	Construction Plant-hire Association Tower Crane Interest Group	
	Tower Crane Technical Information Note	
TIN 023	**Luffing Jib Tower Cranes - Information and Actions for Owners/Suppliers**	

The HSE investigation into the collapse of a luffing jib tower crane at a housing project in Liverpool in January 2007, has highlighted a number of issues with lifting light loads at minimum radius and in wind speeds approaching the luffing jib tower crane manufacturer's limiting values.

The likely sequence of events leading to the collapse of the crane was as follows:-

- Immediately before the collapse, the crane was lifting a light load with its jib almost vertical, whilst at the same time a gust of wind, at or above the safe in-service limit of the crane, lifted the jib momentarily.
- This was sufficient to release tension in the luffing rope which then came off the sheaves in the reeving system and jammed. The driver then tried to lower the jib, however, because the luffing rope was jammed, slack rope paid out from the luffing rope winch drum and formed a loop at the back of the counter jib.
- The luffing rope jam subsequently became free and the jib went in to free fall, until it took up all the slack in the rope. At this point a massive shock load was imparted to the crane structure via the luffing rope.
- This caused the jib to bend, the bolts holding the main crane assembly to the top of the crane tower (via the slewing ring) to fail and the slewing ring to fracture. The crane assembly then toppled from the tower landing upside down on the building below (the concrete counterweights falling out in the process, one of which killed a joiner working in the building below).

The purpose of this TIN is to draw the following points to the attention of all luffing jib tower crane owners and suppliers:-

1. As a result of the investigation the HSE has written to the majority of tower crane owners and suppliers, and requested them to take a number of actions as follows:-
   a. First, consult the manufacturers of the cranes under your control to see if the failure mechanism described in the report is relevant to the cranes they have supplied to you (and act on any recommendations they may make).
   b. Second, review your own equipment, systems and procedures and take any necessary action.
   c. Third, provide information to your own staff and those who operate or hire your cranes.

   Note: *These actions are detailed on Page 2 of this document and the HSE's original text is given in Annex 1.*
2. The HSE have made available a copy of their Technical Report of the investigation and this is reproduced at Annex 2.
3. The HSE have asked all tower crane owners and suppliers to whom they have written to reply to the letter with 28 days, setting out the responses they have received from the manufacturers and the actions that they have taken or plan to take, to minimise the possibility of a further incident. You may wish to use the action list on Page 2 as a template for your reply.

Measures to be Taken by Tower Crane Owners

Item	Category	Action Required	Comments
1.	**Cranes**	Consider each model of crane in your fleet.	
2.		Is it a luffing crane?	If not, no further action is required.
3.		Is the luffing function rope operated?	If not, no further action is required.
4.		Do the operating instructions adequately address minimum radius conditions and the lifting of light loads?	If they do not, you should ask the manufacturer to review and amend the instructions.
5.		Determine and list the stability factor at the maximum permissible in-service wind speed for each possible jib length.	This will require information from the crane's manufacturer. The stability factor is the ratio between the moment due to the maximum in-service wind blowing on to the lower face of the jib at minimum radius and the moment due to the self weight of the jib at minimum radius, plus the hoist rope and hook block. This factor should be provided for each possible length of jib as the longest jib may not be the worst case.
6.		List the control measures provided to prevent ropes coming off sheaves.	These may include bars, covers or guide shoes.
7.		Assess the control measures provided to prevent ropes coming off sheaves to determine if they are adequate or if further action is required.	This will involve assessing the number and position of sheave guards, together with measurement of any gap between the guard and sheave flanges. If your assessment indicates that further action is required this should be undertaken following in consultation with the manufacturer.
8.		List the protective and limiting devices provided to sense luffing rope conditions.	These may include rope proximity detection devices and luffing winch torque measuring systems.

Measures to be Taken by Tower Crane Owners (continued)			
9.		Assess the protective and limiting devices provided to sense luffing rope conditions to determine if they are adequate or if further action is required.	If your assessment indicates that these devices are not fitted or are not adequate you should ask the manufacturer consider fitting/improving these devices.
10.		Document the outcome of the assessments and formulate an action plan.	Prioritise and tackle the most important things first. As you complete each action, record it on your plan.
11.		After three months review the action plan to see if any amendment is required.	
12.	**Operators**	Make your operators of luffing jib tower cranes aware of the Liverpool incident and the probable cause so that they are aware of the problems of operating in high winds with light loads at minimum radius.	**TIN 025** addresses this issue.
13.		Devise safety procedures for recovery in the case of a luffing jib being blown back or held up by the wind.	**TIN 025** addresses this issue
14.	**Users (including Principal Contractors and Appointed Persons)**	All users of your tower cranes, including, Principal Contractors and Appointed Persons, should be made aware of the circumstances of the Liverpool incident and the steps they need to take when managing lifting at or near minimum radius with luffing jib tower cranes.	**TIN 024** addresses these issues

Annex 1- Action Required by HSE from Owners and Suppliers

1. ***Contacting Manufacturers***

1.1 *You should consult the manufacturers of your luffing cranes to see whether the failure mode identified by HSE's technical investigation is relevant. In particular they should satisfy you:*

- 1.1.a *Their calculations of safe in-service wind speeds ensure jibs remain stable within the full range of in-service conditions.*
- 1.1.b *Sufficient tension is continually imparted in the luffing rope to prevent slack rope conditions.*
- 1.1.c *The design of luffing hoist pulley blocks minimises the possibility of ropes coming off the pulleys.*

1.2 *You should ask them to consider fitting protective device(s) to detect low tension in luffing ropes, and/or rope displacement.*

1.3 *You should ask them to review and, if necessary, revise their operating instructions for use of their cranes with particular regard to minimum radius conditions and the lifting of light loads.*

1.4 *You should ask them to consider whether any changes they decide to make are reflected in their maintenance instructions.*

1.5 *Finally, you should ask them to contact their customers to make sure that they are aware of the failure mode and any action they should take to minimise risk.*

2. ***Owner/Supplier actions***

2.1 *In addition to consulting manufacturers, you should ensure any features of their cranes intended to prevent displacement of ropes are in place, in good order and functioning properly. You should also ensure that anemometers are working properly.*

2.2 *As necessary you should provide those using your cranes who manage lifting operations, including principal contractors and appointed persons, with appropriate information about the failure mode and the steps needed to minimise recurrence.*

2.3 *If you provide cranes with operators you should make sure the operators are aware of the failure mode so that when operating in similar conditions they are forewarned.*

2.4 *If appropriate you should devise safe procedures for recovery in case of an incident and instruct operators accordingly*.

3. ***Information for Principal Contractors and Appointed Persons***

3.1 *You should alert them to the circumstances and advise them that in planning and managing lifts they should give particular consideration to working at or near minimum radius including:*

- 3.1.a *Taking particular care when planning lifting in this situation.*
- 3.1.b *Ensuring the luffing rope is constantly under tension, e.g. by adding additional "dead" weight to the hook block or load.*
- 3.1.c *Being particularly careful when operating in gusty wind conditions taking in to account the particular characteristics of the site.*
- 3.1.d *Ensuring any safety devices fitted to the crane are functioning properly.*
- 3.1.e *Verifying the competence and experience of their Appointed Person to manage lifting operations involving luffing cranes.*
- 3.1.f *Checking the crane operators' understanding of what to do in the event of an emergency.*

Annex 2- HSE Technical Report

Report on technical aspects of HSE's investigation into the collapse of a luffing tower crane at a Liverpool construction site on 15th January 2007

Date of Issue: 16 July 2008

Status: Final

TIN 023

Luffing Jib Tower Cranes - Information and Actions for Owners/Suppliers

Introduction

1. *This report summarises the technical findings of HSE's investigation into the failure of a luffing jib tower crane on a Liverpool construction site on 15 January 2007. It also summarises the actions that HSE has or will be taking to ensure any lessons arising from the incident are promulgated and measures are taken to prevent recurrence.*

The incident

2. *On 15th January 2007, a luffing tower crane failed catastrophically in service at a housing project in Colquitt Street Liverpool.*
3. *The crane collapsed when the slew ring bolts failed and the slew ring fractured allowing the main crane assembly to fall from its tower and land upside down on top of the building being constructed.*
4. *One site worker, a Polish joiner, was killed and the crane driver was injured (not seriously). Irreparable damage was caused to the crane, the part of the building under construction and adjacent parked vehicles.*

The crane

5. *The crane was a luffing tower crane (see Photograph 1, Appendix 1) consisting of a slewing unit, operator's cab, counterweights, luffing hoist and winch drums and jib attached via a slewing ring to the top of a tower comprised of a number of sections. The tower sections were pinned together and secured to a specially constructed foundation pad (see Illustration 1, Appendix 1).*
6. *Modes of operation included rotation (slewing), raising and lowering of the jib (luffing) and raising and lowering of the hook block (hoisting). The combination of slewing and luffing enabled the crane to cover a large circular area with a relatively small inner circle around the tower which could not be reached. Luffing cranes are commonly used in inner city areas.*
7. *The operator controlled the crane from a cab using joystick controllers located either side of his seating position. Luffing and hoisting operations were controlled by frequency converters that enabled speed variation whilst raising or lowering the jib and hook block depending on which direction and how far the joysticks were moved.*
8. *The luffing rope was reeved around a fixed pulley block which was secured to the A frame and a flying multiplier block which was connected in turn to the end of the jib via. a solid linkage (see Illustration 2, Appendix 1).*
9. *The crane was equipped with a rated capacity indicator and limiter and an anemometer. Limit switches were fitted which prevented the jib from luffing beyond the maximum and minimum angles of safe operation. At the time of the incident the crane was fitted with a 45 metre jib and the hook block was reeved in a single fall. The crane cab was 32 metres above the ground.*

10. When the crane was in use the jib would be prevented from moving over top dead centre. This was achieved automatically by limit switches within the electrical control system associated with the luffing hoist and physically by spring-loaded buffer stops.

Purpose of this report

11. HSE's role in the investigation has been to: gather and establish the facts; identify immediate and underlying causes; identify any lessons to be learned; prevent recurrence; and detect breaches of legislation for which HSE is the enforcing authority. As the incident resulted in a workplace death, a joint HSE and Merseyside Police investigation was launched in accordance with the Work-Related Death Protocol. Primacy for the investigation was handed to HSE on 7 July 2008 and an inquest was held by HM Coroner for Liverpool on 8 July 2008 at which a verdict of accidental death was returned.

12. HSE's investigations are continuing and no final conclusions have yet been made on enforcement action. However, HSE is concerned that the investigation has identified a potential failure mode that may be applicable to other luffing cranes. Therefore, and without prejudice to consideration of whether or not legal proceedings will be instigated, HSE is making this information available out of our concern for the safety of workers and others and to prevent a recurrence of this incident.

13. Both the owners and manufacturers of the crane involved in this incident have given HSE full co-operation during the investigation and concur with our conclusions on the mode of failure and with our intention to make these matters public.

Significant elements of the investigation

14. The crane wreckage was surveyed, photographed and filmed. Loose items were collected and a fingertip search was undertaken around the scene.

15. The crane tower was dismantled and visually examined at the scene before being returned to the crane owner.

16. The main crane assembly was recovered and, along with other recovered items, transported to the Health and Safety Laboratories (HSL) for further examination.

17. Detailed examinations were made of the key components of the crane and its control systems and the dimensions were checked to verify it had been configured in accordance with the manufacturers instructions.

18. Wind data was obtained from three, local meteorological stations and analysed in detail by a wind engineering specialist.

19. Eyewitness statements were taken, their content considered and compared against the findings of the examinations.

20. A visit was paid to the crane manufacturer's plant in Spain to obtain further information about the crane.

21. Enquiries were made of operators of different makes and models of luffing jib cranes to find out more about the configuration of protective devices fitted to pulley blocks to prevent ropes coming off the pulleys in slack rope conditions.

Findings from the on-site investigation

22. The slew ring bolts and the ring itself had failed allowing the entire crane assembly to separate from its tower and fall on the building being constructed, penetrating several slaps in the process. Irreparable damage was caused to the crane, building and adjacent parked vehicles.

23. An acute compound bend had occurred in the jib but there was no damage on the ground and its free end was relatively undamaged.

24. The counterweights had fallen from their cradle and had penetrated the slabs.

25. The tower was largely undamaged but two securing pins had failed at the tower base making the tower unstable. There was evidence from damage to the edges of the opening in the upper floor slab through which the tower projected that it had deflected considerably.

26. A steel weight from the over-hoist limiting mechanism/ rope change device was found on a pavement having been projected over the roof of a two storey occupied domestic dwelling.

27. A large portion of the hoist rope was found across an adjacent car park and had come to rest against the entrance of a number of occupied dwellings.

28. An anemometer display unit was detached from its magnetic fixing within the driver's cab.

Reports from eye witnesses

29. During the lifting operation the lower face of the jib was facing in to the prevailing wind.

30. At the time of the incident the crane was being used to lift a relatively light load (approximately 0.2 tonnes) and was being operated at its minimum radius.

31. Some eyewitnesses described the crane shaking violently just before it collapsed.

32. Some eyewitnesses suggested that the load may have snagged on the tower just prior to the incident.

33. Some witnesses recall seeing a loop of rope paying out from the rear of the luffing hoist.

34. Some witnesses also mentioned the crane slewing immediately before the collapse.

Further findings by HSL and HSE Specialist Inspectors

35. *The crane was CE marked in accordance with the Machinery Directive indicating it had been subjected to a conformity assessment with the Essential Health & Safety Requirements (EHSRs) and/ or relevant standards.*
36. *The crane components had been assembled in accordance with the manufacturer's specifications and did not show significant signs of wear or pre-existing damage.*
37. *Witness marks on the luffing limit buffers indicated that they had been partially compressed.*
38. *Several pulleys on the luffing hoist fixed block and the flying multiplier block had failed and witness marks on remaining pulleys indicated that the luffing hoist rope had come off the pulleys.*
39. *Examination of the fixed pulley block showed it was fitted with a single retaining bar designed to prevent the ropes coming off the pulleys whereas the flying pulley block was fitted with 4 such retaining bars.*
40. *A limited survey of pulley systems fitted to cranes supplied by other manufacturers showed variations in design. Some were apparently similar to that fitted to the crane involved in the incident, and others had better protection to prevent ropes from coming off the pulleys.*
41. *The slew ring and its bolts had failed through a single overload event.*
42. *The two tower pins had failed through a single overload event.*
43. *The jib was not damaged at the buffer position.*
44. *The limit switches and associated control systems to prevent over-luffing of the jib were found to be working.*
45. *The anemometer display unit was found to be functioning (although it was not clearly established whether the display was receiving a signal at the time of the incident as the input cable connection was not secure).*
46. *The anemometer alarms were set to around 50km/h (31mph) whereas the safe operating limit for the crane in service was around 72km/h (45mph).*
47. *A leading wind engineering specialist analysed local wind data on HSE's behalf and concluded that wind gusts at the time of the incident may have exceeded the safe in-service limits for the crane. These gusts are likely to have been very short in duration (around 1 sec) and may not have been detected by the anemometer which had a 3 sec sampling period.*

Conclusions

48. Based on examination of the wreckage, consideration of eyewitness accounts and subsequent investigations at HSL and elsewhere HSE has been able to determine a scenario that most probably explains how the incident occurred.

49. As the crane was lifting a light load at minimum radius with its jib almost vertical it would be more susceptible to wind loading especially when facing in to the wind.

50. A single gust of wind is unlikely to have lasted long enough to hold the jib in a hung position or to lift the jib by a large amount but even a short duration gust may have been enough to lift the jib momentarily, causing tension to be released in the luffing rope. The rope could have jumped from one or more of the pulleys in the fixed pulley block and/ or the flying block of the luffing mechanism and become jammed.

51. Alternatively the luffing rope could have come off one or more of the pulleys in the fixed pulley block and/ or the flying block for some other reason, e.g. because of disintegration of the blocks' components or mis-tracking of the rope on the pulley whilst at reduced tension due to reasons other than wind.

52. The design of the protective device on the fixed block – the single bar – was not adequate to prevent the rope from coming off the pulleys and jump into the gaps between them.

53. As the wind gust subsided, the jib, under gravity, restored tension on the luffing rope causing it to jam between the pulleys and the casings of the blocks. This resulted in the jib hanging in a position near to minimum radius.

54. With the luffing rope jammed the driver then attempted to lower the jib and, possibly, slew the crane, unaware that the jammed luffing rope was winding out behind him creating a loop of slack rope.

55. The subsequent freeing of the luffing rope could have occurred because of disintegration of the block components. However, there is some evidence the load, a relatively light reinforcing cage for a concrete column, became jammed against something – most likely the lighting rig on the crane tower.

56. The observed slewing of the crane would be consistent with the crane operator turning the jib away from the direction of the wind - normal practice if a jib is held up by the wind. Slewing with a snagged load would have put tension into the hoist rope.

57. We believe that the slewing motion either by itself, or possibly combined with the load suddenly freeing, imparted sufficient force to free the jammed luffing rope.

58. Release of the hoist rope after it was in tension would also account for the rope snaking around the adjoining car park.

59. Once the luffing rope was freed the jib would then go in to free-fall until its downward movement was halted as the slack in the luffing rope was taken up. The elasticity present in the luffing rope and other components then imparted an oscillating movement in the jib, creating high dynamic shock loading throughout the entire structure.

60. This loading would be sufficient to cause the jib to bend, slewing ring bolts to fail, the slewing ring to fracture and the two tower pins to shear.

61. As the crane assembly toppled over the counterweights that normally would have been held in position by their own weight, fell out.

Relevant standards

62. The crane was designed and manufactured to meet the requirements of the Machinery Directive (implemented in the UK through the Supply of Machinery (Safety) Regulations 1992, as amended). In particular, the crane satisfied the requirements of the harmonised European standard on tower cranes (EN 14339:2006) which carries a presumption of conformity with the Essential Health and Safety Requirements (EHSRs) of the Machinery Directive, but only if followed in full. (Appendix 2 contains summarises relevant EHSRs and standards).

63. Compliance with such standards is one way manufacturers are deemed to have complied with the Directive and legislation implementing it in Member States. However, following the standard is not mandatory - other methods can be used, so long as the crane meets the EHSRs as listed in Schedule 3 to the Regulations, but in this case, the level of risk reduction required needs to be at least the same as achieved if the standard was followed.

64. The brief survey of the design of protective devices on cranes supplied by other manufacturers suggests greater compliance with the relevant EHSRs can be achieved but that the protective devices on the incident crane were not markedly worse that those of others.

Action required

65. From our investigation, it would appear that better protective devices to prevent luffing ropes from coming off their pulleys would significantly reduce the potential for further events, particularly where wind and operating conditions provide potential for slack rope conditions to arise. And alternative or additional precautions may also be required.

66. HSE recognises these are complex issues to address necessitating engagement with the crane hire community, crane manufacturers and suppliers, inspection bodies, national and international standards bodies and others.

67. To stimulate discussion and encourage preventive activity HSE has decided to share the findings of its investigation with to interested parties by sending this report to them. We expect those parties who have control over the design and integrity of luffing cranes to examine their designs and existing machines and:

67.1. Decide whether the findings of this report have significant implications; and

67.2. Develop an action plan for dealing with any identified issues.

68. HSE will engage with our partners in the UK construction industry to ensure they are aware of our findings and the actions we will be taking. This will include the Construction Industry Advisory Committee (CONIAC) and the Tower Cranes Group of the Strategic Forum for Construction.

69. HSE will raise with EU colleagues and, if necessary, the European Commission our concerns about EN 14339:2006 and the design of luffing mechanisms across a range of manufacturers which could leave luffing cranes vulnerable to this failure mode. Through this we expect to determine whether action is required to amend the standard. This will be taken forward initially via. the Senior Labour Inspector Committee's MACHEX working group.

70. HSE also intends to commission HSL to undertake research in to the effects of wind on the safety and integrity of luffing cranes.

71. HSE will hold talks with the Construction Plant Hire Association (CPA) and other relevant trade associations to stimulate them to raise awareness in the crane hire and user communities and to consider the need for the production of guidance on measures which can be taken to mitigate recurrence including:

71.1. The specification of maximum wind speeds for cranes of this type supplied by other manufacturers and whether these adequately reflect the tighter margins of safety required when cranes are operating at or close to minimum radius;

71.2. The selection of anemometers which may not necessarily alarm when wind gust speeds are of short duration even when they are approaching the safe limits for the crane;

71.3. The installation of slack rope devices to provide a better means of warning of the effects of counteracting forces on the jib; and

71.4. The preparation of emergency recovery plans to cater for hanging jibs or other conditions rather than relying on the training of and intuitive actions of the driver.

72. HSE will also discuss the incident with the independent examination body community, via SAFED and INITA, so that competent persons conducting thorough examinations in accordance with LOLER can assess the effectiveness of precautions to prevent ropes coming off their pulleys.

73. Finally, HSE will discuss our findings with the United Crane Operators Association to enlist their participation in raising of awareness and developing of solutions.

Annex 1 - PHOTOGRAPHS AND ILLUSTRATIONS

Photograph 1: Luffing jib tower crane similar to that involved in the accident

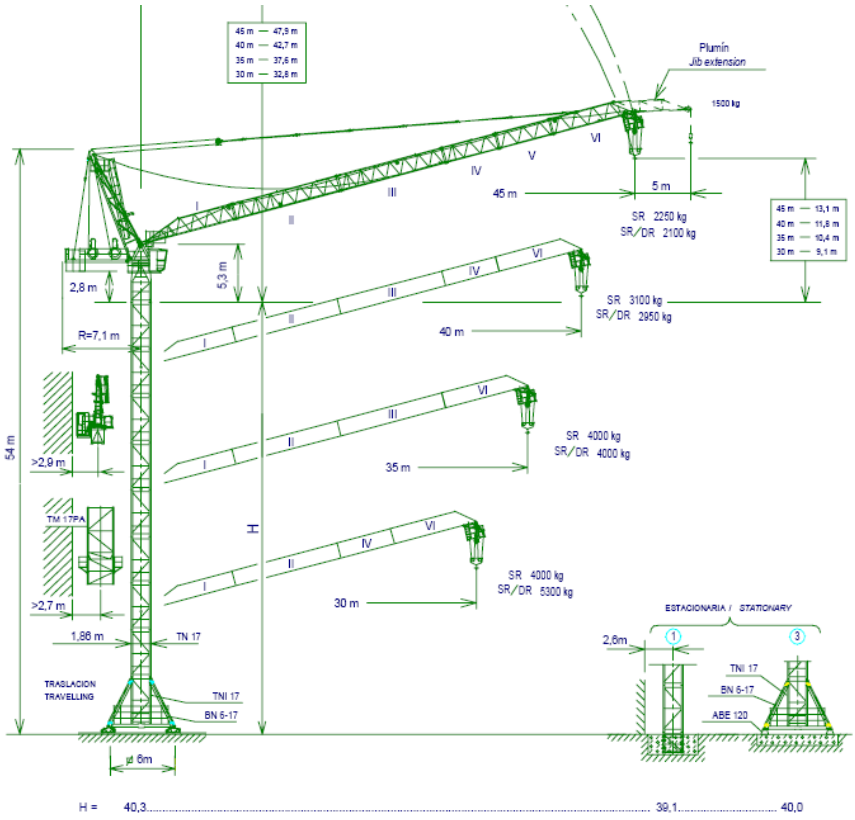

Illustration 1: JASO138PA Scale drawing

Appendix 1

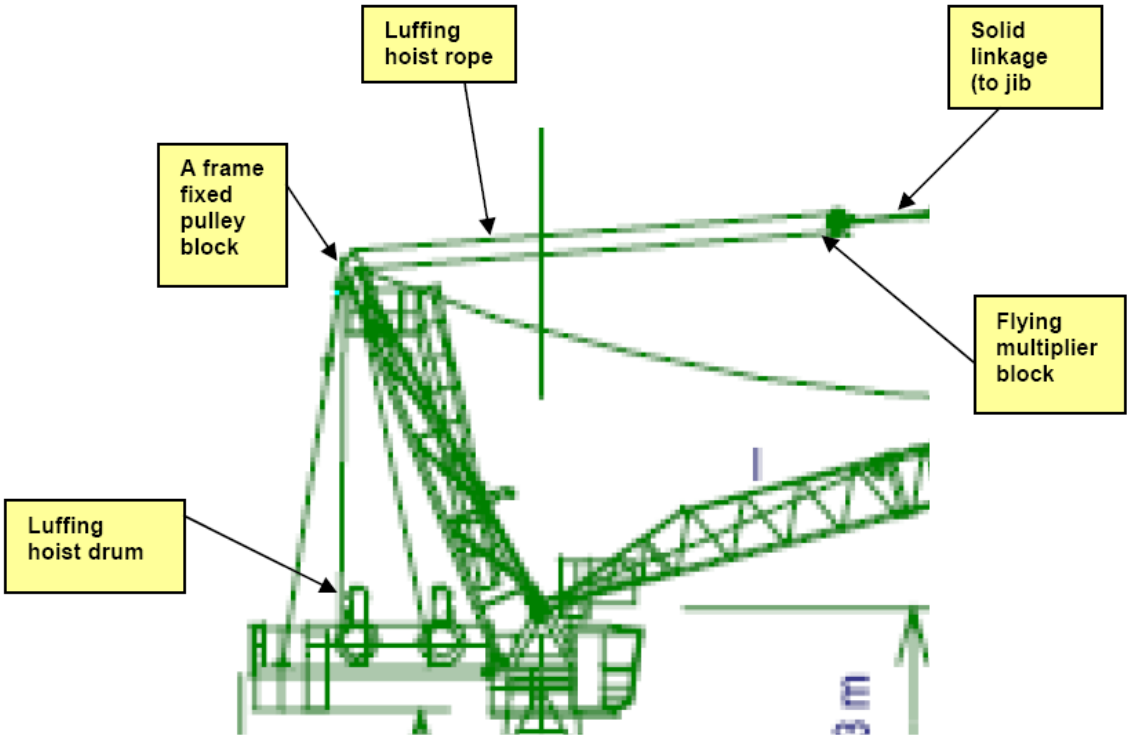

Illustration 2: Schematic of luffing hoist configuration

Appendix 1- ESHRs and Standards Relevant to Prevention of Ropes Jumping From Sheaves

EHSR 4.1.2.4 says Pulleys, drums and wheels must have a diameter commensurate with the size of rope or chains with which they can be fitted. Drums and wheels must be so designed, constructed and installed that the ropes or chains with which they are equipped can wind round without falling off

One way to ensure compliance with these EHSR's is to satisfy current harmonised European standards - for example BSEN14339:2006 Cranes - Safety - Tower cranes.

In turn this standard refers to other harmonised standards, for example, Clause 5.3.2.1 refers to BSEN13135-2:2004 Cranes- Safety - Design - Requirements for equipment - Part2: Non-electro technical equipment.

Clause 5.4.1.4 of BSEN 13135 includes requirements for rope sheaves and compensating sheaves - for example it says ***'Rope sheaves and compensating sheaves shall have protection against the ropes jumping out of the grooves (e.g in the case of a slack rope)****'.*

Pulley sheave requirements are also covered in older British standards, for example, BS2799:1974, Specification for Power-driven tower cranes for building and engineering construction.

In particular, Clause 3.6 Rope pulleys and sub section 3.6.3 Guarding says that ***Provision shall be made to retain the ropes in the grooves unless there is no likelihood of them becoming unloaded in service.***

*Similarly, Clause 4.3.4 of BS6570:1986, Code of practice for the selection, care and maintenance of steel wire ropes says; '****if required, a rope guard should be fitted to prevent the rope jumping or riding off the sheave.***