Investigation of the February 5, 2016 Crane Collapse at 40 Worth Street, New York, NY

U.S. Department of Labor
Occupational Safety and Health Administration
Directorate of Construction

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Report

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1. Introduction

The OSHA Regional Administrator, Region II in New York requested the Directorate of Construction (DOC), OSHA National Office, in Washington, DC to provide engineering assistance in its investigation of the February 5 crane collapse in Tribeca in lower Manhattan, NYC. A massive crane collapse had occurred on Worth Street, killing a person near his car and injuring two other persons. The incident attracted considerable media attention and was the subject of prolonged discussion on TV.

Two structural engineers from DOC visited the sprawling yard in Brooklyn where the crane components were stored for examination by the interested parties. The Operator's manual for the crane was obtained from the crane's manufacturer, and the CPU data from the crane's computer were also obtained. DOC performed an engineering analysis to determine the cause of the collapse. Several interviews were conducted to learn about the activities immediately preceding the incident. Photographs and videos taken by different entities were also examined.

The following is our report.

2. The Incident

On February 5, 2016 at approximately 8:15 a.m., a Liebherr crawler crane, approximately 570 ft. high, collapsed along Worth Street towards West Broadway and Church Street, killing one motorist. The deceased was near his parked car when the boom of the crane fell over the car. Two other persons in two separate cars were also injured, one with extensive severe injuries. The crane operator sustained minor injuries.

It was windy and snowing at the time of the collapse. The crane operator was attempting to lay down the crane due to high wind when the crane suddenly collapsed and overturned at 180^o. The crane had a luffing jib, 371 ft. long and a 194 ft. long boom. There was no load on either the boom or the jib hooks. A few days prior to the incident, the crane was situated on Worth Street to install generators and cooling towers on the roof of the 25-story building at 60 Hudson Street, Manhattan, NY. Below is a google satellite map of the area, and photographs taken after the incident.

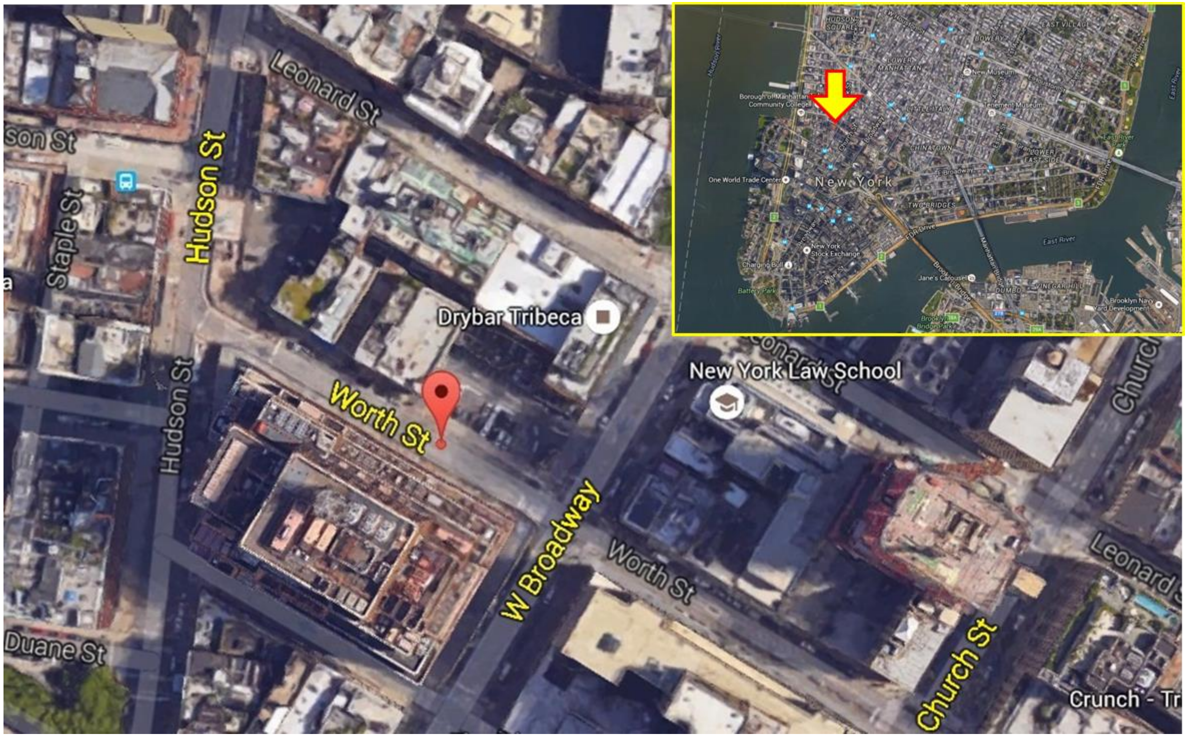


Figure 1 Project location plan (taken from Google Maps).

The crawler crane, Model No. LR 1300, Serial Number 138064, was manufactured by Liebherr Nenzing Crane Co. in Austria. The crane was owned by Bay Crane Services Inc. (Bay Crane) with multiple offices in New York, and was leased to Galasso Trucking & Rigging, Inc., (GTI) of Maspeth, NY. The crane operator was hired by GTI. GTI retained an engineering consultant, MRA Engineering, PC, of West Hempstead, NY, to select and position an appropriate crane on a nearby street to replace generators and cooling towers on the roof of 60 Hudson Street, Manhattan, NY. MRA prepared a document consisting of several pages showing the proposed location of the crane and its reach to the roof of the 25-story buildings. The document was approved by the NYC Transit and NYC Department of Buildings under the application CN# 1157/15, see appendix. MRA also produced a document “crane engineering calculation” on December 3, 2015, revised on December 30, 2015.

On the morning of February 5, 2016, the crane operator arrived and noticed the prevailing winds. It was soon decided that the luffing jib and the boom should be laid down on the ground in the direction of W. Broadway and Church Street. The operator later reported that the he kept the boom angle at approximately 80^o and the luffing jib at 45^o, and began to lower the crane to the ground. The standard procedure is to lower the jib at an angle to the ground and then straighten the boom and jib in a straight line as the jib head is equipped with a set of wheels to roll on the pavement. As the operator noted, the wind increased and the boom along with the jib flipped towards the ground together and overturned. The crane boom fell parallel to Worth Street with its head at the intersection of the W. Broadway Street. The jib heel section with the A-frame remained connected to the boom. The jib head section ended up much further towards Church Street after hitting several buildings. The jib head section finally bent and rested against a building. See Figs. 1 to 5 showing the boom and the jib lying on the ground. The base of the crane along with the counterweights overturned 180^o but remained over the 12x12 cribbing, see Fig. 6. As a result of the incident, a number of streets was closed with several buildings damaged.

Figure 2 Jib head section after the incident – aerial view.

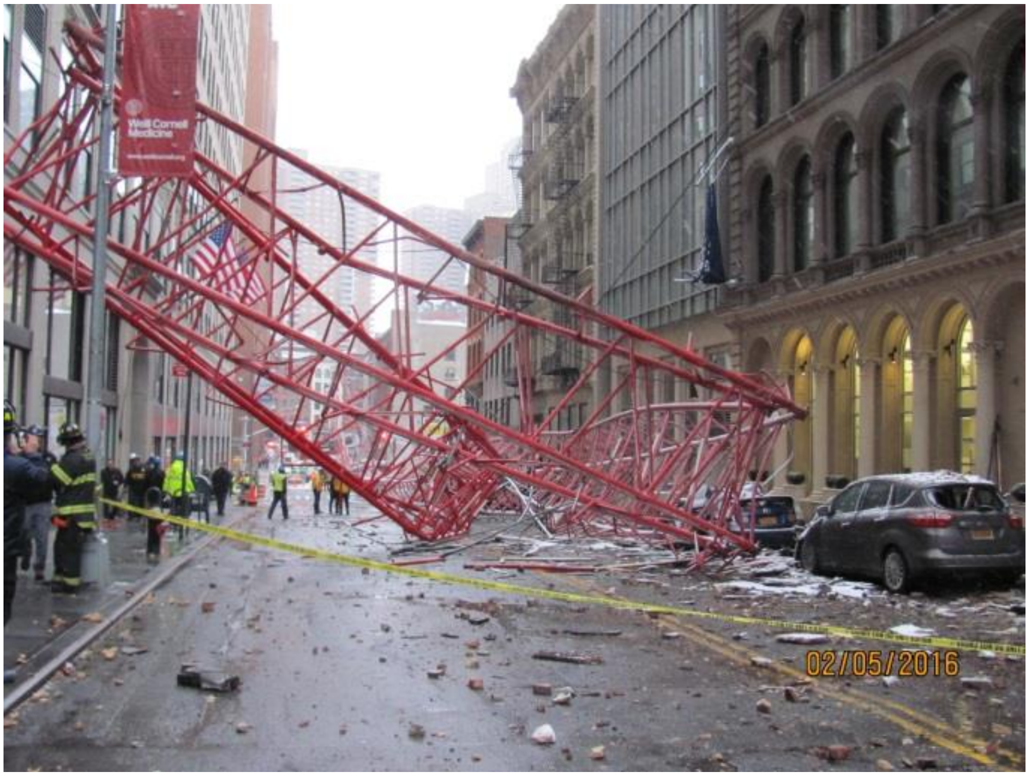


Figure 3 Jib head section after the incident – street view 1.

Figure 4 Jib head section after the incident – street view 2.

Figure 5 Boom and jib on the ground after the incident – aerial view.

Figure 6 Boom and jib on the ground after the incident – street view.

Figure 7 Crane and counterweights after the incident.

The Boom:

The boom (No. 2821), 9'-9" wide and 8'-1" deep was 194 ft. long, and consisted of a heel section, 33'-9" long weighing approximately 16,000 pounds, one 20'-6" long section weighing approximately 5,100 pounds, three 40' long intermediate sections weighing approximately 9,100 pounds each and a head section 27' long weighing approximately 11,900 pounds. These weights included winch, rope and pendants. All sections were steel pipe sections. The following are the typical section, weights reproduced from the Liebherr technical data (see Fig. 8). The entire boom weighed approximately 60,000 pounds. For computation purposes, a weight of 61,440 pounds was used by Liebherr in its calculation of "Input for the calculation of ground pressure of LR 1300" (see Fig. 10) was considered.

Luffing Jib:

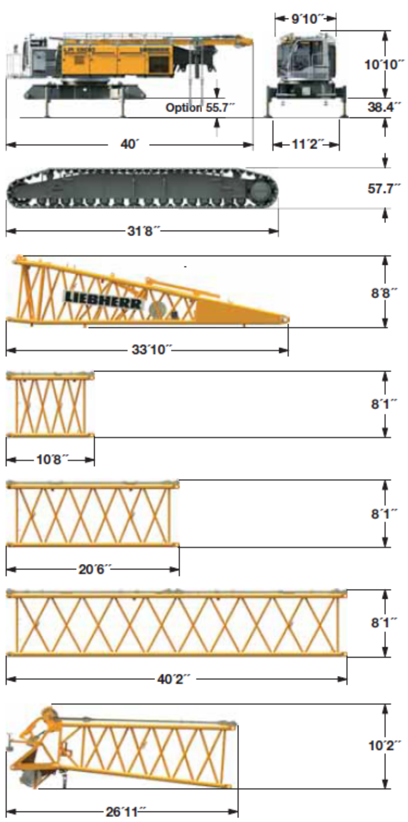
The luffing jib (No. 2316), 371' long, 8' x 6' consisted of a heel section, 38' long weighing approximately 18,000 pounds, with one 10' long section weighing approximately 1,300 pounds, one 20' long section weighing approximately 2,100 pounds, and seven 40' long intermediate sections weighing approximately 4,000 pounds each and a jib head section 35' long weighing approximately 5,000 pounds. All sections were steel with round shapes. The following weights are reproduced from the Liebherr technical data publication (see Fig. 9). The entire jib along with pendants weighed approximately 54,000 pounds. However, for the purposes of computations, the weight of 58,490 pounds (see Fig. 10) was indicated by Liebherr in its calculations of "Input for the calculation of ground pressure of LR 1300".

Counterweights:

There were eight basic counterweights weighing 22,000 pounds each, six basic counterweights weighing 11,000 pounds each with a counterweight body of 32,000 pounds. In addition, there were four counterweights in the body section of the crane, each weighing 31,500 pounds. The two crawlers weighed 49,200 pounds each.

Transport dimensions and weights

Basic machine and boom (No. 2821.xx)



Basic machine		
with A-frame, 2x 33,725 lbf crane winches, without boom foot, basic counterweight and crawlers		
Width		9'10"
Weight without hoist rope		101,450 lbs
Weight of hoist rope		2.75 lbs/ft

Crawler		**2x**
	Optional	Standard
Track pads	59 inch	47.2 inch
Width	59 inch	55.1 inch
Weight	57,765 lbs	49,275 lbs

Boom foot (No. 2821.30)	
Width	9'9"
Weight without winch	12,570 lbs
Weight incl. winch and rope	16,315 lbs

Boom section (No. 2821.30)	**10 ft**
Width	9'9"
Weight incl. main boom pendants	3,090 lbs
Weight incl. main boom and luffing jib pendants	3,310 lbs

Boom section (No. 2821.30)	**20 ft**
Width	9'9"
Weight incl. main boom pendants	4,700 lbs
Weight incl. main boom and luffing jib pendants	5,100 lbs

Boom section (No. 2821.30)	**40 ft**
Width	9'9"
Weight incl. main boom pendants	8,290 lbs
Weight incl. main boom and luffing jib pendants	9,090 lbs

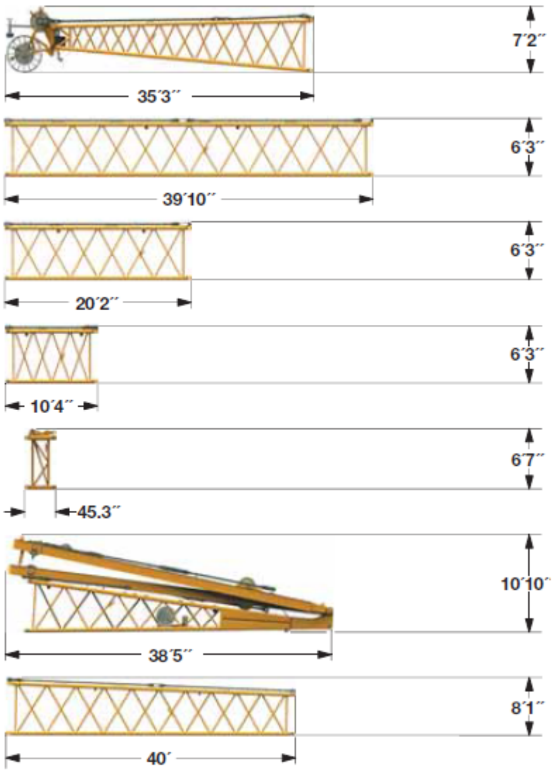
Boom head (No. 2821.24)	
Width	9'9"
Weight incl. main boom pendants	11,905 lbs

*) Weights depend on the equipment installed

Figure 8 Boom dimensions.

Transport dimensions and weights

Luffing jib (No. 2316.xx)



Item		
Luffing jib head (No. 2316.20)		
	Width	8´
	Weight*	5,070 lbs
Luffing jib section (No. 2316.20)		**40 ft**
	Width	8´
	Weight*	3,970 lbs
Luffing jib section (No. 2316.20)		**20 ft**
	Width	8´
	Weight*	2,100 lbs
Luffing jib section (No. 2316.20)		**10 ft**
	Width	8´
	Weight*	1,325 lbs
L-boom jib section (No. 2316.20)		**39.4 inch**
	Width	8´
	Weight*	1,415 lbs
Luffing jib foot with A-frames (No. 2316.22)		
	Width	8´9´´
	Weight*	17,800 lbs
L-boom section tapered (No. 2821/2316.24)		**40 ft**
	Width	9´9´´
	Weight*	5,955 lbs

Figure 9 Luffing jib dimensions.

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	**Ausl. Konfiguration** / **Boom configuration**	Boom & Luffing Jib
Länge Wippspitze / Length of luffing jib	max 203.4	370.7 ft		Luffing jib 2316
			Derrick / **Super lift**: No	Fixed Jib 1008
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	**Input - Units**	American Units
Winkel Fixe Spitze / Offset angle fixed jib		30°		
Spur UW / Track width		22 ft	**Lastfall** / Load Case	
Bodenplatten / Track shoes		4 ft		
Ballast am Unterwagen / Carbody counterweight		125.7 **1000 lbs**	**Ausladung** / Load radius	ok 128.0 ft
Ballast am Oberwagen / Counterweight		273.4 **1000 lbs**	**Last** / Load	8.0 1000 lbs
Ballast am Derrick / Super lift couterweight		0.0 **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**

34.1 psi (.144)
= 4.9104 ksf

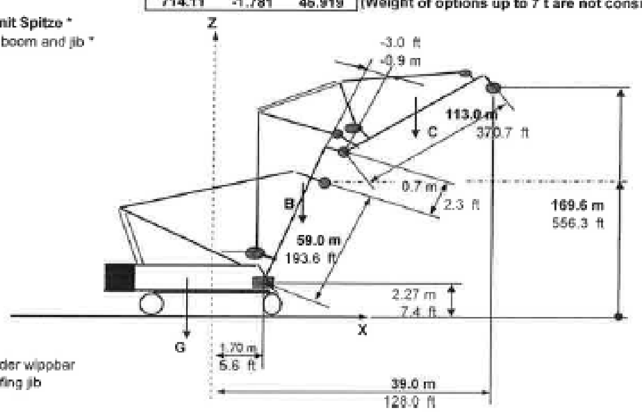
Eckdaten für die Berechnung des Bodendruckes:
Technical datas for the calculation of ground pressure

Vertikalkraft am Drehkranz statisch / Vertical load at the slewing ring without dynamic effects	**2137 kN**	480454 lbf
Moment am Drehkranz statisch / Moment at the slewing ring without dynamic effects	**-1759 kNm**	-1297110 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	58.49	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	45.919	**(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

Figure 10 Liebherr input for the calculation of ground pressure of LR 1300.

3. Data from the Crane's Computer (CPU data)

The crane was equipped with a computer that recorded operations of the crane. Liebherr downloaded the data from the crane's computer, and the data was made available to OSHA by the New York City District Attorney's office. A sample page from the CPU data is shown below, see Fig. 11

The computer time in the CPU data did not correspond to Eastern Standard Time (EST). However, the incident time of approximately 8:15 a.m. could be related to the corresponding computer time of 9:29 a.m. when the crane overturned. The data contained hundreds of readings at intervals of fractions of seconds showing boom angle, luffing jib angle, error messages, if any, and various other information, e.g. utilization factors, fall back support information, and information about various switches. Such readings were recorded in multiple lines, each line for a specific point in time. Each line did not provide all the data; for instance some lines contained information about boom angle only while others provided jib angles, maximum utilization and radius only. Selected data are extracted from the CPU output to show the crane boom angle variations on the day of the collapse and the day before.

Fig. 12 shows selected CPU data on the day of the incident. The boom angles and jib angles are highlighted. As can be seen, the boom angle was 80° on February 5 at 7:49 a.m. computer time. Then at 9:28 a.m. computer time, the boom angle was reduced to 69.4° and at computer time of 9:29 a.m., the computer generated an error message. Immediately thereafter, the boom angle dived to 34.5° with the jib at an angle of 13.9°. Within seconds the boom and jib angles became 0° and the crane overturned and collapsed. The local time was approximately 8:15 a.m.

The Table 1 and the graph (fig. 13) show the boom angle on the day of the incident and the previous evening. The table shows that the boom angle was approximately 87° on the evening of February 4, 2016. The last recorded boom angle on February 4 was 87.4° at 6:53 p.m. computer time. On the morning of the day of the incident, the first recorded boom angle was 80°, an unexplained variation of 7° from the previous evening. The top ten lines of the following figure indicating the boom angles suddenly reversed upwards after being on the ground (stack index 262962 to 263026), are not considered reliable. This could have been the result of the overturning of the base of the crane including the operator's cabin.

	Group	Subgroup	Priority	Text	State	Code	Time	Last Time Occurrences	No. of Occ.	Stack Index	Startup	User Acknowledged	Service Acknowledged	Additional Info 1	Additional Info 2
4	user	hs	info		-	0x00000143	2/5/2016 9:29	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	2/5/2016 9:29	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	2/5/2016 9:29	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	2/5/2016 9:29	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	2/5/2016 9:29	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	2/5/2016 9:29	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	2/5/2016 9:29	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	2/5/2016 9:29	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	2/5/2016 9:29	0:00:00	0	262973	No	No	No	0x42363A3D	0x00000000
10	user	hs	error	load sensor left, main boom, signal 2 o.k.	-	0x00000217	2/5/2016 9:29	0:00:00	0	262972	No	No	No	0x00000002	0x00000000
10	user	hs	error	load sensor left, main boom, signal 1 o.k.	-	0x00000217	2/5/2016 9:29	0:00:00	0	262971	No	No	No	0x00000001	0x00000000
10	user	hs	error	load sensor right, main boom, signal 2 o.k.	-	0x0000021A	2/5/2016 9:29	0:00:00	0	262970	No	No	No	0x00000002	0x00000000
10	user	hs	error	load sensor right, main boom, signal 1 o.k.	-	0x0000021A	2/5/2016 9:29	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	2/5/2016 9:29	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	2/5/2016 9:29	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	2/5/2016 9:29	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	2/5/2016 9:29	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	2/5/2016 9:29	0:00:00	0	262964	No	No	No	0x00000000	0x00000000
4	user	hs	info		-	0x00000144	2/5/2016 9:29	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	2/5/2016 9:29	0:00:00	0	262962	No	No	No	0x41200000	0x00000000
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	2/5/2016 9:29	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	2/5/2016 9:29	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	2/5/2016 9:29	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	2/5/2016 9:29	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	2/5/2016 9:29	0:00:00	0	262957	No	No	No	0x4171999A	0x00000000
4	user	hs	info		-	0x00000122	2/5/2016 9:29	0:00:00	0	262956	No	No	No	0x41D4CCCD	0x3F800000

Figure 11 Sample page from CPU data.

Priority	Text	Time	Stack Index
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°	2/5/2016 9:29	262961
info	fall back support main boom is deactivated, angle main boom: 15.1°	2/5/2016 9:29	262960
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°	2/5/2016 9:29	262957
info	upper limit switch luffing jib deactivated, main boom angle: 18.4, luffing jib angle: 26.6	2/5/2016 9:29	262955
info	upper limit switch luffing jib activated, main boom angle: 18.4, luffing jib angle: 26.6	2/5/2016 9:29	262953
info	upper limit switch luffing jib deactivated, main boom angle: 18.4, luffing jib angle: 26.6	2/5/2016 9:29	262948
info	upper limit switch luffing jib activated, main boom angle: 21.1, luffing jib angle: 27.7	2/5/2016 9:29	262945
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?)	2/5/2016 9:29	262937
info	lower limit switch luffing jib activated, main boom angle: 23.4, luffing jib angle: 26.3	2/5/2016 9:29	262936
info	upper limit switch luffing jib activated, main boom angle: 23.4, luffing jib angle: 26.3	2/5/2016 9:29	262935
info	upper limit switch luffing jib deactivated, main boom angle: 34.5, luffing jib angle: 13.9	2/5/2016 9:29	262931
info	upper limit switch luffing jib activated, main boom angle: 34.5, luffing jib angle: 13.9	2/5/2016 9:29	262929
error	angle sensor pivot piece and boom head, luffing jib, signals not equal	2/5/2016 9:29	262908
info	fall back support main boom is deactivated, angle main boom: 69.4°	2/5/2016 9:28	262907
info	fall back support main boom limit switch is activated, angle main boom: 69.4°	2/5/2016 9:28	262906
info	fall back support main boom is deactivated, angle main boom: 69.4°	2/5/2016 9:28	262905
info	lml utilization less than 110%, maximum utilization: 163.4%, at radius: 105.1m	2/5/2016 9:28	262903
info	lml utilization less than 110%, maximum utilization: 112.8%, at radius: 100.1m	2/5/2016 9:19	262898
info	lml utilization less than 110%, maximum utilization: 166.8%, at radius: 101.7m	2/5/2016 9:19	262895
info	lml utilization less than 110%, maximum utilization: 219.6%, at radius: 104.1m	2/5/2016 9:19	262892
info	lml utilization less than 110%, maximum utilization: 182.9%, at radius: 102.9m	2/5/2016 9:19	262889
info	lml utilization less than 110%, maximum utilization: 165.7%, at radius: 104.6m	2/5/2016 9:15	262881
info	fall back support main boom limit switch is activated, angle main boom: 80.0°	2/5/2016 7:49	262855

CPU data shows main boom angle varying from 80° to 0° on the day of the incident

Figure 12 Main boom angle on the day of the incident.

Table 1 Data taken from the CPU output

	Date	Time	Boom angle	Stack Index	Date	Time	Boom angle	Stack Index
Data not reliable. Boom angle shown is probably after overturning of the crane	**5-Feb-16**	9:29:42 AM	4.7	263026	**4-Feb-16**	6:53:33 PM	87.4	262851
		9:29:42 AM	22.6	263006		5:08:12 PM	87	262844
		9:29:41 AM	22.9	263000		5:06:46 PM	87	262843
		9:29:41 AM	22.9	262998		5:01:30 PM	87.2	262840
		9:29:41 AM	56.8	262992		5:01:21 PM	87.2	262839
		9:29:41 AM	22.9	262990		4:41:38 PM	87.1	262835
		9:29:41 AM	22.8	262988		4:40:25 PM	87	262833
		9:29:41 AM	22.8	262985		4:40:23 PM	87.1	262832
		9:29:41 AM	45.6	262977		4:40:14 PM	87.1	262831
		9:29:41 AM	45.6	262973		4:40:05 PM	87	262830
		9:29:40 AM	10	262962		4:40:00 PM	87.2	262829
Boom angle 0° Collapse of crane		**9:29:40 AM**	**0**	**262961**		4:39:50 PM	87	262828
		9:29:40 AM	15.1	262960		4:39:41 PM	86.9	262827
		9:29:40 AM	15.1	262959		4:39:31 PM	87.4	262826
		9:29:40 AM	15.1	262957		4:39:25 PM	87.2	262825
		9:29:40 AM	18.4	262955		4:39:14 PM	87.3	262824
		9:29:40 AM	18.4	262953		4:39:11 PM	87.1	262823
		9:29:40 AM	18.4	262952		4:37:27 PM	87.2	262822
		9:29:40 AM	18.4	262951		4:37:21 PM	86.9	262821
		9:29:40 AM	18.4	262950		4:37:11 PM	87.2	262820
		9:29:40 AM	18.4	262948		4:37:06 PM	86.9	262819
		9:29:40 AM	21.1	262945		4:20:16 PM	87.1	262818
		9:29:40 AM	21.1	262944		4:19:02 PM	87	262817
		9:29:40 AM	21.1	262942		4:19:01 PM	87	262816
		9:29:40 AM	21.1	262940		4:18:47 PM	87	262815
		9:29:40 AM	21.1	262938		4:18:42 PM	87	262814
		9:29:40 AM	26.3	262937		4:18:31 PM	87.1	262813
		9:29:40 AM	23.4	262936		4:18:25 PM	87	262812
		9:29:40 AM	23.4	262935		4:18:15 PM	87	262811
		9:29:38 AM	34.5	262931		4:18:08 PM	87.1	262810
		9:29:38 AM	34.5	262929		4:17:58 PM	87.1	262809
		9:28:49 AM	69.4	262907				
		9:28:49 AM	69.4	262906				
		9:28:49 AM	69.4	262905				
		7:49:56 AM	80	262855				

Note: The boom angle when the system was shut down on 4-Feb-16 was 87.4°. On Feb. 5th, the day of the incident, the main boom angle was at 80° at 7:49 AM and then it became 0° at 9:29 AM.

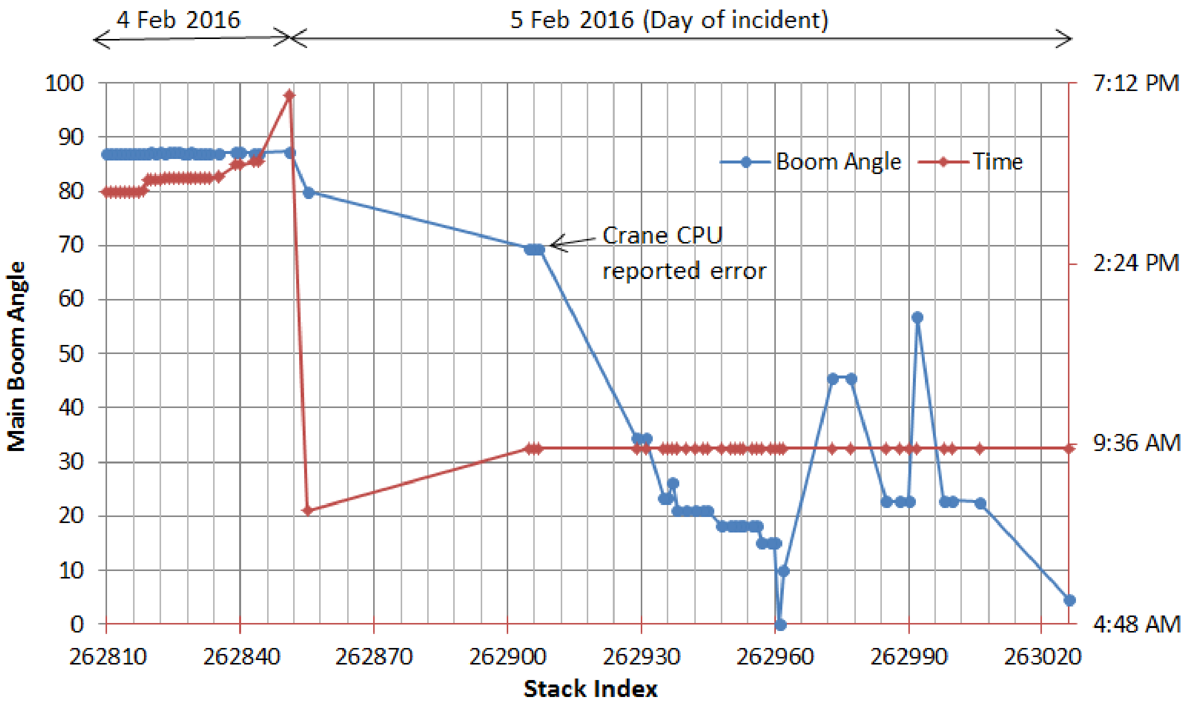


Figure 13 Plot of boom angle and computer time (data taken from Crane CPU output).

4. Engineering Analysis

Cranes generally collapse due to structural failures of the boom/jib, tipping due to lack of stability, failure of outrigger supports, wire rope fractures and mechanical and hydraulic issues. In this case the crane tipped over or overturned as it failed to remain stable under a decreasing boom angle and increasing wind.

The centers of gravity of the boom and the jib were considered to be 84 ft. and 132 ft., respectively from their foot. The offset between the axis of the jib and the boom was also considered. In the overturning analysis of the crane, various cases were considered under varying conditions of the boom angles and the luffing jib. In all cases, the only load on the jib hook considered was the headache ball. There was no load on the boom hook other than its own weight. For the purpose of our analysis, the weight provided in the Liebherr operating manual was considered, as the actual weights matched closely with the Liebherr weights. Wind was considered to be acting on the exposed surface area of the jib and the boom with due consideration of higher wind speeds at higher elevations.

Wind:

Wind data was obtained from the National Weather Service recorded at four locations, i.e, at Central Park, at John F Kennedy International Airport, at La Guardia Airport and at Newark Liberty International Airport. The wind data and station details are presented below.

Table 2 Wind data and station details

Location	Elevation (ft. above sea level)	Time	Wind Speed (MPH)	Wind Gusts (MPH)
Central Park	130	8:16am	13	22
John F Kennedy International Airport	11	7:51am	21	30
La Guardia Airport	11	8:17am	17	26
Newark Liberty International Airport	7	7:51am	20	NA

JFK and Newark Airports reported 20-21 mph wind with gust up to 30 mph while La Guardia and Central Park reported 13 to 17 mph wind with gust up to 26 mph. The gusts were reported to be in the range of 22 to 30 mph. Five basic wind speeds were considered, e.g., 20, 22, 25, 26 and 30 mph to analyze the tipping and stability of the crane. The anemometer towers are typically located at 10 meters (33 ft.) above ground level. The recorded wind speed at 33 ft. could be misleading as the wind speed would be much higher at the boom and the jib of the crane, as the crane was approximately 550 ft. tall.

The crane was situated on Worth Street with high-rise buildings of various heights and configurations located parallel and at right angles to the street, giving rise to wind turbulence, disturbances and gusts. Other than conducting a wind tunnel test to accurately determine the wind speeds along the vertical profile of the crane, all methods to compute the wind loads are approximate but are considered satisfactory for this investigation. The wind's contribution to stability proved to be significant in spite of the large weight of the machine and the relatively small sail area of the steel frame members. The wind profiles considered in the analysis are given below, using the logarithmic wind speed profile for the reference wind speed of 20, 22, 25, 26 and 30 mph at the reference elevation of 33 ft. Other methods also yielded similar results.

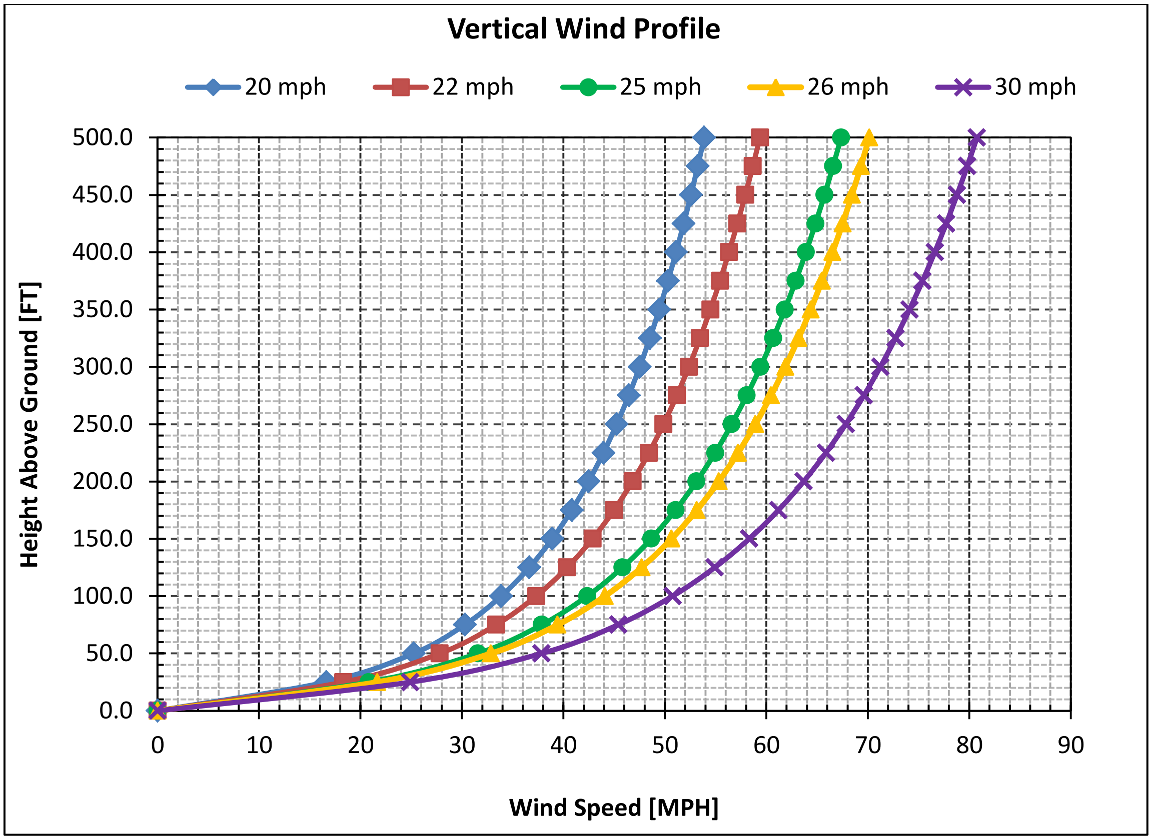


Figure 14 Wind speed profile

Wind pressure on crane components increases with the increasing wind speed and increasing height in the ratio of the square of the wind speeds. Compared to the 20 mph wind speed, the wind pressure on the crane jib and boom increases by 65% and 119% at 25 and 30 mph wind speeds, respectively. All five speeds were considered in the analysis.

A line diagram of the vertical profile of the crane is shown below, see Fig. 15.

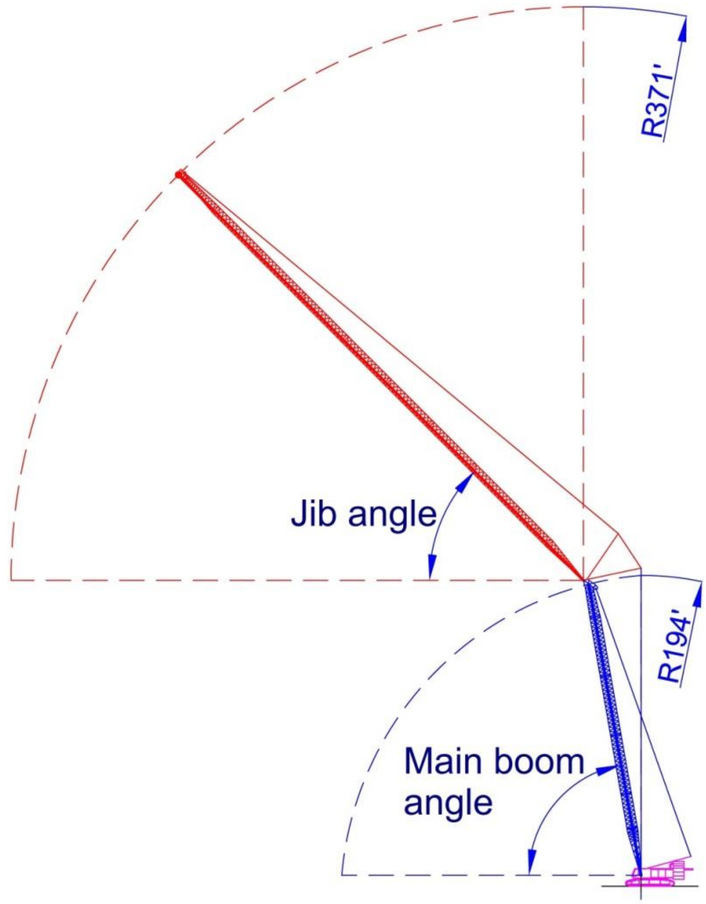


Figure 15 Crane vertical profile

Wind loads were computed by the formula p = 0.00256 V^2 where p is the wind pressure in pounds per square foot and V is the wind speed in miles per hour. Other than pendants, the majority of the structural members of the boom and jib were round shapes to minimize the effects of wind. A shape factor of 0.5 was used to arrive at the wind loads on round members.

Overturning safety factor:

Generally the factor of safety against overturning varies from 1.0 to 1.33. Liebherr provided a factor of safety of 1.33 at 360 degrees of swing. The worst scenario for overturning occurs when the boom is on the side, i.e., at right angles to the main axis of the crane base. In this case, the boom and the jib were located along the main axis of the base, thus providing a greater margin of safety. When the factor of safety against overturning approaches 1.0, collapse of the crane becomes imminent as was the case here.

Below are the various cases considered with and without the wind and the, related factor of safety. Boom and luffing jibs were considered to be 194 ft. and 371 ft., respectively. In all cases a hook load of 2,000 pounds was considered at the luffing jib and at the boom. No other loads were assumed at the jib and boom blocks.

Table 3 Summary of various cases studied

Case No.	Radius (ft.)	Boom angle (°)	Jib angle (°)
CASE_1	296	80.0	45.0
CASE_2	328	80.0	37.5
CASE_3	331	69.4	45.0
CASE_4	345	69.4	41.8
CASE_5	344	65.0	45.0
CASE_6	401	60.0	35.0
CASE_7	405	80.0	0.0
CASE_8	439	69.4	0.0

Case I:

The crane boom is considered at an angle of 80^o with the luffing jib at 45^o.

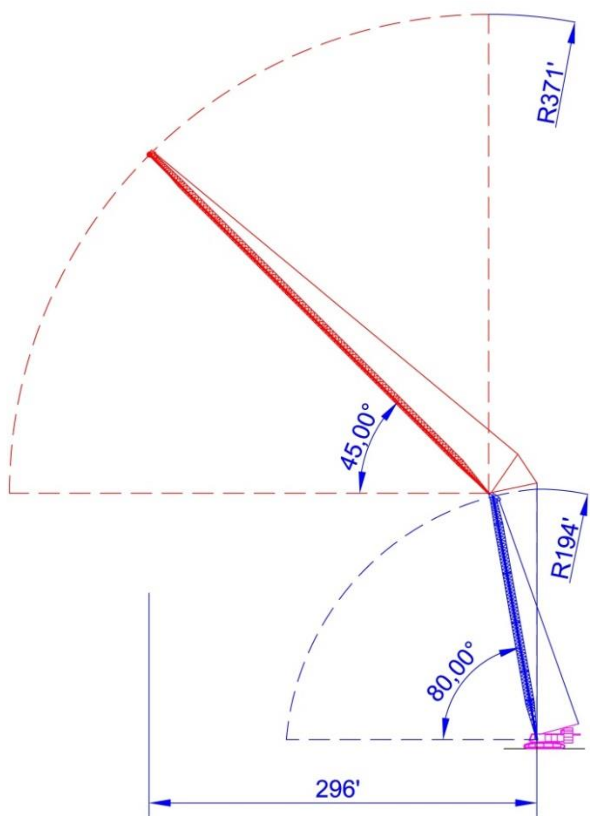


Figure 16 Case I **-** Crane vertical profile.

The safety factors (SF) for crane tipping are determined for the conditions without and with wind loads, as

For condition w/o wind

SF = 1.789

For condition w/ wind

Wind speed, mph	20	22	25	26	30
SF =	1.380	1.315	1.222	1.190	1.073

Case II:

The crane boom is considered at an angle of 80^o with the luffing jib at 37.5^o.

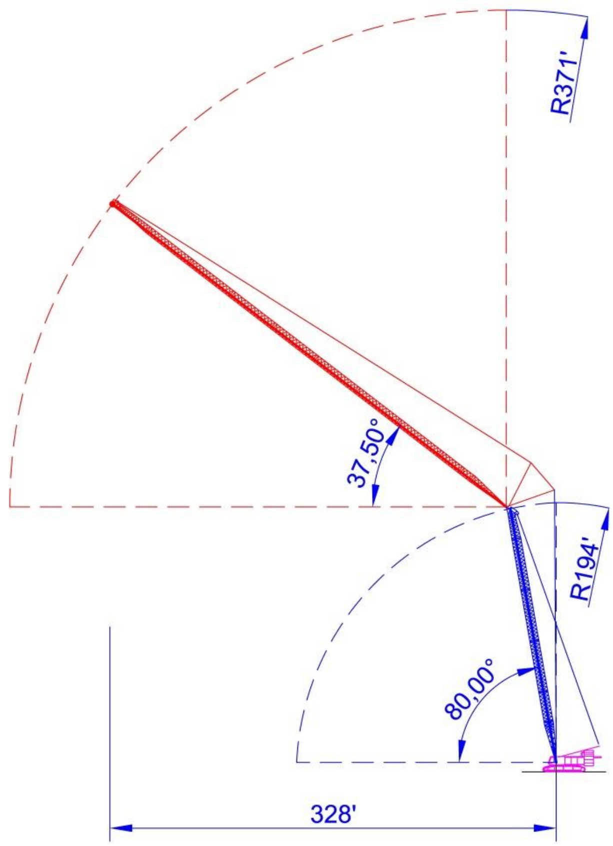


Figure 17 Case II **-** Crane vertical profile.

The safety factors (SF) for crane tipping are determined for the conditions without and with wind loads, as

For condition w/o wind

SF = 1.627

For condition w/ wind

Wind speed, mph	20	22	25	26	30
SF =	1.341	1.292	1.220	1.194	1.099

Case III :

The crane boom is considered at an angle of 69.4^o with the luffing jib at 45^o.

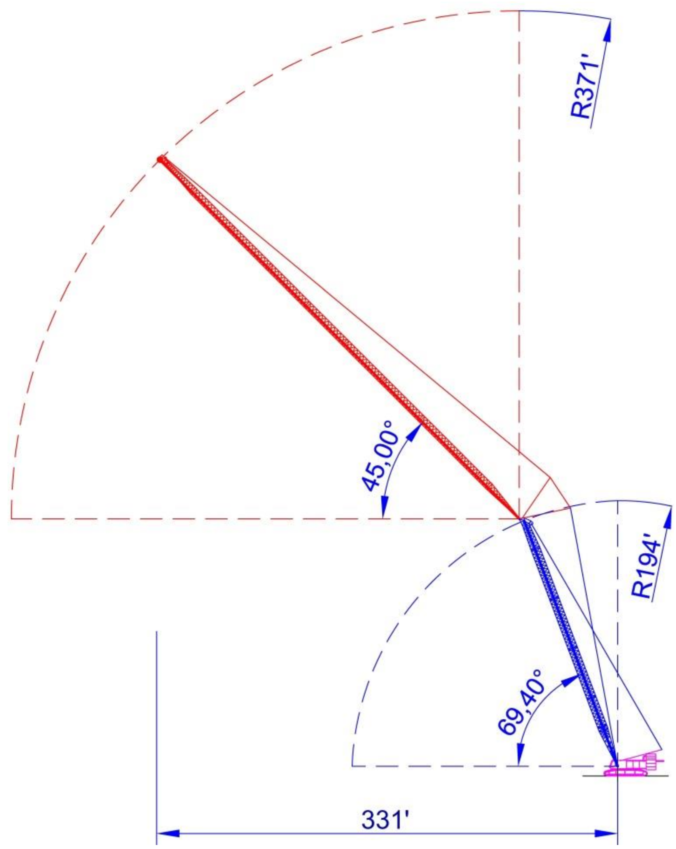


Figure 18 Case III **-** Crane vertical profile.

The safety factors (SF) for crane tipping are determined for the conditions without and with wind loads, as

For condition w/o wind
SF = 1.276

For condition w/ wind

Wind speed, mph	20	22	25	26	30
SF =	1.061	1.024	0.969	0.950	0.877

Case IV:

The crane boom is considered at an angle of 69.4^o with the luffing jib at 41.8^o.

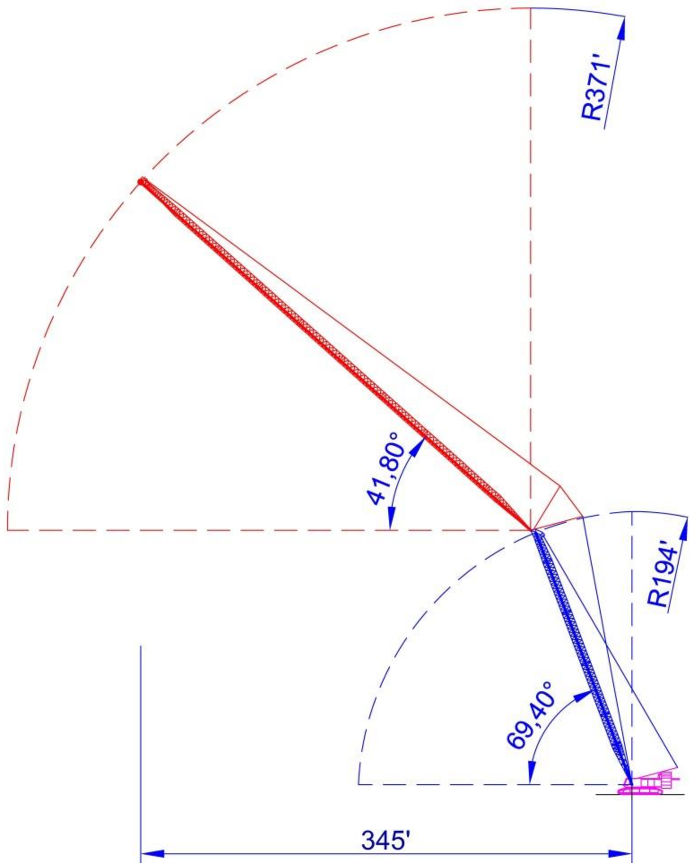


Figure 19 Case IV **-** Crane vertical profile.

The safety factors (SF) for crane tipping are determined for the conditions without and with wind loads, as

For condition w/o wind
SF = 1.237

For condition w/ wind

Wind speed, mph	20	22	25	26	30
SF =	1.050	1.017	0.968	0.950	0.884

Case V

The crane boom is considered at an angle of 65° with the luffing jib at 45°.

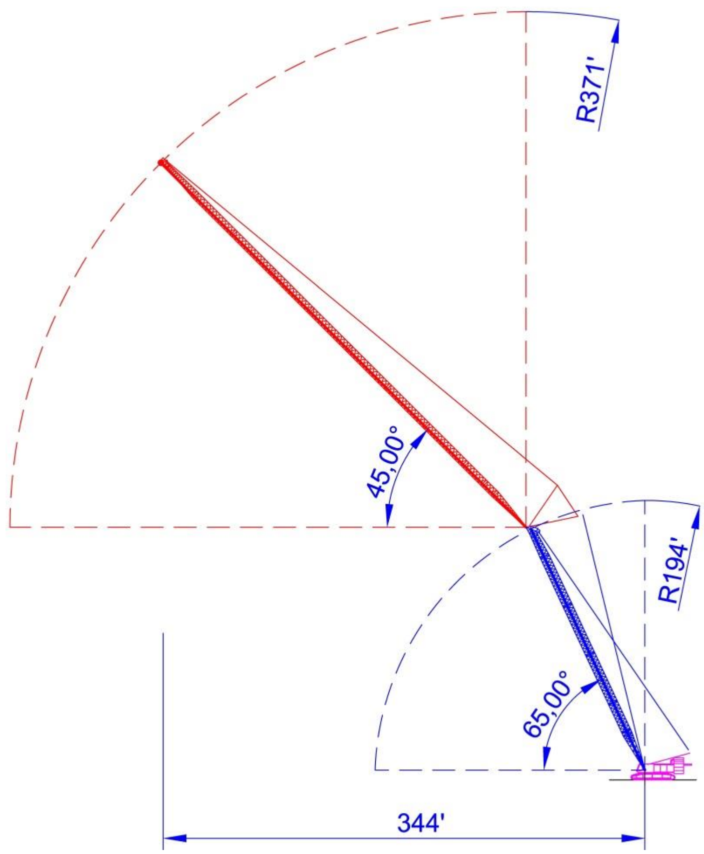


Figure 20 Case V **-** Crane vertical profile.

The safety factors (SF) for crane tipping are determined for the conditions without and with wind loads, as

For condition w/o wind

SF = 1.145

For condition w/ wind

Wind speed, mph	20	22	25	26	30
SF =	0.974	0.943	0.898	0.882	0.821

Case VI

The crane boom is considered at an angle of 60^{o} with the luffing jib at 35^{o}.

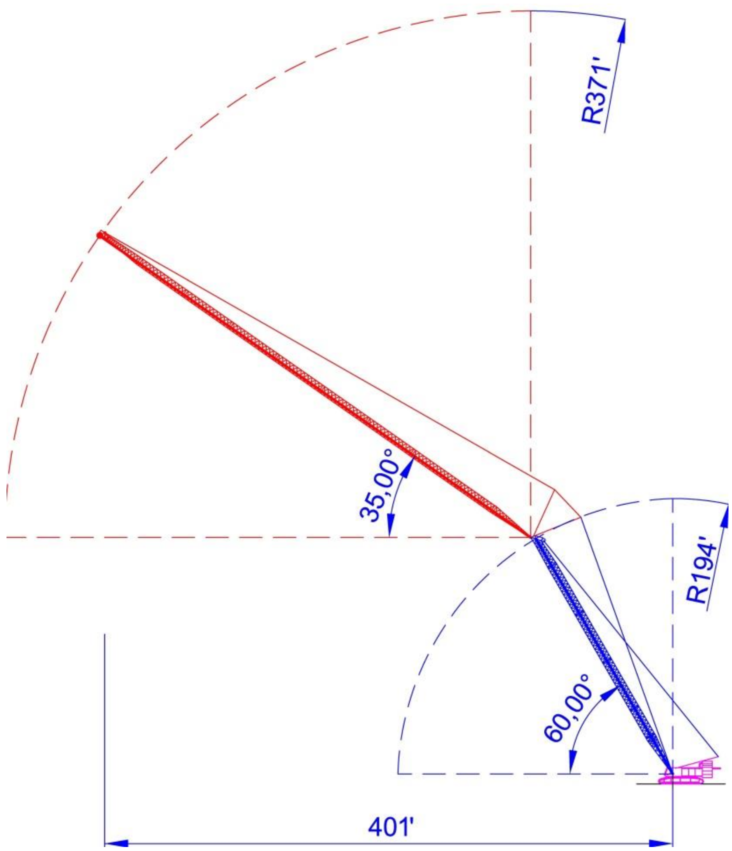


Figure 21 Case VI **-** Crane vertical profile.

The safety factors (SF) for crane tipping are determined for the conditions without and with wind loads, as

For condition w/o wind

SF = 0.958

For condition w/ wind

Wind speed, mph	20	22	25	26	30
SF =	0.870	0.853	0.827	0.818	0.780

Case VII

The crane boom is considered at an angle of 80^o with the luffing jib at 0^o.

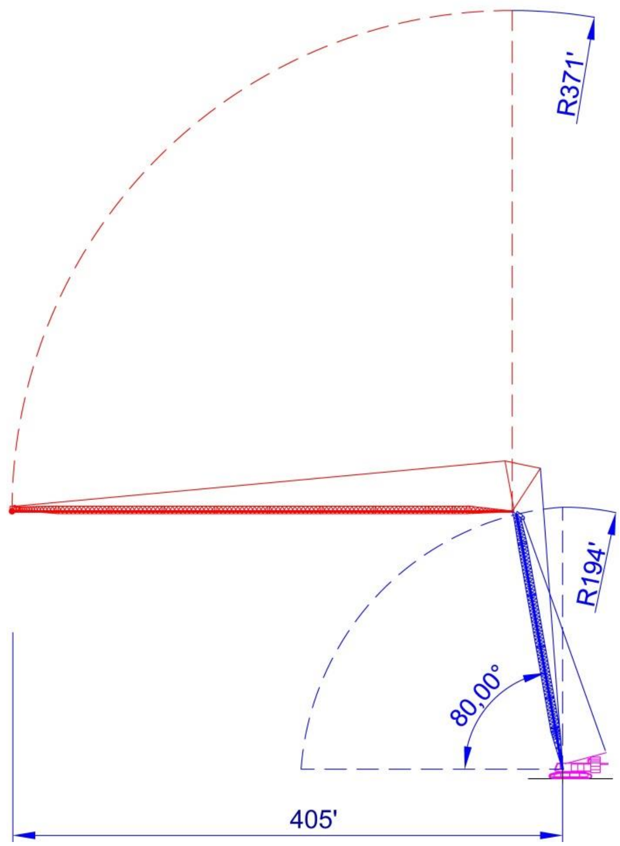


Figure 22 Case VII **-** Crane vertical profile.

The safety factors (SF) for crane tipping are determined for the conditions without and with wind loads, as

For condition w/o wind

SF = 1.317

For condition w/ wind

Wind speed, mph	20	22	25	26	30
SF =	1.243	1.228	1.205	1.196	1.162

Case VIII

The crane boom is considered at an angle of 69.4° with the luffing jib at 0°.

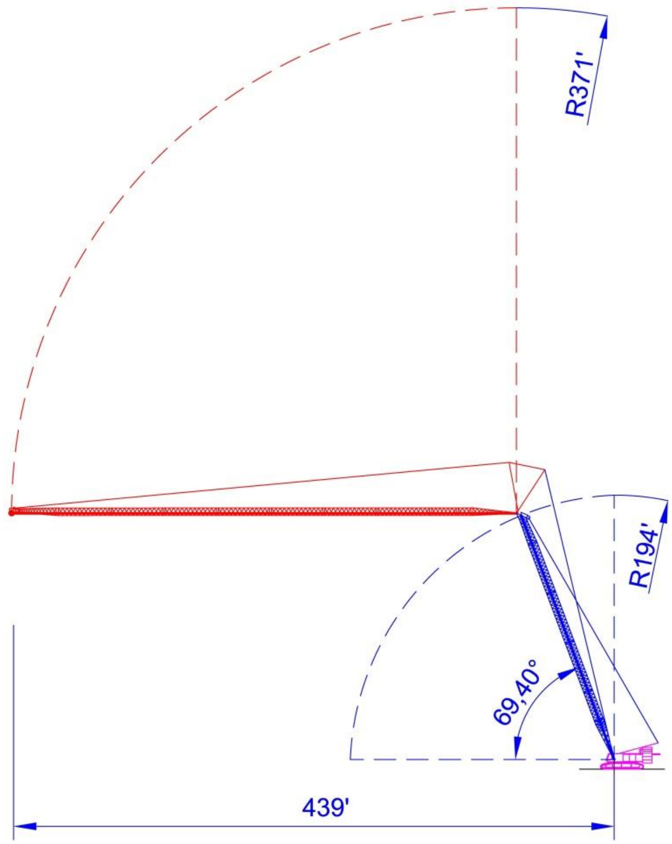


Figure 23 Case VIII **-** Crane vertical profile.

The safety factors (SF) for crane tipping are determined for the conditions without and with wind loads, as

For condition w/o wind
SF = 1.016

For condition w/ wind

Wind speed, mph	20	22	25	26	30
SF =	0.974	0.966	0.953	0.948	0.927

Table 4 Summary of results

Case No.	Boom Angle (°)	Jib Angle (°)	Wind Load	S.F.				
				Basic Wind Speed (MPH)				
				20	22	25	26	30
CASE_1	80.0	45.0	No	1.789				
			Yes	1.380	1.315	1.222	1.190	1.073
CASE_2	80.0	37.5	No	1.627				
			Yes	1.341	1.292	1.220	1.194	1.099
CASE_3	69.4	45.0	No	1.276				
			Yes	1.061	1.024	0.969	0.950	0.877
CASE_4	69.4	41.8	No	1.237				
			Yes	1.050	1.017	0.968	0.950	0.884
CASE_5	65.0	45.0	No	1.145				
			Yes	0.974	0.943	0.898	0.882	0.821
CASE_6	60.0	35.0	No	0.958				
			Yes	0.870	0.853	0.827	0.818	0.780
CASE_7	80.0	0.0	No	1.317				
			Yes	1.243	1.228	1.205	1.196	1.162
CASE_8	69.4	0.0	No	1.016				
			Yes	0.974	0.966	0.953	0.948	0.927

Highlighted are the cases where instability is either about to occur or already in the process of collapse.

It must be noted that the stability of the crane with its pre-incident configuration of the boom and the jib was largely governed by the angle of the boom, and was less dependent on the angle of the jib. The above cases indicate a range of factors of safety against overturning with and without wind. As can be seen, the wind reduces the factor of safety significantly. Case 1, 2 and 7 indicate that if the boom angle was maintained at 80 degrees, there was an adequate factor of safety even with the prevailing winds. Therefore, the luffing jib could have been lowered to the ground without any detrimental effect despite the prevailing winds if the boom was maintained at an angle of 80 degrees. However if the boom angle was lowered to 69.4^o, the crane's stability was jeopardized in the face of the prevailing winds regardless of the angle of the jib , and the failure would been imminent as was the actual case. The load chart provided by Liebherr, see Fig. 27, does not provide any load carrying capacity when the boom angle is lower than 75^o with a combination of a 194 ft. long boom and a 371 ft. long jib. It must therefore be inferred that the boom could not be lowered to less than 75 degrees in any event.

Operation of Crane in the event of Wind as per crane manufacturer.

The operator's manual section 6.7 "Restrictions due to wind" explains the procedure to be followed in the event of wind.

6.7 Restrictions due to wind

The current wind speed is shown on the operational screen for lifting operations on the monitor.

The following three steps describe the procedure in the event of wind:

– Reducing the lifting capacity
– Placing the boom in its parked position
– Laying down the boom

6.7.1 Reducing the lifting capacity

The reduction of the lifting capacity for crane operation in the event of wind can be found in the load chart manual.

6.7.2 Parked positions for boom configurations

The parking position of the boom applies up to the maximum wind speed. Above this speed the boom must be set down.

Parked position of the 2821 main boom + 2316 luffing jib

Description	Value
Maximum wind speed	22 m/s
Main boom length	20 m to 74 m

Description	Value
Main boom angle	80°
Jib length	20 m to 68 m
Jib angle	66° to 70°

Tab. 226 Parked position of the 2821 main boom + 2316 luffing jib (1/2)

Description	Value
Maximum wind speed	18 m/s
Main boom length	20 m to 74 m
Main boom angle	80°
Jib length	71 m to 86 m
Jib angle	66° to 70°

Tab. 227 Parked position of the 2821 main boom + 2316 luffing jib (2/2)

Note

▶ All combinations with a jib length of 89 m to 113 m must be laid down when the wind speed reaches a value at which work is no longer permitted (see load charts foreword).

Figure 24 Operation of crane in the event of wind.

The crane had a combination of 2821 type main boom and 2316 type luffing jib. The main boom was 194 ft. (59 m) and the luffing jib was 371 ft. (113 m). The above Fig. 24 is applicable to a combination of boom and jib where the jib length has a maximum length of 282 ft. The length of the jib in this instance was 371ft., therefore, the option of a parked position for a jib length of 371 ft. is eliminated. The manufacturer directs the user to lay down the boom and the jib for more than 292 ft. (89 m) in the event that the wind speed is in excess of the allowable wind speed, see Fig. 24 above. Work with the crane is then not permitted. The manufacturer's manual and documents do not provide a direct reading of the wind speed at which work must be stopped, and the boom and jib laid down. It, however, provides a range of load carrying capacity at various wind speeds for different combinations of boom and jib lengths. When the reduction is 100% at a certain wind speed, it must be presumed that the work must be stopped. The reduction of the lifting capacity is provided in the load chart below. Regardless of the boom length, if the jib length is between 312 ft. and 371 ft., the load reduction is 100% for wind speed greater than 20 mph (9 m/s), see Fig. 25 below. Although there is a stipulation in the Liebherr document that if the wind speed falls between the two limits, use the higher wind speed, Liebherr in its letter to OSHA maintained that 20 mph is the cut-off point.

<table>
<tr><th>Jib length

Jib 2316</th><th>20 m
(66 ft) to
26 m
(85 ft)</th><th>29 m
(95 ft) to
50 m
(164 ft)</th><th>53 m
(174 ft) to
74 m
(243 ft)</th><th>77 m
(253 ft) to
92 m
(302 ft)</th><th>95 m
(312 ft) to
113 m
(371 ft)</th></tr>
<tr><th>Main boom length</th><th colspan="5">20 m (66 ft) to 68 m (223 ft)</th></tr>
<tr><th>Wind speed</th><th colspan="5">Reduction of load by</th></tr>
<tr><td>7 m/s
22.97 ft/s</td><td>0 %</td><td>0 %</td><td>0 %</td><td>0 %</td><td>0 %</td></tr>
<tr><td>9 m/s
29.53 ft/s</td><td>10 %</td><td>10 %</td><td>10 %</td><td>10 %</td><td rowspan="4">100 %</td></tr>
<tr><td>11 m/s
36.09 ft/s</td><td rowspan="2">20 %</td><td>20 %</td><td>20 %</td><td>40 %</td></tr>
<tr><td>13 m/s
42.65 ft/s</td><td>30 %</td><td>40 %</td><td>70 %</td></tr>
<tr><td>16 m/s
52.49 ft/s</td><td>30 %</td><td>50 %</td><td>70 %</td><td>100 %</td></tr>
<tr><td>Over
16 m/s
(52.49 ft/s)</td><td colspan="5">100 % = Operation prohibited</td></tr>
</table>

Figure 25 Operation of crane in the event of wind (from the load chart manual).

In addition, in Section 6.7.3 of the manual, see Fig. 26 below, it states that:

> *The "laying-down wind speed" for the boom is reached when the maximum permissible wind speeds for the parked position are exceeded or expected to be exceeded."*

For this crane with the configuration of a 194 ft. main boom and a 371 ft. luffing jib, there was 100% reduction of the crane capacity above 20 mph wind speed, and therefore the work must be stopped and the boom must be set down. The wind speed on the day of the incident was above the threshold limit.

Section 6.7.3 of the manual (see fig. 26 below), states that:

The entire boom must be laid down on the ground against the wind before the maximum permissible wind speed is reached. If it is not possible to lay down with a boom combination including a luffing jib, lay the jib head section on the ground and support the sides of the boom.

6.7.3 Laying down the boom

The "laying-down wind speed" for the boom is reached when the maximum permissible wind speeds for the parked position are exceeded or expected to be exceeded.

DANGER
Wind load too high!
Risk of machine toppling over, structural breakdown.

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

If it is not possible to lay down with a boom combination including a luffing jib:
▶ Lay the jib head section on the ground and support the sides of the boom.

Observe the following safety guidelines and notes:
- 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 (but only near the ground), this may lead to the destruction of the boom or of the swing brake.
- Always set the main boom down so that it is facing either into or against the wind. If the main boom can only be set down crosswise to the wind direction due to limited space, then the setting down has to be completed before the wind reaches the maximum permissible speed.
- 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, as a rule 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.

Note
▶ The safest measure that can be taken is always to lay down the boom.

Figure 26 Laying down the boom (from operator's manual, page 572).

Load chart for combination of 194 ft. long boom and 371 ft. jib

Reproduced below is the load chart from Liebherr indicating the loads that can be safely hoisted with boom angles of 88, 83 and 75 degrees. Loads chart are not provided for boom angles lower than 75 degrees. It is therefore presumed that a boom with the given configuration of a boom length of 194 ft. and a jib length of 371 ft. could not be positioned lower than 75 degrees. In this configuration, given the boom angle of 75 degrees, the jib angle could vary from 65 to 40 degrees. At the jib angle of 40 degrees and the boom angle of 75 degrees, the capacity of the crane is just 2,300 pounds including the weight of the block, etc.

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		

	88° Main boom angle			83° Main boom angle			75° Main boom angle			65° Main boom angle			45° Main boom angle		
Outreach [ft]	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) 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 27 Load chart (taken from MRA Engineering report).

MRA Engineering, P.C.

As mentioned earlier, Galasso Trucking & Rigging Inc. retained a consultant, MRA Engineering, P.C. to prepare an application for approval by New York City indicating the type and size of the crane to be used in the project. Based upon its computations, MRA prepared an application which was approved by the NYC. The application ran into several pages, proposing the subject crane to be used with specified lengths of the boom and the jib. The application also contained the following instructions:

"*Cranes to be stowed overnight or in severe weather conditions as per manufacturer's recommended procedures found in the operator's crane manual."* MRA also provided a sketch showing the manner in which the crane needed to be stowed, although a few details like the angle of the boom and the jib are lacking. The sketch, however, provides an overall arrangement for stowing the crane overnight and during severe weather conditions. MRA's above instruction contained a directive "as per manufacturer's recommended procedures found in the operator's crane manual". However, Liebherr in its manual did not recommend that the crane be stowed or parked in the manner suggested by MRA, but rather they instructed the user of the crane, due to the long length of the jib, to lay down the crane instead of jack knifing it, in the event the wind speed is anticipated to be in excess of 20 mph. Bay Crane, which owned the crane, requested Liebherr, after the incident, to determine whether the subject crane could be jack knifed under severe weather conditions instead of laying it down on the ground. Liebherr stated in its email of February 5, 2016, the day of the incident, that Liebherr could make such a determination if asked by the "customer" with the specific configurations of the boom and the jib. In an email of February 5, 2016, after the incident, Liebherr stated that the subject crane could be parked in a jack knife position up to a maximum wind speed of 67 mph provided certain conditions were met. This determination by Liebherr overrides the instructions provided in the Liebherr manual and provides alternate options to the user and is in general agreement with MRA's instructions to Galasso, although MRA's instructions lacked information about the angle of the boom and the maximum wind speed.

At the end of the day on February 4, 2016, the weather forecast for the wind for the night and the next morning were reportedly known to Galasso Trucking & Rigging Inc. but no decision was taken to lay down the crane. That proved to be a grievous error.

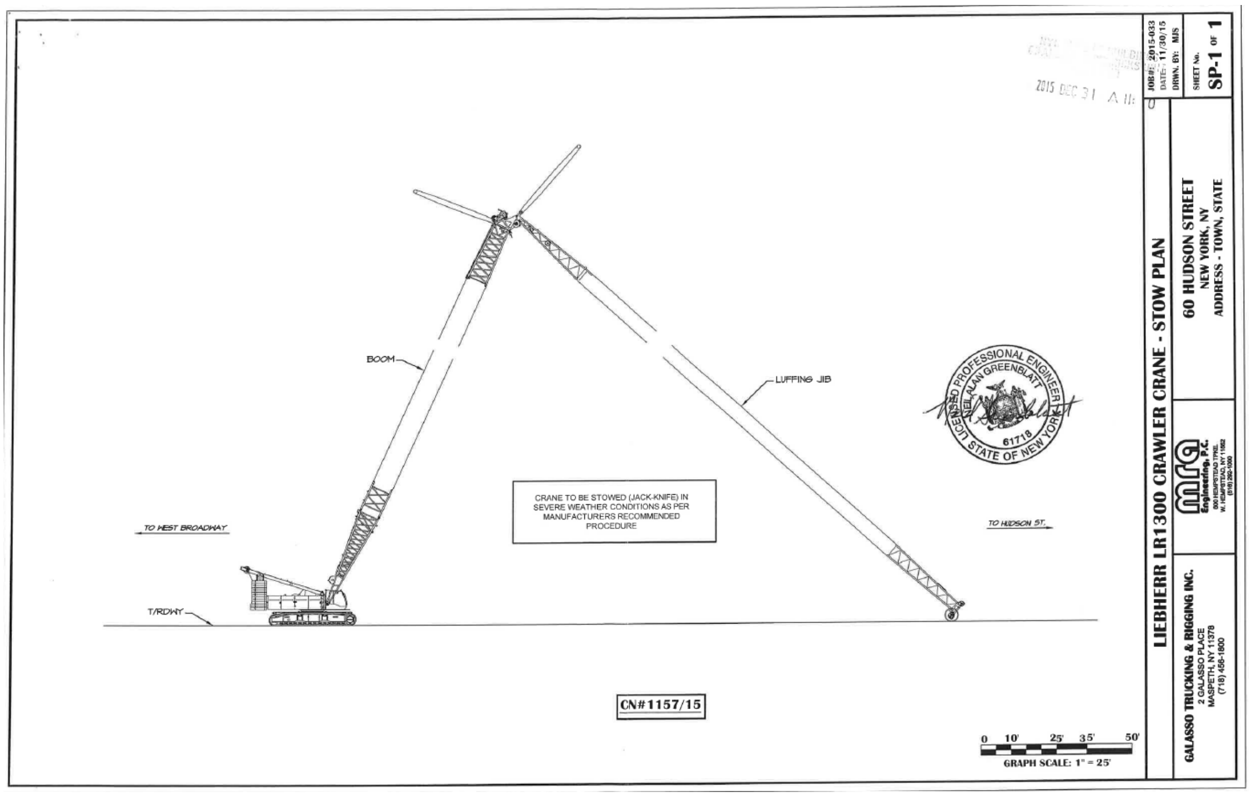


Figure 28 Stow Plan from the consultant

February 4 and 5, 2016

The day before the incident, February 4, 2015, CPU data indicates that the boom for the entire day remained at approximately 87 degrees, and the jib at 78 degrees. On February 5, 2016, the day of the incident, the first reading of the boom angle at the computer time of 7:49 a.m. is indicated at 80 degrees by the CPU data. The change of 7 degrees in the boom angle from the previous evening to the next morning is not explained. No meaningful activity occurred from 7:49 a.m. until 9:14 a.m (computer time). For the next 14 minutes, i.e., 9:14 a.m. to 9:28 a.m., the jib angle varies from 34 to 39 degrees with the radius ranging from 329 to 344 ft., assuming that the boom remained at 80 degrees. For these 14 minutes, it is believed that the stability of the crane was not jeopardized even in prevailing winds because the boom angle was maintained at 80 degrees. CPU data, however, indicate that there were multiple instances in these 14 minutes when the crane was over 110% of its capacity momentarily but immediately returned to 110% or below. At approximately 9:28 a.m., the crane operator suddenly lowered the boom angle to 69.4

degrees at which time the stability of the crane was lost and tipping began until the entire crane and the jib were on the ground. CPU data indicates a decreasing angle of the boom until it reached zero degrees. We cannot say with certainty whether the crane operator knowingly lowered the boom angle to 69.4 degrees or if it was a case of human error on the part of the crane operator. The crane operator, however, is reported to have said in several interviews that he maintained the boom angle at 80 degrees and did not lower it to 69 degrees. There are indications in the CPU data that an attempt was made during the ensuing collapse to raise the jib but it had little impact because the boom was dropping too fast. CPU data indicate that the jib was raised from 13 to 26 degrees during the collapse but to no avail.

It is understood that in the near future the length of the wire ropes would be field measured in the Brooklyn Yard where the remnants of the crane have been stored to calculate the angle of the boom and the jib immediately preceding the collapse. That field measurement had not been done at the time this report was completed.

A review of videos taken during the collapse of the crane by amateur videographers publicly available on youtube.com indicates that the jib was at approximately 45 degrees and the boom was at approximately 70 degrees at the time of the collapse.

5. Conclusions

1. The crane was not stowed/parked overnight on the evening of February 4, 2016, as per the instructions of the consultant, MRA Engineering, retained by Galasso Trucking & Rigging, Inc. This contributed to the collapse.
2. Liebherr's manual recommends that the crane be laid on the ground when the wind is forecast to be above 20 mph. The crane was not laid down during the night between February 4 and February 5, 2016 although Galasso knew that the wind would be severe during the night and the early morning.
3. Crane CPU retrieved after the incident indicated that the boom angle of the crane was lowered to 69.4 degrees at or near the time of the collapse in violation of the manufacturer's manual. This contributed to the collapse. Crane in the present configuration has no load carrying capacity below the boom angle of 75 degrees. Crane could be operated in wind not exceeding 20 mph and at a boom angle not lower than 75 degrees. In the event wind exceeds 20 mph, crane must be laid down. The stability of the crane was highly sensitive to lower boom angle.
4. After the incident, Bay Crane, which owned the crane, asked the crane manufacturer, Leibherr to determine the "Jack Knife" position of the crane in the event of high winds. A Jack Knife position was not an option provided by Liebherr in its manual unless specifically computed and determined by Liebherr on a case-by-case basis. This inquiry should have been made before the incident.
5. The collapse of the crane occurred when the boom of the crane was lowered to an angle of less than 75 degrees in a prevailing wind contrary to the manufacturer's instructions. It is believed that the crane operator lowered the boom to around 70 degrees.
6. Liebherr's crane manuals for the operators and users of the crane were deficient because the procedure for laying down cranes with a luffing jib, 371 ft. long and a boom 194 ft. long lacked clarity. In the interest of job safety, Liebherr must add a section to its manuals with clear instructions on details for the proper way to lay down the boom and the jib in the event of high winds to avoid instability.

APPENDIX

(Taken from MRA application CN#1157/15)

MRA Job# 2015-033
LR1300

NYC Buildings

CD4: Tower & Mobile Crane / Derrick / Mast Climber / Pile Driver On-Site Inspection Application / Certificate

File 4 copies / Application must be typewritten

CN 115 7 16

CN Number:

2015 DEC -4 P 12: 39

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)*

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 — Invoice/Receipt Number — Fee Paid
Examiner's Name (please print) — Inspector's Name (please print)
Signature — (Issuance) Date — Signature — Date
Expiration date — Badge Number

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) 292-6407

December 3, 2015

The City of New York
Department of Buildings
Division of Cranes & Derricks
280 Broadway – 5th Floor
New York, NY 10007

CN1157 15

Re: 60 Hudson St., NYC
60 Hudson St
New York, NY
CD#'s 3822, 3870, 4463 or 4606

To Whom It May Concern:

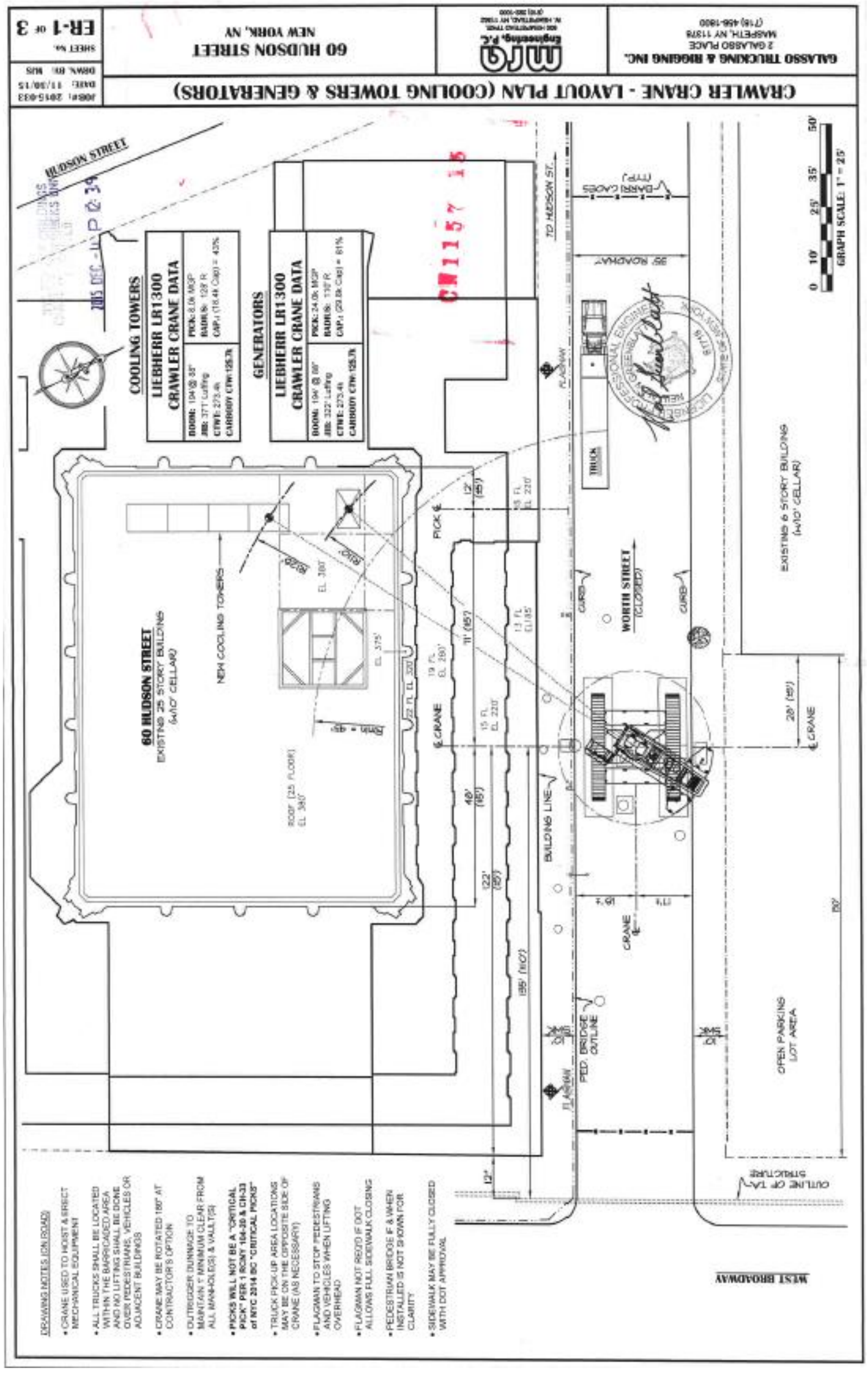
Please be advised that I, Neil Greenblatt, a duly licensed engineer have visited the above referenced site and make the following statements:

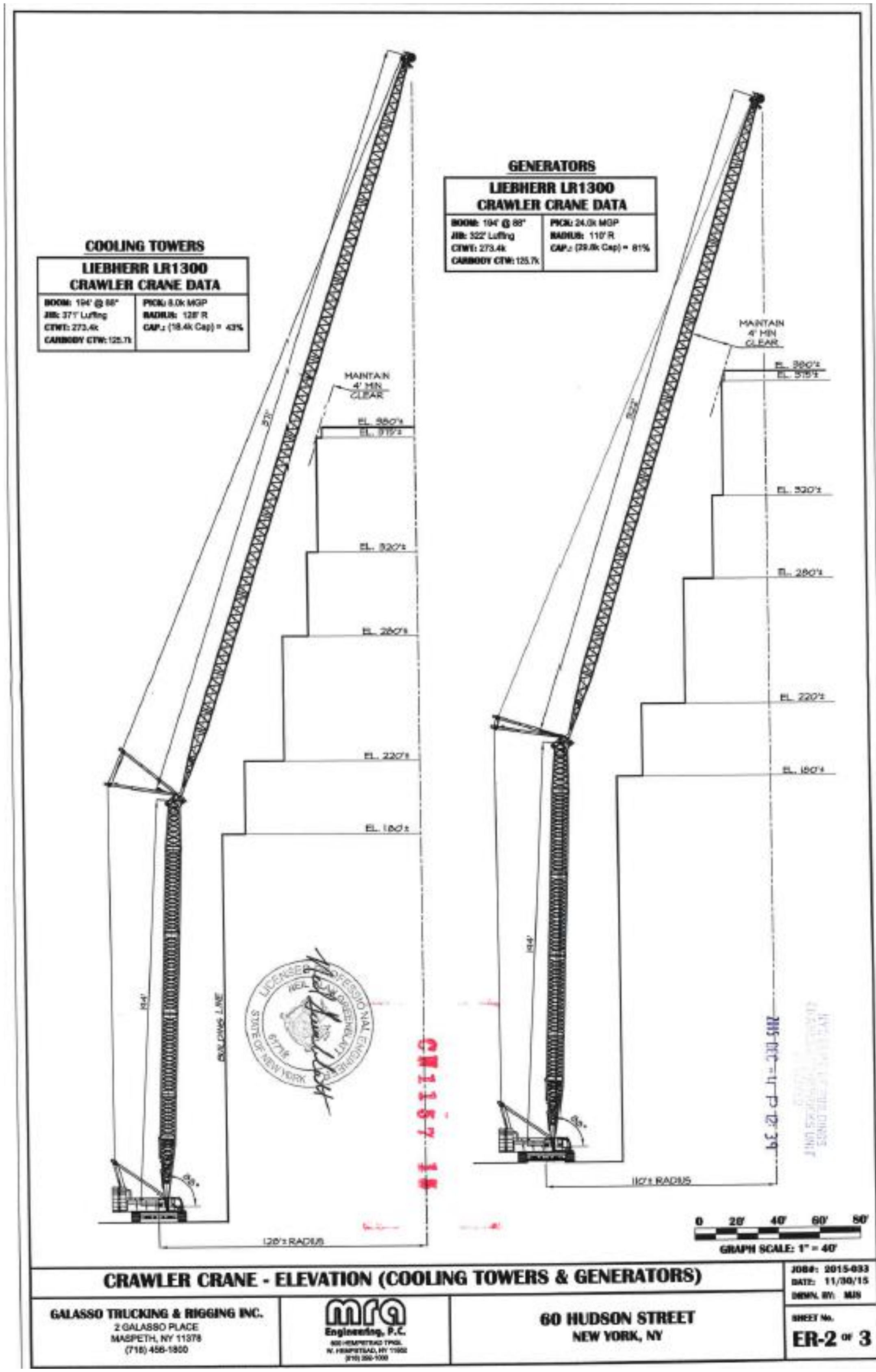
A. That the crane shall be operated in a level position at all times and shall not be operated during periods of high wind.
B. That the crane to be used is a Liebherr LR1300 with 194' boom + 371/322' luffing jib and 273.4k + 125.7k ctwt (CD#'s 3822, 3870, 4463 or 4606). All pick/radii limitations shall 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.

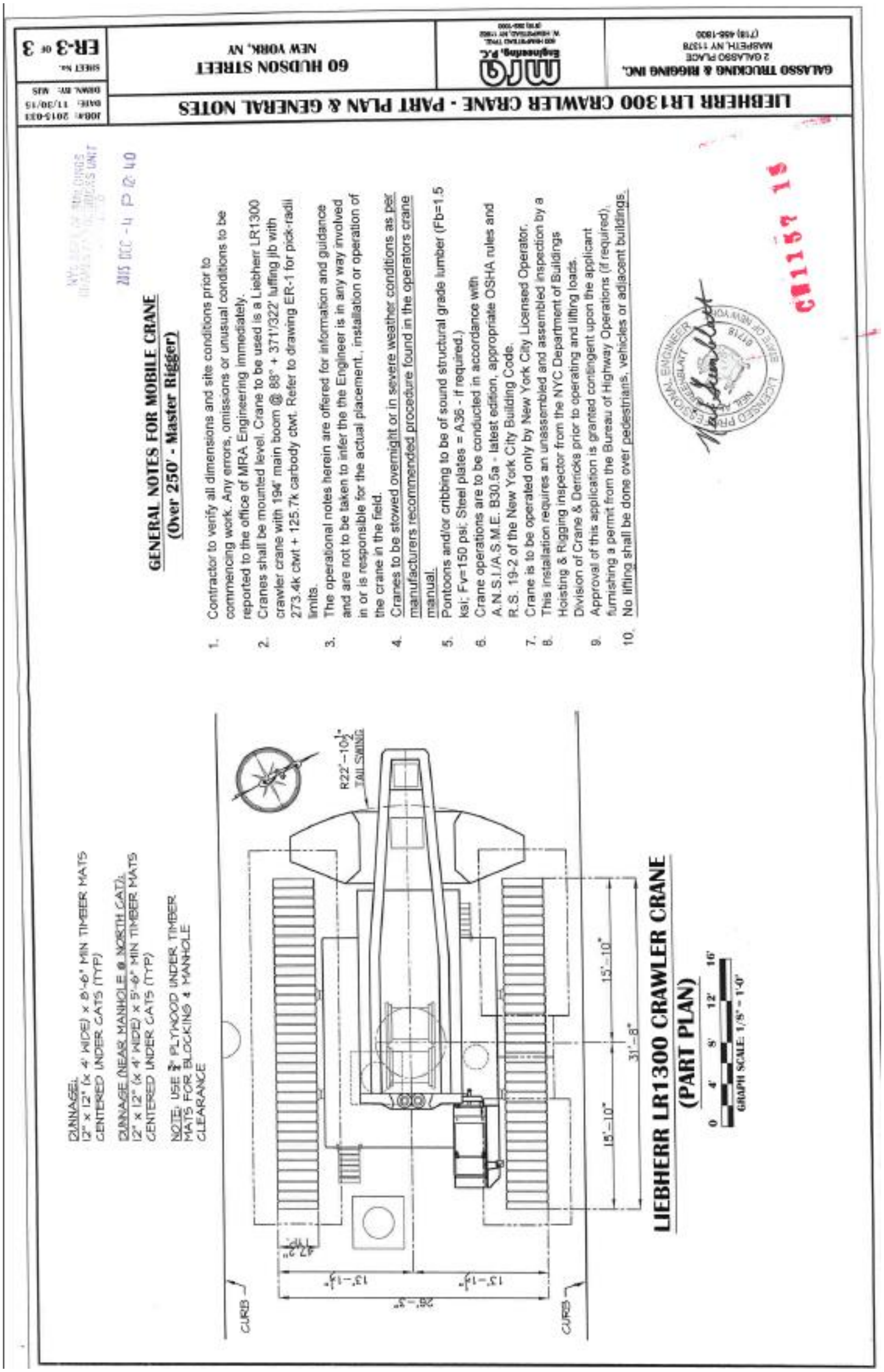
Very truly yours,

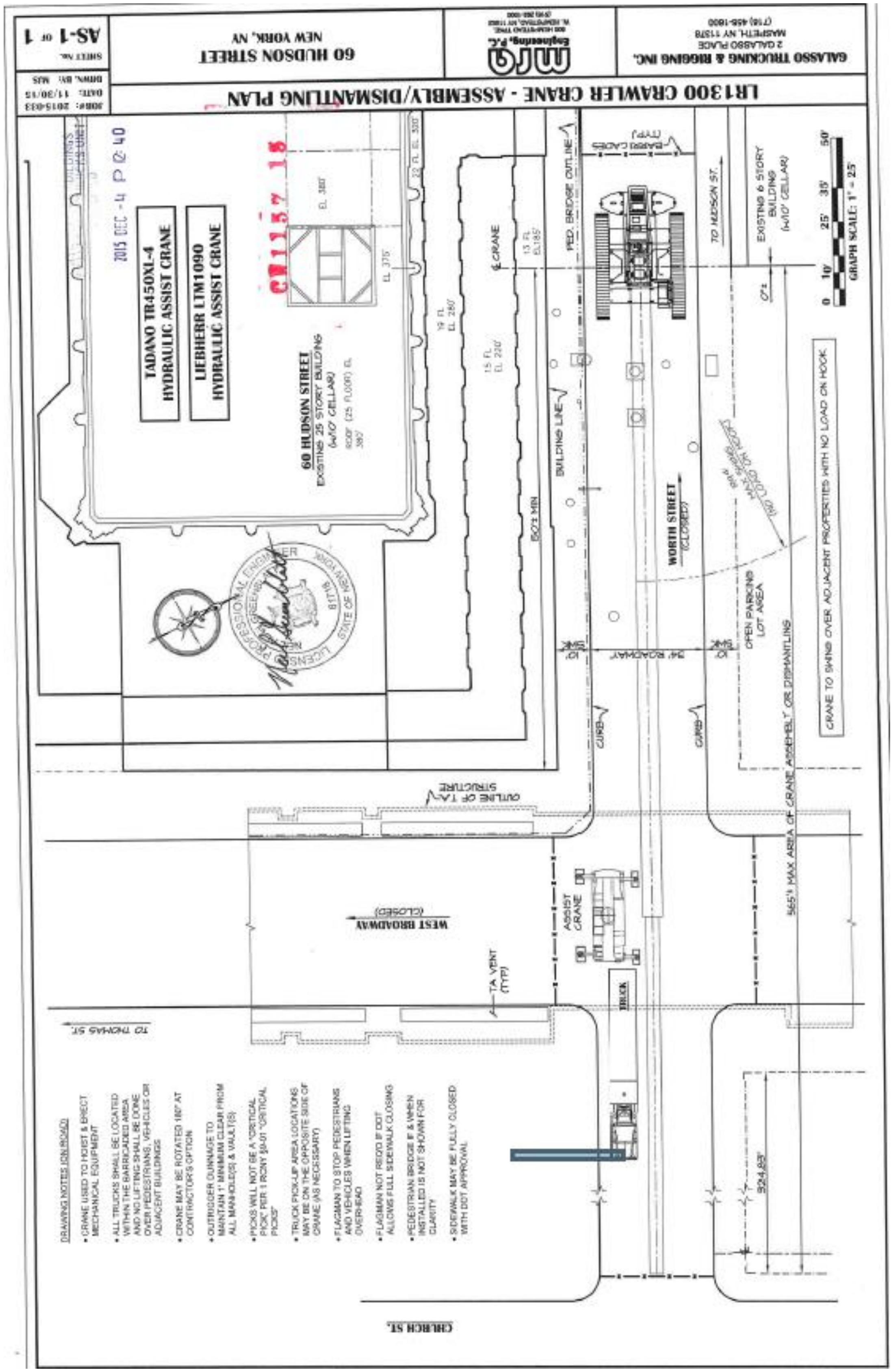
Neil Alan Greenblatt

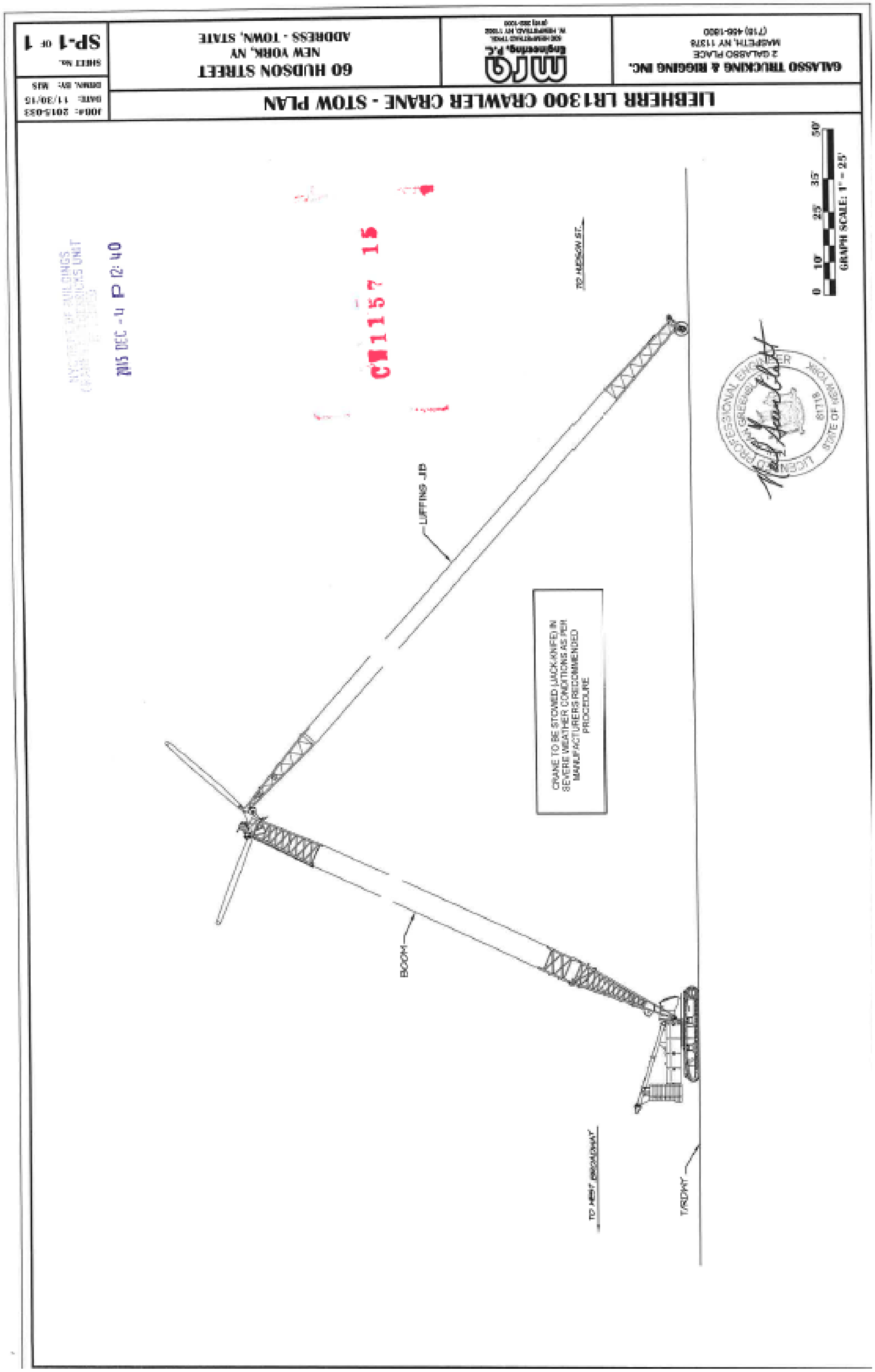
LICENSED PROFESSIONAL ENGINEER NEIL ALAN GREENBLATT 61718 STATE OF NEW YORK


CRAWLER CRANE - LAYOUT PLAN (COOLING TOWERS & GENERATORS)
60 HUDSON STREET
NEW YORK, NY
GALASSO TRUCKING & RIGGING INC.
ER-1 of 3
HUDSON STREET
COOLING TOWERS
LIEBHERR LR1300
CRAWLER CRANE DATA
GENERATORS
LIEBHERR LR1300
CRAWLER CRANE DATA
60 HUDSON STREET
EXISTING 25 STORY BUILDING
NEW COOLING TOWERS
WORTH STREET
BUILDING LINE
EXISTING 6 STORY BUILDING
OPEN PARKING LOT AREA
WEST BROADWAY
DRAWING NOTES (ON ROAD)
GRAPH SCALE: 1" = 25'


COOLING TOWERS
LIEBHERR LR1300
CRAWLER CRANE DATA
BOOM: 194' @ 88°
JIB: 371' Luffing
CTWT: 273.4k
CARBODY CTW: 125.7k
PICK: 8.0k MGP
RADIUS: 128' R
CAP.: (18.4k Cap) = 43%
GENERATORS
LIEBHERR LR1300
CRAWLER CRANE DATA
BOOM: 194' @ 88°
JIB: 322' Luffing
CTWT: 273.4k
CARBODY CTW: 125.7k
PICK: 24.0k MGP
RADIUS: 110' R
CAP.: (29.8k Cap) = 81%
MAINTAIN
4' MIN
CLEAR
EL. 320'±
EL. 280'±
EL. 220'±
EL. 180'±
194'
128'± RADIUS
110'± RADIUS
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.
60 HUDSON STREET
NEW YORK, NY
SHEET No.
ER-2 OF 3


DUNNAGE:
12" x 12" (x 4' WIDE) x 8'-6" MIN TIMBER MATS CENTERED UNDER CATS (TYP)
DUNNAGE (NEAR MANHOLE @ NORTH CAT):
12" x 12" (x 4' WIDE) x 5'-6" MIN TIMBER MATS CENTERED UNDER CATS (TYP)
NOTE: USE ¾" PLYWOOD UNDER TIMBER MATS FOR BLOCKING & MANHOLE CLEARANCE
CURB
CURB
R22'-10½" TAIL SWING
13'-1½"
13'-1½"
26'-3"
15'-10"
15'-10"
31'-8"
LIEBHERR LR1300 CRAWLER CRANE
(PART PLAN)
0 4' 8' 12' 16'
GRAPH SCALE: 1/8" = 1'-0"
2015 DEC -4 P 12:40
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.
CN1157 15
LIEBHERR LR1300 CRAWLER CRANE - PART PLAN & GENERAL NOTES
GALASSO TRUCKING & RIGGING INC.
2 GALASSO PLACE
MASPETH, NY 11378
(718) 456-1800
mra
Engineering, P.C.
60 HUDSON STREET
NEW YORK, NY
JOB#: 2015-033
DATE: 11/30/15
DRWN. BY: MJS
SHEET No.
ER-3 of 3


LR1300 CRAWLER CRANE - ASSEMBLY/DISMANTLING PLAN
60 HUDSON STREET
NEW YORK, NY
GALASSO TRUCKING & RIGGING INC.
AS-1 of 1
TADANO TR450XL-4
HYDRAULIC ASSIST CRANE
LIEBHERR LTM1090
HYDRAULIC ASSIST CRANE
60 HUDSON STREET
WORTH STREET
(CLOSED)
WEST BROADWAY
(CLOSED)
CHURCH ST.
TO THOMAS ST.
CRANE TO SWING OVER ADJACENT PROPERTIES WITH NO LOAD ON HOOK
GRAPH SCALE: 1" = 25'


LIEBHERR LR1300 CRAWLER CRANE - STOW PLAN
GALASSO TRUCKING & RIGGING INC.
60 HUDSON STREET
NEW YORK, NY
ADDRESS - TOWN, STATE
SP-1 OF 1
GRAPH SCALE: 1" = 25'
LUFFING JIB
BOOM
CRANE TO BE STOWED (JACK-KNIFED) IN SEVERE WEATHER CONDITIONS AS PER MANUFACTURERS RECOMMENDED PROCEDURE