

# Investigation of the March 15, 2008 Fatal Tower Crane Collapse at 303 East 51<sup>st</sup> Street, New York, NY

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

September 2008



# **REPORT**

## **Investigation of the March 15, 2008 Fatal Tower Crane Collapse at 303 East 51<sup>st</sup> Street, New York, NY**

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## REPORT

### The incident:

On March 15, 2008 at approximately 2:30 P.M. a tower crane approximately 250 ft. high collapsed in uptown Manhattan, NY, killing six construction employees. In addition, a civilian in a nearby apartment was also killed when part of the crane struck the apartment building. The crane was used in the construction of a 43-story concrete framed building located at 303 E. 51<sup>st</sup> Street. At the time of the incident, employees were placing lateral tie beams on the 18<sup>th</sup> floor of the building under construction to provide lateral support to the crane. The crane was “jumped” about an hour earlier by adding four additional sections to the tower mast. The jumping of the crane took place without any reported problems.

The building under construction, a 43-story condominium, was framed in poured-in- place columns and beams/slabs. The crane mast was located on the south side of the building under construction. The center of the mast was approximately 22 feet away from the exterior of the building, see Fig. 1 through 5. At the top of the crane mast was the crane platform with operator cab, machinery and a 120 ft. long boom.

The following were the key contractors:

1. Joy Contractors Inc., (Joy) of Elizabeth, NJ, subcontractor for concrete structure
2. Rapetti Rigging Services, Inc., (Rapetti) responsible for crane erection, jumping and rigging
3. Reliance Construction Group, of Quebec, Canada, General Contractor

The tower crane, model M440E, involved in the incident was manufactured by Favelle Favco (Favco) of Harlingen, Texas, see Fig. 6. The crane was reported to be 1 year old and is owned by New York Crane of New Jersey. The foundation and the tie beams were designed by Stroh Engineering Services, PC, of West Babylon, NY. The total height of the crane at its final stage was to be 472 ft. high. At the time of the incident, the height of the crane was approximately 250

ft. The tower consisted of typical sections, 13'-1/2" (4 meters) high. The sections were bolted together at four leg sections by four 2" diameter bolts, specially manufactured by Favco, see Fig. 8 & 9. The mast consisted of four wide flange shape legs 6'-10" center to center on all four sides. All structural steel conformed to Australian standards. The equivalent U.S. steel shape for the legs is W12x106 (Grade 50). The mast legs were connected to each other by horizontal and diagonal members. On two opposite sides, the horizontal and diagonal members consisted of round steel pipes. On the other two opposite sides, the horizontal and diagonal members consisted of steel angles, see Fig. 8. The diagonal pipes were reversed in direction on opposite faces.

The crane was erected so that the crane column flanges were parallel to the building. The north face of the crane mast was closest to the building. The diagonal bracings on the east and west sides consisted of 6" steel pipes welded to the mast leg flanges. The horizontal members on the east and west sides were 5" steel pipes, also welded to mast leg flanges. The knee bracings on the north and south sides consisted of steel angles 6x6x3/4". The horizontal members on the north and south sides were 6x6x1/2". Both steel angles were welded to the mast leg flanges.

The crane mast was laterally supported by steel beam ties connected to the building's structural slabs at the 3<sup>rd</sup> and the 9<sup>th</sup> floor. The ties at each floor consisted of three wide flange beams fastened at one end to the building floors and at the other end pinned to a square steel collar surrounding the mast of the crane. The tie beams on the 3<sup>rd</sup> and the 9<sup>th</sup> floors were installed using a mobile crane at the time of the initial installation of the crane. The employees were installing the tie beams on the 18<sup>th</sup> floor without using any mobile crane. This was the first time the employees were installing the tie beams in this manner by using the crane itself.

As the building construction progressed, the building increased in height. At the time of the incident, the 19<sup>th</sup> floor was already poured with forming in progress for the 20<sup>th</sup> floor. Under the 19<sup>th</sup> floor, there was one level of shoring and two levels of reshoring. Subsequently, on the day of the incident, the crane height was also increased by four sections to a total height of 250'. The crane was then placed back in operation. The next thing to accomplish was to connect the mast to the 18<sup>th</sup> floor slab through the tie beams to provide lateral support to the mast. The process to

accomplish this task was first to erect a steel collar around the crane mast by suspending it from the mast steel members above the collar. At this time, the collar would not be physically connected to the mast but will have an approximate gap of 2” between the collar and the mast. Then the collar to the 18<sup>th</sup> floor was to be connected by three tie beams. One end of the tie beams would be fastened to the structural floor slab, and the other end placed in the collar pocket and pinned. The crane mast would then be re-plumbed, and the gap between the collar and the mast would then be eliminated by tightening the blocks to provide a tight fit. There would be no positive connection between the collar and the mast. The tie beams were to transfer lateral loads only, and not the gravity loads.

The collar weighed approximately 11,200 pounds and came in two halves. The collar was fabricated by the crane manufacturer in 2006 (Model: Building Ties BT110393, Serial No: 012, 018). Each half of the collar is made of a C shape, and when bolted together at its final location, it becomes a square shaped collar ready to receive tie beams. Each half of the collar essentially consists of approximately U.S. W12x87 oriented about the minor axis on all three sides. 2” thick plates were welded to the flange tips of the collar beam parallel to the web of the collar beam, see Fig. 10. The vertical space between the two plates provided the pocket for the tie beam connection to the collar. Through the two plates was a hole for a 3” diameter pin to fasten the tie beams.

After the crane was successfully “jumped”, the employees were then ready to erect the collar and then to install tie beams on the 18<sup>th</sup> floor. Approximately one hour before the incident, the crane hoisted the first half of the collar, weighing approximately 5,600 pounds, and brought it near the 18<sup>th</sup> floor, see Fig. 13 & 14. Each half of the collar was equipped with six lifting lugs from which it could be supported, see Fig 11. For the sake of discussion and clarity for this report, see Fig. 12, each supporting lug has been marked as A through F, in one half of the collar and G through L in the other half. These alphabetical markings were made by the author of this report and not by the manufacturer. The crane hoisted the first half of the collar on the east side of the crane mast by using lugs marked as C and D. As the hoist approached the crane mast, the employees using the tag line positioned the collar by hanging it at northeast and southeast corners by two 2-inch wide polyester slings choked around the column flanges and the steel

angles of the K braces. Each sling was attached to a come along which was, in turn, connected to chain fall fastened to the collar lifting lugs marked B and E. Both slings used at the southeast and northeast corners were manufactured by LiftAll.

In a similar manner, the other half of the collar was then brought by the crane on the west side of the crane mast, again lifting at lugs marked I and J, see Fig. 12. This half of the collar was also hung by two 2" wide polyester slings on the northwest and southwest corners using lugs marked H and K using the same arrangement described above. The sling at the northwest corner was manufactured by LiftAll Company. The sling at the southwest corner was manufactured by Metro Wire Rope of Union, NJ. When both halves of the collar were leveled and plumbed, the two halves were bolted together with four bolts on the north side and four bolts on the south side.

There were no reported problems to this point. The employees then began to maneuver to place tie beams into the collar. As stated earlier, there were three tie beams to be placed, for configuration of the tie beams, see Fig. 5 through 7. At the northwest end, there were two tie beams to be placed, and on the northeast side one tie beam was to be placed. At the time of the incident, only the east tie beam, still supported by the crane, was placed in the pocket of the collar but the pin was not yet placed when suddenly the employees heard a popping sound. Then the employees heard another popping sound followed by a third sound. Soon the collar was sliding down freely to the lower collar, nine stories below, near the 9<sup>th</sup> floor. It struck the collar at the 9<sup>th</sup> level and sheared the tie beams. Next, the two collars then fell together over the last collar near the 3<sup>rd</sup> floor and rested over it, see Fig. 15 through 21. The west and the middle tie beams remained on the 18<sup>th</sup> floor. The east and west tie beams of the 9<sup>th</sup> floor failed at the welded connection to the 9<sup>th</sup> floor slab and got sheared off at the collar. Only the middle tie beam on the 9<sup>th</sup> floor remained connected to the floor slab, see Fig. 22. All three tie beams on the 3<sup>rd</sup> floor remained connected.

The lack of lateral ties transformed the crane mast into a free-standing structure with no lateral support above the 3<sup>rd</sup> floor. The crane mast leaned a little towards the north and then fell towards the south, pivoting near the base of the mast, see Fig. 29 & 30. The crane boom was facing towards the north and the counterweights were towards the south. The crane fell in one

piece striking the building, known as 300-304 E. 51 St., across the street. The crane mast was sheared off at the roof of the building with the top portion of the mast including the crane superstructure separating from the lower portion of the mast. The top portion of the crane somersaulted and landed one block away over another building, see Fig. 32 & 33. The tie beam hoisted by the crane which was placed in the pocket of the collar but not yet pinned flew over 306 and 308 E. 50<sup>th</sup> Street buildings, damaging both structures.

At the time of the incident, there were six Joy employees on the crane mast assisting with the placement of the tie beams. Five were killed, and one was seriously injured. The crane operator, also a Joy employee, was also killed. In addition, a civilian located in the building where the crane superstructure landed was also killed. The president of Rapetti, located on the 18<sup>th</sup> floor assisting with the placement of the tie beams, sustained serious injuries.

### **Analysis:**

Based upon review of available information, eyewitness statements, and all documents, the use of polyester slings and the manner they were rigged around the mast column, resting in the V shape made by the column legs and the steel angle braces, warranted further engineering evaluation by OSHA. It was readily acknowledged that none of the slings were protected against sharp edges of the column legs and the steel angle legs. OSHA proceeded to determine whether the slings placed in the V-shaped crotch could have a significantly reduced capacity to support the load.

There were four slings used to support the collar. All were 2" wide polyester slings, 6 ft. long. Three were manufactured by LiftAll Company, and one was manufactured by Metro Wire Rope. Post-collapse examination of the slings revealed that the Metro sling was used at the southwest corner of the collar, and had a rated capacity of 6,400 pounds, 5,100 pounds and 12,800 pounds under vertical, choker and V basket configurations, respectively, see Fig. 23. The Metro sling bore a serial # Sample-028. The Liftall slings had a similar rated capacity i.e., 6,400 pounds, 5,000 pounds and 12,800 pounds under vertical, choker and basket configurations, respectively, see Fig. 24. Two LiftAll slings, type EE2-802D, bore serial numbers 1049068. The other

LiftAll sling had a serial number, 1020620. The come alongs, Series 653 hand operated load hoists, were manufactured by Columbus McKinnon Corporation of Amherst, NY, and had a rated capacity of 3 tons each. With a usual factor of safety of 4, each sling, if choked properly and in a good condition, would provide an ultimate failure capacity of approximately 20,000 pounds. Given the weight of the collar to be 11,200 pounds, four slings, if all are supporting the collar weight equally, would provide a factor of safety of approximately 7 or more. However, if the slings are not choked properly, and if one of the four slings fails, the capacity of the remaining slings would be greatly reduced.

All four slings failed in the incident, with each sling shearing in two pieces, see Fig. 25 through 28. Out of the eight broken pieces of the slings, only seven were retrieved. Of the seven retrieved pieces, two were still attached to the top most collar lugs at points E and K along with come alongs and chain falls. It was later concluded that the missing piece was the choked portion of the Metro sling located at the southwest corner of the collar.

The seven retrieved slings were marked as follows. The suffix A indicates that one end of the slings was attached to the come alongs. The serial numbers of come alongs are provided below.

1A	57" long	Metro	(Come along Serial Number R8120)
2A	58" long	LiftAll	(Come along Serial Number R8113)
4A	24" long	LiftAll	(Come along Serial Number Q8552)
7A	26" long	LiftAll	(Come along Serial Number xx474)
11	11" long	LiftAll	
12	47" long	LiftAll	
13	47" long	LiftAll	

Close examination of the slings indicated that the matching pieces were:

2A with 11

4A with 12

7A with 13

1A's matching piece could not be found.

### **OSHA retained sling expert:**

OSHA retained a sling expert to examine the sling remnants and opine on the failure characteristics of the slings; see Appendix A for his full report. The sling expert conducted microscopic examination of the fractured surfaces of the slings. The expert was further asked to conduct actual tests of similar new slings at Southwest Research Institute (SRI), San Antonio, TX to determine failure loads of the slings when subjected to sharp edges of the supporting wide flange shapes. The conclusions of his report are contained in Appendix A. The tests at SRI were conducted by rigging the slings around 4" deep wide flange shapes. The tests indicated that the slings failed at loads significantly lower than their ultimate capacities due to contact with edges of the wide flanges. The tests conducted at SRI, however, did not replicate the actual manner the slings were rigged at the site. OSHA was most interested to determine the load carrying capacity of the slings when trapped in a V-shaped notch with sharp edges of the crane mast legs and the steel angles of the braces.

### **Lehigh University Fritz Laboratory tests:**

OSHA contracted with Advanced Technology for Large Structural Systems Research Center (ATLSS) of Lehigh University, Bethlehem, PA to determine the load carrying capacities of the slings under conditions replicating the actual manner they were used. The tests were performed at Fritz Engineering Laboratory (Fritz) of Lehigh University, PA. OSHA rented a section of the crane mast similar to the one used at the site and transported to the Fritz. 12 slings (9 manufactured by LiftAll, and 3 manufactured by Metro) were tested choked around the column flange and trapped in the V shape, as discussed above. It was concluded that under sustained load, the slings failed at approximately 7,100 pounds, significantly lower than 20,000 pounds (5,000 pounds x factor of safety of 4.0 = 20,000 pounds). If loads are quickly applied, the failure loads were approximately 9,000 to 10,000 pounds, see Fritz data in Appendix B. Most interestingly, the failure was preceded by popping sounds similar to what the employees had described to have heard before the incident.

The entire crane mast section was supported on a steel dunnage on the Fritz's concrete floor. Slings were tested one at a time. A tension load was created on the slings. The tensile test fixture included a cylindrical base, a pull bar and a forcing member. The pull bar included a limiting member, a specimen-fixing member and a shaft member. Air was used in the cylinder to produce the tensile force.

The sling was choked around the wide flange of the crane mast leg passing through a V- shaped notch between the angle of vertical knee bracing and the tip of the flange of the mast leg. The sling at the other end was connected to the hook. A chain was passing through the eye bar of the hook and was connected to the cylinder shaft. Air pressure was introduced in the cylinder to induce tension on the slings and the magnitude of tension was increased in segments until the sling failed. The elongation of the slings under load was also measured until the failure of the sling. The graph was drawn for the elongation of the sling against the induced tension load. The sling was choked clockwise as well as counter-clockwise around the column during the testing. Similar testing was carried out by choking the slings at other end of the column where round diagonal bracing was located. It was discovered that the sling was invariably trapped in the V-shaped notch created by the leg flange and steel angle brace regardless of whether there was a diagonal pipe brace or not. However, testing was also conducted by forcing the sling to touch the round pipe brace.

In summary, it was found that the slings failed under a tensile load of 7,100 to 10,100 lbs. The sling under a sustained load failed at 7,100 lbs. Initially a tension of approximately 6,000 pounds was placed on the sling. This did not produce any fracture. Then a higher tension of 7,000 pounds was placed. After a few minutes, the sling began to fracture and consequently the tension on the cylinder was partially relieved. The tension was brought back up to 7,000 pounds, after a few minutes the sling suffered further fracture, relieving the cylinder of the load. This cycle continued until the sling completely failed at approximately 7,100 pounds. All slings failed in an angular direction by being cut between the edges of the wide flange of column and the angle leg of knee bracing. This was similar to the fracture pattern observed in the slings involved in the incident. Manual observation of the failed slings indicated that there was heat generated in the fibers of the sling at a failure point, resulting in melting of the fibers. Further, it

was observed that there were three angular cut marks or impressions where the sling touched the other (remaining three) flanges of the wide flange legs.

The slings elongated considerably under loads, and the elongations were inconsistent. The following are the elongations of the slings as recorded by Fritz at 2,800 pounds,  $\frac{1}{4}$  of the collar weight:

Sling test #	Elongation
2	5 $\frac{1}{2}$ "
3	4 $\frac{1}{2}$ "
4	3 $\frac{3}{8}$ "
5	3"
6	Not recorded
7	4 $\frac{3}{4}$ "
8	3 $\frac{3}{8}$ "
9	3"
10	5 $\frac{1}{2}$ "
11	2 $\frac{1}{4}$ "
12	6"

As is obvious, the elongations of the slings are not consistent. The magnitude of elongations indicates that the collar must be leveled by using come alongs. Under sustained loads, there could be additional elongations after the collar has been leveled. Therefore, there could be a need for constant monitoring of the level of the collar. If the leveling is not undertaken at all four corners, and if the collar is permitted to dip at one corner greater than at other corners, then the load of the collar might be taken by only two slings instead of the four due to the rigidity of the collar. This would double the load on the supporting slings.

### **Standard Erection Procedure as per the crane manufacturer:**

The standard erection procedure of the “ext.climbing/tie erection sequence” is contained in Favelle Favco drawing No. A1-1100.123, issue B, of January 27, 2006. The procedure consisted of five stages with details provided for each stage, see Fig. 11. As described above, each half of the collar is provided with six points where it could be supported or suspended. The drawing A1-1100.123 in Section B-B describes points B and E, and corresponding points H and K as lifting points. The other points (i.e., A, C, D and F, and the corresponding G, I, J and L) are identified as chain block points. From the ground, the collar was supposed to have been hoisted by the crane at the lifting points, (i.e., B and E,) and the other corresponding lifting points H and K to transport it to the final location. Unfortunately, the collar was hoisted at points C and D, and at corresponding points I and J. When the collar was positioned around the crane mast, the employees had no alternative but to suspend the collar from points B and E, and corresponding points H and K. Therefore, because of location of points, B, E, H and K, the slings were choked around the column, thus landing the slings in the V-shaped groove. This resulted in a drastic reduction in the load carrying capacity. If the collar had been supported at points A and F, and corresponding points G and L, and later after the crane hoist was detached from the collar, at points C and D, and corresponding points I and J, the slings would have had adequate capacity because the slings would have been supported from steel members directly above the collar. This would have completely eliminated the need to choke the slings in the manner it was done. Furthermore, the drawing No. A1-1100.123 required that each half of the collar be supported at four points instead of two. If the instructions contained in the drawing were followed, the collar would have been supported at eight locations, until the two halves were bolted together.

### **Metro Wire Rope Sling and failure scenario:**

Post-incident examination of the Metro sling revealed that the sling was already frayed and deteriorated even before it was used to support the collar, (see expert’s report in Appendix A). The situation worsened when the sling was choked around the column, landing it in the V-shaped groove. The degradation and damage to the slings were so extensive that the Metro sling should have been discarded and not used. If, indeed, the Metro sling failed first, then the load of the

collar could have been supported by the two opposite diagonal slings, each supporting approximately 5,600 pounds under static loading. With the impact factor due to dynamic loading, and the contributing load of the tie beam, the slings could have reached the failure loads.

## **Conclusions:**

1. The choice of using polyester slings to suspend the collar at four points was questionable as they are subject to large elongations under tensile loads, thus creating a need to constantly monitor and level the collar.
2. The collar was rigged improperly in that the slings used to suspend the collar were choked around the vertical legs of the crane mast and was seated in the V-shaped groove between the angle bracing and the flange of the crane mast leg. This significantly reduced the load carrying capacity of the slings.
3. The slings were not protected against sharp edges for cuts and abrasions.
4. A deteriorated sling, which should have been discarded if proper inspection of the sling was done prior to its use, was used to suspend the collar.
5. The crane raised the collar from the ground hoisting it at locations different from the crane manufacturer's recommendations. This led the employees to suspend the collar from locations above which there were no horizontal members. This resulted in choking the slings around the legs of the crane mast.
6. Each collar half was suspended at two points instead of at four points as recommended by the crane manufacturer.



# Crane Collapse Buildings Status 3/18/2008 09:00

Printed: 18 Mar 2008 09:00

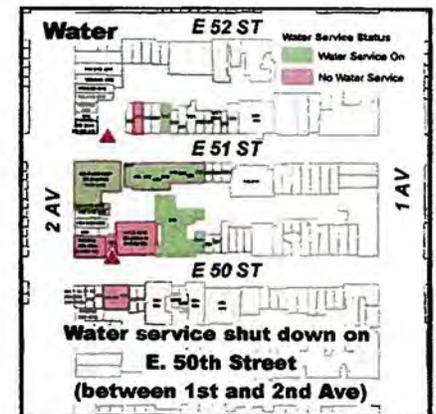
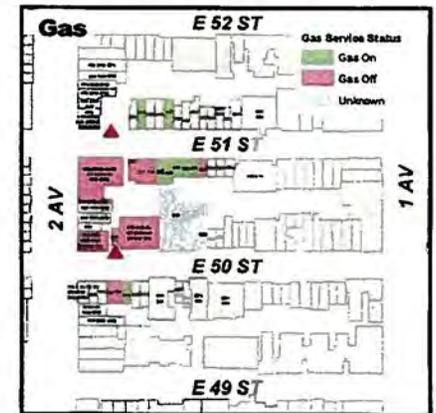
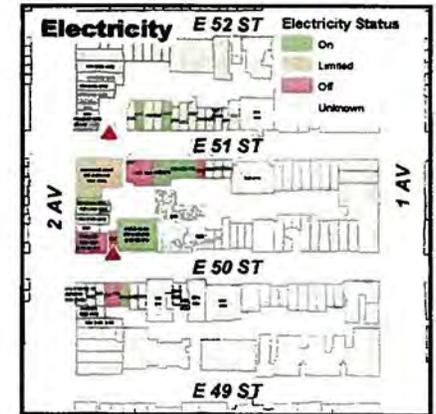
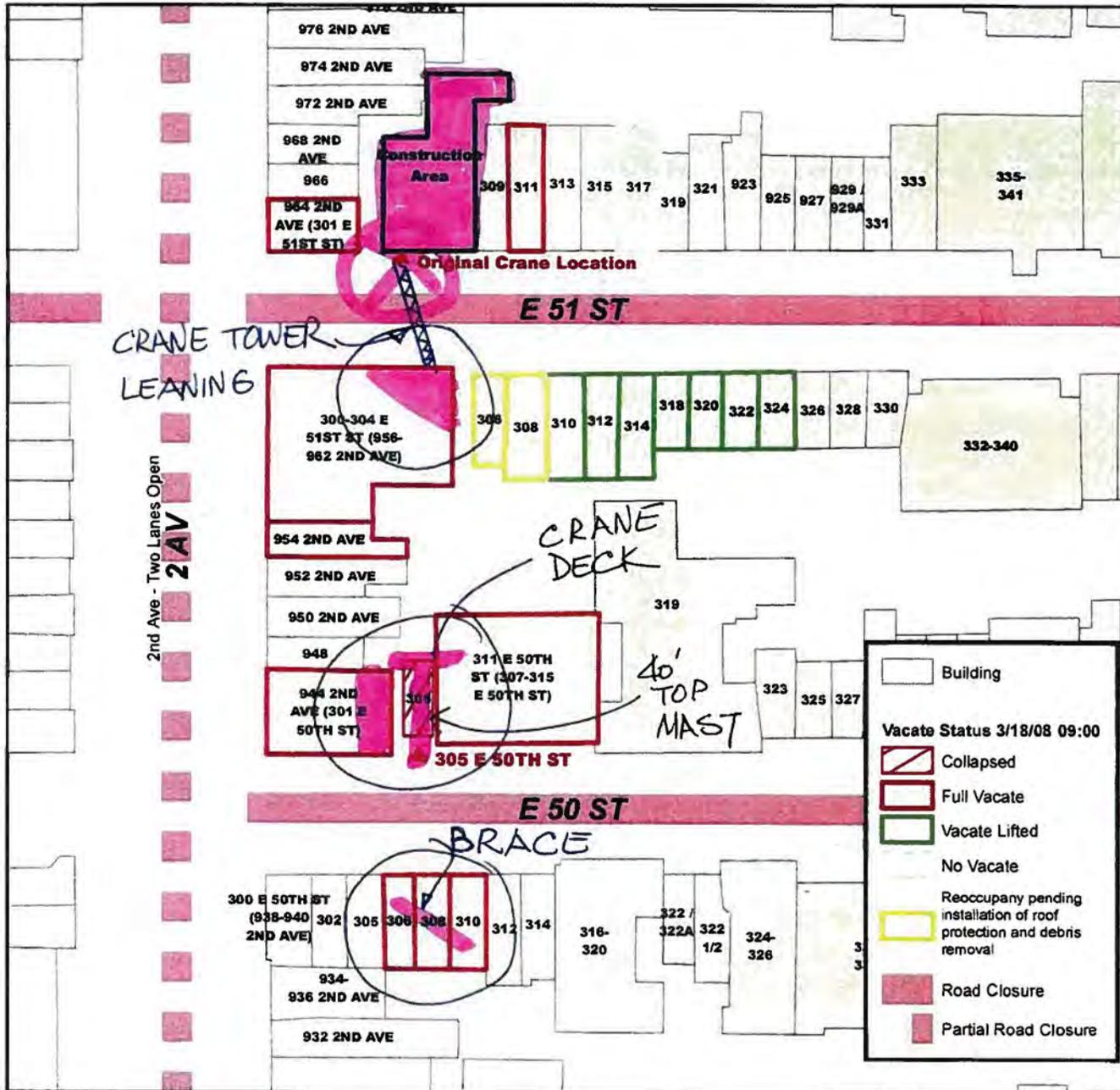
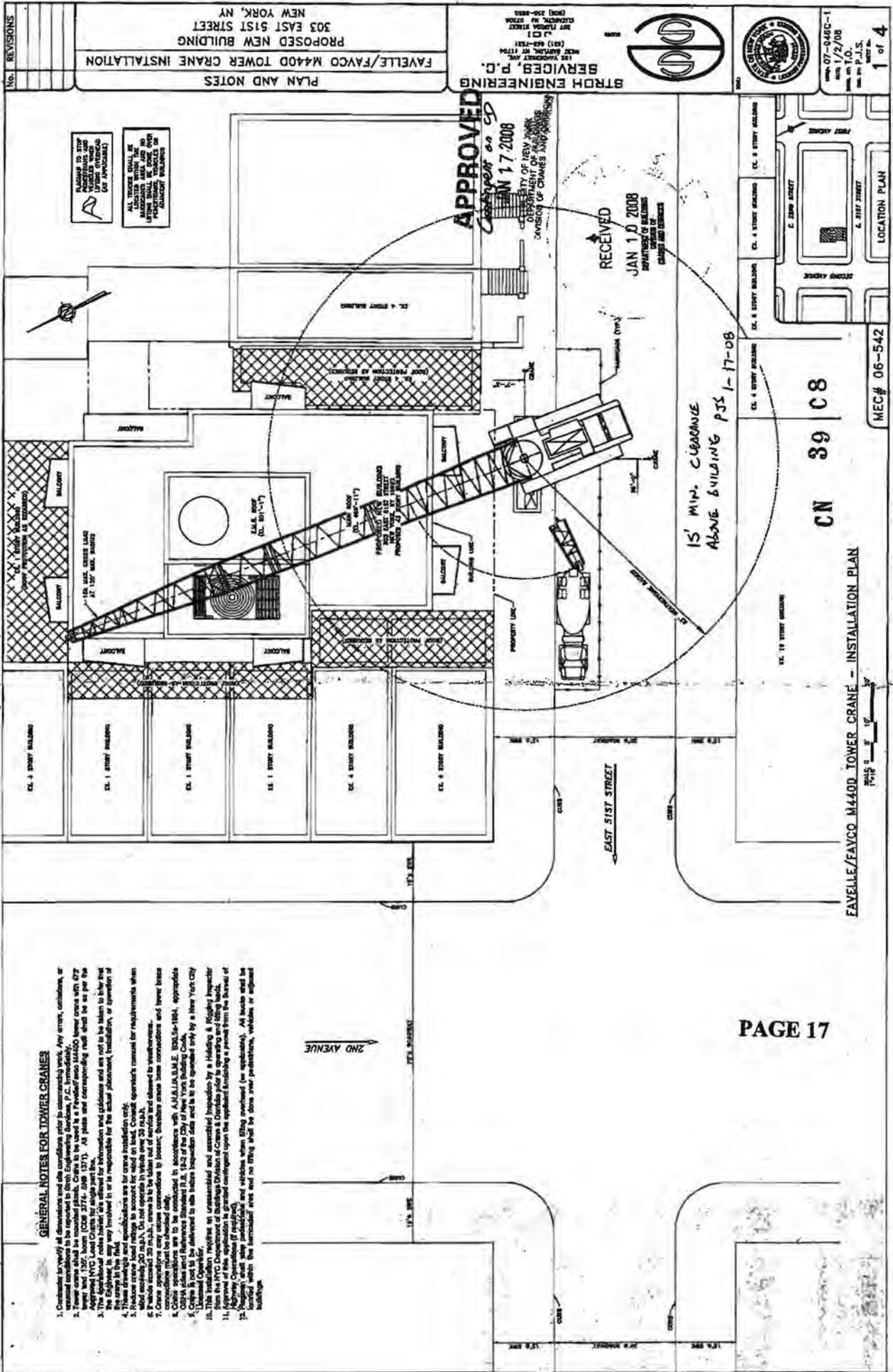


FIGURE 2



**GENERAL NOTES FOR TOWER CRANES**

1. Consider by all dimensions and site conditions prior to commencing work. Any errors, omissions, or unusual conditions to be reported to both Engineering Services, P.C. immediately.
2. Tower cranes shall be mounted on a concrete pad. Cranes to be used in a Favelle/Fayco M4400 tower crane with 67' tower and 100' boom (CM 3742, 398 1071). All parts and corresponding code shall be as per the manufacturer's specifications.
3. The operational code books are attached for information and guidance and are not to be taken to be the Engineer's, in any way involved in or is responsible for the actual placement, installation, or operation of the cranes.
4. These drawings and specifications are for crane installation only.
5. Tower crane load ratings to account for wind on load. Crane operator's manual for requirements when wind speeds 20 mph. Do not operate in winds over 20 mph.
6. Tower crane shall be installed on a concrete pad. Crane operator's manual for requirements.
7. Crane operators carry out crane operations to lowest, heaviest crane same conditions and lowest lease rate.
8. Crane operations are to be conducted in accordance with A.N.A.S.I.M.E. 100.55-1984, appropriate to the crane type and manufacturer's specifications.
9. Crane shall not be delivered to site before inspection date and to be operated only by a New York City Licensed Operator.
10. This installation requires an unassisted and unattended inspection by a Licensed Flight Inspector (LF) and a Licensed Operator (LO) to be performed by the applicant.
11. Approval of this application is granted contingent upon the applicant furnishing a permit from the Bureau of Fire Department.
12. Project shall be completed and site shall be returned to original condition, unless otherwise indicated.

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NO. REVISIONS	PLAN AND NOTES	<b>STROH ENGINEERING</b> SERVICES, P.C. 102 WASHINGTON AVE. NEW YORK, NY 10038 (212) 694-1811 FAX (212) 694-1811 (212) 694-1811 (212) 694-1811		1 of 4 DRAWN BY P.J.S. DATE 1/2/08
	FAYELLE/FAYCO M4400 TOWER CRANE INSTALLATION PROPOSED NEW BUILDING 303 EAST 51ST STREET NEW YORK, NY			

**APPROVED**  
 January 17, 2008  
 CITY OF NEW YORK  
 DEPARTMENT OF BUILDINGS  
 DIVISION OF CRANES AND RIGGING

RECEIVED  
 JAN 17 2008  
 DEPARTMENT OF BUILDINGS  
 DIVISION OF CRANES AND RIGGING

15' MIN. CLEARANCE  
 ABOVE BUILDING PJS 1-17-08

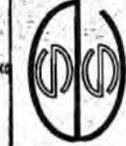
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FAYELLE/FAYCO M4400 TOWER CRANE - INSTALLATION PLAN

MEC# 06-542

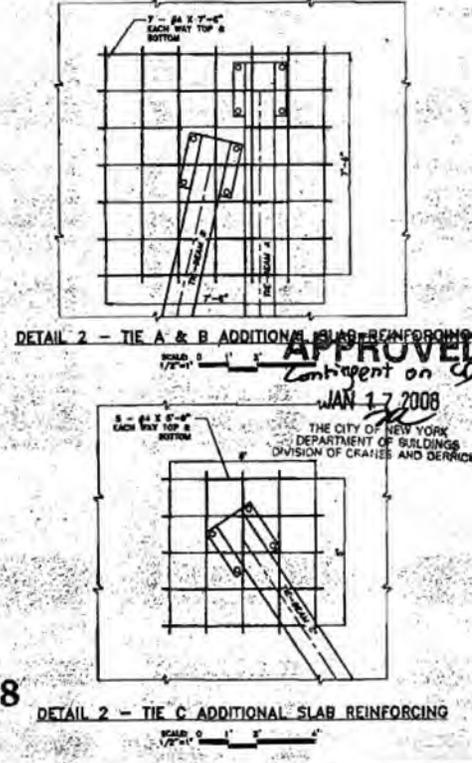
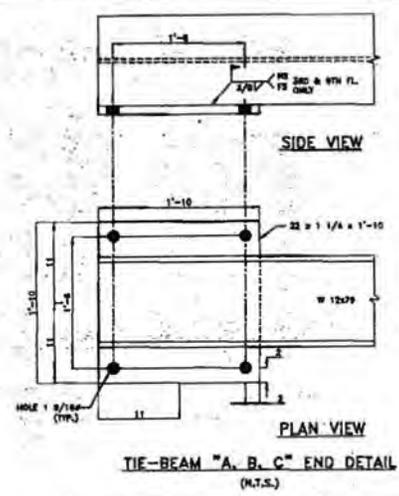
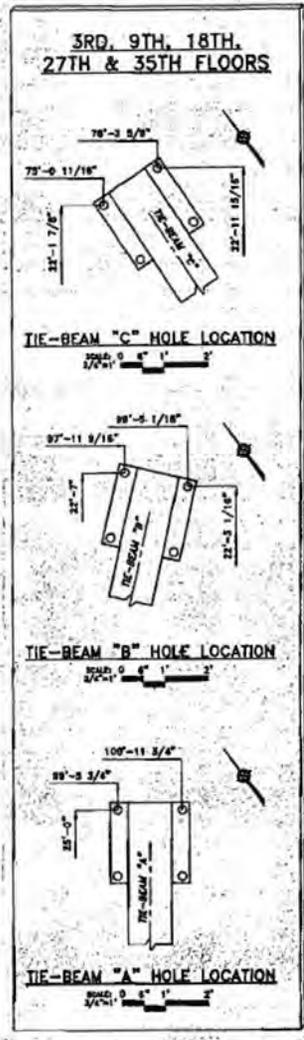
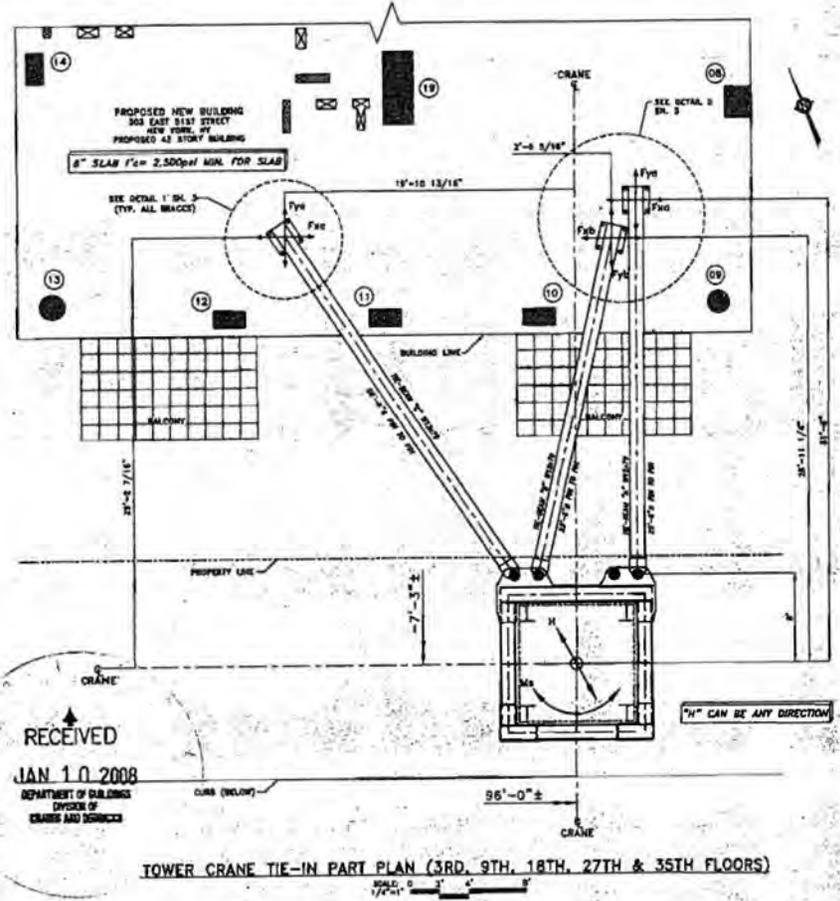
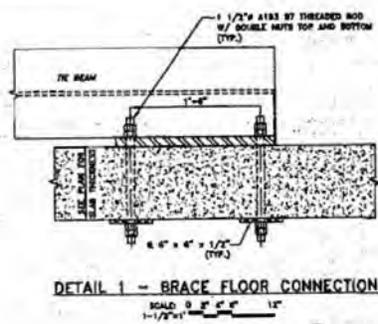
FIGURE 3





**FAVELLE/FAVCO M4400 TOWER CRANE MAXIMUM REACTION FORCES AT ANCHORAGE AND THE LOADS**

		IN SERVICE (33 MPa)	OUT OF SERVICE (90 MPa)
SWAYING MOMENT:	Max	335 K-FT	0 K-FT
	M	73 KIP	105 KIP
HORIZONTAL FORCE FROM CRANE:	F <sub>max</sub>	51 KIP	75 KIP
	F <sub>min</sub>	0 KIP	0 KIP
ANCHOR REACTION - TIE BEAM "A":	F <sub>max</sub>	58 KIP	63 KIP
	F <sub>min</sub>	13 KIP	18 KIP
ANCHOR REACTION - TIE BEAM "B":	F <sub>max</sub>	81 KIP	132 KIP
	F <sub>min</sub>	62 KIP	90 KIP
ANCHOR REACTION - TIE BEAM "C":	F <sub>max</sub>	51 KIP	75 KIP
	F <sub>min</sub>	52 KIP	57 KIP
TIE-BEAM REACTION:	F <sub>max</sub>	110 KIP	140 KIP
	F <sub>min</sub>		



CN 39 08

FIGURE 5

STROH ENGINEERING SERVICES, P.C. 150 WEST WASHINGTON AVE. NEW YORK, NY 10039 (212) 693-7521 (212) 693-8838 FAX (212) 693-7521

FAYELLE/FAYCO M440D TOWER CRANE INSTALLATION ELEVATIONS AND JUMP SCHEDULE

PROPOSED NEW BUILDING 503 EAST 51ST STREET NEW YORK, NY

APPROVED on JAN 17 2008 THE CITY OF NEW YORK DEPARTMENT OF BUILDINGS DIVISION OF CRANES AND DERRISKS

FIG. 07-046C-1 Date: 1/2/08 Drawn by: J.C.S. Check by: P.J.S. 4 of 4

CN 39 08

**TOWER TIE-IN SECTIONS**

TIE	TOWER STYLE	STANDARD
1	3	STANDARD
2	7	STANDARD
3	14/18	STANDARD
4	23	STANDARD
5	29	EXPANDED

**FAYELLE/FAYCO M440D JUMP SCHEDULE**

JUMP	NO. OF SECTIONS	LAST FLOOR POURED	TC-AS USED
1	18	18A,12'	1, 2, 3
2	18 - 22	24A,12'	1, 2, 3, 4
3	23 - 30	30A,12'	1, 2, 3, 4, 5
4	31 - 35	36A,12'	1, 2, 3, 4, 5

NOTED: AS TO BE CHECKED OUT OF SERVICE AND ALLOWED TO REMAIN/REMOVE WHEN WORK EXCEEDS 30 MPH.

RECEIVED JAN 10 2008 DEPARTMENT OF BUILDINGS DIVISION OF CRANES AND DERRISKS

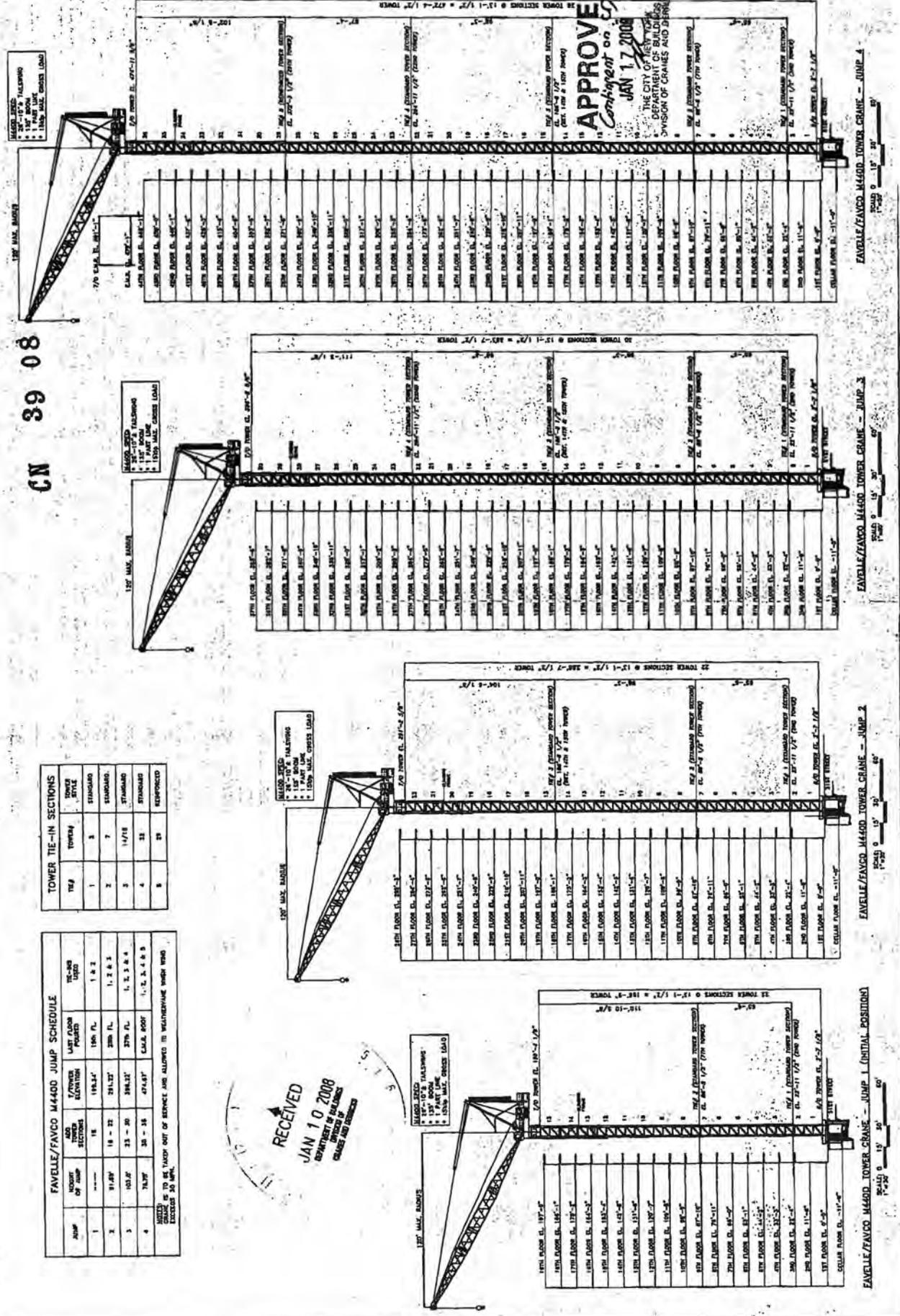
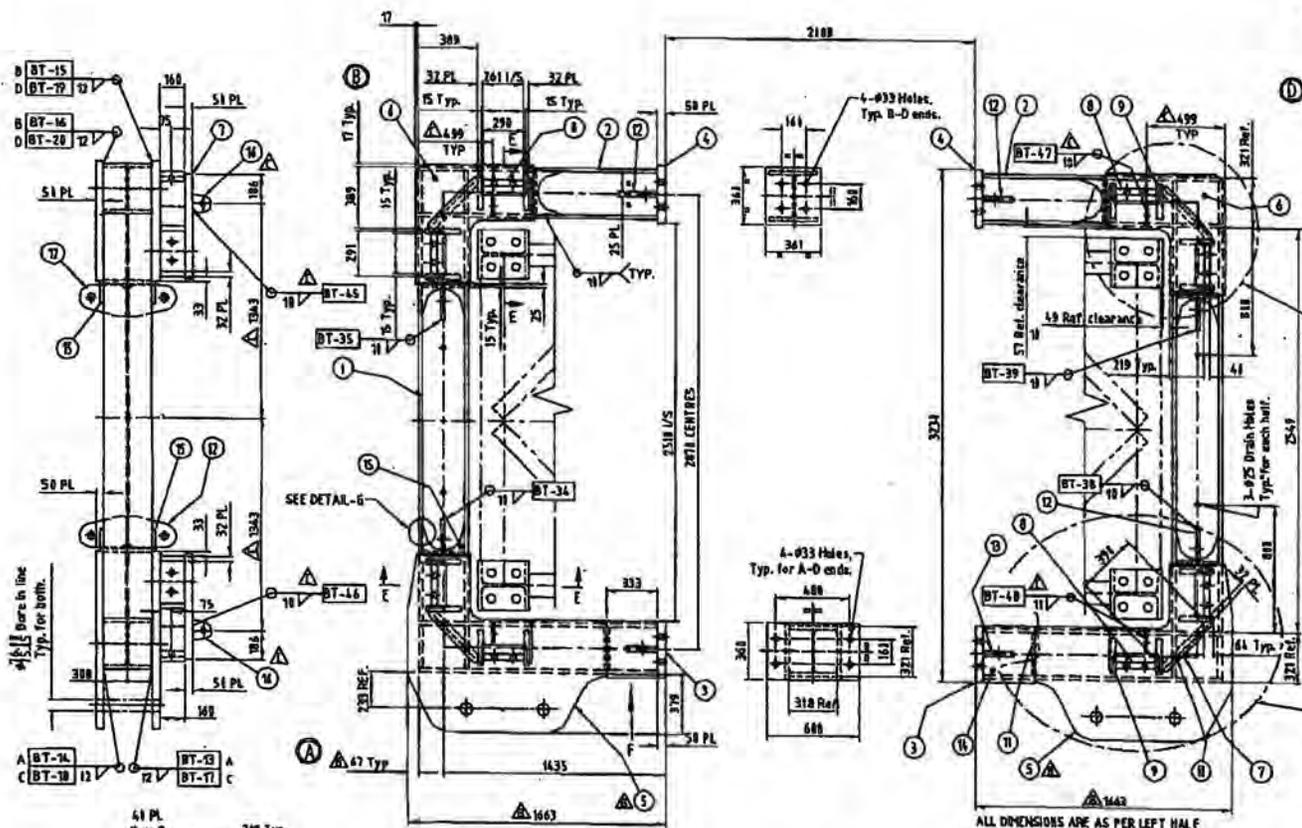


FIGURE 6



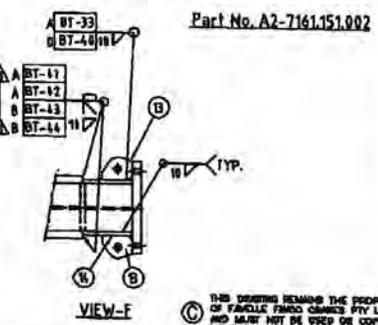
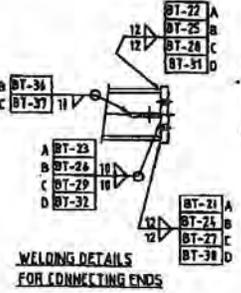
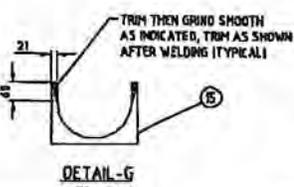
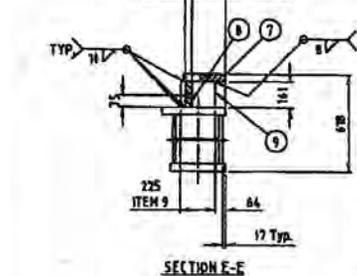
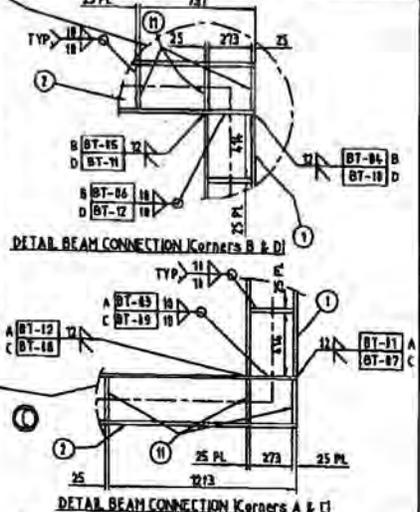






**Material List**

Col.	Item Code	Qty	Description	Length	Material	kg
P 1	UC 2	378	UC 137	2549	3800% FFC SPEC 94	698
P 2	UC 4	378	UC 137	1546	3800% FFC SPEC 94	847
P 3	PL 3	58	PL x 368	680	3500% FFC SPEC 94	171
P 4	PL 2	58	PL x 368	368	3500% FFC SPEC 94	171
P 5	PL 4	58	PL x 1125	1281	3500% FFC SPEC 94	1519
P 6	PL 4	58	PL x 762	764	3500% FFC SPEC 94	457
P 7	PL 4	58	PL x 648	648	3500% FFC SPEC 94	278
P 8	PL 8	41	PL x 161	268	3500% FFC SPEC 94	97
P 9	PL 16	32	PL x 161	225	3500% FFC SPEC 94	145
P 10	PL 4	32	PL x 161	398	3500% FFC SPEC 94	63
P 11	PL 32	25	PL x 145	271	3500% FFC SPEC 94	252
P 12	PL 12	25	PL x 288	318	3500% FFC SPEC 94	111
P 13	PL 4	25	PL x 151	218	3500% FFC SPEC 94	21
P 14	PL 4	25	PL x 333	368	3500% FFC SPEC 94	94
P 15	PL 12	28	PL x 288	288	3500% FFC SPEC 94	32
P 16	PL 4	67	LIFTING LUGS	128	46-PHENOLIAN	4



Part No. A2-7161.151.001

Part No. A2-7161.151.002

DO NOT SCALE FROM DRAWING IF IN DOUBT ASK FFC PTY LTD ENGINEERING DEPT.

Item No.	Item Description	QTY	REVISION	DATE
1	ITEM NO. 6 BOLTS BT-43 - BT-48 ADDED	-	05	C
2	ITEM 3 REVERSED, BOLTS BT-11 - BT-44 ADDED	-	05	B
3	ITEM 5 & 4 MATERIALS WERE ADDED, PRIMARY	-		
4	NOTE ADDED TO ITEM 1-3 & 11	-		
5	ORIGINAL DRAWING TAKEN FROM A2-7161.4	-	05	A

**FAYAT FAYAT** Favos Favos Cranes Pty. Ltd.  
 10/11, 10/12, 10/13, 10/14, 10/15, 10/16, 10/17, 10/18, 10/19, 10/20, 10/21, 10/22, 10/23, 10/24, 10/25, 10/26, 10/27, 10/28, 10/29, 10/30, 10/31, 10/32, 10/33, 10/34, 10/35, 10/36, 10/37, 10/38, 10/39, 10/40, 10/41, 10/42, 10/43, 10/44, 10/45, 10/46, 10/47, 10/48, 10/49, 10/50, 10/51, 10/52, 10/53, 10/54, 10/55, 10/56, 10/57, 10/58, 10/59, 10/60, 10/61, 10/62, 10/63, 10/64, 10/65, 10/66, 10/67, 10/68, 10/69, 10/70, 10/71, 10/72, 10/73, 10/74, 10/75, 10/76, 10/77, 10/78, 10/79, 10/80, 10/81, 10/82, 10/83, 10/84, 10/85, 10/86, 10/87, 10/88, 10/89, 10/90, 10/91, 10/92, 10/93, 10/94, 10/95, 10/96, 10/97, 10/98, 10/99, 10/100

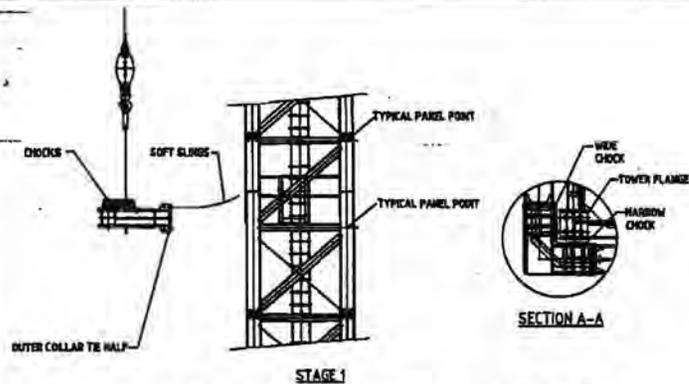
**BT110 - 393**

**BUILDING TIES - DETAILS**

Scale: 1:20

Project: A2-7161.151

FIGURE 10



STAGE 1

1.1 DETERMINE CORRECT ORIENTATION OF INNER AND OUTER COLLAR TIE HALVES RELATIVE TO THE TOWER. THE INNER COLLAR TIE HALF INCORPORATES THE PIN CONNECTION BRACKETS TO CONNECT IT TO THE BUILDING VIA THE TIE BEAMS. THE OUTER COLLAR TIE HALF SHOULD BE ORIENTED TO SPAN THE TWO TOWER LEGS CLOSEST TO AND FACING THE BUILDING. THE OUTER COLLAR TIE HALF SHOULD BE ORIENTED TO SPAN THE OTHER TWO TOWER LEGS WHICH ARE FURTHEST FROM THE BUILDING.

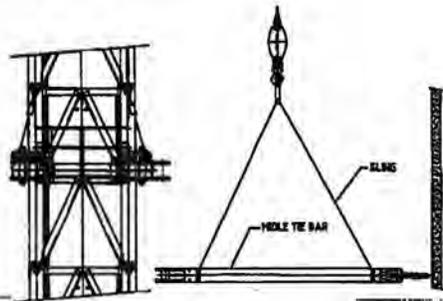
1.2 CHECK CONFIGURATION OF THE CHOCKS IN BOTH THE COLLAR TIE HALVES AND RECONFIGURE IF NECESSARY. AT EACH CORNER OF EACH COLLAR TIE HALF THERE SHOULD BE A NARROW AND A WIDE CHOCK. THE NARROW CHOCK SHOULD BE LOCATED SO THAT IT WILL BEAR ON THE FACE OF THE TOWER LEG FLANGE, AND THE WIDE CHOCK SHOULD BE LOCATED SO THAT IT WILL BEAR ON THE EDGES OF THE TOWER LEG FLANGES AS SHOWN IN SECTION A-A.

1.3 FULLY RETRACT ALL CHOCKS INTO THE COLLARS BY USING THE DRIVING SCREWS TO ENSURE MAXIMUM CLEARANCE BETWEEN CHOCKS & TOWER LEGS WILL BE ACHIEVED. DETERMINE WHETHER THE COLLAR TIE HALVES ARE TO BE ATTACHED TO THE TOWER LEGS WITH THE CHOCKS ON TOP OR BELOW THE CENTRELINE OF THE COLLAR. IF THE CENTRELINE OF THE COLLAR WILL BE BELOW THE NEAREST TOWER PANEL POINT WHEN ATTACHED TO THE TOWER, THEN THE COLLAR TIE HALVES SHOULD BE ORIENTED TO BE LIFTED WITH THE CHOCKS ARRANGED TO BE ON THE TOP OF THE COLLAR TIE HALVES. OTHERWISE IF THE CENTRELINE OF THE COLLAR WILL BE ABOVE THE NEAREST TOWER PANEL POINT WHEN ATTACHED TO THE TOWER, THEN THE COLLAR TIE HALVES SHOULD BE ORIENTED TO BE LIFTED WITH THE CHOCK ON THE BOTTOM OF THE COLLAR TIE HALVES.  
NOTE: THE CENTRELINE OF THE CHOCKS ARE TO BE LOCATED NOT MORE THAN 200mm FROM A TOWER PANEL POINT OF A NON REINFORCED TOWER. IF THIS DIMENSION EXCEEDS 200mm THEN A REINFORCED TOWER MUST BE USED.

1.5 ATTACH TWO EQUAL LENGTH SLINGS TO THE APPROPRIATE LIFTING POINTS OF THE OUTER COLLAR TIE USING 'D' SHACKLES. THE INCLUDED ANGLE AT THE APEX OF THE SLINGS SHOULD NOT EXCEED 60 DEGREES AND EACH SLING SHOULD BE RATED FOR AT LEAST 2 TONNES EWL.

1.6 MAKE PROVISION FOR PULLING THE COLLAR TIE HALF TOWARDS THE TOWER LEGS WHEN RAISED TO THE CORRECT HEIGHT POSITION. 1.6a ATTACH A SOFT SLING TO THE CENTRE OF THE COLLAR TIE HALF OF SUFFICIENT LENGTH, TO ENABLE PERSONNEL TO USE IT TO PULL THE COLLAR HALF IN AND AGAINST THE TOWER LEGS WITH THE CRANE BOOM LIFTING THE COLLAR TIE HALF AT MINIMUM RADIUS.

1.7 LIFT THE OUTER COLLAR TIE HALF TO THE DESIRED ATTACHMENT POINT ON THE TOWER USING THE LIFTING SLINGS AND THE CRANE MAIN HOIST WITH THE BOOM AT MINIMUM RADIUS.



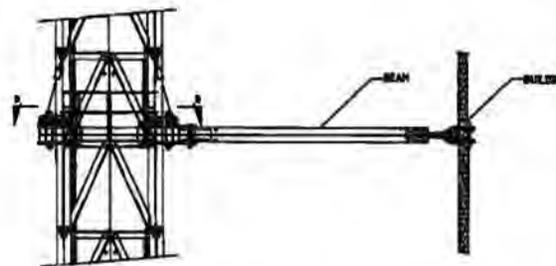
STAGE 4

4.1 ATTACH SLINGS TO THE MIDDLE TIE BAR SO THAT IT IS LIFTED IN A HORIZONTAL ATTITUDE.

4.2 USING THE CRANE OR OTHER SUITABLE LIFTING DEVICES LIFT THE MIDDLE TIE BAR INTO POSITION BETWEEN ITS RESPECTIVE PIN CONNECTION BRACKETS ON THE COLLAR AND THE PIN ATTACHMENT POINT ON THE BUILDING.

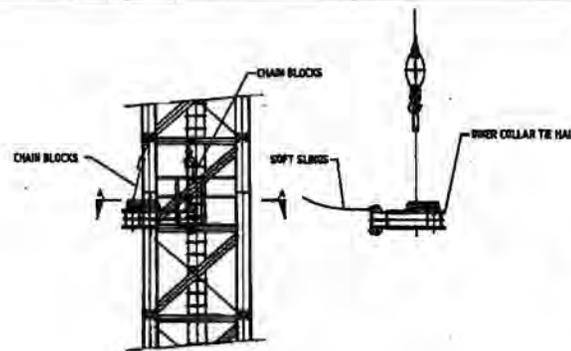
4.3 INSTALL PINS TO SECURE THE MIDDLE TIE TO THE BUILDING PIN CONNECTION BRACKET, AND THE COLLAR PIN CONNECTION BRACKET.

4.4 REPEAT STAGES 4.1 TO 4.3 FOR BOTH OUTER TIE BARS.



STAGE 5

5.1 USING DRIVING SCREWS ADJUST ALL CHOCKS UNTIL EACH ONE JUST TOUCHES A TOWER LEG.  
5.2 TIGHTEN CHOCKS UNIFORMLY ONTO THE TOWER LEGS USING A RATTLE GUN OR SIMILAR.  
5.3 REMOVE ALL CHAIN BLOCKS ADJACENT TO THE BOLTED CONNECTION.



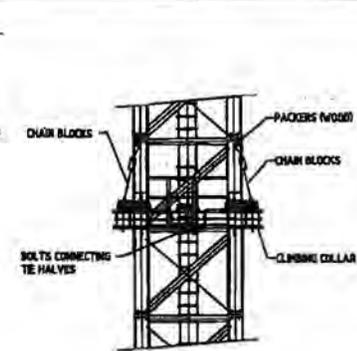
STAGE 2

2.1 WITH THE OUTER COLLAR TIE HALF AT THE CORRECT HEIGHT PULL IT IN TO POSITION AND TIE IT TO THE TOWER LEGS TO PREVENT IT FROM SWINGING BACK OUT.

2.2 ATTACH A 2 TONNE MINIMUM CHAIN BLOCK TO EACH OF THE 4 UNUSED CHAIN BLOCK POINTS ON THE OUTER COLLAR TIE HALF AND CONNECT THE OTHER ENDS TO THE TOWER BRACING.

2.3 USING THE 4 CHAIN BLOCKS, TAKE THE LOAD OF THE OUTER COLLAR TIE HALF OFF THE LIFTING SLINGS SO THAT THEY CAN BE DISCONNECTED FROM IT.

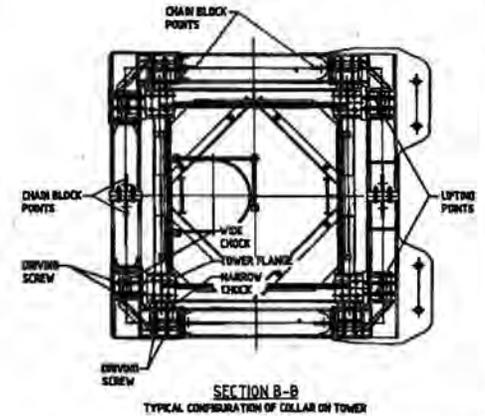
2.4 REPEAT STAGES 1A TO 2.3 ABOVE TO LOCATE THE INNER COLLAR TIE HALF.



STAGE 3

3.1 USING THE CHAIN BLOCKS ON THE COLLAR TIE HALVES RAISE OR LOWER THEM AS NECESSARY UNTIL THEY ARE CORRECTLY LOCATED AT THE RIGHT HEIGHT POSITION ON THE TOWER LEGS.

3.2 BOLT THE INNER AND OUTER COLLAR TIE HALVES TOGETHER, USING THE BOLT SIZES AND BOLT TORQUES SPECIFIED ON THE RELEVANT COLLAR ASSEMBLY DRAWING.



SECTION B-B  
TYPICAL CONFIGURATION OF COLLAR ON TOWER

DESIGN	DESIGNED BY	DATE	BY
27/01/06	27/01/06	2006	2006
Checked	By	Revision	2006
<b>F/FILE</b> <b>FINCO</b> Favella Favco Cranes Pty. Ltd. A subsidiary of Fiddell Engineering Ltd 2006 1st Floor 2/4, 1234			
Project	M440E		
Doc	Activity No. 100		
EXT. CLIMBING COLLAR/TIE ERECTION SEQUENCE			
Drawn	Checked	Rev. Drawn	Scale
05	AMC	27/01/06	1:1
Sheet	1 of 1		
Approved	By	Approved	By
HP			
			A1-1100.123

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FIGURE 11

BUILDING UNDER CONSTRUCTION

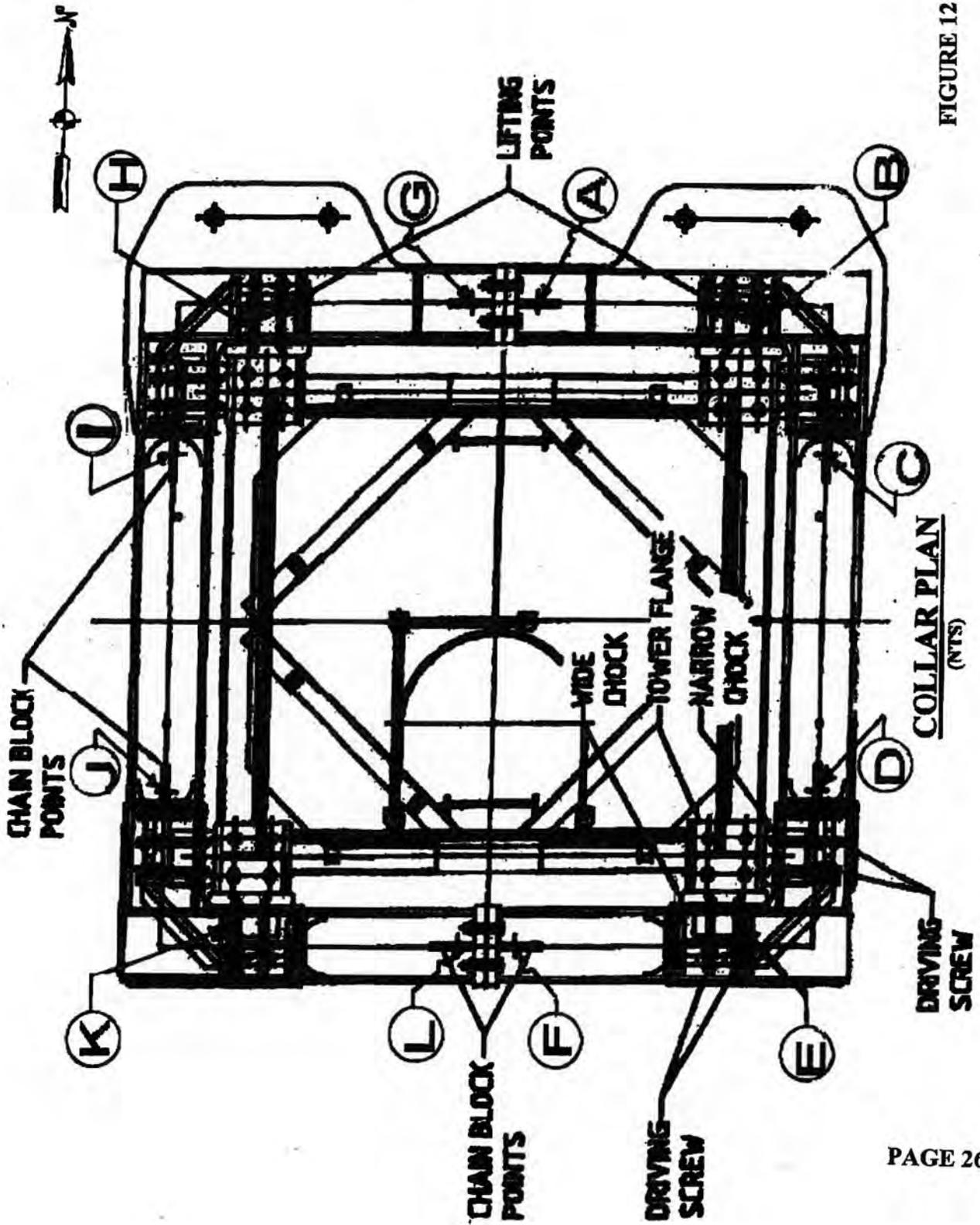
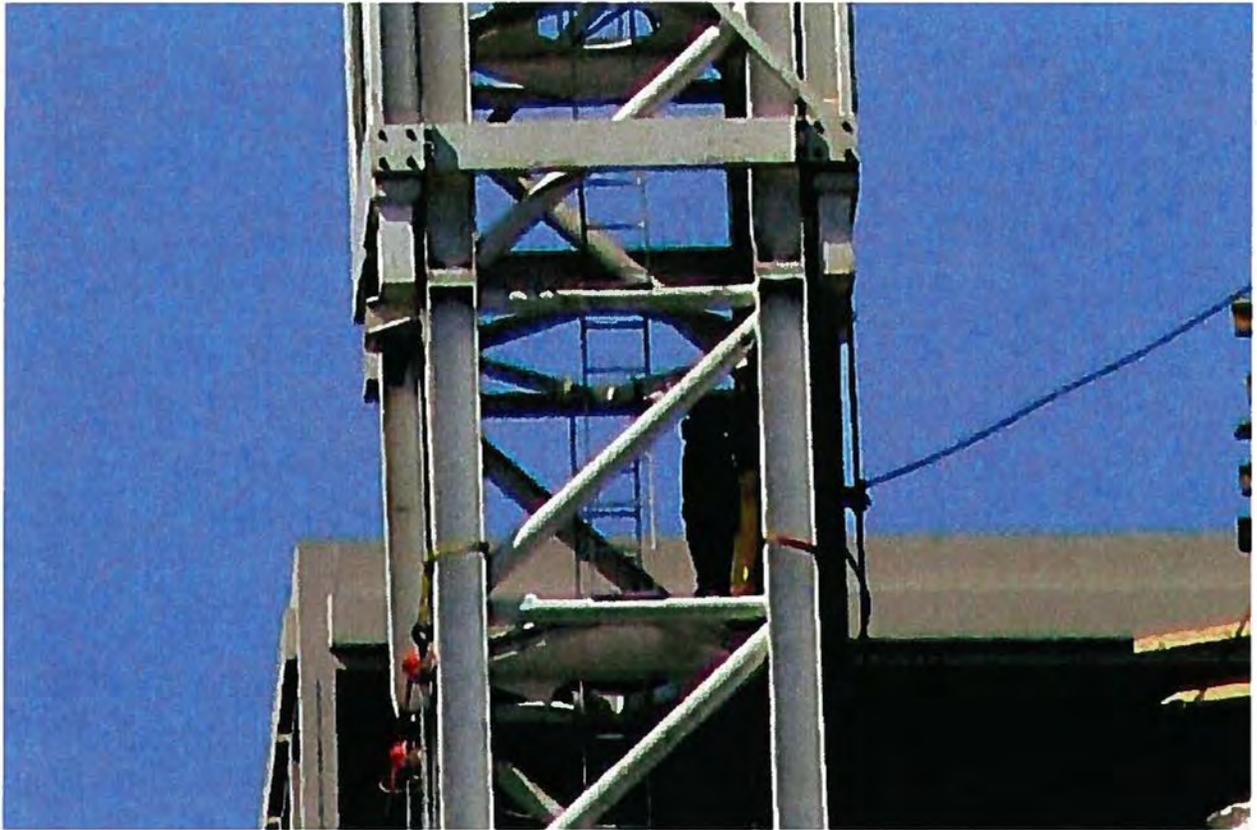


FIGURE 12



Crane at 303 East 51st Street, New York City

**FIGURE 13**



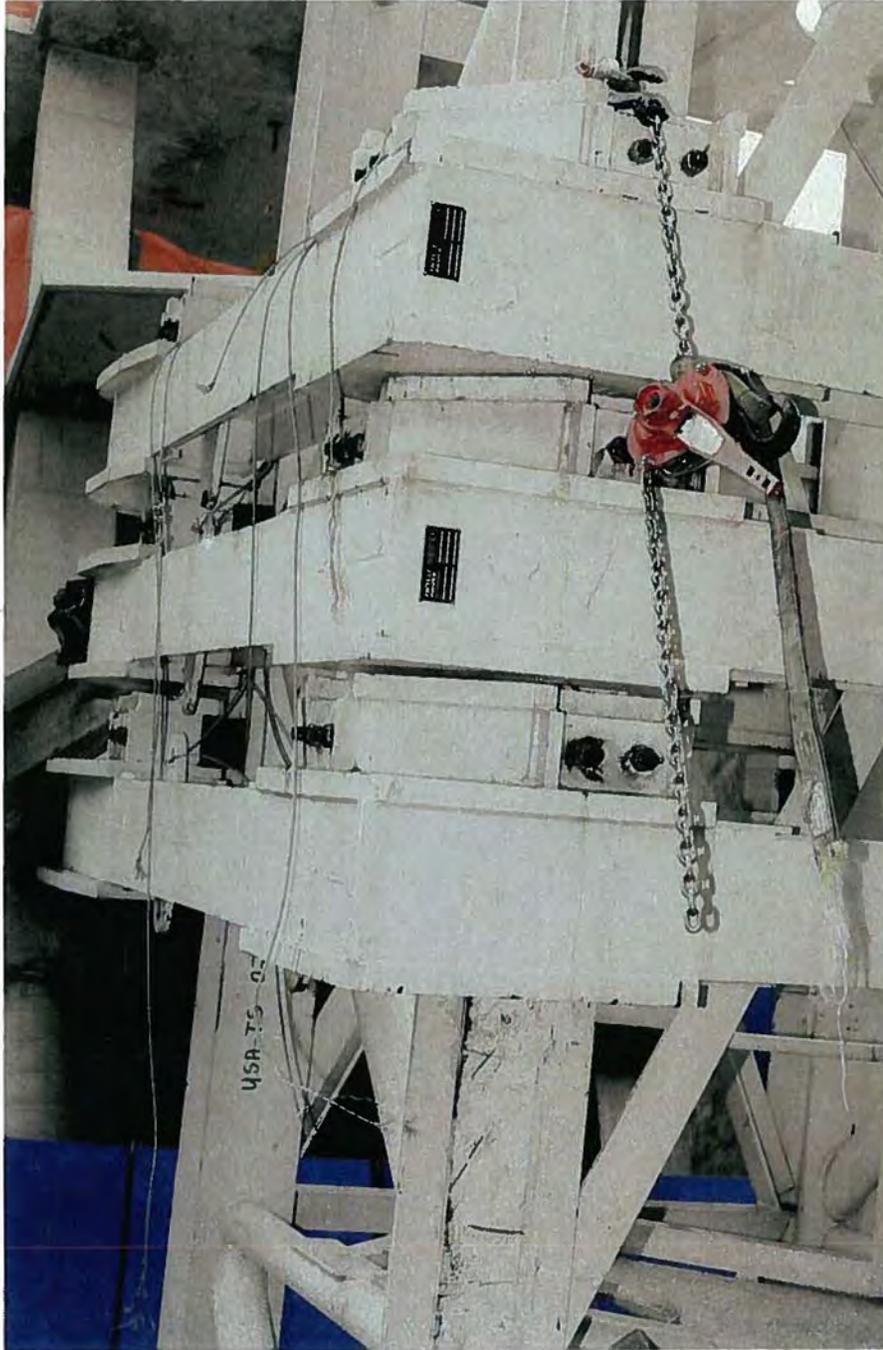
**FIGURE 14**



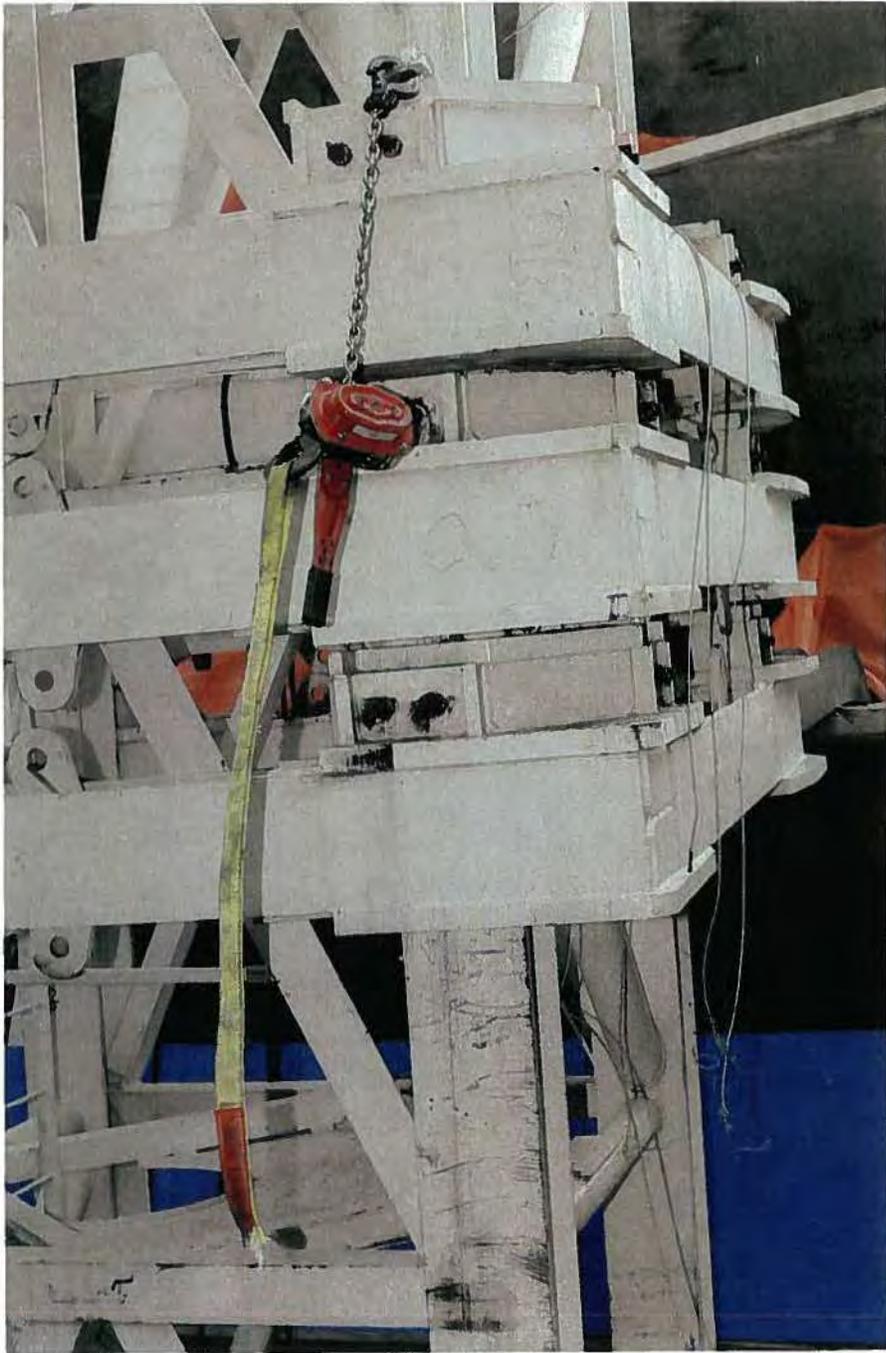
**FIGURE 15**



**FIGURE 16**



**FIGURE 17**



**FIGURE 18**



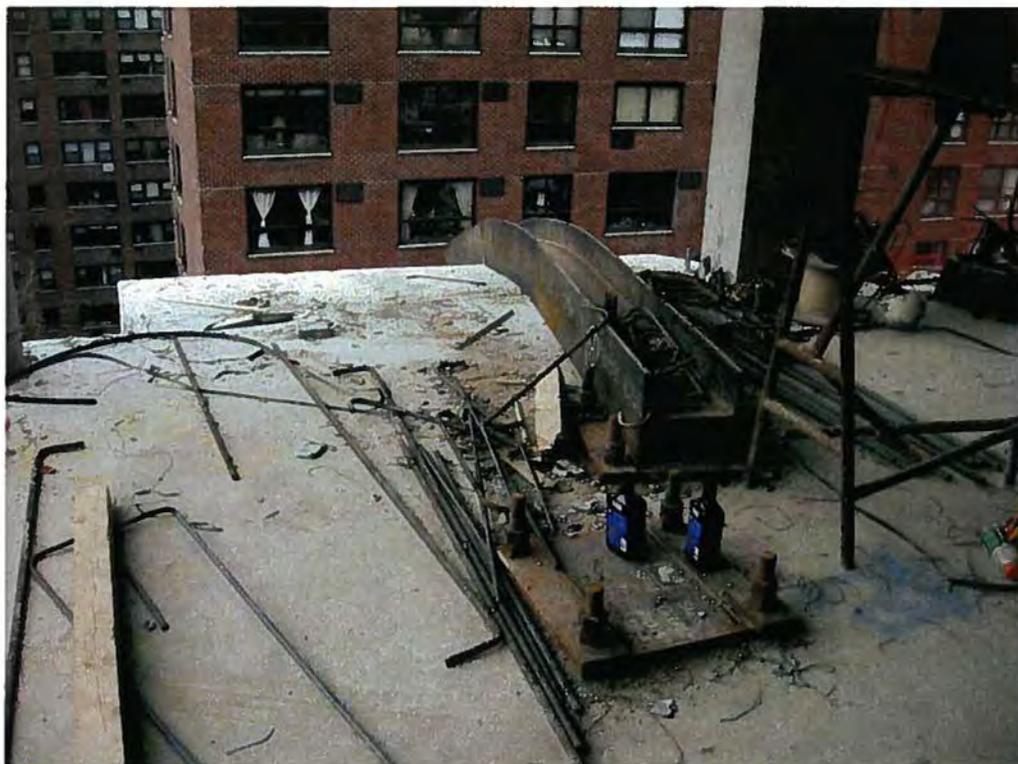
**FIGURE 19**



**FIGURE 20**



**FIGURE 21**



**FIGURE 22**

9<sup>th</sup> flr



FIGURE 23



FIGURE 24



**FIGURE 25**



**FIGURE 26**



FIGURE 27



FIGURE 28



**FIGURE 29**



**FIGURE 30**



**FIGURE 31**



**FIGURE 32**



**FIGURE 33**

# **APPENDIX A**

**(No. of sheets 41 including this sheet)**



**PELLOW**  
**ENGINEERING SERVICES, INC.**

**DONALD L. PELLOW**

**SLING BREAKAGE INVESTIGATION  
FOR  
DEPARTMENT OF LABOR – OSHA**

**CRANE COLLAPSE  
EAST 51 ST STREET  
NEW YORK, NY**

**DONALD L. PELLOW – P.E.  
ENGINEERING CONSULTANT  
AUGUST, 2008**

## **SLING BREAKAGE INVESTIGATION FOR DEPARTMENT OF LABOR - OSHA CRANE COLLAPSE EAST 51 ST STREET – NEW YORK, NY AUGUST, 2008**

### **INTRODUCTION**

On March 15, 2008, a tower crane on East 51<sup>st</sup> Street collapsed while being erected against the side of a building. The tower crane structural sections had reached approximately 190' above ground level when the mishap occurred. As a 11,280 pound steel collar was being maneuvered into place around the tower structure, the web slings holding the collar ruptured, resulting in the collar falling. The collar proceeded to descend to the ground, stripping a second collar from its connection to the building at about the 100' level, resulting in these two collars falling further and striking a third collar at about the 30' level.

The tower crane then became totally unsupported and began to topple, and finally fell against an adjacent building. The boom of the crane, along with the counterweights and cab, was catapulted across the top of several buildings, finally crushing through the top of a housing unit. This crane collapse resulted in the death of several persons and injuries many others.

Pellow Engineering Services, Inc. was contacted to review the evidence, with specific focus on the cause of failure of the four web slings supporting the top collar. The investigation was to include an examination of the rigging at the Manhattan New York OSHA office, followed by an inspection of several tower crane remnants and the steel collar in a warehouse at Pier #39 in New York City. Subsequent to this initial inspection, a more in depth analysis of the web slings and testing of new, unused exemplar web slings was conducted at Southwest Research Institute, a Nationally Recognized Testing Laboratory in San Antonio, Texas. At the testing and evaluation at SWRI, multiple photographs were taken and a video recording was made of various inspection and testing procedures. Following this testing, another series of tests was conducted at Lehigh University using an actual section of the crane tower and exemplar web slings.

### **FINDINGS**

#### **INVESTIGATION AT OSHA & WAREHOUSE IN NEW YORK**

The initial investigation at the Manhattan OSHA office in New York City involved reviewing the evidence collected regarding the rigging supporting the steel collar. The four chain hoists and seven of the web sling remnants were inspected, measured and photographed (Photograph #1). Each of the chain hoists is rated at 3 tons, thereby

# APPENDIX A

providing a total of 12 tons of lifting capacity. As noted in Photograph #2, these chain hoists have been damaged from the accident, but still appeared to be in working condition. Three of the hoists were still in a locked position, while the fourth, which was connected to sling samples #2A & 12, was in the open position. The chain was moved through the drive sprockets with ease (Photograph #3), but when the latch was moved to the locked position, the hoist did hold the chain securely. It is not believed that any slippage of the chains occurred at the time of the accident, but that the latch on one hoist was open due to the accident and subsequent recovery of evidence. A white, powdery substance was noticed on the bottom of two of the chain hoists (Photograph #4), but it is believed that this is possibly a cement residue resulting from the impact of the hoists against the ground during the crane collapse.

The four web slings which ruptured during the accident are 2" wide, 2-ply, polyester web slings, 6' in length. Three of the slings have tags attached that indicate they were supplied by the LiftAll Company (Photograph #5), while the fourth sling came from Metro Wire Rope Corporation (Photograph #6). The LiftAll sling tags list a rated capacity of 5000 # for a choker hitch, while the Metro sling tag lists 5100 #.

Due to all four web slings breaking, there would have been eight sling remnants remaining. However, only seven sling sections were discovered, with the choked section of the Metro sling missing. The sling remnants were matched with opposing mates, and was accomplished by comparing types, lengths and angular cuts as much as possible (Photograph #7). The photographs from the scene of the accident assisted in positioning the slings on the collars (Photograph #8). Photograph #9 depicts the Metro sling, sample 1A, at the southwest corner of the collar, and Photograph #10 shows the southeast corner with sample #11 at the southeast corner. It was determined from segments of the torn identification tag that sample 2A is the companion section of this sling.

Inspection at the warehouse included inspection of a lower tower crane section along with the steel collar that was attached to the slings which failed. Photograph #11 shows a section of the crane tower on a flatbed truck. It was originally thought that the slings were choked around the 6" angular struts, but was later discovered following this inspection, that the slings were actually choked around the vertical 12" I-beams. A photograph taken by an individual of the tower crane approximately 55 minutes prior to the accident reveals that the slings were attached to the vertical I-beams (Photograph #12).

Inspection of the steel collar shows that it is comprised of two sections. A metal tag attached to one of the sections lists a weight of 11,280 # (Photograph #13). Photograph #14 depicts one of the four welded eye pads to which the chain hoist hooks were attached with the use of shackles.

## INSPECTION & TESTING AT SOUTHWEST RESEARCH INSTITUTE

Three boxes of evidence were shipped from the Manhattan OSHA office to SWRI for evaluation, testing and photographing (Photograph # 15). These boxes were opened by Donald Pellow upon his arrival on June 3, 2008.

### SUMMARY OF CONTENTS OF BOXES OF EVIDENCE

BOX	CONTENTS
# 1	DVD of still photographs taken at accident scene Schematic of a tower crane section Sling samples: # 7A – 26” in length #11 - 14” in length
# 2	Sling samples: # 1A – 58” in length # 2A – 58” in length # 4A – 25” in length # 12 - 47” in length # 13 - 47” in length
# 3	Twelve new, unused slings; six, 6’ in length six, 4’ in length (Only the 4’ long slings were tested, leaving the 6’ long slings for future testing. Four of these slings are from LiftAll and two from Metro Wire Rope)

Box #1 contains a DVD of still photographs taken at the accident scene and a schematic of a tower crane section (these items have been retained by Donald Pellow). The other two bags within the package contain sling samples #7A and #11 (Photograph #16). Box #2 contains sling samples #1A, 2A, 4A, 12 and 13 (Photograph #17). Box #3 contains 12 new, unused exemplar slings (Photograph #18). Only the 4’ long slings were tested, leaving the 6’ slings for possible future testing.

The seven sling remnants were once again inspected and matched against companion breaks (Photograph #19). That is, sample 1A from Metro which was left dangling from the chain hoist attaché to the collar has no match; samples #2A & #11 are matches (confirmed from matching torn segments of the red sling tag); samples #4A & #12 appear to be mates; and samples # 7A & 13 appear to be mates (Photograph #19).

The four slings were aligned with the intact eyes together to provide an inspection of the relative locations of the field breaks (Photograph #20). Samples #1A, Metro sling, and #2A, LiftAll sling, both measure 58” from the bearing of the sling eye to the failure location. At the failure location, both of the failure edges display angular cuts through most of the 2” width of the slings, with the longer, stretched fibers parting in a tensile

mode. The shorter samples # 12 and #13, each measuring 47" in length from bearing of eyes to the break, contain diagonal cuts almost entirely across the sling widths. These differences in lengths provide evidence that the longer sling remnants ruptured at different edges of the I-beams than did the shorter remnants.

## SLING SAMPLE 1A – METRO SLING

Inspection of this sample #1A shows the angular cut across and down the body of the sling (Photograph #21). Closer inspection reveals the depth and length of the cut, and the final elongated polyester fibers which parted last in tensile (Photograph #22). This protrusion and separation of the small bundle of cut fibers at the edge of the sling in the upper section of the photograph also suggests that the sling was "bunched" in the crease at the intersection of the I-beam and the diagonal bracing. More evidence of this "bunching" is depicted in the position of this sling in Photograph #12. At even a higher magnification, it is discovered that some of the outer fiber surfaces have experienced ultraviolet degradation, a usual byproduct of exposure to the sunlight (Photograph #23). This is evidenced by the lighter, bleached color on the outside of the sling. The most magnified view of the cut of the fibers at the failure location reveals the sliced edge of the sling, the melting and fusing of the cut fiber ends, and the existence of some bleached outer fibers from ultraviolet degradation (Photograph #24).

"Bunching" in this incident is defined as the folding over and deformation of the web sling width into the "V" configuration. This results from the web sling being forced into the 45 degree crease where the vertical I-beams of the crane tower are attached to the diagonal bracing.

Although the informational tag is still legible, the warning tag is completely washed out and is entirely illegible (Photograph #25). This suggests long term use and exposure to many months of exposure to the environmental elements.

Along the body of the sling, there is a series of three angular cuts across the sling width. Photograph #26 shows one of these cuts. These cuts are spaced approximately 11 ½" to 12" apart, and all three have exposed bright, yellow colored fibers. These spacings correlate to the angular positioning of the sling against the edges of the I-beams of the vertical chords of the tower crane structure, and the angular cuts replicate the direction of contact of the sling choked around the vertical I-beam. Two of the cuts are on one side of the sling, while the one closest the intact eye is on the opposite side. This suggests that the sling was twisted close to the choke.

This sling is quite different in appearance than the three LiftAll slings. Not only has it experienced partial loss of the yellow coloring, an indication of Ultraviolet degradation, the sling eye is a half twist eye, whereas the three LiftAll slings have flat, fold-back eyes.

# APPENDIX A

There are several locations of severe damage along this sling body that appear to have existed prior to this lift, based upon the coloring of the exposed fibers at the points of damage. For example, there are significant edge cuts (Photograph #27), crushed locations not corresponding to the angular cuts (Photograph # 28) and snags and punctures (Photograph #29). Based upon these findings, this sling should have been retired prior to this lift, and never should have been used in this damaged condition.

## SLING SAMPLES 2A & 11 – LIFTALL SLING

The two matched ends of this sling (Photograph #30) show that there has been an angular cut across about 1 ½” of the 2” of the sling body width at the point of failure. There are three locations, starting at 12” from the failure end and spaced about 11 ½” to 12” apart, along the length of the sling which reveal deep impressed creases. These angular deep creases have not cut through the polyester fibers, but again correlate to the position of the sling against the edges of the I-beam.

A close up view of the failure edge displays the linear configuration of the cut across the sling (Photograph #31). The elongated fibers at the left of this photograph show that the last fibers that were not cut have pulled apart in tensile. The highly magnified views of the two sides of this cut confirm that the fibers have been cut, and many of the fibers have fused together from the frictional heat developed from the sling sliding against the edge of a hard surface (Photographs #32 & #33).

## SLING SAMPLES 4A & 12 – LIFTALL SLINGS

Photograph #34 depicts the ends of the break with samples 4A and 12. This angular cut has extended across almost the entire width of the sling body. The straight line cut is depicted on the left side of Photograph #35, while the elongated fibers on the right side show the last fibers to pull apart in tensile. A magnified view of the cut on sample #12 is shown in Photograph #36, which also reveals the melting and fusing of the fibers along the cut edge from the heat developed during the movement and rupture of the sling against a the edge of hard surface.

## SLING SAMPLES 7A & 13 – LIFTALL SLING

Photograph #37 show the matched failure ends of samples 7A and 13. The linear, angular cut across most of the width of the sling is depicted in Photograph #38. The few fibers at the edge of this rupture are the last fibers to pull apart in tensile after the cut has occurred. A highly magnified view of sample #7A shows the directionality of the cut and the fusion of many of the fibers at the point of failure (Photograph #39)

## TESTING OF EXEMPLAR SLINGS AT SWRI

The six slings tested are shown in Photograph #40. Four of these slings are from LiftAll and two are from Metro Wire Rope. However, the sling tags containing the lifting capacities are similar to the tag on the Metro sling which ruptured on the tower crane. The ultimate strength tests were conducted at SWRI on a 400,000 # Tinius Olsen tensile testing machine. The configuration of testing consists of placing one eye of a sling around a 1 3/4" diameter pin at the top dead end, and choking the other end around the live end (Photograph #41). This machine was last calibrated on February 4, 2008 by the Tinius Olsen Company (photograph #42).

When testing was initially planned at SWRI, the information provided stated that the slings were choked round the 6" angular struts of the crane. Therefore, SWRI set up testing to replicate this condition. Two working days prior to testing, it was discovered that the slings had actually been choke around the 12" vertical I-beam chords of the tower crane, and not the 6" horizontal struts. SWRI was able to expedite fabrication of a new test frame using an I-beam so testing could continue on the imposed, limited time schedule to complete this phase of testing. However, this test frame was unable to accommodate a 12" I-beam. Therefore, a section of a 4" I-beam, which is the largest that could be accommodated in the test frame, was welded to the two plates, at about a 13 degree angle. This angle is the largest that could be used in this testing equipment without side loading and possible fracturing the testing pin on the bottom of the frame. Therefore, these tests reflect the loading of the sling against similar edges of an I-beam, but at a small diagonal angle than was experienced on the tower crane. Testing at a larger horizontal angle, as was experienced on the crane at the time of the accident, provides more sliding of the slings against the steel edges and more "bunching" of the slings in the "V" area where the vertical I-beams of the crane tower are attached to diagonal bracing. This was accomplished at Lehigh University.

The first series of SWRI tests positions the lower sling eye choked around the angular I-beam (Photograph #43). The edges of the I-beam closely duplicate the edges of the I-beam chords of the tower crane, and the angle will induce some limited movement of the sling along the I-beam during testing (Photograph #44). The first test, involving a LiftAll sling, broke at 15,275 # at the lower edge of the beam closest to the choked eye (Photograph #45). A close up view of the break shows the cutting of the sling along the edge of the beam, and reveals that the fibers have fused along this cut from movement of the sling against the edge of the I-beam (Photograph #46). After removal of the sling from the test frame, the side view of the sling break reveals that the break occurred at the angle of the beam in relation to the sling body and that the cut fibers extend across most of the sling body width (photograph # 47).

Inspection of the edge of the I-beam where the web sling broke reveals that the polyester fibers of the sling have been cut and melted on the edge of the beam (Photograph #48). There is also evidence of slight slippage of the sling at the edge of the beam. A larger included angle of the beam with the sling would be expected to produce more slippage and a lower breaking strength.

The second sling tested was from Metro Wire Rope. The same type of break occurred at the same location at a force of 16,291 #.

The second series of tests consists of choking the lower eyes around a 1 3/4" diameter pin (Photograph #49). As expected, the slings failed at the choked location on the pin. The LiftAll sling broke at 21,410 # and the unidentified sling broke at 20,102 # (Photograph #50). After removal from the pin, the sling break show that the fibers have parted in a tensile and shearing (Photograph #51) and there is no sign of cut fibers.

The fifth test involves placing a side restraint against the side of the sling as it is choked around the I-Beam (Photograph #52). It was the intent to possibly introduce a sideward shearing force and bunching, but this small angle resulted in only preventing the sling from sliding along the I-beam. This test sample broke at 16,576 #.

The last test involves testing a sling with both eyes around 1 3/4" pins. This is expected to produce the highest breaking strength of all tests. The sling began parting at 32,767 # with all fibers elongating and pulling apart in a tensile mode (Photograph #53). There is no cutting, and the elongation and stretching of the fibers are identical in appearance to the last fibers in the incident slings which pulled apart in tensile after cutting occurred.

## SUMMARY OF TEST DATA & OPINIONS

SLING SAMPLE	RIGGING	BREAKING STRENGTH	LOCATION OF BREAK
LiftAll	Choke around I-Beam	15,275 #	Leading Edge of I-Beam
Metro Wire Rope	"	16,291 #	Leading Edge of I-Beam
LiftAll	Choke around 1 3/4" Pin	21,410 #	At Choke of Eye
Metro Wire Rope	"	20,102 #	At Choke of Eye
LiftAll	Choke around I-Beam	16,576 #	Leading Edge of I-Beam
LiftAll	Eye & Eye with Both Ends Around 1 3/4" Pins	32,767 #	In Body of Sling

These tests could not fully model the sling configuration that was present at the time of the incident. However, this data does confirm that a significant loss in web sling strength is experienced when pulling against the edge of an I-beam. Only slight "bunching" and sliding of the web slings did occur during these tests; however, more severe "bunching" and sliding of the slings on the tower of the crane will produce much more loss in strength. Additional testing at Lehigh University, as described later, confirms this expectation of greater loss with a more severe angle of loading.

From these tests, it is apparent that the cutting edge of the I-Beam at 13 degrees will reduce the strength of a new, unused sling by 50%. However, it is expected that pulling downward on a sling choked around a vertical I-Beam at approximately 45 degrees with the diagonal bracing will result in more slippage of the sling and more severe cutting. This will result in a breaking strength significantly lower than the approximate 16,000 # obtained in these tests. That is, at a greater sling angle with the diagonal bracing, as was experienced on the crane tower, the more severe "bunching" will further reduce the sling strength by unbalancing the loading across the sling width.

This greater angle of 45 degrees will also promote more sling slippage of the slings against the edges of the I-beams during loading, resulting in a dynamic cutting action on the sling and instantaneous frictional heat, both of which reduce the strength of web slings. The Lehigh University tests, along with accident investigations involving failures of web slings, verify that these factors of loading a web sling against a hard, unyielding edge, along with movement of the sling and frictional heat, do result in significant strength loss. In addition, "bunching", or folding of the sling in the crease between the vertical I-beam and the edge of a diagonal brace, will further reduce the strength of the sling.

The Metro sling, which appears to have broken first, was in a damaged condition prior to this lift and was in a weakened condition. So with the additional damaging factors as previously described, plus the fact that the sling was twisted at least once, the Metro sling was most likely being loaded very close to its remaining breaking strength just prior to its rupturing. At this critical moment, any slight movement or shock loading within the lifting system could cause the Metro sling to part.

It is reported that the collar was being manipulated by use a crowbar and a workman was working on top of the collar. These dynamics could likely have caused the Metro sling to finally part. When the Metro sling did fail, the collar tilted, placing most, if not all, of the load on the two adjacent slings. This does not account for the additional dynamic loading on these slings resulting from the shock or impact loading from the falling edge of the collar. The tilting of the collar would also produce movement in the system and possible sliding of the slings against the I-beams and diagonal bracing.

Once the Metro sling parted, the evidence suggests that the southeast LiftAll sling (samples 2A & 11) then failed in an identical manner that the Metro sling broke; i.e., in the "V" crease where severe "bunching" has developed. Once these two slings had failed, the last two slings on the north side received an additional loading from shock and cutting action which caused them to cut and fail along an edge of the vertical I-beams.

## **TESTING AT LEHIGH UNIVERSITY**

Final testing was conducted in the Fritz Laboratory at Lehigh University on August 19, 2008. These tests were conducted on an actual section of the crane tower involved in the accident. New, unused, 6' long, polyester web slings were obtained from Metro Wire

Rope and LiftAll, manufacturers of the slings involved in the accident. From photographs taken just prior to the accident, it was possible to discern the position of the web slings on the tower and to duplicate these loading conditions in the laboratory.

A series of breaking strength tests on several slings was conducted. These all involved the web slings being choked around the vertical I-beams of the tower section in a like manner as seen in Photograph # 12.

All test results, data and loading graphs are available in the Lehigh University report. All of the slings broke at very low values in the "V" crease where the vertical I-beams connect to the diagonal bracing. This is the location where severe "bunching", cutting and sliding of the slings occurs. The configuration of the breaks and location of partial diagonal cuts are identical to those found on the Metro Wire Rope sling (SW corner) and the LiftAll sling (SE corner) involved in the accident. As expected, all slings broke at very low values, nearing the rated capacities of new, unused slings.

In all tests, as the slings were being subjected to increasing loads, the slings would abruptly slip and adjust through the choke. These adjusting movements began at about 2500# and continued at various load levels up to breaking strength. Audible tearing of the web filaments began at approximately 5500# and continued until final breaking strength.

When pulled to ultimate strength, the forces required to break the slings in the "V" crease were consistent. With the additional third ply of material in the location of the choke, both the Metro Wire Rope and the LiftAll slings broke in the range of 9550 # to 10,169#. With only two plies of webbing in the "V" crease, the breaking strengths range from 7788# to 8421#. This slight decrease was expected due to the extra ply of webbing in the cutting area. Placement of rubber pads in the "V" crease and on the edges of the beam provided only a small amount of protection, as the breaking strength reached only about 11,000#.

The result that is remarkable is test sling #11. This sling was loaded to about 7000#, slightly above where web fibers began to fail in the "V" crease. This load was sustained for a period of time during which webbing fibers continued to fail. The sling eventually failed at this load of approximately 7000#, which shows a delayed, prolonged failure.

## **SUMMARY**

- A. The investigation of the failed slings, along with the tests conducted at SWRI and Lehigh University, indicate that one of the factors that led to the failures of the four slings is cutting of the sling webbing against the edges of the vertical I-beam chords of the tower crane at an angular direction.
- B. The test results at Lehigh University indicate that the Metro Wire Rope web sling in the SW corner and the LiftAll web sling in the SE corner failed in the "V" crease of the tower section where the vertical I-beams are attached to the diagonal bracing. This "bunching" is another factor in causing the sling to fail by further

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- decreasing the strength of the slings and promoting additional cutting against the diagonal bracing.
- C. A third cause of the slings failing was the use of a deteriorated web sling that showed conditions of retirement prior to the lift. The Metro Wire Rope web sling (SW corner) was in a highly worn and used condition prior to this accident. It is believed that this was the first sling to fail. Because of an identical mode and location of break, it is believed that the second sling to fail was the LiftAll sling on the SE corner. The last two slings to break appear to be the LiftAll slings on the NE and NW corners. These two slings on the north side broke at the edges of the vertical I-beams from being cut under a shock loading.
  - D. The Metro web sling in the SW corner appears to have been used for a much longer period of time than the three LiftAll slings. Prior to being used in this lift, the Metro sling appears to have lost a considerable amount of strength from ultraviolet degradation, edge cuts, snags, punctures and crushing. The fact that the edges of the I-beam cut through the sling fibers at all contact points of this sling, as opposed to only crushing the other three slings at the contact points (aside from the failure of the two slings on the north side), is further evidence of the weakened condition of the Metro sling.
  - E. The inspection criteria used for synthetic web slings is listed in the ASME B 30.9 – Slings safety standard and in the OSHA regulation 29 CFR 1910.184 regarding slings. Directions on inspections and warnings against using damaged slings are provided in ASME B 30.9, OSHA Regulation 29 CFR 1910.184 and on the LiftAll warning tags attached to the slings. If these standards, regulations and industry warnings on inspection had been followed, this sling would never have been used. In addition, if these standards, regulations and warnings on use of synthetic web slings had been followed, this rigging procedure would never have been done.
  - F. The choking of the web slings around the vertical I-beams was inappropriate and dangerous. This rigging promotes downward sliding of the slings and abrasion and cutting of the slings against the edges of the I-beam. The 90 degree turn from the normal and expected pulling direction also decreases the sling strength. There should have been a reduced loading capacity determined by the riggers when using a choke angle less than the normal expected minimum of 120 degrees, as noted in ASME B 30.9.
  - G. The choking of slings around the vertical I-beam also placed a shearing and cutting action on the sling during downward loading from the resulting angular positioning of the slings against the I-beam edges. From the downward pulling of the sling at the choked location the slings will reposition themselves at an angle around the I-beam, as depicted in Photograph #12. This action places more pressure on one edge of the sling and will cause slings to fail in shearing and cutting at greatly reduced values as compared to the same loading conditions without this angular loading.
  - H. Appropriate corner protectors or other proven sling protection system should have been used to prevent cutting, abrasion or other damage to the sling. ASME B 30.9, OSHA Regulation 29 CFR 1910.184 and the LiftAll sling warning tag all state that slings shall be padded to protect sling from being damaged or cut from

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edges of the load. No padding or protection was provided to the slings to prevent the cutting which occurred. The Lehigh University tests show that a soft rubber cushion is insufficient to protect web slings from being cut when positioned as they were at the time of the accident.

## ROOT CAUSES OF WEB SLING FAILURES

- A. Use of the highly worn and weakened Metro sling from previous wear and damage. If properly inspected according to ASME safety standard on slings, government OSHA regulation 29 CFR 1910.184 and sling manufacturers warnings, this sling would not have been used.
- B. Choking the slings around vertical I-beam chords of the tower crane structure which induced sliding of the slings along the I-beam edges; shearing and cutting of the sling at reduced strength levels; and reduced sling capacity due to decreasing the choker angle below the normal 120 degrees.
- C. Placing web slings in the "V" crease of the I-beams and diagonal bracing subjected the slings to severe "bunching" and reduced strength.
- D. Not providing padding or other devices which would prevent cutting and damaging the sling from the edges of the I-beam.
- E. Not providing sling protection which would have prevented "bunching" at the "V" crease at the intersection of the vertical I-beams and diagonal bracing.

## COMMENTS AND DISCUSSION

The SWRI testing provides supportive evidence that the slings were cut and that greatly reduced sling strengths are the result of cutting and abrasion action against hard edges.

The Lehigh University tests provides supportive evidence that "bunching" of web slings in a "V" crease results in additional significant strength loss of the slings. The rigging of slings against vertical columns and/or diagonal bracing allows slings to slide along the steel edges, resulting in cutting and frictional heat, both of which reduce sling strength.

Inspection of slings prior to each use is critical in assuring the use of undamaged slings. It is extremely important that a sling be removed from service if any of the retirement criteria is evident.



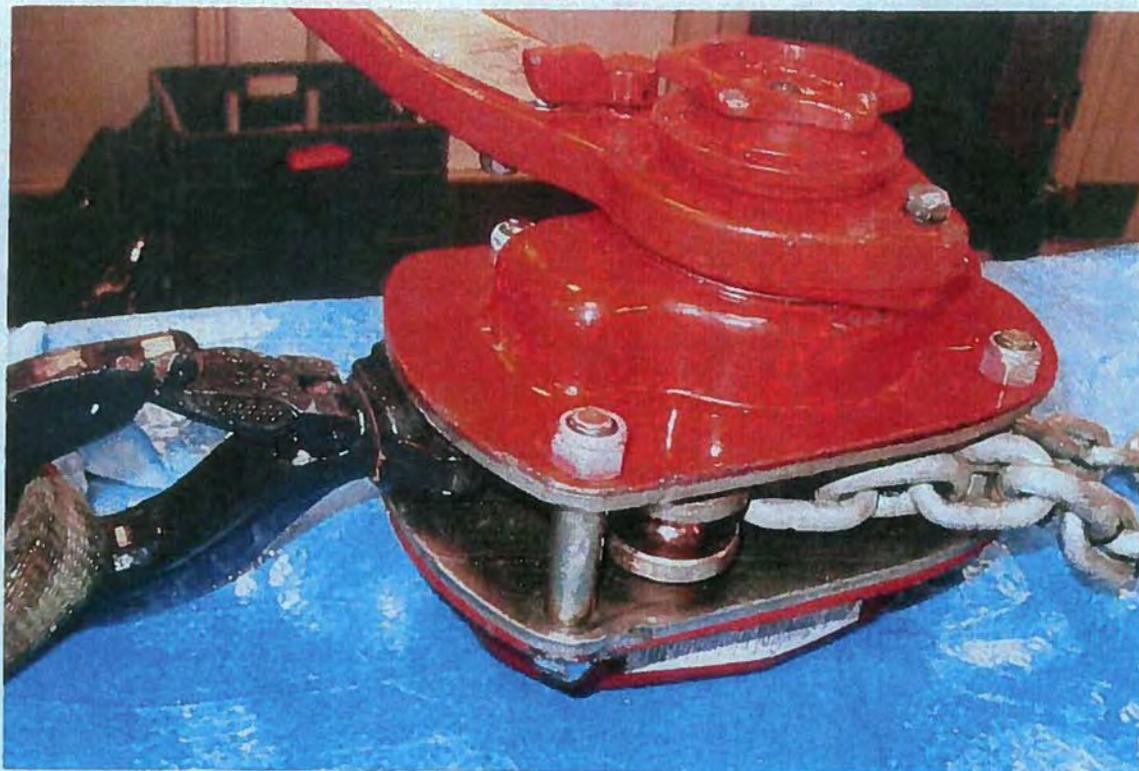
Donald L. Pellow - P.E.  
Engineering Consultant



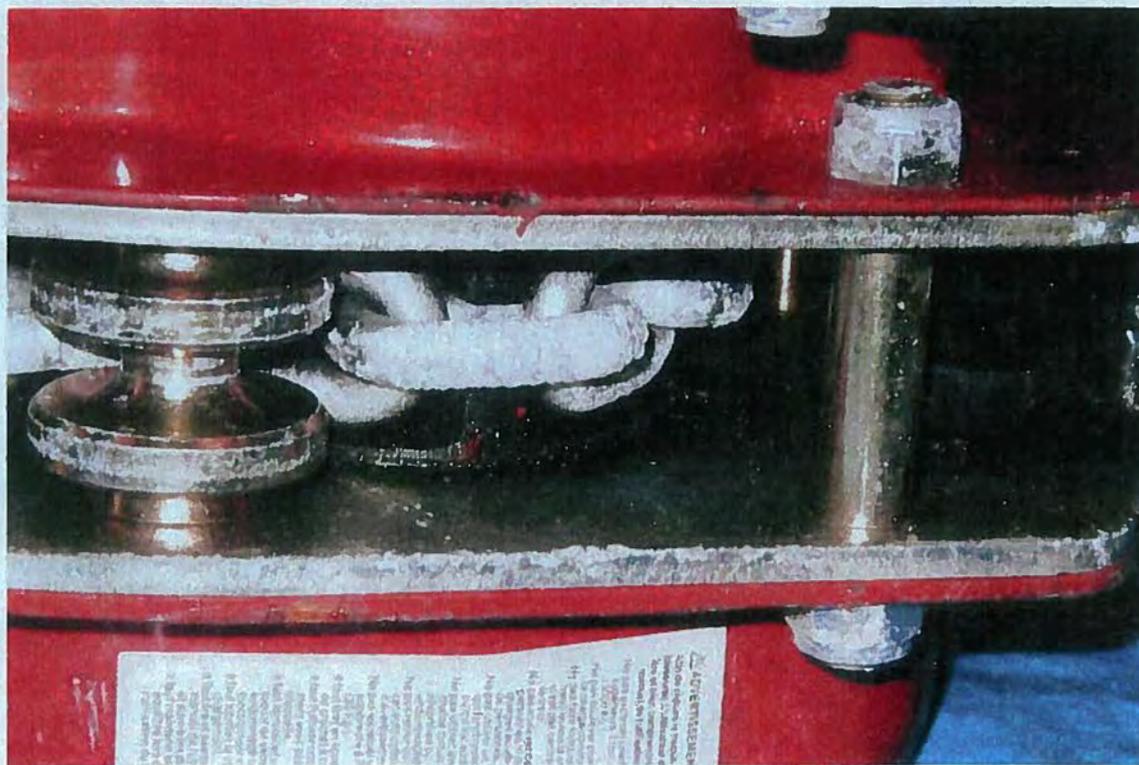
PHOTOGRAPH #1  
INSPECTION AT NEW YORK OSHA OFFICE



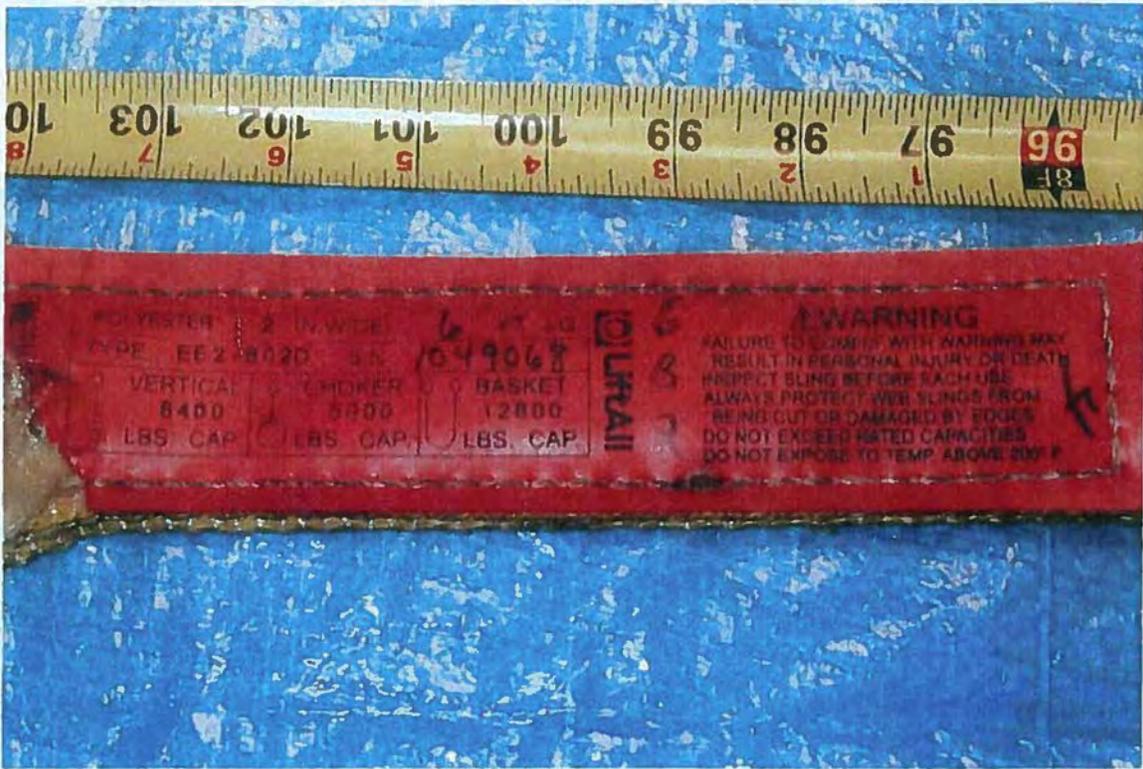
PHOTOGRAPH #2  
ONE OF THE FOUR CHAIN HOISTS BEING USED AT TIME OF ACCIDENT



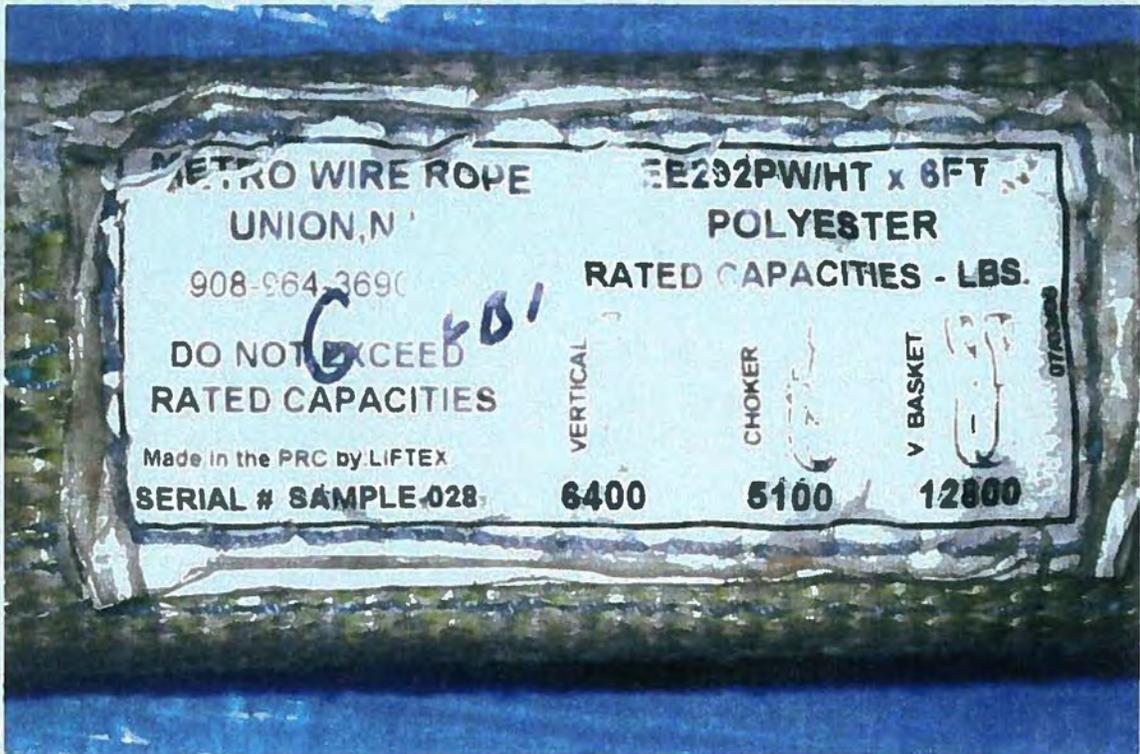
**PHOTOGRAPH #3**  
**CHAIN POSITION AFTER BEING PULLED THROUGH HOIST**



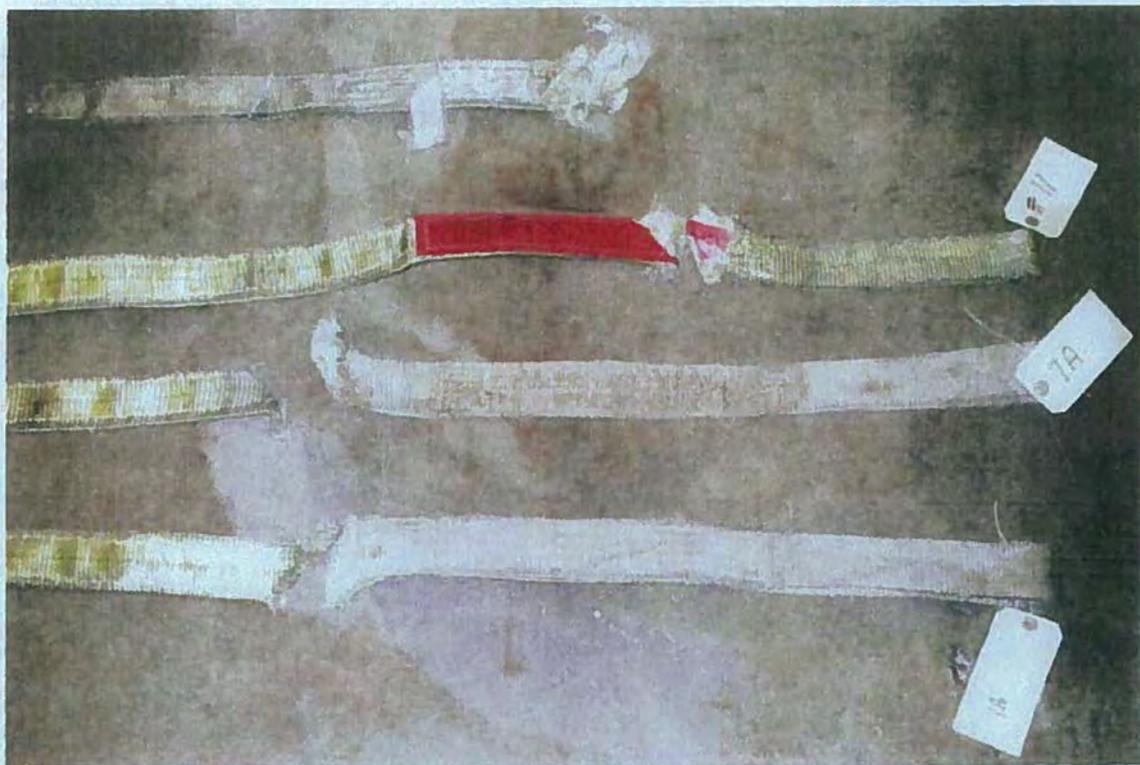
**PHOTOGRAPH #4**  
**WHITE, POWDERY SUBSTANCE ON CHAIN HOIST**



PHOTOGRAPH #5  
TAG ON ONE OF LIFTALL WEB SLINGS



PHOTOGRAPH #6  
TAG ON THE ONLY METRO WEB SLING



**PHOTOGRAPH #7  
MATCHING ENDS OF SLING REMNANTS FOUND**



**PHOTOGRAPH #8  
SLING ASSEMBLIES ON COLLAR FOLLOWING ACCIDENT**

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**PHOTOGRAPH #9  
METRO SLING STILL  
ATTACHED TO FALLEN  
COLLAR**

**PHOTOGRAPH #10  
LIFTALL SLING STILL  
ATTACHED TO FALLEN  
COLLAR**





**PHOTOGRAPH #11  
CRANE SECTION IN STORAGE AT WAREHOUSE**



**PHOTOGRAPH #12**  
**TOWER CRANE APPROXIMATELY 55 MINUTES PRIOR TO ACCIDENT**  
**( NOTE WEB SLINGS ON LOWER TOWER SECTION )**



**PHOTOGRAPH #13  
BOTH HALVES OF COLLAR IN STORAGE WAREHOUSE**



**PHOTOGRAPH #14  
WELDED PAD EYE ON COLLAR**



PHOTOGRAPH #15  
THREE BOXES OF EVIDENCE AS RECEIVED AT SWRI



PHOTOGRAPH #16  
CONTENTS OF BOX #1

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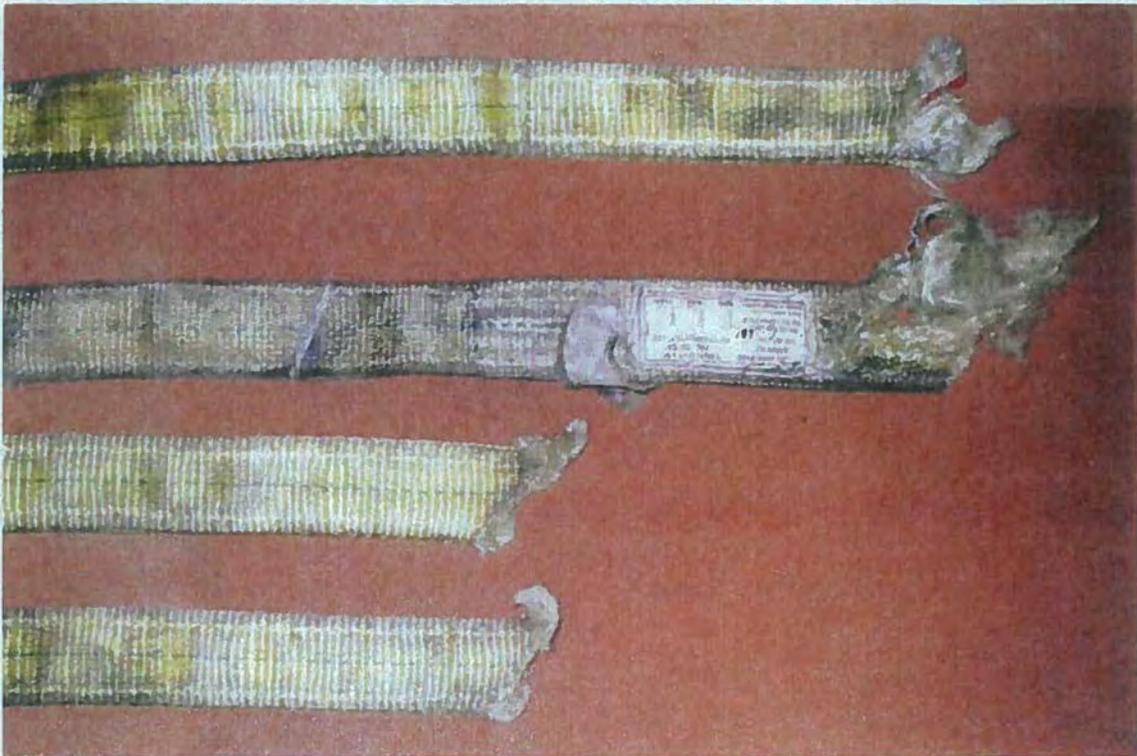
**PHOTOGRAPH #17  
CONTENTS OF BOX #2**



**PHOTOGRAPH #18  
CONTENTS OF BOX #3**



**PHOTOGRAPH #19  
MATCHED SLING REMNANTS**



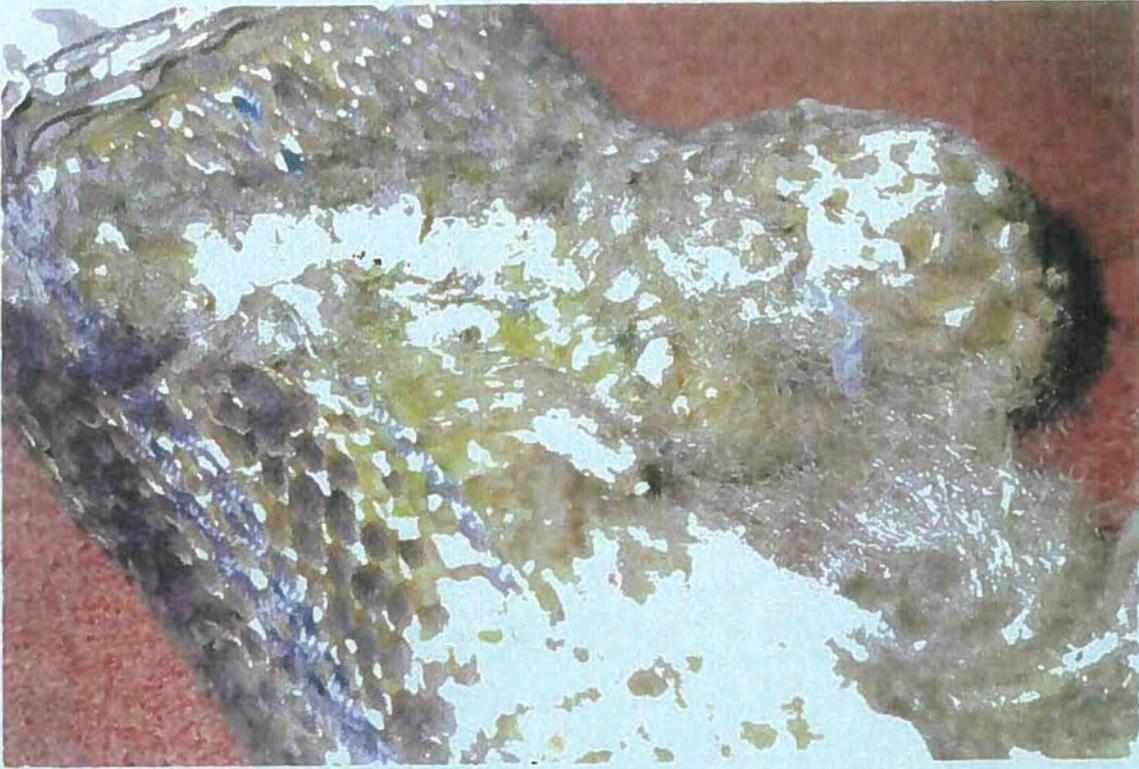
**PHOTOGRAPH #20  
COMPARATIVE LENGTH OF SLINGS STILL ATTACHED TO COLLAR**



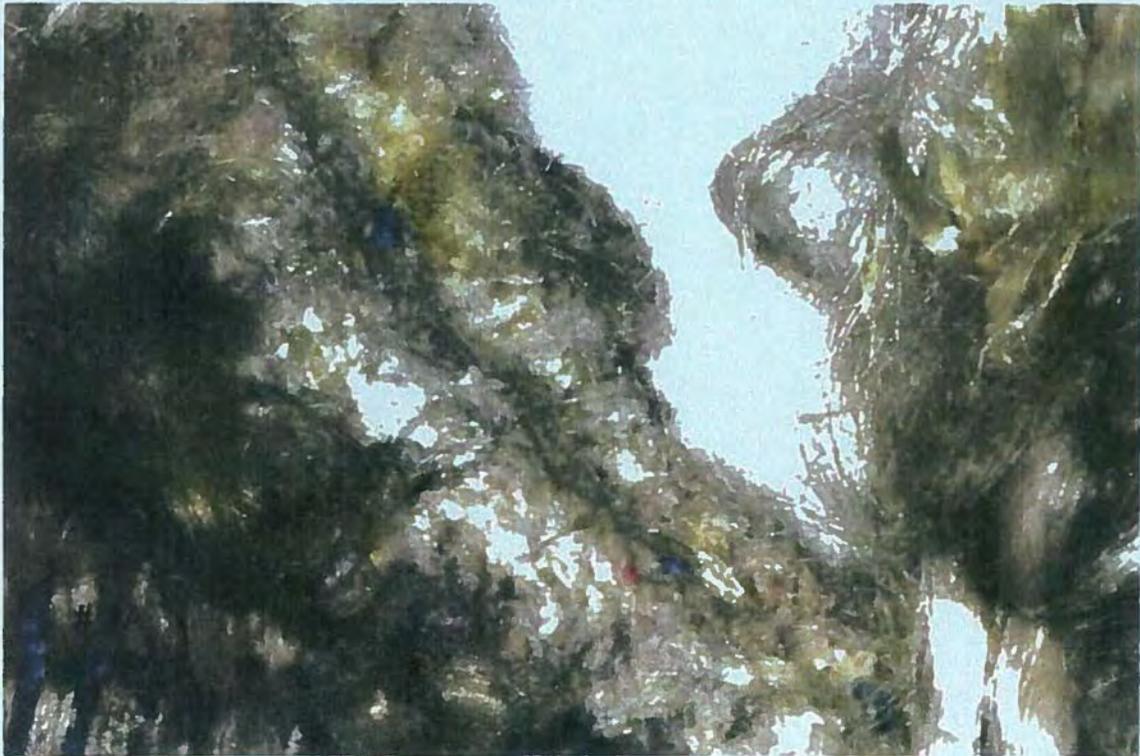
PHOTOGRAPH #21  
FAILURE END OF METRO SLING - SAMPLE 1A



PHOTOGRAPH #22  
CLOSE UP OF FAILURE END OF METRO SLING - SAMPLE 1A



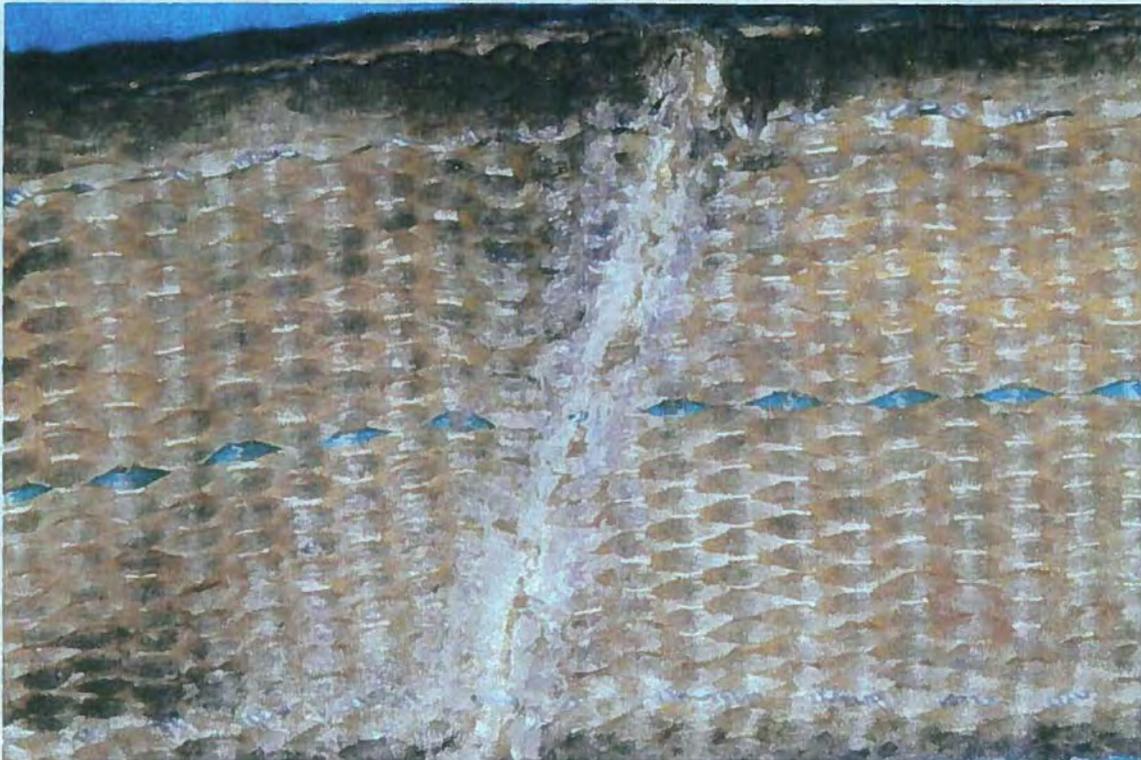
**PHOTOGRAPH #23  
MAGNIFIED VIEW OF FAILURE END OF METRO SLING – SAMPLE 1A**



**PHOTOGRAPH #24  
HIGHLY MAGNIFIED VIEW OF FAILURE END OF METRO SLING – SAMPLE 1A**



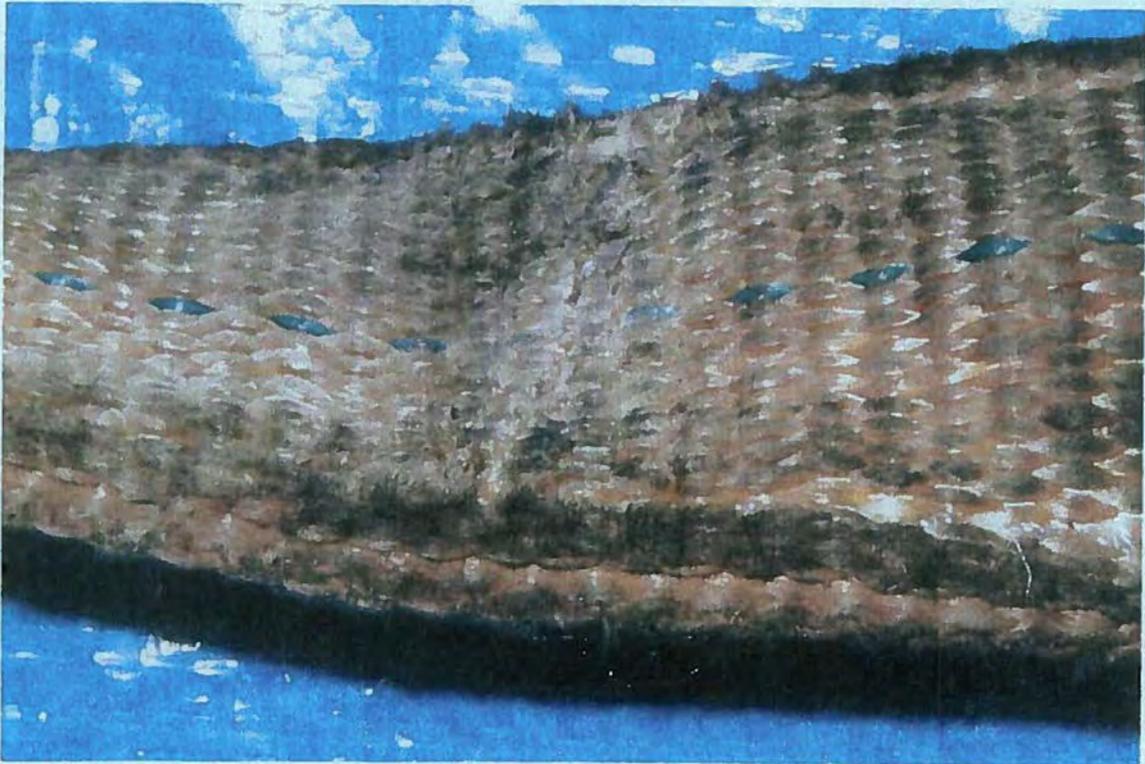
**PHOTOGRAPH #25  
FADED WARNING TAG ON METRO SLING – SAMPLE 1A**



**PHOTOGRAPH #26  
ONE OF THREE PARTIAL CUTS ON METRO SLING – SAMPLE 1A**



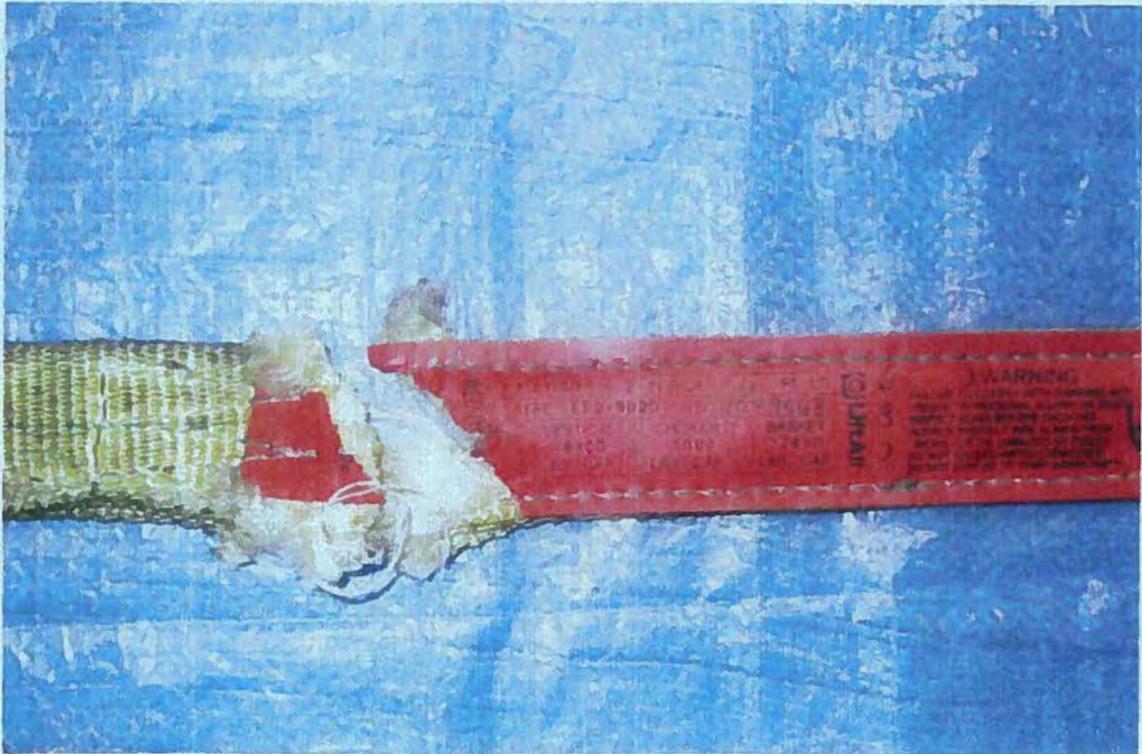
**PHOTOGRAPH #27  
EDGE CUTS ON METRO SLING – SAMPLE 1A**



**PHOTOGRAPH #28  
SEVERE CRUSHING ON METRO SLING – SAMPLE 1A**



**PHOTOGRAPH #29  
SNAGS & PUNCTURES ON METRO SLING – SAMPLE 1A**



**PHOTOGRAPH #30  
MATCHED CUT ENDS OF LIFTALL SLING – SAMPLES 2A & 11**



2A

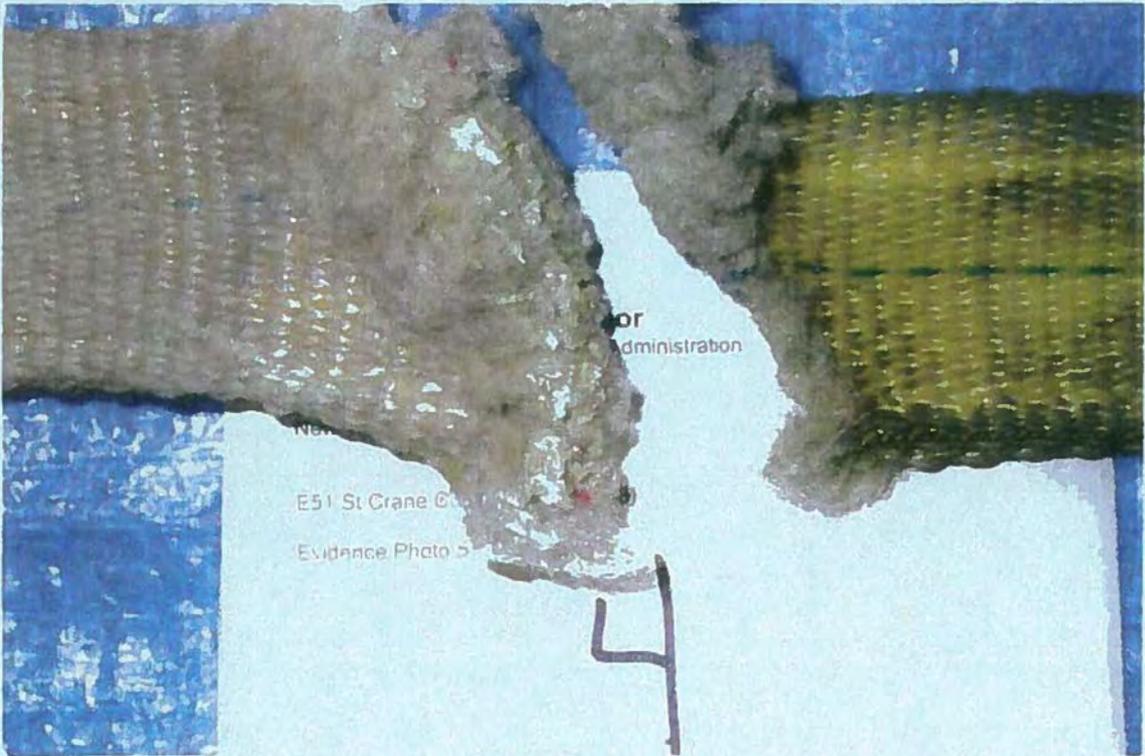
PHOTOGRAPH #31  
CLOSE UP OF FAILURE END OF LIFTALL SLING - SAMPLE 2A



PHOTOGRAPH #32  
MAGNIFIED VIEW OF FAILURE END OF LIFTALL SLING - SAMPLE 2A



PHOTOGRAPH #33  
HIGHLY MAGNIFIED VIEW FAILURE END OF LIFTALL SLING – SAMPLE 11



PHOTOGRAPH #34  
MATCHED FAILURE ENDS OF LIFTALL SLING – SAMPLES 4A & 12



**PHOTOGRAPH #35  
CLOSE UP OF FAILURE END OF LIFTALL SLING – SAMPLE 12**



**PHOTOGRAPH #36  
HIGHLY MAGNIFIED VIEW OF FAILURE END OF LIFTALL SLING – SAMPLE 12**



PHOTOGRAPH #37  
MATCHED FAILURE ENDS OF LIFTALL SLING – SAMPLES 7A & 13

# 13, A



PHOTOGRAPH #38  
MAGNIFIED VIEW OF FAILURE END OF LIFTALL SLING – SAMPLE 13



**PHOTOGRAPH #39  
HIGHLY MAGNIFIED VIEW OF FAILURE END OF LIFTALL SLING – SAMPLE 7A**

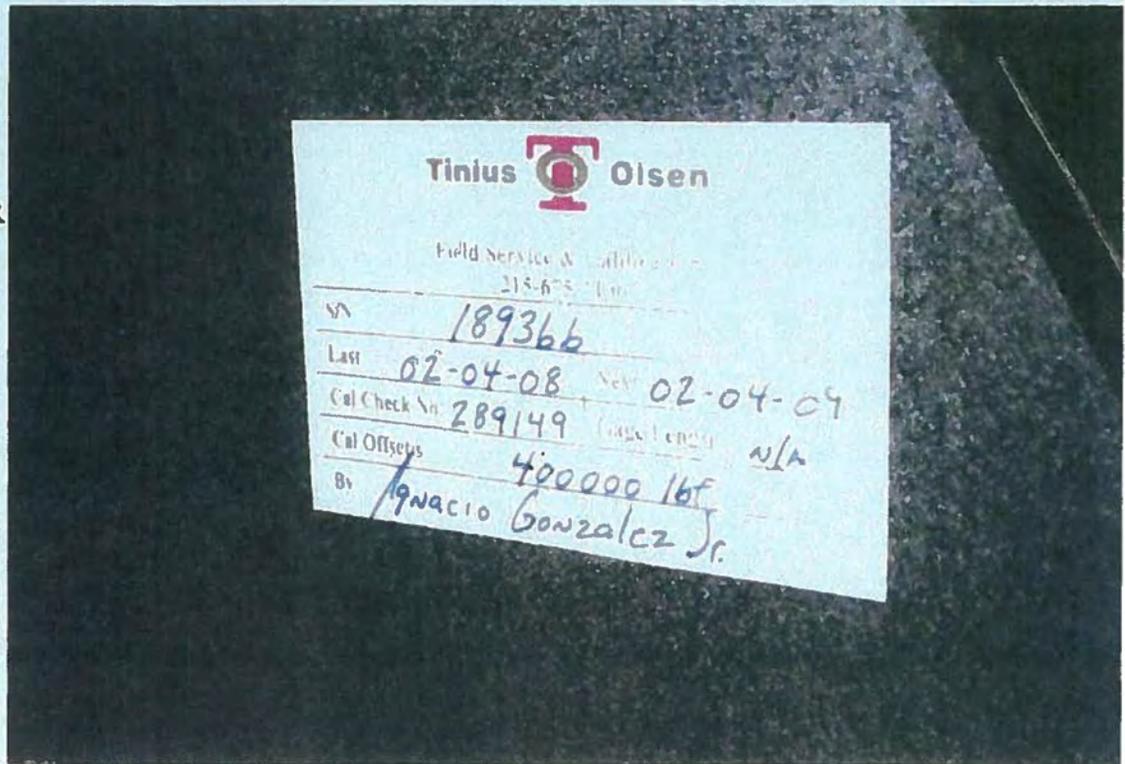


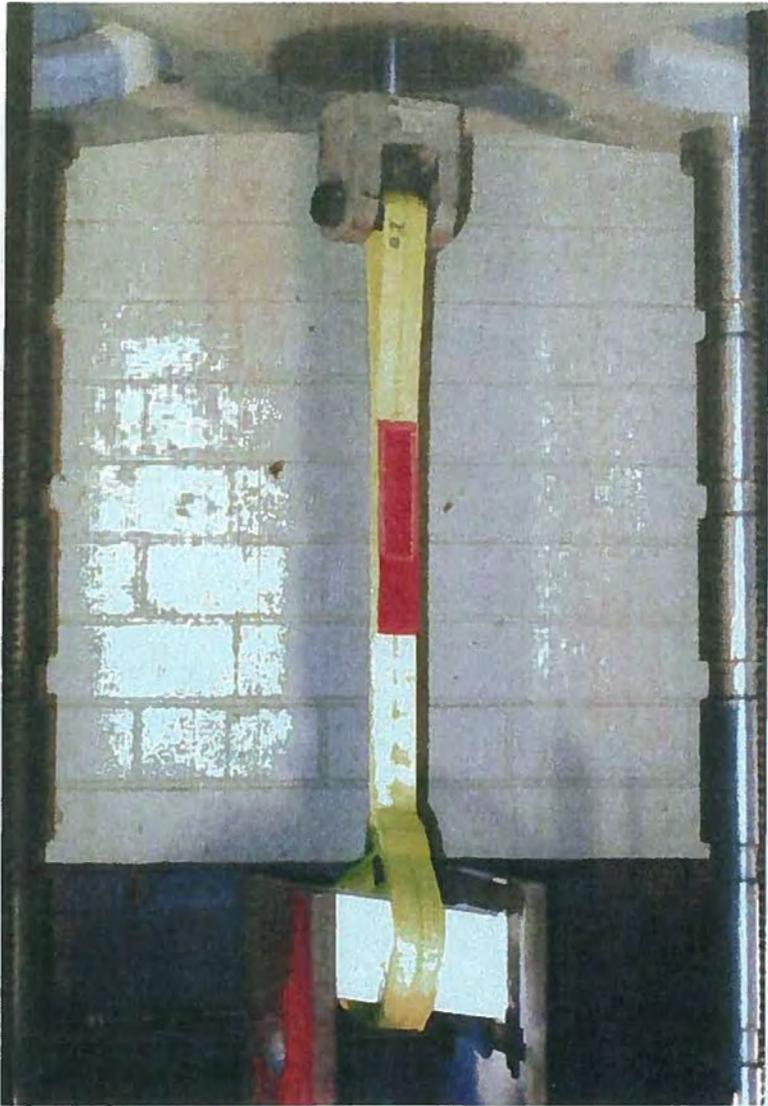
**PHOTOGRAPH #40  
SIX SLINGS TESTED AT SWRI**



PHOTOGRAPH #41  
SETUP OF TESTING ON TINIUS OLSEN  
TENSILE MACHINE

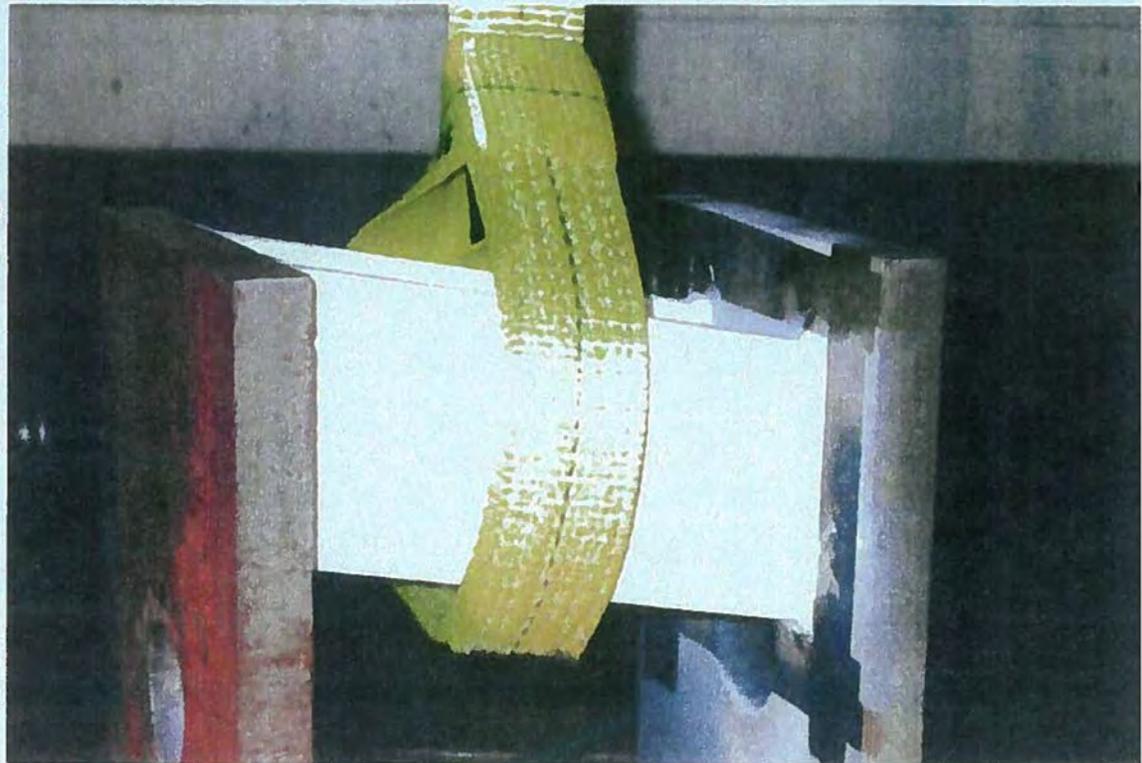
PHOTOGRAPH #42  
CALIBRATION STICKER  
ON TINIUS OLSEN  
TENSILE MACHINE

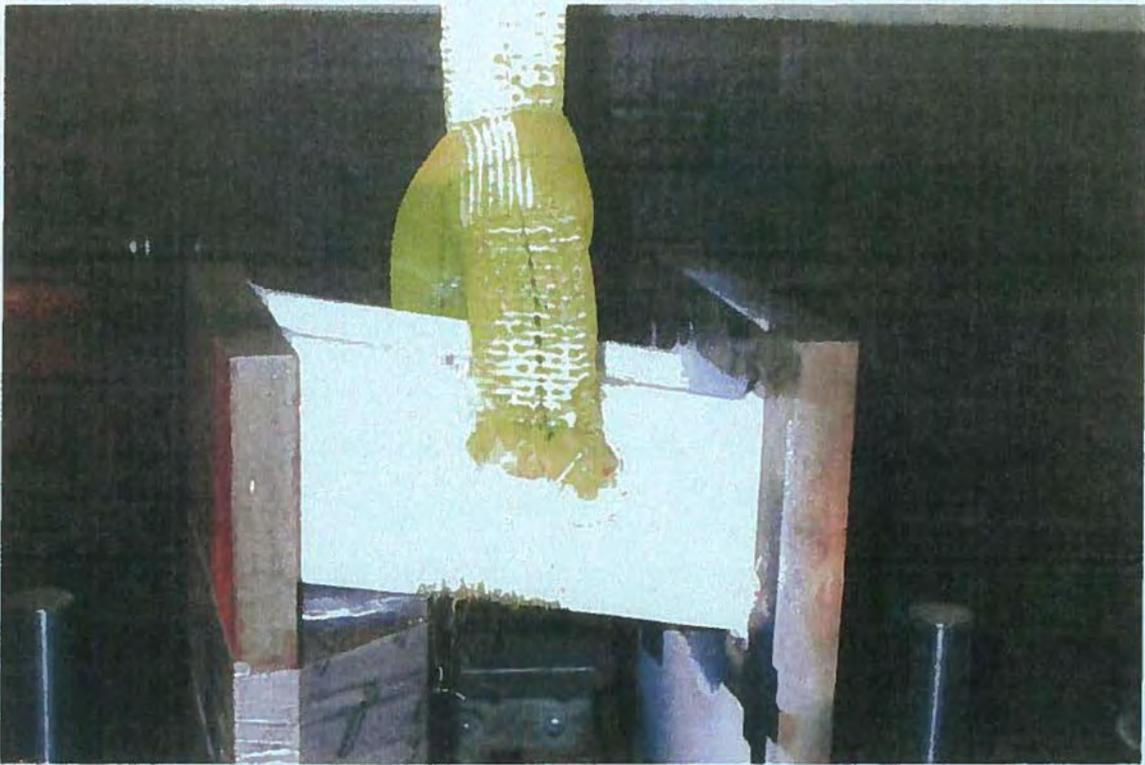




**PHOTOGRAPH #43  
LOWER EYE CHOKED AROUND I-BEAM  
UPPER EYE AROUND 1 3/4" DIAMETER PIN**

**PHOTOGRAPH #44  
CHOKED EYE AROUND  
PIN PRIOR TO TESTING**





**PHOTOGRAPH #45  
FAILED SLING AT EDGE OF I-BEAM - SWRI TESTING**



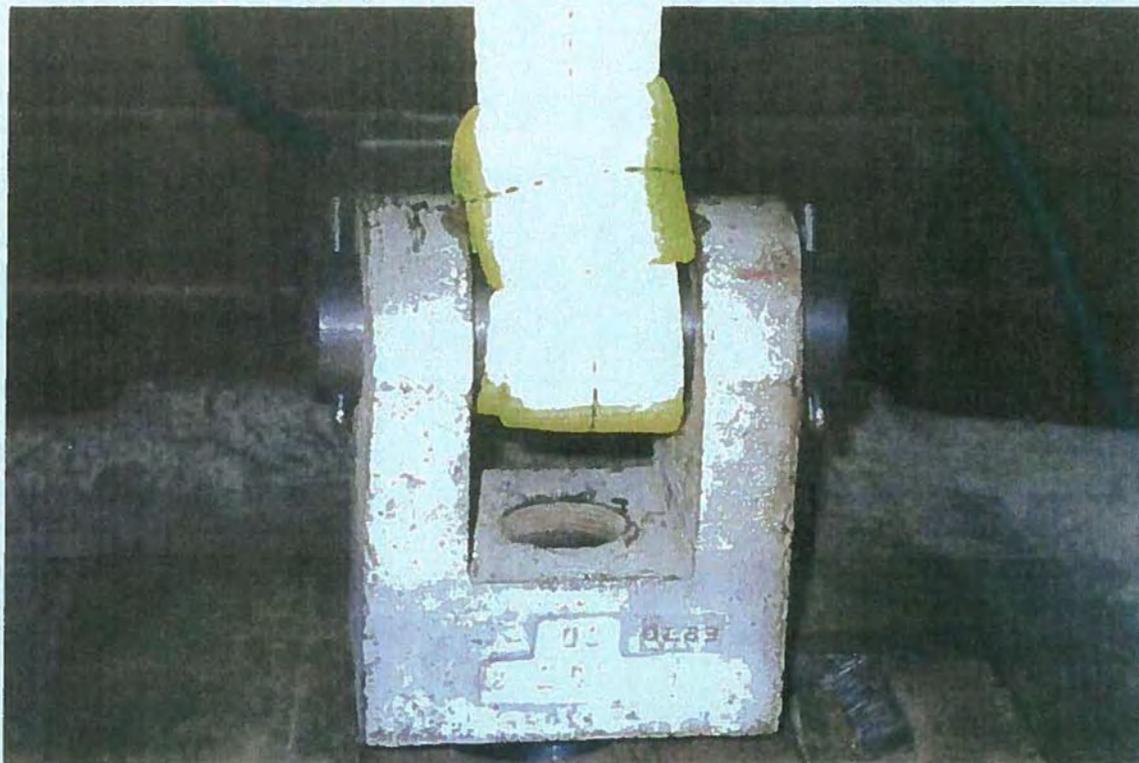
**PHOTOGRAPH #46  
CLOSE UP OF FAILED SLING AT EDGE OF I-BEAM**



**PHOTOGRAPH #47  
MATCHED FAILED ENDS OF SLING TESTED AROUND I-BEAM**



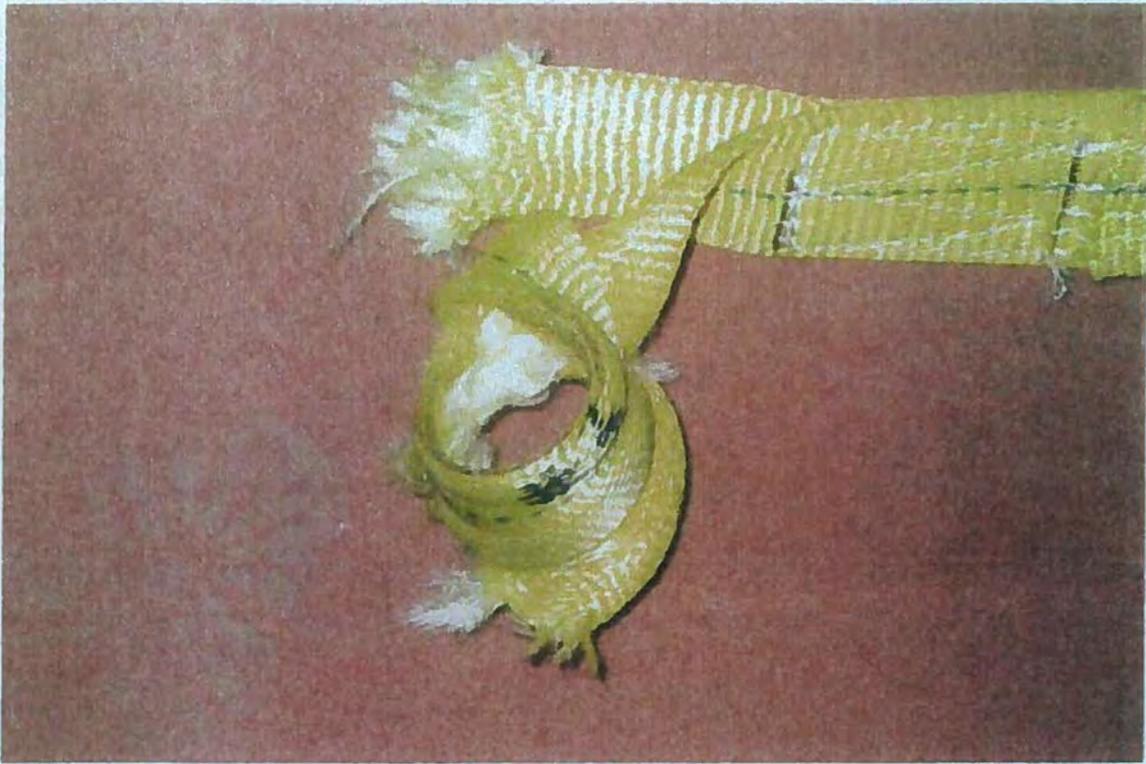
**PHOTOGRAPH #48  
MELTED WEB FIBERS REMAINING ON EDGE OF I-BEAM**



**PHOTOGRAPH #49  
SETUP OF SLING TEST CHOKED AROUND A PIN**



**PHOTOGRAPH #50  
FAILURE OF SLING BEING CHOKED AROUND A PIN**



**PHOTOGRAPH #51  
FAILURE ENDS OF SLING BEING CHOKED AROUND A PIN**



**PHOTOGRAPH #52  
SETUP OF TEST WITH SIDE RESTRAINT ON I-BEAM**



**PHOTOGRAPH #53  
FIBERS OF WEB SLING FAILING IN TENSILE TEST  
BOTH EYES ON PINS**

# **APPENDIX B**

**(No. of sheets 2 including this sheet)**

OSHA 51st Street Crane Collapse Sling Evaluation Summary

Sling	Designation/Test Description	Angle re:		Cosine of Angle	Correction Factor	Measured Max Load (lbs)	Actual Sling Max Load (lbs)
		Horizontal (degrees)	Vertical (degrees)				
1	LiftAll NW, Restroke	N/A	N/A	N/A	N/A	9991	N/A
2	LiftAll NW, 3 ply in notch	84.3	5.7	0.9951	1.0049	9503	9550
3	LiftAll NW, 2 ply in notch	82.5	7.5	0.9914	1.0087	8348	8421
4	Metro NW 3 ply in notch	81.6	8.4	0.9893	1.0108	10061	10169
5	Metro NW, 3 ply in notch	82.4	7.6	0.9912	1.0089	9837	9924
6*	LiftAll NW, 2 ply in notch, fast	N/A	N/A	N/A	1.0087	8300	8372
7	Metro NW, 3 ply in notch, sustained	82.6	7.4	0.9919	1.0082	9807	9887
8	LiftAll SW, 2 ply in notch	84.4	5.6	0.9952	1.0048	7751	7788
9	LiftAll SW, 2 ply in notch, pushed down	84.9	5.1	0.9960	1.0040	7816	7847
10	LiftAll SW, 2 ply in notch, pushed down, rubber	82.1	7.9	0.9905	1.0096	11101	11208
11	LiftAll SW, 2 ply in notch, pushed down, sustained	N/A	N/A	N/A	1.0040	7074	7102
12	LiftAll SW, 2 ply in notch, pushed down, rubber	N/A	N/A	N/A	1.0096	11121	11228

6\* Data compromised - not retrievable: 8300 lbs max load based on value observed on DAS screen during test