U.S. Department of Labor

Occupational Safety and Health Administration
Washington, D.C. 20210

Reply to the Attention of:

January 13, 2009

Memorandum For: Dean McDaniel, Regional Administrator
Region VI, Dallas, TX

Mark Briggs, Area Director
Houston South Area Office

From: for Mohammad Ayub
Office of Engineering Services
Directorate of Construction

Subject: Investigation of the July 18, 2008 Fatal Collapse of a Deep South Crane at Lyondell Basell Houston Refinery in Pasadena, TX

At your request, Dr. Scott Jin, PE, an engineer with this office, accompanied by Kelly Knighton, Assistant Area Director, visited the incident site on July 30-31, 2008. We also reviewed photographs, videos, witness statements, the operator's manual and other technical information on the crane, and an OSHA crane expert's investigation report. In addition, we performed an engineering analysis on the condition of the boom during the collapse. The following report is for your information.

The Project and the Crane

Lyondell Basell Houston Refinery (LHR) in Pasadena, TX was in the initial stages of a large turnaround in their Coking Unit. Part of the turnaround consisted of removing the derricks from the top of the structure and then the coking drums. Deep South Crane & Rigging Company (DSC) was retained by LHR to bring one of world's largest mobile cranes to the site to perform the work.

The Versa crane TC36000, involved in the incident, was designed and built by DSC in 1998 in accord with ASTM B-30.5-1994. The crane was assembled at the Lyondell Basell site with a 420′ boom, 240′ mast, 61′ spar and 836,000 pounds of main counterweight attached to the spar (Figures 1 and 2). An additional 836,000 pounds of auxiliary counterweight was to be attached to its pendants suspended from the mast tip at 105′ from the axis of the crane. With this configuration, the crane would have a one million pound lifting capacity at a maximum boom radius of 160′. The incident occurred during the installation of the auxiliary counterweight.

The Incident

The erection of the crane began approximately four weeks before the date of the incident. On the day of the incident, July 18, 2008, DSC started the process of positioning the auxiliary counterweight that was to be attached to the suspended pendants to achieve the superlift capacity. At approximately 9:00 a.m., the main winch stopped working. This was the winch designed to lower and raise both the mast and the boom together. The crane supervisor called the DSC main office in Baton Rouge, LA. With their phone assistance, the crane supervisor was able to test the control panel and to replace the winch operation lever. It appeared that the problem was resolved.

Before lunch, two ironworkers with DSC were in a JLG aerial lift attempting to attach two metal bars on to the auxiliary counterweight tray. An assist crane, an 80-ton Demag, was also used in this effort. After lunch, they continued to connect the upper end of the metal bars to pendants suspended from the tip of the mast. In the meantime, the ironworkers were giving signals to the TC36000 crane operator to adjust the tip location of the mast. During this process, suddenly after a loud noise, the boom fell backwards (overhauled) and collapsed onto the mast, the spar, the assist crane and the JLG lift. As a result, four employees were killed and six others were injured.

The incident occurred at approximately 1:40 p.m. On the day of the incident, July 18, 2008, the wind was from the southeast at approximately 6.9 mph at 1:00 p.m. and at 5.8 mph at 1:53 p.m. The temperature that day was 91°F and the humidity was 49-50%.

Analysis and Discussion

Boom Radius at the Time of the Collapse

From the coordinates of the base pin of the boom and the lower pin of the boom stop as well as the distance from the base pin to the boom stop connection and the compressed length of the boom stop, it was determined that the boom stop failed at a boom angle of 79.2° (Section A-1 of Appendix A). The corresponding boom radius was 84.9′. Through the same procedure in Section A-2, it was determined that the mast stop failed at a mast angle of 61.0° (Section A-2). The corresponding mast radius was 113′. It should be noted that all of the input quantities were provided by DSC.

Since at the time of the incident the mast was approximately at a radius of 105′ for attaching the auxiliary counterweight tray, the corresponding mast angle was calculated to be 63.2° (Section A-2). Thus, the mast stop did not fail (63.2° > 61.0°) at the time when the boom stop failed. This finding was also confirmed by a 34-second video from the area office. In this video, the boom started to fail at the ninth second at a boom angle of around 79° to 80°. The mast started to fail at the nineteenth second at a mast angle of around 61° to 60°.

Boom Radius at the Overhaul

As presented in Figure 2, the actual suspended load on the boom tip during the incident was 73,330 pounds (36.7 tons). Through interpolation of the overhaul chart (Figure 3), the boom was determined to be overhauled at a radius of 114′. The corresponding boom angle was 75.0°. Thus, after the overhaul the boom had to travel about 29′ before it reached its collapsed position. Based on the witness accounts, it would take at least 5 to

10 minutes for the boom and the mast to travel this 29′ distance even with the main winch cable continuing to apply the pulling force. It should be noted that due to the effects of the overhaul, some of the elastic stretch in the winch cable had to be recovered until the spring pack of the boom stop started to provide additional resistance. In addition, due to the temporary reduction of the pulling force after the boom overhaul, the winch should have rotated at a faster speed. These conditions should have been noticed by the crane supervisor and the crane operator.

Contribution of the Boom Stops

Based on the review of seven overhaul chards for the TC36000 crane, identified in Figures 4 and 5, the same minimum suspended load was applicable for all of the auxiliary counterweights at 66′. In addition, between these two figures, the same minimum suspended load was also applicable for two different main counterweights, 430 kips and 627 kips, respectively. Thus, the minimum suspended loads are independent of the amounts for the main and the auxiliary counterweights. However, these loads are dependent upon the boom length, the boom radius, the mast length and the mast radius.

As a result, it is believed that the overhaul of the boom was due to a balanced condition at its base pin between its own weight and the weight of the assembly of the boom pendants, the mast and the assembly of the mast pendants. In this condition, the mast cable at the tip of the spar had to be slacked. Thus, the main counterweight was not included in the balanced system and the auxiliary counterweight rested on the ground.

Based on the calculation in Section A-4, it was found that the resisting moments against the overhaul were from the weight of the boom and the suspended load. In addition, the moments were about the same within each chart, regardless of the boom radii or boom angles. For the case under investigation, the resisting moments varied from 36,500 ft-kips to 35,100 ft-kips for the boom radii from 85′ to 135′ (boom angle from 79.1° to 72.0°). The variations were less than 4%.

However, the resisting moment of both boom stops was estimated to be 16,800 ft-kips (Section A-3) before the failure. Thus, it was concluded that the effect of the boom stops was not considered in the preparation of the overhaul charts. In fact, the boom stops had contributed a maximum of 47% additional resisting moment before its failure. Thus, after the boom overhauled, the main winch cable had to apply additional pulling force to fail the boom stops and this caused the collapse of the boom.

Design of Boom Stops

From the calculations in Section A-5, the boom stops were not designed to develop the ultimate strength of the boom in bending at the point where the boom stop acted on the boom. Thus, the DSC did not comply with the industry practice of SAE J220, Section 4.1(a). In addition, the spring pack of the boom stop was fully compressed at the failure of the boom stop. Thus, the boom stop had used both the available spring energy and elastic energy, but it still could not prevent the boom from collapsing. Therefore, DSC did not comply with the industry practice of SAE J220, Section 4.1(b).

Based on ASTM B-30.5-1994, Section 5-1.9(a), "(Boom) Stops shall be provided to resist the boom falling backwards." In addition, the Office of Construction Standards and Guidance, Directorate of Construction, also contacted a representative of the crane industry who provided the consensus view that, "The boom stop is typically designed to stop the boom." However, the boom stops in this case were not designed to stop the boom from falling backwards and this caused the incident. Thus, DSC was in violation of the above industry practice.

Meeting with DSC

On August 26, 2008, the Houston Area Office conducted a meeting with the owner and key personnel of DSC, the OHSA crane expert and the OSHA investigation team. DSC provided the following information:

- On the day of the incident, DSC's main office provided technical assistance over the telephone to the TC36000 crane supervisor on how to test and change the main winch lever that was not functioning.
- This lever was for the main winch that operated both the mast and the boom together.
- The boom stops were set at a boom angle of around 80°.
- If the key switch was in position to move the mast (and the boom) up and down, it would not stop the boom when the boom reached 80° (the collapse angle).
- There was no limit switch in the mast stops.
- DSC admitted that the boom should have been down to 180′ in radius before raising the mast (and the boom) with the main winch.

Conclusions

1. The Versa crane 26000, involved in the incident, was tested in September 2000 and January 2003 as per SAE J987 by All Test & Inspection, Inc. Thus, it appeared that the crane met the test requirements of SAE J987.

2. From the site inspection, the crane was assembled in accordance with the configuration specified in Figure 2.

3. Based on our analysis, the boom stop failed at a boom angle of 79.2° and the mast stop failed at an angle of 60.8°. At the time of the boom stop failure, the mast was at an angle of around 63.3°. Thus, the boom stop failed first.

4. From the evaluation of the video made immediately before the incident, Deep South Crane & Rigging Company (DSC) operated the crane at a boom angle of around 79° to 80°. This angle was beyond its allowable overhaul angle of 75°. Thus, DSC operated the crane in an unsafe condition.

5. Based on our analysis, after the boom overhauled the main winch cable had to apply additional pulling force to cause the failure of the boom stops and this caused the collapse of the boom.

6. Deep South Crane & Rigging Company (DSC) did not design the boom stops to prevent the boom from falling backwards. Thus, DSC did not comply with the following industry standards:

   - ASTM B30.5-1994, Section 5-1.9(a).
   - SAE J220, Section 4.1.

7. The incident was caused by the failure of the boom stops.

8. From the weather report, the wind was not a factor in causing the incident.

If you have any questions or would like clarification of any of the above comments, please feel free to call Scott Jin of this office at (202) 693-2335.

Attachments: Five Figures and Appendix A.

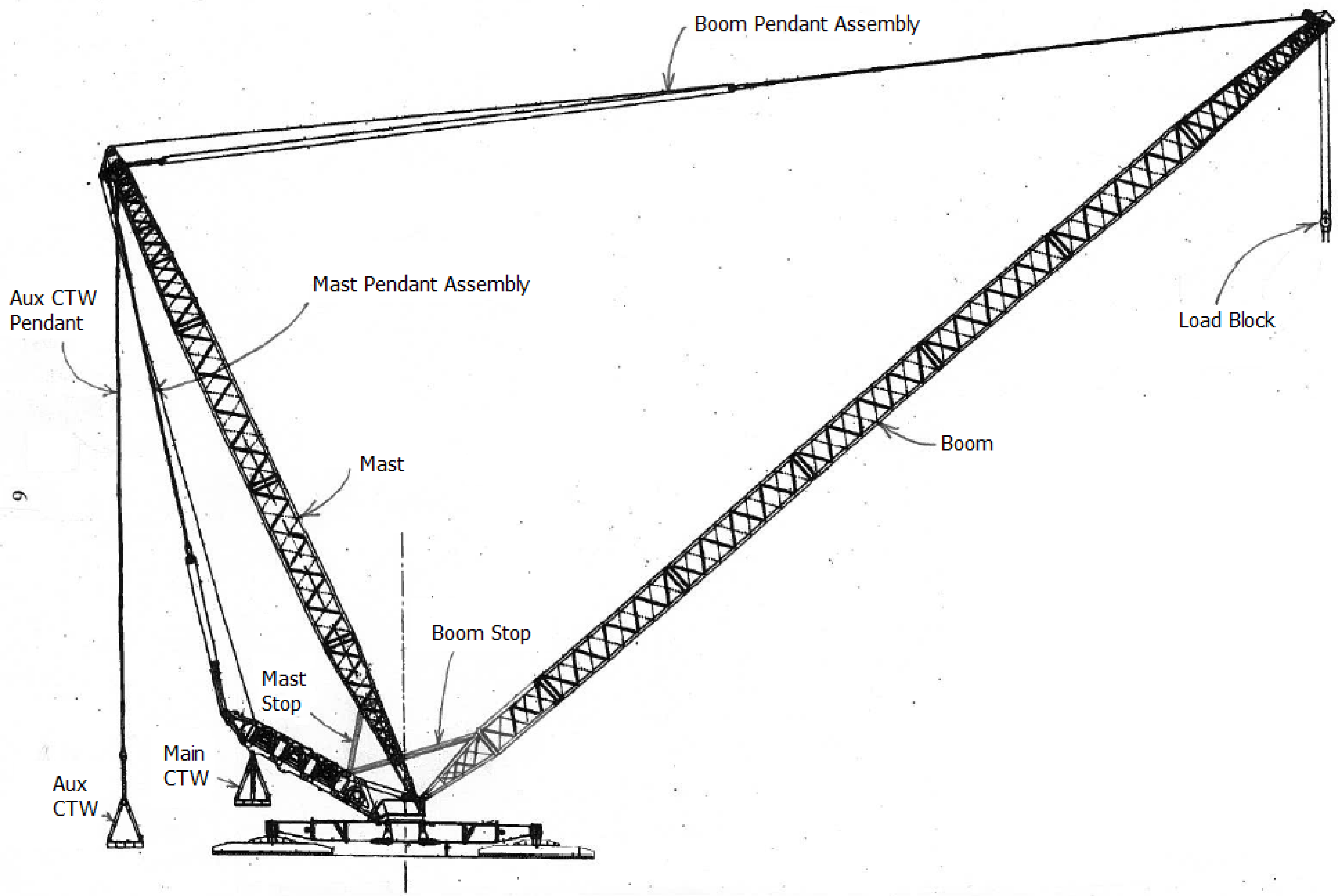

Figure 1. Configuration of the Versa Crane TC36000 Involved in the July 18, 2008 Incident (Modified from DSC, 2008).

TC36000-Versa-VII with boom V7BT-20-155x126X; mast C4/7MPOT-02-155x126S; and stability of 75%

Crane Setup Cover Sheet

Lower is EXTENDED OUTRIGGERS

Upper is C7-D04-S61upDeg30-M46-10TB-A105-0TB
- **D = Number drum shafts assemblies on machine**
- **S = Spar Length to nearest ft, tip up/down and spar angle from horizontal**
- **M = Main CWT from spar foot in ft - in**
- **A = Aux CWT radius in ft - in**
- **TA = Small CWT tray (1200 kips)**
- **TB = Large CWT tray (3000 kips)**

Lattice box section codes
"a" = 106x106 box; "b" = 130x106 box; "c" = 155x126 box; "e" = 52x 52 box
"f" = 55x 45 box; "g" = 130x 52 box; "h" = 85x 71 box; "i" = 56x 56 box

BOOM is V7BT-20-155x126X; suspension 2 bars at 1850 kips each

Boom Length (ft)	Boom Makeup 81.5K 38.5K 70.0K 68.5K 60.5K 60.5K 60.5K 55.6K 41.5K	Parts Boom hoist	Mast Length (ft)
420.0	B 30 X c+ I 30 X c+ I 60 X c+ I 60 X c+ I 60 H c+ I 60 H c+ I 60 H c+ IT60S+T c	28	240.0

Mast is C4/7MPOT-02-155x126S; suspension 2 bars at 1850 kips each; mast cwt suspension 2 bars at 1850 kips each

Mast Length (ft)	Mast Makeup 57.9K 48.5K 48.5K 57.4K 33.5K
240.0	MB 60 S c+ I 60 S c+ I 60 S c+ IT60S+MTc

TC36000-Versa-VII-2008.02.27.15.18.40-A-w-20-1.00

Notes

1. Weight of the suspended loads at the time of the incident:

Block Assemblies 14,840# x 2	29,680
Five Pins 2,080# x 5	10,400
Tension Link 600#	600
Equalizer Bars 3,400# x 2	6,800
Lower Links 3,050# x 2	6,100
Swivel 13,000#	13,000
Cable 3.5#/′ x 30′ x 40 parts	4,200
Whip Line Attachment 2,550#	2,550
Total	73,330 pounds = 36.7 tons

Figure 2. Setup and Individual Weights of the TC36000 Crane Involved in the July 18, 2008 Incident (Modified from DSC, 2008).

TC36000-Versa-VII with boom V7BT-20-155x126X; mast C4/7MPOT-02-155x126S; and stability of 75%

Over haul chart

Rated Radius (ft)	Minimum suspened load (tons) on boom tip to stop boom over hauling Maximum load not to exceed Rating Chart capacity	Rated Radius (ft)
	Aux CWT = 0 kips at 105.0 ft Main CWT = 836 kips	
	Mast length 240 ft	
	Boom length 420 ft	
80	120.4	80
85	103.7	85
90	88.9	90
95	75.8	95
100	64.1	100
105	53.5	105
110	44.0	110
115	35.2	115
120	27.3	120
125	20.0	125
130	13.2	130
135	7.0	135
140		140
145		145
150		150
155		155
160		160
165		165
170		170
180		180
190		190
200		200
210		210
220		220
230		230
240		240
250		250
260		260
270		270
280		280
290		290
300		300
310		310
320		320
330		330
340		340
350		350

← Interpolation

$$\frac{36{,}7-35{,}2}{44{,}0-35{,}2} = \frac{x}{5'}$$

$$x = 0{,}852'$$

Boom Radius

$$R = 115' - 0{,}852' = 114.1'$$

Say 114'.

Boom Angle

$$\theta = \cos^{-1}\left(\frac{114' - 5{,}5'}{420'}\right)$$

$$= 75^{\circ}$$

TC36000-Versa-VII-2008.02.27.15.18.40-A-w-20-1.00

Notes:

1. Boom Angle (θ) $= \cos^{-1}\left(\dfrac{\text{Boom Radius} - 5{,}5'}{420'}\right)$

Figure 3. Overhaul Chart of the TC36000 Crane Involved in the July 18, 2008 Incident (Modified from DSC, 2008).

36000-Versa-VII with boom V7BT-10-155x126X; mast V7MC-02-155x126S and stability of 75%
Over haul chart

Rated Radius (ft)	Minimum suspened load (tons) on boom tip to stop boom over hauling Maximum load not to exceed Rating Chart capacity	Rated Radius (ft)
	Aux CWT = All at 66.0 ft Main CWT = 430 kips	
	Mast length 180 ft	
	Boom length 270 ft	
55	107.4	55
60	88.5	60
65	72.7	65
70	59.3	70
75	47.9	75
80	38.0	80
85	29.2	85
90	21.5	90
95	14.7	95
100	8.6	100
110		110
120		120
130		130
140		140
150		150
160		160
170		170
180		180
190		190
200		200
210		210
220		220
230		230
240		240
250		250
260		260
270		270

36000-Versa-VII-2004.01.25.16.24.48-A-w-20-1.00

Notes:

1. $\text{Mast Angle}(\phi) = \cos^{-1}\left(\frac{\text{Mast Radius} + 3'}{\text{Mast Length}}\right)$

Figure 4. Typical Overhaul Chart 1 of the TC36000 Crane (Modified from DSC, 2008).

36000-Versa-VII with boom V7BT-10-155x126X; mast V7MC-02-155x126S and stability of 75%
Over haul chart

Rated Radius (ft)	Minimum suspened load (tons) on boom tip to stop boom over hauling Maximum load not to exceed Rating Chart capacity	Rated Radius (ft)
	Aux CWT = All at 66.0 ft Main CWT = 627 kips	
	Mast length 180 ft	
	Boom length 270 ft	
55	107.4	55
60	88.5	60
65	72.7	65
70	59.3	70
75	47.9	75
80	38.0	80
85	29.2	85
90	21.5	90
95	14.7	95
100	8.6	100
110		110
120		120
130		130
140		140
150		150
160		160
170		170
180		180
190		190
200		200
210		210
220		220
230		230
240		240
250		250
260		260
270		270

36000-Versa-VII-2004.01.25.15.16.55-A-w-20-1.00

Figure 5. Typical Overhaul Chart 2 of the TC36000 Crane (Modified from DSC, 2008).