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The effect of wind loading on the jib of a luffing tower crane

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The effect of wind loading on the jib of a luffing tower crane

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Following a luffing crane collapse in Liverpool in January 2007, the UK Health and Safety Executive (HSE) were concerned that standards concerned with tower crane manufacture may not offer sufficient protection in relation to slack rope conditions on a luffing tower crane. HSE wished to determine if foreseeable conditions could be identified that could give rise to dangerous operational conditions below maximum in service wind speeds. A luffing tower crane was erected at the Health and Safety Laboratory (HSL), Buxton. Measurements of wind speed and luffing system tension were taken to determine combinations of wind speed and jib elevation likely to result in slack luffing rope conditions. Calculations of jib wind loading were carried out using four standards, FEM 1.001, FEM 1.004, ISO 4302 and BS EN 13001- 2:2004. Wind loading calculations compared closely with values obtained during the tests. The jib was found to be susceptible to uncontrolled movement below the maximum in service wind speed and at jib elevations within the limits specified by the manufacturer. Differences of up to 150% between wind speed readings provided by anemometers fitted at the jib outer end and the ‘A’ frame were experienced during the testing.

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CONTENTS

CONTENTS (continued)

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Thanks are also due to Mr Bosko Mujika of Jaso Equipos de Obras y Construcciones S.L who provided details, calculations and technical drawings for the crane used in testing. Much of the work described in this report would have been made very much more difficult without this generous assistance from the crane manufacturer.

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EXECUTIVE SUMMARY

In a luffing crane, the hook block is located at the end of the jib and the angle of the jib is altered by raising and lowering it to place the load on the hook the required distance from the mast.

On some cranes the jib is raised and lowered (luffing) using wire rope wound around a luffing winch drum and travelling over two sets of pulleys. One set of pulleys at the top of the tower head or 'A' frame are fixed in position whereas the other set are fitted in a pulley block that is not fixed in any single position and is commonly referred to as the "flying" or "floating" pulley block. The flying pulley block is usually attached to the jib at a single pivot towards the hook end of the jib by a series of tie bars pinned together

Objectives

Following an incident in Liverpool in January 2007, HSE were concerned that current standards concerned with tower crane manufacture may not offer sufficient protection in relation to preventing and guarding against slack rope conditions on a luffing type crane. The standards deal in a simple manner by "winding off" (ceasing operation of the crane) should the wind speed reach pre-determined levels, known as the maximum in service wind speed, despite the number of variables involved.

Mr Ian Simpson, FOD Mechanical Portfolio Holder (Lifting Equipment & Lifting Operations) requested that HSL obtain and test a luffing tower crane to determine if foreseeable conditions could be identified which might arise that could give rise to dangerous operational conditions for the crane.

The standards also provide guidance on how the wind force acting on the crane structure can be calculated. Mr Simpson requested that wind force calculations be carried out in accordance with the standards on the jib of the crane used in testing and that the results of these calculations be compared with results from testing of the crane to determine if the calculations provided a reasonable estimate of the wind force.

Main Findings

A suitable luffing type tower crane was identified and erected at HSL. The crane was fitted with instrumentation to measure and log the wind speeds at the outer end of the jib and on top of the 'A' frame of the crane, the latter being the location for wind measuring instrumentation most commonly used by the U.K. Tower Crane Industry. Because the jib of a luffing crane is raised and lowered during operation to manoeuvre the hook/load being carried by the crane there was a difference in height between the two wind measuring instruments of between nominally 3 to 33m. The crane was also fitted with instrumentation to measure and record the tension in the luffing system which altered according to the angle of elevation of the jib and speed of the wind acting against the jib.

Calculations of wind loading were carried out using four standards, FEM 1.001, FEM 1.004, ISO 4302 and BS EN 13001- 2:2004. It was found that the method of calculating the wind force acting on the jib of the crane was reasonably close to values obtained during testing of the crane and so can be used with confidence to predict the wind loads on the jib of the crane used in testing. Consequently, it would be expected that they provide similar reasonably accurate results when applied to other structures, e.g. other crane jibs and mast sections etc.

The jib of the crane used in testing at HSL was proven by calculation and testing to be susceptible to uncontrolled movement arising from wind loading below the maximum in service wind speed and at jib elevations within the normal maximum and minimum radius quoted by the manufacturer. Uncontrolled movement took place when the wind speed was approaching, but below, the maximum in service wind speed and when the jib of the crane was close to its maximum elevation or minimum radius.

On one occasion, during testing of the crane at HSL the jib of the crane suffered an uncontrolled movement and was "blown back" against a spring buffer arrangement mounted on the jib support 'A' frame. At this time the luffing system lost tension and the luffing rope became slack. The guarding on the crane against slack rope conditions was ineffective in preventing the luffing rope from leaving the grooves of one of the 'A' frame pulleys.

Following this event, the crane manufacturer and their U.K. representative's implemented modifications to prevent reoccurrence. These consisted of a system to maintain tension in the luffing system as the jib approached minimum radius and improved physical guarding against rope leaving the grooves of the 'A' frame pulleys. These modifications were fitted to the crane at HSL. Subsequent testing of the crane under similar conditions whereby the uncontrolled movement of the jib first took place showed that these modifications were effective in preventing the slack rope conditions from arising. Since tension was maintained in the luffing system at all operational angles of the jib the improved physical guarding against the rope leaving the grooves of pulleys could not be assessed.

Significant differences between the readings of the two wind instruments fitted at the outer end of the jib and on the 'A' frame were found on occasion during the testing. Consequently, wind speed readings obtained from an anemometer mounted on the 'A' frame of a luffing tower crane may not, on occasion, be an accurate representation of the wind speed being experienced by other parts of the crane structure, e.g. the outer end of the jib. This may give rise to unintentional operation of the crane at wind speeds approaching or perhaps exceeding the maximum in service wind speed.

1 INTRODUCTION

On Monday 15 January 2007 a luffing tower crane collapsed at the Elysian Fields Construction Site, Colquitt Street, Liverpool injuring the driver and killing a construction worker on the ground. The crane involved in this incident was a J138PA manufactured by Jaso Equipos de Obras y Construcciones S.L. of Idiazabal, Gipuzkoa, Spain.

Subsequent investigation by HSE (assisted by HSL) determined that, at the time of the accident, the crane was being operated within its duty envelope as specified by the manufacturer. However, the jib was facing towards the wind and had been raised to near or at its maximum angle of elevation in order to bring the hook as close towards the central mast section as possible. The hook was very lightly loaded and the wind speed was close to, but within, the maximum in service wind speed. Under these conditions the system of ropes used to raise and lower the crane jib could have become slack, jumped from their pulleys and become jammed or tangled. The accident raised the issue of the effect of wind on luffing jib cranes when working close to minimum radius. In particular, the susceptibility of uncontrolled movement of the jib, resulting from the action of the wind, was of concern.

The crane was approximately three years old and its manufacturer had followed the Harmonised European Standard for Tower Cranes, BS EN 14439:2006 "*Cranes – Safety – Tower Cranes*". The effect of wind on the jib of a tower crane is covered in BS EN 14339 by reference to a set of FEM standards. FEM Standards are produced by a European Trade Association representing crane manufacturers and provide information to designers on the loadings for both the in service and out of service wind conditions and associated factors of safety. According to relevant FEM and other European standards the maximum in service wind speed is 20 m/s.

The HSE view was that the current standard may not offer sufficient protection in relation to preventing and guarding against slack rope conditions. The standard deals in a simple manner with "winding off" (ceasing operation of the crane) should the wind speed reach pre-determined levels despite the number of variables involved. These variables include weight on the hook, jib angle and its orientation i.e. facing into or away from the wind and if the wind speed is steady or gusting. Consideration of these variables could argue for a more complex solution than the current requirement for the manufacturer to quote a single wind speed limit.

Consequently, Mr Ian Simpson, FOD Mechanical Portfolio Holder (Lifting Equipment & Lifting Operations) requested that HSL obtain and test a luffing tower crane to determine if foreseeable conditions could be identified which might arise within the variables that could give rise to dangerous operational conditions for the crane.

The objective of this project was to determine the effect of different wind speeds on the jib of the crane at different angles of elevation and therefore establish likely combinations of wind speed versus jib angle at which the wind would be expected to hold the jib in the elevated position or force it backwards.

Mr Robert Richardson of HSL Engineering Support Unit wrote Section 4 of this report, which is concerned with the instrumentation fitted to the crane under test. Mr Richard Isherwood, also of HSL Engineering Safety Unit, wrote all other sections. Photographs shown in this report were taken by members of the Visual Presentation Services Section of HSL, Mr Richardson, Mr Isherwood, or Mr Gary Potter of Falcon Crane Hire Ltd. All measurements given in this report are for indication only unless a statement of accuracy accompanies them.

2 DESCRIPTION OF A LUFFING TOWER CRANE

In a luffing tower crane, the hook block is located at the end of the jib and the angle of the jib is altered by raising and lowering it to place the load on the hook the required distance from the mast. This is different to a saddle type tower crane having a fixed horizontal jib and positioning the load being achieved by a trolley carrying the hook block traversing along the jib. The closest a load can be positioned to the mast section of a luffing crane is usually referred to as the “minimum radius”. To achieve minimum radius would imply that the jib of the luffing crane be raised to as steep an angle as normally possible. Similarly, the furthest a load can be positioned from the mast section of the crane is usually referred to as the “maximum radius”. To achieve maximum radius would imply that the jib of the luffing crane be lowered to as shallow an angle as normally possible.

Features of a typical luffing tower crane are shown in Figure 1 and its principles of construction and operation are described below.

The mast or tower is made up of sections fixed end to end. Adjoining sections are attached at each corner by large diameter pins or bolts. Ladders are usually positioned in the centre of the mast and platforms or decks located at intervals in the mast sections to assist personnel climbing the mast.

A slewing ring is usually located at the top of the upper mast section. The slewing ring consists of two large diameter steel rings or races permitted to rotate relative to one another by rollers or balls fitted in the internal space between the two races. The slewing ring acts as a large horizontal bearing allowing the top part of the crane to rotate (slew) through 360º whilst the mast section remains stationary.

The top of the crane consists of a large flat deck or platform attached to the slewing ring and this is usually referred to as the counterjib. A triangular upright frame usually referred to as the tower head or ‘A’ frame is usually mounted on the counterjib together with the hoist and luffing winch drums, associated drive motors, gearboxes, motor controllers, counterweights and the driver’s cab. The jib is usually attached to the counterjib or the ‘A’ frame and raised and lowered (luffing) using wire rope wound around the luffing winch drum and travelling over two sets of pulleys. One set of pulleys at the top of the ‘A’ frame are fixed in position whereas the other set are fitted in a pulley block that is not fixed in any single position and is commonly referred to as the “flying” or “floating” pulley block. The flying pulley block is usually attached to the jib at a single pivot towards the hook end of the jib by a series of tie bars pinned together. The wire rope is either payed out or wound in by rotating the luffing drum in the appropriate direction. This has the effect of raising or lowering the jib as the length of rope reeved between the ‘A’ frame pulleys and the flying pulley blocks alters.

The hook block used for lifting and lowering items is raised and lowered using a hoist rope wrapped around a hoist drum. This drum is located on the counterjib platform together with its associated drive motor and motor controller. The hoist rope is usually reeved around a pulley located on the ‘A’ frame.

The jibs of luffing cranes are usually constructed of tubular section steel welded in a triangular or square lattice type structure. The complete jib assembly usually comprises several separate sections joined together and a mesh steel walkway usually extends along the length of the jib to provide access to a cage, basket or platform at the jib end.

Some luffing cranes raise and lower the jib by using a hydraulic cylinder that is usually located underneath the jib. In this type of luffing crane there is no use of ropes and pulleys to control the jib as described above and consequently this type of crane has not been considered further in this report.

3 CRANE USED IN TESTING

In order to carry out testing, the crane used would need to be a luffing tower crane whose jib angle was controlled by a rope/pulley system and fitted with sufficient instrumentation to monitor the tension in the luffing system under different conditions of wind speed and jib angle to predict when the jib of the crane may be expected to be held or supported by the wind.

A specification for the crane was written and members of the Tower Crane Industry in the United Kingdom were invited to tender for its supply and associated technical support. The specification for the tender is given in Appendix 1.

From the replies to the tender, Falcon Crane Hire of Shipdham, Norfolk were selected to provide a Jaso J80 PA luffing crane for use in the testing.

3.1 DETAILS OF THE JASO J80 PA LUFFING CRANE USED IN TESTING

The Jaso J80 PA luffing crane is manufactured by Jaso Equipos de Obras Y Construcciones S.L. of Idiazabal, Gipuzkoa, Spain and is the smallest capacity of luffing crane in the manufacturers portfolio of luffing cranes, comprising versions of the J80, J138, J180 and J280 cranes.

The main features of the J80 PA were as described in Section 2 with the jib angle being controlled by a rope/pulley system. The crane was of standard configuration and its main components had not been significantly mechanically modified. However, the crane had been adapted by Falcon Crane Hire Ltd to enable it to be operated via remote control as specified in the tender and some electrical modifications to fit the equipment used in the testing of the crane were required. These are described in Section 4.

A general view of the crane at HSL is shown in Figure 2. The erection details of the crane (taken from the duty board) were:

Make	*Jaso*	***Model***	*J80PA*
Plant No	*TC128*	***Serial No***	*0102*
Jib	*40 m*	***Tower Ht***	*9.5 m*

Base Type	*Ballast Base*
Counter Ballast	*8,580 kg*
Base Ballast	*41,000 kg*
RADIUS	***SWL***
18.3 m	*5,000 kg*
40 m	*1,300 kg*

Max. Operating Wind Speed

33 M.P.H / 53 K.P.H.

As shown above, the duty board of the crane stated that the maximum operating wind speed of the crane used in testing was 33 m.p.h/53 k.p.h. This is equivalent to approximately 15 m/s, which is less than the maximum in service wind speed of 20 m/s stated in the crane manual and relevant FEM and other standards. I understand that the lower limit of 15 m/s is a voluntary limit adopted by much of the U.K. tower crane industry following the Liverpool incident of January 2007 described in Section 1.0. Since this is a voluntary limit it is possible that operators who have not agreed to abide by the voluntary lower limit could still operate the crane at the maximum in service wind speed of 20 m/s.

Section 4.1 of chapter 01/000/10 of the manufacturer's handbook or manual supplied with the crane carried the following instructions in relation to wind speed when operating the crane:

"*Stop crane operation when the wind speed exceeds 20 m/s even when the jib is in the wind direction. Under these circumstances, proceed setting the crane in vane………It is particularly prohibited to operate the crane with wind speeds higher than 72 km/h"*. (72 km/h = 20 m/s).

Chapters 01/130/10, 01/140/00 and 01/140/05 of the manual are concerned with fitting anemometers to measure wind speed. In chapter 01/130/10 it is stated that "*..it is the crane operators responsibility to put the crane out of service with wind speeds greater than 72 km/h"*. Chapter 01/140/00 states that the anemometer station or head "*…will always be positioned in the highest part of the crane"* and chapter 01/140/05 states the anemometer "*should be placed on the top of the crane, the highest position"*. An accompanying diagram appears to show the anemometer head positioned in the vicinity of the 'A' frame pulleys of a luffing crane.

Chapter 03/060/05 of the manual is titled "*Security measures in the works with crane"*. Instructions on page 4 of this chapter forbid working "*with winds over 70 km/h, the "service wind limit". When this is reached the crane should be stopped and put out of service"*.

An Ascorel Alize 3 anemometer was fitted to the crane to measure wind speed. The head unit was attached at the top of the 'A' frame, in the vicinity of the 'A' frame pulleys, and the digital read out of the wind speed from this was located in the driver's cab. Two alarm thresholds were set by Falcon Crane Hire Ltd when the crane was erected at HSL. The first "pre alarm" activated a flashing amber light located on the outside of the driver's cab and sounded an audible alarm in the driver's cab if the wind speed exceeded 11 m/s. The second "alarm" activated a flashing red light located on the outside of the driver's cab and an audible alarm inside and outside the driver's cab if the wind speed exceeded 15 m/s. It should be noted that activation of this alarm did not inhibit or prevent any of the functions of the crane from being operated. The height of the anemometer head unit above ground level at the base of the crane was approximately 19.33 m.

A rated capacity indicator manufactured by Wylie was also located in the cab of the crane. This unit provided a display of the operational parameters of the crane including the working radius, jib angle and proportion of the safe working limit of the crane being lifted.

The jib was attached to the 'A' frame at two pivot points and was raised and lowered using wire rope, nominally 14 mm diameter, wound around the luffing winch drum and travelling over the two sets of pulleys described in Section 2. Each set of pulleys consisted of four individual pulleys positioned side by side (four at the top of the 'A' frame and four in the floating block). The luffing rope was terminated on the 'A' frame in the region of the four fixed pulleys. The floating pulley block was attached to five rigid tie bars and the other end of the assembly was attached to the jib.

The luffing drum motor control employed a position sensor that acted to slow the speed of the jib as it approached the upper and lower limits of its travel and stop it when those limits had been reached. In addition, limit switches were fitted to the 'A' frame in the vicinity of the jib pivots to prevent the jib from exceeding these limits in the event that the position sensor failed or suffered some other malfunction. According to the Wylie readout, at maximum radius (nominally 40 m) the jib angle was approximately 15º to the horizontal and at minimum radius (nominally 3.6 m) the jib angle was approximately 85º to the horizontal.

A spring buffer arrangement was fitted to the 'A' frame to act as an ultimate physical stop for the jib should it go past its minimum radius position. In normal operation of the crane the spring buffer did not contact the jib even when the jib was at the minimum radius (3.6 m) and a gap between the jib and spring buffers was always present. The gap at minimum radius is shown in Figure 3.

A slack rope detection device was fitted to the luffing drum and pulleys at the top of the 'A' frame. This was activated by contact with loose or slack luffing rope at the luffing drum or at the pulleys and, if activated, inhibited the unwinding of the luffing drum and hence prevented the jib of the crane from being lowered.

Safety bars were fitted across the sets of pulleys at the top of the 'A' frame and in the floating block in close proximity to the edges of the pulleys. These were intended to guard against the luffing rope from leaving the grooves of the pulleys. There were four bars around the pulleys of the floating block and one bar associated with the 'A' frame pulleys. The A' frame pulley safety bar is shown in Figure 4 and it can be seen that it was not positioned directly beneath the pulleys. The 'A' frame anemometer is also shown in Figure 4.

3.1.1 The J80 PA Crane Jib

The jib was constructed of tubular section steel welded in a triangular lattice type structure. The top tubular section is referred to in this report as the top chord and the tubular sections at each side are referred to as the side chords. Lengths of smaller tubular section steel were welded between the top and side chords as bracing/stiffening members.

The complete jib assembly was nominally 40 m long and comprised five separate sections. The inner jib section nearest the 'A' frame and incorporating the pivots is referred to in this report as jib section 1 and the outer jib section (hook end) as jib section 5. The joints between each section were pinned type joints, no bolts or other fasteners were used.

A mesh steel walkway, approximately 250 mm wide ran along the length of the jib. The mesh was located within two lengths of 40 mm x 40 mm right steel angle section, one length per side. According to Jaso, the mesh had an area of 40,600 mm^2 (0.0406 m^2) per metre length. Hence, the area of the walkway was (2 x 40 mm x 1000 mm) + 40,600 mm^2 = 120,600 mm^2 (0.1206 m^2) per metre length.

A platform or basket was positioned at the outer end of jib section 5 at the hook end. This platform was constructed from tubular aluminium sections and had a solid floor constructed from aluminium plate, i.e. the floor was not a mesh. The floor was measured to be 900 mm x 560 mm and consequently its area was 504,000 mm^2 (0.504 m^2). According to drawing 202.38.000 supplied by Jaso the platform floor was nominally 6 mm thick.

The mass of each of the jib sections is given in the manual for the crane (supplied by Falcon Cranes Ltd) and these were checked by lifting them using a mobile crane with a direct reading tensile load cell in the liftline during erection of the crane at HSL. The following results were obtained:

Table 1 – Comparison of mass of jib sections and end platform given in the crane manual with measured values

	Mass given in the manual (kg)	Measured Mass (kg)
Jib Section 1	866	896
Jib Section 2	687	699
Jib Section 3	684	547
Jib Section 4	276	289
Jib Section 5	488	618
Jib End Platform	26	46
Hook Block	217	217
Total	3,244	3,312

The crane manufacturer, Jaso, made available drawings showing the principal details of each jib section. Details from these drawings are given in Figures 5 to 9 and the theoretical centre of gravity of each jib section as determined by Jaso of each jib section is marked on each of these drawings.

During erection of the crane at HSL the approximate positions of the centre of gravity of each jib section was determined by deliberately creating an uneven lift using a mobile crane such that the section was at an angle to the ground. A heavy plumb bob was attached to the hook of the mobile crane with string such that it hung vertically. A line was marked on the section where the vertical string passed over it. The section was then lowered and re-slung such that it lay at an angle to the ground in the opposite direction to the initial lift. A similar vertical line on the section was marked and the intersection of the two lines was taken to be the centre of gravity of the section. The position of the centre of gravity for each jib section determined in this manner compared with the theoretical position advised by Jaso are also shown in Figures 5 to 9. The jib end platform was fitted to jib section 5 when the position of its centre of gravity was measured.

In addition, the overall length of jib sections 1, 2, 3 and 4 was measured to enable the distance of the centres of gravity of each of the jib sections from the jib pivot point to be established.

4 INSTRUMENTATION

The Jaso J80 crane hired for the purpose of this research was fitted with the standard-fit instrumentation, providing data to the operator, in addition to providing feedback to activate the control system safety interlocks and trigger warning devices. For the purposes of this research, it was necessary to fit additional instrumentation to the crane to provide data that would not normally be available, but also advantageous to monitor the relevant information that would be generally available to the operator.

With the main focus of the research aimed at monitoring the wind loading effects acting on the jib, the principal data required was an indication of the load being applied to the jib, and the wind speed acting on the jib. However, in addition to these primary indicators, information would also be required to allow the operator, who was situated remotely for safety reasons, to know how the jib was positioned relative to the wind direction, and also to record the angle to which the jib was raised.

4.1 JIB LOAD MONITORING

A system to measure the wind load on the jib was required, however it would also be necessary to observe the way in which the crane reacted to the wind load. Consequently whatever system was employed would need to avoid affecting the behaviour of the crane under wind loading conditions. The solution would therefore need to be unobtrusive and not affect the functionality of the crane, yet still provide a reliable indication of the load.

It would not be possible to measure the jib wind loading directly without affecting the behaviour of the crane. For instance the installation of a load cell between the jib and a fixed point on the ‘A’ frame would be likely to alter the stiffness of the jib and supply greater support than would normally be present. It would therefore be necessary to compromise on the most direct way to indicate the load, for a solution that provided the least impact on the structure. As the construction of the crane relies upon the luffing line to support the jib at the chosen angle, an obvious solution was to monitor the load in this line. However, as the luffing line is a flexible structure, any load cell installed in the line would be affected by the mass of the line itself, in addition to the loading of the line due to the jib.

The chosen solution was to replace one of the pins in the link plates joining the tie-bars forming the luffing line, with a load pin. This was installed in the first link plate, located closest to the attachment point to the jib. This device is a steel pin, which has been fitted with internal strain gauges to form a load cell. A similar system forms the axle of the hoist pulley on the ‘A’ frame, to monitor the load in the hoist line. This load pin was custom built for this research, and supplied as a calibrated package along with power supply/amplifier by Straightpoint UK, serial number 19035 to match the dimensions of the original link pin which it replaced. It was delivered with a manufacturer’s calibration, and proof tested to 15 tonnes.

Load pins function in one direction only, and therefore the orientation of their installation is important. The orientation and location of the load pin were provided by a slot machined into the free-end of the pin. It was therefore necessary to carry out minor modifications to the link plate in which the load pin was installed. This involved the addition of two tapped holes to one side of the link, which were positioned to avoid creating any weak points in the link. A small plate was manufactured, which when bolted into the tapped holes, located the load pin in the slot, preventing any movement. The load pin and retaining plate in position in the luffing tie bars is shown in Figure 10.

It should be noted that this was not the load pin design chosen by HSL and ordered from the suppliers. This system resembled a bolt, with a large head at one end and a thread at the other, with an additional hole through which a split pin could be installed. This would have provided a more secure means of mounting the load pin and would not have required any modifications to the link plate.

It is normal HSL policy to calibrate load cells on an annual basis, however, since the load cell was forming an integral part of the crane, it was not practical to remove it after the initial 12 month period had elapsed. The load cell was therefore used beyond the period of calibration for some of the latter tests. In order to provide some degree of certainty to the results recorded during this period, once the crane had been dismantled, the load cell was returned to the supplier for recalibration and found to be still performing satisfactorily.

4.2 WIND SPEED MONITORING

The standard-fit anemometer provided with the hire crane was an Ascorel Alize 3. The anemometer head unit was mounted on the 'A' frame, with a display unit (incorporating a siren) located inside the driver's cab. The associated external warning siren and lights were located on the outside of the driver's cab, facing the jib. The crane hire company was contacted prior to the erection of the crane to determine the type of system that would be fitted and its location. From this information, it was determined that the unit would not provide a data output type compatible with the logging equipment to be used for testing, was not calibrated to traceable standards, and the location of the anemometer head unit would provide a wind speed reading from a location which could be at least 30m lower than tip of the jib. It was consequently decided at the outset of the project that an additional anemometer should be sourced, and fitted at the end of the jib.

Fitting an anemometer at the end of a luffing jib crane posed several additional problems. The main problem being that a standard cup and cone anemometer must be fitted such that the cups can rotate about a vertical axis, therefore a device would be required that could compensate for the change of luffing angle of the jib. Additionally, the anemometer would have to be mounted in such a position that it was not unduly affected by "shadowing" from the jib over the range of movement of the jib. The indication of this anemometer would also be affected by slewing the crane, either adding to, or subtracting from the actual windspeed, due to the relative movement of the anemometer through the air at the tip of the jib. This would be particularly evident when slewing at maximum radius, where the greatest jib tip speeds would be achieved. However, for the purposes of this research, an accurate indication of windspeed during slewing operations was not required.

Solid state sonic anemometers are available, which can accommodate for angular measurements of windspeed, however, while these are capable of accommodating the roll, pitch and yaw of a sea-faring vessel, the extremes of angle posed by the tests proposed would not have been accommodated. There was a possibility of using such a device mounted on its side, which would overcome these operating restrictions, but then an additional device would have been required to indicate wind direction for the purposes of these tests. These sonic anemometers also tend not to be supplied with a traceable calibration and generally use RS232 or RS485 technology to communicate with a paired display unit. They do not generally provide the voltage output required as an input to a data-logger, and have cable length restrictions.

The issues identified above ruled out the use of a sonic anemometer for this research. However, if fitment of anemometers to the end of the jib of luffing jib cranes was adopted, with no moving parts, this kind of system could present some advantages over traditional cup and cone types.

The solution chosen for this research was a Vector Instruments A100L2/PC3, serial number 12303, with cup set serial number CVLM. This provided a choice of digital pulse, or analogue voltage output, and was supplied with a manufacturer's calibration. Being a traditional cup and cone type of anemometer, this required a gimbal system to be designed and manufactured, which would maintain the anemometer in the correct orientation no matter what angle the jib was raised to.

4.3 WIND DIRECTION MONITORING

There was no requirement for the research to identify the wind direction relative to the points of the compass. The direction was only necessary to identify the angle of the wind relative to the jib. This would allow the test operator to identify how close the wind direction was to acting directly face-on to the jib, such that the crane could be slewed to face directly into the wind.

Weather vanes, like cup and cone anemometers, need to be installed such that they can rotate in the horizontal plane. As no compass point orientation was required, there was no need to source a self-referencing type of vane. Consequently, a basic Vector Instruments W200P (serial number 53512) was chosen, and installed on the gimbal mechanism to maintain its orientation on the horizontal plane. This instrument provides an analogue voltage output with a theoretical minimum output voltage at 0 degrees, and the maximum output voltage at 360 degrees. However, as these two directions are actually the same, being due north, the instrument has a small dead band of approximately 3.5 degrees between 356.5 and 0.0 degrees. To avoid this affecting the testing, the vane was orientated such that a wind blowing end-on to the jib was at the mid-point of the range of the vane, i.e. due south (180 degrees).

Figures 11a and 11b show the anemometer and weather vane fitted to the outer end of the crane jib.

4.4 JIB ANGLE MONITORING

The jib was fitted with an inclinometer, Level Developments SCA121T-D03, serial number 2050800112B11. This device provides an analogue voltage output relating to the angle of inclination to which it is subjected. The output of this inclinometer is sinusoidal rather than directly proportional. Although this could be compensated for during data analysis, it was important for the inclinometer to provide a reasonably accurate representation of the angle in real-time, as this would be required by the operator during testing.

The minimum operational jib angle of the Jaso J80 is approximately 15 degrees, with the maximum approximately 85 degrees. With a range of approximately 70 degrees required, an inclinometer providing 90 degrees either side of horizontal was mounted in a custom-built enclosure on a base inclined at 50 degrees. When fitted to the crane jib, this would effectively mean that at the midpoint of the luffing range, the inclinometer would be horizontal. It would therefore only be the 35 degrees either side of zero of the sinusoidal output that would be used, which over this range is reasonably linear. The 50 degree offset was then corrected in the data logger and the output calibrated against a calibrated digital inclinometer.

The inclinometer was fitted to the first section of jib, closest to the 'A' frame, and adjacent to the standard fit inclinometer used to display the radius to the driver. Due to the flexibility of the jib, any angle displayed by this device may not accurately describe the angle of all sections of the jib, but being rigidly fixed to the pivot at one end, this section would be likely to offer the most consistent readings over the range of the jib. The location of the inclinometers is shown in Figures 12a and 12b.

4.5 OTHER LOGGED CHANNELS

In addition to the instrumentation installed by HSL for the purposes of this research, the standard-fit instrumentation provided with the crane was also installed. Two wireless video cameras were installed in the cab which could monitor the cab displays provided to the operator from this standard-fit equipment. The operation of these was not wholly reliable, being dependent on the orientation of the crane, as at certain angles the signal could be masked by the jib and ‘A’ frame structures. They did however serve as a useful back-up.

The slack rope detector would normally alarm in the cab, however because this crane had been modified to function via remote control, a warning light had instead been installed at the base of the tower. Partly as this could not be seen from the control building, and partly because it would provide a useful record of operation, this was fitted in parallel with a transformer to reduce the voltage to 5V, which could then be recorded by the data logger when the alarm was triggered.

During commissioning tests it was noticed that there could be significant differences between the windspeed indicated by the standard-fit Ascorel Alize 3 and the HSL anemometer. This was not unexpected, as with the 40m jib of the crane, there could be at least 30m height difference between the two anemometers. However, with the lower reading frequently being that of the standard-fit equipment, and this providing the display and alarms that would, in normal operation, alert the operator to excessive windspeed conditions, it became desirable to record the output provided by this system.

This proved to be far from straightforward. The Ascorel system utilises a 4 – 20mA loop, which both provides power to the anemometer head unit, and carries a digital pulse signal from the head unit to be decoded by the display. The display unit has an output intended to provide a means of interfacing with Ascorel data loggers, however this utilises a CAN bus system, so was not readily appropriate for conversion to an analogue signal.

Several attempts were made to produce a system which could be connected in parallel with the display unit. It was desirable to maintain the operation of the display unit and associated alarms, as these were required for the crane to be safely operated and to pass safety inspections. Using a resistor placed across the 4 – 20mA loop, the current pulse output from the anemometer head unit could be converted to a low voltage pulse. This could then be input to a frequency to analogue convertor to provide a voltage output for the data logger. With some assistance from Ascorel, a working system was produced, however the head unit was unable to sustain the drain posed by running the two systems in parallel.

During discussions with Ascorel, it transpired that they were currently in the development phase of a system to carry out the same conversion. With their superior knowledge of the operation of the Alize, it was decided to wait for this system to go into production, and purchase the unit when it became available.

Upon arrival, the Ascorel conversion unit was tested and found to function perfectly in parallel with the display unit. The output now required a calibration to ensure that the data logger was recording the same reading as shown on the display unit. This was carried out by clamping the spindle of an Alize 3 anemometer head unit in the chuck of a variable speed cordless drill. With the data logger set to display an instantaneous voltage readout, and the Alize 3 display unit connected in parallel, the voltage displayed on the logger could be recorded against the corresponding readout from the display over a range of simulated windspeeds. This allowed a calibration to be carried out, the value of which could be applied to the conversion function of the data logger to give a readout in m/s.

4.6 DATA LOGGER

The function of the data logger was more diverse than would usually be the case with this kind of research. Not only would the logger have to record the information streaming from the various sensors and inputs, but it would also have to provide this data to the operator in near real-time, to enable them to safely control the crane from the control building situated approximately 70m away. Also, given the location of the crane, the probability of lightning strikes was much higher than would normally be expected, so the information had to be conveyed to the operator using a system which provided isolation from the crane structure.

A Graphtec GL900 data logger was selected for the purpose. This small, self-contained data-logger could be installed in the cab of the crane, thus minimising the length of the cables that would be required to run between the sensors and the logger, and keeping the instrument in a relatively secure and dry location. The data logger in position in the cab of the crane is shown in Figure 13. This data logger also allows calibration factors to be applied to the input channels to convert the voltage input from the sensors into the relevant engineering units. This was particularly important to the operator, who would have to rely on these readings to control the crane.

The data logger provides Ethernet support, allowing it to be linked to, and controlled by another computer on the network. As a result, the logger could be connected to a computer in the control building via a non-electrically conductive, fibre optic cable, allowing the operator to be isolated from any lightning strikes occurring to the crane. This control computer could display the information provided by the data logger in near real-time, and also allow control and downloading of the recorded data.

Various wireless systems were considered for communication between the sensors and logger. These could significantly reduce installation time, and isolate the sensors from the data logger in case of lightning strike. However, given the anticipated duration of the research, these devices would have either required several changes of batteries, or the installation of permanent power supply cables. The inaccessible location of many of the sensors meant that of these two options, it would be simpler overall to install permanent power supply cables. If a power supply cable was to be used, it could be easily upgraded to a muti-core cable, allowing the signal to be transmitted back to the cab, with minimal extra effort.

Consequently it was decided to use cables to connect the sensors to their power supplies and to the data logger, unplugging the cables after testing to reduce the risk of damage to the data logger resulting from lightning strike. The gimbal system supporting the anemometer and weather vane, was fitted with a lightning conductor grounded to the jib structure.

A wireless link was also considered for connection between the data logger and the control computer, however few of these systems are designed for live data transmission of this volume, over this distance, and the reliability of the signal was questionable given the proximity to large metallic structures. This questionable reliability was demonstrated by the video cameras, which were transmitting live footage from the cab back to a monitor in the control building. These functioned reliably only when the mast and jib of the crane were not masking the direct line between the camera aerials and their receivers in the control building. The radio control unit for the crane did however prove to be reliable, even with the crane in unfavourable positions.

The data logger was programmed to record at 10 samples per second across all 6 channels. With the research aimed at studying relatively low speed events, there was little to be gained by logging at any greater speed. Given that the time frame of each test session could potentially span several hours, and many individual tests would be performed, logging at a much greater rate could have created very large data files and increased the burden on data analysis.

Averaging of anemometer outputs is commonplace, with many systems reporting a reading which represents the average of, for instance, the last ten seconds of data samples. This can allow a more stable display to the observer than a constantly changing figure. This was not carried out with either anemometer at the data logger as, if required, it could very easily be averaged later, at the data analysis stage, to whatever averaging rate was desired.

4.7 WEATHER STATION

In addition to the instrumentation fitted to the crane, a weather station was installed on the control room building. This system was used only for indication of current wind conditions, and weather monitoring. It was not recorded by the data logger.

4.8 VIDEO CAMERAS

Two digital wireless video cameras were installed in the cab of the crane to provide video and sound replication of the displays and warning alarms which would normally be available to an operator in the cab. These were focused on the Wylie jib angle and lifting weight display, and the Ascorel windspeed indicator (this camera image also included the screen of the data logger). The images from these cameras were relayed back to a monitor in the control room for the operator's information. This system could also be used to relay feedback to the operator if the crane needed to be operated without the data logger.

Although providing a useful visual and audio back-up to the operator, the footage was not recorded. The information from the Wylie display was not required for the scope of this research, and the information from the Ascorel display was being recorded independently by the data logger.

The signal from the cameras proved not to be wholly reliable, due mainly to obstructions between the transmission and receiver aerials. These obstructions being principally the jib and mast, which presented problems in certain slew positions. Unfortunately the most affected position appeared to be when the jib was facing towards the direction of the most commonly prevailing wind, resulting in screen refreshes being unpredictable. However, as this was only used as a back-up indicator, this did not present any issues that affected the testing.

5 JIB WIND LOADING CALCULATIONS

5.1 PREAMBLE

As stated in Section 1 the manufacturer of the crane involved in the January 2007 incident in Liverpool had followed the Harmonised European Standard for Tower Cranes, BS EN 14439:2006 "*Cranes – Safety – Tower Cranes*".

Paragraph 5.2.2.4 of BS EN 14439:2006 states that *"Wind forces shall be determined with an appropriate and recognised method e.g. F.E.M. 1.001."*.

F.E.M. 1.001 (all parts) *"Rules for the Design of Hoisting Appliances"* (3rd edition) dates from October 1998 and is considered to be a "normative reference" in BS EN 14439:2006, i.e. it is considered indispensable when considering and applying BS EN 14439:2006.

Booklet 2 of F.E.M. 1.001 is titled *"Rules for the Design of Hoisting Appliances – Classification and Loading on Structures and Mechanisms"*. Section 2.2.4.1, contained in booklet 2, is concerned with defining in service and out of service wind speeds and gives methods of calculating the forces acting on the structure of the crane arising from the action of the wind.

Another F.E.M. standard exists and is also concerned with the calculation of wind loads on cranes. This is F.E.M. 1.004 *"Heavy Lifting Appliances – Section 1 – Recommendations for the Calculation of Wind Loads on Crane Structures"*. This particular standard dates from July 2000 and according to its preface "*This recommendation is specifically consecrated to the calculation of the wind loads on crane structures. It can replace the subclause 2.2.4.1. of the booklet 2 of the Rules for the Design of Hoisting Appliances F.E.M. 1.001…*".

Other standards also give methods of calculating the forces acting on the structure of the crane arising from the action of the wind. These include BS EN 13001 – 2:2004 *"Crane Safety – General Design – Part 2 Load Actions"* and ISO 4302 *"Cranes – Wind Load Assessment"*. However, both these standards predate BS EN 14439:2006 and are not specifically named in BS EN 14439:2006 to be normative references. However, section 5.2.1 of BS EN 14439 does state that *"…EN 13001 can be used on trial…"*.

F.E.M. 1.004 also states *"other recommendations or work results can also be used provided that the same level of safety is obtained"*. In F.E.M. 1.004 this is understood as a recommendation or incitement to use *"alternative recommendations or works, which are of first importance and reliable, in preference of national or international statement, and written by recognized institutions or organisms"*.

Hence, four standards have been identified that can be used to calculate the wind loads on the jib of the crane, these being:

- F.E.M. 1.001 *"Rules for the Design of Hoisting Appliances – Classification and Loading on Structures and Mechanisms"*

- F.E.M. 1.004 *"Heavy Lifting Appliances – Section 1 – Recommendations for the Calculation of Wind Loads on Crane Structures"*

- ISO 4302 *"Cranes – Wind Load Assessment"*

- BS EN 13001 – 2:2004 *"Crane Safety – General Design – Part 2 Load Actions"*

Of these, the two F.E.M. standards (1.001 and 1.004) can be considered to be normative references in BS EN 14439:2006 and, as such, consulted for wind loading calculations without further consideration of whether they can be safely applied being required. The other two standards (BS EN 13001 – 2:2004 and ISO 4302) are not considered to be normative references in BS EN 14439:2006 and as such should not perhaps be consulted for wind loading calculations without further consideration that they provide the same levels of safety as the F.E.M. standards.

5.2 WIND LOADING CALCULATIONS

Each of the four standards referenced in Section 5.1 follow a similar method of calculating the wind loads on the crane structure.

The wind load is calculated using the equation:

$$F = A \times q \times Cr$$

Where:

F is the wind load (N)
A is the effective frontal area of the part under consideration (m^2)
q is the wind pressure corresponding to the appropriate design condition (N/m^2)
Cr is the shape coefficient in the direction of the wind for the part under consideration

Each of the four standards provides information and methods for determining the effective frontal area, wind pressure and shape coefficient used in the above equation.

It is also assumed in each of the four standards that the wind can blow horizontally from any direction and that the wind speed, or velocity, is constant, i.e. no changes in wind speed for different heights above ground level are accounted for.

In this report the appropriate design condition is taken to be the maximum in service wind. This is the maximum wind in which the crane is designed to operate. Section 4.1 of the crane manual is concerned with safe operation of the crane and states that the crane should not be operated at wind speeds in excess of 20 m/s (72 km/hour). This is consistent with Table T.2.2.4.1.2.1 of F.E.M. 1.001 which specifies the in service design wind speed to be 20 m/s and also defines the in service design wind pressure to be 250 N/m^2.

Wind loading on the underside of the jib, i.e. blowing directly onto the two side chords will result in an applied moment about the jib pivot points. Since the jib elevation is controlled by a rope and pulley system the crane structure does not provide a reaction to this moment and it is only principally the moment at the jib pivot points arising from the self weight of the jib and the hook block and any load on the hook that reacts against the moment arising from wind loading to prevent the jib from being moved by the wind. The moment arising from the self weight of the jib, hook block and any load being lifted reduces as the jib is elevated since the centre of gravity of the load and jib sections approaches the jib pivot points and consequently the moment arm reduces. Conversely, the moment resulting from wind loading increases as the jib is elevated because the frontal area of the jib presented to the wind increases as the jib is elevated. If the situation is reached when the moment at the jib pivot points resulting from the wind loading exceeds the moment at the jib pivot points arising from the self weight of the jib etc then the jib will be moved by the wind in the direction of the ‘A’ frame of the crane.

The moment at the jib pivot points arising from the weight of the jib and hook block have been calculated for jib angles of between 0º to 90º. These calculations have been performed on the theoretical properties of the jib sections i.e. the masses provided in the crane manual and positions of centre of gravity provided by Jaso and also on the properties of the crane jib sections measured during erection of the crane at HSL given in Table 1 and Figures 5 to 9 and are given in Appendix 2.

Wind loading calculations on the crane jib in accordance with each of the four standards identified in Section 5.1 are given in Appendices 3 to 7. These calculations are for the condition whereby the hook is not loaded and the wind is taken to be blowing directly onto the underside of the jib, i.e. blowing directly onto the two side chords at speeds of between 0 m/s to 20 m/s at jib angles between 15º to 90º to the horizontal. The calculations have been performed on the theoretical properties of the jib sections i.e. the masses provided in the crane manual and positions of centre of gravity provided by Jaso and also on the masses and centre of gravity of the crane jib sections measured during erection of the crane at HSL given in Table 1 and Figures 5 to 9. Since the jib sections are reasonably regular shaped structures it is assumed in this report that the centre of gravity of a jib section is in nominally the same position as its centre of area. Any difference between the two is negligible and that no significant difference exists if the wind loading was taken to act at the centre of area instead of the centre of gravity of a particular jib section.

The calculated wind loading for the different wind speeds and different jib angles have then been used to determine the resulting moment at the jib pivot points and compared with the moment at the jib pivot points arising from the weight of the jib and hook block at the same jib angle. Graphs 1 to 8a show the calculated moment resulting from wind loading against the angle of the jib for different wind speeds. The heavy black line on graphs 1 to 8a represents the calculated moment arising from the weight of the jib and hook block for different jib angles. The point at which the wind speed line crosses this line indicates the point where the two moments are numerically equal and this is the point at which it may be expected that the jib is being balanced or supported by the wind loading. Wind speeds above this at the same angle of the jib will be likely to result in the jib being moved towards the 'A' frame since the moment arising from the wind loading exceeds that of the self weight of the jib and hook block. Table 2 summarises the wind speed and jib angles where this is predicted by the calculations.

Reference to Table 2 and graphs 1 to 8a shows that, according to the calculations, the jib of the crane may be moved by wind loading at elevations above approximately 81º at wind speeds less than the in service design speed of 20 m/s.

The calculations above do not take account of the weight of the luffing rope deployed, the floating pulley block, the luffing tie bars or the tension in the luffing system. They also do not take into account any load on the hook of the crane, i.e. they assume that the crane is in the most vulnerable operational condition.

Table 2 – Calculated wind speeds required to support the crane jib

	Calculated Wind Speed To Support the Jib (m/s)							
	Theoretical Properties of the Jib Calculation Method of Wind Loading				Measured Jib Properties Calculation Method of Wind Loading			
Jib Angle	F.E.M. 1.001	F.E.M. 1.004	BS EN 13001	ISO 4302	F.E.M. 1.001	F.E.M. 1.004	BS EN 13001	ISO 4302
80º	> 20	> 20	> 20	> 20	> 20	> 20	> 20	> 20
81º	> 20	19 to 20	19 to 20	> 20	> 20	19 to 20	> 20	> 20
82º	19 to 20	18 to 19	18 to 19	19 to 20	19 to 20	18 to 19	18 to 19	19 to 20
83º	18 to 19	16 to17	17 to 18	17 to 18	18 to 19	17 to 18	17 to 18	18 to 19
84º	16 to 17	15 to 16	15 to16	16 to 17	16 to 17	15 to 16	16 to 17	16 to 17
85º	14 to 15	13 to 14	14 to 15	14 to 15	14 to 15	14 to 15	14 to 15	14 to 15
86º	13 to 14	12 to 13	12 to 13	12 to 13	13 to 14	12 to 13	12 to 13	13 to 14

5.2.1 Anomalies with the Standards

The following anomalies with the four standards were noted whilst they were being consulted to calculate the wind loadings given in Appendices 4 to 7.

5.2.1.1 Wind Pressure

FEM 1.004 and BS EN 13001 – 2:2004 specify that the in service wind speed is 20 m/s and the corresponding in service wind pressure is 250 N/m^2. The equation relating wind pressure to wind speed is specified in both these standards to be:

$$q = \tfrac{1}{2} \times \rho \times v^2$$

Where

q is the wind pressure
ρ is the density of air, specified in FEM 1.004 and BS EN 13001 – 2:2004 to be 1.25 kg/m^3
v is the wind speed

For both FEM 1.004 and BS EN 13001 – 2:2004 the wind speed of 20 m/s does result in a wind pressure of 250 N/m^2 when the equation is followed, i.e:

$$\tfrac{1}{2} \times 1.25 \times 20^2 = 250 \text{ N/m}^2$$

FEM 1.001 and ISO 4302 also specify that the in service wind speed is 20 m/s and the corresponding in service wind pressure is 250 N/m^2. The equation relating wind pressure to wind speed is specified in both these standards to be:

$$q = 0.613 \times v^2$$

Where q is the “dynamic” wind pressure and v is the wind speed.

If the wind speed is 20 m/s then

$$q = 0.613 \times 20^2 = 245.2 \text{ N/m}^2$$

which is slightly less than the specified in service wind pressure of 250 N/m^2 quoted in FEM 1.001 and ISO 4302. It is possible that this small difference may be due to an interpretation of "dynamic" wind pressure but this is not explained in either standard and no guidance is given concerning any correction factors that may be required to obtain "dynamic" in service wind pressures at wind speeds other than 20 m/s. Consequently, the calculations in Appendices 4 and 7 concerned with FEM 1.001 and ISO 4302 use a value of q = 250 N/m^2 for a wind speed of 20 m/s as specified in the standards. For other wind speeds the corresponding value of q calculated using the equation is used.

5.2.1.2 Figure FA3. 1 of FEM 1.004

Figure FA3.1 of FEM 1.004 is a graph showing aerodynamic coefficients of spatial lattice work members related to the solidity ratio. Various shapes of different lattices are shown with the wind striking them from different directions. I believe that the intention is that the user selects the most appropriate lattice/wind direction/solidity ratio combination and reads the corresponding aerodynamic coefficient from the graph. However, the scale on the graph for the aerodynamic coefficient is blank and hence no value can be obtained for it from this particular diagram.

5.2.1.3 Shielding of the Jib Side Lattices

All four standards used in the wind loading calculations use similar wording when considering whether or not to include wind loading on frames or members shielded by other frames or members directly exposed to the wind.

The text of the four standards refer to the situation where "*..parallel frames or members are positioned so that shielding takes place , the wind loads on the windward frame or member and on the unsheltered parts of those behind it are calculated using the appropriate shape coefficients…*".

The wind loading on the shielded frames or members is multiplied by a shielding factor which is dependant upon the solidity ratio and spacing ratio of members under consideration. Diagrams are provided in each of the standards to specify how to derive solidity and spacing ratios for different situations

In FEM 1.004, ISO 4302 and BS EN 13001 – 2:2004 the diagrams only show parallel frames or members. Triangular sections are not considered and no method to derive spacing ratios for triangular sections is provided in these three standards. Hence, it is interpreted that no shielding of the side lattices is intended to be applied when considering FEM 1.004, ISO 4302 and BS EN 13001 – 2:2004.

However, in FEM 1.001 information is provided to derive solidity and spacing ratios for a triangular lattice frame although the text concerned with shielding factors only refers to parallel frames or members. Hence, it is somewhat uncertain whether or not to include the wind loading on the shielded side lattices in this case. The text implies that it should not be considered because the members are not parallel to each other but a diagram does specify a method whereby the shielding factor can be derived for a triangular lattice jib.

In this report, the calculations on the five jib sections carried out in Appendix 3 in accordance with FEM 1.001 do include the contribution from the shielded side lattices and equations 1 to 5 are derived that express the wind loading on each jib section in terms of the wind pressure multiplied by a constant. The constants for each jib section are:

Jib Section 1 – 3.72

Jib Section 2 – 4.19

Jib Section 3 – 4.08

Jib Section 4 – 2.09

Jib Section 5 – 3.01

If the contribution from the shielded side lattices in equations 1 to 5 are neglected, the constants would reduce to:

Jib Section 1 – 3.50

Jib Section 2 – 3.85

Jib Section 3 – 3.78

Jib Section 4 – 1.94

Jib Section 5 – 2.81

This is a difference of between nominally 6% to 8% and consequently the inclusion or otherwise of the shielded side lattices would not be expected to impact particularly significantly on the calculated wind loads.

5.2.1.4 Wind Loading an Inclined Jib

All four standards used in the wind loading calculations assume that the wind blows horizontally. If the jib is inclined, i.e. not at an angle of 90º to the wind the effective areas of the jib sections and platform are reduced.

Allowance is made in three of the four standards (FEM 1.001, FEM 1.004 and ISO 4302) for this by multiplying the wind pressure by $\sin^2$ of the angle between the direction of the wind velocity and the member under consideration.

Allowance is also made for this in BS EN 13001 – 2:2004, however in this case the wind pressure is multiplied by the sin of the angle between the direction of the wind velocity and the member under consideration.

Although perhaps not an anomaly as such it is interesting to note the difference between the standards in this regard.

6 TESTING OF THE CRANE

6.1 CRANE SET UP

The crane was erected and set up at HSL on 6 and 7 April 2009 by representatives of Falcon Crane Hire Ltd. The crane was positioned on an existing HSL facility used in the past to investigate the performance of mobile crane outriggers. This facility was located on an exposed hillside at HSL and incorporated a large deep concrete slab, suitable to mount the crane on. A small building referred to as Building 12 was located approximately 75m from the concrete slab and this was used as a base to operate the crane from via remote control and download the readings from the data logger onto a laptop computer. An exclusion zone of nominally 50m diameter was enforced by erecting deer fencing around the concrete slab. No power was available at the concrete slab hence electricity to power the crane and instrumentation during testing was supplied via a containerised diesel engine powered generator also supplied by Falcon Crane Hire Ltd. As part of the set up during erection of the crane, the minimum and maximum radius of the crane were adjusted using the Wylie instrumentation.

The crane underwent a thorough examination on 8 April 2009, after which it was passed as safe to operate. Before any formal testing was carried out a period of training and familiarisation in operating the crane and instrumentation fitted to it was undertaken.
During this process the jib was raised from its maximum radius to its minimum radius to check the correct operation of the HSL inclinometer. It was found that at minimum radius, the HSL inclinometer gave a reading of 86º to the horizontal compared with a reading of 85º from the Wylie system in the cab. The jib angle at maximum radius was 15º indicated by both inclinometers.

6.2 TEST PROCEDURE

During familiarisation the following test procedure was developed as being the simplest and easiest manner in which to operate the crane and obtain data:

6.2.1 Checks Before Testing

Unlock and enter the crane compound. Perform basic visual checks on the electricity generator, e.g. fuel and oil levels and check for any obvious leaks or other problems. Start the electricity generator and allow the speed to stabilise whilst visually checking for any obvious leaks or other problems. Switch the generator over to supply power to the crane.

Walk around the crane ballast and visually inspect the base and ballast weights for any obvious problems. Climb the mast to the counterjib whilst observing the condition of the mast section pins joining each section together, in particular check for any missing or displaced pins.

Engage the slewing motor mechanical brake. Switch the crane power on using the remote control and connect the HSL instrument cables to the data logger in the cab. Check that the data logger is operating correctly and the display of readings is reasonable for the wind speed, jib angle etc.

Check that the crane instrumentation is operating correctly. Operate the slewing and luffing functions and ensure that movements are smooth and start/stop when required. Check that the slewing brake and luffing brake release and engage correctly when the controls are operated.
Leave the crane and close the crane compound gate but leave unlocked. Set the laptop up in Building 12 and connect to the data logger. Ensure that the remote readings from the data logger on the laptop are reasonable for the wind speed, jib angle etc. Ensure that the crane responds satisfactorily to the remote control unit.

6.2.2 Data Collection

Establish the prevailing wind direction from the wind vane fitted to the end of the jib and slew the crane such that the jib is facing into the wind. This is indicated by a 180º reading from the wind vane. Set the jib angle at the required elevation and allow the load cell readings to stabilise. Start the data logger and log readings over a period of time until it is judged that sufficient data has been collected. Stop the data logger and set the jib at the next required elevation and allow the load cell readings to stabilise and repeat until data collection is complete.

In all data collection the reading from the anemometer fitted to the 'A' frame was used as a guide to the wind speed. This was because under normal operating conditions at a construction site this anemometer would be used by the crane operator to determine if the crane should be used or "winded off".

The minimum radius position of the jib was taken to be when the jib was stopped from further elevation by the control system.

6.2.3 Checks After Testing

When data collection is completed set the jib of the crane to a radius of not less than 20 m. Shutdown the laptop and disconnect from the data logger. Enter the crane compound and climb the mast to the counterjib. Disengage the slewing motor mechanical brake to permit the crane to weathervane. Remove the HSL instrument cables from the data logger in the cab. Switch off the crane power using the remote control and lock the cab. Switch the generator over so that the power supply to the crane is cut. Shut down the generator and inspect for leaks and any obvious problems. Lock the gate of the crane compound when leaving.

6.3 RESULTS OF TESTING

6.3.1 Load Cell Readings to Determine the Effect of Wind Loading on the Jib

Data collection from the crane was performed whenever the wind conditions were favourable. Readings of wind speed from the 'A' frame anemometer and jib end anemometer, load cell reading, jib angle, and wind direction were logged. In addition if the slack rope detection protection fitted to the crane was activated at any time this alarm was also logged. However, this protection was not sophisticated enough to be able to distinguish if it had been activated at the luffing drum or the 'A' frame pulleys.

The data gathered from the 'A' frame anemometer is split into five categories:

- Very calm or still conditions - wind speeds below 1.99 m/s
- "Calm" - wind speeds between 2 and 4.99 m/s
- "Low" - wind speeds between 5 and 9.99 m/s
- "Medium" - wind speeds between 10 and 14.99 m/s
- "High" - wind speeds between 15 m/s and 20 m/s

During data collection at any given angle of the jib the wind did not tend to blow consistently directly onto the jib at 180º as indicated by the wind vane at the end of the jib. It was not practical to keep slewing the crane during testing so that the jib was always exactly facing the wind because the wind direction could alter faster than the crane could be slewed to meet it. Consequently, all results presented in this report have been "filtered" from the collected data so that load cell readings for different wind speeds obtained at wind directions as close as possible to 180º and only between 175º and 185º have been used in subsequent analysis.

The results from testing in the still conditions have been used to "datum" the load cell readings, i.e. provide readings from the load cell that are nominally unaffected by wind loadings at a particular angle of the jib. These readings are then compared with load cell readings at the same jib angle at the higher wind speeds to determine if the wind loading at those wind speeds was affecting the jib.

The calculated wind speeds to support the crane jib shown in Graphs 1 – 8a indicated that the jib should remain stable (i.e. not be physically lifted towards the 'A' frame) at wind speeds of up to 20 m/s at jib angles up to nominally 80º. Overall experience in operation of the crane during testing confirmed this and little or no testing was carried out at lower jib angles with wind speeds below nominally 5 m/s.

The average readings from the load cell for a particular jib angle under the different conditions are given in Table 3 and shown in Graph 9.

<u>Table 3 – Load Cell Readings for different Jib angles under different Wind Conditions</u>

	AVERAGE LOAD CELL READING (tonnes)				
JIB ANGLE	Still Conditions Wind Speed < 1.99 m/s	Calm Conditions Wind Speed 2 – 4.99 m/s	Low Conditions Wind Speed 5 – 9.99 m/s	Medium Conditions Wind Speed 10 – 14.99 m/s	High Conditions Wind Speed 15 – 20 m/s
15º	10.58	/	/	/	/
20º	9.78	/	9.96	9.96	9.91
25º	9.2	/	9.17	8.94	8.90
30º	8.54	/	8.27	8.26	8.17
35º	7.99	/	7.70	7.57	7.51
40º	7.40	7.43	7.09	7.03	6.90
45º	6.92	6.80	6.77	6.25	6.13
50º	6.24	6.26	6.09	5.68	5.53
55º	5.76	5.69	5.59	5.28	5.10
60º	5.14	5.11	5.00	4.61	4.54
65º	4.69	4.57	4.29	4.01	3.80
70º	4.01	4.02	3.52	3.42	3.17
75º	3.40	3.30	2.87	2.51	2.26
80º	2.53	2.47	1.96	1.68	1.41
86º	1.48	1.36	1.23	/	/

On occasion whilst testing at a jib angle of nominally 80º during high wind conditions (> 15 m/s) the jib of the crane could be seen to be bouncing, i.e. being pushed towards the 'A' frame and then falling back until restrained by the luffing system. Load cell readings and readings of minimum and maximum wind speed recorded from the 'A' frame anemometer when this was observed are given in Table 4 overleaf.

Table 4 – Load Cell Readings during observed Jib bouncing (jib angle nominally 80º)

	16 November 2009	Date 16 July 2010
Minimum Wind Speed (m/s)	15.5	15.0
Average Wind Speed (m/s)	16.0	15.4
Maximum Wind Speed (m/s)	16.2	16.5
Minimum Load Cell Reading (tonnes)	1.24	1.03
Average Load Cell Reading (tonnes)	1.41	1.27
Maximum Load Cell Reading (tonnes)	1.61	1.73

6.3.2 Discrepancy between the Anemometers

During testing of the crane it was observed that on occasion there could be a discrepancy between the wind speed readings provided by the anemometer fitted at the top of the 'A' frame and the anemometer fitted at the end of the jib. Table 5 below gives some examples where this was observed.

Table 5 – Observed Differences between anemometer readings

Date	Jib Angle	'A' Frame anemometer reading (m/s)	Jib end anemometer reading (m/s)	Difference (m/s)	% age difference
16 July 2010	84º	9.9	16.1	6.2	63%
		8.9	16.8	7.9	89%
30 November 2009	15º	5.6	8.7	3.1	55%
		6.2	4.3	- 1.9	- 31%
	50º	9.9	5.3	- 4.6	- 46%
9 November 2009	65º	1.0	2.5	1.5	150%
11 December 2009	30º	0	1.5	1.5	/

6.3.3 Jib "Blow Back" Incident During Testing

On 16 November 2009, testing was being carried out at wind speeds in the region of the maximum in service design speed of 20 m/s. The testing commenced at approximately 11:36 am and the first readings were taken at a jib angle of nominally 20º to the horizontal. During testing the jib was raised in steps of 5º intervals until it had reached an angle of nominally 80º to the horizontal at approximately 13:17 pm.

At nominally 80º to the horizontal the wind speeds were logged for approximately 14 minutes. The minimum, maximum and average wind speeds from both anemometers were recorded to be:

- 'A' frame anemometer 5.4 m/s minimum, 16.2 m/s maximum and 8.8 m/s average
- Jib end anemometer 6.8 m/s minimum, 18.9 m/s maximum and 12.7 m/s average.

The wind speed readings and load cell readings with the jib at 80º to the horizontal are given in Graph 10. Physical observation of the crane jib revealed that it was "bouncing" towards the 'A' frame under action of the wind at the start of this 14 minute test period but that this had ceased at the end of it. Graph 10 shows that the load cell readings at the start of the test period were approaching and in some cases below the "datum" values for a jib angle of 80º and also 86º, which was in keeping with the observed jib movement.

The last recorded wind speeds from the 'A' frame anemometer at the jib angle of 80º were nominally 6 to 9 m/s and nominally 9 m/s to 14 m/s from the jib end anemometer. Since both readings were below the in service design wind speed of 20 m/s it was decided to raise the jib angle to minimum radius to collect data at this jib angle. The data logger was stopped from recording as per the procedure detailed in Section 6.2.2 at 13:31 (timed from the clock on the lap top used to record the data) and the remote control operated to raise the jib. As the jib was being raised the wind speed from the driver,s cab display was being manually observed using the monitor in the control room and seen to be between 8 m/s to 10 m/s. Before the jib could be raised to minimum radius (86º) using the luffing system it went back, contacted the spring buffer of the 'A' frame and remained in that position. The data logger was started at 13:31 and data following the event for approximately 8 minutes was obtained. This data shows that the wind speed following the event was between nominally 6 m/s to 12 m/s measured by the 'A' frame anemometer and nominally 12 m/s to 16 m/s measured using the jib end anemometer. The wind speeds after the incident are given in Graph 11.

When the jib went back against the spring buffer arrangement the luffing system visibly lost tension and the slack rope protection system activated, however it is not known if this was at the 'A' frame pulleys, at the luffing winch drum or both these locations. The load cell reading with no tension in the luffing line was recorded to be 0.65 tonnes.

Activation of the slack rope system inhibited unwinding the luffing winch and luffing rope could not be payed out. However, the luffing winch could still be operated in the winding direction and it was possible to take some of the slack out of the luffing rope. The crane was slewed out of the wind such that the underside of the jib was not facing into the wind and the wind was acting on the back of the jib. The jib then fell under the action of the spring buffer arrangement and the wind until the luffing system became completely taut. This cleared the slack rope protection and complete raise and lower control of the luffing system was restored.

The jib was then lowered using the remote control until it was at an angle of approximately 75º. At this point the slack rope protection system activated again and further lowering of the jib using the remote control was inhibited. As before, it was unknown which device (the 'A' frame pulleys, the luffing winch drum or both these) had activated. It was of some concern that the jib could not be lowered past 75º to the horizontal since the operating radius at this angle was well within the radius of 20 m required for the crane to weather vane whilst unattended. This meant that if the crane were to be left in this condition it may not have weather vaned properly and if the wind were sufficiently strong, structural damage may have resulted.

Up to this point all the foregoing luffing and slewing operations had been made using the remote control unit for the crane from the control room (building 12). Because the jib could not be lowered past 75º to the horizontal it was necessary to access the counterjib of the crane to inspect the luffing winch drum and the 'A' frame pulleys. Inspection showed that the luffing rope had become layered or wrapped over itself on the luffing drum and was contacting the slack rope detector even when the system was tight. It was also observed that the luffing rope had left the groove of one of the 'A' frame pulleys, this being the third pulley from the left when viewed from the counterweights as shown in Figures 14a and 14b.

The jib was lowered using the luffing motor contactor located in the machine control cabinet on the counterjib (this overrode the various protection systems including the slack rope detection system) until the erection/safety ropes started to tighten. The crane was left in this condition since the jib was beyond the 20m radius and so could weather vane correctly and if the luffing system had subsequently failed in any way the jib would not drop suddenly and shock load the structure of the crane.

6.3.3.1 Damage Caused to the Crane

Mr Gary Potter of Falcon Crane Hire Ltd attended site the following day (17 November 2009) to inspect the crane. Damage to the luffing rope (flattening/kinking) had occurred and the 'A' frame pulley from which the rope had left the groove was damaged by way of nicking and gouging of the material on its edge. This damage is shown in Figures 15 and 16.

During this visit Mr Potter managed to replace the luffing rope in the groove of the pulley and the crane was left in free slew with the jib being supported by the safety/erection ropes and the luffing system. It was agreed that a new luffing rope and pulley would be required to return the crane to service.

6.3.3.2 Rectification of the Crane

A new luffing rope and 'A' frame pulley were fitted on 20 November 2009 by Mr Potter and the crane was returned to service and further testing in different wind speeds continued.

In addition, the incident was taken up with Jaso and Falcon Crane Hire by HSE. Jaso provided calculations that confirmed that the jib of the J80 crane could be affected by wind speeds of 70 km/hr (19.45 m/s) at a radius of 6.5 m (equivalent to a jib angle of 80.6º according to the Jaso calculations) and design changes were proposed by them to prevent this. These consisted of:

- Longer springs in the spring buffer arrangement and a spacer or "make up piece" on the jib itself. These enabled the springs to contact the jib before it reached minimum radius and hence provide a force to effectively "push" the jib away from the 'A' frame as it approached maximum elevation and

- A guide arrangement having four curved "fingers" that fitted closely underneath each groove of the four pulleys of the 'A' frame to prevent rope from leaving the pulley groove.

It was agreed that the crane at HSL would be fitted with both modifications and subsequent testing carried out to determine their effectiveness.

The modifications were carried out on 24 and 25 February 2010 by Mr Philip Gale and Mr R Tourney of Falcon Crane Hire Ltd. They were accompanied by Mr Josu Arizkorreta of Jaso.

Upon completion of the modifications the spring buffer started to contact the jib when it was raised to an angle of nominally 80º and the springs compressed as the jib was raised to maximum elevation. At the maximum jib elevation of nominally 86º (minimum radius) the springs were observed to still have some compression remaining, i.e. they were not "coil bound". Figures 17a, 17b and 17c show the longer spring arrangement before and after the jib had contacted it.

Testing in still and calm conditions was carried out to determine the effect of the longer springs on the tension in the luffing system. The results of this testing are given in Table 6 and shown in Graph 12. The load cell readings are compared with readings taken on 15 February 2010, following the repair of the crane but prior to the spring modification and are used as a "datum" to determine the effect of the spring modifications on the load cell readings and hence tension in the luffing system. In Table 6, only the load cell readings at jib angles between 75º and 86º are given, i.e. from just before the jib contacted the new longer springs, as the jib contacted them and subsequently compressed them. Readings below 75º have not been included in this table since the jib was not contacting the springs and so the load cell readings would be unaffected by the new springs. However, for completeness all load cell readings are shown in Graph 12

Table 6 – Effect of Modified Buffer Springs on Load Cell Readings (Still/Calm Wind Conditions)

	LOAD CELL READING (tonnes)	
	Original Springs	Longer Modified Springs
Jib Angle		
75º	3.52	3.45
76º	3.35	3.31
77°	3.22	3.13
78º	3.08	3.00
79º	2.90	2.83
80º	2.79	2.69
81º	2.52	2.49
82º	2.39	2.50
83º	2.16	2.65
84º	1.93	2.80
85º	1.69	2.95
86º	1.48	3.25

Table 6 and Graph 12 show that the tension in the luffing system was increased by the longer modified springs when compared with the original springs at jib angles greater than nominally 80 – 81º. This was as a result of the longer springs pushing against the jib after it had contacted the modified spring buffer arrangement. The greater the jib angle the greater the spring compression and hence the greater the force imparted by the springs acting against the jib.

Further testing was also carried under high wind speed conditions with the jib facing into the wind. The results of this testing are given in Table 7 and are shown in Graph 13. During this testing the jib was raised to its maximum elevation of nominally 86º in recorded wind speeds of up to 16 m/s measured using the 'A' frame anemometer and 19.4 m/s measured using the jib end anemometer. It was observed that the jib was steady at this time, the luffing system remained taught and the jib did not move back towards the 'A' frame under action of the wind. During testing at this time in these conditions, the jib was seen to be bouncing as described previously when it was just about to contact the springs.

Table 7 –Load Cell Readings with longer modified springs (High Wind Condition)

	LOAD CELL READING (tonnes)
	Longer Modified Springs
Jib Angle	
75°	2.26
80°	1.41
81°	1.27
82°	1.25
83°	1.44*
84°	1.39
85°	1.97*
86°	1.78

the load cell reading at 83° and 85° jib angles were obtained at a nominal wind speed of 13 m/s, just below the 15 m/s lower limit for "High Wind Conditions"

7 ASSESSMENT

7.1 ASSESSMENT OF THE TESTING

7.1.1 Crane in the "as received" condition at HSL

The first phase of testing was carried out with the crane as originally supplied by Falcon Crane Hire Ltd. Some modifications were required to fit the HSL instrumentation to it but these modifications were of a relatively minor nature and did not significantly impact upon or were detrimental to the mechanical performance of the crane.

In particular, the crane was as delivered and unmodified with respect to the relationship between the end of the original spring buffer arrangement on the 'A' frame and the arc of movement of the jib and the positioning of the safety bar associated with the luffing rope pulleys of the 'A' frame.

The minimum "datum" load cell reading was 1.48 tonnes. This was recorded in still conditions with the jib raised to its maximum elevation of 86º. Under these conditions the jib was not being significantly affected by wind loading and was observed to be steady and not bouncing. Hence, load cell readings of 1.48 tonnes can be considered as a threshold whereby load cell readings greater than this should ensure that the jib of the crane remains stable and is unlikely to be blown against the 'A' frame.

The results of testing showed that the jib of the crane remained stable and relatively unaffected by wind loading on the underside of the jib at wind speeds in the region of the maximum in service wind speed of 20 m/s and at jib angles approaching nominally 75 º to 80º. Readings from the load cell for any given jib angle up to 75º did tend to reduce as wind speed increased and this was more pronounced for the larger angles than the smaller angles. This indicates that some of the moment arising from the weight of the jib was being reacted by wind loading and this increased as the jib angle and wind speed increased. However no readings approached the threshold 1.48 tonne figure.

At and above a jib angle of nominally 80º the jib exhibited more sensitivity to the combination of angle and wind speed. At 80º the average load cell reading under high wind conditions was below that of the 1.48 tonnes threshold (1.41 tonnes and 1.27 tonnes) and the jib could be seen to be bouncing. When bouncing the load cell readings were between 1.03 and 1.73 tonnes. At this point the jib could be considered to be becoming unstable, if not unstable already and in my opinion would be approaching the point at which it would be expected to be blown against the 'A' frame. Hence, testing under high wind conditions at a jib angle of 80º did confirm that the jib of this crane could be susceptible to uncontrolled movement arising from wind loading.

Testing at a jib angle of 86º was confined to still, calm and low wind conditions due to the observed sensitivity of the jib at angles above nominally 80º under the medium and high wind conditions.

7.1.2 Discrepancy between the anemometers

As stated in Section 6.3.2, on occasion significant discrepancy was observed between the wind speed readings provided by the anemometers fitted to the 'A' frame and at the end of the jib. Usually, it was found that the jib end anemometer gave readings greater than those supplied by the anemometer on the 'A' frame at the same time. However, this was not always the case, sometimes the 'A' frame anemometer gave readings greater than those supplied by the anemometer at the end of the jib.

Differences between the two anemometers were not constant; generally it was found during testing that the two anemometers were reasonably close to each other with only small differences between the two. On other occasions one anemometer (usually the jib end anemometer) could be supplying a reading more than double than that of the other anemometer.

No cause for this was established during the testing and no work was undertaken to try and determine its cause. Possible reasons could include:

- Shielding of the 'A' frame anemometer by the crane jib

- Wind speed being "layered" with different wind speeds at different heights above the ground

The crane, as delivered, was fitted with a single anemometer fitted to the 'A' frame and under normal operating conditions this would provide the only indication of wind speed to a crane operator. It is readily apparent that actual wind speeds being experienced at the end of the jib of the crane may be greater than that shown by the 'A' frame anemometer and that this may lead to operation of the crane at unknown higher wind speeds than indicated to the operator.

FEM 1.001 states *"Where a wind speed measuring device is to be attached to an appliance it shall normally be placed at the maximum height of the appliance. In cases where the wind speed at a different lever* (sic – level?) *is more significant to the safety of the appliance, the manufacturer shall state the height at which the device shall be placed"*.

The instructions for positioning an anemometer given in the manual for the crane were consistent with FEM 1.001 since the manual specified that anemometers should be placed in *"the highest part of the crane"* and *"…placed on the top of the crane, the highest position"*. The custom and practice within the UK Tower Crane Industry would indicate that anemometers are positioned at the top of the 'A' frame.

This is understandable and acceptable to FEM 1.001 when considering a conventional "saddle jib" type tower crane where the jib and counterjib lie nominally horizontal to the ground and are not raised and lowered during operation of the crane. For such cranes the top of the 'A' frame is usually at the maximum height above ground.

However, on a luffing crane, the height above ground of the end of the jib can often significantly exceed the height above ground of an anemometer fitted to the 'A' frame. On the Jaso J80 PA crane used in testing at HSL the difference in height between the two anemometers could be as much as nominally 33 m if the jib were raised to its maximum elevation. However, when the jib was at or near its minimum elevation (maximum radius) the anemometer at the outer end of the jib was nominally only 3.4 m higher than the 'A' frame anemometer.

The reason(s) why the anemometer readings could be so different is not of particular interest in the context of this project. It is sufficient to note that this was experienced on numerous occasions during testing of the crane and that it occurred whilst the crane was being operated under "normal" conditions. Consequently, it would be expected that a luffing tower crane located on a construction site could experience similar differences in wind speed between the outer end of the jib and the 'A' frame.

This could be of concern if a luffing tower crane operator only has an indication of wind speed from an anemometer mounted on the 'A' frame. It is possible that the situation could be reached whereby, unknown to the crane driver, wind speeds at the outer end of the jib exceed the maximum in service wind speed of 20 m/s when the indicated wind speed from an anemometer fitted to the 'A' frame is below the set pre alarm or alarm threshold of the 'A' frame anemometer.

Hence, the possibility exists for the crane to be operated in a potentially dangerous condition without the driver being aware of it.

7.1.3 Jib "Blow Back Incident During Testing

Immediately prior to the jib being blown against the 'A' frame it was at an angle of nominally 80º. The actual uncontrolled movement of the jib occurred as it was being raised from 80º to 86º.

Although not being formally logged at the time the wind speed as the jib was passing through the angles between 80º and 86º was visually observed to be between 8 m/s and 10 m/s from the 'A' frame anemometer. Subsequent wind speed measurements logged from the 'A' frame anemometer immediately after the event were in this region (nominally 6 m/s to 12 m/s) and wind speeds from the jib end anemometer were nominally 12 m/s to 16 m/s. These wind speeds are below the maximum in service wind speed of 20 m/s and hence the blow back during testing confirmed that this particular crane jib is susceptible to uncontrolled movement arising from wind loading at wind speeds below the maximum in service wind speed of 20 m/s when elevated above nominally 80º.

7.1.4 Crane Modifications

Following the uncontrolled movement of the jib described in Section 6.3.3, the crane manufacturer, Jaso, modified the crane as described in Section 6.3.3.2. The modifications consisted of fitting longer springs in the spring buffer on the 'A' frame to contact the jib before it reached minimum radius and hence provide a force to effectively "push" the jib away from the 'A' frame as it approached maximum elevation and a guide arrangement having four curved "fingers" that fitted closely underneath each groove of the four pulleys of the 'A' frame to prevent rope from leaving the pulley groove.

Testing the crane in high wind conditions after the modifications had been carried out showed that the longer springs were very effective in preventing uncontrolled movement of the jib when it was raised above nominally 80º to its maximum elevation of 86º. Reference to Graph 13 shows that the in high wind conditions the load cell reading when the jib was contacting the spring buffer was very close to the 1.48 tonne threshold figure obtained in still conditions. At the 86º maximum elevation of the jib the load cell reading was 1.78 tonnes compared with 1.48 tonnes obtained without the modified springs (i.e. no force applied to the jib) under still conditions.

Since the uncontrolled movement of the jib was avoided by the longer springs, the luffing system remained in tension at all times and the effectiveness of the curved "finger" guides in preventing the luffing rope from leaving the pulley groove could not be assessed.

It is my understanding that Jaso implemented similar modifications to the spring buffer arrangement on their range of luffing tower cranes and that Falcon Crane Hire, being the sole importer/agents for Jaso in the U.K, completed fitting the modifications to all the Jaso luffing tower cranes in their fleet in 2011.

7.2 ASSESEMENT OF THE WIND LOADING CALCULATIONS

The wind loading calculations carried out according to FEM 1.001, FEM 1.004, BS EN 13001 – 2:2004 and ISO 4302 showed that the jib of the crane could be susceptible to being supported by wind loading at jib angles above approximately 81º at wind speeds less than the in service wind speed of 20 m/s.

The calculated wind speeds to support the jib ranged from 12 m/s to 14 m/s at a jib angle of 86º and 18 m/s to 20 m/s at a jib angle of 81º/82º.

These figures are reasonably close to the figures obtained during testing. The jib was seen to bounce at an angle of nominally 80º and wind speeds between 15 m/s and 20 m/s and the jib was blown back against the 'A' frame at a jib angle above 80º and wind speeds in the region of 8 m/s to 10 m/s from the 'A' frame anemometer and possibly (but not confirmed) in the region of 15 m/s from the jib end anemometer.

This would indicate that the calculation methods given in the four standards provided a reasonable estimate of wind loading on the jib of the crane used in the testing and so may be expected to provide reasonably accurate results when applied to other structures, e.g. other crane jibs and mast sections etc.

8 CONCLUSIONS

8.1 Wind loading calculations according to:

- F.E.M. 1.001 *"Rules for the Design of Hoisting Appliances – Classification and Loading on Structures and Mechanisms"*
- F.E.M. 1.004 *"Heavy Lifting Appliances – Section 1 – Recommendations for the Calculation of Wind Loads on Crane Structures".*
- BS EN 13001 – 2:2004 *"Crane Safety – General Design – Part 2 Load Actions"*
- ISO 4302 *"Cranes – Wind Load Assessment".*

can be used with confidence to provide an estimate of the wind loading on the jib of the luffing crane used in this testing and may therefore be used to predict combinations of jib angle/wind speed when uncontrolled movement of the jib may be expected.

8.1.1 Consequently, they may be expected to provide reasonably accurate results when applied to other structures, e.g. other crane jibs and mast sections etc.

8.2 The jib of the crane used in testing at HSL was proven by calculation and testing to be susceptible to uncontrolled movement arising from wind loading below the maximum in service wind speed and at jib elevations within the normal maximum and minimum radius quoted by the manufacturer

8.3 This information could be used to offer more protection against uncontrolled movement of a luffing crane jib than simply "winding off" or not operating a luffing crane in conditions where the maximum in service wind speed is experienced

8.4 Wind speed readings obtained from an anemometer mounted on the 'A' frame of a luffing tower crane may not, on occasion, be an accurate representation of the wind speed being experienced by other parts of the crane structure, e.g. the outer end of the jib. This may give rise to unintentional operation of the crane at wind speeds approaching or perhaps exceeding the maximum in service wind speed.

8.5 The guarding against slack rope conditions originally fitted to the crane when first erected at HSL was ineffective in preventing the luffing rope from leaving the groove of one of the 'A' frame pulleys.

8.5.1 The modifications to the spring buffer arrangement introduced by Jaso following the jib blow back event during testing of the J80 PA crane at HSL were successful in preventing uncontrolled movement of the crane jib at its maximum elevation (minimum radius) under high wind conditions.

8.5.2 Similar modifications were introduced for other luffing tower cranes in the manufacturer's portfolio and these were implemented by Falcon Crane Hire on their fleet of cranes in the U.K. by 2011.

9 REFERENCES

1. Manual del Fabricante (Manufacturer's Handbook) J 80 PA.
Jaso Equipos de Obras Y Construcciones S.L. Issue dated 24 November 2003

2. Federation Europeene de la Manutention FEM 1.001 3rd Edition revised 1 October 1998. Section 1 Heavy Lifting Appliances "Rules for the Design of Hoisting Appliances Booklet 2 Classification and Loading on Structures and Mechanisms".

3. Federation Europeene de la Manutention FEM 1.004 30 July 2000. Section 1 Heavy Lifting Appliances "Recommendation for the Calculation of Wind Loads on Crane Structures".

4. International Standard ISO 4302 "Cranes – Wind load assessment" First edition 15 May 1981. Reference number ISO 4302 – 1981(E)

5. British Standard BS EN 13001 – 2:2004 "Crane Safety – General Design – Part 2: Load Actions. Dated December 2004.

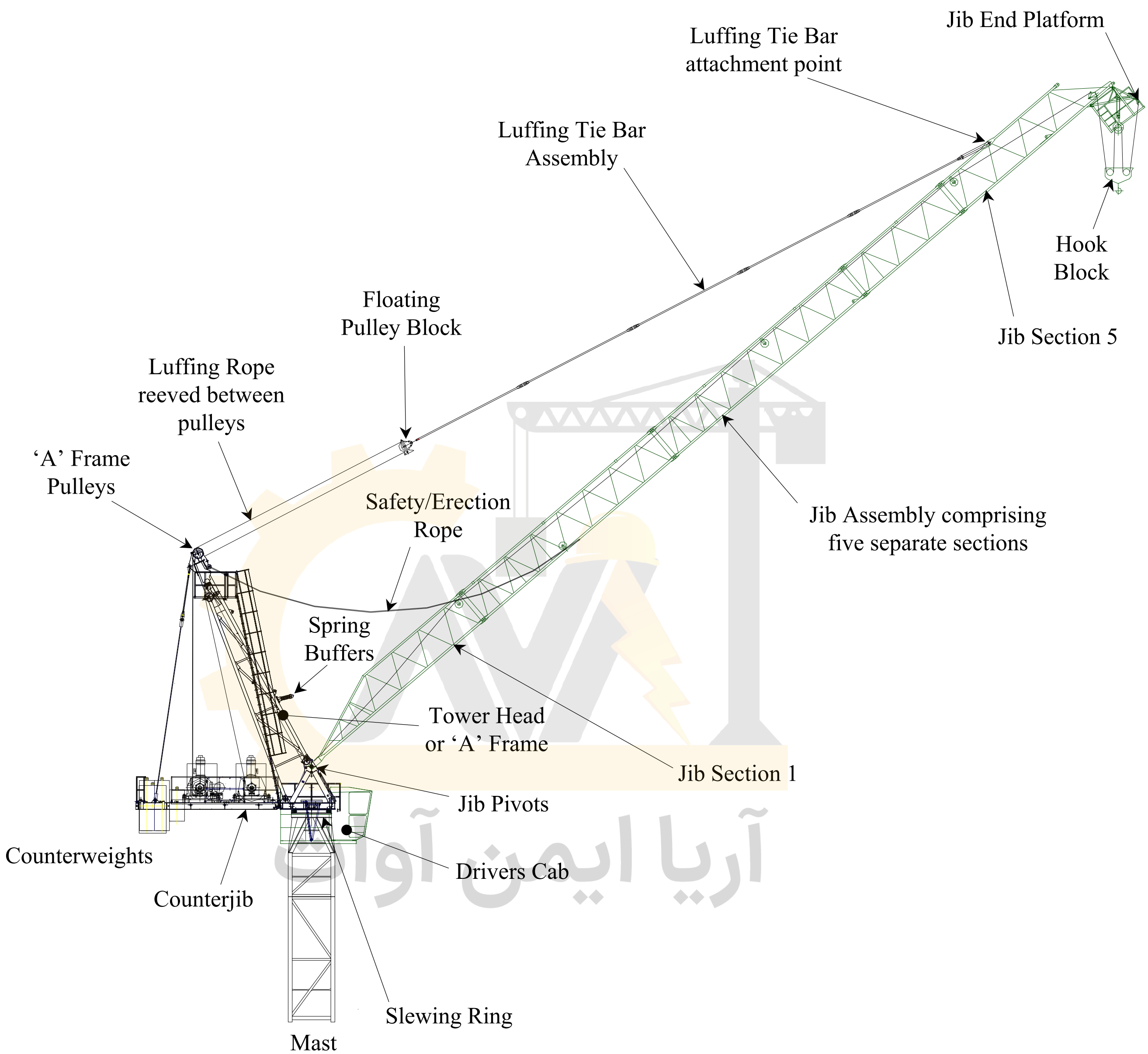


Figure 1 - Sketch (not to scale) showing the main features and nomenclature of the crane

Figure 2 – General View of the Crane erected at HSL

HSL VPS Photograph 1004014_058.jpg (cropped)

Figure 3 – Crane at Minimum radius and gap between Jib Section 1 Top Chord and Spring Buffers

Richard Isherwood Photographs P2150099.jpg (cropped) and P2150096.jpg

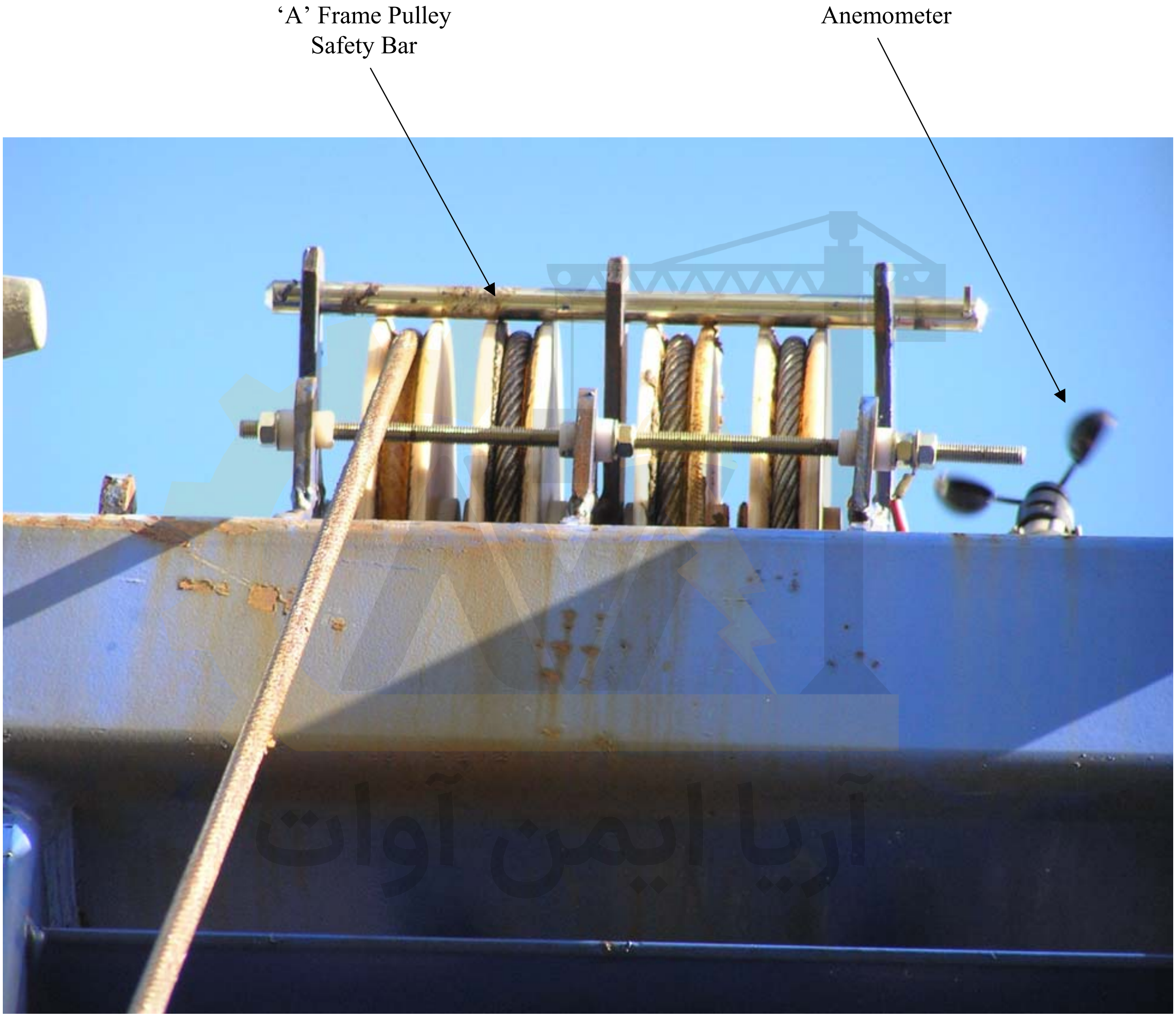


Figure 4 – 'A' Frame Pulley Safety Bar and Anemometer fitted to the 'A' frame

Richard Isherwood Photograph PB170064.jpg

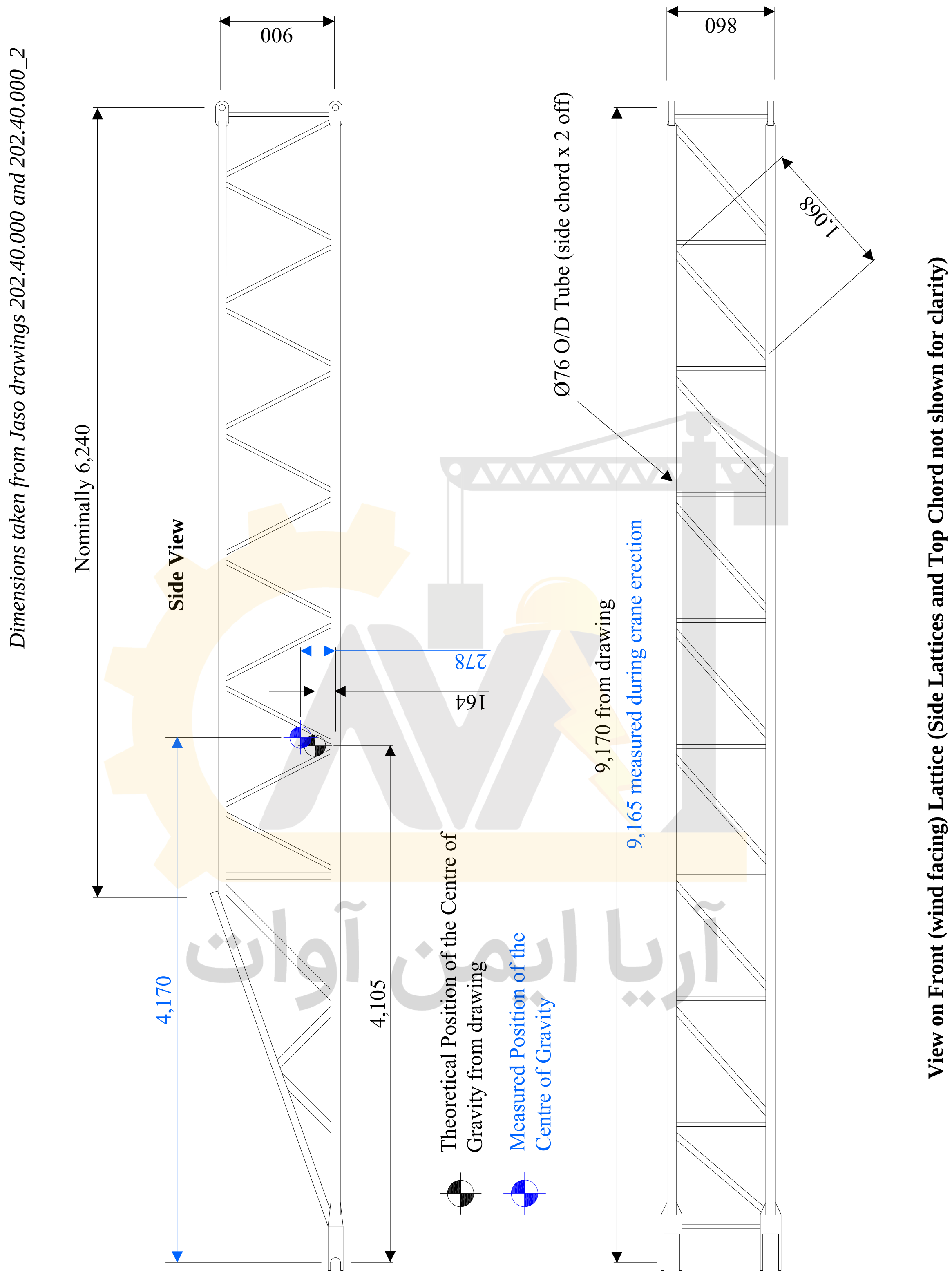


Figure 5 – Sketch of Jib Section 1 (not to scale) showing principal dimensions and positions of Centre of Gravity (dimensions in mm)

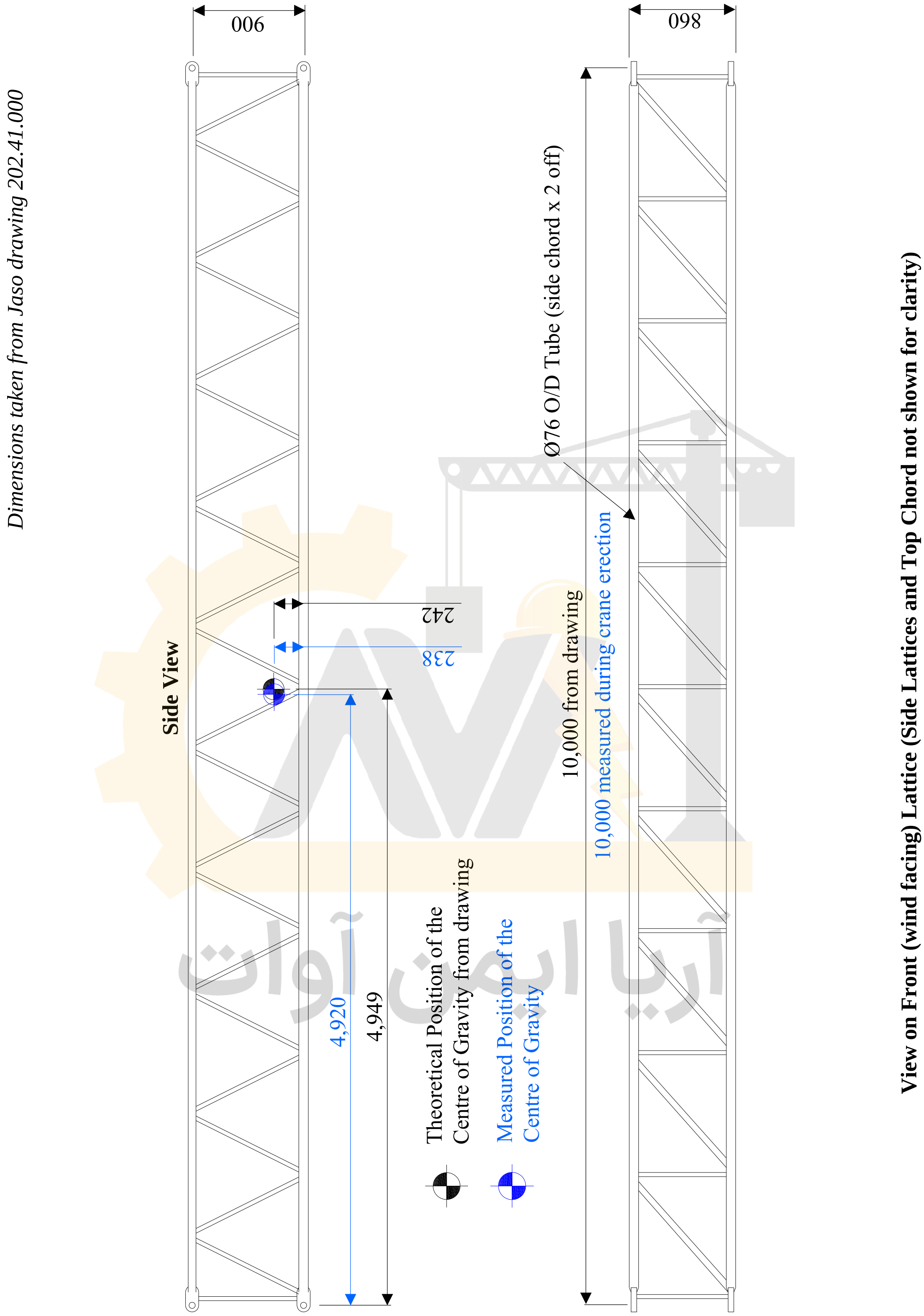


Figure 6 – Sketch of Jib Section 2 (not to scale) showing principal dimensions and positions of Centre of Gravity (dimensions in mm)

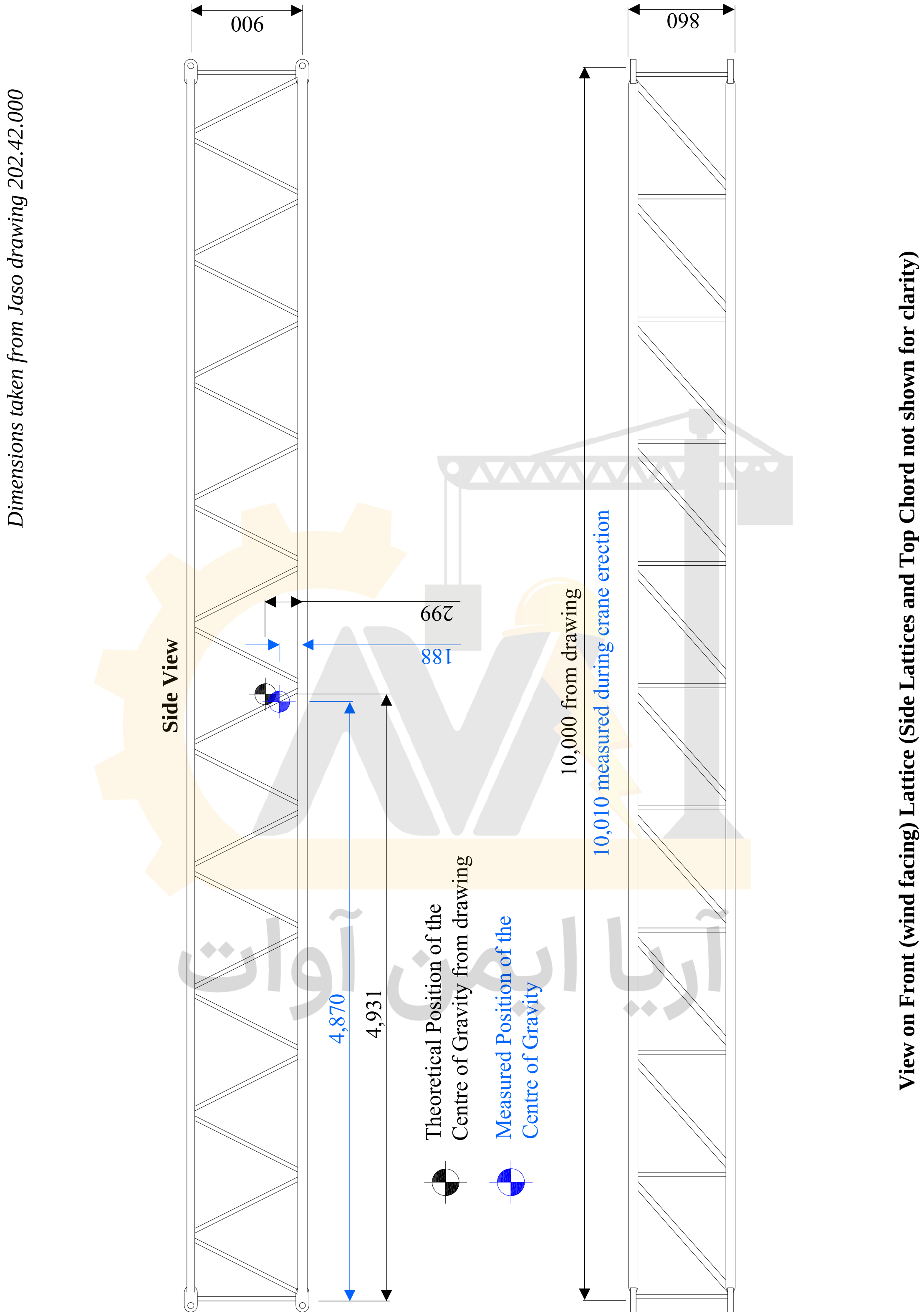


Figure 7 – Sketch of Jib Section 3 (not to scale) showing principal dimensions and positions of Centre of Gravity (dimensions in mm)

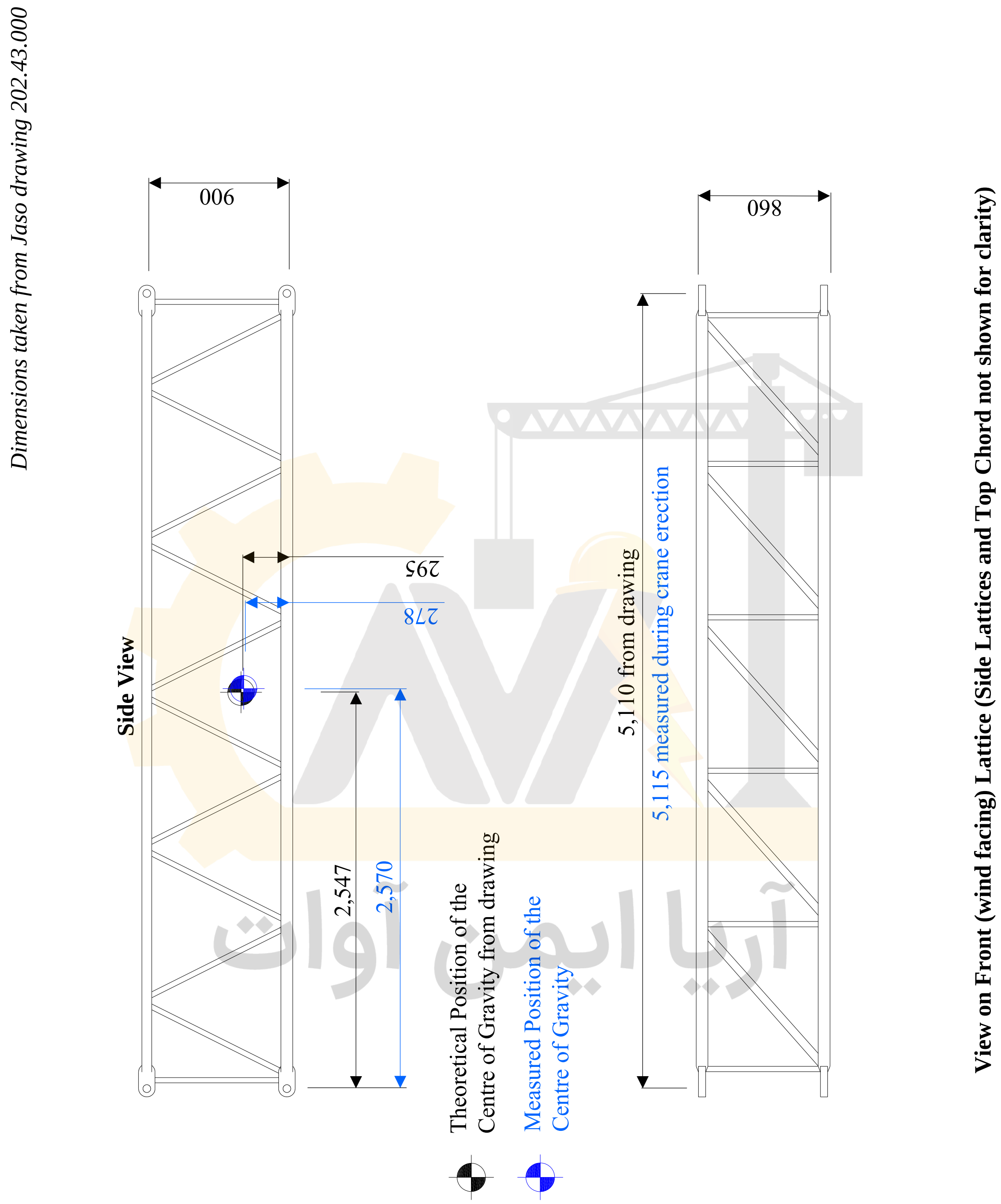


Figure 8 – Sketch of Jib Section 4 (not to scale) showing principal dimensions and positions of Centre of Gravity (dimensions in mm)

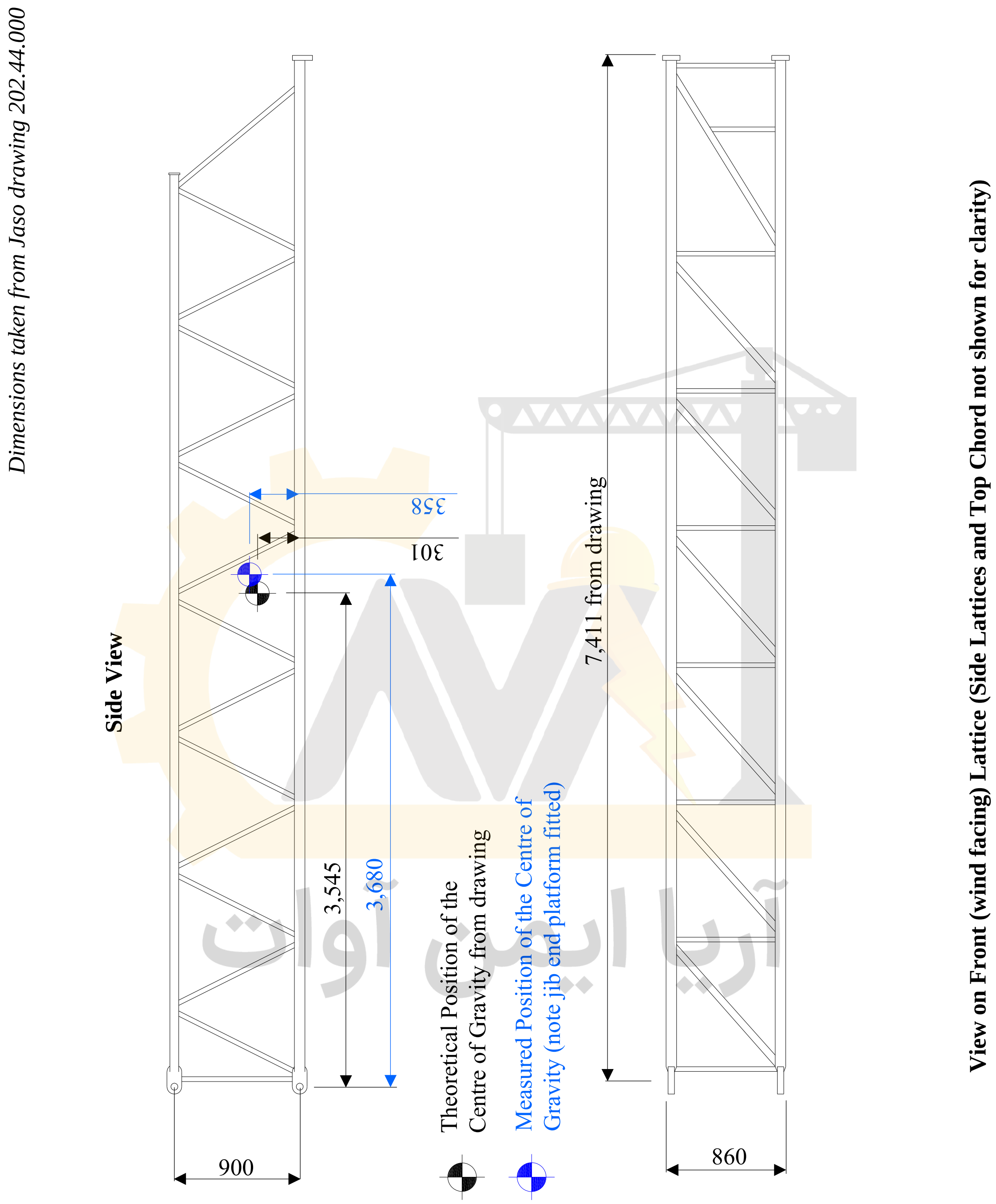


Figure 9 – Sketch of Jib Section 5 (not to scale) showing principal dimensions and positions of Centre of Gravity (dimensions in mm)

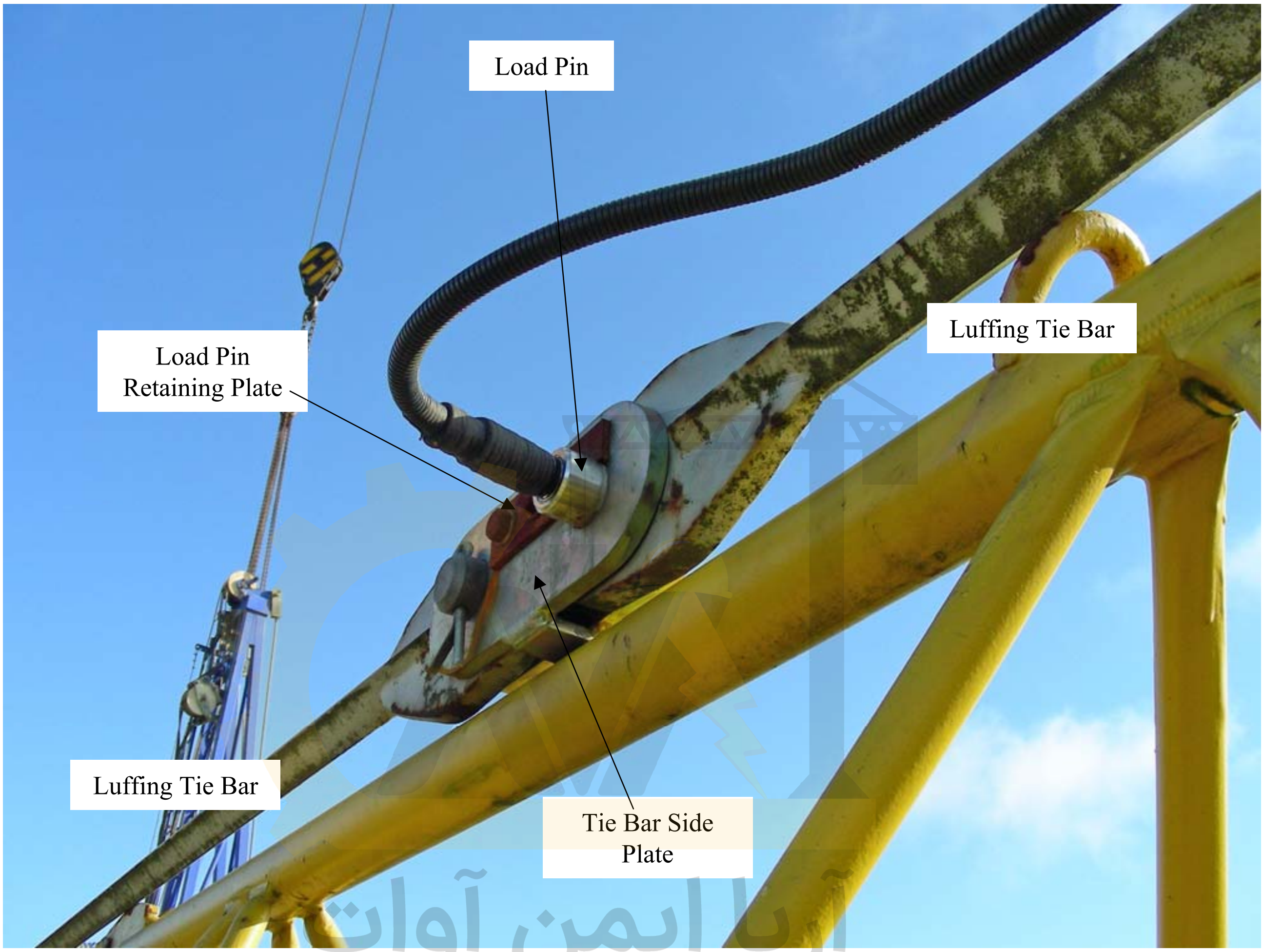


Figure 10 – Load Pin fitted in the Luffing Tie Bar Assembly

Richard Isherwood Photograph DSCN0642 lightened.jpg

Figure 11a – General View of HSL Anemometer and Weather Vane fitted at the outer end of Jib Section 5

HSL VPS Photograph 1004014_079.jpg

Figure 11b – Close up of HSL Anemometer and Weather Vane fitted at the outer end of Jib Section 5

Richard Isherwood Photograph DSCN0638.jpg

Figure 12a – Crane Inclinometer fitted close to the pivot end of Jib Section 1

Richard Isherwood Photograph P9220085.jpg

Figure 12b – HSL Inclinometer fitted close to the Crane Inclinometer

Richard Isherwood Photograph P9220084.jpg

Figure 13 – Data Logger Installed in the Cab of the Crane

Richard Isherwood Photograph P9220075.jpg

Figure 14a – General view of the Luffing Rope out of the groove of the third 'A' Frame Pulley from the left

Richard Isherwood Photograph PB170062.jpg

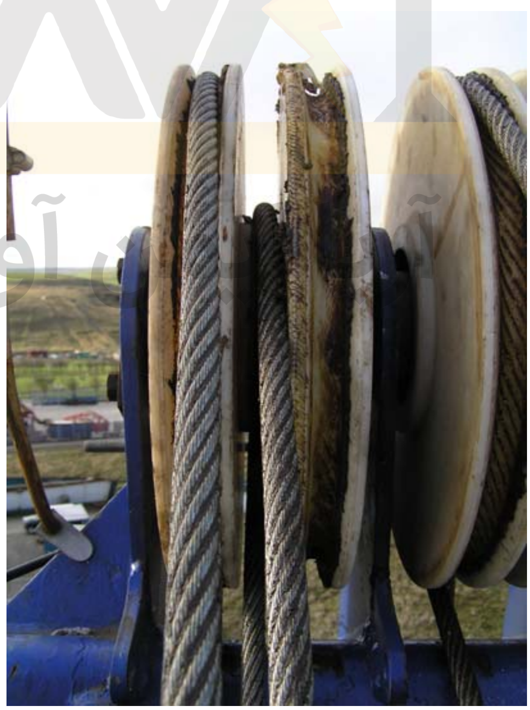


Figure 14b – Detail of the Luffing Rope out of the groove of the third 'A' Frame Pulley from the left (photograph is taken from the opposite side to that of Figure 11a)

Photograph PB170058.jpg (rotated) taken by Mr Gary Potter of Falcon Crane Hire

Figure 15 – Damage by way of “kinking” to the Luffing Rope

Photograph PB170060.jpg taken by Mr Gary Potter of Falcon Crane Hire

Figure 16 – Damage to 'A' Frame Pulley after the Luffing Rope had left the groove

Richard Isherwood Photograph PB25068 adjusted.jpg

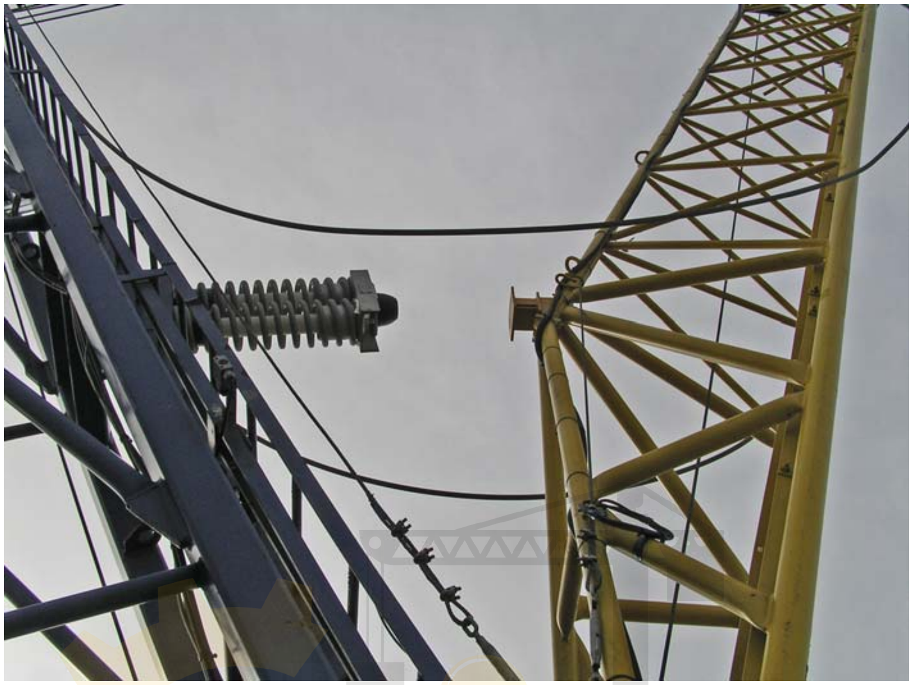


Figure 17a – Longer Springs in the Spring Buffer and Jib "make up piece"

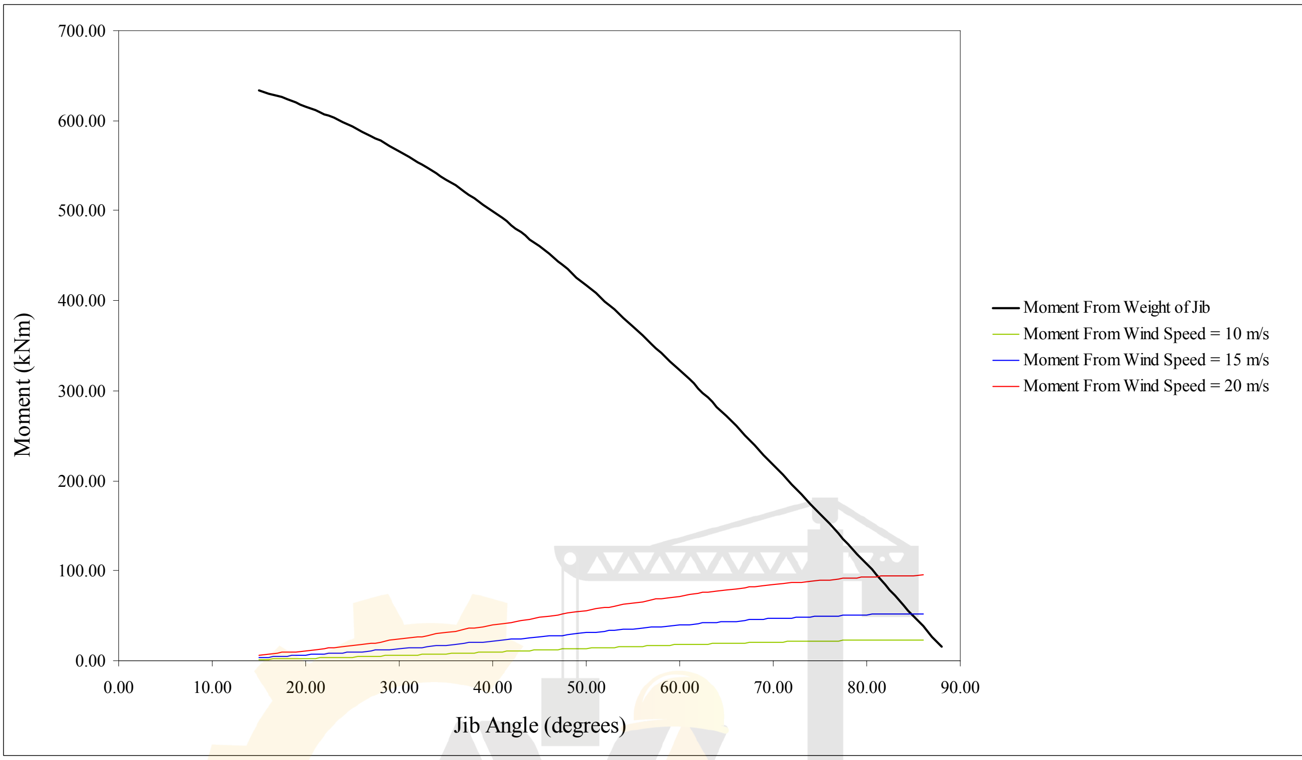
Richard Isherwood Photograph PB3030103 lightness adjusted.jpg

Figure 17b – Jib "make up piece" just starting to contact the longer springs in the Spring Buffer at a jib angle of nominally 80º

Richard Isherwood Photograph PB3030105.jpg

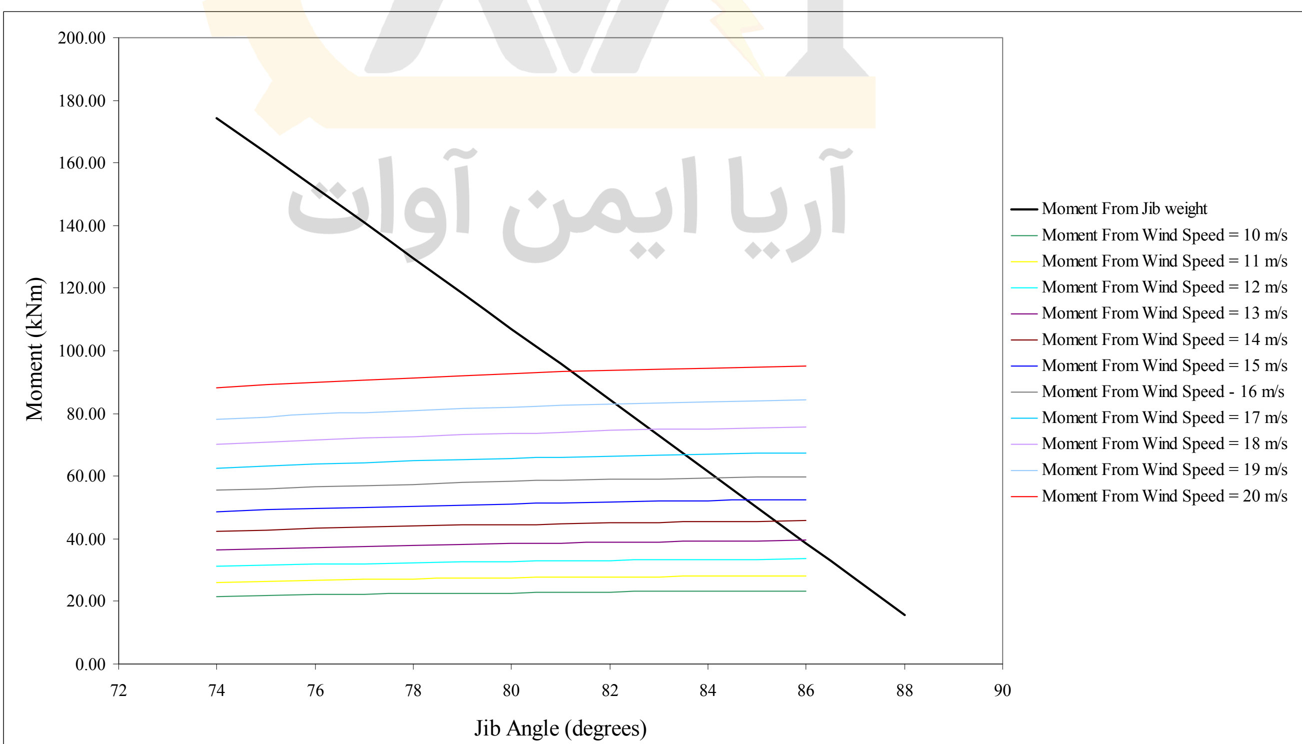
Figure 17c –Compression of the longer springs in the Spring Buffer at a jib angle of nominally 86º

Richard Isherwood Photograph PB3030107.jpg



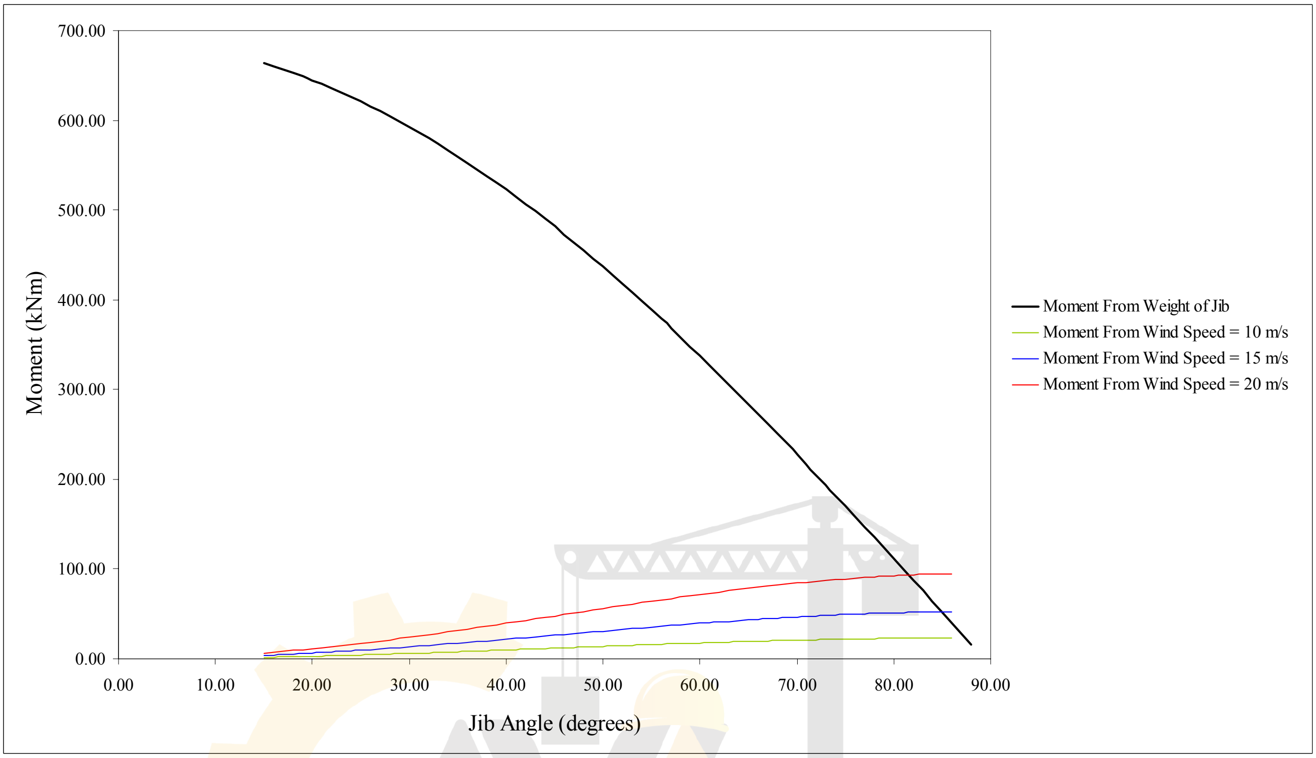
Graph 1 – Moment against Jib Angle for different wind speeds

FEM 1.001 Theoretical Jib Properties



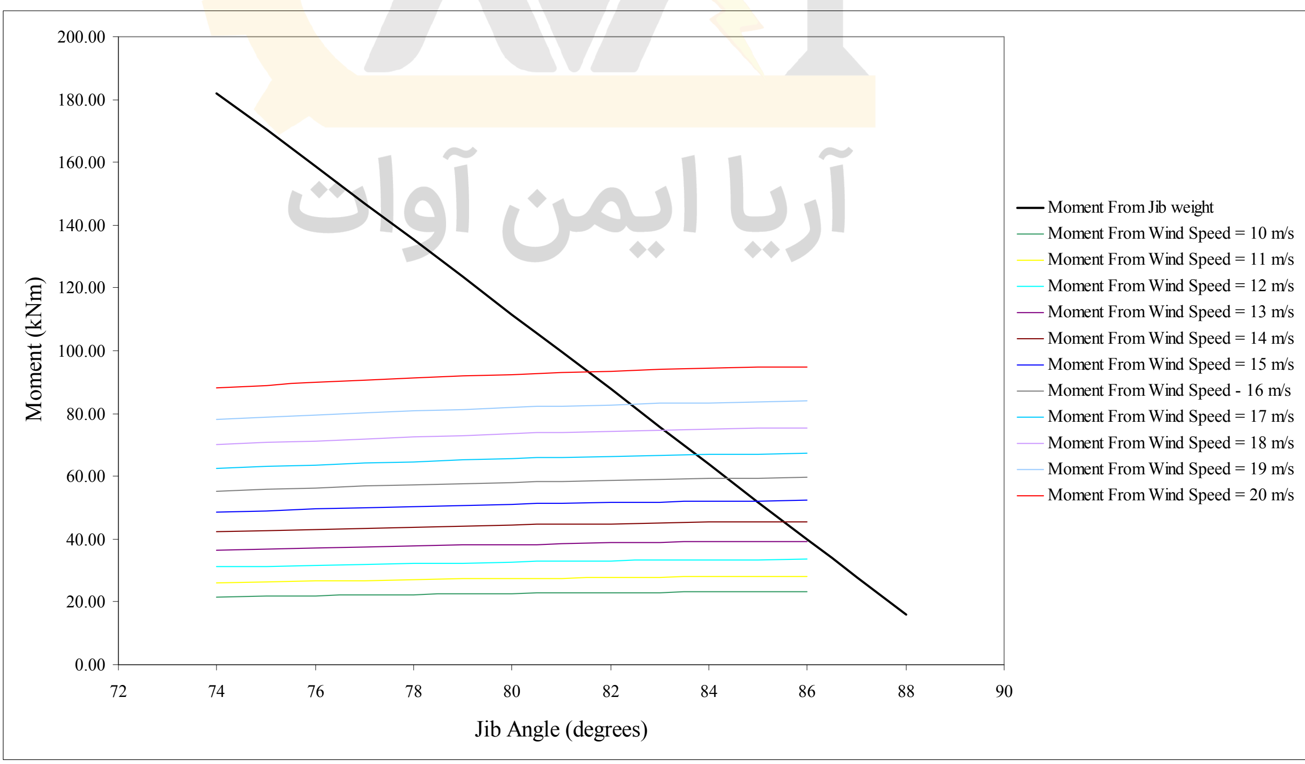
Graph 1a – Moment against Jib Angle for different wind speeds (detail)

FEM 1.001 Theoretical Jib Properties



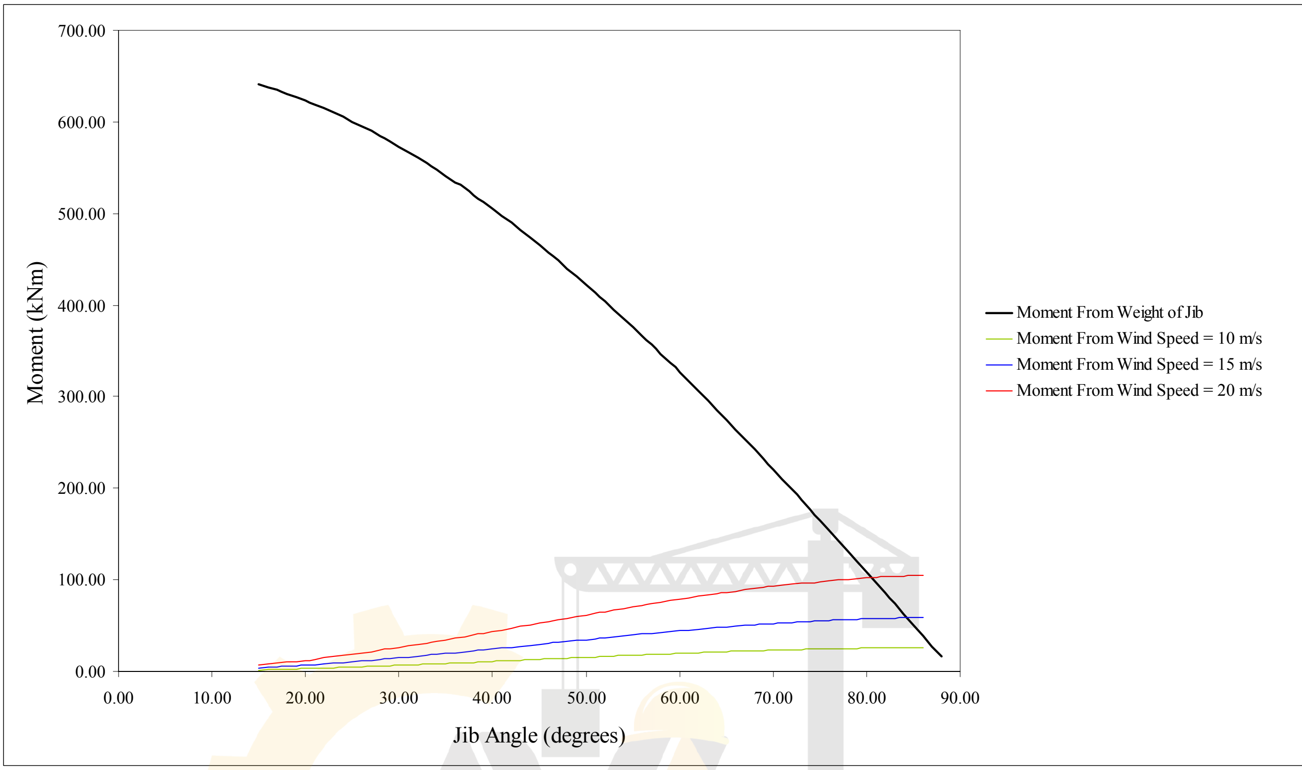
Graph 2 – Moment against Jib Angle for different wind speeds

FEM 1.001 Measured Jib Properties



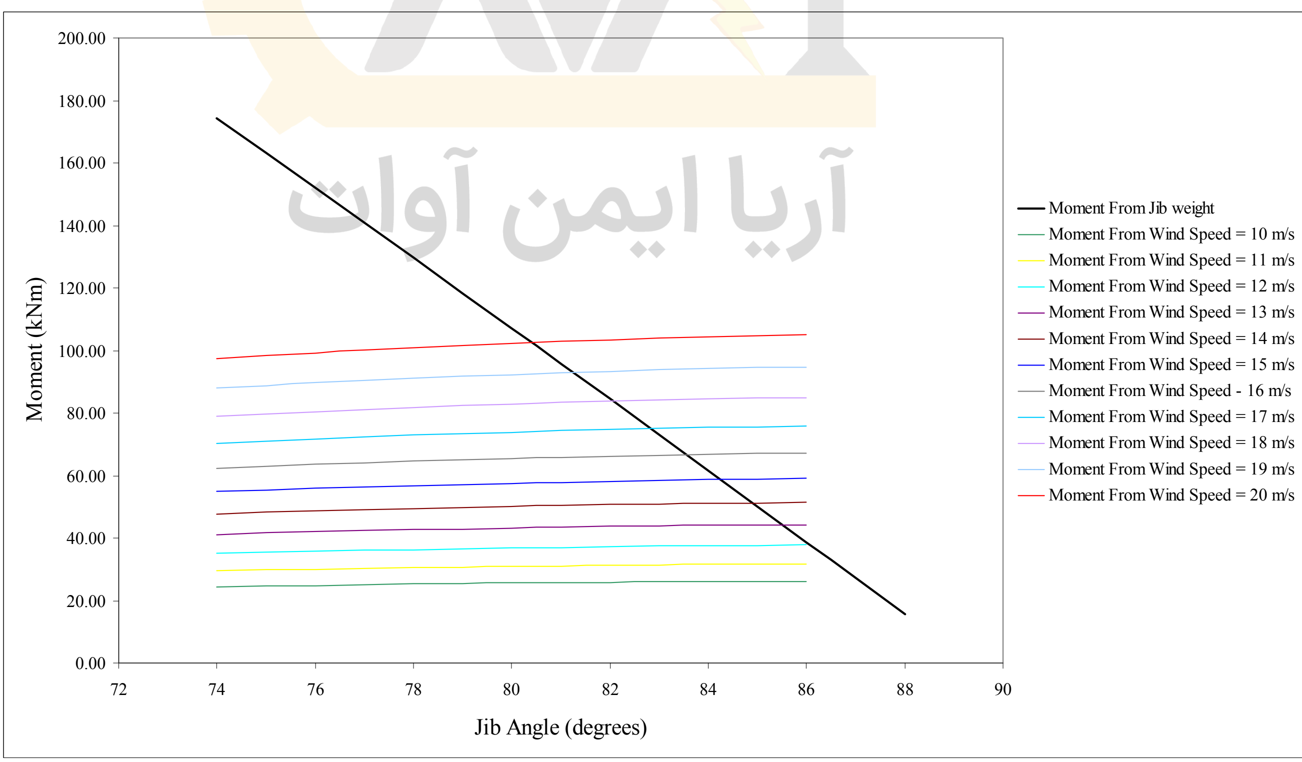
Graph 2a – Moment against Jib Angle for different wind speeds (detail)

FEM 1.001 Measured Jib Properties



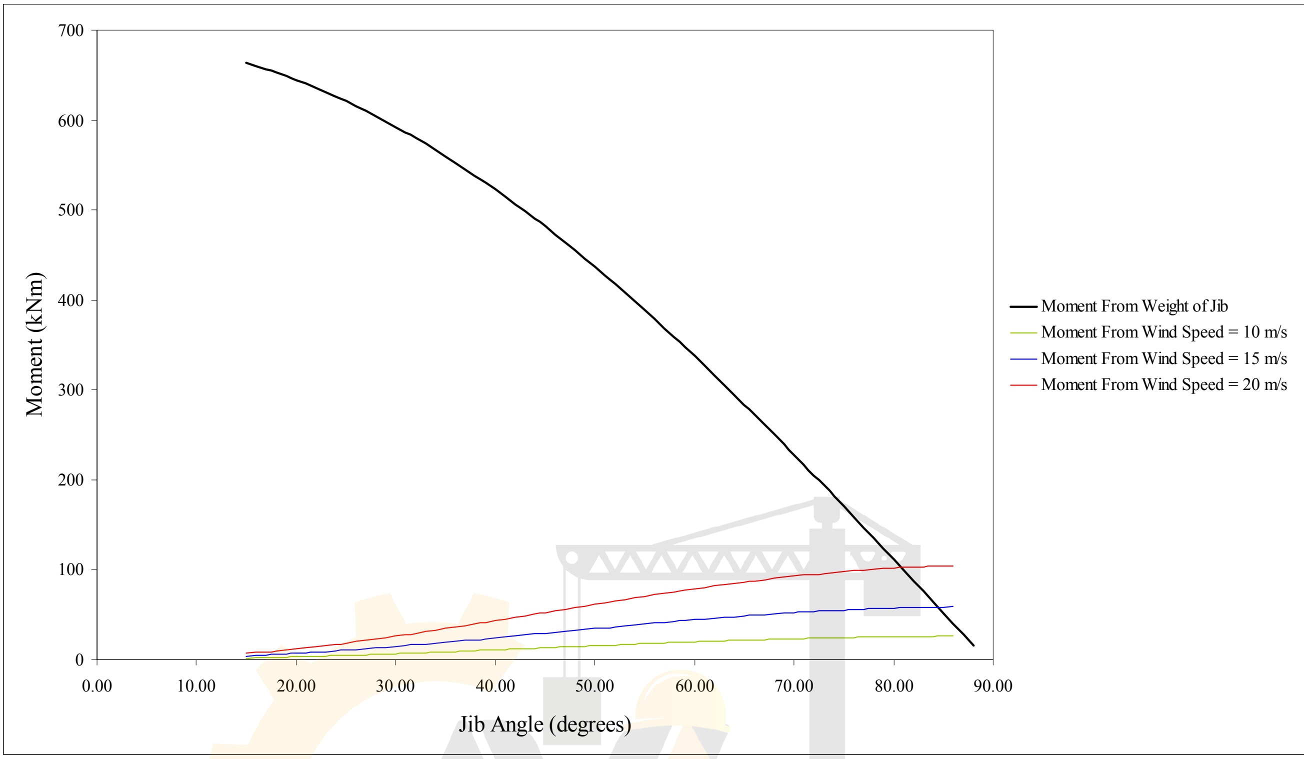
Graph 3 – Moment against Jib Angle for different wind speeds

FEM 1.004 Theoretical Jib Properties



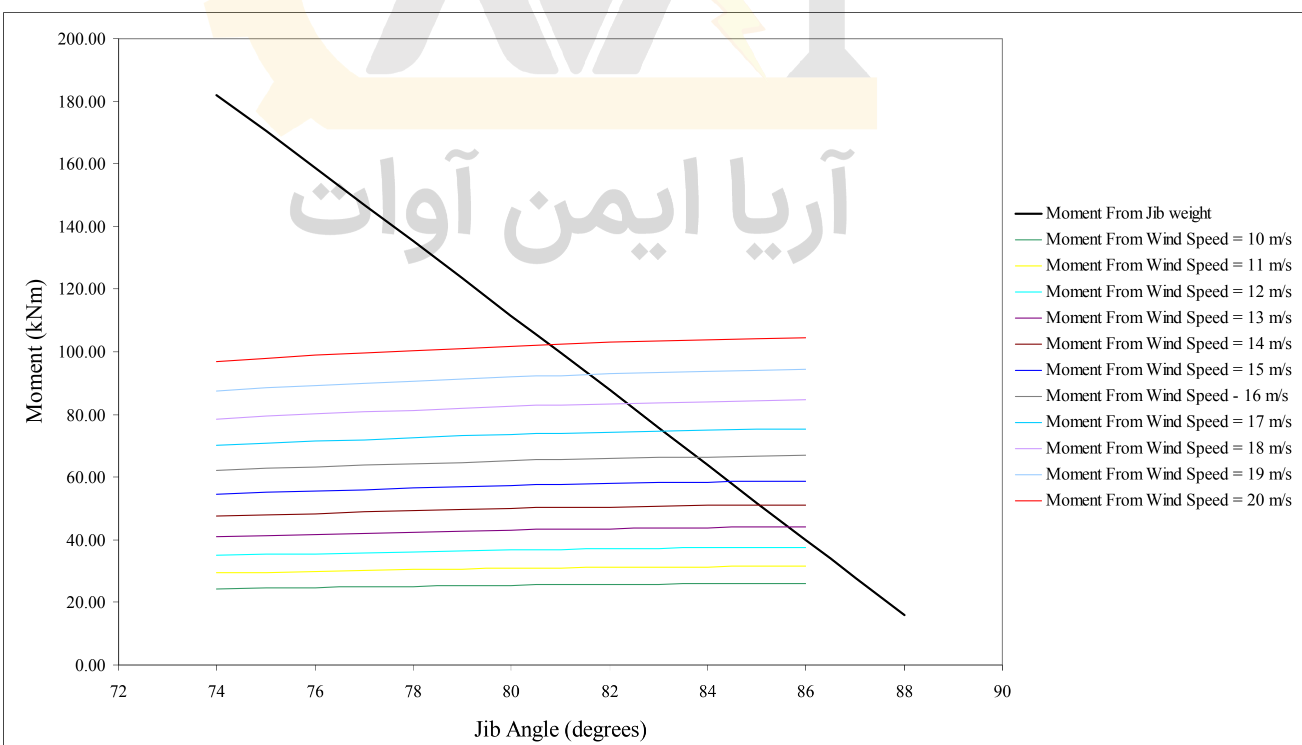
Graph 3a – Moment against Jib Angle for different wind speeds (detail)

FEM 1.004 Theoretical Jib Properties



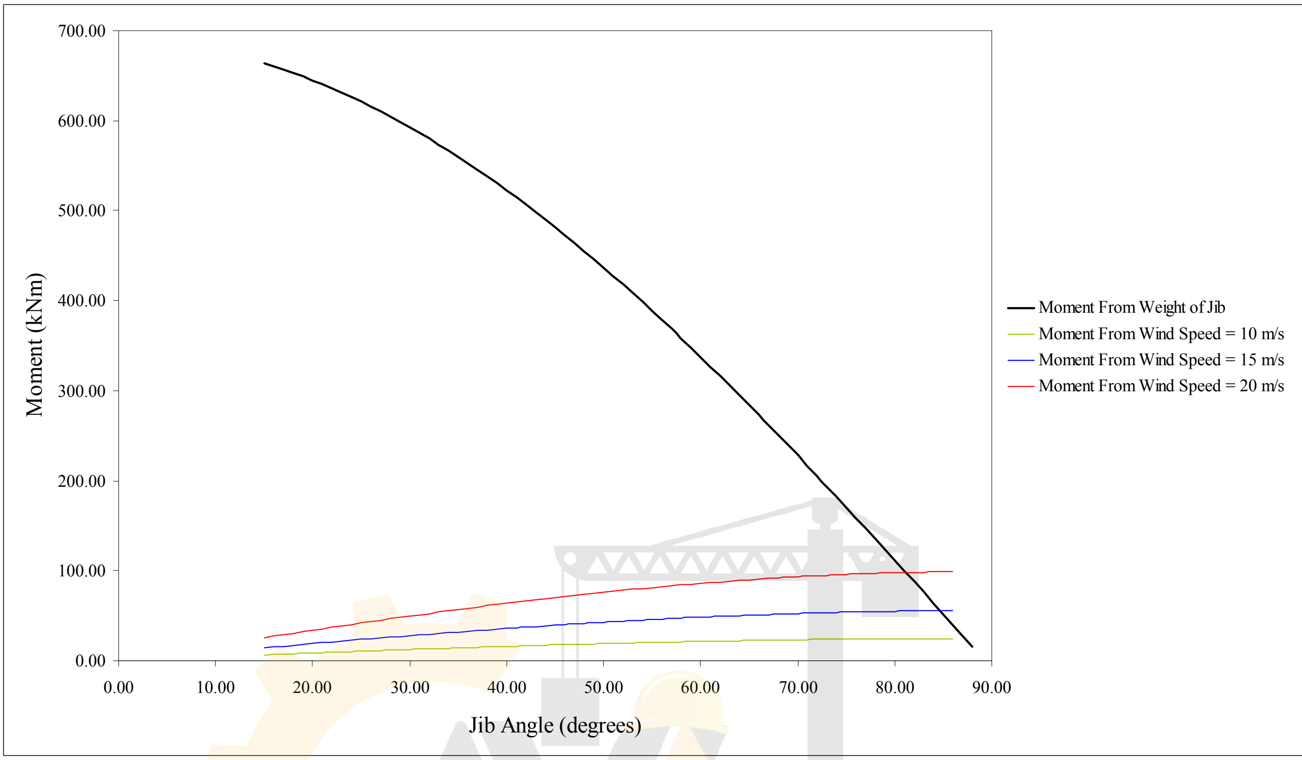
Graph 4 – Moment against Jib Angle for different wind speeds

FEM 1.004 Measured Jib Properties



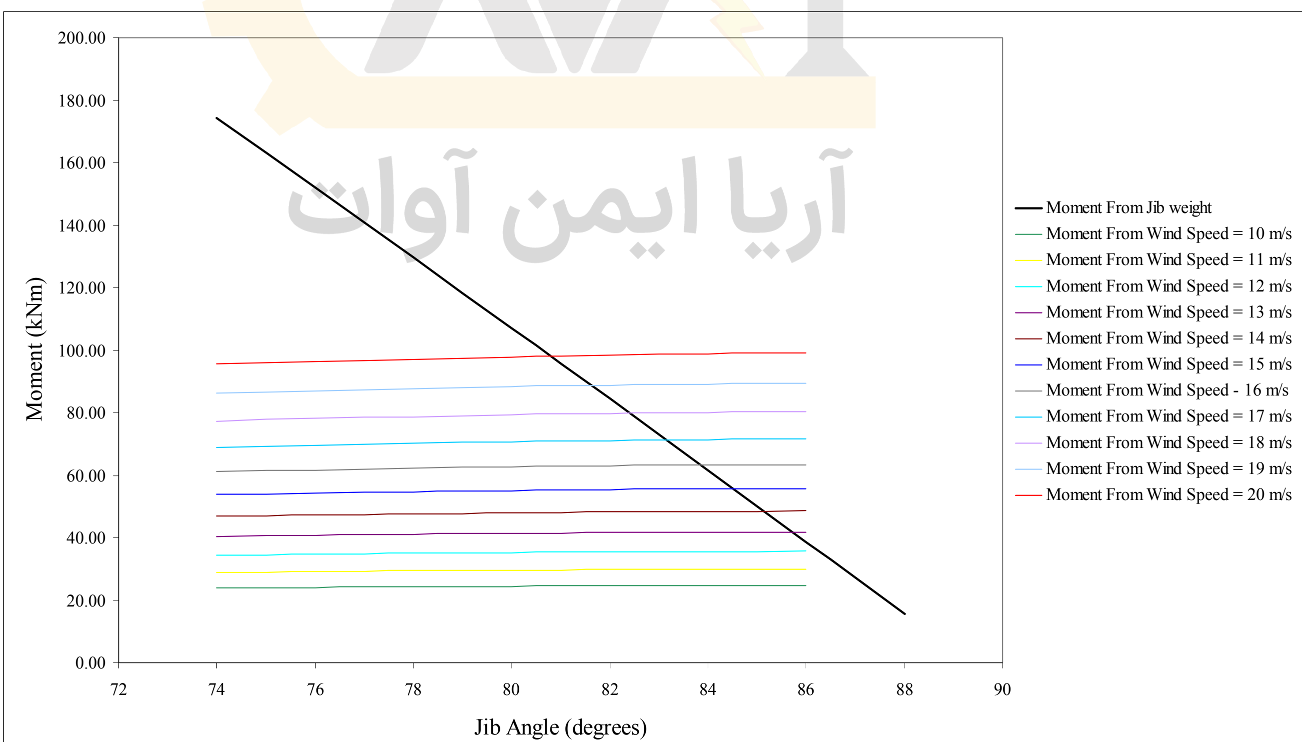
Graph 4a – Moment against Jib Angle for different wind speeds (detail)

FEM 1.004 Measured Jib Properties



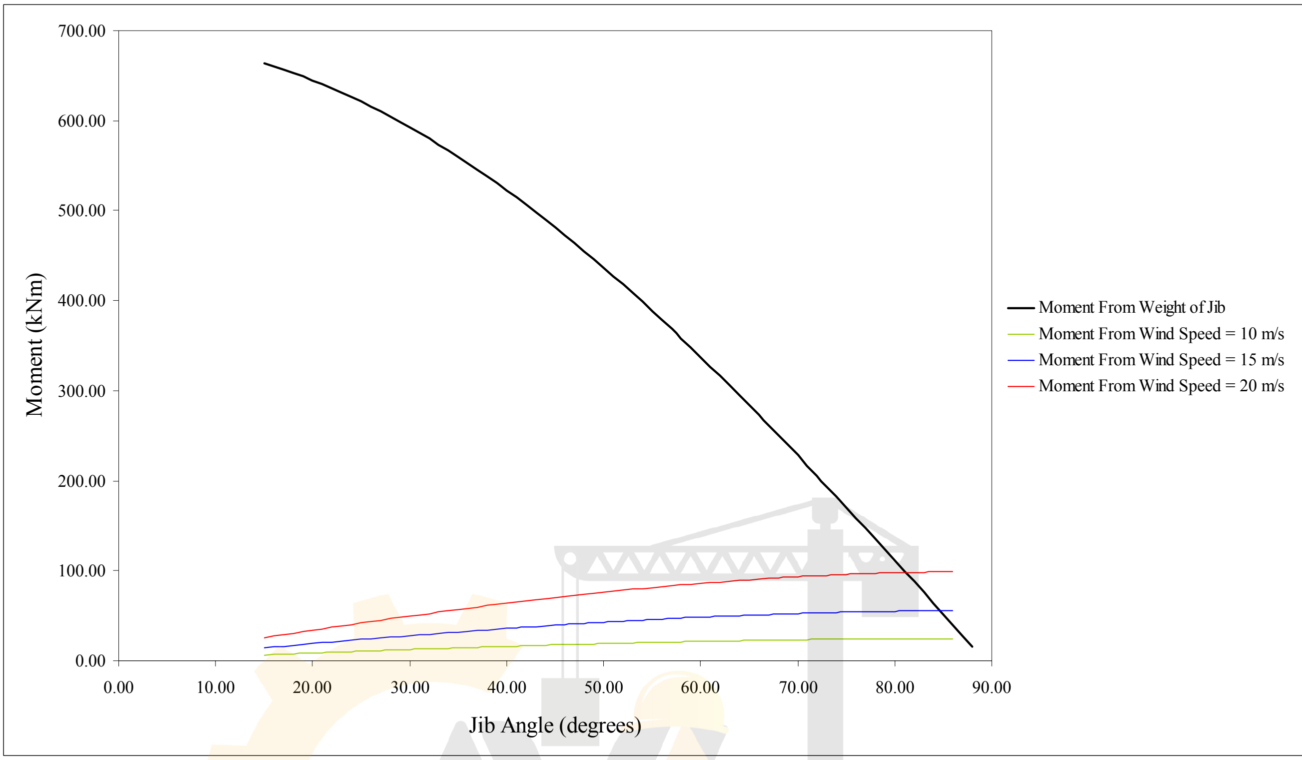
Graph 5 – Moment against Jib Angle for different wind speeds

BS EN 13001 – 2:2004 Theoretical Jib Properties



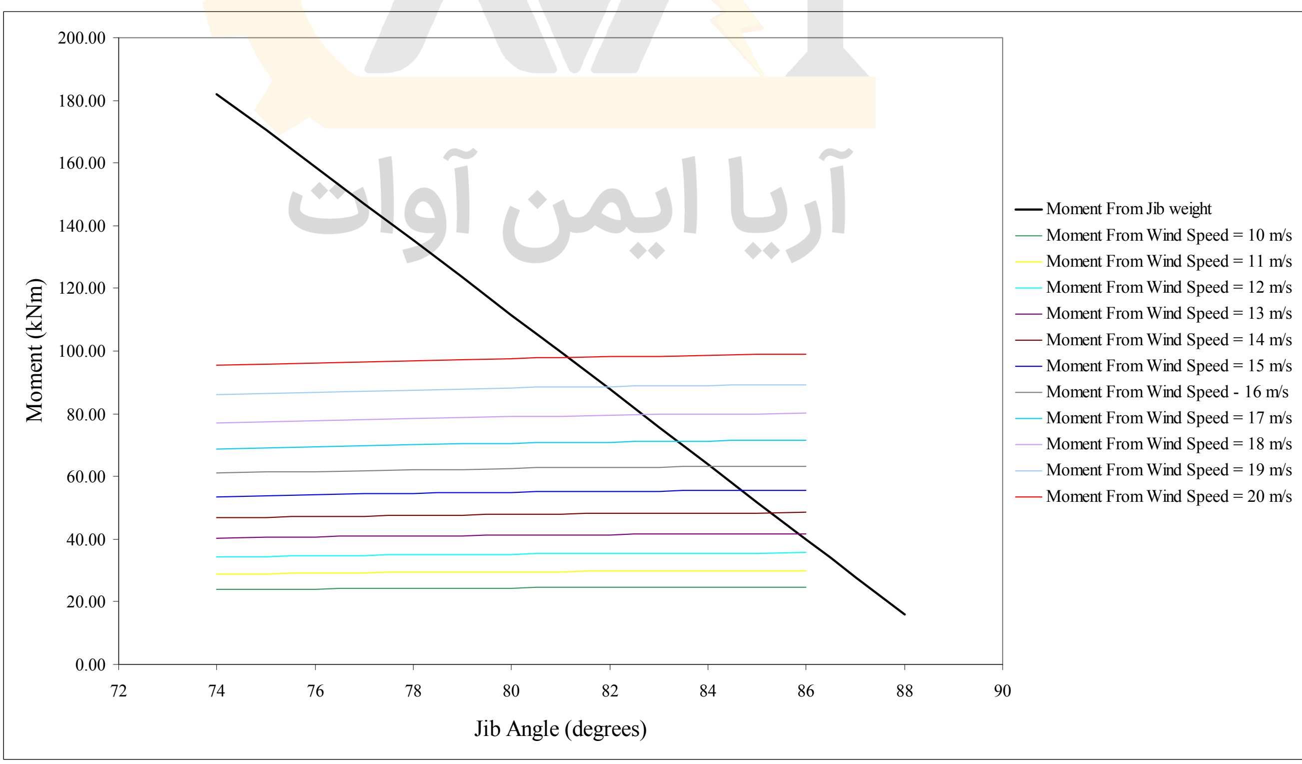
Graph 5a – Moment against Jib Angle for different wind speeds (detail)

BS EN 13001 – 2:2004 Theoretical Jib Properties



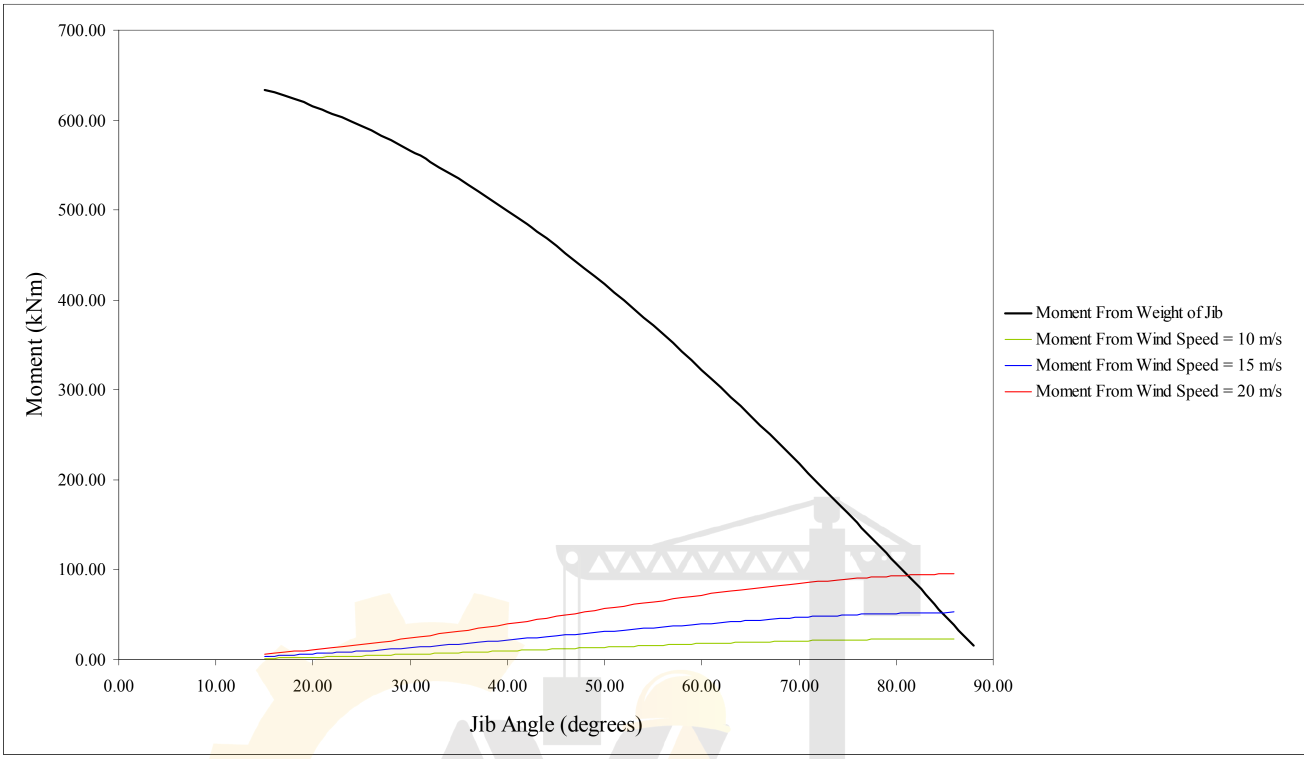
Graph 6 – Moment against Jib Angle for different wind speeds

BS EN 13001 – 2:2004 Measured Jib Properties



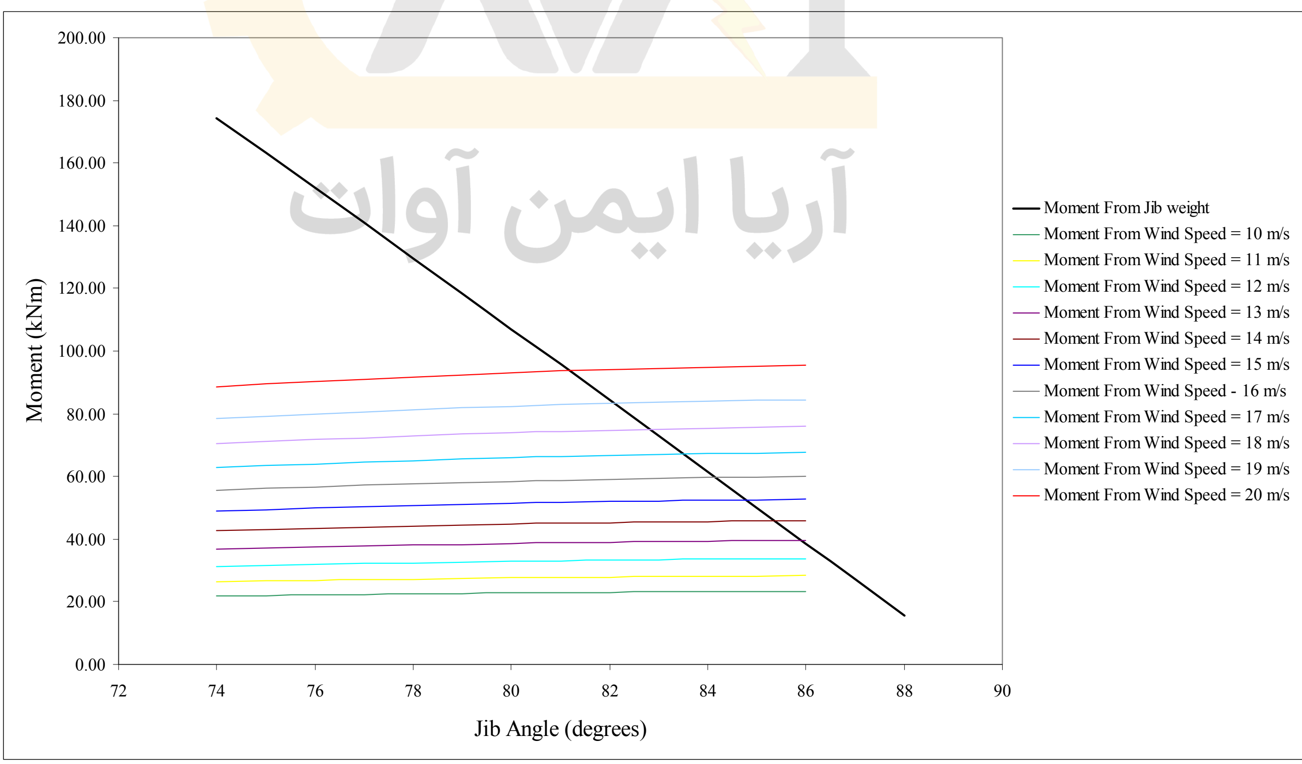
Graph 6a – Moment against Jib Angle for different wind speeds (detail)

BS EN 13001 – 2:2004 Measured Jib Properties



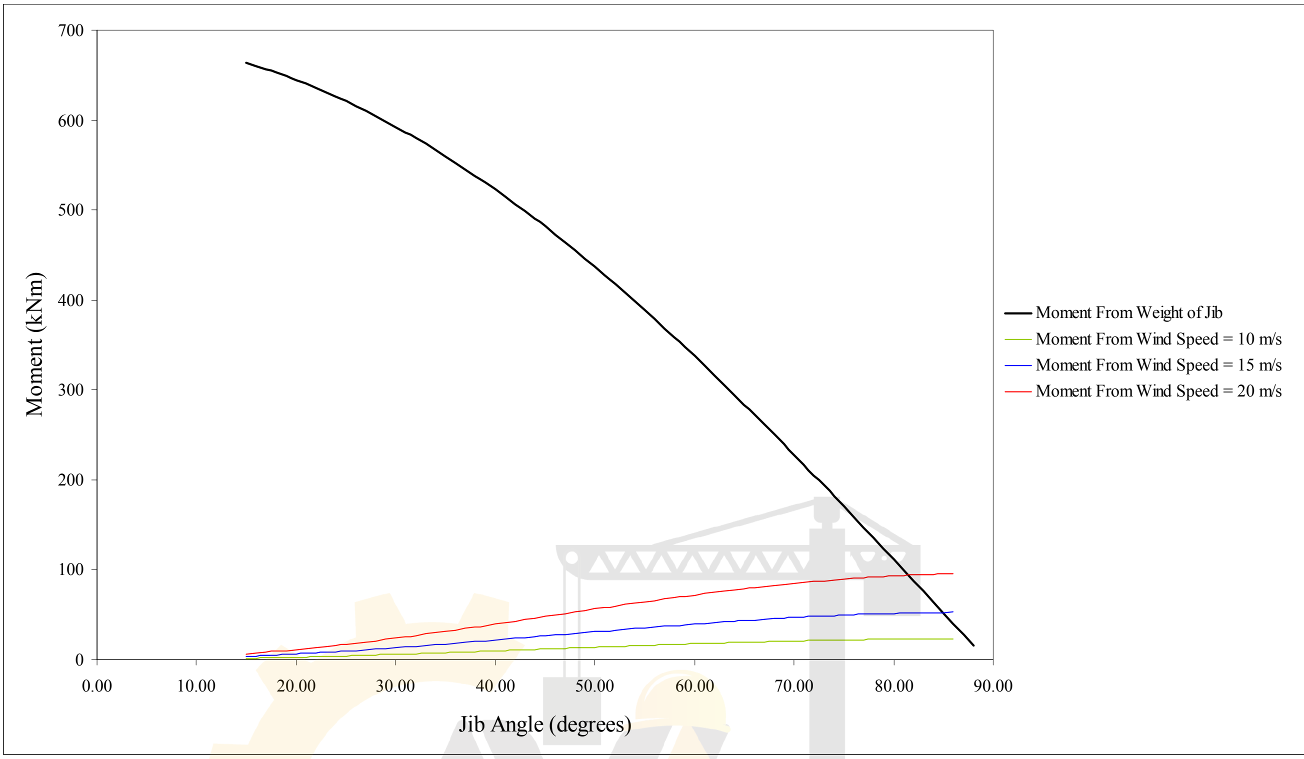
Graph 7 – Moment against Jib Angle for different wind speeds

ISO 4302 Theoretical Jib Properties



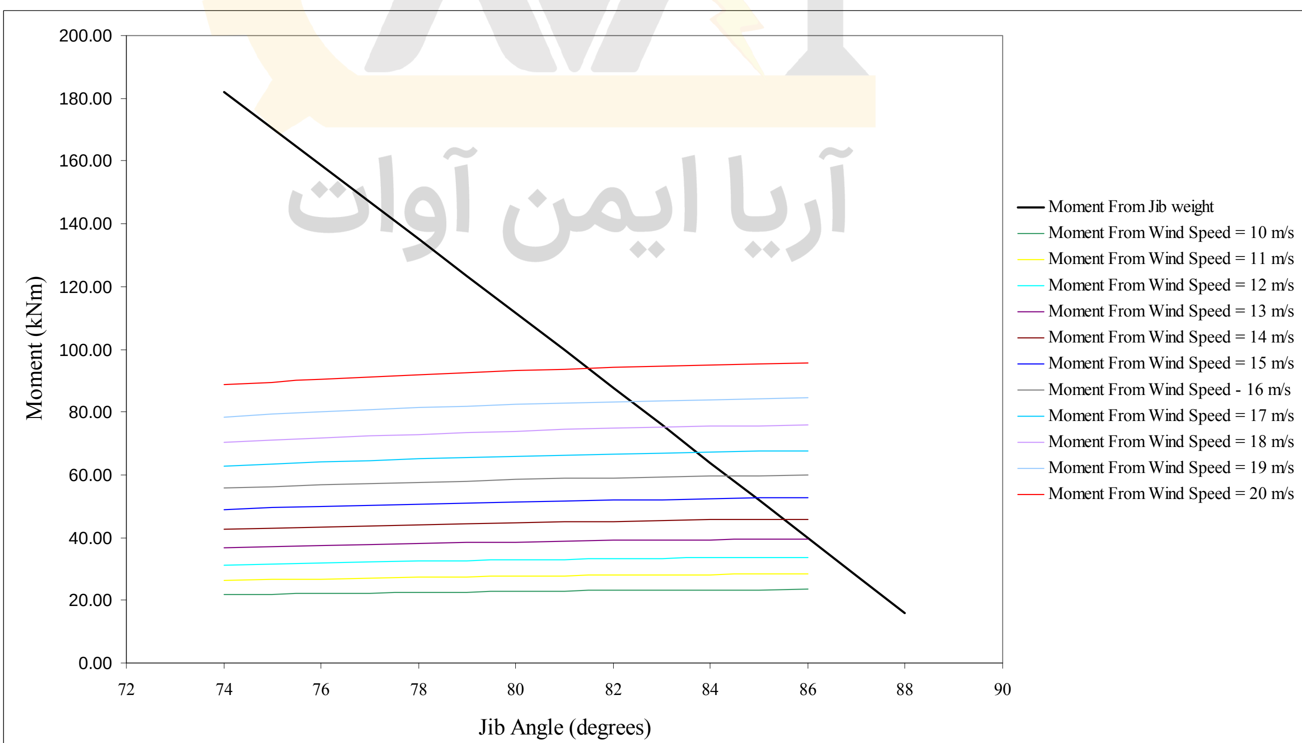
Graph 7a – Moment against Jib Angle for different wind speeds (detail)

ISO 4302 Theoretical Jib Properties



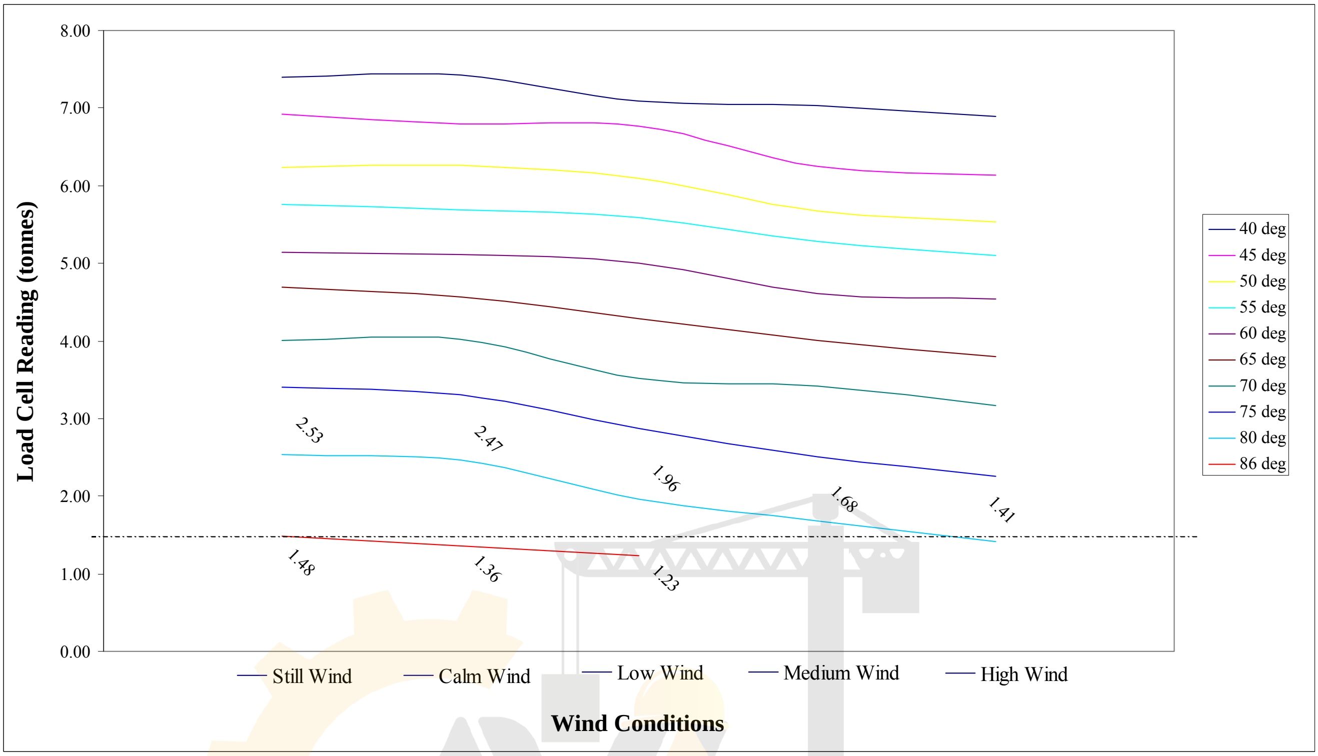
Graph 8 – Moment against Jib Angle for different wind speeds

ISO 4302 Measured Jib Properties

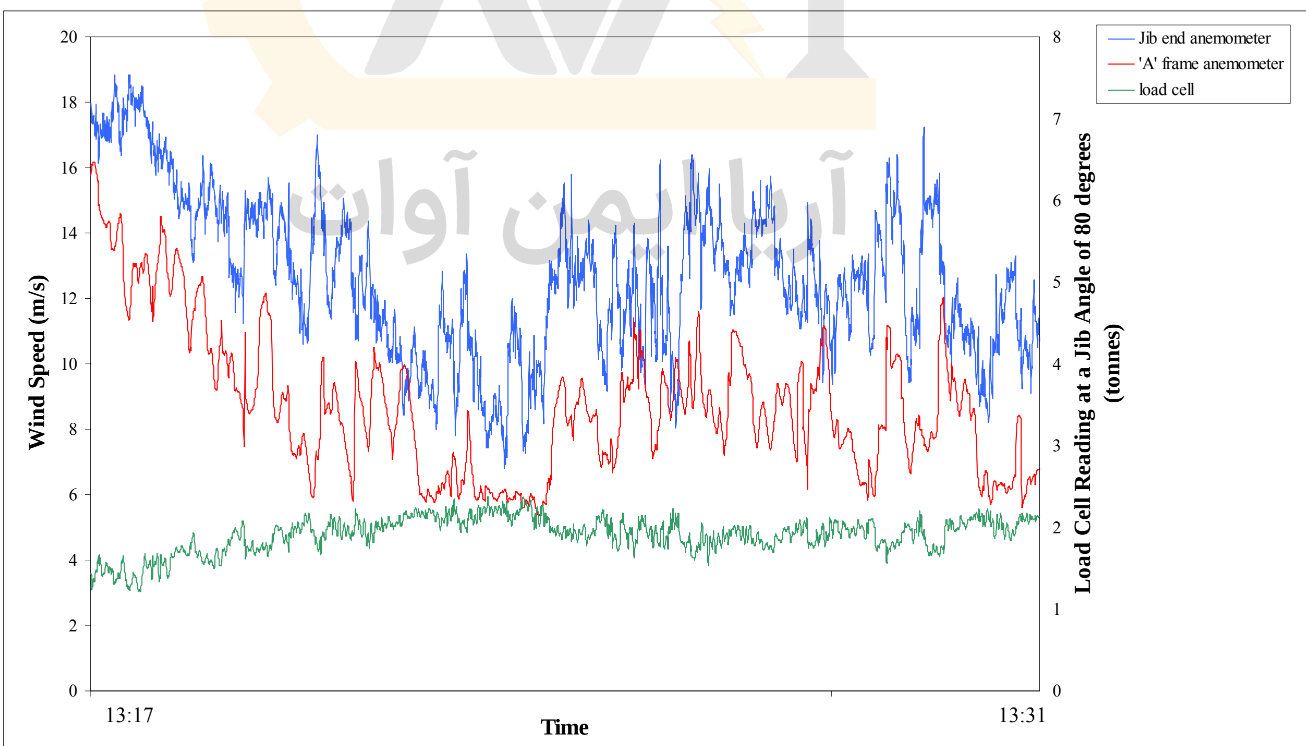


Graph 8a – Moment against Jib Angle for different wind speeds (detail)

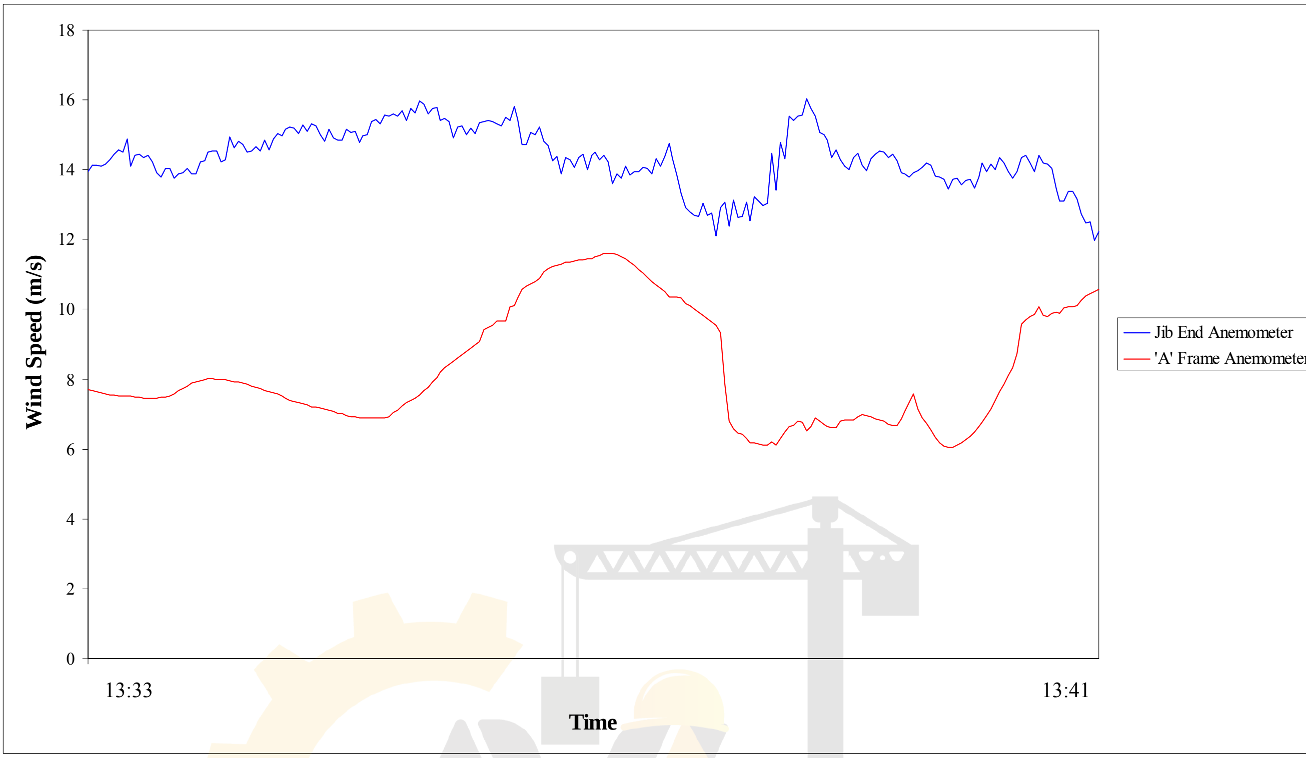
ISO 4302 Measured Jib Properties



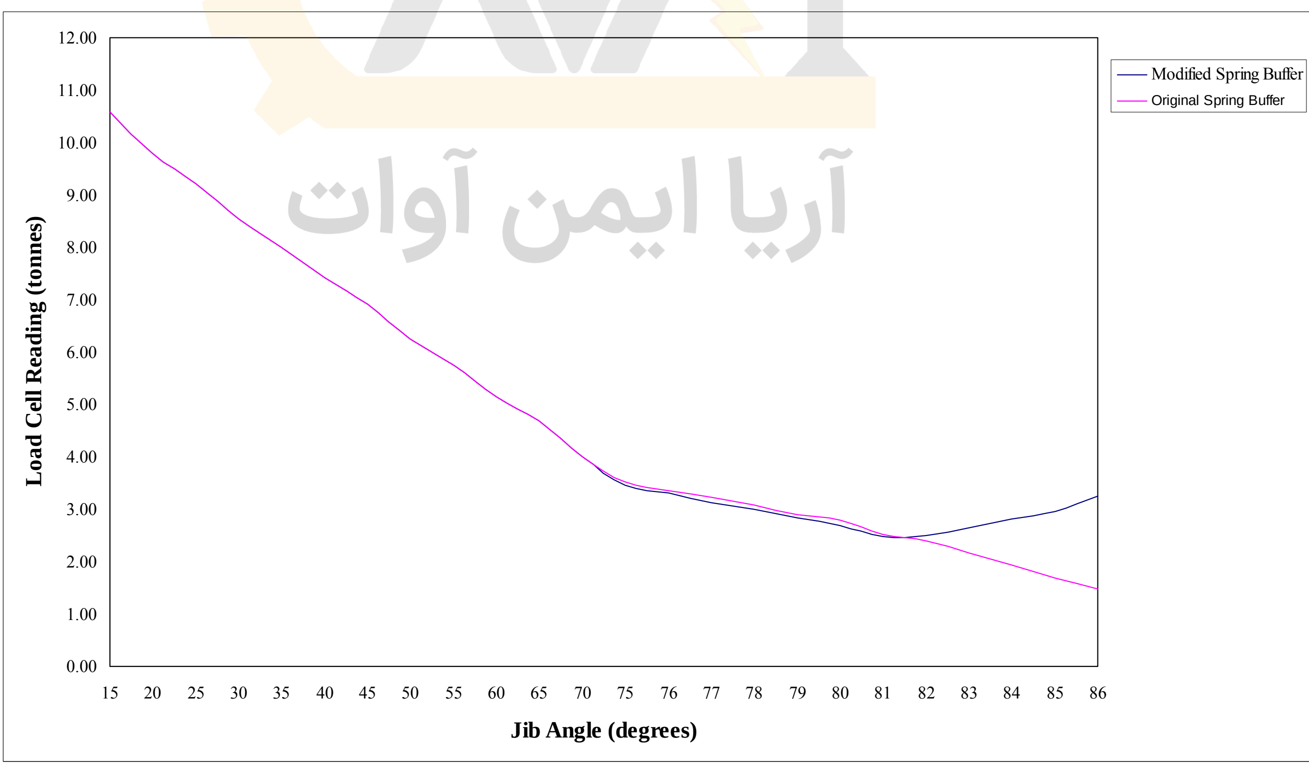
Graph 9 – Load Cell Readings for Different Jib Angles under Different Wind Conditions



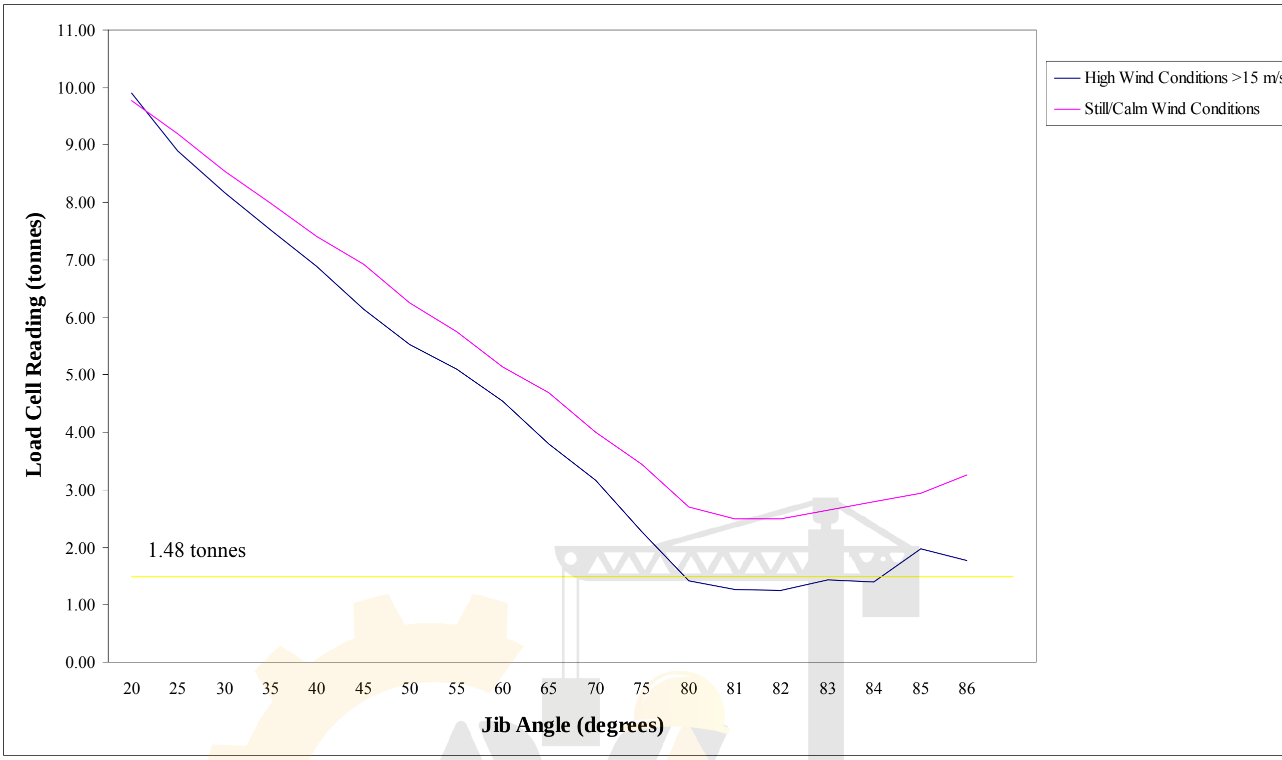
Graph 10 – Wind Speed and Load Cell Readings for the 14 minute test prior to the jib blow back on 16 November 2009



Graph 11 – Wind Speed Readings for the 8 minute period following the jib blow back on 16 November 2009



Graph 12 – Load Cell Readings v. Jib Angle in Still/Calm Wind Conditions with Original and Modified Spring Buffers



Graph 13 – Load Cell Readings v. Jib Angle in Still/Calm and High Wind Conditions with Modified Spring Buffers

(Note - The load cell reading at 83º and 85º jib angles were obtained at a nominal wind speed of 13 m/s, just below the 15 m/s lower limit for “High Wind Conditions”)

APPENDIX 1

Specification for tender to supply the Luffing crane used in testing

Specification for Luffing Crane

Introduction

In January 2007 a luffing jib tower crane collapsed on a construction site in Liverpool resulting in the fatality of a construction worker. An HSE investigation found that the luffing rope could have become slack, jumped from one or more of the sheaves and become jammed whilst the crane was being operated within the duty envelope of the crane as specified by the manufacturer. The jib had been raised to maximum elevation in order to bring the hook as close towards the mast as possible. The hook was very lightly loaded and the wind speed was close to, but within, the maximum in service wind speed. This accident has raised the issue of the effect of wind on luffing jib cranes when working close to minimum radius.

HSE view is that current harmonised European standards for tower cranes may not offer sufficient protection in relation to preventing and guarding against slack rope conditions. Consideration of a number of variables (including jib angle, weight on the hook and angle of the jib to the wind direction) could result in a more complex solution than just the current requirement for the manufacturer to quote a single maximum wind speed limit. In order to argue successfully for a change in the European standards, HSE requires convincing data to show that below that maximum limit there may be foreseeable conditions which might arise within the variables that could give rise to "danger". This data is essential if HSE were to press for revision or safeguard action against the standards.

Consequently, it is intended to erect a luffing crane at the Health and Safety Laboratory (HSL) at Buxton, Derbyshire with sufficient instrumentation to monitor the tension in the luffing system under different conditions of wind speed, jib angles and weight on the hook. The intention is to gather data from the instrumentation to predict when the jib of the crane may be expected to be held or supported by the wind.

This will require the erection and use of a luffing crane at HSL and we would now welcome assistance from the Tower Crane Industry to work with us on this project and in the provision of a suitable crane for the testing.

Details

The HSL site at Buxton is approximately 1,100 – 1,200 feet (335 – 365 m) above sea level. In the past, wind speeds of up to 32 m/s (115 km/hr, 72 m.p.h.) have been measured in the location at HSL where it is intended to erect the crane. The location is relatively remote and there are no permanent power or water supplies near to hand.

For the testing, we require a luffing crane having the following characteristics: -

- A jib length of 40 – 45 metres.

- The luffing system to be operated via ropes and pulleys.

- The facility to operate the slew, hoist and luffing functions via remote control from the ground at a distance of up to nominally 100 metres from the crane.

- An approximate or nominal maximum jib angle of 70 - 80º to the horizontal when the jib is raised to its maximum elevation (minimum radius).

- The height under hook is not of particular importance to us. It is only required that the crane is reasonably clear of the ground, consequently we believe that the use of two or three mast sections would be suitable.

- The base of the crane to be of the cruciform base ballast type, foundation anchors, fixing angles or holding down bolts are not preferred.

- Wind instrumentation should be fitted in accordance with the manufacturers instructions concerning the positioning of the anemometer(s).

In addition to the above, we require the following to be also supplied: -

- Assistance in determining the specifications and design for the base or foundations of the crane.

- Advice in determining the most suitable means of meeting the power consumption requirements of the crane at HSL, e.g. by portable generator (preferably diesel engine powered) or installation of suitable cable from the most appropriate power source.

- Delivery and Erection of the crane.

- On site training for up to five persons in the use of the crane. This to include: all required daily/weekly safety checks and routine maintenance and simple pedestrian operation of the crane via the slewing, luffing and lifting functions.

- Provision of technical support to the crane via regular major maintenance inspections at the minimum interval recommended by the manufacturer. Also telephone contact (including out of normal working hours) followed by site visits, where necessary, to diagnose/rectify any problems that may arise between the regular inspections.

- Assistance and advice in the planning of a procedure for the safe recovery of the crane should the jib fall or be pushed against the tower head and remains in that position and, if required, on site assistance in the implementation of that procedure.

- Dismantling and transport of the crane from HSL upon completion of the testing.

- Access to the necessary manufacturing drawings and details from the erection manual to determine:

    1. The weight of each individual jib section.

    2. The position of the centre of gravity of each individual jib section.

    3. The weights and centres of gravity of other components e.g. platform at the jib end, hook and hook block and the luffing system assembly including pulley block and tie bars.

    4. Appropriate methods of attaching our own instrumentation to record tension in the luffing system and check and compare the wind data supplied by the original instrumentation.

At this stage in the project we are unsure as to exactly how long the data gathering exercise will take to complete. However, we envisage that we will require the crane to be on site at HSL for approximately three to four months following erection in order to conduct the envisaged test programme. It must be realised from the outset that this is a relatively "fluid" situation and that the crane may be on site for longer than this.

As part of the work involved HSL will need to weigh and establish the centres of gravity of the jib sections and other components during erection of the crane. This will involve lifting and slinging the components at an angle several times using the mobile crane. Consequently, the erection of the crane may take longer than is considered usual due to this extra work. It may be beneficial if a gap of suitable duration (e.g. perhaps one week) is planned between delivery of the crane and start of erection to enable this to be carried out without inconveniencing the erection team.

Tenders for the provision of a crane and support in accordance with the above are now invited. Should you require any more information or details then please do not hesitate to contact us.

Richard Isherwood
26 September 2008

APPENDIX 2

Calculation of the moment acting at the jib pivot points arising from the weight of the jib and hook block of the crane

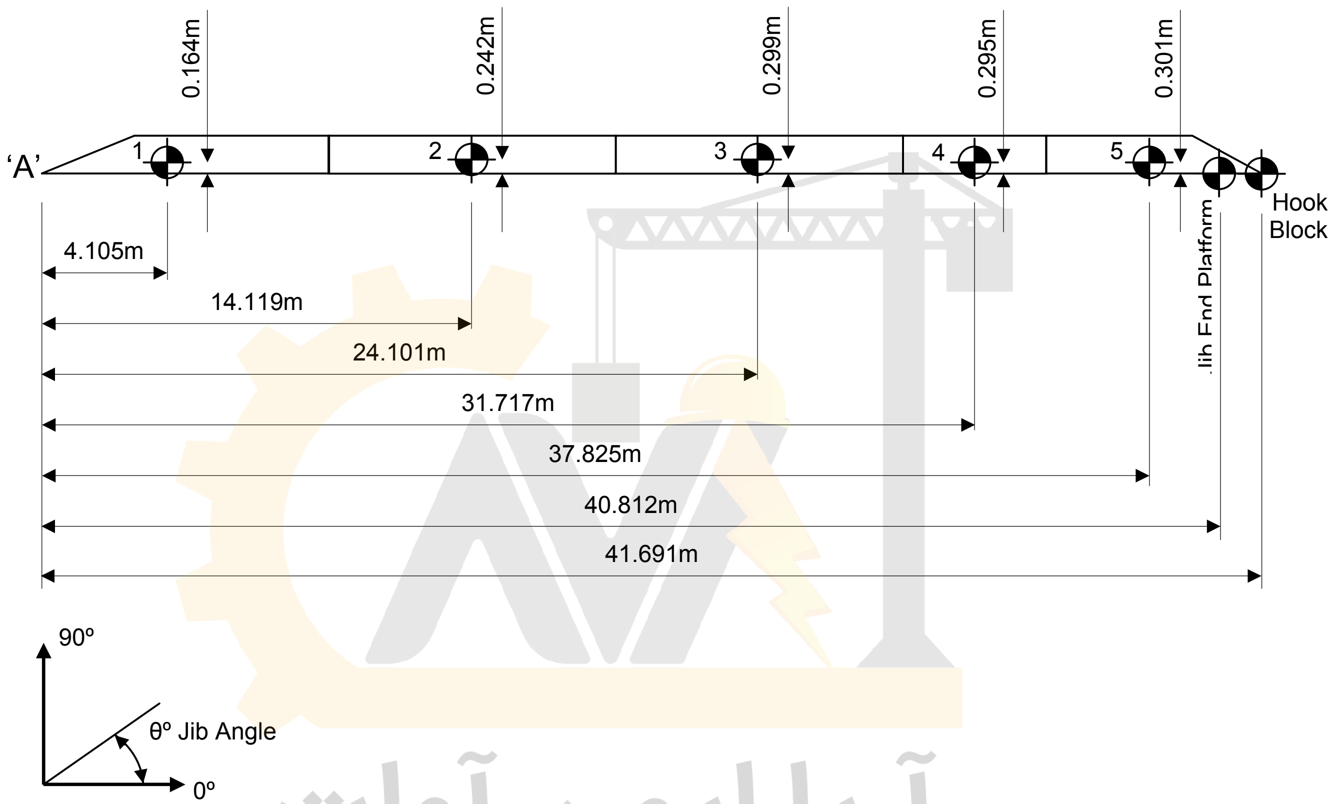
1. Theoretical properties of the jib sections i.e. the masses provided in the crane manual and positions of centre of gravity provided by Jaso

2. Masses and positions of centre of gravity measured during erection of the crane at HSL

Appendix 2

Calculation of the moment acting at the jib pivot points due to the weight of the jib and hook block

1. Theoretical properties of the jib sections i.e. the masses provided in the crane manual and positions of centre of gravity provided by Jaso



Mass of Jib Section 1 W_1 = 866 kg (8,495.5 N)
Mass of Jib Section 2 W_2 = 687 kg (6,739.5 N)
Mass of Jib Section 3 W_3 = 684 kg (6,710.0 N)
Mass of Jib Section 4 W_4 = 276 kg (2,707.6 N)
Mass of Jib Section 5 W_5 = 488 kg (4,787.3 N)
Mass of Jib End Platform W_p = 26 kg (255.1 N)
Mass of Hook Block W_{HB} = 217 kg (2,128.8 N)
Total Mass of Jib, Platform & Hook Block = 3,244 kg (31,823.64 N)

The moment, M, acting at the jib pivot point 'A' arising from the weight of each jib section is given by:

$M = W(x\cos\theta - y\sin\theta)$ where

W is the weight of the jib section (N)
x is the horizontal distance from 'A' to the centre of gravity of the jib section (m)
y is the vertical distance from 'A' to the centre of gravity of the jib section (m)
θ is the angle to the horizontal of the jib (degrees)

For any given jib angle to the horizontal, the total moment acting at the jib pivot point 'A' arising from the weight of each jib section is given by adding the moment arising from each individual jib section 1 to 5 ($M_1 – M_5$) and that arising from the jib end platform (M_P) and hook block (M_{HB}), i.e:

$$M_{TOTAL} = M_1 + M_2 + M_3 + M_4 + M_5 + M_P + M_{HB}$$

As an example, for a jib angle of 64º to the horizontal the total moment acting at the jib pivot point 'A' arising from the weight of the jib and hook block is:

$M_{TOTAL64º}$ = (8,495.5 x (4.105 x cos64º - 0.164 x sin64º)) ………Jib section 1 (M_1)
+ (6,739.5 x (14.119 x cos64º - 0.242 x sin64º)) ……..Jib section 2 (M_2)
+ (6,710.0 x (24.101 x cos64º - 0.299 x sin64º)) ……..Jib section 3 (M_3)
+ (2,707.6 x (31.707 x cos64º - 0.295 x sin64º)) …..…Jib section 4 (M_4)
+ (4,787.3 x (37.825 x cos64º - 0.301 x sin64º)) ……..Jib section 5 (M_5)
+ (255.1 x (40.812 x cos64º - 0 x sin64º)) …………....Jib End Platform (M_p)
+ (2,128.8 x (41.691 x cos64º - 0 x sin64º)) ………..…Hook Block (M_{HB})

= 281.9 KNm

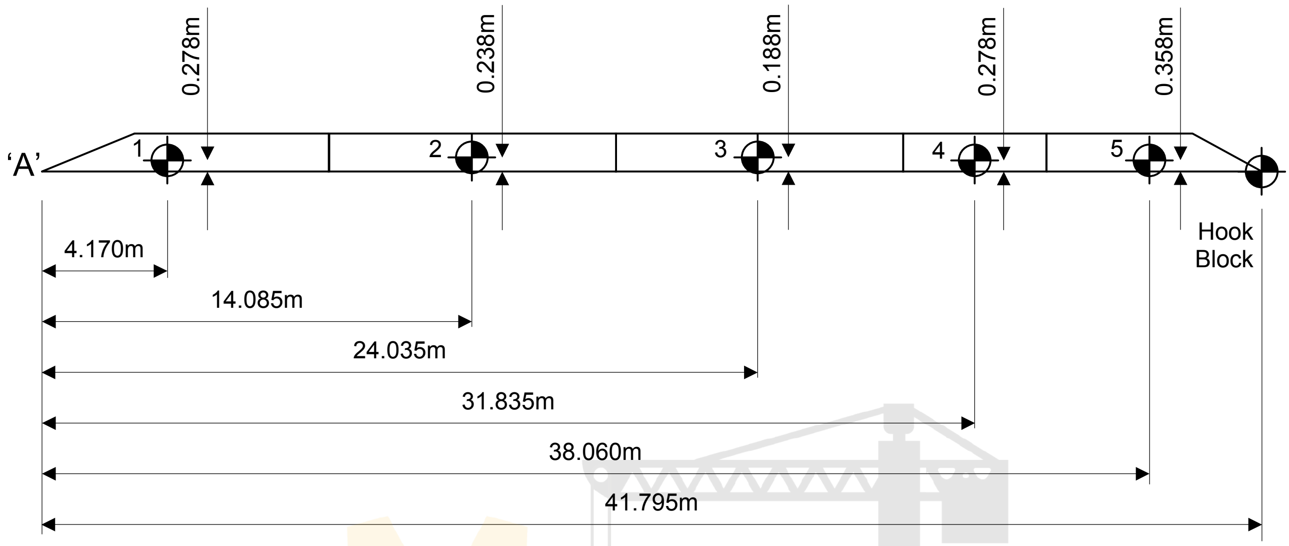
The same calculation can be performed on the other jib angles between 0º (horizontal) and 90º (vertical).

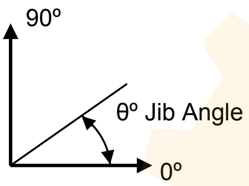
Table 1 on page 3 of this appendix gives the total moment acting at the jib pivot point 'A' arising from the weight of the jib, jib end platform and hook block for jib angles between 0º (horizontal) and 90º (vertical).

Jib Angle (º)	Moment (KNm)		Jib Angle (º)	Moment (KNm)
0	657.9		46	451.8
1	657.6		47	443.3
2	657.2		48	434.8
3	656.6		49	426.1
4	655.8		50	417.3
5	654.7		51	408.4
6	653.5		52	399.3
7	652.1		53	390.1
8	650.4		54	380.8
9	648.6		55	371.4
10	646.6		56	361.8
11	644.4		57	352.2
12	642.0		58	342.4
13	639.4		59	332.6
14	636.6		60	322.6
15	633.6		61	312.6
16	630.4		62	302.4
17	627.0		63	292.2
18	623.4		64	281.9
19	619.7		65	271.4
20	615.7		66	260.9
21	611.6		67	250.4
22	607.2		68	239.7
23	602.7		69	229.0
24	598.0		70	218.2
25	593.2		71	207.3
26	588.1		72	196.4
27	582.9		73	185.4
28	577.4		74	174.3
29	571.9		75	163.2
30	566.1		76	152.1
31	560.2		77	140.9
32	554.0		78	129.7
33	547.8		79	118.4
34	541.3		80	107.1
35	534.7		81	95.7
36	527.9		82	84.4
37	521.0		83	73.0
38	513.9		84	61.5
39	506.7		85	50.1
40	499.3		86	38.6
41	491.7		87	27.2
42	484.0		88	15.7
43	476.2		89	4.2
44	468.2		90	-7.3
45	460.0			

Table 1 - Moment acting at the jib pivot points arising from the weight of the jib (theoretical jib properties)

2. Masses and positions of centre of gravity measured during erection of the crane at HSL





Mass of Jib Section 1 W_1 = 896 kg (8,789.8 N)
Mass of Jib Section 2 W_2 = 699 kg (6,857.2 N)
Mass of Jib Section 3 W_3 = 547 kg (5,366.1 N)
Mass of Jib Section 4 W_4 = 289 kg (2,835.1 N)
Mass of Jib Section 5 W_5 = 664 kg (6,513.8 N) (includes Jib End Platform)
Mass of Hook Block W_{HB} = 217 kg (2,128.8 N)
Total Mass of Jib, Platform & Hook Block = 3,312 kg (32,490.7 N)

The moment, M, acting at the jib pivot point 'A' arising from the weight of each jib section is given by:

$M = W(x\cos\theta - y\sin\theta)$ where

W is the weight of the jib section (N)
x is the horizontal distance from 'A' to the centre of gravity of the jib section (m)
y is the vertical distance from 'A' to the centre of gravity of the jib section (m)
θ is the angle to the horizontal of the jib (degrees)

For any given jib angle to the horizontal, the total moment acting at the jib pivot point 'A' arising from the weight of each jib section is given by adding the moment arising from each individual jib section 1 to 5 ($M_1 - M_5$) and that arising from the hook block (M_{HB}), i.e:

$M_{TOTAL} = M_1 + M_2 + M_3 + M_4 + M_5 + M_{HB}$ (the jib end platform is included in M_5)

As an example, for a jib angle of 53º to the horizontal the total moment acting at the jib pivot point 'A' arising from the weight of the jib and hook block is:

$M_{TOTAL53^o}$ = (8,789.8 x (4.170 x cos53º - 0.278 x sin53º)) ....Jib section 1 (M_1)
+ (6,857.2 x (14.085 x cos53º - 0.238 x sin53º)) ....Jib section 2 (M_2)
+ (5,366.1 x (24.035 x cos53º - 0.188 x sin53º)) ....Jib section 3 (M_3)
+ (2,835.1 x (31.835 x cos53º - 0.278 x sin53º)) ....Jib section 4 (M_4)
+ (6,513.8 x (38.060 x cos53º - 0.358 x sin53º)) ....Jib section 5 (M_5)
+ (2,128.8 x (41.795 x cos53º - 0 x sin53º)) ....Hook Block (M_{HB})

= 408.2 KNm

Table 2 on page 6 of this appendix gives the total moment acting at the jib pivot point 'A' arising from the weight of the jib, jib end platform and hook block for jib angles between 0º (horizontal) and 90º (vertical).

Jib Angle (º)	Moment (KNm)		Jib Angle (º)	Moment (KNm)
0	689.1		46	472.8
1	688.9		47	464.0
2	688.4		48	455.0
3	687.8		49	445.9
4	686.9		50	436.7
5	685.8		51	427.3
6	684.5		52	417.8
7	683.0		53	408.2
8	681.3		54	398.4
9	679.4		55	388.5
10	677.2		56	378.6
11	674.9		57	368.4
12	672.4		58	358.2
13	669.6		59	347.9
14	666.7		60	337.5
15	663.5		61	326.9
16	660.2		62	316.3
17	656.6		63	305.5
18	652.9		64	294.7
19	648.9		65	283.8
20	644.8		66	272.8
21	640.4		67	261.7
22	635.9		68	250.5
23	631.1		69	239.3
24	626.2		70	228.0
25	621.1		71	216.6
26	615.8		72	205.2
27	610.3		73	193.6
28	604.6		74	182.1
29	598.8		75	170.4
30	592.7		76	158.8
31	586.5		77	147.0
32	580.1		78	135.3
33	573.5		79	123.4
34	566.7		80	111.6
35	559.8		81	99.7
36	552.7		82	87.8
37	545.4		83	75.8
38	538.0		84	63.9
39	530.4		85	51.9
40	522.6		86	39.9
41	514.7		87	27.9
42	506.6		88	15.9
43	498.4		89	3.8
44	490.0		90	-8.2
45	481.5			

Table 6 - Moment acting at the jib pivot points arising from the weight of the jib (measured jib properties)

APPENDIX 3

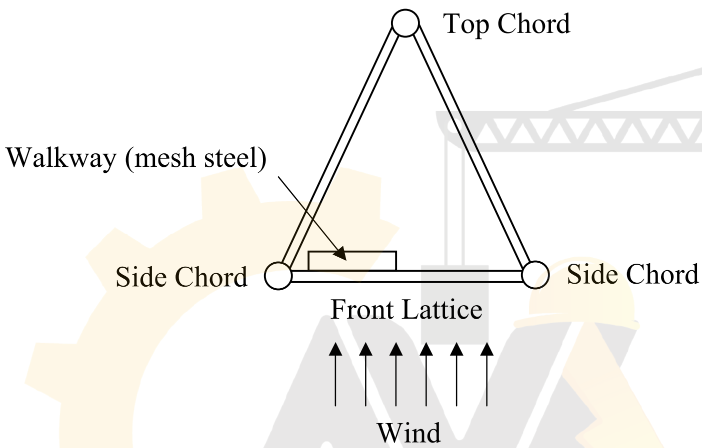
Calculation of the jib lattice area and moment acting at the jib pivot points arising from the wind loading on the jib of the crane

Appendix 3

Calculation of the Wind Loading on the Jib Components

1.0 Front Lattice Areas

Each of the four standards referenced in Section 5.1 and used to calculate the wind loading on the crane jib follow a similar method. Each method uses the area exposed to the wind. In this report, the wind is taken to act directly on the underside of the jib and so it is necessary to calculate the area of the front lattice of each jib section between and including the two side chords, i.e. :



1.1 Front Lattice Area of Jib Section 1

2 x Side Chords – 9,170 mm long x 76 mm diameter
9 x Cross Tubes – 708 mm long x 33.7 mm diameter
9 x Diagonal Tubes – 1,068 mm long x 48.3 mm diameter
1 x Walkway – 9,170 mm long x 0.1206 m^2 per metre length (ref Section 3.1.1)

Front Lattice Area of Jib Section 1 (FL_1) = (2 x 9.170 x 0.076) + (9 x 0.708 x 0.0337) + (9 x 1.068 x 0.0483) + (9.170 x 0.1206) = 3.18 m^2

Front Lattice Area of Jib Section 1 (FL_1) = **3.18** m^2

1.2 Front Lattice Area of Jib Section 2

2 x Side Chords – 10,000 mm long x 76 mm diameter
11 x Cross Tubes – 708 mm long x 33.7 mm diameter
10 x Diagonal Tubes – 1,068 mm long x 48.3 mm diameter
1 x Walkway – 10,000 mm long x 0.1206 m^2 per metre length (ref Section 3.1.1)

Front Lattice Area of Jib Section 2 (FL_2) = (2 x 10 x 0.076) + (11 x 0.708 x 0.0337) + (10 x 1.068 x 0.0483) + (10 x 0.1206) = 3.50 m^2

Front Lattice Area of Jib Section 2 (FL_2) = **3.50** m^2

1.3 Front Lattice Area of Jib Section 3

2 x Side Chords – 10,000 mm long x 76 mm diameter
11 x Cross Tubes – 708 mm long x 33.7 mm diameter
10 x Diagonal Tubes – 1,068 mm long x 42.4 mm diameter
1 x Walkway – 10,000 mm long x 0.1206 m^2 per metre length (ref Section 3.1.1)

Front Lattice Area of Jib Section 3 (FL_3) = (2 x 10 x 0.076) + (11 x 0.708 x 0.0337) + (10 x 1.068 x 0.0424) + (10 x 0.1206) = 3.44 m^2

Front Lattice Area of Jib Section 3 (FL_3) = **3.44** m^2

1.4 Front Lattice Area of Jib Section 4

2 x Side Chords – 5,110 mm long x 76 mm diameter
6 x Cross Tubes – 708 mm long x 33.7 mm diameter
5 x Diagonal Tubes – 1,068 mm long x 42.4 mm diameter
1 x Walkway – 5,110 mm long x 0.1206 m^2 per metre length (ref Section 3.1.1)

Front Lattice Area of Jib Section 4 (FL_4) = (2 x 5.11 x 0.076) + (6 x 0.708 x 0.0337) + (5 x 1.068 x 0.0424) + (5.11 x 0.1206) = 1.76 m^2

Front Lattice Area of Jib Section 4 (FL_4) = **1.76** m^2

1.5 Front Lattice Area of Jib Section 5

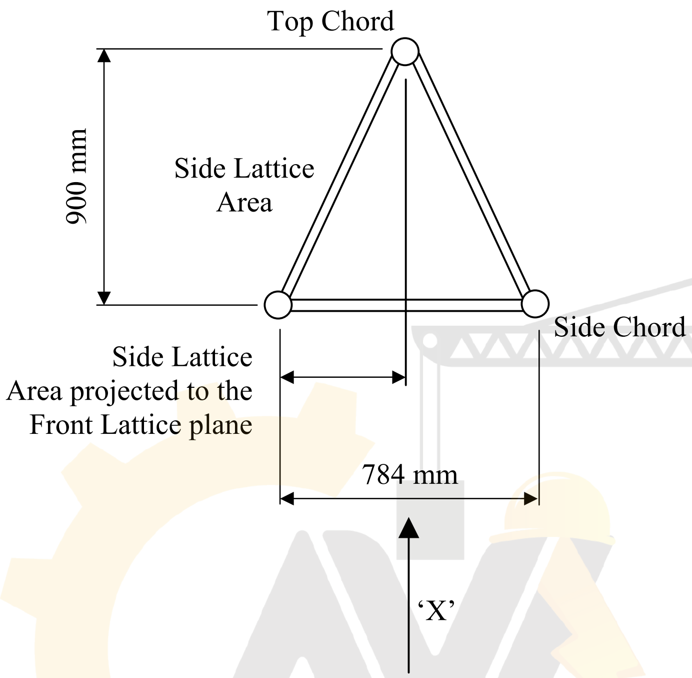
2 x Side Chords – 7,411 mm long x 76 mm diameter
8 x Cross Tubes – 708 mm long x 33.7 mm diameter
6 x Diagonal Tubes – 1,068 mm long x 42.4 mm diameter 1 x Short Cross Tube – 354 mm long x 42.4 mm diameter
1 x Diagonal Tube – 1,315 mm long x 42.4 mm diameter (1,315 mm length has been scaled from the crane manufacturers drawing used to prepare Figure 10)
1 x Walkway – 7,411 mm long x 0.1206 m^2 per metre length (ref Section 3.1.1)

Front Lattice Area of Jib Section 5 (FL_5) = (2 x 7.411 x 0.076) + (8 x 0.708 x 0.0337) + (6 x 1.068 x 0.0424) + (1 x 0.354 x 0.0424) + (1 x 1.315 x 0.0424) + (7.411 x 0.1206) = 2.55 m^2

Front Lattice Area of Jib Section 5 (FL_5) = **2.55** m^2

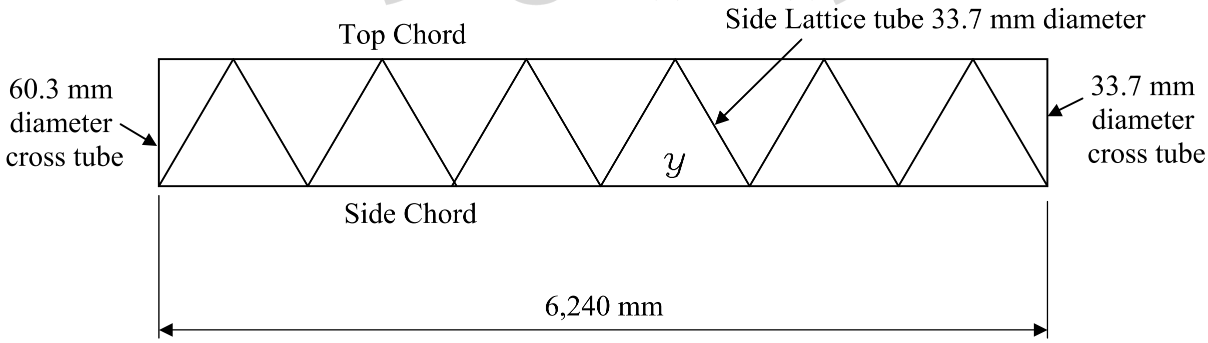
2.0 Projected Area of Side Lattices

The wind will also act on the top chord and the side lattice structure of each jib section. Consequently, it is necessary to calculate the area of each of these sections on the same plane as the front lattice. Each jib section is triangular having a height of nominally 900 mm and a width of nominally 784 mm between centres of the top and side chords, i.e.



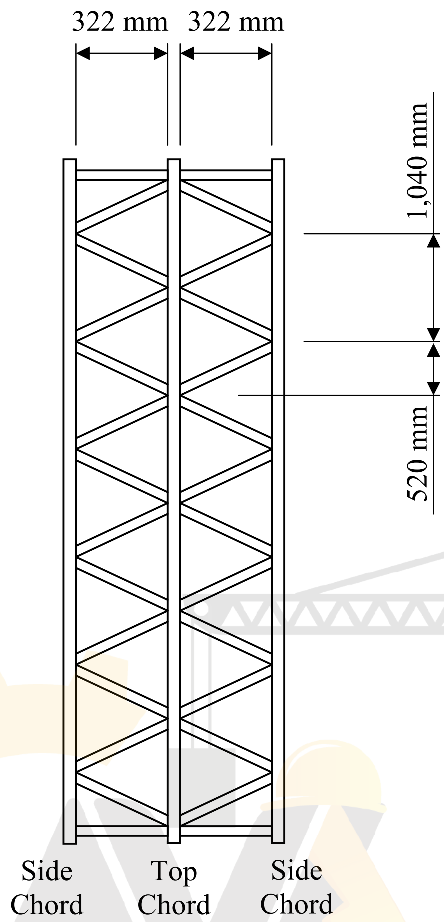
2.1 Projected Side Lattice Area for Jib Section 1

Reference to Figure 5 shows that one side lattice of jib section 1 has a total of 12 angled side lattice tubes having a diameter of 33.7 mm in a segment of the jib nominally 6,240 mm long (scaled from the crane manufacturers drawing used to prepare Figure 5). There are also two cross tubes having diameters of 60.3 mm and 33.7 mm at each end of the angled side lattice tubes, i.e.



The distance apart of the side lattice tubes, distance y = 6,240/6 = 1,040 mm

Viewing directly on to the underside of the jib, i.e. in the direction of arrow 'X' in the diagram at the top of the page shows that the edges of the top and side chords are 322 mm apart in the plane of the front lattice. The side lattice tubes and both cross tubes all lie within this 322 mm wide plane, i.e.



Since the cross tubes are straight, their length can be taken to be 316 mm. The length of the side lattice tubes in the plane of the front lattice is given by:

$(322^2 + 520^2)^{1/2} = 612$ mm

There are two side lattices, hence the total projected side lattice area of jib section 1 is given by:

2 x ((0.322 x 0.0603) + (12 x 0.612 x 0.0337) + (0.322 x 0.0337)) = **0.56 m^2**

2.1.1 Top Chord Area for Jib Section 1

In addition to the two side lattices, the area of the top chord of jib section 1 must also be calculated. This is 6,240 mm long and 63.5 mm diameter. The area is given by:

6.24 x 0.0635 = **0.40 m^2**

2.2 Side Lattice Area for Jib Section 2

Reference to Figure 6 shows that one side lattice of jib section 2 has a total of 20 angled side lattice tubes having a diameter of 33.7 mm a nominally 10,000 mm long jib section. There are also two cross tubes having a diameter 33.7 mm at each end of the angled side lattice tubes.

Using the same method as previously, distance y = 10,000/10 = 1,000 mm and half this distance is 500 mm.

The length of the side lattice tubes in the plane of the front lattice is given by:

$(322^2 + 500^2)^{1/2} = 595$ mm

There are two side lattices, hence the total projected side lattice area of jib section 1 is given by:

2 x ((20 x 0.595 x 0.0337) + (2 x 0.322 x 0.0337)) = **0.84 m^2**

2.2.1 Top Chord Area for Jib Section 2

In addition to the two side lattices, the area of the top chord of jib section 2 must also be calculated. This is 10,000 mm long and 63.5 mm diameter. The area is given by:

10 x 0.0635 = **0.63 m^2**

2.3 Side Lattice Area for Jib Section 3

Reference to Figure 7 shows that one side lattice of jib section 3 has a total of 20 angled side lattice tubes having a diameter of 26.9 mm in a nominally 10,000 mm long jib section. There are also two cross tubes having a diameter of 26.9 mm at each end of the angled side lattice tubes.

Using the same method as previously, distance y = 10,000/10 = 1,000 mm and half this distance is 500 mm.

The length of the side lattice tubes in the plane of the front lattice is given by:

$(322^2 + 500^2)^{1/2} = 595$ mm

There are two side lattices, hence the total projected side lattice area of jib section 1 is given by:

2 x ((20 x 0.595 x 0.0269) + (2 x 0.322 x 0.0269)) = **0.67 m^2**

2.3.1 Top Chord Area for Jib Section 3

In addition to the two side lattices, the area of the top chord of jib section 3 must also be calculated. This is 10,000 mm long and 63.5 mm diameter. The area is given by:

10 x 0.0635 = **0.63 m^2**

2.4 Side Lattice Area for Jib Section 4

Reference to Figure 8 shows that one side lattice of jib section 4 has a total of 10 angled side lattice tubes having a diameter of 26.9 mm in a nominally 5,110 mm long jib section. There are also two cross tubes having a diameter of 26.9 mm at each end of the angled side lattice tubes.

Using the same method as previously, distance y = 5,110/5 = 1,022 mm and half this distance is 511 mm.

The length of the side lattice tubes in the plane of the front lattice is given by:

$(322^2 + 511^2)^{1/2} = 604$ mm

There are two side lattices, hence the total projected side lattice area of jib section 1 is given by:

2 x ((10 x 0.604 x 0.0269) + (2 x 0.322 x 0.0269)) = **0.36 m^2**

2.4.1 Top Chord Area for Jib Section 4

In addition to the two side lattices, the area of the top chord of jib section 4 must also be calculated. This is 5,110 mm long and 63.5 mm diameter. The area is given by:

5.11 x 0.0635 = **0.32 m^2**

2.5 Side Lattice Area for Jib Section 5

Reference to Figure 9 shows that one side lattice of jib section 5 has a total of 13 angled side lattice tubes having a diameter of 42. 4 mm at an angle in the nominally 7,411 mm long jib section. There is one cross tube having a diameter of 26.9 mm at one end of the angled side lattice tubes. There is also one angled tube having a diameter of 42.4 mm at the other end of the angled side lattice tubes, at the outer end of the jib section

Using the same method as previously, distance y = 7,411/6 = 1,235 mm and half this distance is 617.5 mm. This will be used in the subsequent calculation, although the single angled tube at the outer end is visually slightly longer than the other 12 angle side lattice tubes

The length of the side lattice tubes in the plane of the front lattice is given by:

$(322^2 + 617.5^2)^{1/2}$ = 696 mm

There are two side lattices, hence the total projected side lattice area of jib section 1 is given by:

2 x ((13 x 0.696 x 0.0424) + (0.322 x 0.0269)) = **0.78 m^2**

2.5.1 Top Chord Area for Jib Section 5

In addition to the two side lattices, the area of the top chord of jib section 5 must also be calculated. The length of this top chord is scaled from the crane manufacturers drawing used to prepare Figure 9 to be nominally 6,500 mm and its diameter is 63.5 mm. Consequently the area of the Top chord of jib section 5 is given by:

6.5 x 0.0635 = **0.41 m^2**

3.0 <u>Area of Jib End Platform</u>

The area of the floor of the jib end platform should also be considered in wind loading calculations. This is stated to be 0.504 m^2 in Section 3.1.1 and is on the same plane as the front lattices of the jib sections.

4.0 Total Area of the Jib Sections

The foregoing calculations of the front lattice areas, the projected area of the side lattices onto the same plane as the front lattice areas and the area of the jib end platform floor are summarised below:

	Area of Front Lattice (m^2)	Projected Area of both Side Lattices onto the same plane as the Front Lattice (m^2)	Area of Top Chord (m^2)	Projected Area of both Side Lattices + Area of Top Chord (m^2)	Floor Area of the Jib end Platform (m^2)
Jib Section 1	3.18	0.56	0.40	0.96	
Jib Section 2	3.50	0.84	0.63	1.47	
Jib Section 3	3.44	0.67	0.63	1.30	
Jib Section 4	1.76	0.36	0.32	0.68	
Jib Section 5	2.55	0.78	0.41	1.19	
Jib End Platform					0.504

5.0 Wind Loading Calculation in accordance with FEM 1.001

According to Section 2.2.4.1.3 of FEM 1.001, the wind load is calculated using the equation:

$$F = A \times q \times Cf$$

Where:

F is the wind load (N)
A is the effective frontal area of the part under consideration (m^2)
q is the wind pressure corresponding to the appropriate design condition (N/m^2)
Cf is the shape coefficient in the direction of the wind for the part under consideration

It is assumed in FEM 1.001 that the wind blows at a constant velocity (V_S m/s) and in a horizontal direction.

5.1 Wind Pressure, q

The wind pressure, q, corresponding to the maximum in service wind speed of 20 m/s is defined in Table T.2.2.4.1.2.1 of FEM 1.001 to be 250 N/m^2. For other wind speeds the wind pressure, q is defined in section 2.2.4.1.1 by:

$$q = 0.613V_S^2$$

5.2 Shape Coefficient, Cf

Section 2.2.4.1.4 of FEM 1.001 provides information on establishing shape coefficients for individual members, single lattice frames and larger objects such as machinery houses etc are given in table T.2.2.4.1.4.1. of FEM 1.001.

Section 2.2.4.1.4 states *"The wind load on single lattice frames may be calculated on the basis of the coefficients for the individual members given in the top part of Table T.2.2.4.1.4.1. In this case the aerodynamic slenderness of each member shall be taken into account. Alternatively the overall coefficients for lattice frames constructed of flat sided and circular sections given in the middle part of the table may be used."*

5.2.1 Shape Coefficient for the jib sections, Cf_{JIB}

In this case, the five jib sections are constructed from circular sections and in table T.2.2.4.1.4.1 two overall coefficients for single lattice frames having circular sections of 1.10 and 0.80 are defined.

The first coefficient of 1.10 is defined for the case where $D \times V_S < 6\ m^2/s$ and the second coefficient of 0.80 is defined for the case where $D \times V_S > 6\ m^2/s$.

In FEM 1.001, D is defined as *"the section diameter in shape factor determination (m)"* and V_S is defined as the *"theoretical wind speed (m/s)"*.

In this case, D is chosen to be 0.076 m which is the largest diameter of any of the circular sections used to construct each of the five jib sections and V_S is chosen to be 20 m/s which is the maximum in service wind speed. Hence,

$D \times V_S = 0.076 \times 20 = 1.52\ m^2/s$

This is less than 6 m^2/s and hence a shape factor of 1.10 will be used when considering the jib sections, i.e. $Cf_{JIB} = 1.10$

5.2.2 Shape Coefficient for the jib end platform, $Cf_{PLATFORM}$

The floor of the jib end platform was a solid flat plate measured to be 900 mm x 560 mm and according to the drawing supplied by the crane manufacturer was nominally 6 mm thick.

The 900 mm dimension lay in the same direction as the longitudinal axis of the jib, i.e. from the inner end to the outer end. The 560 mm dimension lay in the direction across the jib, i.e. from side chord to side chord. According to Figure 2.2.4.1.4.1 of FEM 1.001 the maximum aerodynamic slenderness (l/b) is less than 5 (900/560 = 1.61). No specific shape factor for flat plates is provided in table T.2.2.4.1.4.1 and hence the category for *"individual members – other sections"* will be used and hence from table T.2.2.4.1.4.1 the shape factor for the jib end platform is defined as 1.30, i.e. $Cf_{PLATFORM} = 1.30$

5.3 Effective frontal area of the part under consideration (m^2)

5.3.1 Front Lattice Areas and Jib Platform Floor

The wind is considered to act directly against the front lattice area of each jib section and the floor of the jib platform. Hence, the areas calculated in Sections 1.1 – 1.5 and 3.0 will be used.

5.3.2 Shielding Coefficient, η

In addition to acting directly against the underside of each jib section, (i.e. directly on each front lattice and the floor of the jib end platform), the wind will also act on the top chord and side lattices of each jib section. However, these members will be shielded by the front lattice of each jib section and will not experience the full force of the wind.

Section 2.2.4.1.4.2 of FEM states *"Where parallel frames or members are positioned so that shielding takes place, the wind loads on the windward frame or member and on the unsheltered parts of those behind it are calculated using the appropriate shape coefficients. The wind load on the sheltered parts is multiplied by a shielding factor, η given in table T.2.2.4.1.4."*. Shielding factors depend upon the solidity ratio and spacing ratio of the lattices of the jib sections and these are defined in Figure 2.2.4.1.4.1 of FEM 1.001

In Figure 2.2.4.1.4.1, the solidity ratio is stated to be *"(the area of solid parts)/(enclosed area)"* and the spacing ratio is stated to be *"(distance between facing sides)/(breadth of members across the wind front) = a/b or a/B"*. Although the text of Section 2.2.4.1.4.2 is specific in specifying frames or members lying parallel to each other a diagram accompanying the spacing ratio definition shows a triangular lattice frame. Hence it is interpreted that the relevant shielding coefficients are intended to be applied to a triangular frame.

Figure 2.2.4.1.4.1 shows that for the five triangular jib sections, 2a = 784 mm and b = 900 mm. Hence the spacing ratio is (784/2)/900 = 0.44.

The solidity ratio of the front lattice of each jib section is given by:

Front Lattice of Jib Section 1 Solidity Ratio = (area of solid parts)/(enclosed area)
= (3.18)/(9.17 x 0.86) = 0.40

Front Lattice of Jib Section 2 Solidity Ratio = (area of solid parts)/(enclosed area)
= (3.50)/(10 x 0.86) = 0.41

Front Lattice of Jib Section 3 Solidity Ratio = (area of solid parts)/(enclosed area)
= (3.44)/(10 x 0.86) = 0.40

Front Lattice of Jib Section 4 Solidity Ratio = (area of solid parts)/(enclosed area)
= (1.76)/(5.11 x 0.86) = 0.40

Front Lattice of Jib Section 5 Solidity Ratio = (area of solid parts)/(enclosed area)
= (2.55)/(7.411 x 0.86) = 0.40

From table T.2.2.4.1.4. the closest shielding coefficient, η to a spacing ratio of 0.44 and solidity ratios of 0.40 – 0.41 is η = 0.21.

5.4 Total Wind Load

5.4.1 Total Wind Load acting directly on individual jib sections

The total wind load on an individual jib section is obtained by adding the wind load acting upon the front lattice and the wind load acting on the area of both side lattices and the top chord. Since the side lattices and the top chord are shielded by the front lattice the shielding coefficient, η obtained in Section 5.3.2 is used in the wind load equation when considering the shielded members. The area of the side lattice is taken to be the area in the same plane as the front lattice, i.e. the projected area of the side lattice being parallel to the area of the front lattice. Hence, wind load on an individual jib section is given by:

$F = (q \times Cf_{JIB} \times A_{FRONTLATTICE}) + (\eta \times q \times Cf_{JIB} \times (A_{SIDELATTICEPROJECTED} + A_{TOP\ CHORD}))$ (N)

For jib section 1, the wind load is:

$F_1 = (q \times 1.1 \times 3.18) + (0.21 \times q \times 1.1 \times 0.96) = 3.72 \times q$ (N)

For jib section 2, the wind load is:

$F_2 = (q \times 1.1 \times 3.50) + (0.21 \times q \times 1.1 \times 1.47) = 4.19 \times q$ (N)

For jib section 3, the wind load is:

$F_3 = (q \times 1.1 \times 3.44) + (0.21 \times q \times 1.1 \times 1.3) = 4.08 \times q$ (N)

For jib section 4, the wind load is:

$F_4 = (q \times 1.1 \times 1.76) + (0.21 \times q \times 1.1 \times 0.68) = 2.09 \times q$ (N)

For jib section 5, the wind load is:

$F_5 = (q \times 1.1 \times 2.55) + (0.21 \times q \times 1.1 \times 1.19) = 3.08 \times q$ (N)

5.4.2 Total Wind Load acting directly on the jib end platform floor

The wind load on the jib end platform floor is given by:

$F_{PLATFORM} = q \times Cf_{PLATFORM} \times A_{PLATFORM} = q \times 1.3 \times 0.504 = 0.66 \times q$ (N)

5.4.3 Total Wind Load acting on the inclined jib

The wind loads acting on the jib sections and jib end platform floor calculated in Sections 5.4.1 and 5.4.2 are derived from the wind blowing horizontally and acting directly against the effective areas, i.e. the wind striking the jib at an angle of 90º. However, the jib angle relative to the horizontal can be altered and therefore the wind will be acting against an inclined effective area. Section 2.2.4.1.4.4 of FEM 1.001 states that *"where the wind blows at an angle to the longitudinal axis of a member or to the surface of a frame, the wind load in the direction of the wind is obtained from:*

$$F = A.q.Cf\sin^2\theta \text{ (N)}$$

Where F, A, q and Cf are defined as in 2.2.4.1.3 and θ is the angle of the wind (θ < 90º) to the longitudinal axis or face".

Hence the equations derived in Sections 5.4.2 and 5.4.3 are adjusted to give the wind loading normal to the underside of the jib sections and jib end platform i.e:

For jib section 1, the wind load normal to the underside of the jib section is:

$F_{N1} = F_1 \text{ x } \sin^2\theta = 3.72\ q \sin^2\theta$ (N) …………………. Equation 1

For jib section 2, the wind load normal to the underside of the jib section is:

$F_{N2} = F_2 \text{ x } \sin^2\theta = 4.19\ q \sin^2\theta$ (N) …………………. Equation 2

For jib section 3, the wind load normal to the underside of the jib section is:

$F_{N3} = F_3 \text{ x } \sin^2\theta = 4.08\ q \sin^2\theta$ (N) …………………. Equation 3

For jib section 4, the wind load normal to the underside of the jib section is:

$F_{N4} = F_4 \text{ x } \sin^2\theta = 2.09\ q \sin^2\theta$ (N) …………………. Equation 4

For jib section 5, the wind load normal to the underside of the jib section is:

$F_{N5} = F_5 \text{ x } \sin^2\theta = 3.08\ q \sin^2\theta$ (N) …………………. Equation 5

The wind load normal to the jib end platform floor is given by:

$F_{NPLATFORM} = F_{PLATFORM} \text{ x } \sin^2\theta = 0.66\ q \sin^2\theta$ (N) …………………. Equation 6

6.0 Wind Loading Calculation in accordance with FEM 1.004

According to Section 4 of FEM 1.004, the wind load is calculated using the equation:

$$F = A \times q \times Cf$$

Where:

F is the wind load (N)
A is the effective frontal area of the part under consideration (m^2)
q is the wind pressure corresponding to the appropriate design condition (N/m^2)
Cf is the shape coefficient in the direction of the wind for the part under consideration

6.1 Wind Pressure, q

Section 2 of FEM 1.004 defines the wind pressure, q as:

$$q = \tfrac{1}{2} \times \rho \times V^2$$

where ρ is air density = 1.25 kg/m^3 and V is the design speed in m/s.

Hence for a maximum design wind speed of 20 m/s the corresponding maximum design wind pressure is $q = \frac{1}{2} \times 1.25 \times 20^2 = 250\ N/m^2$

Allowance is also made for gust wind velocity by incorporating a gust response factor of 1.1 and according to table T.1 the wind speed in service reduces slightly to 18.18 m/s for the same maximum design pressure which results in a wind pressure in service of 207 N/m^2.

6.2 Shape Coefficient, Cf

According to Section 5 of FEM 1.004 the shape coefficient Cf is dependant upon the Reynolds number of the airflow over the section under consideration and is defined as:

$$Cf = K\lambda \times Kt \times Kr \times Cfo$$

Where Kλ, Kt and Kr characterise the influence of the slenderness, turbulence and edge radius and Cfo is the reference shape coefficient.

According to Appendix 1 of FEM 1.004 the Reynolds number is given by:

$$Re = (D \times V)/\nu$$

Where D is the characteristic dimension of the section perpendicular to the wind (m), V is the wind speed (m/s) and ν is the kinematic viscosity of air = 15×10^{-6} (m^2/s).

6.2.1 Reference Shape Coefficient for the jib sections, Cfo_{JIB}

For the jib sections, D is taken to be 0.076 m which is the largest diameter of any of the circular sections used to construct each of the five jib sections and V_S is chosen to be 20 m/s which is the maximum in service wind speed.

Hence the maximum Reynolds number for a jib section is $Re_{JIB} = (0.076 \times 20)/\ 15 \times 10^{-6} = 1.01 \times 10^{-5}$.

According to section 5.3 of FEM 1.004 the shape coefficients for Lattice towers and plane lattices are given in table T.A.3 of appendix 3 (of FEM 1.004). Table T.A.3 provides the method of calculating the characteristic area and solidity ratio (ψ) of various lattice structures. It also refers to different figures to determine the shape coefficient. These figures are graphs that Cfo can be read directly from if the Reynolds number and solidity ratios are known.

For the five jib sections row 3 of table T.A.3 is most appropriate. This is concerned with the jib lattice individual members being circular and without attaching gusset plates. From table T.A.3 row 3 the characteristic area, A, is defined as the sum of the projected areas of all individual members of one wall (d) on to its plane. The solidity ratio (ψ) is defined as A/(d x l), i.e. the characteristic area divided by the enclosed area. The appropriate graph to use to determine the shape coefficient is stated to be Figure F.A.3.2

For jib section 1 the characteristic area and solidity ratio is :

$A_1 = 3.18\ m^2$ (underside of jib lattice) and $\psi_1 = 3.18/(9.17 \times 0.86) = 0.40$

For jib section 2 the characteristic area and solidity ratio is :

$A_2 = 3.50\ m^2$ (underside of jib lattice) and $\psi_2 = 3.50/(10.0 \times 0.86) = 0.41$

For jib section 3 the characteristic area and solidity ratio is :

$A_3 = 3.44\ m^2$ (underside of jib lattice) $\psi_3 = 3.44/(10.0 \times 0.86) = 0.40$

For jib section 4 the characteristic area and solidity ratio is :

$A_4 = 1.76\ m^2$ (underside of jib lattice) and $\psi_4 = 1.75/(5.11 \times 0.86) = 0.40$

For jib section 5 the characteristic area and solidity ratio is :

$A_5 = 2.55\ m^2$ (underside of jib lattice) and $\psi_5 = 2.54/(7.411 \times 0.86) = 0.40$

From Figure F.A.3.2, Cfo for all the individual jib sections is taken to be 1.28. However, in this diagram Cfo is now referred to as an "aerodynamic coefficient" and not the reference shape coefficient as previously.

The diagram shows that since the maximum Reynolds number is less than 2×10^5, Cfo will not alter at wind speeds below 20 m/s, i.e. the 1.28 figure remains constant for wind speeds up to the maximum in service design wind speed of 20 m/s.

Equations to calculate Kλ, Kr and Kt are defined in Section 5.1 of FEM 1.004 for Reynolds numbers less than and greater than 3×10^5. However, This section is concerned with *"individual members, frames etc"*. Section 5.3 is concerned with lattices and no reference is made to Kλ, Kr, Kt in this section or any subsequent tables and graphs referred to by this section. A value of Cfo for a lattice is simply read from the appropriate graph and as stated above is renamed as an "aerodynamic coefficient".

Section 5.2 of FEM 1.004 is concerned with shielding and specifically states that it is concerned with parallel frames or members. Shielding factors depend upon the solidity ratio and spacing ratio of the frames or members involved and these are defined in Figure F.5.1.b of FEM 1.004 together with accompanying diagrams. None of these diagrams show a triangular lattice frame and no method of calculating the spacing ratio for a triangular lattice frame is specified. Hence, it is interpreted that no shielding factor is intended to be applied.

Consequently the value of Cfo = 1.28 for the five jib sections is taken to be the final value of Cf_{JIB}.

6.2.2 *Reference Shape Coefficient for the jib end platform, $Cfo_{PLATFORM}$*

The floor of the jib end platform was a solid flat plate measured to be 900 mm x 560 mm and according to the drawing supplied by the crane manufacturer was nominally 6 mm thick.

The 900 mm dimension lay in the same direction as the longitudinal axis of the jib, i.e. from the inner end to the outer end. The 560 mm dimension lay in the direction across the jib, i.e. from side chord to side chord.

No specific shape coefficient for flat plates is provided in FEM 1.004 for Reynolds numbers above or below 3×10^5. Consequently, the floor of the jib end platform is considered to be an individual non circular plane member having a solidity ratio of 1. From table T.A.3 row 1 the appropriate figure to select Cfo from is stated to be Figure F.A.3.4. and from this a value of Cfo = 2 is obtained. As before, no adjustment for Kλ, Kr, Kt or any shielding factors is made.

6.3 *Total Wind Load*

6.3.1 *Total Wind Load acting directly on individual jib sections*

The total wind load on an individual jib section is obtained by the equation F = A x q x Cf

For jib section 1, the wind load is:

$F_1 = 3.18 \times 1.28 \times q = 4.07 \times q$ (N)

For jib section 2, the wind load is:

$F_2 = 3.50 \times 1.28 \times q = 4.48 \times q$ (N)

For jib section 3, the wind load is:

$F_3 = 3.44 \times 1.28 \times q = 4.40 \times q$ (N)

For jib section 4, the wind load is:

$F_4 = 1.76 \times 1.28 \times q = 2.25 \times q$ (N)

For jib section 5, the wind load is:

$F_5 = 2.55 \times 1.28 \times q = 3.26 \times q$ (N)

6.3.2 *Total Wind Load acting directly on the jib end platform floor*

The wind load on the jib end platform floor is given by:

$F_{PLATFORM} = q \times Cf_{PLATFORM} \times A_{PLATFORM} = q \times 2 \times 0.504 = 1.01 \times q$ (N)

6.3.3 *Total Wind Load acting on the inclined jib*

The wind loads acting on the jib sections and jib end platform floor calculated in Sections 6.3.1 and 6.3.2 are derived from the wind blowing horizontally and acting directly against the effective areas, i.e. the wind striking the jib at an angle of 90º. However, the jib angle relative to the horizontal can be altered and therefore the wind will be acting against an inclined effective area. Section 5.4 of FEM 1.004 states that *"where the wind blows at an angle to the* *longitudinal axis of a member or to the surface of a frame, the wind load in the direction of the wind is obtained from:*

$$F = A.q.Cf\sin^2\theta \text{ (N)}$$

Where F, A, q and Cf are as defined in 3.1 and θ is the angle of the wind (θ < 90°) to the longitudinal axis or face".

Hence the equations derived in Sections 6.3.1 and 6.3.2 are adjusted to give the wind loading normal to the underside of the jib sections and jib end platform i.e:

For jib section 1, the wind load normal to the underside of the jib section is:

$F_{N1} = F_1 \times \sin^2 \theta = 4.07\ q \sin^2 \theta$ (N) …………………. Equation 1a

For jib section 2, the wind load normal to the underside of the jib section is:

$F_{N2} = F_2 \times \sin^2 \theta = 4.48\ q \sin^2 \theta$ (N) …………………. Equation 2a

For jib section 3, the wind load normal to the underside of the jib section is:

$F_{N3} = F_3 \times \sin^2 \theta = 4.40q \sin^2 \theta$ (N) …………………. Equation 3a

For jib section 4, the wind load normal to the underside of the jib section is:

$F_{N4} = F_4 \times \sin^2 \theta = 2.25\ q \sin^2 \theta$ (N) …………………. Equation 4a

For jib section 5, the wind load normal to the underside of the jib section is:

$F_{N5} = F_5 \times \sin^2 \theta = 3.26\ q \sin^2 \theta$ (N) …………………. Equation 5a

The wind load normal to the jib end platform floor is given by:

$F_{NPLATFORM} = F_{PLATFORM} \times \sin^2 \theta = 1.01\ q \sin^2 \theta$ (N) …………………. Equation 6a

7.0 <u>Wind Loading Calculation in accordance with ISO 4302</u>

According to Section 2 of ISO 4302, the dynamic wind pressure, ρ is calculated using the equation:

$$\rho = 0.613 \times 10^{-3} \times V^2 \ \text{(kPa or kN/m}^2\text{)}$$

Where V is the wind speed in m/s

According to Section 4 of ISO 4302, the wind load *"for most complete and part structures, and individual members used in crane structures"* is calculated using the equation:

$$F = A \times \rho \times Cf$$

Where

F is the wind load (kN)
A is the effective frontal area of the part under consideration, i.e. the solid area projection on to a plane perpendicular to the wind direction (m^2)
ρ is the wind pressure corresponding to the appropriate design condition (kN/ m^2)
Cf is the force coefficient in the direction of the wind for the part under consideration

7.1 Force Coefficient for the jib sections, Cf_{JIB}

According to Section 5.1 of ISO 4302 the force coefficient, Cf for a single lattice frame is given in Table 2. Table 2 provides two values for single lattice frames having circular sections of 1.2 and 0.8.

The first coefficient of 1.2 is defined for the case where $D \times V_S < 6$ m^2/s and the second coefficient of 0.80 is defined for the case where $D \times V_S > 6$ m^2/s.

In ISO 4302, D is defined as *"the diameter of a circular section (m) and* V_S is defined as the *"design wind speed (m/s)"*.

In this case, D is chosen to be 0.076 m which is the largest diameter of any of the circular sections used to construct each of the five jib sections and V_S is chosen to be 20 m/s which is the maximum in service wind speed. Hence,

$D \times V_S = 0.076 \times 20 = 1.52$ m^2/s

This is less than 6 m^2/s and hence a shape factor of 1.20 will be used when considering the jib sections.

Section 5.2 of ISO 4302 is concerned with shielding and specifically states that it is concerned with parallel frames or members. Shielding factors depend upon the solidity ratio and spacing ratio of the frames or members involved and these are defined in Figure 2 of ISO 4302 together with accompanying diagrams. None of these diagrams show a triangular lattice frame and no method of calculating the spacing ratio for a triangular lattice frame is specified. Hence, it is interpreted that no shielding factor is intended to be applied.

Consequently the value of 1.2 for the five jib sections is taken to be the final value of Cf_{JIB}.

i.e. $Cf_{JIB} = 1.2$

7.2 *Force Coefficient for the jib end platform, $Cf_{PLATFORM}$*

The floor of the jib end platform was a solid flat plate measured to be 900 mm x 560 mm and according to the drawing supplied by the crane manufacturer was nominally 6 mm thick.

The 900 mm dimension lay in the same direction as the longitudinal axis of the jib, i.e. from the inner end to the outer end. The 560 mm dimension lay in the direction across the jib, i.e. from side chord to side chord.

A force coefficient for flat plates is provided in table 2 of ISO 4302 and this is dependant upon the aerodynamic slenderness (l/b) where l is the length of the member and b is the breadth of the section across the wind front. An accompanying diagram to determine the aerodynamic slenderness definition is provided and from this the aerodynamic slenderness floor of the jib end platform is determined to be 900/560 = 1.6

From table 2 there is no corresponding value for the force coefficient for an aerodynamic slenderness of 1.6. The smallest value for aerodynamic slenderness in table 2 is 5 and the corresponding value for the force coefficient is 1.3. This is also the smallest force coefficient for a flat plate in table 2 and consequently will be used for the jib end platform force coefficient. Hence

$$Cf_{PLATFORM} = 1.3$$

7.3 *Total Wind Load*

7.3.1 *Total Wind Load acting directly on individual jib sections*

The total wind load on an individual jib section is obtained by the equation F = A x ρ x Cf

For jib section 1, the wind load is:

$F_1 = 3.18 \times 1.2 \times \rho = 3.82 \times \rho$ (N)

For jib section 2, the wind load is:

$F_2 = 3.50 \times 1.2 \times \rho = 4.20 \times \rho$ (N)

For jib section 3, the wind load is:

$F_3 = 3.44 \times 1.2 \times \rho = 4.13 \times q$ (N)

For jib section 4, the wind load is:

$F_4 = 1.76 \times 1.2 \times \rho = 2.11 \times \rho$ (N)

For jib section 5, the wind load is:

$F_5 = 2.55 \times 1.2 \times \rho = 3.06 \times \rho$ (N)

7.3.2 *Total Wind Load acting directly on the jib end platform floor*

The wind load on the jib end platform floor is given by:

$F_{PLATFORM} = \rho \times Cf_{PLATFORM} \times A_{PLATFORM} = \rho \times 1.3 \times 0.504 = 0.655 \times \rho$ (N)

7.3.3 Total Wind Load acting on the inclined jib

The wind loads acting on the jib sections and jib end platform floor calculated in Sections 7.3.1 and 7.3.2 are derived from the wind blowing horizontally and acting directly against the effective areas, i.e. the wind striking the jib at an angle of 90º. However, the jib angle relative to the horizontal can be altered and therefore the wind will be acting against an inclined effective area. Section 5.4 of ISO 4302 states that *"where the wind blows at an angle to the longitudinal axis of a member or to the surface of a frame, the force in the direction of the wind, F, in newtons, is obtained from the equation:*

$$F = A.\ \rho.Cf\sin^2\theta$$

Where F, A, ρ *and Cf are as defined in clause 4 and θ is the angle of the wind (θ < 90º) to the longitudinal axis or face".*

Hence the equations derived in Sections 7.3.1 and 7.3.2 are adjusted to give the wind loading normal to the underside of the jib sections and jib end platform i.e:

For jib section 1, the wind load normal to the underside of the jib section is:

$F_{N1} = F_1 \text{ x } \sin^2\theta = 3.82\ \rho \sin^2\theta$ (N) …………………. Equation 1b

For jib section 2, the wind load normal to the underside of the jib section is:

$F_{N2} = F_2 \text{ x } \sin^2\theta = 4.20\ \rho \sin^2\theta$ (N) …………………. Equation 2b

For jib section 3, the wind load normal to the underside of the jib section is:

$F_{N3} = F_3 \text{ x } \sin^2\theta = 4.13\ \rho \sin^2\theta$ (N) …………………. Equation 3b

For jib section 4, the wind load normal to the underside of the jib section is:

$F_{N4} = F_4 \text{ x } \sin^2\theta = 2.11\ \rho \sin^2\theta$ (N) …………………. Equation 4b

For jib section 5, the wind load normal to the underside of the jib section is:

$F_{N5} = F_5 \text{ x } \sin^2\theta = 3.06\ \rho \sin^2\theta$ (N) …………………. Equation 5b

The wind load normal to the jib end platform floor is given by:

$F_{NPLATFORM} = F_{PLATFORM} \text{ x } \sin^2\theta = 0.655\ \rho \sin^2\theta$ (N) …………………. Equation 6b

8.0 <u>Wind Loading Calculation in accordance with BS EN 13001 – 2:2004</u>

According to Section 4.2.3.1 of BS EN 13001 – 2:2004, the wind loads (regarding the crane structure) assumed to act perpendicularly to the longitudinal axis of a crane member are calculated by

$$F = q(3) \times C \times A$$

Where:

F is the wind load
A is the characteristic area of the member under consideration
C is the aerodynamic coefficient of the member under consideration
q(3) is the wind pressure at v(3) = $0.5 \times \rho \times v(3)^2$
ρ is the density of air = 1.25 kg/m^3
v(3) is the gust wind velocity averaged over a period of 3 seconds = 1.5 x v, where v is the mean wind velocity, averaged over 10 minutes in 10 m height above flat ground or sea level.

Table 4 of section 4.2.3.1 defines v as 13.3 m/s for category 2, the normal wind state. The corresponding resultant values for v(3) and q in Table 4 are quoted as 20 m/s and 250 N/m^2 respectively. These are consistent with the equations above.

Values for C and A are given in annex A of BS EN 13001 – 2:2004

8.1 Aerodynamic Coefficient for the jib sections, C_{JIB}

According to annex A of BS EN 13001 – 2:2004 the aerodynamic coefficient, Co for a triangular spatial lattice structure having circular sections is given in Figure A8. The value of Co is read directly from the relevant figure and is dependant upon the solidity ratio (ψ) of the lattice and Reynolds number.

The solidity ratio (ψ) is defined in section A1 of annex A as *"the sum of the areas of the individual members with gusset plates projected to the plane of the characteristic height d of the lattice structure member/the area enclosed by the boundary of the lattice structure member in the plane of its characteristic height d"*. This definition is only concerned with plane lattice structures and hence the solidity ratio of the lattice directly facing the wind, i.e. the underside of the jib is calculated as follows:

For jib section 1 the solidity ratio is :

ψ_1 = 3.18/(9.17 x 0.86) = 0.40

For jib section 2 the solidity ratio is :

ψ_2 = 3.50/(10.0 x 0.86) = 0.41

For jib section 3 the solidity ratio is :

ψ_3 = 3.44/(10.0 x 0.86) = 0.40

For jib section 4 the solidity ratio is :

ψ_4 = 1.76/(5.11 x 0.86) = 0.40

For jib section 5 the solidity ratio is :

$\psi_5 = 2.55/(7.411 \times 0.86) = 0.40$

Annex A defines Reynolds number (Re) as:

$Re = 0.667 \times 10^6 \times v \times d$

Where

d is the characteristic dimension of a member (m)

v is the wind speed

In this case, d is chosen to be 0.076 m which is the largest diameter of any of the circular sections used to construct each of the five jib sections and v is chosen to be 20 m/s which is the maximum in service wind speed. Hence,

$Re = 0.667 \times 10^6 \times 0.076 \times 20 = 1.01 \times 10^6\ m^2/s$

From the relevant graph of Figure A8 the aerodynamic coefficient, Co, for the five jib sections is read directly as 1.28. Reynolds number is less than 2×10^5 and according to the graph the aerodynamic coefficient will not alter at wind speeds below 20 m/s, i.e. the 1.28 figure remains constant for wind speeds up to the maximum in service design wind speed of 20 m/s.

Table A.6 of annex A is concerned with shielding factors that depend upon the solidity ratio and spacing ratio of the frames or members involved and these are defined in Figure A.9 of annex A. No method of calculating the spacing ratio for a triangular lattice frame is specified. Hence, it is interpreted that no shielding factor is intended to be applied.

Section A1 of annex A states that the aerodynamic coefficient, $Ca = Co \times \Psi$, where Ψ is a reduction factor that accounts for members of finite length. Ψ depends on the aerodynamic slenderness ratio, λ, and the solidity ratio if the member is a lattice.

The aerodynamic slenderness ratio, λ, is defined in annex A as $\lambda = la/d$

Where d is as defined previously as 0.076 m and

$la = lo \times \alpha r$

Where lo is the length of the member, i.e. the distance between the free ends of the member or, in the case the member is connected to other members , the distance between the centres of their joints and αr is the relative aerodynamic length which is given in table A.1 of annex A.

In this case it is assumed that the members of the lattice of the underside of the jib are not obstructed by adjacent obstacles and so $\alpha r = 1$.

Hence la is taken to be the length of the individual jib sections and the aerodynamic slenderness ratio for each jib section is the length of each jib section divided by 0.076 m, i.e:

$\lambda_{JIBSECTION\ 1} = 9.17/0.076 = 121$

$\lambda_{JIBSECTION\ 2} = 10/0.076 = 131$

$\lambda_{JIBSECTION\ 3}$ = 10/0.076 = 131

$\lambda_{JIBSECTION\ 4}$ = 5.11/0.076 = 67

$\lambda_{JIBSECTION\ 5}$ = 7.411/0.076 = 98

Values of Ψ are read from a graph given in section A.1 and for a solidity ratio of 0.40 – 0.41 and slenderness ratios of 67 – 131, the smallest value of Ψ = 0.98. Hence Ca for all five jib sections is:

Ca = Co x Ψ = 1.28 x 0.98 = 1.25

Although not specifically stated in annex A, this aerodynamic coefficient, Ca, is taken to be the same aerodynamic coefficient C referred to in Section 4.2.3.1 of BS EN 13001-2:2004 and used in the equation, F = q(3) x C x A to determine the wind load. Hence the Aerodynamic Coefficient for the jib sections, C_{JIB} = Ca = C = 1.25.

8.2 Force Coefficient for the jib end platform, $C_{PLATFORM}$

The floor of the jib end platform was a solid flat plate measured to be 900 mm x 560 mm and according to the drawing supplied by the crane manufacturer was nominally 6 mm thick.

The 900 mm dimension lay in the same direction as the longitudinal axis of the jib, i.e. from the inner end to the outer end. The 560 mm dimension lay in the direction across the jib, i.e. from side chord to side chord.

A force coefficient for flat plates is provided in table A.3 of BS EN 13001-2:2004 and this is dependant upon the section ratio (b/d) where b is the thickness of the flat member and d is the breadth of the section across the wind front. An accompanying diagram to determine the aerodynamic slenderness definition is provided and from this the largest section ratio of the jib end platform is determined to be 6/560 = 0.01.

From table A.3 the corresponding value for the force coefficient, Co, for a flat plate having a section ratio of < 0.1 is 2.0 when the wind is acting directly against the flat plate.

As before Co should be adjusted by the factor Ψ, which depends on the aerodynamic slenderness ratio, λ, and the solidity ratio if the member is a lattice.

The aerodynamic slenderness ratio, λ, is defined in annex A as λ = la/d = 900/560 = 1.6 and the solidity ratio = 1.

From the graph given in section A.1 of annex A, a value for Ψ = 0.62 is obtained. Hence Ca for the jib end platform is:

Ca = Co x Ψ = 2.0 x 0.62 = 1.24

Although not specifically stated in annex A, this aerodynamic coefficient, Ca, is taken to be the same aerodynamic coefficient C referred to in Section 4.2.3.1 of BS EN 13001-2:2004 and used in the equation, F = q(3) x C x A to determine the wind load. Hence the Aerodynamic Coefficient for the jib end platform, $C_{PLATFORM}$ = Ca = C = 1.24.

8.3 Total Wind Load

8.3.1 Total Wind Load acting directly on individual jib sections

The total wind load on an individual jib section is obtained by the equation F = q(3) x C x A
For jib section 1, the wind load is:

F_1 = 3.18 x 1.25 x q(3) = 3.98 x q(3) (N)

For jib section 2, the wind load is:

F_2 = 3.50 x 1.25 x q(3) = 4.38 x q(3) (N)

For jib section 3, the wind load is:

F_3 = 3.44 x 1.25 x q(3) = 4.30 x q(3) (N)

For jib section 4, the wind load is:

F_4 = 1.76 x 1.25 x q(3) = 2.20 x q(3) (N)

For jib section 5, the wind load is:

F_5 = 2.55 x 1.25 x q(3) = 3.19 x q(3) (N)

8.3.2 Total Wind Load acting directly on the jib end platform floor

The wind load on the jib end platform floor is given by:

$F_{PLATFORM}$ = q(3) x $C_{PLATFORM}$ x $A_{PLATFORM}$ = q(3) x 1.24 x 0.504 = 0.62 x q(3) (N)

8.3.3 Total Wind Load acting on the inclined jib

The wind loads acting on the jib sections and jib end platform floor calculated in Sections 8.3.1 and 8.3.2 are derived from the wind blowing horizontally and acting directly against the effective areas, i.e. the wind striking the jib at an angle of 90º. However, the jib angle relative to the horizontal can be altered and therefore the wind will be acting against an inclined effective area. Section 4.2.3.1 of BS EN 13001 – 2:2004 states that *"Considering a crane member, the component v* of the wind velocity acting perpendicularly to the longitudinal axis of the crane member shall be applied; it is calculated by* $v^* = v \times \sin \alpha_w$ where *α_w is the angle between the direction of the wind velocity v and the longitudinal axis of the member under consideration".*

Hence the equations derived in Sections 8.3.1 and 8.3.2 are adjusted to give the wind loading normal to the underside of the jib sections and jib end platform i.e:

For jib section 1, the wind load normal to the underside of the jib section is:

$F_{N1} = F_1 \times \sin \theta = 3.98\ q(3) \sin \theta$ (N) …………………. Equation 1c

For jib section 2, the wind load normal to the underside of the jib section is:

$F_{N2} = F_2 \times \sin \theta = 4.38\ q(3) \sin \theta$ (N) …………………. Equation 2c

For jib section 3, the wind load normal to the underside of the jib section is:

$F_{N3} = F_3 \text{ x } \sin\theta = 4.30\ q(3) \sin\theta$ (N) …………………. Equation 3c

For jib section 4, the wind load normal to the underside of the jib section is:

$F_{N4} = F_4 \text{ x } \sin\theta = 2.20\ q(3) \sin\theta$ (N) …………………. Equation 4c

For jib section 5, the wind load normal to the underside of the jib section is:

$F_{N5} = F_5 \text{ x } \sin\theta = 3.19\ q(3) \sin\theta$ (N) …………………. Equation 5c

The wind load normal to the jib end platform floor is given by:

$F_{NPLATFORM} = F_{PLATFORM} \text{ x } \sin\theta = 0.62\ q(3) \sin\theta$ (N) …………………. Equation 6c

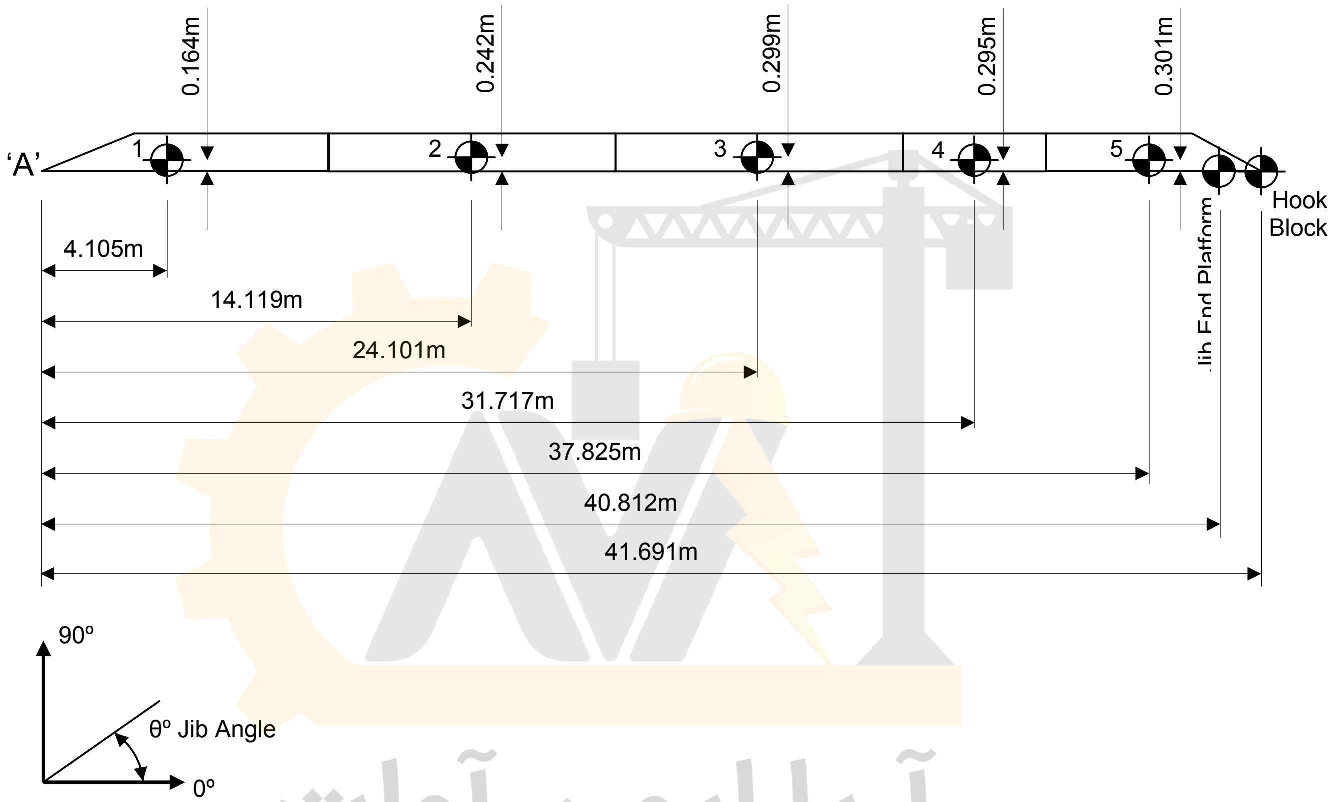
APPENDIX 4

Calculation of the wind loading and consequent moment acting at the jib pivot point according to FEM 1.001 *"Rules for the Design of Hoisting Appliances – Classification and Loading on Structures and Mechanisms"*

Appendix 4

Calculation of the moment acting at the jib pivot points due to wind loading on the jib and jib end platform according to FEM 1.001

1. Theoretical properties of the jib sections i.e. the masses provided in the crane manual and positions of centre of gravity provided by Jaso



The moment, M_{WIND}, acting at the jib pivot point 'A' arising from the wind loading is given by:

$M_{WIND} = F_N \cos(\tan^{-1} y/x) x$ where

F_N is the wind load normal to the underside of the jib component under consideration (N)
x is the dimension along the jib section from 'A' to the centre of gravity of the jib section (m)
y is the dimension from 'A' to the centre of gravity of the jib section perpendicular to the x is the dimension (m)

Since the centre of gravity of the jib sections are slightly offset from the pivot point in the vertical (y) direction the term $\cos(\tan^{-1} y/x)$ in the above equation resolves F_N (the wind load normal to the underside of the jib component under consideration) to the lever arm joining the centre of gravity to the pivot point such that the resultant force is completely perpendicular to the lever arm. However, the angles between the centres of gravity of the jib sections and the pivot point are very small such that $\cos(\tan^{-1} y/x)$ tends to unity. Hence this is ignored and the moment, M_{WIND}, acting at the jib pivot point 'A' arising from the wind loading is given by:

$M_{WIND} = F_N\, x$ where

F_N is the wind load normal to the underside of the jib component under consideration (N)
x is the dimension along the jib section from 'A' to the centre of gravity of the jib section (m)

Since the wind load, F_N, is normal to the underside of the jib component under consideration, x remains constant at the dimensions shown in the sketch above as the angle of the jib to the horizontal alters.

For any given jib angle to the horizontal, the total moment acting at the jib pivot point 'A' arising from the wind load acting on each jib section is given by adding the moment arising from each individual jib section 1 to 5 (M_{WIND1} – M_{WIND5}) and that arising from the jib end platform ($M_{WINDPLATFORM}$), i.e:

$$M_{WINDTOTAL} = M_{WIND1} + M_{WIND2} + M_{WIND3} + M_{WIND4} + M_{WIND5} + M_{WINDPLATFORM}$$

The wind loading on each jib section and the jib end platform has been calculated in Appendix 3 according to FEM 1.001, FEM 1.004, ISO 4302 and BS EN 13001 – 2:2004 and equations for F_N derived.

Example Calculation – FEM 1.001 (wind speed = 15 m/s, jib angle = 57º to the horizontal)

Assuming a wind speed of 15 m/s, the wind pressure q is given by:

$$q = 0.613 \times 15^2 = 137.9 \text{ N/m}^2$$

Using equations 1 – 6 derived in Appendix 3 Section 5.4.3, for a jib angle of 57º to the horizontal the wind load normal to the underside of the jib component under consideration and acting at the centre of gravity is:

For jib section 1, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$$F_{N1} = 3.72\, q \sin^2 \theta = 3.72 \times 137.9 \times \sin^2 57º = 360.8 \text{ N}$$
$$M_{WIND1} = 360.8 \times 4.105 = 1.48 \text{ kNm}$$

For jib section 2, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$$F_{N2} = 4.19\, q \sin^2 \theta = 4.19 \times 137.9 \times \sin^2 57º = 406.4 \text{ N}$$
$$M_{WIND2} = 406.4 \times 14.119 = 5.74 \text{ kNm}$$

For jib section 3, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$$F_{N3} = 4.08\, q \sin^2 \theta = 4.08 \times 137.9 \times \sin^2 57º = 395.7 \text{ N}$$
$$M_{WIND3} = 395.7 \times 24.101 = 9.54 \text{ kNm}$$

For jib section 4, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$$F_{N4} = 2.09\, q \sin^2 \theta = 2.09 \times 137.9 \times \sin^2 57º = 202.7 \text{ N}$$
$$M_{WIND4} = 202.7 \times 31.717 = 6.43 \text{ kNm}$$

For jib section 5, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N5} = 3.08\ q \sin^2 \theta = 3.08 \times 137.9 \times \sin^2 57^o = 298.7$ N
$M_{WIND5} = 298.7 \times 37.825 = 11.30$ kNm

The wind load normal to the jib end platform floor and resulting moment at the jib pivot point is:

$F_{NPLATFORM} = 0.66\ q \sin^2 \theta = 0.66 \times 137.9 \times \sin^2 57^o = 64.0$ N
$M_{WINDPLATFORM} = 64.0 \times 40.812 = 2.61$ kNm

The total moment at the jib pivot point due to wind loading at a wind speed of 15 m/s and a jib angle of 57º to the horizontal is:

$M_{WINDTOTAL} = 1.48 + 5.74 + 9.54 + 6.43 + 11.30 + 2.61 = 37.10$ kNm

Similar calculations can be performed for different wind speeds and jib angles and the resultant moments at the jib pivot point are given in Table 1 of this appendix.

Jib Angle (°)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
15	0.02	0.06	0.14	0.25	0.39	0.57	0.77	1.01	1.27	1.57	1.90	2.26	2.65	3.08	3.53	4.02	4.54	5.09	5.67	6.41
16	0.02	0.07	0.16	0.29	0.45	0.64	0.87	1.14	1.44	1.78	2.16	2.57	3.01	3.49	4.01	4.56	5.15	5.77	6.43	7.26
17	0.02	0.08	0.18	0.32	0.50	0.72	0.98	1.28	1.62	2.00	2.43	2.89	3.39	3.93	4.51	5.13	5.79	6.49	7.24	8.17
18	0.02	0.09	0.20	0.36	0.56	0.81	1.10	1.43	1.81	2.24	2.71	3.22	3.78	4.39	5.04	5.73	6.47	7.25	8.08	9.13
19	0.02	0.10	0.22	0.40	0.62	0.89	1.22	1.59	2.01	2.49	3.01	3.58	4.20	4.87	5.59	6.36	7.18	8.05	8.97	10.14
20	0.03	0.11	0.25	0.44	0.69	0.99	1.34	1.76	2.22	2.74	3.32	3.95	4.64	5.38	6.17	7.02	7.93	8.89	9.90	11.19
21	0.03	0.12	0.27	0.48	0.75	1.08	1.48	1.93	2.44	3.01	3.64	4.34	5.09	5.90	6.78	7.71	8.70	9.76	10.87	12.28
22	0.03	0.13	0.30	0.53	0.82	1.18	1.61	2.11	2.67	3.29	3.98	4.74	5.56	6.45	7.40	8.42	9.51	10.66	11.88	13.42
23	0.04	0.14	0.32	0.57	0.89	1.29	1.75	2.29	2.90	3.58	4.33	5.15	6.05	7.02	8.05	9.16	10.35	11.60	12.92	14.60
24	0.04	0.16	0.35	0.62	0.97	1.40	1.90	2.48	3.14	3.88	4.69	5.59	6.56	7.60	8.73	9.93	11.21	12.57	14.00	15.82
25	0.04	0.17	0.38	0.67	1.05	1.51	2.05	2.68	3.39	4.19	5.07	6.03	7.08	8.21	9.42	10.72	12.10	13.57	15.12	17.08
26	0.05	0.18	0.41	0.72	1.13	1.62	2.21	2.88	3.65	4.51	5.45	6.49	7.61	8.83	10.14	11.53	13.02	14.60	16.27	18.38
27	0.05	0.19	0.43	0.77	1.21	1.74	2.37	3.09	3.91	4.83	5.85	6.96	8.17	9.47	10.87	12.37	13.97	15.66	17.45	19.71
28	0.05	0.21	0.47	0.83	1.29	1.86	2.53	3.31	4.19	5.17	6.25	7.44	8.73	10.13	11.63	13.23	14.93	16.74	18.66	21.08
29	0.06	0.22	0.50	0.88	1.38	1.98	2.70	3.53	4.46	5.51	6.67	7.94	9.31	10.80	12.40	14.11	15.93	17.86	19.89	22.47
30	0.06	0.23	0.53	0.94	1.47	2.11	2.87	3.75	4.75	5.86	7.09	8.44	9.91	11.49	13.19	15.01	16.94	18.99	21.16	23.91
31	0.06	0.25	0.56	1.00	1.55	2.24	3.05	3.98	5.04	6.22	7.53	8.96	10.51	12.19	13.99	15.92	17.97	20.15	22.45	25.37
32	0.07	0.26	0.59	1.05	1.65	2.37	3.23	4.21	5.33	6.58	7.97	9.48	11.13	12.90	14.81	16.86	19.03	21.33	23.77	26.85
33	0.07	0.28	0.63	1.11	1.74	2.50	3.41	4.45	5.63	6.95	8.42	10.02	11.75	13.63	15.65	17.80	20.10	22.53	25.11	28.36
34	0.07	0.29	0.66	1.17	1.83	2.64	3.59	4.69	5.94	7.33	8.87	10.56	12.39	14.37	16.50	18.77	21.19	23.75	26.47	29.90
35	0.08	0.31	0.69	1.23	1.93	2.78	3.78	4.94	6.25	7.71	9.33	11.11	13.04	15.12	17.36	19.75	22.29	24.99	27.85	31.46
36	0.08	0.32	0.73	1.30	2.03	2.92	3.97	5.18	6.56	8.10	9.80	11.66	13.69	15.88	18.23	20.74	23.41	26.25	29.24	33.04
37	0.08	0.34	0.76	1.36	2.12	3.06	4.16	5.43	6.88	8.49	10.28	12.23	14.35	16.64	19.11	21.74	24.54	27.51	30.66	34.63
38	0.09	0.36	0.80	1.42	2.22	3.20	4.35	5.69	7.20	8.89	10.75	12.80	15.02	17.42	20.00	22.75	25.68	28.79	32.08	36.24
39	0.09	0.37	0.84	1.49	2.32	3.34	4.55	5.94	7.52	9.29	11.24	13.37	15.69	18.20	20.89	23.77	26.84	30.09	33.52	37.87
40	0.10	0.39	0.87	1.55	2.42	3.49	4.75	6.20	7.85	9.69	11.72	13.95	16.37	18.99	21.80	24.80	28.00	31.39	34.97	39.51
41	0.10	0.40	0.91	1.61	2.52	3.63	4.94	6.46	8.17	10.09	12.21	14.53	17.05	19.78	22.71	25.83	29.16	32.70	36.43	41.16
42	0.10	0.42	0.94	1.68	2.62	3.78	5.14	6.72	8.50	10.50	12.70	15.12	17.74	20.58	23.62	26.87	30.34	34.01	37.90	42.81
43	0.11	0.44	0.98	1.74	2.73	3.93	5.34	6.98	8.83	10.91	13.20	15.70	18.43	21.37	24.54	27.92	31.52	35.33	39.37	44.48

Table 1 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Theoretical jib Properties (FEM 1.001)

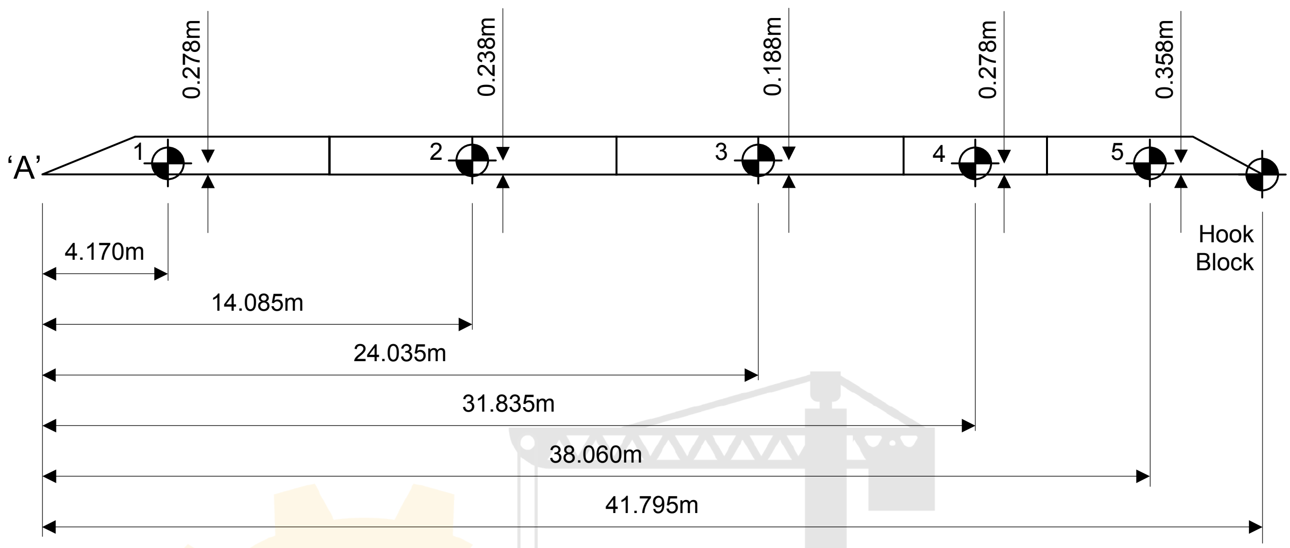
Jib Angle (°)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
44	0.11	0.45	1.02	1.81	2.83	4.07	5.54	7.24	9.16	11.31	13.69	16.29	19.12	22.18	25.46	28.96	32.70	36.66	40.84	46.14
45	0.12	0.47	1.06	1.88	2.93	4.22	5.74	7.50	9.50	11.72	14.19	16.88	19.81	22.98	26.38	30.01	33.88	37.98	42.32	47.81
46	0.12	0.49	1.09	1.94	3.03	4.37	5.94	7.76	9.83	12.13	14.68	17.47	20.50	23.78	27.30	31.06	35.06	39.31	43.80	49.48
47	0.13	0.50	1.13	2.01	3.14	4.51	6.15	8.03	10.16	12.54	15.17	18.06	21.19	24.58	28.22	32.10	36.24	40.63	45.27	51.15
48	0.13	0.52	1.17	2.07	3.24	4.66	6.34	8.29	10.49	12.95	15.67	18.65	21.88	25.38	29.13	33.15	37.42	41.95	46.74	52.81
49	0.13	0.53	1.20	2.14	3.34	4.81	6.54	8.55	10.82	13.35	16.16	19.23	22.57	26.18	30.05	34.19	38.60	43.27	48.21	54.46
50	0.14	0.55	1.24	2.20	3.44	4.95	6.74	8.81	11.14	13.76	16.65	19.81	23.25	26.97	30.96	35.22	39.76	44.58	49.67	56.11
51	0.14	0.57	1.27	2.27	3.54	5.10	6.94	9.06	11.47	14.16	17.13	20.39	23.93	27.75	31.86	36.25	40.92	45.88	51.12	57.75
52	0.15	0.58	1.31	2.33	3.64	5.24	7.13	9.32	11.79	14.56	17.62	20.97	24.61	28.54	32.76	37.27	42.08	47.17	52.56	59.38
53	0.15	0.60	1.35	2.39	3.74	5.38	7.33	9.57	12.11	14.95	18.10	21.53	25.27	29.31	33.65	38.28	43.22	48.45	53.99	60.99
54	0.15	0.61	1.38	2.46	3.84	5.52	7.52	9.82	12.43	15.35	18.57	22.10	25.93	30.08	34.53	39.29	44.35	49.72	55.40	62.59
55	0.16	0.63	1.42	2.52	3.93	5.66	7.71	10.07	12.74	15.73	19.04	22.66	26.59	30.84	35.40	40.28	45.47	50.97	56.80	64.16
56	0.16	0.64	1.45	2.58	4.03	5.80	7.90	10.31	13.05	16.11	19.50	23.21	27.23	31.59	36.26	41.25	46.57	52.21	58.17	65.72
57	0.16	0.66	1.48	2.64	4.12	5.94	8.08	10.55	13.36	16.49	19.95	23.75	27.87	32.32	37.11	42.22	47.66	53.43	59.53	67.26
58	0.17	0.67	1.52	2.70	4.22	6.07	8.26	10.79	13.66	16.86	20.40	24.28	28.50	33.05	37.94	43.17	48.73	54.63	60.87	68.77
59	0.17	0.69	1.55	2.76	4.31	6.20	8.44	11.03	13.95	17.23	20.84	24.81	29.11	33.76	38.76	44.10	49.79	55.82	62.19	70.26
60	0.18	0.70	1.58	2.81	4.40	6.33	8.62	11.25	14.24	17.58	21.28	25.32	29.72	34.47	39.57	45.02	50.82	56.97	63.48	71.72
61	0.18	0.72	1.61	2.87	4.48	6.46	8.79	11.48	14.53	17.94	21.70	25.83	30.31	35.15	40.36	45.92	51.83	58.11	64.75	73.15
62	0.18	0.73	1.65	2.92	4.57	6.58	8.96	11.70	14.81	18.28	22.12	26.32	30.89	35.83	41.13	46.79	52.83	59.22	65.99	74.55
63	0.19	0.74	1.68	2.98	4.65	6.70	9.12	11.91	15.08	18.61	22.52	26.80	31.46	36.48	41.88	47.65	53.79	60.31	67.20	75.91
64	0.19	0.76	1.70	3.03	4.74	6.82	9.28	12.12	15.34	18.94	22.92	27.27	32.01	37.12	42.62	48.49	54.74	61.37	68.38	77.25
65	0.19	0.77	1.73	3.08	4.81	6.93	9.44	12.33	15.60	19.26	23.30	27.73	32.55	37.75	43.33	49.30	55.66	62.40	69.52	78.54
66	0.20	0.78	1.76	3.13	4.89	7.04	9.59	12.52	15.85	19.57	23.68	28.18	33.07	38.35	44.03	50.09	56.55	63.40	70.64	79.80
67	0.20	0.79	1.79	3.18	4.97	7.15	9.73	12.71	16.09	19.87	24.04	28.61	33.57	38.94	44.70	50.86	57.42	64.37	71.72	81.02
68	0.20	0.81	1.81	3.22	5.04	7.26	9.88	12.90	16.33	20.16	24.39	29.02	34.06	39.51	45.35	51.60	58.25	65.31	72.76	82.20
69	0.20	0.82	1.84	3.27	5.11	7.36	10.01	13.08	16.55	20.44	24.73	29.43	34.54	40.05	45.98	52.31	59.06	66.21	73.77	83.34
70	0.21	0.83	1.86	3.31	5.18	7.45	10.14	13.25	16.77	20.70	25.05	29.81	34.99	40.58	46.58	53.00	59.83	67.08	74.74	84.44
71	0.21	0.84	1.89	3.35	5.24	7.55	10.27	13.42	16.98	20.96	25.36	30.18	35.42	41.08	47.16	53.66	60.58	67.91	75.67	85.49
72	0.21	0.85	1.91	3.39	5.30	7.63	10.39	13.57	17.18	21.21	25.66	30.54	35.84	41.57	47.72	54.29	61.29	68.71	76.56	86.49
73	0.21	0.86	1.93	3.43	5.36	7.72	10.51	13.72	17.37	21.44	25.95	30.88	36.24	42.03	48.24	54.89	61.97	69.47	77.41	87.45
74	0.22	0.87	1.95	3.47	5.42	7.80	10.62	13.87	17.55	21.67	26.21	31.20	36.61	42.46	48.75	55.46	62.61	70.19	78.21	88.36

Table 1 - (continued) Moment at the Jib Pivot Point due to Wind Loading (kNm)
Theoretical jib Properties (FEM 1.001)

Jib Angle (°)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
75	*0.22*	*0.88*	*1.97*	*3.50*	*5.47*	*7.88*	*10.72*	*14.00*	*17.72*	*21.88*	*26.47*	*31.50*	*36.97*	*42.88*	*49.22*	*56.00*	*63.22*	*70.88*	*78.97*	*89.22*
76	*0.22*	*0.88*	*1.99*	*3.53*	*5.52*	*7.95*	*10.82*	*14.13*	*17.88*	*22.07*	*26.71*	*31.79*	*37.31*	*43.27*	*49.67*	*56.51*	*63.79*	*71.52*	*79.69*	*90.03*
77	*0.22*	*0.89*	*2.00*	*3.56*	*5.56*	*8.01*	*10.91*	*14.25*	*18.03*	*22.26*	*26.93*	*32.05*	*37.62*	*43.63*	*50.08*	*56.99*	*64.33*	*72.12*	*80.36*	*90.78*
78	*0.22*	*0.90*	*2.02*	*3.59*	*5.61*	*8.08*	*10.99*	*14.36*	*18.17*	*22.43*	*27.14*	*32.30*	*37.91*	*43.97*	*50.47*	*57.43*	*64.83*	*72.68*	*80.98*	*91.49*
79	*0.23*	*0.90*	*2.03*	*3.61*	*5.65*	*8.13*	*11.07*	*14.46*	*18.30*	*22.59*	*27.34*	*32.53*	*38.18*	*44.28*	*50.83*	*57.84*	*65.29*	*73.20*	*81.56*	*92.14*
80	*0.23*	*0.91*	*2.05*	*3.64*	*5.68*	*8.19*	*11.14*	*14.55*	*18.42*	*22.74*	*27.51*	*32.74*	*38.43*	*44.57*	*51.16*	*58.21*	*65.72*	*73.68*	*82.09*	*92.74*
81	*0.23*	*0.91*	*2.06*	*3.66*	*5.72*	*8.23*	*11.21*	*14.64*	*18.53*	*22.87*	*27.68*	*32.94*	*38.65*	*44.83*	*51.46*	*58.55*	*66.10*	*74.11*	*82.57*	*93.28*
82	*0.23*	*0.92*	*2.07*	*3.68*	*5.75*	*8.28*	*11.27*	*14.72*	*18.62*	*22.99*	*27.82*	*33.11*	*38.86*	*45.06*	*51.73*	*58.86*	*66.45*	*74.50*	*83.00*	*93.77*
83	*0.23*	*0.92*	*2.08*	*3.70*	*5.77*	*8.32*	*11.32*	*14.78*	*18.71*	*23.10*	*27.95*	*33.26*	*39.04*	*45.27*	*51.97*	*59.13*	*66.75*	*74.84*	*83.38*	*94.20*
84	*0.23*	*0.93*	*2.09*	*3.71*	*5.80*	*8.35*	*11.36*	*14.84*	*18.78*	*23.19*	*28.06*	*33.39*	*39.19*	*45.45*	*52.18*	*59.37*	*67.02*	*75.14*	*83.72*	*94.58*
85	*0.23*	*0.93*	*2.09*	*3.72*	*5.82*	*8.38*	*11.40*	*14.89*	*18.85*	*23.27*	*28.15*	*33.51*	*39.32*	*45.61*	*52.35*	*59.57*	*67.25*	*75.39*	*84.00*	*94.90*
86	*0.23*	*0.93*	*2.10*	*3.73*	*5.83*	*8.40*	*11.43*	*14.93*	*18.90*	*23.33*	*28.23*	*33.60*	*39.43*	*45.73*	*52.50*	*59.73*	*67.43*	*75.60*	*84.23*	*95.16*
87	*0.23*	*0.94*	*2.10*	*3.74*	*5.85*	*8.42*	*11.46*	*14.96*	*18.94*	*23.38*	*28.29*	*33.67*	*39.52*	*45.83*	*52.61*	*59.86*	*67.57*	*75.76*	*84.41*	*95.36*
88	*0.23*	*0.94*	*2.11*	*3.75*	*5.85*	*8.43*	*11.47*	*14.99*	*18.97*	*23.42*	*28.34*	*33.72*	*39.58*	*45.90*	*52.69*	*59.95*	*67.68*	*75.87*	*84.54*	*95.51*
89	*0.23*	*0.94*	*2.11*	*3.75*	*5.86*	*8.44*	*11.49*	*15.00*	*18.99*	*23.44*	*28.36*	*33.75*	*39.61*	*45.94*	*52.74*	*60.00*	*67.74*	*75.94*	*84.62*	*95.59*
90	*0.23*	*0.94*	*2.11*	*3.75*	*5.86*	*8.44*	*11.49*	*15.01*	*18.99*	*23.45*	*28.37*	*33.76*	*39.62*	*45.96*	*52.75*	*60.02*	*67.76*	*75.97*	*84.64*	*95.62*

Table 1 - (continued) Moment at the Jib Pivot Point due to Wind Loading (kNm)
Theoretical Jib properties (FEM 1.001)

2. Masses and positions of centre of gravity measured during erection of the crane at HSL



As before, the moment, M_{WIND}, acting at the jib pivot point 'A' arising from the wind loading is given by:

$M_{WIND} = F_N x$ where

F_N is the wind load normal to the underside of the jib component under consideration (N)
x is the dimension along the jib section from 'A' to the centre of gravity of the jib section (m)

Since the wind load, F_N, is normal to the underside of the jib component under consideration, x remains constant at the dimensions shown in the sketch above as the angle of the jib to the horizontal alters.

For any given jib angle to the horizontal, the total moment acting at the jib pivot point 'A' arising from the wind load acting on each jib section is given by adding the moment arising from each individual jib section 1 to 5 ($M_{WIND1} - M_{WIND5}$). In this case, the position of the centre of gravity for Jib section 5 incorporates the jib end platform since the platform was fitted when the position of the centre of gravity was measured during erection of the crane at HSL. To determine M_{WIND5}, the wind load on the jib and on the end platform are added and then multiplied by the x dimension.

$M_{WINDTOTAL} = M_{WIND1} + M_{WIND2} + M_{WIND3} + M_{WIND4} + M_{WIND5}$

Example Calculation – FEM 1.001 (wind speed = 16 m/s, jib angle = 77º to the horizontal)

Assuming a wind speed of 16 m/s, the wind pressure q is given by:

$q = 0.613 \times 16^2 = 156.9 \text{ N/m}^2$

Using equations 1 – 6 derived in Appendix 3 Section 5.4.3, for a jib angle of 77º to the horizontal the wind load normal to the underside of the jib component under consideration and acting at the centre of gravity is:

For jib section 1, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N1} = 3.72\ q \sin^2 \theta = 3.72 \times 156.9 \times \sin^2 77^o = 554.1$ N
$M_{WIND1} = 554.1 \times 4.170 = 2.31$ kNm

For jib section 2, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N2} = 4.19\ q \sin^2 \theta = 4.19 \times 156.9 \times \sin^2 77^o = 624.1$ N
$M_{WIND2} = 624.1 \times 14.085 = 8.79$ kNm

For jib section 3, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N3} = 4.08\ q \sin^2 \theta = 4.08 \times 156.9 \times \sin^2 77^o = 607.80$ N
$M_{WIND3} = 607.80 \times 24.035 = 14.61$ kNm

For jib section 4, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N4} = 2.09\ q \sin^2 \theta = 2.09 \times 156.9 \times \sin^2 77^o = 311.3$ N
$M_{WIND4} = 311.3 \times 31.835 = 9.91$ kNm

For jib section 5, the wind load normal to the underside of the jib section is:

$F_{N5} = 3.08\ q \sin^2 \theta = 3.08 \times 156.9 \times \sin^2 77^o = 458.8$ N

The wind load normal to the jib end platform floor is:

$F_{NPLATFORM} = 0.66\ q \sin^2 \theta = 0.66 \times 156.9 \times \sin^2 77^o = 98.3$ N

For jib section 5 and the jib end platform, the resulting moment at the jib pivot point is:

$M_{WIND5} = (458.8 + 98.3) \times 38.060 = 21.20$ kNm

The total moment at the jib pivot point due to wind loading at a wind speed of 16 m/s and a jib angle of 77º to the horizontal is:

$M_{WINDTOTAL} = 2.31 + 8.79 + 14.61 + 9.91 + 21.20 = 56.82$ kNm

Similar calculations can be performed for different wind speeds and jib angles and the resultant moments at the jib pivot point are given in Table 2 of this appendix.

Jib Angle (º)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
15	*0.02*	*0.06*	*0.14*	*0.25*	*0.39*	*0.56*	*0.77*	*1.00*	*1.27*	*1.57*	*1.90*	*2.26*	*2.65*	*3.07*	*3.52*	*4.01*	*4.53*	*5.08*	*5.65*	*6.39*
16	*0.02*	*0.07*	*0.16*	*0.28*	*0.44*	*0.64*	*0.87*	*1.14*	*1.44*	*1.78*	*2.15*	*2.56*	*3.00*	*3.48*	*4.00*	*4.55*	*5.13*	*5.76*	*6.41*	*7.25*
17	*0.02*	*0.08*	*0.18*	*0.32*	*0.50*	*0.72*	*0.98*	*1.28*	*1.62*	*2.00*	*2.42*	*2.88*	*3.38*	*3.92*	*4.50*	*5.12*	*5.78*	*6.48*	*7.22*	*8.15*
18	*0.02*	*0.09*	*0.20*	*0.36*	*0.56*	*0.80*	*1.09*	*1.43*	*1.81*	*2.23*	*2.70*	*3.22*	*3.77*	*4.38*	*5.02*	*5.72*	*6.45*	*7.23*	*8.06*	*9.11*
19	*0.02*	*0.10*	*0.22*	*0.40*	*0.62*	*0.89*	*1.21*	*1.59*	*2.01*	*2.48*	*3.00*	*3.57*	*4.19*	*4.86*	*5.58*	*6.35*	*7.16*	*8.03*	*8.95*	*10.11*
20	*0.03*	*0.11*	*0.25*	*0.44*	*0.68*	*0.98*	*1.34*	*1.75*	*2.22*	*2.74*	*3.31*	*3.94*	*4.62*	*5.36*	*6.15*	*7.00*	*7.91*	*8.86*	*9.87*	*11.16*
21	*0.03*	*0.12*	*0.27*	*0.48*	*0.75*	*1.08*	*1.47*	*1.92*	*2.43*	*3.00*	*3.63*	*4.32*	*5.08*	*5.89*	*6.76*	*7.69*	*8.68*	*9.73*	*10.84*	*12.25*
22	*0.03*	*0.13*	*0.30*	*0.53*	*0.82*	*1.18*	*1.61*	*2.10*	*2.66*	*3.28*	*3.97*	*4.73*	*5.55*	*6.43*	*7.38*	*8.40*	*9.48*	*10.63*	*11.85*	*13.38*
23	*0.04*	*0.14*	*0.32*	*0.57*	*0.89*	*1.29*	*1.75*	*2.28*	*2.89*	*3.57*	*4.32*	*5.14*	*6.03*	*7.00*	*8.03*	*9.14*	*10.32*	*11.57*	*12.89*	*14.56*
24	*0.04*	*0.15*	*0.35*	*0.62*	*0.97*	*1.39*	*1.90*	*2.48*	*3.13*	*3.87*	*4.68*	*5.57*	*6.54*	*7.58*	*8.70*	*9.90*	*11.18*	*12.53*	*13.97*	*15.78*
25	*0.04*	*0.17*	*0.38*	*0.67*	*1.04*	*1.50*	*2.05*	*2.67*	*3.38*	*4.18*	*5.05*	*6.01*	*7.06*	*8.19*	*9.40*	*10.69*	*12.07*	*13.53*	*15.08*	*17.03*
26	*0.04*	*0.18*	*0.40*	*0.72*	*1.12*	*1.62*	*2.20*	*2.88*	*3.64*	*4.49*	*5.44*	*6.47*	*7.59*	*8.81*	*10.11*	*11.50*	*12.99*	*14.56*	*16.22*	*18.33*
27	*0.05*	*0.19*	*0.43*	*0.77*	*1.20*	*1.74*	*2.36*	*3.08*	*3.90*	*4.82*	*5.83*	*6.94*	*8.15*	*9.45*	*10.84*	*12.34*	*13.93*	*15.62*	*17.40*	*19.66*
28	*0.05*	*0.21*	*0.46*	*0.82*	*1.29*	*1.86*	*2.53*	*3.30*	*4.17*	*5.15*	*6.24*	*7.42*	*8.71*	*10.10*	*11.60*	*13.19*	*14.89*	*16.70*	*18.61*	*21.02*
29	*0.05*	*0.22*	*0.49*	*0.88*	*1.37*	*1.98*	*2.69*	*3.52*	*4.45*	*5.50*	*6.65*	*7.91*	*9.29*	*10.77*	*12.37*	*14.07*	*15.88*	*17.81*	*19.84*	*22.42*
30	*0.06*	*0.23*	*0.53*	*0.94*	*1.46*	*2.10*	*2.86*	*3.74*	*4.74*	*5.85*	*7.07*	*8.42*	*9.88*	*11.46*	*13.15*	*14.97*	*16.90*	*18.94*	*21.10*	*23.84*
31	*0.06*	*0.25*	*0.56*	*0.99*	*1.55*	*2.23*	*3.04*	*3.97*	*5.02*	*6.20*	*7.51*	*8.93*	*10.48*	*12.16*	*13.96*	*15.88*	*17.93*	*20.10*	*22.39*	*25.30*
32	*0.07*	*0.26*	*0.59*	*1.05*	*1.64*	*2.36*	*3.22*	*4.20*	*5.32*	*6.57*	*7.95*	*9.46*	*11.10*	*12.87*	*14.77*	*16.81*	*18.98*	*21.28*	*23.71*	*26.78*
33	*0.07*	*0.28*	*0.62*	*1.11*	*1.73*	*2.50*	*3.40*	*4.44*	*5.62*	*6.94*	*8.39*	*9.99*	*11.72*	*13.60*	*15.61*	*17.76*	*20.05*	*22.47*	*25.04*	*28.29*
34	*0.07*	*0.29*	*0.66*	*1.17*	*1.83*	*2.63*	*3.58*	*4.68*	*5.92*	*7.31*	*8.85*	*10.53*	*12.36*	*14.33*	*16.45*	*18.72*	*21.13*	*23.69*	*26.40*	*29.82*
35	*0.08*	*0.31*	*0.69*	*1.23*	*1.92*	*2.77*	*3.77*	*4.92*	*6.23*	*7.69*	*9.31*	*11.08*	*13.00*	*15.08*	*17.31*	*19.69*	*22.23*	*24.93*	*27.77*	*31.38*
36	*0.08*	*0.32*	*0.73*	*1.29*	*2.02*	*2.91*	*3.96*	*5.17*	*6.54*	*8.08*	*9.78*	*11.63*	*13.65*	*15.83*	*18.18*	*20.68*	*23.35*	*26.18*	*29.17*	*32.95*
37	*0.08*	*0.34*	*0.76*	*1.36*	*2.12*	*3.05*	*4.15*	*5.42*	*6.86*	*8.47*	*10.25*	*12.20*	*14.31*	*16.60*	*19.06*	*21.68*	*24.48*	*27.44*	*30.57*	*34.54*
38	*0.09*	*0.35*	*0.80*	*1.42*	*2.22*	*3.19*	*4.34*	*5.67*	*7.18*	*8.86*	*10.72*	*12.76*	*14.98*	*17.37*	*19.94*	*22.69*	*25.62*	*28.72*	*32.00*	*36.15*
39	*0.09*	*0.37*	*0.83*	*1.48*	*2.32*	*3.33*	*4.54*	*5.93*	*7.50*	*9.26*	*11.21*	*13.34*	*15.65*	*18.15*	*20.84*	*23.71*	*26.76*	*30.01*	*33.43*	*37.77*
40	*0.10*	*0.39*	*0.87*	*1.55*	*2.42*	*3.48*	*4.73*	*6.18*	*7.83*	*9.66*	*11.69*	*13.91*	*16.33*	*18.94*	*21.74*	*24.73*	*27.92*	*31.30*	*34.88*	*39.40*
41	*0.10*	*0.40*	*0.91*	*1.61*	*2.52*	*3.62*	*4.93*	*6.44*	*8.15*	*10.06*	*12.18*	*14.49*	*17.01*	*19.73*	*22.65*	*25.77*	*29.09*	*32.61*	*36.33*	*41.05*
42	*0.10*	*0.42*	*0.94*	*1.68*	*2.62*	*3.77*	*5.13*	*6.70*	*8.48*	*10.47*	*12.67*	*15.08*	*17.69*	*20.52*	*23.56*	*26.80*	*30.26*	*33.92*	*37.80*	*42.70*
43	*0.11*	*0.44*	*0.98*	*1.74*	*2.72*	*3.92*	*5.33*	*6.96*	*8.81*	*10.88*	*13.16*	*15.66*	*18.38*	*21.32*	*24.47*	*27.84*	*31.43*	*35.24*	*39.26*	*44.36*

Table 2 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Measured Jib Properties (FEM 1.001)

Jib Angle (º)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
44	*0.11*	*0.45*	*1.02*	*1.81*	*2.82*	*4.06*	*5.53*	*7.22*	*9.14*	*11.28*	*13.65*	*16.25*	*19.07*	*22.12*	*25.39*	*28.89*	*32.61*	*36.56*	*40.74*	*46.02*
45	*0.12*	*0.47*	*1.05*	*1.87*	*2.92*	*4.21*	*5.73*	*7.48*	*9.47*	*11.69*	*14.15*	*16.84*	*19.76*	*22.92*	*26.31*	*29.93*	*33.79*	*37.88*	*42.21*	*47.68*
46	*0.12*	*0.48*	*1.09*	*1.94*	*3.03*	*4.36*	*5.93*	*7.74*	*9.80*	*12.10*	*14.64*	*17.42*	*20.45*	*23.72*	*27.23*	*30.98*	*34.97*	*39.20*	*43.68*	*49.35*
47	*0.13*	*0.50*	*1.13*	*2.00*	*3.13*	*4.50*	*6.13*	*8.00*	*10.13*	*12.51*	*15.13*	*18.01*	*21.14*	*24.52*	*28.14*	*32.02*	*36.15*	*40.52*	*45.15*	*51.01*
48	*0.13*	*0.52*	*1.16*	*2.07*	*3.23*	*4.65*	*6.33*	*8.27*	*10.46*	*12.91*	*15.63*	*18.60*	*21.83*	*25.31*	*29.06*	*33.06*	*37.32*	*41.84*	*46.62*	*52.67*
49	*0.13*	*0.53*	*1.20*	*2.13*	*3.33*	*4.79*	*6.53*	*8.52*	*10.79*	*13.32*	*16.12*	*19.18*	*22.51*	*26.11*	*29.97*	*34.10*	*38.49*	*43.15*	*48.08*	*54.32*
50	*0.14*	*0.55*	*1.24*	*2.20*	*3.43*	*4.94*	*6.72*	*8.78*	*11.12*	*13.72*	*16.60*	*19.76*	*23.19*	*26.90*	*30.88*	*35.13*	*39.66*	*44.46*	*49.54*	*55.96*
51	*0.14*	*0.56*	*1.27*	*2.26*	*3.53*	*5.08*	*6.92*	*9.04*	*11.44*	*14.12*	*17.09*	*20.34*	*23.87*	*27.68*	*31.78*	*36.15*	*40.82*	*45.76*	*50.98*	*57.60*
52	*0.15*	*0.58*	*1.31*	*2.32*	*3.63*	*5.23*	*7.12*	*9.29*	*11.76*	*14.52*	*17.57*	*20.91*	*24.54*	*28.46*	*32.67*	*37.17*	*41.96*	*47.05*	*52.42*	*59.22*
53	*0.15*	*0.60*	*1.34*	*2.39*	*3.73*	*5.37*	*7.31*	*9.55*	*12.08*	*14.91*	*18.05*	*21.48*	*25.21*	*29.23*	*33.56*	*38.18*	*43.10*	*48.32*	*53.84*	*60.83*
54	*0.15*	*0.61*	*1.38*	*2.45*	*3.83*	*5.51*	*7.50*	*9.80*	*12.40*	*15.31*	*18.52*	*22.04*	*25.87*	*30.00*	*34.44*	*39.18*	*44.23*	*49.59*	*55.25*	*62.42*
55	*0.16*	*0.63*	*1.41*	*2.51*	*3.92*	*5.65*	*7.69*	*10.04*	*12.71*	*15.69*	*18.99*	*22.60*	*26.52*	*30.75*	*35.30*	*40.17*	*45.35*	*50.84*	*56.64*	*63.99*
56	*0.16*	*0.64*	*1.45*	*2.57*	*4.02*	*5.79*	*7.88*	*10.29*	*13.02*	*16.07*	*19.45*	*23.14*	*27.16*	*31.50*	*36.16*	*41.14*	*46.45*	*52.07*	*58.02*	*65.55*
57	*0.16*	*0.66*	*1.48*	*2.63*	*4.11*	*5.92*	*8.06*	*10.53*	*13.32*	*16.45*	*19.90*	*23.68*	*27.80*	*32.24*	*37.01*	*42.11*	*47.53*	*53.29*	*59.38*	*67.08*
58	*0.17*	*0.67*	*1.51*	*2.69*	*4.20*	*6.05*	*8.24*	*10.76*	*13.62*	*16.82*	*20.35*	*24.22*	*28.42*	*32.96*	*37.84*	*43.05*	*48.60*	*54.49*	*60.71*	*68.59*
59	*0.17*	*0.69*	*1.55*	*2.75*	*4.30*	*6.19*	*8.42*	*11.00*	*13.92*	*17.18*	*20.79*	*24.74*	*29.04*	*33.68*	*38.66*	*43.98*	*49.65*	*55.67*	*62.02*	*70.07*
60	*0.18*	*0.70*	*1.58*	*2.81*	*4.38*	*6.31*	*8.59*	*11.22*	*14.21*	*17.54*	*21.22*	*25.25*	*29.64*	*34.37*	*39.46*	*44.90*	*50.69*	*56.82*	*63.31*	*71.53*
61	*0.18*	*0.72*	*1.61*	*2.86*	*4.47*	*6.44*	*8.77*	*11.45*	*14.49*	*17.89*	*21.64*	*25.76*	*30.23*	*35.06*	*40.25*	*45.79*	*51.70*	*57.96*	*64.58*	*72.95*
62	*0.18*	*0.73*	*1.64*	*2.92*	*4.56*	*6.56*	*8.93*	*11.67*	*14.77*	*18.23*	*22.06*	*26.25*	*30.81*	*35.73*	*41.02*	*46.67*	*52.69*	*59.07*	*65.81*	*74.35*
63	*0.19*	*0.74*	*1.67*	*2.97*	*4.64*	*6.68*	*9.10*	*11.88*	*15.04*	*18.56*	*22.46*	*26.73*	*31.37*	*36.39*	*41.77*	*47.53*	*53.65*	*60.15*	*67.02*	*75.71*
64	*0.19*	*0.76*	*1.70*	*3.02*	*4.72*	*6.80*	*9.26*	*12.09*	*15.30*	*18.89*	*22.86*	*27.20*	*31.92*	*37.03*	*42.50*	*48.36*	*54.59*	*61.21*	*68.19*	*77.04*
65	*0.19*	*0.77*	*1.73*	*3.07*	*4.80*	*6.91*	*9.41*	*12.29*	*15.56*	*19.21*	*23.24*	*27.66*	*32.46*	*37.65*	*43.22*	*49.17*	*55.51*	*62.23*	*69.34*	*78.33*
66	*0.20*	*0.78*	*1.76*	*3.12*	*4.88*	*7.03*	*9.56*	*12.49*	*15.81*	*19.52*	*23.61*	*28.10*	*32.98*	*38.25*	*43.91*	*49.96*	*56.40*	*63.23*	*70.45*	*79.59*
67	*0.20*	*0.79*	*1.78*	*3.17*	*4.95*	*7.13*	*9.71*	*12.68*	*16.05*	*19.81*	*23.98*	*28.53*	*33.49*	*38.84*	*44.58*	*50.72*	*57.26*	*64.20*	*71.53*	*80.81*
68	*0.20*	*0.80*	*1.81*	*3.22*	*5.03*	*7.24*	*9.85*	*12.87*	*16.28*	*20.10*	*24.32*	*28.95*	*33.97*	*39.40*	*45.23*	*51.46*	*58.10*	*65.13*	*72.57*	*81.98*
69	*0.20*	*0.82*	*1.83*	*3.26*	*5.10*	*7.34*	*9.99*	*13.04*	*16.51*	*20.38*	*24.66*	*29.35*	*34.44*	*39.95*	*45.86*	*52.18*	*58.90*	*66.03*	*73.58*	*83.12*
70	*0.21*	*0.83*	*1.86*	*3.30*	*5.16*	*7.43*	*10.12*	*13.22*	*16.73*	*20.65*	*24.98*	*29.73*	*34.90*	*40.47*	*46.46*	*52.86*	*59.67*	*66.90*	*74.54*	*84.21*
71	*0.21*	*0.84*	*1.88*	*3.34*	*5.23*	*7.53*	*10.24*	*13.38*	*16.93*	*20.91*	*25.30*	*30.10*	*35.33*	*40.97*	*47.04*	*53.52*	*60.42*	*67.73*	*75.47*	*85.26*
72	*0.21*	*0.85*	*1.90*	*3.38*	*5.29*	*7.61*	*10.36*	*13.54*	*17.13*	*21.15*	*25.59*	*30.46*	*35.75*	*41.46*	*47.59*	*54.15*	*61.13*	*68.53*	*76.36*	*86.26*
73	*0.21*	*0.86*	*1.92*	*3.42*	*5.35*	*7.70*	*10.48*	*13.69*	*17.32*	*21.39*	*25.88*	*30.79*	*36.14*	*41.92*	*48.12*	*54.75*	*61.80*	*69.29*	*77.20*	*87.22*

Table 2 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Measured Jib Properties (FEM 1.001)

Jib Angle (°)	Wind Speed (m/s)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
74	0.22	0.86	1.94	3.46	5.40	7.78	10.59	13.83	17.50	21.61	26.15	31.11	36.52	42.35	48.62	55.32	62.45	70.01	78.00	88.12
75	0.22	0.87	1.96	3.49	5.45	7.85	10.69	13.96	17.67	21.82	26.40	31.42	36.87	42.76	49.09	55.85	63.05	70.69	78.76	88.98
76	0.22	0.88	1.98	3.52	5.50	7.93	10.79	14.09	17.83	22.02	26.64	31.70	37.21	43.15	49.54	56.36	63.63	71.33	79.48	89.79
77	0.22	0.89	2.00	3.55	5.55	7.99	10.88	14.21	17.98	22.20	26.86	31.97	37.52	43.51	49.95	56.83	64.16	71.93	80.15	90.54
78	0.22	0.89	2.01	3.58	5.59	8.05	10.96	14.32	18.12	22.37	27.07	32.22	37.81	43.85	50.34	57.28	64.66	72.49	80.77	91.25
79	0.23	0.90	2.03	3.61	5.63	8.11	11.04	14.42	18.25	22.53	27.26	32.45	38.08	44.16	50.70	57.68	65.12	73.01	81.34	91.90
80	0.23	0.91	2.04	3.63	5.67	8.16	11.11	14.51	18.37	22.68	27.44	32.66	38.33	44.45	51.03	58.06	65.54	73.48	81.87	92.49
81	0.23	0.91	2.05	3.65	5.70	8.21	11.18	14.60	18.48	22.81	27.60	32.85	38.55	44.71	51.33	58.40	65.93	73.91	82.35	93.03
82	0.23	0.92	2.06	3.67	5.73	8.26	11.24	14.68	18.57	22.93	27.75	33.02	38.75	44.95	51.60	58.70	66.27	74.30	82.78	93.52
83	0.23	0.92	2.07	3.69	5.76	8.29	11.29	14.74	18.66	23.04	27.87	33.17	38.93	45.15	51.83	58.97	66.58	74.64	83.16	93.95
84	0.23	0.93	2.08	3.70	5.78	8.33	11.33	14.80	18.73	23.13	27.99	33.31	39.09	45.33	52.04	59.21	66.84	74.94	83.49	94.33
85	0.23	0.93	2.09	3.71	5.80	8.35	11.37	14.85	18.80	23.21	28.08	33.42	39.22	45.48	52.21	59.41	67.07	75.19	83.78	94.64
86	0.23	0.93	2.09	3.72	5.82	8.38	11.40	14.89	18.85	23.27	28.16	33.51	39.33	45.61	52.36	59.57	67.25	75.40	84.01	94.90
87	0.23	0.93	2.10	3.73	5.83	8.40	11.43	14.92	18.89	23.32	28.22	33.58	39.41	45.71	52.47	59.70	67.40	75.56	84.19	95.11
88	0.23	0.93	2.10	3.74	5.84	8.41	11.44	14.95	18.92	23.36	28.26	33.63	39.47	45.78	52.55	59.79	67.50	75.67	84.31	95.25
89	0.23	0.94	2.10	3.74	5.84	8.42	11.45	14.96	18.94	23.38	28.29	33.66	39.51	45.82	52.60	59.85	67.56	75.74	84.39	95.34
90	0.23	0.94	2.10	3.74	5.85	8.42	11.46	14.97	18.94	23.38	28.29	33.67	39.52	45.83	52.61	59.86	67.58	75.76	84.42	95.37

Table 2 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Measured Jib Properties (FEM 1.001)

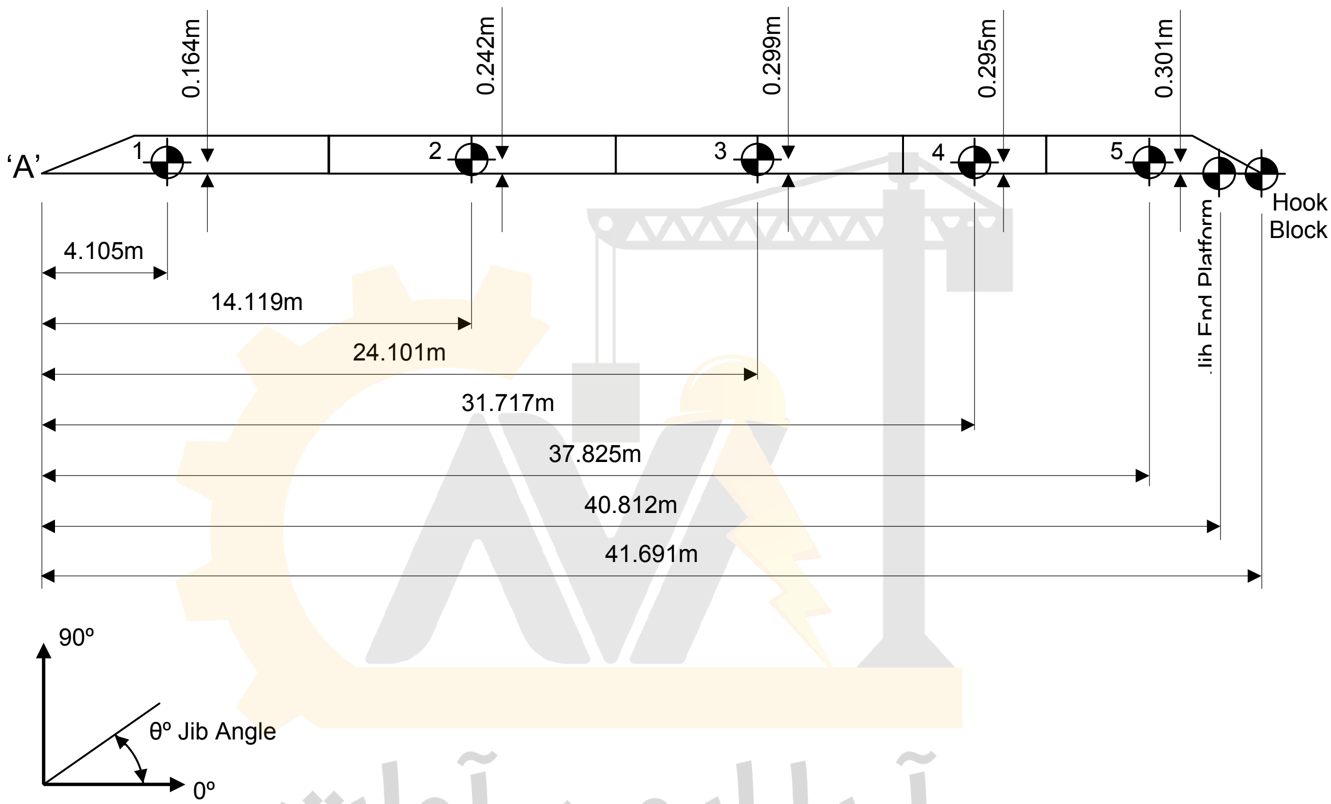
APPENDIX 5

Calculation of the wind loading and consequent moment acting at the jib pivot point according to FEM 1.004 *"Heavy Lifting Appliances – Section 1 – Recommendations for the Calculation of Wind Loads on Crane Structures"*.

Appendix 5

Calculation of the moment acting at the jib pivot points due to wind loading on the jib and jib end platform according to FEM 1.004

1. Theoretical properties of the jib sections i.e. the masses provided in the crane manual and positions of centre of gravity provided by Jaso



The moment, M_{WIND}, acting at the jib pivot point 'A' arising from the wind loading is given by:

$M_{WIND} = F_N \cos(\tan^{-1} y/x)x$ where

F_N is the wind load normal to the underside of the jib component under consideration (N)
x is the dimension along the jib section from 'A' to the centre of gravity of the jib section (m)
y is the dimension from 'A' to the centre of gravity of the jib section perpendicular to the x is the dimension (m)

Since the centre of gravity of the jib sections are slightly offset from the pivot point in the vertical (y) direction the term $\cos(\tan^{-1} y/x)$ in the above equation resolves F_N (the wind load normal to the underside of the jib component under consideration) to the lever arm joining the centre of gravity to the pivot point such that the resultant force is completely perpendicular to the lever arm. However, the angles between the centres of gravity of the jib sections and the pivot point are very small such that $\cos(\tan^{-1} y/x)$ tends to unity. Hence this is ignored and the moment, M_{WIND}, acting at the jib pivot point 'A' arising from the wind loading is given by:

$M_{WIND} = F_N\, x$ where

F_N is the wind load normal to the underside of the jib component under consideration (N)
x is the dimension along the jib section from 'A' to the centre of gravity of the jib section (m)

Since the wind load, F_N, is normal to the underside of the jib component under consideration, x remains constant at the dimensions shown in the sketch above as the angle of the jib to the horizontal alters.

For any given jib angle to the horizontal, the total moment acting at the jib pivot point 'A' arising from the wind load acting on each jib section is given by adding the moment arising from each individual jib section 1 to 5 (M_{WIND1} – M_{WIND5}) and that arising from the jib end platform ($M_{WINDPLATFORM}$), i.e:

$$M_{WINDTOTAL} = M_{WIND1} + M_{WIND2} + M_{WIND3} + M_{WIND4} + M_{WIND5} + M_{WINDPLATFORM}$$

The wind loading on each jib section and the jib end platform has been calculated in Appendix 3 according to FEM 1.001, FEM 1.004, ISO 4302 and BS EN 13001 – 2:2004 and equations for F_N derived.

Example Calculation – FEM 1.004 (wind speed = 10 m/s, jib angle = 31º to the horizontal)

Assuming a wind speed of 10 m/s, the wind pressure q is given by:

$$q = ½ \times \rho \times v^2 = ½ \times 1.25 \times 10^2 = 62.5\ N/m^2$$

Using equations 1a – 6a derived in Appendix 3 Section 6.3.3 for a jib angle of 31º to the horizontal the wind load normal to the underside of the jib component under consideration and acting at the centre of gravity is:

For jib section 1, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N1} = 4.07\ q \sin^2 \theta = 4.07 \times 62.5 \times \sin^2 31^\circ = 67.5$ N
$M_{WIND1} = 67.5 \times 4.105$ m $= 0.27$ kNm

For jib section 2, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N2} = 4.48\ q \sin^2 \theta = 4.48 \times 62.5 \times \sin^2 31^\circ = 74.3$ N
$M_{WIND2} = 74.3 \times 14.119$ m $= 1.05$ kNm

For jib section 3, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N3} = 4.40\ q \sin^2 \theta = 4.40 \times 62.5 \times \sin^2 31^\circ = 72.9$ N
$M_{WIND3} = 72.9 \times 24.101$ m $= 1.76$ kNm

For jib section 4, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N4} = 2.25\ q \sin^2 \theta = 2.25 \times 62.5 \times \sin^2 31^\circ = 37.3$ N
$M_{WIND4} = 37.3 \times 31.717$ m $= 1.18$ kNm

For jib section 5, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N5} = 3.26\ q\ \sin^2\theta = 3.26 \times 62.5 \times \sin^2 31^o = 54.05$ N
$M_{WIND5} = 54.05 \times 37.825$ m $= 2.04$ kNm

The wind load normal to the jib end platform floor and resulting moment at the jib pivot point is:

$F_{NPLATFORM} = 1.01\ q\ \sin^2\theta = 1.01 \times 62.5 \times \sin^2 31^o = 16.7$ N
$M_{WINDPLATFORM} = 16.7 \times 40.812 = 0.68$ kNm

The total moment at the jib pivot point due to wind loading at a wind speed of 10 m/s and a jib angle of 31º to the horizontal is:

$M_{WINDTOTAL} = 0.27 + 1.05 + 1.76 + 1.18 + 2.04 + 0.68 = 6.98$ kNm

Similar calculations can be performed for different wind speeds and jib angles and the resultant moments at the jib pivot point are given in Table 1 of this appendix.

Jib Angle (º)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
15	*0.02*	*0.07*	*0.16*	*0.28*	*0.44*	*0.64*	*0.87*	*1.13*	*1.43*	*1.77*	*2.14*	*2.54*	*2.99*	*3.46*	*3.97*	*4.52*	*5.10*	*5.72*	*6.38*	*7.07*
16	*0.02*	*0.08*	*0.18*	*0.32*	*0.50*	*0.72*	*0.98*	*1.28*	*1.62*	*2.00*	*2.42*	*2.88*	*3.39*	*3.93*	*4.51*	*5.13*	*5.79*	*6.49*	*7.23*	*8.01*
17	*0.02*	*0.09*	*0.20*	*0.36*	*0.56*	*0.81*	*1.10*	*1.44*	*1.83*	*2.25*	*2.73*	*3.25*	*3.81*	*4.42*	*5.07*	*5.77*	*6.51*	*7.30*	*8.14*	*9.02*
18	*0.03*	*0.10*	*0.23*	*0.40*	*0.63*	*0.91*	*1.23*	*1.61*	*2.04*	*2.52*	*3.05*	*3.63*	*4.26*	*4.94*	*5.67*	*6.45*	*7.28*	*8.16*	*9.09*	*10.07*
19	*0.03*	*0.11*	*0.25*	*0.45*	*0.70*	*1.01*	*1.37*	*1.79*	*2.26*	*2.79*	*3.38*	*4.02*	*4.72*	*5.48*	*6.29*	*7.16*	*8.08*	*9.06*	*10.09*	*11.18*
20	*0.03*	*0.12*	*0.28*	*0.49*	*0.77*	*1.11*	*1.51*	*1.97*	*2.50*	*3.08*	*3.73*	*4.44*	*5.21*	*6.05*	*6.94*	*7.90*	*8.91*	*9.99*	*11.14*	*12.34*
21	*0.03*	*0.14*	*0.30*	*0.54*	*0.85*	*1.22*	*1.66*	*2.17*	*2.74*	*3.39*	*4.10*	*4.88*	*5.72*	*6.64*	*7.62*	*8.67*	*9.79*	*10.97*	*12.23*	*13.55*
22	*0.04*	*0.15*	*0.33*	*0.59*	*0.93*	*1.33*	*1.81*	*2.37*	*3.00*	*3.70*	*4.48*	*5.33*	*6.25*	*7.25*	*8.33*	*9.47*	*10.69*	*11.99*	*13.36*	*14.80*
23	*0.04*	*0.16*	*0.36*	*0.64*	*1.01*	*1.45*	*1.97*	*2.58*	*3.26*	*4.03*	*4.87*	*5.80*	*6.80*	*7.89*	*9.06*	*10.31*	*11.63*	*13.04*	*14.53*	*16.10*
24	*0.04*	*0.17*	*0.39*	*0.70*	*1.09*	*1.57*	*2.14*	*2.79*	*3.53*	*4.36*	*5.28*	*6.28*	*7.37*	*8.55*	*9.82*	*11.17*	*12.61*	*14.13*	*15.75*	*17.45*
25	*0.05*	*0.19*	*0.42*	*0.75*	*1.18*	*1.70*	*2.31*	*3.01*	*3.81*	*4.71*	*5.70*	*6.78*	*7.96*	*9.23*	*10.60*	*12.06*	*13.61*	*15.26*	*17.00*	*18.84*
26	*0.05*	*0.20*	*0.46*	*0.81*	*1.27*	*1.82*	*2.48*	*3.24*	*4.10*	*5.07*	*6.13*	*7.30*	*8.56*	*9.93*	*11.40*	*12.97*	*14.64*	*16.42*	*18.29*	*20.27*
27	*0.05*	*0.22*	*0.49*	*0.87*	*1.36*	*1.96*	*2.66*	*3.48*	*4.40*	*5.43*	*6.58*	*7.83*	*9.18*	*10.65*	*12.23*	*13.91*	*15.71*	*17.61*	*19.62*	*21.74*
28	*0.06*	*0.23*	*0.52*	*0.93*	*1.45*	*2.09*	*2.85*	*3.72*	*4.71*	*5.81*	*7.03*	*8.37*	*9.82*	*11.39*	*13.08*	*14.88*	*16.80*	*18.83*	*20.98*	*23.25*
29	*0.06*	*0.25*	*0.56*	*0.99*	*1.55*	*2.23*	*3.04*	*3.97*	*5.02*	*6.20*	*7.50*	*8.92*	*10.47*	*12.15*	*13.94*	*15.87*	*17.91*	*20.08*	*22.37*	*24.79*
30	*0.07*	*0.26*	*0.59*	*1.05*	*1.65*	*2.37*	*3.23*	*4.22*	*5.34*	*6.59*	*7.98*	*9.49*	*11.14*	*12.92*	*14.83*	*16.88*	*19.05*	*21.36*	*23.80*	*26.37*
31	*0.07*	*0.28*	*0.63*	*1.12*	*1.75*	*2.52*	*3.43*	*4.48*	*5.67*	*6.99*	*8.46*	*10.07*	*11.82*	*13.71*	*15.74*	*17.91*	*20.21*	*22.66*	*25.25*	*27.98*
32	*0.07*	*0.30*	*0.67*	*1.18*	*1.85*	*2.67*	*3.63*	*4.74*	*6.00*	*7.40*	*8.96*	*10.66*	*12.51*	*14.51*	*16.66*	*18.96*	*21.40*	*23.99*	*26.73*	*29.62*
33	*0.08*	*0.31*	*0.70*	*1.25*	*1.96*	*2.82*	*3.83*	*5.01*	*6.34*	*7.82*	*9.46*	*11.26*	*13.22*	*15.33*	*17.60*	*20.02*	*22.60*	*25.34*	*28.24*	*31.29*
34	*0.08*	*0.33*	*0.74*	*1.32*	*2.06*	*2.97*	*4.04*	*5.28*	*6.68*	*8.25*	*9.98*	*11.87*	*13.93*	*16.16*	*18.55*	*21.11*	*23.83*	*26.72*	*29.77*	*32.98*
35	*0.09*	*0.35*	*0.78*	*1.39*	*2.17*	*3.12*	*4.25*	*5.55*	*7.03*	*8.68*	*10.50*	*12.49*	*14.66*	*17.00*	*19.52*	*22.21*	*25.07*	*28.11*	*31.32*	*34.70*
36	*0.09*	*0.36*	*0.82*	*1.46*	*2.28*	*3.28*	*4.46*	*5.83*	*7.38*	*9.11*	*11.02*	*13.12*	*15.40*	*17.86*	*20.50*	*23.32*	*26.33*	*29.52*	*32.89*	*36.44*
37	*0.10*	*0.38*	*0.86*	*1.53*	*2.39*	*3.44*	*4.68*	*6.11*	*7.74*	*9.55*	*11.56*	*13.75*	*16.14*	*18.72*	*21.49*	*24.45*	*27.60*	*30.94*	*34.48*	*38.20*
38	*0.10*	*0.40*	*0.90*	*1.60*	*2.50*	*3.60*	*4.90*	*6.40*	*8.10*	*9.99*	*12.09*	*14.39*	*16.89*	*19.59*	*22.49*	*25.59*	*28.88*	*32.38*	*36.08*	*39.98*
39	*0.10*	*0.42*	*0.94*	*1.67*	*2.61*	*3.76*	*5.12*	*6.68*	*8.46*	*10.44*	*12.64*	*15.04*	*17.65*	*20.47*	*23.50*	*26.73*	*30.18*	*33.84*	*37.70*	*41.77*
40	*0.11*	*0.44*	*0.98*	*1.74*	*2.72*	*3.92*	*5.34*	*6.97*	*8.82*	*10.89*	*13.18*	*15.69*	*18.41*	*21.35*	*24.51*	*27.89*	*31.49*	*35.30*	*39.33*	*43.58*
41	*0.11*	*0.45*	*1.02*	*1.82*	*2.84*	*4.09*	*5.56*	*7.26*	*9.19*	*11.35*	*13.73*	*16.34*	*19.18*	*22.24*	*25.54*	*29.05*	*32.80*	*36.77*	*40.97*	*45.40*
42	*0.12*	*0.47*	*1.06*	*1.89*	*2.95*	*4.25*	*5.79*	*7.56*	*9.56*	*11.81*	*14.29*	*17.00*	*19.95*	*23.14*	*26.56*	*30.22*	*34.12*	*38.25*	*42.62*	*47.22*
43	*0.12*	*0.49*	*1.10*	*1.96*	*3.07*	*4.42*	*6.01*	*7.85*	*9.93*	*12.26*	*14.84*	*17.66*	*20.73*	*24.04*	*27.60*	*31.40*	*35.44*	*39.74*	*44.28*	*49.06*

Table 1 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Theoretical Jib Properties (FEM 1.004)

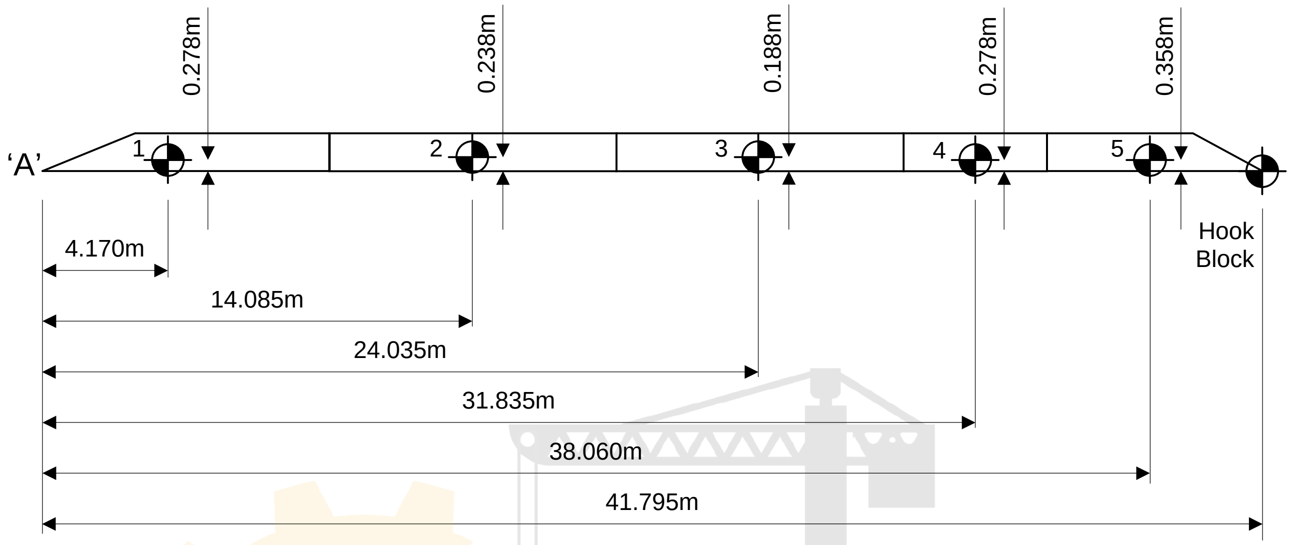
Jib Angle (°)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
44	0.13	0.51	1.15	2.04	3.18	4.58	6.23	8.14	10.31	12.72	15.40	18.32	21.50	24.94	28.63	32.57	36.77	41.23	45.93	50.90
45	0.13	0.53	1.19	2.11	3.30	4.75	6.46	8.44	10.68	13.18	15.95	18.99	22.28	25.84	29.66	33.75	38.10	42.72	47.60	52.74
46	0.14	0.55	1.23	2.18	3.41	4.91	6.69	8.73	11.05	13.64	16.51	19.65	23.06	26.74	30.70	34.93	39.43	44.21	49.26	54.58
47	0.14	0.56	1.27	2.26	3.53	5.08	6.91	9.03	11.42	14.10	17.07	20.31	23.84	27.64	31.73	36.11	40.76	45.70	50.92	56.42
48	0.15	0.58	1.31	2.33	3.64	5.24	7.14	9.32	11.80	14.56	17.62	20.97	24.61	28.54	32.77	37.28	42.09	47.18	52.57	58.25
49	0.15	0.60	1.35	2.40	3.75	5.41	7.36	9.61	12.17	15.02	18.17	21.63	25.38	29.44	33.79	38.45	43.41	48.66	54.22	60.08
50	0.15	0.62	1.39	2.48	3.87	5.57	7.58	9.90	12.53	15.47	18.72	22.28	26.15	30.33	34.82	39.61	44.72	50.13	55.86	61.89
51	0.16	0.64	1.43	2.55	3.98	5.73	7.80	10.19	12.90	15.93	19.27	22.93	26.91	31.21	35.83	40.77	46.02	51.60	57.49	63.70
52	0.16	0.65	1.47	2.62	4.09	5.89	8.02	10.48	13.26	16.37	19.81	23.58	27.67	32.09	36.84	41.92	47.32	53.05	59.11	65.50
53	0.17	0.67	1.51	2.69	4.20	6.05	8.24	10.76	13.62	16.82	20.35	24.22	28.42	32.96	37.84	43.06	48.61	54.49	60.71	67.27
54	0.17	0.69	1.55	2.76	4.31	6.21	8.46	11.05	13.98	17.26	20.88	24.85	29.17	33.83	38.83	44.18	49.88	55.92	62.30	69.03
55	0.18	0.71	1.59	2.83	4.42	6.37	8.67	11.32	14.33	17.69	21.41	25.48	29.90	34.68	39.81	45.30	51.13	57.33	63.87	70.77
56	0.18	0.72	1.63	2.90	4.53	6.52	8.88	11.60	14.68	18.12	21.93	26.10	30.63	35.52	40.78	46.40	52.38	58.72	65.42	72.49
57	0.19	0.74	1.67	2.97	4.64	6.68	9.09	11.87	15.02	18.55	22.44	26.71	31.34	36.35	41.73	47.48	53.60	60.09	66.95	74.19
58	0.19	0.76	1.71	3.03	4.74	6.83	9.29	12.14	15.36	18.96	22.95	27.31	32.05	37.17	42.67	48.55	54.81	61.44	68.46	75.86
59	0.19	0.77	1.74	3.10	4.84	6.97	9.49	12.40	15.69	19.37	23.44	27.90	32.74	37.97	43.59	49.60	55.99	62.77	69.94	77.50
60	0.20	0.79	1.78	3.16	4.94	7.12	9.69	12.66	16.02	19.78	23.93	28.48	33.42	38.76	44.50	50.63	57.15	64.08	71.39	79.11
61	0.20	0.81	1.82	3.23	5.04	7.26	9.88	12.91	16.34	20.17	24.41	29.05	34.09	39.54	45.38	51.64	58.29	65.35	72.82	80.68
62	0.21	0.82	1.85	3.29	5.14	7.40	10.07	13.16	16.65	20.56	24.87	29.60	34.74	40.29	46.25	52.63	59.41	66.60	74.21	82.23
63	0.21	0.84	1.88	3.35	5.23	7.54	10.26	13.40	16.96	20.93	25.33	30.14	35.38	41.03	47.10	53.59	60.50	67.83	75.57	83.74
64	0.21	0.85	1.92	3.41	5.33	7.67	10.44	13.63	17.25	21.30	25.77	30.67	36.00	41.75	47.93	54.53	61.56	69.02	76.90	85.21
65	0.22	0.87	1.95	3.47	5.41	7.80	10.61	13.86	17.54	21.66	26.21	31.19	36.60	42.45	48.73	55.45	62.59	70.18	78.19	86.64
66	0.22	0.88	1.98	3.52	5.50	7.92	10.78	14.08	17.83	22.01	26.63	31.69	37.19	43.13	49.51	56.34	63.60	71.30	79.44	88.03
67	0.22	0.89	2.01	3.57	5.59	8.04	10.95	14.30	18.10	22.34	27.03	32.17	37.76	43.79	50.27	57.20	64.57	72.39	80.66	89.37
68	0.23	0.91	2.04	3.63	5.67	8.16	11.11	14.51	18.36	22.67	27.43	32.64	38.31	44.43	51.00	58.03	65.51	73.45	81.83	90.67
69	0.23	0.92	2.07	3.68	5.75	8.27	11.26	14.71	18.62	22.98	27.81	33.09	38.84	45.05	51.71	58.83	66.42	74.46	82.97	91.93
70	0.23	0.93	2.10	3.73	5.82	8.38	11.41	14.90	18.86	23.28	28.17	33.53	39.35	45.64	52.39	59.61	67.29	75.44	84.06	93.14
71	0.24	0.94	2.12	3.77	5.89	8.49	11.55	15.09	19.09	23.57	28.52	33.95	39.84	46.20	53.04	60.35	68.13	76.38	85.10	94.29
72	0.24	0.95	2.15	3.82	5.96	8.59	11.69	15.26	19.32	23.85	28.86	34.34	40.31	46.75	53.66	61.06	68.93	77.28	86.10	95.40
73	0.24	0.96	2.17	3.86	6.03	8.68	11.82	15.43	19.53	24.11	29.18	34.73	40.75	47.26	54.26	61.73	69.69	78.13	87.05	96.46
74	0.24	0.97	2.19	3.90	6.09	8.77	11.94	15.59	19.74	24.37	29.48	35.09	41.18	47.76	54.82	62.37	70.42	78.94	87.96	97.46

Table 1 - (continued) Moment at the Jib Pivot Point due to Wind Loading (kNm)
Theoretical jib Properties (FEM 1.004)

Jib Angle (°)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
75	0.25	0.98	2.21	3.94	6.15	8.86	12.06	15.75	19.93	24.60	29.77	35.43	41.58	48.22	55.36	62.98	71.10	79.71	88.81	98.41
76	0.25	0.99	2.23	3.97	6.21	8.94	12.16	15.89	20.11	24.83	30.04	35.75	41.95	48.66	55.86	63.55	71.75	80.43	89.62	99.30
77	0.25	1.00	2.25	4.01	6.26	9.01	12.27	16.02	20.28	25.03	30.29	36.05	42.31	49.07	56.33	64.09	72.35	81.11	90.37	100.14
78	0.25	1.01	2.27	4.04	6.31	9.08	12.36	16.15	20.44	25.23	30.53	36.33	42.64	49.45	56.76	64.59	72.91	81.74	91.08	100.92
79	0.25	1.02	2.29	4.07	6.35	9.15	12.45	16.26	20.58	25.41	30.74	36.59	42.94	49.80	57.17	65.05	73.43	82.32	91.72	101.63
80	0.26	1.02	2.30	4.09	6.39	9.21	12.53	16.37	20.71	25.57	30.94	36.83	43.22	50.12	57.54	65.47	73.91	82.86	92.32	102.29
81	0.26	1.03	2.32	4.12	6.43	9.26	12.60	16.46	20.84	25.72	31.13	37.04	43.47	50.42	57.88	65.85	74.34	83.34	92.86	102.89
82	0.26	1.03	2.33	4.14	6.46	9.31	12.67	16.55	20.94	25.86	31.29	37.24	43.70	50.68	58.18	66.20	74.73	83.78	93.35	103.43
83	0.26	1.04	2.34	4.16	6.49	9.35	12.73	16.63	21.04	25.98	31.43	37.41	43.90	50.91	58.45	66.50	75.07	84.17	93.78	103.91
84	0.26	1.04	2.35	4.17	6.52	9.39	12.78	16.69	21.13	26.08	31.56	37.56	44.08	51.12	58.68	66.77	75.37	84.50	94.15	104.32
85	0.26	1.05	2.36	4.19	6.54	9.42	12.82	16.75	21.20	26.17	31.66	37.68	44.22	51.29	58.88	66.99	75.63	84.79	94.47	104.67
86	0.26	1.05	2.36	4.20	6.56	9.45	12.86	16.79	21.25	26.24	31.75	37.79	44.35	51.43	59.04	67.18	75.83	85.02	94.73	104.96
87	0.26	1.05	2.37	4.21	6.57	9.47	12.89	16.83	21.30	26.30	31.82	37.87	44.44	51.54	59.17	67.32	76.00	85.20	94.93	105.19
88	0.26	1.05	2.37	4.21	6.58	9.48	12.90	16.86	21.33	26.34	31.87	37.92	44.51	51.62	59.26	67.42	76.11	85.33	95.07	105.35
89	0.26	1.05	2.37	4.22	6.59	9.49	12.92	16.87	21.35	26.36	31.90	37.96	44.55	51.67	59.31	67.48	76.18	85.41	95.16	105.44
90	0.26	1.05	2.37	4.22	6.59	9.49	12.92	16.88	21.36	26.37	31.91	37.97	44.56	51.68	59.33	67.50	76.21	85.43	95.19	105.47

Table 1 - (continued) Moment at the Jib Pivot Point due to Wind Loading (kNm)
Theoretical Jib properties (FEM 1.004)

2. Masses and positions of centre of gravity measured during erection of the crane at HSL



As before, the moment, M_{WIND}, acting at the jib pivot point 'A' arising from the wind loading is given by:

$M_{WIND} = F_N \, x$ where

F_N is the wind load normal to the underside of the jib component under consideration (N)
x is the dimension along the jib section from 'A' to the centre of gravity of the jib section (m)

Since the wind load, F_N, is normal to the underside of the jib component under consideration, x remains constant at the dimensions shown in the sketch above as the angle of the jib to the horizontal alters.

For any given jib angle to the horizontal, the total moment acting at the jib pivot point 'A' arising from the wind load acting on each jib section is given by adding the moment arising from each individual jib section 1 to 5 ($M_{WIND1} - M_{WIND5}$). In this case, the position of the centre of gravity for Jib section 5 incorporates the jib end platform since the platform was fitted when the position of the centre of gravity was measured during erection of the crane at HSL. To determine M_{WIND5}, the wind load on the jib and on the end platform are added and then multiplied by the x dimension.

$M_{WINDTOTAL} = M_{WIND1} + M_{WIND2} + M_{WIND3} + M_{WIND4} + M_{WIND5}$

Example Calculation – FEM 1.004 (wind speed = 14 m/s, jib angle = 48º to the horizontal)

Assuming a wind speed of 14 m/s, the wind pressure q is given by:

$q = ½ \times \rho \times v^2 = ½ \times 1.25 \times 14^2 = 122.5 \text{ N/m}^2$

Using equations 1a – 6a derived in Appendix 3 Section 6.3.3 for a jib angle of 48º to the horizontal the wind load normal to the underside of the jib component under consideration and acting at the centre of gravity is:

For jib section 1, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N1} = 4.07\ q \sin^2 \theta = 4.07 \times 122.5 \times \sin^2 48^o = 275.4$ N
$M_{WIND1} = 275.4 \times 4.17$ m = 1.15 kNm

For jib section 2, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N2} = 4.48\ q \sin^2 \theta = 4.48 \times 122.5 \times \sin^2 48^o = 303.1$ N
$M_{WIND2} = 303.1 \times 14.085$ m = 4.27 kNm

For jib section 3, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N3} = 4.40\ q \sin^2 \theta = 4.40 \times 122.5 \times \sin^2 48^o = 297.7$ N
$M_{WIND3} = 297.7 \times 24.035$ m = 7.15 kNm

For jib section 4, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N4} = 2.25\ q \sin^2 \theta = 2.25 \times 122.5 \times \sin^2 48^o = 152.2$ N
$M_{WIND4} = 152.2 \times 31.835$ m = 4.85 kNm

For jib section 5, the wind load normal to the underside of the jib section is:

$F_{N5} = 3.26\ q \sin^2 \theta = 3.26 \times 122.5 \times \sin^2 48^o = 220.6$ N

The wind load normal to the jib end platform floor is:

$F_{NPLATFORM} = 1.01\ q \sin^2 \theta = 1.01 \times 122.5 \times \sin^2 48^o = 68.3$ N

For jib section 5 and the jib end platform, the resulting moment at the jib pivot point is:

$M_{WIND5} = (220.6 + 68.3) \times 38.060 = 11.00$ kNm

The total moment at the jib pivot point due to wind loading at a wind speed of 14 m/s and a jib angle of 48º to the horizontal is:

$M_{WINDTOTAL} = 1.15 + 4.27 + 7.15 + 4.85 + 11.00 = 28.42$ kNm

Similar calculations can be performed for different wind speeds and jib angles and the resultant moments at the jib pivot point are given in Table 2 of this appendix.

Jib Angle (º)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
15	*0.02*	*0.07*	*0.16*	*0.28*	*0.44*	*0.63*	*0.86*	*1.13*	*1.42*	*1.76*	*2.13*	*2.53*	*2.97*	*3.45*	*3.96*	*4.50*	*5.08*	*5.70*	*6.35*	*7.03*
16	*0.02*	*0.08*	*0.18*	*0.32*	*0.50*	*0.72*	*0.98*	*1.28*	*1.62*	*1.99*	*2.41*	*2.87*	*3.37*	*3.91*	*4.49*	*5.11*	*5.76*	*6.46*	*7.20*	*7.98*
17	*0.02*	*0.09*	*0.20*	*0.36*	*0.56*	*0.81*	*1.10*	*1.44*	*1.82*	*2.24*	*2.71*	*3.23*	*3.79*	*4.40*	*5.05*	*5.74*	*6.48*	*7.27*	*8.10*	*8.97*
18	*0.03*	*0.10*	*0.23*	*0.40*	*0.63*	*0.90*	*1.23*	*1.60*	*2.03*	*2.51*	*3.03*	*3.61*	*4.24*	*4.91*	*5.64*	*6.42*	*7.24*	*8.12*	*9.05*	*10.03*
19	*0.03*	*0.11*	*0.25*	*0.45*	*0.70*	*1.00*	*1.36*	*1.78*	*2.25*	*2.78*	*3.37*	*4.01*	*4.70*	*5.45*	*6.26*	*7.12*	*8.04*	*9.01*	*10.04*	*11.13*
20	*0.03*	*0.12*	*0.28*	*0.49*	*0.77*	*1.11*	*1.50*	*1.97*	*2.49*	*3.07*	*3.72*	*4.42*	*5.19*	*6.02*	*6.91*	*7.86*	*8.87*	*9.95*	*11.08*	*12.28*
21	*0.03*	*0.13*	*0.30*	*0.54*	*0.84*	*1.21*	*1.65*	*2.16*	*2.73*	*3.37*	*4.08*	*4.85*	*5.70*	*6.61*	*7.58*	*8.63*	*9.74*	*10.92*	*12.17*	*13.48*
22	*0.04*	*0.15*	*0.33*	*0.59*	*0.92*	*1.33*	*1.80*	*2.36*	*2.98*	*3.68*	*4.46*	*5.30*	*6.22*	*7.22*	*8.29*	*9.43*	*10.65*	*11.93*	*13.30*	*14.73*
23	*0.04*	*0.16*	*0.36*	*0.64*	*1.00*	*1.44*	*1.96*	*2.56*	*3.25*	*4.01*	*4.85*	*5.77*	*6.77*	*7.85*	*9.02*	*10.26*	*11.58*	*12.98*	*14.47*	*16.03*
24	*0.04*	*0.17*	*0.39*	*0.69*	*1.09*	*1.56*	*2.13*	*2.78*	*3.52*	*4.34*	*5.25*	*6.25*	*7.34*	*8.51*	*9.77*	*11.12*	*12.55*	*14.07*	*15.68*	*17.37*
25	*0.05*	*0.19*	*0.42*	*0.75*	*1.17*	*1.69*	*2.30*	*3.00*	*3.80*	*4.69*	*5.67*	*6.75*	*7.92*	*9.19*	*10.55*	*12.00*	*13.55*	*15.19*	*16.92*	*18.75*
26	*0.05*	*0.20*	*0.45*	*0.81*	*1.26*	*1.82*	*2.47*	*3.23*	*4.09*	*5.04*	*6.10*	*7.26*	*8.52*	*9.89*	*11.35*	*12.91*	*14.58*	*16.34*	*18.21*	*20.18*
27	*0.05*	*0.22*	*0.49*	*0.87*	*1.35*	*1.95*	*2.65*	*3.46*	*4.38*	*5.41*	*6.55*	*7.79*	*9.14*	*10.60*	*12.17*	*13.85*	*15.63*	*17.53*	*19.53*	*21.64*
28	*0.06*	*0.23*	*0.52*	*0.93*	*1.45*	*2.08*	*2.83*	*3.70*	*4.69*	*5.79*	*7.00*	*8.33*	*9.78*	*11.34*	*13.02*	*14.81*	*16.72*	*18.74*	*20.88*	*23.14*
29	*0.06*	*0.25*	*0.56*	*0.99*	*1.54*	*2.22*	*3.02*	*3.95*	*5.00*	*6.17*	*7.46*	*8.88*	*10.43*	*12.09*	*13.88*	*15.79*	*17.83*	*19.99*	*22.27*	*24.68*
30	*0.07*	*0.26*	*0.59*	*1.05*	*1.64*	*2.36*	*3.22*	*4.20*	*5.32*	*6.56*	*7.94*	*9.45*	*11.09*	*12.86*	*14.76*	*16.80*	*18.96*	*21.26*	*23.69*	*26.25*
31	*0.07*	*0.28*	*0.63*	*1.11*	*1.74*	*2.51*	*3.41*	*4.46*	*5.64*	*6.96*	*8.42*	*10.03*	*11.77*	*13.65*	*15.67*	*17.82*	*20.12*	*22.56*	*25.14*	*27.85*
32	*0.07*	*0.29*	*0.66*	*1.18*	*1.84*	*2.65*	*3.61*	*4.72*	*5.97*	*7.37*	*8.92*	*10.61*	*12.46*	*14.45*	*16.58*	*18.87*	*21.30*	*23.88*	*26.61*	*29.48*
33	*0.08*	*0.31*	*0.70*	*1.25*	*1.95*	*2.80*	*3.82*	*4.98*	*6.31*	*7.79*	*9.42*	*11.21*	*13.16*	*15.26*	*17.52*	*19.93*	*22.50*	*25.23*	*28.11*	*31.14*
34	*0.08*	*0.33*	*0.74*	*1.31*	*2.05*	*2.95*	*4.02*	*5.25*	*6.65*	*8.21*	*9.93*	*11.82*	*13.87*	*16.09*	*18.47*	*21.01*	*23.72*	*26.59*	*29.63*	*32.83*
35	*0.09*	*0.35*	*0.78*	*1.38*	*2.16*	*3.11*	*4.23*	*5.53*	*6.99*	*8.64*	*10.45*	*12.43*	*14.59*	*16.93*	*19.43*	*22.11*	*24.96*	*27.98*	*31.17*	*34.54*
36	*0.09*	*0.36*	*0.82*	*1.45*	*2.27*	*3.26*	*4.44*	*5.80*	*7.35*	*9.07*	*10.97*	*13.06*	*15.33*	*17.77*	*20.40*	*23.22*	*26.21*	*29.38*	*32.74*	*36.27*
37	*0.10*	*0.38*	*0.86*	*1.52*	*2.38*	*3.42*	*4.66*	*6.08*	*7.70*	*9.51*	*11.50*	*13.69*	*16.07*	*18.63*	*21.39*	*24.34*	*27.47*	*30.80*	*34.32*	*38.03*
38	*0.10*	*0.40*	*0.90*	*1.59*	*2.49*	*3.58*	*4.88*	*6.37*	*8.06*	*9.95*	*12.04*	*14.33*	*16.81*	*19.50*	*22.39*	*25.47*	*28.75*	*32.24*	*35.92*	*39.80*
39	*0.10*	*0.42*	*0.94*	*1.66*	*2.60*	*3.74*	*5.09*	*6.65*	*8.42*	*10.40*	*12.58*	*14.97*	*17.57*	*20.38*	*23.39*	*26.61*	*30.04*	*33.68*	*37.53*	*41.58*
40	*0.11*	*0.43*	*0.98*	*1.74*	*2.71*	*3.90*	*5.31*	*6.94*	*8.78*	*10.85*	*13.12*	*15.62*	*18.33*	*21.26*	*24.40*	*27.76*	*31.34*	*35.14*	*39.15*	*43.38*
41	*0.11*	*0.45*	*1.02*	*1.81*	*2.82*	*4.07*	*5.54*	*7.23*	*9.15*	*11.30*	*13.67*	*16.27*	*19.09*	*22.14*	*25.42*	*28.92*	*32.65*	*36.60*	*40.78*	*45.19*
42	*0.12*	*0.47*	*1.06*	*1.88*	*2.94*	*4.23*	*5.76*	*7.52*	*9.52*	*11.75*	*14.22*	*16.92*	*19.86*	*23.03*	*26.44*	*30.09*	*33.96*	*38.08*	*42.43*	*47.01*
43	*0.12*	*0.49*	*1.10*	*1.95*	*3.05*	*4.40*	*5.98*	*7.81*	*9.89*	*12.21*	*14.77*	*17.58*	*20.63*	*23.93*	*27.47*	*31.25*	*35.28*	*39.56*	*44.07*	*48.83*

Table 2 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Measured Jib Properties (FEM 1.004)

Jib Angle (°)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
44	*0.13*	*0.51*	*1.14*	*2.03*	*3.17*	*4.56*	*6.21*	*8.11*	*10.26*	*12.67*	*15.33*	*18.24*	*21.41*	*24.83*	*28.50*	*32.43*	*36.60*	*41.04*	*45.72*	*50.66*
45	*0.13*	*0.52*	*1.18*	*2.10*	*3.28*	*4.72*	*6.43*	*8.40*	*10.63*	*13.12*	*15.88*	*18.90*	*22.18*	*25.72*	*29.53*	*33.60*	*37.93*	*42.52*	*47.38*	*52.50*
46	*0.14*	*0.54*	*1.22*	*2.17*	*3.40*	*4.89*	*6.66*	*8.69*	*11.00*	*13.58*	*16.43*	*19.56*	*22.95*	*26.62*	*30.56*	*34.77*	*39.25*	*44.01*	*49.03*	*54.33*
47	*0.14*	*0.56*	*1.26*	*2.25*	*3.51*	*5.05*	*6.88*	*8.99*	*11.37*	*14.04*	*16.99*	*20.22*	*23.73*	*27.52*	*31.59*	*35.94*	*40.57*	*45.49*	*50.68*	*56.16*
48	*0.14*	*0.58*	*1.30*	*2.32*	*3.62*	*5.22*	*7.10*	*9.28*	*11.74*	*14.50*	*17.54*	*20.87*	*24.50*	*28.41*	*32.62*	*37.11*	*41.89*	*46.97*	*52.33*	*57.98*
49	*0.15*	*0.60*	*1.35*	*2.39*	*3.74*	*5.38*	*7.33*	*9.57*	*12.11*	*14.95*	*18.09*	*21.53*	*25.27*	*29.30*	*33.64*	*38.27*	*43.21*	*48.44*	*53.97*	*59.80*
50	*0.15*	*0.62*	*1.39*	*2.46*	*3.85*	*5.55*	*7.55*	*9.86*	*12.48*	*15.40*	*18.64*	*22.18*	*26.03*	*30.19*	*34.66*	*39.43*	*44.51*	*49.91*	*55.61*	*61.61*
51	*0.16*	*0.63*	*1.43*	*2.54*	*3.96*	*5.71*	*7.77*	*10.15*	*12.84*	*15.85*	*19.18*	*22.83*	*26.79*	*31.07*	*35.67*	*40.58*	*45.81*	*51.36*	*57.23*	*63.41*
52	*0.16*	*0.65*	*1.47*	*2.61*	*4.07*	*5.87*	*7.99*	*10.43*	*13.20*	*16.30*	*19.72*	*23.47*	*27.55*	*31.95*	*36.67*	*41.73*	*47.10*	*52.81*	*58.84*	*65.20*
53	*0.17*	*0.67*	*1.51*	*2.68*	*4.19*	*6.03*	*8.20*	*10.71*	*13.56*	*16.74*	*20.26*	*24.11*	*28.29*	*32.81*	*37.67*	*42.86*	*48.38*	*54.24*	*60.44*	*66.97*
54	*0.17*	*0.69*	*1.55*	*2.75*	*4.29*	*6.18*	*8.42*	*11.00*	*13.92*	*17.18*	*20.79*	*24.74*	*29.03*	*33.67*	*38.65*	*43.98*	*49.65*	*55.66*	*62.02*	*68.72*
55	*0.18*	*0.70*	*1.59*	*2.82*	*4.40*	*6.34*	*8.63*	*11.27*	*14.27*	*17.61*	*21.31*	*25.36*	*29.77*	*34.52*	*39.63*	*45.09*	*50.90*	*57.07*	*63.58*	*70.45*
56	*0.18*	*0.72*	*1.62*	*2.89*	*4.51*	*6.49*	*8.84*	*11.55*	*14.61*	*18.04*	*21.83*	*25.98*	*30.49*	*35.36*	*40.59*	*46.18*	*52.14*	*58.45*	*65.13*	*72.16*
57	*0.18*	*0.74*	*1.66*	*2.95*	*4.62*	*6.65*	*9.05*	*11.82*	*14.95*	*18.46*	*22.34*	*26.59*	*31.20*	*36.19*	*41.54*	*47.26*	*53.36*	*59.82*	*66.65*	*73.85*
58	*0.19*	*0.76*	*1.70*	*3.02*	*4.72*	*6.80*	*9.25*	*12.08*	*15.29*	*18.88*	*22.84*	*27.18*	*31.90*	*37.00*	*42.47*	*48.33*	*54.56*	*61.16*	*68.15*	*75.51*
59	*0.19*	*0.77*	*1.74*	*3.09*	*4.82*	*6.94*	*9.45*	*12.34*	*15.62*	*19.29*	*23.34*	*27.77*	*32.59*	*37.80*	*43.39*	*49.37*	*55.74*	*62.49*	*69.62*	*77.14*
60	*0.20*	*0.79*	*1.77*	*3.15*	*4.92*	*7.09*	*9.65*	*12.60*	*15.95*	*19.69*	*23.82*	*28.35*	*33.27*	*38.58*	*44.29*	*50.40*	*56.89*	*63.78*	*71.07*	*78.74*
61	*0.20*	*0.80*	*1.81*	*3.21*	*5.02*	*7.23*	*9.84*	*12.85*	*16.26*	*20.08*	*24.30*	*28.91*	*33.93*	*39.35*	*45.18*	*51.40*	*58.03*	*65.06*	*72.48*	*80.32*
62	*0.20*	*0.82*	*1.84*	*3.27*	*5.12*	*7.37*	*10.03*	*13.10*	*16.58*	*20.46*	*24.76*	*29.47*	*34.58*	*40.11*	*46.04*	*52.39*	*59.14*	*66.30*	*73.87*	*81.85*
63	*0.21*	*0.83*	*1.88*	*3.33*	*5.21*	*7.50*	*10.21*	*13.34*	*16.88*	*20.84*	*25.21*	*30.01*	*35.22*	*40.84*	*46.89*	*53.35*	*60.22*	*67.52*	*75.23*	*83.35*
64	*0.21*	*0.85*	*1.91*	*3.39*	*5.30*	*7.63*	*10.39*	*13.57*	*17.18*	*21.20*	*25.66*	*30.53*	*35.83*	*41.56*	*47.71*	*54.28*	*61.28*	*68.70*	*76.55*	*84.82*
65	*0.22*	*0.86*	*1.94*	*3.45*	*5.39*	*7.76*	*10.56*	*13.80*	*17.46*	*21.56*	*26.09*	*31.05*	*36.44*	*42.26*	*48.51*	*55.19*	*62.31*	*69.85*	*77.83*	*86.24*
66	*0.22*	*0.88*	*1.97*	*3.50*	*5.48*	*7.89*	*10.73*	*14.02*	*17.74*	*21.91*	*26.51*	*31.54*	*37.02*	*42.94*	*49.29*	*56.08*	*63.31*	*70.97*	*79.08*	*87.62*
67	*0.22*	*0.89*	*2.00*	*3.56*	*5.56*	*8.01*	*10.90*	*14.23*	*18.02*	*22.24*	*26.91*	*32.03*	*37.59*	*43.59*	*50.04*	*56.94*	*64.28*	*72.06*	*80.29*	*88.96*
68	*0.23*	*0.90*	*2.03*	*3.61*	*5.64*	*8.12*	*11.06*	*14.44*	*18.28*	*22.56*	*27.30*	*32.49*	*38.13*	*44.23*	*50.77*	*57.77*	*65.21*	*73.11*	*81.46*	*90.26*
69	*0.23*	*0.92*	*2.06*	*3.66*	*5.72*	*8.24*	*11.21*	*14.64*	*18.53*	*22.88*	*27.68*	*32.94*	*38.66*	*44.84*	*51.47*	*58.57*	*66.12*	*74.12*	*82.59*	*91.51*
70	*0.23*	*0.93*	*2.09*	*3.71*	*5.79*	*8.34*	*11.36*	*14.83*	*18.77*	*23.18*	*28.05*	*33.38*	*39.17*	*45.43*	*52.15*	*59.34*	*66.98*	*75.10*	*83.67*	*92.71*
71	*0.23*	*0.94*	*2.11*	*3.75*	*5.87*	*8.45*	*11.50*	*15.02*	*19.01*	*23.47*	*28.39*	*33.79*	*39.66*	*45.99*	*52.80*	*60.07*	*67.82*	*76.03*	*84.71*	*93.86*
72	*0.24*	*0.95*	*2.14*	*3.80*	*5.94*	*8.55*	*11.63*	*15.19*	*19.23*	*23.74*	*28.73*	*34.19*	*40.12*	*46.53*	*53.42*	*60.78*	*68.61*	*76.92*	*85.71*	*94.97*
73	*0.24*	*0.96*	*2.16*	*3.84*	*6.00*	*8.64*	*11.76*	*15.36*	*19.44*	*24.00*	*29.05*	*34.57*	*40.57*	*47.05*	*54.01*	*61.45*	*69.37*	*77.77*	*86.66*	*96.02*

Table 2 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Measured Jib Properties (FEM 1.004)

Jib Angle (°)	Wind Speed (m/s)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
74	*0.24*	*0.97*	*2.18*	*3.88*	*6.06*	*8.73*	*11.88*	*15.52*	*19.65*	*24.25*	*29.35*	*34.93*	*40.99*	*47.54*	*54.57*	*62.09*	*70.09*	*78.58*	*87.56*	*97.02*
75	*0.24*	*0.98*	*2.20*	*3.92*	*6.12*	*8.82*	*12.00*	*15.67*	*19.84*	*24.49*	*29.63*	*35.27*	*41.39*	*48.00*	*55.10*	*62.69*	*70.78*	*79.35*	*88.41*	*97.96*
76	*0.25*	*0.99*	*2.22*	*3.95*	*6.18*	*8.90*	*12.11*	*15.82*	*20.02*	*24.71*	*29.90*	*35.59*	*41.76*	*48.44*	*55.60*	*63.26*	*71.42*	*80.07*	*89.21*	*98.85*
77	*0.25*	*1.00*	*2.24*	*3.99*	*6.23*	*8.97*	*12.21*	*15.95*	*20.19*	*24.92*	*30.15*	*35.88*	*42.11*	*48.84*	*56.07*	*63.80*	*72.02*	*80.74*	*89.96*	*99.68*
78	*0.25*	*1.00*	*2.26*	*4.02*	*6.28*	*9.04*	*12.31*	*16.07*	*20.34*	*25.11*	*30.39*	*36.16*	*42.44*	*49.22*	*56.51*	*64.29*	*72.58*	*81.37*	*90.66*	*100.45*
79	*0.25*	*1.01*	*2.28*	*4.05*	*6.32*	*9.11*	*12.39*	*16.19*	*20.49*	*25.29*	*30.60*	*36.42*	*42.74*	*49.57*	*56.91*	*64.75*	*73.10*	*81.95*	*91.31*	*101.17*
80	*0.25*	*1.02*	*2.29*	*4.07*	*6.36*	*9.16*	*12.47*	*16.29*	*20.62*	*25.46*	*30.80*	*36.66*	*43.02*	*49.90*	*57.28*	*65.17*	*73.57*	*82.48*	*91.90*	*101.83*
81	*0.26*	*1.02*	*2.30*	*4.10*	*6.40*	*9.22*	*12.55*	*16.39*	*20.74*	*25.61*	*30.98*	*36.87*	*43.27*	*50.19*	*57.61*	*65.55*	*74.00*	*82.96*	*92.44*	*102.42*
82	*0.26*	*1.03*	*2.32*	*4.12*	*6.43*	*9.27*	*12.61*	*16.47*	*20.85*	*25.74*	*31.15*	*37.07*	*43.50*	*50.45*	*57.91*	*65.89*	*74.39*	*83.40*	*92.92*	*102.96*
83	*0.26*	*1.03*	*2.33*	*4.14*	*6.46*	*9.31*	*12.67*	*16.55*	*20.95*	*25.86*	*31.29*	*37.24*	*43.70*	*50.68*	*58.18*	*66.20*	*74.73*	*83.78*	*93.35*	*103.43*
84	*0.26*	*1.04*	*2.34*	*4.15*	*6.49*	*9.35*	*12.72*	*16.62*	*21.03*	*25.96*	*31.41*	*37.38*	*43.87*	*50.88*	*58.41*	*66.46*	*75.03*	*84.12*	*93.72*	*103.85*
85	*0.26*	*1.04*	*2.34*	*4.17*	*6.51*	*9.38*	*12.76*	*16.67*	*21.10*	*26.05*	*31.52*	*37.51*	*44.02*	*51.06*	*58.61*	*66.69*	*75.28*	*84.40*	*94.04*	*104.20*
86	*0.26*	*1.04*	*2.35*	*4.18*	*6.53*	*9.40*	*12.80*	*16.72*	*21.16*	*26.12*	*31.61*	*37.61*	*44.14*	*51.20*	*58.77*	*66.87*	*75.49*	*84.63*	*94.30*	*104.48*
87	*0.26*	*1.05*	*2.36*	*4.19*	*6.54*	*9.42*	*12.83*	*16.75*	*21.20*	*26.18*	*31.67*	*37.69*	*44.24*	*51.31*	*58.90*	*67.01*	*75.65*	*84.81*	*94.50*	*104.71*
88	*0.26*	*1.05*	*2.36*	*4.19*	*6.55*	*9.44*	*12.85*	*16.78*	*21.24*	*26.22*	*31.72*	*37.75*	*44.31*	*51.38*	*58.99*	*67.11*	*75.76*	*84.94*	*94.64*	*104.87*
89	*0.26*	*1.05*	*2.36*	*4.20*	*6.56*	*9.45*	*12.86*	*16.79*	*21.25*	*26.24*	*31.75*	*37.79*	*44.35*	*51.43*	*59.04*	*67.17*	*75.83*	*85.02*	*94.73*	*104.96*
90	*0.26*	*1.05*	*2.36*	*4.20*	*6.56*	*9.45*	*12.86*	*16.80*	*21.26*	*26.25*	*31.76*	*37.80*	*44.36*	*51.45*	*59.06*	*67.20*	*75.86*	*85.04*	*94.76*	*104.99*

Table 2 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Measured Jib Properties (FEM 1.004)

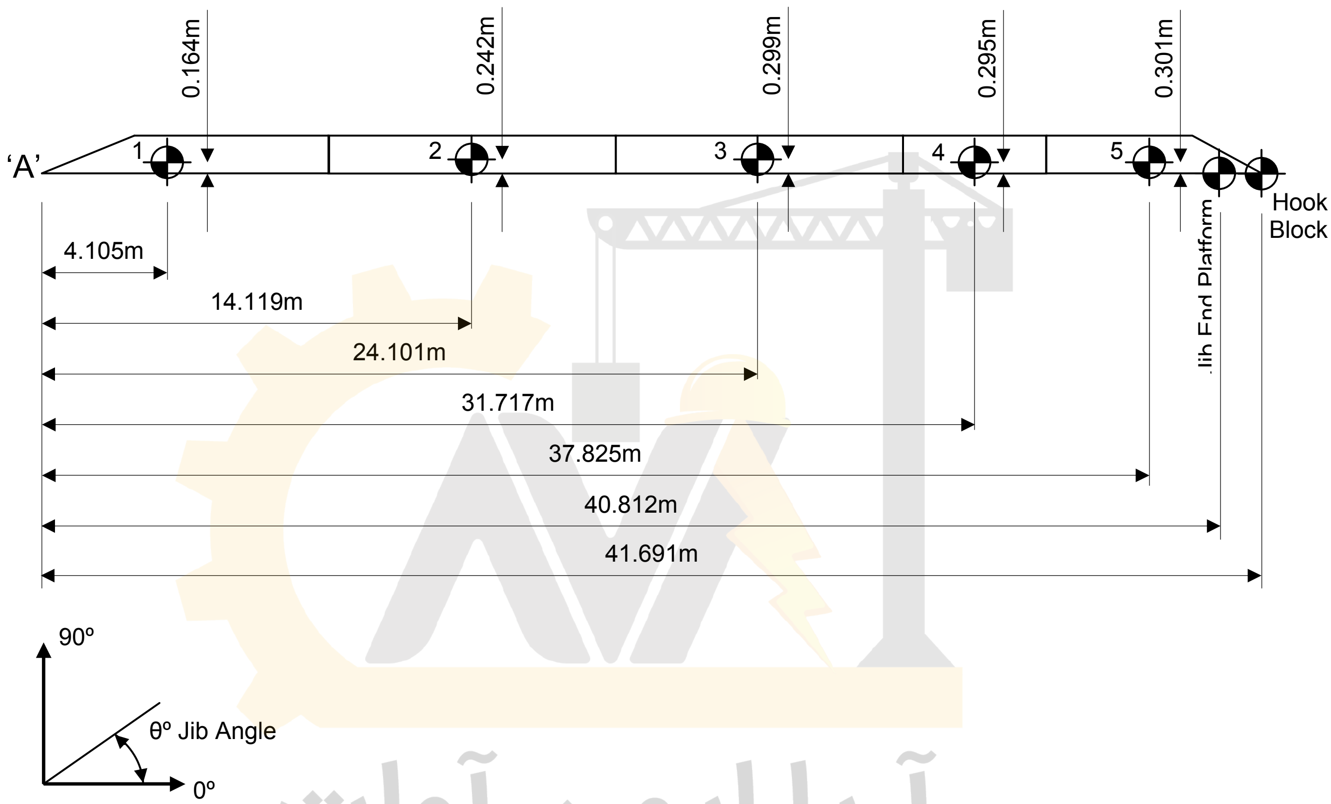
APPENDIX 6

Calculation of the wind loading and consequent moment acting at the jib pivot point according to ISO 4302 *"Cranes – Wind Load Assessment"*

Appendix 6

Calculation of the moment acting at the jib pivot points due to wind loading on the jib and jib end platform according to ISO 4302

1. Theoretical properties of the jib sections i.e. the masses provided in the crane manual and positions of centre of gravity provided by Jaso



The moment, M_{WIND}, acting at the jib pivot point 'A' arising from the wind loading is given by:

$M_{WIND} = F_N \cos(\tan^{-1} y/x) x$ where

F_N is the wind load normal to the underside of the jib component under consideration (N)
x is the dimension along the jib section from 'A' to the centre of gravity of the jib section (m)
y is the dimension from 'A' to the centre of gravity of the jib section perpendicular to the x is the dimension (m)

Since the centre of gravity of the jib sections are slightly offset from the pivot point in the vertical (y) direction the term $\cos(\tan^{-1} y/x)$ in the above equation resolves F_N (the wind load normal to the underside of the jib component under consideration) to the lever arm joining the centre of gravity to the pivot point such that the resultant force is completely perpendicular to the lever arm. However, the angles between the centres of gravity of the jib sections and the pivot point are very small such that $\cos(\tan^{-1} y/x)$ tends to unity. Hence this is ignored and the moment, M_{WIND}, acting at the jib pivot point 'A' arising from the wind loading is given by:

$M_{WIND} = F_N\, x$ where

F_N is the wind load normal to the underside of the jib component under consideration (N)
x is the dimension along the jib section from 'A' to the centre of gravity of the jib section (m)

Since the wind load, F_N, is normal to the underside of the jib component under consideration, x remains constant at the dimensions shown in the sketch above as the angle of the jib to the horizontal alters.

For any given jib angle to the horizontal, the total moment acting at the jib pivot point 'A' arising from the wind load acting on each jib section is given by adding the moment arising from each individual jib section 1 to 5 (M_{WIND1} – M_{WIND5}) and that arising from the jib end platform ($M_{WINDPLATFORM}$), i.e:

$M_{WINDTOTAL} = M_{WIND1} + M_{WIND2} + M_{WIND3} + M_{WIND4} + M_{WIND5} + M_{WINDPLATFORM}$

The wind loading on each jib section and the jib end platform has been calculated in Appendix 3 according to FEM 1.001, FEM 1.004, ISO 4302 and BS EN 13001 – 2:2004 and equations for F_N derived.

Example Calculation – ISO 4302 (wind speed = 13 m/s, jib angle = 45º to the horizontal)

Assuming a wind speed of 10 m/s, the wind pressure ρ is given by:

$\rho = 0.613\ v^2 = 0.613 \times 13^2 = 103.6\ N/m^2$

Using equations 1b – 6b derived in Appendix 3 Section 7.3.3 for a jib angle of 45º to the horizontal the wind load normal to the underside of the jib component under consideration and acting at the centre of gravity is:

For jib section 1, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N1} = 3.82\ \rho \sin^2 \theta = 3.82 \times 103.6 \times \sin^2 45º = 197.9$ N
$M_{WIND1} = 197.9 \times 4.105 = 0.81$ kNm

For jib section 2, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N2} = 4.20\ \rho \sin^2 \theta = 4.20 \times 103.6 \times \sin^2 45º = 217.6$ N
$M_{WIND2} = 217.6 \times 14.119 = 3.07$ kNm

For jib section 3, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N3} = 4.13\ \rho \sin^2 \theta = 4.13 \times 103.6 \times \sin^2 45º = 213.9$ N
$M_{WIND3} = 213.9 \times 24.101 = 5.16$ kNm

For jib section 4, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N4} = 2.11\ \rho \sin^2 \theta = 2.11 \times 103.6 \times \sin^2 45º = 109.3$ N
$M_{WIND4} = 109.3 \times 31.717 = 3.47$ kNm

For jib section 5, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N5} = 3.06\ \rho \sin^2 \theta = 3.06 \times 103.6 \times \sin^2 45^{\circ} = 158.5$ N
$M_{WIND5} = 158.5 \times 37.825 = 5.99$ kNm

The wind load normal to the jib end platform floor and resulting moment at the jib pivot point is:

$F_{NPLATFORM} = 0.655\ \rho \sin^2 \theta = 0.655 \times 103.6 \times \sin^2 45^{\circ} = 33.9$ N
$M_{WINDPLATFORM} = 33.9 \times 40.812 = 1.38$ kNm

The total moment at the jib pivot point due to wind loading at a wind speed of 13 m/s and a jib angle of 45º to the horizontal is:

$M_{WINDTOTAL} = 0.81 + 3.07 + 5.16 + 3.47 + 5.99 + 1.38 = 19.88$ kNm

Similar calculations can be performed for different wind speeds and jib angles and the resultant moments at the jib pivot point are given in Table 1 of this appendix.

Jib Angle (°)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
15	*0.02*	*0.06*	*0.14*	*0.25*	*0.39*	*0.57*	*0.77*	*1.01*	*1.28*	*1.58*	*1.91*	*2.27*	*2.66*	*3.09*	*3.55*	*4.04*	*4.56*	*5.11*	*5.69*	*6.43*
16	*0.02*	*0.07*	*0.16*	*0.29*	*0.45*	*0.64*	*0.88*	*1.14*	*1.45*	*1.79*	*2.16*	*2.57*	*3.02*	*3.50*	*4.02*	*4.58*	*5.17*	*5.79*	*6.45*	*7.29*
17	*0.02*	*0.08*	*0.18*	*0.32*	*0.50*	*0.72*	*0.99*	*1.29*	*1.63*	*2.01*	*2.43*	*2.90*	*3.40*	*3.94*	*4.53*	*5.15*	*5.81*	*6.52*	*7.26*	*8.20*
18	*0.02*	*0.09*	*0.20*	*0.36*	*0.56*	*0.81*	*1.10*	*1.44*	*1.82*	*2.25*	*2.72*	*3.24*	*3.80*	*4.40*	*5.06*	*5.75*	*6.49*	*7.28*	*8.11*	*9.17*
19	*0.02*	*0.10*	*0.22*	*0.40*	*0.62*	*0.90*	*1.22*	*1.60*	*2.02*	*2.49*	*3.02*	*3.59*	*4.22*	*4.89*	*5.61*	*6.39*	*7.21*	*8.08*	*9.01*	*10.17*
20	*0.03*	*0.11*	*0.25*	*0.44*	*0.69*	*0.99*	*1.35*	*1.76*	*2.23*	*2.75*	*3.33*	*3.96*	*4.65*	*5.40*	*6.19*	*7.05*	*7.96*	*8.92*	*9.94*	*11.23*
21	*0.03*	*0.12*	*0.27*	*0.48*	*0.76*	*1.09*	*1.48*	*1.93*	*2.45*	*3.02*	*3.66*	*4.35*	*5.11*	*5.92*	*6.80*	*7.74*	*8.73*	*9.79*	*10.91*	*12.33*
22	*0.03*	*0.13*	*0.30*	*0.53*	*0.83*	*1.19*	*1.62*	*2.11*	*2.68*	*3.30*	*4.00*	*4.76*	*5.58*	*6.47*	*7.43*	*8.45*	*9.54*	*10.70*	*11.92*	*13.47*
23	*0.04*	*0.14*	*0.32*	*0.57*	*0.90*	*1.29*	*1.76*	*2.30*	*2.91*	*3.59*	*4.35*	*5.17*	*6.07*	*7.04*	*8.08*	*9.20*	*10.38*	*11.64*	*12.97*	*14.65*
24	*0.04*	*0.16*	*0.35*	*0.62*	*0.97*	*1.40*	*1.91*	*2.49*	*3.15*	*3.89*	*4.71*	*5.61*	*6.58*	*7.63*	*8.76*	*9.97*	*11.25*	*12.61*	*14.06*	*15.88*
25	*0.04*	*0.17*	*0.38*	*0.67*	*1.05*	*1.51*	*2.06*	*2.69*	*3.40*	*4.20*	*5.09*	*6.05*	*7.10*	*8.24*	*9.46*	*10.76*	*12.15*	*13.62*	*15.17*	*17.14*
26	*0.05*	*0.18*	*0.41*	*0.72*	*1.13*	*1.63*	*2.22*	*2.89*	*3.66*	*4.52*	*5.47*	*6.51*	*7.64*	*8.86*	*10.18*	*11.58*	*13.07*	*14.65*	*16.33*	*18.44*
27	*0.05*	*0.19*	*0.44*	*0.78*	*1.21*	*1.75*	*2.38*	*3.10*	*3.93*	*4.85*	*5.87*	*6.98*	*8.20*	*9.51*	*10.91*	*12.42*	*14.02*	*15.72*	*17.51*	*19.78*
28	*0.05*	*0.21*	*0.47*	*0.83*	*1.30*	*1.87*	*2.54*	*3.32*	*4.20*	*5.19*	*6.28*	*7.47*	*8.77*	*10.17*	*11.67*	*13.28*	*14.99*	*16.81*	*18.73*	*21.15*
29	*0.06*	*0.22*	*0.50*	*0.89*	*1.38*	*1.99*	*2.71*	*3.54*	*4.48*	*5.53*	*6.69*	*7.97*	*9.35*	*10.84*	*12.45*	*14.16*	*15.99*	*17.92*	*19.97*	*22.56*
30	*0.06*	*0.24*	*0.53*	*0.94*	*1.47*	*2.12*	*2.88*	*3.77*	*4.77*	*5.88*	*7.12*	*8.47*	*9.94*	*11.53*	*13.24*	*15.06*	*17.00*	*19.06*	*21.24*	*23.99*
31	*0.06*	*0.25*	*0.56*	*1.00*	*1.56*	*2.25*	*3.06*	*4.00*	*5.06*	*6.24*	*7.55*	*8.99*	*10.55*	*12.24*	*14.05*	*15.98*	*18.04*	*20.23*	*22.54*	*25.46*
32	*0.07*	*0.26*	*0.59*	*1.06*	*1.65*	*2.38*	*3.24*	*4.23*	*5.35*	*6.61*	*8.00*	*9.52*	*11.17*	*12.95*	*14.87*	*16.92*	*19.10*	*21.41*	*23.86*	*26.95*
33	*0.07*	*0.28*	*0.63*	*1.12*	*1.75*	*2.51*	*3.42*	*4.47*	*5.65*	*6.98*	*8.45*	*10.05*	*11.80*	*13.68*	*15.71*	*17.87*	*20.17*	*22.62*	*25.20*	*28.47*
34	*0.07*	*0.29*	*0.66*	*1.18*	*1.84*	*2.65*	*3.61*	*4.71*	*5.96*	*7.36*	*8.90*	*10.60*	*12.44*	*14.42*	*16.56*	*18.84*	*21.27*	*23.84*	*26.57*	*30.01*
35	*0.08*	*0.31*	*0.70*	*1.24*	*1.94*	*2.79*	*3.79*	*4.96*	*6.27*	*7.74*	*9.37*	*11.15*	*13.08*	*15.18*	*17.42*	*19.82*	*22.38*	*25.09*	*27.95*	*31.58*
36	*0.08*	*0.33*	*0.73*	*1.30*	*2.03*	*2.93*	*3.98*	*5.20*	*6.59*	*8.13*	*9.84*	*11.71*	*13.74*	*15.94*	*18.29*	*20.81*	*23.50*	*26.34*	*29.35*	*33.16*
37	*0.09*	*0.34*	*0.77*	*1.36*	*2.13*	*3.07*	*4.18*	*5.46*	*6.90*	*8.52*	*10.31*	*12.27*	*14.40*	*16.71*	*19.18*	*21.82*	*24.63*	*27.62*	*30.77*	*34.76*
38	*0.09*	*0.36*	*0.80*	*1.43*	*2.23*	*3.21*	*4.37*	*5.71*	*7.23*	*8.92*	*10.79*	*12.85*	*15.08*	*17.48*	*20.07*	*22.84*	*25.78*	*28.90*	*32.20*	*36.38*
39	*0.09*	*0.37*	*0.84*	*1.49*	*2.33*	*3.36*	*4.57*	*5.97*	*7.55*	*9.32*	*11.28*	*13.42*	*15.75*	*18.27*	*20.97*	*23.86*	*26.94*	*30.20*	*33.65*	*38.01*
40	*0.10*	*0.39*	*0.88*	*1.56*	*2.43*	*3.50*	*4.76*	*6.22*	*7.88*	*9.72*	*11.77*	*14.00*	*16.43*	*19.06*	*21.88*	*24.89*	*28.10*	*31.50*	*35.10*	*39.66*
41	*0.10*	*0.41*	*0.91*	*1.62*	*2.53*	*3.65*	*4.96*	*6.48*	*8.20*	*10.13*	*12.26*	*14.59*	*17.12*	*19.85*	*22.79*	*25.93*	*29.27*	*32.82*	*36.57*	*41.31*
42	*0.11*	*0.42*	*0.95*	*1.69*	*2.63*	*3.79*	*5.16*	*6.74*	*8.54*	*10.54*	*12.75*	*15.17*	*17.81*	*20.65*	*23.71*	*26.97*	*30.45*	*34.14*	*38.04*	*42.97*
43	*0.11*	*0.44*	*0.99*	*1.75*	*2.74*	*3.94*	*5.36*	*7.01*	*8.87*	*10.95*	*13.24*	*15.76*	*18.50*	*21.45*	*24.63*	*28.02*	*31.63*	*35.47*	*39.52*	*44.64*

Table 1 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Theoretical Jib Properties (ISO 4302)

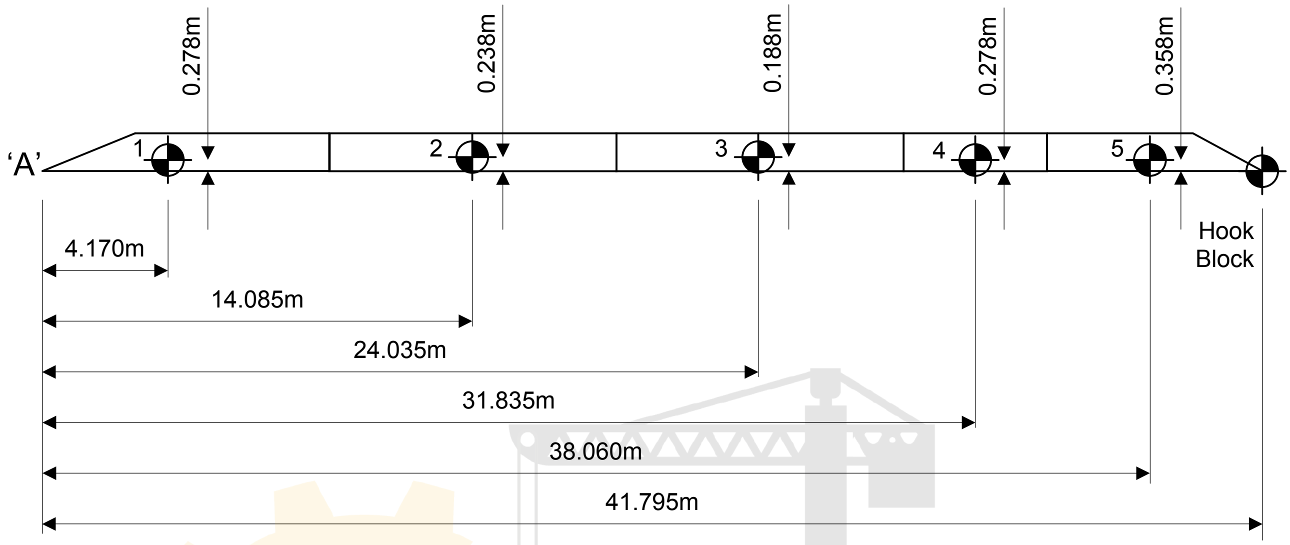
Jib Angle (°)	Wind Speed (m/s)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
44	*0.11*	*0.45*	*1.02*	*1.82*	*2.84*	*4.09*	*5.56*	*7.27*	*9.20*	*11.36*	*13.74*	*16.35*	*19.19*	*22.26*	*25.55*	*29.07*	*32.82*	*36.79*	*41.00*	*46.31*
45	*0.12*	*0.47*	*1.06*	*1.88*	*2.94*	*4.24*	*5.77*	*7.53*	*9.53*	*11.77*	*14.24*	*16.94*	*19.89*	*23.06*	*26.48*	*30.12*	*34.01*	*38.13*	*42.48*	*47.99*
46	*0.12*	*0.49*	*1.10*	*1.95*	*3.04*	*4.38*	*5.97*	*7.79*	*9.86*	*12.18*	*14.74*	*17.54*	*20.58*	*23.87*	*27.40*	*31.17*	*35.19*	*39.46*	*43.96*	*49.66*
47	*0.13*	*0.50*	*1.13*	*2.01*	*3.15*	*4.53*	*6.17*	*8.06*	*10.20*	*12.59*	*15.23*	*18.13*	*21.27*	*24.67*	*28.32*	*32.23*	*36.38*	*40.78*	*45.44*	*51.34*
48	*0.13*	*0.52*	*1.17*	*2.08*	*3.25*	*4.68*	*6.37*	*8.32*	*10.53*	*13.00*	*15.73*	*18.72*	*21.97*	*25.47*	*29.24*	*33.27*	*37.56*	*42.11*	*46.92*	*53.01*
49	*0.13*	*0.54*	*1.21*	*2.14*	*3.35*	*4.83*	*6.57*	*8.58*	*10.86*	*13.40*	*16.22*	*19.30*	*22.65*	*26.27*	*30.16*	*34.32*	*38.74*	*43.43*	*48.39*	*54.67*
50	*0.14*	*0.55*	*1.24*	*2.21*	*3.45*	*4.97*	*6.77*	*8.84*	*11.19*	*13.81*	*16.71*	*19.89*	*23.34*	*27.07*	*31.07*	*35.35*	*39.91*	*44.75*	*49.86*	*56.32*
51	*0.14*	*0.57*	*1.28*	*2.27*	*3.55*	*5.12*	*6.96*	*9.10*	*11.51*	*14.21*	*17.20*	*20.47*	*24.02*	*27.86*	*31.98*	*36.39*	*41.08*	*46.05*	*51.31*	*57.97*
52	*0.15*	*0.58*	*1.32*	*2.34*	*3.65*	*5.26*	*7.16*	*9.35*	*11.84*	*14.61*	*17.68*	*21.04*	*24.70*	*28.64*	*32.88*	*37.41*	*42.23*	*47.35*	*52.76*	*59.60*
53	*0.15*	*0.60*	*1.35*	*2.40*	*3.75*	*5.40*	*7.36*	*9.61*	*12.16*	*15.01*	*18.16*	*21.62*	*25.37*	*29.42*	*33.77*	*38.43*	*43.38*	*48.63*	*54.19*	*61.22*
54	*0.15*	*0.62*	*1.39*	*2.46*	*3.85*	*5.55*	*7.55*	*9.86*	*12.48*	*15.40*	*18.64*	*22.18*	*26.03*	*30.19*	*34.66*	*39.43*	*44.52*	*49.91*	*55.61*	*62.82*
55	*0.16*	*0.63*	*1.42*	*2.53*	*3.95*	*5.68*	*7.74*	*10.11*	*12.79*	*15.79*	*19.11*	*22.74*	*26.69*	*30.95*	*35.53*	*40.43*	*45.64*	*51.16*	*57.01*	*64.40*
56	*0.16*	*0.65*	*1.46*	*2.59*	*4.04*	*5.82*	*7.93*	*10.35*	*13.10*	*16.18*	*19.57*	*23.29*	*27.34*	*31.70*	*36.39*	*41.41*	*46.75*	*52.41*	*58.39*	*65.97*
57	*0.17*	*0.66*	*1.49*	*2.65*	*4.14*	*5.96*	*8.11*	*10.59*	*13.41*	*16.55*	*20.03*	*23.84*	*27.97*	*32.44*	*37.24*	*42.38*	*47.84*	*53.63*	*59.76*	*67.51*
58	*0.17*	*0.68*	*1.52*	*2.71*	*4.23*	*6.09*	*8.29*	*10.83*	*13.71*	*16.93*	*20.48*	*24.37*	*28.60*	*33.17*	*38.08*	*43.33*	*48.91*	*54.84*	*61.10*	*69.03*
59	*0.17*	*0.69*	*1.56*	*2.77*	*4.32*	*6.22*	*8.47*	*11.07*	*14.01*	*17.29*	*20.92*	*24.90*	*29.22*	*33.89*	*38.91*	*44.27*	*49.97*	*56.02*	*62.42*	*70.52*
60	*0.18*	*0.71*	*1.59*	*2.82*	*4.41*	*6.35*	*8.65*	*11.30*	*14.30*	*17.65*	*21.36*	*25.42*	*29.83*	*34.60*	*39.71*	*45.19*	*51.01*	*57.19*	*63.72*	*71.98*
61	*0.18*	*0.72*	*1.62*	*2.88*	*4.50*	*6.48*	*8.82*	*11.52*	*14.58*	*18.00*	*21.78*	*25.92*	*30.42*	*35.29*	*40.51*	*46.09*	*52.03*	*58.33*	*64.99*	*73.42*
62	*0.18*	*0.73*	*1.65*	*2.94*	*4.59*	*6.60*	*8.99*	*11.74*	*14.86*	*18.35*	*22.20*	*26.42*	*31.01*	*35.96*	*41.28*	*46.97*	*53.02*	*59.44*	*66.23*	*74.83*
63	*0.19*	*0.75*	*1.68*	*2.99*	*4.67*	*6.73*	*9.15*	*11.96*	*15.13*	*18.68*	*22.61*	*26.90*	*31.58*	*36.62*	*42.04*	*47.83*	*54.00*	*60.53*	*67.45*	*76.20*
64	*0.19*	*0.76*	*1.71*	*3.04*	*4.75*	*6.84*	*9.32*	*12.17*	*15.40*	*19.01*	*23.00*	*27.38*	*32.13*	*37.26*	*42.78*	*48.67*	*54.94*	*61.60*	*68.63*	*77.54*
65	*0.19*	*0.77*	*1.74*	*3.09*	*4.83*	*6.96*	*9.47*	*12.37*	*15.66*	*19.33*	*23.39*	*27.84*	*32.67*	*37.89*	*43.49*	*49.49*	*55.87*	*62.63*	*69.78*	*78.84*
66	*0.20*	*0.79*	*1.77*	*3.14*	*4.91*	*7.07*	*9.62*	*12.57*	*15.91*	*19.64*	*23.77*	*28.28*	*33.19*	*38.50*	*44.19*	*50.28*	*56.76*	*63.64*	*70.90*	*80.10*
67	*0.20*	*0.80*	*1.79*	*3.19*	*4.99*	*7.18*	*9.77*	*12.76*	*16.15*	*19.94*	*24.13*	*28.72*	*33.70*	*39.08*	*44.87*	*51.05*	*57.63*	*64.61*	*71.99*	*81.33*
68	*0.20*	*0.81*	*1.82*	*3.24*	*5.06*	*7.28*	*9.91*	*12.95*	*16.39*	*20.23*	*24.48*	*29.13*	*34.19*	*39.65*	*45.52*	*51.79*	*58.47*	*65.55*	*73.04*	*82.51*
69	*0.21*	*0.82*	*1.85*	*3.28*	*5.13*	*7.38*	*10.05*	*13.13*	*16.61*	*20.51*	*24.82*	*29.54*	*34.66*	*40.20*	*46.15*	*52.51*	*59.28*	*66.46*	*74.05*	*83.65*
70	*0.21*	*0.83*	*1.87*	*3.32*	*5.20*	*7.48*	*10.18*	*13.30*	*16.83*	*20.78*	*25.15*	*29.92*	*35.12*	*40.73*	*46.76*	*53.20*	*60.06*	*67.33*	*75.02*	*84.75*
71	*0.21*	*0.84*	*1.89*	*3.37*	*5.26*	*7.57*	*10.31*	*13.47*	*17.04*	*21.04*	*25.46*	*30.30*	*35.56*	*41.24*	*47.34*	*53.86*	*60.80*	*68.17*	*75.95*	*85.81*
72	*0.21*	*0.85*	*1.92*	*3.41*	*5.32*	*7.66*	*10.43*	*13.62*	*17.24*	*21.29*	*25.76*	*30.65*	*35.97*	*41.72*	*47.90*	*54.49*	*61.52*	*68.97*	*76.85*	*86.81*
73	*0.22*	*0.86*	*1.94*	*3.44*	*5.38*	*7.75*	*10.55*	*13.77*	*17.43*	*21.52*	*26.04*	*30.99*	*36.37*	*42.18*	*48.43*	*55.10*	*62.20*	*69.73*	*77.70*	*87.77*
74	*0.22*	*0.87*	*1.96*	*3.48*	*5.44*	*7.83*	*10.66*	*13.92*	*17.61*	*21.75*	*26.31*	*31.31*	*36.75*	*42.62*	*48.93*	*55.67*	*62.85*	*70.46*	*78.50*	*88.69*

Table 1 - (continued) Moment at the Jib Pivot Point due to Wind Loading (kNm)
Theoretical jib Properties (ISO 4302)

Jib Angle (°)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
75	0.22	0.88	1.98	3.51	5.49	7.90	10.76	14.05	17.79	21.96	26.57	31.62	37.11	43.04	49.40	56.21	63.46	71.14	79.27	89.55
76	0.22	0.89	1.99	3.55	5.54	7.98	10.86	14.18	17.95	22.16	26.81	31.91	37.44	43.43	49.85	56.72	64.03	71.79	79.99	90.36
77	0.22	0.89	2.01	3.57	5.59	8.04	10.95	14.30	18.10	22.34	27.04	32.17	37.76	43.79	50.27	57.20	64.57	72.39	80.66	91.12
78	0.23	0.90	2.03	3.60	5.63	8.11	11.03	14.41	18.24	22.52	27.25	32.42	38.05	44.13	50.66	57.64	65.07	72.95	81.29	91.83
79	0.23	0.91	2.04	3.63	5.67	8.16	11.11	14.51	18.37	22.68	27.44	32.66	38.32	44.45	51.02	58.05	65.54	73.47	81.87	92.48
80	0.23	0.91	2.05	3.65	5.71	8.22	11.18	14.61	18.49	22.82	27.62	32.87	38.57	44.74	51.36	58.43	65.96	73.95	82.40	93.09
81	0.23	0.92	2.07	3.67	5.74	8.26	11.25	14.69	18.60	22.96	27.78	33.06	38.80	45.00	51.66	58.77	66.35	74.38	82.88	93.63
82	0.23	0.92	2.08	3.69	5.77	8.31	11.31	14.77	18.69	23.08	27.92	33.23	39.00	45.23	51.93	59.08	66.70	74.77	83.31	94.12
83	0.23	0.93	2.09	3.71	5.80	8.35	11.36	14.84	18.78	23.18	28.05	33.39	39.18	45.44	52.17	59.35	67.00	75.12	83.70	94.55
84	0.23	0.93	2.09	3.72	5.82	8.38	11.41	14.90	18.85	23.28	28.17	33.52	39.34	45.62	52.37	59.59	67.27	75.42	84.03	94.93
85	0.23	0.93	2.10	3.74	5.84	8.41	11.44	14.95	18.92	23.36	28.26	33.63	39.47	45.78	52.55	59.79	67.50	75.67	84.31	95.25
86	0.23	0.94	2.11	3.75	5.85	8.43	11.48	14.99	18.97	23.42	28.34	33.72	39.58	45.90	52.69	59.95	67.68	75.88	84.54	95.51
87	0.23	0.94	2.11	3.76	5.87	8.45	11.50	15.02	19.01	23.47	28.40	33.80	39.66	46.00	52.81	60.08	67.83	76.04	84.73	95.72
88	0.24	0.94	2.12	3.76	5.88	8.46	11.52	15.04	19.04	23.51	28.44	33.85	39.72	46.07	52.89	60.17	67.93	76.16	84.85	95.86
89	0.24	0.94	2.12	3.76	5.88	8.47	11.53	15.06	19.06	23.53	28.47	33.88	39.76	46.11	52.94	60.23	67.99	76.23	84.93	95.95
90	0.24	0.94	2.12	3.77	5.88	8.47	11.53	15.06	19.06	23.53	28.48	33.89	39.77	46.13	52.95	60.25	68.01	76.25	84.96	95.98

Table 1 - (continued) Moment at the Jib Pivot Point due to Wind Loading (kNm)
Theoretical Jib properties (ISO 4302)

2. Masses and positions of centre of gravity measured during erection of the crane at HSL



As before, the moment, M_{WIND}, acting at the jib pivot point 'A' arising from the wind loading is given by:

$M_{WIND} = F_N x$ where

F_N is the wind load normal to the underside of the jib component under consideration (N)
x is the dimension along the jib section from 'A' to the centre of gravity of the jib section (m)

Since the wind load, F_N, is normal to the underside of the jib component under consideration, x remains constant at the dimensions shown in the sketch above as the angle of the jib to the horizontal alters.

For any given jib angle to the horizontal, the total moment acting at the jib pivot point 'A' arising from the wind load acting on each jib section is given by adding the moment arising from each individual jib section 1 to 5 ($M_{WIND1} - M_{WIND5}$). In this case, the position of the centre of gravity for Jib section 5 incorporates the jib end platform since the platform was fitted when the position of the centre of gravity was measured during erection of the crane at HSL. To determine M_{WIND5}, the wind load on the jib and on the end platform are added and then multiplied by the x dimension.

$M_{WINDTOTAL} = M_{WIND1} + M_{WIND2} + M_{WIND3} + M_{WIND4} + M_{WIND5}$

Example Calculation – ISO 4302 (wind speed = 16 m/s, jib angle = 82º to the horizontal)

Assuming a wind speed of 16 m/s, the wind pressure ρ is given by:

$\rho = 0.613\ v^2 = 0.613 \times 16^2 = 156.93\ N/m^2$

Using equations 1b – 6b derived in Appendix 3 Section 7.3.3 for a jib angle of 82º to the horizontal the wind load normal to the underside of the jib component under consideration and acting at the centre of gravity is:

For jib section 1, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N1} = 3.82\ \rho \sin^2 \theta = 3.82 \times 156.93 \times \sin^2 82^\circ = 587.9$ N
$M_{WIND1} = 587.9 \times 4.17 = 2.45$ kNm

For jib section 2, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N2} = 4.20\ \rho \sin^2 \theta = 4.20 \times 156.93 \times \sin^2 82^\circ = 646.3$ N
$M_{WIND2} = 646.3 \times 14.085 = 9.10$ kNm

For jib section 3, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N3} = 4.13\ \rho \sin^2 \theta = 4.13 \times 156.93 \times \sin^2 82^\circ = 635.6$ N
$M_{WIND3} = 635.6 \times 24.035 = 15.28$ kNm

For jib section 4, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N4} = 2.11\ \rho \sin^2 \theta = 2.11 \times 156.93 \times \sin^2 82^\circ = 324.7$ N
$M_{WIND4} = 324.7 \times 31.835 = 10.34$ kNm

For jib section 5, the wind load normal to the underside of the jib section is:

$F_{N5} = 3.06\ \rho \sin^2 \theta = 3.06 \times 156.93 \times \sin^2 82^\circ = 470.90$ N

The wind load normal to the jib end platform floor is:

$F_{NPLATFORM} = 0.655\ \rho \sin^2 \theta = 0.655 \times 156.93 \times \sin^2 82^\circ = 100.8$ N

For jib section 5 and the jib end platform, the resulting moment at the jib pivot point is:

$M_{WIND5} = (470.90 + 100.8) \times 38.060 = 21.76$ kNm

The total moment at the jib pivot point due to wind loading at a wind speed of 16 m/s and a jib angle of 82º to the horizontal is:

$M_{WINDTOTAL} = 2.45 + 9.10 + 15.28 + 10.34 + 21.76 = 58.93$ kNm

Similar calculations can be performed for different wind speeds and jib angles and the resultant moments at the jib pivot point are given in Table 2 of this appendix.

Jib Angle (º)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
15	0.02	0.06	0.14	0.25	0.39	0.57	0.77	1.01	1.27	1.57	1.90	2.26	2.66	3.08	3.54	4.03	4.54	5.09	5.68	6.41
16	0.02	0.07	0.16	0.29	0.45	0.64	0.87	1.14	1.44	1.78	2.16	2.57	3.01	3.50	4.01	4.57	5.15	5.78	6.44	7.27
17	0.02	0.08	0.18	0.32	0.50	0.72	0.98	1.28	1.63	2.01	2.43	2.89	3.39	3.93	4.51	5.14	5.80	6.50	7.24	8.18
18	0.02	0.09	0.20	0.36	0.56	0.81	1.10	1.43	1.82	2.24	2.71	3.23	3.79	4.39	5.04	5.74	6.48	7.26	8.09	9.14
19	0.02	0.10	0.22	0.40	0.62	0.90	1.22	1.59	2.02	2.49	3.01	3.58	4.20	4.88	5.60	6.37	7.19	8.06	8.98	10.15
20	0.03	0.11	0.25	0.44	0.69	0.99	1.35	1.76	2.22	2.75	3.32	3.95	4.64	5.38	6.18	7.03	7.94	8.90	9.91	11.20
21	0.03	0.12	0.27	0.48	0.75	1.09	1.48	1.93	2.44	3.01	3.65	4.34	5.09	5.91	6.78	7.72	8.71	9.77	10.88	12.29
22	0.03	0.13	0.30	0.53	0.82	1.19	1.61	2.11	2.67	3.29	3.99	4.74	5.57	6.46	7.41	8.43	9.52	10.67	11.89	13.43
23	0.04	0.14	0.32	0.57	0.90	1.29	1.76	2.29	2.90	3.58	4.34	5.16	6.06	7.02	8.06	9.17	10.36	11.61	12.94	14.62
24	0.04	0.16	0.35	0.62	0.97	1.40	1.90	2.49	3.15	3.88	4.70	5.59	6.56	7.61	8.74	9.94	11.22	12.58	14.02	15.84
25	0.04	0.17	0.38	0.67	1.05	1.51	2.05	2.68	3.40	4.19	5.07	6.04	7.09	8.22	9.43	10.73	12.12	13.58	15.13	17.10
26	0.05	0.18	0.41	0.72	1.13	1.62	2.21	2.89	3.65	4.51	5.46	6.50	7.62	8.84	10.15	11.55	13.04	14.61	16.28	18.40
27	0.05	0.19	0.44	0.77	1.21	1.74	2.37	3.10	3.92	4.84	5.85	6.97	8.18	9.48	10.89	12.39	13.98	15.67	17.46	19.73
28	0.05	0.21	0.47	0.83	1.29	1.86	2.54	3.31	4.19	5.17	6.26	7.45	8.74	10.14	11.64	13.24	14.95	16.76	18.68	21.10
29	0.06	0.22	0.50	0.88	1.38	1.99	2.70	3.53	4.47	5.52	6.68	7.94	9.32	10.81	12.41	14.12	15.94	17.88	19.92	22.50
30	0.06	0.23	0.53	0.94	1.47	2.11	2.88	3.76	4.75	5.87	7.10	8.45	9.92	11.50	13.20	15.02	16.96	19.01	21.18	23.93
31	0.06	0.25	0.56	1.00	1.56	2.24	3.05	3.98	5.04	6.23	7.53	8.97	10.52	12.20	14.01	15.94	17.99	20.17	22.48	25.39
32	0.07	0.26	0.59	1.05	1.65	2.37	3.23	4.22	5.34	6.59	7.98	9.49	11.14	12.92	14.83	16.87	19.05	21.36	23.80	26.88
33	0.07	0.28	0.63	1.11	1.74	2.51	3.41	4.46	5.64	6.96	8.42	10.03	11.77	13.65	15.67	17.82	20.12	22.56	25.14	28.40
34	0.07	0.29	0.66	1.17	1.83	2.64	3.60	4.70	5.95	7.34	8.88	10.57	12.40	14.39	16.51	18.79	21.21	23.78	26.50	29.93
35	0.08	0.31	0.70	1.24	1.93	2.78	3.78	4.94	6.26	7.72	9.34	11.12	13.05	15.14	17.38	19.77	22.32	25.02	27.88	31.49
36	0.08	0.32	0.73	1.30	2.03	2.92	3.97	5.19	6.57	8.11	9.81	11.68	13.71	15.89	18.25	20.76	23.44	26.28	29.28	33.07
37	0.09	0.34	0.77	1.36	2.13	3.06	4.17	5.44	6.89	8.50	10.29	12.24	14.37	16.66	19.13	21.76	24.57	27.54	30.69	34.67
38	0.09	0.36	0.80	1.42	2.22	3.20	4.36	5.69	7.21	8.90	10.77	12.81	15.04	17.44	20.02	22.78	25.71	28.83	32.12	36.29
39	0.09	0.37	0.84	1.49	2.32	3.35	4.56	5.95	7.53	9.30	11.25	13.39	15.71	18.22	20.92	23.80	26.87	30.12	33.56	37.91
40	0.10	0.39	0.87	1.55	2.42	3.49	4.75	6.21	7.86	9.70	11.74	13.97	16.39	19.01	21.82	24.83	28.03	31.42	35.01	39.55
41	0.10	0.40	0.91	1.62	2.53	3.64	4.95	6.47	8.18	10.10	12.22	14.55	17.07	19.80	22.73	25.86	29.20	32.73	36.47	41.20
42	0.11	0.42	0.95	1.68	2.63	3.78	5.15	6.73	8.51	10.51	12.72	15.13	17.76	20.60	23.65	26.90	30.37	34.05	37.94	42.86
43	0.11	0.44	0.98	1.75	2.73	3.93	5.35	6.99	8.84	10.92	13.21	15.72	18.45	21.40	24.56	27.95	31.55	35.37	39.41	44.53

Table 2 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Measured Jib Properties (ISO 4302)

Jib Angle (°)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
44	*0.11*	*0.45*	*1.02*	*1.81*	*2.83*	*4.08*	*5.55*	*7.25*	*9.17*	*11.33*	*13.71*	*16.31*	*19.14*	*22.20*	*25.49*	*29.00*	*32.73*	*36.70*	*40.89*	*46.19*
45	*0.12*	*0.47*	*1.06*	*1.88*	*2.93*	*4.23*	*5.75*	*7.51*	*9.51*	*11.74*	*14.20*	*16.90*	*19.83*	*23.00*	*26.41*	*30.05*	*33.92*	*38.03*	*42.37*	*47.86*
46	*0.12*	*0.49*	*1.09*	*1.94*	*3.04*	*4.37*	*5.95*	*7.77*	*9.84*	*12.15*	*14.70*	*17.49*	*20.53*	*23.81*	*27.33*	*31.09*	*35.10*	*39.35*	*43.85*	*49.53*
47	*0.13*	*0.50*	*1.13*	*2.01*	*3.14*	*4.52*	*6.15*	*8.04*	*10.17*	*12.56*	*15.19*	*18.08*	*21.22*	*24.61*	*28.25*	*32.14*	*36.28*	*40.68*	*45.32*	*51.20*
48	*0.13*	*0.52*	*1.17*	*2.07*	*3.24*	*4.67*	*6.35*	*8.30*	*10.50*	*12.96*	*15.69*	*18.67*	*21.91*	*25.41*	*29.17*	*33.19*	*37.46*	*42.00*	*46.80*	*52.87*
49	*0.13*	*0.53*	*1.20*	*2.14*	*3.34*	*4.81*	*6.55*	*8.56*	*10.83*	*13.37*	*16.18*	*19.25*	*22.59*	*26.20*	*30.08*	*34.23*	*38.64*	*43.32*	*48.26*	*54.53*
50	*0.14*	*0.55*	*1.24*	*2.20*	*3.44*	*4.96*	*6.75*	*8.82*	*11.16*	*13.77*	*16.67*	*19.84*	*23.28*	*27.00*	*30.99*	*35.26*	*39.81*	*44.63*	*49.73*	*56.18*
51	*0.14*	*0.57*	*1.28*	*2.27*	*3.54*	*5.10*	*6.95*	*9.07*	*11.48*	*14.18*	*17.15*	*20.41*	*23.96*	*27.79*	*31.90*	*36.29*	*40.97*	*45.93*	*51.18*	*57.82*
52	*0.15*	*0.58*	*1.31*	*2.33*	*3.64*	*5.25*	*7.14*	*9.33*	*11.81*	*14.58*	*17.64*	*20.99*	*24.63*	*28.57*	*32.80*	*37.31*	*42.12*	*47.23*	*52.62*	*59.44*
53	*0.15*	*0.60*	*1.35*	*2.40*	*3.74*	*5.39*	*7.34*	*9.58*	*12.13*	*14.97*	*18.12*	*21.56*	*25.30*	*29.34*	*33.69*	*38.33*	*43.27*	*48.51*	*54.05*	*61.06*
54	*0.15*	*0.61*	*1.38*	*2.46*	*3.84*	*5.53*	*7.53*	*9.83*	*12.44*	*15.36*	*18.59*	*22.12*	*25.96*	*30.11*	*34.57*	*39.33*	*44.40*	*49.78*	*55.46*	*62.66*
55	*0.16*	*0.63*	*1.42*	*2.52*	*3.94*	*5.67*	*7.72*	*10.08*	*12.76*	*15.75*	*19.06*	*22.68*	*26.62*	*30.87*	*35.44*	*40.32*	*45.52*	*51.03*	*56.86*	*64.24*
56	*0.16*	*0.65*	*1.45*	*2.58*	*4.03*	*5.81*	*7.91*	*10.33*	*13.07*	*16.13*	*19.52*	*23.23*	*27.26*	*31.62*	*36.30*	*41.30*	*46.62*	*52.27*	*58.24*	*65.79*
57	*0.17*	*0.66*	*1.49*	*2.64*	*4.13*	*5.94*	*8.09*	*10.57*	*13.37*	*16.51*	*19.98*	*23.77*	*27.90*	*32.36*	*37.15*	*42.27*	*47.71*	*53.49*	*59.60*	*67.33*
58	*0.17*	*0.68*	*1.52*	*2.70*	*4.22*	*6.08*	*8.27*	*10.80*	*13.67*	*16.88*	*20.43*	*24.31*	*28.53*	*33.09*	*37.98*	*43.22*	*48.79*	*54.70*	*60.94*	*68.85*
59	*0.17*	*0.69*	*1.55*	*2.76*	*4.31*	*6.21*	*8.45*	*11.04*	*13.97*	*17.25*	*20.87*	*24.83*	*29.15*	*33.80*	*38.80*	*44.15*	*49.84*	*55.88*	*62.26*	*70.34*
60	*0.18*	*0.70*	*1.58*	*2.82*	*4.40*	*6.34*	*8.63*	*11.27*	*14.26*	*17.60*	*21.30*	*25.35*	*29.75*	*34.50*	*39.61*	*45.07*	*50.88*	*57.04*	*63.55*	*71.80*
61	*0.18*	*0.72*	*1.62*	*2.87*	*4.49*	*6.46*	*8.80*	*11.49*	*14.54*	*17.96*	*21.73*	*25.86*	*30.35*	*35.19*	*40.40*	*45.97*	*51.89*	*58.18*	*64.82*	*73.23*
62	*0.18*	*0.73*	*1.65*	*2.93*	*4.57*	*6.59*	*8.97*	*11.71*	*14.82*	*18.30*	*22.14*	*26.35*	*30.93*	*35.87*	*41.17*	*46.85*	*52.88*	*59.29*	*66.06*	*74.63*
63	*0.19*	*0.75*	*1.68*	*2.98*	*4.66*	*6.71*	*9.13*	*11.93*	*15.09*	*18.63*	*22.55*	*26.83*	*31.49*	*36.52*	*41.93*	*47.71*	*53.85*	*60.38*	*67.27*	*76.00*
64	*0.19*	*0.76*	*1.71*	*3.03*	*4.74*	*6.83*	*9.29*	*12.14*	*15.36*	*18.96*	*22.94*	*27.31*	*32.05*	*37.17*	*42.66*	*48.54*	*54.80*	*61.44*	*68.45*	*77.33*
65	*0.19*	*0.77*	*1.74*	*3.08*	*4.82*	*6.94*	*9.45*	*12.34*	*15.62*	*19.28*	*23.33*	*27.76*	*32.58*	*37.79*	*43.38*	*49.36*	*55.72*	*62.47*	*69.60*	*78.63*
66	*0.20*	*0.78*	*1.76*	*3.13*	*4.90*	*7.05*	*9.60*	*12.54*	*15.87*	*19.59*	*23.70*	*28.21*	*33.11*	*38.40*	*44.08*	*50.15*	*56.61*	*63.47*	*70.72*	*79.89*
67	*0.20*	*0.80*	*1.79*	*3.18*	*4.97*	*7.16*	*9.75*	*12.73*	*16.11*	*19.89*	*24.07*	*28.64*	*33.61*	*38.98*	*44.75*	*50.92*	*57.48*	*64.44*	*71.80*	*81.11*
68	*0.20*	*0.81*	*1.82*	*3.23*	*5.04*	*7.26*	*9.89*	*12.91*	*16.34*	*20.18*	*24.42*	*29.06*	*34.10*	*39.55*	*45.40*	*51.66*	*58.32*	*65.38*	*72.85*	*82.30*
69	*0.20*	*0.82*	*1.84*	*3.27*	*5.11*	*7.36*	*10.02*	*13.09*	*16.57*	*20.46*	*24.75*	*29.46*	*34.57*	*40.10*	*46.03*	*52.37*	*59.12*	*66.28*	*73.85*	*83.43*
70	*0.21*	*0.83*	*1.87*	*3.32*	*5.18*	*7.46*	*10.16*	*13.27*	*16.79*	*20.73*	*25.08*	*29.85*	*35.03*	*40.62*	*46.64*	*53.06*	*59.90*	*67.16*	*74.82*	*84.53*
71	*0.21*	*0.84*	*1.89*	*3.36*	*5.25*	*7.55*	*10.28*	*13.43*	*17.00*	*20.98*	*25.39*	*30.22*	*35.46*	*41.13*	*47.22*	*53.72*	*60.65*	*67.99*	*75.75*	*85.58*
72	*0.21*	*0.85*	*1.91*	*3.40*	*5.31*	*7.64*	*10.40*	*13.59*	*17.20*	*21.23*	*25.69*	*30.57*	*35.88*	*41.61*	*47.77*	*54.35*	*61.36*	*68.79*	*76.64*	*86.59*
73	*0.21*	*0.86*	*1.93*	*3.43*	*5.37*	*7.73*	*10.52*	*13.74*	*17.39*	*21.47*	*25.97*	*30.91*	*36.28*	*42.07*	*48.30*	*54.95*	*62.04*	*69.55*	*77.49*	*87.55*

Table 2 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Measured Jib Properties (ISO 4302)

Jib Angle (°)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
74	0.22	0.87	1.95	3.47	5.42	7.81	10.63	13.88	17.57	21.69	26.24	31.23	36.66	42.51	48.80	55.52	62.68	70.27	78.30	88.46
75	0.22	0.88	1.97	3.50	5.48	7.88	10.73	14.02	17.74	21.90	26.50	31.54	37.01	42.92	49.28	56.06	63.29	70.96	79.06	89.32
76	0.22	0.88	1.99	3.54	5.52	7.96	10.83	14.14	17.90	22.10	26.74	31.82	37.35	43.31	49.72	56.57	63.87	71.60	79.78	90.13
77	0.22	0.89	2.01	3.57	5.57	8.02	10.92	14.26	18.05	22.28	26.96	32.09	37.66	43.68	50.14	57.05	64.40	72.20	80.45	90.88
78	0.22	0.90	2.02	3.59	5.61	8.08	11.00	14.37	18.19	22.46	27.17	32.34	37.95	44.02	50.53	57.49	64.90	72.76	81.07	91.59
79	0.23	0.90	2.04	3.62	5.65	8.14	11.08	14.48	18.32	22.62	27.37	32.57	38.22	44.33	50.89	57.90	65.37	73.28	81.65	92.24
80	0.23	0.91	2.05	3.64	5.69	8.20	11.15	14.57	18.44	22.76	27.55	32.78	38.47	44.62	51.22	58.28	65.79	73.76	82.18	92.84
81	0.23	0.92	2.06	3.66	5.72	8.24	11.22	14.65	18.55	22.90	27.71	32.97	38.70	44.88	51.52	58.62	66.18	74.19	82.66	93.39
82	0.23	0.92	2.07	3.68	5.75	8.29	11.28	14.73	18.64	23.02	27.85	33.15	38.90	45.12	51.79	58.93	66.52	74.58	83.10	93.87
83	0.23	0.92	2.08	3.70	5.78	8.32	11.33	14.80	18.73	23.12	27.98	33.30	39.08	45.32	52.03	59.20	66.83	74.92	83.48	94.31
84	0.23	0.93	2.09	3.71	5.80	8.36	11.38	14.86	18.81	23.22	28.09	33.43	39.24	45.50	52.24	59.43	67.10	75.22	83.81	94.68
85	0.23	0.93	2.10	3.73	5.82	8.39	11.41	14.91	18.87	23.29	28.19	33.54	39.37	45.66	52.41	59.63	67.32	75.47	84.09	95.00
86	0.23	0.93	2.10	3.74	5.84	8.41	11.45	14.95	18.92	23.36	28.26	33.64	39.48	45.78	52.56	59.80	67.51	75.68	84.32	95.26
87	0.23	0.94	2.11	3.75	5.85	8.43	11.47	14.98	18.96	23.41	28.32	33.71	39.56	45.88	52.67	59.93	67.65	75.84	84.50	95.47
88	0.23	0.94	2.11	3.75	5.86	8.44	11.49	15.00	18.99	23.44	28.37	33.76	39.62	45.95	52.75	60.02	67.75	75.96	84.63	95.61
89	0.23	0.94	2.11	3.75	5.87	8.45	11.50	15.02	19.01	23.47	28.39	33.79	39.66	45.99	52.80	60.07	67.82	76.03	84.71	95.70
90	0.23	0.94	2.11	3.76	5.87	8.45	11.50	15.02	19.01	23.47	28.40	33.80	39.67	46.01	52.81	60.09	67.84	76.05	84.74	95.73

Table 2 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Measured Jib Properties (ISO 4302)

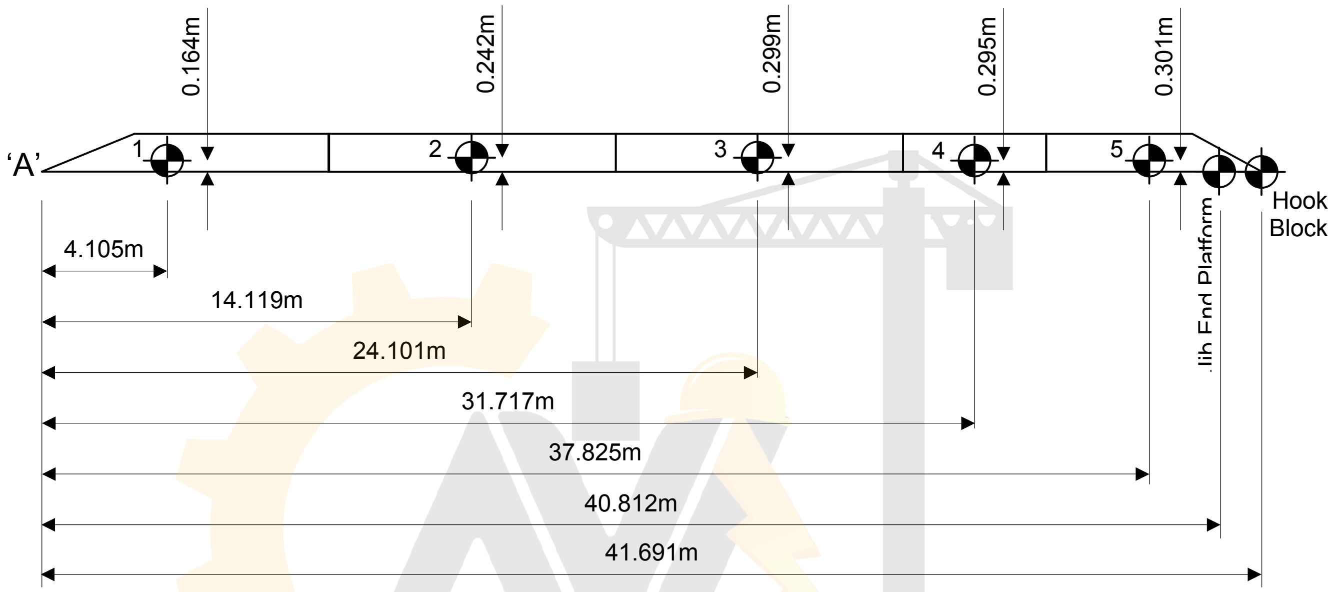
APPENDIX 7

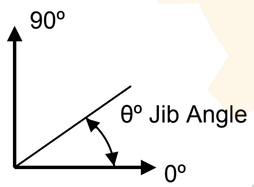
Calculation of the wind loading and consequent moment acting at the jib pivot point according to BS EN 13001 – 2:2004 *"Crane Safety – General Design – Part 2 Load Actions"*

Appendix 7

Calculation of the moment acting at the jib pivot points due to wind loading on the jib and jib end platform according to BS EN 13001 – 2 :2004

1. Theoretical properties of the jib sections i.e. the masses provided in the crane manual and positions of centre of gravity provided by Jaso





The moment, M_{WIND}, acting at the jib pivot point 'A' arising from the wind loading is given by:

$M_{WIND} = F_N \cos(\tan^{-1} y/x)x$ where

F_N is the wind load normal to the underside of the jib component under consideration (N)
x is the dimension along the jib section from 'A' to the centre of gravity of the jib section (m)
y is the dimension from 'A' to the centre of gravity of the jib section perpendicular to the x is the dimension (m)

Since the centre of gravity of the jib sections are slightly offset from the pivot point in the vertical (y) direction the term $\cos(\tan^{-1} y/x)$ in the above equation resolves F_N (the wind load normal to the underside of the jib component under consideration) to the lever arm joining the centre of gravity to the pivot point such that the resultant force is completely perpendicular to the lever arm. However, the angles between the centres of gravity of the jib sections and the pivot point are very small such that $\cos(\tan^{-1} y/x)$ tends to unity. Hence this is ignored and the moment, M_{WIND}, acting at the jib pivot point 'A' arising from the wind loading is given by:

$M_{WIND} = F_N\, x$ where

F_N is the wind load normal to the underside of the jib component under consideration (N)
x is the dimension along the jib section from 'A' to the centre of gravity of the jib section (m)

Since the wind load, F_N, is normal to the underside of the jib component under consideration, x remains constant at the dimensions shown in the sketch above as the angle of the jib to the horizontal alters.

For any given jib angle to the horizontal, the total moment acting at the jib pivot point 'A' arising from the wind load acting on each jib section is given by adding the moment arising from each individual jib section 1 to 5 (M_{WIND1} – M_{WIND5}) and that arising from the jib end platform ($M_{WINDPLATFORM}$), i.e:

$M_{WINDTOTAL} = M_{WIND1} + M_{WIND2} + M_{WIND3} + M_{WIND4} + M_{WIND5} + M_{WINDPLATFORM}$

The wind loading on each jib section and the jib end platform has been calculated in Appendix 3 according to FEM 1.001, FEM 1.004, ISO 4302 and BS EN 13001 – 2:2004 and equations for F_N derived.

Example Calculation – BS EN 13001 – 2:2004 (wind speed = 6 m/s, jib angle = 28º to the horizontal)

Assuming a wind speed of 6 m/s, the wind pressure q is given by:

$q = ½ \times \rho \times v^2 = ½ \times 1.25 \times 6^2 = 22.5\ N/m^2$

Using equations 1c – 6c derived in Appendix 3 Section 8.3.3 for a jib angle of 28º to the horizontal the wind load normal to the underside of the jib component under consideration and acting at the centre of gravity is:

For jib section 1, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N1} = 3.98\ q \sin\theta = 3.98 \times 22.5 \times \sin 28º = 42.04\ N$
$M_{WIND1} = 42.04 \times 4.105 = 171.18\ Nm$

For jib section 2, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N2} = 4.38\ q \sin\theta = 4.38 \times 22.5 \times \sin 28º = 46.27\ N$
$M_{WIND2} = 46.27 \times 14.119 = 653.24\ Nm$

For jib section 3, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

$F_{N3} = 4.30\ q \sin\theta = 4.30 \times 22.5 \times \sin 28º = 45.42\ N$
$M_{WIND3} = 45.42 \times 24.101 = 1094.70\ Nm$

For jib section 4, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

F_{N4} = 2.20 q sin θ = 2.20 x 22.5 x sin 28º = 23.24 N
M_{WIND4} = 23.24 x 31.717 = 737.07 Nm

For jib section 5, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

F_{N5} = 3.19 q sin θ = 3.19 x 22.5 x sin 28º = 33.70 N
M_{WIND5} = 33.70 x 37.825 = 1,274.56 Nm

The wind load normal to the jib end platform floor and resulting moment at the jib pivot point is:

$F_{NPLATFORM}$ = 0.62 q sin θ = 0.62 x 22.5 x sin 28º = 6.5 N
$M_{WINDPLATFORM}$ = 6.5 x 40.812 = 265.28 Nm

The total moment at the jib pivot point due to wind loading at a wind speed of 6 m/s and a jib angle of 28º to the horizontal is:

$M_{WINDTOTAL}$ = 171.18 + 653.24 + 1094.70 + 737.07 + 1,274.56 + 265.28 = 4.20 kNm

Similar calculations can be performed for different wind speeds and jib angles and the resultant moments at the jib pivot point are given in Table 1 of this appendix.

Jib Angle (°)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
15	0.06	0.26	0.58	1.03	1.61	2.32	3.15	4.12	5.21	6.43	7.78	9.26	10.87	12.60	14.47	16.46	18.59	20.84	23.22	25.72
16	0.07	0.27	0.62	1.10	1.71	2.47	3.36	4.38	5.55	6.85	8.29	9.86	11.57	13.42	15.41	17.53	19.79	22.19	24.72	27.40
17	0.07	0.29	0.65	1.16	1.82	2.62	3.56	4.65	5.88	7.26	8.79	10.46	12.28	14.24	16.35	18.60	20.99	23.54	26.23	29.06
18	0.08	0.31	0.69	1.23	1.92	2.76	3.76	4.91	6.22	7.68	9.29	11.06	12.98	15.05	17.28	19.66	22.19	24.88	27.72	30.71
19	0.08	0.32	0.73	1.29	2.02	2.91	3.96	5.18	6.55	8.09	9.79	11.65	13.67	15.86	18.20	20.71	23.38	26.21	29.20	32.36
20	0.08	0.34	0.76	1.36	2.12	3.06	4.16	5.44	6.88	8.50	10.28	12.24	14.36	16.66	19.12	21.76	24.56	27.53	30.68	33.99
21	0.09	0.36	0.80	1.42	2.23	3.21	4.36	5.70	7.21	8.90	10.77	12.82	15.05	17.45	20.04	22.80	25.73	28.85	32.15	35.62
22	0.09	0.37	0.84	1.49	2.33	3.35	4.56	5.96	7.54	9.31	11.26	13.40	15.73	18.24	20.94	23.83	26.90	30.16	33.60	37.23
23	0.10	0.39	0.87	1.55	2.43	3.50	4.76	6.21	7.86	9.71	11.75	13.98	16.41	19.03	21.84	24.85	28.06	31.46	35.05	38.83
24	0.10	0.40	0.91	1.62	2.53	3.64	4.95	6.47	8.19	10.11	12.23	14.55	17.08	19.81	22.74	25.87	29.21	32.74	36.48	40.43
25	0.11	0.42	0.95	1.68	2.63	3.78	5.15	6.72	8.51	10.50	12.71	15.12	17.75	20.58	23.63	26.88	30.35	34.02	37.91	42.00
26	0.11	0.44	0.98	1.74	2.72	3.92	5.34	6.97	8.82	10.89	13.18	15.68	18.41	21.35	24.51	27.88	31.48	35.29	39.32	43.57
27	0.11	0.45	1.02	1.80	2.82	4.06	5.53	7.22	9.14	11.28	13.65	16.24	19.06	22.11	25.38	28.88	32.60	36.55	40.72	45.12
28	0.12	0.47	1.05	1.87	2.92	4.20	5.72	7.47	9.45	11.67	14.11	16.80	19.71	22.86	26.25	29.86	33.71	37.79	42.11	46.66
29	0.12	0.48	1.08	1.93	3.01	4.34	5.90	7.71	9.76	12.05	14.58	17.35	20.36	23.61	27.10	30.84	34.81	39.03	43.49	48.18
30	0.12	0.50	1.12	1.99	3.11	4.47	6.09	7.95	10.06	12.42	15.03	17.89	21.00	24.35	27.95	31.80	35.90	40.25	44.85	49.69
31	0.13	0.51	1.15	2.05	3.20	4.61	6.27	8.19	10.37	12.80	15.48	18.43	21.63	25.08	28.79	32.76	36.98	41.46	46.20	51.19
32	0.13	0.53	1.19	2.11	3.29	4.74	6.45	8.43	10.67	13.17	15.93	18.96	22.25	25.81	29.63	33.71	38.05	42.66	47.53	52.67
33	0.14	0.54	1.22	2.17	3.38	4.87	6.63	8.66	10.96	13.53	16.37	19.49	22.87	26.52	30.45	34.64	39.11	43.85	48.85	54.13
34	0.14	0.56	1.25	2.22	3.47	5.00	6.81	8.89	11.25	13.89	16.81	20.01	23.48	27.23	31.26	35.57	40.15	45.02	50.16	55.58
35	0.14	0.57	1.28	2.28	3.56	5.13	6.98	9.12	11.54	14.25	17.24	20.52	24.09	27.93	32.07	36.48	41.19	46.18	51.45	57.01
36	0.15	0.58	1.31	2.34	3.65	5.26	7.16	9.35	11.83	14.60	17.67	21.03	24.68	28.63	32.86	37.39	42.21	47.32	52.72	58.42
37	0.15	0.60	1.35	2.39	3.74	5.38	7.33	9.57	12.11	14.95	18.09	21.53	25.27	29.31	33.65	38.28	43.22	48.45	53.98	59.81
38	0.15	0.61	1.38	2.45	3.82	5.51	7.50	9.79	12.39	15.30	18.51	22.03	25.85	29.98	34.42	39.16	44.21	49.56	55.22	61.19
39	0.16	0.63	1.41	2.50	3.91	5.63	7.66	10.01	12.67	15.64	18.92	22.52	26.43	30.65	35.18	40.03	45.19	50.66	56.45	62.55
40	0.16	0.64	1.44	2.56	3.99	5.75	7.83	10.22	12.94	15.97	19.33	23.00	26.99	31.30	35.94	40.89	46.16	51.75	57.66	63.89
41	0.16	0.65	1.47	2.61	4.08	5.87	7.99	10.43	13.20	16.30	19.72	23.47	27.55	31.95	36.68	41.73	47.11	52.82	58.85	65.21
42	0.17	0.67	1.50	2.66	4.16	5.99	8.15	10.64	13.47	16.63	20.12	23.94	28.10	32.59	37.41	42.56	48.05	53.87	60.02	66.50
43	0.17	0.68	1.53	2.71	4.24	6.10	8.30	10.85	13.73	16.95	20.50	24.40	28.64	33.21	38.13	43.38	48.97	54.90	61.17	67.78

Table 1 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Theoretical Jib Properties (BS EN 13001 – 2:2004)

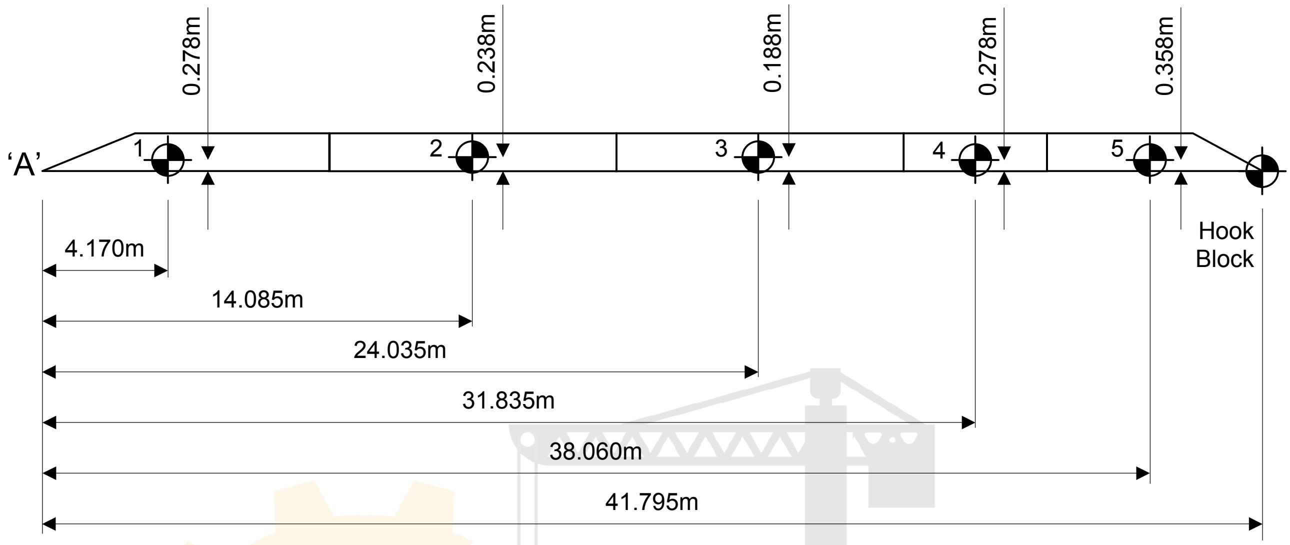
Jib Angle (°)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
44	0.17	0.69	1.55	2.76	4.32	6.21	8.46	11.05	13.98	17.26	20.89	24.85	29.17	33.83	38.84	44.19	49.88	55.92	62.31	69.04
45	0.18	0.70	1.58	2.81	4.39	6.33	8.61	11.24	14.23	17.57	21.26	25.30	29.69	34.44	39.53	44.98	50.78	56.93	63.43	70.28
46	0.18	0.71	1.61	2.86	4.47	6.43	8.76	11.44	14.48	17.87	21.63	25.74	30.21	35.03	40.22	45.76	51.65	57.91	64.52	71.49
47	0.18	0.73	1.64	2.91	4.54	6.54	8.90	11.63	14.72	18.17	21.99	26.17	30.71	35.62	40.89	46.52	52.52	58.88	65.60	72.69
48	0.18	0.74	1.66	2.95	4.62	6.65	9.05	11.82	14.96	18.47	22.34	26.59	31.21	36.19	41.55	47.27	53.36	59.83	66.66	73.86
49	0.19	0.75	1.69	3.00	4.69	6.75	9.19	12.00	15.19	18.75	22.69	27.00	31.69	36.75	42.19	48.01	54.19	60.76	67.70	75.01
50	0.19	0.76	1.71	3.05	4.76	6.85	9.33	12.18	15.42	19.03	23.03	27.41	32.17	37.31	42.83	48.73	55.01	61.67	68.71	76.14
51	0.19	0.77	1.74	3.09	4.83	6.95	9.46	12.36	15.64	19.31	23.37	27.81	32.63	37.85	43.45	49.43	55.81	62.56	69.71	77.24
52	0.20	0.78	1.76	3.13	4.89	7.05	9.59	12.53	15.86	19.58	23.69	28.20	33.09	38.38	44.05	50.12	56.59	63.44	70.68	78.32
53	0.20	0.79	1.79	3.18	4.96	7.14	9.72	12.70	16.07	19.84	24.01	28.58	33.54	38.89	44.65	50.80	57.35	64.29	71.64	79.38
54	0.20	0.80	1.81	3.22	5.03	7.24	9.85	12.87	16.28	20.10	24.32	28.95	33.97	39.40	45.23	51.46	58.09	65.13	72.57	80.41
55	0.20	0.81	1.83	3.26	5.09	7.33	9.97	13.03	16.49	20.35	24.63	29.31	34.40	39.89	45.80	52.11	58.82	65.95	73.48	81.41
56	0.21	0.82	1.85	3.30	5.15	7.42	10.09	13.18	16.69	20.60	24.93	29.66	34.81	40.37	46.35	52.73	59.53	66.74	74.36	82.40
57	0.21	0.83	1.88	3.33	5.21	7.50	10.21	13.34	16.88	20.84	25.21	30.01	35.22	40.84	46.89	53.35	60.22	67.52	75.23	83.35
58	0.21	0.84	1.90	3.37	5.27	7.59	10.33	13.49	17.07	21.07	25.50	30.34	35.61	41.30	47.41	53.94	60.90	68.27	76.07	84.29
59	0.21	0.85	1.92	3.41	5.32	7.67	10.44	13.63	17.25	21.30	25.77	30.67	35.99	41.74	47.92	54.52	61.55	69.01	76.89	85.19
60	0.22	0.86	1.94	3.44	5.38	7.75	10.54	13.77	17.43	21.52	26.04	30.99	36.37	42.18	48.42	55.09	62.19	69.72	77.68	86.07
61	0.22	0.87	1.96	3.48	5.43	7.82	10.65	13.91	17.60	21.73	26.30	31.29	36.73	42.59	48.90	55.63	62.81	70.41	78.45	86.93
62	0.22	0.88	1.97	3.51	5.48	7.90	10.75	14.04	17.77	21.94	26.55	31.59	37.08	43.00	49.36	56.16	63.40	71.08	79.20	87.76
63	0.22	0.89	1.99	3.54	5.53	7.97	10.85	14.17	17.93	22.14	26.79	31.88	37.42	43.39	49.81	56.68	63.98	71.73	79.92	88.56
64	0.22	0.89	2.01	3.57	5.58	8.04	10.94	14.29	18.09	22.33	27.02	32.16	37.74	43.77	50.25	57.17	64.54	72.36	80.62	89.33
65	0.23	0.90	2.03	3.60	5.63	8.11	11.03	14.41	18.24	22.52	27.25	32.43	38.06	44.14	50.67	57.65	65.08	72.96	81.29	90.08
66	0.23	0.91	2.04	3.63	5.67	8.17	11.12	14.53	18.39	22.70	27.47	32.69	38.36	44.49	51.07	58.11	65.60	73.55	81.94	90.80
67	0.23	0.91	2.06	3.66	5.72	8.23	11.21	14.64	18.53	22.87	27.68	32.94	38.65	44.83	51.46	58.55	66.10	74.11	82.57	91.49
68	0.23	0.92	2.07	3.69	5.76	8.29	11.29	14.74	18.66	23.04	27.88	33.17	38.93	45.15	51.84	58.98	66.58	74.64	83.17	92.15
69	0.23	0.93	2.09	3.71	5.80	8.35	11.37	14.85	18.79	23.20	28.07	33.40	39.20	45.47	52.19	59.38	67.04	75.16	83.74	92.79
70	0.23	0.93	2.10	3.74	5.84	8.41	11.44	14.94	18.91	23.35	28.25	33.62	39.46	45.76	52.53	59.77	67.48	75.65	84.29	93.40
71	0.23	0.94	2.11	3.76	5.87	8.46	11.51	15.04	19.03	23.49	28.43	33.83	39.70	46.05	52.86	60.14	67.90	76.12	84.81	93.97
72	0.24	0.95	2.13	3.78	5.91	8.51	11.58	15.12	19.14	23.63	28.59	34.03	39.94	46.32	53.17	60.50	68.29	76.56	85.31	94.52
73	0.24	0.95	2.14	3.80	5.94	8.55	11.64	15.21	19.25	23.76	28.75	34.22	40.16	46.57	53.46	60.83	68.67	76.99	85.78	95.05
74	0.24	0.96	2.15	3.82	5.97	8.60	11.70	15.29	19.35	23.88	28.90	34.39	40.37	46.81	53.74	61.14	69.03	77.39	86.22	95.54

Table 1 - (continued) Moment at the Jib Pivot Point due to Wind Loading (kNm)
Theoretical jib Properties (BS EN 13001 – 2:2004)

Jib Angle (°)	Wind Speed (m/s)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
75	*0.24*	*0.96*	*2.16*	*3.84*	*6.00*	*8.64*	*11.76*	*15.36*	*19.44*	*24.00*	*29.04*	*34.56*	*40.56*	*47.04*	*54.00*	*61.44*	*69.36*	*77.76*	*86.64*	*96.00*
76	*0.24*	*0.96*	*2.17*	*3.86*	*6.03*	*8.68*	*11.81*	*15.43*	*19.53*	*24.11*	*29.17*	*34.72*	*40.74*	*47.25*	*54.25*	*61.72*	*69.68*	*78.11*	*87.03*	*96.44*
77	*0.24*	*0.97*	*2.18*	*3.87*	*6.05*	*8.72*	*11.86*	*15.49*	*19.61*	*24.21*	*29.29*	*34.86*	*40.92*	*47.45*	*54.47*	*61.98*	*69.97*	*78.44*	*87.40*	*96.84*
78	*0.24*	*0.97*	*2.19*	*3.89*	*6.08*	*8.75*	*11.91*	*15.55*	*19.69*	*24.30*	*29.41*	*35.00*	*41.07*	*47.64*	*54.68*	*62.22*	*70.24*	*78.75*	*87.74*	*97.22*
79	*0.24*	*0.98*	*2.20*	*3.90*	*6.10*	*8.78*	*11.95*	*15.61*	*19.76*	*24.39*	*29.51*	*35.12*	*41.22*	*47.81*	*54.88*	*62.44*	*70.49*	*79.03*	*88.05*	*97.56*
80	*0.24*	*0.98*	*2.20*	*3.92*	*6.12*	*8.81*	*11.99*	*15.66*	*19.82*	*24.47*	*29.61*	*35.24*	*41.35*	*47.96*	*55.06*	*62.64*	*70.72*	*79.28*	*88.34*	*97.88*
81	*0.25*	*0.98*	*2.21*	*3.93*	*6.14*	*8.83*	*12.03*	*15.71*	*19.88*	*24.54*	*29.70*	*35.34*	*41.47*	*48.10*	*55.22*	*62.83*	*70.92*	*79.51*	*88.59*	*98.17*
82	*0.25*	*0.98*	*2.21*	*3.94*	*6.15*	*8.86*	*12.06*	*15.75*	*19.93*	*24.61*	*29.77*	*35.43*	*41.58*	*48.23*	*55.36*	*62.99*	*71.11*	*79.72*	*88.83*	*98.42*
83	*0.25*	*0.99*	*2.22*	*3.95*	*6.17*	*8.88*	*12.08*	*15.78*	*19.98*	*24.66*	*29.84*	*35.51*	*41.68*	*48.34*	*55.49*	*63.13*	*71.27*	*79.91*	*89.03*	*98.65*
84	*0.25*	*0.99*	*2.22*	*3.95*	*6.18*	*8.90*	*12.11*	*15.82*	*20.02*	*24.71*	*29.90*	*35.58*	*41.76*	*48.43*	*55.60*	*63.26*	*71.42*	*80.06*	*89.21*	*98.84*
85	*0.25*	*0.99*	*2.23*	*3.96*	*6.19*	*8.91*	*12.13*	*15.84*	*20.05*	*24.75*	*29.95*	*35.64*	*41.83*	*48.52*	*55.69*	*63.37*	*71.54*	*80.20*	*89.36*	*99.01*
86	*0.25*	*0.99*	*2.23*	*3.97*	*6.20*	*8.92*	*12.15*	*15.86*	*20.08*	*24.79*	*29.99*	*35.69*	*41.89*	*48.58*	*55.77*	*63.45*	*71.63*	*80.31*	*89.48*	*99.15*
87	*0.25*	*0.99*	*2.23*	*3.97*	*6.20*	*8.93*	*12.16*	*15.88*	*20.10*	*24.81*	*30.02*	*35.73*	*41.93*	*48.63*	*55.83*	*63.52*	*71.71*	*80.39*	*89.58*	*99.25*
88	*0.25*	*0.99*	*2.23*	*3.97*	*6.21*	*8.94*	*12.17*	*15.89*	*20.11*	*24.83*	*30.05*	*35.76*	*41.97*	*48.67*	*55.87*	*63.57*	*71.76*	*80.46*	*89.64*	*99.33*
89	*0.25*	*0.99*	*2.24*	*3.97*	*6.21*	*8.94*	*12.17*	*15.90*	*20.12*	*24.84*	*30.06*	*35.77*	*41.99*	*48.69*	*55.90*	*63.60*	*71.80*	*80.49*	*89.68*	*99.37*
90	*0.25*	*0.99*	*2.24*	*3.98*	*6.21*	*8.95*	*12.18*	*15.90*	*20.13*	*24.85*	*30.07*	*35.78*	*41.99*	*48.70*	*55.91*	*63.61*	*71.81*	*80.51*	*89.70*	*99.39*

Table 1 - (continued) Moment at the Jib Pivot Point due to Wind Loading (kNm)
Theoretical Jib properties (BS EN 13001 – 2:2004)

2. Masses and positions of centre of gravity measured during erection of the crane at HSL



As before, the moment, M_{WIND}, acting at the jib pivot point 'A' arising from the wind loading is given by:

$M_{WIND} = F_N\, x$ where

F_N is the wind load normal to the underside of the jib component under consideration (N)
x is the dimension along the jib section from 'A' to the centre of gravity of the jib section (m)

Since the wind load, F_N, is normal to the underside of the jib component under consideration, x remains constant at the dimensions shown in the sketch above as the angle of the jib to the horizontal alters.

For any given jib angle to the horizontal, the total moment acting at the jib pivot point 'A' arising from the wind load acting on each jib section is given by adding the moment arising from each individual jib section 1 to 5 ($M_{WIND1} - M_{WIND5}$). In this case, the position of the centre of gravity for Jib section 5 incorporates the jib end platform since the platform was fitted when the position of the centre of gravity was measured during erection of the crane at HSL. To determine M_{WIND5}, the wind load on the jib and on the end platform are added and then multiplied by the x dimension.

$M_{WINDTOTAL} = M_{WIND1} + M_{WIND2} + M_{WIND3} + M_{WIND4} + M_{WIND5}$

Example Calculation – BS EN 13001 – 2:2004 (wind speed = 12 m/s, jib angle = 65º to the horizontal)

Assuming a wind speed of 12 m/s, the wind pressure q is given by:

$q = ½ \times \rho \times v^2 = ½ \times 1.25 \times 12^2 = 90\ N/m^2$

Using equations 1c – 6c derived in Appendix 3 for a jib angle of 65º to the horizontal the wind load normal to the underside of the jib component under consideration and acting at the centre of gravity is:

For jib section 1, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

F_{N1} = 3.98 q sin θ = 3.98 x 90 x sin 65º = 324.64 N
M_{WIND1} = 324.64 x 4.17 = 1.35 kNm

For jib section 2, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

F_{N2} = 4.38 q sin θ = 4.38 x 90 x sin 65º = 357.27 N
M_{WIND2} = 357.27 x 14.085 = 5.03 kNm

For jib section 3, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

F_{N3} = 4.30 q sin θ = 4.30 x 90 x sin 65º = 350.74 N
M_{WIND3} = 350.74 x 24.035 = 8.43 kNm

For jib section 4, the wind load normal to the underside of the jib section and resulting moment at the jib pivot point is:

F_{N4} = 2.20 q sin θ = 2.20 x 90 x sin 65º = 179.45 N
M_{WIND4} = 178.63 x 31.835 m = 5.69 kNm

For jib section 5, the wind load normal to the underside of the jib section is:

F_{N5} = 3.19 q sin θ = 3.19 x 90 x sin 65º = 260.20 N

The wind load normal to the jib end platform floor is:

$F_{NPLATFORM}$ = 0.62 q sin θ = 0.62 x 90 x sin 65º = 50.6 N

For jib section 5 and the jib end platform, the resulting moment at the jib pivot point is:

M_{WIND5} = (260.20 + 50.6) x 38.060 = 11.83 kNm

The total moment at the jib pivot point due to wind loading at a wind speed of 12 m/s and a jib angle of 65º to the horizontal is:

$M_{WINDTOTAL}$ = 1.35 + 5.03 + 8.43 + 5.69 + 11.83 = 32.33 kNm

Similar calculations can be performed for different wind speeds and jib angles and the resultant moments at the jib pivot point are given in Table 2 of this appendix.

Jib Angle (º)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
15	0.06	0.26	0.58	1.03	1.60	2.31	3.14	4.11	5.20	6.42	7.76	9.24	10.84	12.58	14.44	16.43	18.54	20.79	23.16	25.67
16	0.07	0.27	0.62	1.09	1.71	2.46	3.35	4.37	5.54	6.83	8.27	9.84	11.55	13.39	15.38	17.49	19.75	22.14	24.67	27.34
17	0.07	0.29	0.65	1.16	1.81	2.61	3.55	4.64	5.87	7.25	8.77	10.44	12.25	14.21	16.31	18.56	20.95	23.49	26.17	28.99
18	0.08	0.31	0.69	1.23	1.92	2.76	3.75	4.90	6.21	7.66	9.27	11.03	12.95	15.02	17.24	19.61	22.14	24.82	27.66	30.65
19	0.08	0.32	0.73	1.29	2.02	2.91	3.96	5.17	6.54	8.07	9.77	11.62	13.64	15.82	18.16	20.66	23.33	26.15	29.14	32.29
20	0.08	0.34	0.76	1.36	2.12	3.05	4.16	5.43	6.87	8.48	10.26	12.21	14.33	16.62	19.08	21.71	24.51	27.47	30.61	33.92
21	0.09	0.36	0.80	1.42	2.22	3.20	4.35	5.69	7.20	8.88	10.75	12.79	15.02	17.41	19.99	22.75	25.68	28.79	32.07	35.54
22	0.09	0.37	0.84	1.49	2.32	3.34	4.55	5.94	7.52	9.29	11.24	13.37	15.70	18.20	20.90	23.78	26.84	30.09	33.53	37.15
23	0.10	0.39	0.87	1.55	2.42	3.49	4.75	6.20	7.85	9.69	11.72	13.95	16.37	18.99	21.80	24.80	28.00	31.39	34.97	38.75
24	0.10	0.40	0.91	1.61	2.52	3.63	4.94	6.45	8.17	10.08	12.20	14.52	17.04	19.76	22.69	25.82	29.14	32.67	36.40	40.34
25	0.10	0.42	0.94	1.68	2.62	3.77	5.13	6.71	8.49	10.48	12.68	15.09	17.71	20.54	23.58	26.82	30.28	33.95	37.83	41.91
26	0.11	0.43	0.98	1.74	2.72	3.91	5.33	6.96	8.80	10.87	13.15	15.65	18.37	21.30	24.45	27.82	31.41	35.21	39.24	43.47
27	0.11	0.45	1.01	1.80	2.81	4.05	5.52	7.20	9.12	11.26	13.62	16.21	19.02	22.06	25.33	28.81	32.53	36.47	40.63	45.02
28	0.12	0.47	1.05	1.86	2.91	4.19	5.70	7.45	9.43	11.64	14.08	16.76	19.67	22.81	26.19	29.80	33.64	37.71	42.02	46.56
29	0.12	0.48	1.08	1.92	3.00	4.33	5.89	7.69	9.74	12.02	14.54	17.31	20.31	23.56	27.04	30.77	34.74	38.94	43.39	48.08
30	0.12	0.50	1.12	1.98	3.10	4.46	6.07	7.93	10.04	12.40	15.00	17.85	20.95	24.30	27.89	31.73	35.83	40.16	44.75	49.59
31	0.13	0.51	1.15	2.04	3.19	4.60	6.26	8.17	10.34	12.77	15.45	18.39	21.58	25.03	28.73	32.69	36.90	41.37	46.10	51.08
32	0.13	0.53	1.18	2.10	3.28	4.73	6.44	8.41	10.64	13.14	15.90	18.92	22.20	25.75	29.56	33.63	37.97	42.57	47.43	52.55
33	0.14	0.54	1.22	2.16	3.38	4.86	6.62	8.64	10.94	13.50	16.34	19.44	22.82	26.47	30.38	34.57	39.02	43.75	48.75	54.01
34	0.14	0.55	1.25	2.22	3.47	4.99	6.79	8.87	11.23	13.86	16.78	19.96	23.43	27.17	31.19	35.49	40.07	44.92	50.05	55.46
35	0.14	0.57	1.28	2.28	3.56	5.12	6.97	9.10	11.52	14.22	17.21	20.48	24.03	27.87	32.00	36.40	41.10	46.07	51.34	56.88
36	0.15	0.58	1.31	2.33	3.64	5.25	7.14	9.33	11.80	14.57	17.63	20.98	24.63	28.56	32.79	37.31	42.12	47.22	52.61	58.29
37	0.15	0.60	1.34	2.39	3.73	5.37	7.31	9.55	12.09	14.92	18.05	21.49	25.22	29.24	33.57	38.20	43.12	48.34	53.86	59.68
38	0.15	0.61	1.37	2.44	3.82	5.50	7.48	9.77	12.36	15.26	18.47	21.98	25.80	29.92	34.34	39.08	44.11	49.46	55.10	61.06
39	0.16	0.62	1.40	2.50	3.90	5.62	7.65	9.99	12.64	15.60	18.88	22.47	26.37	30.58	35.11	39.94	45.09	50.55	56.33	62.41
40	0.16	0.64	1.43	2.55	3.98	5.74	7.81	10.20	12.91	15.94	19.28	22.95	26.93	31.24	35.86	40.80	46.06	51.63	57.53	63.75
41	0.16	0.65	1.46	2.60	4.07	5.86	7.97	10.41	13.18	16.27	19.68	23.42	27.49	31.88	36.60	41.64	47.01	52.70	58.72	65.06
42	0.17	0.66	1.49	2.65	4.15	5.97	8.13	10.62	13.44	16.59	20.07	23.89	28.04	32.52	37.33	42.47	47.94	53.75	59.89	66.36
43	0.17	0.68	1.52	2.71	4.23	6.09	8.29	10.82	13.70	16.91	20.46	24.35	28.58	33.14	38.04	43.29	48.87	54.78	61.04	67.63

Table 2 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Measured Jib Properties (BS EN 13001 – 2:2004)

Jib Angle (°)	Wind Speed (m/s)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
44	0.17	0.69	1.55	2.76	4.31	6.20	8.44	11.02	13.95	17.22	20.84	24.80	29.11	33.76	38.75	44.09	49.77	55.80	62.17	68.89
45	0.18	0.70	1.58	2.80	4.38	6.31	8.59	11.22	14.20	17.53	21.21	25.24	29.63	34.36	39.45	44.88	50.67	56.80	63.29	70.12
46	0.18	0.71	1.61	2.85	4.46	6.42	8.74	11.41	14.45	17.83	21.58	25.68	30.14	34.96	40.13	45.66	51.54	57.78	64.38	71.34
47	0.18	0.73	1.63	2.90	4.53	6.53	8.88	11.60	14.69	18.13	21.94	26.11	30.64	35.54	40.80	46.42	52.40	58.75	65.46	72.53
48	0.18	0.74	1.66	2.95	4.61	6.63	9.03	11.79	14.92	18.42	22.29	26.53	31.14	36.11	41.46	47.17	53.25	59.70	66.51	73.70
49	0.19	0.75	1.68	2.99	4.68	6.74	9.17	11.98	15.16	18.71	22.64	26.94	31.62	36.67	42.10	47.90	54.08	60.62	67.55	74.85
50	0.19	0.76	1.71	3.04	4.75	6.84	9.31	12.16	15.38	18.99	22.98	27.35	32.10	37.23	42.73	48.62	54.89	61.54	68.56	75.97
51	0.19	0.77	1.73	3.08	4.82	6.94	9.44	12.33	15.61	19.27	23.31	27.75	32.56	37.76	43.35	49.33	55.68	62.43	69.56	77.07
52	0.20	0.78	1.76	3.13	4.88	7.03	9.57	12.50	15.82	19.54	23.64	28.13	33.02	38.29	43.96	50.01	56.46	63.30	70.53	78.15
53	0.20	0.79	1.78	3.17	4.95	7.13	9.70	12.67	16.04	19.80	23.96	28.51	33.46	38.81	44.55	50.69	57.22	64.15	71.48	79.20
54	0.20	0.80	1.81	3.21	5.01	7.22	9.83	12.84	16.25	20.06	24.27	28.88	33.90	39.31	45.13	51.35	57.97	64.99	72.41	80.23
55	0.20	0.81	1.83	3.25	5.08	7.31	9.95	13.00	16.45	20.31	24.57	29.25	34.32	39.81	45.70	51.99	58.69	65.80	73.32	81.24
56	0.21	0.82	1.85	3.29	5.14	7.40	10.07	13.15	16.65	20.55	24.87	29.60	34.74	40.29	46.25	52.62	59.40	66.60	74.20	82.22
57	0.21	0.83	1.87	3.33	5.20	7.49	10.19	13.31	16.84	20.79	25.16	29.94	35.14	40.75	46.78	53.23	60.09	67.37	75.06	83.17
58	0.21	0.84	1.89	3.36	5.26	7.57	10.30	13.46	17.03	21.03	25.44	30.28	35.53	41.21	47.31	53.83	60.76	68.12	75.90	84.10
59	0.21	0.85	1.91	3.40	5.31	7.65	10.41	13.60	17.21	21.25	25.71	30.60	35.92	41.65	47.82	54.40	61.42	68.86	76.72	85.01
60	0.21	0.86	1.93	3.44	5.37	7.73	10.52	13.74	17.39	21.47	25.98	30.92	36.29	42.08	48.31	54.97	62.05	69.57	77.51	85.88
61	0.22	0.87	1.95	3.47	5.42	7.81	10.63	13.88	17.56	21.68	26.24	31.23	36.65	42.50	48.79	55.51	62.67	70.26	78.28	86.74
62	0.22	0.88	1.97	3.50	5.47	7.88	10.73	14.01	17.73	21.89	26.49	31.52	37.00	42.91	49.25	56.04	63.26	70.93	79.03	87.56
63	0.22	0.88	1.99	3.53	5.52	7.95	10.82	14.14	17.89	22.09	26.73	31.81	37.33	43.30	49.70	56.55	63.84	71.57	79.75	88.36
64	0.22	0.89	2.01	3.57	5.57	8.02	10.92	14.26	18.05	22.28	26.96	32.09	37.66	43.68	50.14	57.05	64.40	72.20	80.44	89.13
65	0.22	0.90	2.02	3.60	5.62	8.09	11.01	14.38	18.20	22.47	27.19	32.36	37.97	44.04	50.56	57.52	64.94	72.80	81.12	89.88
66	0.23	0.91	2.04	3.62	5.66	8.15	11.10	14.50	18.35	22.65	27.41	32.62	38.28	44.39	50.96	57.98	65.46	73.38	81.76	90.60
67	0.23	0.91	2.05	3.65	5.71	8.22	11.18	14.61	18.49	22.82	27.61	32.86	38.57	44.73	51.35	58.42	65.96	73.94	82.39	91.29
68	0.23	0.92	2.07	3.68	5.75	8.28	11.26	14.71	18.62	22.99	27.81	33.10	38.85	45.06	51.72	58.85	66.43	74.48	82.98	91.95
69	0.23	0.93	2.08	3.70	5.79	8.33	11.34	14.81	18.75	23.15	28.01	33.33	39.12	45.37	52.08	59.25	66.89	74.99	83.56	92.58
70	0.23	0.93	2.10	3.73	5.82	8.39	11.42	14.91	18.87	23.30	28.19	33.55	39.37	45.66	52.42	59.64	67.33	75.48	84.10	93.19
71	0.23	0.94	2.11	3.75	5.86	8.44	11.49	15.00	18.99	23.44	28.36	33.76	39.62	45.95	52.74	60.01	67.75	75.95	84.63	93.77
72	0.24	0.94	2.12	3.77	5.89	8.49	11.55	15.09	19.10	23.58	28.53	33.95	39.85	46.22	53.05	60.36	68.14	76.40	85.12	94.32
73	0.24	0.95	2.13	3.79	5.93	8.54	11.62	15.17	19.20	23.71	28.69	34.14	40.07	46.47	53.35	60.70	68.52	76.82	85.59	94.84

Table 2 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Measured Jib Properties (BS EN 13001 – 2:2004)

Jib Angle (°)	Wind Speed (m/s) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
74	0.24	0.95	2.14	3.81	5.96	8.58	11.68	15.25	19.30	23.83	28.84	34.32	40.28	46.71	53.62	61.01	68.88	77.22	86.03	95.33
75	0.24	0.96	2.16	3.83	5.99	8.62	11.73	15.33	19.40	23.95	28.98	34.49	40.47	46.94	53.88	61.31	69.21	77.59	86.45	95.79
76	0.24	0.96	2.17	3.85	6.01	8.66	11.79	15.40	19.49	24.06	29.11	34.64	40.66	47.15	54.13	61.58	69.52	77.94	86.84	96.23
77	0.24	0.97	2.17	3.87	6.04	8.70	11.84	15.46	19.57	24.16	29.23	34.79	40.83	47.35	54.35	61.84	69.81	78.27	87.21	96.63
78	0.24	0.97	2.18	3.88	6.06	8.73	11.88	15.52	19.64	24.25	29.34	34.92	40.98	47.53	54.56	62.08	70.09	78.57	87.55	97.00
79	0.24	0.97	2.19	3.89	6.08	8.76	11.93	15.58	19.71	24.34	29.45	35.05	41.13	47.70	54.76	62.30	70.33	78.85	87.86	97.35
80	0.24	0.98	2.20	3.91	6.10	8.79	11.96	15.63	19.78	24.42	29.54	35.16	41.26	47.86	54.94	62.51	70.56	79.11	88.14	97.66
81	0.24	0.98	2.20	3.92	6.12	8.82	12.00	15.67	19.83	24.49	29.63	35.26	41.38	48.00	55.10	62.69	70.77	79.34	88.40	97.95
82	0.25	0.98	2.21	3.93	6.14	8.84	12.03	15.71	19.89	24.55	29.71	35.35	41.49	48.12	55.24	62.85	70.95	79.55	88.63	98.21
83	0.25	0.98	2.21	3.94	6.15	8.86	12.06	15.75	19.93	24.61	29.78	35.44	41.59	48.23	55.37	63.00	71.12	79.73	88.83	98.43
84	0.25	0.99	2.22	3.95	6.16	8.88	12.08	15.78	19.97	24.66	29.83	35.51	41.67	48.33	55.48	63.12	71.26	79.89	89.01	98.63
85	0.25	0.99	2.22	3.95	6.17	8.89	12.10	15.81	20.01	24.70	29.89	35.57	41.74	48.41	55.57	63.23	71.38	80.02	89.16	98.79
86	0.25	0.99	2.23	3.96	6.18	8.90	12.12	15.83	20.03	24.73	29.93	35.61	41.80	48.48	55.65	63.31	71.48	80.13	89.28	98.93
87	0.25	0.99	2.23	3.96	6.19	8.91	12.13	15.85	20.05	24.76	29.96	35.65	41.84	48.53	55.71	63.38	71.55	80.22	89.38	99.04
88	0.25	0.99	2.23	3.96	6.19	8.92	12.14	15.86	20.07	24.78	29.98	35.68	41.87	48.56	55.75	63.43	71.61	80.28	89.45	99.11
89	0.25	0.99	2.23	3.97	6.20	8.92	12.15	15.86	20.08	24.79	29.99	35.70	41.89	48.59	55.78	63.46	71.64	80.32	89.49	99.16
90	0.25	0.99	2.23	3.97	6.20	8.93	12.15	15.87	20.08	24.79	30.00	35.70	41.90	48.59	55.78	63.47	71.65	80.33	89.50	99.17

Table 2 - Moment at the Jib Pivot Point due to Wind Loading (kNm)
Measured Jib Properties (BS EN 13001 – 2:2004)

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HSE

Health and Safety Executive

The effect of wind loading on the jib of a luffing tower crane

Following a luffing crane collapse in Liverpool in January 2007, the UK Health and Safety Executive (HSE) were concerned that standards concerned with tower crane manufacture may not offer sufficient protection in relation to slack rope conditions on a luffing tower crane. HSE wished to determine if foreseeable conditions could be identified that could give rise to dangerous operational conditions below maximum in service wind speeds. A luffing tower crane was erected at the Health and Safety Laboratory (HSL), Buxton. Measurements of wind speed and luffing system tension were taken to determine combinations of wind speed and jib elevation likely to result in slack luffing rope conditions. Calculations of jib wind loading were carried out using four standards, FEM 1.001, FEM 1.004, ISO 4302 and BS EN 13001-2:2004. Wind loading calculations compared closely with values obtained during the tests. The jib was found to be susceptible to uncontrolled movement below the maximum in service wind speed and at jib elevations within the limits specified by the manufacturer. Differences of up to 150% between wind speed readings provided by anemometers fitted at the jib outer end and the 'A' frame were experienced during the testing.

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