot be avoided, redundant support features should be considered.

### **Welding**

- A2.34 The majority of lifting systems will be welded structures. Particular attention should be given to the justification and detailing of welds. Fillet welds have poor fatigue performance and should be avoided wherever reasonably practicable.
- A2.35 Suitable design codes and standards should be used for assessing the fatigue life of welded structures, e.g. BS 7608 [21].
- A2.36 The potential for lamellar tearing in welded structures should be considered. This occurs through inclusions in the parent plate material under the weld. Measures should be taken to prevent this occurring (e.g. material selection and non-destructive testing techniques).

### **Cast Iron**

- A2.37 Careful consideration should be given to the suitability of cast iron, especially in tension. Grey cast iron is prone to brittle fracture and there is also uncertainty in its behaviour under fatigue loading. Proof testing will therefore have limited value when

compared to similar tests performed on ductile materials. NDT examination of such materials is also very problematic.

- A2.38 Cast iron should not be used for load bearing components. However, inspectors should be aware that cast iron might have been used in the load path of older cranes, e.g. hoist gear boxes. The suitability of cast iron should be justified in such applications.

### Seismic Considerations

- A2.39 Lifting structures and mechanisms are vulnerable to seismic accelerations and have complex interactions with the supporting structure and other SSCs. The dynamic seismic loading will frequently dominate the design of such structures. The External Hazards TAG NS-TAST-GD-013 [22] should be consulted with respect to seismic design.
- A2.40 The seismic analysis might identify the requirement for special engineered features to limit and control the effects of seismic events. Inspectors should review the tangible benefits of such systems and judge whether they improve safety by delivering their design intent.

Seismic features that might be considered are:

- a. Plain (unflanged) wheels on one rail may be used to accommodate any relative displacement of the two gantries/rails either side of the building. Guide rollers may also be used, instead of flange wheels, to limit skewing effects and sideways movement of the crane. Whether flanged wheels or guide rollers are used, these should withstand the normal service loads, fault conditions and horizontal seismic reactions.
- b. Seismic restraints provide a redundant and diverse means of preventing crane derailment. The restraints should be of sufficient depth to accommodate any uplift that might occur.
  - i. For overhead cranes, it may not be necessary to prevent vertical movement as any uplift should effectively isolate the crane from the seismic acceleration. It should be noted that overhead crane gantry systems will need to be designed to react the uplift forces.
  - ii. For cranes that lift outside their wheelbase (e.g. dockside cranes and jib cranes) vertical uplift on one side might occur. A suitable restraint system will be required to prevent overturning.
- c. Seismic triggers might be required to isolate the crane, cutting power to the drives and applying the brakes. Inspectors should be aware that normal braking systems themselves may not offer sufficient frictional resistance to prevent horizontal movement along the crane rails. Additional braking systems (e.g. seismic rail clamps) may be required. The effects of spurious operation of the brakes/clamps should be assessed as they might generate significant reactions between the crane and the supporting building structure.

Where seismic triggers are used, the equipment that isolates the plant must be seismically justified to maintain the isolation throughout the event, e.g. contactors and brakes will need to be seismically qualified against the maximum dynamic loadings. In addition, plant and control systems that are not seismically justified may be damaged and so will not be serviceable during any subsequent recovery of a suspended load.

## Wind pressure

- A2.41 Inspectors should be aware of the difficulties of justifying external cranes and temporary lifting systems (e.g. lifting gantries, mobile cranes and tower cranes) against in-service and maximum out-of-service wind loads to the level of confidence expected in a nuclear safety justification. Inspectors should seek detailed advice on the peak gust loadings that should apply to such structures and which may be intensified by the local topography and surrounding buildings. SAP EHA.11 (Weather conditions).
- A2.42 Inspectors should also note that the wind pressure on the load itself can significantly affect the stability and strength of external cranes. It is therefore necessary to consider the implications for such systems if the load or crane cannot be moved or removed from the lifting system in the event of high winds.

## Wheels and Rails for EOT Cranes

- A2.43 The alignment of crane wheels and gantry rails is critical for satisfactory operation. Poor alignment can result in accelerated wear of wheel flanges reducing their resistance to skewing and side loadings. Lubrication systems (e.g. graphite) may slow down the rate of wear.
- A2.44 The maintenance instructions should identify when wheel replacement is required.

## Appendix 3: Guidance for Electrical Control and Instrumentation (EC&I) specialist inspectors

### Introduction

- A3.1 Lifting systems incorporate a variety of EC&I systems and, in that respect, are no different to any other powered mechanical system. This section provides guidance on aspects of EC&I systems that are relevant to lifting operations. Inspectors should apply the appropriate SAPs and TAGs relevant to the EC&I specialism in their assessments.

### Motor drives

- A3.2 A wide range of electric motor drives have been used on crane systems over the years, ranging from direct current (DC) motors to alternating current (AC) synchronous induction motors. The torque speed characteristics of each motor type and its failure modes will be different.
- A3.3 Inspectors should be aware of such issues and note that modern applications of AC motors may incorporate frequency control to give variable torque and speed characteristics. Such systems are usually based on digital software and failures of both hardware and software should be considered.
- A3.4 Where detailed fault analysis requires the examination of stalled conditions such as those arising from restrained loads or double-blocking, inspectors should be aware of the need to examine the complete drive system inertia and motor characteristics. Energy dissipating devices and/or torque limiters may be necessary to limit the loads applied to the lifting machinery and any other equipment and structures that could be affected, e.g. nuclear fuel stringers or reactor cores.
- A3.5 Inspectors should be aware that during faulted conditions the maximum drive torques within the drive system could arise from the crane motor rather than from the load at the crane drum. Reverse torques may also be generated. The characteristics of the motor and its control system therefore need to be thoroughly understood if the design is to be tolerant to motor faults, e.g. snagged loads, double blocking, spurious brake applications and other faulted conditions.
- A3.6 Hydraulic and pneumatic motors and actuators may be used, which will have different characteristics and failure modes to electrical drive systems, e.g. mobile cranes (hydraulic motors) and air hoists.

### Software in motor controllers and other devices

- A3.7 Modern frequency controlled drives incorporate software driven control systems that vary the frequency of supply to the motor and other parameters in response to the motor and system inertia and torque. The failure modes of such software driven systems should be established.
- A3.8 Software changes should be controlled (LC20 and 22) and the effect of such changes on the drive characteristics should be assessed.

### Control Instrumentation and Protection

- A3.9 Most industrial cranes will have simple control systems that combine control, protection and motor circuits into a single system. There will be little or no

segregation or diversity in such systems and they may be vulnerable to spurious movement. These systems are there to protect the crane from damage. It is unlikely that they will protect the process or other plant and equipment.

- A3.10 Various approaches have been taken to addressing the problem of hoist drive train failure, ranging from redundant and duplex systems, to the provision of emergency braking and protection systems that detect drive train failure or discrepancies in drive ratio between the input and output speed. In assessing such systems, inspectors need to consider the response of the mechanical system.
- A3.11 Zoning systems and crash/collision protection systems should be considered to prevent the initiation of faults that could challenge the integrity of the lifting system or other SSCs within the facility.
- A3.12 Such protection systems will typically be found on fuel handling systems, in cell cranes and other sensitive nuclear lifting equipment where out of sequence movements and other faults need to be detected and prevented. These are likely to comprise multi-channel protection systems. See NS-TAST-GD-003.



## Appendix 4 – Use of mobile lifting equipment

### Introduction

- A4.1 Mobile lifting equipment might be used where there is no suitable permanent lifting provision. It offers a solution which, if implemented adequately and safely, can reduce long term risk and facilitate hazard reduction.
- A4.2 Mobile lifting equipment should not be used routinely for hazardous nuclear operations, especially where there is a risk of significant off-site radiological hazards.
- A4.3 Where the use of mobile lifting equipment is deemed necessary and proportionate (e.g. for refurbishment work, decommissioning activities or emergency requirements), its use should undergo detailed assessment and rigorous procedural control.
- A4.4 The safety case should demonstrate that the risks associated with use of mobile lifting equipment, including the effects of catastrophic failure, are tolerable and risk is ALARP.
- A4.5 The safety case should identify all reasonably practicable measures to reduce the consequences of mobile lifting equipment failure. For example, removal of nuclear inventory, plant shutdown and exclusion of personnel within the collapse zone of the lifting equipment.
- A4.6 The safety case should identify the need for an adequately resourced emergency plan in the event of catastrophic failure.

### Planning of lifting operations and site preparation

- A4.7 Adequate planning and site preparation requires a multi-discipline and multi-organisation approach. There should be adequate communication between all parties so that the hazards and risks associated with the lifting operation are fully understood.
- A4.8 BS7121[12] is a source of relevant good practice for the safe use of cranes. Appendix E provides additional recommendations for operation of cranes on or adjacent to a site of exceptional hazards. This is relevant to nuclear sites and adjacent (e.g. construction) sites.
- A4.7 The Construction Plant-hire Association (CPA) produces guidance covering different types of mobile lifting equipment such as mobile and tower cranes. [www.cpa.uk.net](http://www.cpa.uk.net)
- A4.8 All types of mobile lifting equipment are vulnerable to environmental hazards (e.g. strong wind, lightning strikes and flash flooding). Licensees should have arrangements in place to ensure that lifting operations are not carried out on or near a nuclear licensed site if there is any indication of adverse weather conditions. These should identify the actions, and timeframe, to make the lifting equipment and load safe.
- A4.9 Mobile lifting equipment might be damaged or weakened by seismic accelerations and other forms of earth movement. These events are unpredictable. The safety case should identify the necessary actions to be taken following such events.

**Mobile cranes**

- A4.10 The wide range and capacities of mobile cranes available provides a considerable lifting capability. However, they should only be used where the safety case demonstrates that risk is ALARP.
- A4.11 Licensees may have generic procedures for determining if a mobile crane is to be permitted to work on specific jobs on individual sites. These procedures should not negate the requirement for an adequate safety case or ONR specialist assessment.
- A4.11 Inspectors should be aware of the vulnerability of mobile cranes. The nuclear and non-nuclear consequences of collapse should be adequately assessed by the safety case.
- A4.12 Many accidents involving mobile cranes are due to inadequate ground conditions. Mobile cranes will overturn if the ground subsides. Inspectors should confirm that the ground conditions have been adequately evaluated and that suitable measures are in place to ensure that the crane will remain stable throughout the lifting operations. Ground conditions should be tested where the risk of collapse is significant.
- A4.13 Underground services and areas of inadequate localised ground strength should be identified. Adequate load spreader plates should be provided under crane stabilisers and support legs. Civil foundations may need to be constructed.
- A4.14 Most mobile cranes are fitted with automatic safe load indicator (ASLI) systems to aid the operator in setting the working load limits with respect to rigging and outrigger configuration. These systems might be used advantageously to reduce risk ALARP. For example, they may enable a smaller and lighter mobile crane to be used.
- A4.15 ASLIs are computer controlled systems. They should not be relied on as the sole means of establishing safe operating limits. The lifting plan should identify how the lifting operation is safely maintained within the rated capacity of the mobile crane for its rigging and outrigger configuration.
- A4.16 Rigging and erection of mobile cranes requires careful attention to the manufacturer's procedures to ensure that the crane is level, adequately supported and correctly configured for the required lifting operations.
- A4.17 Human error can lead to equipment failure. Failure to follow manufacturer's requirements correctly, or failures in the rigging system under the hook, can result in catastrophic collapse of the crane. This can result in toppling of the complete crane or buckling of the main boom.
- A4.18 Mobile cranes have complex boom extending features with slewing and luffing capability, operated by non-redundant hydraulic systems. The actions and safety measures to be taken, should these fail, should be identified in the operating instructions.
- A4.19 Mobile cranes are vulnerable to damage and abuse unless their operation and maintenance is strictly controlled. Inspectors should seek assurance that the crane being used is in satisfactory condition and has not undergone some form of repair or modification prior to its arrival on site.

A4.20 Inspectors should pay particular focus in ensuring that the scope and extent of EIM&T of mobile cranes is proportionate to the risk. Evidence should be sought that EIM&T has been carried out in accordance with the manufacturer's instructions and by competent SQEP persons.

A4.21 Mobile cranes contain hydraulic oils and are mounted on a vehicle chassis that contains fuel and lubrication systems. The potential fire risk should be addressed.

### **Tower Cranes**

A4.22 Tower cranes are likely to be in position for extended periods. The effects of extreme weather conditions on their strength and stability should be addressed by the safety case.

A4.23 To minimise wind loadings, tower cranes are normally allowed to weather vane (free slew). The siting and configuration of a tower crane must therefore allow for this free movement such that collision with other plant and equipment, e.g. other tower cranes and high structures (permanent and temporary), do not occur.

A4.20 Tower cranes might have self-erecting capabilities. This introduces additional risk of human and software errors during assembly that might affect extension and retraction operations. Inspectors should ensure that manufacturer's instructions are followed and those carrying out erection tasks are competent SQEP. The potential for out of sequence extension or retraction should be identified within the safety case and appropriate actions and safety measures identified.

### **Mobile gantry lifting and jacking systems**

A4.21 Mobile gantry lifting and jacking systems may be used for temporary lifting operations. They can provide a greater lifting capability than a mobile crane. These systems present similar hazards to mobile and tower cranes but a different level of risk. For example, a structural collapse may be more energetic but confined to a limited area. The safety case should demonstrate that the risk of using a gantry lifting or jacking system is ALARP.

A4.22 Gantry systems can be large and heavy and may be in position for several weeks or months. It is therefore anticipated that civil foundations will be designed and constructed to support them.

A4.23 The safety case should address the need for these systems to be designed to withstand a variety of climatic conditions (e.g. wind, rain and snow), degradation mechanisms (e.g. corrosion) and external hazards (e.g. seismic).

## Appendix 5 – Guidance to inspectors on the selection and use of British Standards and European harmonised standards for the design of lifting equipment structures and mechanisms

- A5.1 Following the introduction of European Directives, the European standards bodies have been drawing up corresponding technical specifications (referred to as ‘harmonised standards’) that meet the essential requirements of the relevant directives. Compliance with these standards provides a presumption of conformity with the essential requirements of the relevant directive.
- A5.2 Inspectors should note that many existing British Standards were drawn up before the Machinery Directive came into effect. Therefore, compliance with a British Standard that is not an EN standard should not be taken as a presumption of conformity with the essential requirements of the Machinery Directive.
- A5.3 A significant number of harmonised standards for cranes and lifting equipment have now been published and these should be considered for their suitability and applicability. Licensees should therefore be able to demonstrate how a selected design code provides a means of compliance with the Machinery Directive, particularly for mechanical strength.
- A5.4 BS466[24] and BS2573[14] Parts 1 and 2 have been used by UK site licensees and crane manufacturers for many years as the principal design codes for the design justification and assessment of overhead cranes and other similar types of mechanical equipment.
- A5.5 BS466 has been withdrawn. ONR does not expect that any part of BS466 should be used for nuclear equipment without appropriate justification. EN 13135[26] specifies the requirements for electrical mechanical, hydraulic and pneumatic equipment used in all type of cranes and their fixed load lifting attachments.
- A5.6 At the time of writing this guidance, BS2573 Parts 1 and 2 were classified as “superseded”, but still “current” standards. They were still available from the British Standards Institution but, with the introduction of the new harmonised standards, ONR understands that these will also be “withdrawn”.
- A5.7 EN13001[15] is a new series of crane design codes applicable to all types of lifting machinery. Other EN standards address specific equipment types.
- A5.8 EN15011[24] is specifically for bridge and gantry cranes and should be used in conjunction with EN13001, e.g. for structural strength and rope system design.
- A5.9 ONR expects that licensees will adopt EN standards as the basis for all lifting equipment design. These codes and standards should be evaluated to determine their adequacy and sufficiency and supplemented or modified as necessary to a level commensurate with the importance of the relevant safety function(s). See ONR SAP ECS.3 (Codes and standards) and subsequent paragraphs.
- A5.10 EN13001 adopts a ‘limit state’ approach which differs to the ‘allowable stress’ approach of BS2573. Consequently, a comparison of the two codes will result in different reserve margins when compared to elastic and plastic limits.
- A5.11 BS2573 design factors are not interchangeable with EN 13001 and the application of previously adopted design factors and enhancements is unlikely to achieve an equivalent design. Analysis supported by a combination of design codes should therefore be avoided or justified. See ONR SAPs Paragraph 173.

- A5.12 The safety case should take account of how the lifting equipment could fail. Nuclear lifting equipment design codes and standards should be suitably applied to provide a gradual and predictable failure mode. See ONR SAP EMC.11 – Failure modes.
- A5.13 In assessing the suitability of a design code, inspectors should consider the requirement of LC15 (Periodic Review). In particular, the need to carry out a comparison against current standards for new plant, evaluate any deficiencies and implement any reasonably practicable improvements to enhance safety.
- A5.14 Where there are impending changes to design codes and standards, a comparison of these standards should be undertaken to demonstrate that appropriate conservatism and safety margins are maintained.

#### **Design classification of lifting equipment structures and mechanisms**

- A5.15 The purpose of design classification of structures and mechanisms is to take into account the significant differences that exist in the operation of lifting equipment. These differences affect fatigue life and component wear and therefore must be addressed by design. The classification of the lifting system, its structures and mechanisms should be demonstrably conservative.
- A5.16 Inspectors should be aware that the working cycles of a lifting system start from the day it is installed through to the day it is taken out of service and should therefore include:
- Loads imposed during the installation of the lifting system.
  - Lifting equipment use for construction and installation of other plant and equipment.
  - Setting to work, testing and commissioning. This is particularly important for store cranes, where the full range of system capability has to be demonstrated before the store inventory is first introduced.
  - Normal plant operation
  - Plant faulted conditions e.g. control and protection system trips and recovery actions
  - Post-operative clean out operations (POCO)
  - Decommissioning operations
  - Maintenance and testing requirements for other plant and equipment
  - In-service inspection requirements for other plant and equipment
  - Lifting system maintenance and in-service testing requirements
- A5.17 The EN13001 classification methodology is different and more detailed than BS466 and BS2573. They are therefore non-interchangeable and equipment classifications based on one standard cannot be used to determine the design factors of another.

## Appendix 6 – Failure modes, protection and mitigation

### Introduction

A6.1 This annex provides additional guidance to inspectors in assessing licensees' safety cases. It identifies the principal faults that can occur during lifting operations and the measures that might be taken to address them. These will be subject to ALARP consideration. Judgements should therefore be proportionate to the severity of the hazard and its consequences.

### Purpose and scope

A6.2 Inspectors should use this annex to satisfy themselves that licensees' safety cases adequately consider all lifting fault conditions and provide adequate safety measures. These may be physical design features and/or operational measures.

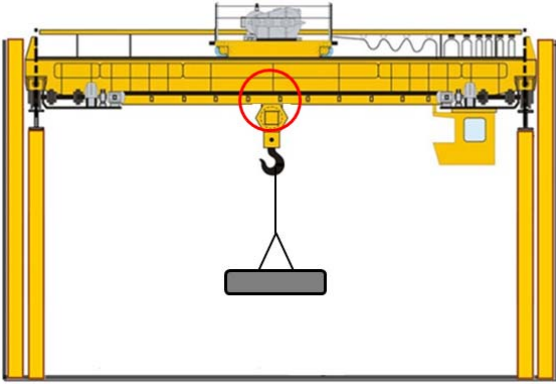
A6.3 Licensees should be able to demonstrate a clear understanding of how faults may propagate, the possible consequences and the appropriate actions required to achieve a safe condition.

A6.4 Preventative and mitigation measures are identified together with operator actions. These take the form of:

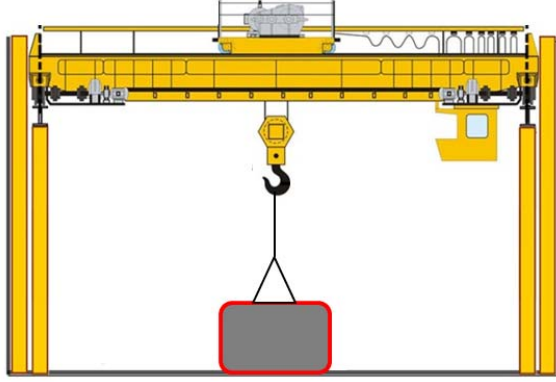
- Planning of lift layout and equipment design
- Indication/ warning systems
- Protection and mitigation systems
- Operator instructions and SQEP
- Recovery to safety
- Reporting of incidents

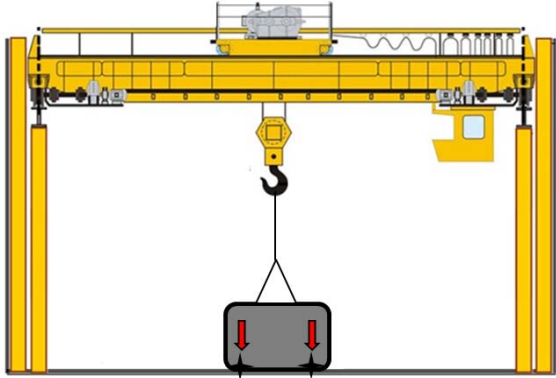
A6.5 This annex focuses on individual faults but other faults may occur through interactions with other plant and equipment. Inspectors should use their judgement and experience to adequately assess each situation to come to an informed judgement.

A6.6 Diagrammatical examples are presented to give inspectors a general appreciation of the lifting faults that can occur. In most cases, these are represented by an overhead crane. Inspectors should use their judgement to understand how these faults will affect the lifting system. Where necessary, the topic specialist should be consulted for further specific guidance.

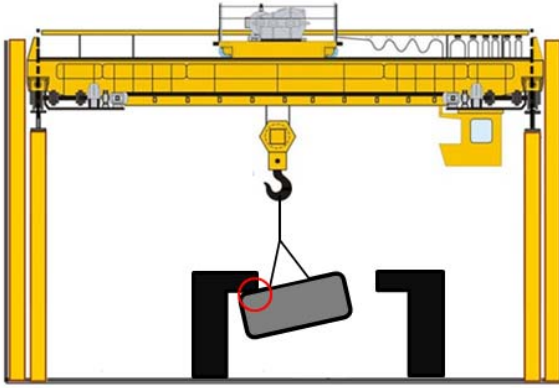
<p><b>FAULT CONDITION:</b></p> <p><b>A6.7 DOUBLE BLOCKING</b></p> <p>Hook block, lifting accessory or load connects with underside of lift (raise direction).</p> <p>Leads to catastrophic hoist component failure and uncontrolled lowering.</p>	
<p>Planning of Lift (layout and equipment design) (LOLER Reg 8)</p>	<ul style="list-style-type: none"> <li>▪ Lifting system design does not require loads to be lifted to the full height of lift available</li> <li>▪ Adequate clearances between load, lifting accessory and underside of crane</li> <li>▪ Lifting configuration (adequate clearance)</li> <li>▪</li> </ul>
<p>Indication / Warning Systems (LOLER Reg 7b)</p>	<ul style="list-style-type: none"> <li>▪ Indication when hook is approaching top of lift.</li> <li>▪ Limit switch to lower only when hook is fully raised.</li> <li>▪ Height indication system</li> </ul>
<p>Protection &amp; Mitigation Systems (LOLER Reg 6)</p>	<ul style="list-style-type: none"> <li>▪ Over raise limits</li> <li>▪ Mechanical torque limiter (with overlower protection system)</li> </ul> <p><b>N.B. electrical overload systems should not be considered as a suitable means of protecting against double blocking)</b></p>
<p>Operator Instructions (LOLER Reg 9)</p>	<ul style="list-style-type: none"> <li>▪ Do not lift loads to full height of lift (e.g. sufficient to clear obstructions only)</li> </ul>
<p>Recovery to Safety</p>	<ul style="list-style-type: none"> <li>▪ Procedure for safe set down of load</li> <li>▪ Lifting zone clear of personnel</li> <li>▪ Thorough examination (competent person)</li> <li>▪ Review and implement prevention actions</li> <li>▪ Reporting of incident and involvement of competent person</li> </ul>
<p>Report incident (LC7) (LOLER Reg 10)</p>	<ul style="list-style-type: none"> <li>▪ Raise incident report</li> <li>▪ Inform ONR (as appropriate under site licence arrangements and RIDDOR)</li> </ul>



<p><b>FAULT CONDITION:</b></p> <p><b>A6.8 OVERLOAD</b></p> <p>Item (including lifting accessories) to be lifted heavier than SWL of lifting device.</p> <p>*SWL= Safe Working Load</p>	
<p>Planning of Lift (layout and equipment design) (LOLER Reg 8)</p>	<ul style="list-style-type: none"> <li>▪ Schedule of loads to be lifted</li> <li>▪ Lifting plans available</li> <li>▪ Weight of item to be lifted known (e.g. marking).</li> <li>▪ Weight of lifting accessories known</li> <li>▪ Dedicated/fixed lifting equipment for items regularly lifted</li> </ul>
<p>Indication / Warning Systems (LOLER Reg 7b)</p>	<ul style="list-style-type: none"> <li>▪ Use of load cells and displays (on the lifting device or incorporated into the lifting arrangement)</li> </ul>
<p>Protection &amp; Mitigation Systems (LOLER Reg 6)</p>	<ul style="list-style-type: none"> <li>▪ Overload trips (typically set at 105 to 110% SWL of lifting device, no greater than proof load = 125% SWL) N.B. should trip all motions except lower</li> <li>▪ Mechanical torque limiter</li> </ul>
<p>Operator Instructions (LOLER Reg 9)</p>	<ul style="list-style-type: none"> <li>▪ Progressive pickup of load (N.B. no travel movement before weight confirmed safe to lift)</li> <li>▪ Lifting supervisor</li> <li>▪ Rigger (for loose lifting equipment)</li> </ul>
<p>Recovery to Safety</p>	<ul style="list-style-type: none"> <li>▪ Recovery procedure</li> <li>▪ Thorough examination (competent person)</li> </ul>
<p>Report incident (LC7) (LOLER Reg 10)</p>	<ul style="list-style-type: none"> <li>▪ Raise incident report</li> <li>▪ Inform ONR (as appropriate under site licence arrangements and RIDDOR)</li> </ul>

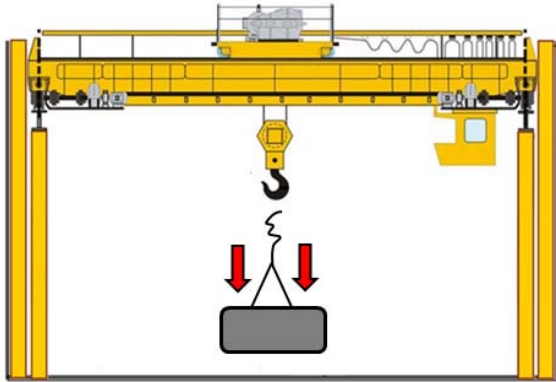
<p><b>FAULT CONDITION:</b></p> <p><b>A6.9 RESTRAINED LOAD</b></p> <p>Item cannot be lifted freely</p>		
<p>Planning of Lift (layout and equipment design) (LOLER Reg 8)</p>	<ul style="list-style-type: none"> <li>▪ Restraining features removed</li> <li>▪ Confirmation carried out to release/break any retention features/effects (e.g. cutting, jacking)</li> </ul>	
<p>Indication / Warning Systems (LOLER Reg 7b)</p>	<ul style="list-style-type: none"> <li>▪ Use of load cells and displays (on the lifting device or incorporated into the lifting arrangement)</li> <li>▪ Compliant lifting systems (e.g. spring arrangement to indicate load being applied)</li> </ul>	
<p>Protection &amp; Mitigation Systems (LOLER Reg 6)</p>	<ul style="list-style-type: none"> <li>▪ Overload trips* (typically set at 105 to 110% SWL of lifting device, no greater than proof load = 125% SWL) N.B. should trip all motions except lower</li> <li>▪ Torque limiter</li> </ul>	
<p>Operator Instructions (LOLER Reg 9)</p>	<ul style="list-style-type: none"> <li>▪ Progressive pickup of load (N.B. no travel movement before weight confirmed safe to lift)</li> <li>▪ Lifting supervisor</li> <li>▪ Rigger (for loose lifting equipment)</li> <li>▪ Thorough examination (competent person)</li> </ul>	
<p>Recovery to Safety</p>	<ul style="list-style-type: none"> <li>▪ Procedure for safe set down</li> <li>▪ Lower only</li> <li>▪ Override facility (automatic reset or management control)</li> </ul>	
<p>Report incident (LC7) (LOLER Reg 10)</p>	<ul style="list-style-type: none"> <li>▪ Raise incident report</li> <li>▪ Inform ONR (as appropriate under site licence arrangements and RIDDOR)</li> </ul>	

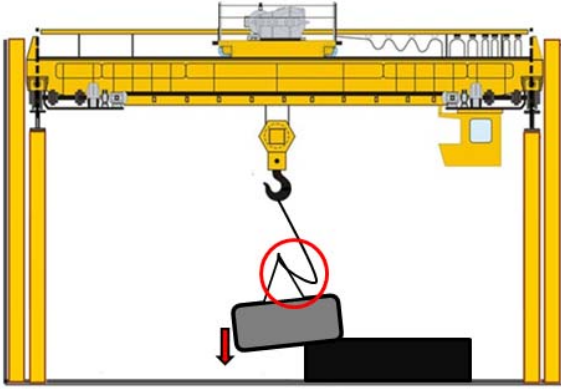
\*Inspectors should note that the response time of electrical overload systems may not prevent major overload (loads experienced are likely to exceed 125%SWL).

<p><b>FAULT CONDITION:</b></p> <p><b>A6.10 LOAD SNAGGING</b></p> <p>Load connects with overhanging obstruction during lift (RAISE DIRECTION)</p>	 <p>The diagram shows a yellow overhead crane with a hook and a grey rectangular load. The load is tilted and is catching on a black L-shaped obstruction that overhangs from the crane's structure. A red circle highlights the point of contact between the load and the obstruction.</p>
<p>Planning of Lift (layout and equipment design) (LOLER Reg 8)</p>	<ul style="list-style-type: none"> <li>▪ Design out obstructions (e.g. no overhanging obstructions, smooth vertical sides)</li> <li>▪ Adequate clearances between load and other plant and equipment</li> <li>▪ Alignment of the load (e.g. north/south) to ensure adequate clearances</li> <li>▪ Detailed zones to ensure loads lifted are clear of obstructions</li> <li>▪ Operator control position to optimise visibility (e.g. use of wireless control)</li> </ul>
<p>Indication / Warning Systems (LOLER Reg 7b)</p>	<ul style="list-style-type: none"> <li>▪ Indication that crane hook is in correct position, e.g. <ul style="list-style-type: none"> <li>– Marker board system</li> <li>– Indication lamps at control position</li> <li>– Laser and floor mounted targets</li> </ul> </li> <li>▪ Overload indication* (N.B. not protection)</li> </ul>
<p>Protection &amp; Mitigation Systems (LOLER Reg 6)</p>	<ul style="list-style-type: none"> <li>▪ Weight tare system – setting weight after it has been lifted and detection of change (N.B. effectiveness may be limited)</li> <li>▪ Tilt detection (if practicable)</li> </ul>
<p>Operator Instructions (LOLER Reg 9)</p>	<ul style="list-style-type: none"> <li>▪ Eliminate load swing</li> <li>▪ Operator diligence (e.g. use of banksman and reliable communication)</li> <li>▪ Ensure adequate visibility of load and obstruction (most advantageous position)</li> <li>▪ Establish exclusion zone for non-essential persons</li> </ul>
<p>Recovery to Safety</p>	<ul style="list-style-type: none"> <li>▪ Set load down safely</li> <li>▪ Emergency plan available <ul style="list-style-type: none"> <li>– Establish exclusion zone</li> <li>– Review hazards (e.g. external damage)</li> <li>– Establish recovery strategy</li> </ul> </li> </ul>
<p>Report incident (LC7) (LOLER Reg 10)</p>	<ul style="list-style-type: none"> <li>▪ Raise incident report</li> <li>▪ Inform ONR (as appropriate under site licence arrangements and RIDDOR)</li> </ul>

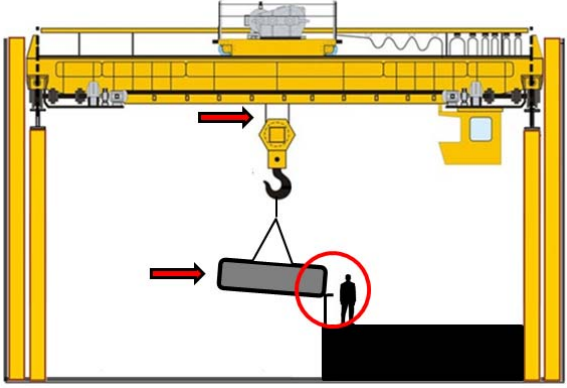
\*Inspectors should note that the response time of electrical overload systems may not prevent major overload (loads experienced are likely to exceed 125%SWL).



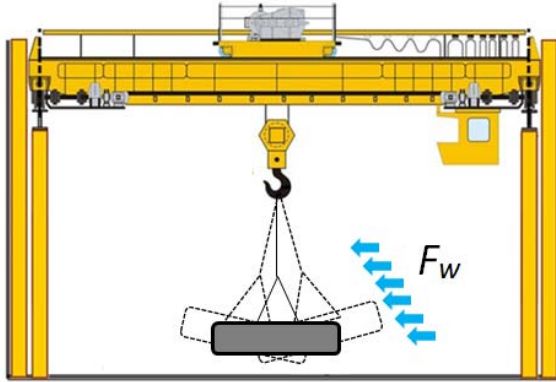
<p><b>FAULT CONDITION:</b></p> <p><b>A6.11 UNCONTROLLED LOWER</b></p> <p>Mechanical or EC&amp;I System failure leading to high speed or free fall descent of load.</p>	
<p>Planning of Lift (layout and equipment design) (LOLER Reg 8)</p>	<ul style="list-style-type: none"> <li>▪ Package drop withstand</li> <li>▪ Structural withstand of Structures Systems and Components (SSCs) vulnerable to impact damage</li> <li>▪ Minimisation of lift heights to within deterministic drop withstand capability of load and SSCs below the load</li> </ul>
<p>Indication / Warning Systems (LOLER Reg 7b)</p>	<ul style="list-style-type: none"> <li>▪ Hoist drive overspeed detection (only suitable for speed control system faults not mechanical failures)</li> </ul>
<p>Protection &amp; Mitigation Systems (LOLER Reg 6)</p>	<ul style="list-style-type: none"> <li>▪ Overspeed trip (application of hoist brakes)</li> <li>▪ Emergency braking (rope barrel)</li> <li>▪ Mechanical comparator (input vs output speed)</li> <li>▪ Motor/load follower system</li> <li>▪ Impact absorbers (in floor)</li> <li>▪ Dead man's handle (only suitable for speed control system faults not mechanical failures)</li> </ul>
<p>Operator Instructions (LOLER Reg 9)</p>	<ul style="list-style-type: none"> <li>▪ Release of controls (only suitable for speed control system faults not mechanical failures)</li> <li>▪ Emergency stop (only suitable for speed control system faults not mechanical failures)</li> <li>▪ Examine load/lifting gear</li> <li>▪ Operator instructions in response to event</li> </ul>
<p>Recovery to Safety</p>	<ul style="list-style-type: none"> <li>▪ Facility emergency plan</li> <li>▪ Establish exclusion zone</li> <li>▪ Health Physics monitoring</li> <li>▪ Identify and review long term actions</li> <li>▪ Damage assessment</li> </ul>
<p>Report incident (LC7) (LOLER Reg 10)</p>	<ul style="list-style-type: none"> <li>▪ Raise incident report</li> <li>▪ Inform ONR (as appropriate under site licence arrangements and RIDDOR)</li> </ul>

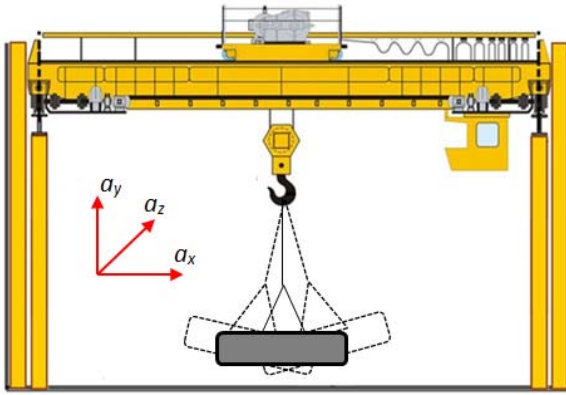
<p><b>FAULT CONDITION:</b></p> <p><b>A6.12 LEDGED LOAD</b></p> <p>Lowered onto overhanging obstruction</p>	
<p>Planning of Lift (layout and equipment design) (LOLER Reg 8)</p>	<ul style="list-style-type: none"> <li>▪ Design out obstructions (e.g. no overhangs)</li> <li>▪ Adequate clearances between load and other plant</li> <li>▪ Control alignment of the load (e.g. north/south) to maximise clearances</li> <li>▪ Detailed zones to ensure loads lifted are clear of obstructions</li> <li>▪ Operator control position to optimise visibility (e.g. use of wireless control)</li> </ul>
<p>Indication / Warning Systems (LOLER Reg 7b)</p>	<ul style="list-style-type: none"> <li>▪ Indication that crane hook is in correct position, e.g. Marker boards and pointers</li> <li>▪ Indication lamps</li> <li>▪ Laser and floor mounted target</li> <li>▪ Load measurement display (N.B. not protection)</li> </ul>
<p>Protection &amp; Mitigation Systems (LOLER Reg 6)</p>	<ul style="list-style-type: none"> <li>▪ Weight tare system* – setting weight after it has been lifted and detection of change (N.B. effectiveness may be limited)</li> <li>▪ Tilt detection</li> </ul>
<p>Operator Instructions (LOLER Reg 9)</p>	<ul style="list-style-type: none"> <li>▪ Ensure load swing eliminated before commencing lifting operation</li> <li>▪ Operator diligence (e.g. use of banksman and reliable communication)</li> <li>▪ Ensure operator visibility of load and obstruction (most advantageous position)</li> <li>▪ Establish exclusion zone for non-essential persons</li> </ul>
<p>Recovery to Safety</p>	<ul style="list-style-type: none"> <li>▪ Emergency plans</li> <li>▪ Establish exclusion zone</li> <li>▪ Review hazards (e.g. external damage)</li> <li>▪ Establish recovery strategy</li> <li>▪ Set load down safely</li> </ul>
<p>Report incident (LC7) (LOLER Reg 10)</p>	<ul style="list-style-type: none"> <li>▪ Raise incident report</li> <li>▪ Inform ONR (as appropriate under site licence arrangements and RIDDOR)</li> </ul>

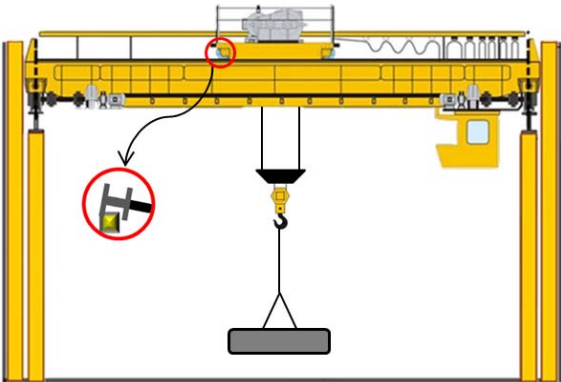
\*Inspectors should note that weight tare and slack rope detection may not be suitable as the ropes might still be under tension following a ledged load condition.

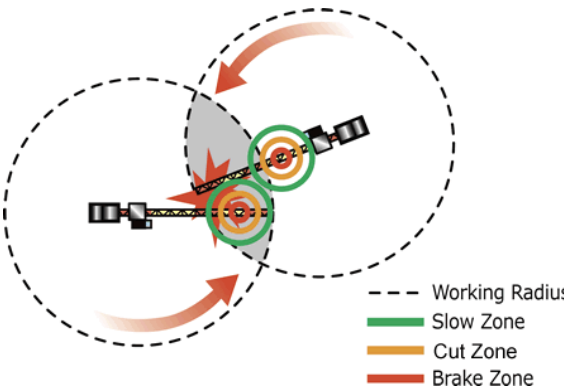
<p><b>FAULT CONDITION:</b></p> <p><b>A6.13 Load collision</b></p> <p>Load connects with overhanging obstruction during movement.</p>	
<p>Planning of Lift (layout and equipment design) (LOLER Reg 8)</p>	<ul style="list-style-type: none"> <li>▪ Predetermined route identified</li> <li>▪ Adequate clearance confirmed along route</li> <li>▪ Potential for load movement/rotation and/or sway considered</li> </ul>
<p>Indication / Warning Systems (LOLER Reg 7b)</p>	<ul style="list-style-type: none"> <li>▪ Control alignment of the load (e.g. north/south) to ensure adequate clearances</li> <li>▪ Pre-determined routes to ensure loads are lifted clear of obstructions</li> <li>▪ Ensure operator visibility of load and obstruction (most advantageous position)</li> <li>▪ Proximity alert system</li> </ul>
<p>Protection &amp; Mitigation Systems (LOLER Reg 6)</p>	<ul style="list-style-type: none"> <li>▪ Physical barriers</li> </ul>
<p>Operator Instructions (LOLER Reg 9)</p>	<ul style="list-style-type: none"> <li>▪ Lifting supervisor and banksman</li> <li>▪ Regain control if possible and assess integrity of load and crane</li> <li>▪ Assess damage if fault occurs and notify supervisor of incident.</li> <li>▪ Reporting of incident and involvement of competent person (inspect for damage)</li> <li>▪ Exclude non-essential persons</li> </ul>
<p>Recovery to Safety</p>	<ul style="list-style-type: none"> <li>▪ Procedure for safe set down</li> <li>▪ Site Emergency planning (for breach of containment)</li> <li>▪ Health physics monitoring</li> <li>▪ Identify and review long term actions</li> </ul>
<p>Report incident (LC7) (LOLER Reg 10)</p>	<ul style="list-style-type: none"> <li>▪ Raise incident report</li> <li>▪ Inform ONR (as appropriate under site licence arrangements and RIDDOR)</li> </ul>

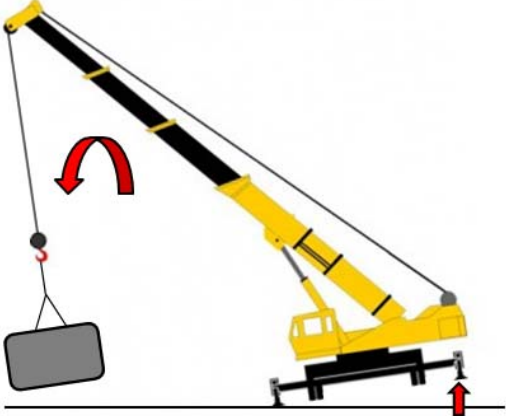


<p><b>FAULT CONDITION:</b></p> <p><b>A6.14 HIGH WIND</b></p> <p>Excessive wind pressure on lifting device or load</p>	 <p>The diagram shows a yellow overhead crane with a hook and a grey rectangular load suspended below it. Blue arrows representing wind force, labeled <math>F_w</math>, are shown blowing from the right towards the load. The crane is supported by two vertical yellow pillars.</p>
<p>Planning of Lift (layout and equipment design) (LOLER Reg 8)</p>	<ul style="list-style-type: none"> <li>▪ Procedure for establishing wind speed before undertaking lifting operations</li> <li>▪ Nature of load (e.g. 'sail' area of load)</li> <li>▪ Appropriate wind speed/height consideration</li> <li>▪ Pre-determined allowable wind speed.</li> </ul>
<p>Indication / Warning Systems (LOLER Reg 7b)</p>	<ul style="list-style-type: none"> <li>▪ Wind speed detectors (anemometers)</li> <li>▪ Warning system if wind speed exceeds allowable during lifting operations</li> </ul>
<p>Protection &amp; Mitigation Systems (LOLER Reg 6)</p>	<ul style="list-style-type: none"> <li>▪ Storm anchors for outdoor cranes</li> <li>▪ Free slew (tower cranes)</li> </ul>
<p>Operator Instructions (LOLER Reg 9)</p>	<ul style="list-style-type: none"> <li>▪ No lifting to commence if wind speed exceeds defined limit.</li> <li>▪ Defined wind speed for stopping operations</li> <li>▪ Procedure for load set down and making load and lifting device safe.</li> <li>▪ Exclude non-essential persons</li> <li>▪ Essential persons at safe distance from lifting operation</li> </ul>
<p>Recovery to Safety</p>	<ul style="list-style-type: none"> <li>▪ Procedure for safe set down of load</li> <li>▪ Procedure for securing lifting device</li> </ul>
<p>Report incident (LC7) (LOLER Reg 10)</p>	<ul style="list-style-type: none"> <li>▪ Raise incident report</li> <li>▪ Inform ONR (as appropriate under site licence arrangements and RIDDOR)</li> </ul>

<p><b>FAULT CONDITION:</b></p> <p><b>A6.15 SEISMIC</b></p> <p>Seismic acceleration increases forces acting on lifting device and load.</p>	
<p>Planning of Lift (layout and equipment design) (LOLER Reg 8)</p>	<ul style="list-style-type: none"> <li>▪ Avoid interactions with building/other equipment</li> <li>▪ Seismic restraints</li> <li>▪ Lifting device and accessories seismically qualified</li> </ul>
<p>Indication / Warning Systems (LOLER Reg 7b)</p>	<ul style="list-style-type: none"> <li>▪ Not practicable – no warning of event.</li> </ul>
<p>Protection &amp; Mitigation Systems (LOLER Reg 6)</p>	<ul style="list-style-type: none"> <li>▪ Seismic isolation triggers, cut power to lifting device.</li> <li>▪ Seismic qualification of critical systems</li> <li>▪ Mechanical and electrical systems qualified against for seismic accelerations</li> <li>▪ Friction clamps and locking systems (prevent movement)</li> </ul>
<p>Operator Instructions (LOLER Reg 9)</p>	<ul style="list-style-type: none"> <li>▪ Seismic event procedures</li> <li>▪ Evacuation protocol if required</li> <li>▪ Site emergency planning</li> </ul>
<p>Recovery to Safety</p>	<ul style="list-style-type: none"> <li>▪ Procedure for safe making lifting system and load safe.</li> <li>▪ Procedure for lowering load.</li> <li>▪ Embargo of lifting operations (assess condition of lifting system and load before return to service).</li> </ul>
<p>Report incident (LC7) (LOLER Reg 10)</p>	<ul style="list-style-type: none"> <li>▪ Raise incident report (site event reporting)</li> <li>▪ Inform ONR (as appropriate under site licence arrangements and RIDDOR)</li> </ul>

<p><b>FAULT CONDITION:</b></p> <p><b>A6.16 DERAILMENT</b></p> <p>Over travel or wheel failure of motor driving. Failure on crab resulting in potential slewing of lifting device.</p>	
<p>Planning of Lift (layout and equipment design) (LOLER Reg 8)</p>	<ul style="list-style-type: none"> <li>▪ Physical end stops and buffers (energy absorbers)</li> <li>▪ Flanged wheels</li> <li>▪ Guide rollers</li> <li>▪ Side restraints (e.g. seismic)</li> <li>▪ Drive system has insufficient tractive effort to cause derailment</li> </ul>
<p>Indication / Warning Systems (LOLER Reg 7b)</p>	<ul style="list-style-type: none"> <li>▪ Control system inhibits fast speed when the lifting system is approaching end stops</li> <li>▪ Proximity alerts when approaching end of travel</li> </ul>
<p>Protection &amp; Mitigation Systems (LOLER Reg 6)</p>	<ul style="list-style-type: none"> <li>▪ Anti-skew detection</li> <li>▪ End of travel limit switch protection (requires back out system)</li> </ul>
<p>Operator Instructions (LOLER Reg 9)</p>	<ul style="list-style-type: none"> <li>▪ Stop lifting operation</li> <li>▪ Report to supervisor</li> <li>▪ Plan recovery</li> </ul>
<p>Recovery to Safety</p>	<ul style="list-style-type: none"> <li>▪ Procedure for safe set down of load</li> <li>▪ Damage assessment (ensuring no further progression of fault)</li> <li>▪ Review and identify long term actions</li> </ul>
<p>Report incident (LC7) (LOLER Reg 10)</p>	<ul style="list-style-type: none"> <li>▪ Raise incident report</li> <li>▪ Inform ONR (as appropriate under site licence arrangements and RIDDOR)</li> </ul>

<p><b>FAULT CONDITION:</b></p> <p><b>A6.17 CRANE TO CRANE COLLISION</b></p> <p>Cranes or loads collide (also applicable to cranes running on the same gantry or one above each other)</p>	 <p>--- Working Radius  <span style="color: green;">—</span> Slow Zone  <span style="color: orange;">—</span> Cut Zone  <span style="color: red;">—</span> Brake Zone</p>
<p>Planning of Lift (layout and equipment design) (LOLER Reg 8)</p>	<ul style="list-style-type: none"> <li>▪ Coverage of each crane clearly defined and non-intersecting</li> <li>▪ Adequate distance between cranes to avoid collisions</li> <li>▪ Adequate clearance between crane jibs to allow for weather vaning (free slewing in wind)</li> <li>▪ Planning of lifting operations identifying potential for collision and measures to avoid</li> <li>▪ Risks reviewed if cranes relocated (e.g. mobile cranes)</li> <li>▪ Parking positions when cranes are not in use</li> </ul>
<p>Indication / Warning Systems (LOLER Reg 7b)</p>	<ul style="list-style-type: none"> <li>▪ Proximity alarms</li> <li>▪ Visual indication</li> </ul>
<p>Protection &amp; Mitigation Systems (LOLER Reg 6)</p>	<ul style="list-style-type: none"> <li>▪ Software tracking of crane/hook position</li> <li>▪ Safe operating zone system</li> <li>▪ Clear visuals for operator during lifting operations.</li> <li>▪ Avoid blind spots and/or obstructions</li> <li>▪</li> </ul>
<p>Operator Instructions (LOLER Reg 9)</p>	<ul style="list-style-type: none"> <li>▪ Planning meetings (identification of risk)</li> <li>▪ Reporting of incident and involvement of competent person (inspect for damage)</li> <li>▪ Lifting supervisor</li> <li>▪ Effective site communication</li> </ul>
<p>Recovery to Safety</p>	<ul style="list-style-type: none"> <li>▪ Procedure for safe set down</li> <li>▪ Assess damage and ensure fault sequences will not develop</li> <li>▪ Thorough examination (competent person)</li> </ul>
<p>Report incident (LC7) (LOLER Reg 10)</p>	<ul style="list-style-type: none"> <li>▪ Raise incident report</li> <li>▪ Inform ONR (as appropriate under site licence arrangements and RIDDOR)</li> </ul>

<p><b>FAULT CONDITION:</b></p> <p><b>A6.18 MOBILE CRANE COLAPSE</b></p>	
<p>Planning of Lift (layout and equipment design) (LOLER Reg 8)</p>	<ul style="list-style-type: none"> <li>▪ Detailed lift plan (loads and radius of lift established)</li> <li>▪ Ground strength and underground infrastructure (e.g. service ducts and drains) established</li> <li>▪ Site layout and lifting restrictions established</li> <li>▪ Restrict proximity to civil works</li> </ul>
<p>Indication / Warning Systems (LOLER Reg 7b)</p>	<ul style="list-style-type: none"> <li>▪ On-screen display of mobile crane and its lifting configuration</li> <li>▪ Load and moment indication (alarm)</li> </ul>
<p>Protection &amp; Mitigation Systems (LOLER Reg 6)</p>	<ul style="list-style-type: none"> <li>▪ Automatic safe load indication</li> </ul>
<p>Operator Instructions (LOLER Reg 9)</p>	<ul style="list-style-type: none"> <li>▪ Progressive pickup of load to confirm load safe to lift</li> <li>▪ Lifting supervisor</li> <li>▪ Effective communication (control of lifting operation)</li> </ul>
<p>Recovery to Safety</p>	<ul style="list-style-type: none"> <li>▪ Operation for safe set down</li> <li>▪ Site procedures</li> <li>▪ Thorough examination (competent person)</li> </ul>
<p>Report incident (LC7) (LOLER Reg 10)</p>	<ul style="list-style-type: none"> <li>▪ Raise incident report</li> <li>▪ Inform ONR (as appropriate under site licence arrangements and RIDDOR)</li> </ul>