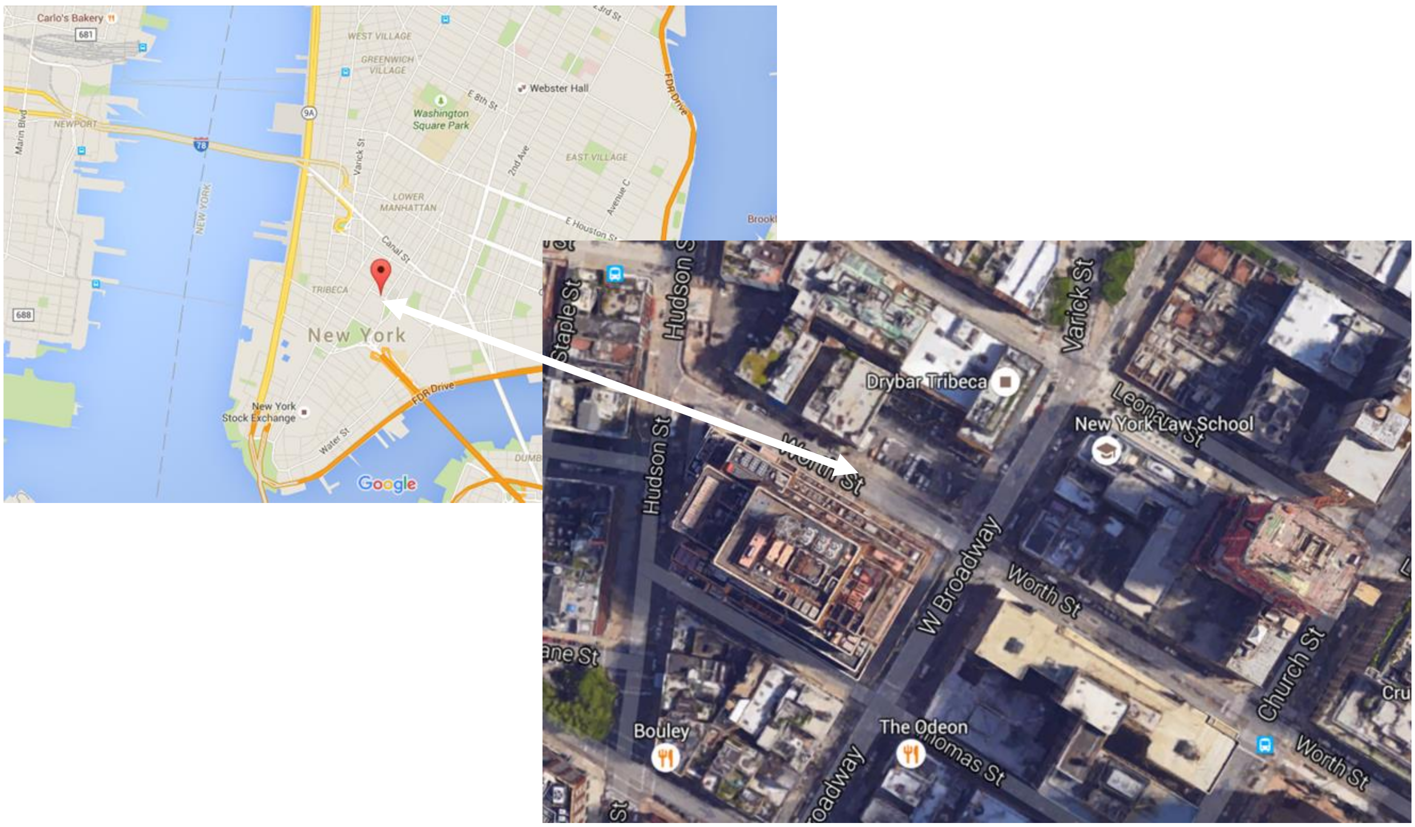
Crane Collapse Investigation

60 Hudson Street (occurred on Worth Street)

February 5, 2016



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Exhibits

1.0 Executive Summary

A Liebherr LR 1300 crawler crane collapsed at 60 Hudson Street in downtown Manhattan around 8:25 am EST on February 5, 2016. The crane fell in a south easterly direction on Worth Street. The collapse resulted in one fatality, three injured pedestrians, damaged buildings on the northeast corner of Church and Worth Streets and damaged cars parked on Worth Street. The crane had a 194 feet main boom and a 371 feet luffing jib for a total boom/jib length of 565 feet. This configuration was included in the DOB approved drawings and confirmed by inspection.

A crane accident of this magnitude is normally a result of a combination of action / inactions / errors that occur over a period of time, and this is true for this accident. CTS concludes that the operator failed to follow DOB regulations and the manufacturer's requirement to secure the crane overnight on February 4th in advance of a forecasted wind/weather event. On the morning of February 5th, the operator continued his improper actions by lowering the main boom to a 72° angle which put the crane at its stability limit. These compounded errors ultimately led the crane to collapse.

The National Weather Service for Manhattan issued a Winter Weather Advisory Thursday afternoon (at 4:09 p.m. on February 4, 2016) for snow into Friday Morning that included a wind forecast of gusts up to 30 mph, and later increased to 35 mph at 8:56 p.m. that evening. The morning of February 5 there was a noticeable increase in wind speeds between 5:00 am and 9:00 am with the prevailing wind direction from the north and north east.

New York City DOB regulations require the operator to understand and follow the manufacturer's recommendations (BC 3301.1.3), and to secure the boom when leaving the site (1 RCNY §3319-01(p)(2)(vi). The operator's manual located in the cab covered requirements the operator should follow in case of wind/weather related events and leaving the machine unattended overnight. When shutting down and leaving the machine overnight, the manual required the operator to place the boom and jib on the ground. Further, the manufacturer required that the crane be placed in the "parked" position" prior to wind speeds reaching the speed at which no work is allowed (out-of-service wind). For this crane's configuration (194 feet main, 371 feet jib), the wind speed was 7 meters per second (15.66 mph), and the "parked" position per the manufacturer was to "Lay down the boom and jib".

The measurement of the unspooled boom and luffing jib hoist ropes show that the boom was at approximately 72° and the luffing jib at approximately 49° at the time of the collapse. The above angles are supported by the data retrieved from the crane's computer and contrary to the operator's belief that the boom was 80° and the luffing jib at 45°.

The evidence did not show any structural or mechanical failures of the crane or its components. In addition, the foundation structure (cribbing) was within acceptable tolerances.

2.0 Background

2.1 Crane Tech Solutions' Role

Department of Buildings (DOB) engaged Crane Tech Solutions, LLC (CTS) the afternoon of February 5, 2016. DOB requested CTS to investigate the facts available prior to the collapse and provide a report outlining the cause(s).

CTS tasks included taking photographic evidence the day of and the day after the collapse, review pertinent documents including but not limited to, applicable regulations, documents submitted to DOB, operator manuals, information provided by the manufacturers, owner, master rigger, and weather forecasts. CTS will discuss each of these in the body of the report.

2.2 The investigation team

CTS, with DOB approval, engaged additional firms to assist with the investigation. AccuWeather Forensic Department ("AWF") of AccuWeather Inc. provided the weather/wind forecasts and wind speed predictions at the time of the collapse. CTS engaged Simpson, Gumpertz & Heger (SGH) to provide structural and wind calculations augmenting CTS's crane experience.

2.3 Investigation Outline

CTS started the evening of the collapse collecting photographic evidence with the focus on trying to determine the potential cause(s) of the collapse. This activity carried into the next day and CTS witnessed the removal of the crane and its components.

The next step was to review various documents that included drawings submitted to DOB, the operator's manuals, and documents provided to DOB from the owner, manufacturer, engineer of record, and the master rigger.

CTS visited the site where the crane and its components were shipped after the collapse (NYPD Brooklyn storage yard formerly known as the South Brooklyn Marine Terminal). The focus of this field work was to witness off-loading the components and weighing them to compare to weights provided by the manufacturer, and take several measurements of the structure.

As mentioned above, the estimate of the wind/weather conditions at the time of the collapse was critical to the investigation and CTS hired AWF. This firm provided the forecasts prior to the collapse as well as an estimated wind speed at the time of the collapse.

To augment its crane experience, CTS hired SGH to assist with the determining the limiting wind speed for the crane's configuration that included crane component weights and their centers of gravity, inertial forces, and their impact to the tipping line which influences the stability of the crane.

The final field work entailed CTS removing and measuring the main boom and luffing jib ropes to determine their respective angles at the time of the collapse. In addition, CTS removed hydraulic fluid for testing and removed the jib hoist brake components to determine if there were mechanical failures and the state of the hydraulic fluid.

The result of the work mentioned above is this report.

3.0 Facts

3.1 Project Description

3.1.1 60 Hudson Street Project

The project consisted of multiple phases spread over a couple of years. The master rigger (GTRI) was a subcontractor to the principal electrical and mechanical contractors.

The key parties involved with the crane activities prior to and at the time of the collapse are:

Operator	Kevin Reilly
Master Rigger	Greg Galasso
Crane User	Galasso Trucking and Rigging, Inc. (GTRI)
Rigging Foreman	Brent Graham
Professional Engineer	MRA Engineering, P.C. (MRA)
Oiler	Steven Mazzacco
Crane owner	Bay Crane Services, Inc. (BCSI)
Manufacturer	Liebherr Nenzing Crane Company(Liebherr)
DOB Inspectors	Dan Myers and Richard Hamilton

The end customer, Datagyrd, was expanding its data center. The project entailed hoisting generators, cooling towers, rigging material, electronic components, and sundry equipment and materials to various elevations at 60 Hudson Street.

The master rigger selected the Liebherr LR 1300 due the project's capacity and reach constraints. The two heaviest lifts were approximately 24,000 pounds and were within the paper load charts provided by Liebherr (Exhibit F). The cooling towers required the longest radius (128'), and they were significantly lighter (8,000 pounds). These were not critical picks pursuant to 1 RCNY 104-20 and Chapter 33 of NYC 2014 Building Code.

The project had several start dates over the planning stage. However, recent correspondence showed that the team had settled on the week of January 16th to January 24th. Due to high winds and expected adverse weather, GTRI decided to delay the project start to January 27 and end on February 7, 2016. The basic plan GTRI developed was [ref 13]:

January 30, 2016, 8:00am	Level Worth Street and set pontoons (crane foundation)
January 30, 2016, 4:00pm	Assemble crawler
February 1, 2016, 7:00am	Hoist equipment to 24th floor and roof (generator and components)
February 2, 2016, 7:00am	Hoist equipment to 24th floor and roof (generator and components)
February 3, 2016, 7:00am	Hoist equipment to 24th floor and roof (Substation temp platform and dunnage)
February 4, 2016, 12:00am	Boom down and extend crawler crane
February 4, 2016, 7:00am	Hoist equipment to 24th floor and roof (Piping as needed, sand filter, remaining pipe, cooling towers
February 5, 2016, 7:00am	Hoist equipment to 24th floor and roof (cooling towers, remove temporary steel)
February 6, 2016, 10:00pm	Dismantle crawler crane
February 7, 2016, 6:00am	Truck crane components back to BCSI
February 7, 2016, 12:00pm	Clean Worth Street and remove pontoons

The project essentially maintained the above schedule with the exception that no lifts were made Wednesday, February 3rd, due to high winds. Thursday was a productive day according to the operator and rigging personnel interviewed.

The above picks required that the crane start in one configuration (194 feet main boom and 331 feet luffing jib) to lift the heavy loads (generators), and then reconfigured to another one (194 feet main boom and 371 feet luffing jib).

3.1.2 Daily Project overview

BCSI and GTRI assembled the crane on January 30, 2016 (configuration was 194 feet main boom and 322 feet luffing jib). According to NYC statute, a DOB inspector (Daniel Meyer) was on site to inspect and witness the assembly. The inspection included a review of the magnetic particle report issued by Certified Testing & Inspections Inc. (CTI). CTI noted all boom and jib sections were acceptable. When the inspection was complete and safety checks performed, the inspector found the crane to be in accordance with CN #1157/15, and hoisting allowed to start. The operator, with the assistance of BCSI and GTRI, raised the boom so it would be ready to work the following day.

Prior to lifting a load, the operator encountered an issue with the crane's computer based load chart. This load chart would not allow the crane to pick the two heaviest loads so he switched the computer to simulate the crane operating in two-part (the rope is routed around a sheave to double the crane's capacity) while the crane was actually in single part. This is confirmed by the data retrieved from the crane's computer [ref 21]. In essence, the operator used an incorrect configuration so the computer would allow the crane to make the pick. The operator said in an interview that he asked a Liebherr technician if this was acceptable and he did not receive a response (positive or negative). The paper load charts showed the lifts could be made safely.

The operator decided to attempt the heavy lifts, with the computer showing the crane was in two-part line, and made them without incident. After the picks, the operator switched the computer back to single part line to coincide with the crane's actual configuration.

The crane performed the two heaviest lifts as well as others Monday and Tuesday without incident. Tuesday afternoon there was a forecast for high winds (20 mph) for Wednesday morning and the site decided not to perform lifts Wednesday and that the operator and oiler would be on site to monitor the crane.

Wednesday morning (February 3, 2016) the site experienced high winds and the operator decided to jack-knife the crane over West Broadway (Photograph 1) around 10:00 a.m. He performed this operation without the assistance of the owner or engineer although he did use them two days earlier to raise the boom. The former point is important because the operator had said in his interview that he had minimal experience with this crane in the configurations for this project.


Photograph 1

The project plan required the crane's luffing jib to be re-configured to make the final lifts (to 371'), and this was included in the approved drawings (ER-2 of 3). Late Wednesday, BCSI and GTRI assisted the operator to lay the boom on the ground.

The crane's re-configuration was completed early Thursday morning

(February 4th). DOB inspector, Richard Hamilton, was present and found the crane to be compliant with the drawings and inspection checklist. The operator boomed up and performed the required safety checks with no issues, rotated 180° (facing west), placed the main boom at an 80° angle and the luffing jib between 67° and 70° (to the horizontal), and slept for a few hours until lifting began.

Thursday morning there was a report of water in the basement of the adjacent building (60 Worth Street). The Master Rigger said that he arrived on site and took a picture of the crane's leveling bubble and it was 1/2° off and he checked the cribbing and did not see any issues. He went into the building to join the team that was charged with finding the water source. After about two hours, the water source was not found. The master rigger went back to the crane and rechecked the bubble and it was in the same position. The operator, master rigger, and professional engineer determined the crane's foundation had not been compromised and work continued. The survey performed the night of the collapse confirms (Exhibit H) that the foundation was not compromised by the water.

According to site personnel, Thursday was a productive day and the job was progressing as planned or slightly ahead of plan, and they completed work around 6:00 p.m.

Late Thursday afternoon there was a meeting to discuss an incoming weather system and according to site personnel (Rigging Foreman and Oiler) the operator attended these discussions. The Rigging Foreman mentioned during his interview that they discussed wind gusts that could be as high as 30 miles per hour. The Rigging Foreman also mentioned that they had decided not to perform lifts Friday due to the pending storm. At the end of work day, the operator decided to leave the crane boomed up with the main boom at 88° and the luffing jib between 67° and 70° and left the site for the evening, which was against the manufacturer's recommendation.

The National Weather Service for Manhattan issued a Winter Weather Advisory Thursday afternoon (at 4:09 p.m. on February 4, 2016) for snow into Friday Morning that included a wind forecast of gusts up to 30 mph, and later that evening (8:56 pm) increased the gusts to 35 mph [ref 2].

The following is an excerpt found on page 2 of the AccuWeather Forensics' report discussing Friday morning's weather conditions (Exhibit B). "… the northerly winds brought colder air into the city on the morning of February 5, 2016. Rain from the storm began to fall steadily between 1:00 a.m. and 2:00 a.m. with the temperature near 40 degrees, and then changed to wet snow an hour later as the temperature fell into the 30s. The snow fell steadily throughout the remainder of the predawn hours and into the daylight hours of the 5th, ending shortly before 12:00 noon. At first, the snow melted on the ground as it fell, but as the air temperature continued to fall, reaching 32 degrees by the time of sunrise, there was a slushy accumulation of snow on untreated paved surfaces and a buildup of wet snow on elevated surfaces. The total snow accumulation on untreated and undisturbed surfaces on Worth Street was between 2 and 3 inches by late morning on February 5th, more than half of which had fallen by 8:00 a.m. During the morning of February 5, 2016, the wind blew consistently from the north and north-east. However, there was a noticeable increase in the speed of the wind between 5:00 a.m. and 9:00 a.m. due to the intensification of the offshore storm." Wind gusts ranging from 29 mph to 38 mph were recorded from relatively open locations (noted in Section 3.3.3.2) around the time of the collapse. However, the wind at the site was complex due to the topography around the crane.

The operator said he arrived Friday morning around 6:50 am and the first wind reading was approximately 15 mph from the crane's anemometer, which was located at the tip of the luffing jib. At 7:40 am, he noticed gusts of 25 mph and made the decision to lower the boom to the jack-knife position similar to the one used Wednesday morning.

Once the operator made the decision to jack-knife the crane, he said during his interview that "*I told them I was gonna swing around, and we were getting ready to [do] that. So I boomed up to 88 degrees to swing the other way. Once I get facing east, I boomed back down to 80 degrees. I walked the machine back 30'. Joe and Steve assisted me, and we put the blocking in front of the cats for me to walk up on.*" The operator used three sheets of ¾ inch plywood (height of 2¼ inches) stacked on top of each other to "block" the tracks. They placed these in front of the cats and he drove (walked) up on them to engage the idler (the main non-driven gear at the front of the tracks).

He said that the site personnel told him the street was ready meaning the flagmen had diverted pedestrian and vehicular traffic and he started to lower the luffing jib down and he said that he kept the main boom at 80° and when he reached "*90% of the chart, and I still got the ball up high that if because [sic] I feel it moving around. I don't want the ball swing around. At 90%, I reach back to push the setup button. And as I turn around, I feel the machine move. I look back out the window, and the f*****g thing coming up. So I try to luff back, and it just went down*."

The operator said that he stayed inside the cab the entire time as the crane body flipped over. One of the windows was broken during the collapse and he crawled out through the opening. Two of the interviewees (oiler and rigging foreman) confirmed that he had glass on him when they reached the cab.

The rigging foreman and other personnel then started toward West Broadway and Church Street to see if there were injured workers or pedestrians. They found one man trapped in a car, and a pedestrian that was crushed by the luffing jib. The Rigging Foreman also went into the building that was hit by the crane with the fire department to see if there were any injuries.

The remainder of February 5, 2016, NYPD secured the area around the collapsed crane and NYFD checked the damaged building and assisted with the fatality and three injured pedestrians.

3.1.3 Post collapse observations on February 5, 2016

CTS arrived on site shortly after 7:00 pm, February 5, 2016 to start the investigation. The crane body had flipped over onto its top (Photograph 2) and the operator's cabin had a broken window. The crane body came to rest immediately adjacent to an open car parking lot on Worth Street and

Photograph 2

Photograph 3

the crawlers were angling slightly to the north east on Worth street. The main boom and luffing jib were on Worth Street in the direction of Church Street (easterly direction) (Photograph 3).

The car body counterweights had fallen onto the pontoons (cribbing/foundation) and the rear counterweights were upside down but remained together. There was about 1 inch of ice and snow on the foundation. CTS saw 3 sheets of stacked plywood on each pontoon (north and south) that

Photograph 4 – North pontoon

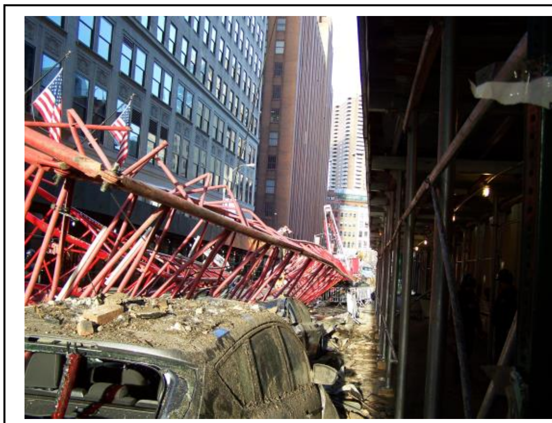
Photograph 5 – South Pontoon

was used to “block” the tracks. These had snow and ice on them. The south side plywood (Photograph 5) sustained damage to the middle of the stack while the north side plywood (Photograph 4) did not have such damage. The foundation appeared level and there was a survey company plotting the various heights.

The heal (first) section of the main boom broke close to the pivot point with the remaining portion under the crane body. The main boom hit a parked car (oiler’s) and a parked van belonging to GTRI. The boom tip landed in the intersection of West Broadway and Worth Street.

The luffing jib tip hit buildings on the north west corner of Church and Worth Streets, which caused the jib to bend up and came to rest shortly before Church Street (Photograph 6). The remainder of the jib landed on parked cars along the north side of Worth Street (Photograph 7).

Photograph 6



Photograph 7

CTS did not see, nor find, signs of a structural failure. There were no broken pendant bars, pins, boom or jib sections, or failed rope. The damage seen to the structure resulted from the collapse and the crane hitting the ground or other ground based objects.

3.2 Crane Information

3.2.1 Crane type and approved configurations

The crane involved in the collapse was a Liebherr crawler crane model LR 1300. Liebherr manufactured the crane in January 2009 and assigned it serial number 138.064. The crane was in an approved configuration at the time of the collapse (main boom of 194 feet and a luffing jib of 371 feet). Figure 1 is a general arrangement drawing for this model crane [ref 1].

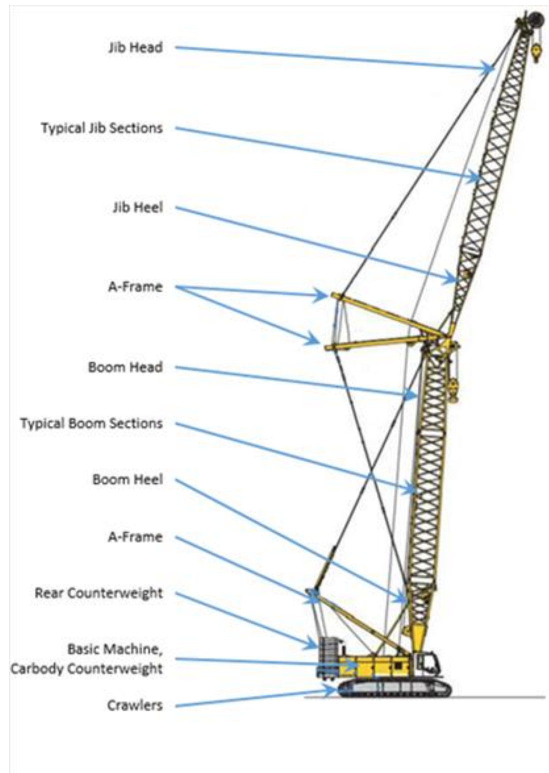


Figure 1 – [ref 1]

The main boom attached to the crane was model number 2821-1 and the luffing jib was 2316-1. The combination determines the maximum in-service wind speed. For the configuration of the collapsed crane, the wind speed was 7 meters per second (15.66 mph) per the manual/load charts.

The main boom consisted of six sections (one 33 foot heal, one 20 foot, three 40 foot, and one 22-foot boom tip). The luffing jib consisted of eleven sections (one 33 foot heal, one 10 foot, one 20 foot, seven 40 foot, and one 33-foot jib tip). Exhibit F provides more detail on the dimensions of the sections and other crane components.

3.2.2 Documents filed with DOB and other agencies

There are two other agencies that have crane related laws, rules, and regulations. The typical process is a professional engineer must obtain approval from the Transit Authority if a crane is placed within 200 feet of a TA structure. The New York City Department of Transportation has a permitting process if a crane is set up on a City street which requires either a partial or complete street closure(s). Both of these conditions existed for the job that the collapsed crane was operating.

Transit Authority

The crane's location was within 200 feet of a Transit Authority (TA) structure and the assembly assist crane would be operating directly above a TA roof structure. MRA submitted the required drawings and the TA approved them on December 30, 2015. The TA review and approval are required to ensure that crane operation does not adversely impact TA operations or one of its structures.

Department of Transportation

The project plan required closing Worth Street between Hudson Street and West Broadway for several days and closing West Broadway at Worth Street three times: the initial assembly, Wednesday night (before the accident) to change the crane's configuration, and the disassembly. Due to the required closures, the Department of Transportation reviewed the closure requests and issued the permits on January 20, 2016.

Department of Buildings

Certificate of Approval (referred to as the Prototype process)

New York City requires all crane models that operate within the jurisdiction be approved by Department of Buildings (DOB) via the issuance of a Certificate of Approval. This requirement is set out in the Building Code (Chapter 3319) and 1 RCNY §3319-01.

The regulatory requirement at the time DOB approved the LR 1300 required a licensed New York State professional engineer to certify the design calculations (BC 3319.4 and RS 19-2, sections 3.1, 3.2, 4.0, 4.1 and 4.2). For this crane, the applicant and professional engineer of record was Jay Shapiro from Howard Shapiro & Associates. The manufacturer was Liebherr Nenzing Crane Company with an office located in Houston, Texas.

In addition to the PE certification, the application required the submittal of various documents that include among others: load charts, possible configurations, operator manuals, and brochures. CTS did not perform a detailed review of this material because it is outside the scope of the investigation. CTS reviewed the load charts in conjunction with the planned lifts, operator's manual, and approved configurations outlined in the Certificate of On-Site Inspection application.

DOB issued a Certificate of Approval for the Liebherr LR 1300 on May 30, 2007 and issued number P481. The application requested a maximum main boom length of 403 feet but DOB granted a maximum of 322 feet, and the maximum luffing jib of 371 feet.

Certificate of Operation (referred to as CD)

The New York City DOB requires that all cranes operating within the jurisdiction pass an annual inspection (some exceptions apply) and safety checks indicating that such crane is in a safe operating condition (BC 3319.5 and 1 RCNY §3319-01.i). The Cranes and Derricks unit of DOB performs these inspections and issues the Certificate of Operation (referred to as the "CD").

DOB issued the crane registration number CD 4463 to the LR 1300 involved in the collapse. DOB provided recent inspection reports that all were marked satisfactory except one where a stop work order was issued. The reason was that the Certificate of Operation had expired. DOB performed a re-inspection on 11/2/15 and found no issues and rescinded the stop work order. At the time of the collapse, the crane had a valid Certificate of Operation in place.

3.2.3 Certificate of on-site Inspection (referred to as the Crane Notice or CN)

The Certificate of On-Site Inspection requires a DOB inspector to visit the site when a crane with a boom length greater than 250 feet is assembled within the jurisdiction. The role of the DOB inspector is to check the crane's configuration and compare it against the approved drawing (discussed in section 3.3), and to witness the checks to ensure the crane's safety devices are installed and operating properly. The inspector follows a DOB checklist and if the crane passes the operator is allowed to operate the crane.

This project required two such inspections. The first one was performed when the crane was assembled on January 30, 2016 and the DOB inspector passed the crane. The second time was the result of the re-configuration completed on February 3, 2016. The crane passed this inspection.

3.3 Document Review

3.3.1 Drawings

GTRI hired MRA to produce the required drawings for the Certificate of On-Site Inspection ("Crane Notice") and worked with GTRI to coordinate efforts with the various city agencies (DOB, DOT, and Transit Authority) to obtain the required permitting (Section 3.2.2).

The application for a Certificate of On-Site Inspection was initially submitted to DOB on December 3, 2015 by MRA Engineering, P.C. and the applicant was Neil Greenblatt, P.E. The application listed four possible machines including the subject crane with the planned configurations.

The submittal included seven (7) drawings (see Exhibit G). The drawings consisted of the following:

- a site general arrangement showing the location of the crane and the radii for the four primary lifts (ER1 of 3),
- two crane configurations (ER-2 of 3),
- adverse weather condition requirements (SP-1 of 1),
- three drawings showing the design of the foundation (pontoons / cribbing) (S-1 of 2, S-2 of 2, ER-3 of 3), and
- a drawing showing the assist crane used during the initial assembly and the crane's re-configuration (AS-1 of 1).

In addition to the drawings, the professional engineer submitted a Ground Bearing Pressure Calculation document (discussed in Section 3.3.3.3) providing necessary information that the crane would not exceed the statutory 3,500 pounds per square foot (psf) pressure on the street (§3310-01.g.7). The professional engineer derived this information from an Excel spreadsheet provided by Liebherr (see Section 3.3.3).

The application also included a letter from the professional engineer of record (Neil Greenblatt) that he visited the site and made the following declarations; *the crane shall be operated in a level position at all times and shall not be operated during periods of high wind*. These comments are directed toward the user and crane operator of the crane.

Cranes and Derricks reviewed the application, discussed it with the engineer of record, and issued its approval on January 12, 2016, and then issued the project crane notice number CN#1157/15.

When asked about the adverse weather drawing showing the direction of the jack-knife position toward Hudson Street, the engineer's response was that "*the manufacturer did not provide the necessary jack-knife criteria so we could not determine whether jack-knifing towards Hudson was feasible. We just showed the crane jack-knifed with a note referring to the manufacturer's* *recommended procedure*." Therefore, the governing comment to the reader of the drawing would be to follow the manufacturer's recommended procedure in case of adverse weather.

3.3.2 Operator's Manual

The document review revealed that there were three different manuals for this model. The manuals are similar in many aspects but there were some differences. The governing manual must be the one in the operator's cabin because it is the one that the operator can refer in case he needs to research a particular task/critical information. Therefore, the following discussion covers this manual.

The manual in the operator's cabin has serial number LR 1300-138009. The areas that CTS reviewed were: boom and jib location when work is interrupted and out-of-service wind, assembly/disassembly procedures, blocked crawler procedure, and usage of the jack-knife position.

Work Interruption

The manual defined a long term interruption as "overnight or several days". The manual (Paragraph 4.23.2, page 275) further requires "the machine's boom (main, fly, jib, etc.) must be completely placed on the ground" (Exhibit F) when the operator and other persons familiar with laying down the boom leave the site.

Restriction due to wind

The manual has a section entitled "5.7 Restriction due to Wind" (pages 308 to 318). The section says and is shown in Exhibit F: "*the following three steps describe the procedure in the event of wind:*

- *reduce the working load,*
- *place the boom in its parked position,*
- *lay down the boom*."

Reduced working load (manual section 5.7.1)

The foreword to the load capacity charts contains critical information (included in Exhibit F) about the crane and more specifically the allowed in-service (operating) wind speeds for the various configurations of the LR 1300 (Section 2.6 – page 10 to 12). The operator also mentioned there was a laminated placard in the cab providing this information. Table 1 includes these values.

Jib Length Jib 2316	20 m (66 ft) to 26 m (85 ft)	29 m (95 ft) to 50 m (164 ft)	53 m (174 ft) to 74 m (243 ft)	77 m (253 ft) to 92 m (302 ft)	95 m (312 ft) to 113 m (371 ft)
Main Boom Length	20 M (66 ft) to 68 m (233 ft)				
Wind Speed	Reduction of load by				
7 m/s 22.97 ft/s (15.66 mph)	0%	0%	0%	0%	0%
9 m/s 29.53 ft/s (20.1 mph)	10%	10%	10%	10%	100%
11 m/s 36.09 ft/s (24.6 mph)	20%	20%	20%	40%	100%
13 m/s 42.65 ft/s (29.1 mph)	20%	30	40	70	100%
16 m/s 52.49 ft/s (35.79 mph)	30	50	70	100	100%
over 16 m/s 52.49 ft/s (35.79 mph)	100% = Operation prohibited				

Table 1 – [ref 6]

In addition to the table, Liebherr requires that for "*wind speeds between given values the maximum wind speed has to be taken*" (Exhibit F) This means that the operator would cease operation before wind speeds exceed or expect to exceed 15.66 mph. A higher wind speed would require the operator to go to the next higher wind speed (20.1 mph) and operation is prohibited on this line.

Another manufacturer requirement contained in the manual regarding wind speeds was "*In bad weather or if a storm is forecast and work is to be interrupted for a day or more, or if the crane operator and assistants will be absent, the entire boom must be placed on the ground*."

Parked position (manual section 5.7.2)

The term "parked" position refers to the boom and luffing jib placement when wind exceeds or is expected to exceed wind velocities the manufacturer for a particular crane configuration.

For the collapsed crane (194 feet main boom and 371 feet luffing jib), the manual says: "*the "parked" position of the boom can be used up to the maximum wind speed, above this speed the boom must be laid down (Tab 91)* (Table 10).

The manual continues by elaborating on the potential dangers for not adhering to the parked positions. It reads:

Danger from toppling of the machine at high wind speeds!

! Turn the boom towards the direction of the wind
! Before the maximum permitted wind speed is exceeded, place the boom in the specified parked position
! Place the suspend counterweight and ballast carriage on the ground (did not apply)
! The guy ropes and anchoring rods must be relieved (did not apply)
! Position the load hook as high as possible.

Lay the boom down (manual section 5.7.2)

The manual defines "*setting-down wind velocity" of the boom is reached when the maximum permissible wind speeds for the parked position are reached or expected to be reached*." In cases where the boom cannot be laid flat, the manual says that the adjustable fly jib (luffing jib) must be placed on the ground and the boom must be supported at the side (jack-knife position). Lastly, the manual requires the boom to be laid down against the wind.

"Blocked" crawlers

When assembling and jack-knifing the crane, the operator mentioned that he "blocked" the crawlers to extend the tipping line. The manual in the cab did not contain a section regarding this procedure. Based upon this manual, the operator should not have used this procedure.

Jack-knife position

The manual does not specifically mention main boom and luffing jib angles in Section 6.15.7 as they relate to assembly and disassembly of a crane's configuration with a main boom shorter than the luffing jib (see figure 2) Further, the manual did not provide a step by step procedure to raise or lower the boom and luffing jib (i.e., angles to use, when to move the main boom, or luffing jib, etc.). The note in Figure 2 says: "*in the case of this combination, no additional limit angles are to be noted when*

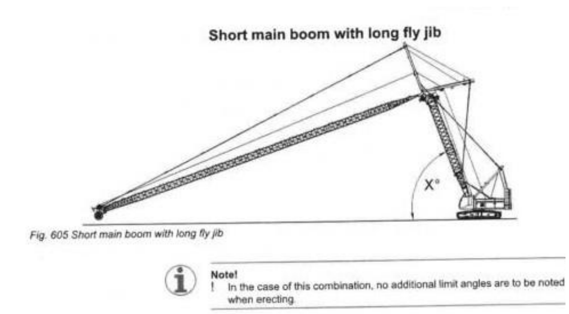


Figure 2 – [ref 5]

erecting."

The manuals also do not include a step by step procedure to jack-knife the crane. While Figure 2 shows the crane in a jacked knifed position, the figure is for use when assembling or disassembling the crane.

After the accident, Bay Crane asked Liebherr a question regarding the jack-knife position for the crane involved in the collapse. Liebherr confirmed that the approved "parked" position was to lay the boom on the ground when the wind speed reaches or expected to exceed the value at which work is no long permitted. According to the chart provided in the manual (Table 1), all work must be suspended at 7 meters per second (15.66 miles per hour) and the boom and jib laid on the ground.

However, Liebherr offered that Bay Crane could use the jack-knife position as the "parked" position with provisos, such as: "*the "parked" position wind could not exceed 67 miles per hour, and the luffing boom tip needed to be suspended with an allowed force of 6,835 pounds to each side*." In other words, Liebherr required the luffing jib tip to be laterally supported with a means to absorb 6,835 pounds on each side with the tip off the ground approximately 1m (3.3'). The email response continues with the jack-knife requirements "*This wind speed is the maximum possible 3-second-gust-wind at maximum elevated height. If higher wind speeds are expected, the boom has to be laid flat on the ground. The hook of luffing jib must to be on the ground for final parking position, and machine should be turned so that the wind comes from behind if it is possible*".

It should be noted that when the operator jack-knifed the crane on Wednesday the tip was resting on the ground and not 1m above the ground nor was it laterally supported as required (Photograph 1).

3.3.3 Other relevant documents

CTS reviewed documents provided by DOB, the crane owner (Bay Crane Service, Inc.), the master rigger (Galasso Trucking and Rigging, Inc.), the manufacturer (Liebherr), the professional engineer (MRA Engineering), AccuWeather, and SGH.

A few terms should be summarized at this point. The first is the "tipping line". In the case of the crawler crane, this would be at the end of both crawlers where they last touch the cribbing (the last link of the track firmly on the ground).

A "moment" is defined as a force (i.e., weight, wind, etc.) multiplied by a distance. There are two moments that affect stability – resisting and overturning. Generally, the resisting moment value results from weight and forces behind the tipping line, and the overturning moment value is the result of weight and forces exerted on the structure beyond the tipping line.

More specifically, the resisting moment on cranes is the weight of the structure located behind the tipping line (i.e., the crane body, counterweights, etc.) multiplied by the distance from the Center of Gravity of these items to the tipping line. The overturning moment is the result of forces (i.e., weight of boom/jib, wind, loads, etc.) exerted on the structure beyond the tipping line multiplied by the horizontal distance from the Center of Gravity of the structure(s) and wind forces applied multiplied by the vertical distance to the tipping line.

If the resisting moment is higher than the overturning moment the crane remains stable. Conversely, if the overturning moment is greater than the resisting moment the crane becomes unstable and would collapse (overturn).

Our report uses the term “limiting wind” speed. This is the calculated wind velocity that would cause the crane to become unstable and collapse at the corresponding main boom and luffing jib angles (Figure 3).

3.3.3.1 Structural Analysis – SGH Report

SGH provided a report discussing the stability of the collapsed crane in the assembled configuration (194 feet main boom and 371 feet luffing jib). They reviewed various documents including the serialized manual (138-064), relevant design standards for stability calculations, product literature and calculations related to the crane’s configuration, and visited the debris storage yard to measure various crane components [ref 1].

The first task SGH performed was to check the Liebherr stability calculation (Section 3.3.3.4) provided to DOB after the accident. The international standards Liebherr used (mentioned in Section 3.3.3.4) defines three limit states of the crane, and SGH compared their calculated values to the ones presented by Liebherr and arrived at similar results for these states.

SGH then reviewed the Ground Bearing Pressure Calculation (GBP) (Section 3.3.3.3.) provided by MRA, and the field weights contained in Table 6. SGH attempted to reconcile the three documents for weight and centers of gravity (vertical and horizontal). They include this in their report. To perform this task, SGH made various calculations in preparing their numbers.

The next step was to verify the wind area provided by Liebherr in the stability calculation for the boom and luffing jib. SGH visited the debris yard to take measurements of key structural components. SGH measured typical boom and jib sections, boom head, jib heel, and jib head. The SGH report provides detail on their procedure, and Table 2 provides a comparison of the Liebherr wind area and the one calculated by SGH.

Parameter		Wind Area Basis	
		LSC Wind Area [Ref. 3]	SGH Wind Area
Boom	Wind Area [ft^2]	910	996
	Center of Pressure above ground [feet]†	96.2	113
	Unit Wind Moment [kip-ft./psf]	88	113
	Unit Wind Moment [% w.r.t. Liebherr]	100%	128.7%
Jib	Wind Area [ft^2]	1203	1064
	Center of Pressure above ground [feet] †	374	371
	Unit Wind Moment [kip-ft./psf]	450	394
	Unit Wind Moment [% w.r.t. Liebherr]	100%	87.7%
Total	Wind Area [ft^2]	2114	2060
	Center of Pressure above ground [feet] †	254	246.2
	Unit Wind Moment [kip-ft./psf]	537	507
	Unit Wind Moment [% w.r.t. Liebherr]	100%	94.4%

Table 2 [ref 1]

+For the boom and jib at 90° (dead vertical)

The sensitivity analysis on wind area showed that the limiting wind speed calculated using the Liebherr value and the one SGH calculated are within 1 mph of each other over the range of wind areas considered.

To analyze the overturning stability of the crane at arbitrary boom and jib angles, SGH generalized the calculation used when checking Liebherr's stability calculation. SGH calculated stability in terms of the limiting wind speed at which overturning would occur for the crane in noted configuration (194 feet main boom and 371 feet luffing jib). For this work, SGH used the weights and center of gravities from the GBP calculation and the wind areas from Liebherr's stability calculation. The limiting wind speeds (from the rear and constant over the entire length of the boom and jib) are shown in Figure 3 for various boom and luffing jib angles. The area in red denotes an unstable state for that particular boom and jib angle combination.

Luffing jib angles less than negative 33° are not possible (jib tip would be below the ground surface). In Figure 3, there are three limiting wind scenarios highlighted. They are: the angles the operator mentioned, (80° for the boom and 45° for the jib), the angles based upon the unspooled rope without elongation of the pendant bars and rope (73° for the boom and 51° for the jib), and the angles including the elongation of the pendant bars and rope (72° for the boom and 49° for the jib).

Unstable condition

Jib Angle	Boom Angle, deg.																								
deg.	70.0	70.5	71.0	71.5	72.0	72.5	73.0	73.5	74.0	74.5	75.0	75.5	76.0	76.5	77.0	77.5	78.0	78.5	79.0	79.5	80.0	80.5	81.0	81.5	82.0
36															12	21	27	32	36	39	43	46	49	52	54
37														7	18	24	29	34	37	41	44	47	50	52	55
38														15	22	27	32	36	39	42	45	48	51	53	55
39													12	20	25	30	34	37	41	44	46	49	51	54	56
40												7	17	23	28	32	36	39	42	45	47	50	52	55	57
41												15	21	26	31	34	38	41	43	46	48	51	53	55	57
42											12	20	25	29	33	36	39	42	45	47	49	52	54	56	58
43										9	18	23	28	31	35	38	41	43	46	48	50	52	54	56	58
44									5	16	22	26	30	33	36	39	42	44	47	49	51	53	55	57	59
45									14	20	25	29	32	35	38	41	43	46	48	50	52	54	56	58	59
46								12	19	23	27	31	34	37	40	42	44	47	49	51	53	55	56	58	60
47							10	17	22	26	30	33	36	39	41	43	46	48	50	52	53	55	57	59	60
48						7	16	21	25	29	32	35	37	40	42	44	47	49	50	52	54	56	57	59	61
49					4	14	20	24	28	31	34	37	39	41	44	46	48	49	51	53	55	56	58	60	61
50					13	19	23	27	30	33	36	38	40	43	45	47	49	50	52	54	55	57	59	60	62
51				12	18	22	26	29	32	35	37	40	42	44	46	48	49	51	53	54	56	58	59	61	62
52			11	17	22	25	28	31	34	36	39	41	43	45	47	49	50	52	54	55	57	58	60	61	62
53		9	16	21	25	28	31	33	36	38	40	42	44	46	48	49	51	53	54	56	57	59	60	61	63
54	8	15	20	24	27	30	33	35	37	39	41	43	45	47	49	50	52	53	55	56	58	59	61	62	63
55	15	19	23	26	29	32	34	37	39	41	43	45	46	48	50	51	53	54	56	57	58	60	61	62	64

Figure 3 – [ref 1]

SGH performed a sensitivity analysis for various input parameters to determine how each affects the stability of the crane in terms of limiting wind speed that would cause overturning with the main boom. These included: basic machine center of gravity, tipping line, wind area, and component mass/inertial forces. These are discussed in Section 6.2 below.

3.3.3.2 Accu Weather Report

Photograph 8 [ref 23]

CTS requested AccuWeather Forensic (AWF) provide published weather forecasts from February 4, 2016 for the morning of February 5, 2016 (Section 6.1). They also were tasked with providing estimated wind speeds during the morning of the collapse.

AWF used wind data from four (4) nearby relatively open locations as the basis for their wind analysis. The locations used were La Guardia Airport, JFK Airport, Robbin Reef, NJ, and Central Park. These sites show a general increase in wind strength from 5:00 a.m. to 8:30 a.m. the morning of the accident. The prevailing wind direction was from the north / northeast. This places the wind at an angle slightly from the rear of the crane based upon the crane's location on Worth Street (see Photograph 8 above).

3.3.3.3 Ground Bearing Pressure Calculation submitted by MRA Engineering

MRA produced a document entitled "Crane Engineering Calculations" (Exhibit G) that included the Ground Bearing Pressure Calculation (GBP). The GBP used was an Excel spreadsheet provided by the manufacturer. The spreadsheet is password protected allowing the user to only input project/crane related data, and CTS could not check the spreadsheet for accuracy.

The Crane Engineering Calculations consisted of 23 pages and the bulk of the pages related to the GBP calculations. The other pages calculated the mat for shear and bending stresses in general and near a manhole under the north track. According to the document, the foundation (pontoons/cribbing) consisted of wooden timbers measuring 12 inches by 12 inches by 4 feet wide by 8 feet 6 inches minimum long under each crawler. The engineer also provided calculations to ensure proper building clearances for the luffing jib. The calculation indicated the configurations as submitted would have the proper clearances.

The necessary inputs to the GBP calculation are: length of boom, length of luffing jib, boom angle, length of high reach boom, length of fixed jib (not applicable), offset angle fixed jib (not applicable), track width, track shoes, car body counterweight, counterweight, unit (metric or American), load radius, boom configuration, and load.

As part of the calculation, the manufacturer provided critical weight and center of gravities of the machine's key structural components (see Table 3 and Figure 4). The input for the table and figure were based upon configuration of the collapsed crane. The X axis is the lateral (horizontal) direction and the Z axis is the longitudinal (vertical) direction.

Center of Gravity	Weight (1,000 pounds	X (feet)	Z (feet)	Remarks
Basic Machine	586.18	-9.324	6.990	With ballast, 1 hoist rope, without block
Boom	61.44	4.560	91.721	Complete system including A-Bock
Jib	58.49	49.401	330.325	Complete system including upper a-frames
Center of Gravity	706.11	-3.252	41.148	Crane standard without load and without optional add on
Including load at boom head	714.11	-1.781	46.919	Weight of options up to 7t are not considered

Table 3 – [ref 4]

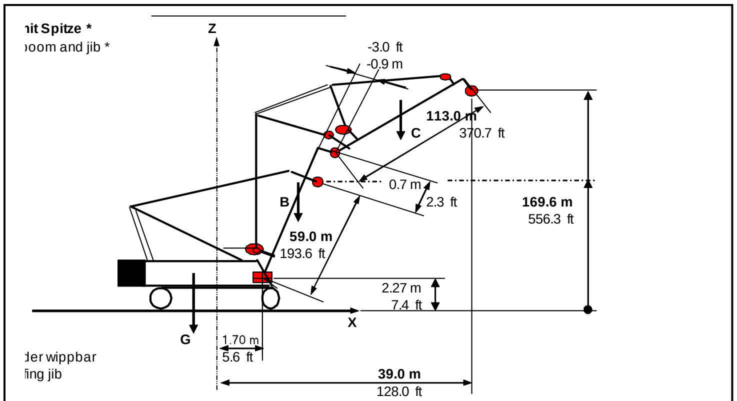


Figure 4 (from Liebherr spreadsheet) – [ref 4]

The engineer submitted six GBP scenarios – two for each luffing jib lengths and two for assembly (one for each luffing jib configuration). The governing condition (highest pressure) was the 194 feet boom and 321.5 feet luffing jib over the corner where the pressure was 3,340 pounds per square foot (psf). The maximum allowed by New York City is 3,500 psf.

"Blocking" the crawlers (see Section 3.3.2) is standard practice in New York City, and the professional engineers did not calculate the ground bearing pressure assuming the operator "blocks" the crawlers. When asked if the operator asked them about "blocking" the crawlers, MRA said that they did not receive a request to calculate the pressure when "blocking" the tracks.

The weight of the crane (706,110 pounds) without the "headache" ball shown above closely aligns to the weight arrived during the field work off-loading the components to the ground (Section 3.4.3). Further, the Ground Bearing Pressure weight is close to the weight provided by BCSI for the off-loading task (see Table 6).

3.3.3.4 Stability Calculation from Liebherr

Liebherr produced a document entitled: "Documentation for determination of stability during erection and lay down of boom" dated February 17, 2016 (Exhibit F). This is a theoretical stability (structural) calculation assuming a crane configuration at 194 feet main boom and 371 feet luffing jib. The analysis references the following international standards.

ISO 4305 second edition 1991-05-15 Mobile cranes – Determination of Stability
ISO 4302 first edition 1981-05-15 Crane – Wind load assessment
ISO 4310 first edition 1981-05-15 Cranes – Test code and procedures, and
Din EN 13000:2004 Cranes – Mobile cranes English translation of DIN EN 13000:2004

The Liebherr document shows (through calculation) a stable crane with a boom angle of 80°, a jib angle of 15°, a wind of 7 m/s (15.66 mph), and no load. Liebherr further concludes that a 70° main boom angle represents the *"critical angle during erection and boom lay down operations*". If one considers the headache ball and rope (approximately 2,000 pounds), the critical angle will be reached sooner.

The analysis provides the weight, center of gravities, and wind areas of critical structural components (Table 4). Liebherr also provided Figure 5 to illustrate the axes used in the stability calculation.

						Wind Area	Angle
Part		Description	Mass	x 0° (inclination)	z 0° (inclination)	Square meters	α
HPT		Main Boom	20.84100	5,075.88	28,872.05	84.43	80.00
OW+ROD+HW		Crane Body	27.44200	(3,171.98)	294.66	26.00	90.00
GG		Upper Counter Weights	124.00000	(7,391.00)	878.00	-	
UW		Tracks (Cats)	42.70000	(1,700.00)	(1,468.00)	15.00	90.00
ZB		Part of crane body	57.00000	(1,700.00)	(1,218.00)	-	
A-Bock1		Support for boom hoist sheaves	2.94500	(5,549.13)	3,925.19	-	
RFS 1		Back Stay for main	0.80000	(1,616.81)	3,161.73	-	
Fix HPT		Pendants for main boom	2.43100	479.94	31,654.20	-	
EZS HPT		Rope for boom hoist	0.31178	(8,140.53)	3,282.57	-	
Hubsl 1		Main hoist rope	0.67979	43,447.87	59,591.44	-	
NDL		Jib	16.32000	63,651.39	72,653.98	111.80	15.00
A-Bock 2		Lower part of A Frame	2.10000	5,727.29	59,586.98	-	
Fix1 NDL	*	Pendants for jib on main boom	1.60700	852.93	34,966.20	-	
Fix2 NDL	*	Pendants for jib	3.56050	64,128.74	77,548.50	-	
A Bock 3		Upper part of A Frame	2.30000	9,414.31	64,651.62	-	
RFS 2		Parts of A frame (end of boom)	0.20000	9,873.84	59,275.08	-	
RFS 3		Parts of A frame (end of boom)	0.14400	11,375.52	58,888.82	-	
EZS NDL		Jib rope	0.29511	4,669.81	64,326.87	-	
Total Mass		metric tonnes	305.67718				

Table 4 [ref 3]

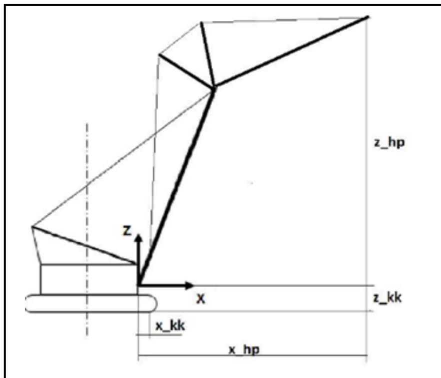


Figure 5 – [ref 3]

To aid in its review, CTS asked Liebherr to provide the wind areas for the main boom and luffing jib at various angles. Table 5 below provides this information.

Main Boom			Luffing Jib	
Angle	Wind Area		Angle	Wind Area
(°)	meters^2		(°)	meters^2
90	84.43		90	111.80
88	84.38		75	107.99
75	81.55		65	101.33
70	79.34		55	91.58
65	76.52		45	79.05
			35	64.13
			25	47.25
			15	28.94
			5	9.74

Table 5 – [ref 15]

The main boom and luffing jib will not operate at a 90° angle, however Liebherr included this value because this position generates the largest wind area.

3.3.3.5 Computer data review

The collapsed crane had a computer that captured various data points. The information contained was downloaded on February 6, 2016 in the presence of Department of Investigations (DOI). A copy of the print out was submitted to DOB by the manufacturer and owner. There were 43 pages that contain details from January 30, 2016 (16:10) to February 5, 2016 (9:30). Reviewing the data, it appears the crane's computer was one hour fast (crane was still in day light savings time).

Exhibit J contains data from the end of February 4, 2016 through the point the engine shut off on February 5, 2016.

The data is an Excel spreadsheet with 16 columns. Wind speed is not a data point captured by the computer. The data print out indicates the crane was started at 7:49 (actually 6:49), February 5, 2016, which coincides with the operator's recollection of when he arrived at the crane. Exhibit J includes the data from when the operator depressed the "assembly on" button until the crane was already or in the processing of collapsing.

According to the data, the operator switched to assembly mode at 9:14 (actually 8:14). It is at this point the Load Moment Limiter (LML) started to exceed 100% indicating that the crane was exceeding its capacity. At 9:19 (8:19), the computer data showed "lml utilization less than 110%, maximum utilization 182.0% at radius of 102.9 m." Liebherr provided the following explanation, "… *in assembly mode the load moment limiter (LML) does not act as a safety automatic stop; … along with a notice of the maximum utilization reached once it exceeds 110% until it was below 110%, along with the radius of the crane at the time of said notice*." In this case and based upon Liebherr's explanation, the crane reached a maximum LML utilization of 182% and the luffing tip was at a radius of 102.9 m (337.6').

During his interview, the operator mentioned that once he pressed the assembly mode button the rear of the crane started to come off the foundation. This is not supported by the facts because there are multiple entries in the computer that relates to the boom/jib exceeding the 110% LML limit and the crane going back under the 110% limit until 9:28 when an entry read "fall back support main boom limit switch is activated, angle main boom 69.4°".

When asked, Liebherr said that this message occurs when the operator moves the boom to an angle less than 70°. Liebherr cautioned that "the message does not indicate if crane is stable or falling at this moment". Further, CTS asked how the boom angle indicator input is derived and Liebherr said that the input is based upon gravity.

3.3.3.6 Cribbing Survey

The evening of the collapse True North Surveyors, Inc. surveyed the cribbing for levelness [ref 22]. The results are shown in Exhibit H. A review of the survey shows an approximate 1inch decline from the rear of the crane to the front (direction the crane fell). This translates to a 0.17° slope, and an approximate increase in radius of about 1.34 feet of the luffing jib without blocking (see Exhibit H for calculation). This was not a contributing factor in the collapse, and provides evidence that the water issue that occurred Thursday at 60 Hudson Street did not adversely affect the foundation.

3.3.3.7 Contract between BSCI and GTRI

BCSI rented the Liebherr LR1300 to GTRI on a "bare" rental basis for one (1) month starting on January 30, 2016. The agreement requires GTRI to employ the Operator and Oiler. Both said that they were employees and paid directly by GTRI.

3.4 Investigative Field Work

The field work completed to date is the initial assessment and measurements taken the night of the accident (February 5 2016), the photographs and measurements taken the day after the collapse (February 6, 2016), off-loading the crane components (March 3, 2016), taking field measurements with the structural engineer (April 28, 2016), removal and measurement of the boom and jib hoist ropes, and the analysis of the hydraulic fluid. Each will be covered in subsequent in section. Exhibit D contains a detailed report of the work performed and provides representative photographs of the work and measurements, and Exhibit E contains the protocols used for the testing phase.

3.4.1 Collapse Site - February 5, 2016

CTS arrived the shortly after 7:00 p.m. on February 5, 2016 and took photographs of the collapsed crane. The main task for the evening was to capture photographic evidence and start to determine the potential causes of the collapse.

3.4.2 Collapse Site - February 6, 2016

CTS arrived at site around 6:00 am to continue capturing photographic evidence and to witness the removal of the crane components from Worth Street.

3.4.3 Off-loading of crane components - March 3, 2016

CTS witnessed the off-loading of the crane components that were delivered to a secure NYPD facility in Brooklyn. BCSI performed the unloading procedures. CTS requested that BCSI weigh each component and provide a document with such weights. Table 6 is a summary of the data collected during this procedure.

	Manufacturer from BCSI (pounds)	**Weight from** Mobile Crane's Load Cell (pounds)	Variance (pounds)
Main Boom (2821)	54,620	49,100	5,520
Luffing Jib (2316)	53,760	45,600	8,160
Pendants	-	13,600	(13,600)
Basic Machine includes crawlers	196,710	192,800	3,910
Counterweights			
Car body counter weights	125,680	125,300	380
Upper counterweight and	274,700	284,200	(9,500)
Miscellaneous Components			
Ball and hook	1,900	1,900	-
Various small components	-	3,200	(3,200)
Bay Misc. box 1	-	7,500	(7,500)
Bay Misc. box 2	-	6,200	(6,200)
Subtotal for Misc. Components	1,900	18,800	(16,900)
Total crane	707,370	729,400	(22,030)

Table 6

CTS took various measurements of the boom and jib components, and took photographs of the components as placed in position by BCSI. In addition, all main boom and luffing jib sections were marked with a sharpie indicating the order each was installed on the crane. The boom sections started with a “B” with the heal being “B1” and the head section being “B6”. The luffing jib sections started with a “J” with the heel being J1 and the tip being J11. All numbers are on the aisle between the boom and jib sections.

3.4.4 Structural engineer field work – April 28, 2016

CTS met with the structural engineer (SGH) engaged to assist the investigation at the secure site so they could take additional measurements. The results are contained in their report (Exhibit C).

3.4.5.1 Visual inspection - September 27, 2016

CTS returned to the secure facility to take additional photographic evidence and finalize the measurements required to complete its investigation. The measurements obtained included the location of the boom pivot in relation to A frame strut 1 pivot, A frame Struts 2 and 3 fixed point and the jib heal section pivot point at the boom tip, and various pendant rod attachment points. These allowed CTS to be able to calculate the boom and jib angles based upon the amount of unspooled rope for each.

3.4.5.2 Destructive testing protocol – September 28, 2016

Removal of boom and luffing jib hoist ropes

The purpose of this work was to determine the boom and luffing jib angles at the time of the collapse.

CTS removed and measured the amount of unspooled boom hoist rope laying on top of the crane body. The rope was cut once during the crane's recovery and CTS took a photograph of the cut ends together. CTS had to cut the rope once to remove the rope from the crane. The total of the two sections was 577.8 feet.

The unspooled luffing jib rope was in two metal bins, and CTS determined the best means to ensure an accurate length of unspooled rope was to remove the rope from the winch rather than the two bins. To do this, CTS removed the brake components from the winch and then unspooled the rope from the drum. The total rope removed was 866.29 feet. However, there was a section of rope that was laying on top of the boom heal section and still attached to the rope on the drum. This section of rope measured 18.94 feet and must be subtracted from the total length to determine the amount of unspooled rope. This amount of rope on the winch must be subtracted from the nominal length of 1,263 feet (provided by Liebherr). Therefore, the unspooled rope amounted to 415.65 feet.

Removal of the luffing jib brake components

CTS removed the luffing jib brake components for two reasons. The first being that it was necessary to remove the rope from the winch and the second to check the components for abnormal wear and determine if there was a mechanical failure.

CTS inspected the braking components of the luffing jib and found no evidence of a mechanical failure. The boom hoist braking was left untouched. The reason was that the crane body and all the counterweights of the crane were overturned. If there would have been an issue with the braking system, then the crane body would not have flipped over and only the boom and jib would have fallen.

Hydraulic fluid analysis

There were six samples of hydraulic fluid taken to determine the fitness for service of the fluid. CTS used two of the six samples and the remaining four are available for further testing.

Hydraulic fluid samples were not available using the manufacturer's recommend procedure / location due to the crane being upside down for almost 40 hours and various hydraulic lines had to be opened to recover the crane. There was not enough fluid in the hydraulic tank. There were two samples from approximately 2 feet from the side of the oil filter assembly, one from the top of the baffles in the oil filter assembly, one from a hydraulic line going in the direction of the tank, and two from a hydraulic line from the oil cooler. CTS sent a sample from the hydraulic filter and one from the oil cooler line for analysis.

The lab results show the oil was in good condition (see Exhibit K), and the laboratory said that the oil appeared to be in good condition and this is in line with CTS thoughts as well.

3.4.6 Interviews and Videos

CTS interviewed several individuals during the course of the investigation. Some of these were in a formal setting (in conjunction with Department of Investigations) and others were informal. Exhibit A provides key information obtained from the interview process.

CTS reviewed three videos from different vantage points and a summary of the findings is in Exhibit D.

4.0 Applicable Laws and Regulations

4.1 NYC Building Code Requirements for Cranes

The applicable code requirements for the accident relate to crane approval, crane site plan, crane operation, inspection, and licensing requirements. Crane approval was covered in Section 3.2.2.

Certification of on-site inspection

The Building Code Section 3319.6 requires the equipment user to obtain a certificate of on-site inspection for the *"use of any crane or derrick used for construction to demolition purposes at each job site*". Section g.7 of 1 RCNY §3319-01 requires a permit from the department of transportation and the pressure on the surface shall not exceed 3,500 pounds per square foot. This section goes further to require timber platforms extending not less than 12 inches beyond the base of the outriggers or crawlers on all sides with enough depth to uniformly distribute the load (introduced by the crane).

Further, DOB requires any crane set up on the sidewalk or roadway with a boom and jib combination greater than 250 feet to submit an application for a Certificate of On-Site Inspection for DOB approval, and a DOB inspector must inspect and ensure the crane is configured as provided in the drawings and the crane's safety devices were working properly prior to the crane going into operation.

Crane Operation

Section 1 RCNY §3319-01.p includes the requirements for all Hoisting Machine Operators (HMO). The applicable line items are as follows:

- p.2.iii – makes the operator responsible for the operation of the crane.

- p.2.vi – requires "*ground chocks shall be set and crane booms shall be lowered to ground level or otherwise fastened securely against displace by wind loads*". This requirement is also in line with the manufacturer's requirements.
- P.2.x – Requires the operator to familiarize himself with the equipment. The manual in the cab provided the position the crane should be in overnight, and when winds were expected to exceed maximum as noted by the manufacturer. Both required the operator to place the boom and luffing jib on the ground.

Rigging Statutes

According to the drawings, the project did not have a critical pick pursuant to 1 RCNY 104-20 and Chapter 33 of NYC 2014 Building Code. If there were critical picks, the statute requires the licensed Master Rigger to supervise such lifts. Since there were none, the licensed rigger could assign a rigging foreman to oversee all lifts.

The heaviest pick was 24,000 pounds (generators) at a radius of 110 feet; using the configuration of 194 feet main boom and 322 feet luffing jib. The crane had an allowable lifting capacity of 31,300 pounds in this configuration. The heavy picks for the 194 feet main boom and 371 feet luffing jib were 8,000 pounds at a radius of 128 feet, and the load chart showed an allowable lifting capacity of 18,800 pounds.

Inspections (CN and CD)

The building code requires an inspection of all cranes that have boom/jib combinations exceeding 250 feet. In the case of the collapsed crane, the total configuration was 565 feet, thereby requiring such inspection. During this project, there were two DOB onsite inspections. The first one was performed on January 31, 2016, this inspection included a review of the magnetic particle inspection report issued by Certified Testing & Inspections Inc. (CTI). CTI noted all boom and luffing jib sections were acceptable. The DOB inspector marked all applicable items satisfactory on the DOB inspection sheet and the crane was allowed to work.

The second inspection took place in the early morning hours of Thursday, February 4, 2016. However, when the inspector arrived the re-configuration crew had already started with the disassembly. The DOB inspector issued a violation to the master rigger for working without a permit. There was a start date on the permit and by starting early they were working without one. After the re-configuration was complete, the DOB inspector inspected the crane and found it to be compliant with the drawings, and marked all items satisfactory on the checklist. The operator raised the boom with the assistance of BCSI, rotated the crane to the west, and awaited lifting instructions.

4.2 Licensure Requirements

Hoisting Machine Operator

1 RCNY §3319-01.p.1.i.A requires that cranes and derricks be operated only by persons licensed as an operator by the Department of Buildings in accordance with Section 28-405 of the Administrative Code of the City of New York.

Further, Section 28-405 divides crane licensure into three classifications (A, B, and C). In order to operate a crane with a boom/jib configuration longer than 200 feet, the statute requires a B license.

The configuration of the collapsed crane required a B license and Mr. Kevin Reilly has an active and valid “B” license (number 9386B).

The operator also had the certificates from National Commission for the Certification of Crane Operators (NCCCO) as required by the Code (1 RCNY §104-09).

Master Rigger

Section §28-404.1 of the Administrative Code requires a licensed rigger to supervise hoisting or lowering any article on the outside of any building unless such work is performed by or under the direct and continuing supervision of the licensed rigger. Further, §104-2 does not require the licensee to be personally on site during rigging operations provided that “*a rigging foreman designated by the licensee pursuant to subdivision is continuously on site and that such rigging foreman performs and/or manages the work under the offsite supervision of the licensee as holder”*.

Since there were no critical picks, Mr. Greg Galasso (Master Rigger license number 199) assigned Mr. Graham Brent as the Rigging Foreman for the project. According to both men in their interviews, they maintained in contact throughout the project which is also required by Code.

4.3 Other regulations (OSHA violations)

OSHA

The United States Department of Labor and more specifically the Occupational Safety and Health Administration (Directorate of Construction) (OSHA) investigated the collapse and issued citations to Galasso Trucking and Rigging, Inc. (GTRI). OSHA found that the crane was not stowed/parked overnight on the evening of February 4, 2016 as per the instructions of the engineer (MRA Engineering) and manufacturer. OSHA issued two citations to GTRI. One citation for not stowing the crane properly prior to the wind/weather event and the second for the employer not following manufacturers procedures by lowering the boom to 69.4°. OSHA noted that a main boom angle lower than the 75° was the angle no operation should occur.

International Standards Organization

The International Organization for Standardization (ISO) is an international standard-setting body composed of representatives from various national standards organizations. The organization promotes worldwide proprietary, industrial, and commercial standards. The standards become law when a jurisdiction includes such in their regulations. The organization has published three applicable standards related to crane stability. Liebherr used them when generating the stability calculation that it provided to DOB after the collapse. They were mentioned in Section 3.3.3.4, and SGH reviewed the report and determined that Liebherr’s calculations (based upon the inputs provided) were correct and the hence the crane’s design complied with these standards.

5.0 Conclusions/causation discussion

The following sections address the various causes.

5.1 Analysis of weather report

It is difficult to estimate the wind at the site due to the topography around the crane. AWF used a process whereby it took the wind from the locations mentioned in Section 3.3.3.2, adjusted it for a specific height (in this case 540 feet) using a roughness table for open areas. AWF then used the roughness table for an urban area to adjust the calculated wind to various heights. The results of this analysis is represented in Table 7. CTS estimates the luffing jib tip was at approximately 472 feet above grade at the time of the collapse using the calculated main boom angle of approximately 72° and a luffing jib angle of approximately 49° (includes elongation of the pendant bars and rope).

Height above street level (feet)	Estimated sustained wind speed between 8:00 and 8:30 a.m. on 2/5/16 (mph)	Estimated peak wind speed (gusts) between 8:00 and 8:30 a.m. on 2/5/16 (mph)
33	12	18
100	19	28
200	23	35
380	27	41
450	28	43
560	30	45

Table 7 – [ref 2]

According to AWF [ref 2], the wind speeds in Table 7 are what would be expected in the free air away from the immediate vicinity of any tall buildings that would block/channel air flow from the north/northeast. The actual air flow in the vicinity of Worth Street between Hudson and Church Streets would become increasingly complex at the lower elevations due to the impact of tall buildings.

The prevailing wind direction was not directly from behind the crane, but rather from an angle between perpendicular and behind the crane. The photograph is Section 3.3.2 shows the prevailing wind (north) as it relates to the crane's location on Worth street. A 10.7 mph from the prevailing wind direction would equate to a 4 mph wind directly from behind the crane.

AccuWeather Forensics (AWF) report [ref 2] provides insight to the forecasted weather from February 4, 2016 and predicted values of wind the morning of the collapse. Various National Weather Service forecasts for Manhattan for Friday, February 5, 2016 are provided below.

AWF also commented on video graphic evidence (Exhibit D) that shows wind channeled down Worth Street (Northwest to Southeast – blowing from behind the crane) including traffic lights swaying, hanging overhead signs blow nearly horizontal, a pole shaking, traffic sign wobbling and an umbrella turned inside out. According to AWF, these indications are consistent with localized, enhanced wind speeds as high as 45 mph or greater.

The wind around the crane at the time of the collapse is very complex to estimate. The AWF report mentions that West Broadway and Varick Street are roughly aligned parallel to the prevailing wind and "there would have been some channeling of the wind down these street resulting in speeds that were generally at least 10 to 20 percent higher than shown in the Table 7 and likely more than 50 percent higher in some locations. Meanwhile, with Worth Street being aligned from the northwest to the southeast, there likely would have been some intermittent and especially turbulent and gusty wind flow in this direction. The 380 feet tall building (60 Hudson Street) to the south of the crane acted as a significant obstacle to the prevailing wind flow and contributed significantly to the channeling of the air flow parallel to Worth Street near the ground. Above 100 feet or so the wind direction would gradually become more aligned with the prevailing wind direction over Manhattan. This direction places the wind to the side and slightly behind the boom and jib.

An additional factor in the wind flow along Worth Street would be the impact of downwash, or downward flowing air. This downwash would force air blowing at higher speeds aloft down to street level, adding to the turbulence and speed or the air being channeled between the buildings near street level.

Ultimately, a wind tunnel or wind modeling study would provide a more accurate wind profile at the time of the collapse. CTS did not pursue one due to the operator's action lowering the boom to its stability limit so such a study would not enhance the conclusions mentioned herein.

Forecast for February 5, 2016 [ref 2]

AccuWeather Forensics provided various forecasts from the National Weather Service for Manhattan issued on February 4, 2016 and the morning of February 5, 2016. These are as follows:

12:27 a.m., February 4, 2016

Friday … cloudy in the morning … then clearing. Breezy with highs in the lower 40s. North winds 15 to 20 mph.

4:09 p.m., February 4, 2016

Winter advisory in effect from 1 am to 10 am Friday …
Friday … cloudy with snow in the morning … then mostly sunny in the afternoon. Total snow accumulation of 2 to 4 inches. Breezy with highs around 40. Northwest winds 15 to 20 mph with gust up to 30 mph. Chance of snow 90 percent.

8:56 p.m., February 4, 2016

Winter advisory in effect from midnight tonight to noon Friday …
Friday … becoming partly sunny in the afternoon. Snow. Total snow accumulations of 2 to4 inches. Windy and cooler with highs in the upper 30s. Northwest winds 15 to 25 mph with gust up to 35 mph. Chance of snow near 100 percent.

12:47 a.m., February 5, 2016

Winter advisory in effect until noon today …
Friday … snow in the morning … then partly sunny with a chance of snow in the afternoon. Total snow accumulation of 2 to 4 inches. Windy and cooler with highs in the upper 30s. Northwest winds 15 to 25 mph with gusts up to 35 mph. Chance of snow near 100 percent.

3:41 a.m., February 5, 2016

Winter advisory in effect until noon today …
Today … snow this morning … then mostly sunny with a slight chance of snow this afternoon. Total snow accumulation of 2 to 4 inches. Windy and cooler with highs in the upper 30s. Northwest winds 15 to 25 mph with gusts up to 35 mph. Chance of snow near 100 percent.

6:35 a.m., February 5, 2016

Winter advisory in effect from until noon today …

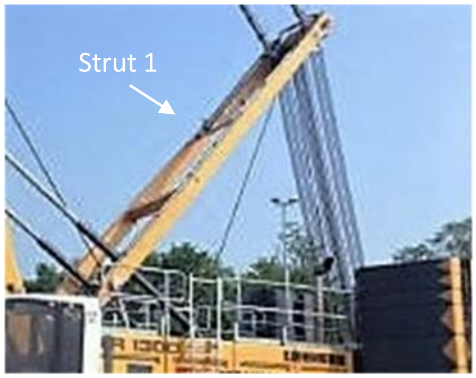
Today … widespread snow this morning … then mostly sunny with a slight chance of snow this afternoon. Total snow accumulation of 2 to 4 inches. Breezy with highs in the upper 30s. North winds 15 to 20 mph with gusts up to 30 mph. Chance of snow near 100 percent.

The rigging foreman mentioned in his interview that the site was aware of the impending storm and said "the wind's going to be horrible". When asked if he checked the weather forecast he said he did and they were expecting "gusting winds 30 plus [mph] and all that other stuff".

5.2 Stability analysis

Boom and luffing jib angles

CTS removed and measured the unspooled boom and luffing jib hoist ropes. The primary reason was to calculate the boom and luffing jib angles. The unspooled rope is the primary variable required to calculate the angles. Ideally, CTS would use a manufacturer's shop drawing, but most manufacturers do not issue such drawing due to intellectual property rights. However, using measurements taken from the field and those contained in the operator's manual, CTS reconstructed the crane's geometry, and generated Figure 7 to assist with this task. When field values were similar to those produced by Liebherr, CTS used the Liebherr values.



Photograph 9

The unspooled boom hoist rope consists of where the rope leaves the winch, travels to the sheave assembly on A-frame strut 1 (moves with boom angle), and goes to the fixed sheave assembly on the car body. The reeving consists of 13 sheaves on strut 1 and 12 on the fixed assembly, and the fixed end is on the car body (see Photograph 9).

The unspooled luffing jib hoist rope has a fixed and a variable component. The fixed portion goes from the winch on top of the boom heal section to a sheave on the boom tip, to a fixed sheave on the lower portion of A-frame strut 2, and then goes up A-frame strut 2 to the sheave assembly on strut 2. The variable portion of the rope travels between the sheave assemblies on strut 2 and to the movable strut 3 (see Figure 6).

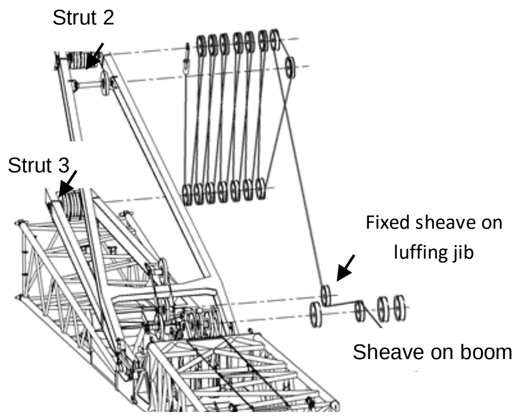


Figure 6 [ref 6]

In addition to the unspooled rope, CTS calculated the estimated elongation of the pendant bars (suspension system) for the boom and luffing jib, and boom and luffing ropes (see Exhibit I for detailed calculations). This resulted in lowering the boom angle by approximately 1° and the luffing jib angle by approximately 2°.

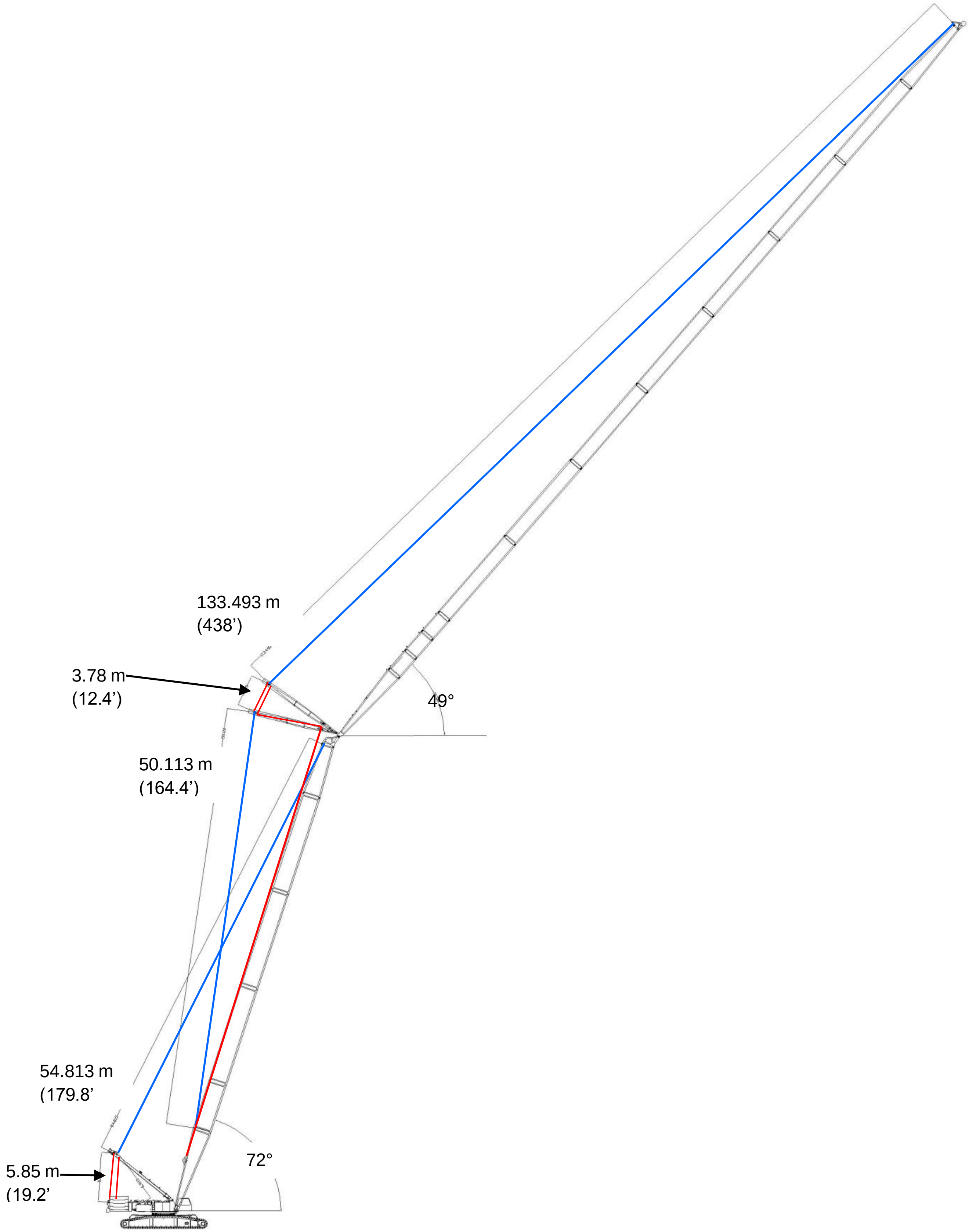


Figure 7 – Boom and jib angles (includes elongation of pendants and rope)

Denotes pendant bars (suspension)
Denotes boom and luffing jib ropes

The calculated boom degree (including elongation mentioned above) at the time where the operator stopped the boom hoist winch was 72° and the luffing jib was 49°. Based upon the limiting wind calculation provided by SGH (Figure 3), the crane would collapse with a wind speed of 4 mph. AWF's wind projections were significantly higher. Therefore, the operator placed the crane in an unstable condition by lowering the boom too far.

Below is a sensitivity analysis (Table 8) using various angles and the calculated unspooled rope for the boom and luffing jib (shaded rows). Comparing an estimated unspooled rope at the angle the operator mentioned (80°) versus the measured length, the measured amount would need to be 26.2 m (86 feet) longer. The operator believed he was between 47° and 45° on the luffing jib which corresponds with the calculated angle.

Boom Hoist						**Luffing jib hoist**				
	Unspooled		Difference				Unspooled		Difference	
Angle	Rope		from measured			Angle	Rope		from measured	
(°)	(m)	(ft)	(m)	(ft)		(°)	(m)	(ft)	(m)	(ft)
80.000	149.9	491.8	26.20	85.96		52.000	119.4	391.6	(7.3)	(24.0)
78.000	156.4	513.2	19.68	64.57		50.000	124.2	407.4	(2.5)	(8.2)
76.000	163.0	534.7	13.13	43.09		48.760	126.9	416.2	0.2	0.6
74.000	169.5	556.2	6.58	21.59		46.000	133.8	438.9	7.1	23.2
72.000	176.1	577.6	0.05	0.17		45.000	136.1	446.7	9.5	31.0
71.940	176.2	578.2	(0.13)	(0.42)		44.000	138.5	454.5	11.8	38.9
70.000	182.6	599.1	(6.48)	(21.26)						
69.400	184.5	605.5	(8.43)	(27.66)						
68.000	189.1	620.3	(12.97)	(42.54)						

Shaded rows represent calculated angles at time of collapse with elongation of pendants and rope

Table 8

As mentioned in Section 3.3.3.5, the computer data indicated a boom angle of 69.4°. The difference between the computer and calculated could be due to the operator reversing direction of the joystick and starting to hoist up. He mentioned this in his statement. This would result in spooling up a portion of the rope previously unspooled.

Structural Stability

SGH created a stability model that determines the limiting wind speed based upon various input parameters. CTS also created such a model and both achieved similar results.

SGH considered the limiting wind speed to be constant and uniform over the height of the crane following the procedure outlined in ISO 4302 §4. Based upon the complexity of the wind in and around the crane at the time of collapse and AWF estimates, the team decided to follow the ISO standard.

SGH performed sensitivity analyses on key input parameters (boom and jib angles, mass/inertial forces, wind area, and tipping line) and their respective impact(s) to the limiting wind speed. Wind can cause overturning from any direction, but since the crane collapsed over the front, SGH and CTS used wing blowing from behind the crane. Also, the prevailing wind at heights was blowing at approximately 65° angle to the crane and slightly from the rear.

The crane is sensitive to the boom and luffing jib angles, and especially as the crane nears its stability limit. For instance, the crane could withstand a 52 mph wind (from the rear and over its entire length) with a boom angle of 80° and a luffing jib angle of 45°. If one uses a 73° boom angle and a 51° luffing angle (CTS calculated angles without elongation), then the crane could withstand a wind speed of 26 mph. However, if you include elongation of the pendant bars and rope, the angles decrease by approximately 1° for the boom (72°) and approximately 2° for the jib then a the limiting wind speed is only 4 mph. Conversely, had the operator left the boom at 85° and the luffing jib at 75° facing with the wind then the limiting wind speed would have been 76 mph. The operator may have been better to have left the boom in the latter configuration instead of lowering the boom, but a wind tunnel study would be necessary to ensure the wind was below this figure. See Figure 8 for more angles and limiting wind speeds.

Jib Angle	Boom Angle, deg.												
deg.	60.0	62.5	65.0	67.5	70.0	73.0	75.0	77.5	80.0	82.5	85.0	87.5	90.0
-36													
-33											79	92	104
-30									29	57	75	90	102
-27									13	52	72	87	101
-24										46	69	85	99
-21										40	66	84	99
-18										33	63	82	98
-15										26	60	81	98
-12										17	58	80	98
-9											57	80	98
-6											55	80	98
-3											55	80	99
0											55	80	99
3											56	80	99
6											57	81	99
9										15	58	81	98
12										24	60	81	97
15										31	61	81	96
18										37	63	80	95
21										42	64	80	93
24									5	46	65	79	92
27									24	50	66	79	90
30									32	52	67	78	88
33									38	55	67	78	87
36								21	43	57	68	77	86
39								30	46	58	68	77	84
42							12	36	49	60	69	76	83
45							25	41	52	61	69	76	83
48						16	32	44	54	62	69	76	82
51						26	37	48	56	63	70	76	82
54					8	33	41	50	58	64	70	76	81
57					22	38	45	53	59	65	71	76	81
60				12	30	42	48	55	61	67	72	77	81
63				24	35	45	51	57	63	68	72	77	81
66			17	30	40	48	53	59	64	69	73	78	82
69			26	36	43	51	56	61	66	70	74	78	82
72			32	40	47	54	58	63	67	71	75	79	83
75			37	44	50	56	60	65	69	73	76	80	84

Crane is unstable

Figure 8 – [ref 1]

SGH evaluated the sensitivity of the limiting wind speed for variability to the weight of the boom and jib and the results are shown in Figure 9. Different factors could contribute to an actual weight being higher than the values in the GBP calculation, such as: manufacturing tolerance standards, Rigging or other accessories that were not included in the input data but present on the crane, and/or Ice, water, and snow accumulation on the lattice structures. Witnesses mentioned that they saw snow accumulation but could not estimate its magnitude. Lattice structures are relatively light weight and the surface areas are sensitive to thin films and coatings.

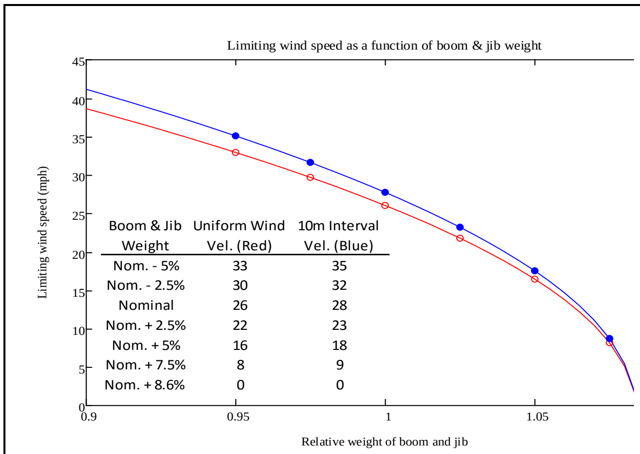


Figure 9 [ref 1]

Another factor that may be considered is the inertial (dynamic) impact and is accounted for in the ISO 4305 Table 1 (Ref 6) limit state by including an additional load at the hoist point that produces an overturning moment equivalent to a 10% increase in the weight of the boom and the jib.

SGH evaluated the sensitivity of the crane to the wind area used and determined that a 10% increase or decrease resulted in a roughly linear variation in limiting wind speed of approximately 5% [ref 1].

As mentioned above, the operator did not “block” the crane properly and thereby changed the tipping line. SGH analyzed the sensitivity of moving the line and the results were that by changing the tipping line 3 inches with respect to the boom pivot point, the limiting wind speed would change by approximately 15% (see Figure 10). As mentioned above, all wind speeds analyzed assumed the wind from the rear and constant over the length of the entire boom and luffing jib. However, SGH reviewed the nominal case and a boom angle of 73 and a luffing jib of 51 using a stratified wind (at 10 m intervals using AWF projected wind speeds and produced the following (Table 9).

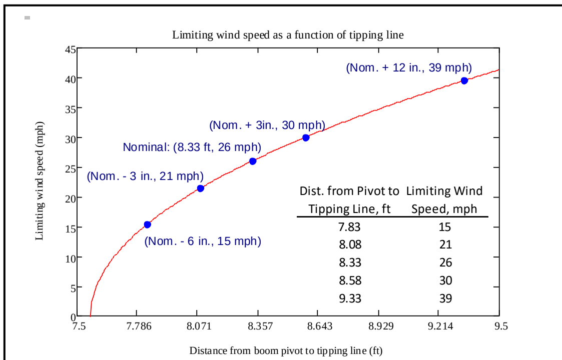


Figure 10 [ref 1]

	Limiting Wind Speed (mph)	
Condition	Uniform	10 m Intervals
Nominal Case	26	28
Nominal plus 5% weight allowance	16	18
Nominal plus 10% dynamic/inertial force allowance	Unstable	Unstable

Table 9 [ref 1]

Conclusions for stability analysis

Based upon the investigation and the sensitivity analyses provided above, CTS and SGH conclude the following related to the effect wind may have had on the collapsed crane.

The stability calculation submitted by Liebherr and using the values therein for component weight, Center of Gravities, wind area, and the in-service wind speed specified in the crane operator's manual (15.66 mph), we find that the crane with the boom at 80° and the jib at 15°, with no suspended load apart from the headache ball, provides the margin against overturning that is required by the ISO 4305 and EN 13000 codes during erection and dismantling.

Using the nominal crane configuration (194 feet main boom and 371 feet luffing jib), the component weights and Center of Gravities from MRA's ground bearing pressure calculation, wind areas from Liebherr's stability calculation, and the boom at 72° and the jib at 49°, the subject crane would likely overturn in a 4 mph wind blowing from behind the crane and along the complete height of the boom and jib without the other contributory factors.

The stability of the crane is sensitive to changes in input parameters, and the limiting wind speed is a function of the small difference between the large self-weight overturning and stabilizing moments. This is particularly true near the stability limit of the crane, where the self-weight overturning and stabilizing moments approach each other.

5.3 Installation analysis

CTS reviewed the configuration of the crane as it was collapsed on Worth Street and the main boom and luffing jib sections coincided with the installation drawings provided to DOB during the Certificate of On-Site Inspection process. CTS did not take exact measurements of the foundation but found no abnormalities in the foundation and this was proved by the survey performed the evening of the collapse (Section 3.3.3.6). The conclusion is the foundation did not contribute to the collapse.

5.4 Analysis of actions/inactions taken by the operator

5.4.1 Weather Forecast for Friday, February 5, 2016

As mentioned in Section 6.1, the National Weather Service consistently forecasted wind gusts exceeding 25 mph from the early afternoon through the time of the collapse, and there was a job site meeting to discuss the incoming storm and the operator attended. During the meeting, gusts of 30 mph plus were mentioned, and the plan was to get all the necessary lifts completed Thursday because the crane was not planned to work Friday.

5.4.2 Failure to stow the crane per manufacturer's recommendation

The operator's manual covered the requirements the operator should follow in case of wind related events and leaving the machine overnight unattended. The manual defines a long term interruption as "*overnight, one or more days*". The manual continues by requiring the operator that when he shuts down and plans to leave the machine overnight, "*the machine's boom (main, fly jib, etc.) must be completely placed on the ground*".

The operator's manual also has a section related to restrictions due to wind (5.7 page 308). The manufacturer says "*the parked position can be used up to the maximum wind speed, above this* *the boom must be laid down*". For the configuration of 194 feet main boom and 371 feet luffing jib, and the "Parked Position" is provided on Tab. 91 in the manual (Table 10).

Description	Value
Maximum wind speed	0 m/s 0 mph
Main boom length	From 20 m (65') to 74 m
Main boom angle	Lay down the boom
Fly jib length	From 89 m (292') to 113 m
Jib Angle	Lay down the boom

Table 10 [ref 5]

The operator must know the operational (in-service) wind speed and this information can be found on Table 1. According to the manual (load chart), the maximum operating wind speed for this crane's configuration is 7 m/s (15.65 mph). The forecasted wind was in excess of 30 mph so the operator should have laid the boom on the ground as directed by the manufacturer.

The failure to follow these instructions led to the crane's collapse the following day.

5.4.3 Boom and jib position

The operator said that the when he put the crane in assembly mode that the functions of the joysticks change. Prior to the switch the main boom and luffing jib hoisting is controlled by the right joystick and the operator must depress a button to move between them (cannot move the boom and luffing jib at the same time). The manual in the crane showed a "T" joy stick for the right lever, but the operator said (confirmed by field photographs) that it was single joystick. The serialize manual shows the installed configuration (two single joy sticks).

After the assembly mode button is depressed the boom and jib controls separate and one joystick controls the boom and one controls the luffing jib. However, the manufacturer does not recommend moving both at the same time.

Reviewing the computer data shows that there was approximately 14 minutes from when the operator switched to assembly mode and the eventual collapse. It is possible that the operator believed that he was lowering the luffing jib but in reality he was lowering the main boom.

According to the field measurement data (unspooled rope and field measurements), the operator lowered the boom to 72° and the luffing jib to 49°. These angles represent the crane at its stability limit requiring a mere 4 mph from the back to cause the collapse. Adjusting the prevailing wind to compensate for its angle to the boom results in a prevailing wind speed of 10.7 mph.

5.4.4 Jack-Knife versus laying the crane down

During his interview, the operator outlined the procedure he used to jack knife the crane February 3rd. He said that he raised the main boom to between 85° and 88°, then lowered the luffing jib until the crane's computer (LMI) told him he was at 90% of its capacity, then lowered the ball to the ground, pressed the assembly mode button (on a panel behind him), and continued lowering the luffing jib until the wheels attached to the jib tip touched the ground.

On the day of the accident, the operator said that he had the main boom at 80° when he started to lower the luffing jib versus the 85° to 88° he used on Wednesday. By doing this, the overturning moment of the crane changed.

When the operator jack-knifed the crane Wednesday morning the procedure he selected was not in accordance with drawing SP-1 of 1 (CN 1157/15) that required the "crane to be stowed (jack-knifed) in severe weather condition as per manufacturers recommended procedure" for two reasons. The approved drawing showed the jack-knifed position toward Hudson Street (180° from the one selected by operator), and the manufacturer required the boom and luffing jib to be laid down on the ground - not jack-knifed. The wording is clear that the crane should be stowed per manufacturer's recommended procedures and the operator should have checked the manual.

5.5 Lowering Procedures used

During his interview, the operator outlined the procedure he used to raise the boom. He mentioned that the "…manual does not want the crane to have a main boom angle higher than 70°" (Figure 2), but he "found out that you needed to luff up a little bit higher [on the main boom] than that". He said that he boomed up to about 76° and then the crane would start lifting the luffing jib. He raised the luffing jib to 10° less than the main boom (in this case 66°). Then he alternated raising the main boom and the luffing jib until he was at 80° with the main boom and 67° to 70° on the luffing jib. He said you could move both the main boom and luffing jib at the same time in assembly mode but Liebherr says you should not. This outlined procedure is not in the manual.

On the day of the accident, the operator boomed down (main boom) to an angle of approximately 72° and a luffing 49° causing the crane to be at its stability limits. When reviewing the computer data, the crane's radius at the time the operator pressed the assembly button was 100.4 m (329'). Using the model CTS developed, this could equate to a main boom angle of 72° and a luffing jib angle of 49°, and the crane is unstable at this point with minimal wind.

5.6. Improperly blocked tracks (crawlers)

The operator incorrectly "blocked" the tracks by using three sheets of ¾ inch plywood (2.25 inches) when the manual (BCSI provided) required precise placement of 25 mm (approximately 1inch) steel plates under the front cleat of the tracks (see Figure 11). When asked about using plywood, the operator responded that he was taught this procedure from other operators. He also said it was in the manual, but this topic was not addressed in the one in the operator's cab.

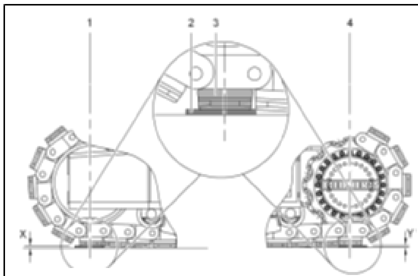


Figure 11 [ref 6]

The manual in the cab did not address blocking the tracks so the operator should not have done this procedure. However, the manual provided by BCSI and Liebherr had a section regarding "blocked" crawlers (section 4.26)". The manual noted that blocked crawlers extends the tipping line, increases the lifting capacity, limits the swing range of the upper carriage (no lifting over the side), prohibits movement of the machine, and can lead to higher ground pressure. Figure 11 shows the correct positioning of the required plates. The thickness for the LR 1300 is 25 mm for the idler (x) and 17 mm for the tumbler (y). For the collapsed crane, proper blocking procedure would have been to use 25 mm steel plates.

The manufacturer issues a caution that inappropriate driving onto the support plates may cause the machine to topple over. In addition, the instructions require that the left and right base plates of the crawler side frames be positioned exactly the same so they both drive onto the support plates at the same time.

The investigation team measured the height of 3.5 inches above the (Photograph 10) Northside crawler pad. The plywood on the Southside pad was farther up the cribbing toward West Broadway, which indicates the Northside Crawler was not supported for approximately two feet . Instead of a straight line the tipping line is a diagonal.

Photograph 10

SGH evaluated the sensitivity of moving the tipping line due to the crane being improperly "blocked". Moving the tipping line three inches results in a decreased limiting wind speed by two mph and a twelve-inch movement an eight mph decrease in limiting wind speed.

CTS concludes that the crane was improperly blocked using 2.25 inches of wood instead of 1 inch of steel and the photographic evidence indicates the operator drove too far onto the plywood on the Northside pontoon.

Incorrect blocking is a contributory cause.

5.7 Analysis of operator's actions based on New York City Building Code

The code covers the requirements of all Hoisting Machine Operations. Below are specific instances that the operator violated code and the reason.

- **NYC BC 3301.1.3** requires that all equipment shall be used in accordance with the specifications of the manufacturer. The operator did not follow the specific instructions contained in the manual for stowing the crane overnight or when wind speeds were expected to exceed the manufacturer's parked position speed.
- **1 RCNY 3319-01(p)(2)(x)** requires operator to familiarize himself with the equipment. The operator lowered the boom to an angle lower than 72° and thereby making the crane unstable and then it collapsed. The operator experienced difficulty raising the boom Wednesday when he said that he needed to be at 76° to start raising the luffing jib.
- **1 RCNY 3319-01(p)(2)(x)** requires operator to familiarize himself with the equipment. The operator's manual in the cab clearly requires the operator to lay the boom down when leaving the machine for a long work interruption that the manufacturer defines as overnight or one or more days.
- **1 RCNY 3319-01(p)(2)(x)** requires the operator to familiarize himself with the equipment. The operator's manual in the cab clearly says that the crane must be in the "parked" position when the allowable speed is exceeded or forecasted to be exceeded. For the configuration of 194 feet main boom and 371 feet luffing jib, the "parked" position is to lay the boom down. The operator clearly did not follow the manufacturer's requirements.
- **1 RCNY 3319-01(p)(2)(x)** requires the operator to familiarize himself with the equipment. He did not fully understand the manual where Table 3.2.1 shows the wind speed the crane can work and the required load chart reductions for the various wind speeds. The last column applies to the collapsed crane. For this configuration, operation is prohibited above 7 m/s (15.66 mph) and the boom should have been laid down.

- **1 RCNY 3319-01(p)(2)(vi)** requires the operator to lower the boom to the ground or secure it against displacement by wind loads or other external forces. The operator did not lower the boom or secure it against displacement.
- **1 RCNY 3319-01(p)(2)(iii)** requires the operator shall be responsible for the operation of the crane. The computer based load chart would not allow the crane to pick the two heaviest loads so the operator switched the computer to simulate the crane operating in two-part line while being in single part.
- **BC3319.6.3** requires the certificate of on-site inspection is valid only if the conditions and statements contained in the approved applications are complied with and the crane is operated in conformance with the provisions. On Wednesday, the operator elected to jack-knife the crane toward West Broadway which is 180° from the direction called for in the drawings provided by the professional engineer (MRA Engineering).
- **1 RCNY 3319-01(p)(2)(iii)** requires operator to familiarize himself with the equipment. He did not use the proper technique to block the tracks. The manual in the cab did not contain this procedure so he should not have "blocked" the tracks. Further, the serialized manual requires the use of steel plate with a thickness of 25 mm with precise placement and he used 3 sheets of ¾ inch plywood (2.25 inches).
- **1 RCNY 3319-01(p)(2)(iii)** requires the operator shall be responsible for the operation of the crane. He witnessed snow on the boom but failed to consider when lowering the boom.
- **BC3319.6.3** requires the certificate of on-site inspection is valid only if the conditions and statements contained in the approved applications are complied with and the crane is operated in conformance with the provisions. The engineer included a drawing that required the operator to stow the crane (jack-knife) in severe weather conditions as per manufacturer recommended procedures. There was a site meeting Thursday afternoon confirmed by two other site personnel that discussed the approaching storm. One of these persons said the gusts of 30 miles per hour were expected.

6.0 Summation

To calculate the boom and luffing jib angles at the time of the collapse, CTS used the length of the unspooled rope, the component weights and CGs from MRA's ground bearing pressure calculation, and wind areas from Liebherr's stability calculation. The results were that the boom was at 73° and the jib at 51°, and the crane would likely overturn in a 26 mph wind blowing from behind the crane, taking wind speed as uniform over the height of the crane. The boom and luffing jib angles change to 72° and 49°, respectively, when calculating the effects of elongation of suspension pendant bars and the boom and luffing jib ropes. In this position, the crane would likely overturn in a 4 mph wind blowing from behind the crane, taking wind speed as uniform over the height of the crane at these angles.

The evidence proves that the operator caused the collapse by not following the manufacturer's recommendation that the boom be lowered to the ground prior to the wind exceeding 15.66 mph, not responding appropriately to a wind event, and lowering the main boom to our calculated 72° and the luffing jib to our calculated 49° angle prior to the collapse**.**

Further, CTS reviewed the reports and documents mentioned above and concludes that the operator’s failure to lower the boom and luffing jib to the ground the night before the collapse (February 4) is the primary cause of the collapse. This error was compounded by the operator lowering the boom to 72° and the luffing jib to 49° angle placed the crane at its stability limit. These compounded errors ultimately led the crane to collapse.

CTS holds this opinion to a reasonable degree of certainty, based upon the information reviewed and available to it at the time of writing. CTS reserves the right to review and possibly modify its findings should new information become available.

List of photographs, figures, and tables

Photograph by number

Figures by number

Tables by number

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Exhibit A – Interview Summaries
60 Hudson Street Crane Collapse Investigation
February 5, 2016

Table of Contents

A.1 Operator – Kevin Reilly – License Number 9386B

Department of Building interviewed Mr. Reilly on May 16, 2016 at DOI's offices at 83 Maiden Lane, New York, NY. The personnel present were: James McElligott – DOI, Patricia Pena - DOB, Frank Hegan – CTS as contractor to DOB, Mitchel Konca – OSHA, David Button – OSHA, and Stacey Richman – Counsel to Mr. Reilly.

The interview started at 6:25 p.m. and was recorded by DOI with the knowledge and acceptance of Mr. Reilly. During the interview, Mr. Reilly provided the following information.

- His training on the Liebherr LR1300 has been from other B operators who have worked this type of crane. Mr. Reilly said he has hundreds of hours operating a Liebherr LR 1300. He has not received training from the manufacturer other than what is in the operator's manual. The majority of this operating time is with a main boom and a luffing jib. He had one project with a similar configuration (194' main boom and a 371' luffing jib), however he says he raised the boom but did not lower it on that project.
- He said that the documents in the crane were the operator's manual, a laminated chart on wind restrictions, and the daily inspection sheets (in his back pack). He said there were no paper load charts in the crane and he was using the one in the computer.
- Mr. Reilly said that he was familiar the operator's manual and he focused on the assembly and disassembly sections.
- When asked what he viewed was his responsibility as a licensed NYC HMO operator, Mr. Reilly responded, "mainly safe operation of the machine."
- Mr. Reilly reviewed the drawings contained in CN1157/15. He said he had not seen the ones specific to the cribbing, but did recall the general arrangement (ER-1 of 3), adverse weather (SP-1 of 1), and the crane configurations (ER3 of 3). Mr. Reilly noted the drawing showed the jack knife position toward Hudson. When asked why he tried to lower it the opposite direction, he said he paced it off and did not think he could jack knife it in that direction. He did not call the Professional Engineer to discuss or seek guidance. He said he made the decision to lower it toward West Broadway. He further said that he did not believe he needed BCSI assistance.
- He worked with the assembly crew on January 31, 2016 and had assistance from Bay Crane raising the boom and jib. Bay Crane also assisted with the laying the boom on the ground the evening of the February 3rd, and the subsequent booming up (after the configuration change) of the crane on February 4th.
- An anemometer was installed at the top of the luffing jib during the assembly process on January 31st. According to the operator, the anemometer stopped working at some point Monday afternoon (February 1st). Mr. Reilly continue to operate the crane, and he said that he relied on weather apps (on his smart phone)

to monitor the wind. The anemometer was replaced Wednesday evening with the configuration change.

- There were two heavy picks (one Monday and one Tuesday) that the crane would not allow him to make the pick (computer chart in single part line). He switched the computer to two-part line (while still in single part) and the computer/crane allowed him to make the pick. He said he did this “only to get the computer to approve those two picks”. The paper load charts provided by BSCI showed sufficient capacity so there was an inconsistency between the paper and computer load charts. A Liebherr technician was on site the morning of February 1st and performed a software update. Mr. Reilly asked him about these picks and the technician responded with a non-answer (neither yes or no). Mr. Reilly decided to make the picks and they were performed without incident.
- The operator left the machine over night with the main boom at 80° and the luffing jib between 67° and 70°. He said this information was in the manual, but it is not.
- There was adverse weather forecasted for Wednesday (February 3rd) and the Mr. Reilly decided to jack knife the crane over West Broadway the morning of February 3rd. He did not request assistance from BCSI for this procedure and said he relied on the oiler for radio communication.
- When he arrived Thursday morning, there was water reported in the basement of 60 Hudson Street so crane operations were halted until they could find the source. Once they determined the crane stability was not affected, they went back to work.
- When asked about the in and out of service wind speed, the operator said; “Fifteen miles an hour are required a 15 percent reduction in capacity; 20 miles an hour, 100 percent reduction and capacity and lay it down [sic].”
- The jack knife procedure he used on the February 3rd was to put the boom at high boom (85° to 88°), luff the jib down until the crane is at 90% of the capacity, press the assembly mode button, lower the ball to the ground, and then finish luffing the jib down and touch down on the big wheels at the jib’s tip.
- When asked about the forecasted weather for FEbruary 5th, Mr. Reilly said that he was watching the Weather Channel which was forecasting light winds (below 10 mph) and snow for the morning of the February 5th.
- The operator did not do his daily inspection because “with the snow, I wasn’t going to work. So I wasn’t gonna [sic] run the machine. I did warm it up.”
- On the morning of the February 5th, Mr. Reilly said in his original statement that initially the winds were between 10 and 12 mph. During the last interview, he said that when he checked NOAA while on site February 5th, the wind was forecasted to be between 20 to 35 mph. At 7:40, he saw a gust of 20 mph and he brought the ball up to limit its swing and decided to lower the boom into the jack knife position. He

did not call Bay Crane for assistance and planned to use the oiler for radio communication following the same procedure he used on February 3rd.

- Once he made his decision to jack knife "I told them I was gonna swing around, and we were getting ready to that. So I boomed up to 88 degrees to swing the other way. Once I get facing east [sic], I boomed back down to 80 degrees. I Walked the machine back 30'. Joe and Steve assist me, and we put the blocking in front of the cats for me to walk up on." He starts to luff down with the main boom at 80° and when he "gets to 90% of the chart, and I still got the ball up high that if because I feel it moving around. I don't want the ball swing around. At 90%, I reach back to push the setup button. And as I turn around, I feel the machine move. I look back out the window, and the f*****g thing coming up. So I try to luff back, and it just went down. [sic]"
- He used three (3) sheets of 3/4" plywood stacked on top of each other under both tracks to "block" them. They would place these in front of the cats (tracks) and he would walk (drive) up on them to engage the tumbler. He was under the impression that this process extends the tipping line for the crane.
- He witnessed snow on the boom, but did not know how much.
- At the time of the collapse, the operator said the main boom was at 80 degrees (he "never lowered that {meaning the boom}") and the last number he saw for the luffing jib was 45 degrees.

A.2 Oiler - Steven Mazzacco

Department of Building interviewed Mr. Mazzacco on May 24, 2016 at DOI's office at 83 Maiden Lane, New York, NY. The personnel present were: Robert Miller – DOI, Patricia Pena - DOB, Tiffany Ingram – DOI, Mr. Mazzacco's Counselors consisting of Andrew Lankler, Joe Perry, and Eric Duppont, and Frank Hegan – CTS assisting DOB in the investigation. All were present at DOI's office except Mr. Hegan who was conferenced in via telephone.

The interview started at 2:24 p.m. and was recorded by DOI with the knowledge and acceptance of Mr. Mazzacco. During the interview, Mr. Mazzacco provided the following information.

- Mr. Mazzacco's said that his primary function was to check and maintain the crane fluid levels and lubricate the machine as needed. He assisted the operator with the daily inspections. He is also a licensed "A" operator with the City of New York.
- He said there was a meeting held Thursday afternoon to discuss the forecasted storm for Friday. He was not sure who was there but confirmed the operator attended the meeting.

- He was walking away from the crane at the time of the incident, and said the "wind might have threw [sic] my hardhat". This is an indication of the severity of winds at the time of collapse.
- There was a site meeting around 7:00 am Friday and it was decided that no lifts would be made. The call to lower the boom was made around 8:10 am.
- He mentioned it takes about 30 minutes to jack knife the boom.
- He says that GTI was signaling the crane, and not him as the operator has said.
- The two mats (pontoons) were not perfectly level with each other resulting in the crane leaning slightly toward the south. To compensate, they use sheets of plywood under the tracks on the southern pontoon.
- He said that the crane was running well, and there was no service maintenance work and he did not add any fluids to the crane during the project.
- He did not notice snow on the boom or jib.

A.3 Master Rigger – Greg Galasso – License number 199

Department of Building interviewed Mr. Galasso on June 14, 2016 at DOI's office at 83 Maiden Lane, New York, NY. The personnel present were: James McElligott – DOI, Patricia Pena - DOB, Mr. Galasso's Counselors consisting of Paul Shechtman and Teresa Lee, Manfred Kohler and Frank Hegan – CTS assisting DOB in the investigation.

The interview started at 8:56 a.m. and was recorded by DOI with the knowledge and acceptance of Mr. Galasso. During the interview, Mr. Galasso provided the following information.

- Mr. Galasso is a licensed Professional Engineer and has been a Licensed Master Rigger since 2008.
- He works for Galasso Trucking and Rigging, Inc. (GTRI) and Galasso Rope Works where he is a Vice President of both and not an owner.
- His duties are to oversee the rigging of the project and he said that his communications were primarily with his foremen (Brent Graham and Joe Valenza).
- He said the project was basically a build out of a data center which required back up power. GTRI did not work directly for the tenant but rather to two (2) companies – the electrical sub-contractor (Hatzel and Buehler) and the mechanical contractor (CCIA).
- His company rented the crane from Bay Crane and when he was sourcing a crane the LR 1300 was the only one that could do the job – reach, capacity, and approved by NYC.

- He did not know the operator – Kevin Reilly. He said that he rented the crane from Bay Crane and they provided/assigned the operator to this project. However, the operator and oiler were on GTI's payroll. When asked if the operator took direction solely from GTI, Mr. Galasso said that only for the project related lift issues and he felt that if it was outside this scope that the operator would probably seek advice from Bay Crane.
- Mr. Galasso was aware of the conflict between the load charts in the crane's computer and the paper ones used to plan the job. He did not know the resolution but the site told him the operator was happy and ready to work.
- The team showed Mr. Galasso the adverse weather drawing indicating the jack knife position was toward Hudson Street. He indicated that this was incorrect and the intent was always to jack knife toward West Broadway (east). He said that in meeting with the engineer, DOB, and DOT the direction was over West Broadway. He also said that he spoke with the professional engineer how they would jack knife over West Broadway.
- He went to the site Thursday morning due to a report of water being in the adjacent building. When he arrived he took a picture of the crane level bubble and noted that it was "½° out but it's still within the first line". He took a picture of it and said he will produce it. He said the cribbing looked good and he visually looked for cracks and signs of the cribbing settling and he did not see any. A team of individuals walked around the building looking for the water source, and he was not sure of the final outcome. He went back to the crane after about 2 hours and the level bubble it was in the exact same place. Mr. Galasso, the professional engineer (Mike Salsille), and Operator were satisfied that the crane's foundation had not been compromised and the site started back to work.
- He said that he was not involved in the weather discussions that took place Thursday afternoon.
- He said he received a text from his Rigging Foreman at 7:30 am Friday morning that the wind was bad. He told them to do what they needed to do and another supervisor later texted him that they were booming the crane down.
- When he arrived at the site Friday morning, he looked that the foundation and it was "dead level". His insurance company surveyed the foundation the evening of the collapse and the CTS is waiting for a company report.

A.4 Rigging Foreman – Brent Graham

Department of Building interviewed Mr. Graham on June 14, 2016 at DOI's office at 83 Maiden Lane, New York, NY. The personnel present were: James McElligott – DOI, Patricia Pena - DOB, Mr. Graham's Counselors consisting of Paul Shechtman and Teresa Lee, Manfred Kohler and Frank Hegan – CTS assisting DOB in the investigation.

The interview started at 11:22 a.m. and was recorded by DOI with the knowledge and acceptance of Mr. Graham. During the interview, Mr. Graham provided the following information.

- Mr. Graham has worked with GTI since 1999
- He said that he was the competent rigging person on site for this project
- He received rigging training from his union (#638) as well as GTRI. The training provided by GTRI consisted of classroom as well as field. The training covered required calculations.
- Mr. Graham does not have a license from NYC. He is a “tear off” from the master rigger – Mr. Greg Galasso, and he has a certificate of fitness issued by NYFD.
- He viewed his job to take the calculations and designs performed by the master rigger and implement them.
- Mr. Graham mentioned that the company which installed the cribbing checked it via laser before they left, but he did not recall the name of the company. DOB should request a copy of this survey to check against the one performed after the accident.
- He said he was aware of the issue between the paper and computer load charts, and did not know the final resolution except that it was resolved by Bay Crane.
- Mr. Graham said there were daily meetings but the operator did not attend them all because some of the topics dealt with subjects other than the planned lifts and he needed to be in the crane.
- Mr. Graham said that the winds were higher at ground level than they were at heights on Thursday.
- Mr. Graham was quite specific that there was a meeting Thursday afternoon (day before the accident) to discuss the in-bound weather. He said the operator attended this meeting. He also said they had been watching the weather on their phones so they knew it was coming.
- Mr. Graham said that the weather prediction was for wind to exceed 30 mph and it was decided that no lifting would take place Friday.
- When asked if jack knifing the crane was considered Thursday, he said “nobody ever thought to lay it down Thursday or anything like that.”
- Shortly before the collapse, Mr. Graham was just east of West Broadway facing the crane signaling the operator and he said he looked up and “saw the wind kind of fighting him (meaning the operator)”.
- He looked up and saw the amount of snow coming down and took a picture (he will try to recover it from his old phone), and he noticed snow accumulation on the boom and jib.

- While the operator was in the process of jack knifing the crane he was watching the luffing jib and noticed that it started to come down too fast and he looked at the crane body and saw the cats coming up. He ran toward West Broadway yelling to the people to get out of the way and safely turned left on West Broadway before the crane hit the ground.
- When asked if the wind was worse Wednesday or Friday, he said it was “way worse on Friday.”
- Mr. Graham also mentioned that (traffic) cones were falling because of the wind.

A.5 Professional Engineer – MRA Engineering

The professional engineering firm that generated the Crane Notice and various calculations for the project was MRA Engineering, and the professional engineer assigned to the project was Michael Salsille. CTS interviewed the firm via telephone, email, and a skype teleconference.

CTS held a Skype teleconference on May 12, 2016 to discuss the Ground Bearing Pressure Calculation the firm submitted to New York City, and ask various questions. The attendees on the call were Neil Greenblatt, Michael Salsille, Manfred Kohler, and Frank Hegan.

MTA Engineering generated the Ground Bearing Pressure Calculation form (GBP) submitted by MRA Engineering to New York City using an Excel spreadsheet provide to them from the Manufacturer. A description of this spreadsheet in included in section 2.2.5.2. The principal reason to discuss this program was due to the fact that the weight of the crane in the GBP is different than the crane’s weight provided by the manufacturer in the stability calculation. After various discussions, MRA engineering was not able to help reconcile the difference.

The project was discussed and more particularly CN 1157/15. The drawings were produced by MRA Engineering and they went to the site to take the necessary measurements to produce the drawings and identify the manholes and vaults on Worth Street where the crane was later assembled. These were included in the crane notice calculation.

There were a few follow up questions that were handled via email. One question related to whether or not the engineer asked/received a response about the jack knife position. The engineer asked if the jack knife position was acceptable but did not receive a response from the manufacturer prior to the collapse. CTS also asked if the engineer had measured the distance from the crane to Hudson Street to see if a jack knife position was actually feasible. The engineer’s response was “The manufacturer did not provide the necessary jack knife criteria so we could not determine whether jack-knifing towards Hudson was feasible. We just showed the crane jack knifed with a note referring to the manufacturer’s recommended procedure. This drawing was required by DOB as part of the Crane Notice approval.

CTS also asked if the engineer had visited the site on Thursday due to the reported water egress into 60 Hudson Street. Michael Salsille went to site that morning and said that water source was not found prior to him leaving the site. However, he said, "The crane was level and the foundation was uncompromised."

CTS asked if MRA was consulted about the adverse weather drawing contained in the CN application (jack knife toward Hudson Street) by site personnel and they said they were not. Further, MRA confirmed that they were not consulted Wednesday morning or the day of the collapse regarding jack knifing the crane.

A.6 DOB Inspector – Dan Myers

CTS talked to Mr. Meyers a number of times related to the collapse during the field work on February 5th and 6th as well as at the Cranes and Derricks offices at 280 Broadway. Mr. Myers was the DOB inspector that first inspected the crane (January 31, 2016). He said the crane passed the on-site inspection, wrote the required report, and work began. He also reviewed the steel structure inspection performed by CTI and all the paper work was in order.

The operator mentioned in his interview that Mr. Meyers impressed upon him that the crane must be put on the ground if wind exceeded 15 mph. He also mentioned that Mr. Meyers was on site prior to the collapse and they just discussed general items. Mr. Meyer denies this later point. He went to the site after the collapse on February 5, 2016; not before.

A.7 Manufacturer – Liebherr

The crane manufacturer is represented by Stella Dugan Gunn LLC and CTS was not allowed to interview a representative of Liebherr during the investigation. The process Liebherr's attorneys required was submit questions and the attorney would elicit a response from Liebherr. This process worked well on some questions but not on others.

A.8 Owner – Bay Crane Services, Inc.

CTS talked to the owners during the field work performed on February 6, 2016, and March 3, 2106. They requested that all questions be made in writing and that they would respond accordingly, which they did (Section 2.2.2).

AccuWeather
FORENSICS

June 30, 2016

Mr. Frank Hegan
Crane Tech Solutions, LLC
2030 Ponderosa Street
Portsmouth, VA 23701

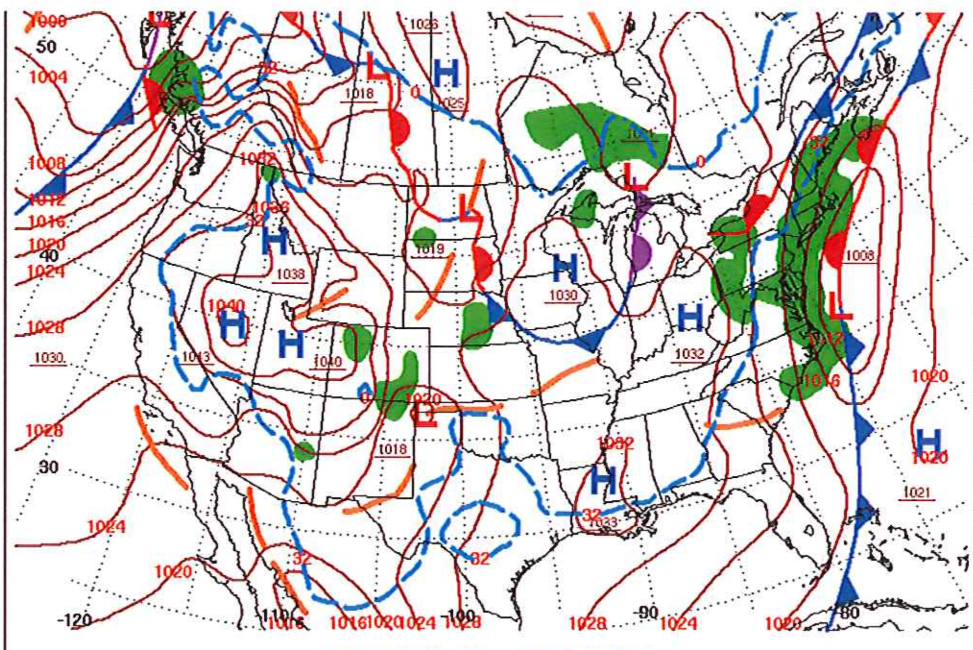
RE: NYC Crane
AccuWeather File Number: 021611

Dear Mr. Hegan:

As you requested, we have investigated the weather conditions in the vicinity of Worth Street between West Broadway and Hudson Street in Manhattan, New York on the morning of February 5, 2016, with particular attention on the wind conditions between 8:00 a.m.[1] and 8:30 a.m. on the 5th. Additionally, we have reviewed forecasts prepared by the National Weather Service for the morning of February 5th. The results of our investigation are presented in the following paragraphs, tables and images.

OVERVIEW OF NEW YORK CITY WEATHER ON FEBRUARY 5, 2016

FRIDAY FEBRUARY 5, 2016



Surface Weather Map at 7:00 A.M. E.S.T.

Our research shows that on the morning of February 5, 2016, an intensifying storm was centered just off the mid-Atlantic coast as shown on the map above. The storm was moving northeastward and was causing a large area of precipitation onshore from Maine to the Carolinas.

---

[1] This and all other time references in this report are expressed in Eastern Standard Time (EST).

385 Science Park Road, State College, PA 16803-2215 P 814.235.8626 F 814.235.8769
E forensics@accuweather.com Forensics.AccuWeather.com

The map shows several isobars, lines of equal surface air pressure, between Pennsylvania and the offshore front and associated low pressure center. This packing of the isobars was causing an increasingly strong flow of air from the north and north-northeast in the New York City area as the storm gained strength that morning.

The weather in Manhattan during the first four days of February 2016 was unusually warm for the season with temperatures mainly in the 40s and 50s. The winds were rather light during much of this time, except during the morning and early afternoon hours of February 3rd when a gusty wind blew from the south. Then, the weather changed on February 5, 2016 as the northerly winds caused by the offshore storm brought colder air into the city. Rain from the storm began to fall steadily between 1:00 a.m. and 2:00 a.m. with the temperature near 40 degrees, and then changed to wet snow an hour later as the temperature fell into the 30s. The snow fell steadily throughout the remainder of the predawn hours and into the daylight hours of the 5th, ending shortly before 12:00 noon. At first the snow melted on the ground as it fell, but as the air temperature continued to fall, reaching 32 degrees by the time of sunrise, there was a slushy accumulation of snow on untreated paved surfaces and a buildup of wet snow on elevated surfaces. The total snow accumulation on untreated and undisturbed surfaces on Worth Street was between 2 and 3 inches by late morning on February 5th, more than half of which had fallen by 8:00 a.m.

SURFACE WINDS IN MANHATTAN ON THE MORNING OF FEBRUARY 5, 2016

During the morning of February 5, 2016, the wind blew consistently from the north and north-northeast. However, there was a noticeable increase in the speed of the wind between 5:00 a.m. and 9:00 a.m. due to the intensification of the offshore storm. Analysis of the wind in the vicinity of Worth Street is made much more complex by the effect on the air flow of the tall buildings of Manhattan. In some places, the wind is largely blocked by upwind buildings and in other places the air flow is channeled and sped up along the streets between the buildings. We will discuss these factors further below. Here, we will begin our wind analysis for the morning of February 5, 2016 by using wind data from nearby relatively open locations where the air flow is mostly unobstructed. These locations include La Guardia Airport and John F. Kennedy International Airport in New York where wind data is available every five minutes. We also found useful wind data, reflecting unobstructed flow, from Robbins Reef in New Jersey on the west side of New York Harbor. This data is available every six minutes. Finally, we have included 5-minute wind data from Central Park in Manhattan in our analysis, although this location experiences generally lower wind speeds on average due to the tall buildings and trees surrounding the observation site in the park. At the start of this assignment, we were provided some weather data from a personal weather station affiliated with Weather Underground and located about 6 blocks to the north-northwest of the Worth Street site in question. Our review of the wind data from this weather station shows it to be inconsistent and thus we did not include it in our analysis. Specifically, the Weather Underground station was reporting wind directions primarily from the east-northeast on the morning of February 5th which differs from the direction observed at all the other reporting sites in the area. Furthermore, the gust speeds reported at that site are erratic, with one gust to 36 mph that seems realistic while all other gusts are considerably lower. This indicates to us that the Weather Underground wind measuring site is either poorly calibrated or, more likely, that it is sited in such a way that wind blowing from the north and north-northeast is at least partially obstructed by other buildings.

The following table shows the highest reported wind gusts during 30-minute intervals from 5:00 a.m. through 9:00 a.m. on February 5, 2016 at the four observing sites listed above that we did use. All wind speeds are in miles per hour (mph). All official wind measurements are taken at approximately 10 meters (33 feet) above the ground, except for at Robbins Reef where the wind measurements are taken about 69 feet above the average sea level of New York Harbor. The peak wind gusts represent a 3-second average peak wind at each observing site.

TIME (EST)	ROBBINS REEF	LA GUARDIA AIRPORT	JFK AIRPORT	CENTRAL PARK
5 to 5:30 a.m.	18 mph	No gusts	29 mph	No gusts
5:30 to 6 a.m.	18 mph	23 mph	29 mph	22 mph
6 to 6:30 a.m.	24 mph	29 mph	33 mph	23 mph
6:30 to 7 a.m.	34 mph	29 mph	33 mph	23 mph
7 to 7:30 a.m.	33 mph	32 mph	32 mph	21 mph
7:30 to 8 a.m.	33 mph	28 mph	30 mph	23 mph
8 to 8:30 a.m.	32 mph	38 mph	35 mph	29 mph
8:30 to 9 a.m.	29 mph	38 mph	33 mph	21 mph

A review of the above table reveals the inherent variability of the atmosphere as wind speeds jump around somewhat from one time period to another. Nevertheless, it is apparent that there was a general increase in the strength of the wind during the period from 5:00 a.m. to 8:30 a.m. on February 5, 2016 as the offshore storm strengthened. Most of the observing sites began to show a general decrease in wind speeds after 8:30 a.m. Again, with the exception of Central Park, the above speeds are representative of the strength of wind gusts in open, unobstructed locations in the New York City area at a height of 10 meters (33 feet) above the ground. The 69-foot wind measurements at Robbins Reef were converted to 33-foot speeds based on the wind shear formula discussed later. As can be seen, peak gusts of approximately 35 mph were occurring 33 feet above the ground in such locations between 8:00 a.m. and 8:30 a.m. on February 5th.

The following table shows average wind direction data from the same four locations during the same 30-minute time periods as the table of wind gust speeds. We are using compass directions in this table, with 360 degrees representing wind blowing from the due north. As examples, wind from 340 degrees is from the north-northwest and from 020 degrees is from the north-northeast. Due east would be 090 degrees and due west would be 270 degrees.

TIME (EST)	ROBBINS REEF	LA GUARDIA AIRPORT	JFK AIRPORT	CENTRAL PARK
5 to 5:30 a.m.	350 degrees	020 degrees	360 degrees	Variable
5:30 to 6 a.m.	350 degrees	020 degrees	360 degrees	030 degrees
6 to 6:30 a.m.	360 degrees	360 degrees	360 degrees	030 degrees
6:30 to 7 a.m.	010 degrees	350 degrees	350 degrees	020 degrees
7 to 7:30 a.m.	010 degrees	360 degrees	360 degrees	020 degrees
7:30 to 8 a.m.	020 degrees	360 degrees	360 degrees	030 degrees
8 to 8:30 a.m.	010 degrees	360 degrees	360 degrees	030 degrees
8:30 to 9 a.m.	010 degrees	360 degrees	350 degrees	030 degrees

This table of wind direction shows that the wind blew persistently from a generally northerly direction between 5:00 a.m. and 9:00 a.m. on February 5, 2016 in the New York City area. The two closest observation sites to Worth Street, which were Robbins Reef and Central Park, showed wind blowing from a little east of due north some of the time, including between 8:00 a.m. and 8:30 a.m.

CHANGE OF WIND SPEEDS WITH HEIGHT ABOVE THE GROUND

To this point in this report, all wind data presented has been for an elevation of 33 feet above the ground. In nearly all atmospheric situations, including during the storm in Manhattan on the morning of February 5, 2016, the speed of the wind increases with height as the drag on the wind by ground-based features diminishes. The change of wind speed with height in the lower portion of the atmosphere near the ground can be described by the following wind shear formula, also known as the log wind profile or log law:

The wind speed at a certain height above ground level is:

$$v = v_{ref} \ln(z/z_0)/\ln(z_{ref}/z_0)$$

v = wind speed at height z above ground level.

v_{ref} = reference speed, i.e. a wind speed we already know at height z_{ref}.

ln(...) is the natural logarithm function.

z = height above ground level for the desired velocity, v.

z_0 = roughness length in the current wind direction.

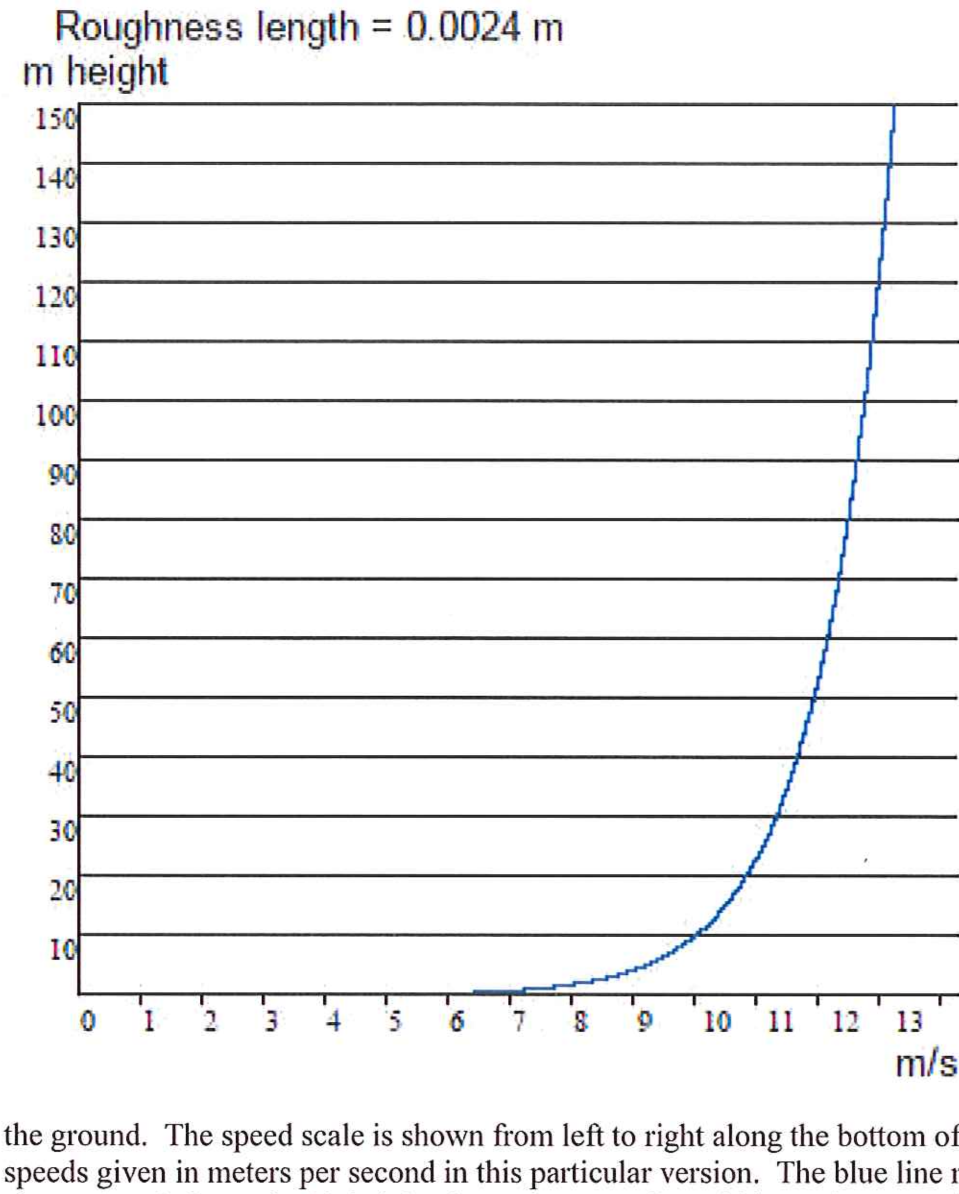
z_{ref} = reference height, i.e. the height where we know the exact wind speed v_{ref}.

The roughness length used in the above equation is a parameter that is dependent on the type of surface the wind blows over before reaching the place where the speed is measured or desired. The roughness length is smallest over very flat surfaces, such as water or a flat field and is greatest over a surface with many tall features, such as a major city center. The following table shows various roughness lengths. The appropriate roughness length for determining the change of wind speed with height at the open exposures of an airport observation site is 0.0024 based on the table. And, as the table shows, the appropriate roughness length to use in the equation when determining wind speeds in Manhattan would be 1.6.

Roughness Classes and Roughness Length Table

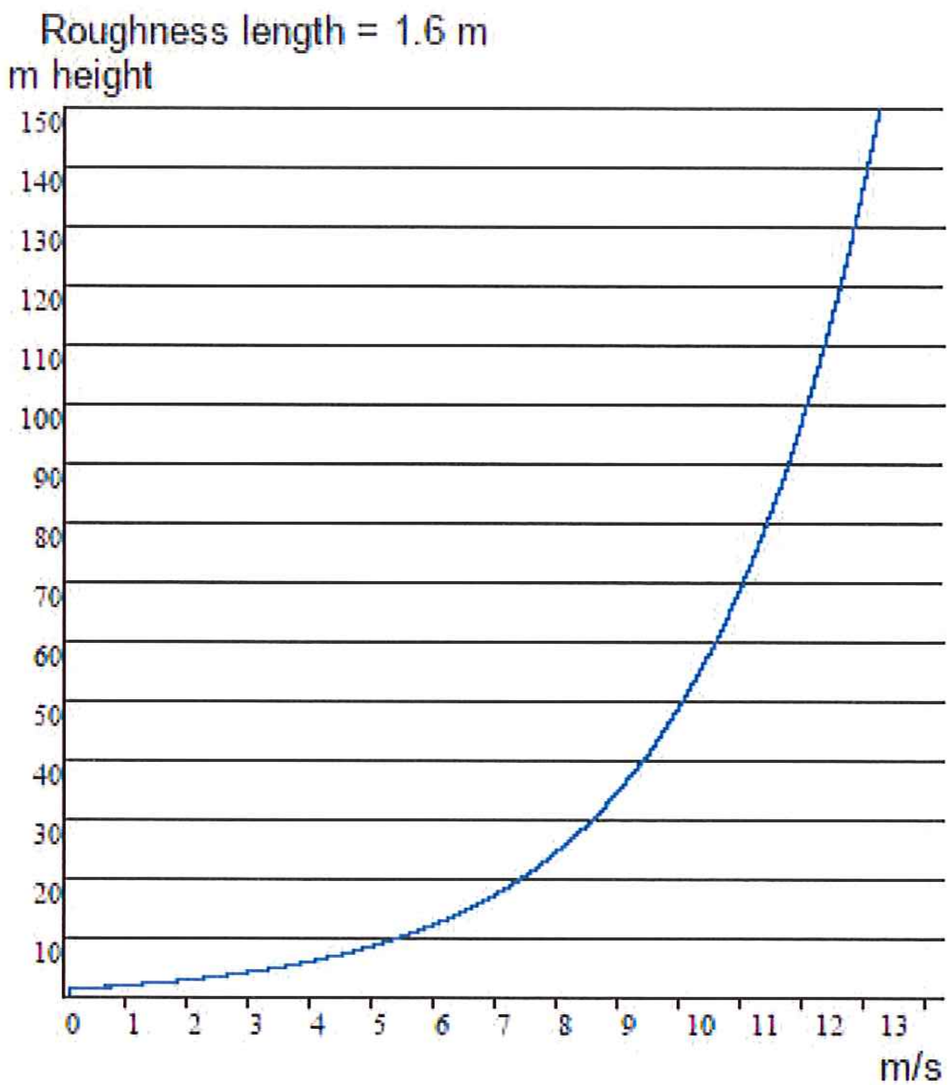
Rough-ness Class	Roughness Length m	Energy Index (per cent)	Landscape Type
0	0.0002	100	Water surface
0.5	0.0024	73	Completely open terrain with a smooth surface, e.g.concrete runways in airports, mowed grass, etc.
1	0.03	52	Open agricultural area without fences and hedgerows and very scattered buildings. Only softly rounded hills
1.5	0.055	45	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 1250 metres
2	0.1	39	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 500 metres
2.5	0.2	31	Agricultural land with many houses, shrubs and plants, or 8 metre tall sheltering hedgerows with a distance of approx. 250 metres
3	0.4	24	Villages, small towns, agricultural land with many or tall sheltering hedgerows, forests and very rough and uneven terrain
3.5	0.8	18	Larger cities with tall buildings
4	1.6	13	Very large cities with tall buildings and skycrapers

The following sample graph, derived from the wind shear equation above, shows the change in wind speed with height over open terrain such as an airport. The height units shown are meters, with the 10-meter height near the bottom of the image being the height of airport wind observations. The top of this particular graph is at 150 meters, which translates to 492 feet above



the ground. The speed scale is shown from left to right along the bottom of the graph, with speeds given in meters per second in this particular version. The blue line representing the change in wind speed with height above the ground would have the same shape if meters per second was converted to miles per hour. This particular graph is for general display purposes and does not show the wind on the morning of February 5, 2016 in New York.

The graph on the previous page displays the variance of wind speed with height over a generally flat surface. In contrast, the graph below shows the expected variance of wind speed with height over a large urban area with many tall buildings such as Manhattan. We have set the wind speed to be the same at the top (150-meter or 492-foot height) of these two sample graphs that we are displaying. Thus, comparing the graph on this page and the one on the previous page, one can readily see the greater reduction of wind speed from top to bottom in Manhattan as compared to the open airport location. Again, the wind speeds shown in this graph are simply to illustrate the impact of a city on the change of wind speed with height and do not represent the actual wind speed on the morning of February 5, 2016.



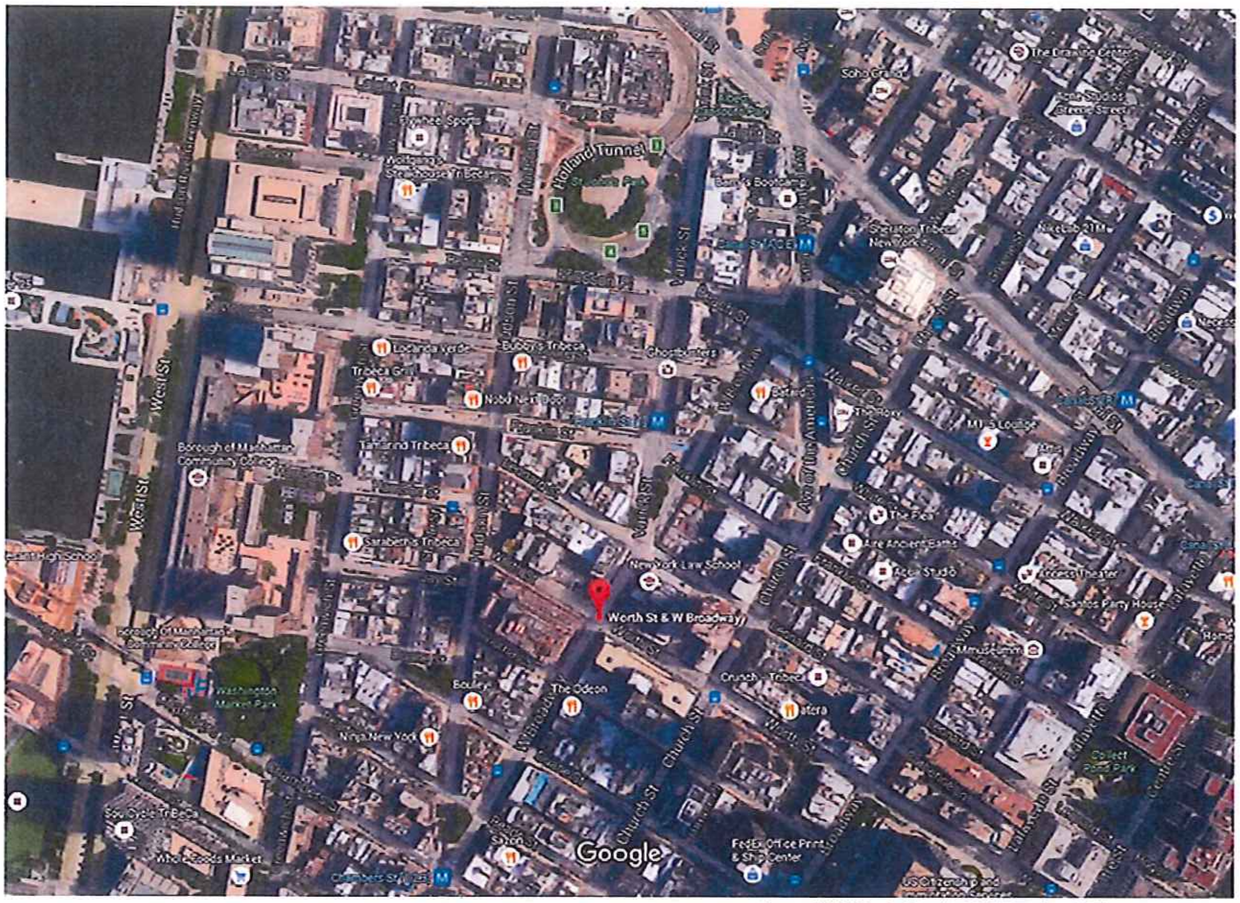
WIND SPEEDS BETWEEN 33 FEET AND 560 FEET OVER WORTH STREET

In this report, we have been asked to estimate the wind speeds between 8:00 a.m. and 8:30 a.m. on the morning of February 5, 2016 at heights of 100 feet, 200 feet, 380 feet, 450 feet and 560 feet above street level on Worth Street. To accomplish that, we first estimated the wind speed at the 560-foot height over the wide open locations. Starting with an average gust speed of 35 mph at the 33-foot (10 meter) height and using the graph shown on page 7 above, we estimate that highest gusts could have reached approximately 45 mph at a height of 560 feet overtop locations with an open exposure. Then, using the graph for the urban environment shown on page 8, we worked downward from above using 45 mph at the 560-foot height and then deriving peak wind speeds at the lower heights based on the graph, which is in turn based on the wind shear equation. The results are shown in the table below. We have also included the 33-foot height for comparison with the winds in open locations presented earlier in this report. Additionally, in the table we have added the sustained (average) wind speeds at each height between 8:00 a.m. and 8:30 a.m. on February 5, 2016, determined by the same methodology described above.

HEIGHT ABOVE STREET LEVEL	ESTIMATED SUSTAINED WIND SPEED BETWEEN 8:00 AND 8:30 A.M. ON 2/5/16	ESTIMATED PEAK WIND SPEED BETWEEN 8:00 AND 8:30 A.M. ON 2/5/16
33 feet	12 mph	18 mph
100 feet	19 mph	28 mph
200 feet	23 mph	35 mph
380 feet	27 mph	41 mph
450 feet	28 mph	43 mph
560 feet	30 mph	45 mph

These wind speeds are what would be expected in the free air away from the immediate vicinity of any tall buildings that would block the flow of air from the north or north-northeast on the morning of February 5, 2016. The actual flow of the air through the vicinity of Worth Street between West Broadway and Hudson Street would become increasingly complex at lower and lower heights as the impact on the air flow of surrounding buildings becomes more significant.

The satellite view of the neighborhood near and to the north of Worth Street shown on the next page was taken by Google early on a sunny day. The location of the intersection of Worth Street and West Broadway is shown with a red marker. The tallest buildings in the neighborhood are producing noticeably dark shadows extending to the west (left on the image) of each building. None of these especially tall buildings can be found to the north of the block of Worth Street between West Broadway and Hudson Street. Thus, the wind was free to blow unobstructed to



Imagery ©2016 Google, Map data ©2016 Google 200 ft

the crane location at least above the heights of the buildings seen to the north of the block of Worth Street in question.

The image above shows that Hudson Street, West Broadway and, beginning a couple of blocks north of Worth Street, Varick Street are all aligned roughly parallel to the wind blowing from the north and north-northeast on the morning of February 5, 2016. Thus, there would have been some channeling of the wind from north to south along these streets, resulting in speeds that were generally at least 10 to 20 percent higher than shown in the table on the previous page and likely more than 50 percent higher in some locations most impacted by this wind speed up. Meanwhile, with Worth Street being aligned from northwest to southeast, there likely would have been some intermittent and especially turbulent and gusty wind flow from northwest to southeast along Worth Street; in other words, blowing from Hudson Street toward West Broadway at least in the lower 100 feet or so above street level. The 380-foot tall building on the south side of Worth Street at the crane collapse location acted as a significant obstacle to the wind flow from the north and north-northeast and thus contributed significantly to the channeling of the air flow parallel to Worth Street near the ground. Above a height of 100 feet or so, the wind direction would gradually become more aligned with the prevailing wind direction over Manhattan, except in the immediate vicinity of the tall building which would continue to force the air flow around it up to its full height. An additional factor in the wind flow along Worth Street would be the impact of *downwash*, or downward flowing air, on the Worth Street side of the face of the 380-foot tall building. This occurs as air blowing from the north and north-northeast is forced to flow around the tall building. Some of this air blows around the sides of the building, some flows upward and over the roof and, from approximately half way up the windward side of the building and below, the air blows down the face of the building toward the street. This downwash will force air blowing at higher speeds aloft down to street level, adding to the turbulence and speed of the air being channeled between the buildings near street level.

We understand that videos taken around the time of the crane collapse show various impacts of these strong gusty winds being channeled along Worth Street in the vicinity of the crane, including traffic lights swaying, hanging overhead signs blow nearly horizontal, a pole shaking, traffic signs wobbling and an umbrella turned inside out. Additionally, one witness recalled having his hard hat blown off and another saw cones being blown around and moved. These indications are consistent with localized, enhanced wind speeds as high as 45 mph or greater due to the combination of channeling parallel to Worth Street and downwash from the 380-foot tall building on the south side of the street.

A detailed computer modeling of the wind flow along Worth Street on the morning of February 5, 2016 would be required to fully understand the details of these interrelated wind factors that were impacting the vicinity of the crane that morning.

NATIONAL WEATHER SERVICE FORECASTS FOR FEBRUARY 5, 2016

We have reviewed the National Weather Service forecasts for Manhattan prepared between 12:00 noon on Thursday, February 4, 2016 and 8:00 a.m. on Friday, February 5, 2016. At midday on the 4^{th}, the expectation was that the snow the following day would remain east of Manhattan. The following forecast was issued at 12:27 p.m. on Thursday the 4^{th}:

> *Tonight...cloudy. A chance of rain in the evening...then a chance of rain and snow after midnight. Much cooler with lows in the lower 30s. North winds 10 to 15 mph. Chance of precipitation 50 percent.*
> *Friday...cloudy in the morning...then clearing. Breezy with highs in the lower 40s. North winds 15 to 20 mph.*

The next National Weather Service forecast for Manhattan, released at 4:09 p.m. on Thursday the 4th, included a newly issued Winter Weather Advisory for snow into Friday morning, and also added gusts up to 30 mph to the wind forecast. The full forecast for the first two time periods was as follows:

> *...Winter Weather Advisory in effect from 1 am to 10 am Friday...*
> *Tonight...cloudy. A chance of rain this evening...then rain and snow after midnight. Snow accumulation around an inch. Breezy and cooler with lows in the mid 30s. North winds 15 to 20 mph. Chance of precipitation 90 percent.*
> *Friday...cloudy with snow in the morning...then mostly sunny in the afternoon. Total snow accumulation of 2 to 4 inches. Breezy with highs around 40. Northwest winds 15 to 20 mph with gusts up to 30 mph. Chance of snow 90 percent.*

The subsequent forecast issued at 8:56 p.m. on February 4th showed a further increase in the wind speeds expected on Friday the 5th:

> *...Winter Weather Advisory in effect from midnight tonight to noon Friday...*
> *Tonight...rain early this evening...then rain and snow after midnight. Snow accumulation around an inch. Breezy and cooler with lows in the lower 30s. North winds 5 to 10 mph...increasing to 15 to 20 mph with gusts up to 30 mph after midnight. Chance of precipitation near 100 percent.*
> *Friday...becoming partly sunny in the afternoon. Snow. Total snow accumulation of 2 to 4 inches. Windy and cooler with highs in the upper 30s. Northwest winds 15 to 25 mph with gusts up to 35 mph. Chance of snow near 100 percent.*

A similar idea was carried into the next National Weather Service forecast issued at 12:47 a.m. on Friday, February 5, 2016, with mainly time reference changes:

> *...Winter Weather Advisory in effect until noon today...*
> *Overnight...rain and snow. Snow accumulation around an inch. Breezy and cooler with lows in the lower 30s. North winds 15 to 20 mph with gusts up to 30 mph. Chance of precipitation near 100 percent.*
> *Friday...snow in the morning...then partly sunny with a chance of snow in the afternoon. Total snow accumulation of 2 to 4 inches. Windy and cooler with highs in the upper 30s Northwest winds 15 to 25 mph with gusts up to 35 mph. Chance of snow near 100 percent.*

The next National Weather Service forecast for Manhattan was issued at 3:41 a.m. on Friday, February 5th and re-issued with identical wording at 5:15 a.m. and read as follows:

> *...Winter Weather Advisory in effect until noon today...*
> *Today...snow this morning...then mostly sunny with a slight chance of snow this afternoon. Total snow accumulation of 2 to 4 inches. Windy and cooler with highs in the upper 30s. Northwest winds 15 to 25 mph with gusts up to 35 mph. Chance of snow near 100 percent.*

The final Manhattan forecast prior to the crane collapse was issued at 6:35 a.m. on Friday, February 5th and included a slight reduction in the wind speeds forecast for that day. The full wording is as follows:

> *...Winter Weather Advisory in effect until noon today...*
> *Today...widespread snow this morning...then mostly sunny with a slight chance of snow this afternoon. Total snow accumulation of 2 to 4 inches. Breezy with highs in the upper 30s. North winds 15 to 20 mph with gusts up to 30 mph. Chance of snow near 100 percent.*

SUMMARY

In summary, we have investigated the wind conditions in the vicinity of Worth Street between West Broadway and Hudson Street in Manhattan, New York on the morning of February 5, 2016. Our research shows that the wind was blowing from the north and north-northeast around an offshore storm that was causing snowfall at that site during much of the morning. There was a pronounced increase in wind speeds between 5:00 a.m. and 8:30 a.m. as the offshore storm intensified. We estimate that between 8:00 a.m. and 8:30 a.m., peak wind speeds reached approximately 28 mph at a height of 100 feet above Worth Street, 35 mph at a height of 200 feet, 41 mph at a height of 380 feet, 43 mph at a height of 450 feet and 45 mph at a height of 560 feet. These are estimated wind speeds in the free air away from the influence of tall buildings. A much more complex, turbulent and gusty wind flow pattern existed along Worth Street than these free air speeds would indicate. This complexity was due to channeling of the wind parallel to Worth Street by building on both sides of the street, plus additional acceleration as downwash of air from the face of the tall building on the south side of the street impinged on the air flow parallel to the street. These factors likely caused intermittent wind gusts to 45 mph or higher in the vicinity of the crane around the time of the collapse.

The National Weather Service forecasts issued from late afternoon on February 4, 2016 through shortly before the time of the crane collapse on the morning of February 5, 2016 called for 2 to

4 inches of snow, accompanied by winds of either 15 to 20 mph or 15 to 25 mph, with gusts up to 30 mph in some forecasts and 35 mph in other forecasts.

This report is based on the weather data available at this time and our best knowledge and understanding of the effect of an urban environment on air flow. There is substantial additional work that can be done to reveal in more detail the wind flow at the site of the crane collapse on Worth Street on the morning of February 5, 2016. Most notably, a computer model simulation of the air flow through the neighborhood in the vicinity of Worth Street could be carried out to ascertain how the buildings along and to the north of Worth Street were modifying the air flow specifically with the particular wind direction and speed that existed that morning.

DATA SOURCES

We relied on the following sources of data in the preparation of this report:

1) *Daily Weather Map* for February 5, 2016, prepared by the National Centers for Environmental Prediction, Hydrometeorological Prediction Center and made available online.
2) *Local Climatological Data* for February 2016 from Central Park, La Guardia Airport and John F. Kennedy International Airport, all in New York, published by the National Climatic Data Center.
3) Weather observations every five minutes for February 5, 2016 from Central Park, La Guardia Airport and John F. Kennedy International Airport, all in New York, taken by the National Weather Service and the Federal Aviation Administration and published by the National Climatic Data Center.
4) Weather observations every six minutes for February 5, 2016 from Robbins Reef, New Jersey, taken by the National Ocean Service and made available online by MesoWest.
5) Reflectivity and Radial Velocity data for selected times on February 5, 2016 from the New York City and Philadelphia National Weather Service Doppler radars, made available online by the National Climatic Data Center.
6) Upper air data from the radiosonde launched at Upton, New York, recorded at 7:00 a.m. on February 5, 2016 and made available by the Plymouth State Weather Center.
7) Online calculator of changes of wind speed with height, available at Katabatic Power website at http://es.ucsc.edu/~jnoble/wind/extrap/ .
8) National Weather Service forecasts for Manhattan issued on February 4 and 5, 2016.
9) Selected maps and satellite views of the Worth Street area of Manhattan, available online.

The information in this report has been determined from the best sources of weather information available to us at this time and is the result of interpretation by our staff of professional meteorologists and represents our opinions to a reasonable degree of scientific certainty. If you should have any additional questions or need additional information, please do not hesitate to contact us.

Sincerely,

Joseph P. Sobel, Ph.D.
Director of Forensic Services

Stephen M. Wistar
Certified Consulting Meteorologist

Investigation of Crane Collapse

Worth Street
New York, NY
7 July 2016
(Revised 22 November 2016)

SGH Project 160246

SIMPSON GUMPERTZ & HEGER
Engineering of Structures and Building Enclosures

PREPARED FOR:

Crane Tech Solutions, LLC
2030 Ponderosa Street
Portsmouth, VA 23701

PREPARED BY:

Simpson Gumpertz & Heger Inc.
41 Seyon Street
Building 1, Suite 500
Waltham, MA 02453
Tel: 781.907.9000
Fax: 781.907.9009

7 July 2016
(Revised 22 November 2016)

Mr. Frank Hegan
Crane Tech Solutions, LLC
2030 Ponderosa Street
Portsmouth, VA 23701

Project 160246 – Investigation of Crane Collapse on 5 February 2016, Worth Street, New York, NY

Dear Mr. Hegan:

This report summarizes an assessment of wind speeds that would cause a Liebherr LR1300 crawler crane to become unstable.

Please contact us if you have questions.

Sincerely yours,

STATE OF NEW YORK
DONALD OWEN DUSENBERRY
No. 72298
LICENSED PROFESSIONAL ENGINEER

Donald O. Dusenberry, P.E.
Senior Principal
NY License No. 072298

P. Graham Cranston
Senior Staff II – Structures

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Encl.

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Letter of Transmittal

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ILLUSTRATIONS

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1. INTRODUCTION

At approximately 8:25 a.m. on 5 February 2016, a Liebherr LR1300 crawler crane overturned while operating on Worth Street between West Broadway and Church Street in New York, NY.

Crane Tech Solutions, LLC (CTS) retained Simpson Gumpertz & Heger Associates, Inc., P.C. (SGH) to assist with an investigation of this failure, on behalf of the New York City Department of Buildings (DOB).

1.1 Background

The address of the project is 60 Hudson Street, New York, NY. The location of the project and the approximate location of the crane at the time of the accident are shown in Figure 1. An aerial photo of the site is shown in Figure 2, and the wreckage of the overturned crane is shown in Figure 3. Additional background is provided in the CTS report [Ref. 8].

1.2 Objective

The objective of our investigation is to review the available relevant information and determine the likely wind speed at which the crane would overturn, and to evaluate the sensitivity of that limiting wind speed to various input parameters used in the analysis.

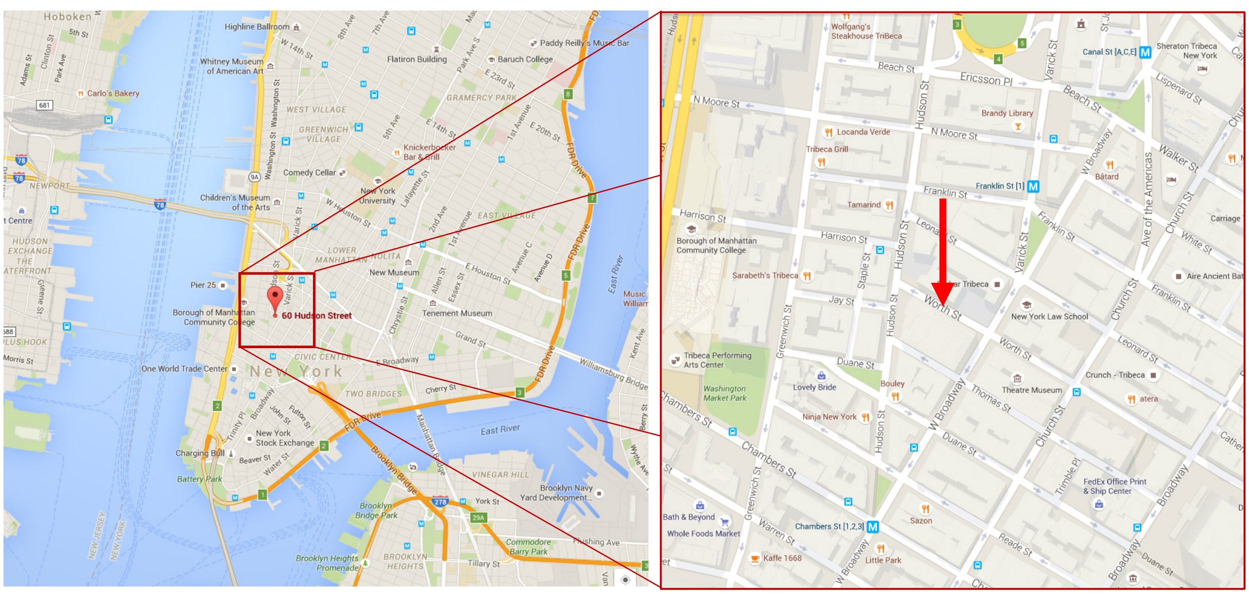


Figure 1 – Project location: 60 Hudson Street, New York, NY. Approximate crane location at time of accident shown by red arrow.

Figure 2 – Project site, with approximate location of the crane at the time of collapse shown by the yellow arrow. The arrow's direction indicates the viewpoint in Figure 3.

1.3 Scope of Work

Our work has consisted of the following tasks:

- Reviews of summaries of interviews with witnesses to the failure.
- Reviews of product literature and calculations related to the configuration and stability of the subject crane.
- Reviews of relevant standards for stability calculations for crawler cranes.
- Visit to the debris storage yard to observe the crane components.
- Calculations of stability.
- Sensitivity analysis of stability.

1.4 Method of Approach

Our assignment focused on stability calculations for the Liebherr LR1300 crane when subjected to wind load. We determined a nominal limiting wind speed blowing from behind the crane, at which the crane would likely become unstable assuming it was configured as indicated by available documents and by interviews with site personnel. We attempted to confirm the accuracy of the weight, center of gravity (CG), and wind area of crane components from field measurements and available documents. In addition, we calculated the sensitivity of the limiting wind speed to changes of various input parameters related to the weight and operation of the crane. We relied on available design guides and standards for guidance to determine wind loads on the crane and the range of some of the parameters in the sensitivity studies. When our assessment of relevant parameters produced values similar to those produced by Liebherr, we generally used the Liebherr values in subsequent analyses. Some of the analyses reported herein could be refined by more in-depth studies and by specific verification of information in the available documents.

Figure 3 – Overturned crane lying along Worth Street, looking WNW [Ref. 15]

1.5 Relevant Parties

The following entities and individuals are involved in the project and subsequent investigation. This is not an exhaustive list; only those entities and individuals pertinent to our report are identified below.

- New York City Department of Buildings (DOB): permitting body for the crane operation
- Liebherr: crane designer and manufacturer
- Bay Crane: crane owner
- Galasso Trucking & Rigging Inc. (GTRI): responsible rigger, crane user
  - Greg Galasso: master rigger
  - Brent Graham: rigging foreman
  - Kevin Reilly: crane operator
- MRA Engineering: engineer of record for crane notice
  - Neil Greenblatt: professional engineer
- Crane Tech Solutions (CTS): lead investigator
  - Frank Hegan: project lead
- Simpson Gumpertz & Heger Associates, Inc., P.C. (SGH): structural engineering subconsultant to CTS
- AccuWeather Forensics: forensic weather analysis subconsultant to CTS

2. DESCRIPTION OF THE STRUCTURE

The general arrangement of the LR1300 crawler crane is shown in Figure 4. Major components are labeled on the left of the figure. The drawing at the right of the figure is part of the permit submittals, and the markup indicating the boom and jib segment numbers is by others. Two configurations are shown in the drawing: 371 ft jib with 128 ft radius, and 322 ft jib with 110 ft radius. At the time of the accident, the crane was configured with a 371 ft jib. We understand that the crane was oriented with its crawlers, boom, and jib approximately parallel with Worth Street, facing generally east-southeast.

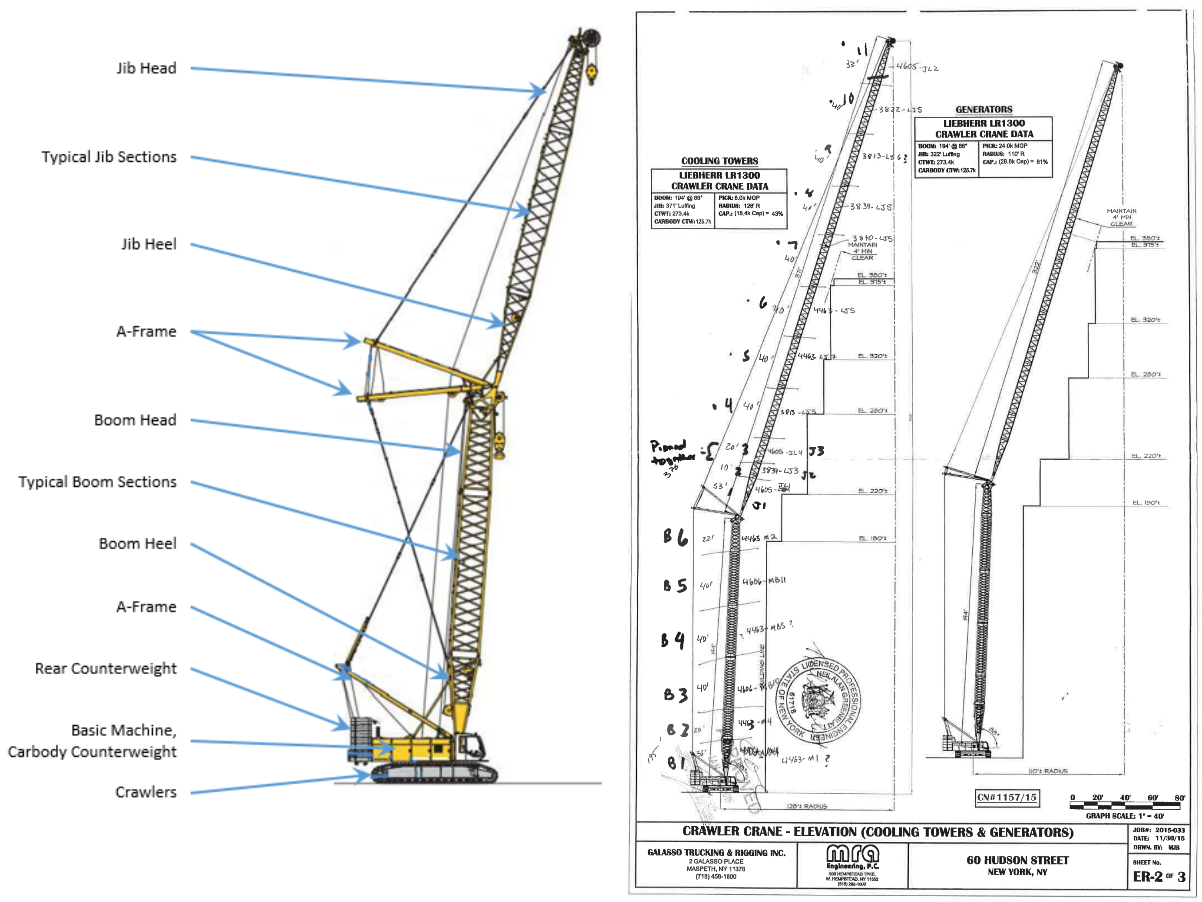


Figure 4 – General arrangement of the LR1300 mobile crane and hoist drawing [Ref. 6]

The arrangement and nomenclature for typical boom and jib sections are shown in Figure 5. Nonstandard sections (jib head, jib heel, and boom head) are shown in Figures 6 through 8.

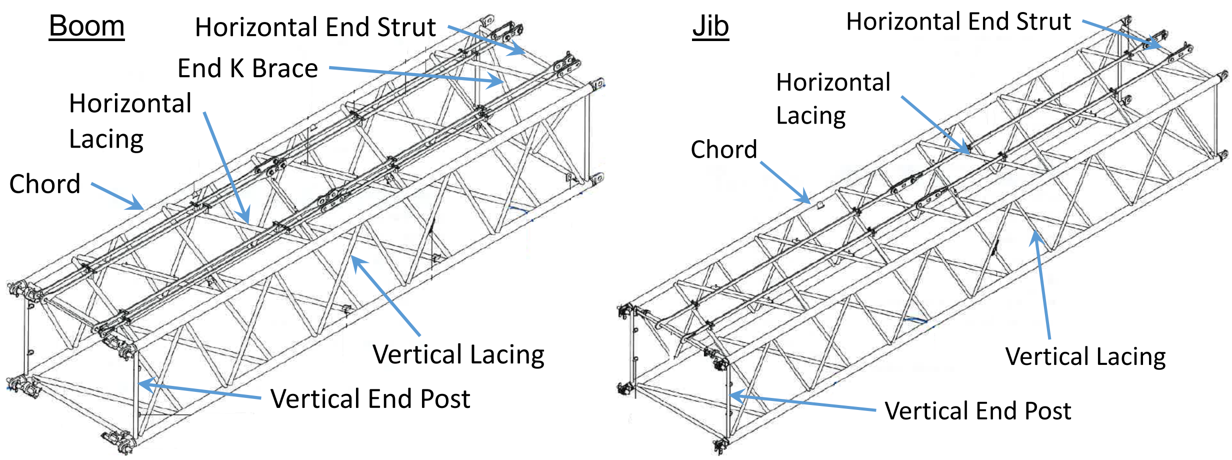


Figure 5 – Typical Boom (left) and Jib (right) Section Arrangement and Nomenclature

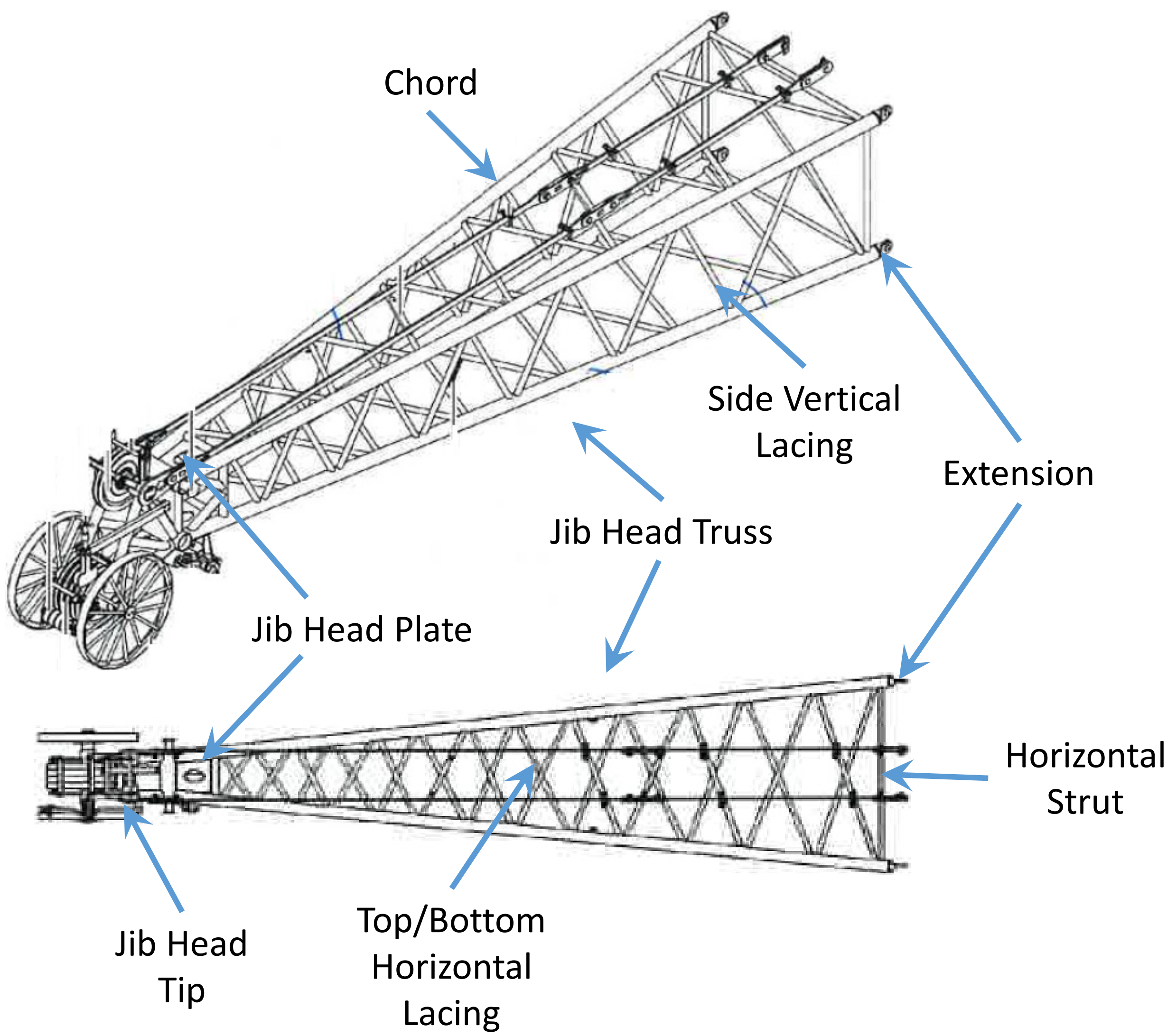


Figure 6 – Jib Head Section Arrangement and Nomenclature

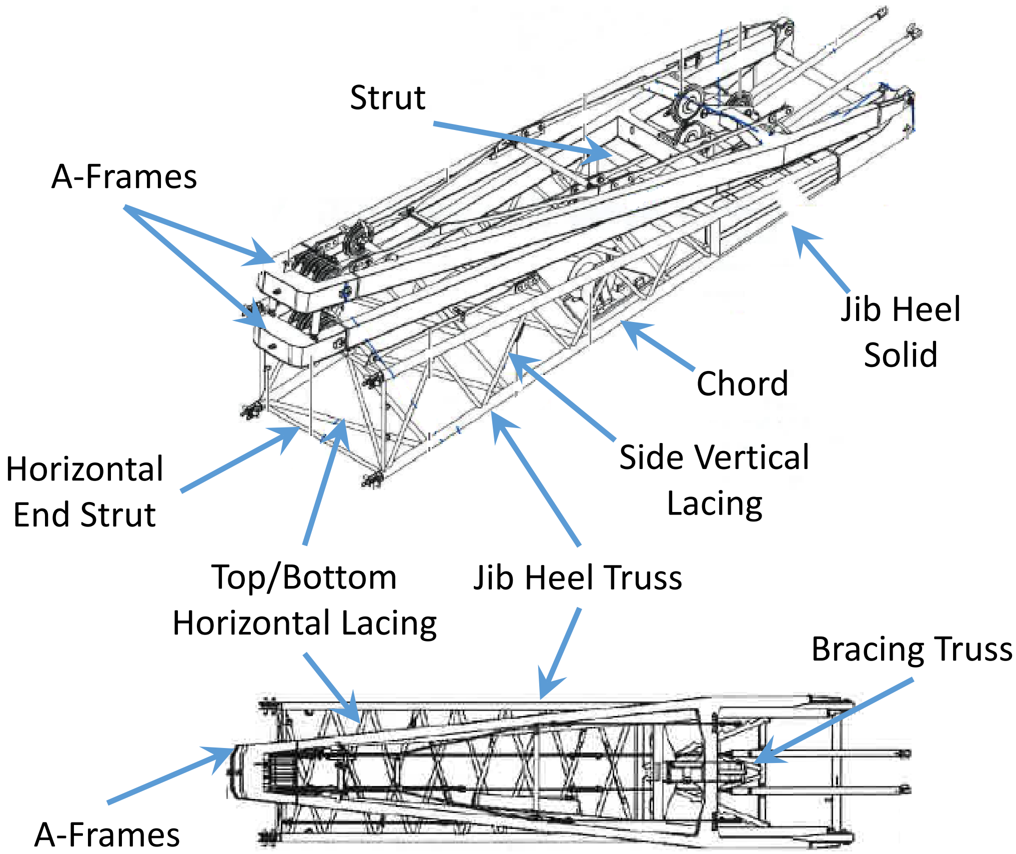


Figure 7 – Jib Heel Section Arrangement and Nomenclature

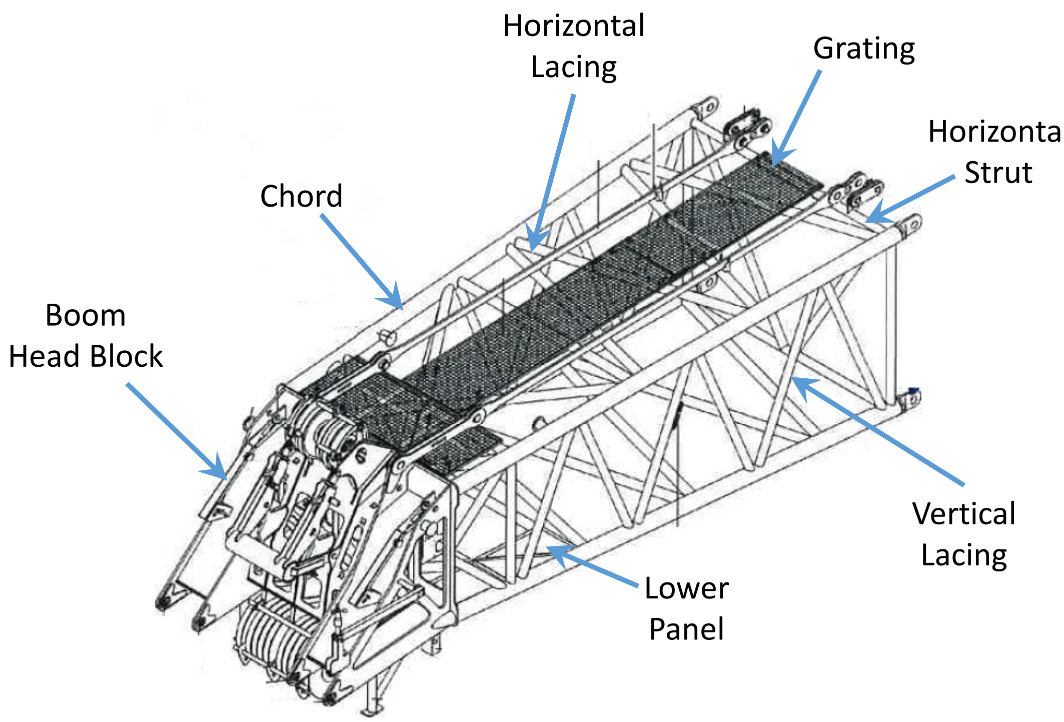


Figure 8 – Boom Head Section Arrangement and Nomenclature

3. DOCUMENTS REVIEWED

We reviewed documents pertinent to the design, erection, operation, and collapse of the crane. The following summarizes principal information pertinent to our analysis and investigation. Bulleted information is either paraphrased or quoted directly from the reference indicated.

3.1 Design Standards and Codes

ISO 4305-91: Mobile cranes – Determination of stability [Ref. 14]

The standard ISO 4305-91 is an international standard addressing the stability of mobile cranes. The 1991 version is incorporated by EN 13000:2004 [Ref. 4] and is referenced in the Liebherr stability calculation [Ref. 3]. We identified the following pertinent provisions of the standard:

> §3.2: Two loading conditions for forward stability are defined in Tables 1 and 2. For crawler cranes, the loading conditions are:
>
> - Table 1: $1.25P + 0.1F$
> - Table 2: $1.1P + W + D$
> - P is the rated capacity
> - F is the load at the hoist point that produces a moment about the boom pivot equal to the moment from self-weight of the boom and jib, and "is intended to simulate the dynamic forces arising during normal controlled operation."
> - W is the effect of in-service wind calculated in accordance with ISO 4302
> - D is "the inertial forces from hoisting, telescoping, slewing, luffing, or travel… For cranes having infinitely variable controls, the value of D shall be taken as 0."
>
> §3.5.1: "The value of P shall be such that, with loading conditions given in table 1 and table 2, in neither case shall the overturning moment of the crane be greater than the stabilizing moment."
>
> §A.3: "The tipping line for crawler cranes is defined as the line joining the axis of the sprocket wheels and the axis of the idler wheel."

We also reviewed the 2014 version of this standard and confirmed the safety factors have not changed from the 1991 version.

ISO 4302-81: Cranes – Wind load assessment [Ref. 13]

The standard ISO 4302-81 is an international standard addressing design wind loads on cranes. The 1981 version is incorporated by ISO 4305-91 [Ref. 14]. We identified the following pertinent provisions of the standard:

§2: The wind pressure is calculated from the formula $p = 0.613\ v_s^2$, where the pressure p is in Pa and the wind speed v_s is in m/s.

§3.1: In-service wind speed for normal cranes installed in the open shall be at least 20 m/s (44.7 mph) according to Table 1. The manufacturer may specify other in-service design wind speeds provided that value is stated on the crane certificate.

§3.1.1: Wind force on the suspended load for normal cranes in the open shall be 3% of the weight of the suspended load.

§4: Wind load F on a structure, component, or member is calculated from the formula:

$$F = A\ p\ C_f$$

where A is the effective frontal area, i.e., the solid area projected onto a plane perpendicular to the wind direction, p is the wind pressure, and C_f is the force coefficient. The design wind pressure may be taken as constant for every 10m vertical interval over the height of the crane. Alternatively, the actual design wind pressure at any height may be calculated, or the design wind pressure at the top of the structure may be taken as constant over the entire height.

§5.3: The overall force coefficient (i.e., drag factor) for lattice towers with round members varies from 1.2 to 2.4 for low wind speeds ($D\ v_s < 6m^2/s$) based on solidity ratio and spacing ratio, and is a constant 1.4 for high wind speeds ($D\ v_s \geq 6m^2/s$) where D is the diameter of the member. The overall force coefficient is applied to the solid area of the windward face.

§5.4: Force F along the wind direction where wind blows at an angle to the member or component is calculated as $F = A\ p\ C_f \sin^2\theta$, where A is the frontal area of the member or component, p is the wind pressure, C_f is the wind force (shape) coefficient, and θ is the angle between the member or component and the wind flow. Note: here F is a general wind force on a component or member and is not related to the equivalent boom and jib weight at the hoist point F in ISO 4305 [Ref. 14].

EN 13000:2004: Cranes – Mobile Cranes [Ref. 4]

EN 13000:2004 is a comprehensive standard for the design, construction, testing, and operation of mobile cranes and that contains provisions for stability. The 2004 version is referenced in the

Liebherr stability calculation [Ref. 3]. We identified the following pertinent provisions of the standard:

> §4.1.2.6: incorporates ISO 4305 for rigid body stability of the crane. Applicable for firm and level ground (up to 1% gradient)
>
> §4.1.2.6.3: When checking stability during erection and dismantling of the unloaded crane, loads that increase the tipping moment shall be amplified with a safety factor ≥ 1.1.
>
> Annex F: instead of an exact calculation of load effects due to acceleration, it is permitted to show that the tipping angle is greater than 4° for crawler cranes.

F.E.M. 1.004: Recommendation for the Calculation of Wind Loads on Crane Structures [Ref. 5]

The standard F.E.M. 1.004 is an industry standard for calculating wind loads on cranes of all types. We identified the following pertinent provisions of the standard:

> §5.4: Force F along the wind direction where wind blows at an angle to the member or component is calculated as $F = A\, q\, C_f \sin^2 \theta$, where A is the frontal area of the member of component, q is the wind pressure, C_f is the wind force (shape) coefficient, and θ is the angle between the member or component and the wind flow. Note: here F is a general wind force on a component or member and is not related to the equivalent boom and jib weight at the hoist point F in ISO 4305 [Ref. 14].

ASCE 7-10: Minimum Design Loads for Buildings and Other Structures [Ref. 2]

The standard ASCE 7-10 is an industry standard for calculating loads for structural design. The current version was published in 2010. We identified the following pertinent provisions of the standard:

> §29.5: "The design wind force for… trussed towers shall be determined by the following equation:
>
> $$F = q_z G C_f A_f$$
>
> where
>
> q_z = velocity pressure evaluated at height z… of the centroid of area A_f
> G = gust effect factor…
> C_f = force coefficients from Figs. 29.5-1 through 29.5-3
> A_f = projected area normal to the wind…"

Figure 29.5-3:

- The wind force coefficient for trussed towers having square cross-section is calculated from the solidity ratio ϵ:

$$C_f = 4.0\epsilon^2 - 5.9\epsilon + 4.0$$

- For towers made from round members, the wind force coefficient may be reduced by multiplying by the factor: $0.51\epsilon^2 + 0.57$, but not > 1.0
- The solidity ratio ϵ is the "ratio of the solid area to gross area of one tower face for the segment under consideration."

3.2 Reports, Calculations, and Other Documents

Liebherr Documentation for Determination of stability during erection and lay down of boom [Ref. 3]. Referred to herein as the "Liebherr Stability Calculation" or "LSC"

Following the accident, Liebherr analyzed the stability of an LR1300 crane according to design standards, and submitted a report documenting their analysis on 17 February 2016. We summarize pertinent information from their calculation as follows:

- The analysis considers an LR1300 crawler crane with a 194 ft boom and 371 ft luffing jib. The primary counterweight is 273 kip and the carbody counterweight is 126 kip.
- The stability limit states evaluated are those from ISO 4305-91 [Ref. 14] and EN 13000:2004 [Ref. 4].
- The weights and centers of gravity of eighteen components used in the calculation are presented in a table. The wind areas for the boom, jib, carbody, and crawlers are also given. The wind speed used in the calculation is 7 m/s (15.7 mph), which reportedly conforms to the operating manual.
- The report states that the "worst conditions in regard of stability" is an 80° boom and a 15° jib.
- The calculation evaluates stability in terms of the load that can be hoisted in a given configuration while providing the safety factors required by the design codes considered.
    - The calculation finds that the crane has adequate overturning resistance to satisfy the requirements of the design standards considered (allowable lifted load is greater than zero), for an 80° boom, a 15° jib, and a 7 m/s (15.7 mph) wind speed.
    - The stability of the crane is evaluated at other boom and jib angles "relevant…during erection". The report concludes that the crane is "physically stable" for boom angles 70°, 75°, and 80°, and jib angles between 15° and -30.3°. However, it concludes that the factor of safety required by EN 13000 is not provided for a 70° boom for some jib angles, and that this represents the critical angle during erection and laydown.

Ground bearing pressure of LR 1300 prepared by Neil Greenblatt/MRA Engineering (revision 1) dated 30 December 2015 [Ref. 7]. Referred to herein as the "MRA Ground Bearing Pressure Calculation" or "MGBP"

As part of the permit submittals for this project, MRA Engineering prepared a calculation of the maximum ground bearing pressure for the crane in operation. The calculation includes geometry of the crane, and summarizes the weight and center of gravity (CG) of the crane. We summarize pertinent information from their calculation as follows:

- The boom angle used in the analysis is 88°. The load radius is 128 ft.
- At the boom head, the offset from the boom axis to the jib heel pivot is 2.3 ft along the boom axis (up), and 3.0 ft transverse to the boom axis (forward).
- The weights and CGs for the major components are reported in Table 1. CG is relative to the boom pivot with the boom oriented forward and parallel to the crawlers. The "X" direction is parallel to the crawlers of the crane and the "Z" direction is vertical.

Table 1 – Component weights and centers of gravity used in MRA Engineering's Ground Bearing Pressure Calculation

Component	Weight, kip	CG X, ft	CG Z, f
Basic Machine	586.18	-9.324	6.990
Boom	61.44	4.560	91.721
Jib	58.49	49.401	330.325
Total	706.11	-3.252	41.148

AccuWeather NYC Crane Report [Ref. 16]

Following the accident, AccuWeather Forensics collected and reviewed available weather data to calculate the probable wind speed at the site at the time the crane overturned. They also reviewed forecasts leading up to the time of the accident. We summarize pertinent information from their report as follows:

- Weather forecasts in the afternoon of 4 February 2016 predicted wind gusts near the site up to 35 mph for 5 February 2016. Forecasts later in the evening of 4 February 2016 predicted wind gusts up to 35 mph for 5 February 2016.
- Based on their analysis of available weather data from several stations around the site, AccuWeather estimates the wind gusts at the time the crane overturned to be up to 45 mph at a height of 560 ft.
- The report states: "…videos taken around the time of the crane collapse show various impacts of these strong gusty winds being channeled along Worth Street in the vicinity of the crane...consistent with localized, enhanced wind speeds as high as 45 mph or greater due to the combination of channeling parallel to Worth Street and downwash from the 380-foot tall building on the south side of the street."

- Detailed computer modeling would be required to determine the wind flow field at the site, accounting for channeling, downwash, and other effects of the surrounding buildings.

- Snow was falling in the morning of 5 February 2016, and 2-3 in. fell by late morning. More than half of that had fallen by 8:00 a.m.

- The report states: "The wind speed at a certain height above ground level is:

$$v = v_{ref} \ln\left(\frac{z}{z_0}\right) \Big/ \ln\left(\frac{z_{ref}}{z_0}\right)$$

  v = wind speed at height z above ground level.
  v_{ref} = reference speed, i.e. wind speed we already know at height z_{ref}.
  z_0 = roughness length in the current wind direction…
  The appropriate roughness length to use … in Manhattan would be 1.6 [m]."

Liebherr responses to interrogatories dated 5 April 2016, 20 April 2016, and 6 June 2016 [Refs. 10-12]

As part of their investigation, CTS posed questions to Liebherr requesting additional information or clarification of materials provided. We summarize pertinent information from their responses as follows:

> 5 April 2016: Liebherr's stability calculation does not consider wind loads on components other than the boom, jib, and basic machine. Wind areas are provided for multiple boom and jib angles.
>
> 20 April 2016: In "assembly mode", the crane system will permit the operator to luff the jib down and move the boom up or down simultaneously.
>
> 6 June 2016: The MRA ground bearing pressure calculation differs from Liebherr's stability calculation because the two have different objectives, namely, ground bearing pressure calculations consider the heaviest basic machine while stability calculations consider the lightest basic machine.

4. INFORMATION OBTAINED FROM OTHERS

As part of our investigation, we received information from other parties. We summarize the principal information relevant to our analysis in the following subsections.

4.1 CTS Field Notes and measured component weights

We received notes prepared by Mr. Frank Hegan of CTS from his 4 March 2016 field visit. He noted dimensions of key components directly on a copy of the crane operator's manual [Ref. 8]. He also took photographs of the crane, which we reviewed.

On 4 March 2016 CTS weighed individual boom and jib sections, A-frames, rigging, pendants, carbody, operator's cab, crawlers, counterweights, and accessories, including the headache ball. We received and reviewed the results of the component weight measurements. Table 2 presents a summary of the measured weights.

Table 2 – CTS field-measured crane component weights

Component	Weight, kip
Basic Machine:	
Carbody and Cab	192.8
Counterweights	409.5
Subtotal Basic Machine	**602.3**
Boom:	
Boom Sections	49.1
Boom pendants	5.1
Subtotal Boom	**54.2**
Jib:	
Jib Sections & A-frames	45.6
Jib Pendants	8.5
Subtotal Jib	**54.1**
Accessories:	
Headache Ball	1.9
Other Components	16.9
Subtotal Accessories	**18.8**
Grand Total	**729.4**

4.2 CTS calculation of boom and jib angle

On 27 and 28 September 2016 CTS measured the length of the boom and jib winch ropes, measured the length of pendant bars of the boom and jib suspension systems, located the attachment points of the suspension and winch ropes, and collected other measurements needed to determine the angle of the boom and jib.

CTS concluded that at the time of the accident, without considering elongation or shortening of components under load, the nominal configuration of the crane was a 73° boom angle and a 51° jib angle. When CTS included the stress-induced elongation of the suspension pendant bars and winch rope in their calculations, they found the boom and jib angles to be 72° and 49°, respectively.

4.3 Interview summaries with project personnel

DOB interviewed the crane operator, rigging crew, and other project personnel on various dates. We received interview summaries prepared by Mr. Frank Hegan of CTS. The following information from the interview summaries is pertinent to our investigation and analysis:

- Interview of Kevin Reilly, crane operator:
    - At 7:40 a.m. on 5 February 2016, Mr. Reilly noted a wind gust of 20 mph and decided to jack-knife the crane (lower the jib and place the jib head on the ground resting on its wheels). He intended to follow the same procedure to jack-knife the crane as the crew had successfully used two days prior (3 February).
    - Just prior to collapse, Mr. Reilly had lowered the jib to approximately 45° with the boom at 80° from horizontal. He reported that he "reach[ed] back to push the setup button. And as [he] turn[ed] around, [he felt] the machine move." He tried to luff the jib back up and the crane collapsed.
    - Mr. Reilly reported that he used three sheets of 3/4 in. plywood to block the crawler tracks and engage the tumbler. In Mr. Reilly's opinion, this procedure is intended to extend the crane's tipping line forward.

- Interview of Greg Galasso, master rigger:
    - Mr. Galasso states that he is a Professional Engineer and a licensed Master Rigger. His duties include overseeing the rigging on the project.
    - He visited the site Thursday morning (the day prior to the accident). He stated that the cribbing "looked good" and that the crane level bubble indicated 1/2° off level.

- Interview of Brent Graham, rigging foreman:
    - Mr. Graham was the competent rigging person on site for the project.
    - He stated that there was a meeting on site Thursday afternoon (the day prior to the accident) when the team discussed the wind forecast for Friday, which called for wind exceeding 30 mph.
    - He recalled an accumulation of snow on the boom and jib shortly before the accident.

4.4 News Media

Several news outlets covered the accident and included photos taken after the accident. Some images appear to show ice accumulation on the crane jib. One such image is reproduced below in Figure 9. We do not know whether this ice was on the structure prior to the collapse.

Figure 9 – Possible ice accumulation on crane jib [Ref. 17]

5. FIELD INVESTIGATION

On 28 April 2016, we visited the laydown yard near 39th Street and 1st Avenue in Brooklyn, New York, where the wreckage of the crane was being stored. We understand that the crane had been brought directly from the project site to the yard. We observed the general condition of the debris, collected measurements of crane components, and took photographs to document the condition of the crane.

General Observations

We made the following general observations:

- The crane components were arranged on the ground in a yard with secured, restricted access. The components were placed on wooden blocking. The components were exposed to the weather.
- The boom and jib were disassembled into their individual sections and arranged in two rows. The counterweights and crawlers had been separated from the basic machine and laid out near the north corner of the laydown area. One of the A-frames had been removed from the jib heel. The suspension bars had been removed and placed in a bundle near the boom head. Two bins of miscellaneous components and debris were located on the northeast side of the laydown area.
- The boom and jib sections were numbered B1 through B6 and J1 through J11, according to their location, from the ground up, in the assembled crane.
- The majority of boom and jib sections had suffered some local plastic deformation to individual members but entire sections remained largely straight. In general, lacing members showed more extensive plastic deformation than did chord members.
- The boom heel section (B1) and the second last jib section (J10) had both been cut into two pieces.
- Each boom section had an FRP grating panel fastened to the back side (Photo 1). The same grating was fastened to the boom head (Photo 2) and jib heel (Photo 3).

Detailed dimensional measurements

We measured dimensions of the following components:

- **Typical boom section:** We measured typical boom section B3 (Photo 4), which appeared to have very little plastic deformation. We measured the total length, width, and depth of the section, the spacing of lacing bars on the side faces and top/bottom faces, and the circumference of chord members and lacing members on all faces. Our measurements are summarized in Table 3.
- **Typical jib section:** We measured typical jib section J6 (Photo 5), which appeared to have the least plastic deformation of the typical jib sections. We measured the total length, width, and depth of the section, the spacing of lacing bars on the side faces and

top/bottom faces, and the circumference of chord members and lacing members on all faces. Our measurements are summarized in Table 3.

- **Boom head section:** We measured key dimensions of the boom head, boom section B6 (Photo 6). We measured the dimensions and member sizes of the truss portion, the dimensions of the solid panels on the bottom side of the truss near the block, and the gross dimensions of the solid block at the tip of the boom head.

- **Jib heel section:** We measured key dimensions of the jib heel, jib section J1 (Photo 7). We measured the dimensions and member sizes of the truss portion, the dimensions of the solid triangular blocks at the base of the jib heel, and the gross dimensions and member sizes of the small bracing truss between the solid blocks at the base of the jib heel. We also measured the dimensions and member sizes of the A-frame still connected to the jib heel section

- **Jib head section:** We measured key dimensions of the jib head, jib section J11 (Photo 8 and Photo 9). We measured the dimensions and member sizes of the truss portion, the dimensions of the solid plates just below the tip, and the geometry and member sizes of the framing and sheaves at the tip of the jib head.

- **FRP grating panels:** We measured the FRP grating panels on the typical boom sections, the boom head section, and the jib heel section (Photo 10). The panels were 31.5 in. wide, with bars 0.25 in. thick in a grid spaced at 1.5625 in. We also measured the length of the panels on the boom head and jib heel sections.

- **A-frame at jib heel:** We measured key dimensions of the A-frame originally connected to the base of the jib heel (Photo 11). We measured the length and width of the A-frame, the width and depth of the members comprising the frame, and the location and size of the sheaves and shafts mounted to the frame.

Table 3 – Measurements of typical boom and jib section geometry and member sizes

Parameter	Typical Boom Section	Typical Jib Section
Total Section length, c/c of eyes [ft]	39.375	39.417
Total Section width, c/c of chords [ft]	9.188	7.521
Total Section depth, c/c of chords [ft]	6.885	5.417
Average lacing working-point spacing along chord [ft]	3.754	3.173
Chord circumference [in]	20.625	17.375
Vertical lacing circumference [in]	9.625	6.125
Horizontal lacing circumference [in]	11.125	7.750

The measurements are used to develop wind areas and drag factors to determine wind load on the crane in various configurations for the stability calculations described in Section 6.3. We did not weigh any components, nor did we measure thicknesses or other dimensions necessary to calculate component weights.

6. ANALYSIS OF OVERTURNING STABILITY

To determine the wind speed that would likely cause the crane to overturn, we performed an overturning stability analysis of the crane. We first repeated the Liebherr stability calculation according to the applicable design codes. Next, we determined the gravity and wind loads acting on the crane, and calculated the limiting wind speed for overturning stability. We also studied the sensitivity of our results to changes in various input parameters used in our analysis. All discussion, justification of assumptions, and interpretation of the results are presented in Section 7.

6.1 Static Overturning Stability According to ISO 4305 and EN 13000 Design Codes

The Liebherr Stability Calculation (LSC) [Ref. 3] reviewed in Section 3 evaluated the stability of the crane first for a boom angle of 80° and a jib angle of 15°, and then for a range of boom and jib angles, according to design codes ISO 4305 [Ref. 14] and EN 13000 [Ref. 4]. We repeated the LSC according to ISO 4305 and EN 13000 using the component weights, centers of gravity, and wind areas from the LSC as inputs to our calculation.

The two codes define three limit states for stability of the crane. The limit states as shown below are modified from the form given in each standard for consistency. Each term in the equations represents a moment about the tipping line of the crane, and the sum must be less than zero for the crane to be stable:

- ISO 4305 Table 1: $1.25P + 0.1F + SW_{ovt} - SW_{stab} < 0$
- ISO 4305 Table 2: $1.1P + W + D + SW_{ovt} - SW_{stab} < 0$
- EN 13000 §4.1.2.6.3: $1.1P + 1.1W + 1.1SW_{ovt} - SW_{stab} < 0$

Here, P is the suspended load, F is the equivalent weight of the boom and jib acting at the hoist point, W is the wind load, D is the inertial forces, SW_{ovt} is the overturning moment from self-weight, and SW_{stab} is the stabilizing moment from self-weight. Both F and D are intended to capture dynamic/inertial forces from operation of the crane [Ref. 14].

We calculated wind loads W according to ISO 4302 [Ref. 13] using wind areas (including drag factors) presented in the LSC. We considered the operating wind speed of 15.7 mph (7 m/s) used in Liebherr's calculation, applied uniformly over the height of the crane. We included a lateral wind force at the hoist point for wind on the suspended load equal to 3% of the weight of the suspended load, acting horizontally from the back of the crane towards the front. ISO 4305 states that for cranes with "infinitely variable controls" inertial forces, D, can be omitted.

Liebherr's calculation did not include inertial forces in the ISO 4305 Table 2 limit state, so we did not include these forces either for this calculation.

We present the results in terms of the allowable (factored) suspended load, P, for each limit state. Our results for each limit state are shown in Table 4, alongside the results from the LSC. The results were calculated for the boom at 80° and the jib at 15° subjected to the operating wind speed of 15.7 mph given in the operators' manual [Ref. 8].

Table 4 – Allowable suspended load for boom at 80° and jib at 15° for 15.7 mph wind

Code Reference	Limit State	Allowable Suspended Load, kip	
		LSC	SGH
ISO 4305 Table 1	$1.25P + 0.1F + W_{ovt} - SW_{stab} < 0$	6.28	6.19
ISO 4305 Table 2	$1.1P + W + D + W_{ovt} - SW_{stab} < 0$	8.62	8.60
EN 13000 Sec. 4.1.2.6.3	$1.1P + 1.1W + 1.1SW_{ovt} - SW_{stab} < 0$	6.44	6.37

6.2 Gravity Loads on the Crane

The MRA Ground Bearing Pressure Calculation (MGBP) [Ref. 7] reports values for the weight and center of gravity (CG) of the basic machine, boom, and jib that differ from those in the LSC [Ref. 3]. Although not given directly in the MGBP, from the jib radius of 128 ft we calculated that the jib angle used in that calculation was 72.3°.

Table 5 compares the summarized values from the two references, and also shows a summary of the CTS measured weights (see Section 4.1). The CG values are calculated for the boom at 88° and jib at 72.3°, the configuration given in the MGBP and the stamped rigging drawing [Ref. 6]. We also included 1.9 kip for the headache ball at the tip of the jib for all three sources of component weight data. CTS measured weights include an additional 16.7 kip of other components not attributed to the basic machine, boom, or jib. We further discuss the distribution of weight over the crane in Section 7.

Table 5 – Major component weights and centers of gravity calculated from Liebherr Stability Calculation [Ref. 3], Ground Bearing Pressure [Ref. 7]. Boom at 88°; jib at 72.3°

Component	Liebherr Stability Calculation			MRA Ground Bearing Pressure			CTS Field Weight, kip
	Weight, kip	CG X, ft	CG Z, ft	Weight, kip	CG X, ft	CG Z, ft	
Basic Machine	554	-23.7	7.2	586	-17.7	14.4	602.3
Boom	70	-10.7	102.7	61	-3.8	99.1	54.2
Jib	50	46.2	355.2	58	41.1	337.7	56.0
Headache ball†	1.9	114.2	556.3	1.9	114.2	556.3	1.9
Other	—	—	—	—	—	—	16.7
Total	676	-16.7	44.5	708	-11.2	49.9	729.4

Note: Centers of gravity are measured from the tipping line.
†1.9 kip headache ball added to all cases

Using the weights and centers of gravity from the MGBP, we calculated the allowable suspended load with the boom at 88° and the jib at 72.3° for the three limit states considered in the previous section (ISO 4305 Tables 1 & 2, and EN 13000 §4.1.2.6.3). The justification for selecting the weight and CG inputs from the MGBP is discussed in Section 7. We considered the boom and jib to be aligned with the crawler tracks, and a 15.7 mph wind blowing from behind the crane (see Section 6.3). In addition to the headache ball, we calculated the allowable suspended load to be 51.2 kip, governed by the EN 13000 limit state. In this configuration, the one analyzed in the MGBP calculation, the crane would provide the factor of safety against overturning required by the standards.

6.3 Wind Loads on the Crane

The overturning moment from wind load on the crane is additive with the overturning moments from self-weight and lifted load when the wind comes generally from behind the crane. Wind can cause overturning in any direction, but given that the crane toppled over the front of the crawlers we analyzed wind blowing from behind the crane.

6.3.1 Wind Velocity Profile with Height

The wind force on crane components is the product of the wind velocity pressure and the wind area (including drag factors) for that component. For out-of-service conditions, ISO 4302 [Ref. 13] permits the use of either uniform wind velocity over the height of the crane equal to the wind velocity at the top of the structure, or with wind velocity calculated at 10 m intervals over the height of the crane. We used both a uniform wind speed and a wind speed profile varying with height in our calculations. For a wind speed that varies with height, we used the log wind profile from the AccuWeather report (see Sec. 3.2 and Ref. 16) using a roughness length of 1.6 m (5.25 ft), which is suggested by AccuWeather for very large cities with tall buildings and skyscrapers. The profile is shown in Figure 10, with the values representing the multiplier to be applied to the wind speed at 482 ft above grade (the elevation of the jib head for the boom at 73° and the jib at 51°, the configuration that CTS calculated from their measurements taking the crane structure as rigid (see Section 4.2). The limiting wind velocity reported is the velocity at the 482 ft for all calculations to facilitate comparisons with the uniform wind pressure results.

We set the gust factor to one following the approach in ISO 4302 [Ref. 13]. The averaging period used is 3-sec gust, compatible with ASCE 7 [Ref. 2].

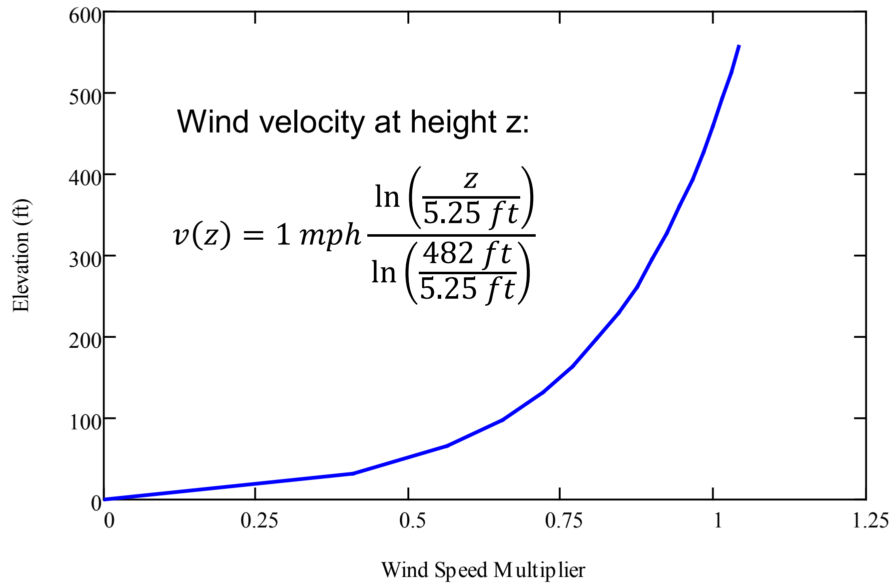


Figure 10 – Wind velocity prolile as a function of height, defined equal to 1 mph at 482 ft above grade (jib head elevation for boom at 73° and jib at 51°)

6.3.2 Wind Areas

We calculated wind areas for the boom and jib based on our field measurements described in Section 5, supplemented by dimensions given in CTS field notes on the operator's manual [Ref. 8]. We calculated the wind areas of the following components:

- Typical boom and jib sections,
- Boom head,
- Jib heel, and
- Jib head.

Because the boom heel is close to the ground it has a negligible effect on the overturning moment from wind, and we assigned the wind area of a typical boom section to the boom heel rather than perform a detailed calculation of the boom heel wind area.

We calculated nominal wind areas for the boom and jib, both at 90° (dead vertical). To determine the wind area at other angles, we multiplied the nominal wind area by the square of the sine of the angle of the component from the horizontal, according to ISO 4302 [Ref. 13] and F.E.M. 1.004 [Ref. 5]. We note that Liebherr calculated wind areas at different angles by multiplying by the sine of the angle rather than sine-squared. Discussion of wind areas at an angle to the flow is presented in Section 7.

Typical Sections

We calculated the wind area of typical boom and jib sections (Figure 5) using wind force coefficients (drag factors) for trussed towers in ASCE 7 [Ref. 2]. The justification for calculating drag factors according to ASCE 7 is included in Section 7. The drag factors for trussed towers in ASCE 7 are calculated from the solidity ratio of the tower face on which the wind acts. The drag factor was calculated from the solidity ratio of the single face, and a reduction factor for round members was applied. For boom sections, we included the FRP grating in the solid area and used the combined tower truss face and grating to calculate the drag factor.

Boom Head

The boom head is separated into the truss portion, the grating, and the block portion (Figure 8). We calculated the wind area of the truss portion with attached FRP grating using the same solid area and drag factors for trussed towers approach used for the typical boom and jib sections described above. For the block, we calculated the wind area using the gross dimensions and a drag factor $C_f = 1.05$ [Ref. 18], assuming the block under wind load behaves as a solid cube.

Jib Heel

The jib heel is separated into the truss portion, the grating, the solid triangular blocks at the base of the jib heel, and the small bracing truss between the solid triangular blocks (Figure 7). We calculated the wind area of the truss portion with attached FRP grating and the bracing truss using the same solid area and drag factors for trussed towers approach used for the typical boom and jib sections described above. For the triangular blocks, we calculated the wind area using the gross dimensions and a drag factor $C_f = 2.16$ [Ref. 18], assuming the blocks under wind load behave as a solid rectangular sections with sufficient length to be approximated by 2D flow. We used the average aspect ratio of 0.27 for the triangular blocks.

Jib Head

The jib head is separated into the tapered truss portion, the plates just below the tip, and the framing and sheaves at the tip of the jib head (Figure 6). We calculated the wind area of the truss portions using the same solid area and drag factors for trussed towers approach used for the typical boom and jib sections described above. For the plates, we calculated the wind area using the gross dimensions and a drag factor $C_f = 2.0$ [Ref. 18], assuming they act as a flat plate.

Comparison of wind areas from field measurements with values provided

We compare the wind area we calculated from our field measurements to the values from the LSC in Table 6. Results are presented for the boom and jib alone, as well as for both the boom and jib together. The overturning moment about the tipping line from a unit wind pressure uniform over the height of the crane shows that the moment calculated using wind areas developed from our field measurements are approximately 6% lower than the moment calculated using Liebherr's wind areas for the full crane.

Table 6 – Wind areas and centers of pressure from Liebherr stability calculation and calculated from SGH field measurements

	Parameter	Wind Area Basis	
		LSC Wind Area [Ref. 3]	SGH Wind Area
Boom	Wind Area [ft^2]	910	996
	Center of Pressure above ground [ft]†	96.2	113
	Unit Wind Moment [kip-ft/psf]	88	113
	Unit Wind Moment [% w.r.t. Liebherr]	100%	128.7%
Jib	Wind Area [ft^2]	1203	1064
	Center of Pressure above ground [ft] †	374	371
	Unit Wind Moment [kip-ft/psf]	450	394
	Unit Wind Moment [% w.r.t. Liebherr]	100%	87.7%
Total	Wind Area [ft^2]	2114	2060
	Center of Pressure above ground [ft] †	254	246.2
	Unit Wind Moment [kip-ft/psf]	537	507
	Unit Wind Moment [% w.r.t. Liebherr]	100%	94.4%

†For the boom and jib at 90° (dead vertical)

6.4 Static Overturning Stability for Variable Boom and Jib Angles

We generalized the calculation presented in Section 6.1 to analyze the overturning stability of the crane at arbitrary boom and jib angles. We calculated stability in terms of the limiting wind speed, uniform over the height, at which overturning would occur for the crane in that configuration.

For this calculation, we used the component weights and centers of gravity provided in the MGBP [Ref. 7], and the wind areas for the boom and jib provided in the LSC [Ref. 3]. We did not include wind load on the basic machine since the overturning moments from that load are negligible. The justification for using these inputs is discussed in Section 7. To determine the wind area for the boom and jib at different angles, we scaled the wind areas by the square of the sine of the angle of that component from horizontal, following the provisions of standards ISO 4302 §5.4 [Ref. 13] and F.E.M. 1.004 §5.4 [Ref. 5]. The limiting wind speeds are shown in Table 7 and at higher resolution in the region of the configuration at collapse in Table 8.

Table 7 – Limiting wind speed [mph] for variable boom and jib angles†. Wind speed constant over the height of the crane.

Jib Angle deg.	Boom Angle, deg.												
	60.0	62.5	65.0	67.5	70.0	73.0	75.0	77.5	80.0	82.5	85.0	87.5	90.0
-36	Jib tip below ground surface												
-33											79	92	104
-30									29	57	75	90	102
-27									13	52	72	87	101
-24										46	69	85	99
-21										40	66	84	99
-18										33	63	82	98
-15										26	60	81	98
-12										17	58	80	98
-9											57	80	98
-6											55	80	98
-3											55	80	99
0											55	80	99
3											56	80	99
6											57	81	99
9										15	58	81	98
12			Unstable							24	60	81	97
15										31	61	81	96
18										37	63	80	95
21										42	64	80	93
24									5	46	65	79	92
27									24	50	66	79	90
30									32	52	67	78	88
33									38	55	67	78	87
36								21	43	57	68	77	86
39								30	46	58	68	77	84
42							12	36	49	60	69	76	83
45							25	41	52	61	69	76	83
48						16	32	44	54	62	69	76	82
51						26	37	48	56	63	70	76	82
54					8	33	41	50	58	64	70	76	81
57					22	38	45	53	59	65	71	76	81
60				12	30	42	48	55	61	67	72	77	81
63				24	35	45	51	57	63	68	72	77	81
66			17	30	40	48	53	59	64	69	73	78	82
69			26	36	43	51	56	61	66	70	74	78	82
72			32	40	47	54	58	63	67	71	75	79	83
75			37	44	50	56	60	65	69	73	76	80	84

† Blue-outlined value corresponds to the configuration calculated by CTS without elongation (see Section 4.2); black-outlined value corresponds to the configuration according to the operator (see Section 4.3).

Table 8 – Limiting speed [mph] for boom and jib angles in the region of the configuration at the time of collapse†. Wind speed constant over the height of the crane.

Jib Angle deg.	Boom Angle, deg.																								
	70.0	70.5	71.0	71.5	72.0	72.5	73.0	73.5	74.0	74.5	75.0	75.5	76.0	76.5	77.0	77.5	78.0	78.5	79.0	79.5	80.0	80.5	81.0	81.5	82.0
36															12	21	27	32	36	39	43	46	49	52	54
37														7	18	24	29	34	37	41	44	47	50	52	55
38														15	22	27	32	36	39	42	45	48	51	53	55
39													12	20	25	30	34	37	41	44	46	49	51	54	56
40					Unstable							7	17	23	28	32	36	39	42	45	47	50	52	55	57
41												15	21	26	31	34	38	41	43	46	48	51	53	55	57
42											12	20	25	29	33	36	39	42	45	47	49	52	54	56	58
43										9	18	23	28	31	35	38	41	43	46	48	50	52	54	56	58
44									5	16	22	26	30	33	36	39	42	44	47	49	51	53	55	57	59
45									14	20	25	29	32	35	38	41	43	46	48	50	52	54	56	58	59
46								12	19	23	27	31	34	37	40	42	44	47	49	51	53	55	56	58	60
47							10	17	22	26	30	33	36	39	41	43	46	48	50	52	53	55	57	59	60
48						7	16	21	25	29	32	35	37	40	42	44	47	49	50	52	54	56	57	59	61
49					4	14	20	24	28	31	34	37	39	41	44	46	48	49	51	53	55	56	58	60	61
50					13	19	23	27	30	33	36	38	40	43	45	47	49	50	52	54	55	57	59	60	62
51				12	18	22	26	29	32	35	37	40	42	44	46	48	49	51	53	54	56	58	59	61	62
52			11	17	22	25	28	31	34	36	39	41	43	45	47	49	50	52	54	55	57	58	60	61	62
53		9	16	21	25	28	31	33	36	38	40	42	44	46	48	49	51	53	54	56	57	59	60	61	63
54	8	15	20	24	27	30	33	35	37	39	41	43	45	47	49	50	52	53	55	56	58	59	61	62	63
55	15	19	23	26	29	32	34	37	39	41	43	45	46	48	50	51	53	54	56	57	58	60	61	62	64

† Blue-outlined value corresponds to the configuration calculated by CTS without elongation and red-outlined value is with elongation (see Section 4.2); black-outlined value corresponds to the configuration according to the operator (see Section 4.3)

The results show that the crane would be unstable at any wind speed for boom angles below 62.5° and would have a limiting wind speed exceeding 55 mph for boom angles of 85° or more, regardless of the angle of the jib. The limiting wind speeds are controlled by ISO 4305 Table 1 [Ref. 14] and EN 13000 §4.1.2.6.3 [Ref. 4].

According to EN 13000 Annex F (refer to Sec. 3.1), as a simplified alternative to an exact calculation of load effects from acceleration it is sufficient to show that the tipping angle exceeds 4° for stationary crawler cranes. The calculation treats the crane components as rigid bodies.

To investigate this simplified approach we calculated the tipping angle: the angle of a vector from the tipping line to the center of gravity of the entire crane measured from vertical. Figure 11 shows the combinations of boom and jib angle that produce tipping angles of 0° (stability limit) and 4° (Annex F limit). The tipping angle with the boom at 73° and the jib at 51° is 0.9° and does not meet the alternative Annex F provision. Interpretation of this result is included in Sec. 7.

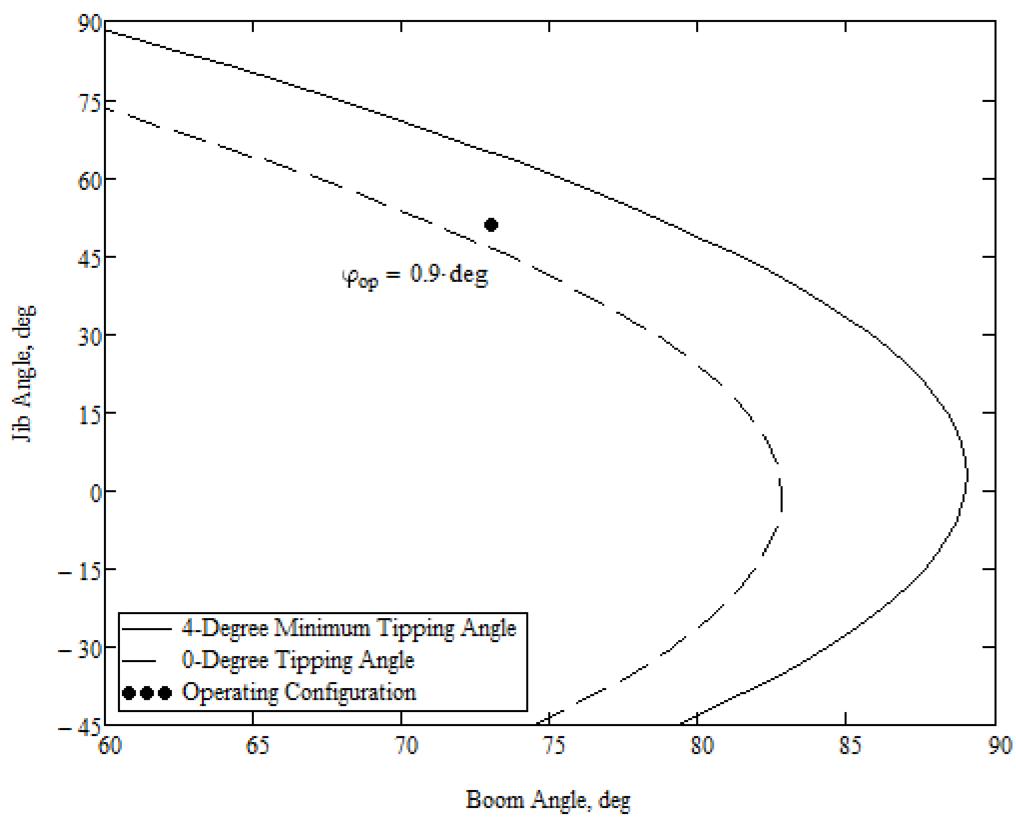


Figure 11 – Tipping angle limits for arbitrary boom and jib angles: EN 13000 Annex F

6.5 Sensitivity Analysis

We performed sensitivity studies of various input parameters to determine their effect on the stability of the crane in terms of the limiting wind speed that would cause overturning of the crane with the boom at 73° and the jib at 51°, the configuration after the accident CTS calculated from field measurements of the winch rope length and other dimensions, treating the crane components as rigid (see Section 4.2). As in Section 6.4, we used component weights and CGs reported in the MGBP [Ref. 7], and wind areas reported in the LSC [Ref. 3] as the baseline for our sensitivity study, varying one parameter at a time (while holding all others constant), and quantifying the change in the limiting wind speed over the range considered for that parameter. We did not include a suspended load on the crane. Without including safety factors in the calculations, we calculated the stability limit (the wind speed that, if sustained, is sufficient to cause overturning) rather than evaluating limit states specified by design codes. Unless otherwise noted, we took the wind speed as constant over the height of the crane for these sensitivity analyses. The justification for using these inputs in the sensitivity calculations is discussed in Section 7.

6.5.1 Sensitivity to Basic Machine Center of Gravity

We calculated the limiting wind speed of the crane for stability as a function of the location of the basic machine CG relative to the tipping line. We held the weight of the basic machine constant and varied its location between the CG of the primary counterweight given in Ref. 3 and the stability limit where the crane would overturn under self-weight alone.

We found that the limiting wind speed would vary significantly as the CG of the basic machine shifts relative to the tipping line. The relationship is highly nonlinear: For the boom angle of 73° and the jib angle of 51°, we find the following:

- If the CG of the basic machine is 17.7 ft aft of the tipping line, the value given in the MGBP [Ref. 3], the limiting wind speed is 26 mph.
- If the CG of the basic machine is 23.5 ft aft of the tipping line, the value given in the LSC [Ref. 7], the limiting wind speed is 70 mph.
- For a hypothetical position of the CG of the basic machine at 16.7 ft aft of the tipping line, the limiting wind speed would be zero. If the CG of the basic machine were closer to the tipping line than 16.7 ft, the crane would be unstable under self-weight.

6.5.2 Sensitivity to boom and jib angle

The limiting wind speed as a function of boom and jib angle is presented generally in Table 7 and at higher resolution for the configurations of interest at the time of collapse (as calculated by CTS and reported by the operator) in Table 8. Relative to the configuration CTS calculated without considering elastic stretch of the suspension pendant bars or winch rope (73° boom angle, 51° jib angle) a 1° reduction in boom angle would lower the limiting wind speed by 31% and a 1° reduction in jib angle would lower the limiting wind speed by 12%. Including the elongation of the suspension pendant bars and winch rope CTS calculated a boom angle of 72° and a jib angle of 49°. In that configuration the limiting wind speed would be 4 mph.

6.5.3 Sensitivity to Tipping Line Location

We evaluated the sensitivity of the stability of the crane to the location of the tipping line, using the boom pivot as a fixed reference point on the basic machine. We considered a shift in the tipping line of 6 in. forward and 1 ft aft, equivalent to 6% and 12%, respectively, of the distance from the boom pivot to the nominal tipping line, and calculated the limiting wind speed. The results are shown in Figure 12.

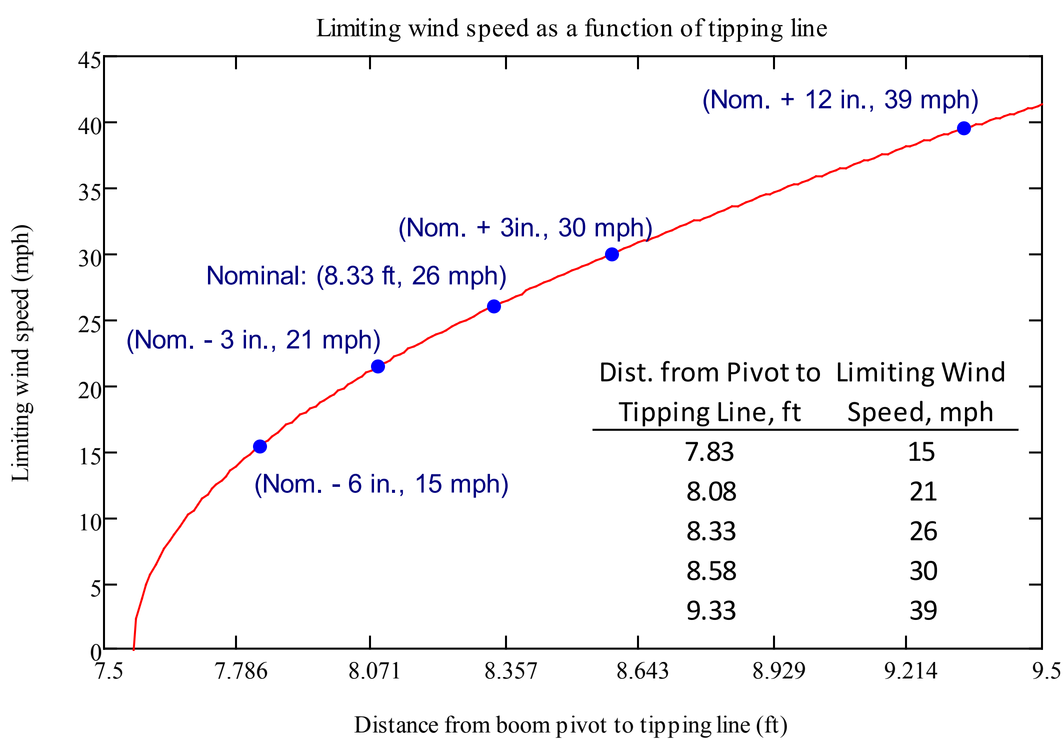
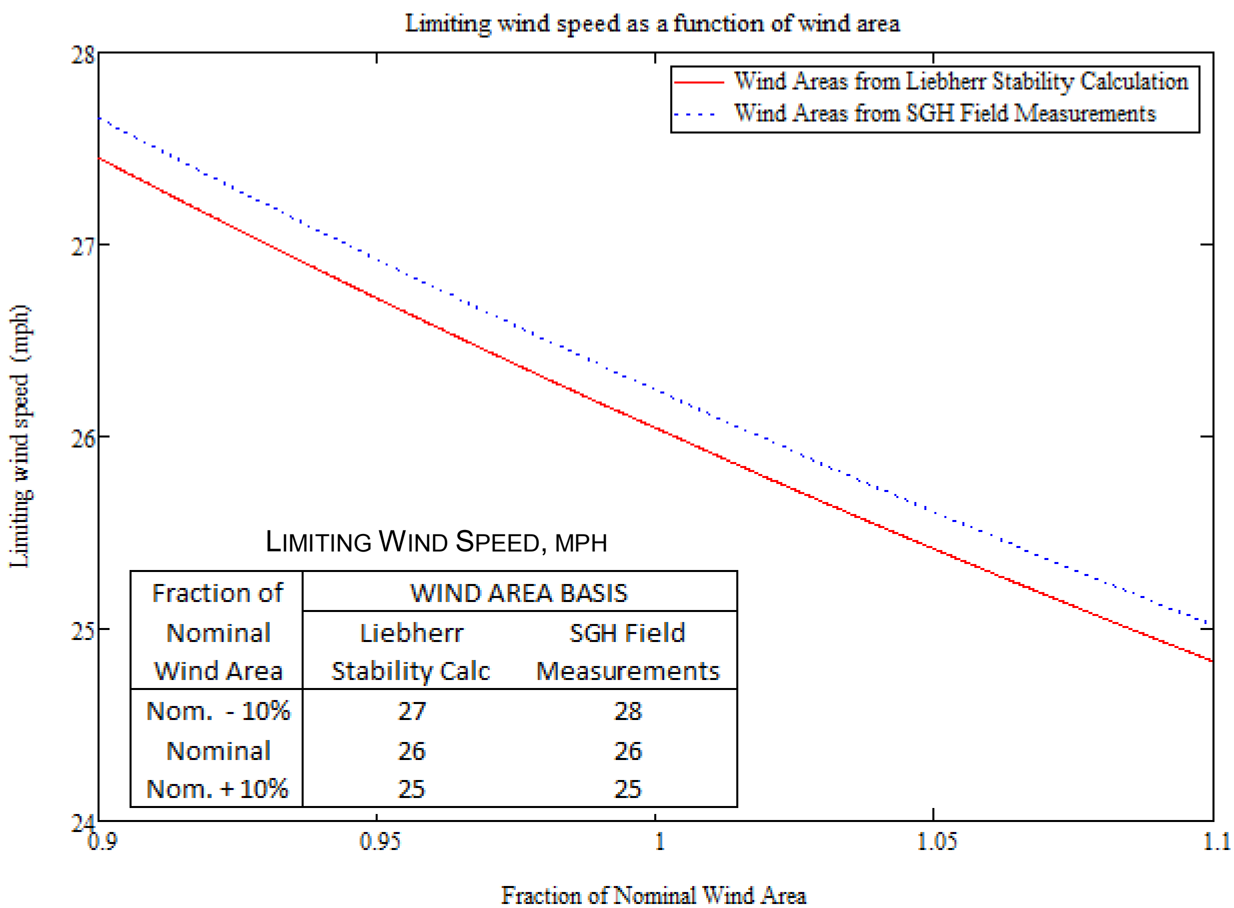


Figure 12 – Sensitivity of overturning stability to the location of the tipping line

The results show a non-linear variation of limiting wind speed with shifts in the tipping line. For a 3 in. change in the location of the tipping line with respect to the boom pivot, the limiting wind speed would change by about 15%.

6.5.4 Sensitivity to Wind Area

We evaluated the sensitivity of the stability of the crane to the wind area used in our calculation. For wind areas from the LSC, and wind areas calculated from SGH field measurements (see Section 6.3), we varied the nominal wind area ±10%, and calculated the limiting wind speed. The results are shown in Figure 13.



Fraction of Nominal Wind Area	WIND AREA BASIS	
	Liebherr Stability Calc	SGH Field Measurements
Nom. - 10%	27	28
Nominal	26	26
Nom. + 10%	25	25

Figure 13 – Sensitivity of overturning stability to wind area

The results show that the limiting wind speeds calculated using wind areas from the LSC and wind areas developed from our field measurements are within 1 mph of each other over the range of wind areas considered. Varying each wind area by 10% results in a roughly linear variation in limiting wind speed of about 5%.

6.5.5 Sensitivity to Component Mass/Inertial Forces

We evaluated the sensitivity of the stability of the crane to the weight of the boom and jib, and to dynamic/inertial forces that could arise during operation. We considered a change in weight of the boom and jib between -5% and +10% and calculated the limiting wind speed for both a uniform wind speed over the height of the crane and a wind speed profile calculated at 10 m intervals. We did not vary the weight of the basic machine. The results are shown in Figure 14.

The results show a non-linear variation in limiting wind speed with changes to the weight of the boom and jib. A 5% increase in the weight of the boom and jib would decrease the limiting wind speed by about 38% for uniform wind speed and 36% for wind speed calculated at 10-m intervals. A 5% decrease in the weight of the boom and jib would increase the limiting wind speed by about 27% for uniform wind speed and 25% for wind speed calculated at 10-m intervals. An increase in boom and jib weight of 8.6% or greater would cause overturning of the crane under self-weight alone.

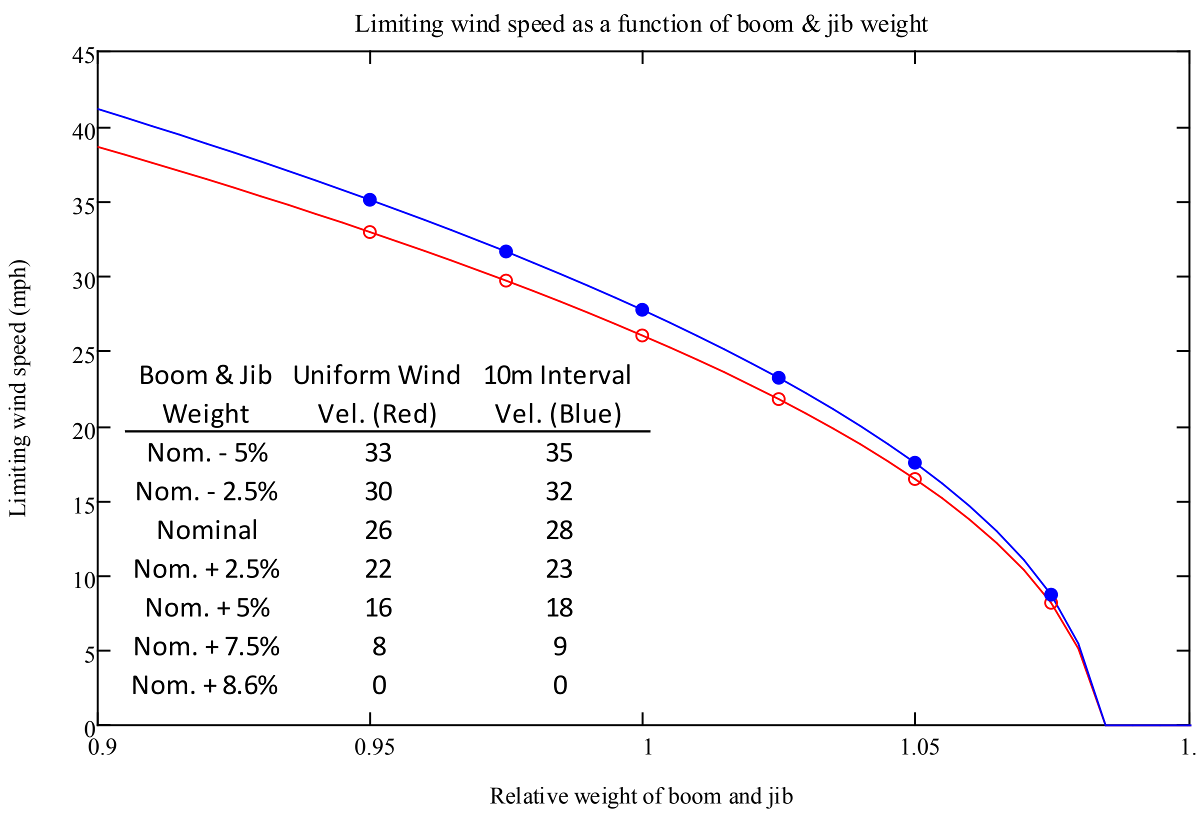


Figure 14 – Sensitivity of overturning stability to boom and jib weight/inertial forces

7. DISCUSSION

We discuss the results of our analyses, the assumptions made in those calculations and their justification, and the sensitivity of our results to various input parameters.

Weight Distribution

Two documents provide information regarding the distribution of weight throughout the crane: Liebherr's stability calculation (LSC) [Ref. 3] and MRA Engineering's ground bearing pressure calculation (MGBP) [Ref. 7]. According to Liebherr [Ref. 10], the calculations have different objectives (critical ground bearing pressure versus critical stability) and therefore two different configurations of the crane are considered. The most significant differences between the two sets of weight distributions are the total weight of the crane, and the location of the CG of the basic machine relative to the tipping line of the crane. A detailed breakdown is presented in Section 6.2 and Table 5.

Liebherr checked the stability of the crane according to ISO 4305 and EN 13000 and found, based on the weight distribution they analyzed, that the crane met the stability limit states of those standards with the required safety factors [Ref. 3] for the operating wind speed of 15.7 mph (7 m/s) given in the operator's manual, for boom angles of 80° and 75°, and jib angles between 15° and -30.3°. We replicated their result in our own calculations (Section 6.1), considering the boom at 80° and the jib at 15°. We also found that the crane with those boom and jib angles, and with the weight distribution based on the MGBP, would meet the stability limit states of ISO 4305 and EN 13000.

As part of its investigation, CTS weighed the recovered crane components (see Section 4.1). They recorded a total weight of 729.4 kip for all crane components. The total weight used in the LSC plus the headache ball is 676 kip. The total weight used in the MGBP plus the headache ball is 708 kip. Since the MGBP is part of the permit submittals for this specific project, and the total weight is closer to the total measured weight, we used the weight distribution from the MGBP with the addition of the headache ball at the jib head tip for the remainder of our calculations.

Wind Speed Profile with Height

To evaluate the sensitivity of calculations to wind profile over the height of the crane, we calculated crane stability using both a uniform wind speed over the height, and a profile of wind speed that varied with height according to the wind profile from the AccuWeather report (see Sec. 6.3.1 and Ref. 16). Both approaches are permitted by ISO 4302 [Ref. 13].

The velocity profile shown in Figure 10 is hypothetical, and approximates the change in wind speed with height for air flowing above a major city. It does not capture the local effects specific to the site. AccuWeather reported that given the complexity of the flow around buildings at the site, computer models of air flow around the nearby buildings would be necessary to ascertain the local flow conditions including downwash, channeling, etc.

Using the wind speed profile varying with height, we found that the wind speed at the jib head at the stability limit increased by approximately 8% compared with the uniform pressure case for the boom at 73° and the jib at 51° (see Section 4.2).

Wind Areas

We measured the geometry and member sizes of the recovered crane components, and calculated effective wind areas including drag factors from these measurements (see Section 6.3 and Table 6). We evaluated approaches published in ASCE 7 [Ref. 2] and ISO 4302 [Ref. 13] for typical boom and jib sections and found that these two approaches are in general agreement. Our calculations following ASCE 7, and based on measurements of the boom head, jib heel, jib head, and typical boom and jib sections, found moments from wind load on the boom and jib at 90° that were within 6% of the moments calculated from wind areas used in the LSC for the boom and jib considered together. Because of the general agreement between our calculated wind areas and the values used in the LSC, we used the wind areas from the LSC in the remainder of our calculations.

To calculate the appropriate wind area of the boom and jib at angles other than 90° (dead vertical), we scaled the areas by the square of the sine of the angle of that component from horizontal:

$$A_w(\theta) = A_w^o \sin^2 \theta$$

Based on Liebherr's 5 April 2016 response to interrogatories, where they provided wind areas at several boom and jib angles (see Section 3.2 and Ref. 10), we determined that the LSC [Ref. 3] scales the wind areas by the sine of the angle only (not sine-squared). However, scaling by sine-squared is supported by the standards ISO 4302 §5.4 [Ref. 13] and F.E.M. 1.004 §5.4 [Ref. 5] and results in smaller wind areas – and therefore higher limiting wind speeds in the stability calculations – for inclined components. Multiplying by sine-squared is intended to capture the effect of the reduced projected area and the incline of the surface on which the wind pressure acts.

Limiting Wind Speed for Stability

We adapted our stability calculation to determine the limiting wind speed at arbitrary boom and jib angles. As discussed in above, we used the weight distribution from the MGBP [Ref. 7], plus the headache ball and the wind areas from the LSC [Ref. 3] as the bases for our analysis. We considered the limiting wind speed to be constant and uniform over the height of the crane, following ISO 4302 §4 [Ref. 13].

In interviews, the crane operator reported that just prior to the collapse, the approximate boom and jib angles were 80° and 45°, respectively (see Section 4.3). We calculated that the limiting wind speed in this configuration would be 52 mph, under the assumptions discussed above.

However, based on their measurement of the winch ropes and suspension pendant bars, CTS calculated the boom and jib angles at the time of collapse were 73° and 51°, respectively (see Section 4.2). We calculated that the limiting wind speed in this configuration would be 26 mph. We also calculated the limiting wind speeds for ranges of boom and jib angles, and these are presented in Table 7.

Adopting the profile of wind speed varying with height, the wind speed at the jib head at the stability limit would increase from 26 to 28 mph for the crane with boom angle 73° and jib angle 51°.

Sensitivity

The overturning stability of the crane is a result of the balance of moments about the tipping line. The moments arise from self-weight and wind loads on the crane, inertial loads from operation, and the suspended (lifted) load at the hoist point. The overturning and stabilizing moments from self-weight are the two largest terms in the moment balance for most boom and jib angles, and the magnitudes of the overturning and stabilizing moments are similar to each other for many combinations of boom and jib angle. The limiting wind speed is a function of this small difference between the large self-weight moments. As a result, the system is sensitive to changes in the input parameters, and becomes more sensitive the closer the crane configuration is to the stability limit – the boundary of the region marked “Unstable” in Table 7. We evaluated the sensitivity of the crane stability with the boom at 73° and the jib at 51° as calculated by CTS without elongation (see Section 4.2).

We previously discussed the two sources of weight distribution information and the justification for selecting the weight distribution from the MGBP [Ref. 7] for the balance of our calculations.

The most significant difference between the two distributions is the location of the basic machine CG from the tipping line, and Section 6.5.1 and Figure 12 show the dependence of limiting wind speed on that distance. The limiting wind speed is sensitive to the location of the CG of the basic machine, and the dependence is nonlinear. We understand that it was not feasible for CTS to verify the location of the CG of the basic machine during their site investigation, and although they requested additional information from Liebherr to resolve the possible discrepancy in the CG of the basic machine, at the time of preparing this report we have yet to receive a response. Given the information available at the time of writing, including CTS measured weights (Section 4.1) and the rigging permit submittal drawing [Ref. 6], it is our opinion that the weight distribution from the MGBP used in the analysis we present here is likely a better representation of the crane than the distribution from the LSC.

In interviews, the crane operator reported that site personnel blocked the crawler tracks with plywood, an action intended to increase the distance from the boom pivot to the tipping line and improve the stability of the crane (Section4.3). We evaluated the sensitivity of the limiting wind speed to the distance from the boom pivot to the tipping line. The results are shown in Figure 12. Our results show that shifting the tipping line by 3 in. would change the limiting wind speed by 15-20% for the boom at 73° and jib at 51°.

This sensitivity near the stability limit is evident in Table 8 where results are presented for boom and jib angles varying by small amounts around the likely configuration at the time of collapse. CTS made two calculations of the boom and jib angle based on measurements of the winch rope and pendant bar lengths. When all components were considered to be rigid, they calculated boom and jib angles of 73° and the jib at 51°, respectively, and we calculate the limiting wind speed in that configuration to be 26 mph. Including the elastic stretch of the pendant bars and winch rope, CTS calculated boom and jib angles of 72° and the jib at 49°, respectively. In that configuration, a 1° reduction of boom angle and 2° reduction of jib angle, the limiting wind speed would be 4 mph.

We evaluated the sensitivity of the limiting wind speed to the wind area used in the calculation. The results are shown in Figure 13. Wind force, and therefore the wind moment, scales linearly with the wind area. Wind speed, however, scales with the square root of the wind force. For that reason, over the range of wind areas considered for our sensitivity analysis the limiting wind speed does not depend strongly on the wind area; a 10% change in wind area yields a 5% change in the limiting wind speed. The plot also shows general agreement between our wind areas calculated from field measurements and common approaches to estimate wind blockage of truss structures (see Sections 5 and 6.3), and the wind areas given in the LSC [Ref. 3]. This similarity supports the use of the LSC wind area values in the analyses we present here.

We evaluated the sensitivity of the limiting wind speed to the weight of the boom and jib, and the results are shown in Figure 14. Different factors could contribute to an actual weight being higher than the values from the MGBP used in our analyses, and the component weights CTS measured on site do exceed the values we used:

- Manufacturing tolerances allow for variability in weight of hollow steel sections. Depending on the standard to which the tubes were manufactured, the weight of round HSS could vary by ±3.5% (ASTM A501) or as much as ±10% (ASTM A53) [Ref. 1].
- Rigging or other accessories that were not included in the input data used in the MGBP may have been present on the crane increasing the effective weight of the boom and jib.
- Ice, water, and/or snow might have accumulated on the lattice structures of the boom and jib. Lattices have high surface area and their weight is sensitive to thin films and coatings. In interviews, the crew reported snow on the crane but did not recall the amount (see Section 4.3). News photos of the event appear to show ice on the crane (Section 4.4, Figure 9), though it is not certain that this ice was on the structure prior to the collapse.

Considering an increase in weight of the boom and jib of 5% to account for the factors listed above, the limiting wind speed would decrease by about 38%, from 26 mph to 16 mph for uniform wind speed over the height.

In interviews, the operator reported that just prior to the collapse he had luffed the jib down to about 45°, then reached behind himself to change the crane's mode to "assembly" when he felt the crane begin to overturn (see Section 4.3). To the extent this action resulted in slowing the jib, the force required to arrest the downward motion of the jib increased the apparent weight of the jib. The effect of this inertial force is also captured in the sensitivity study presented in Figure 14.

Inertial (or dynamic) force is accounted for in the ISO 4305 Table 1 [Ref. 14] limit state by including an additional load at the hoist point that produces an overturning moment equivalent to a 10% increase in the weight of the boom and the jib (denoted $0.1F$ in Section 6.1). Without additional information on the rate at which the operator luffed the boom and the braking characteristics of the crane, we evaluated the influence of inertial forces on the stability of the crane. The crane would become unstable with an increase of 8.6% in the weight of the boom and jib, for a boom angle of 73° and jib angle of 51°.

The design code EN 13000 Annex F [Ref. 4] permits a simplified calculation to show that the tipping angle of the crane is greater than 4° instead of detailed stability calculation including inertial forces. We found that for the boom at 73° and jib at 51°, the tipping angle is 0.9° (Figure 11) and therefore the simplified tipping angle calculation is not sufficient to prove safety against overturning.

For each of the conditions addressed in the foregoing sensitivity study on component mass and inertia effects, we also considered a wind speed profile varying with height. At the stability limit with varying wind speed, the wind speeds reported are those at the jib head, 482 ft above the street level:

- For the nominal case, with the boom at 73°, jib at 51°, component weight and CGs from the MGBP [Ref. 7], the wind speed at the jib head at the stability limit would be 28 mph.
- For a 5% increase in weight of the boom and jib for uncertainties in component mass, the wind speed at the jib head at the stability limit would decrease from 28 mph to 18 mph.
- For a 10% effective increase in the weight of the boom and jib to account for dynamic/inertial effects, the crane would be unstable under gravity/inertial forces alone, and would not require wind to overturn.

Summary

According to CTS calculations, treating the crane components as rigid, the crane overturned when the boom and jib angles were approximately 73° and 51°, respectively. Based on the available information from documents relevant to the project, published standards, information from others, and our own field investigations, we calculated limiting wind speeds at which the crane in that configuration would likely overturn. The justification for the assumptions inherent in the analyses reported herein has been discussed above.

We also evaluated the sensitivity of the limiting wind speed to various input parameters. We found that the stability is dominated by the overturning and stabilizing moments from self-weight, but also that near the stability limit of the crane, where the overturning and stabilizing moments approach each other, the limiting wind speed is very sensitive to the input parameters that affect the weight distribution used in the analysis.

In Table 9, we summarize the limiting wind speed at which the crane would overturn considering possible variations in boom and jib weight and inertial forces.

Table 9 – Summary of limiting wind speeds for the boom at 73° and jib at 51°. Results for calculations with uniform wind velocity and wind velocity profile at 10 m intervals.

Condition	Limiting Wind Speed, mph	
	Uniform	10m Intervals
Nominal Case	26	28
Nominal plus 5% weight allowance	16	18
Nominal plus 10% dynamic/inertial force allowance	Unstable	Unstable

8. CONCLUSIONS

We analyzed the stability of the LR1300 crane that was used on the 60 Hudson Street project and overturned during a wind event on the morning of 5 February 2016. For the analyses reported herein, we relied heavily on data and information provided in Liebherr documentation.

Based on our investigation to date and the analysis reported herein we conclude the following:

- Using the values for component weight, CG, and wind area given in Liebherr's stability calculation and the wind speed specified in the crane operator's manual (15.7 mph), we find that the crane with the boom at 80° and the jib at 15°, with no suspended load apart from the headache ball, provides the margin against overturning that is required by the ISO 4305 and EN 13000 codes during erection and dismantling. The stability of the crane is sensitive to the component masses and centers of gravity.

- As it was likely configured on 5 February 2016, based on component weights and CGs from MRA's ground bearing pressure calculation and wind areas from Liebherr's stability calculation, with the boom at 73° and the jib at 51°, the subject crane would likely overturn in a 26 mph wind blowing from behind the crane, taking wind speed as uniform over the height of the crane. Including an estimate of the effects of elongation of suspension pendant bars and winch rope, the boom and jib angles to be 72° and 49°, respectively. In this configuration the subject crane would likely overturn in a 4 mph wind blowing from behind the crane, taking wind speed as uniform over the height of the crane.

- The limiting wind speed is a function of the small difference between the large self-weight overturning and stabilizing moments. As a result, the stability of the crane is sensitive to changes in the input parameters, particularly near the stability limit of the crane, where the self-weight overturning and stabilizing moments approach each other. For example, taking wind speed as uniform over the height of the crane:

    - Considering a possible 1° reduction in boom angle the limiting wind speed would be 18 mph; considering a possible 1° reduction in jib angle the limiting wind speed would be 23 mph.
    - Considering a possible 5% increase in boom and jib weight the limiting wind speed would be 16 mph.
    - Considering possible dynamic/inertial forces equivalent to a 10% increase in boom and jib weight the crane would be unstable under gravity/inertial forces alone, and would not require wind to overturn.
    - Other input variables, such as location of the center of gravity, use of blocking at the tipping line, and effective wind area also influence limiting wind speed.

- Assuming an approximate log wind speed profile that increases with height, using a roughness length of 1.6 m, the limiting wind speeds increase compared with those calculated assuming a uniform wind speed. For the nominal case with the boom at 73° and the jib at 51°, the subject crane would likely overturn in a wind blowing from behind the crane where the wind speed at the jib head (482 ft above grade) is 28 mph. For the other cases analyzed in the sensitivity study, the wind speed at the jib head at the stability limit increases 8% compared with the uniform wind speed case.

We hold these opinions to a reasonable degree of engineering certainty, based on the information available to us at the time of writing. We reserve the right to review and possibly modify our findings should new information become available.

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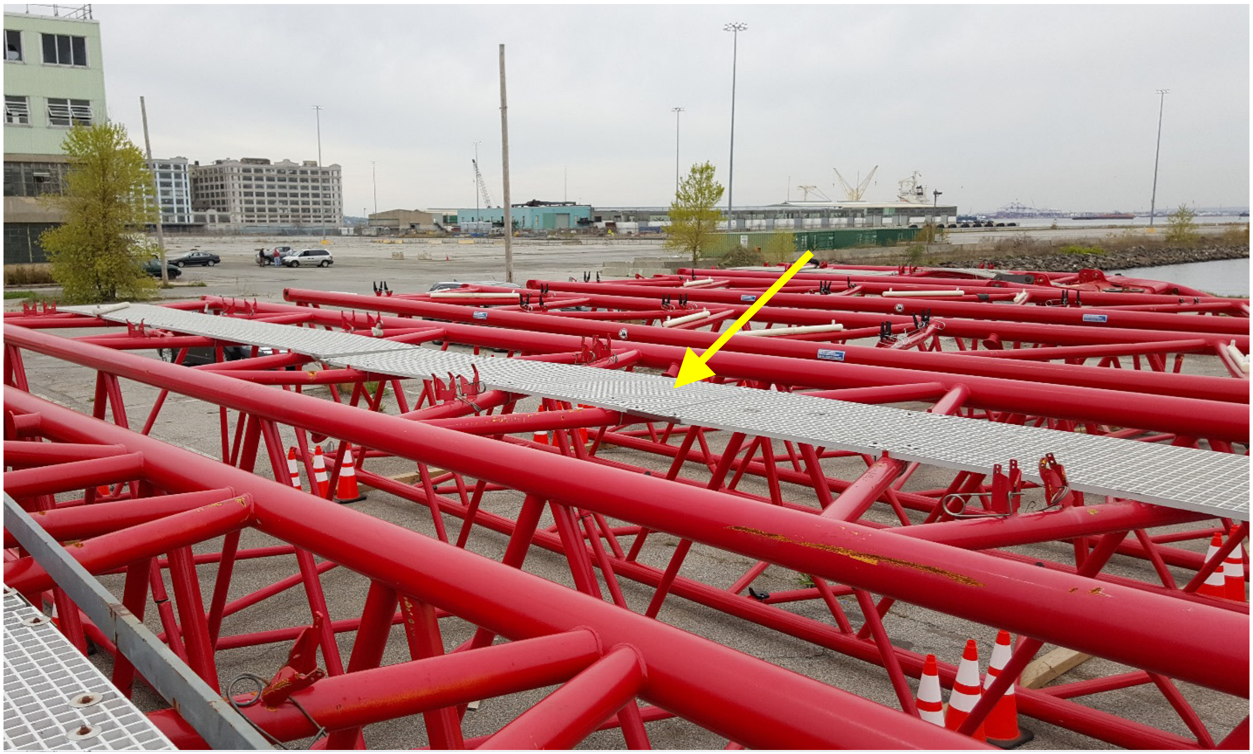

Photo 1 – FRP grating panel fastened to back side of typical boom section

Photo 2 – FRP grating panel fastened to boom head

Photo 3 – FRP grating panel fastened to jib heel

Photo 4 – Typical boom section B3

Photo 5 – Typical jib section J6

Photo 6 –Boom head (boom section B6)

Photo 7 –Jib heel (jib section J1)

Photo 8 –Jib head (jib section J11) viewed from beyond tip

Photo 9 – Tip of jib head (jib section J11)

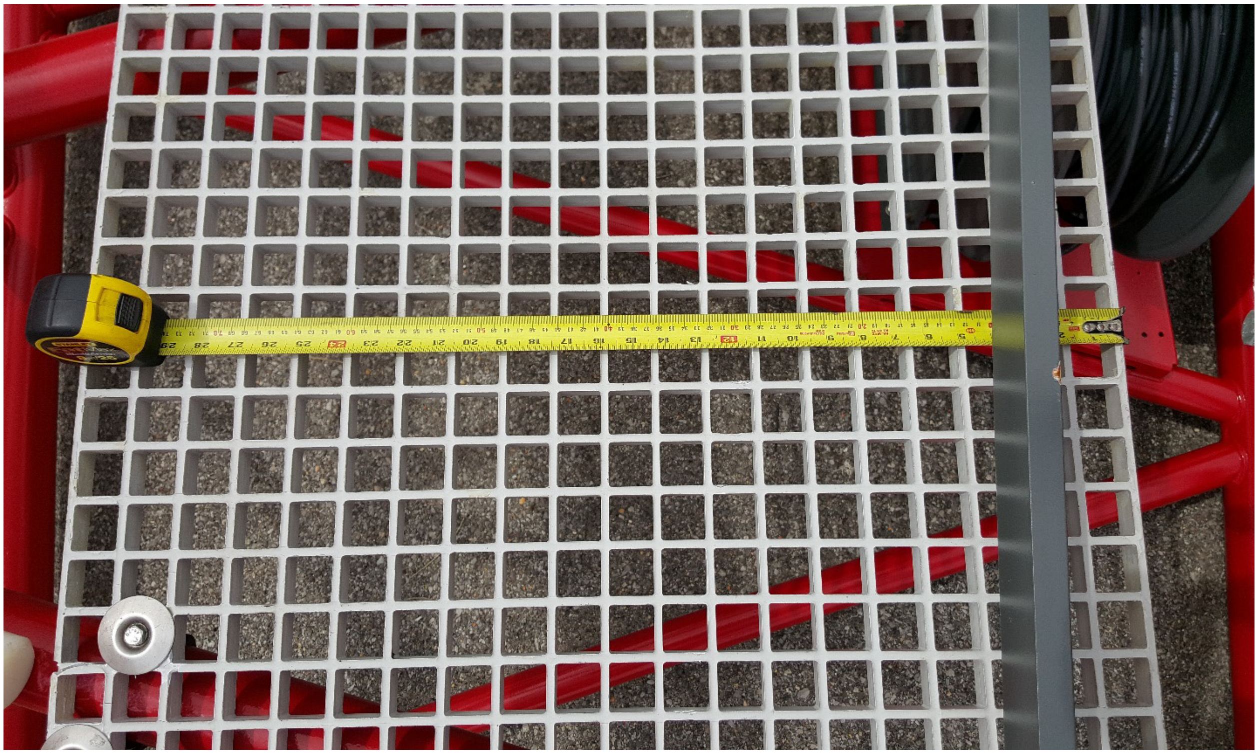

Photo 10 – Measurement of FRP grating panel on jib heel section

Photo 11 – A-frame disconnected from jib heel

Exhibit D - Field Work

60 Hudson Street Crane Collapse Investigation
February 5, 2016

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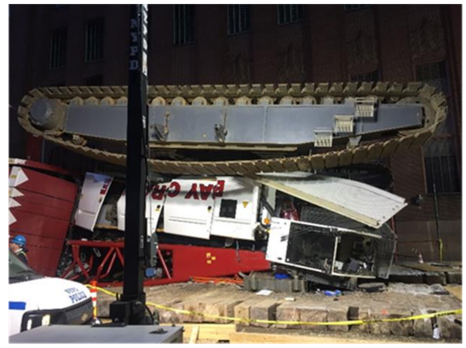
D.1 Collapse site - February 5, 2016



Photograph D.1

CTS arrived the shortly after 7:00 p.m. on February 5, 2016 and took photographs of the collapsed crane and met with DOB representative Ashraf Omran, Executive Director of Cranes and Derricks. The crane body had flipped over onto its top shown in Photograph D.1.

The first item reviewed was the foundation (pontoons). To the naked eye, the cribbing appeared level, and the survey performed that evening confirmed it.

CTS looked into the operator's cab and found a paper load chart that was for the earlier configuration (194' main boom and 322' luffing jib), but not the configuration of the collapsed crane.

There were three stacked sheets of plywood on each pontoon used to "block" the tracks (intended to increase the tipping line). The south side stack was further east than the one on the north side. The stack on the north side measured 3½" and the front of the crawler appears to have made a depression approximately 24" from the edge of the plywood, while the front edge of the south side appears to have made a depression mid-stack (photographs D.2 and D.3, respectively).

Photograph D.2 (north side)

Photograph D.3 (south side)

CTS then walked the crane looking for signs of structural failure. This included inspecting the main boom and luffing jib for indications of structural failure as well as the pendant bars for breakage and abnormalities. None were found.

After the walk around and taking photographs of various components, CTS and DOB discussed the preliminary findings. These covered wind, snow, and "blocking" the tracks as possible factors leading up to the collapse. It was night and difficult to see all the details and the team agreed to start at 6:00 a.m. the next morning.

Con-Ed was onsite for two reasons. The first was the leaking hydraulic and diesel fuel into the vaults under the crane. The second was that Con-Ed was concerned about the release of dielectric fluid because there was a junction underneath where the crane body turned over. This fluid is a non-conductive liquid used in steel pipes for insulating and cooling electrical transmission feeder cables, and a substance closely monitored by the EPA. The close proximity to the Hudson River added to the concern. Con Ed had recovery trucks on site throughout the time CTS was on site.

D.2 Collapse Site - February 6, 2016

CTS representatives arrived at the site at 6:00 am and noticed the sheets of plywood had been moved from their location from the evening of February 5th (Photograph D.4). CTS was unable to determine why and who moved them. CTS continued searching for possible signs of a structural failure during the day time and did not find any.


Photograph D.4

During the morning, CTS noted the configuration of the main boom and luffing jib sections. Starting with the main boom at the crane body and moving toward the tip of the jib, the following is the order of the sections: main boom 4463-M1, 4463-M4, 4606-MB10, 4463-MB5, 4606-MB11, 4463-M2; luffing jib 4606-JL1, 3839-LJ3, 4605-JL4, 3813-LJ5, 4463-LJ7, 4463-LJ5, 3870-LJ4, 3839-LJ5, 3813-LJ6, 3822-LJ5, and 4605-JL2.

The upper "A" frame was in the same geometric pattern as when the crane started to fall at the intersection of Worth Street and West Broadway. One of the segments did come free of the pivot point by approximately 24" on both sides (Photograph D.5).


Photograph D.5

To assist with calculating the luffing jib angle at the time of the collapse, a CTS representative was lifted in a man basket to measure the distance between the two struts of the upper "A" frame. The distance measured was 160" center of one sheave to the center of the other. CTS used a retractable measuring tape, and took the measurement twice with the same result. Due to the height and location of the man basket, CTS was not able to photograph the tape measure showing this distance.

By late morning (approximately 10:30), CTS finished taking photographic evidence of the crane's structural components and the crane's recovery / removal phase started. Bay Crane Service, Inc. (BCSI) led the recovery effort and was supported by Galasso Trucking and Rigging, Inc. There were four mobile cranes assigned to remove the various components. DOI instructed BCSI to transport the crane components to a secure NYPD location in Brooklyn, New York (South Brooklyn Marine Terminal).

The recovery crew first secured the two "A" frame struts, cut the rope between the two struts, and removed the strut that had broken away from its pivot point. BSCI had two crews working the recovery. One was removing the luffing jib and main boom sections from the street and the other concentrating on the main car body. The luffing jib and main boom crew started at the tip of the jib and systematically cut/unpinned each section and placed them on flatbed trailers. Each section was then moved away from the collapsed crane for eventual delivery to the secured site.

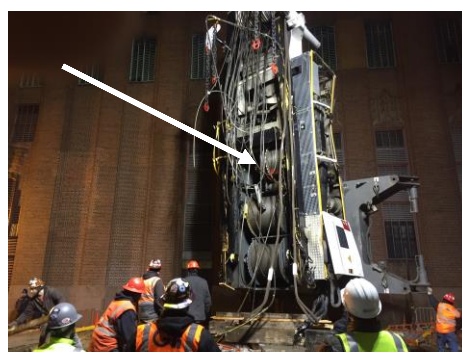
In order to remove the last three (3) luffing jib sections (tip), BCSI had to cut the luffing jib tip section (4605-JL2) that had been bent up due to its impact to the adjacent building. In addition, BCSI made another cut near the connection to the second and third section (3813-LJ6 and 3822-LJ5) in order to remove these two sections. Once these cuts were made the sections were removed, placed on flat bed trailers, moved from Worth Street, and sent to the secure yard. BCSI was able to remove the remaining sections by unpinning the sections up to the main boom heal section (4463-M1), which required cutting.

The other crew was assigned the task of removing components from the crane body and placing them on flat bed trailers. The operator's cab was removed as well as the car body counterweights. The recovery then removed the tracks and BCSI built up shoring to remove them (Photograph D.6). They removed the South side crawler first and then the North side.

Photograph D.6

A problematic issue was the removal or the rear counter weights. Fortunately, the holding straps did not fail and kept the two sets stacked as they were installed. However, they were leaning which presented a possibility that when they started removing them that they would collapse onto the street causing more damage. Con Edison was concerned about the vault that contained dielectric fluid underneath the crane so additional caution was necessary. They used shoring and welding of lifting eyes onto various sections in order to remove the counter weights. BCSI did so without incident.

A member of the BCSI crew sprayed a red line across the main boom hoist rope winch to indicate the rope that was on the drum prior to flipping the crane back over (Photograph D.7). BCSI sprayed a white line on the luffing jib hoist winch for the same reason. This was referred to during the destructive testing and discussed in Section D.5.



Photograph D.7

The damaged cars along Worth Street were removed as they became free of the crane components resting on them. CTS did not know where BCSI sent them.

The last step was to "right" the crane (turn the crane back over) to transport it to the secure yard. The crew made modification to the lifting eyes on the crane to accomplish the task. The car body was turned over onto its undercarriage. This step was completed just before mid-night, and then CTS representatives left the site.

D.3 Off-loading crane components from Trailers – March 3, 2016

BCSI used twenty-eight 40' trailers to remove the crane components from Worth Street and all were delivered to the secure NYPD yard in Brooklyn. The owners of the trailers requested that they be returned and asked NYPD and DOB if they could off load the crane components to the ground. The agencies agreed to this process and DOB requested a CTS representative witness this process.

BCSI led the effort and produced a document listing the various crane components by name and included the manufacturer's weight. In addition to the list of components, BSCI provided a recommended lay out of the components, which was acceptable to CTS. In addition to the BCSI crew, the following agencies were represented for the off-loading: DOI, DOB, NYPD, and OSHA.

The attendees assembled at the secure lot on March 3, 2016 and work began around 8:00 am. While BCSI set up the mobile crane, CTS documented the contents of each trailer along with the respective trailer's license plate number.

BCSI weighed each crane component using the mobile crane's load cell as it was off-loaded from the trailer. The procedure followed for every lift was to record the weight of just the rigging over the component, attach the component, weigh and record the weight of the component, subtract the rigging weight from the first step to arrive at the net weight, and then place it in the designated area on wood cribbing. Exhibit D includes more detail of the lifts, and Table D.1 contains a summary of the main components.

	Manufacturer Weight from BCSI (pounds)	**Weight from** Mobile Crane's Load Cell (net) (pounds)	Variance (pounds)
Main Boom (2821)	54,620	49,100	5,520
Luffing Jib (2316)	53,760	45,600	8,160
Pendants	-	13,600	(13,600)
Basic Machine includes crawlers	196,710	192,800	3,910
Counterweights			
Car body counter weights	125,680	125,300	380
Upper counterweight and tray	274,700	284,200	(9,500)
Miscellaneous Components			
Ball and hook	1,900	1,900	-
Various small components	-	3,200	(3,200)
Bay Misc. box 1	-	7,500	(7,500)
Bay Misc. box 2	-	6,200	(6,200)
Subtotal for Misc. Components	1,900	18,800	(16,900)
Total crane	707,370	729,400	(22,030)

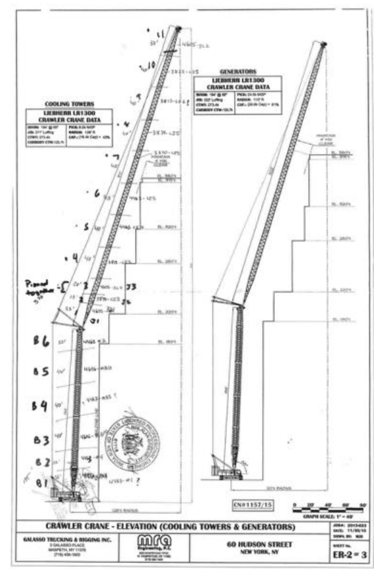
Table D.1

The weights obtained from the mobile crane should not be considered exact and may vary for a few reasons. The load cell was not specifically certified for this work prior to using it. The computer would only read in increments of 200 pounds and the reading would fluctuate due to the load and boom movement.

The primary goal was to arrive at a total weight for the crane to compare against the weight obtained from the Ground Bearing Pressure document discussed in Section 3.3.3.3 and the Stability Calculation discussed in Section 3.3.3.4.

The results show a total weight of 729,400 pounds. The weight provided by BCSI (from the manufacturer) for this task was 707,370 (includes the ball and hook) representing an approximate 3% difference (22,030lbs).

CTS monitored the weighing of the boom and jib components, and then started measuring various boom and luffing jib components while the BCSI crew off-loaded the remaining components and recorded the weights. CTS measured these components to assist in the calculation of the wind area for the main boom, luffing jib, and upper “A” frame. This information was provided to SGH who later took additional measurements.



The boom sections all had some local plastic deformation to individual members, however entire sections remained largely straight so measurements were able to be taken. The jib sections suffered the most damage because they either fell on cars or were attached to others that did. In general, the lacing showed more deformation that the chords.

All main boom and luffing jib sections were marked with a sharpie indicating the order each was installed on the crane. The boom sections started with a “B” with the heal being “B1” and the head section being “B6”. The luffing jib sections started with a “J” with the heel being J1 and the tip being J11 (Figure to the right). All numbers are on the aisle between the boom and jib sections.

The field work concluded at approximately 4:30 p.m. BCSI placed tarps around the crane body and the operator’s cab to protect them from the elements. All other components were exposed to weather.

D.4 Engineering field work to measure steel structure – April 28, 2016

The team’s structural engineer (“SGH”) requested a site visit to the laydown yard to inspect the crane wreckage. The field work started at 8:30 a.m. on April 28, 2016 at the secure NYPD yard. The attendees were engineers from SGH, CTS, DOB, DOI, and NYPD.

The primary purpose was to augment and check the measurements CTS provided earlier to determine the wind area of the boom and luffing jib.

SGH measured a typical boom, and a typical jib and Table D.2 provides the results of these measurements. SGH also measured key aspects of the boom head, jib heal, jib head, fiberglass grating, panels, and the upper “A” frame.

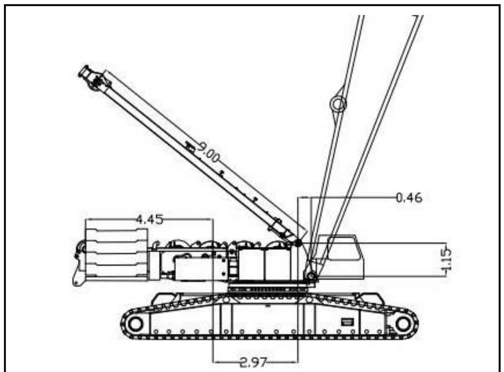
Parameter	Typical Boom	Typical Jib
Total Section length, c/c of eyes [feet]	39.375	39.417
Total Section width, c/c of chords [feet]	9.188	7.521
Total Section depth, c/c of chords [feet]	6.885	5.417
Average lacing working-point spacing along chord [feet]	3.754	3.173
Chord circumference [inches]	20.625	17.375
Vertical lacing circumference [inches]	9.625	6.125
Horizontal lacing circumference [inches]	11.125	7.750

Table D.2

The field work was completed at approximately 2:00 pm, April 28, 2016.

D.5 Non-destructive testing – September 27, 2016

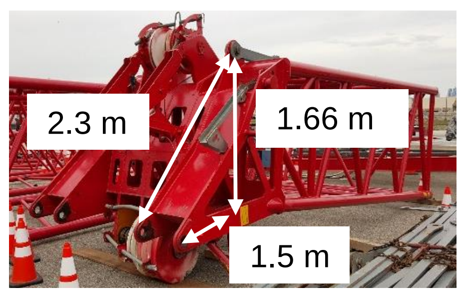
CTS produced a visual evaluation protocol (Exhibit E), and travelled to the secure yard to perform the outlined tasks. CTS started and completed the visual inspection on September 27, 2016. The work entailed obtaining additional photographs and taking measurements to complete a dimensional drawing of the key elements of the boom and luffing jib hoisting systems. These measurements allowed CTS to calculate the boom and jib angles at the time of the collapse.



Drawing D.1

The primary measurements on the crane body focused on the position of the boom heal pivot, A Frame Strut 1 pivot, boom hoist luffing winch, fixed sheave assembly on the crane body, the sheave assembly on A frame strut 1, and the number of sheave on each assembly. Drawing D.1 provides these measurements, and they are from the center of the connection point or drum.

The boom head measurements consisted of determining the relative positioning of the attachment point of the connecting rods (suspension bars) from A frame strut 1 to the top of the boom head and the connection point of the luffing jib near the bottom of the head section. Photograph D.8 shows the boom head and the measurements obtained.

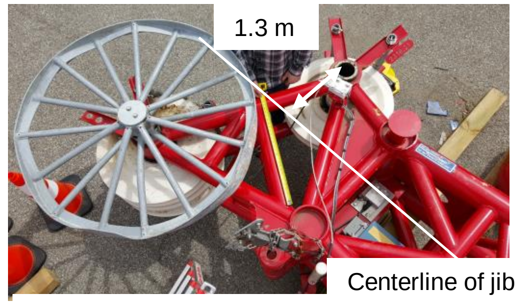


Photograph D.8

The upper frame consisted of struts 2 (closest to the crane body) and 3. The required measurements for this area included: the length of the struts (center of connection point to center of the sheaves) which was 10 m, the distance from the strut connection point and the boom/luffing jib connection point (0.48 m) (Photograph D.9), the distance from the deflecting sheave to the sheave assembly on strut 2 (9.0 m), and the number of sheaves on each strut (14).

Photograph D.9

The dimension on the jib head consisted of obtaining an estimated jib centerline and measuring to the connection point of the suspension rods from strut 3. Photograph D.10 provides the field measurements.



Photograph D.10

CTS also took photographs of several other components for various attendees due limiting them from walking amount the various components and not allowing them to climb a ladder to view the top of the crane body. Section D.10 has a selection of them. The attendees requested photographs of the Liebherr manufacturer tag on each boom and jib section and inside the operator's cab and particularly the left and right control panels. They did not request any specific measurements. Below is a list of some of the other measurements CTS attained.

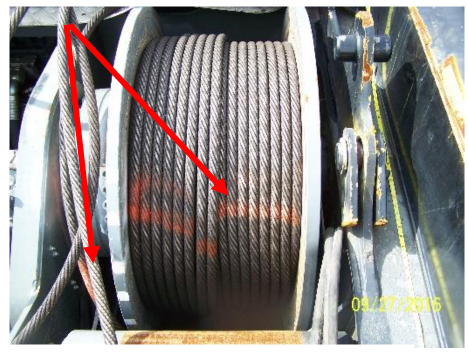
1. A-Frame strut 1 pivot to boom winch – 9'9"
2. Boom winch to fixed sheave bank – 14'7"
3. Length of A frame strut 1 (pivot to sheave bank) – 29'5"
4. Length of A frame strut 2 (on ground) (pivot to sheaves) – 33'
5. Length of A frame strut 3 (on jib heal) (pivot to sheaves) – 33'
6. Circumference of sheaves in jib hoist system – 4'8"
7. Jib heal section lower cord length – 33'
8. Jib heal section upper cord length – 33'
9. Boom winch circumference (lower layer) – 8'2"
10. Boom winch circumference (higher layer) – 8'7½"
11. Length of boom hoist rope not on drum (to center of becket) – 577'9½"
12. Length of jib hoist rope on drum – 866'3½"
13. Length of jib hoist rope not on drum from white line – 227¼"
14. Nominal length of jib hoist rope – 1,263' (provided by Liebherr)
15. Circumference of boom sheaves 177 cm (69.7")
16. Length of long pendant bar – 5,690 mm (manual shows 5,700 mm)
17. Diameter of connection hole on pendant bar – 65mm
18. Distance between A-Frame struts 2 and 3 pivot and jib/boom pivot – 1'7" (on jib heal section)
19. Sheaves on A-Frame struts 2 and 3 sheave assemblies – 7 sheaves each
20. Sheaves on A-Frame strut 1 – 13 sheaves
21. Sheaves on crane body (fixed) – 12 sheaves

D.6 Destructive testing – September 28, 2016

CTS provided a destructive testing protocol (Section E) to the attendees. The work started at approximately 7:30 am on September 28, 2016. The primary tasks were to obtain the lengths of the unspooled rope for the boom and luffing jib hoists. This was necessary to calculate the boom and luffing jib angles at the time of the collapse. To determine if there was a mechanical failure, CTS took hydraulic fluid samples (see Section D.7) and disassembled the jib hoist brake. CTS used Hoffman Equipment to assist with these tasks.

The attendees were not allowed on top of the crane body for safety reasons. CTS set up a wireless camera with a remote monitor so the attendees could take pictures or video the live streaming. CTS did not record the video.

The crane recovery team sprayed a red line across the boom hoist winch to ensure that the amount of the rope on the drum did not change when the crane was turned back over (Photograph D.11). The red arrows point to this line and the one end that fell to the side of the winch.



Photograph D.11

CTS aligned the rope on top of the crane body with the sheave banks to make the removal easier and pulled the rope with a forklift to lay it on the ground for measurement. CTS cut the rope once to remove the unspooled rope with an abrasive cutting tool, and videotaped the procedure. The cut was at the red painted line (Photograph D.12) on the length that was off to the side of the drum. There was one other cut that the recovery team made on February 6th in order to right the crane (Photograph D.13), and the recovery team clamped one end to prevent unspooling.

Photograph D.12

Photograph D.13

Once the entire rope was removed, CTS measured it using a 100-foot metal measuring tape, and marked the rope at 100-foot intervals. There were two sections of rope due to the cuts and the sections measured 501 feet 2½ inches and 76 feet 7 inches. The total length of the unspooled boom hoist rope was 577 feet 9½ inches. The measurement ended at the center of the becket.

The recovery team cut the luffing jib rope numerous times on February 6th to aid in the crane's removal and placed the cut rope into two metal bins (see Section D.10 for photographs). The manufacturer offered the nominal length of the rope 1,263 feet (385 meters). With the total length, CTS decided to remove the rope from the luffing hoist drum and subtract the two numbers to arrive at the length of unspooled rope rather than emptying the two bins.

Photograph D.14

The recovery team sprayed a white line across the luffing jib winch on February 6th to ensure the ability to measure the rope on the drum at the time of the collapse (Photograph D.14) at a later time. There was a length of rope unspooled on top of the boom heal section that measured 227¼ inches. CTS considered this rope as unspooled and subtracted it from the total length measured because the calculation needed only the rope on the drum at the time of the collapse.

To remove the rope, CTS and Hoffman disassembled the jib hoist brake and kept custody of the components. Once removed, the winch was free spinning and CTS used a forklift to pull the rope off the drum. The total length removed was 866 feet 3½ inches (end to end). Therefore, the length of rope on the drum at the time of the collapse was 415.65 feet (1,263 – 866.29 + 18.94).

D.7 Mechanical Systems – September 28, 2016

As mentioned in Section D.6, CTS and Hoffman removed the luffing jib winch brake components (see Photographs D.15 and D.16). There was no noticeable wear on the components.

Photograph D.15

Photograph D.16

CTS did not remove the brake components of the boom hoist winch due to the fact that the crane body flipped upside down. Had the brakes not held, the boom would have fallen by itself and the crane body would have remained upright.

There were six hydraulic fluid samples taken from the crane. CTS checked the hydraulic tank and there was little, if any, due to the crane being upside down for approximately 40 hours. CTS witnessed the hydraulic fluid leaking onto the ground at the collapse site. In addition, the recovery team disconnected several hydraulic hoses in order to remove the crane on February 6th. The manufacturer recommended to take a sample from the breather assembly but CTS could not do so due to the lack of fluid. CTS could not remove the filters because A Frame Strut 1 was blocking their removal.

The samples removed were as follows: two samples from approximately 2 feet from the side of the oil filter assembly (Photograph D.17), one from the top of the baffles in the oil filter assembly, one from a hydraulic line going in the direction of the tank (number 4 in Photograph 18), and two from a hydraulic line from/to the oil cooler (number 5 and 6 in Photograph D.18).

Photograph D.17

Photograph D.18

CTS sent a sample from the side of the filter assembly and one from the hydraulic cooler line to an independent lab and has maintained custody of the other four samples.

D.8 Interviews

CTS interviewed several individuals during the course of the investigation. Some of these were in a formal setting (in conjunction with Department of Investigations) and others were informal. Exhibit A provides key information obtained from the interview process.

D.9 Video Review

CTS reviewed three videos from different vantage points and below is a summary of the findings.

D.9.1 Dashboard Camera

The first video was from a dashboard camera in a private vehicle. The video had high resolution and positioned in the center of the dashboard. Below are CTS's comments:

- The camera was facing directly at the front of the crane. Could not see jib due to precipitation in the air and horizon was gray.
- Saw numerous wind events such as: traffic lights moving, overhead sign almost blown horizontal (90 degrees at 8:19 a.m. and 60 degrees at 8:23 a.m.), pole shaking, traffic sign wobbling, and a small umbrella turn inside out.
- It was snowing (small flakes).

- Started to see movement at 8:25:32 a.m.

Witnessed the crane collapse between 8:25:55 and 8:26:03.

D.9.2 NY Law on Worth Street

The view was immediately outside their door at ground level aiming diagonally across the street toward the crane (could not see the crane). There was a structure blocking approximately half the field of view.

- Video was short and only captured the jib after the crane was already falling. Could not see the boom or the machine deck.
- Two US Flags across the street were being blown almost horizontal during the time of the video down Worth Street from the direction of the crane (parallel to the jib).

D.9.3 Zito Video

Mr. Zito captured the crane collapsing from an office building adjacent to the crane and at heights above the tip of the jib.

- The video appears to capture the time immediately before the crane lost stability and followed the crane to the ground.
- It appears the operator is lowering the boom by comparing the angles to the building immediately to the south of the crane body.
- Could not see the machine house clearly enough to see if there were people around but could see it flip over.
- The main boom and upper A frame are white, which possibly denotes snow/ice accumulation.

D.10 Field Photographs

Exhibit E – Protocols for field work

60 Hudson Street Crane Collapse Investigation
February 5, 2016

Table of Contents

E.1 Visual Evaluation

1. Provide attendees a copy of this protocol and an overview of the placement of the components. There will be a sign in sheet that all parties must provide their name, organization they represent, their organization if different, email address, and telephone number.

2. Explain to attendees that all parties must remain as a group and no one is allowed to start reviewing another component until all parties have finished their review of a particular component.

3. The parties will provide a list, verbal or written, of the components they wish to examine and CTS will prioritize them to achieve an orderly route through the components. Below is a general order that may be changed subject to the on-site discussion.

4. The parties will not be allowed to remove any components or samples, move components or parts, or open any access doors. CTS will take the measurements for the various parties at their direction. However, the parties may take as many photographs as they wish.

    a. The first component will be the two tracks (cats)
    b. Main boom heal section
    c. Main boom 20 foot section
    d. Main boom 40 foot sections (one at a time)
    e. Main boom head section
    f. Jib heel section and one piece of the "A" frame
    g. Jib heel section 10 foot and 20 foot sections are still pinned together so these will be viewed together
    h. Jib heel 40 foot' sections (one at a time)
    i. Jib head section
    j. Cribbing
    k. Single piece of "A" frame
    l. Counter weights
    m. Operator's cab – CTS will take photographs for attendees.
    n. Two steel bins with miscellaneous parts. They will not be removed from the bins so the parties must look at them from the top and through the messed grating on the sides.
    o. Crane house. Access is only available via ladder. As such, only CTS representatives climb and make measurements. CTS will take photographs and set up a remote video camera so attendees can see the work being performed. No attendee will be allowed to climb.

E.2 Destructive testing

A. Provide attendees a copy of this protocol and an overview of the placement of the components. There will be a sign in sheet that all parties must provide their name, organization they represent, their organization if different, email address, and telephone number.

B. Open and examine the boom angle indicator box.

C. Remove and measure the boom hoist rope on the crane body. Wind it onto a wooden spool. Leave the rope currently spooled on the drum.

D. Remove the rope from the jib hoist drum and measure it and place it on an empty wooden spool.

E. All measurements will be done using a 100’ metal measuring tape, and CTS will mark the rope at 100’ intervals.

F. Seizing wire shall be placed on either side of all cuts to prevent loosening or unlaying of the wire rope during cutting and handling.

G. Cutting the wire rope shall be accomplished with the use of an abrasive wheel cut-off machine. Individual wires may be cut with the use of wire cutters. CTS will video tape the rope cutting.

H. Take oil samples from four different locations. CTS took six oil samples: two samples from approximately 2 feet from the side of the oil filter assembly, one from the top of the baffles in the oil filter assembly, one from a hydraulic line going in the direction of the hydraulic tank, and two from a hydraulic line to/from the oil cooler. A separate protocol is in Section E.3 for the oil testing.

I. Inspect jib hydraulic brake components.

J. Check the fill cap assemblies, magnetic separators, and filters in hydraulic system and note issues / concerns.

E.3 Hydraulic fluid testing

Due to the crane being upside down and the crane having various hydraulic leaks, CTS was not able to obtain oil samples from the manufacturer's recommended location. Six oil samples were drawn on September 28, 2016 from different locations. There were two samples from approximately 2 feet from the side of the oil filter assembly, one from the top of the baffles in the oil filter assembly, one from a hydraulic line going in the direction of the tank, and two from a hydraulic line from the oil cooler.

CTS will send two samples (one from the side of the filter assembly and one from the hydraulic cooler line). These samples will be sent to a reputable laboratory to determine the viscosity, water content, particle content and suspended metals.

EVALUATION

A. The samples will be sent to Analytical Testing Services, Inc. in Franklin, Pennsylvania via Federal Express (address below).
B. The laboratory will test for the viscosity of the oil using the ASTM D445 - 11a Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity).
C. To test for water content, the ASTM E1064-05 - Standard Test Method for Water in Organic Liquids by Coulometric Karl Fischer Titration will be used.
D. Particle contamination will be checked using the ISO 4406:1999 - Hydraulic fluid power -- Fluids -- Method for coding the level of contamination by solid particles standard.
E. The laboratory will use the ASTM D5185 - 09 Standard Test Method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) testing standard.

The above tests will consume most if not all of the samples so none will be returned to DOB.

All steps taken pursuant to this protocol will be fully documented and a detailed report issued by the laboratory.

Analytical Testing Services, Inc.
190 Howard Street, Suite 404
Franklin, PA 16323-0061

Exhibit F – Manufacturer provided information
60 Hudson Street Crane Collapse Investigation
February 5, 2016

Table of Contents

LR1300

Load capacities main boom + luffing jib

Ident. no.:	9839979/151075/	Main boom foot:	2821-1
Slewing range:	360 °	Main boom head:	2821-1
Foot print:	2 - Wide track		
Rear counterweight [1000 lbs]:	273.4		
Carbody counterweight [1000 lbs]:	125.7		

	88° Main boom angle			83° Main boom angle			75° Main boom angle			65° Main boom angle			45° Main boom angle		
Outreach [ft]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]
194 ft Main boom, Load fall point 1 - Jib head Jib head (2316-1) 371 ft Jib															
94	78.0	565	20.4												
95	77.9	565	20.4												
100	77.1	564	20.4												
105	76.3	563	20.3												
110	75.5	562	20.0												
115	74.7	560	19.6												
120	73.9	559	19.4												
125	73.1	557	19.1												
130	72.3	556	18.8												
135	71.5	554	18.5												
140	70.6	552	18.3												
143				73.0	556	19.0									
145	69.8	550	18.1	72.6	555	19.0									
150	69.0	548	17.9	71.8	553	18.9									
155	68.1	546	17.6	71.0	551	18.8									
160	67.3	544	17.3	70.1	550	18.4									
165	66.5	542	17.0	69.3	548	18.1									
170	65.6	540	16.7	68.5	546	17.8									
175	64.7	538	16.4	67.6	544	17.5									
180	63.9	535	16.2	66.8	542	17.3									
185	63.0	533	15.9	65.9	539	17.0									
190	62.1	530	15.7	65.1	537	16.7									
195	61.3	527	15.5	64.2	535	16.5									
200	60.4	524	15.3	63.4	532	16.2									
205	59.5	522	15.1	62.5	530	16.0									
210	58.6	518	14.9	61.6	527	15.8									
215	57.6	515	14.7	60.7	524	15.6									
217							65.0	531	15.2						
220	56.7	512	14.5	59.8	521	15.4	64.5	530	15.2						
225	55.8	509	14.3	58.9	518	15.2	63.7	527	14.9						
230	54.8	505	14.1	58.0	515	15.0	63.0	525	14.3						
235	53.9	502	13.9	57.1	512	14.8	62.1	523	13.7						
240	52.9	498	13.7	56.2	508	14.6	61.3	520	13.0						
245	51.9	494	13.6	55.2	505	14.4	60.4	517	12.4						
250	50.9	490	13.4	54.3	501	14.2	59.5	514	11.8						
255	49.9	486	13.3	53.3	498	14.0	58.6	511	11.3						
260	48.9	481	13.0	52.3	494	13.9	57.7	508	10.7						
265	47.8	477	11.8	51.3	490	13.7	56.7	505	10.2						
270	46.8	472	10.7	50.3	486	13.6	55.8	502	9.7						
275	45.7	467	9.5	49.3	481	12.9	54.9	498	9.3						
280	44.6	462	8.4	48.3	477	11.8	53.9	494	8.8						
285	43.5	457	7.4	47.2	472	10.6	53.0	491	8.4						
290	42.3	451	6.4	46.1	468	9.4	52.0	487	7.9						
295	41.2	446	5.4	45.0	463	8.3	51.0	483	7.5						
300	40.0	440	4.4	43.9	457	7.3	50.0	479	7.1						
305	38.7	434	3.5	42.8	452	6.2	49.0	474	6.8						
310				41.6	446	5.2	47.9	470	6.4						
315				40.4	441	4.2	46.9	465	6.0						
320				39.2	435	3.3	45.8	460	5.7						
325							44.7	455	5.0						
330							43.6	450	4.3						
335							42.4	445	3.6						
340							41.3	439	3.0						
345							40.1	433	2.3						

Figure 2: Load capacity of the main boom with luffing jib

1.15 Main boom - overview

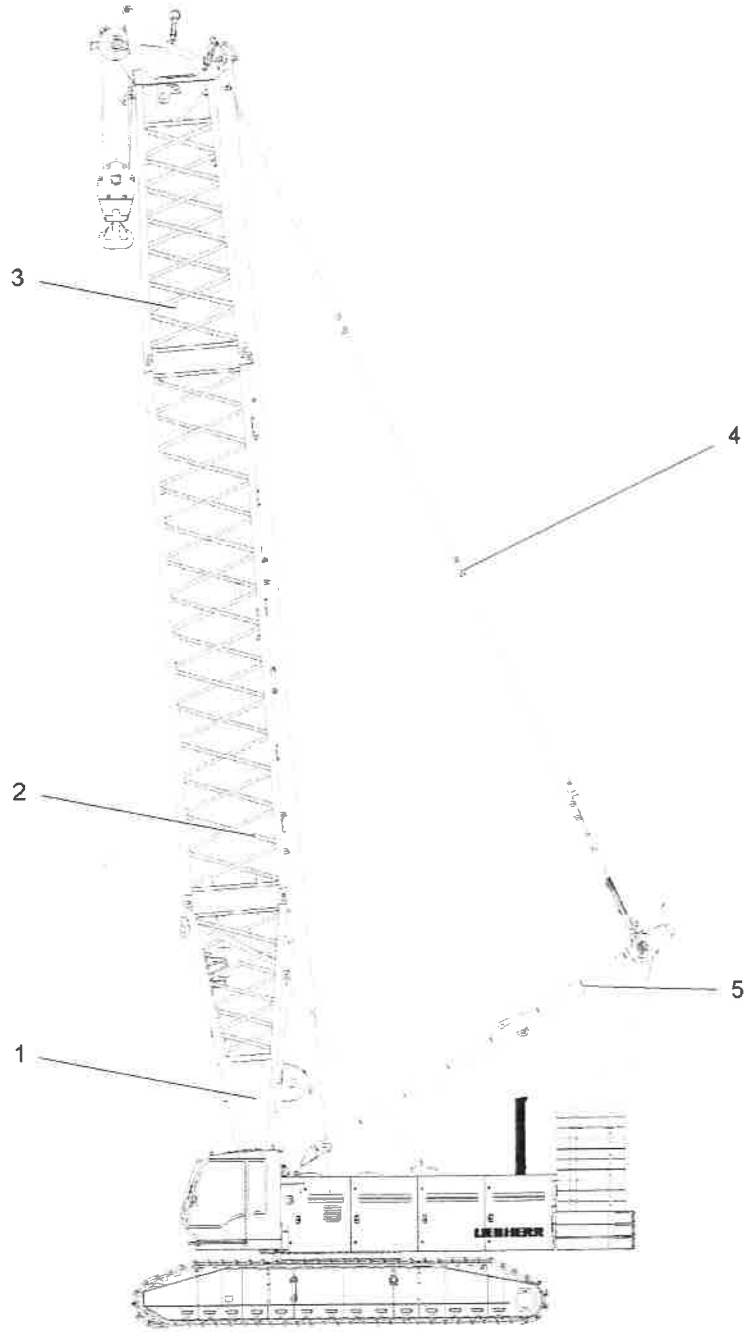


Fig. 19 Main boom - overview

1 Pivot piece
2 Intermediate pieces
3 Boom head
4 Main boom anchoring rods
5 A-frame 1

LWN/8.07/en

The main boom is composed of:

- the pivot piece Fig. 19-**1**
- a selection of intermediate pieces Fig. 19-**2**
- the boom head Fig. 19-**3**

The main boom anchoring rods Fig. 19-**4** connect the A-frame 1 Fig. 19-**5** to the boom head Fig. 19-**3**.

LWN/8.07/en

1.16 Main boom pivot piece 2821

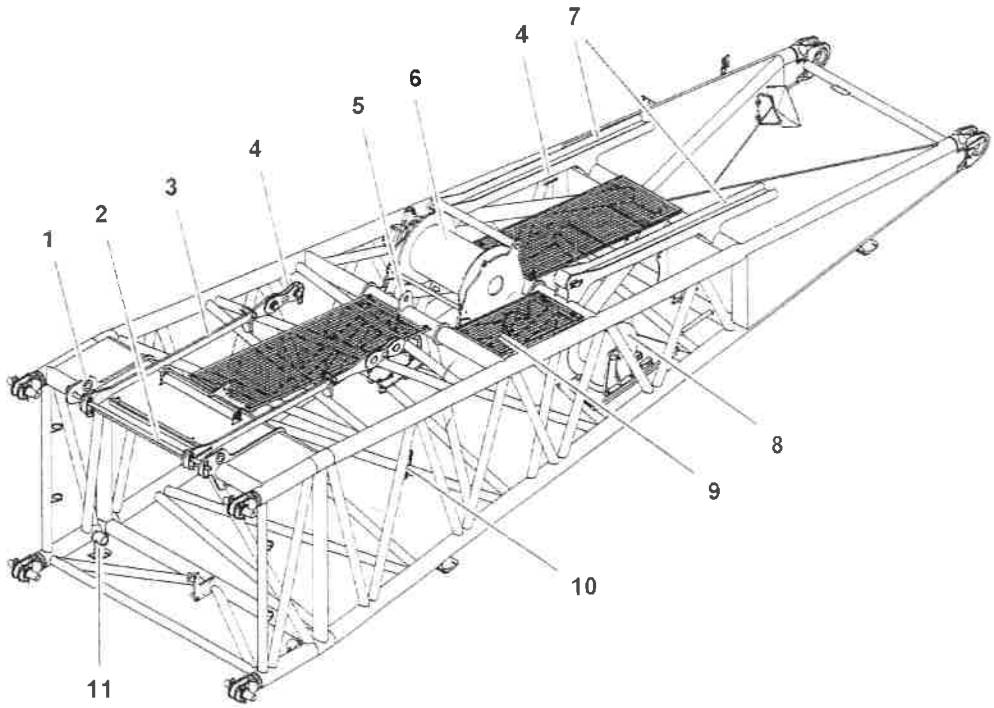


Fig. 20 Main boom pivot piece 2821

1 Pivot point for fly jib anchoring rods
2 Transport fixations for anchoring rods
3 Anchoring rod
4 Attachment point (4x)
5 Attachment point of the mounting cylinder
6 Fly jib adjusting winch
7 Guides for tilting-back supports (2x)
8 Cable drum
9 Grating
10 Nameplate
11 Support (foldable)

The main boom pivot piece Fig. 20
- has an extremely robust tubular construction.
- supports the entire boom.
- is fastened at two pivot points on the superstructure on which it swivels.

For transportation purposes the main boom pivot piece can be removed from the superstructure with the mounting cylinder and loaded.
The mounting cylinder is bolted to the pivot point Fig. 20-**5** to lift the assembled pivot piece while the machine is being assembled.
The anchoring rods Fig. 20-**3** are immobilized for transport in fixtures Fig. 20-**2** and secured in place with retaining springs.
The grating Fig. 20-**9** simplifies mounting operations when assembling or dismantling the boom.
The tilting-back supports with spherical ends move smoothly in the two guides Fig. 20-**7** on the main boom pivot piece and prevent the main boom from tipping backwards.
When using an adjustable fly jib, a fly jib adjusting winch Fig. 20-**6** is also mounted on the main boom pivot piece. The fly jib tensioning rods are fixed on the pivot points for fly jib anchoring rods Fig. 20-**1**.

LWN/8.07/en

Four attachment points Fig. 20-**4** are provided for loading the main boom pivot piece. The mounting tackle of the mounting cylinder or of an auxiliary crane can be fitted here.

The cable drum Fig. 20-**8** accommodates the electrical connecting cable for the boom head.

The system number and the dead weight incl. anchoring rods can be found on the nameplate Fig. 20-**10**. The weight is given with and without fly jib adjusting winch.

Technical data	
Width	2970 mm 9 ft 9 in
Height	2650 mm 8 ft 8 in
Length	10300 mm 33 ft 10 in
Weight with anchoring rods, fly jib adjusting winch and rope	7300 kg 16100 lb
Weight with anchoring rods, without fly jib adjusting winch	5700 kg 12570 lb

Tab. 9

LWN/8.07/en

1.18 Boom intermediate piece 2821 6 m 20 ft

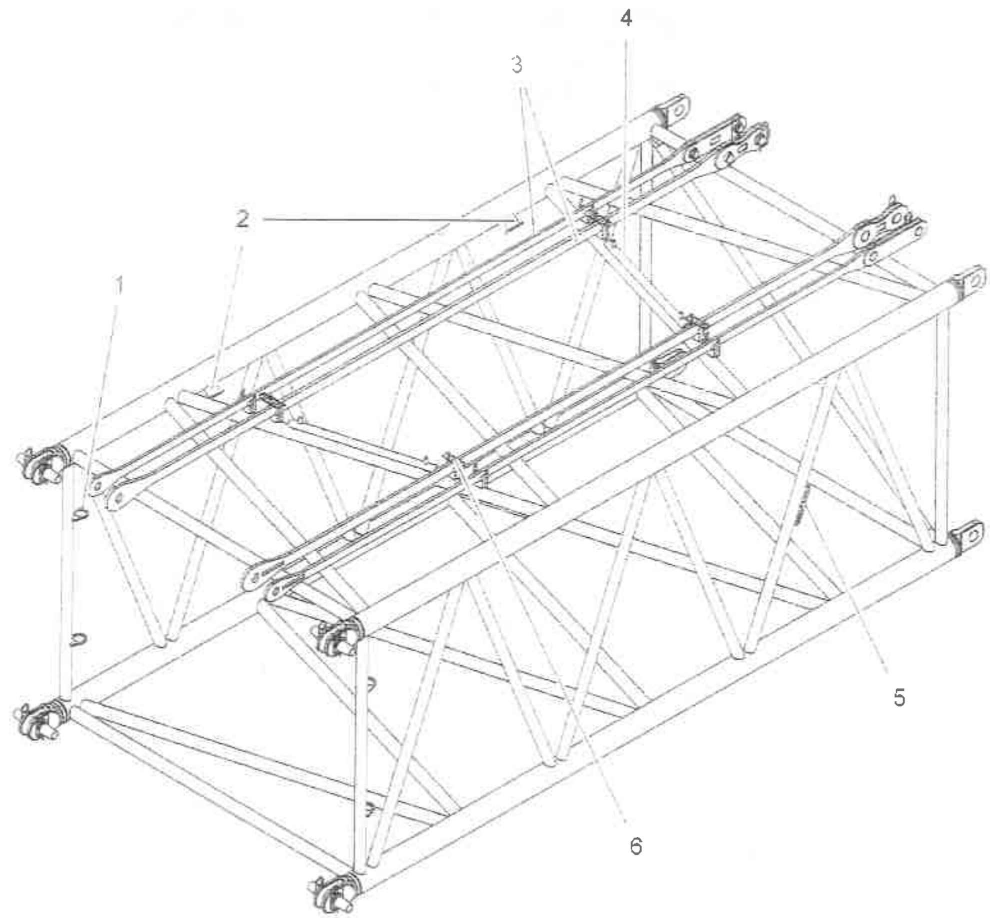


Fig. 23 Boom intermediate piece 6 m 20 ft

1 Transport holders for double-tapered pins (4x)
2 Attachment points (4x)
3 Anchoring rods
4 Rope support
5 Nameplate
6 Transport fixations for anchoring rods

This boom intermediate piece must be bolted immediately after the pivot piece or after the 3 m 10 ft intermediate piece.

Two boom anchoring rods Fig. 23-**3** are allocated to the boom intermediate piece; if an adjustable jib is being used, then two jib tensioning rods are also allocated. For transport, these anchoring rods and tensioning rods are placed in the fixtures Fig. 23-**6** and secured in place with retaining springs.

Four attachment points Fig. 23-**2** are provided for loading the boom intermediate piece. The mounting tackle can be slung here.

The rope support Fig. 23-**4** protects the hoisting rope and the struts against damage.

For transport, the double tapered pins are placed in fixtures Fig. 23-**1** and secured in place with retaining springs.

The system number and the dead weight incl. anchoring rods can be found on the nameplate Fig. 23-**5**.

LWN/8.07/en

Technical data	
Width	2970 mm 9 ft 9 in
Height	2470 mm 8 ft 1 in
Length	6250 mm 20 ft 6 in
Weight with anchoring rods	1700 kg 3748 lb

Tab. 12

Anchoring rod 6 m 20 ft

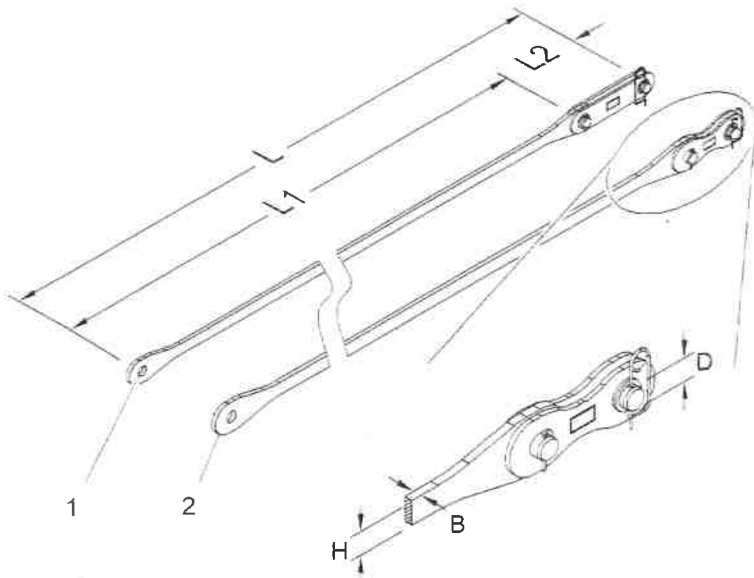


Fig. 24 Anchoring rod 6 m 20 ft

1 fly jib stay rope rod

2 Main boom anchoring rod

Note!
Note about the fly jib stay rope rod Fig. 24-**1**:

! The fly jib stay rope rods Fig. 24-**1** are only on the main boom intermediate piece if an adjustable fly jib is supplied.

! The fly jib stay rope rod Fig. 24-**1** is exactly the same length Fig. 24-**L** as the main boom anchoring rods. Fig. 24-**2**

! All other detailed dimensions are the same as for the fly jib anchoring rods on the fly jib intermediate piece.

Technical data	
Width Fig. 24-**2** B	25 mm 0.98 in
Height Fig. 24-**2** H	77 mm 3 in
Bolt diameter Fig. 24-**2** D	65 mm 2.6 in
Total length Fig. 24-**2** L	6000 mm 19 ft 8.2 in

LWN/8.07/en

Technical data	
Length of the anchoring rod Fig. 24-**2** L1	5700 mm 18 ft 8.4 in
Length of the coupling link Fig. **24-2** L2	300 mm 11.8 in

Tab. 13

LWN/8.07/en

1.19 Boom intermediate piece 2821 12 m 39 ft

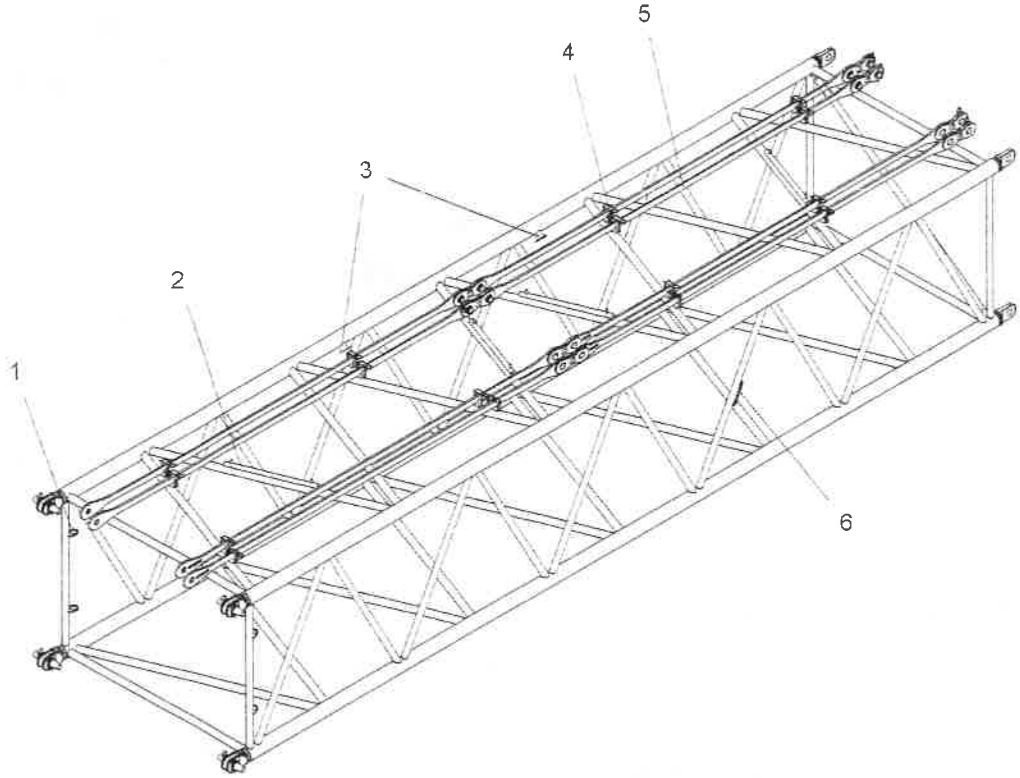


Fig. 25 Boom intermediate piece 2821 12 m 39 ft

1 Transport holders for double-tapered pins (4x)
2 Rope support
3 Attachment points (4x)
4 Transport fixations for anchoring rods
5 Anchoring rods
6 Nameplate

Two anchoring rods Fig. 25-**5** are allocated to the boom intermediate piece: if an adjustable jib is being used, then two jib tensioning rods are also allocated. For transport, these anchoring rods and tensioning rods are placed in the fixtures Fig. 25-**4** and secured in place with retaining springs.

Four attachment points Fig. 25-**3** are provided for loading the boom intermediate piece. The mounting tackle can be slung here.

The rope support Fig. 25-**2** protects the hoisting rope and the struts against damage.

For transport, the double tapered pins are placed in fixtures Fig. 25-**1** and secured in place with retaining springs.

The system number and the dead weight incl. anchoring rods can be found on the nameplate Fig. 25-**6**.

Technical data	
Width	2970 mm 9 ft 9 in
Height	2470 mm 8 ft 1 in
Length	12250 mm 40 ft 2 in
Weight with anchoring rods	2900 kg 6393 lb

Tab. 14

LWN/8.07/en

Anchoring rod 12 m 39 ft

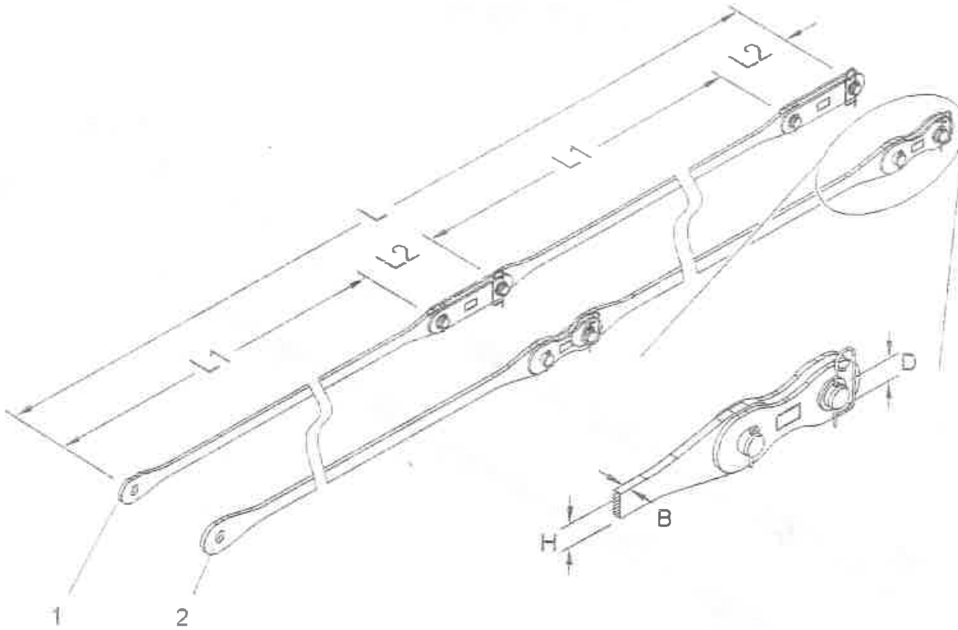


Fig. 26 Anchoring rod 12 m 39 ft

1 fly jib stay rope rod

2 Main boom anchoring rod

Note!

Note about the fly jib stay rope rod Fig. 26-**1**:

! The fly jib stay rope rods Fig. 26-**1** are only on the main boom intermediate piece if an adjustable fly jib is supplied.

! The fly jib stay rope rod Fig. 26-**1** is exactly the same length Fig. 26-**L** as the main boom anchoring rods. Fig. 26-**2**

! All other detailed dimensions are the same as for the fly jib anchoring rods on the fly jib intermediate piece.

Technical data	
Width Fig. 26-**2** B	25 mm 0.98 in
Height Fig. 26-**2** H	77 mm 3 in
Bolt diameter Fig. 26-2 D	65 mm 2.6 in
Total length Fig. 26-**2** L	12000 mm 39 ft 4.4 in
Length of the anchoring rod Fig. 26-**2** L1	5700 mm 18 ft 8.4 in
Length of the coupling link Fig. 26-**2** L2	300 mm 11.8 in

Tab. 15

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1.20 2821 boom head

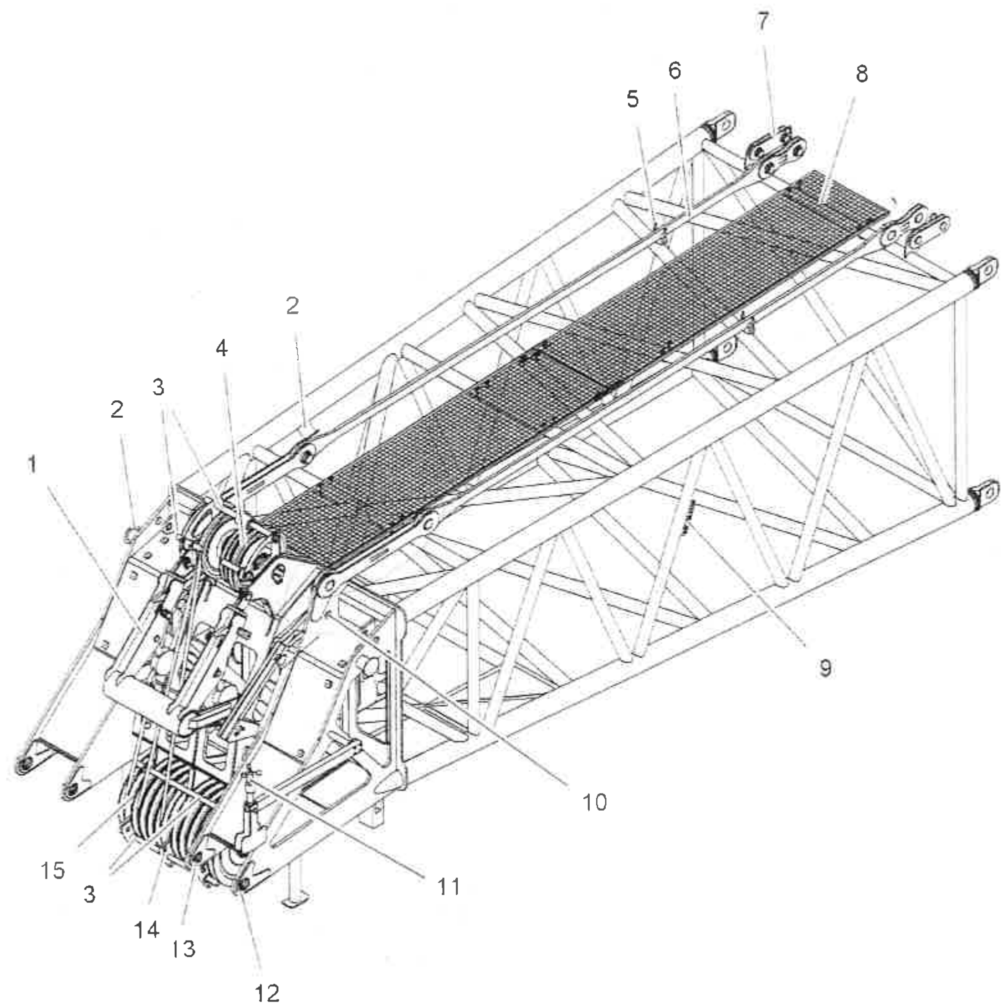

Fig. 27 2821 boom head

1 Tilting-back support guide rails
2 Attachment points (4x)
3 Rope guard tubes
4 Gantry pulleys
5 Transport fixations for anchoring rods
6 Anchoring rods (2x)
7 Coupling links
8 Grating
9 Nameplate
10 Bolting point for tilting-back supports
11 Anemometer
12 Pivot point for fly jib pivot piece
13 Pivot point for fly jib pivot piece or tip boom
14 Pivot point for additional rope pulleys
15 Rope pulleys (10x)

This boom head is designed to allow an adjustable or fixed fly jib or a tip boom to be attached.
Four attachment points Fig. 27-**2** are provided for loading the boom head. The mounting tackle can be slung here.
The rope guard tubes Fig. 27-**3** prevent the hoisting rope from jumping out of the rope pulleys Fig. 27-**14** and gantry pulleys Fig. 27-**4**. The rope is fed onto the rope pulley over the gantry pulley.
The anchoring rods Fig. 27-**6** are immobilized for transport in fixtures Fig. 27-**5** and secured in place with retaining springs.

1.37 Adjustable fly jib - overview

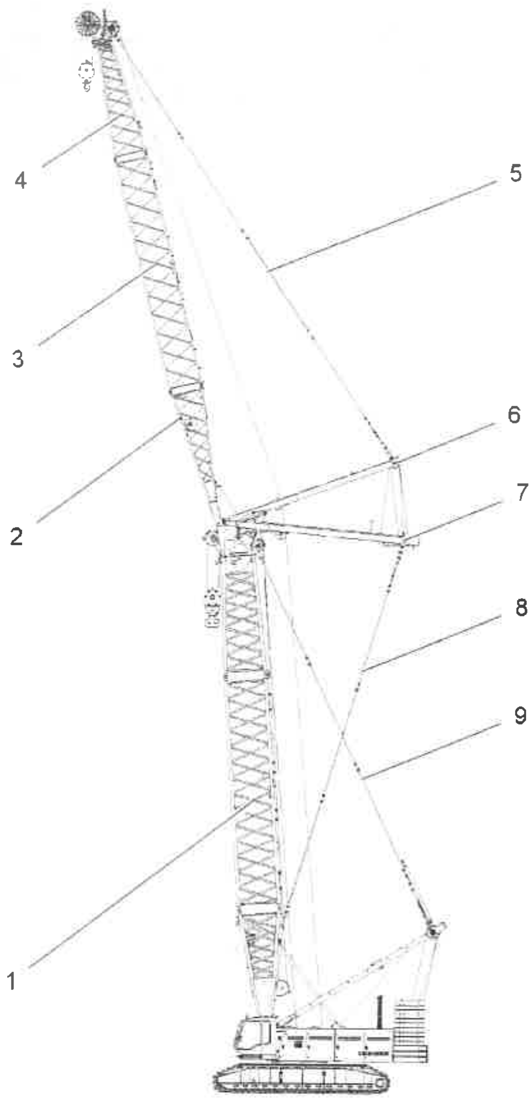

Fig. 52 Adjustable fly jib - overview

1 Main boom
2 Fly jib pivot piece
3 Intermediate pieces
4 Boom head
5 Fly jib anchoring rods
6 A-frame 3
7 A-frame 2
8 Stay rope rods
9 Main boom anchoring rods

The adjustable fly jib is composed of:
- the fly jib pivot piece
- a selection of intermediate pieces
- the boom head

The boom is adjusted with the aid of the fly jib adjusting winch, the rope of which between A-frame 2 Fig. 52-**7** and A-frame 3 Fig. 52-**6** is reeved several times.
The fly jib anchoring rods Fig. 52-**5** connect the A-frame 3 Fig. 52-**6** to the boom head Fig. 52-**4**.
The stay rope rods Fig. 52-**8** connect the A-frame 3 Fig. 52-**7** to the boom head Fig. 52-**1**. They are bolted to the main boom pivot piece.

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1.38 Fly jib pivot piece 2316

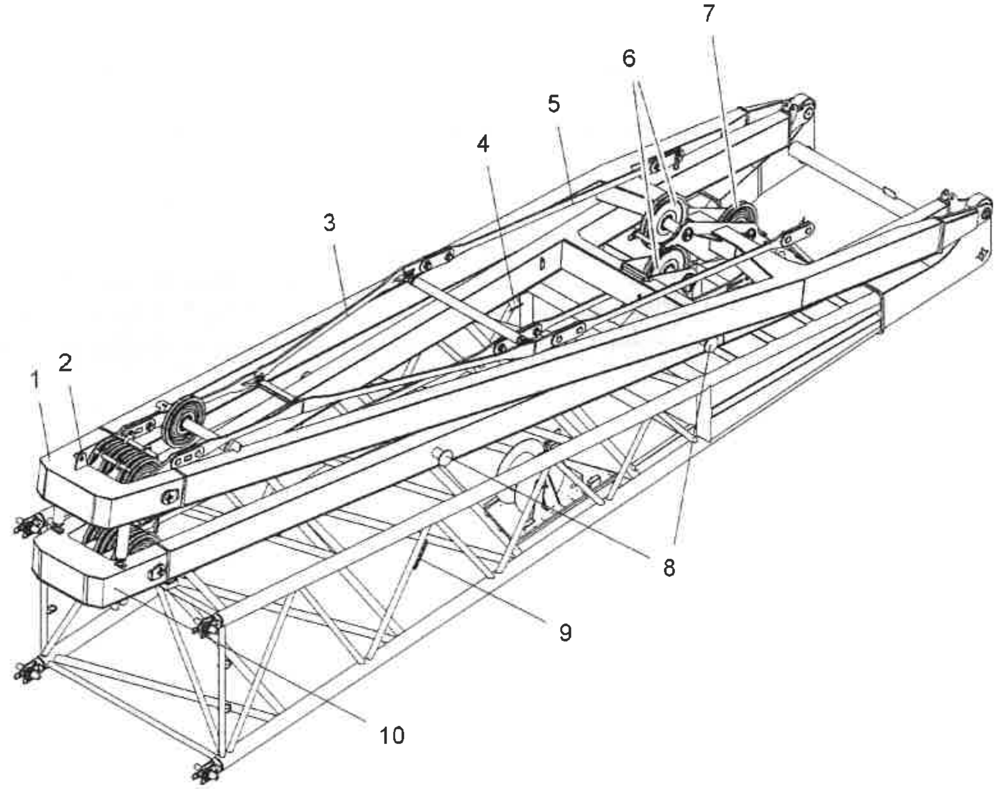

Fig. 53 Fly jib pivot piece 2316

1 A-frame 2
2 Pull strap
3 Crossbar
4 Attachment point (4x)
5 Fly jib tensioning rods
6 Deflection pulley for hoisting rope
7 Deflection pulley for fly jib luffing rope
8 Attachment point (4x) only for A-frames 2 and 3
9 Nameplate
10 A-frame 3

Danger!
Danger from incorrect slinging.

! The attachment points Fig. 53-**4** must be used to load the fly jib pivot piece.

! Only use the attachment points Fig. 53-**8** when the A-frames are unbolted from the fly jib pivot piece.

In the transport position, A -frame 2 Fig. 53-**1** is held by the supports on A-frame 3 Fig. 53-**10**. During transportation, A-frame 3 lies with its supports on the fly jib pivot piece.
The crossbar Fig. 53-**3** braces A-frame 2 by means of the fly jib tensioning rods Fig. 53-**5** and coupling links on the boom head.

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The two deflection pulleys Fig. 53-**6**

- guide the hoisting rope through the A-frames.
- are equipped with a rope guard tube to prevent the hoisting rope from jumping out.

The pull strap Fig. 53-**2** on A-frame 2 is provided for erecting the A-frames when assembling the boom.

The system number and the dead weight incl. anchoring rods can be found on the nameplate Fig. 53-**9**.

Technical data	
Width	2630 mm 8 ft 8 in
Height	3300 mm 10 ft 10 in
Length	11720 mm 38 ft 5 in
Weight with tilting-back supports, tensioning rods and anchoring rods	7895 kg 17405 lb

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1.39 Fly jib intermediate piece 2316 3 m 10 ft

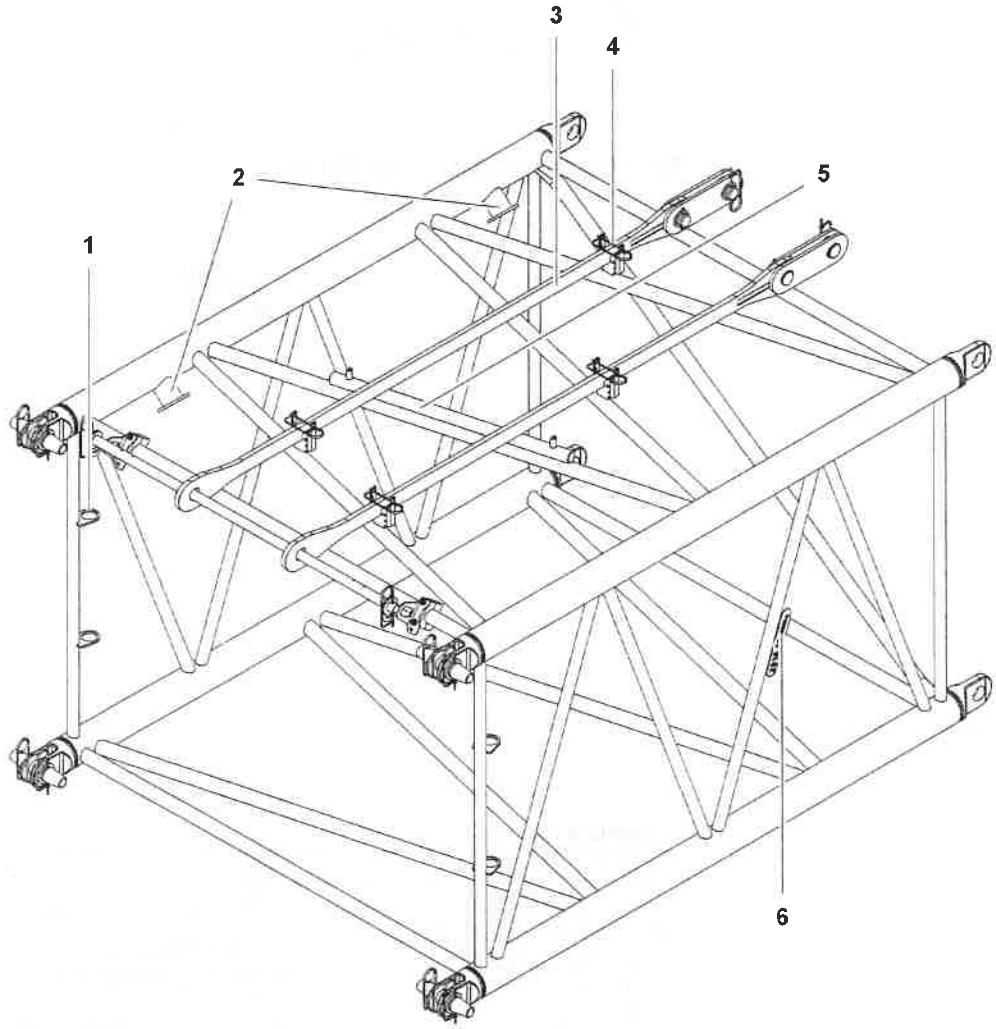

Fig. 54 Fly jib intermediate piece 2316 3 m 10 ft

1 Transport holders for double-tapered pins (4x)
2 Attachment points (4x)
3 Anchoring rod
4 Transport fixations for anchoring rods
5 Rope support
6 Nameplate

Two anchoring rods are Fig. 54-**3** allocated to the fly jib intermediate piece. For transport, these anchoring rods are placed in fixtures Fig. 54-**4** and secured in place with retaining springs.

Four attachment points Fig. 54-**2** are provided for loading the boom intermediate piece. The mounting tackle can be slung here.

The rope support Fig. 54-**5** protects the hoisting rope and the struts against damage.

For transport, the double tapered pins are placed in fixtures Fig. 54-**1** and secured in place with retaining springs.

The system number and the dead weight incl. anchoring rods can be found on the nameplate Fig. 54-**6**.

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Technical data	
Width	2430 mm 7 ft 12 in
Height	1910 mm 6 ft 3 in
Length	3150 mm 10 ft 4 in
Weight with anchoring rods	600 kg 1323 lb

Tab. 37

Anchoring rod 3 m 10 ft

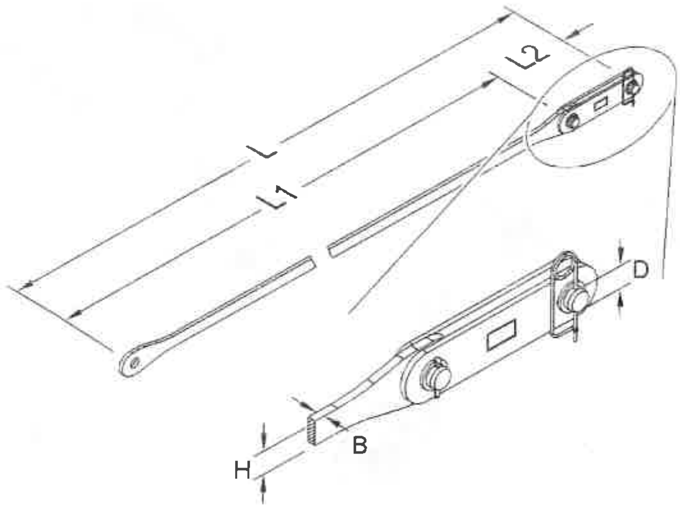

Fig. 55 Anchoring rod 3 m 10 ft

Technical data	
Width Fig. 54-**6** B	22 mm 0.8 in
Height Fig. 24-**6** H	66 mm 2.6 in
Bolt diameter Fig. 24-**6** D	55 mm 2.17 in
Total length Fig. 24-**6** L	3000 mm 9 ft 10.1 in
Length of the anchoring rod Fig. 24-**6** L1	2730 mm 8 ft 6.7 in
Length of the coupling link Fig. 24-**6** L2	270 mm 1 ft 10.6 in

Tab. 38

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1.40 Fly jib intermediate piece 2316 6 m 20 ft

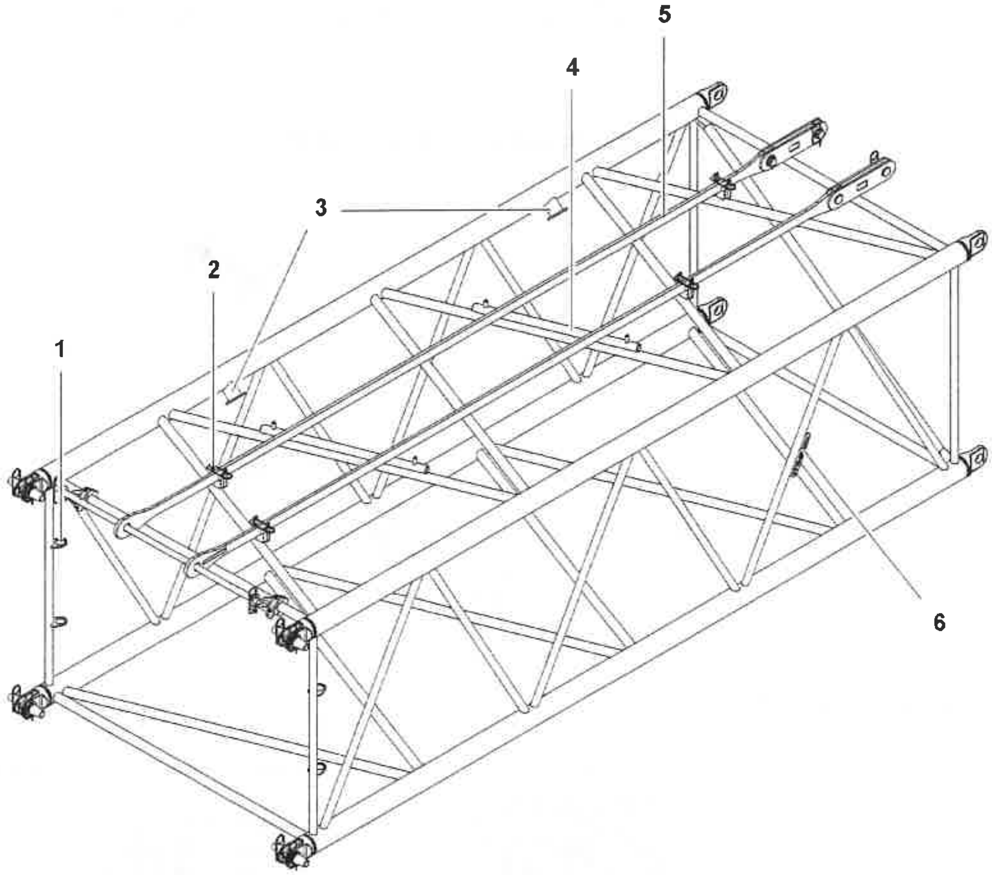

Fig. 56 Fly jib intermediate piece 2316 6 m 20 ft

1 Transport holders for double-tapered pins (4x)
2 Transport fixations for anchoring rods
3 Attachment points (4x)
4 Rope support
5 Anchoring rod
6 Nameplate

Two anchoring rods are Fig. 56-**5** allocated to the fly jib intermediate piece. For transport, these anchoring rods are placed in fixtures Fig. 56-**2** and secured in place with retaining springs.
Four attachment points Fig. 56-**3** are provided for loading the boom intermediate piece. The mounting tackle can be slung here.
The rope support Fig. 56-**4** protects the hoisting rope and the struts against damage.
For transport, the double tapered pins are placed in fixtures Fig. 56-**1** and secured in place with retaining springs.
The system number and the dead weight incl. anchoring rods can be found on the nameplate Fig. 56-**6**.

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Technical data	
Width	2430 mm 7 ft 12 in
Height	1910 mm 6 ft 3 in
Length	6150 mm 20 ft 2 in
Weight with anchoring rods	950 kg 2094 lb

Tab. 39

Anchoring rod 6 m 20 ft

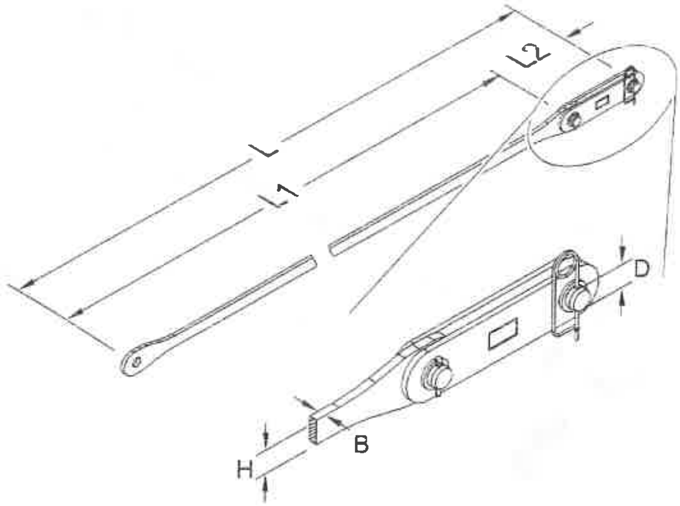

Fig. 57 Anchoring rod 6 m 20 ft

Technical data	
Width Fig. 56-**6** B	22 mm 0.8 in
Height Fig. 24-**6** H	66 mm 2.6 in
Bolt diameter Fig. 24-**6** D	55 mm 2.17 in
Total length Fig. 24-**6** L	3000 mm 9 ft 10.1 in
Length of the anchoring rod Fig. 24-**6** L1	5580 mm 18 ft 3.7 in
Length of the coupling link Fig. 24-**6** L2	420 mm 1 ft 1.45 in.

Tab. 40

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1.41 Fly jib intermediate piece 2316 12 m 39 ft

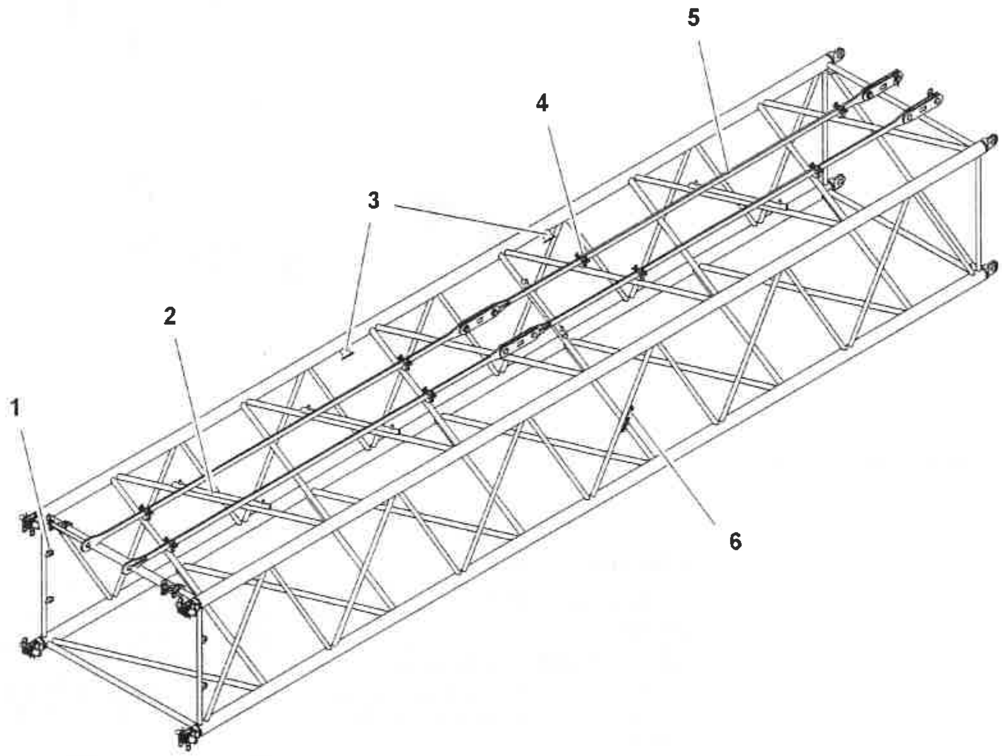

Fig. 58 Fly jib intermediate piece 2316 12 m 39 ft

1 Transport holders for double-tapered pins (4x)
2 Rope support
3 Attachment points (4x)
4 Transport fixations for anchoring rods
5 Anchoring rod
6 Nameplate

Two anchoring rods are Fig. 58-**5** allocated to the fly jib intermediate piece. For transport, these anchoring rods are placed in fixtures Fig. 58-**4** and secured in place with retaining springs.
Four attachment points Fig. 58-**3** are provided for loading the boom intermediate piece. The mounting tackle can be slung here.
The rope support Fig. 58-**2** protects the hoisting rope and the struts against damage.
For transport, the double tapered pins are placed in fixtures Fig. 58-**1** and secured in place with retaining springs.
The system number and the dead weight incl. anchoring rods can be found on the nameplate Fig. 58-**6**.

Technical data	
Width	2430 mm 7 ft 12 in
Height	1910 mm 6 ft 3 in
Length	12150 mm 39 ft 10 in
Weight with anchoring rods	1750 kg 3858 lb

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Anchoring rod 12 m 39 ft

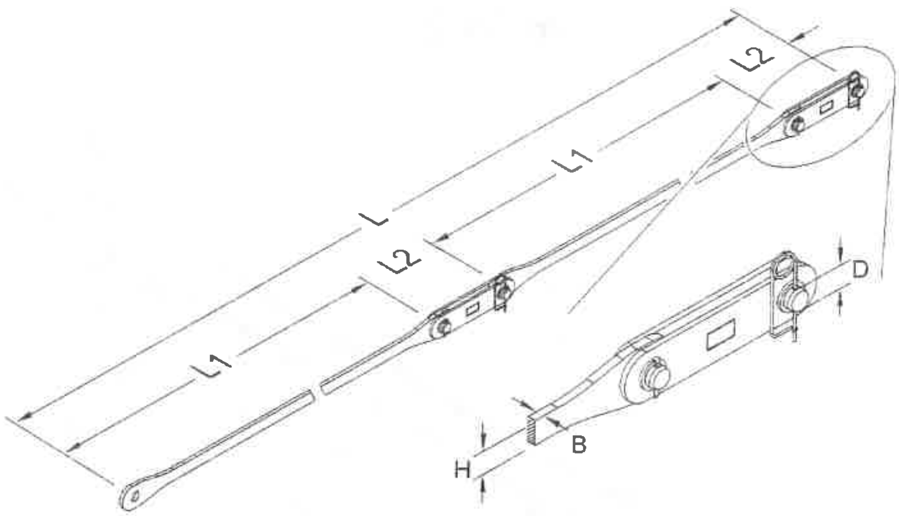

Fig. 59 Anchoring rod 12 m 39 ft

Technical data	
Width Fig. 58-**6** B	22 mm 0.8 in
Height Fig. 59-**6** H	66 mm 2.6 in
Bolt diameter Fig. 59-**6** D	55 mm 2.17 in
Total length Fig. 59-**6** L	12000 mm 39 ft 4.4 in
Length of the anchoring rod Fig. 59-**6** L1	5580 mm 18 ft 3.7 in
Length of the coupling link Fig. 59-**6** L2	420 mm 1 ft 1.45 in.

Tab. 42

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1.42 Fly jib head 2316

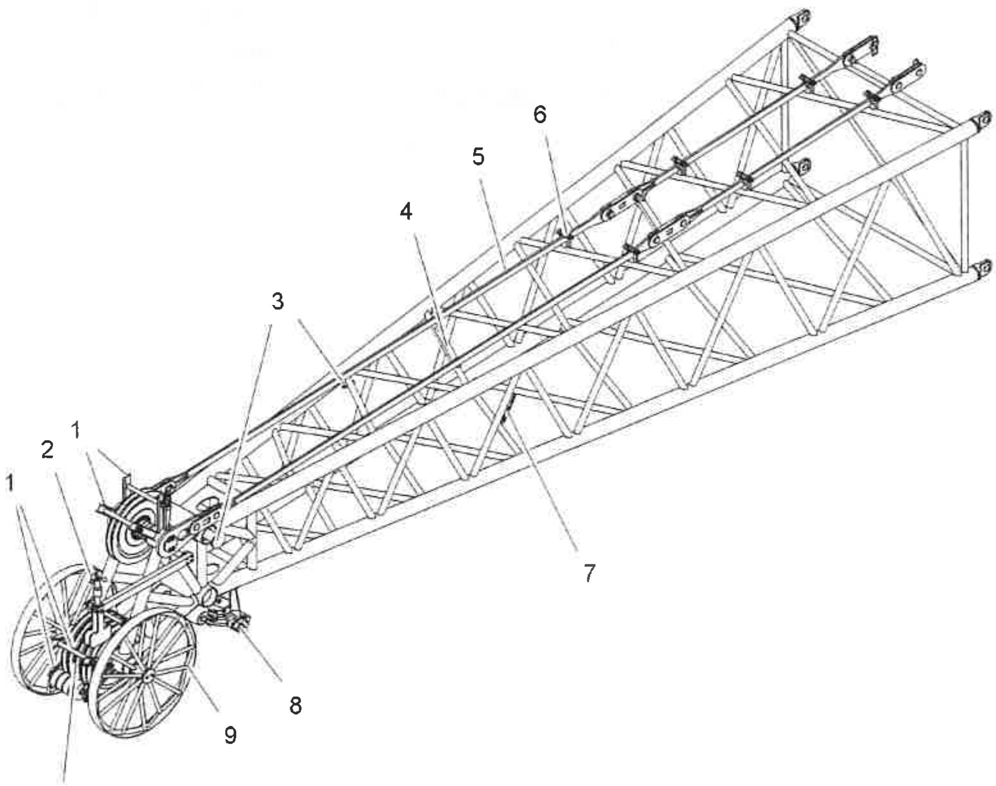

Fig. 60 Fly jib head 2316

1 Rope guard tubes
2 Anemometer
3 Attachment points (4x)
4 Rope support
5 Anchoring rods (2x)
6 Transport fixations for anchoring rods
7 Nameplate
8 Installation position for hoisting limit switch
9 Running wheel
10 Rope pulleys (2x)

This fly jib head is designed to allow a tip boom.

The rope guard tubes Fig. 60-**1** prevent the hoisting rope from jumping out of the rope pulley Fig. 60-**10**.

The anemometer Fig. 60-**2** records the wind speed at the tip of the boom.

Four attachment points Fig. 60-**3** are provided for loading the fly jib head. The mounting tackle can be slung here.

The rope support Fig. 60-**4** protects the hoisting rope, anchoring rods and the struts against damage.

For transport, the anchoring rods are placed in fixtures Fig. 60-**6** and secured in place with retaining springs.

The system number and the dead weight incl. anchoring rods can be found on the nameplate Fig. 60-**7**.

The hoisting limit switch Fig. 60-**8**

- prevents the load hook from colliding with the jib head
- is attached to either one or the other side of the jib head depending on the reeving.

While the jib is being erected or laid down, the jib head runs along the ground on the running wheels Fig. 60-**9**.

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Technical data	
Width	2430 mm 7 ft 12 in
Height	2200 mm 7 ft 3 in
Length	10750 mm 35 ft 3 in
Weight with anchoring rods	1800 kg 3968 lb

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4.23 Leaving the machine

When shutting down the machine, a distinction is made between:
- **A short work interruption:** Waiting time, breaks
- **A long work interruption** Over night, one or more days

Warning:
Unauthorized operation.
! When leaving the machine, it must be protected against unauthorized use, vandalism and any possible adverse environmental impact.

4.23.1 Short work interruption

The machine operator and other persons familiar with the laying down of the boom remain on the site.
The following points must be observed:
- The machine must not impede traffic.
- Lower all loads fully to the ground and secure them.
- Put the boom into its parked position. .
- There must be no hoisting load on the load hook.
- The diesel engine must be shut down before leaving the cab and the cab must be locked.

4.23.2 Long work interruption

The machine operator and other persons familiar with the laying down of the boom leave the site.
- ▶ The machine's boom (main, fly jib, etc.) must be completely placed on the ground.
- ▶ If a Derrick is being used: The ballast carriage and the suspended counterweight must be laid flat on the ground.

4.23.3 Checks before leaving the machine

- ▶ The load must be set down on the ground and sufficiently secured.
- ▶ The machine is on sufficiently supportive subsoil , and in the correct parked position according to the set-up. (For more information see: Chapter nn – Page m.)
- ▶ The machine must not impede any public safety facilities for persons or animals.
- ▶ The shut-down machine must not be placed in in areas used by vehicular traffic or impede traffic.
- ▶ The place where the machine is left must be adequately secured. (Night: flashing light)
- ▶ Ensure that a power supply is provided for the safety equipment (e.g. helicopter warning lights).

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- The ignition key must be pulled out and kept safely, the cab must be locked.
- The machinery space must be locked.
- The auxiliary heating must be switched off or correctly programmed.

5.7 Restrictions due to wind

Note!
! The current wind speed is shown in the power operation screen on the LCD screen.

The following three steps describe the procedure in the event of wind:
- Reduce the working load
- Place the boom in its parked position
- Lay down the boom

5.7.1 Reduction of working load

Note!
! The reduction of the working load for power operation in wind can be found in the load capacity charts.

5.7.2 Parked position for boom configurations

The parked position of the boom can be used up to the maximum wind speed, above this speed the boom must be laid down.

Danger!
Danger from toppling of the machine at high wind speeds!
! Turn the boom towards the direction of the wind
! Before the maximum permitted wind speed is exceeded, place the boom in the specified parked position.
! Place the suspended counterweight and the ballast carriage on the ground.
! The guy ropes and anchoring rods must be relieved.
! Place the load on the ground.
! Position the load hook as high as possible.

Parked position with main boom incl. tip boom

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	Up to 29 m 95 ft
Main boom angle	54° to 60°

Tab. 69

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Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	From 29 m 95 ft to 104 m 341 ft
Main boom angle	72° to 80°

Tab. 70

Parked position with main boom and reducing piece

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	Up to 117 m 384 ft
Main boom angle	72° to 80°

Tab. 71

Description	Value
Maximum wind speed	20 m/s 45 mph
Main boom length	From 117 m 384 ft to 123 m 404 ft
Main boom angle	72° to 80°

Tab. 72

Parked position with main boom and fixed fly jib 0906

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	Up to 29 m 95 ft
Main boom angle	68° to 72°
Fly jib lengths	All
Jib angle	15° and 30°

Tab. 73

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	From 29 m 95 ft to 95 m 312 ft
Main boom angle	72° to 78°
Fly jib lengths	All
Jib angle	15° and 30°

Tab. 74

Parked position with main boom and fixed fly jib 1008

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Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	Up to 26 m 85 ft
Main boom angle	68° to 72°
Fly jib lengths	All
Jib angle	15° and 30°

Tab. 75

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	From 29 m 95 ft to 86 m 282 ft
Main boom angle	72° to 78°
Fly jib lengths	All
Jib angle	15° and 30°

Tab. 76

Parked position with main boom and fixed fly jib 1713

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	Up to 83 m 272 ft
Main boom angle	72° to 78°
Fly jib lengths	All
Jib angle	15° and 30°

Tab. 77

Parked position with main boom incl. tip boom

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	Up to 29 m 95 ft
Main boom angle	54° to 60°

Tab. 78

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	From 29 m 95 ft to 104 m 341 ft
Main boom angle	72° to 80°

Tab. 79

Parked position with main boom and reducing piece

LWN/8.07/en

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	Up to 117 m 384 ft
Main boom angle	72° to 80°

Tab. 80

Description	Value
Maximum wind speed	20 m/s 45 mph
Main boom length	From 117 m 384 ft to 123 m 404 ft
Main boom angle	72° to 80°

Tab. 81

Parked position with main boom and fixed fly jib 0906

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	Up to 29 m 95 ft
Main boom angle	68° to 72°
Fly jib lengths	All
Jib angle	15° and 30°

Tab. 82

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	From 29 m 95 ft to 95 m 312 ft
Main boom angle	72° to 78°
Fly jib lengths	All
Jib angle	15° and 30°

Tab. 83

Parked position with main boom and fixed fly jib 1008

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	Up to 26 m 85 ft
Main boom angle	68° to 72°
Fly jib lengths	All
Jib angle	15° and 30°

Tab. 84

LWN/8.07/en

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	From 29 m 95 ft to 86 m 282 ft
Main boom angle	72° to 78°
Fly jib lengths	All
Jib angle	15° and 30°

Tab. 85

Parked position with main boom and fixed fly jib 1713

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	Up to 83 m 272 ft
Main boom angle	72° to 78°
Fly jib lengths	All
Jib angle	15° and 30°

Tab. 86

Parked position with main boom and adjustable fly jib 1916

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	From 20 m 65 ft to 74 m 243 ft
Main boom angle	80°
Fly jib lengths	From 20 m 65 ft to 80 m 262 ft
Jib angle	66° to 70°

Tab. 87

Description	Value
Maximum wind speed	18 m/s 40 mph
Main boom length	From 20 m 65 ft to 74 m 243 ft
Main boom angle	80°
Fly jib lengths	From 83 m 272 ft to 95 m 312 ft
Jib angle	64° to 70°

Tab. 88

Parked position with main boom and adjustable fly jib 2316

LWN/8.07/en

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	From 20 m 65 ft to 74 m 243 ft
Main boom angle	80°
Fly jib lengths	From 20 m 65 ft to 68 m 223 ft
Jib angle	66° to 70°

Tab. 89

Description	Value
Maximum wind speed	18 m/s 40 mph
Main boom length	From 20 m 65 ft to 74 m 243 ft
Main boom angle	80°
Fly jib lengths	From 71 m 233 ft to 86 m 282 ft
Jib angle	66° to 70°

Tab. 90

Description	Value
Maximum wind speed	0 m/s 0 mph
Main boom length	From 20 m 65 ft to 74 m 243 ft
Main boom angle	Lay down the boom
Fly jib lengths	From 89 m 292 ft to 113 m 371 ft
Jib angle	Lay down the boom

Tab. 91

Parked position with main boom incl. tip boom

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	Up to 29 m 95 ft
Main boom angle	54° to 60°

Tab. 92

Description	Value
Maximum wind speed	22 m/s 49 mph
Main boom length	From 29 m 95 ft to 104 m 341 ft
Main boom angle	72° to 80°

Tab. 93

Parked position with main boom and reducing piece

LWN/8.07/en

Description	Value
Maximum wind speed	0 m/s 0 mph
Main boom length	From 20 m 71 ft to 74 m 233 ft
Main boom angle	Lay down the boom
Fly jib lengths	From 86.5 m 282 ft
Jib angle	Lay down the boom

Tab. 114

Observe the following safety guidelines and instructions:

- The machine operator must remain informed of the weather situation at all times.
- Always lay down the entire main boom flat on the ground. Resting it across an undulation in the ground is always dangerous. If the main boom is not set down completely flat on the ground (but only near the ground), this may lead to the destruction of the boom or of the slewing gear brakes.
- Always set the main boom down so that it is either facing into or against the wind. If the main boom can only be set down cross wise to the wind direction due to limited space, then the setting down has to be completed before the wind reaches the maximum permissible strength.
- In bad weather or if a storm is forecast and work is to be interrupted for a day or more, or if the crane operator and assistants will be absent, the entire boom must be placed on the ground.
- If during planning it is noticed that the boom cannot be set down completely at the site due to a lack of space and there is danger of a storm: Contact the manufacturer in time to arrange special protective measures against storm damage.

Lay down the boom

The “setting-down wind velocity” of the boom is reached when the maximum permissible wind speeds for the parked position are reached or expected to be reached.

Danger!
Risk of machine toppling over and structural collapse, due to high wind velocity!

! The entire boom must be laid down on the ground **before** the maximum permissible wind speed is reached.

! If this is not possible with the boom combination with adjustable fly jib, the fly jib must be placed on the ground and the boom must be supported at the side.

! The boom is to be laid down against the wind.

Note!

! Laying down the boom is the safest thing to do and should be carried out whenever possible.

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The pulley block should be reeved in accordance with the reeving diagrams in chapter 6 of the operating manual.

If the load fall point 2 (main boom head) is preselected, the LML assumes that an unloaden load hook/pulley block with a dead weight of 5500lbs (2.5t) is attached at the load fall point 1 (jib head).

To ensure that at minimum radius the pulley block can always be lowered to the ground, the maximum possible reeving, which depends on the hoisting rope (rope length) used, must be checked. More details can be found in chapter 6 "Required hoist rope length" of the operating manual.

The machine is approved for use in an outside temperature range from -4°F to +104°F (-20°C to +40°C).

Dynamic effects due to hoisting and lowering of the load, booming, slewing, travelling and wind must be considered by the machine operator. The machine operator shall therefore reduce load ratings in order to take these conditions into account.

Rated load capacities do not account for effects of wind on a suspended load or boom. Judgement and experience of the machine operator, job planners and supervisors must be used to compensate for affect of wind on the lifted load and boom by reducing ratings, reducing speeds or a combination of both. Local conditions have to be considered additionally (e.g. wind effects between and around buildings). As a guideline the following table shows rating reductions [%] which shall be used as a minimum. For changing wind speeds an especially for gusts of wind the maximum wind speed must be used. For wind speeds between given values the maximum wind speed has to be taken. The following table is valid only for this machine and the attached chart.

Jib type 2316-2 Jib length [ft (m)]	66 - 85 (20 - 26)	95 - 164 (29 - 50)	174 - 243 (53 - 74)	253 - 302 (77 - 92)	312 - 371 (95 - 113)
Main boom length [ft (m)]	95 - 233 (20 - 71)	95 - 233 (20 - 71)	95 - 233 (20 - 71)	95 - 233 (20 - 71)	95 - 233 (20 - 71)
Wind speed [mph (m/s)]	Reduction by: [%]				
15 (7)	0	0	0	0	0
20 (9)	10	10	10	10	100
25 (11)	20	20	20	40	100
30 (13)	20	30	40	70	100
35 (16)	30	50	70	100	100
over 35 (16)	100 = Operation prohibited				

Jib type 1916-3 Jib length [ft (m)]	66 - 85 (20 - 26)	95 - 164 (29 - 50)	174 - 243 (53 - 74)	253 - 312 (77 - 95)
Main boom length [ft (m)]	95 - 233 (29 - 74)	95 - 233 (29 - 74)	95 - 233 (29 - 74)	95 - 233 (29 - 74)
Wind speed [mph (m/s)]	Reduction by: [%]			
15 (7)	0	0	0	0
20 (9)	0	0	10	10
25 (11)	0	0	10	30
30 (13)	10	10	10	40
35 (16)	20	20	50	100
over 35 (16)	Operation prohibited			

Chapter 5 "Boom park position" of the operating manual describes the permitted park positions of the machine.

If a wind speed in excess of 50mph (22m/s) is expected or has been forecast, then the entire boom must be laid flat on the ground. All combinations with jib type 2316-2 and luffing jib lengths of 233ft (71m) or more must be laid on the ground when the wind speed exceeds 40.3mph (18m/s). All combinations with jib type 2316-2 and luffing jib lengths of 292ft (89m) or more must be laid on the ground when the wind speed exceeds a value where working is not allowed anymore. All combinations with jib type 1916-3 and luffing jib lengths of 272ft (83m) or more must be laid on the ground when the wind speed exceeds 40.3mph (18m/s) (see chapters 2 and 5 of the operating manual).

The wind load applied in the load capacity calculation is based on 0.84 square inch per lbs (1.2m²/t) of the load. If this ratio is greater for light loads with a large surface area, then the manufacturer should be asked to provide details of the reduced load capacities in advance.

The machine operator must hold the qualifications stated in chapter 2 "Personal attributes required of the machine operator" of the operating manual. The machine operator and all other personnel who are involved with its operation must have read and understood the latest applicable ANSI code for mobile crane (ANSI B30.5).

Travelling inevitably produces certain dynamic effects on the machine. For this reason a machine's load must always be reduced before the machine starts to travel. The load reduction should be calculated as follows:

Load capacity - 10%
Load capacity - 2200lbs (1000kg)

The lower value must be used.

The machine must only be moved very slowly (less than 0.9mph (0.4m/s)) and only when the subsoil is level and firm. Any dynamic effects must be reduced to the absolute minimum. The load must not be allowed to sway. See also chapter 5 "Moving the machine on ground slope" of the operating manual.

Blocked crawlers:

Using the load capacities over the tipping edge tumbler or idler the degree rating is limited (± 45° alongside to the crawlers). Travelling is not permitted. See also chapter 4 "Blocked Crawlers" of the operating manual.

Documentation for

Determination of stability during erection and lay down of boom

In accordance with

DIN EN 13000: 2004

ISO 4305 1991-05-15

Rev.	Description	Date	Prepared	Approved
00	First issue of the document	17.02.2016	Broger	Goellnitz
01	Second issue of the document	05.04.2016	Broger	Goellnitz

Table of contents

1 General

The determination of stability is done for LR1300 with a 194 ft (59 m) main boom and a 371 ft (113 m) luffing jib, in combination with rear counterweight 273.4 (1000 lbs) and carbody counterweight 125.7 (1000 lbs).

Figure 1: Picture of LR 1300 with main boom and luffing jib

The load capacities of the configuration is shown in Figure 2.

LIEBHERR

LR1300

Load capacities main boom + luffing jib

Ident. no.:	9839979/151075/	Main boom foot:	2821-1
Slewing range:	360 °	Main boom head:	2821-1
Foot print:	2 - Wide track		
Rear counterweight [1000 lbs]:	273.4		
Carbody counterweight [1000 lbs]:	125.7		

	88° Main boom angle			83° Main boom angle			75° Main boom angle			65° Main boom angle			45° Main boom angle		
Outreach [ft]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]
194 ft Main boom, Load fall point 1 - Jib head Jib head (2316-1) 371 ft Jib															
94	78.0	565	20.4												
95	77.9	565	20.4												
100	77.1	564	20.4												
105	76.3	563	20.3												
110	75.5	562	20.0												
115	74.7	560	19.6												
120	73.9	559	19.4												
125	73.1	557	19.1												
130	72.3	556	18.8												
135	71.5	554	18.5												
140	70.6	552	18.3												
143				73.0	556	19.0									
145	69.8	550	18.1	72.6	555	19.0									
150	69.0	548	17.9	71.8	553	18.9									
155	68.1	546	17.6	71.0	551	18.8									
160	67.3	544	17.3	70.1	550	18.4									
165	66.5	542	17.0	69.3	548	18.1									
170	65.6	540	16.7	68.5	546	17.8									
175	64.7	538	16.4	67.6	544	17.5									
180	63.9	535	16.2	66.8	542	17.3									
185	63.0	533	15.9	65.9	539	17.0									
190	62.1	530	15.7	65.1	537	16.7									
195	61.3	527	15.5	64.2	535	16.5									
200	60.4	524	15.3	63.4	532	16.2									
205	59.5	522	15.1	62.5	530	16.0									
210	58.6	518	14.9	61.6	527	15.8									
215	57.6	515	14.7	60.7	524	15.6									
217							65.0	531	15.2						
220	56.7	512	14.5	59.8	521	15.4	64.5	530	15.2						
225	55.8	509	14.3	58.9	518	15.2	63.7	527	14.9						
230	54.8	505	14.1	58.0	515	15.0	63.0	525	14.3						
235	53.9	502	13.9	57.1	512	14.8	62.1	523	13.7						
240	52.9	498	13.7	56.2	508	14.6	61.3	520	13.0						
245	51.9	494	13.6	55.2	505	14.4	60.4	517	12.4						
250	50.9	490	13.4	54.3	501	14.2	59.5	514	11.8						
255	49.9	486	13.3	53.3	498	14.0	58.6	511	11.3						
260	48.9	481	13.0	52.3	494	13.9	57.7	508	10.7						
265	47.8	477	11.8	51.3	490	13.7	56.7	505	10.2						
270	46.8	472	10.7	50.3	486	13.6	55.8	502	9.7						
275	45.7	467	9.5	49.3	481	12.9	54.9	498	9.3						
280	44.6	462	8.4	48.3	477	11.8	53.9	494	8.8						
285	43.5	457	7.4	47.2	472	10.6	53.0	491	8.4						
290	42.3	451	6.4	46.1	468	9.4	52.0	487	7.9						
295	41.2	446	5.4	45.0	463	8.3	51.0	483	7.5						
300	40.0	440	4.4	43.9	457	7.3	50.0	479	7.1						
305	38.7	434	3.5	42.8	452	6.2	49.0	474	6.8						
310				41.6	446	5.2	47.9	470	6.4						
315				40.4	441	4.2	46.9	465	6.0						
320				39.2	435	3.3	45.8	460	5.7						
325							44.7	455	5.0						
330							43.6	450	4.3						
335							42.4	445	3.6						
340							41.3	439	3.0						
345							40.1	433	2.3						

Figure 2: Load capacity of the main boom with luffing jib

1 General

The determination of stability is done for LR1300 with a 194 ft (59 m) main boom and a 371 ft (113 m) luffing jib, in combination with rear counterweight 273.4 (1000 lbs) and carbody counterweight 125.7 (1000 lbs).

Figure 1: Picture of LR 1300 with main boom and luffing jib

The load capacities of the configuration is shown in Figure 2.

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LR1300

Load capacities main boom + luffing jib

Ident. no.:	9839979/151075/	Main boom foot:	2821-1
Slewing range:	360 °	Main boom head:	2821-1
Foot print:	2 - Wide track		
Rear counterweight [1000 lbs]:	273.4		
Carbody counterweight [1000 lbs]:	125.7		

	88° Main boom angle			83° Main boom angle			75° Main boom angle			65° Main boom angle			45° Main boom angle		
Outreach [ft]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Rope pulley height [ft]	Load capacity [1000 lbs]
194 ft Main boom, Load fall point 1 - Jib head Jib head (2316-1) 371 ft Jib															
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345							40.1	433	2.3						

Figure 2: Load capacity of the main boom with luffing jib

2 General Arrangement

The following picture shows the arrangement of the different parts of the crane.

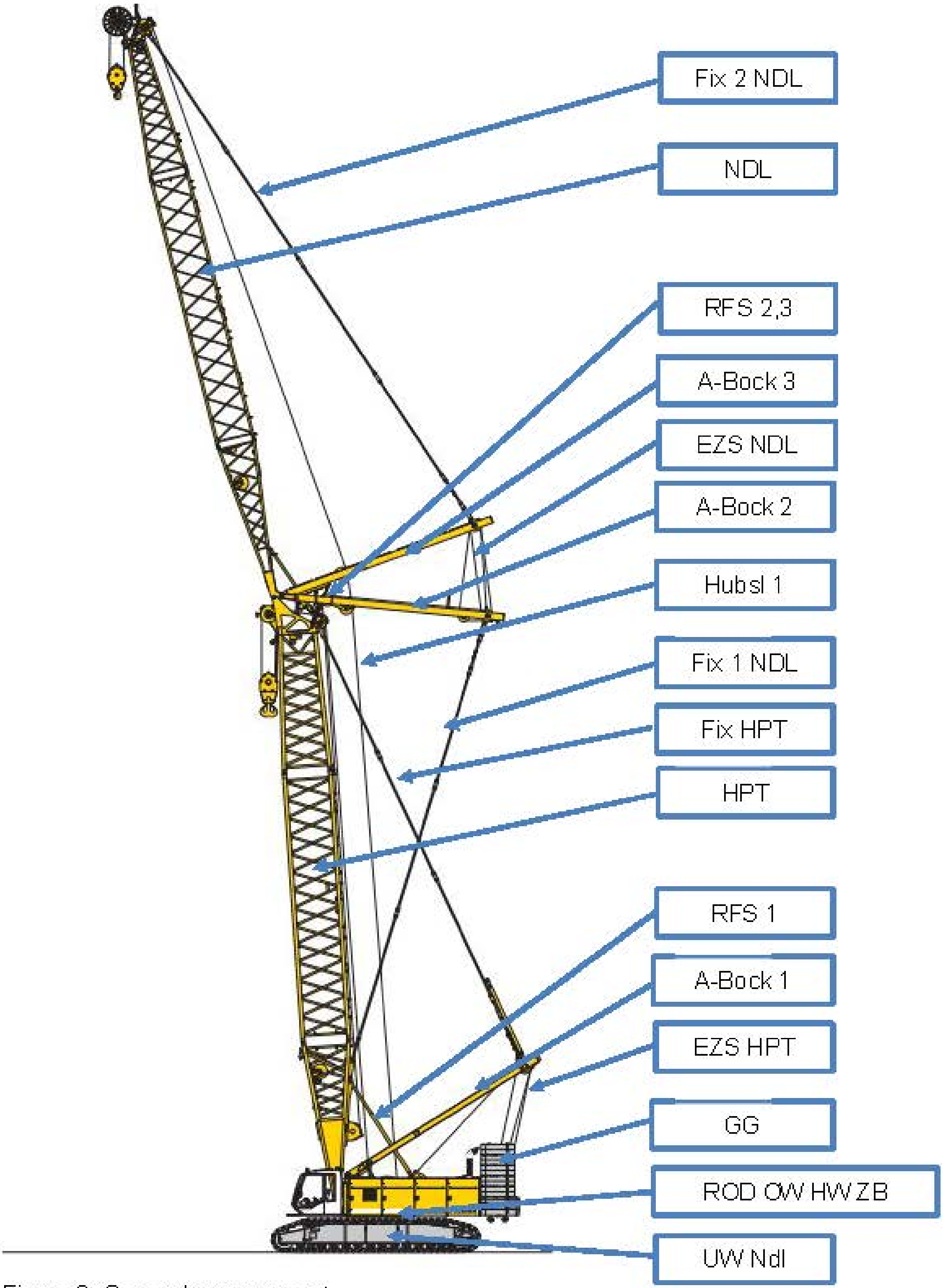
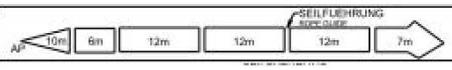


Figure 3: General arrangement

2.1 Main boom and luffing jib

The arrangement of the main boom and the luffing jib are shown in Figure 4 and Figure 5.

LR1300 Mode 1 HPT / Main boom

AUSLEGERLAENGE BOOM LENGTH	KONFIGURATION CONFIGURATION	POS SEILFUEHRUNG ROPE GUIDE	SYMBOLISCHE DARSTELLUNG SYMBOLIC DRAWING	gueltig fuer valid for
59 m	1x6m + 3x12m	40 m		

Legende LR 1300
legend

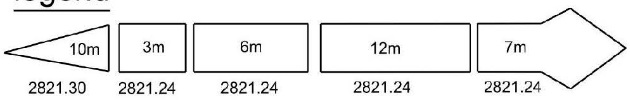


Figure 4: Arrangement of the main boom (59m)

LR1300 Mode 4 verstellbare Nadelausleger 2316 / luffing jib

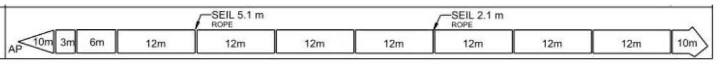
AUSLEGERLAENGE BOOM LENGTH	KONFIGURATION CONFIGURATION	ABSPANNSEIL I GUY ROPE I: CODE CODE	ABSPANNSEIL I GUY ROPE I: SEILLAENGE ROPE LENGTH	ABSPANNSEIL I GUY ROPE I: MONTAGE BEI ASSEMBLY AT	ABSPANNSEIL II GUY ROPE II: CODE CODE	ABSPANNSEIL II GUY ROPE II: SEILLAENGE ROPE LENGTH	ABSPANNSEIL II GUY ROPE II: MONTAGE BEI ASSEMBLY AT	SYMBOLISCHE DARSTELLUNG SYMBOLIC DRAWING
113 m	1x3m + 1x6m + 7x12m	4.21	5.1 m (3.0 + 2.1)	31 m	7.37	2.1 m	67 m	

Figure 5: Arrangement of the luffing jib (113m)

2.2 Properties of the Components

The following components are considered in the calculation:

Table A: Mass and centres of gravity for different crane parts, printed for a main boom angle of 80° and a luffing jib angle of 15 °

Part	Mass	x, 0° (Inclination)	z, 0° (Inclination)	A,Wind Area in m^2 at 90°	α
HPT	20.841	5075.88498	28872.05463	84.43	80
OW+ROD+HW	27.442	-3171.97726	204.6622	26	90
GG	124	-7391	878	0	
UW	42.7	-1700	-1468	15	90
ZB	57	-1700	-1218	0	
A-Bock1	2.945	-5549.13439	3925.19309	0	
RFS 1	0.8	-1616.81313	3161.73456	0	
FIX HPT	2.431	479.94468	31654.20082	0	
EZS HPT	0.31178	-8140.53152	3282.57005	0	
Hubsl 1	0.67979	43447.86877	59591.44197	0	
NDL	16.32	63651.39263	72653.9765	111.8	15
A-Bock2	2.1	5727.29106	59586.5748	0	
FIX1 NDL	1.607	852.92637	34966.1991	0	
FIX2 NDL	3.5605	64123.74436	77548.5004	0	
A-Bock3	2.3	9414.31145	64651.62134	0	
RFS 2	0.2	9873.83644	59275.07555	0	
RFS 3	0.144	11375.51919	58888.81998	0	
EZS NDL	0.29511	4669.81079	64326.87057	0	

…where M is the overall mass of the part in metric tons, x and z are the x and z-coordinate in mm of the centre of gravity with its coordinate system shown in Figure 6. A is the area of the wind in square meters, and α is the angle of the component to horizontal in degree.

Table A represents the worst conditions in regard of stability proof.

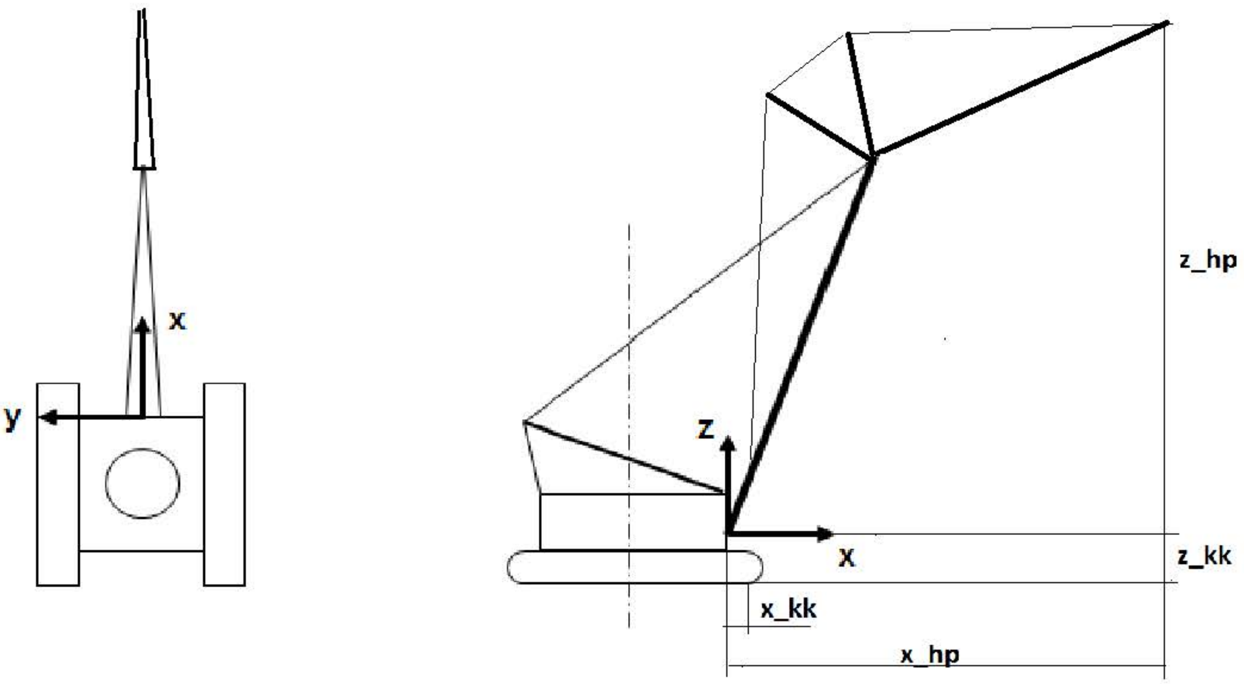


Figure 6: Coordinate system used in Table , and the distances from the origin to the tipping line x_kk and z_kk and the coordinates to the hoisting point x_hp and z_hp.

The variable x_kk can be seen in the operating manual on page 54, x_kk=L5-L4-L3=2540 mm. z_kk=2350mm and the variables x_hp and z_hp are dependent on the main boom and jib position. According to ISO 4310-1981 F_1, the weight of the main boom and jib reduced in the head of the jib, can be calculated as follows:

$$F_1 = \frac{mG + g(j+n)}{j+k} = \frac{20.841 * 5076 + 16.32 * 63651}{120545} = 9.495\ t$$

... where G is the mass of the main boom, g is the mass of the jib, and m and j are the corresponding radii of the centers of gravity and (j+k) is the radius of the hoisting point.

2.3 Stability according to ISO 4305:1991 table 1

According to ISO 4305 Table 1 the stability of crawler crane can be determined as follows:

Table 1

Machine configuration/condition	**Loading**	**Value to be taken into consideration** [1)]
On outriggers/crawlers[2)]	Applied load	$1{,}25P + 0{,}1F$
On wheels (tyres)[2)]	Applied load	$1{,}33P + 0{,}1F$
On crawlers/wheels (tyres) when travel speed up to 0,4 m/s is permissible	Applied load	$1{,}33P + 0{,}1F$
On crawlers/wheels (tyres) when travel speed greater than 0,4 m/s is permissible	Applied load	$1{,}5P + 0{,}1F$

1) In these formulae

P is the rated capacity (hoist medium load) as specified by the crane manufacturer for the various configurations of the crane. It shall be for the hoist medium load of the crane as defined by ISO 4306-1 (see 3.5.1).

F is the load from the mass of the jib and fly jib referred to the jib head or fly jib head. (See ISO 4310 for the determination of *F*.)

The value to be taken into consideration is intended to simulate the dynamic forces arising during normal controlled operation.

2) For these configurations, the crane condition is stationary and relates to the travel of the crane as a whole but is not related to hoisting, luffing, telescoping and slewing.

Figure 7: Table 1 of ISO 4305:1991, highlighted in red are the values used

The stability is determined using the following formula:

$$M_{stand} + (1.25\,P + 0.1\,F_1)\left(x_{hp} - x_{kk}\right) = 0$$

$$P = \frac{-\frac{M_{stand}}{\left(x_{hp} - x_{kk}\right)} - 0.1\,F_1}{1.25}$$

… where M_{stand} is the overall stabilizing Moment, $F_1$is calculated according to ISO 4310, P is the load on the jib head and x_{hp} is the horizontal distance between the hoisting point and the line about which the crane may tip. The Stabilizing moment M_{stand} is defined as :

$$M_{stand} = \sum_{all\ parts} M * (x - x_{kk}) = 532093\ tmm$$

$$P = \frac{-\frac{532093\ tmm}{117985\ mm} + 0.1 * 9.495\ t}{1.25} = 2.85\ t$$

2.4 Stability according to ISO 4305:1991 table 2

Table 2

Machine configuration/condition	Loading	Value to be taken into consideration[1)]
On outriggers/crawlers[2)]	Applied load	1,1P
	Wind load	W
	Inertia forces	D

Figure 8: Partial view of Table 2 of ISO 4305:1991

The stability is determined using the following formula:

$$M_{stand} + (1.1\,P)\left(x_{hp} - x_{kk}\right) + 0.03P\left(z_{hp} + z_{kk}\right) + M_D + M_W = 0$$

$$P = \frac{-M_{stand} - M_D - M_W}{1.1\left(x_{hp} - x_{kk}\right) + 0.03 * \left(z_{hp} + z_{kk}\right)} = 3.91\ t$$

where M_{stand} is again the overall stabilizing Moment, M_D is the Moment due to inertia forces and is set to zero in accordance with ISO 4305 table 2. The term $0.03(1.1\ P)$represents the wind forces acting on the load (see ISO 4302). M_W is the moment due to wind effects on the structure:

$$M_W = \sum_{alls\ parts} A * \sin(\alpha) * p_w * (z + z_{kk}) = \ 14556\ tmm$$

Where A,α and z are from Table , p_w is the wind pressure, defined as:

$$p_w = 0.613 * \frac{v_w^2}{10000} = 0.613 * \frac{7^2}{10000} = 0.0030037\frac{t}{m^2}$$

The wind speed is taken as $v_w = 7m/s$ according to the operating manual.

2.5 Stability according to EN 13000

According to DIN 13000:2010-5 (E) section 4.1.2.6.3 the stability during erection and dismantling is considered a special loading condition.

4.1.2.6.3 Stability during erection and dismantling

The rigid body stability for erection of the unloaded crane and its dismantling procedure shall be considered as a special loading condition. The dead loads and the additional loads (gravitational, wind loads, etc.) increasing the tipping moment shall be amplified with a safety coefficient ≥ 1,1.

Figure 9: Excerpt from DIN EN 13000:2010-5 (E)

The following formula is used to determine the stability:

$$1.1 * M_{stand\_pos} + M_{stand\_neg} + (1.1 * P)(x_{hp} - x_{kk}) + 0.03P(z_{hp} + z_{kk}) + 1.1 * M_W = 0$$

$$P = \frac{-1.1 * M_{stand_{pos}} - M_{stand_{neg}} - 1.1 * M_W}{1.1\,(x_{hp} - x_{kk}) + 0.03 * (z_{hp} + z_{kk}) * 1.1} = 2.92\ t$$

Where M_{stand_pos} consists of the dead loads decreasing the tipping moment and $M_{stand_{neg}}$ are the components increasing the tipping moment.

3 Proof

The proof of rigid body stability is fulfilled, when the force P calculated in chapters 2.3, 2.4 and 2.5 are positive. This means at the considered position of the main boom (80°) and the jib (15°), all three proofs are fulfilled.

The following tables show the three proof types for all relevant positions of the main boom and luffing jib during erection.

Table B: Proof of the rigid body stability for main boom angle **80°** and different luffing jib angles, shown are the values of P for different luffing jib angles.

HPT 80°	wind speed		7 m/s
NDL Angle [°]	P [t] (ISO 4305 T1)	P [t] (ISO 4305 T2)	P [t] EN 13000
15	2.85	3.91	2.92
7.5	2.55	3.61	
0	2.43	3.52	2.47
-7.5	2.49	3.58	
-15	2.73	3.85	
-22.5	3.17	4.35	
-32	4.09	5.41	4.28

The results in table B show, that the crane at main boom angle 80° is stable in all proofs even when exposed to wind.

Table C: Proof of the rigid body stability for main boom angle **75°** and different luffing jib angles, shown are the values of P for different luffing jib angles.

HPT 75°	wind speed		7 m/s
NDL Angle [°]	P [t] (ISO 4305 T1)	P [t] (ISO 4305 T2)	P [t] EN 13000
15	1.39	2.35	1.23
7.5	1.13	2.1	
0	1.03	2.01	0.89
-7.5	1.07	2.05	
-15	1.27	2.27	
-22.5	1.63	2.68	
-30.3	2.22	3.36	2.25

The results in table C show, that the crane at main boom angle 75° is stable in all proofs even when exposed to wind.

Table D: Proof of the rigid body stability for main boom angle **70°** and different luffing jib angles, shown are the values of P for different luffing jib angles.

HPT 70°	wind speed	7	m/s
NDL Angle [°]	P [t] (ISO 4305 T1)	P [t] (ISO 4305 T2)	P [t] EN 13000
15	0.07	0.95	-0.24
7.5	-0.15	0.73	
0	-0.24	0.65	-0.54
-7.5	-0.21	0.67	
-15	-0.05	0.84	
-22.5	0.25	1.18	
-30.3	0.73	1.74	0.47

The results in table D show, that the crane at main boom angle 70° is physically stable (ISO 4305 T2) even when exposed to wind. However the required safety factors for the other proofs are not fully given. Thus the main boom angle 70° represents the critical angle during erection and boom lay down operation.

4 Standards and Literature

ISO 4305 second edition 1991-05-15 Mobile cranes-Determination of Stability
ISO 4302 first edition 1981-05-15 Cranes-Wind load assessment
ISO 4310 first edition 1981-05-01 Cranes-Test code and procedures
DIN EN 13000:2004 Cranes-Mobile cranes English translation of DIN EN 13000:2004

5 Alteration Information

Date	Index	Alterations	Name

Configuration: 194' boom + 371' luffing jib w/273.4k+125.7k ctwt.

LR1300 Mode 4:	SN 138.064
main boom 2821:	194ft = 59m à Winkel = 80°
luffing boom 2316:	371ft = 113m à Winkel = -31.7°
counter weight:	m = 273400lbs = 124t
carbody weight:	m = 125700lbs = 57t

The following parking position is only allowed exceptionally for this configuration and NOT for regular use!!
Maximum wind speed = 30meter/second (67miles/hour)
Attention: This wind speed is the maximum possible 3-second-gust-wind at maximum elevated height. If higher wind speeds are expected, the boom has to be laid flat on the ground.

Parking Position for wind speed of 30meter/second (67miles/hour):

- main boom at 80°
- luffing boom approximately at -31.7°
- tip of luffing boom should be approximately 1m (3.5ft) above ground
- the hook of luffing jib has to be on the ground for final parking position
- machine should be turned, so that the wind comes from behind if it is possible

Securing boom in parking position:

- the luffing boom tip needs to be suspended with an allowed force of 3.1t (6835lbs) to each side

Klappmesserstellung
jack-knife position

6	08.01.2016	Konfigurationen hinzu	M. Eder	TBBK	M. Eder	TBBK
5	03.02.2015	Konfigurationen hinzu	M. Eder	TBBK	M. Eder	TBBK
4	27.10.2014	Formelfehler ausgebessert	M. Eder	TBBK	M. Eder	TBBK
3	09.09.2014	HPT in Tabelle ausgebessert	M. Eder	TBBK	M. Eder	TBBK
2	05.08.2014	Klappmesserpositionen der Auslegerkonfigurationen	A. Hille	TBF	M. Eder	TBBK
1	05.08.2014	Klappmesserpositionen der Auslegerkonfigurationen	A. Hille	TBF	M. Eder	TBBK
0	24.10.2013	Init	M. Eder	TBHS	M. Eder	TBHS
REV	DATE	DESCRIPTION	ISSUED	DEPARTM	APPROVED	DEPARTM

Inhaltsverzeichnis / table of contents

1 Anweisungen zur Klappmesserstellung

Die Parkposition und die maximal zulässigen Windgeschwindigkeiten sind in der Betriebsanleitung angeführt. Die Klappmesserstellung ist eine spezielle Parkposition des Auslegers, welche höhere Windgeschwindigkeiten zulässt. Überschreitet der Wind diesem Wert, ist der Ausleger abzulegen.

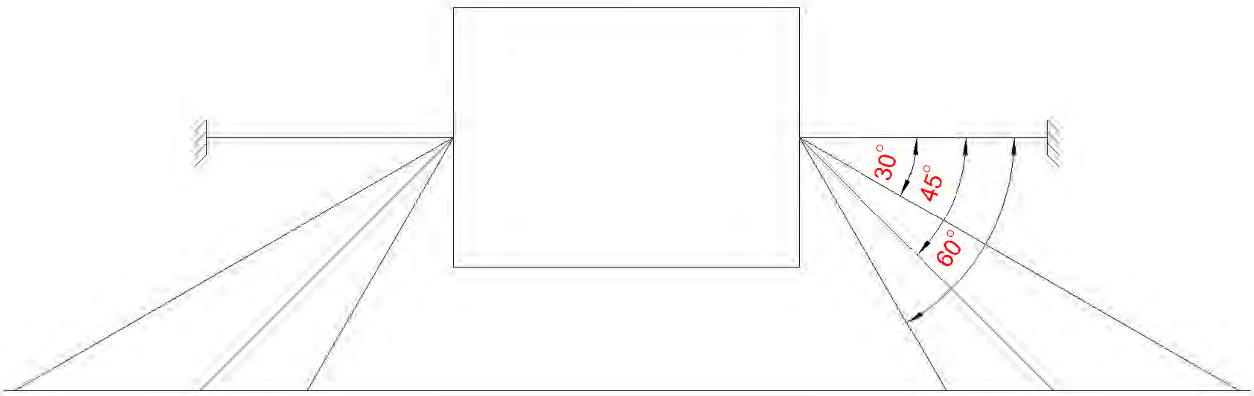
- Die Anweisung ist gültig für alle LR-Raupenkrane der Liebherr-Werk Nenzing GmbH in Verbindung mit einer wippbaren Nadel

Eckpunkte der Angaben sind:
- Sämtliche Haken müssen am Boden abgelegt werden
- Die Abspannung muss auf beiden Seiten erfolgen

Die angegebene Abspannungslast bezieht sich auf eine horizontale Abspannung. Wenn diese nicht eingehalten werden kann, muss die Abspannlast umgerechnet werden um die horizontale Abspannlast gewährleisten zu können.

$$Abspannlast\ Neu = \frac{Abspannlast}{\cos(x°)}$$

BSP.: Angabe 3t seitlicher Abspannung bei 0°
Bei 0° = 3t entspricht einem Faktor von 1
Bei 30° = 3.5t entspricht einem Faktor von 1.17
Bei 45° = 4.2t entspricht einem Faktor von 1.4
Bei 60° = 6t entspricht einem Faktor von 2



Zusätzliche Anforderungen:
- Die Abspannung muss so erfolgen, dass die Lackierung nicht beschädigt wird.
  Empfehlung: Kunststoffschlingen verwenden

1 Instructions for jack-knife position

The parked position of the boom applies up to the maximum wind speed and is stated within the manual. The jack-knife position is a special parking position of the boom/luffing jib combination, which is able to withstand higher wind speeds. Above this speed the boom must be set down.

- The instruction is valid for all LR - cranes of the Liebherr-Werk Nenzing GmbH in combination with a luffing jib.

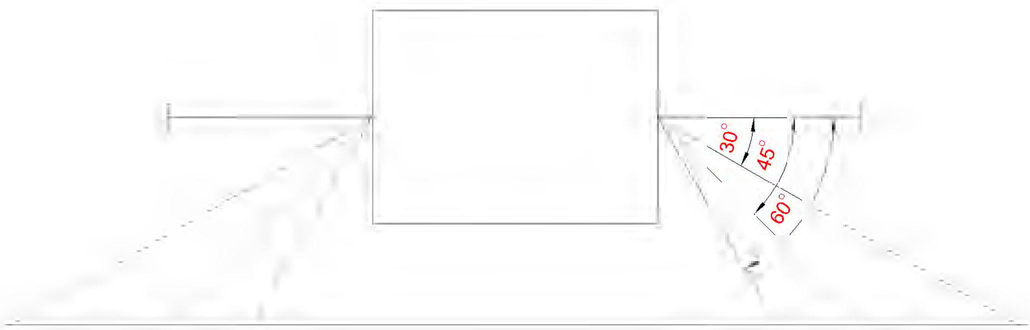
Key points of information are:

- All hooks must be placed on the ground
- The rigging must be done on both sides

The specified load refers to a horizontal bracing. If this cannot be met, the horizontal load must be converted to ensure the required horizontal load.

$$new\ horizontal\ load = \frac{horizontal\ load}{\cos(x°)}$$

E.g.: Specification 3t rigging to the side (0°)
At 0° = 3t equates to a factor of 1
At 30° = 3.5t equates to a factor of 1.17
At 45° = 4.2t equates to a factor of 1.4
At 60° = 6t equates to a factor of 2



Additional requirements:

- The rigging must be attached so that the paint does not get damaged.
  Recommendation: Use plastic round slings

2 Klappmesserpositionen der Auslegerkonfigurationen

Voraussetzungen bzw. Randbedingungen:

- Die Geräte sind vollballastiert.
- Der Nadelkopf soll sich ca. 1m über dem Boden befinden.
- Der Haltestrang ist gespannt.
- Der Haken muss auf dem Boden liegen.
- Bei höheren Windgeschwindigkeiten muss der Ausleger am Boden abgelegt werden.

2 Jack-knife positions of boom configurations

Assumptions:

- Full counterweight on cranes
- The luffing jib head must be about 1m above the ground.
- The pendent strap is tensioned.
- The hook must be on the ground.
- At higher wind speeds, the boom must be placed on the ground.

Crane Modell	Crane Typ	Main Boom Type	Main Boom [ft]	Main Boom [m]	Main Boom angle [°]	Luffing jib Type	Luffing jib [ft]	Luffing jib [m]	Luffing jib angle [°]	maximum Windspeed [mph]	maximum Windspeed [m/s]	horizontal load at luffing jib tip [lbs]	horizontal load at luffing jib tip [t]
LR 1100	1001.01	1311	105	32	65	1008	105	32	-69	78	35	2205	1,0
		1311	105	32	65	1309	104	31,7	-71	78	35	2205	1,0
LR1130	1002.01-03	2017	164	50	88	1309	228	69,5	-47	67	30	3086	1,4
LR1140 + LR 1160	1003.01-03	2018	104	31,7	65	1309	104	31,7	-71	111	50	1102	0,5
		2018	152	46,4	31	1309	84	25,7	-77	67	30	2205	1,0
		2018	152	46,4	67	1309	151	46,1	-72	82	37	3307	1,5
		2018	152	46,4	85	1309	200	60,8	-51	89	40	4409	2,0
		2018	191	58,1	25	1309	84	25,7	-88	56	25	1543	0,7
		2018	191	58,1	64	1309	181	55,1	-76	67	30	2646	1,2
		2018	104	31,7	67	1713	105	32	-72	111	50	4630	2,1
		2018	152	46,4	22	1713	66	20	-68	67	30	2205	1,0
		2018	152	46,4	32	1713	85	26	-83	67	30	2205	1,0
		2018	152	46,4	68	1713	154	47	-70	85	38	3748	1,7
		2018	152	46,4	85	1713	203	62	-50	85	38	4630	2,1
LR 1200 +LR 1200SX + LR1250	1004.01-02	2320	105	32	65	1713	105	32	-70	100	45	3968	1,8
		2320	154	47	23	1713	66	20	-70	62	28	2205	1,0
		2320	154	47	30	1713	85	26	-71	62	28	1984	0,9
		2320	154	47	67	1713	154	47	-71	78	35	3307	1,5
		2320	154	47	86	1713	203	62	-51	78	35	3968	1,8
		2320	194	59	25	1713	85	26	-88	51	23	1543	0,7
		2320	194	59	68	1713	194	59	-72	62	28	2646	1,2
		2320	203	62	18	1713	66	20	-88	51	23	1764	0,8
		2320	203	62	68	1713	203	62	-71	62	28	2646	1,2
		2320	95	29	65	1916	203	62	-26	80	36	5512	2,5
		2320	95	29	80	1916	213	65	-27	80	36	5071	2,3
		2320	105	32	65	1916	105	32	-70	100	45	3968	1,8
		2320	144	44	75	1916	174	53	-53	89	40	5732	2,6
		2320	154	47	23	1916	66	20	-70	62	28	2205	1,0
		2320	154	47	30	1916	85	26	-71	62	28	1984	0,9
		2320	154	47	67	1916	154	47	-71	73	33	3307	1,5
		2320	154	47	80	1916	174	53	-63	80	36	5952	2,7
		2320	154	47	86	1916	203	62	-51	78	35	3968	1,8
		2320	184	56	80	1916	223	68	-56	53	24	2425	1,1
		2320	194	59	25	1916	85	26	-88	51	23	1543	0,7
		2320	194	59	68	1916	194	59	-72	62	28	2646	1,2
	MF	2320	174	53	80	1916 MF	235	71,5	-48	71	32	4409	2,0
LR 1280	1005.02	2220	180	55	60	1916	164	50	-78	62	28	2425	1,1
LR 1300 + LR 1300SX	1006.01	2821	105	32	66	1916	105	32	-72	100	45	3968	1,8
		2821	154	47	24	1916	66	20	-88	56	25	1323	0,6
		2821	154	47	32	1916	85	26	-88	56	25	1323	0,6
		2821	154	47	67	1916	154	47	-71	73	33	2866	1,3
		2821	154	47	86	1916	203	62	-51	78	35	3968	1,8
		2821	154	47	88	1916	262	80	-37	73	33	4409	2,0
		2821	194	59	25	1916	85	26	-88	47	21	1102	0,5
		2821	194	59	68	1916	194	59	-72	62	28	2646	1,2
		2821	203	62	18	1916	66	20	-88	47	21	1323	0,6
		2821	203	62	68	1916	203	62	-72	58	26	2425	1,1
		2821	213	65	34	1916	125	38	-82	49	22	2205	1,0
		2821	105	32	66	2316	105	32	-72	100	45	5512	2,5
		2821	125	38	65	2316	125	38	-70	78	35	4409	2,0
		2821	125	38	45	2316	95	29	-76	67	30	2866	1,3
		2821	134	41	55	2316	115	35	-84	71	32	2205	1,0
		2821	144	44	88	2316	203	62	-47	80	36	5952	2,7
		2821	144	44	88	2316	282	86	-32	71	32	5952	2,7
		2821	154	47	24	2316	66	20	-88	56	25	1984	0,9
		2821	154	47	32	2316	85	26	-88	56	25	1984	0,9
		2821	154	47	67	2316	154	47	-71	73	33	4189	1,9
		2821	154	47	86	2316	203	62	-51	78	35	5512	2,5
		2821	154	47	88	2316	262	80	-37	73	33	5952	2,7
		2821	164	50	55	2316	134	41	-87	60	27	5071	2,3
		2821	164	50	59	2316	144	44	-86	53	24	4409	2,0
		2821	174	53	76	2316	125	38	-66	53	24	2205	1,0
		2821	174	53	43	2316	125	38	-79	51	23	2205	1,0
		2821	174	53	58	2316	154	47	-79	58	26	2646	1,2
		2821	184	56	53	2316	154	47	-78	51	23	2425	1,1
		2821	194	59	25	2316	85	26	-88	47	21	1543	0,7
		2821	194	59	68	2316	194	59	-72	62	28	3527	1,6
		2821	194	59	88	2316	322	98	-38	71	32	7055	3,2
		2821	194	59	80	2316	351	107	-33,7	67	30	6614	3,0
		2821	194	59	80	2316	371	113	-31,7	67	30	6834	3,1
		2821	203	62	18	2316	66	20	-88	47	21	1543	0,7
		2821	203	62	68	2316	203	62	-72	58	26	3307	1,5
		2821	203	62	88	2316	322	98	-40	71	32	7716	3,5
		2821	223	68	65	2316	253	77	-54	49	22	5952	2,7

4.26 Blocked crawlers*

To extend the tipping line of the machine, steel plates of a precise thickness can be inserted underneath the tumbler or idler. The difference in height between the running rollers and the tumbler (or the running rollers and the idler) is evened out.

Blocked crawlers:
- extends the tipping line.
- increases the lifting capacity.
- limits the swing range of the uppercarriage.
- prohibits movement of the machine.
- can lead to higher ground pressures.

The example below explains the system. This example only applies to one machine configuration.

DANGER
Incorrect operation of blocked crawlers!
Structural breakdown.
The structure curve specifies the minimum loading limit of the components (swing, pendant straps, A-frames, chord pipes, diagonals, etc.).

▶ Work only with values that are within the structure curve (grey load chart value).

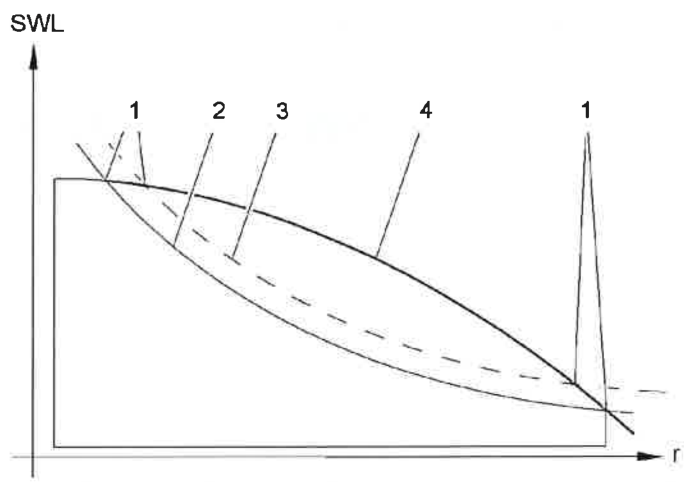


Fig. 990 Diagram

1 Intersection between tilt curve and structure curve
2 Tilt curve for maximum counter-weight (360 °)
3 Tilt curve for blocked crawlers (limited swing angle)
4 Structure curve of the machine

The tilt curve is calculated from the equilibrium of weights rotating forwards and backwards (dead weight + load weights). The minimum of the two curves gives the valid load capacity chart.

Blocked crawlers can extend the normal lifting capacity range that is limited by the machine tilt curve **2**. It may be the case that the extended tilt curve **3** is intersected by the falling structure curve **4**. If this is the case, the structure curve takes precedence with respect to the maximum radius.

Make sure that the support plates are laid out in the required numbers.

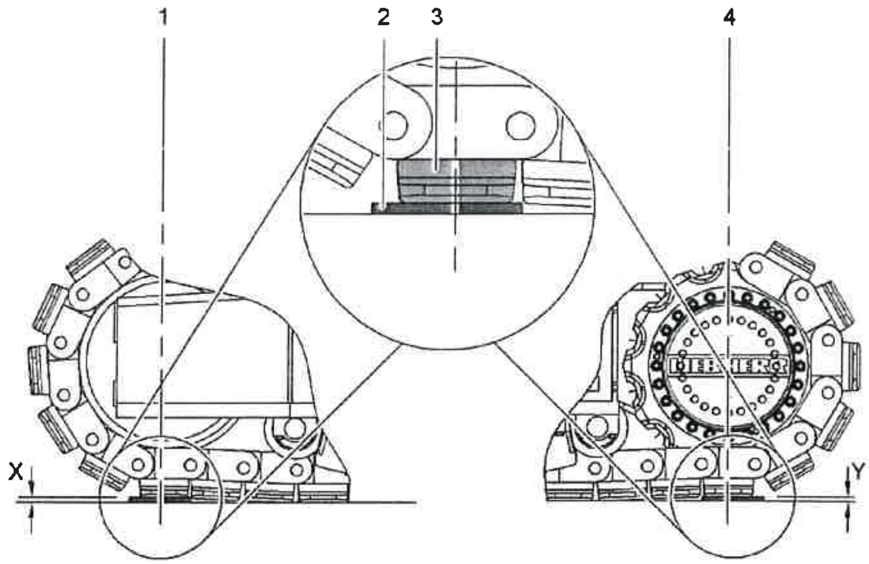


Fig. 991 Positioning of the support plates

1 Center line of idler
2 Support plate
3 Ground plate
4 Center line of tumbler

Model	Idler X	Tumbler Y
LR1100	20 mm	20 mm
LR1130	25 mm	25 mm
LR1160	20 mm	20 mm
LR1200	22 mm	15 mm
LR1280	22 mm	15 mm
LR1300	25 mm	17 mm

Tab. 206 Positioning of the support plates

4.26.1 Driving onto the support plates

DANGER
Inappropriate driving onto support plates!
Machine toppling over.

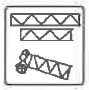
▶ The left and right base plates of the crawler side frames must be positioned exactly the same so they are both driven onto the support plates at the same time.

▶ Equalise the crawler position on both sides simultaneously. When necessary, move the crawlers towards one another.

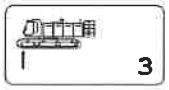
▶ Place support plates in front of the crawler side frames.

▶ Move precisely onto the support plates (see: fig. 991, page 501) .

- ▶ Lock and disable the crawlers (For more information see: 4.19.3 Crawler deactivation*, page 474) .



- ▶ Press the *Setup screen* button.
  ▷ The *Setup screen* screen page appears on the monitor.



- ▶ In the *Track width adjustment* input field, select the *Blocked Crawlers* setting.

- ▶ Press the *Confirm input* button.
  ▷ The setup is recalculated.

4.26.2 Working with Blocked Crawlers

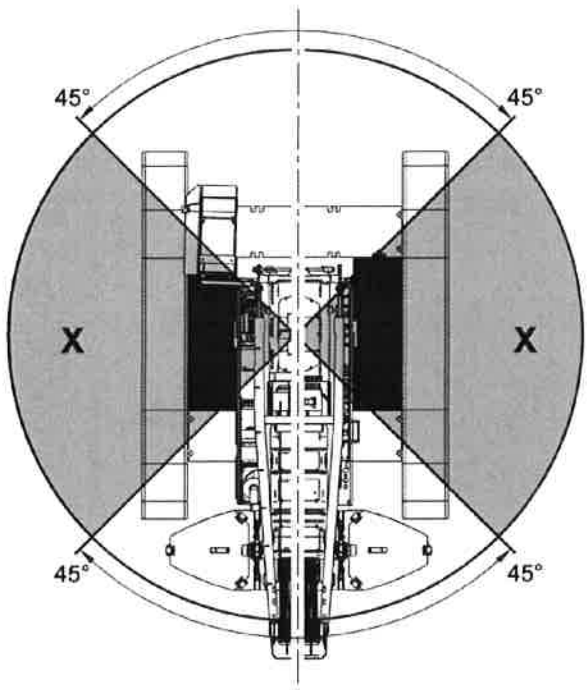


Fig. 995 Limitation of swing angle

X Blocked area

DANGER
Uppercarriage swing angle is too great!
Machine toppling over.

- ▶ Rotation is permitted only up to an angle of ±45 ° from the direction of the crawler side frames.
- ▶ Do not move into the blocked area **X**.

In EU load charts, the swing movement will be automatically restricted via the swing angle transmitter.

Exhibit D – Important Regulatory Documents
60 Hudson Street Crane Collapse Investigation
February 5, 2016

Table of Contents

MRA Job# 2015-033
LR1300

NYC Buildings

BUILDINGS CRANES & DERRICKS UNIT RECEIVED 2015 DEC -4 P 12:40

CD4: Tower & Mobile Crane / Derrick / Mast Climber / Pile Driver On-Site Inspection Application / Certificate

File 4 copies / Application must be typewritten

CN Number: CN 11587 15

1A Application Type

[X] New [ ] Renewal [ ] Amendment

1B Equipment Type

[ ] Mobile Crane [X] Mobile Tower Crane [ ] Fix / Climber Tower Crane [ ] Derrick [ ] Mast Climber [ ] Pile Driver

2 Location Information

Borough: Manhattan Block: 144 Lot: 40
Address: 60 Hudson St Job Number: 140244670

3A Crane / Derrick / Mast Climber / Pile Driver Information

	CD Number	Serial Number	Expiration Date
1	3822	138-009	7/11/2013
2	3870	138-017	10/25/2015
3	4463	138.064	4/17/2014
4	4606	138.243	9/30/2016
5			
6			

3B Configuration / Phase Information

	Mast (ft)	Boom (ft)	Jib (ft)	Total (ft)
1	N/A	194	371/322	565/516
2	N/A	194	371/322	565/516
3	N/A	194	371/322	565/516
4	N/A	194	371/322	565/516
5	N/A			
6	N/A			

4 Applicant Information

Name: Neil Greenblatt E-Mail: neil@mraengineering.com
Title: P.E Lic #: 61718
Business Name: MRA Engineering, P.C.
Address: 600 Hempstead Turnpike
City: West Hempstead State: NY Zip: 11552
Phone: (516) 292-1000 Fax: (516) 292-6407

5 Equipment User Information

Name: Greg Galasso E-Mail:
Title: President
Company: Galasso Trucking & Rigging, Inc.
Address: 2 Galasso Place
City: Maspeth State: NY Zip: 11378
Phone: (718) 456-1800 Fax:

6 Statement and Signature

- This On-Site Inspection Certificate will only be used for the tower & mobile crane / derrick / mast climber / pile driver at the above mentioned site and conforms with approved plans.
- Falsification of any statement is a misdemeanor and is punishable by a fine or imprisonment, or both. It is unlawful to give to a city employee, or for a city employee to accept, any benefit, monetary or otherwise, either as a gratuity for properly performing the job or in exchange for special consideration. Violation is punishable by imprisonment or fine or both. I understand that if I am found after hearing to have knowingly or negligently made a false statement or to have knowingly or negligently falsified or allowed to be falsified any certificate, form, signed statement, application, report or certification of the correction of a violation required under the provisions of this code or of a rule of any agency, I may be barred from filing further applications or documents with the Department.

6A Applicant's Statement

The applicant, having been authorized by the owner of the premises, building or structure, hereby makes application for the approval of the use of the tower & mobile crane / derrick / mast climber / pile driver described above to be used to the above mentioned site in accordance with the accompanying plans and specifications.

Name (please print): Neil Greenblatt, P.E.
Signature: [signature] Date: 12/3/2015
Seal *(apply seal, then sign and date over seal)*

STATE OF NEW YORK NEIL GREENBLATT PROFESSIONAL ENGINEER

6B Equipment User's Statement

I hereby state that the above equipment will not be used until a valid On-Site inspection is obtained.

Signature: [signature] Date: 12/3/2015

6C Crane Safety Coordinator's Statement

As a Professional Engineer or a person having at least five years of construction experience, I hereby certify that I will act as the designated safety coordinator and shall be responsible for the control of pedestrian and vehicular traffic within the designated hoist areas. I shall also supervise compliance with this On-site Inspection Certificate and its drawings.

Name: Greg Galasso License Number:
Address: 2 Galasso Place
City: Maspeth State: NY Zip: 11378
Phone: (718) 456-1800 Fax:
Signature: [signature] Date: 12/3/2015

6D Mast Climber Supervisor's Statement

I am a Professional Engineer or an experienced person qualified for the installation, dismantling, operation and maintenance of the equipment listed in section 3A above. I am aware that this equipment shall not be used as a personnel or material hoist. I will supervise the mast climber installation and operation for this project in accordance with NYC approved drawings, Manufacturer's recommendations and all applicable Federal, State and City laws, rules and regulations.

Name: License Number:
Address:
City: State: Zip:
Phone: Fax:
Signature: Date:

Additional Information:

Internal Use Only

Date Received: 12/4/15 Invoice/Receipt Number: 6161655 Fee Paid: $250
Examiner's Name (please print): Inspector's Name (please print):
Signature: (Issuance) Date: JAN 12 2016 Signature: Date:
Expiration date: 1-12-17 Badge Number:

APPROVED
THE CITY OF NEW YORK DEPARTMENT OF BUILDINGS DIVISION OF CRANES AND DERRICKS

12/14

MRA ENGINEERING, P.C.

NEIL GREENBLATT, P.E.
PRESIDENT

600 HEMPSTEAD TURNPIKE – LOWER LEVEL, WEST HEMPSTEAD, NY 11552-1036
OFFICE: (516) 292-1000 FAX: (516) 292-8407

December 3, 2015

2015 DEC -4 P 12:40

CN 1157 15

The City of New York
Department of Buildings
Division of Cranes & Derricks
280 Broadway – 5th Floor
New York, NY 10007

Re: 60 Hudson St., NYC
60 Hudson St
New York, NY
CD#'s 3822, 3870, 4463 or 4606

To Whom It May Concern:

Please be advised that I, Neil Greenblatt, a duly licensed engineer have visited the above referenced site and make the following statements:

A. That the crane shall be operated in a level position at all times and shall not be operated during periods of high wind.

B. That the crane to be used is a Liebherr LR1300 with 194' boom + 371/322' luffing jib and 273.4k + 125.7k ctwt (CD#'s 3822, 3870, 4463 or 4606). All pick/radii limitations shall be as noted on drawing ER-1. **Only 1 crane shall be on-site at any 1 time under this Crane Notice Application**

C. That the crane does not impose more than 3500 pounds per square foot bearing pressure on roadway and sidewalk as per New York City Building Code requirements.

D. That the crane shall be supported according to drawings ER-1 thru 3, latest revision.

E. That there are no vaults or underground structures within the immediate area of crane operation.

Very truly yours,

Neil Alan Greenblatt

LICENSED PROFESSIONAL ENGINEER NEIL ALAN GREENBLATT 61718 STATE OF NEW YORK

X:\MRADocuments\Amidocs\Amletter\Engineer\2015\E2015-033

GTi Galasso Trucking & Rigging Inc.

2 Galasso Place, Maspeth, New York 11378
www.galasso.com

Office 718.456.1800
Fax 718.456.7860

MEMBER Specialized Carriers & Rigging Association

Galasso fully endorses the national certification program offered by the National Commission for the Certification of Crane Operators (NCCCO).

NYC DEPT. OF BUILDINGS CRANES & DERRICKS UNIT RECEIVED

2015 DEC -4 P 12:40

November 30, 2015

CN1157 15

NYCDOB Div. of Cranes & Derricks
280 Broadway - 5th Floor
New York, NY 10007

Re: 60 Hudson St., NYC

To whom this may concern;

I, Greg L. Galasso, holding Master Rigger's NYC License #199 or my designee, will be present at the above referenced location to supervise hoist.

The crane shall be used to hoist mechanical equipment. All loads shall not be lifted over any adjacent structures. All picks and corresponding radii shall be within the Approved NYC Load Charts. I or my designee, shall supervise the erection and operation of the hydraulic crane.

Very truly yours,

Greg L. Galasso
Master Riggers
NYC Lic. No. 199

NYC Buildings

NYC DEPT. OF BUILDINGS RECEIVED

CD12: Designation of Crane Safety Coordinator

CD Number: 3822, 3870, 4463 or 4606 **CN Number:** Master Rigger 2015 DEC -4 P 12:40

1	**Location Information**

House No(s) 60 Street Name Hudson Street

Borough Manhattan Block 144 Lot 40

2	**Owner or Contractor Statement**

Name Brent Graham Telephone (718) 456-1800

Address 2 Galasso Place, Maspeth, NY 11378

I have been apprised of the requirements to provide flag person to stop pedestrian traffic when lifting over the sidewalk and to stop vehicular traffic when lifting over the roadway. I am also aware that closing of sidewalk or roadway or temporary obstruction of same requires concurrent approval from the Department of Transportation. Mr./Ms. Brent Graham, representing the owner or contractor, has been designated as safety coordinator to ensure that these safety precautions are adhered to.

Signature Brent Graham Date 12/2/15

3	**Crane Safety Coordinator Statement**

Name Brent Graham Telephone (718) 456-1800

Address 2 Galasso Place, Maspeth, NY 11378

I, Brent Graham, am a PE, RA or a person having at least 5 years of construction experience. I hereby certify that I will act as the designated Crane Safety Coordinator and shall be responsible for the control of pedestrian and vehicular traffic within the designated hoisting areas.
I will also supervise compliance with the Crane Notice Application and the drawings which form part of this On-Site Hoisting Device Application.

Signature Brent Graham Date 12/2/15

CN1157 15

NYC Buildings

CD12: Designation of Crane Safety Coordinator

NYC DEPT OF BUILDINGS CRANES & DERRICKS UNIT RECEIVED 2015 DEC -4 P 12:40

CD Number: 3822, 3870, 4463 or 4606 **CN Number:** Master Rigger

1 Location Information

House No(s) 60 Street Name Hudson Street

Borough Manhattan Block 144 Lot 40

2 Owner or Contractor Statement

Name Karl Deans Telephone (718) 456-1800

Address 2 Galasso Place, Maspeth, NY 11378

I have been apprised of the requirements to provide flag person to stop pedestrian traffic when lifting over the sidewalk and to stop vehicular traffic when lifting over the roadway. I am also aware that closing of sidewalk or roadway or temporary obstruction of same requires concurrent approval from the Department of Transportation. Mr./Ms. Karl Deans, representing the owner or contractor, has been designated as safety coordinator to ensure that these safety precautions are adhered to.

Signature Karl Deans Date 12/2/15

3 Crane Safety Coordinator Statement

Name Karl Deans Telephone (718) 456-1800

Address 2 Galasso Place, Maspeth, NY 11378

I, Karl Deans, am a PE, RA or a person having at least 5 years of construction experience. I hereby certify that I will act as the designated Crane Safety Coordinator and shall be responsible for the control of pedestrian and vehicular traffic within the designated hoisting areas.
I will also supervise compliance with the Crane Notice Application and the drawings which form part of this On-Site Hoisting Device Application.

Signature Karl Deans Date 12/2/15

CN 1157 16

NYC Buildings

CD12: Designation of Crane Safety Coordinator

NYC DEPT. OF BUILDINGS CRANES & DERRICKS UNIT

2015 DEC -4 P 12:40

CD Number: 3822, 3870, 4463 or 4606 CN Number: Master Rigger

1 Location Information

House No(s) 60 Street Name Hudson Street

Borough Manhattan Block 144 Lot 40

2 Owner or Contractor Statement

Name Steve Bland Telephone (718) 456-1800

Address 2 Galasso Place, Maspeth, NY 11378

I have been apprised of the requirements to provide flag person to stop pedestrian traffic when lifting over the sidewalk and to stop vehicular traffic when lifting over the roadway. I am also aware that closing of sidewalk or roadway or temporary obstruction of same requires concurrent approval from the Department of Transportation. Mr./Ms. Steve Bland, representing the owner or contractor, has been designated as safety coordinator to ensure that these safety precautions are adhered to.

Signature Steve Bland Date 12/1/15

3 Crane Safety Coordinator Statement

Name Steve Bland Telephone (718) 456-1800

Address 2 Galasso Place, Maspeth, NY 11378

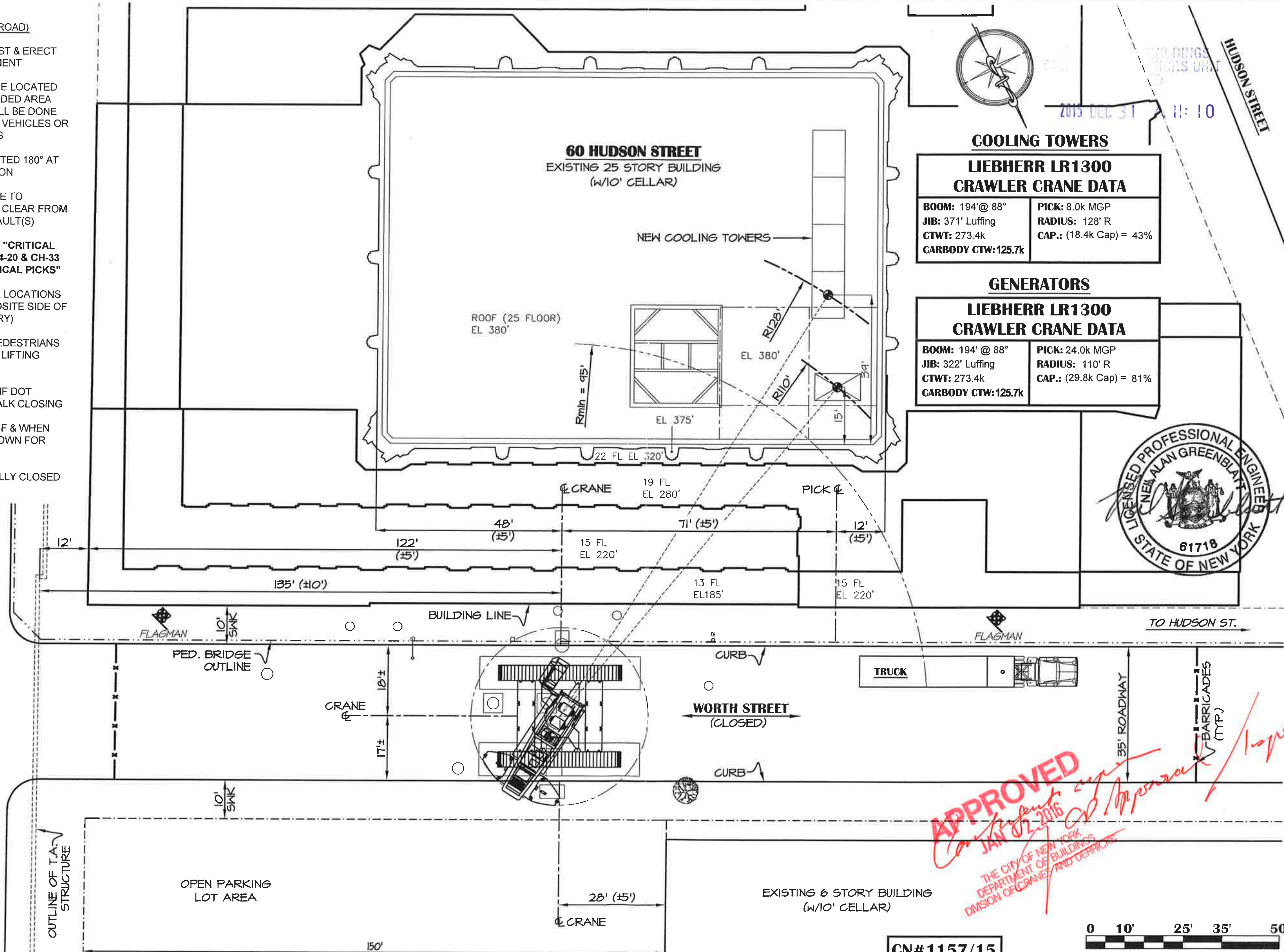
I, Steve Bland, am a PE, RA or a person having at least 5 years of construction experience. I hereby certify that I will act as the designated Crane Safety Coordinator and shall be responsible for the control of pedestrian and vehicular traffic within the designated hoisting areas.
I will also supervise compliance with the Crane Notice Application and the drawings which form part of this On-Site Hoisting Device Application.

Signature Steve Bland Date 12/1/15

CN1157 15

DRAWING NOTES (ON ROAD)

- CRANE USED TO HOIST & ERECT MECHANICAL EQUIPMENT
- ALL TRUCKS SHALL BE LOCATED WITHIN THE BARRICADED AREA AND NO LIFTING SHALL BE DONE OVER PEDESTRIANS, VEHICLES OR ADJACENT BUILDINGS
- CRANE MAY BE ROTATED 180° AT CONTRACTOR'S OPTION
- OUTRIGGER DUNNAGE TO MAINTAIN 1' MINIMUM CLEAR FROM ALL MANHOLE(S) & VAULT(S)
- **PICKS WILL NOT BE A "CRITICAL PICK" PER 1 RCNY 104-20 & CH-33 of NYC 2014 BC "CRITICAL PICKS"**
- TRUCK PICK-UP AREA LOCATIONS MAY BE ON THE OPPOSITE SIDE OF CRANE (AS NECESSARY)
- FLAGMAN TO STOP PEDESTRIANS AND VEHICLES WHEN LIFTING OVERHEAD
- FLAGMAN NOT REQ'D IF DOT ALLOWS FULL SIDEWALK CLOSING
- PEDESTRIAN BRIDGE IF & WHEN INSTALLED IS NOT SHOWN FOR CLARITY
- SIDEWALK MAY BE FULLY CLOSED WITH DOT APPROVAL



COOLING TOWERS

LIEBHERR LR1300 CRAWLER CRANE DATA

BOOM: 194'@ 88°	**PICK:** 8.0k MGP
JIB: 371' Luffing	**RADIUS:** 128' R
CTWT: 273.4k	**CAP.:** (18.4k Cap) = 43%
CARBODY CTW: 125.7k	

GENERATORS

LIEBHERR LR1300 CRAWLER CRANE DATA

BOOM: 194' @ 88°	**PICK:** 24.0k MGP
JIB: 322' Luffing	**RADIUS:** 110' R
CTWT: 273.4k	**CAP.:** (29.8k Cap) = 81%
CARBODY CTW: 125.7k	

LICENSED PROFESSIONAL ENGINEER
NEIL ALAN GREENBLATT
STATE OF NEW YORK
61718

APPROVED
JAN 0 2 2016
THE CITY OF NEW YORK
DEPARTMENT OF BUILDINGS
DIVISION OF CRANES AND DERRICKS

CN#1157/15

0 10' 25' 35' 50'
GRAPH SCALE: 1" = 25'

CRAWLER CRANE LAYOUT PLAN (COOLING TOWERS & GENERATORS)

60 HUDSON STREET
NEW YORK, NY

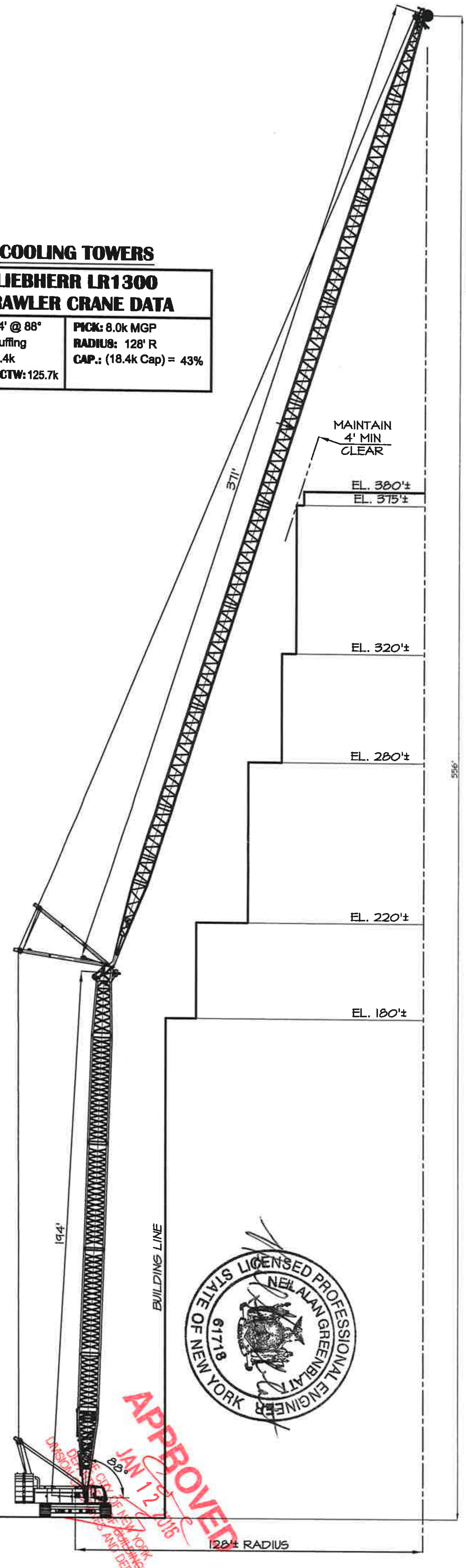
GALASSO TRUCKING & RIGGING INC.
2 GALASSO PLACE
MASPETH, NY 11378
(718) 456-1800

mra Engineering, P.C.
800 HEMPSTEAD TPKE.
W. HEMPSTEAD, NY 11552
(516) 292-1000

JOB#: 2015-033
DATE: 11/30/15
DRWN. BY: MJS
SHEET No. ER-1 OF 3

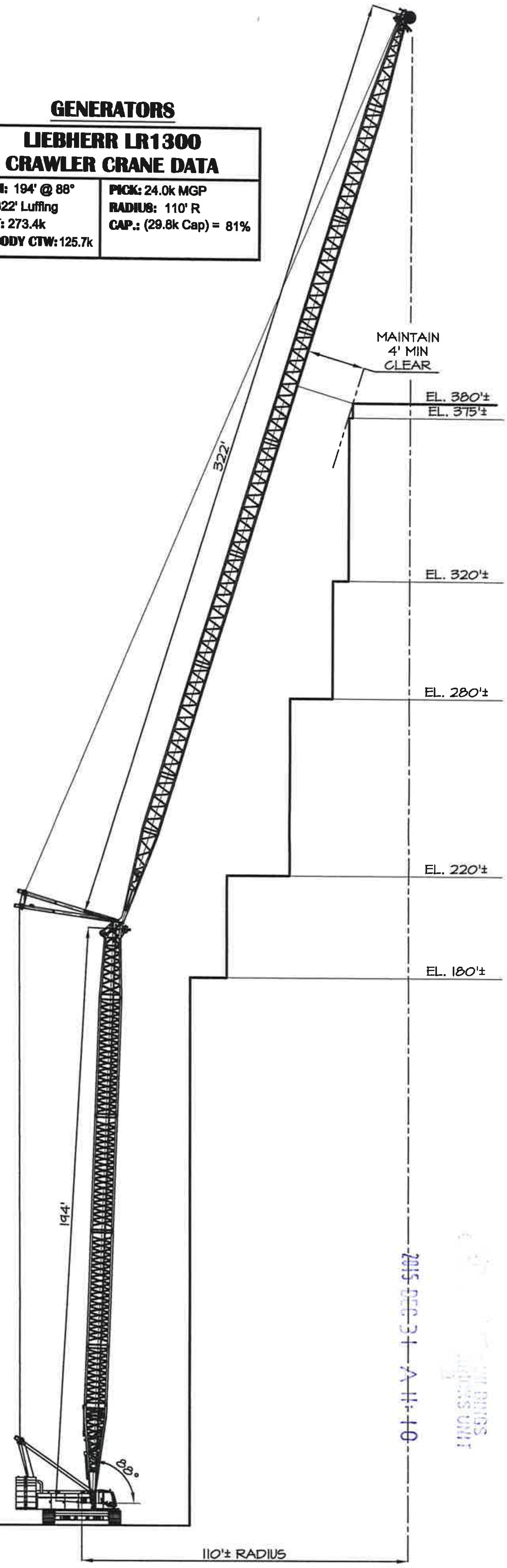
COOLING TOWERS

LIEBHERR LR1300 CRAWLER CRANE DATA	
BOOM: 194' @ 88°	**PICK:** 8.0k MGP
JIB: 371' Luffing	**RADIUS:** 128' R
CTWT: 273.4k	**CAP.:** (18.4k Cap) = 43%
CARBODY CTW: 125.7k	



GENERATORS

LIEBHERR LR1300 CRAWLER CRANE DATA	
BOOM: 194' @ 88°	**PICK:** 24.0k MGP
JIB: 322' Luffing	**RADIUS:** 110' R
CTWT: 273.4k	**CAP.:** (29.8k Cap) = 81%
CARBODY CTW: 125.7k	



LICENSED PROFESSIONAL ENGINEER NEIL ALAN GREENBLATT 61718 STATE OF NEW YORK

APPROVED JAN 12 2016 DEPT. OF BUILDINGS CITY OF NEW YORK

2015 DEC 31 A 11:10

CN#1157/15

0 20' 40' 60' 80'
GRAPH SCALE: 1" = 40'

CRAWLER CRANE - ELEVATION (COOLING TOWERS & GENERATORS)

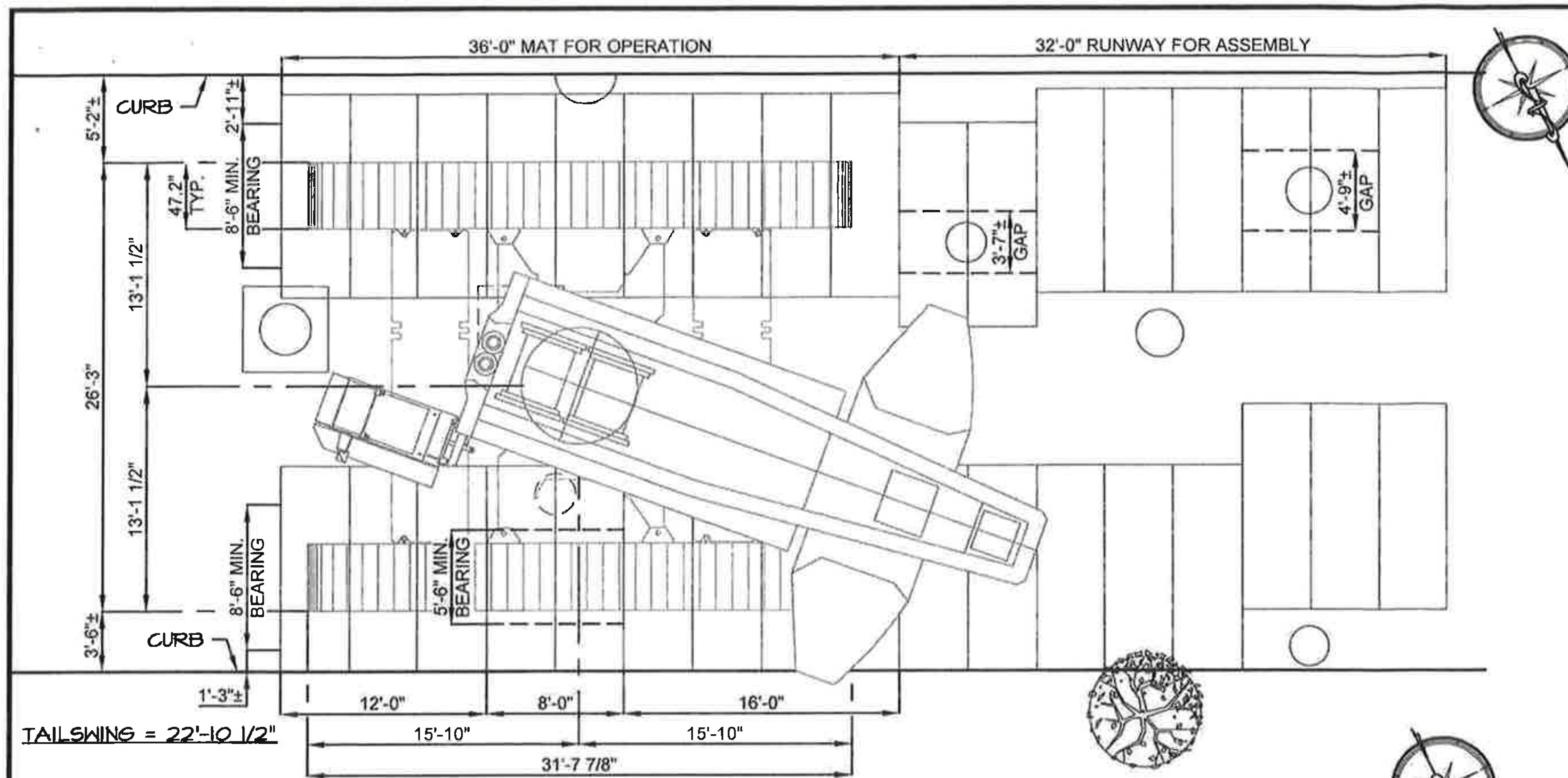
JOB#: 2015-033
DATE: 11/30/15
DRWN. BY: MJS

GALASSO TRUCKING & RIGGING INC.
2 GALASSO PLACE
MASPETH, NY 11378
(718) 456-1800

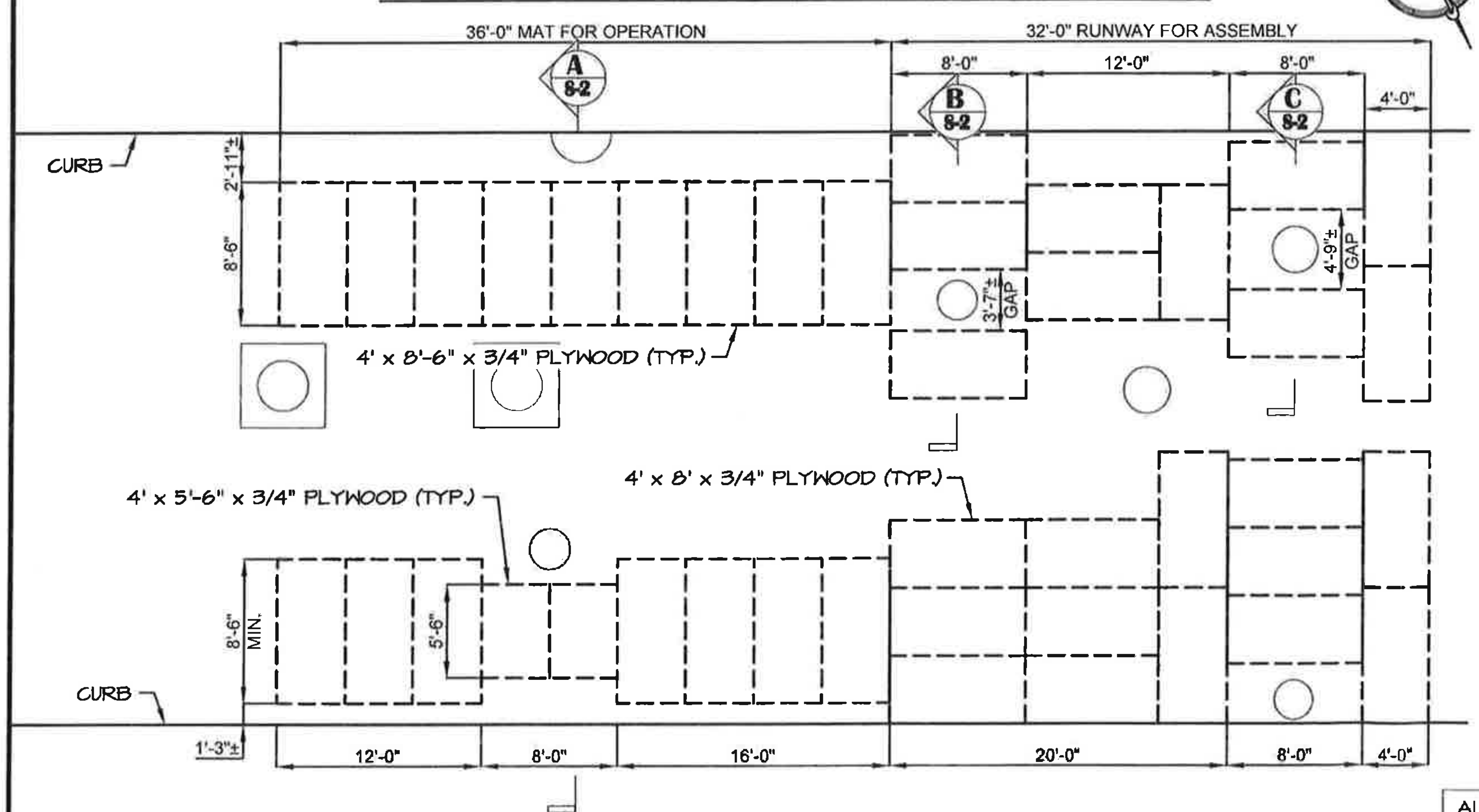
mra Engineering, P.C.
600 HEMPSTEAD TPKE.
W. HEMPSTEAD, NY 11552
(516) 292-1000

60 HUDSON STREET
NEW YORK, NY

SHEET No. ER-2 OF 3



LIEBHERR LR1300 CRAWLER CRANE - PART PLAN



LIEBHERR LR1300 CRAWLER CRANE - BOTTOM LAYER PLYWOOD PLAN

ALL '±' DIMENSIONS ARE WITHIN 3" UNLESS OTHERWISE NOTED

DUNNAGE FOR OPERATION:
TOP LAYER: 12" x 12" (x 4' WIDE) x 12' TIMBER MATS (EFFECTIVE BEARING LENGTH = 8'-6") CENTERED UNDER CATS (TYP. - U.O.N.)

MIDDLE LAYER: GRAVEL/SOIL/RCA FOR LEVELING

BOTTOM LAYER: 3/4" PLYWOOD UNDER TIMBER MATS FOR BLOCKING & MANHOLE CLEARANCE

DUNNAGE FOR ASSEMBLY RUNWAY:
TOP LAYER: 12" x 12" (x 4' WIDE) x 12' TIMBER MATS CENTERED UNDER CATS (TYP.)

MIDDLE LAYER: GRAVEL/SOIL/RCA FOR LEVELING

BOTTOM LAYER: 3/4" PLYWOOD UNDER TIMBER MATS FOR BLOCKING & MANHOLE CLEARANCE

GENERAL NOTES FOR MOBILE CRANE
(Over 250' - Master Rigger)

1. Contractor to verify all dimensions and site conditions prior to commencing work. Any errors, omissions or unusual conditions to be reported to the office of MRA Engineering immediately.
2. Cranes shall be mounted level. Crane to be used is a Liebherr LR1300 crawler crane with 194' main boom @ 88° + 371'/322' luffing jib with 273.4k ctwt + 125.7k carbody ctwt. Refer to drawing ER-1 for pick-radii limits.
3. The operational notes herein are offered for information and guidance and are not to be taken to infer the the Engineer is in any way involved in or is responsible for the actual placement., installation or operation of the crane in the field.
4. Cranes to be stowed overnight or in severe weather conditions as per manufacturers recommended procedure found in the operators crane manual.
5. Pontoons and/or cribbing to be of sound structural grade lumber (Fb=1.5 ksi; Fv=150 psi; Steel plates = A36 - if required.)
6. Crane operations are to be conducted in accordance with A.N.S.I./A.S.M.E. B30.5a - latest edition, appropriate OSHA rules and R.S. 19-2 of the New York City Building Code.
7. Crane is to be operated only by New York City Licensed Operator.
8. This installation requires an unassembled and assembled inspection by a Hoisting & Rigging inspector from the NYC Department of Buildings Division of Crane & Derricks prior to operating and lifting loads.
9. Approval of this application is granted contingent upon the applicant furnishing a permit from the Bureau of Highway Operations (if required).
10. No lifting shall be done over pedestrians, vehicles or adjacent buildings.

LICENSED PROFESSIONAL ENGINEER NEIL ALAN GREENBLATT 061718 STATE OF NEW YORK

CN#1157/15

APPROVED JAN 12 2016 THE CITY OF NEW YORK DEPARTMENT OF BUILDINGS DIVISION OF CRANES AND DERRICKS

0 5' 10' 15' 20'
GRAPHICAL SCALE: 1" = 10'

REV. 1 - 12/28/15
JOB#: 2015-033
DATE: 11/30/15
DRWN. BY: MJS

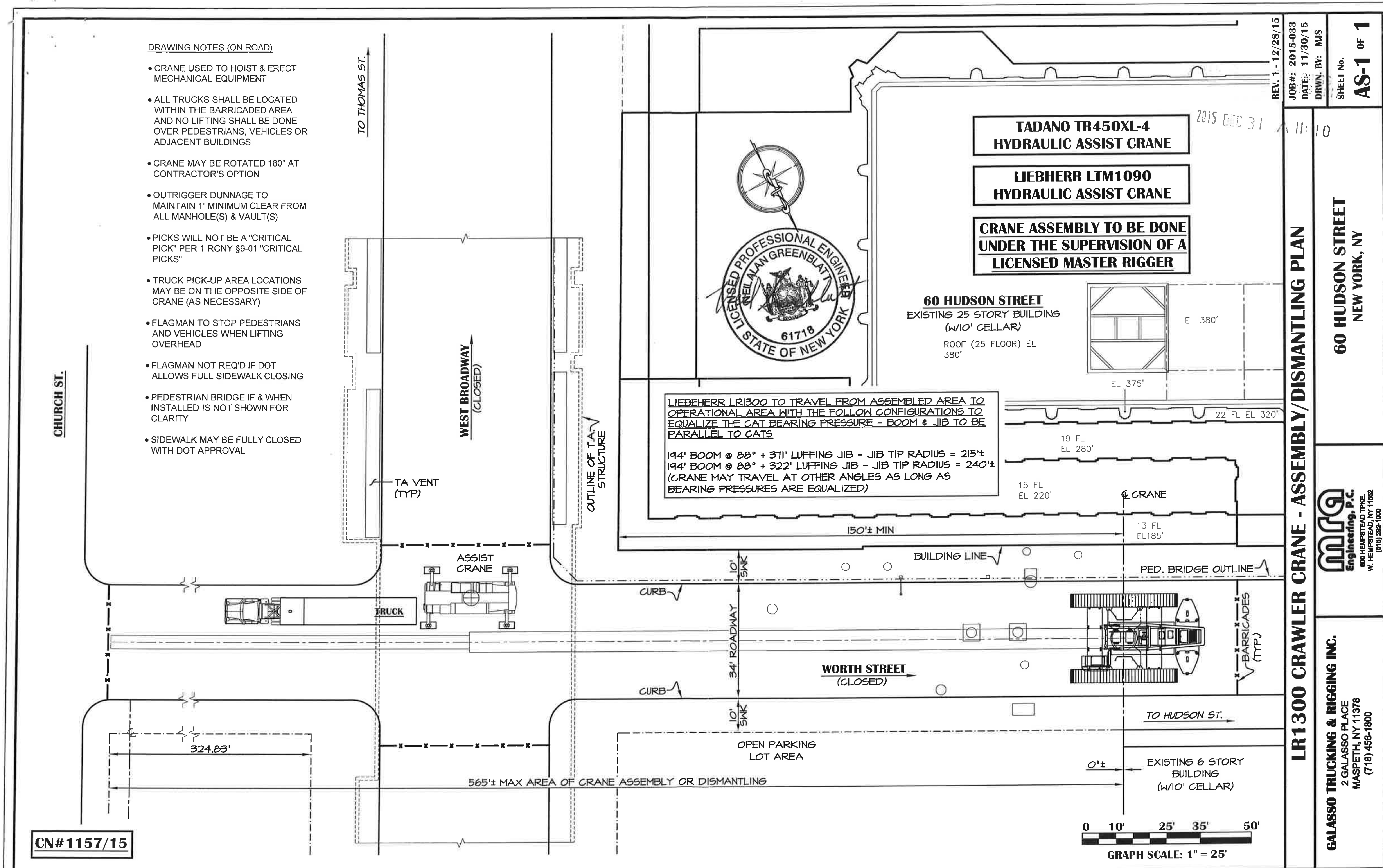
SHEET No. ER-3 OF 3

LIEBHERR LR1300 CRAWLER CRANE - PART PLAN & GENERAL NOTES

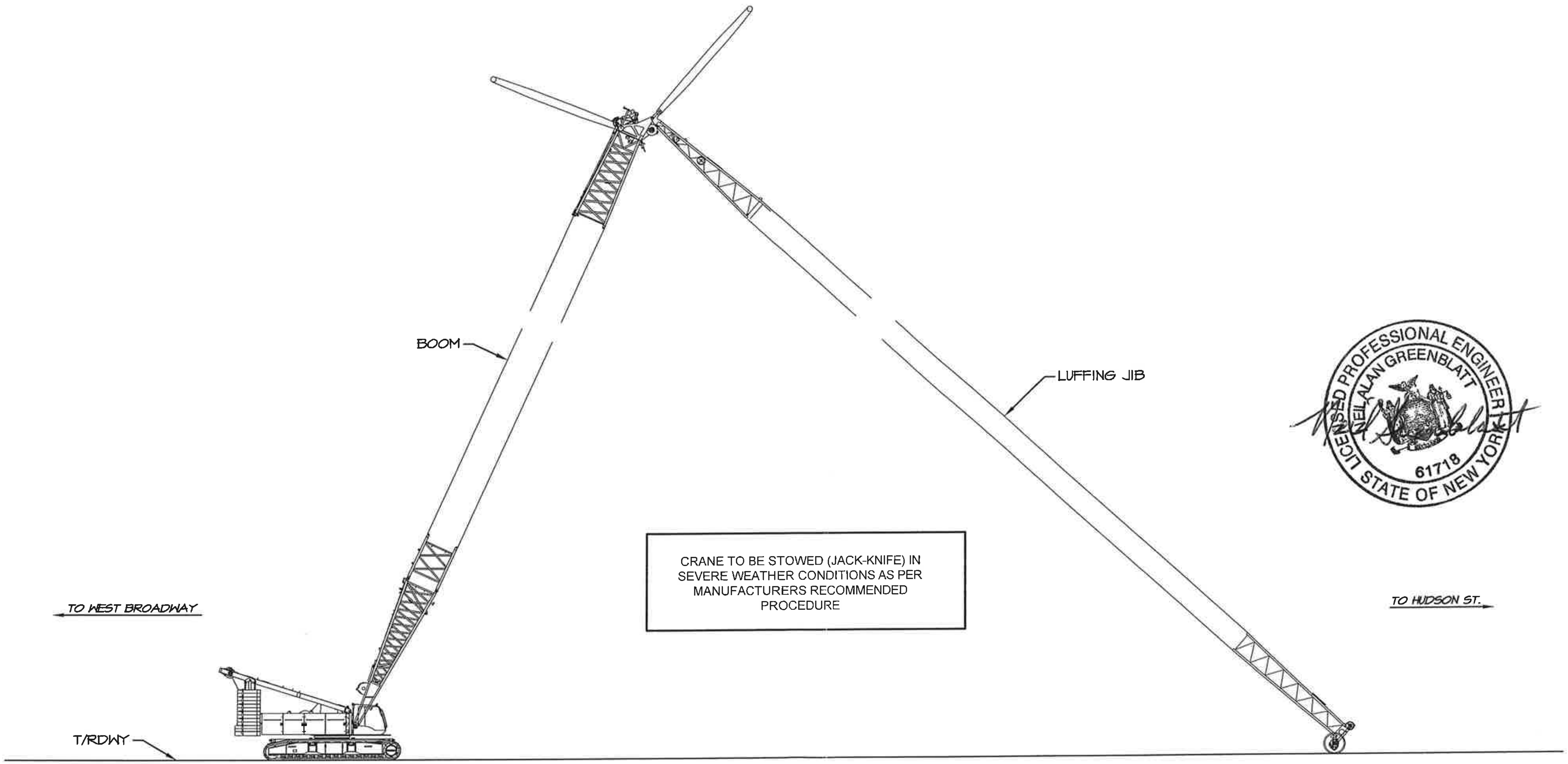
60 HUDSON STREET
NEW YORK, NY

mra Engineering, P.C.
600 HEMPSTEAD TPKE.
W. HEMPSTEAD, NY 11552
(516) 292-1000

GALASSO TRUCKING & RIGGING INC.
2 GALASSO PLACE
MASPETH, NY 11378
(718) 456-1800



DRAWING NOTES (ON ROAD)
• CRANE USED TO HOIST & ERECT MECHANICAL EQUIPMENT
• ALL TRUCKS SHALL BE LOCATED WITHIN THE BARRICADED AREA AND NO LIFTING SHALL BE DONE OVER PEDESTRIANS, VEHICLES OR ADJACENT BUILDINGS
• CRANE MAY BE ROTATED 180° AT CONTRACTOR'S OPTION
• OUTRIGGER DUNNAGE TO MAINTAIN 1' MINIMUM CLEAR FROM ALL MANHOLE(S) & VAULT(S)
• PICKS WILL NOT BE A "CRITICAL PICK" PER 1 RCNY §9-01 "CRITICAL PICKS"
• TRUCK PICK-UP AREA LOCATIONS MAY BE ON THE OPPOSITE SIDE OF CRANE (AS NECESSARY)
• FLAGMAN TO STOP PEDESTRIANS AND VEHICLES WHEN LIFTING OVERHEAD
• FLAGMAN NOT REQ'D IF DOT ALLOWS FULL SIDEWALK CLOSING
• PEDESTRIAN BRIDGE IF & WHEN INSTALLED IS NOT SHOWN FOR CLARITY
• SIDEWALK MAY BE FULLY CLOSED WITH DOT APPROVAL
TO THOMAS ST.
CHURCH ST.
WEST BROADWAY (CLOSED)
OUTLINE OF T.A. STRUCTURE
TA VENT (TYP)
TADANO TR450XL-4 HYDRAULIC ASSIST CRANE
LIEBHERR LTM1090 HYDRAULIC ASSIST CRANE
CRANE ASSEMBLY TO BE DONE UNDER THE SUPERVISION OF A LICENSED MASTER RIGGER
2015 DEC 31 A 11:10
LICENSED PROFESSIONAL ENGINEER NEIL ALAN GREENBLATT 61718 STATE OF NEW YORK
60 HUDSON STREET
EXISTING 25 STORY BUILDING (W/10' CELLAR)
ROOF (25 FLOOR) EL 380'
EL 380'
EL 375'
22 FL EL 320'
19 FL EL 280'
15 FL EL 220'
13 FL EL185'
LIEBEHERR LR1300 TO TRAVEL FROM ASSEMBLED AREA TO OPERATIONAL AREA WITH THE FOLLOW CONFIGURATIONS TO EQUALIZE THE CAT BEARING PRESSURE - BOOM & JIB TO BE PARALLEL TO CATS
194' BOOM @ 88° + 371' LUFFING JIB - JIB TIP RADIUS = 215'±
194' BOOM @ 88° + 322' LUFFING JIB - JIB TIP RADIUS = 240'±
(CRANE MAY TRAVEL AT OTHER ANGLES AS LONG AS BEARING PRESSURES ARE EQUALIZED)
℄ CRANE
150'± MIN
BUILDING LINE
PED. BRIDGE OUTLINE
ASSIST CRANE
TRUCK
CURB
10' SWK
34' ROADWAY
WORTH STREET (CLOSED)
BARRICADES (TYP.)
TO HUDSON ST.
OPEN PARKING LOT AREA
324.83'
565'± MAX AREA OF CRANE ASSEMBLY OR DISMANTLING
0"±
EXISTING 6 STORY BUILDING (W/10' CELLAR)
0 10' 25' 35' 50'
GRAPH SCALE: 1" = 25'
CN#1157/15
REV. 1 - 12/28/15
JOB#: 2015-033
DATE: 11/30/15
DRWN. BY: MJS
SHEET No. AS-1 OF 1
60 HUDSON STREET NEW YORK, NY
LR1300 CRAWLER CRANE - ASSEMBLY/DISMANTLING PLAN
mrg Engineering, P.C. 600 HEMPSTEAD TPKE. W. HEMPSTEAD, NY 11552 (516) 292-1000
GALASSO TRUCKING & RIGGING INC. 2 GALASSO PLACE MASPETH, NY 11378 (718) 456-1800



2015 DEC 31 A 11: 0

LICENSED PROFESSIONAL ENGINEER
NEIL ALAN GREENBLATT
61718
STATE OF NEW YORK

CN#1157/15

0 10' 25' 35' 50'

GRAPH SCALE: 1" = 25'

LIEBHERR LR1300 CRAWLER CRANE - STOW PLAN

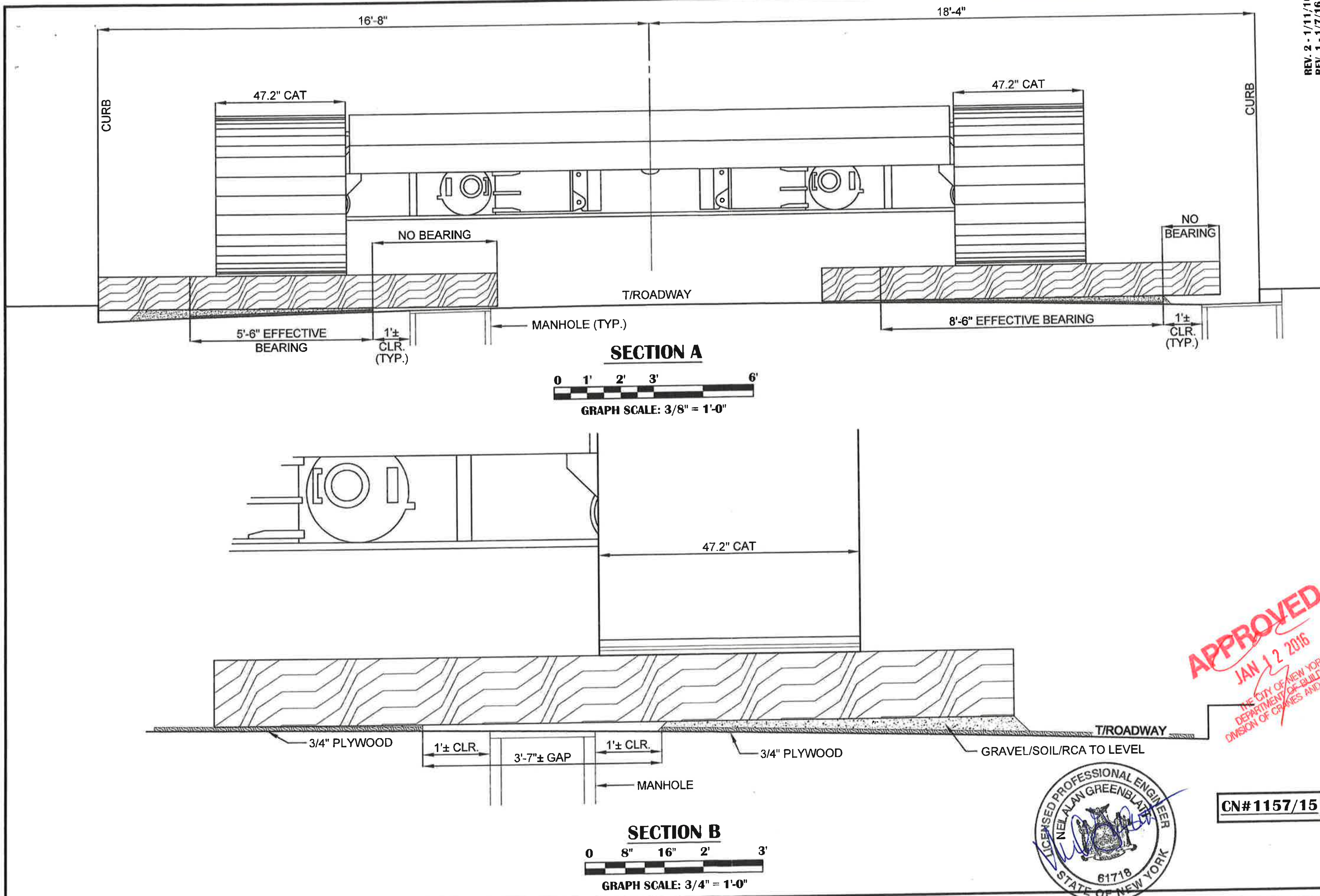
60 HUDSON STREET
NEW YORK, NY
ADDRESS - TOWN, STATE

JOB#: 2015-033
DATE: 11/30/15
DRWN. BY: MJS

SHEET No. SP-1 OF 1

mrg Engineering, P.C.
600 HEMPSTEAD TPKE.
W. HEMPSTEAD, NY 11552
(516) 292-1000

GALASSO TRUCKING & RIGGING INC.
2 GALASSO PLACE
MASPETH, NY 11378
(718) 456-1800



REV. 2 - 1/11/16
REV. 1 - 1/7/16

JOB #: 2015-033
DATE: 12/28/15
DRWN. BY: MJS

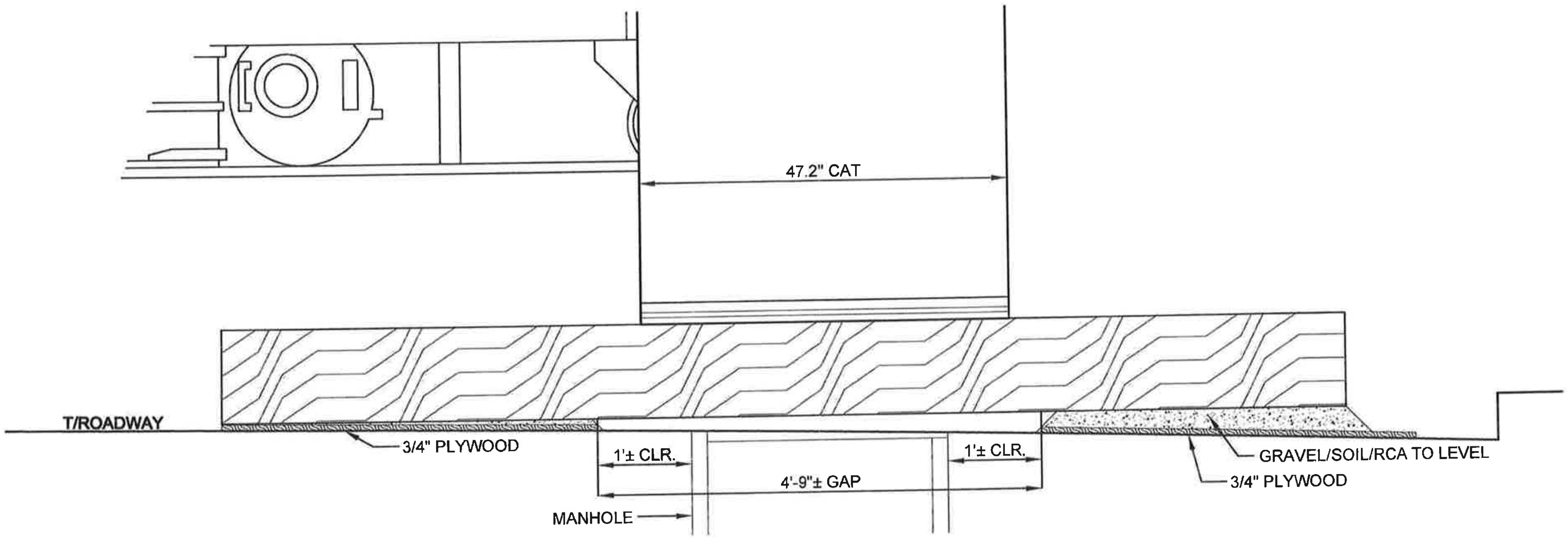
SHEET No. S-1 OF 2

LIEBHERR LR1300 CRAWLER CRANE - SECTIONS

60 HUDSON STREET
NEW YORK, NY

mra Engineering, P.C.
600 HEMPSTEAD TPKE.
W. HEMPSTEAD, NY 11552
(516) 292-1000

GALASSO TRUCKING & RIGGING INC.
2 GALASSO PLACE
MASPETH, NY 11378
(718) 456-1800



SECTION C

0 8" 16" 2' 3'

GRAPH SCALE: 3/4" = 1'-0"

APPROVED
JAN 12 2016
THE CITY OF NEW YORK
DEPARTMENT OF BUILDINGS
DIVISION OF CRANES AND DERRICKS

LICENSED PROFESSIONAL ENGINEER
NEIL ALAN GREENBLATT
61718
STATE OF NEW YORK

CN#1157/15

JOB#: 2015-033
DATE: 1/11/16
DRWN. BY: MJS

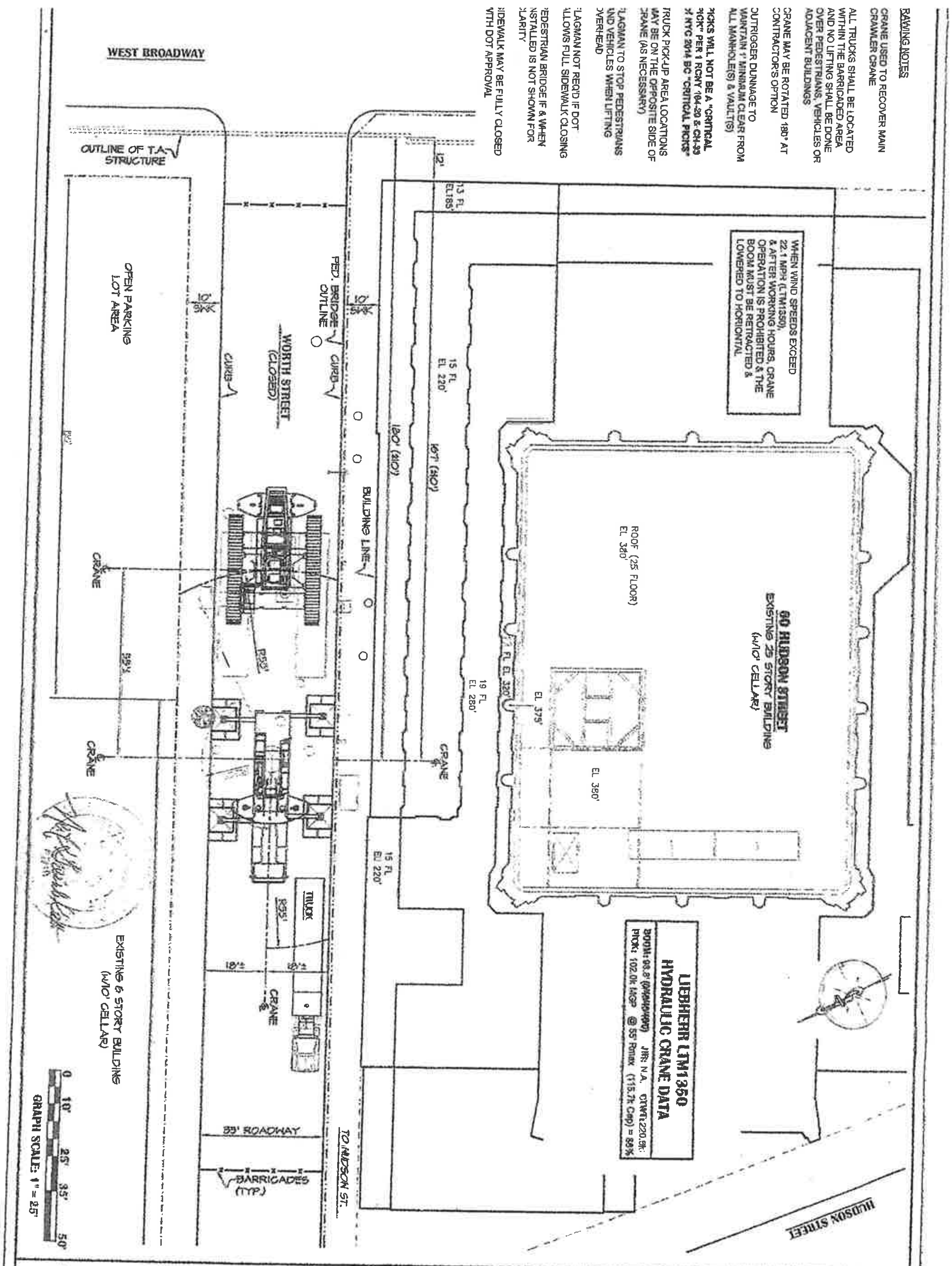
SHEET No.
S-2 OF 2

LIEBHERR LR1300 CRAWLER CRANE - SECTION C

60 HUDSON STREET
NEW YORK, NY

mrg Engineering, P.C.
600 HEMPSTEAD TPKE.
W. HEMPSTEAD, NY 11552
(516) 292-1000

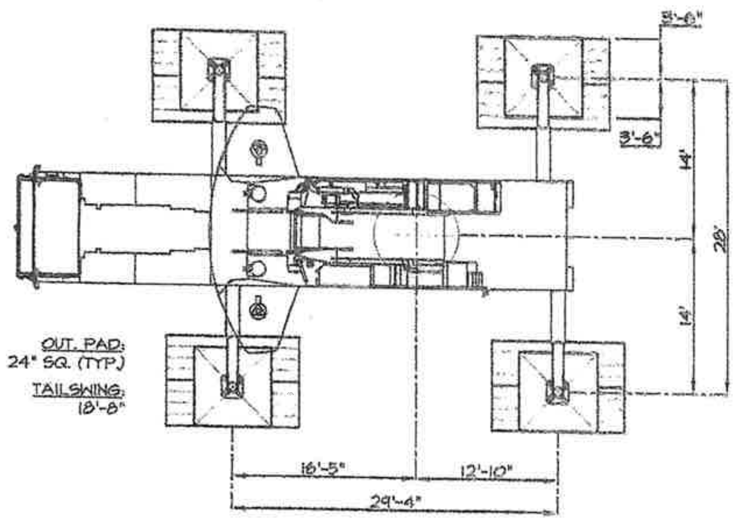
GALASSO TRUCKING & RIGGING INC.
2 GALASSO PLACE
MASPETH, NY 11378
(718) 456-1800



LIEBHER LTM1350 HYDRAULICR CRANE - LR1300 RECOVERY LAYOUT PLAN

BAY CRANE SERVICE, INC. 11-02 43rd AVENUE LONG ISLAND CITY, NY 11101 (718) 392-0800	mra Engineering, P.C.	60 HUDSON STREET NEW YORK, NY	JOB#: 2016-033 DATE: 2/5/16 DRWN. BY: SRS SHEET No. CR-1 OF 2

OUTRIGGER DUNNAGE:
TOP LAYER: 7' x 7' x 2" MIN. STEEL PLATE;
BOTTOM LAYER: 7 @ 12" x 12" x 12' MIN TIMBERS CENTERED UNDER ALL OUTRIGGERS



LIEBHERR LTM1350
HYDRAULIC CRANE - PART PLAN

0 5' 10' 15' 20'

GRAPHICAL SCALE: 1" = 10'

DUNNAGE NOTES

- WOOD, CONCRETE/STONE OR STEEL BLOCKING MAY BE ADDED TO LEVEL CRANE (AS REQUIRED)
- OUTRIGGER DUNNAGE MAY BE LARGER & THICKER THAN SPECIFIED ON THIS DRAWING
- TIMBER OR PLYWOOD MAY BE USED UNDER DUNNAGE AS REQUIRED TO MAKE UP FOR PAVEMENT INCONSISTENCIES & ALLOW FOR FULL BEARING

GENERAL NOTES FOR MOBILE CRANES

1. Contractor to verify all dimensions and site conditions prior to commencing work. Any errors, omissions or unusual conditions to be reported to the office of MRA Engineering immediately.
2. Cranes shall be mounted level. Crane to be used is a Liebherr LTM1350 hydraulic crane. Refer to drawing ER-1 for pick-radii limits.
3. The operational notes herein are offered for information and guidance and are not to be taken to infer the the Engineer is in any way involved in or is responsible for the actual placement., installation or operation of the crane in the field.
4. Cranes to be stowed overnight or in severe weather conditions as per manufacturers recommended procedure found in the operators crane manual.
5. Pontoons and/or cribbing to be of sound structural grade lumber (Fb=1.5 ksi; Fv=150 psi; Steel plates = Grade A36 - if required.)
6. Crane operations are to be conducted in accordance with A.N.S.I./A.S.M.E. B30.5-2014, appropriate OSHA rules and RCNY 3319-01.
7. Crane is to be operated only by New York City Licensed Operator.
8. No lifting shall be done over pedestrians, adjacent buildings or occupied vehicles.

LIEBHER LTM1350 HYDRAULICR CRANE - PART PLAN & NOTES

BAY CRANE SERVICE, INC. 11-02 43rd AVENUE LONG ISLAND CITY, NY 11101 (718) 392-0800	mra Engineering, P.C. 600 HEMPSTEAD TPKE. W. HEMPSTEAD, NY 11552 (516) 292-1000	60 HUDSON STREET NEW YORK, NY	JOB#: 2015-033 DATE: 2/5/16 DRWN. BY: SRS SHEET No. CR-2 OF 2

CRANE ENGINEERING CALCULATIONS

JOBSITE:
60 HUDSON ST.
NEW YORK, NY

CRANE:
LIEBHERR LR1300
(CD#'s 3822, 3870, 4463 or 4606)

CRANE USER:
GALASSO TRUCKING & RIGGING, INC.
2 GALASSO PLACE, MASPETH, NY 11378
(718) 456-1800

ERECTION ENGINEER:
NEIL GREENBLATT P.E. / MRA ENGINEERING PC
600 HEMPSTEAD TPKE.
W. HEMPSTEAD, NY 11552
(516) 292-1000

DECEMBER 3, 2015 – Rev. 1 – 12/30/15

LIEBHERR

LR1300

Load capacities main boom + luffing jib

Ident. no.:	9839979/95738/	Main boom foot:	2821-1
Slewing range:	360 °	Main boom head:	2821-1
Foot print:	2 - Wide track		
Rear counterweight [1000 lbs]:	273.4		
Carbody counterweight [1000 lbs]:	125.7		

194 ft Main boom, Load fall point 1 - Jib head
Jib head (2316-1) 371 ft Jib

Outreach [ft]	88° Main boom angle			83° Main boom angle			75° Main boom angle			65° Main boom angle			45° Main boom angle		
	Jib angle [°]	Lift height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Lift height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Lift height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Lift height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Lift height [ft]	Load capacity [1000 lbs]
94	78.0	565	20.4												
95	77.9	565	20.4												
100	77.1	564	20.4												
105	76.3	563	20.3												
110	75.5	562	20.0												
115	74.7	560	19.6												
120	73.9	559	19.4												
125	73.1	557	19.1												
130	72.3	556	18.8												
135	71.5	554	18.5												
140	70.6	552	18.3												
143				73.0	556	19.0									
145	69.8	550	18.1	72.6	555	19.0									
150	69.0	548	17.9	71.8	553	18.9									
155	68.1	546	17.6	71.0	551	18.8									
160	67.3	544	17.3	70.1	550	18.4									
165	66.5	542	17.0	69.3	548	18.1									
170	65.6	540	16.7	68.5	546	17.8									
175	64.7	538	16.4	67.6	544	17.5									
180	63.9	535	16.2	66.8	542	17.3									
185	63.0	533	15.9	65.9	539	17.0									
190	62.1	530	15.7	65.1	537	16.7									
195	61.3	527	15.5	64.2	535	16.5									
200	60.4	524	15.3	63.4	532	16.2									
205	59.5	522	15.1	62.5	530	16.0									
210	58.6	518	14.9	61.6	527	15.8									
215	57.6	515	14.7	60.7	524	15.6									
217							65.0	531	15.2						
220	56.7	512	14.5	59.8	521	15.4	64.5	530	15.2						
225	55.8	509	14.3	58.9	518	15.2	63.7	527	14.9						
230	54.8	505	14.1	58.0	515	15.0	63.0	525	14.3						
235	53.9	502	13.9	57.1	512	14.8	62.1	523	13.7						
240	52.9	498	13.7	56.2	508	14.6	61.3	520	13.0						
245	51.9	494	13.6	55.2	505	14.4	60.4	517	12.4						
250	50.9	490	13.4	54.3	501	14.2	59.5	514	11.8						
255	49.9	486	13.3	53.3	498	14.0	58.6	511	11.3						
260	48.9	481	13.0	52.3	494	13.9	57.7	508	10.7						
265	47.8	477	11.8	51.3	490	13.7	56.7	505	10.2						
270	46.8	472	10.7	50.3	486	13.6	55.8	502	9.7						
275	45.7	467	9.5	49.3	481	12.9	54.9	498	9.3						
280	44.6	462	8.4	48.3	477	11.8	53.9	494	8.8						
285	43.5	457	7.4	47.2	472	10.6	53.0	491	8.4						
290	42.3	451	6.4	46.1	468	9.4	52.0	487	7.9						
295	41.2	446	5.4	45.0	463	8.3	51.0	483	7.5						
300	40.0	440	4.4	43.9	457	7.3	50.0	479	7.1						
305	38.7	434	3.5	42.8	452	6.2	49.0	474	6.8						
310				41.6	446	5.2	47.9	470	6.4						
315				40.4	441	4.2	46.9	465	6.0						
320				39.2	435	3.3	45.8	460	5.7						
325							44.7	455	5.0						
330							43.6	450	4.3						
335							42.4	445	3.6						
340							41.3	439	3.0						
345							40.1	433	2.3						

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Eingabedaten zur Berechnung des Bodendruckes beim LR 1300

Input for the calculation of ground pressure of LR 1300

Länge Hauptausleger / Length of boom	min 20.0 / max 223.1	193.6	ft
Länge Wippspitze / Length of luffing jib	max 203.4	370.7	ft
Winkel Hauptausleger / Boom angle		88°	
Länge Hauptausleger Leicht / Length of high reach boom	max 0.0	403.5	ft
Länge Fixe Spitze / Length of fixed jib	max 0.0	85.3	ft
Winkel Fixe Spitze / Offset angle fixed jib		30°	
Spur UW / Track width		22	ft
Bodenplatten / Track shoes		4	ft
Ballast am Unterwagen / Carbody counterweight		125.7	1000 lbs
Ballast am Oberwagen / Counterweight		273.4	1000 lbs
Ballast am Derrick / Super lift couterweight		0.0	1000 lbs

(Nur bei Betrieb mit Wippspitze von Bedeutung)
(Angle is only necessary for operation with luffing jib)

Ausl. Konfiguration / **Boom configuration**	Boom & Luffing Jib	
	Luffing jib 2316	
Derrick Super lift	No	Fixed Jib 1008

Input - Units	American Units	
Lastfall / Load Case		
Ausladung / Load radius	ok 128.0	ft
Last / Load	8.0	1000 lbs
Ballast-Radius / Radius couterweight	0.0	ft

Bodendruck Ground pressure	Längs front (rear)	Seite Load over side	Eck corner	Diagramm siehe Blatt "ground pressure" / Diagramm see at sheet "ground pressure"
kg/cm²	2.3	1.9	2.4	**Gerät auf festem, anpassungsfähigem Untergrund**
psi	32.7	27.0	34.1	**Crawlers on compact ground**
kg/cm²	3.2	2.6	3.4	**Gerät auf Beton, Stahlplatten etc.**
psi	45.5	37.0	48.4	**Crawlers on concrete or steel plates**

Eckdaten für die Berechnung des Bodendruckes:
Technical datas for the calculation of ground pressure

34.1 psi (.144)

Vertikalkraft am Drehkranz statisch / Vertical load at the slewing ring without dynamic effects	**2137**	**kN**	480454 lbf
Moment am Drehkranz statisch / Moment at the slewing ring without dynamic effects	**-1759**	**kNm**	-1297110 ft lbf

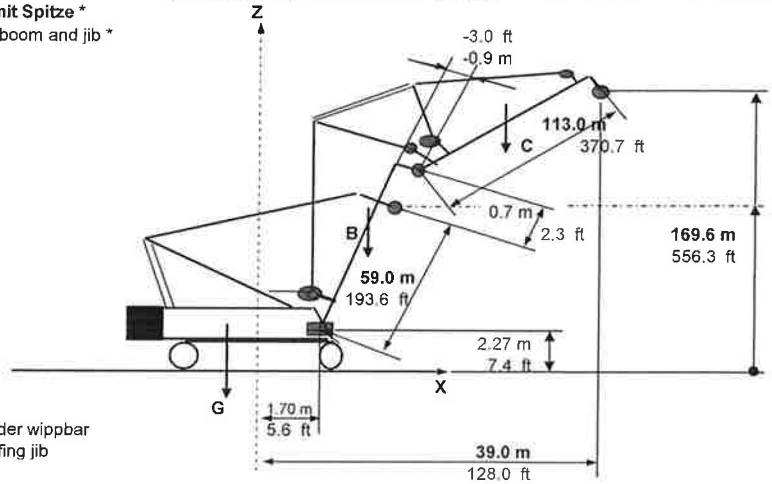
= 4.9104 ksf

Schwerpunkt Grundgerät, Ausleger und Spitze *

Center of gravity of basic machine, boom and jib *

Schwerpunkte / Center of gravity		**Gewicht** / weight / [1000 lbs]	**X** / [ft]	**Z** / [ft]	**Bemerkung** / Remarks
Grundgerät / Basic machine	G	586.18	-9.324	6.990	**Mit Ballast, 1 Hubseil, ohne Haken** / With ballast, 1 hoist rope, without hook
Ausleger / Boom	B	61.44	4.560	91.721	**Komplettes System incl. A-Bock** / Complete system incl. A-frame
Spitze * / Jib *	C	58.49	49.401	330.325	**Komplettes System incl. obere A-Böcke** / Complete system incl. upper A-frames
Schwerpunkt / Center of gravity		706.11	-3.252	41.148	**Kran Standard ohne Last und ohne Optionen** / Crane standard without load and without optional add on
		including load at boom head			
		714.11	-1.781	46.919	**(Weight of options up to 7 t are not considered)**

Geometrie mit Spitze *
System with boom and jib *



*) Spitze fix oder wippbar
*) Fixed or luffing jib

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Calculation of ground pressure LR 1300

Crawlers on compact ground

Load:	**3.6 t**	Radius:	**39.0 m**	Boom:	**59.0 m**	Luffer:	**113.0 m**
		Counter weight at the -		Upper carriage:	**124.0 t**	Carbody:	**57.0 t**

Forces at the slewing ring:			Dimensions of the undercarriage:			
Moment	1758.6	[kNm]	Width of track shoes	b	1200.0	[mm]
Ver.Load	2137.2	[kN]	Length of crawlers	l	8435.0	[mm]
Center of gravity	542.9	[mm]	Track width	s	6800.0	[mm]
Weight of undercarriage	1102.0	[kN]	Tipping line	kk	7100.0	[mm]

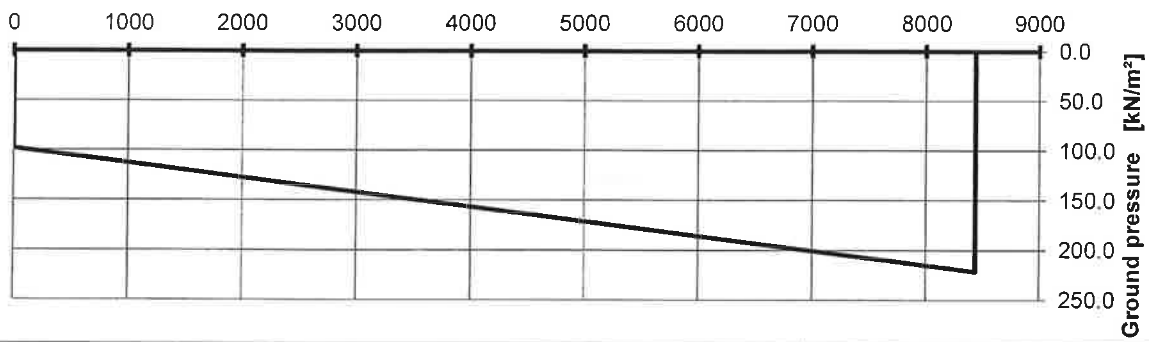
Load over front:
p max 221.8 kN/m² = 2.300 kg/cm² distribution of pressure in shape of trapezium

Load over side:
p average 185.6 kN/m² = 1.900 kg/cm² distribution of pressure in shape of trapezium

Maximum ground pressure at an angle of: **30.0°** (0° = longitudinal to the crawlers)
p max 232.8 kN/m² = 2.400 kg/cm² distribution of pressure in shape of trapezium

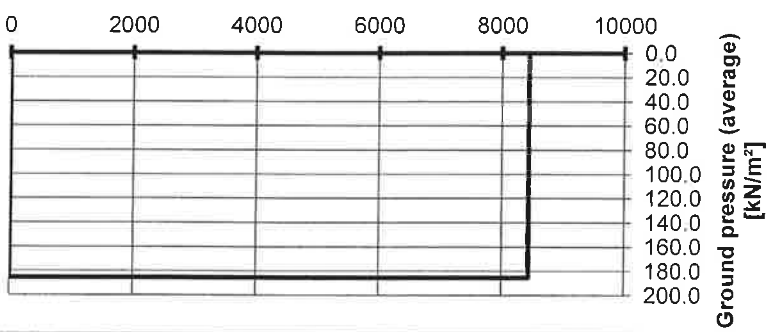
Load longitudinal to the crawlers

Distribution of pressure along the crawlers [mm]



Load over the side

Distribution along the crawlers [mm]



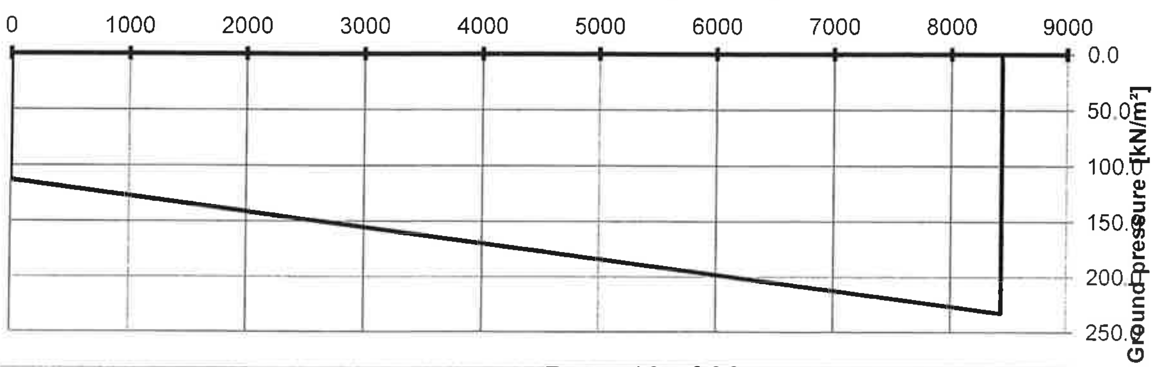
Load over the side

Ground pressure under front track
185.6 kN/m²
26.39 psi

Ground pressure under rear track
134.5 kN/m²
19.12 psi

Load over the edge

Distribution of pressure along the crawler [mm]



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Eingabedaten zur Berechnung des Bodendruckes beim LR 1300

Input for the calculation of ground pressure of LR 1300

Länge Hauptausleger Length of boom	min 20.0 max 223.1	193.6	ft
Länge Wippspitze Length of luffing jib	max 203.4	370.7	ft
Winkel Hauptausleger Boom angle		88°	
Länge Hauptausleger Leicht Length of high reach boom	max 0.0	403.5	ft
Länge Fixe Spitze Length of fixed jib	max 0.0	85.3	ft
Winkel Fixe Spitze Offset angle fixed jib		30°	
Spur UW / Track width		22	ft
Bodenplatten / Track shoes		4	ft
Ballast am Unterwagen Carbody counterweight		125.7	1000 lbs
Ballast am Oberwagen Counterweight		273.4	1000 lbs
Ballast am Derrick Super lift couterweight		0.0	1000 lbs

(Nur bei Betrieb mit Wippspitze von Bedeutung)
(Angle is only necessary for operation with luffing jib)

Ausl. Konfiguration Boom configuration	Boom & Luffing Jib
	Luffing jib 2316
Derrick Super lift No	Fixed Jib 1008
Input - Units	American Units

Lastfall
Load Case

Ausladung Load radius	ok	94.3	ft
Last Load		2.5	1000 lbs
Ballast-Radius Radius couterweight		0.0	ft

Bodendruck Ground pressure	Längs front (rear)	Seite Load over side	Eck corner	Diagramm siehe Blatt "ground pressure" Diagramm see at sheet "ground pressure"
kg/cm²	3.0	2.2	3.4	**Gerät auf festem, anpassungsfähigem Untergrund**
psi	42.7	31.3	48.4	**Crawlers on compact ground**
kg/cm²	4.4	3.0	5.0	**Gerät auf Beton, Stahlplatten etc.**
psi	62.6	42.7	71.1	**Crawlers on concrete or steel plates**

Eckdaten für die Berechnung des Bodendruckes:
Technical datas for the calculation of ground pressure

48.4psi (.144)

= 6.969 ksf

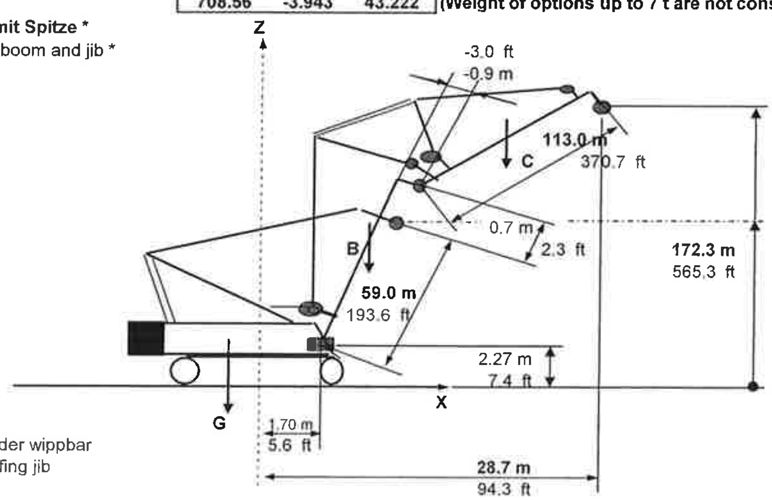
Vertikalkraft am Drehkranz statisch Vertical load at the slewing ring without dynamic effects	2112 kN	474787 lbf	
Moment am Drehkranz statisch Moment at the slewing ring without dynamic effects	-3862 kNm	-2848710 ft lbf	

Schwerpunkt Grundgerät, Ausleger und Spitze *

Center of gravity of basic machine, boom and jib *

Schwerpunkte Center of gravity		Gewicht weight [1000 lbs]	X [ft]	Z [ft]	Bemerkung Remarks
Grundgerät Basic machine	G	586.18	-9.324	6.990	**Mit Ballast, 1 Hubseil, ohne Haken** With ballast, 1 hoist rope, without hook
Ausleger Boom	B	61.44	4.560	91.721	**Komplettes System incl. A-Bock** Complete system incl. A-frame
Spitze * Jib *	C	58.44	36.900	333.338	**Komplettes System incl. obere A-Böcke** Complete system incl. upper A-frames
Schwerpunkt Center of gravity		706.06	-4.291	41.374	**Kran Standard ohne Last und ohne Optionen** Crane standard without load and without optional add on
		including load at boom head			
		708.56	-3.943	43.222	**(Weight of options up to 7 t are not considered)**

Geometrie mit Spitze *
System with boom and jib *



*) Spitze fix oder wippbar
*) Fixed or luffing jib

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Calculation of ground pressure LR 1300

Crawlers on compact ground

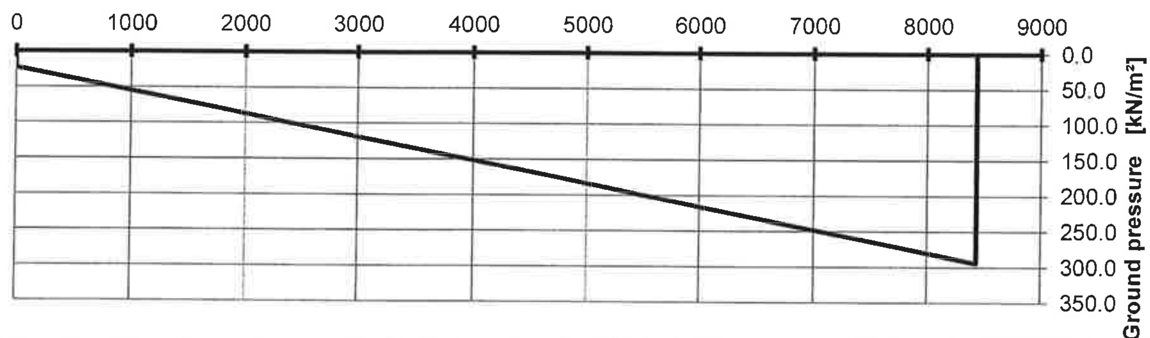
Load:	**1.1 t**	Radius:	**28.7 m**	Boom:	**59.0 m**	Luffer:	**113.0 m**
		Counter weight at the -		Upper carriage:	**124.0 t**	Carbody:	**57.0 t**

Forces at the slewing ring:			Dimensions of the undercarriage:			
Moment	3862.3	[kNm]	Width of track shoes	b	1200.0	[mm]
Ver.Load	2112.0	[kN]	Length of crawlers	l	8435.0	[mm]
Center of gravity	1201.7	[mm]	Track width	s	6800.0	[mm]
Weight of undercarriage	1102.0	[kN]	Tipping line	kk	7100.0	[mm]

Load over front:				
p max	294.5 kN/m²	=	3.000 kg/cm²	distribution of pressure in shape of trapezium
Load over side:				
p average	214.9 kN/m²	=	2.200 kg/cm²	distribution of pressure in shape of trapezium
Maximum ground pressure at an angle of:			**35.0°**	(0° = longitudinal to the crawlers)
p max	336.4 kN/m²	=	3.400 kg/cm²	distribution of pressure in shape of trapezium

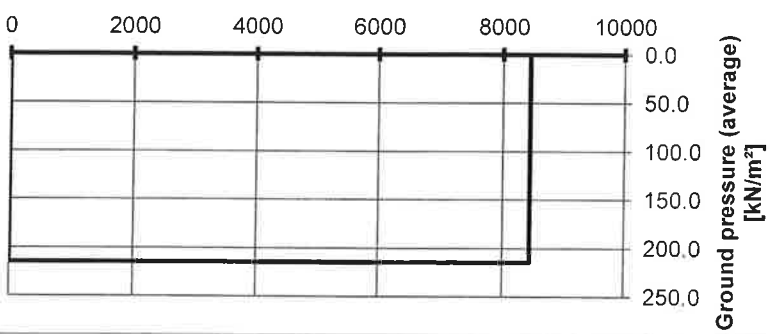
Load longitudinal to the crawlers

Distribution of pressure along the crawlers [mm]



Load over the side

Distribution along the crawlers [mm]



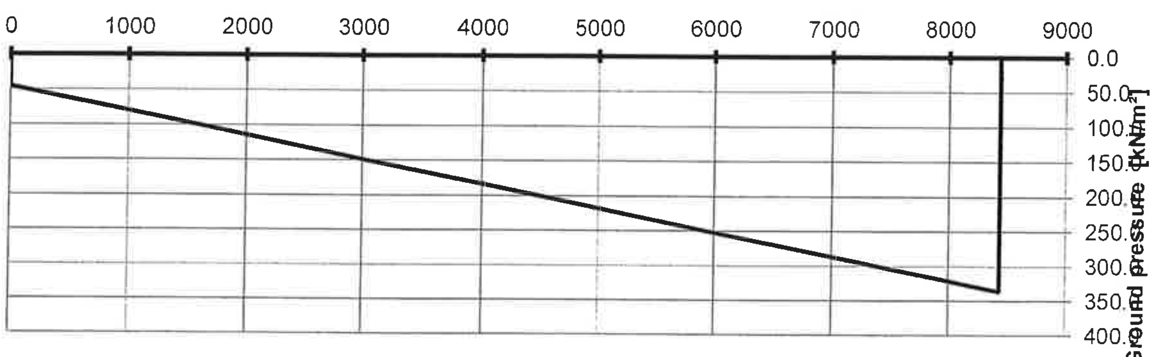
Load over the side

Ground pressure
under front track
214.9 kN/m²
30.56 psi

Ground pressure
under rear track
102.6 kN/m²
14.60 psi

Load over the edge

Distribution of pressure along the crawler [mm]



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LIEBHERR

LR1300

Load capacities main boom + luffing jib

Ident. no.:	9839979/95738/	Main boom foot:	2821-1
Slewing range:	360 °	Main boom head:	2821-1
Foot print:	2 - Wide track		
Rear counterweight [1000 lbs]:	273.4		
Carbody counterweight [1000 lbs]:	125.7		

Outre-ach [ft]	88° Main boom angle			83° Main boom angle			75° Main boom angle			65° Main boom angle			45° Main boom angle		
	Jib angle [°]	Lift height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Lift height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Lift height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Lift height [ft]	Load capacity [1000 lbs]	Jib angle [°]	Lift height [ft]	Load capacity [1000 lbs]
194 ft Main boom, Load fall point 1 - Jib head Jib head (2316-1) 322 ft Jib															
84	78.0	517	32.5												
85	77.8	517	32.5												
90	76.9	516	32.5												
95	76.0	515	31.9												
100	75.1	513	31.6												
105	74.1	512	31.4												
110	73.2	510	31.3												
115	72.3	509	30.8												
120	71.3	507	30.3												
125	70.4	505	29.9												
128				73.0	508	30.8									
130	69.4	504	29.6	72.7	508	30.8									
135	68.5	502	29.3	71.7	506	30.7									
140	67.5	499	28.8	70.8	504	30.5									
145	66.5	497	28.3	69.8	503	30.1									
150	65.5	495	27.8	68.9	501	29.6									
155	64.5	493	27.3	67.9	499	29.2									
160	63.6	490	26.9	66.9	497	28.8									
165	62.5	488	26.5	65.9	494	28.3									
170	61.5	485	26.1	64.9	492	27.9									
175	60.5	482	25.8	64.0	490	27.5									
180	59.5	479	25.0	63.0	487	27.1									
185	58.4	476	24.2	61.9	484	26.8									
190	57.4	473	23.5	60.9	482	26.5									
195	56.3	470	22.7	59.9	479	26.2									
196							65.0	486	23.8						
200	55.2	466	22.1	58.8	476	25.7	64.3	485	23.1						
205	54.1	462	21.4	57.8	472	25.3	63.3	482	22.2						
210	53.0	459	20.8	56.7	469	24.9	62.3	480	21.3						
215	51.8	455	20.3	55.6	466	24.5	61.3	477	20.5						
220	50.7	451	19.7	54.5	462	24.2	60.2	474	19.7						
225	49.5	446	19.3	53.4	459	23.8	59.5	472	18.9						
230	48.3	442	18.9	52.3	455	23.5	58.4	469	18.3						
235	47.1	437	18.6	51.2	451	23.3	57.4	466	17.6						
240	45.9	433	18.4	50.0	447	23.0	56.3	462	16.9						
245	44.6	428	18.1	48.8	442	22.3	55.2	459	16.3						
250	43.3	422	17.8	47.6	438	21.6	54.1	455	15.7						
255	42.0	417	17.6	46.4	433	20.9	53.0	452	15.1						
260	40.6	411	17.3	45.1	428	20.2	51.9	448	14.5						
265	39.2	405	17.1	43.8	423	19.6	50.8	444	14.0						
270	37.7	398	16.9	42.5	417	19.0	49.6	440	13.5						
275	36.2	392	16.6	41.2	412	18.4	48.4	435	13.0						
276										55.0	446	6.4			
280	34.7	385	16.4	39.8	406	17.8	47.2	430	12.5	54.6	445	6.2			
285	33.1	377	16.3	38.3	400	17.3	46.0	426	12.0	53.5	441	5.8			
290	31.4	369	15.3	36.9	393	16.8	44.7	421	11.6	52.3	437	5.5			
295	29.6	360	14.4	35.3	386	16.2	43.4	416	11.2	51.2	433	5.1			
300	27.7	351	13.4	33.7	378	15.7	42.1	410	10.7	50.0	429	4.8			
305	25.7	341	12.4	32.1	371	15.2	40.7	404	10.3	48.9	425	4.5			
310	23.5	330	11.4	30.3	362	14.6	39.3	398	10.0	47.7	420	4.2			
315	21.1	317	10.4	28.5	353	13.8	37.9	392	9.6	46.4	415	3.9			
320	18.4	303	9.3	26.5	343	13.0	36.4	385	9.2	45.2	410	3.6			
325	15.3	286	8.3	24.4	333	12.1	34.9	378	8.9	43.9	405	3.4			
330				22.1	321	11.3	33.3	371	8.6	42.6	400	3.0			
335				19.6	307	10.4	31.6	363	8.3	41.3	394	2.6			
340				17.9	298	9.6	29.8	354	8.0	39.9	388	2.3			
345							28.0	345	7.6						
350							26.0	335	7.2						
355							23.8	324	6.8						
360							21.5	312	6.4						
365							18.9	298	6.0						
370							15.8	282	5.6						

Eingabedaten zur Berechnung des Bodendruckes beim LR 1300

Input for the calculation of ground pressure of LR 1300

Länge Hauptausleger / Length of boom	min 20.0 / max 223.1	193.6	ft
Länge Wippspitze / Length of luffing jib	max 203.4	321.5	ft
Winkel Hauptausleger / Boom angle		88°	
Länge Hauptausleger Leicht / Length of high reach boom	max 0.0	403.5	ft
Länge Fixe Spitze / Length of fixed jib	max 0.0	85.3	ft
Winkel Fixe Spitze / Offset angle fixed jib		30°	
Spur UW / Track width		22	ft
Bodenplatten / Track shoes		4	ft
Ballast am Unterwagen / Carbody counterweight		125.7	1000 lbs
Ballast am Oberwagen / Counterweight		273.4	1000 lbs
Ballast am Derrick / Super lift couterweight		0.0	1000 lbs

Ausl. Konfiguration / **Boom configuration**: Boom & Luffing Jib; Luffing jib 2316; Fixed Jib 1008

Derrick Super lift: No

(Nur bei Betrieb mit Wippspitze von Bedeutung)
(Angle is only necessary for operation with luffing jib)

Input - Units: American Units

Lastfall
Load Case

Ausladung / Load radius	ok	110.0	ft
Last / Load		24.0	1000 lbs
Ballast-Radius / Radius couterweight		0.0	ft

Bodendruck Ground pressure	Längs front (rear)	Seite Load over side	Eck corner	Diagramm siehe Blatt "ground pressure" Diagramm see at sheet "ground pressure"
kg/cm²	1.8	1.7	1.9	**Gerät auf festem, anpassungsfähigem Untergrund**
psi	25.6	24.2	27.0	**Crawlers on compact ground**
kg/cm²	2.6	2.4	2.6	**Gerät auf Beton, Stahlplatten etc.**
psi	37.0	34.1	37.0	**Crawlers on concrete or steel plates**

27psi (.144) = 3.88 ksf

Eckdaten für die Berechnung des Bodendruckes:
Technical datas for the calculation of ground pressure

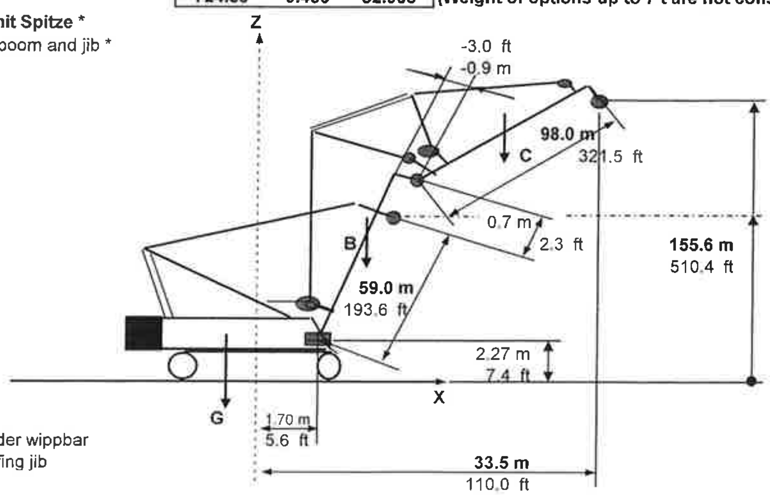
Vertikalkraft am Drehkranz statisch / Vertical load at the slewing ring without dynamic effects	2185	kN	491130 lbf
Moment am Drehkranz statisch / Moment at the slewing ring without dynamic effects	-491	kNm	-362309 ft lbf

Schwerpunkt Grundgerät, Ausleger und Spitze *

Center of gravity of basic machine, boom and jib *

Schwerpunkte / Center of gravity		Gewicht weight [1000 lbs]	X [ft]	Z [ft]	Bemerkung / Remarks
Grundgerät / Basic machine	G	586.18	-9.324	6.990	**Mit Ballast, 1 Hubseil, ohne Haken** / With ballast, 1 hoist rope, without hook
Ausleger / Boom	B	61.44	4.560	91.721	**Komplettes System incl. A-Bock** / Complete system incl. A-frame
Spitze * / Jib *	C	52.96	41.356	309.608	**Komplettes System incl. obere A-Böcke** / Complete system incl. upper A-frames
Schwerpunkt / Center of gravity		700.58	-4.275	37.299	**Kran Standard ohne Last und ohne Optionen** / Crane standard without load and without optional add on
		including load at boom head			
		724.58	-0.490	52.968	**(Weight of options up to 7 t are not considered)**

Geometrie mit Spitze *
System with boom and jib *



*) Spitze fix oder wippbar
*) Fixed or luffing jib

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Calculation of ground pressure LR 1300

Crawlers on compact ground

Load:	**10.9 t**	Radius:	**33.5 m**	Boom:	**59.0 m**	Luffer:	**98.0 m**
		Counter weight at the -		Upper carriage:	**124.0 t**	Carbody:	**57.0 t**

Forces at the slewing ring:			Dimensions of the undercarriage:		
Moment	491.2	[kNm]	Width of track shoes	b	1200.0 [mm]
Ver.Load	2184.7	[kN]	Length of crawlers	l	8435.0 [mm]
Center of gravity	149.5	[mm]	Track width	s	6800.0 [mm]
Weight of undercarriage	1102.0	[kN]	Tipping line	kk	7100.0 [mm]

Load over front:

p max 179.6 kN/m² = 1.800 kg/cm² distribution of pressure in shape of trapezium

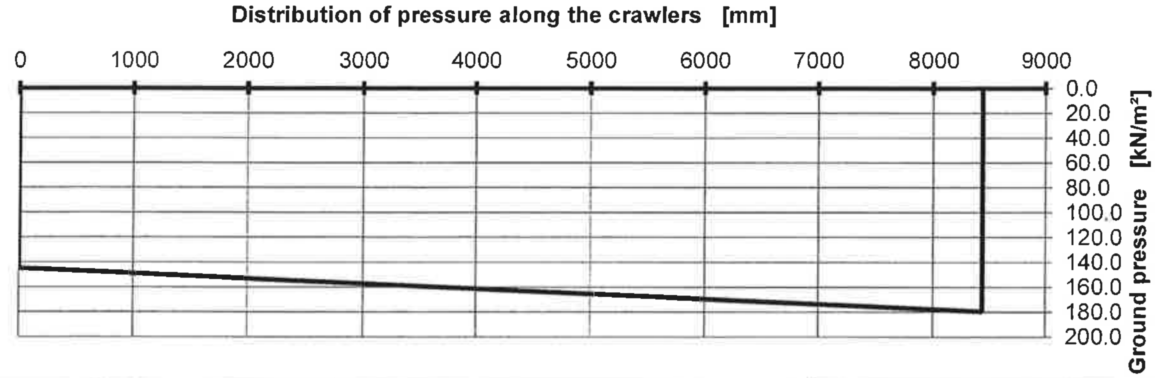
Load over side:

p average 169.5 kN/m² = 1.700 kg/cm² distribution of pressure in shape of trapezium

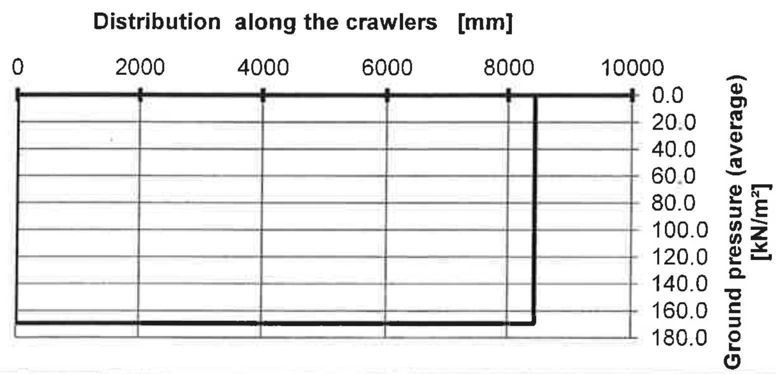
Maximum ground pressure at an angle of: **25.0°** (0° = longitudinal to the crawlers)

p max 181.4 kN/m² = 1.900 kg/cm² distribution of pressure in shape of trapezium

Load longitudinal to the crawlers



Load over the side

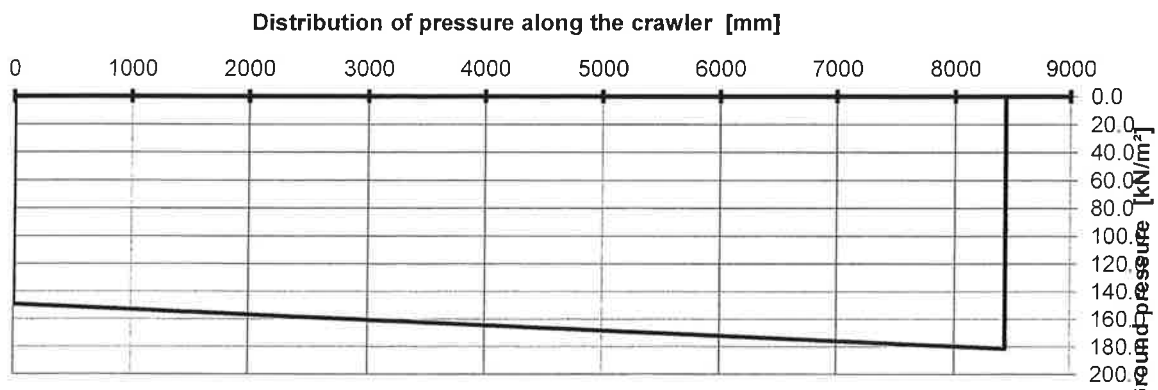


Load over the side

Ground pressure under front track
169.5 kN/m²
24.11 psi

Ground pressure under rear track
155.2 kN/m²
22.08 psi

Load over the edge



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Eingabedaten zur Berechnung des Bodendruckes beim LR 1300

Input for the calculation of ground pressure of LR 1300

Ausl. Konfiguration Boom configuration	Boom & Luffing Jib		
	Luffing jib 2316		
Derrick Super lift	No	Fixed Jib 1008	

Länge Hauptausleger Length of boom	min 20.0 max 223.1	193.6	ft
Länge Wippspitze Length of luffing jib	max 203.4	321.5	ft
Winkel Hauptausleger Boom angle		88°	← → (Nur bei Betrieb mit Wippspitze von Bedeutung) (Angle is only necessary for operation with luffing jib)
Länge Hauptausleger Leicht Length of high reach boom	max 0.0	403.5	ft
Länge Fixe Spitze Length of fixed jib	max 0.0	85.3	ft
Winkel Fixe Spitze Offset angle fixed jib		30°	
Spur UW / Track width		22	ft
Bodenplatten / Track shoes		4	ft
Ballast am Unterwagen Carbody counterweight		125.7	1000 lbs
Ballast am Oberwagen Counterweight		273.4	1000 lbs
Ballast am Derrick Super lift couterweight		0.0	1000 lbs

Input - Units		American Units	
Lastfall Load Case			
Ausladung Load radius	ok	84.0	ft
Last Load		2.5	1000 lbs
Ballast-Radius Radius couterweight		0.0	ft

Bodendruck Ground pressure	Längs front (rear)	Seite Load over side	Eck corner	Diagramm siehe Blatt "ground pressure" Diagramm see at sheet "ground pressure"
kg/cm²	3.2	2.3	3.8	**Gerät auf festem, anpassungsfähigem Untergrund**
psi	45.5	32.7	54.0	**Crawlers on compact ground**
kg/cm²	4.9	3.1	5.7	**Gerät auf Beton, Stahlplatten etc.**
psi	69.7	44.1	81.1	**Crawlers on concrete or steel plates**

CENTER AROUND MANHOLE

54psi (144) = 7.776 ksf

Eckdaten für die Berechnung des Bodendruckes:
Technical datas for the calculation of ground pressure

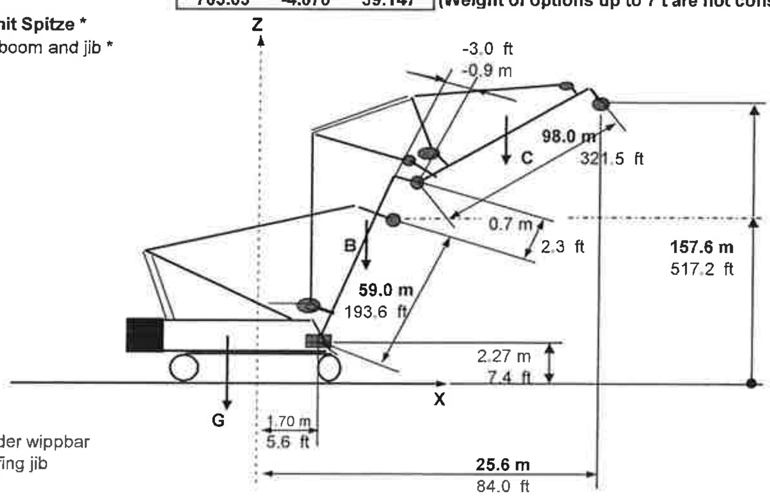
Vertikalkraft am Drehkranz statisch Vertical load at the slewing ring without dynamic effects	2087	kN	469154 lbf
Moment am Drehkranz statisch Moment at the slewing ring without dynamic effects	-4540	kNm	-3348226 ft lbf

Schwerpunkt Grundgerät, Ausleger und Spitze *

Center of gravity of basic machine, boom and jib *

Schwerpunkte Center of gravity		Gewicht weight [1000 lbs]	X [ft]	Z [ft]	Bemerkung Remarks
Grundgerät Basic machine	G	586.18	-9.324	6.990	**Mit Ballast, 1 Hubseil, ohne Haken** With ballast, 1 hoist rope, without hook
Ausleger Boom	B	61.44	4.560	91.721	**Komplettes System incl. A-Bock** Complete system incl. A-frame
Spitze * Jib *	C	52.91	31.981	311.758	**Komplettes System incl. obere A-Böcke** Complete system incl. upper A-frames
Schwerpunkt Center of gravity		700.53	-4.987	37.441	**Kran Standard ohne Last und ohne Optionen**
		including load at boom head			Crane standard without load and without optional add on
		703.03	-4.670	39.147	**(Weight of options up to 7 t are not considered)**

Geometrie mit Spitze *
System with boom and jib *



*) Spitze fix oder wippbar
*) Fixed or luffing jib

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Calculation of ground pressure LR 1300

Crawlers on compact ground

Load:	**1.1 t**	Radius:	**25.6 m**	Boom:		**59.0 m**	Luffer:	**98.0 m**
		Counter weight at the -		Upper carriage:		**124.0 t**	Carbody:	**57.0 t**
Forces at the slewing ring:				Dimensions of the undercarriage:				
Moment		4539.6	[kNm]	Width of track shoes	b	1200.0	[mm]	
Ver.Load		2086.9	[kN]	Length of crawlers	l	8435.0	[mm]	
Center of gravity		1423.6	[mm]	Track width	s	6800.0	[mm]	
Weight of undercarriage		1102.0	[kN]	Tipping line	kk	7100.0	[mm]	

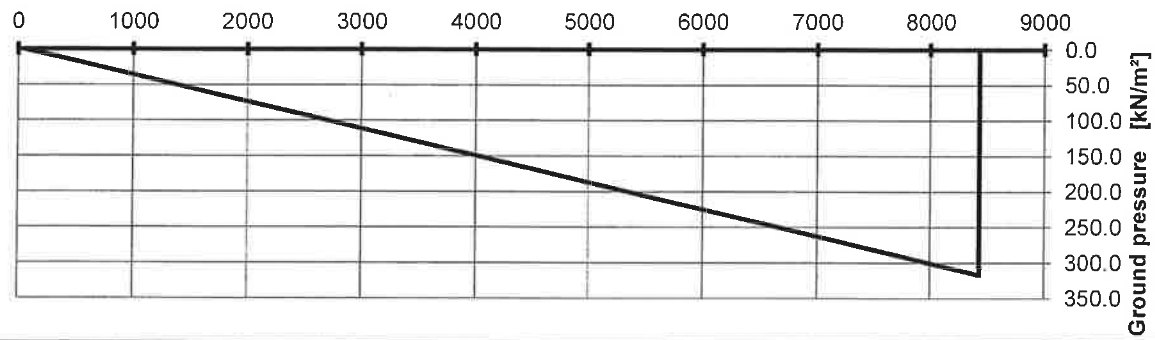
Load over front:
p max 317.0 kN/m² = 3.200 kg/cm² — distribution of pressure triangular
new l=l' 8381.8 [mm]

Load over side:
p average 223.5 kN/m² = 2.300 kg/cm² — distribution of pressure in shape of trapezium

Maximum ground pressure at an angle of: **35.0°** (0° = longitudinal to the crawlers)
p max 374.0 kN/m² = 3.800 kg/cm² — distribution of pressure in shape of trapezium

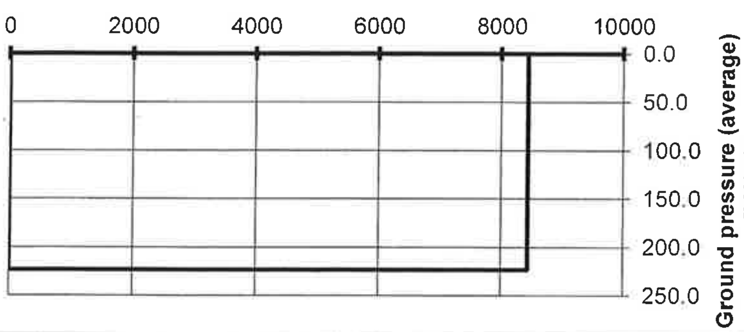
Load longitudinal to the crawlers

Distribution of pressure along the crawlers [mm]



Load over the side

Distribution along the crawlers [mm]



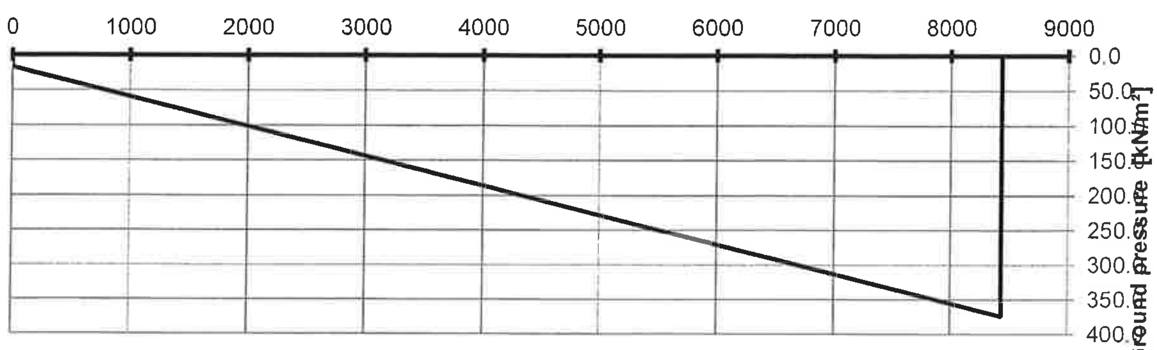
Load over the side

Ground pressure
under front track
223.5 kN/m²
31.79 psi

Ground pressure
under rear track
91.6 kN/m²
13.02 psi

Load over the edge

Distribution of pressure along the crawler [mm]



***Crane Model:* Liebherr LR 1300 Crawler Crane**

This document will analyze the pontoon support platform for a crawler crane.
Design is based on 12" x 12" timbers.

Crane information:

Center to center width of crane over crawlers	$W_{crane} := 8000 \cdot mm$	$W_{crane} = 26.247\,ft$
Tread width	$w_t := 4 \cdot ft$	
Tread bearing width	$w_b := 1200 \cdot mm$	$w_b = 3.937\,ft$
Tread bearing length	$l_b := 8381.8 \cdot mm$	$l_b = 27.5\,ft$
Maximum pressure	$q_{max} := 54 \cdot psi$	$q_{max} = 7.776\,ksf$
Minimum pressure	$q_{min} := 0 \cdot psi$	
Average Max. Pressure (2' from q_{max})	$q_4 := q_{max} - \frac{(q_{max} - q_{min})}{l_b} \cdot 2 \cdot ft$	$q_4 = 7.21\,ksf$
Maximum load on 12 x 12 timber	$P := (q_4) \cdot w_b$	$P = 28.39 \frac{kip}{ft}$
Maximum allowable bearing pressure	$F_p := 3.5 \cdot ksf$	
Timber dimensions	$b := 12.0 \cdot in$	
	$d := 12.0 \cdot in$	

Mat Analysis:

Use 4' x 8'-6" Min. Pontoons $L_p := 8.5 \cdot ft$ Effective Pontoon Length Under Cat: $L_e := 8.5 \cdot ft$
(Under CATS)

$f_p := \frac{P}{L_e}$ $f_p = 3.34\,ksf$ < $F_p = 3.5\,ksf$ **OK**

Pontoon Moment Arm: $Arm := \frac{L_e}{2} - \frac{w_b}{2}$ $Arm = 2.28\,ft$

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Check Mat for Shear and Bending Stresses:

Shear:

$V := f_p \cdot 1 \cdot ft \cdot Arm$ $\quad V = 7.62\,kip$

$A_v := 1 \cdot ft \cdot d$ $\quad A_v = 144\,in^2$

$f_v := \frac{3 \cdot V}{2 \cdot A_v}$ $\quad f_v = 79\,psi$ $\quad < \quad F_v := 150 \cdot psi$ $\quad$ **OK**

Bending:

$M := f_p \cdot 1 \cdot ft \cdot \frac{Arm^2}{2}$ $\quad M = 8.7\,kip \cdot ft$ $\quad S_{pontoon} := b \cdot \frac{d^2}{6}$ $\quad S_{pontoon} = 288\,in^3$

$f_b := \frac{M}{S_{pontoon}}$ $\quad f_b = 362\,psi$ $\quad < \quad F_b := 1500 \cdot psi$ $\quad$ **OK**

USE : 12" x 12" Pontoons - 4' wide x 8'-6" min. long under each crawler

12/23

Crane Model: **Liebherr LR 1300 Crawler Crane** (NEAR MANHOLE - NORTH CAT)

This document will analyze the pontoon support platform for a crawler crane.
Design is based on 12" x 12" timbers.

Crane information:

Center to center width of crane over crawlers	$W_{crane} := 8000 \cdot mm$	$W_{crane} = 26.247\,ft$	
Tread width	$w_t := 4 \cdot ft$		
Tread bearing width	$w_b := 1200 \cdot mm$	$w_b = 3.937\,ft$	
Tread bearing length	$l_b := 8381.8 \cdot mm$	$l_b = 27.5\,ft$	
Maximum pressure	$q_{max} := 32.7 \cdot psi$	$q_{max} = 4.709 \cdot ksf$	
Minimum pressure	$q_{min} := 0 \cdot psi$		
Average Max. Pressure (2' from q_{max})	$q_4 := q_{max} - \frac{(q_{max} - q_{min})}{l_b} \cdot 2 \cdot ft$		$q_4 = 4.37 \cdot ksf$
Maximum load on 12 x 12 timber	$P := (q_4) \cdot w_b$		$P = 17.19 \cdot \frac{kip}{ft}$
Maximum allowable bearing pressure	$F_p := 3.5 \cdot ksf$		
Timber dimensions	$b := 12.0 \cdot in$ $d := 12.0 \cdot in$		

Mat Analysis:

Use 4' x 5'-6" Min. Pontoons $L_p := 5.5 \cdot ft$ Effective Pontoon Length Under Cat: $L_e := 5.5 \cdot ft$

$f_p := \frac{P}{L_e}$ $f_p = 3.13 \cdot ksf$ < $F_p = 3.5 \cdot ksf$ **OK**

Pontoon Moment Arm: $Arm := \frac{L_e}{2} - \frac{w_b}{2}$ $Arm = 0.78\,ft$

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Check Mat for Shear and Bending Stresses:

Shear:

$V := f_p \cdot 1 \cdot ft \cdot Arm$ $\qquad V = 2.44 \cdot kip$

$A_v := 1 \cdot ft \cdot d$ $\qquad A_v = 144 \cdot in^2$

$f_v := \frac{3 \cdot V}{2 \cdot A_v}$ $\qquad f_v = 25 \cdot psi \quad < \quad F_v := 150 \cdot psi$ **OK**

Bending:

$M := f_p \cdot 1 \cdot ft \cdot \frac{Arm^2}{2}$ $\qquad M = 1 \cdot kip \cdot ft$ $\qquad S_{pontoon} := b \cdot \frac{d^2}{6}$ $\qquad S_{pontoon} = 288 \cdot in^3$

$f_b := \frac{M}{S_{pontoon}}$ $\qquad f_b = 40 \cdot psi \quad < \quad F_b := 1500 \cdot psi$ **OK**

USE : 12" x 12" Pontoons - 4' wide x 5'-6" min. long under CAT

(NEAR MANHOLE UNDER NORTH CAT)

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Runway For Crane Assembly

Eingabedaten zur Berechnung des Bodendruckes beim LR 1300
Input for the calculation of ground pressure of LR 1300

Länge Hauptausleger Length of boom	min 20.0 max 223.1	193.6	ft
Länge Wippspitze Length of luffing jib	max 203.4	321.5	ft
Winkel Hauptausleger Boom angle		88°	
Länge Hauptausleger Leicht Length of high reach boom	max 0.0	403.5	ft
Länge Fixe Spitze Length of fixed jib	max 0.0	85.3	ft
Winkel Fixe Spitze Offset angle fixed jib		30°	
Spur UW / Track width		22	ft
Bodenplatten / Track shoes		4	ft
Ballast am Unterwagen Carbody counterweight		125.7	1000 lbs
Ballast am Oberwagen Counterweight		273.4	1000 lbs
Ballast am Derrick Super lift couterweight		0.0	1000 lbs

(Nur bei Betrieb mit Wippspitze von Bedeutung)
(Angle is only necessary for operation with luffing jib)

Ausl. Konfiguration **Boom configuration**	Boom & Luffing Jib
	Luffing jib 2316
Derrick Super lift No	Fixed Jib 1008

Input - Units		American Units
Lastfall Load Case		
Ausladung Load radius	ok	240.0 ft
Last Load		2.0 1000 lbs
Ballast-Radius Radius couterweight		13.0 ft

Equalize Cal Bearing Pressure For Travel

Bodendruck Ground pressure	Längs front (rear)	Seite Load over side	Eck corner	Diagramm siehe Blatt "ground pressure" Diagramm see at sheet "ground pressure"
kg/cm²	1.6	1.6	1.6	**Gerät auf festem, anpassungsfähigem Untergrund**
psi	22.8	22.8	22.8	**Crawlers on compact ground**
kg/cm²	2.2	2.2	2.2	**Gerät auf Beton, Stahlplatten etc.**
psi	31.3	31.3	31.3	**Crawlers on concrete or steel plates**

Eckdaten für die Berechnung des Bodendruckes:
Technical datas for the calculation of ground pressure

Vertikalkraft am Drehkranz statisch Vertical load at the slewing ring without dynamic effects	2086	kN	468981 lbf
Moment am Drehkranz statisch Moment at the slewing ring without dynamic effects	17	kNm	12623 ft lbf

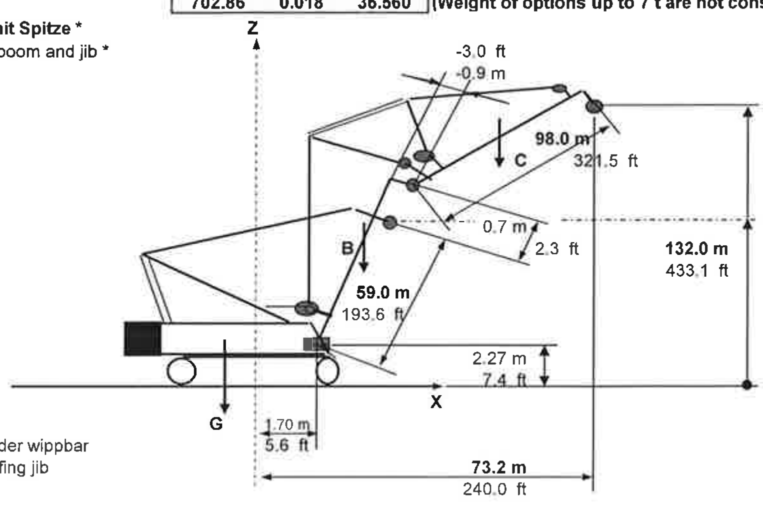
22.8 psi = 3283 #/ft2
< 3.5 KSF

Schwerpunkt Grundgerät, Ausleger und Spitze *
Center of gravity of basic machine, boom and jib *

Pontoons Only Reqd To Level Crane

Schwerpunkte Center of gravity		**Gewicht** weight [1000 lbs]	**X** [ft]	**Z** [ft]	**Bemerkung** Remarks
Grundgerät Basic machine	G	586.18	-9.324	6.990	**Mit Ballast, 1 Hubseil, ohne Haken** With ballast, 1 hoist rope, without hook
Ausleger Boom	B	61.44	4.560	91.721	**Komplettes System incl. A-Bock** Complete system incl. A-frame
Spitze * Jib *	C	53.24	88.615	283.564	**Komplettes System incl. obere A-Böcke** Complete system incl. upper A-frames
Schwerpunkt Center of gravity		700.86	-0.667	35.429	**Kran Standard ohne Last und ohne Optionen** Crane standard without load and without optional add on
		including load at boom head 702.86	0.018	36.560	**(Weight of options up to 7 t are not considered)**

Geometrie mit Spitze *
System with boom and jib *



*) Spitze fix oder wippbar
*) Fixed or luffing jib

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Calculation of ground pressure LR 1300

Crawlers on compact ground

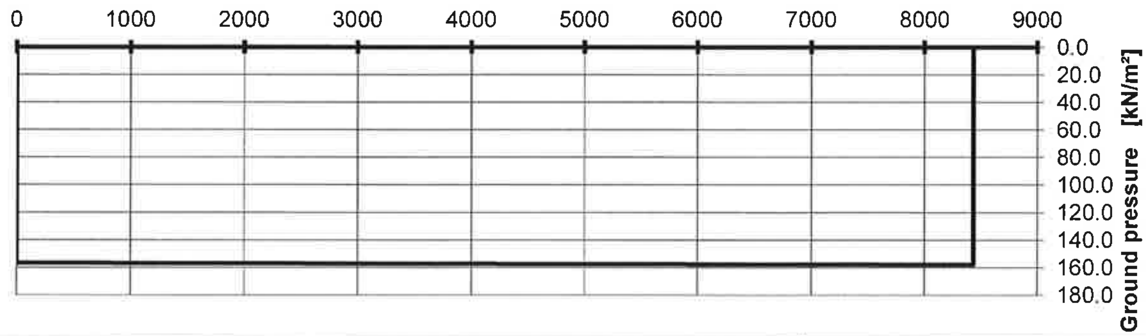
Load:	**0.9 t**	Radius:	**73.2 m**	Boom:	**59.0 m**	Luffer:	**98.0 m**
		Counter weight at the -		Upper carriage:	**124.0 t**	Carbody:	**57.0 t**

Forces at the slewing ring:			Dimensions of the undercarriage:			
Moment	17.1	[kNm]	Width of track shoes	b	1200.0	[mm]
Ver.Load	2086.1	[kN]	Length of crawlers	l	8435.0	[mm]
Center of gravity	5.4	[mm]	Track width	s	6800.0	[mm]
Weight of undercarriage	1102.0	[kN]	Tipping line	kk	7100.0	[mm]

Load over front:					
p max	158.1 kN/m²	=	1.600 kg/cm²	distribution of pressure in shape of trapezium	
Load over side:					
p average	157.7 kN/m²	=	1.600 kg/cm²	distribution of pressure in shape of trapezium	
Maximum ground pressure at an angle of:				**25.0°**	(0° = longitudinal to the crawlers)
p max	158.1 kN/m²	=	1.600 kg/cm²	distribution of pressure in shape of trapezium	

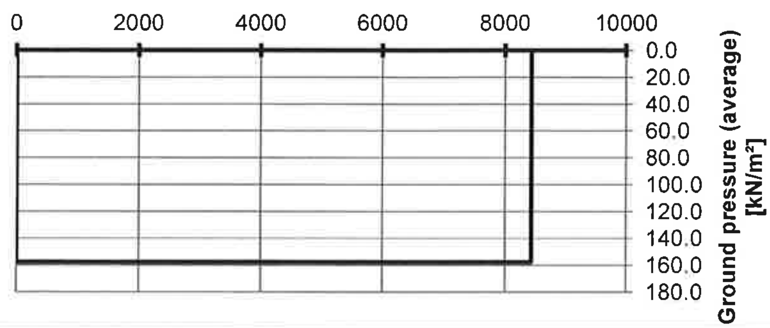
Load longitudinal to the crawlers

Distribution of pressure along the crawlers [mm]



Load over the side

Distribution along the crawlers [mm]



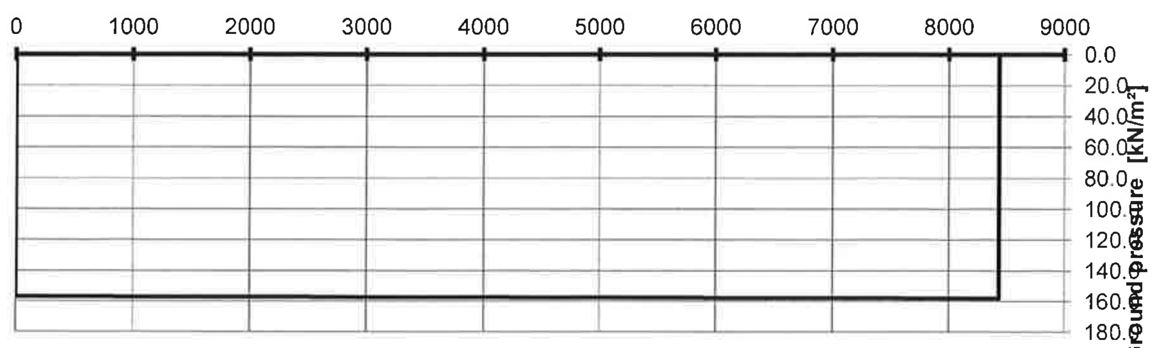
Load over the side

Ground pressure under front track
157.7 kN/m²
22.44 psi

Ground pressure under rear track
157.2 kN/m²
22.36 psi

Load over the edge

Distribution of pressure along the crawler [mm]



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Runway For Crane Assembly

Eingabedaten zur Berechnung des Bodendruckes beim LR 1300
Input for the calculation of ground pressure of LR 1300

Ausl. Konfiguration Boom configuration		Boom & Luffing Jib	←
		Luffing jib 2316	
Derrick Super lift	No	Fixed Jib 1008	

Länge Hauptausleger Length of boom	min 20.0 max 223.1	193.6	ft
Länge Wippspitze Length of luffing jib	max 203.4	370.7	ft
Winkel Hauptausleger Boom angle		88°	←→ (Nur bei Betrieb mit Wippspitze von Bedeutung) (Angle is only necessary for operation with luffing jib)
Länge Hauptausleger Leicht Length of high reach boom	max 0.0	403.5	ft
Länge Fixe Spitze Length of fixed jib	max 0.0	85.3	ft
Winkel Fixe Spitze Offset angle fixed jib		30°	
Spur UW / Track width		22	ft
Bodenplatten / Track shoes		4	ft
Ballast am Unterwagen Carbody counterweight		125.7	1000 lbs
Ballast am Oberwagen Counterweight		273.4	1000 lbs
Ballast am Derrick Super lift couterweight		0.0	1000 lbs

Input - Units		American Units	
Lastfall Load Case			
Ausladung Load radius	ok	215.0	ft
Last Load		2.0	1000 lbs
Ballast-Radius Radius couterweight		13.0	ft

● Equalize Cut Bearing Pressure For Travel

Bodendruck Ground pressure	Längs front (rear)	Seite side	Eck corner	Diagramm siehe Blatt "ground pressure" Diagramm see at sheet "ground pressure"
		Load over		
kg/cm²	1.7	1.6	1.7	Gerät auf festem, anpassungsfähigem Untergrund
psi	24.2	22.8	24.2	Crawlers on compact ground
kg/cm²	2.3	2.2	2.3	Gerät auf Beton, Stahlplatten etc.
psi	32.7	31.3	32.7	Crawlers on concrete or steel plates

Eckdaten für die Berechnung des Bodendruckes:
Technical datas for the calculation of ground pressure

Vertikalkraft am Drehkranz statisch Vertical load at the slewing ring without dynamic effects	2111	kN	474495 lbf
Moment am Drehkranz statisch Moment at the slewing ring without dynamic effects	57	kNm	41958 ft lbf

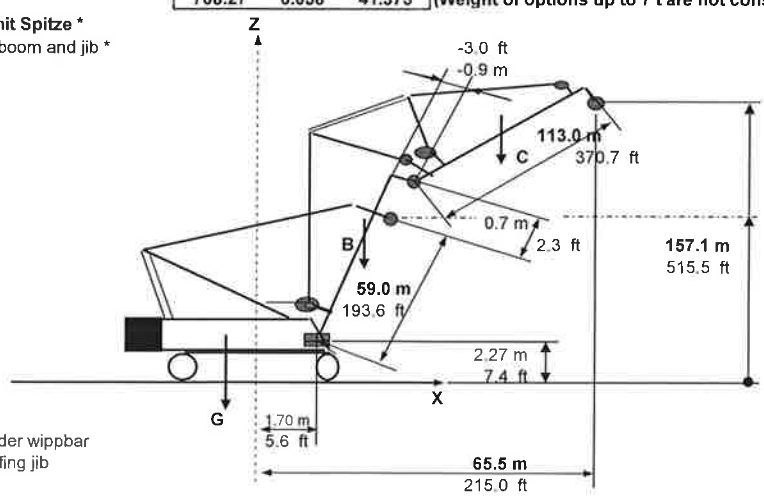
24.2 psi = 3485 #/ft² < 3.5 KSF

Pontoon on Req'd To level Crane

Schwerpunkt Grundgerät, Ausleger und Spitze *
Center of gravity of basic machine, boom and jib *

Schwerpunkte Center of gravity		**Gewicht** weight [1000 lbs]	**X** [ft]	**Z** [ft]	**Bemerkung** Remarks
Grundgerät Basic machine	G	586.18	-9.324	6.990	**Mit Ballast, 1 Hubseil, ohne Haken** With ballast, 1 hoist rope, without hook
Ausleger Boom	B	61.44	4.560	91.721	**Komplettes System incl. A-Bock** Complete system incl. A-frame
Spitze * Jib *	C	58.65	81.788	316.127	**Komplettes System incl. obere A-Böcke** Complete system incl. upper A-frames
Schwerpunkt Center of gravity		706.27	-0.551	40.033	**Kran Standard ohne Last und ohne Optionen** Crane standard without load and without optional add on
		including load at boom head 708.27	0.058	41.375	**(Weight of options up to 7 t are not considered)**

Geometrie mit Spitze *
System with boom and jib *



*) Spitze fix oder wippbar
*) Fixed or luffing jib

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Calculation of ground pressure LR 1300

Crawlers on compact ground

Load:	**0.9 t**	Radius:	**65.5 m**	Boom:	**59.0 m**	Luffer:	**113.0 m**
		Counter weight at the -		Upper carriage:	**124.0 t**	Carbody:	**57.0 t**

Forces at the slewing ring:			Dimensions of the undercarriage:			
Moment	56.9	[kNm]	Width of track shoes	b	1200.0	[mm]
Ver.Load	2110.7	[kN]	Length of crawlers	l	8435.0	[mm]
Center of gravity	17.7	[mm]	Track width	s	6800.0	[mm]
Weight of undercarriage	1102.0	[kN]	Tipping line	kk	7100.0	[mm]

Load over front:

p max 160.7 kN/m² = 1.700 kg/cm² distribution of pressure in shape of trapezium

Load over side:

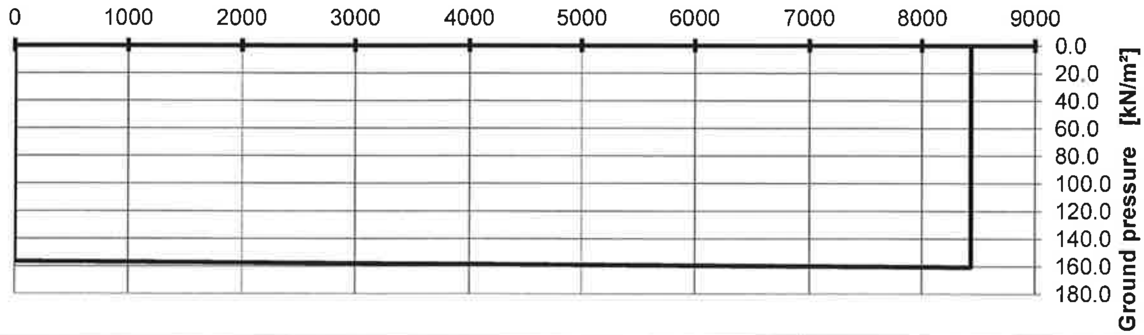
p average 159.5 kN/m² = 1.600 kg/cm² distribution of pressure in shape of trapezium

Maximum ground pressure at an angle of: **25.0°** (0° = longitudinal to the crawlers)

p max 160.9 kN/m² = 1.700 kg/cm² distribution of pressure in shape of trapezium

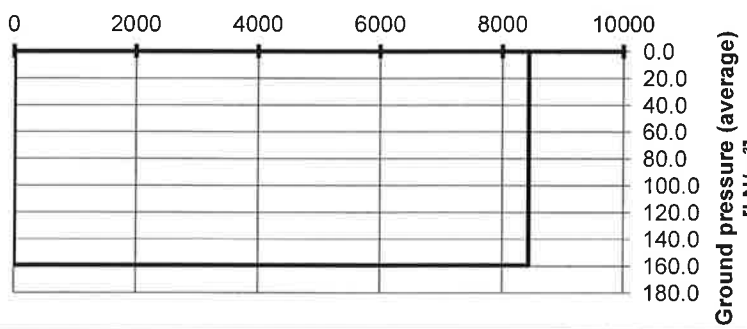
Load longitudinal to the crawlers

Distribution of pressure along the crawlers [mm]



Load over the side

Distribution along the crawlers [mm]



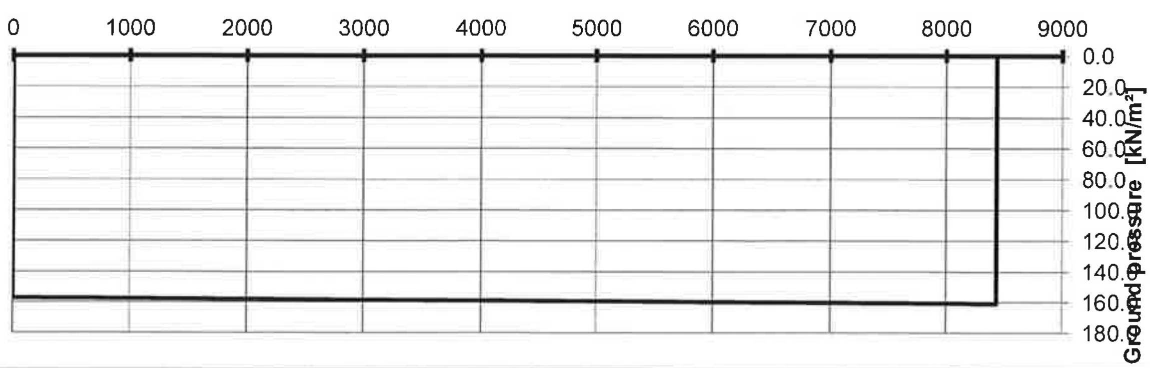
Load over the side

Ground pressure under front track
159.5 kN/m²
22.69 psi

Ground pressure under rear track
157.9 kN/m²
22.45 psi

Load over the edge

Distribution of pressure along the crawler [mm]



Crane Model: **Liebherr LR1300 Crawler Cranes**

This document will analyze the pontoon support platform with a gap present for a crawler crane. Design is based on 12" x 12" timbers.

Crane information:

Crane is in a balanced condition during travel.

Tread bearing width	$w_b := 47.25 \cdot in$	
Tread bearing length	$l_b := 8435 \cdot mm$	$l_b = 27.674\,ft$
Maximum pressure	$q_{max} := 24.2 \cdot psi$	
Minimum pressure	$q_{min} := 24.2 \cdot psi$	
Total Crane Weight	$W_t := (q_{max} + q_{min}) \cdot (w_b) \cdot (l_b)$	$W_t = 759.45\,kip$
Uniform Load Under Cats	$\omega := \dfrac{W_t}{2 \cdot (l_b)}$	$\omega = 13.72 \dfrac{kip}{ft}$

Mat Analysis: Worst case when Cat is @ mid span:

Length of gap	$L := 4.75 \cdot ft$	
Maximum Moment	$M_{max} := \dfrac{(\omega \cdot L)}{4} \cdot 1ft$	$M_{max} = 16.3\,kip \cdot ft$
Area of Pontoon	$A_p := (12 \cdot in)^2$	$A_p = 144\,in^2$
Section Modulus of pontoon	$S_{pontoon} := b \cdot \dfrac{d^2}{6}$	$S_{pontoon} = 288\,in^3$

Bending strees $f_b := \dfrac{M_{max}}{S_{pontoon}}$ $f_b = 0.7\,ksi$ $<$ $F_b := 1.5 \cdot ksi$ **OK**

Maximum shear occurs when cat is @ end of gap $V_{max} := \omega$ Very conservative

$f_v := \dfrac{\omega \cdot (1.5)}{A_p} \cdot 1ft$ $f_v = 0.14\,ksi$ $<$ $F_v := .15 \cdot ksi$ **OK**

19/23

LUFFING JIB CLEARANCE CALCULATIONS FOR LIEBHERR LR1300

Reference: Cranes & Derricks, 2nd Edition, by Howard I. Shapiro, P.E., et al.

Main Boom Length	$L_{boom} := 59 \cdot m$	$L_{boom} = 194\ ft$
Luffing Jib Length	$L_{jib} := 98.14 \cdot m$	$L_{jib} = 322 \cdot ft$
Main Boom angle	$\theta_b := 88 \cdot deg$	
Luffing jib radius	$R := 110 \cdot ft$	
Perpendicular distance from obstruction to crane centerline	$g := 70 \cdot ft$	
Perpendicular distance from obstruction to load centerline	$e := 15 \cdot ft$	
Height of obstruction	$H := 380 \cdot ft$	
Main boom foot pin radius	$t_b := 1500 \cdot mm$	
Main boom foot pin height	$h_b := 2900 \cdot mm$	$h_b = 9.5\ ft$
Jib adapter length	$ja_l := 0 \cdot mm$	
Jib adapter depth	$ja_d := 0 \cdot mm$	
Jib head depth	$jh_d := 450 \cdot mm$	$jh_d = 1.48\ ft$
Luffing jib width	$B := 2000 \cdot mm$	
Luffing jib depth	$D := 2000 \cdot mm$	
Luffing jib foot pin radius	$t_j := \left[\left(L_{boom} + ja_l\right) \cdot \cos\left(\theta_b\right) + ja_d \cdot \sin\left(\theta_b\right)\right] + t_b$	
Luffing jib foot pin height	$h_j := \left(L_{boom} + ja_l\right) \cdot \sin\left(\theta_b\right) - ja_d \cdot \cos\left(\theta_b\right) + h_b$	
Angle between jib foot and jib head	$\gamma_j := \mathrm{atan}\left(\frac{jh_d}{L_{jib}}\right)$	
Length between jib foot and jib head	$d_j := \sqrt{jh_d^2 + L_{jib}^2}$	
Varying angle to horizontal	$\beta_j := \mathrm{acos}\left(\frac{R - t_j}{d_j}\right)$	
Luffing jib angle	$\theta_j := 73 \cdot deg$	
Luffing jib tip height	$H_{tip} := \left(L_{jib} \cdot \sin\left(\theta_j\right) + h_j\right)$	$H_{tip} = 510.879\ ft$

20/23

LUFFING JIB CLEARANCE CALCULATIONS FOR LIEBHERR LR1300

Reference: Cranes & Derricks, 2nd Edition, by Howard I. Shapiro, P.E., et al.

Boom Length	$L_{boom} = 194\,ft$
Luffing + Fixed Jib Length	$L_{jib} = 322\,ft$
Luffing jib width	$B = 78.7 \cdot in$
Luffing jib depth	$D = 78.7 \cdot in$
Luffing jib foot pin radius	$t_j = 11.7\,ft$
Luffing jib foot pin height	$h_j = 203.0\,ft$
Main boom angle	$\theta_b = 88 \cdot deg$
Luffing jib angle	$\theta_j = 73 \cdot deg$
Luffing jib radius	$R = 110\,ft$
Luffing jib tip height	$H_{tip} = 510.9\,ft$
Perpendicular distance from obstruction to crane centerline	$g = 70\,ft$
Perpendicular distance from obstruction to load centerline	$e = 15\,ft$
Height of obstruction	$H = 380\,ft$

$$\tau := \operatorname{atan}\left(\frac{g+e}{R \cdot \tan(\theta_j)}\right) \qquad \tau = 13.292 \cdot deg$$

$$\phi := \operatorname{asin}\left(\frac{g+e}{R}\right) \qquad \phi = 50.599 \cdot deg$$

$$A := \frac{1 + (\sin(\tau))^2}{\cos(\tau)} \qquad A = 1.082$$

$$C := \frac{1}{A} \cdot \left[\left(R - t_j - \frac{H - h_j}{\tan(\theta_j)} - \frac{D}{2 \cdot \sin(\theta_j)}\right) \cdot \sin(\phi) - \frac{B}{2} \cdot \cos(\phi) - e\right] \qquad C = 13.3\,ft$$

Clearance

21/23

LUFFING JIB CLEARANCE CALCULATIONS FOR LIEBHERR LR1300

Reference: Cranes & Derricks, 2nd Edition, by Howard I. Shapiro, P.E., et al.

Main Boom Length	$L_{boom} := 59 \cdot m$	$L_{boom} = 194\,ft$
Luffing Jib Length	$L_{jib} := 113 \cdot m$	$L_{jib} = 371 \cdot ft$
Main Boom angle	$\theta_b := 88 \cdot deg$	
Luffing jib radius	$R := 128 \cdot ft$	
Perpendicular distance from obstruction to crane centerline	$g := 70 \cdot ft$	
Perpendicular distance from obstruction to load centerline	$e := 39 \cdot ft$	
Height of obstruction	$H := 380 \cdot ft$	
Main boom foot pin radius	$t_b := 1500 \cdot mm$	
Main boom foot pin height	$h_b := 2900 \cdot mm$	$h_b = 9.5\,ft$
Jib adapter length	$ja_l := 0 \cdot mm$	
Jib adapter depth	$ja_d := 0 \cdot mm$	
Jib head depth	$jh_d := 450 \cdot mm$	$jh_d = 1.48\,ft$
Luffing jib width	$B := 2000 \cdot mm$	
Luffing jib depth	$D := 2000 \cdot mm$	
Luffing jib foot pin radius	$t_j := \left[\left(L_{boom} + ja_l\right) \cdot \cos\left(\theta_b\right) + ja_d \cdot \sin\left(\theta_b\right)\right] + t_b$	
Luffing jib foot pin height	$h_j := \left(L_{boom} + ja_l\right) \cdot \sin\left(\theta_b\right) - ja_d \cdot \cos\left(\theta_b\right) + h_b$	
Angle between jib foot and jib head	$\gamma_j := \operatorname{atan}\left(\frac{jh_d}{L_{jib}}\right)$	
Length between jib foot and jib head	$d_j := \sqrt{jh_d^{\,2} + L_{jib}^{\,2}}$	
Varying angle to horizontal	$\beta_j := \operatorname{acos}\left(\frac{R - t_j}{d_j}\right)$	
Luffing jib angle	$\theta_j := 72 \cdot deg$	
Luffing jib tip height	$H_{tip} := \left(L_{jib} \cdot \sin\left(\theta_j\right) + h_j\right)$	$H_{tip} = 555.556\,ft$

22/23

LUFFING JIB CLEARANCE CALCULATIONS FOR LIEBHERR LR1300

Reference: Cranes & Derricks, 2nd Edition, by Howard I. Shapiro, P.E., et al.

Boom Length	$L_{boom} = 194\ ft$
Luffing + Fixed Jib Length	$L_{jib} = 371\ ft$
Luffing jib width	$B = 78.7 \cdot in$
Luffing jib depth	$D = 78.7 \cdot in$
Luffing jib foot pin radius	$t_j = 11.7\ ft$
Luffing jib foot pin height	$h_j = 203.0\ ft$
Main boom angle	$\theta_b = 88 \cdot deg$
Luffing jib angle	$\theta_j = 72 \cdot deg$
Luffing jib radius	$R = 128\ ft$
Luffing jib tip height	$H_{tip} = 555.6\ ft$
Perpendicular distance from obstruction to crane centerline	$g = 70\ ft$
Perpendicular distance from obstruction to load centerline	$e = 39\ ft$
Height of obstruction	$H = 380\ ft$

$$\tau := \operatorname{atan}\left(\frac{g + e}{R \cdot \tan(\theta_j)}\right) \qquad \tau = 15.466 \cdot deg$$

$$\phi := \operatorname{asin}\left(\frac{g + e}{R}\right) \qquad \phi = 58.382 \cdot deg$$

$$A := \frac{1 + (\sin(\tau))^2}{\cos(\tau)} \qquad A = 1.111$$

$$C := \frac{1}{A} \cdot \left[\left(R - t_j - \frac{H - h_j}{\tan(\theta_j)} - \frac{D}{2 \cdot \sin(\theta_j)}\right) \cdot \sin(\phi) - \frac{B}{2} \cdot \cos(\phi) - e\right] \qquad C = 5.8\ ft$$

Clearance

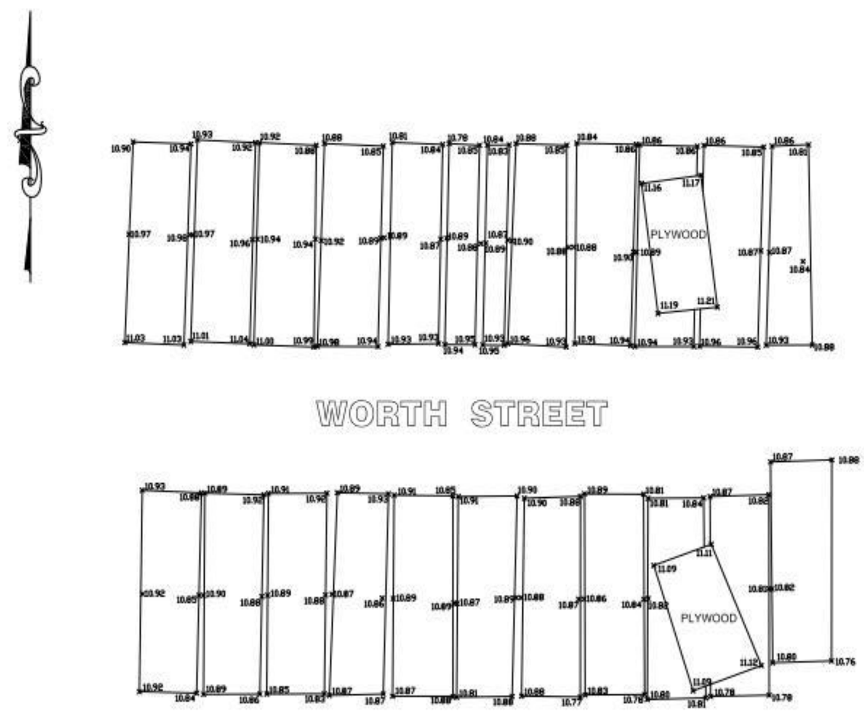
23/23

Exhibit H – Cribbing / Foundation Survey and Calculations

60 Hudson Street Crane Collapse Investigation

February 5, 2016

Table of Contents



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ARCHITECTURAL SURVEY

SITUATED IN

THE BOROUGH OF MANHATTAN

CITY OF NEW YORK

STATE OF NEW YORK

WORTH STREET CRANE PAD

True North Surveyors, Inc.
111 Kosciuszko Road, Whitehouse Station, NJ 08889
phone: (908) 534-6248 fax: (908) 534-6237

Date

John J.Vida N.Y.P.L.S. Lic. No. 050298
PROFESSIONAL LAND SURVEYOR

Calculations:

Input data:

Length of crawlers - 8,500 mm (27.9 feet)

Distance decline from the edge of mat to plywood – 10.97 to 10.89 = 0.96 inches

X = $\sqrt{27.9^2 + 0.08^2}$ = $\sqrt{778.42}$ = 27.900116

Sin (x°) = .08 feet / 27.900116 feet = 0.164°

Tan (x°) = 0.08 feet / 29.9 feet = 0.164°

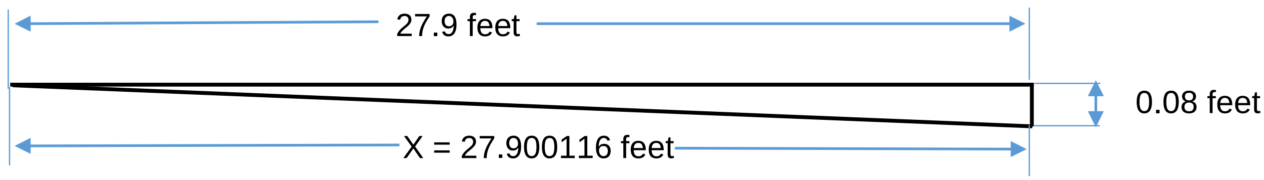

Exhibit I – Boom and Jib Angle Calculation

60 Hudson Street Crane Collapse Investigation
February 5, 2016

CTS used the measurements obtained from the various field work at the NYPD facility, where the crane components are presently stored, and more specifically, mentioned in Exhibit D Section D.5. Some of these measurements were obtained from damaged components and as such there may be an element of field measurement variation.

The measurements were inputted into a basic Auto Cad drawing for the LR 1300. The drawing was in a library of Auto Cad drawing accessible to the public. CTS modified the drawing based upon field measurements and dimensions from the operator's manual. The result is the Figure provided in Section 6.2, and included in this exhibit. The drawing is metric due to many of the dimensions provided by Liebherr were metric.

Once CTS created the drawing, CTS rotated the boom until the known length of unspooled rope equated to the rope between the fixed sheave assembly on the crane body to the sheave assembly on A frame strut 1 (25-part line) plus the length of rope from the winch to the sheave assembly on Strut 1.

The jib angle was derived by starting with the boom angle mentioned above, and rotating the jib angle to equal the distance between the sheaves banks between strut 2 and 3, and adding this length to the fixed portion of the unspooled rope from the luffing jib winch to the sheave assembly on strut 2.

The result of the above showed that the boom was at a 73° angle and the luffing jib was at 51° at the time the operator stopped moving the joystick.

CTS then generated a sensitivity analysis in Section 6.2 to show how the amount of unspooled rope would change based upon different boom and jib angles.

The next step CTS performed was to take into consideration elongation of the steel pendant bars (suspension) based upon self-weight (no load except the head ache ball). Below is process used to perform these calculations.

Pendant Bars (suspension system)

Boom Hoist

$$S = \frac{\text{(weight of headache ball * tip radius) + (weight of jib * Jib CoG) + (weight of boom * boom CoG)}}{\text{Perpendicular distance from the center of the pendant bars to boom pivot point}}$$

$$\frac{(0.9\text{ t} * 97.5\text{ m}) + (26.6\text{ t} * 47.5\text{ m}) + (27.9\text{ t} * 8.6\text{ m})}{9.45\text{ m}} = \frac{1{,}591\text{ mt}}{9.45\text{ m}} = 168\text{ t} / 2 = 84\text{ t per pendant}$$

$$A = \text{Height of pendant bar * width of pendant bar} = 2.5\text{ cm} * 7.7\text{ cm} = 19.25\text{ cm}^2$$

$$E = \frac{\text{S * Length of Pendant bars}}{\text{A * 2,100}} = \frac{84\text{t} * 5{,}470\text{ cm}}{19.25\text{ cm}^2 * 2{,}100} = \frac{459{,}480}{40{,}425} = \mathbf{11.366\text{ cm}}$$

Luffing jib

$$S = \frac{\text{(weight of headache ball * hook radius from jib pivot point) + (weight of jib * Jib CoG from jib pivot point)}}{\text{Perpendicular distance from the center of the pendant bars to jib pivot point}}$$

$$\frac{(0.9\ t * 78\ m) + (26.6\ t * 28.3\ m)}{10.6\ m} = \frac{822.99\ mt}{10.6\ m} = 77.64\ t / 2 = 38.82\ t \text{ per pendant bar}$$

A = Height of pendant bar * width of pendant bar = 2.2 cm * 6.6 cm = 14.5 cm^2

Top Suspension (strut 3 to jib tip)

$$E_{(top)} = \frac{\text{S * Length of Pendant bars}}{\text{A * 2,100}} = \frac{38.8t * 11,335\ cm}{14.5\ cm^2 * 2,100} = \frac{439,798}{30,450} = \mathbf{14.39\ cm}$$

Bottom Suspension (boom heal to strut 2)

$$E_{(bottom)} = \frac{\text{S * Length of Pendant bars}}{\text{A * 2,100}} = \frac{38.8t * 5005\ cm}{14.5\ cm^2 * 2,100} = \frac{194,194}{30,450} = \mathbf{6.38\ cm}$$

Where S = tension in the boom and jib pendant bars (suspension).
A = cross section area of boom and jib pendants
E = the elongation of the pendant bars
2,100 is the elastic modulus

Hoist Ropes

Boom Hoist Rope

Total force = 168.4 t divided by the number of parts of line (25) = 6.74 t line pull per part line

$$A = \frac{\text{Rope diameter}^2 * \pi * \text{filling factor}}{4} = \frac{2.4^2 * 3.1416 * 0.766}{4} = \frac{13.86}{4} = 3.465\ cm^2$$

$$E = \frac{\text{Force per part line * length of unspooled rope}}{\text{Area of rope * 2,100}} = \frac{6.74 * 17,600}{3.465 * 2,100} = \frac{118,624}{7,276.5} = 16.30/25 = \mathbf{0.65\ cm}$$

Luffing Jib Rope

Total force = 77.64 t divided by the number of ropes (14) = 5.55 t line pull per part line

$$A = \frac{\text{Rope diameter}^2 * \pi * \text{filling factor}}{4} = \frac{2.0^2 * 3.1416 * 0.766}{4} = \frac{13.86}{4} = 2.406\ cm^2$$

$$E = \frac{\text{Force per part line * length of unspooled rope}}{\text{Area of rope * 2,100}} = \frac{5.55 * 11,300}{2,406 * 2,100} = \frac{62,715}{5,052.6} = 12.41/14 = \mathbf{0.9\ cm}$$

Where A = cross section area of boom pendant
E = the elongation of the rope
2,100 is the elastic modulus

The bolded numbers above were added to the respective pendant bar lengths and the respective rope. The angles were then re-generated. The boom angle reduced to 72° and the luffing jib to 49° as a result of elongation of the pendant bars and rope.

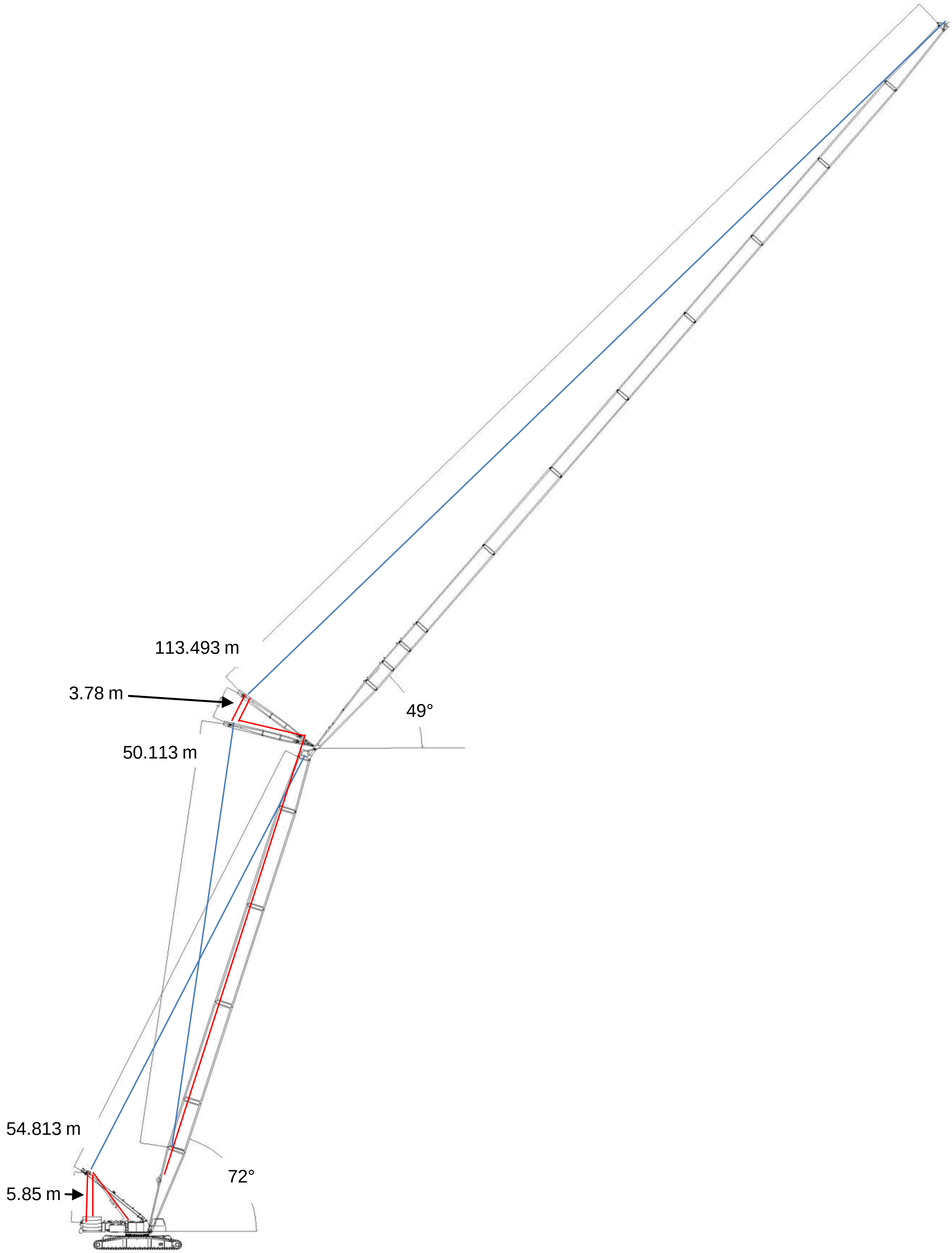

Figure 6.2.1 – Boom and jib angles (includes elongation of pendants and rope)

Denotes pendant bars (suspension)

Denotes boom and luffing jib ropes

Exhibit J - Selected Crane's Computer Data
60 Hudson Street Crane Collapse Investigation
Febrauary 5, 2016

	Group	Subgroup	Priority	Text	State	Code	Time	Last Time Occurrences	No. of Occ.	Stack Index	Startup	User Acknowledged	Service Acknowledge	Additional Info 1	Additional Info 2
February 5, 2016															
4	outer	syscheck	info	the system was shut down at 2016-02-05T09:30:02	+	0x43000034	9:30:02 AM	0:00:00	0	263032	No	No	No	0x56B46B9A	0x00000000
4	user	hs	info	diesel engine: EDC requires engine stop	+	0x000001BF	9:29:45 AM	0:00:00	0	263031	No	No	No	0x00000000	0x00000000
8	user	hs	warning	diesel engine: lub oil pressure too low	+	0x000001B5	9:29:45 AM	0:00:00	0	263030	No	No	No	0x00000000	0x00000000
8	undefined	undefined	warning	Engine control unit: Error oil pressure sensor: Exceed limit2 Supervisory threshold 2 exceeded or under-run. OilPressure no more in the normal operations status	+	0x0004B519	9:29:45 AM	0:00:00	0	263029	No	No	No	0x00000000	0x00000000
8	outer	can	warning	external message from CAN module at line 2 module number 91 Engine control unit: Error oil pressure sensor: Exceed limit2 Supervisory threshold 2 exceeded or under-run. OilPressure no more in the normal operations status	+	0x4200007D	9:29:45 AM	0:00:00	0	263028	No	No	No	0x0002005B	0x00000000
10	user	hs	error	assembly operation, Toping down stopped! (flap is locked while toping down?)	+	0x00000140	9:29:42 AM	0:00:00	0	263027	No	No	No	0x00000000	0x00000000
4	user	hs	info	luffing jib upper limit switch by boom angle, main boom angle: 4.7, luffing jib angle: 0.0	+	0x000002B7	9:29:42 AM	0:00:00	0	263026	No	No	No	0x40966666	0x00000000
10	user	hs	error	pressure sensor +4D-B22 signal too low or not connected	+	0x0000007B	9:29:42 AM	0:00:00	0	263025	No	No	No	0x00000000	0x00000000
10	user	hs	error	pressure sensor +4D-B12 signal too low or not connected	+	0x00000077	9:29:42 AM	0:00:00	0	263024	No	No	No	0x00000000	0x00000000
10	user	hs	error	pressure sensor +4D-B11 signal too low or not connected	+	0x00000075	9:29:42 AM	0:00:00	0	263023	No	No	No	0x00000000	0x00000000
10	user	hs	error	rotation angle sensor slewing gear, signal too low or not connected	+	0x0000012E	9:29:42 AM	0:00:00	0	263022	No	No	No	0x00000000	0x00000000
8	user	hs	warning	feed pressure hoisting gear 2 too low	+	0x00000071	9:29:42 AM	0:00:00	0	263021	No	No	No	0x00000000	0x00000000
8	user	hs	warning	feed pressure hoisting gear 1 too low	+	0x00000070	9:29:42 AM	0:00:00	0	263020	No	No	No	0x00000000	0x00000000
10	user	hs	error	pressure sensor +4D-B21 signal too low or not connected	+	0x00000079	9:29:42 AM	0:00:00	0	263019	No	No	No	0x00000000	0x00000000
10	user	hs	error	pressure sensor +4G-B01 signal too low or not connected	+	0x00000087	9:29:42 AM	0:00:00	0	263018	No	No	No	0x00000000	0x00000000
10	user	hs	error	pressure sensor +4H-B01 signal too low or not connected	+	0x0000008F	9:29:42 AM	0:00:00	0	263017	No	No	No	0x00000000	0x00000000
8	user	hs	warning	load sensor left and right, main boom, signals equal again maximum load left 8.4kN, maximum load right 185.4kN	-	0x00000244	9:29:42 AM	0:00:00	0	263016	No	No	No	0x41063332	0x43396B32
8	user	hs	warning	splitter gear box temperature too high	+	0x0000002D	9:29:42 AM	0:00:00	0	263015	No	No	No	0x00000000	0x00000000
8	user	hs	warning	hydraulic oiltank content too low	+	0x00000025	9:29:42 AM	0:00:00	0	263014	No	No	No	0x00000000	0x00000000
10	user	hs	error	fueltank sensor signal too low or not connected	+	0x00000021	9:29:42 AM	0:00:00	0	263013	No	No	No	0x00000000	0x00000000
4	user	hs	info	lower limit switch a-frame in the front activated	+	0x000002BE	9:29:42 AM	0:00:00	0	263012	No	No	No	0x00000000	0x00000000
4	user	hs	info	upper limit switch a-frame activated	+	0x000002BD	9:29:42 AM	0:00:00	0	263011	No	No	No	0x00000000	0x00000000
4	user	hs	info	lower limit switch hoisting gear 2 activated	+	0x000002BB	9:29:42 AM	0:00:00	0	263010	No	No	No	0x00000000	0x00000000
4	user	hs	info	lower limit switch hoisting gear 1 activated	+	0x000002BA	9:29:42 AM	0:00:00	0	263009	No	No	No	0x00000000	0x00000000
10	user	hs	error	load sensor left, main boom, signal 2 too low or not connected	+	0x00000217	9:29:42 AM	0:00:00	0	263008	No	No	No	0x00000002	0x00000000
10	user	hs	error	load sensor left, main boom, signal 1 too low or not connected	+	0x00000217	9:29:42 AM	0:00:00	0	263007	No	No	No	0x00000001	0x00000000
4	user	hs	info	luffing jib lower limit switch by boom angle, main boom angle: 22.6, luffing jib angle: 7.6	+	0x000002B8	9:29:42 AM	0:00:00	0	263006	No	No	No	0x41B4CCCD	0x40F33333
10	user	hs	error	load sensor right, main boom, signal 1 too low or not connected	+	0x0000021A	9:29:42 AM	0:00:00	0	263005	No	No	No	0x00000001	0x00000000
10	can	application	error	Module Error: Analog Input Module Type AE16 Safety Check on channel 3 failed. Primary and secondary measurement not identically. Channel is deactivated (deliver zero value).	+	0x72000066	9:29:42 AM	0:00:00	0	263004	No	No	No	0x00000000	0x00000000
8	outer	can	warning	external message from CAN module at line 2 module number 42 Module Error: Analog Input Module Type AE16 Safety Check on channel 3 failed. Primary and secondary measurement not identically. Channel is deactivated (deliver zero value).	+	0x42000079	9:29:42 AM	0:00:00	0	263003	No	No	No	0x0002002A	0x00000000
10	can	application	error	Module Error: Analog Input Module Type AE16 Safety Check on channel 14 failed. Primary and secondary measurement not identically. Channel is deactivated (deliver zero value).	+	0x72000071	9:29:42 AM	0:00:00	0	263002	No	No	No	0x00000000	0x00000000
8	outer	can	warning	external message from CAN module at line 2 module number 41 Module Error: Analog Input Module Type AE16 Safety Check on channel 14 failed. Primary and secondary measurement not identically. Channel is deactivated (deliver zero value).	+	0x42000079	9:29:42 AM	0:00:00	0	263001	No	No	No	0x00020029	0x00000000
4	user	hs	info	upper limit switch main boom activated, main boom angle: 22.9	+	0x000002BC	9:29:41 AM	0:00:00	0	263000	No	No	No	0x41B73333	0x00000000
10	user	hs	error	load sensor right, main boom, signal 2 too low or not connected	+	0x0000021A	9:29:41 AM	0:00:00	0	262999	No	No	No	0x00000002	0x00000000
4	user	hs	info	main boom lower limit switch by boom angle, main boom angle: 22.9	+	0x000002B6	9:29:41 AM	0:00:00	0	262998	No	No	No	0x41B73333	0x00000000
4	user	hs	info	lml stop backwards, utilization: 0.0	+	0x000002B4	9:29:41 AM	0:00:00	0	262997	No	No	No	0x00000000	0x00000000
4	user	hs	info	lml stop, utilization: 125.0	+	0x000002B3	9:29:41 AM	0:00:00	0	262996	No	No	No	0x42FA0000	0x00000000
8	user	hs	warning	load sensor left and right, main boom, signals not equal load left 8.4kN, load right 0.0kN	+	0x00000244	9:29:41 AM	0:00:00	0	262995	No	No	No	0x41063332	0x00000000
10	user	hs	error	angle sensor pivot piece and boom head, main boom, signals equal again	-	0x000001E5	9:29:41 AM	0:00:00	0	262994	No	No	No	0x00000000	0x00000000
10	user	hs	error	load sensor right, main boom, signal 2 o.k.	-	0x0000021A	9:29:41 AM	0:00:00	0	262993	No	No	No	0x00000002	0x00000000
4	user	hs	info	radius limitation boom lowering stopped: main boom angle: 56.8, luffing jib angle: 167.4	+	0x000002C6	9:29:41 AM	0:00:00	0	262992	No	No	No	0x426350D7	0x432769D1

	Group	Subgroup	Priority	Text	State	Code	Time	Last Time Occurrences	No. of Occ.	Stack Index	Startup	User Acknowledged	Service Acknowledge	Additional Info 1	Additional Info 2
8	user	hs	warning	assembly operation off, set assembly operation: load on main boom: 0.0to, load on luffing jib: 1.5to	-	0x0000010D	9:29:41 AM	0:00:00	0	262991	No	No	No	0x00000000	0x3FC00000
4	user	hs	info	upper limit switch main boom deactivated, main boom angle: 22.9	-	0x000002BC	9:29:41 AM	0:00:00	0	262990	No	No	No	0x41B73333	0x00000000
10	user	hs	error	load sensor right, main boom, signal 2 too low or not connected	+	0x0000021A	9:29:41 AM	0:00:00	0	262989	No	No	No	0x00000002	0x00000000
4	user	hs	info	upper limit switch main boom activated, main boom angle: 22.8	+	0x000002BC	9:29:41 AM	0:00:00	0	262988	No	No	No	0x41B66666	0x00000000
10	user	hs	error	pressure sensor 1, fall back support of the luffing jib, signal too low or not connected	+	0x00000101	9:29:41 AM	0:00:00	0	262987	No	No	No	0x00000000	0x00000000
4	user	hs	info	fall back support of the luffing jib snaped in the flap; angle of the luffing jib: 19.0°, engine running: 1 (1=yes/0=no), (in case of 0: maybe ignition turned on in that second?)	+	0x00000122	9:29:41 AM	0:00:00	0	262986	No	No	No	0x41980000	0x3F800000
4	user	hs	info	upper limit switch luffing jib activated, main boom angle: 22.8, luffing jib angle: 19.0	+	0x000002BF	9:29:41 AM	0:00:00	0	262985	No	No	No	0x41B66666	0x41980000
10	user	hs	error	pressure of the fall back support of the luffing jib too low	+	0x00000109	9:29:41 AM	0:00:00	0	262984	No	No	No	0x00000000	0x00000000
10	user	hs	error	angle sensor pivot piece, main boom, signal too low or not connected	+	0x000001E1	9:29:41 AM	0:00:00	0	262983	No	No	No	0x00000000	0x00000000
10	user	hs	error	pressure of the fall back support of the luffing jib o.k.	-	0x00000109	9:29:41 AM	0:00:00	0	262982	No	No	No	0x00000000	0x00000000
4	user	hs	info		-	0x00000143	9:29:41 AM	0:00:00	0	262981	No	No	No	0x42363A3D	0x41B9999A
10	user	hs	error	pressure of the fall back support of the luffing jib too low	+	0x00000109	9:29:41 AM	0:00:00	0	262980	No	No	No	0x00000000	0x00000000
10	user	hs	error	pressure sensor 2, fall back support of the luffing jib, signal too low or not connected	+	0x00000103	9:29:41 AM	0:00:00	0	262979	No	No	No	0x00000000	0x00000000
10	user	hs	error	angle sensor boom head, main boom, signal too low or not connected	+	0x000001E3	9:29:41 AM	0:00:00	0	262978	No	No	No	0x00000000	0x00000000
4	user	hs	info	control input of flap (overtopping guard strut of luffing fly-jib) reports: Flap is not extended! Angle main boom: 45.6°, luffing jib: 23.2°	+	0x00000143	9:29:41 AM	0:00:00	0	262977	No	No	No	0x42363A3D	0x41B9999A
10	user	hs	error	angle sensor pivot piece, luffing jib, signal too low or not connected	+	0x000001E6	9:29:41 AM	0:00:00	0	262976	No	No	No	0x00000000	0x00000000
10	user	hs	error	load sensor right, luffing jib, signal too low or not connected	+	0x000001D4	9:29:41 AM	0:00:00	0	262975	No	No	No	0x00000000	0x00000000
10	user	hs	error	load sensor left, luffing jib, signal too low or not connected	+	0x000001D2	9:29:41 AM	0:00:00	0	262974	No	No	No	0x00000000	0x00000000
4	user	hs	info	upper limit switch main boom deactivated, main boom angle: 45.6	-	0x000002BC	9:29:41 AM	0:00:00	0	262973	No	No	No	0x42363A3D	0x00000000
10	user	hs	error	load sensor left, main boom, signal 2 o.k.	-	0x00000217	9:29:41 AM	0:00:00	0	262972	No	No	No	0x00000002	0x00000000
10	user	hs	error	load sensor left, main boom, signal 1 o.k.	-	0x00000217	9:29:41 AM	0:00:00	0	262971	No	No	No	0x00000001	0x00000000
10	user	hs	error	load sensor right, main boom, signal 2 o.k.	-	0x0000021A	9:29:41 AM	0:00:00	0	262970	No	No	No	0x00000002	0x00000000
10	user	hs	error	load sensor right, main boom, signal 1 o.k.	-	0x0000021A	9:29:41 AM	0:00:00	0	262969	No	No	No	0x00000001	0x00000000
10	user	hs	error	load sensor left, main boom, signal 2 too low or not connected	+	0x00000217	9:29:41 AM	0:00:00	0	262968	No	No	No	0x00000002	0x00000000
10	user	hs	error	load sensor left, main boom, signal 1 too low or not connected	+	0x00000217	9:29:41 AM	0:00:00	0	262967	No	No	No	0x00000001	0x00000000
10	user	hs	error	load sensor right, main boom, signal 2 too low or not connected	+	0x0000021A	9:29:41 AM	0:00:00	0	262966	No	No	No	0x00000002	0x00000000
10	user	hs	error	load sensor right, main boom, signal 1 too low or not connected	+	0x0000021A	9:29:41 AM	0:00:00	0	262965	No	No	No	0x00000001	0x00000000
10	user	hs	error	angle sensor pivot piece and boom head, main boom, signals not equal	+	0x000001E5	9:29:41 AM	0:00:00	0	262964	No	No	No	0x00000000	0x00000000
4	user	hs	info		-	0x00000144	9:29:41 AM	0:00:00	0	262963	No	No	No	0x00000000	0x00000000
4	user	hs	info	upper limit switch main boom activated, main boom angle: 10.0	+	0x000002BC	9:29:40 AM	0:00:00	0	262962	No	No	No	0x41200000	0x00000000
Boom and jib are on the ground															
4	user	hs	info	control input of flap (overtopping guard strut of luffing fly-jib) reports: Flap is extended -> Error! Angle main boom: 0.0°, luffing fly-jib: 0.0°	+	0x00000144	9:29:40 AM	0:00:00	0	262961	No	No	No	0x00000000	0x00000000
4	user	hs	info	fall back support main boom is deactivated, angle main boom: 15.1°	-	0x000002B9	9:29:40 AM	0:00:00	0	262960	No	No	No	0x4171999A	0x00000000
4	user	hs	info	fall back support main boom limit switch is activated, angle main boom: 15.1°	+	0x000002B9	9:29:40 AM	0:00:00	0	262959	No	No	No	0x4171999A	0x00000000
10	user	hs	error	load sensor left and right, luffing jib, signals equal again	-	0x000001D6	9:29:40 AM	0:00:00	0	262958	No	No	No	0x00000000	0x00000000
10	user	hs	error	fall back support main boom limit switch is activated, contact of the fall back support is geometrical not possible, angle main boom: 15.1°	+	0x000001EC	9:29:40 AM	0:00:00	0	262957	No	No	No	0x4171999A	0x00000000
4	user	hs	info		-	0x00000122	9:29:40 AM	0:00:00	0	262956	No	No	No	0x41D4CCCD	0x3F800000

	Group	Subgroup	Priority	Text	State	Code	Time	Last Time Occurrences	No. of Occ.	Stack Index	Startup	User Acknowledged	Service Acknowledge	Additional Info 1	Additional Info 2
4	user	hs	info	upper limit switch luffing jib deactivated, main boom angle: 18.4, luffing jib angle: 26.6	-	0x000002BF	9:29:40 AM	0:00:00	0	262955	No	No	No	0x41933333	0x41D4CCCD
4	user	hs	info	fall back support of the luffing jib snaped in the flap; angle of the luffing jib: 26.6°, engine running: 1 (1=yes/0=no), (in case of 0: maybe ignition turned on in that second?)	+	0x00000122	9:29:40 AM	0:00:00	0	262954	No	No	No	0x41D4CCCD	0x3F800000
4	user	hs	info	upper limit switch luffing jib activated, main boom angle: 18.4, luffing jib angle: 26.6	+	0x000002BF	9:29:40 AM	0:00:00	0	262953	No	No	No	0x41933333	0x41D4CCCD
4	user	hs	info	fall back support main boom is deactivated, angle main boom: 18.4°	-	0x000002B9	9:29:40 AM	0:00:00	0	262952	No	No	No	0x41933333	0x00000000
4	user	hs	info	fall back support main boom limit switch is activated, angle main boom: 18.4°	+	0x000002B9	9:29:40 AM	0:00:00	0	262951	No	No	No	0x41933333	0x00000000
4	user	hs	info	fall back support main boom is deactivated, angle main boom: 18.4°	-	0x000002B9	9:29:40 AM	0:00:00	0	262950	No	No	No	0x41933333	0x00000000
4	user	hs	info		-	0x00000122	9:29:40 AM	0:00:00	0	262949	No	No	No	0x41D4CCCD	0x3F800000
4	user	hs	info	upper limit switch luffing jib deactivated, main boom angle: 18.4, luffing jib angle: 26.6	-	0x000002BF	9:29:40 AM	0:00:00	0	262948	No	No	No	0x41933333	0x41D4CCCD
10	user	hs	error	load sensor left and right, luffing jib, signals not equal	+	0x000001D6	9:29:40 AM	0:00:00	0	262947	No	No	No	0x00000000	0x00000000
4	user	hs	info	fall back support of the luffing jib snaped in the flap; angle of the luffing jib: 27.7°, engine running: 1 (1=yes/0=no), (in case of 0: maybe ignition turned on in that second?)	+	0x00000122	9:29:40 AM	0:00:00	0	262946	No	No	No	0x41DD999A	0x3F800000
4	user	hs	info	upper limit switch luffing jib activated, main boom angle: 21.1, luffing jib angle: 27.7	+	0x000002BF	9:29:40 AM	0:00:00	0	262945	No	No	No	0x41A8CCCD	0x41DD999A
4	user	hs	info	fall back support main boom limit switch is activated, angle main boom: 21.1°	+	0x000002B9	9:29:40 AM	0:00:00	0	262944	No	No	No	0x41A8CCCD	0x00000000
4	user	hs	info		-	0x00000122	9:29:40 AM	0:00:00	0	262943	No	No	No	0x41DD999A	0x3F800000
4	user	hs	info	upper limit switch luffing jib deactivated, main boom angle: 21.1, luffing jib angle: 27.7	-	0x000002BF	9:29:40 AM	0:00:00	0	262942	No	No	No	0x41A8CCCD	0x41DD999A
4	user	hs	info	fall back support of the luffing jib snaped in the flap; angle of the luffing jib: 27.7°, engine running: 1 (1=yes/0=no), (in case of 0: maybe ignition turned on in that second?)	+	0x00000122	9:29:40 AM	0:00:00	0	262941	No	No	No	0x41DD999A	0x3F800000
4	user	hs	info	upper limit switch luffing jib activated, main boom angle: 21.1, luffing jib angle: 27.7	+	0x000002BF	9:29:40 AM	0:00:00	0	262940	No	No	No	0x41A8CCCD	0x41DD999A
4	user	hs	info		-	0x00000122	9:29:40 AM	0:00:00	0	262939	No	No	No	0x41DD999A	0x3F800000
4	user	hs	info	upper limit switch luffing jib deactivated, main boom angle: 21.1, luffing jib angle: 27.7	-	0x000002BF	9:29:40 AM	0:00:00	0	262938	No	No	No	0x41A8CCCD	0x41DD999A
4	user	hs	info	fall back support of the luffing jib snaped in the flap; angle of the luffing jib: 26.3°, engine running: 1 (1=yes/0=no), (in case of 0: maybe ignition turned on in that second?)	+	0x00000122	9:29:40 AM	0:00:00	0	262937	No	No	No	0x41D26666	0x3F800000
4	user	hs	info	lower limit switch luffing jib activated, main boom angle: 23.4, luffing jib angle: 26.3	+	0x000002C0	9:29:40 AM	0:00:00	0	262936	No	No	No	0x41BB3333	0x41D26666
4	user	hs	info	upper limit switch luffing jib activated, main boom angle: 23.4, luffing jib angle: 26.3	+	0x000002BF	9:29:40 AM	0:00:00	0	262935	No	No	No	0x41BB3333	0x41D26666
10	user	hs	error	wind speed sensor luffing jib, signal too low or not connected	+	0x000000F4	9:29:39 AM	0:00:00	0	262934	No	No	No	0x00000000	0x00000000
10	user	hs	error	wind speed sensor main boom, signal too low or not connected	+	0x000000EE	9:29:39 AM	0:00:00	0	262933	No	No	No	0x00000000	0x00000000
4	user	hs	info		-	0x00000122	9:29:38 AM	0:00:00	0	262932	No	No	No	0x415E6666	0x3F800000
4	user	hs	info	upper limit switch luffing jib deactivated, main boom angle: 34.5, luffing jib angle: 13.9	-	0x000002BF	9:29:38 AM	0:00:00	0	262931	No	No	No	0x420A0000	0x415E6666
4	user	hs	info	fall back support of the luffing jib snaped in the flap; angle of the luffing jib: 13.9°, engine running: 1 (1=yes/0=no), (in case of 0: maybe ignition turned on in that second?)	+	0x00000122	9:29:38 AM	0:00:00	0	262930	No	No	No	0x415E6666	0x3F800000
4	user	hs	info	upper limit switch luffing jib activated, main boom angle: 34.5, luffing jib angle: 13.9	+	0x000002BF	9:29:38 AM	0:00:00	0	262929	No	No	No	0x420A0000	0x415E6666
4	user	hs	info	upper limit switch hoisting gear 2 activated	+	0x000000FA	9:29:38 AM	0:00:00	0	262928	No	No	No	0x00000000	0x00000000
4	user	hs	info	upper limit switch hoisting gear 1 activated	+	0x000000F9	9:29:38 AM	0:00:00	0	262927	No	No	No	0x00000000	0x00000000
10	user	hs	error	angle sensor pivot piece and boom head, luffing jib, signals equal again	-	0x000001EA	9:29:38 AM	0:00:00	0	262926	No	No	No	0x00000000	0x00000000
10	user	hs	error	wind speed sensor luffing jib, signal o.k.	-	0x000000F5	9:29:38 AM	0:00:00	0	262925	No	No	No	0x00000000	0x00000000
10	can	application	error	Module Error: Analog Input Module Type AE16 Safety Check on channel 7 failed. Primary and secondary measurement not identically. Channel is deactivated (deliver zero value).	+	0x7200006A	9:29:38 AM	0:00:00	0	262924	No	No	No	0x00000000	0x00000000

	Group	Subgroup	Priority	Text	State	Code	Time	Last Time Occurrences	No. of Occ.	Stack Index	Startup	User Acknowledged	Service Acknowledge	Additional Info 1	Additional Info 2
8	outer	can	warning	external message from CAN module at line 2 module number 42 Module Error: Analog Input Module Type AE16 Safety Check on channel 7 failed. Primary and secondary measurement not identically. Channel is deactivated (deliver zero value).	+	0x42000079	9:29:38 AM	0:00:00	0	262923	No	No	No	0x0002002A	0x00000000
10	user	hs	error	wind speed sensor luffing jib, signal too high or bridged to power supply	+	0x000000F5	9:29:38 AM	0:00:00	0	262922	No	No	No	0x00000000	0x00000000
10	user	hs	error	angle sensor boom head, luffing jib, signal too low or not connected	+	0x000001E8	9:29:38 AM	0:00:00	0	262921	No	No	No	0x00000000	0x00000000
4	user	hs	info		-	0x000000F9	9:29:38 AM	0:00:00	0	262920	No	No	No	0x00000000	0x00000000
4	user	hs	info	upper limit switch hoisting gear 1 activated	+	0x000000F9	9:29:38 AM	0:00:00	0	262919	No	No	No	0x00000000	0x00000000
4	user	hs	info		-	0x000000F9	9:29:37 AM	0:00:00	0	262918	No	No	No	0x00000000	0x00000000
4	user	hs	info	upper limit switch hoisting gear 1 activated	+	0x000000F9	9:29:37 AM	0:00:00	0	262917	No	No	No	0x00000000	0x00000000
4	user	hs	info		-	0x000000F9	9:29:37 AM	0:00:00	0	262916	No	No	No	0x00000000	0x00000000
4	user	hs	info	upper limit switch hoisting gear 1 activated	+	0x000000F9	9:29:37 AM	0:00:00	0	262915	No	No	No	0x00000000	0x00000000
4	user	hs	info		-	0x000000F9	9:29:37 AM	0:00:00	0	262914	No	No	No	0x00000000	0x00000000
4	user	hs	info	upper limit switch hoisting gear 1 activated	+	0x000000F9	9:29:37 AM	0:00:00	0	262913	No	No	No	0x00000000	0x00000000
4	user	hs	info		-	0x000000F9	9:29:37 AM	0:00:00	0	262912	No	No	No	0x00000000	0x00000000
4	user	hs	info	upper limit switch hoisting gear 1 activated	+	0x000000F9	9:29:37 AM	0:00:00	0	262911	No	No	No	0x00000000	0x00000000
4	user	hs	info		-	0x000000F9	9:29:37 AM	0:00:00	0	262910	No	No	No	0x00000000	0x00000000
4	user	hs	info	upper limit switch hoisting gear 1 activated	+	0x000000F9	9:29:36 AM	0:00:00	0	262909	No	No	No	0x00000000	0x00000000
10	user	hs	error	angle sensor pivot piece and boom head, luffing jib, signals not equal	+	0x000001EA	9:29:34 AM	0:00:00	0	262908	No	No	No	0x00000000	0x00000000
4	user	hs	info	fall back support main boom is deactivated, angle main boom: 69.4°	-	0x000002B9	9:28:49 AM	0:00:00	0	262907	No	No	No	0x428ACCCD	0x00000000
4	user	hs	info	fall back support main boom limit switch is activated, angle main boom: 69.4°	+	0x000002B9	9:28:49 AM	0:00:00	0	262906	No	No	No	0x428ACCCD	0x00000000
4	user	hs	info	fall back support main boom is deactivated, angle main boom: 69.4°	-	0x000002B9	9:28:49 AM	0:00:00	0	262905	No	No	No	0x428ACCCD	0x00000000
4	user	hs	info	lml utilization ok	-	0x000003B1	9:28:39 AM	0:00:00	0	262904	No	No	No	0x00000000	0x00000000
4	user	hs	info	lml utilization less than 110%, maximum utilization: 163.4%, at radius: 105.1m	-	0x000000F3	9:28:39 AM	0:00:00	0	262903	No	No	No	0x4323622E	0x42D23D91
4	user	hs	info	lml utilization higher than 110%	+	0x000000F3	9:28:34 AM	0:00:00	0	262902	No	No	No	0x42DE5C3E	0x42CCFC4C
4	user	hs	info	entry switch closed (utilization forward: 37.6, backward 0.0)	+	0x00000255	9:27:13 AM	0:00:00	0	262901	No	No	No	0x42166665	0x00000000
4	user	hs	info	entry switch opened (utilization forward: 35.8, backward 0.0)	-	0x00000255	9:23:54 AM	0:00:00	0	262900	No	No	No	0x420F570C	0x00000000
4	user	hs	info	lml utilization ok	-	0x000003B1	9:19:58 AM	0:00:00	0	262899	No	No	No	0x00000000	0x00000000
4	user	hs	info	lml utilization less than 110%, maximum utilization: 112.8%, at radius: 100.1m	-	0x000000F3	9:19:58 AM	0:00:00	0	262898	No	No	No	0x42E1944D	0x42C82454
4	user	hs	info	lml utilization higher than 110%	+	0x000000F3	9:19:57 AM	0:00:00	0	262897	No	No	No	0x42DE20CD	0x42C72AEA
4	user	hs	info	lml utilization ok	-	0x000003B1	9:19:51 AM	0:00:00	0	262896	No	No	No	0x00000000	0x00000000
4	user	hs	info	lml utilization less than 110%, maximum utilization: 166.8%, at radius: 101.7m	-	0x000000F3	9:19:51 AM	0:00:00	0	262895	No	No	No	0x4326C9A8	0x42CB798C
4	user	hs	info	lml utilization higher than 110%	+	0x000000F3	9:19:48 AM	0:00:00	0	262894	No	No	No	0x42DFE392	0x42C7A86A
4	user	hs	info	lml utilization ok	-	0x000003B1	9:19:41 AM	0:00:00	0	262893	No	No	No	0x00000000	0x00000000
4	user	hs	info	lml utilization less than 110%, maximum utilization: 219.6%, at radius: 104.1m	-	0x000000F3	9:19:41 AM	0:00:00	0	262892	No	No	No	0x435BA1C3	0x42D0200D
4	user	hs	info	lml utilization higher than 110%	+	0x000000F3	9:19:39 AM	0:00:00	0	262891	No	No	No	0x42E848BD	0x42C70E96
4	user	hs	info	lml utilization ok	-	0x000003B1	9:19:35 AM	0:00:00	0	262890	No	No	No	0x00000000	0x00000000
4	user	hs	info	lml utilization less than 110%, maximum utilization: 182.9%, at radius: 102.9m	-	0x000000F3	9:19:35 AM	0:00:00	0	262889	No	No	No	0x4336ECCA	0x42CDE09E
4	user	hs	info	lml utilization higher than 110%	+	0x000000F3	9:19:35 AM	0:00:00	0	262888	No	No	No	0x4336ECCA	0x42CF691E
4	user	hs	info	lml utilization ok	-	0x000003B1	9:19:31 AM	0:00:00	0	262887	No	No	No	0x00000000	0x00000000

	Group	Subgroup	Priority	Text	State	Code	Time	Last Time Occurrences	No. of Occ.	Stack Index	Startup	User Acknowledged	Service Acknowledge	Additional Info 1	Additional Info 2
4	user	hs	info	lml utilization less than 110%, maximum utilization: 182.9%, at radius: 104.5m	-	0x000000F3	9:19:31 AM	0:00:00	0	262886	No	No	No	0x4336ECCA	0x42D10B6C
4	user	hs	info	lml utilization higher than 110%	+	0x000000F3	9:19:29 AM	0:00:00	0	262885	No	No	No	0x42EE9BA9	0x42CC5995
4	user	hs	info	entry switch closed (utilization forward: 125.0, backward 0.0)	+	0x00000255	9:19:11 AM	0:00:00	0	262884	No	No	No	0x42FA0000	0x00000000
4	user	hs	info	entry switch opened (utilization forward: 125.0, backward 0.0)	-	0x00000255	9:18:04 AM	0:00:00	0	262883	No	No	No	0x42FA0000	0x00000000
4	user	hs	info	lml utilization ok	-	0x000003B1	9:15:37 AM	0:00:00	0	262882	No	No	No	0x00000000	0x00000000
4	user	hs	info	lml utilization less than 110%, maximum utilization: 165.7%, at radius: 104.6m	-	0x000000F3	9:15:37 AM	0:00:00	0	262881	No	No	No	0x4325A91B	0x42D124C5
4	user	hs	info	lml utilization higher than 110%	+	0x000000F3	9:15:20 AM	0:00:00	0	262880	No	No	No	0x42DCC68B	0x42CA2EBA
4	user	hs	info	lml utilization ok	-	0x000003B1	9:15:19 AM	0:00:00	0	262879	No	No	No	0x00000000	0x00000000
4	user	hs	info	lml utilization less than 110%, maximum utilization: 122.6%, at radius: 101.3m	-	0x000000F3	9:15:19 AM	0:00:00	0	262878	No	No	No	0x42F52C8C	0x42CA80D7
4	user	hs	info	lml utilization higher than 110%	+	0x000000F3	9:15:14 AM	0:00:00	0	262877	No	No	No	0x42DC2DDD	0x42C8E48A
4	user	hs	info	lml utilization ok	-	0x000003B1	9:15:09 AM	0:00:00	0	262876	No	No	No	0x00000000	0x00000000
4	user	hs	info	lml utilization less than 110%, maximum utilization: 111.8%, at radius: 100.4m	-	0x000000F3	9:15:09 AM	0:00:00	0	262875	No	No	No	0x42DF801D	0x42C8B73D
4	user	hs	info	lml utilization higher than 110%	+	0x000000F3	9:15:07 AM	0:00:00	0	262874	No	No	No	0x42DD5E00	0x42C7F454
4	outer	message	info	system was started 2016-02-05T07:49:45 total number of system starts 5232	+	0x4600002D	9:14:56 AM	0:00:00	0	262873	No	No	No	0x56B45419	0x00001470
8	user	hs	warning	assembly operation on	+	0x0000010D	9:14:56 AM	0:00:00	0	262872	No	No	No	0x00000000	0x3FC00000
4	user	hs	info	lml o.k., utilization: 94.8	-	0x000002B3	9:14:53 AM	0:00:00	0	262871	No	No	No	0x42BDA10C	0x00000000
4	user	hs	info	lml stop, utilization: 100.1	+	0x000002B3	9:14:50 AM	0:00:00	0	262870	No	No	No	0x42C81C05	0x00000000
4	user	hs	info	lml o.k., utilization: 93.3	-	0x000002B3	9:14:45 AM	0:00:00	0	262869	No	No	No	0x42BA83ED	0x00000000
4	user	hs	info	lml stop, utilization: 100.6	+	0x000002B3	9:14:43 AM	0:00:00	0	262868	No	No	No	0x42C9424A	0x00000000
4	user	hs	info	lml o.k., utilization: 92.7	-	0x000002B3	9:14:38 AM	0:00:00	0	262867	No	No	No	0x42B97F3D	0x00000000
4	user	hs	info	lml utilization ok	-	0x000003B1	9:14:37 AM	0:00:00	0	262866	No	No	No	0x00000000	0x00000000
4	user	hs	info	lml utilization less than 110%, maximum utilization: 110.1%, at radius: 100.0m	-	0x000000F3	9:14:37 AM	0:00:00	0	262865	No	No	No	0x42DC44FB	0x42C7EF21
4	user	hs	info	lml utilization higher than 110%	+	0x000000F3	9:14:36 AM	0:00:00	0	262864	No	No	No	0x42DC2133	0x42C7E66E
4	user	hs	info	lml stop, utilization: 100.8	+	0x000002B3	9:14:35 AM	0:00:00	0	262863	No	No	No	0x42C980E7	0x00000000
4	user	hs	info	entry switch closed (utilization forward: 17.9, backward 0.0)	+	0x00000255	9:10:39 AM	0:00:00	0	262862	No	No	No	0x418F1ABC	0x00000000
4	user	hs	info	entry switch opened (utilization forward: 15.2, backward 0.0)	-	0x00000255	9:09:08 AM	0:00:00	0	262861	No	No	No	0x4173E7B7	0x00000000
4	user	hs	info	entry switch closed (utilization forward: 21.3, backward 0.0)	+	0x00000255	9:08:33 AM	0:00:00	0	262860	No	No	No	0x41AAB20C	0x00000000
4	user	hs	info	entry switch opened (utilization forward: 14.0, backward 0.0)	-	0x00000255	8:27:32 AM	0:00:00	0	262859	No	No	No	0x41609613	0x00000000
4	user	hs	info	entry switch closed (utilization forward: 20.0, backward 0.0)	+	0x00000255	8:27:31 AM	0:00:00	0	262858	No	No	No	0x41A019EF	0x00000000
4	user	hs	info	entry switch opened (utilization forward: 17.6, backward 0.0)	-	0x00000255	8:27:30 AM	0:00:00	0	262857	No	No	No	0x418C8DB2	0x00000000
4	user	hs	info	entry switch closed (utilization forward: 17.5, backward 0.0)	+	0x00000255	8:26:39 AM	0:00:00	0	262856	No	No	No	0x418BA8FE	0x00000000
4	user	hs	info	fall back support main boom limit switch is activated, angle main boom: 80.0°	+	0x000002B9	7:49:56 AM	0:00:00	0	262855	No	No	No	0x42A00000	0x00000000
4	user	hs	info		-	0x000001A6	7:49:56 AM	0:00:00	0	262854	No	No	No	0x00000000	0x00000000
4	user	hs	info	diesel engine: starter activated	+	0x000001A6	7:49:55 AM	0:00:00	0	262853	Yes	No	No	0x00000000	0x00000000
February 4, 2016															
4	outer	syscheck	info	the system was shut down at 2016-02-04T18:54:40	+	0x43000034	6:54:40 PM	0:00:00	0	262852	No	No	No	0x56B39E70	0x00000000
4	user	hs	info	upper limit switch main boom deactivated, main boom angle: 87.4	-	0x000002BC	6:53:33 PM	0:00:00	0	262851	No	No	No	0x42AECCCD	0x00000000

denotes engine startup or shut down
denotes where computer captured a boom angle
denotes where computer captured when crane was over 110% utilized

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October 14, 2016

Frank Hegan
Crane Tech Solutions
2030 Ponderosa St
Portsmouth, VA 23701

Dear Frank:

The following is the analyses for the sample submitted.

ATS Lab ID		**103160**
Crane Tech ID:		**2 Hydraulic Assembly LR1300 9/28/2016 Side of Return Filter Assembly**
Test Method	**Description**	**Results**
ASTM D445	Kinematic Viscosity @ 40°C	33.03 cSt
ISO 4406	Particle Count	Particle/ml
	4µ	738.4
	6µ	161.7
	14µ	17.8
	21µ	8.5
	38µ	2.5
	70µ	0.6
	Cleanliness Code	17/15/11
ASTM E1064	Karl Fisher Water Content	143 ppm
ASTM D5185	Elemental Analysis by iCP-AES	ppm

ASTM D5185						
	Si	2	Al	1	Cr	0
	Cu	4	Mn	0	Fe	2
	Ni	0	Pb	0	Sn	1
	Na	2	B	5	Ca	98
	Mg	4	P	242	Zn	315
	Mo	0	Ti	1	Ba	0
	K	5	Cd	0	V	0

Thank you for your business, and we look forward to working with you in the future.

Very truly yours,

Richard M. Eakin,
President

Reference: Final Report and Invoice #9240 emailed to Frank Hegan at fhegan@ct-sol.com on Oct-14-2016.

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October 14, 2016

Frank Hegan
Crane Tech Solutions
2030 Ponderosa St
Portsmouth, VA 23701

Dear Frank:

The following is the analyses for the sample submitted.

ATS Lab ID						**103161**
Crane Tech ID:						**6 Line to Cooler NYC 9/28/2016**
Test Method	**Description**					**Results**
ASTM D445	Kinematic Viscosity @ 40°C					33.00 cSt
ISO 4406	Particle Count					Particle/ml
	4µ					199.1
	6µ					46.6
	14µ					5.5
	21µ					2.5
	38µ					0.4
	70µ					0.1
	Cleanliness Code					15/13/10
ASTM E1064	Karl Fisher Water Content					153 ppm
ASTM D5185	Elemental Analysis by iCP-AES					ppm
	Si	1	Al	1	Cr	0
	Cu	3	Mn	0	Fe	2
	Ni	0	Pb	0	Sn	0
	Na	2	B	3	Ca	87
	Mg	4	P	219	Zn	285
	Mo	0	Ti	1	Ba	0
	K	5	Cd	0	V	0

Thank you for your business, and we look forward to working with you in the future.

Very truly yours,

Richard M. Eakin,
President

Reference: Final Report and Invoice #9240 emailed to Frank Hegan at fhegan@ct-sol.com on Oct-14-2016.