NC State Research Report on Single Plate Shear Connections

September 8, 2003

By: Emmett Sumner, Ph.D, P.E.

Submitted to: Thomas Schlafly, AISC Director of Research

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The American structural steel industry has used a connection type called 'shear bars' for over 40 years. In that time much consideration has been given to how these connections comply with the flexibility requirements for simple connections. Experimental work has determined the connections will perform adequately if the shear plates are designed to yield or the bolts are permitted to 'plow' and the welds and bolts are designed to prevent fracture.

While much work has been done to show the bolts will plow, there was still a question about whether the bolts had to be designed to consider moment from the beam end rotation. This moment is usually modeled as an eccentricity from the weld, from a modeled point of inflection, or some place between those two places and depending on the stiffness of the framing members, composite action and other parameters.

Dr. E Sumner of North Carolina State University was asked by WW Steel of Oklahoma City to conduct tests to show consideration of the eccentricity was not necessary in the selection of number size and grade of bolts.

The ensuing material summarizes hose tests. Text summarizing the results and describing conclusions have not been received to date and are therefore not in the attached material. This information has been distributed to a task group of the Manual Committee.

Single Plate (Shear Tab) Connection Test Summary Sheet

Test ID: Test 3A (Flexible, Slotted)
Test Date: May 23, 2003
Sponsor: W & W Steel Company
Tested By: N.C. State University

Connection Description

Three bolt single plate connection with a flexible support condition, short slotted holes, and snug tight bolts.

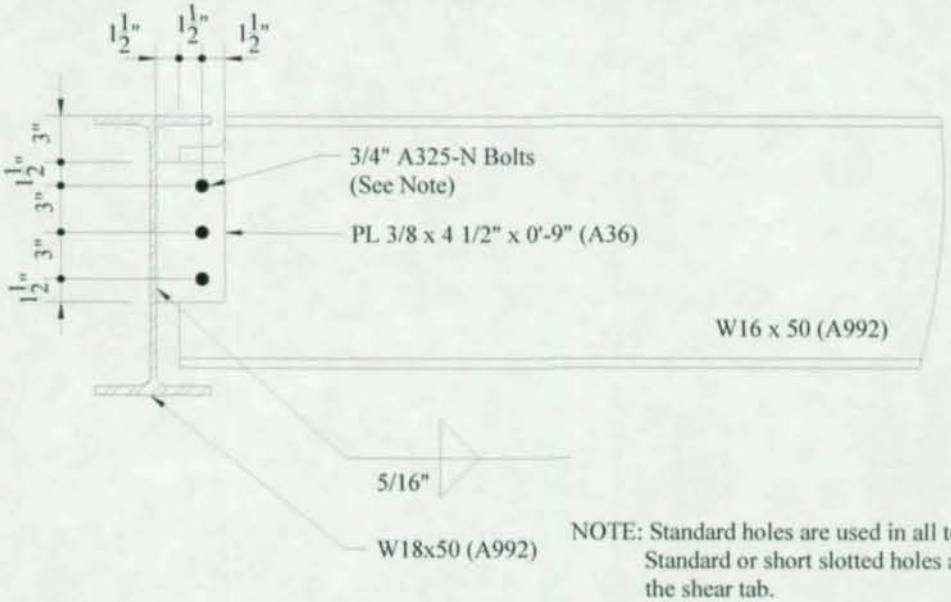
Shear Tab	Plate Size: PL 3/8" x 4 1/2" x 0'-9"			Fy =	43.2 ksi
	Steel Grade: A36			Fu =	63.4 ksi
Bolts	Diameter:	0.75	in.		
	Bolt Grade:	A325			
	Ft =	106.4	ksi	(Measured)	
	Pretension:	10	kips	(snug-tight)	
	Thread Location: Included in shear plane				
Beam	Section: W16x50			Fy =	54.1 ksi
	Steel Grade: A992			Fu =	69.3 ksi
Girder	Section: W18x50				
	Steel Grade: A992				

Experimental Results

Maximum Applied Shear at Connection =	71.8	kips
Maximum Beam End Rotation at Connection =	0.039	rad
Maximum Girder Rotation at Connection =	0.114	rad
Maximum Vertical Beam Deflection at Connection =	1.12	in.
Maximum Vertical Girder Deflection at Conneciton =	0.16	in.

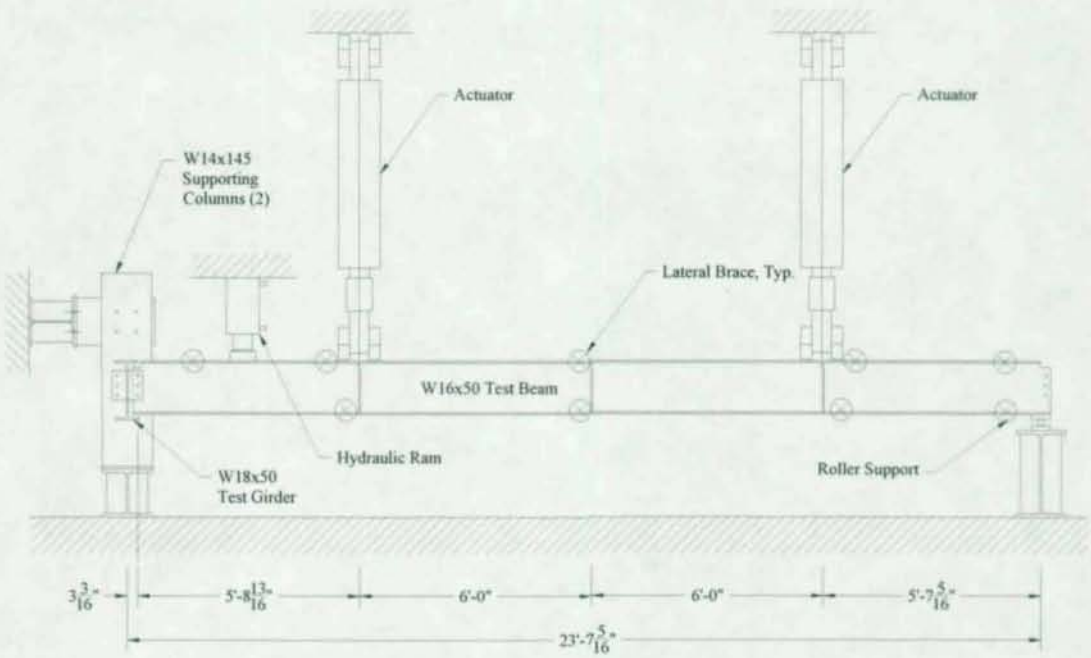
Test observations:

- Elastic rotation of the supporing girder observed at 30 kips.
- Beam yielding at quarter points and midspan observed at 56 kips.
- Severe yielding of beam at quarter points and midspan, observed at 60 kips. Large rotaion and small yielding of the top flange of the girder was observed at 62 kips. The test was paused and braces were installed adjacent ot the connection region to restrain the lateral movement of the girder top flange.
- At approximately 64 kips and 0.038 rad beam rotation, the test was paused and additional load was applied adjacent to the connection region using a hydraulic ram.
- Continued beam yielding and lateral torsional buckling of the beam between lateral brace points was observed.
- Shear rupture of the connection bolts was observed at 71.8 kips.
- Failure of the a lateral brace mechanism located at the 3/4 load point was observed at the time of bolt failure.

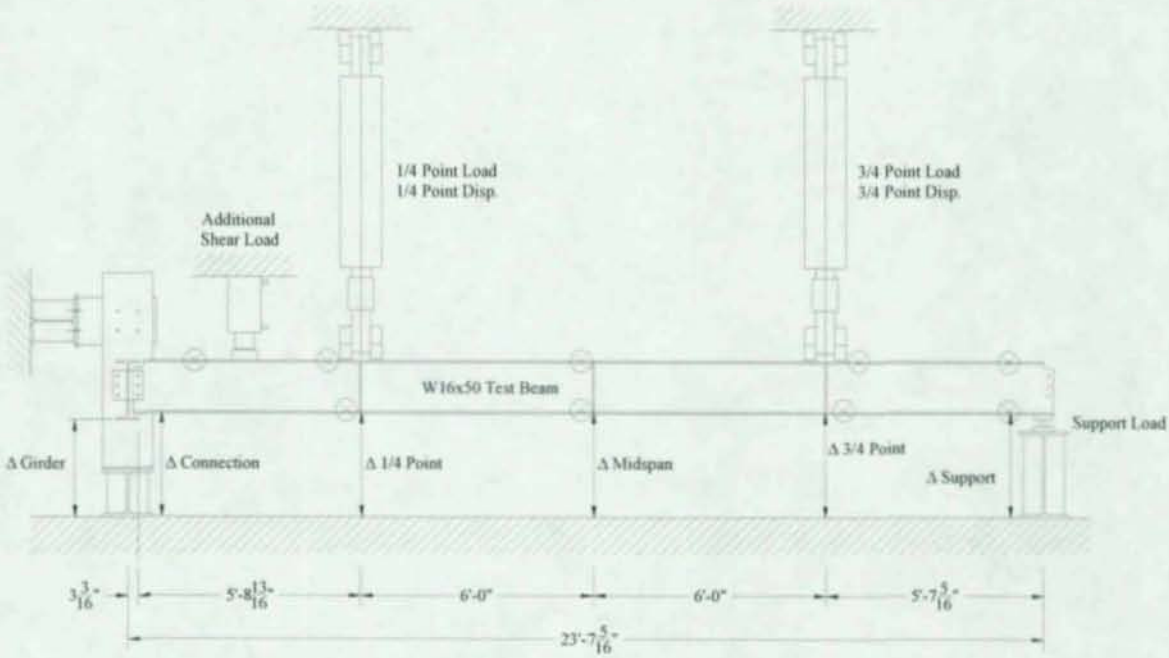


NOTE: Standard holes are used in all test beams. Standard or short slotted holes are used in the shear tab.

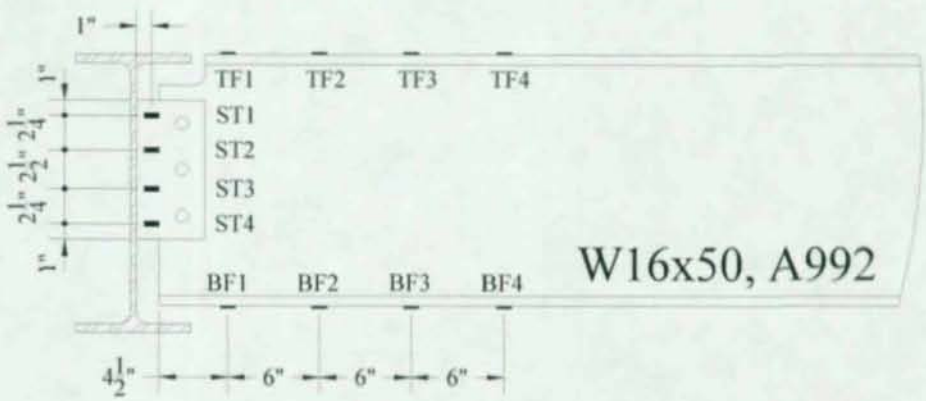
Detail of Single Plate (Shear Tab) Connection



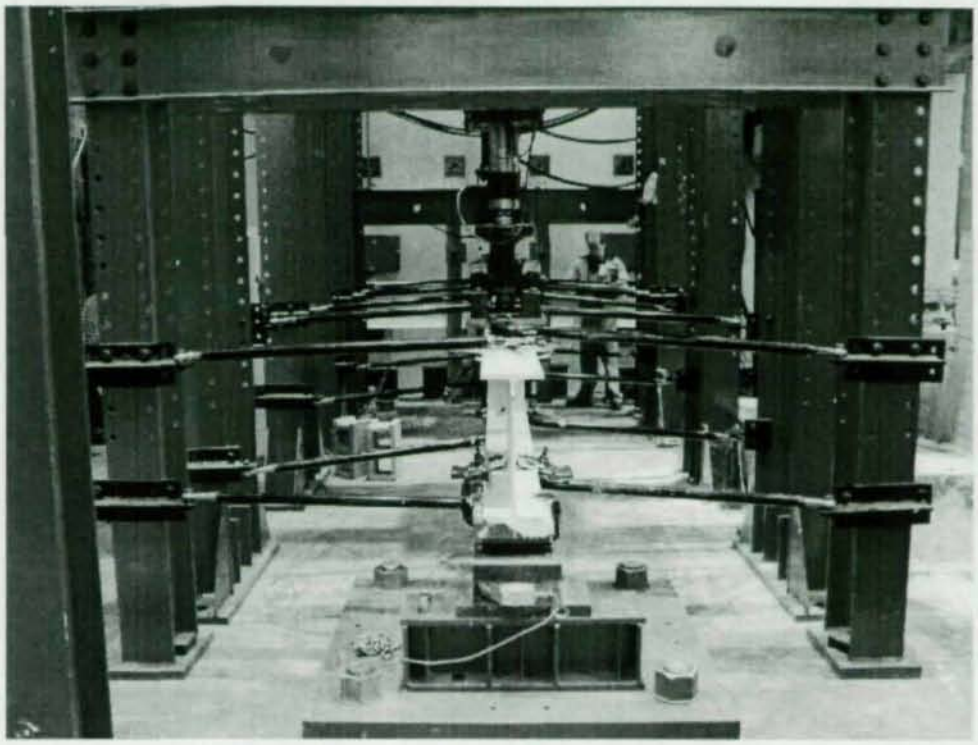
Elevation of Test Setup



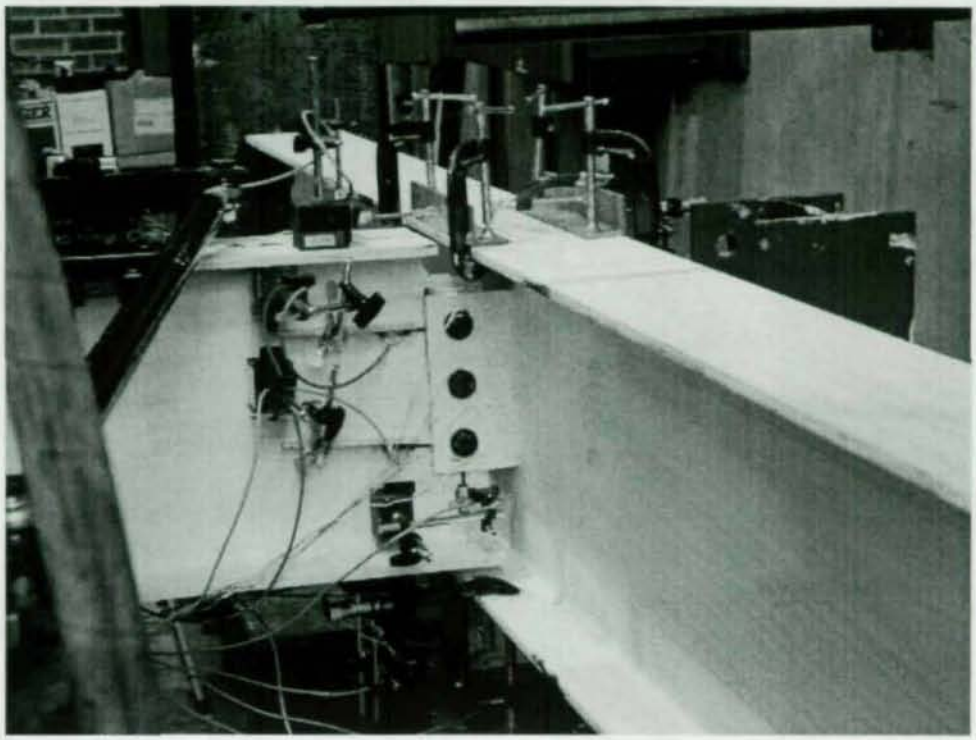
Elevation of Test Setup Showing Instrumentation



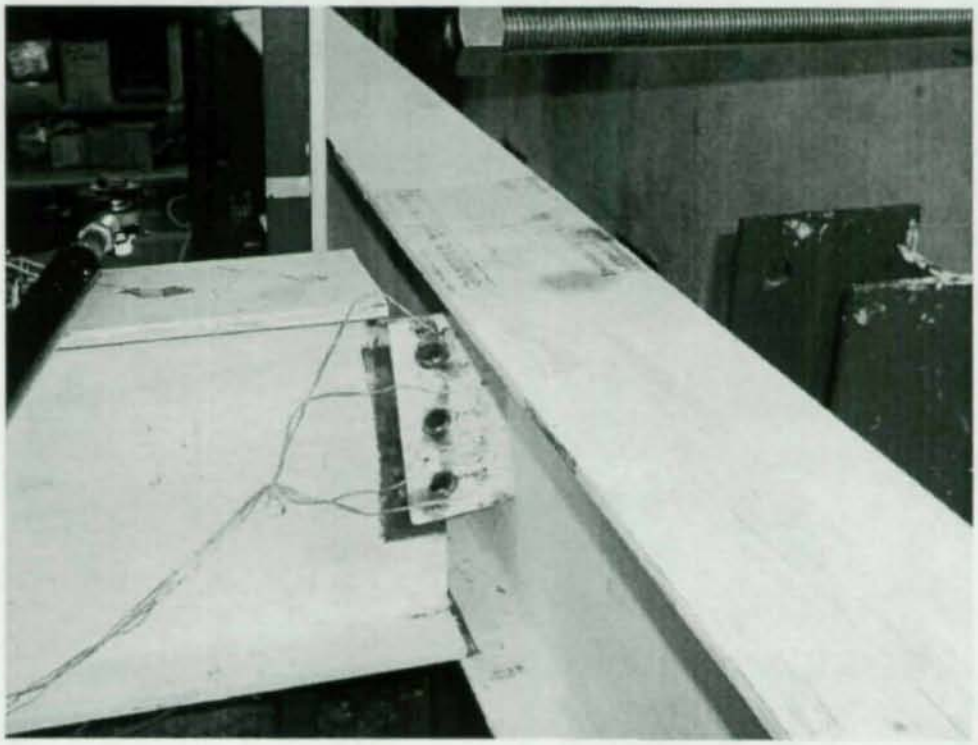
Connection Region Strain Gage Instrumentation



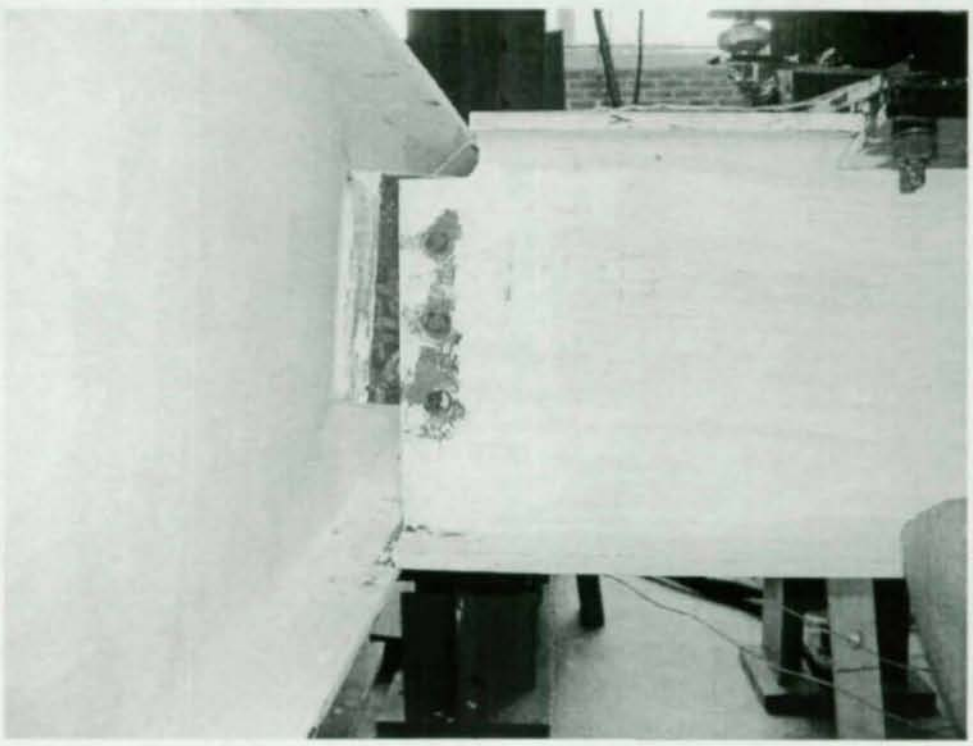
Test 3A – Overall Veiw of Test Setup



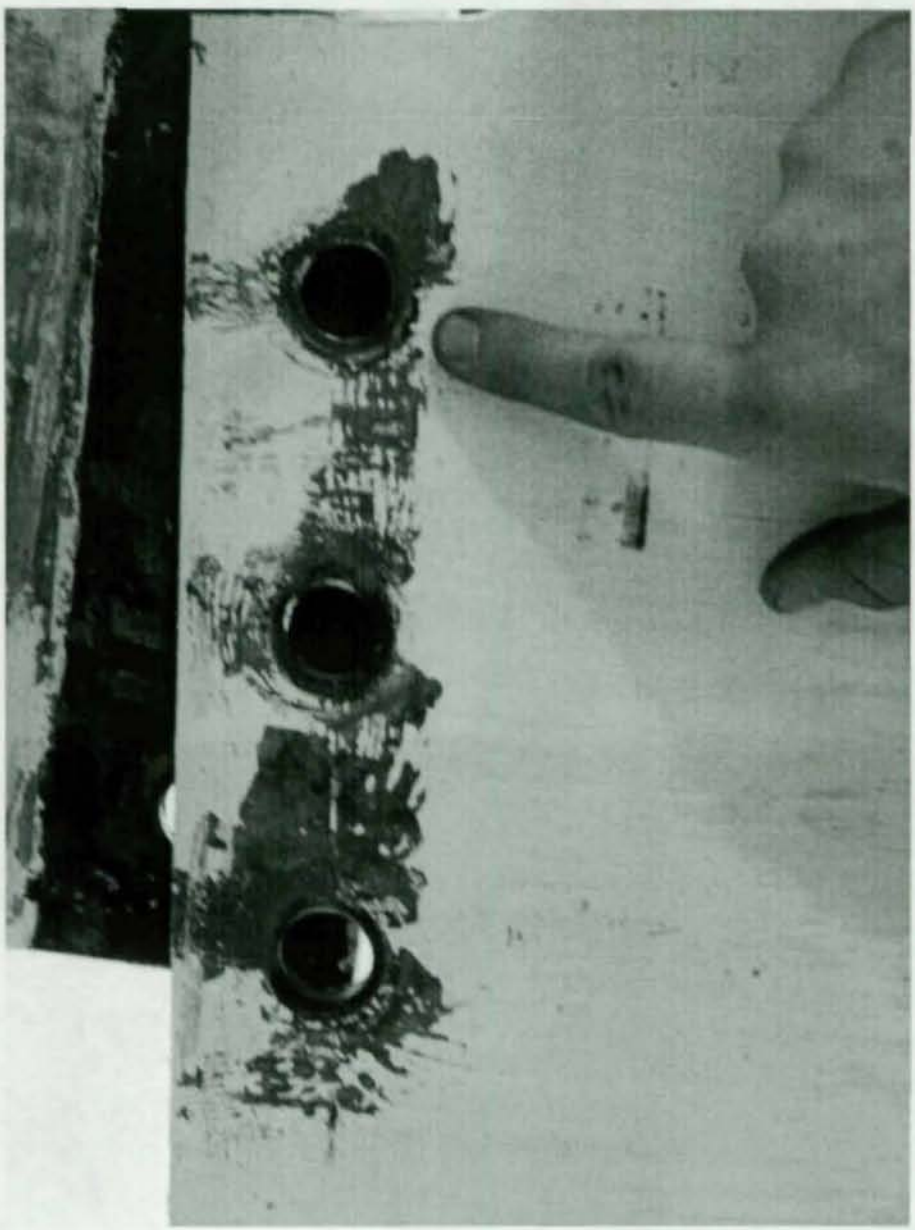
Test 3A – Connection Region Before Test



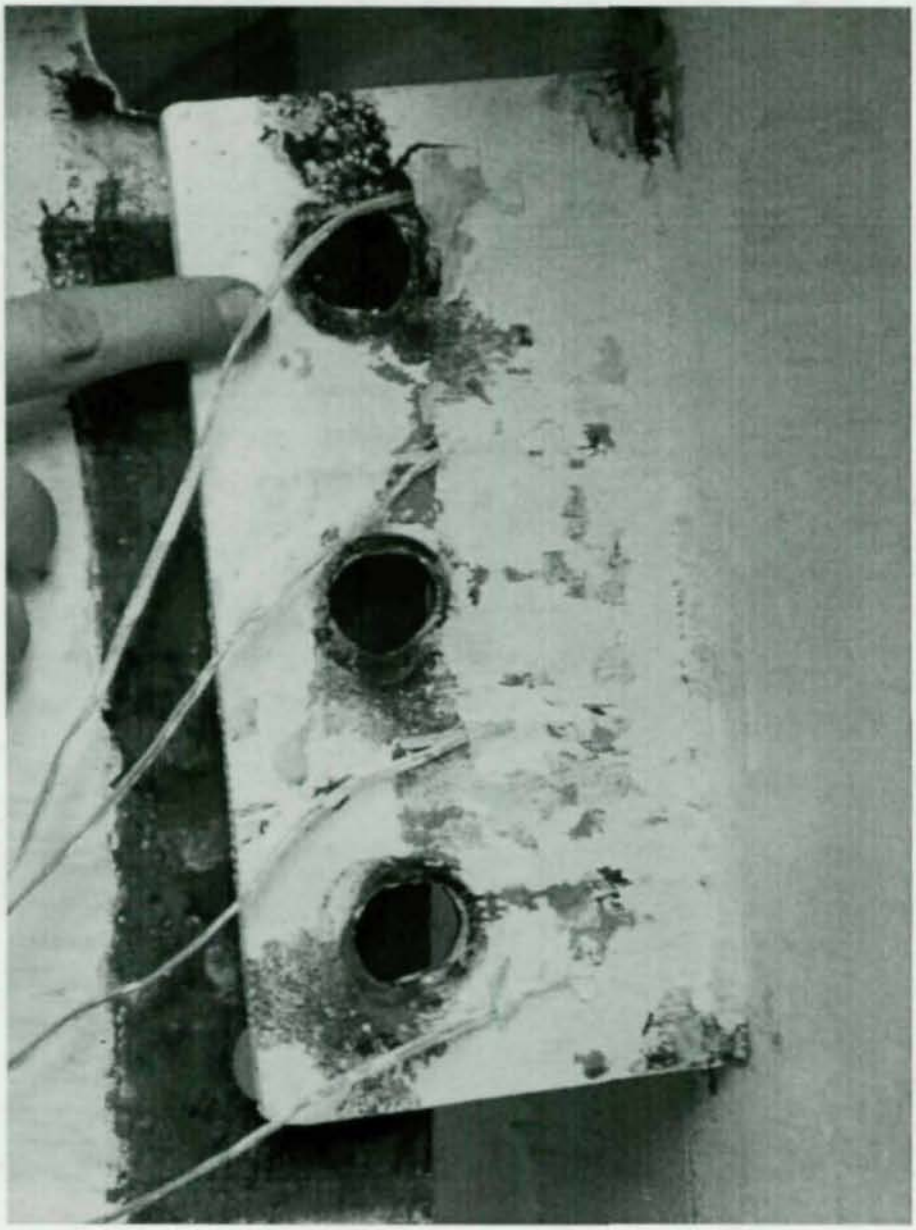
Test 3A – Connection Region at End of Test



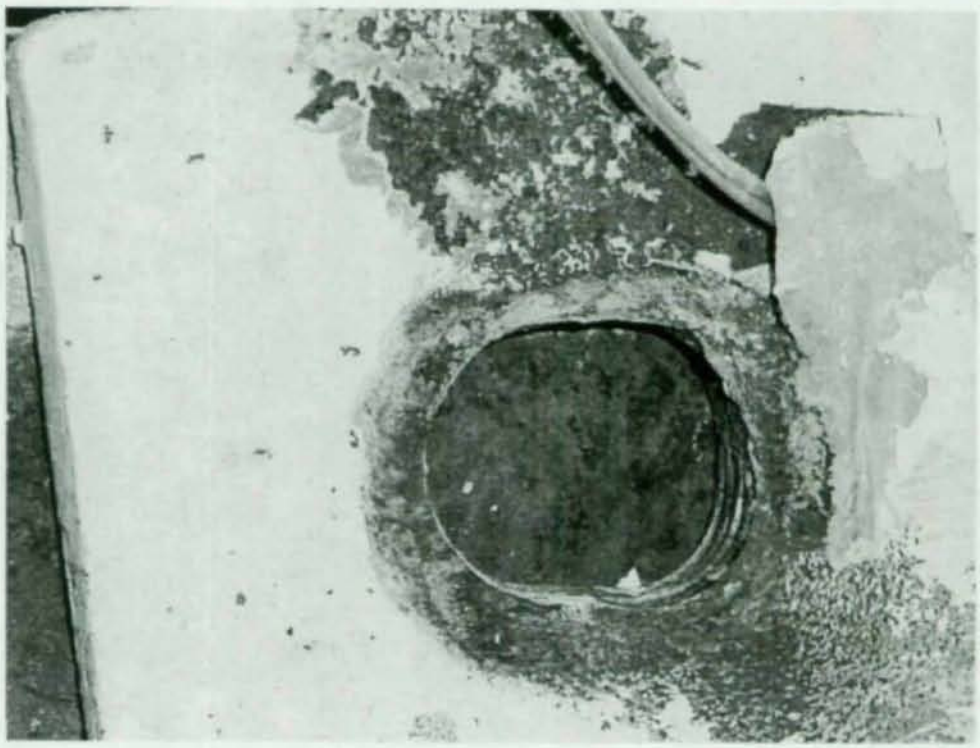
Test 3A – Connection Region at End of Test



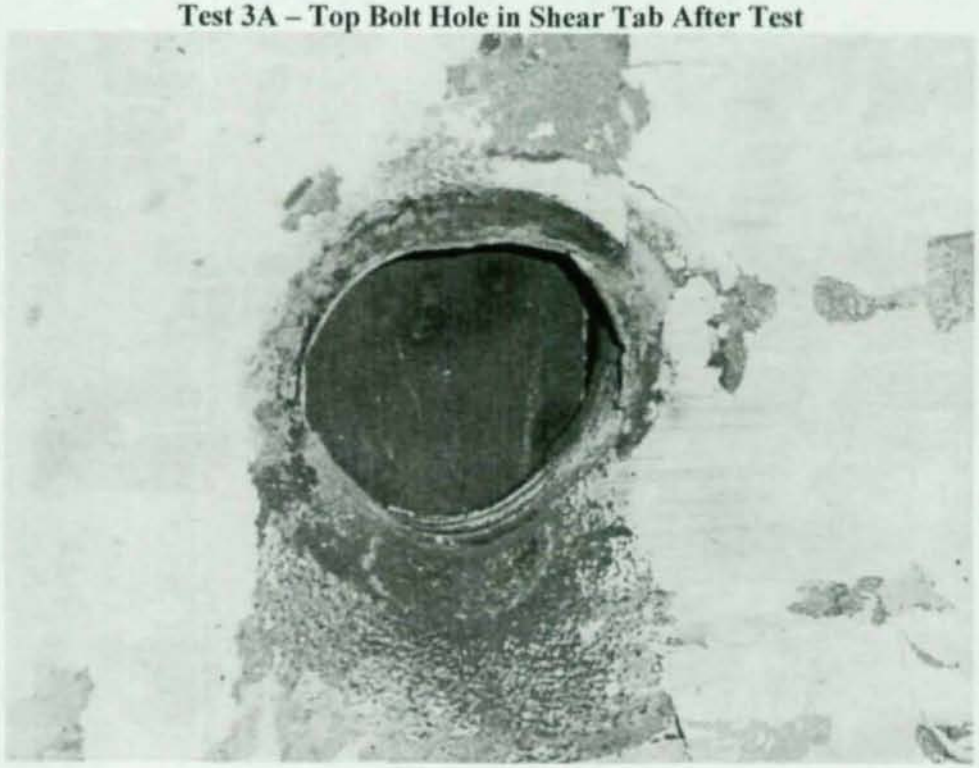
Test 3A – Connection Region at End of Test



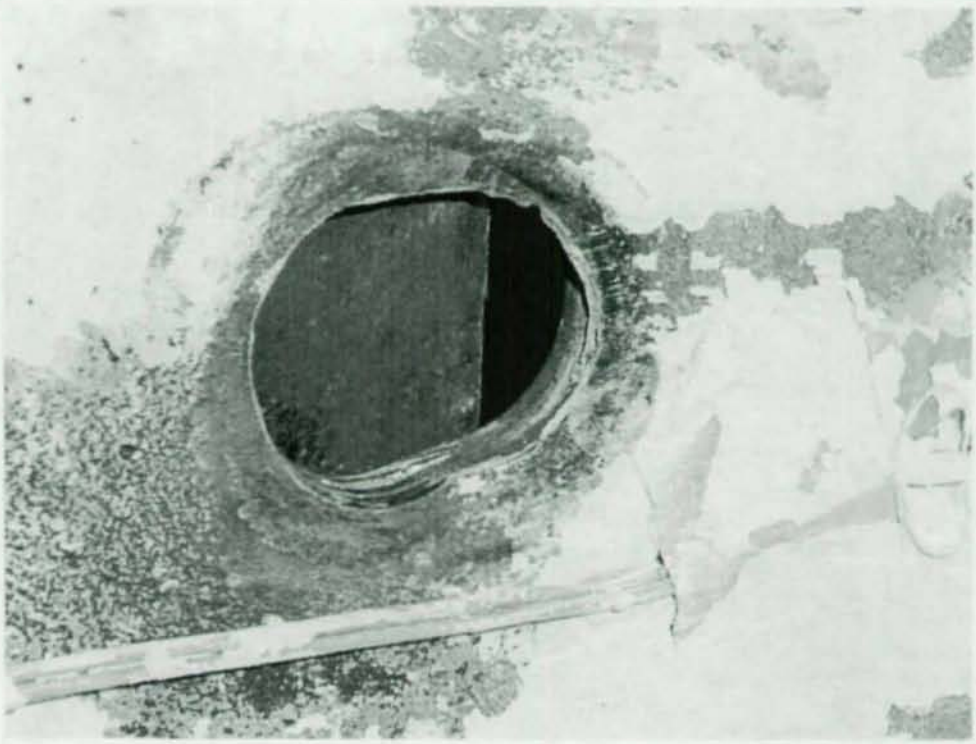
Test 3A – Shear Tab After Test



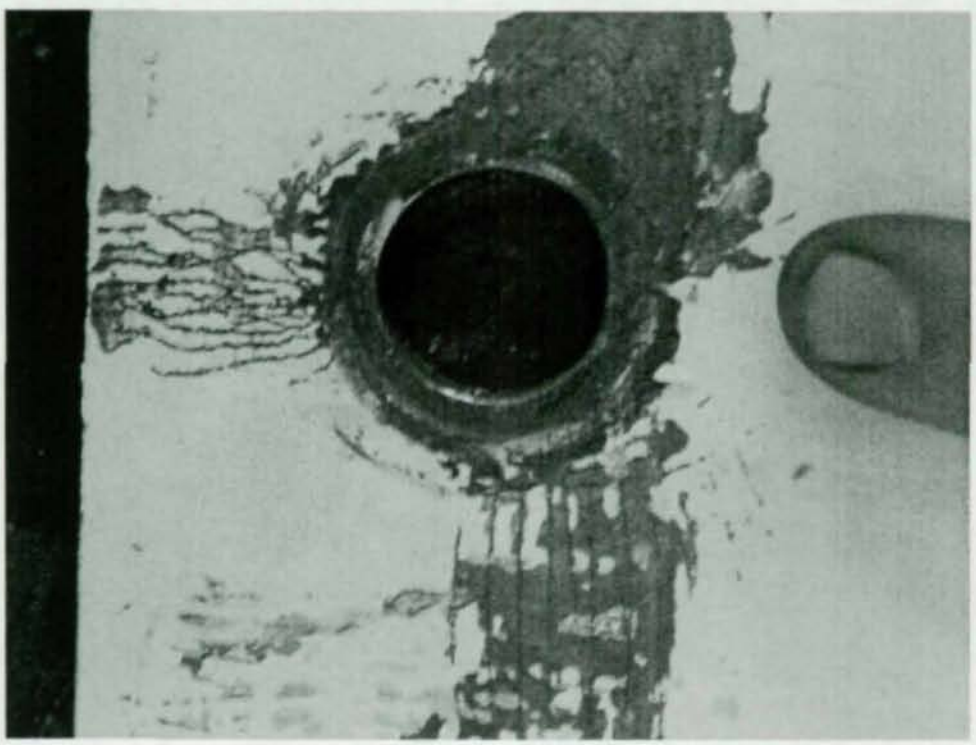
Test 3A – Top Bolt Hole in Shear Tab After Test



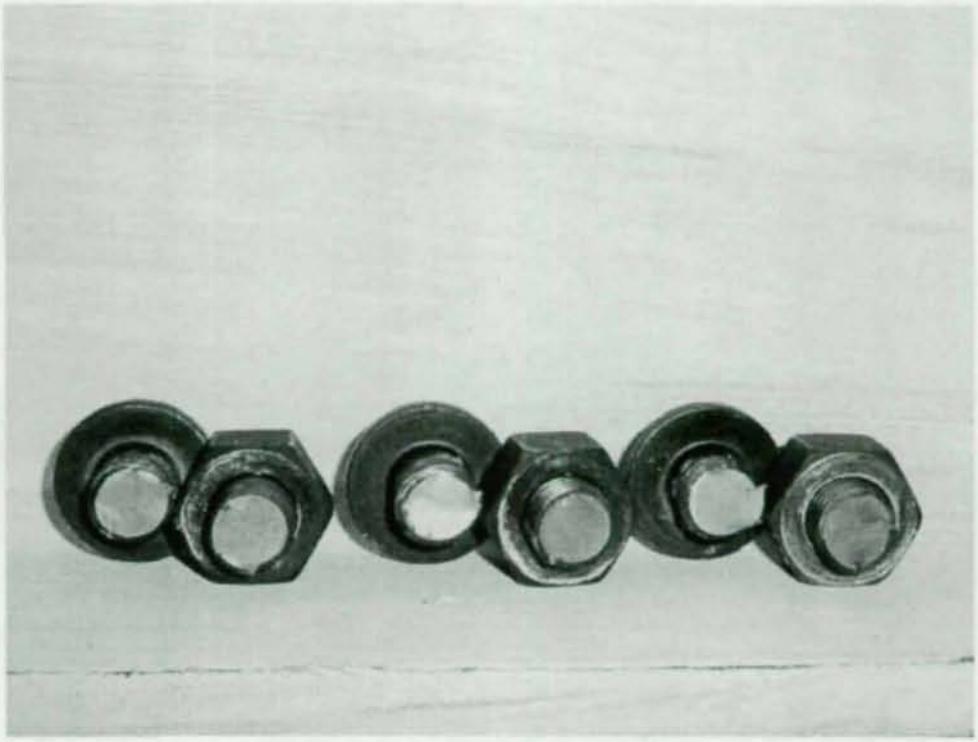
Test 3A – Center Bolt Hole in Shear Tab After Test



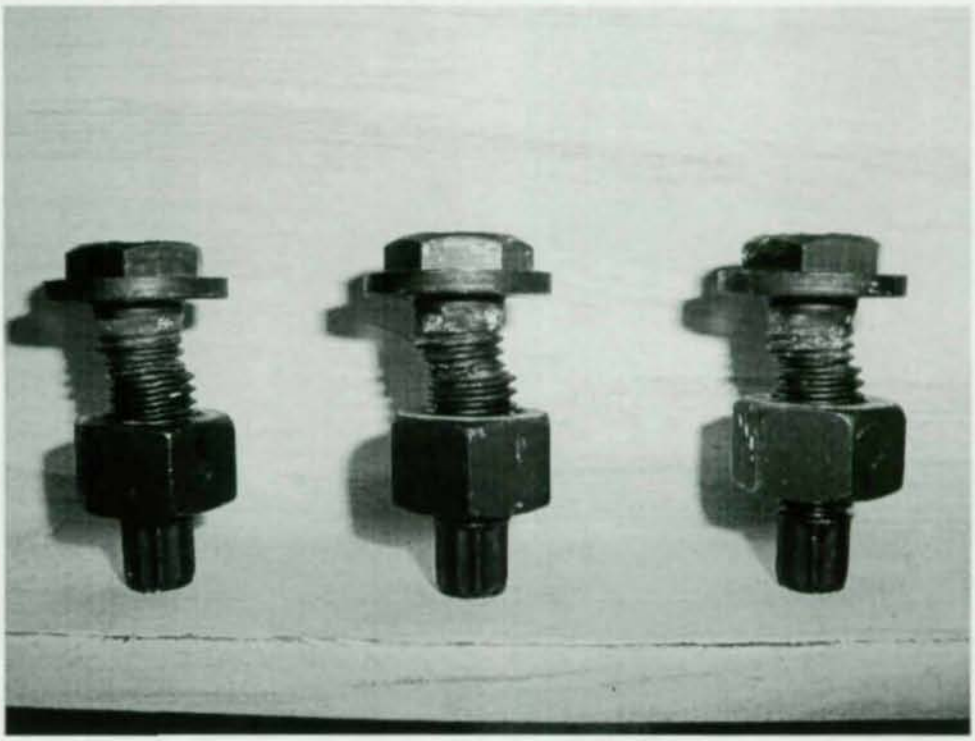
Test 3A – Bottom Bolt Hole in Shear Tab After Test



Test 3A – Top Bolt Hole in Beam Web After Test

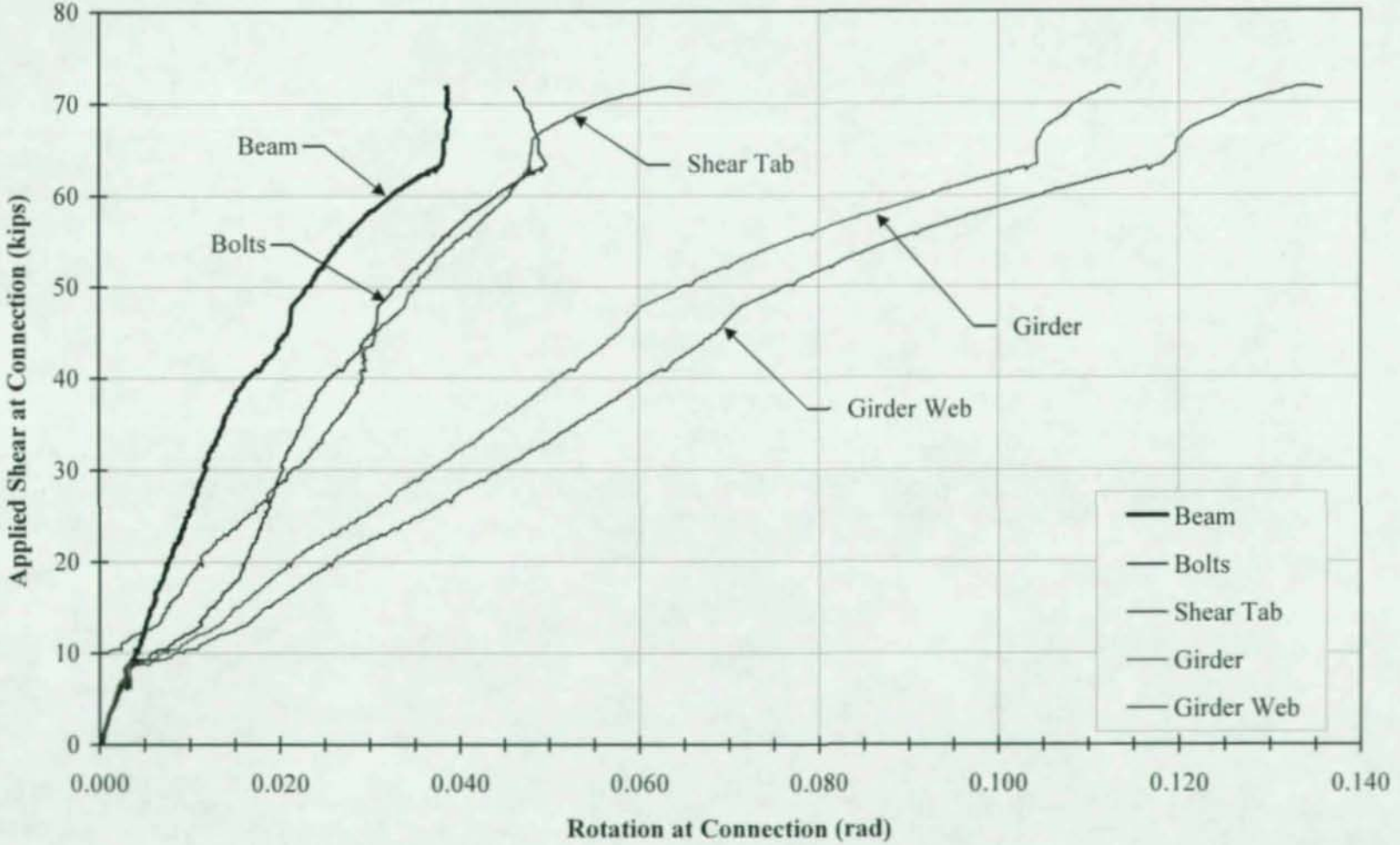


Test 3A – Connection Bolts at End of Test

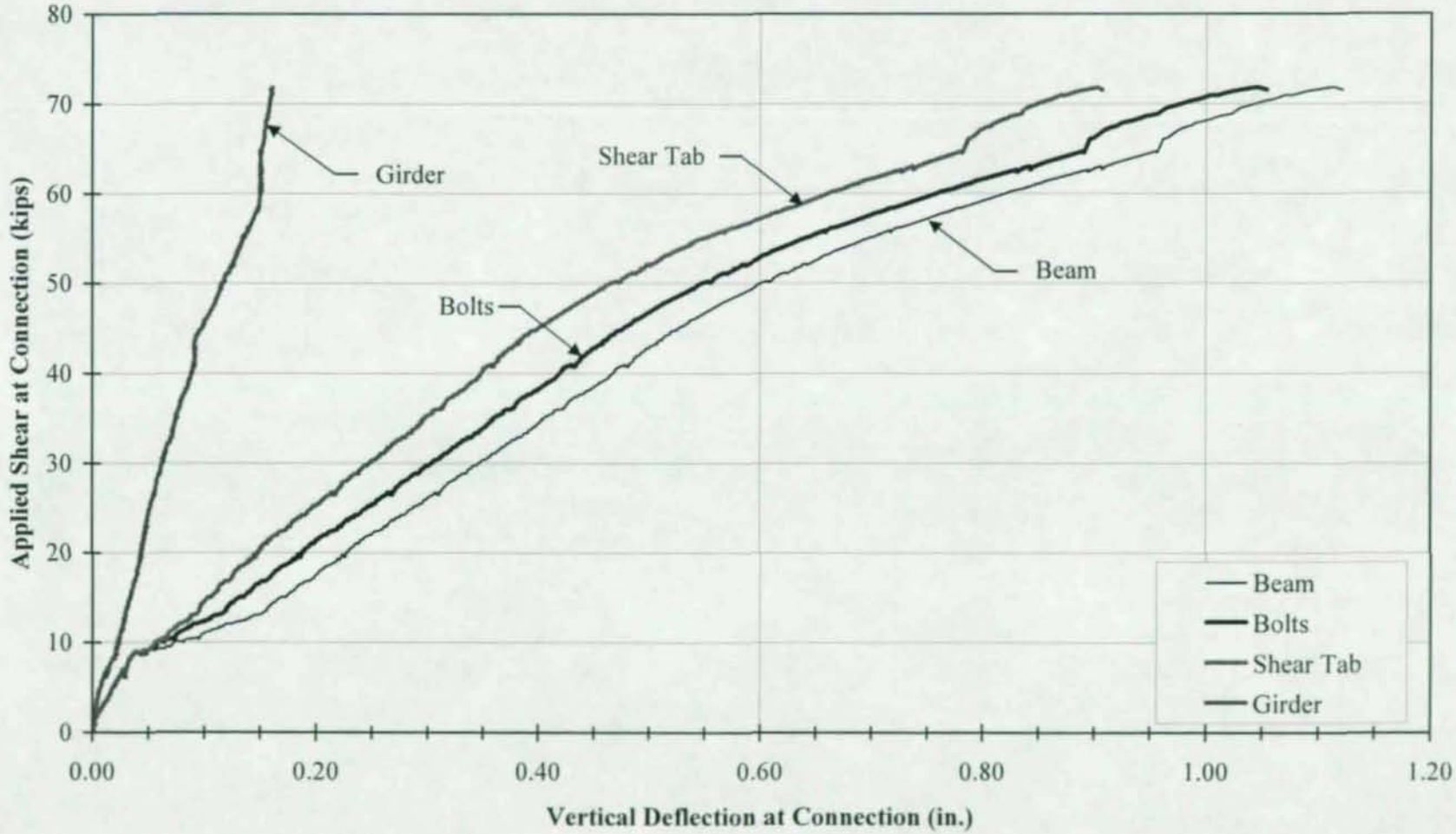


Test 3A – Connection Bolts at End of Test (fit back together)

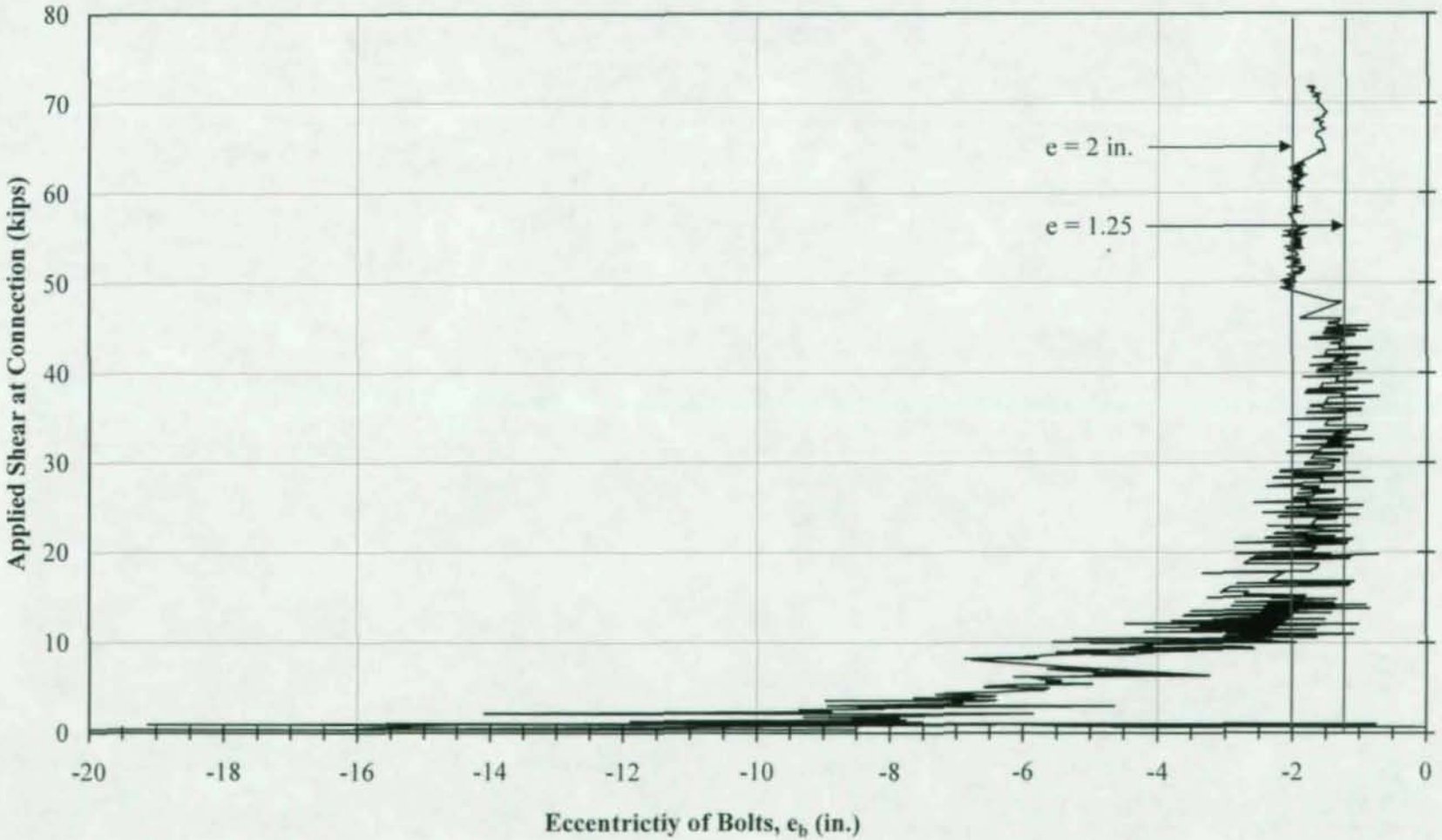
Test 3A (Flexible, Slotted)
Applied Shear vs. Rotation



Test 3A (Flexible, Slotted)
Applied Shear vs. Deflection



Test 3A (Flexible, Slotted)
Applied Shear vs. Bolt Eccentrictiy



Single Plate (Shear Tab) Connection Test Summary Sheet

Test ID: Test 6A (Flexible, Standard, Two-Bolt)
Test Date: July 17, 2003
Sponsor: W & W Steel Company
Tested By: Emmett Sumner, Ph. D., P.E. and Dustin Creech, EI
Tested By: Constructed Facilities Laboritory (CFL), North Carolina State University

Two bolt single plate connection with a flexible support condition, standard holes, and snug tight bolts.

Shear Tab
Plate Size: PL 3/8" x 4 1/2" x 0'-6"
Steel Grade: A36
Fy = 43.2 ksi
Fu = 63.4 ksi

Bolts
Diameter: 0.75 in.
Bolt Grade: A325
Ft = 106.4 ksi (Measured)
Pretension: 10 kips (snug-tight)
Thread Location: Included in shear plane

Beam
Section: W16x50
Steel Grade: A992
Fy = 54.1 ksi
Fu = 69.3 ksi

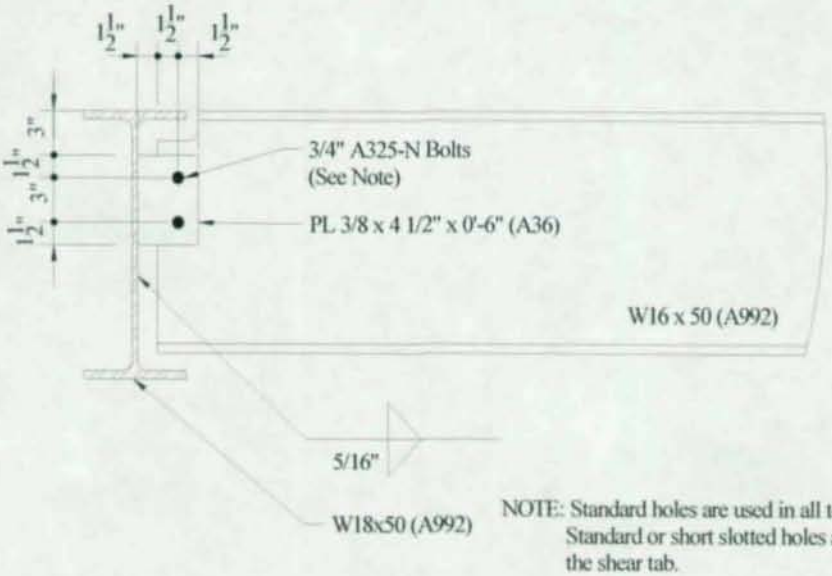
Girder
Section: W18x50
Steel Grade: A992

Experimental Results

Maximum Applied Shear at Connection =	44.2	kips
Maximum Beam End Rotation at Connection =	0.012	rad
Maximum Girder Rotation at Connection =	0.083	rad
Maximum Vertical Beam Deflection at Connection =	0.78	in.
Maximum Vertical Girder Deflection at Conneciton =	0.09	in.

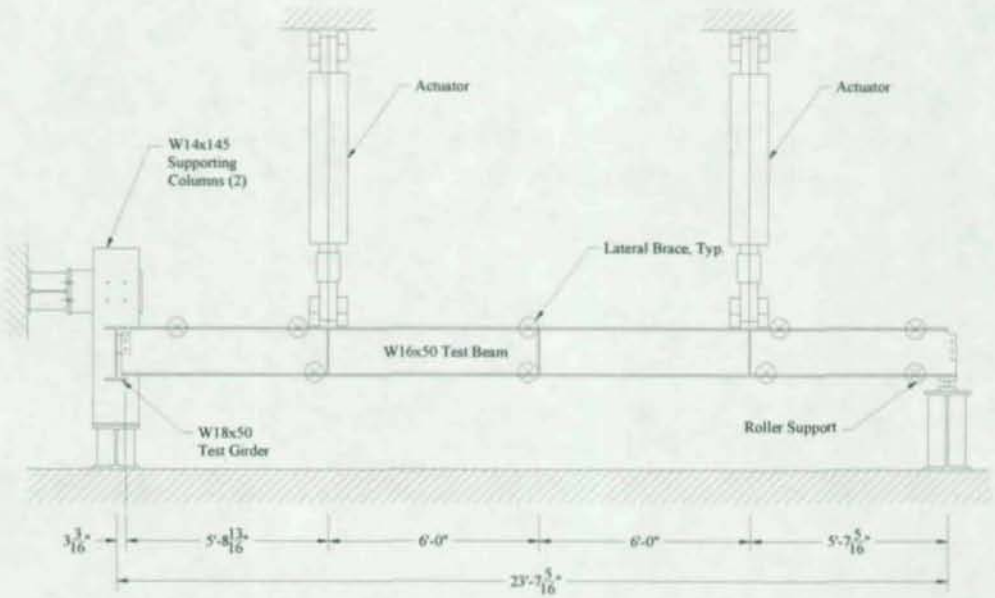
Test observations:

- At service load conditions, 18kips, girder experienced some elastic rotation.
- At 30 kips, first appearance of concentrated yielding near brace at midspan.
- At 40 kips, the test was paused and a visible increase in girder rotation as well as slight curvature of beam was noted. Data indicated a leveling slope in connection rotation, suggesting approach of failure
- Testing resumed and shear rupture of the connection bolts was observed at 44 kips. The beam was unyielded from test.

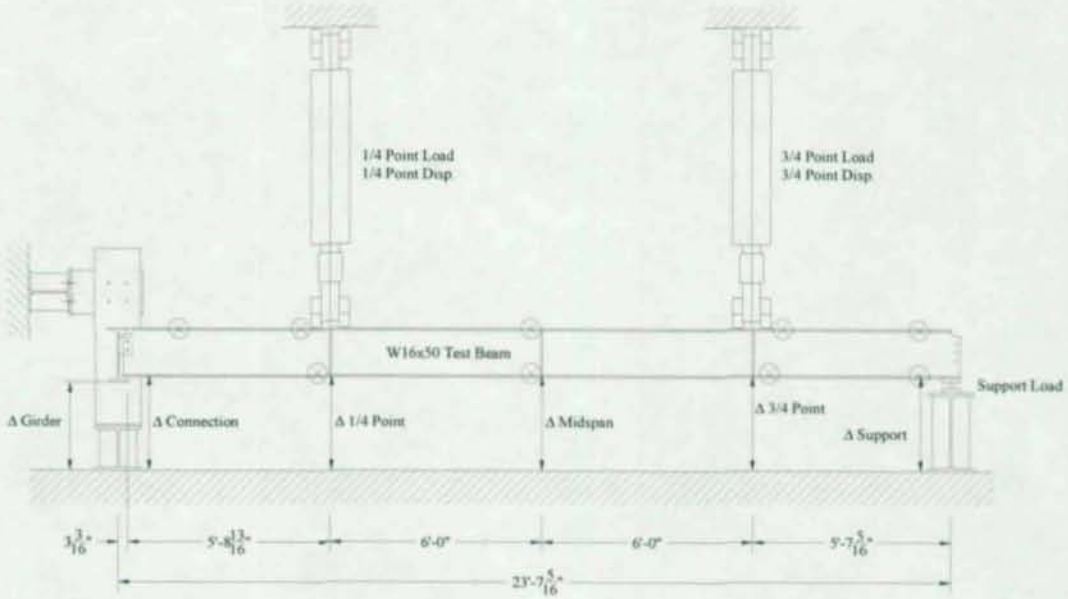


NOTE: Standard holes are used in all test beams. Standard or short slotted holes are used in the shear tab.

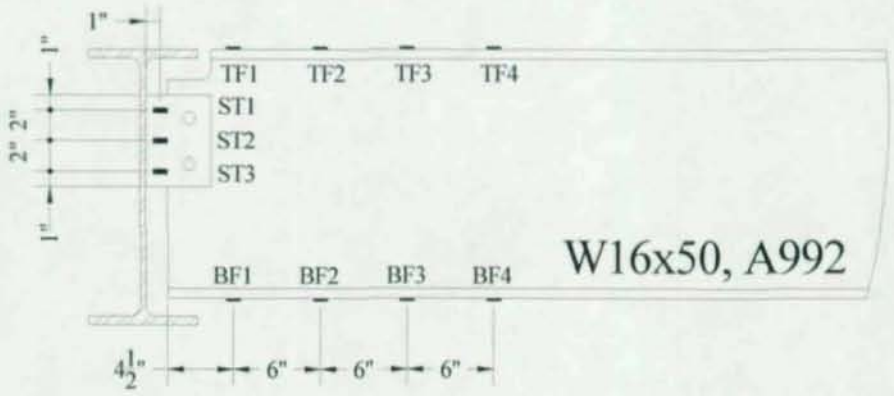
Detail of Single Plate (Shear Tab) Connection



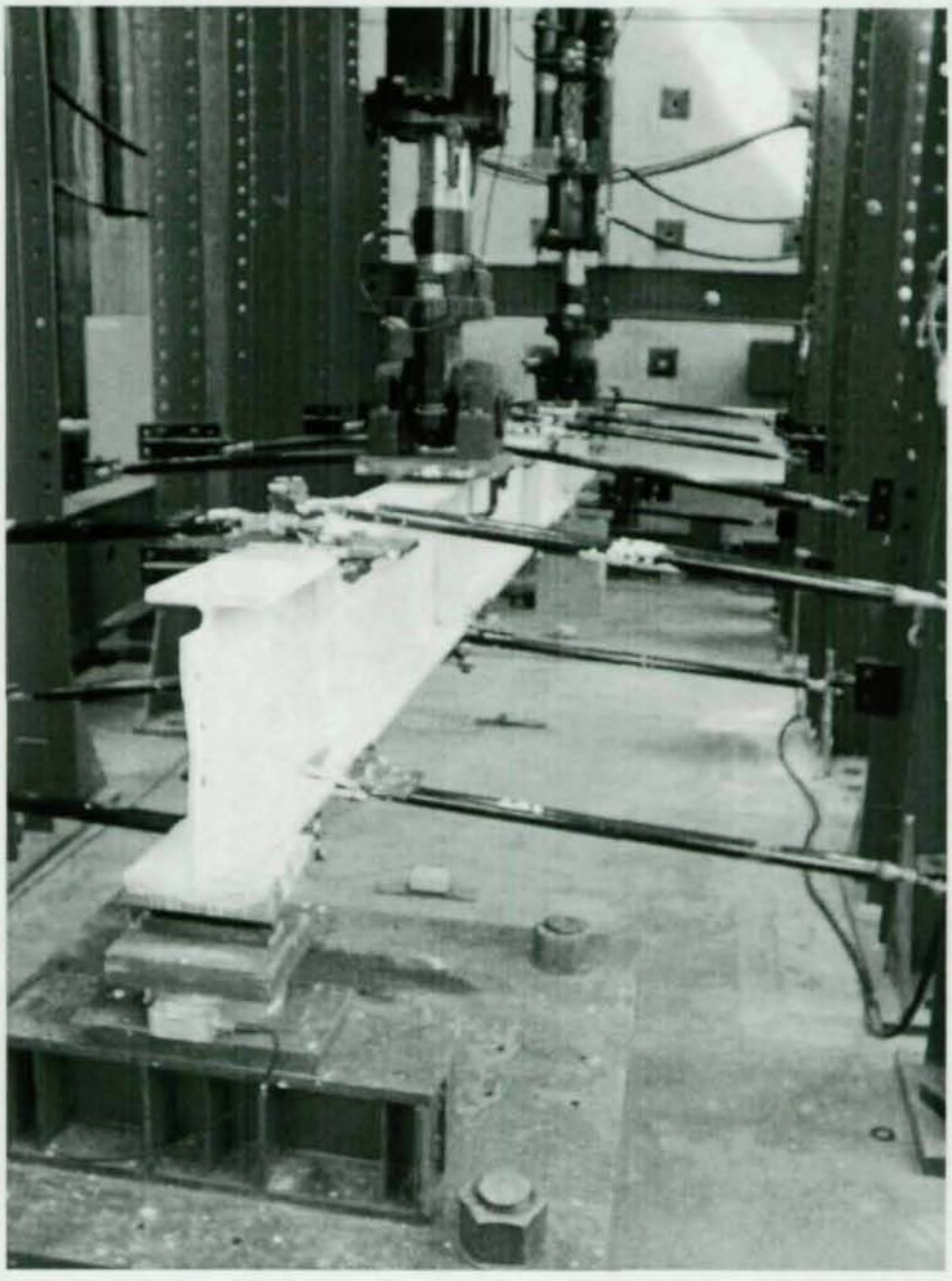
Elevation of Test Setup



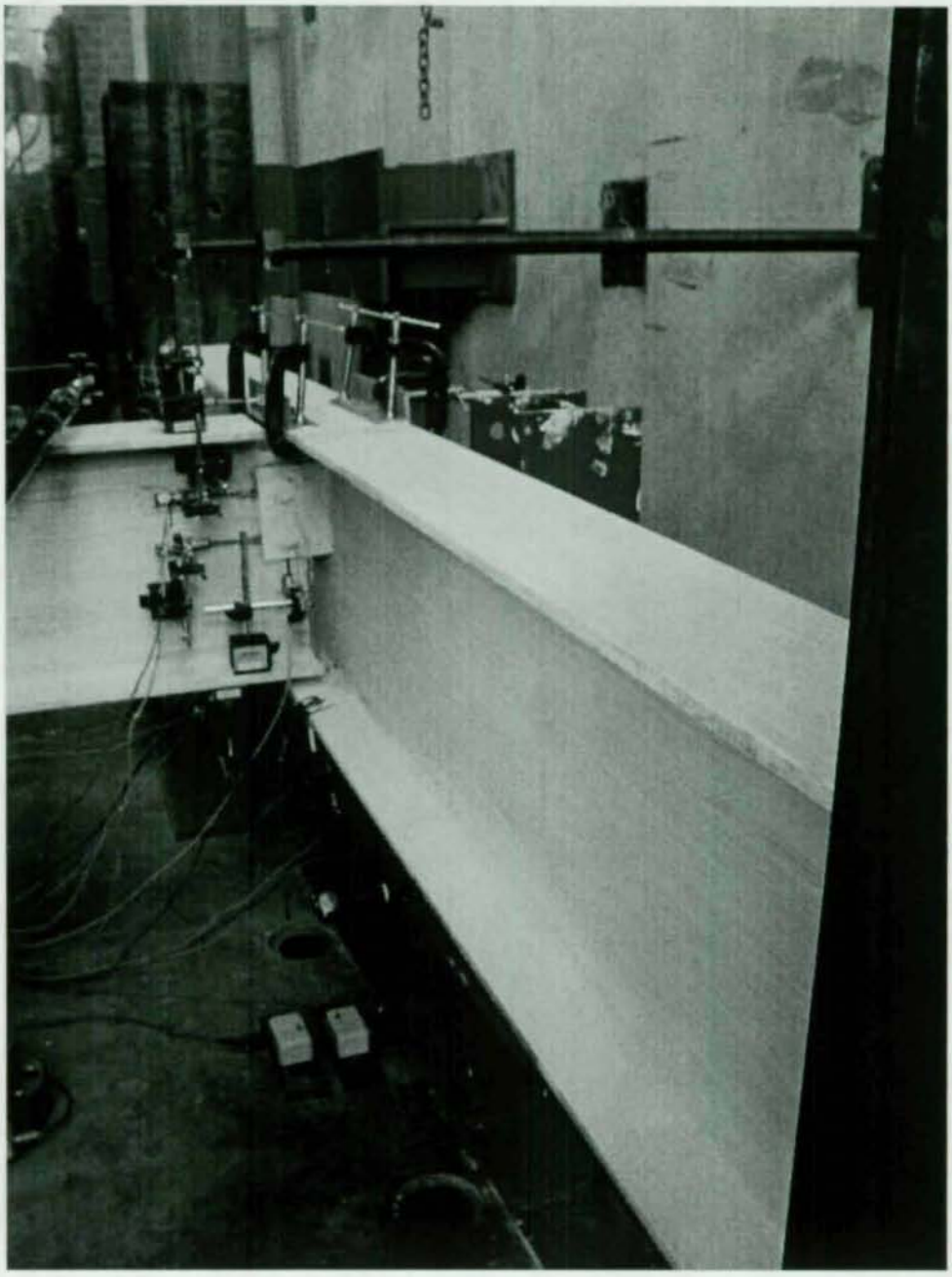
Elevation of Test Setup Showing Instrumentation



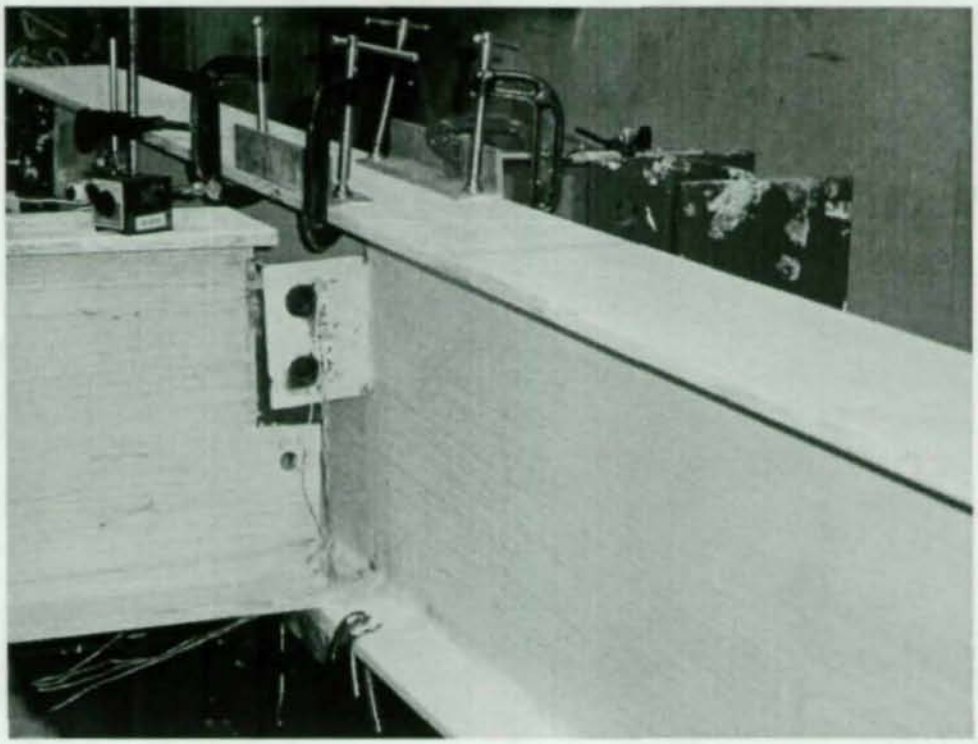
Connection Region Strain Gage Instrumentation



Test 6A – Overall View of Test Setup

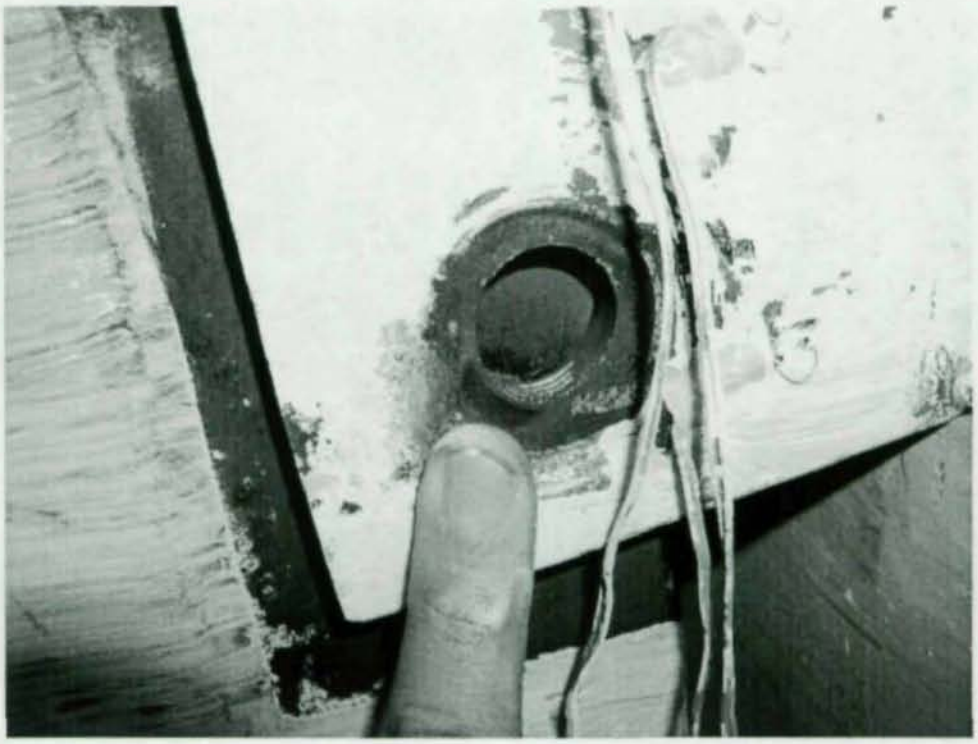


Test 6A – Connection Region Before Test

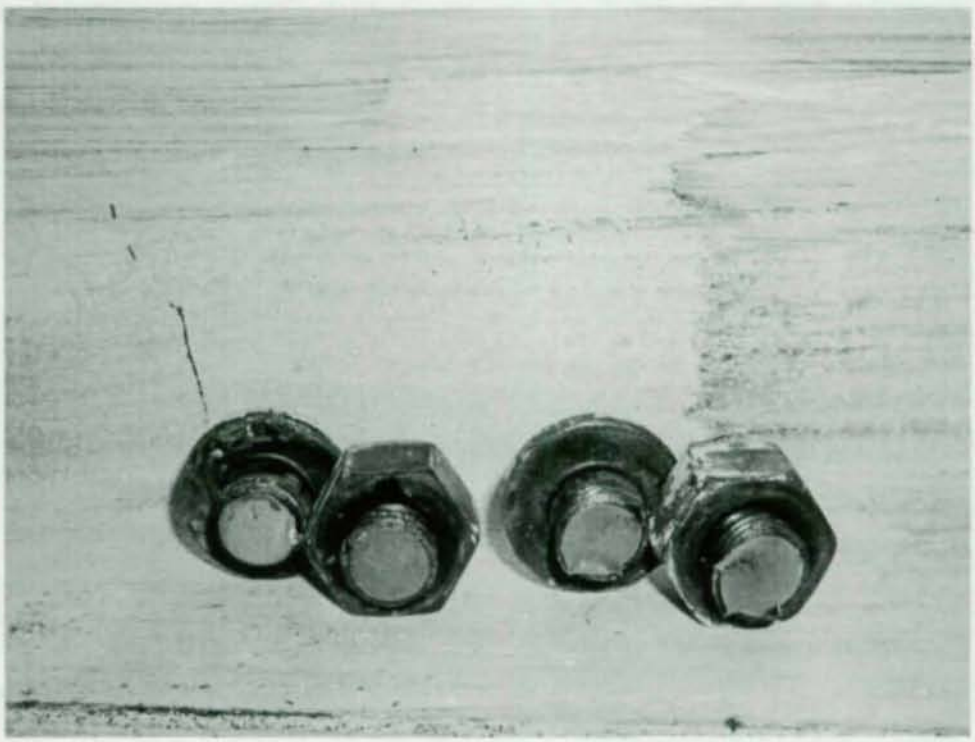


Test 6A – Connection Region at End of Test

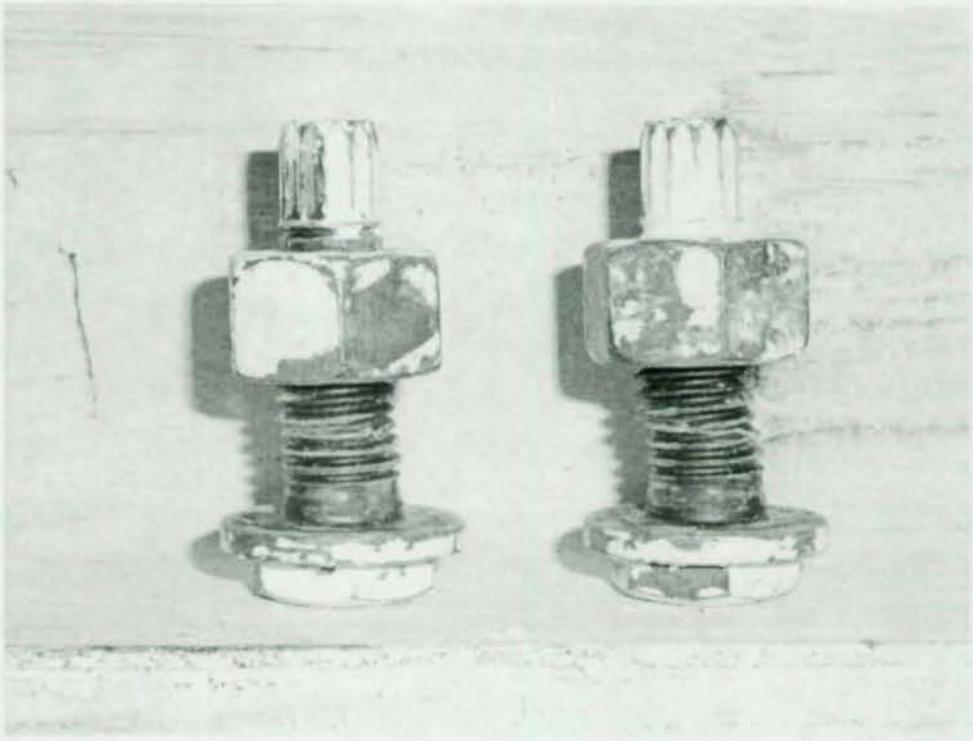
Test 6A – Top Bolt Hole in Shear Tab at End of Test



Test 6A – Bottom Bolt Hole in Shear Tab at End of Test

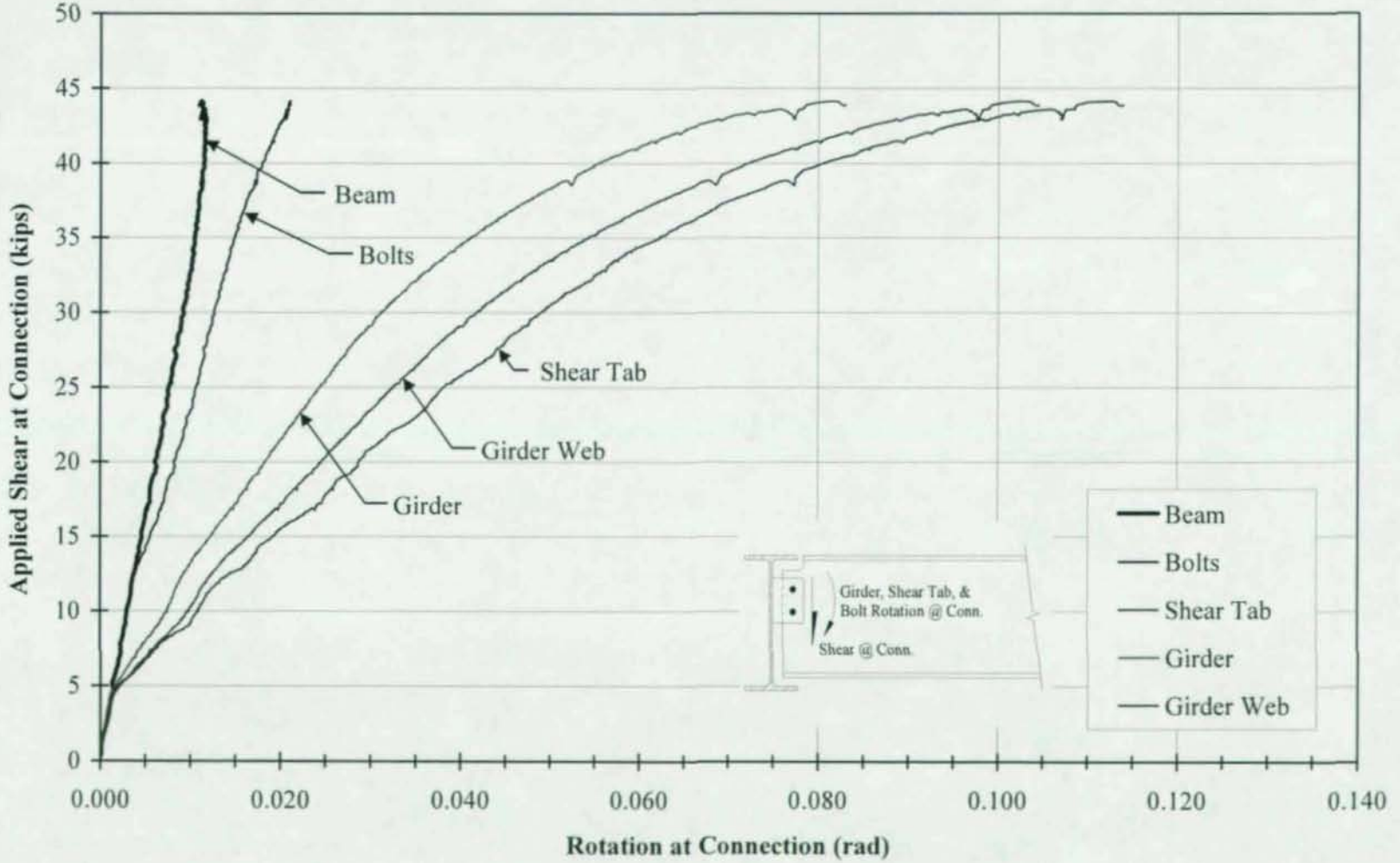


Test 6A – Connection Bolts at End of Test

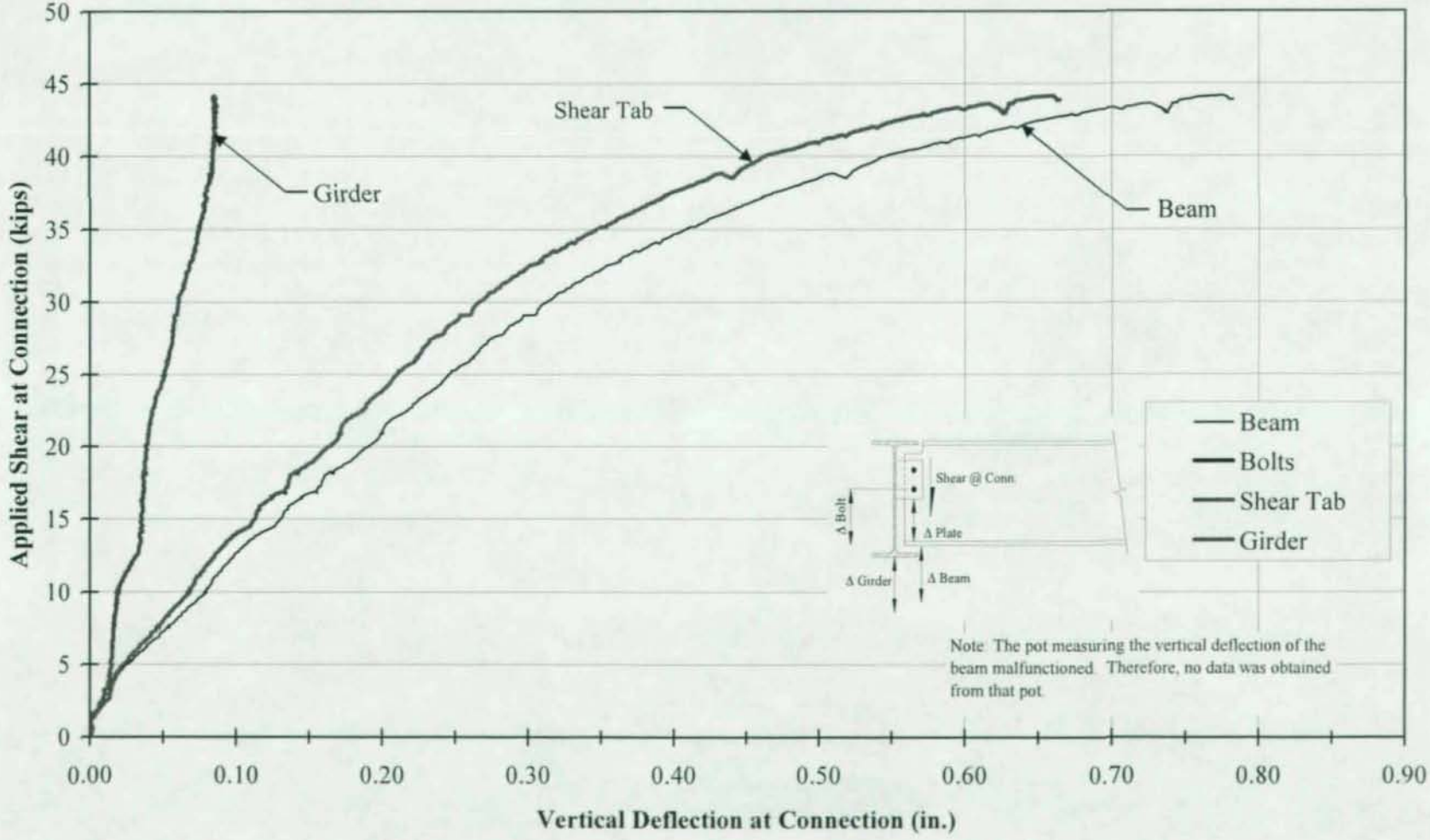


Test 6A – Connection Bolts at End of Test (fit back together)

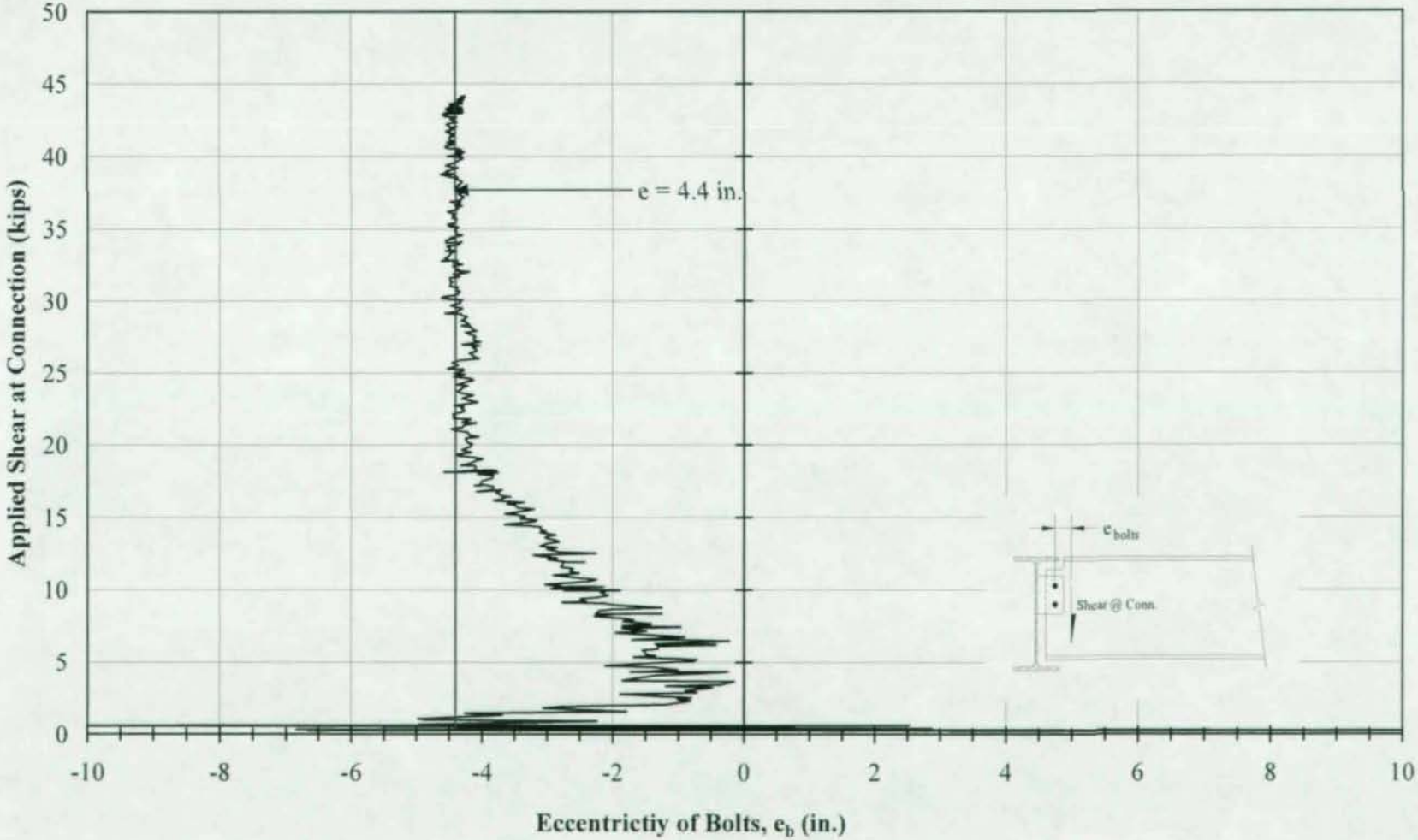
Test 6A (Flexible, Standard, Two-Bolt)
Applied Shear vs. Rotation



Test 6A (Flexible, Standard, Two-Bolt)
Applied Shear vs. Deflection



Test 6A (Flexible, Standard, Two-Bolt)
Applied Shear vs. Bolt Eccentrictiy



Single Plate (Shear Tab) Connection Test Summary Sheet

Test ID: Test 7A (Flexible, Slotted, Two-Bolt)
Test Date: August 29, 2003
Sponsor: W & W Steel Company
Tested By: Emmett Sumner, Ph. D., P.E. and Dustin Creech, EI
Tested By: Constructed Facilities Laboritory (CFL), North Carolina State University

Two bolt single plate connection with a flexible support condition, slotted holes, and snug tight bolts.

Shear Tab
Plate Size: PL 3/8" x 4 1/2" x 0'-6" — Fy = 43.2 ksi
Steel Grade: A36 — Fu = 63.4 ksi

Bolts
Diameter: 0.75 in.
Bolt Grade: A325
Ft = 106.4 ksi (Measured)
Pretension: 10 kips (snug-tight)
Thread Location: Included in shear plane

Beam
Section: W16x50 — Fy = 54.1 ksi
Steel Grade: A992 — Fu = 69.3 ksi

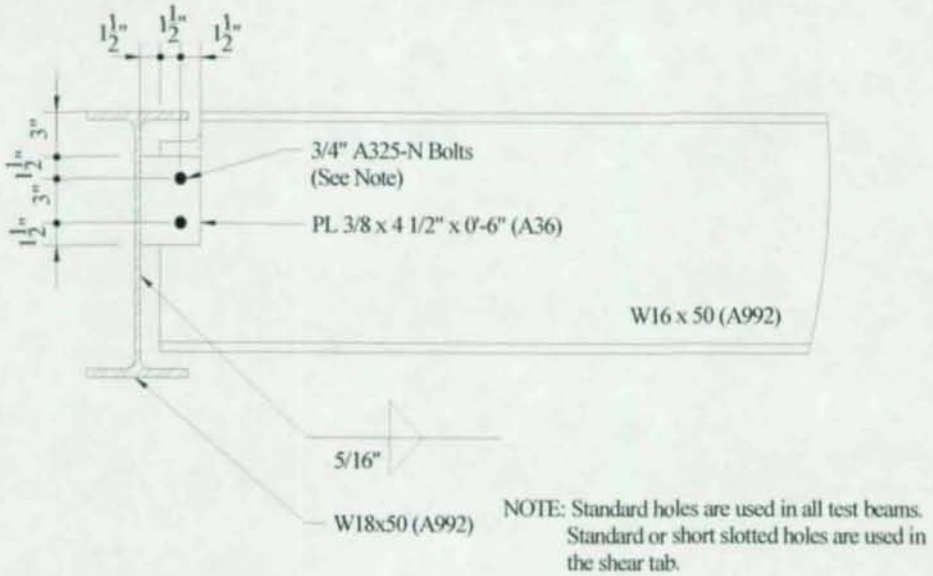
Girder
Section: W18x50
Steel Grade: A992

Experimental Results

Maximum Applied Shear at Connection =	45.45	kips
Maximum Beam End Rotation at Connection =	0.011	rad
Maximum Girder Rotation at Connection =	0.099	rad
Maximum Vertical Beam Deflection at Connection =	1.11	in.
Maximum Vertical Girder Deflection at Conneciton =	0.07	in.

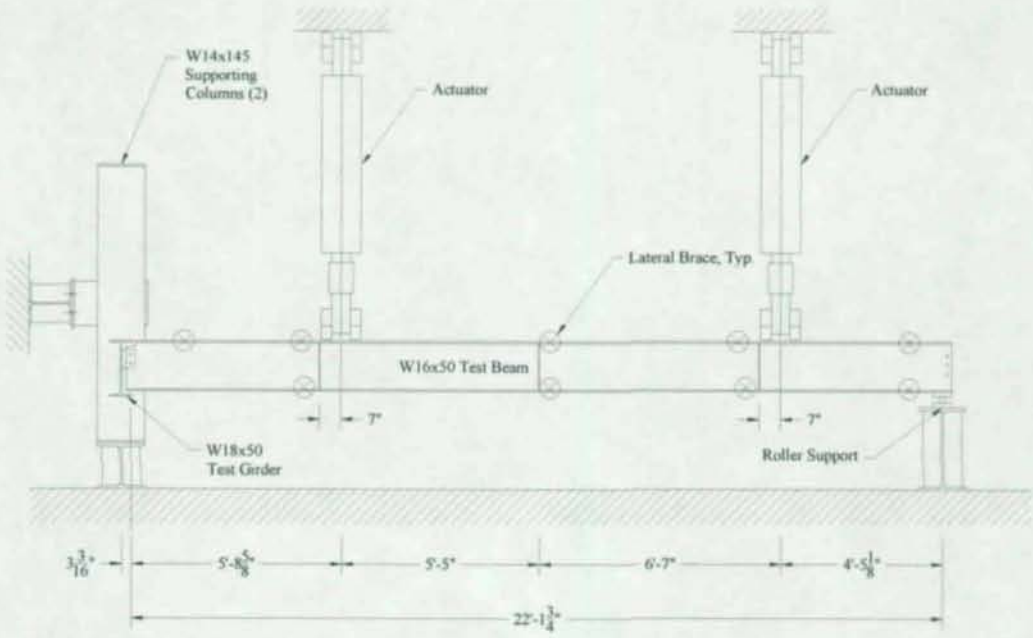
Test observations:

- At service load conditions, 18kips, the connection exhibited slight rotation The first appearance of concentrated yield marks at midspan of top flange was noted.
- At 30 kips, an increase in concentrated yielding at midspan of beam as well as an increase in rotation at connection was observed.
- At 40 kips, yielding of the shear tab and localized yielding on web near all stiffeners was noted.
- Shear rupture of the connection bolts was observed at 45 kips. Upon examination of the connection, failure of the top portion of the shear tab weld was noted. Although the beam underwent localized yielding, overall, the beam was relatively unyielded.

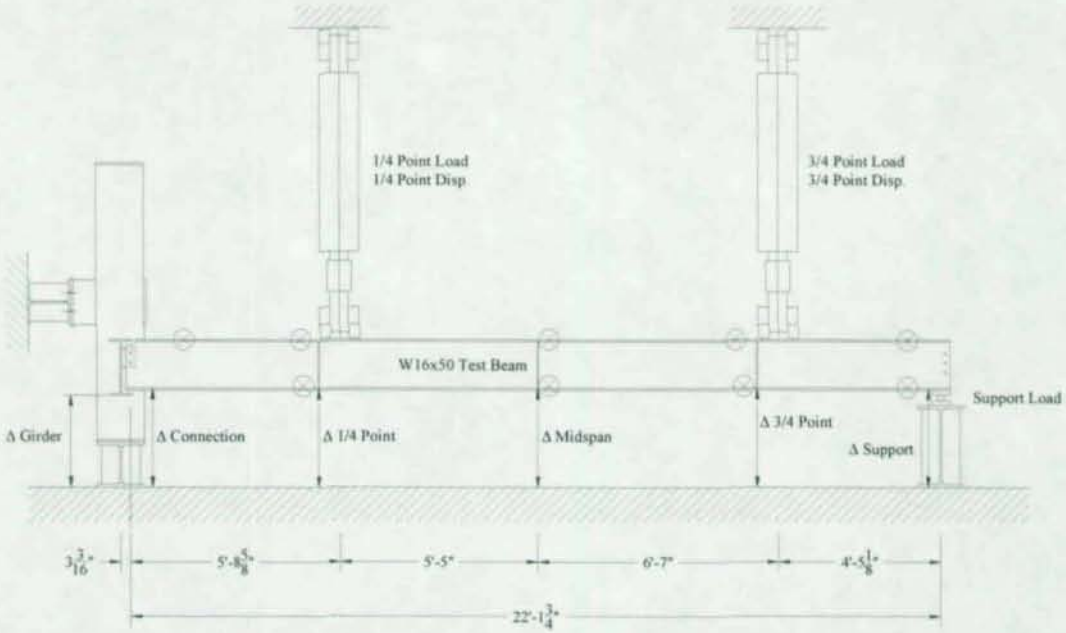


NOTE: Standard holes are used in all test beams. Standard or short slotted holes are used in the shear tab.

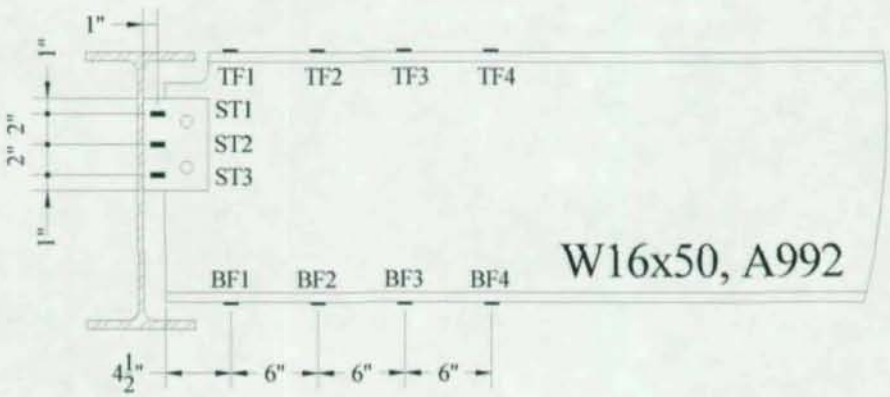
Detail of Single Plate (Shear Tab) Connection



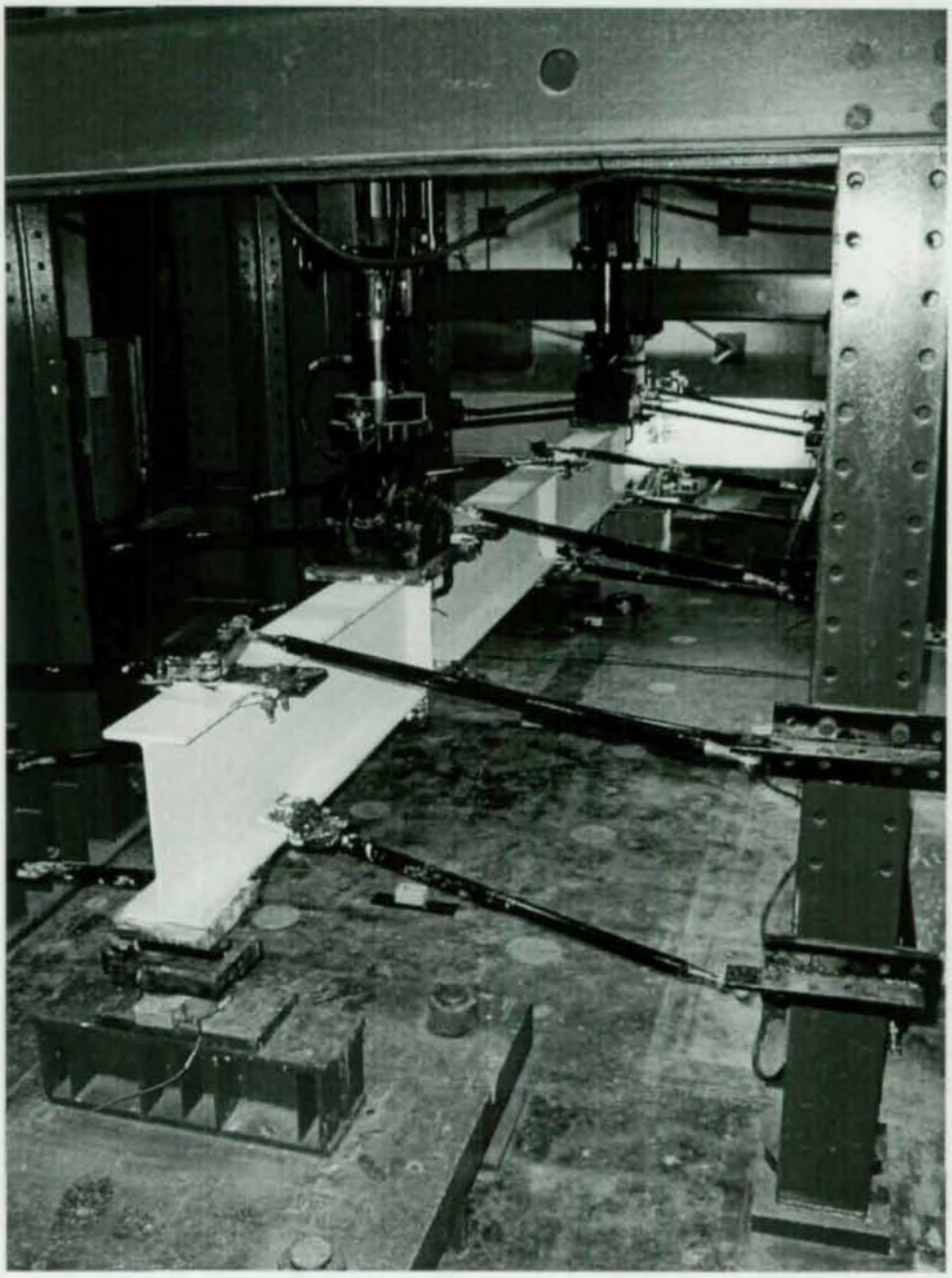
Elevation of Test Setup



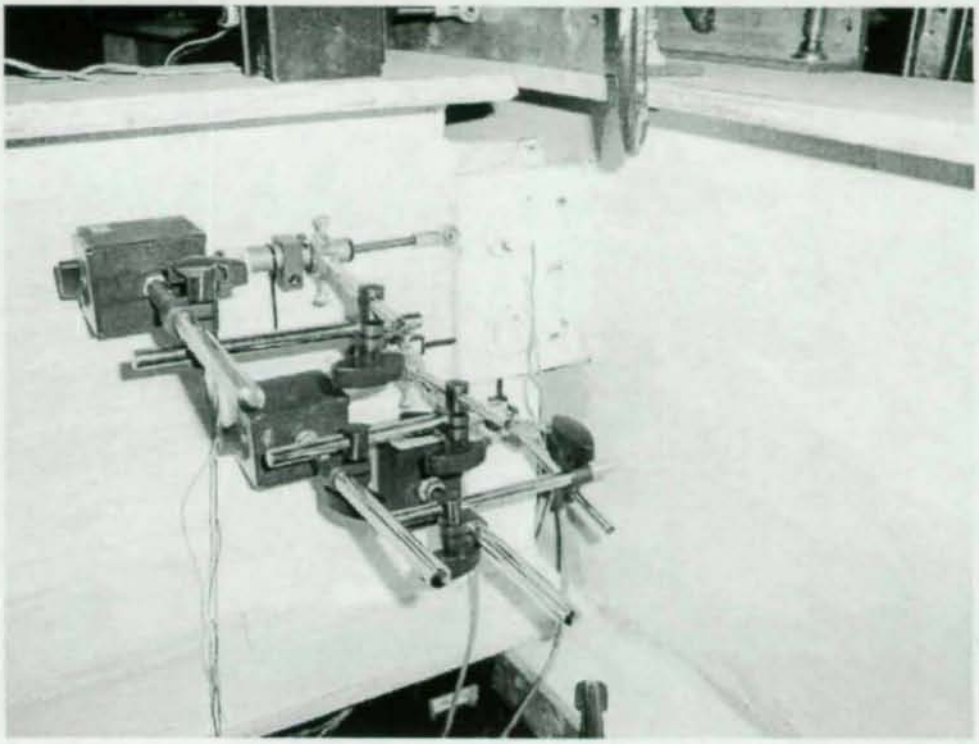
Elevation of Test Setup Showing Instrumentation



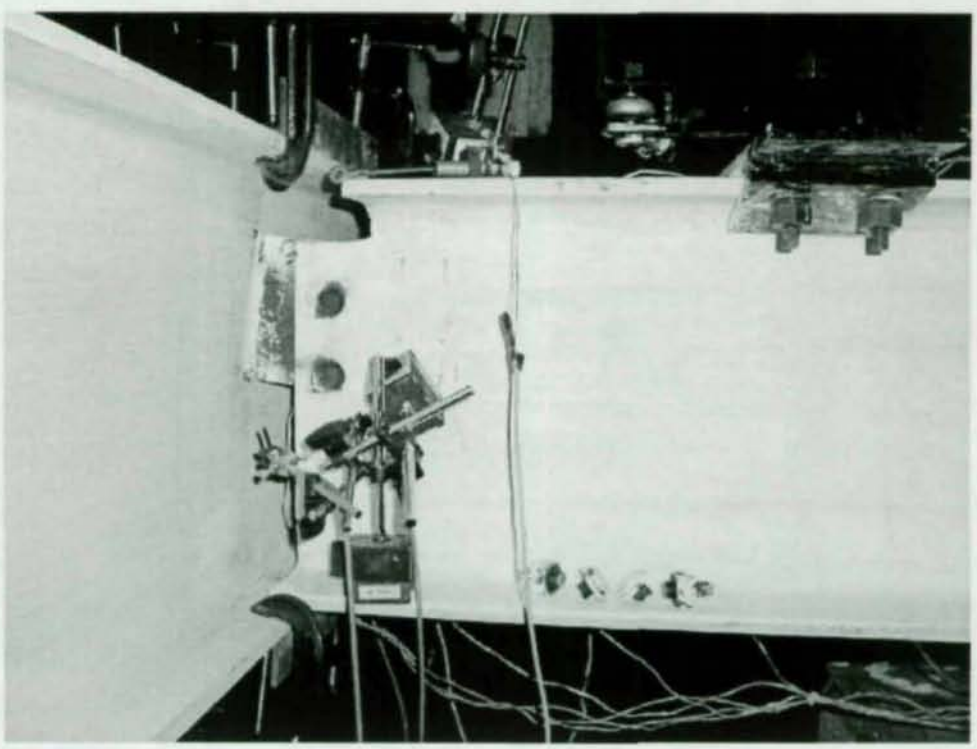
Connection Region Strain Gage Instrumentation



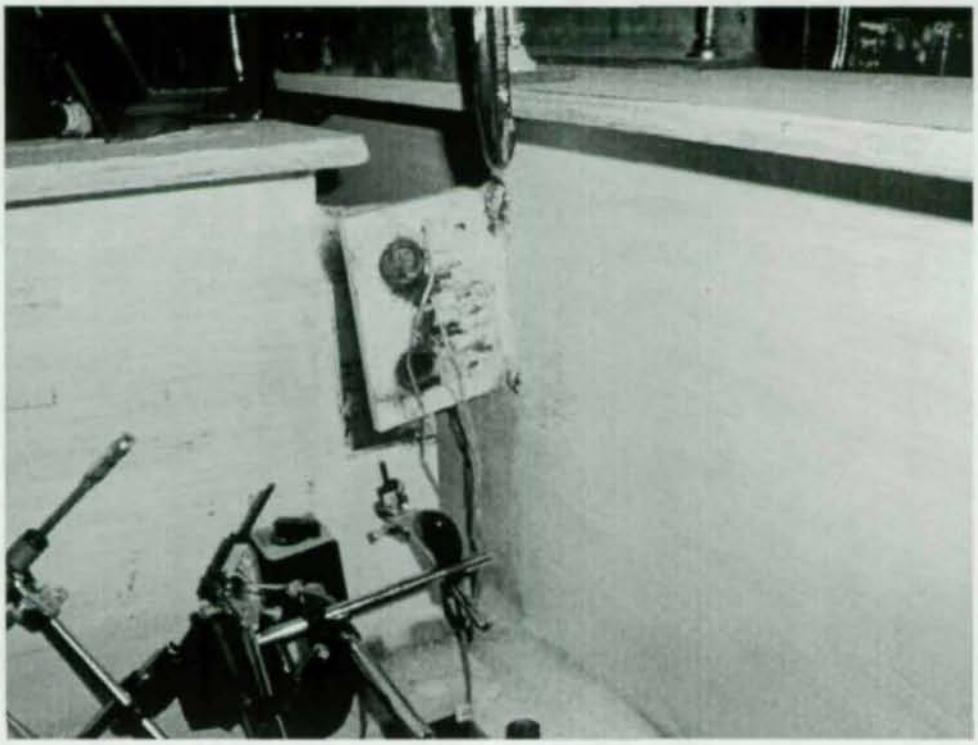
Test 7A – Overall View of Test Setup



Test 7A – Connection Region Before Test

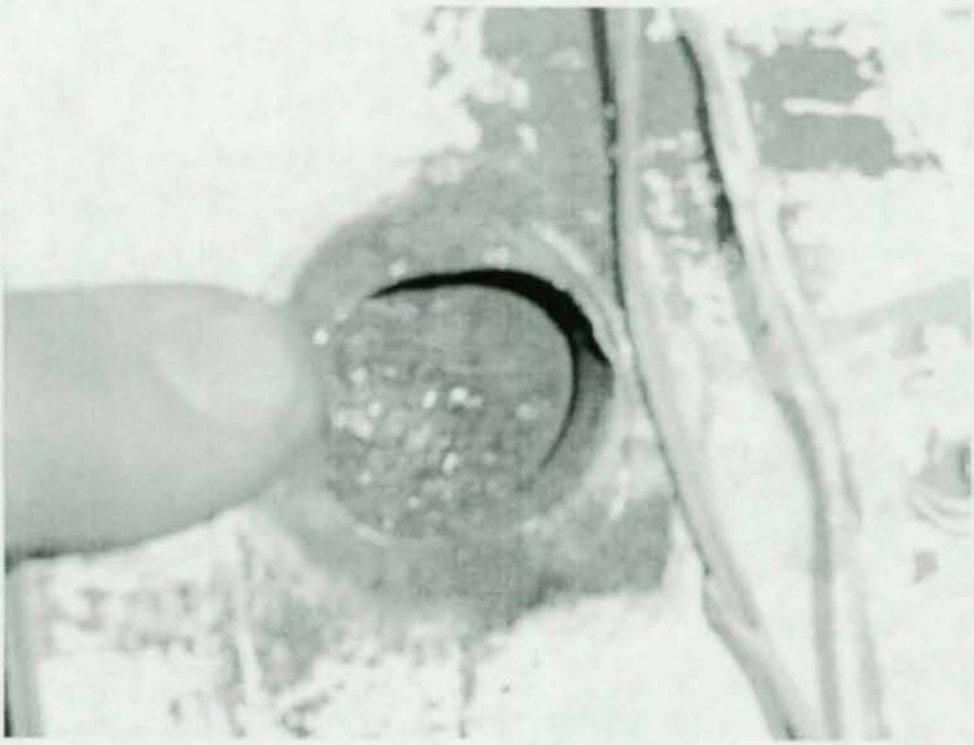


Test 7A – Connection Region at End of Test



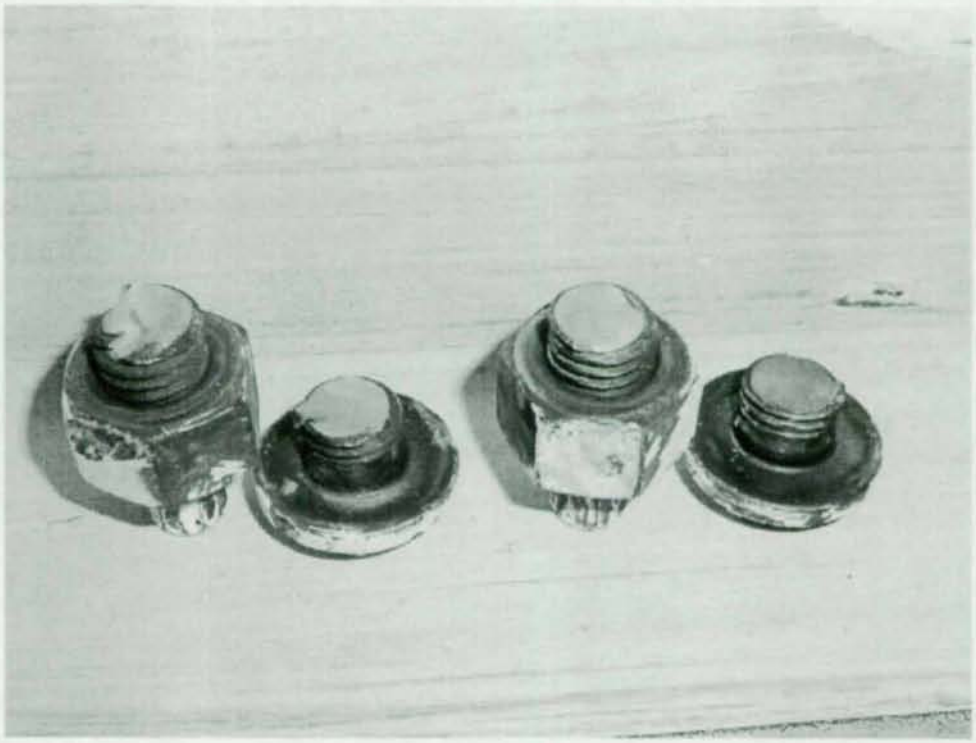
Test 7A – Connection Region at End of Test

Test 7A – Top Bolt Hole in Shear Tab at End of Test

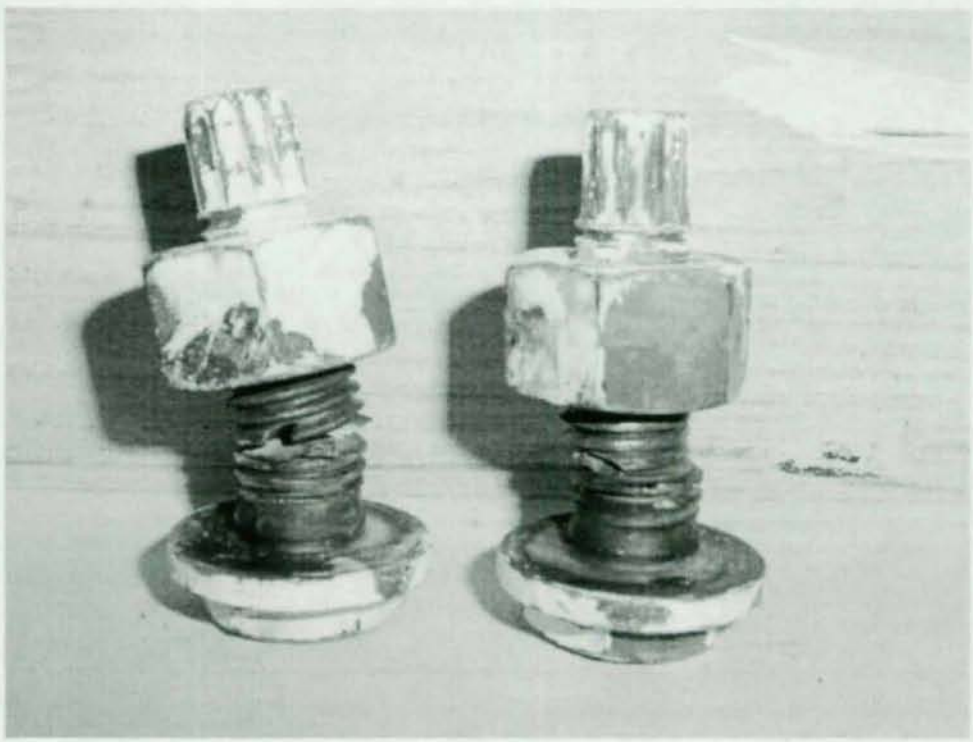


Test 7A – Bottom Bolt Hole in Shear Tab at End of Test

Test 7A – Failure of Shear Tab Weld at End of Test

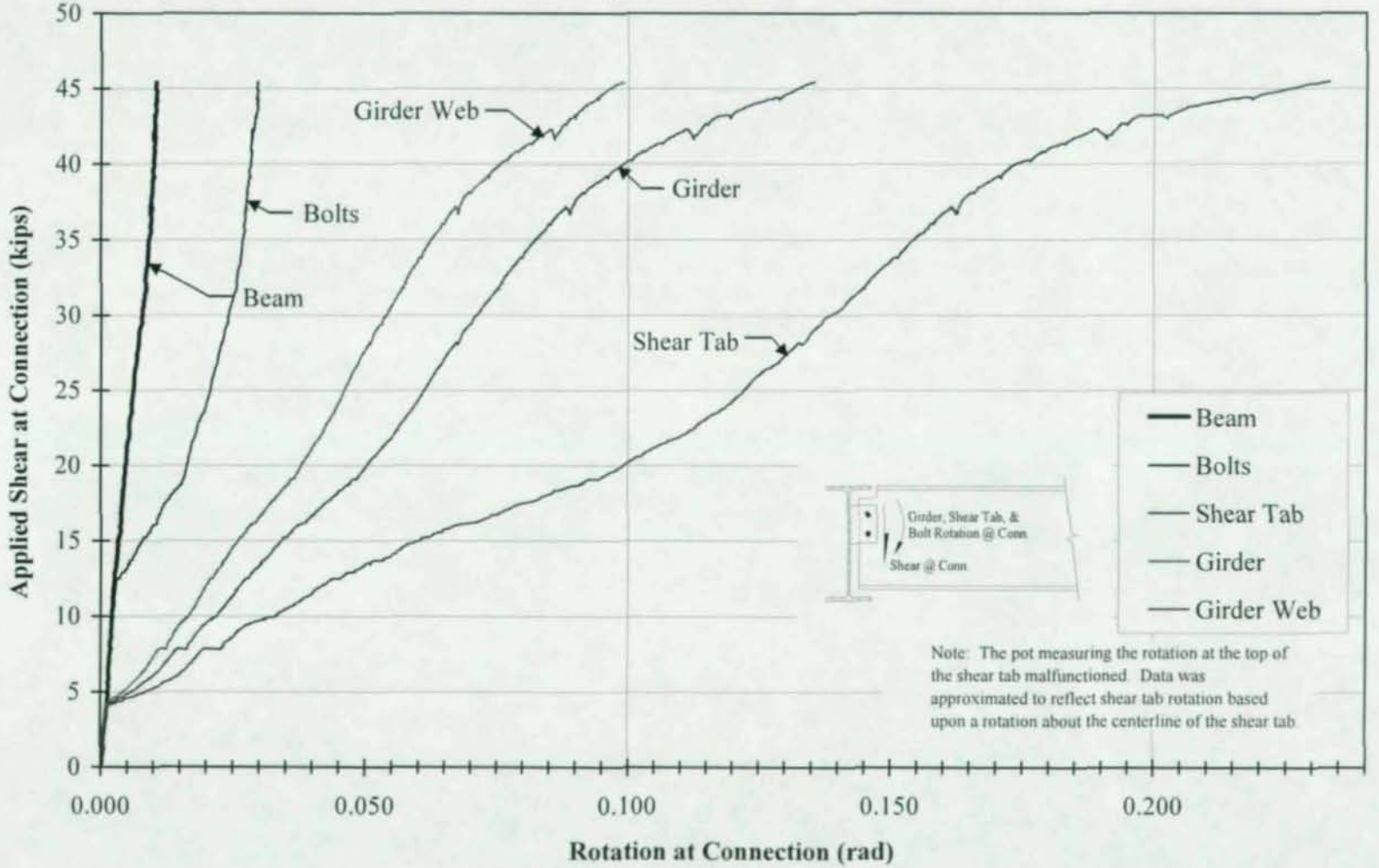


Test 7A – Connection Bolts at End of Test

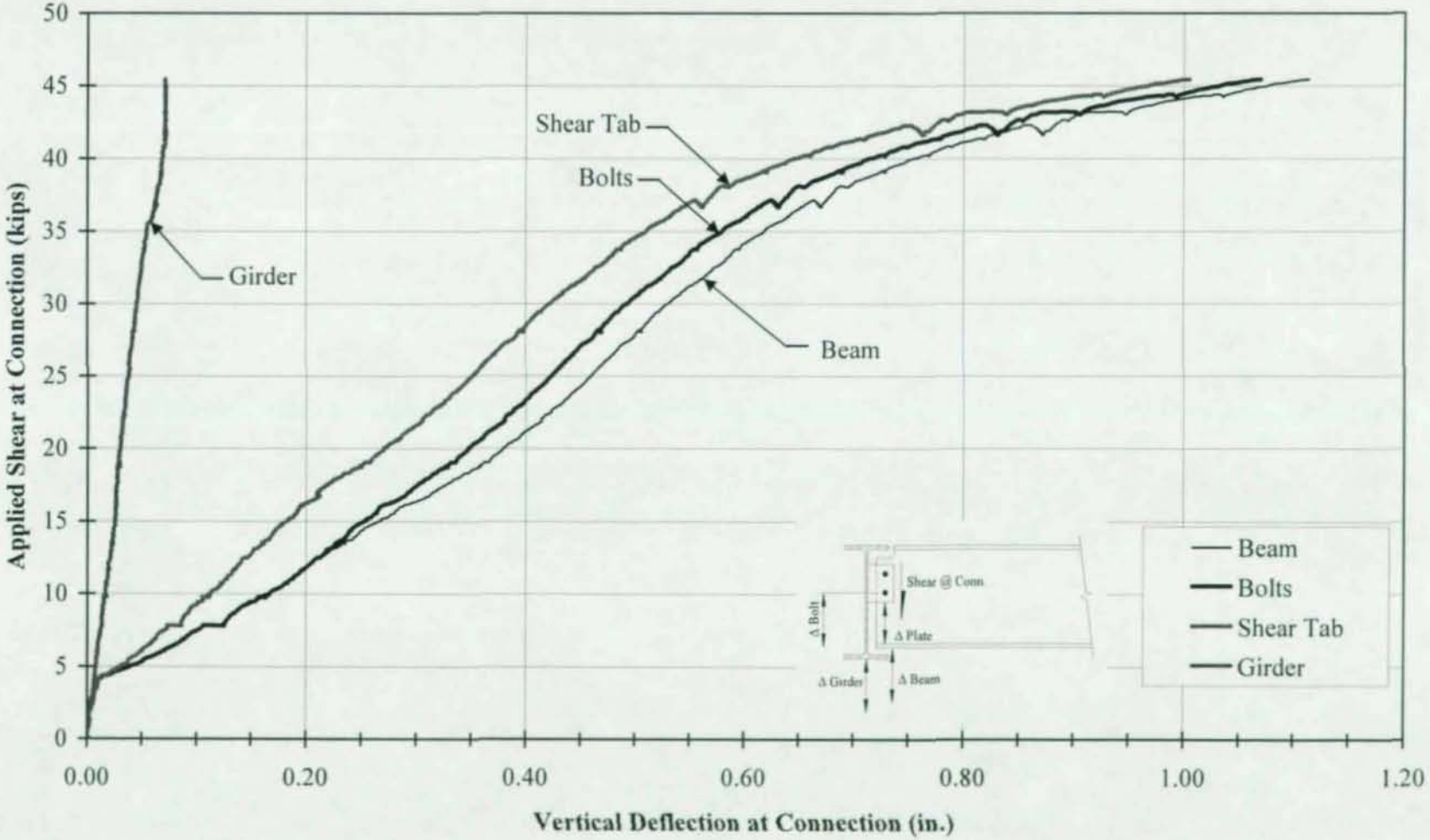


Test 7A – Connection Bolts at End of Test (fit back together)

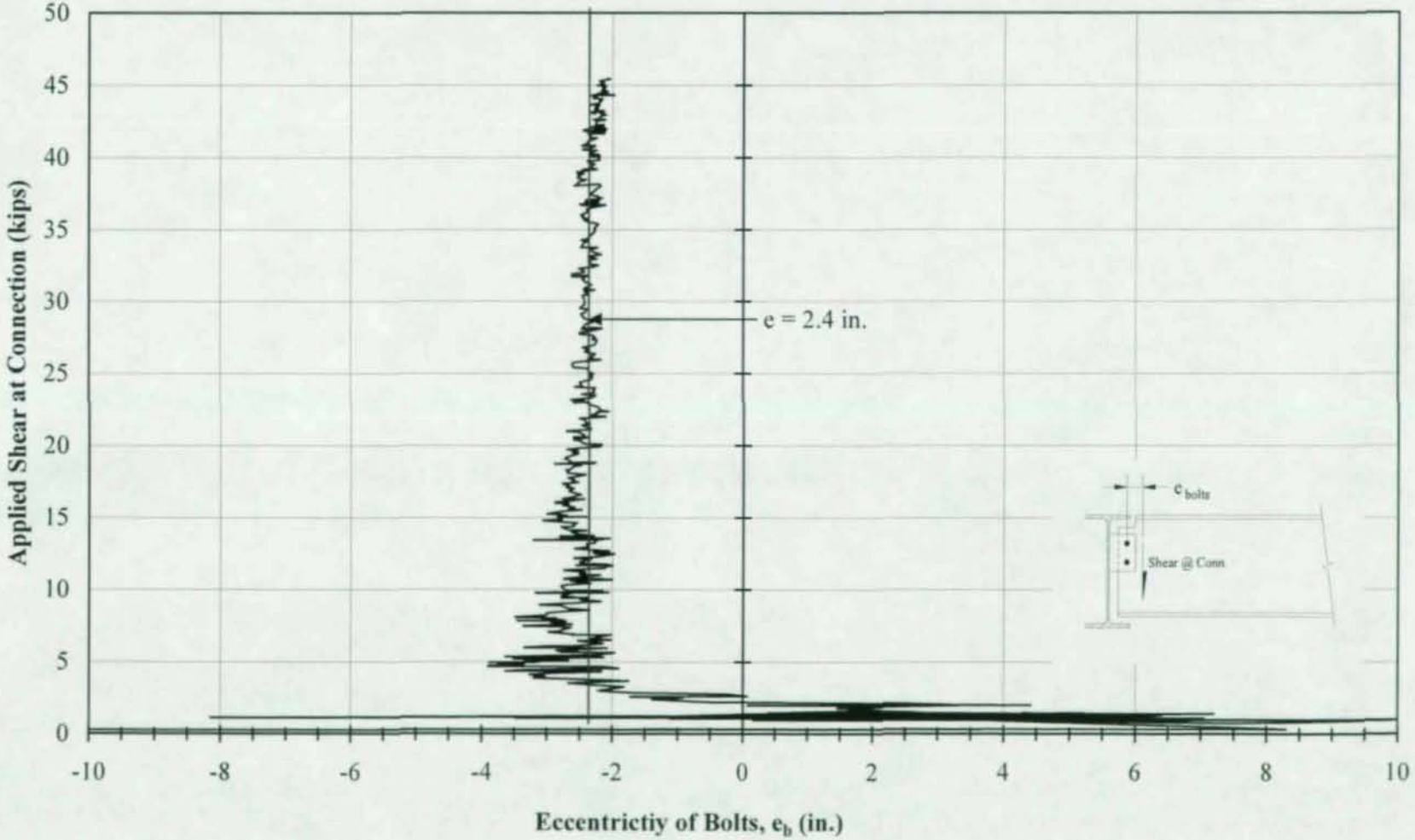
Test 7A (Flexible, Slotted, Two-Bolt)
Applied Shear vs. Rotation



Test 7A (Flexible, Slotted, Two-Bolt)
Applied Shear vs. Deflection



Test 7A (Flexible, Slotted, Two-Bolt)
Applied Shear vs. Bolt Eccentrictiy



Single Plate (Shear Tab) Connection Test Summary Sheet

Test ID: Test 8A (Flexible, Slotted, Welded Plate, Two-Bolt)
Test Date: September 8, 2003
Sponsor: W & W Steel Company
Tested By: Emmett Sumner, Ph. D., P.E. and Dustin Creech, EI
Tested By: Constructed Facilities Laboritory (CFL), North Carolina State University

Connection Description

Two bolt single plate connection with a flexible support condition, slotted holes, welded tie plate between top flange of girder and beam, and snug tight bolts.

Shear Tab
Plate Size: PL 3/8" x 4 1/2" x 0'-6" — Fy = 43.2 ksi
Steel Grade: A36 — Fu = 63.4 ksi

Bolts
Diameter: 0.75 in.
Bolt Grade: A325
Ft = 106.4 ksi (Measured)
Pretension: 10 kips (snug-tight)
Thread Location: Included in shear plane

Beam
Section: W16x50 — Fy = 54.1 ksi
Steel Grade: A992 — Fu = 69.3 ksi

Girder
Section: W18x50
Steel Grade: A992

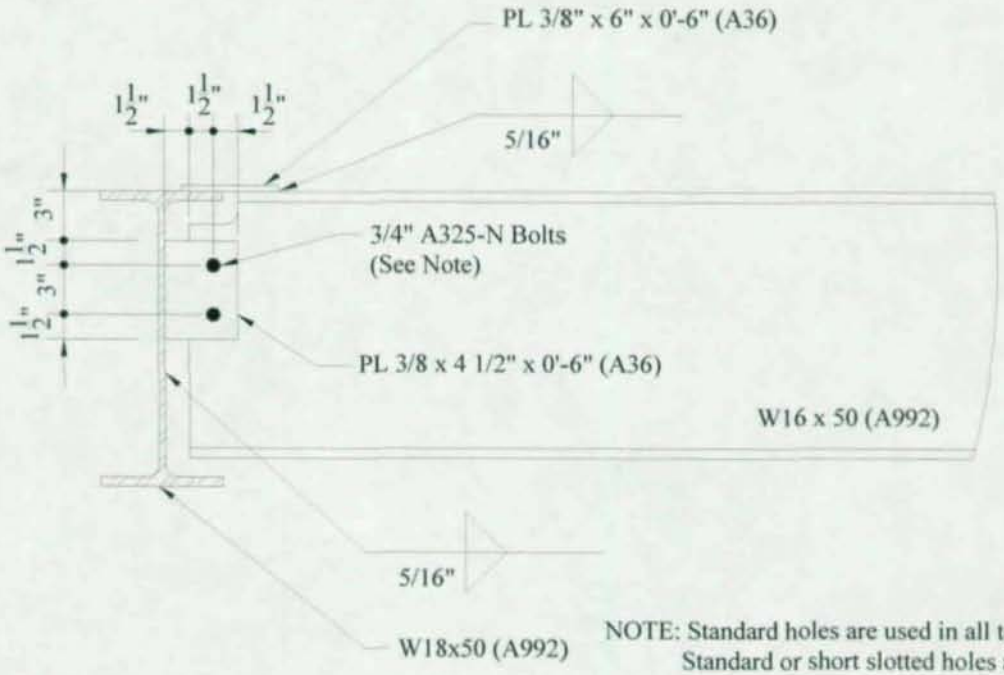
Tie Plate
Plate Size: PL 3/8" x 6" x 6"
Steel Grade: A36

Experimental Results

Maximum Applied Shear at Connection =	47.93	kips
Maximum Beam End Rotation at Connection =	0.013	rad
Maximum Girder Rotation at Connection =	0.032	rad
Maximum Vertical Beam Deflection at Connection =	1.08	in.
Maximum Vertical Girder Deflection at Conneciton =	0.15	in.

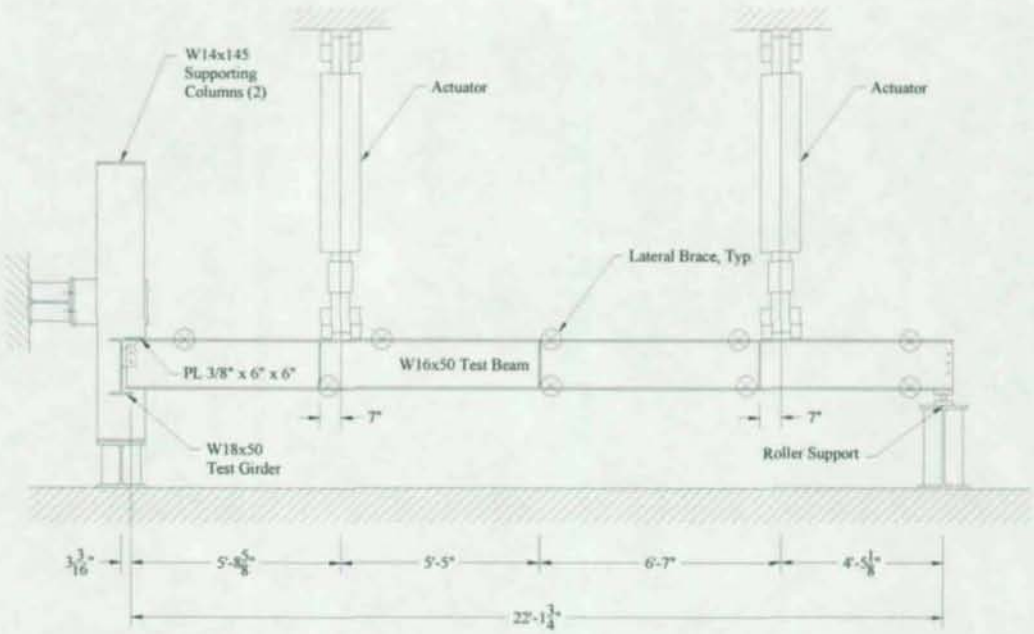
Test observations:

- At 11 kips, a shift at the connection was noted, resulting in an increase in beam deflection and connection rotation.
- At service load conditions, 18 kips, there was slight rotation at connection with minimal girder rotation due to restraints.
- At 30 kips, a visible rotation at connection was noted.
- The connection sustained loading up to 46 kips. After which a weakening of connection was noted as the load dropped slightly.
- Connection sustained an increase in load. Failure occurred at 48 kips when the bottom bolt sheared and the top portion of the shear tab weld failed. The top bolt was reasonably straight and the beam was relatively unyielded.

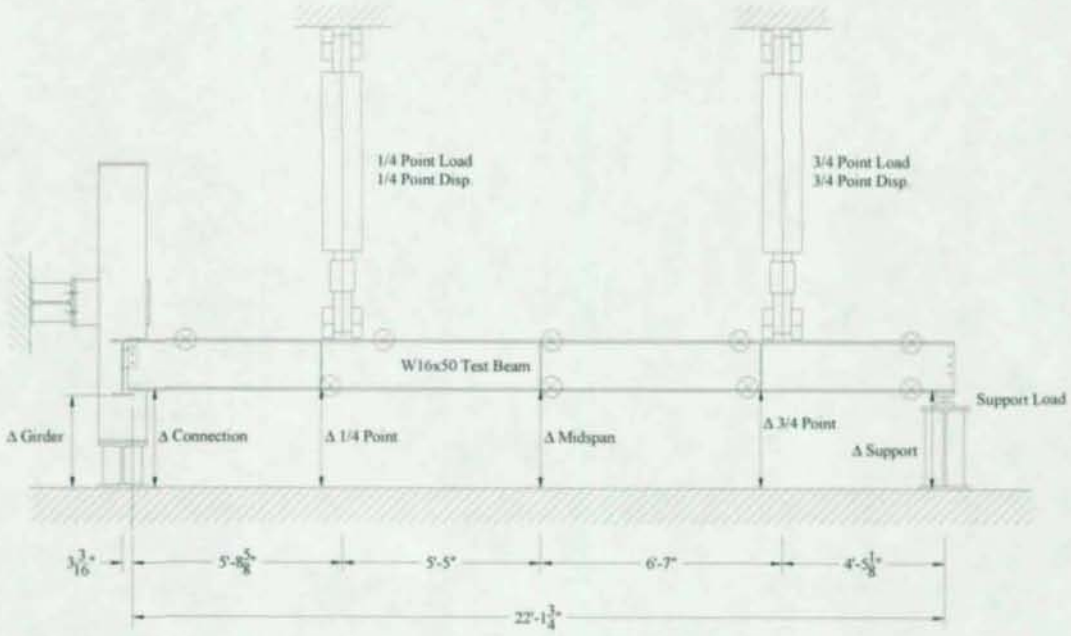


NOTE: Standard holes are used in all test beams. Standard or short slotted holes are used in the shear tab.

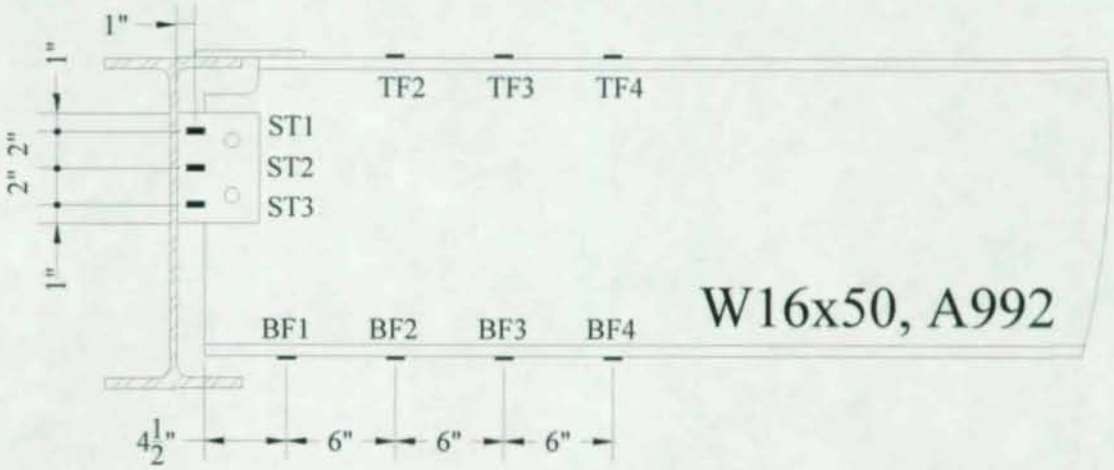
Detail of Single Plate (Shear Tab) Connection



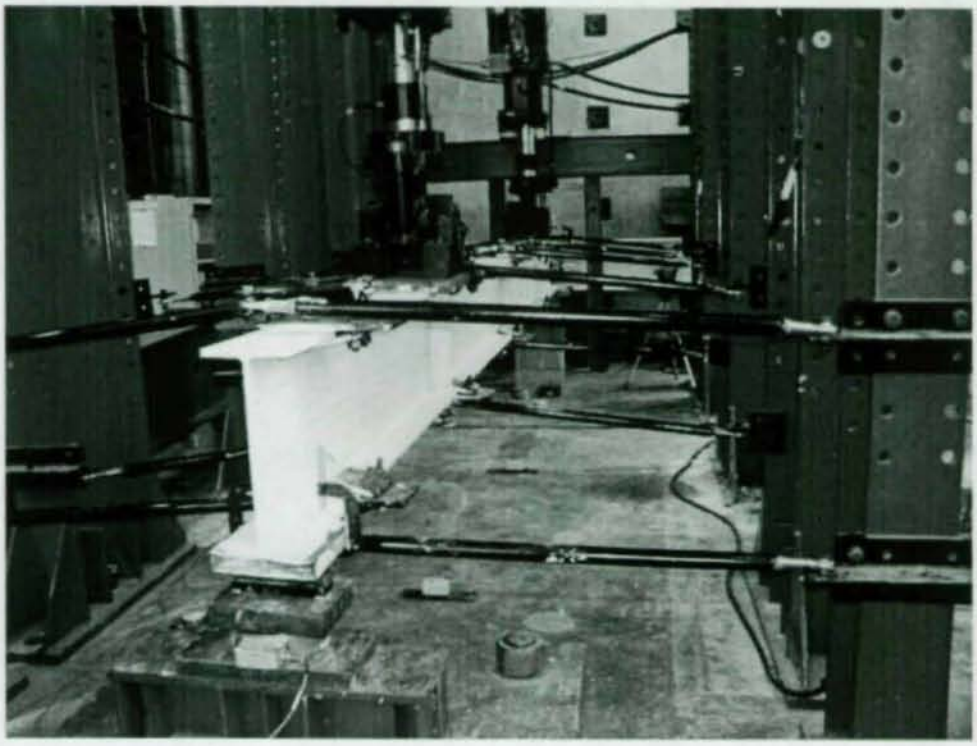
Elevation of Test Setup



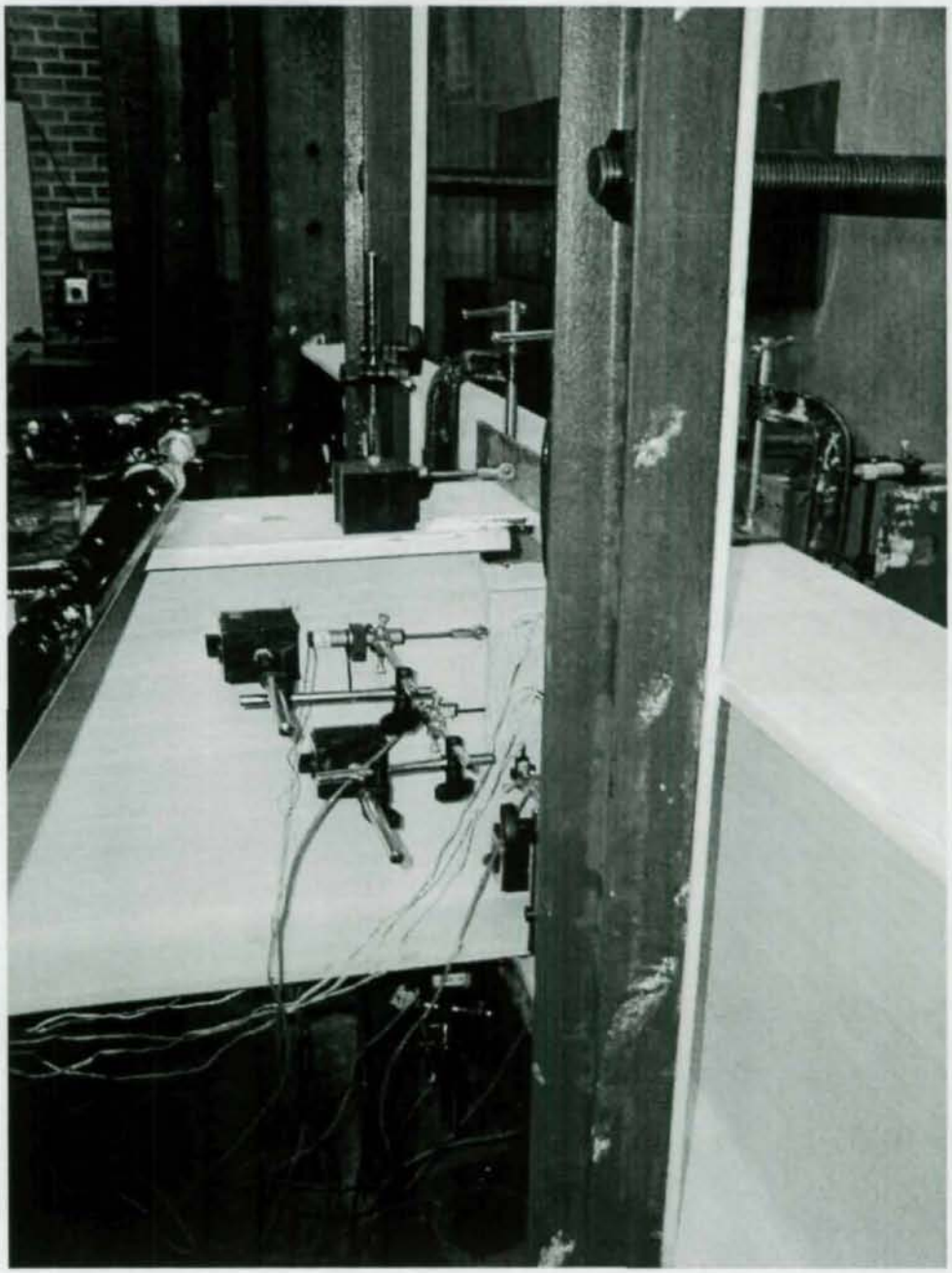
Elevation of Test Setup Showing Instrumentation



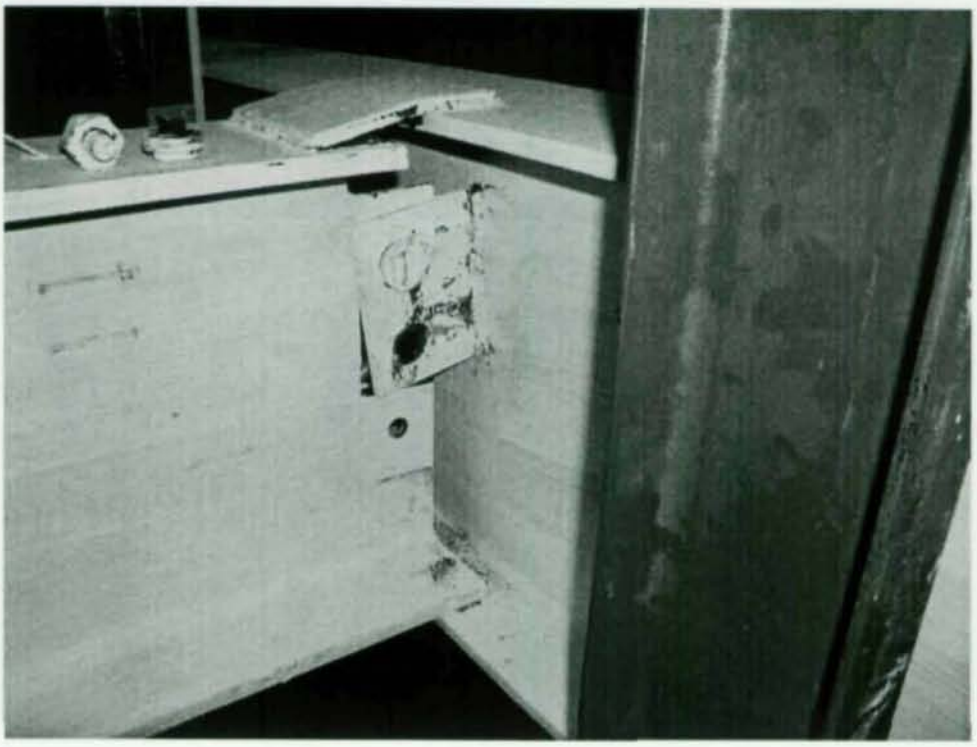
Connection Region Strain Gage Instrumentation



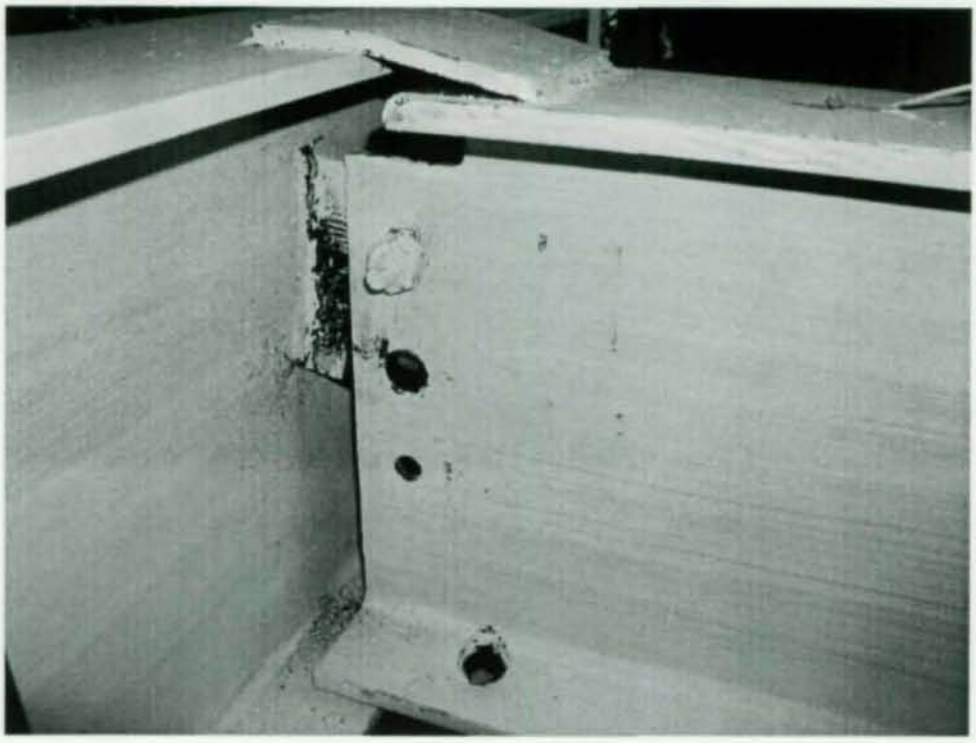
Test 8A – Overall View of Test Setup



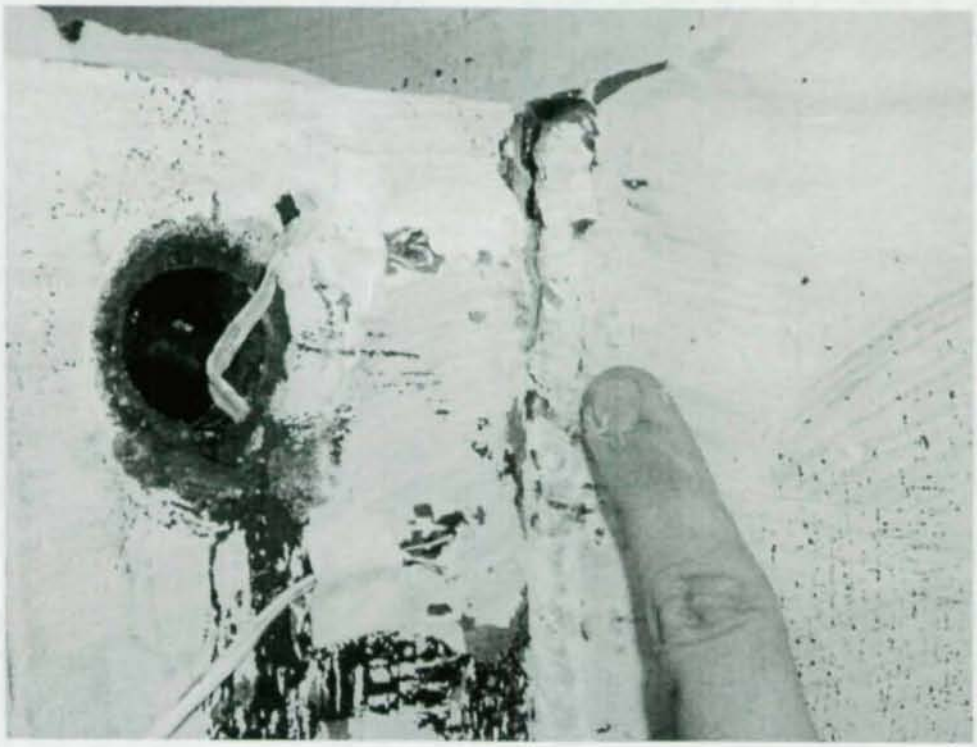
Test 8A – Connection Region Before Test



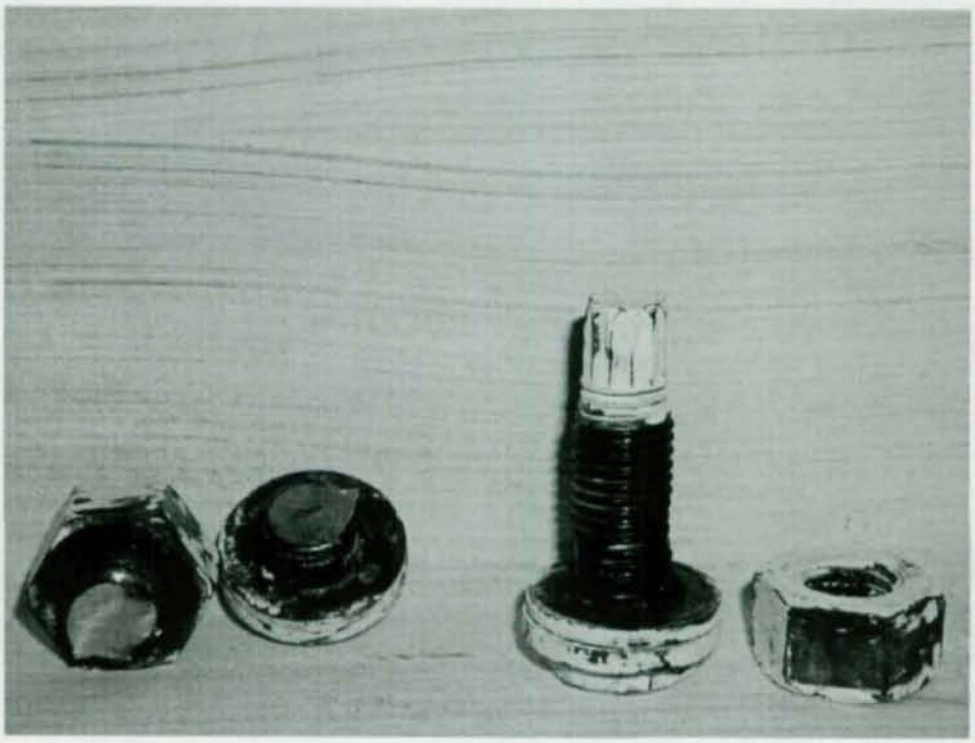
Test 8A – Connection Region at End of Test



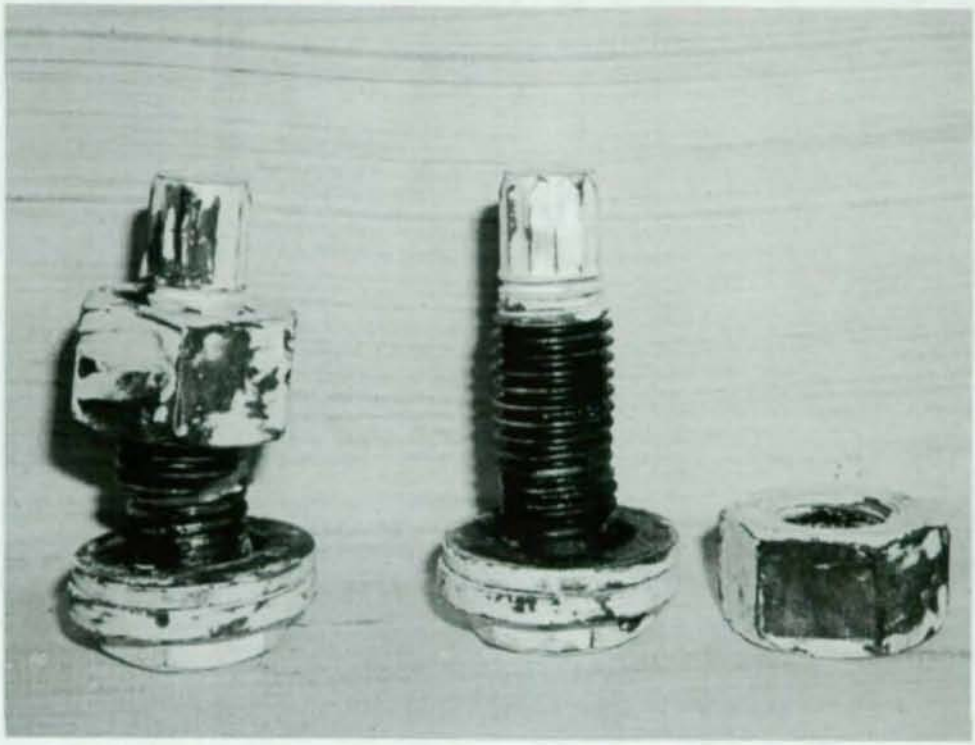
Test 8A – Connection Region at End of Test



Test 8A – Failure of Shear Tab Weld at End of Test

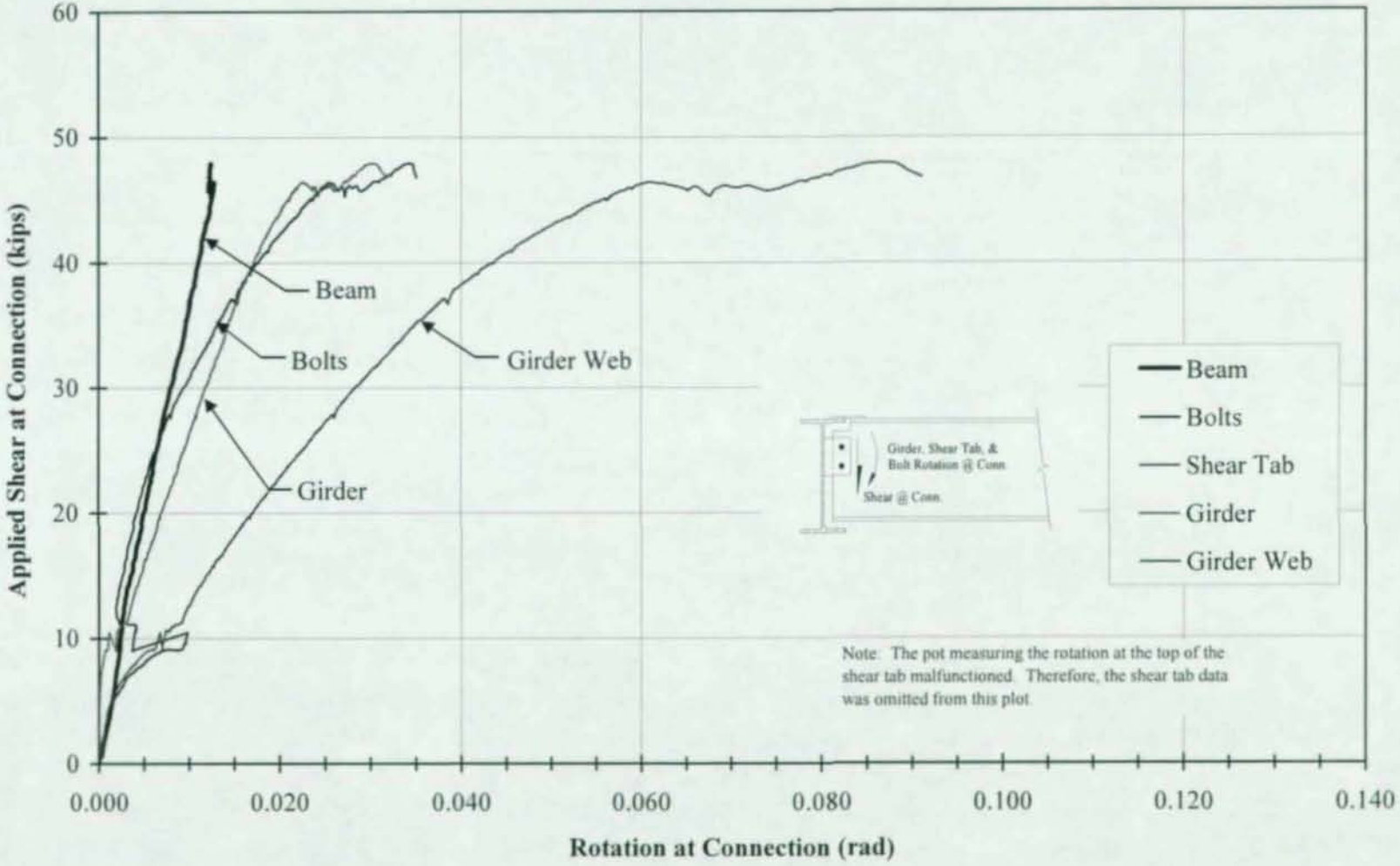


Test 8A – Connection Bolts at End of Test

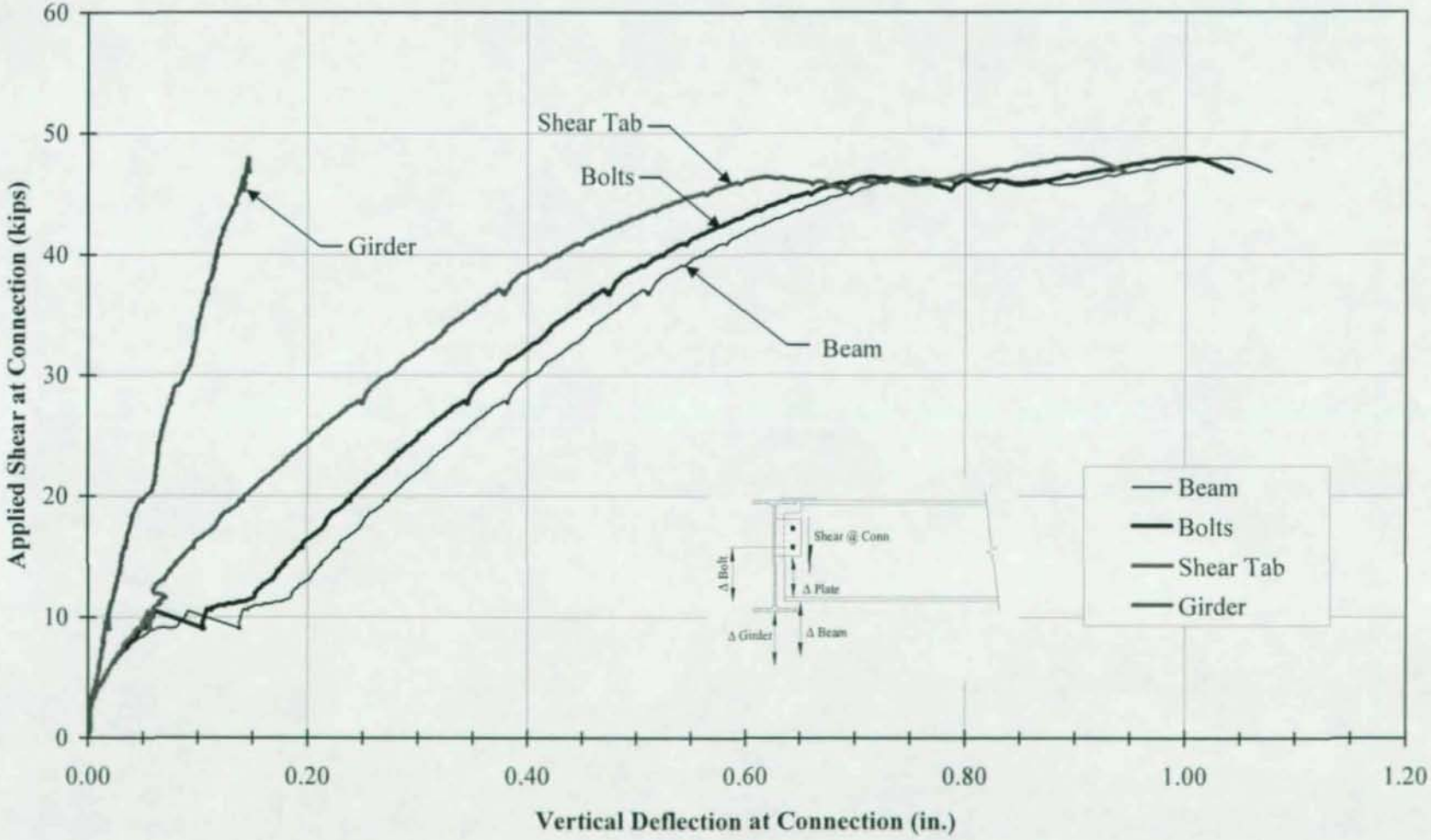


Test 8A – Connection Bolts at End of Test (fit back together)

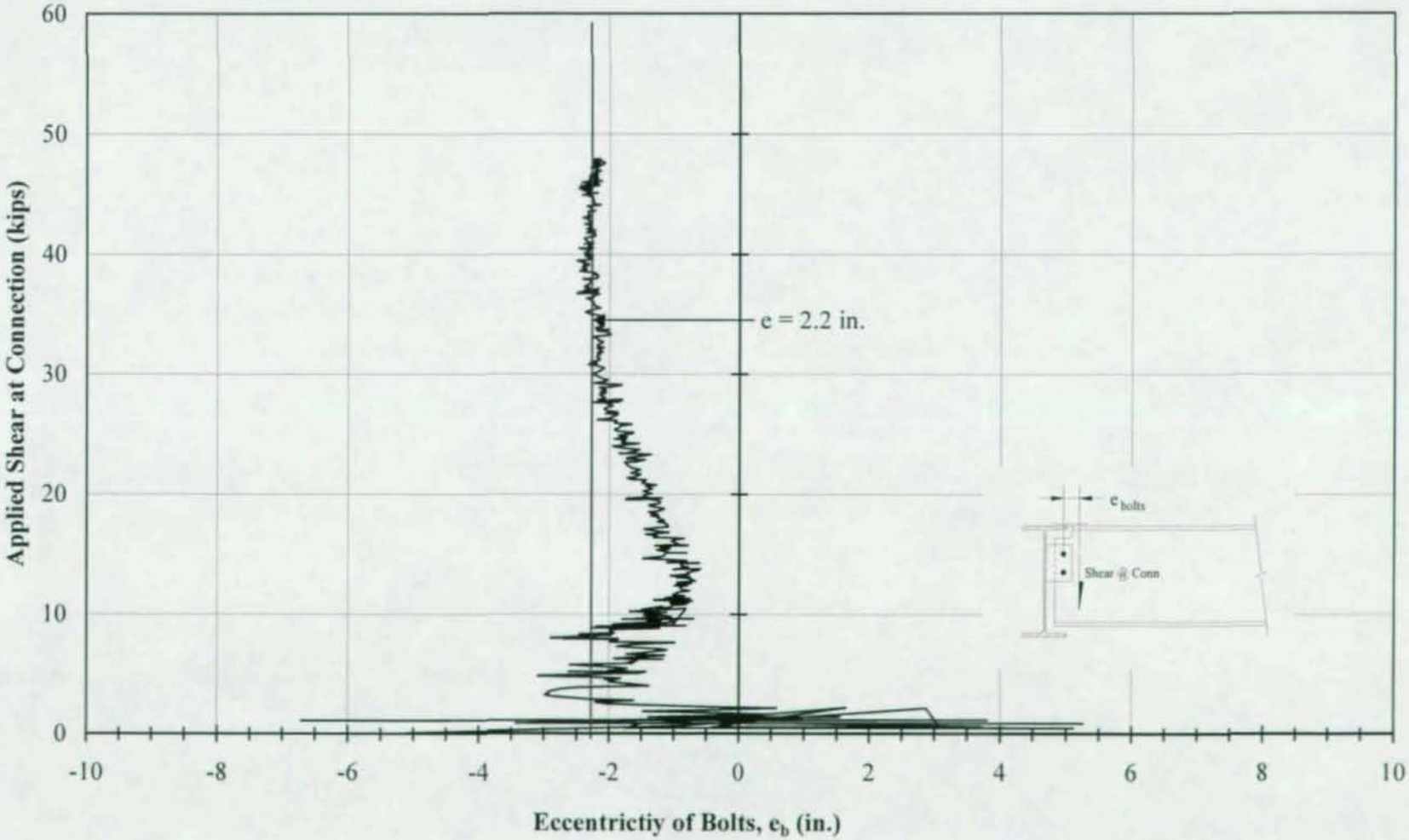
Test 8A (Flexible, Slotted, Slab Restraint, Two-Bolt)
Applied Shear vs. Rotation



Test 8A (Flexible, Slotted, Slab Restraint, Two-Bolt)
Applied Shear vs. Deflection



Test 8A (Flexible, Slotted, Slab Restraint, Two-Bolt)
Applied Shear vs. Bolt Eccentrictiy



Test Matrix

Test No.	Support Condition	No. Bolts[1,2]	Hole Type	Simulated Slab Restraint	Completed
1	Rigid [2]	3	Short Slots	No	Y
2	Rigid [2]	3	Standard	No	Y
3	Flexible [3]	3	Short Slots	No	Y
4	Flexible [3]	3	Standard	No	Y
5	Flexible [3]	3	Short Slots	Yes	Y
6	Flexible [3]	2	Standard	No	Y
7	Flexible [3]	2	Short Slots	No	Y
8	Flexible [3]	2	Short Slots	Yes	Y
9	Rigid [4]	7	Short Slots	No	
10	Flexible [5]	7	Short Slots	Yes	

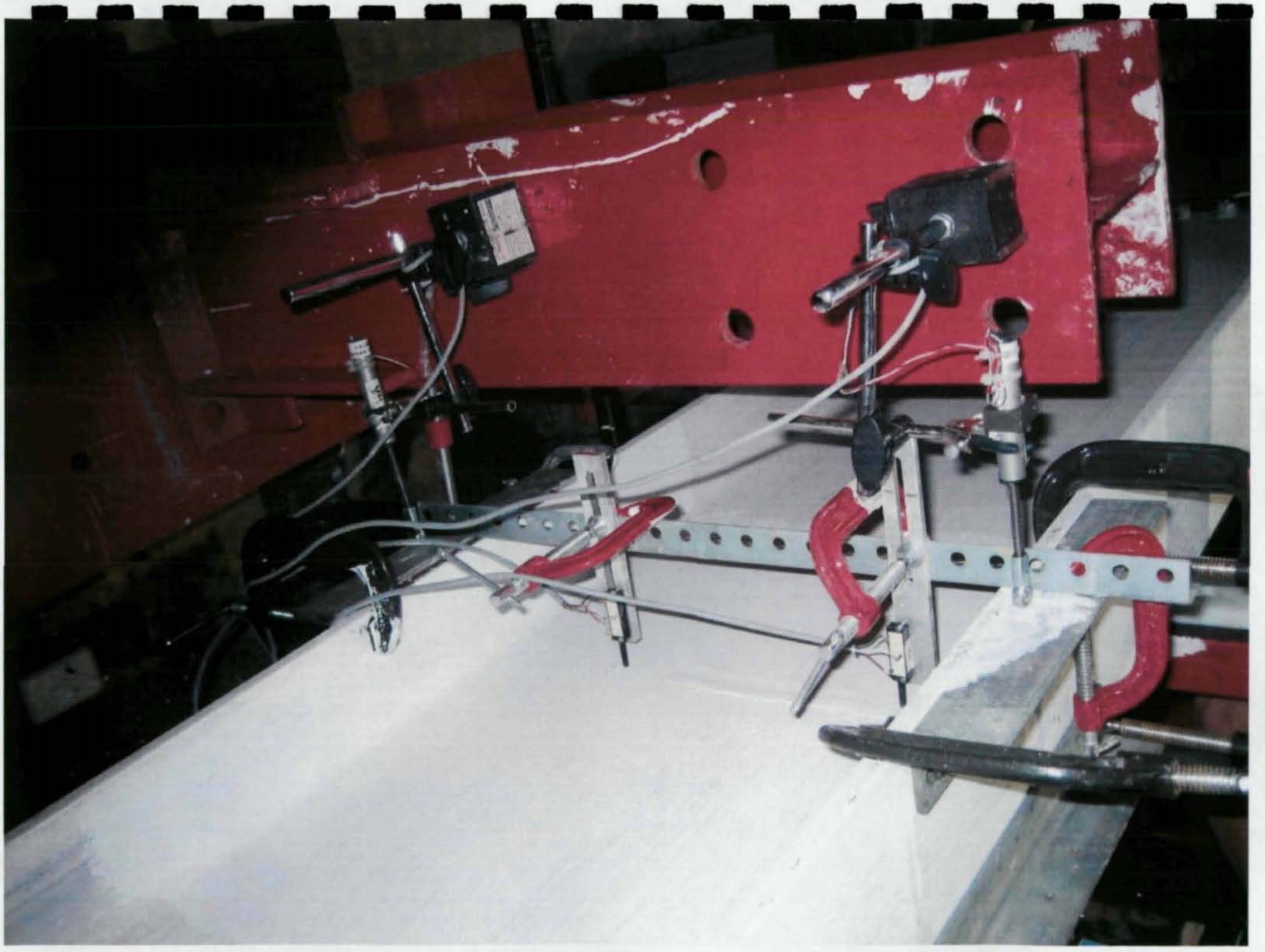
Notes:
1. 3/4 in. diameter A325-N bolts used in all connections.
2. W16x50 beam and W14x145 column used for 2 and 3-bolt rigid support tests.
3. W16x50 beam, W18x50 girder, and two W14x90 columns used for 2 and 3-bolt flexible support tests.
4. W27x84 beam and W14x145 column used for 7-bolt rigid support test.
5. W27x84 beam, W30x99 girder, and two W14x90 columns used for 7-bolt flexible support test.
6. 3/8 in. thick shear tab used for all connections.

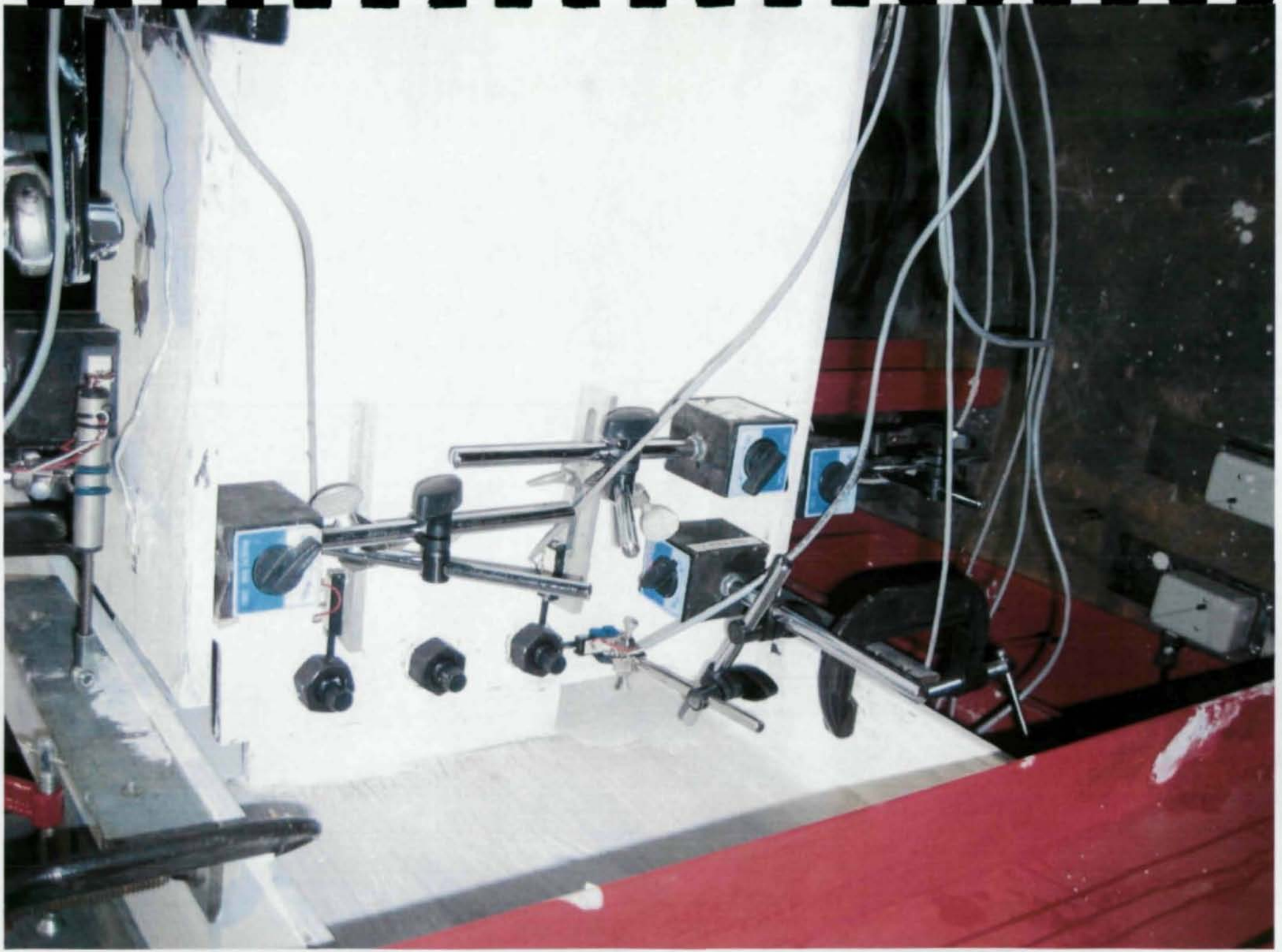
Summary of Test Results

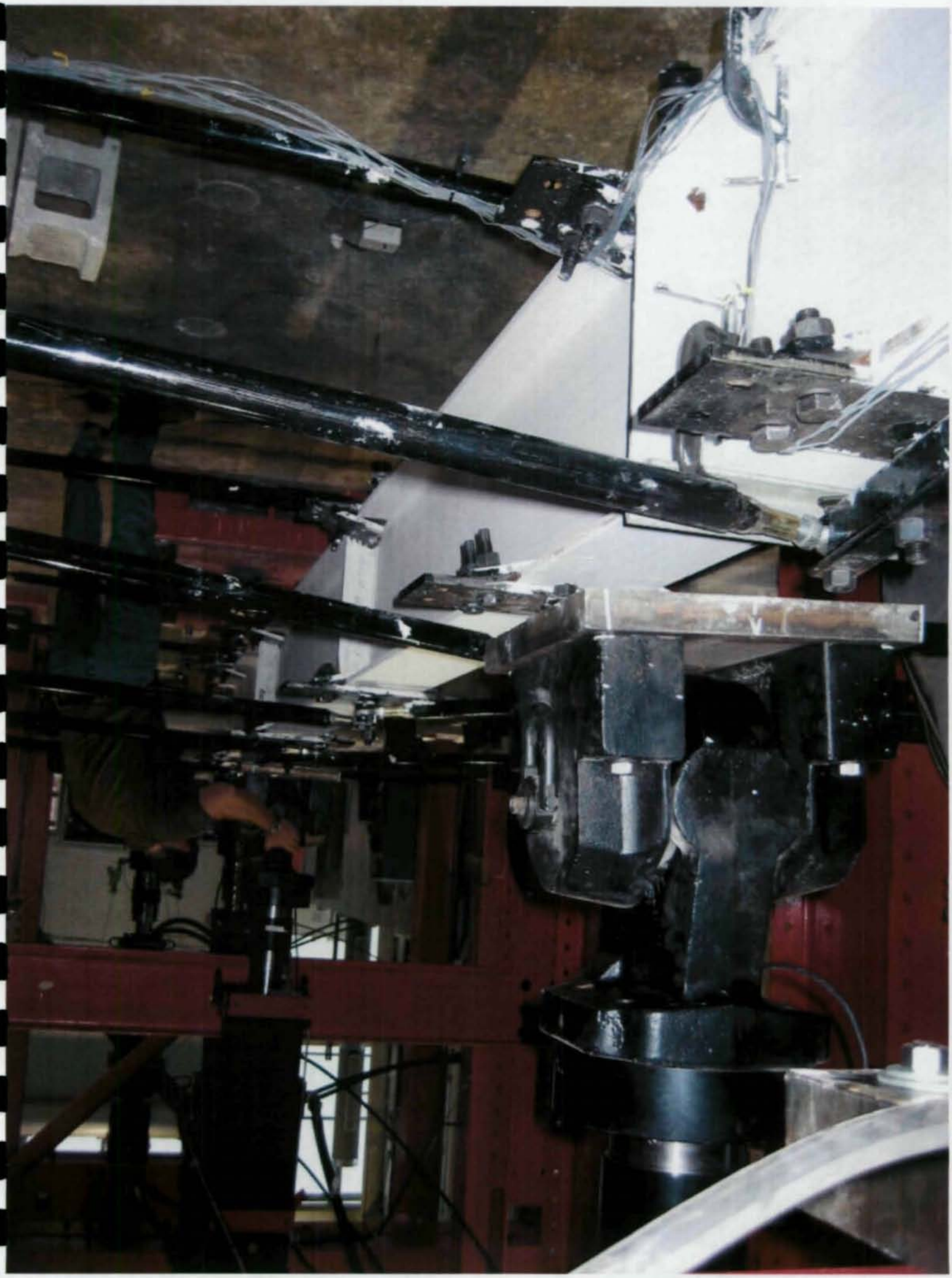
Test No.	Description	Max. Applied Shear at Conn. [1] (kips)	Beam End Rotation at Max. Shear (rad)	Bolt Eccentricity (in.)	At Approximate Design Load [3]	
					Beam End Rotation (rad)	Girder Rotation [4] (rad)
1	3 bolt, rigid, short slots	78.8 [2]	0.036	1.6	0.008	-
2	3 bolt, rigid, standard	90.7	0.027	2.0	0.008	-
3	3 bolt, flexible, short slots	71.8	0.039	1.7	0.011	0.037 (0.66 in.)
4	3 bolt, flexible, standard	61.4	0.023	2.0	0.010	0.031 (0.56 in.)
5	3 bolt, flexible, short slots, simulated slab restraint	75.6	0.031	0.1	0.010	0.017 (0.31 in.)
6	2 bolt, flexible, standard	44.2	0.012	4.4	0.005	0.013 (0.23 in.)
7	2 bolt, flexible, short slots	45.5	0.011	2.4	0.003	0.026 (0.47 in.)
8	2 bolt, flexible, short slots, simulated slab restraint	47.9	0.013	2.2	0.004	0.005 (0.09 in.)
9	7 bolt, flexible, short slots					
10	7 bolt, flexible, short slots, simulated slab restraint					

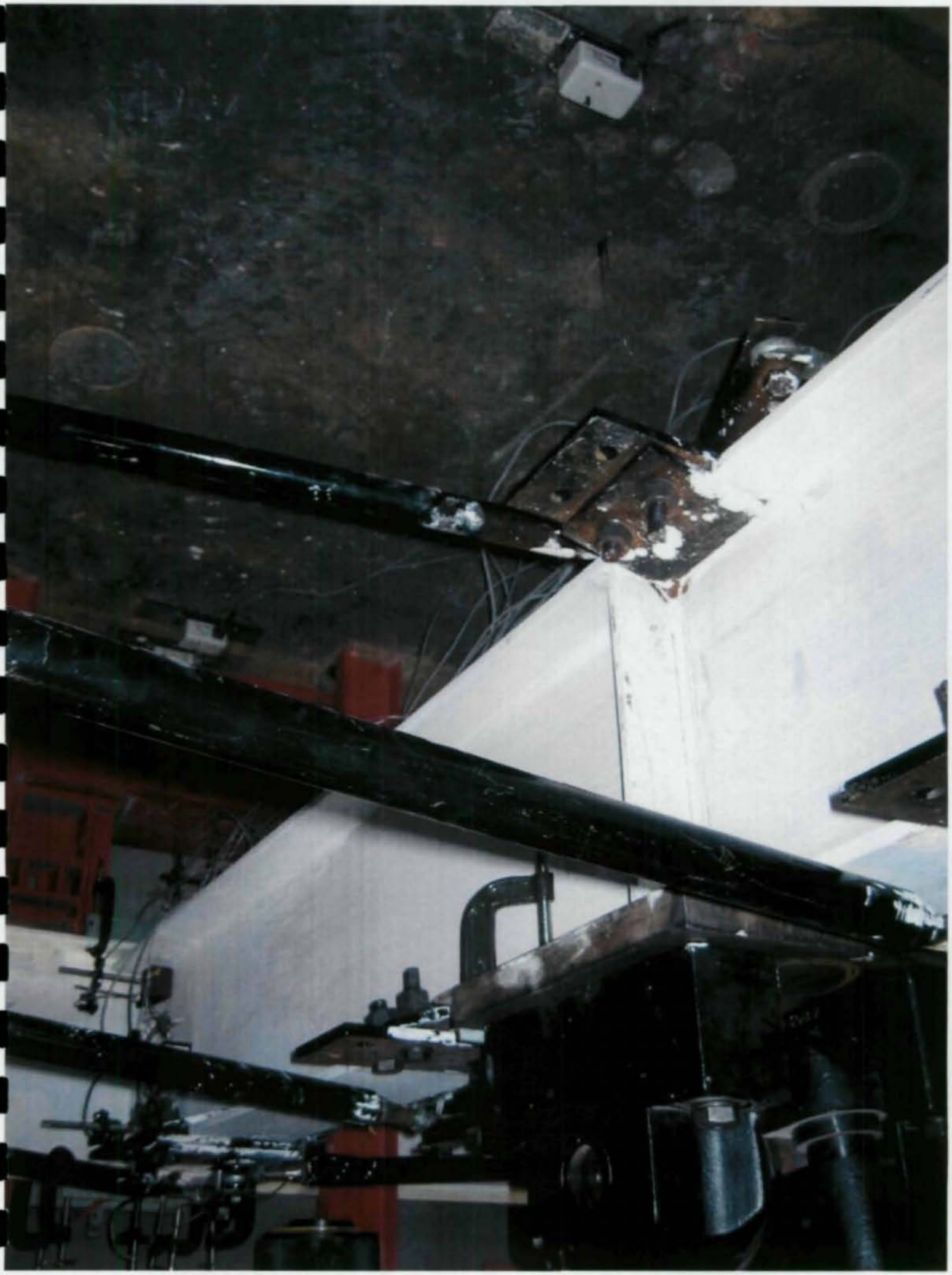
Notes:
1. Tests stopped after shear rupture of connection bolts.
2. Test stopped prior to shear rupture of connection bolts.
3. Shear at the connneciton = 30 kips (3-bolt), 15 kips (2-bolt), 100 kips (7-bolt)
4. Value in parentheses ( ) is the girder flange horizontal displacement resulting from the observed rotation

Appendix A
Photos of Destructive Testing







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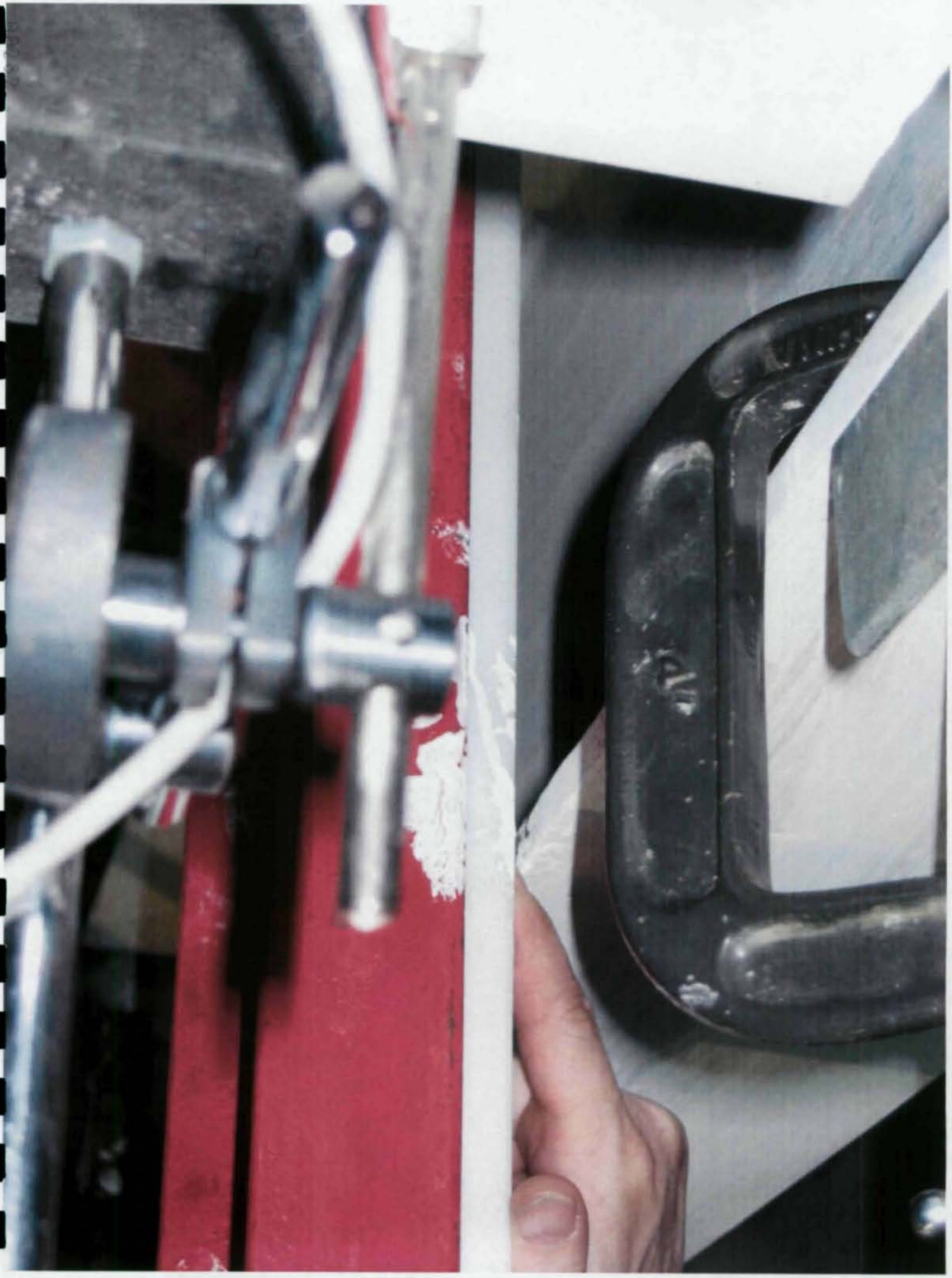
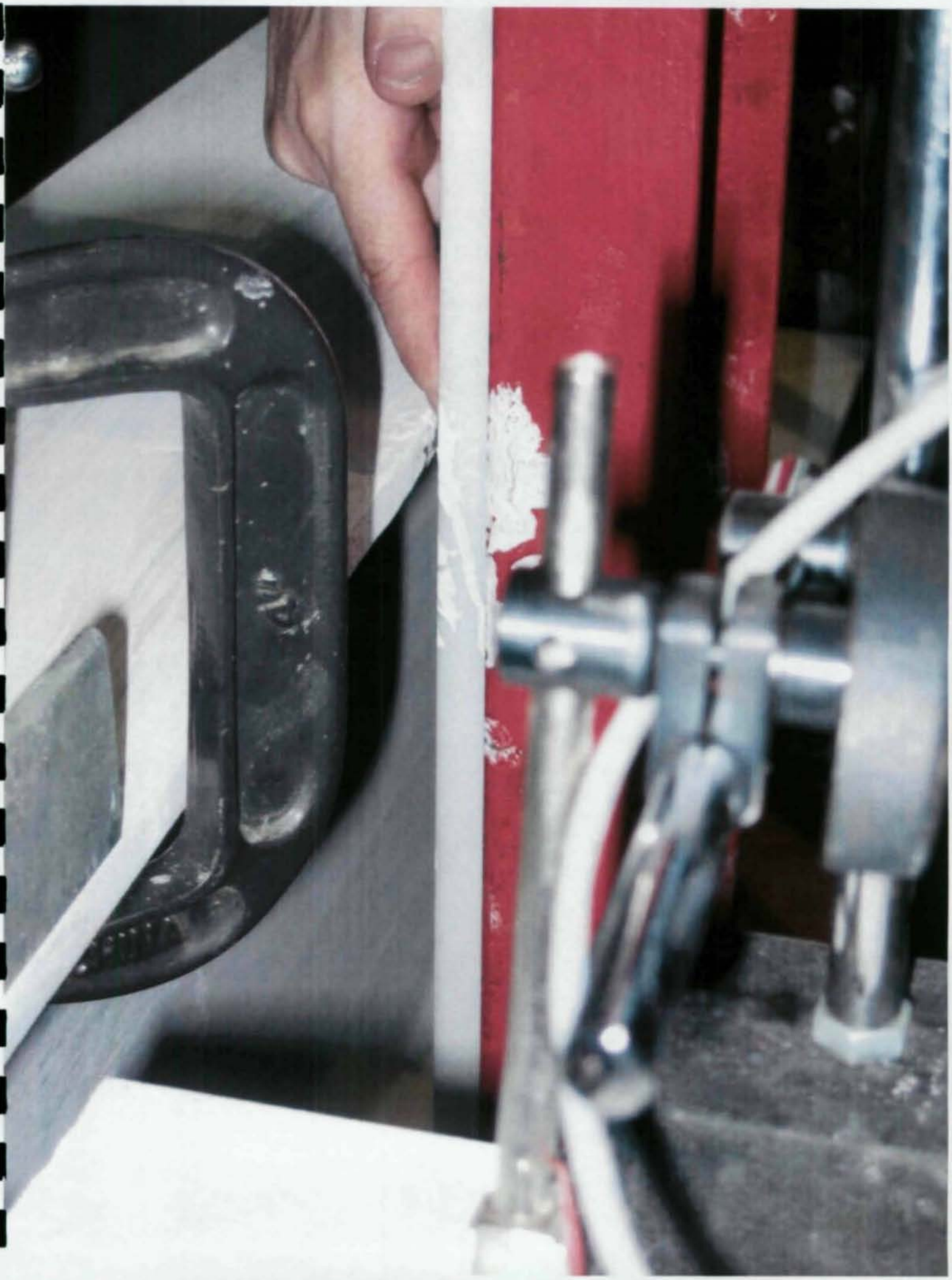
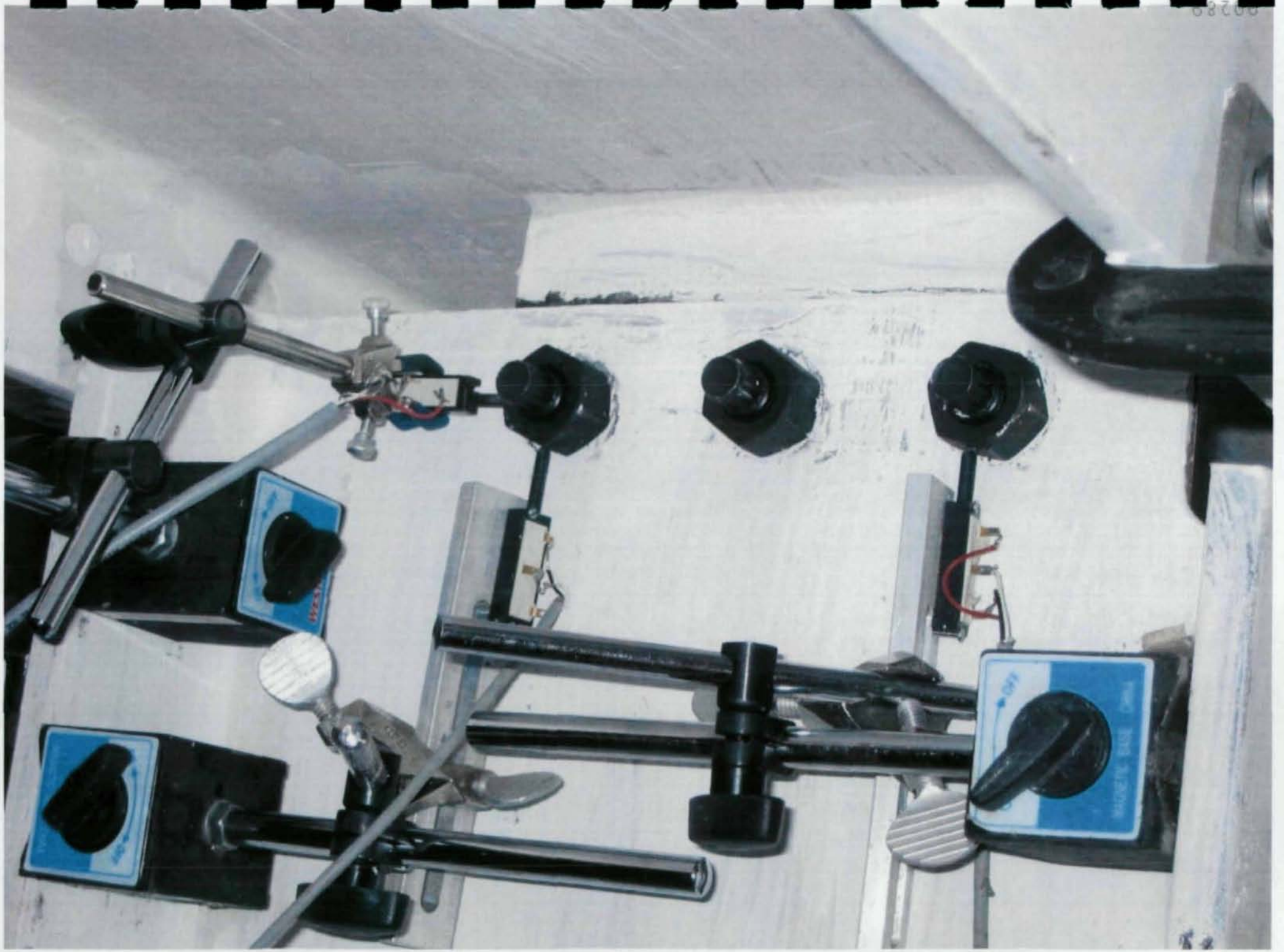
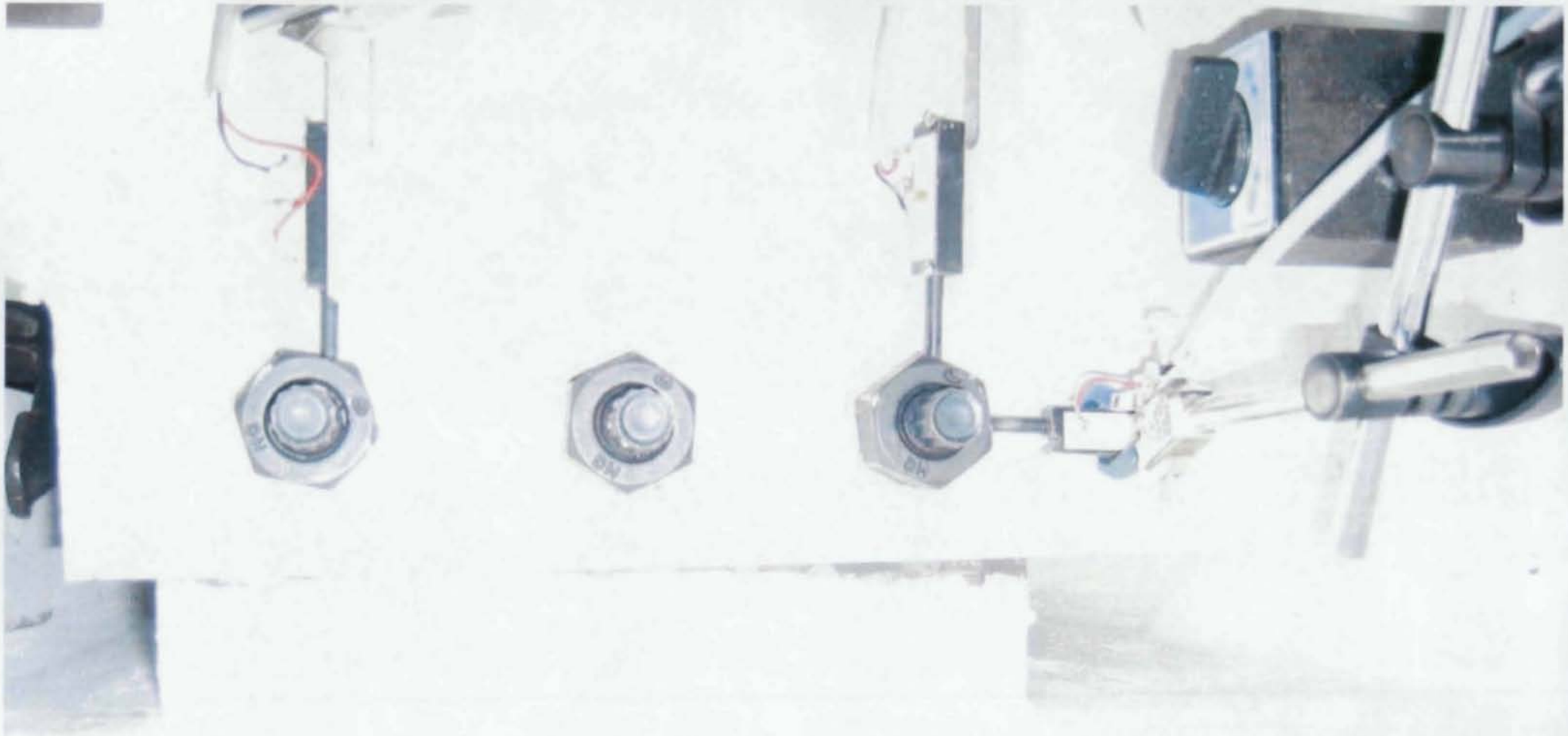
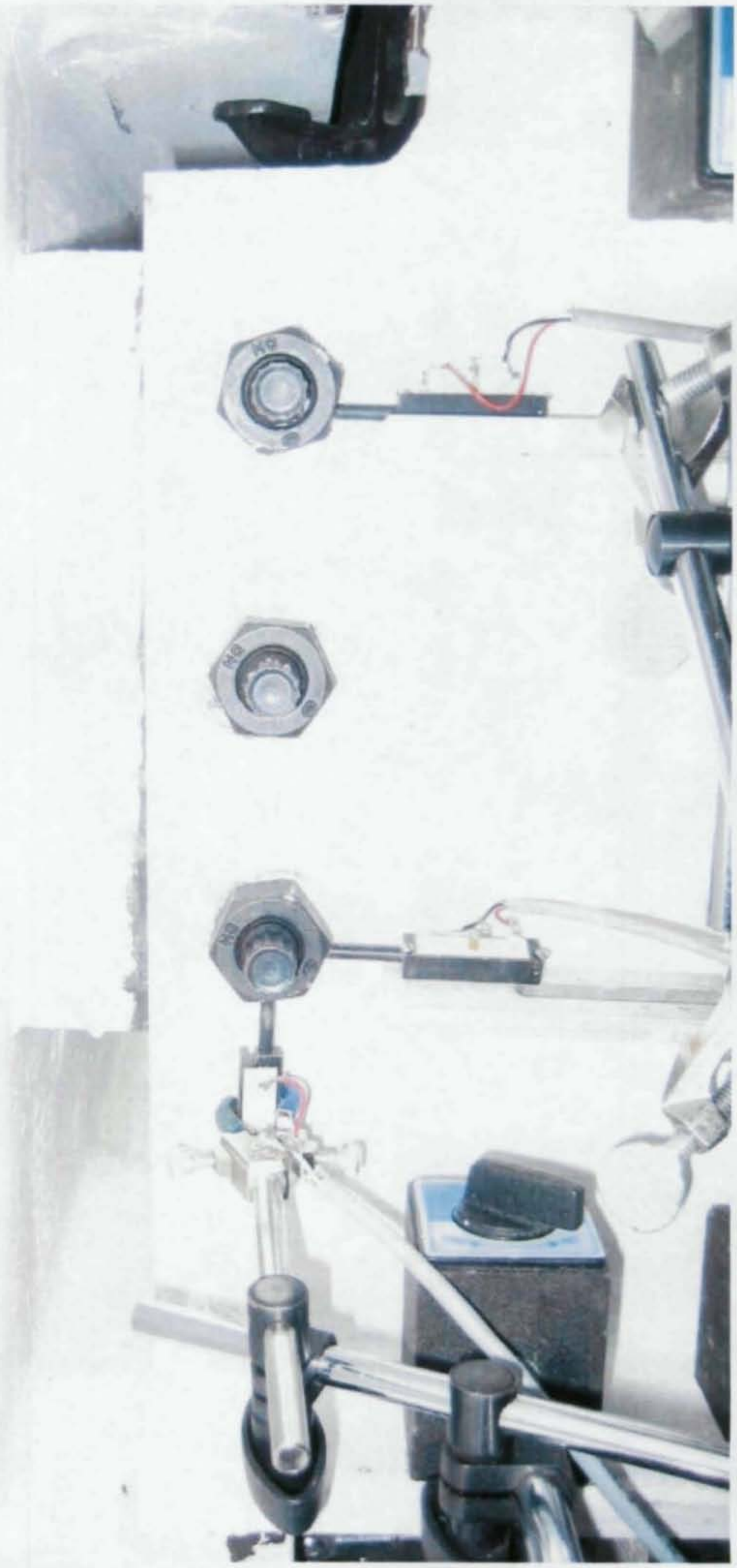




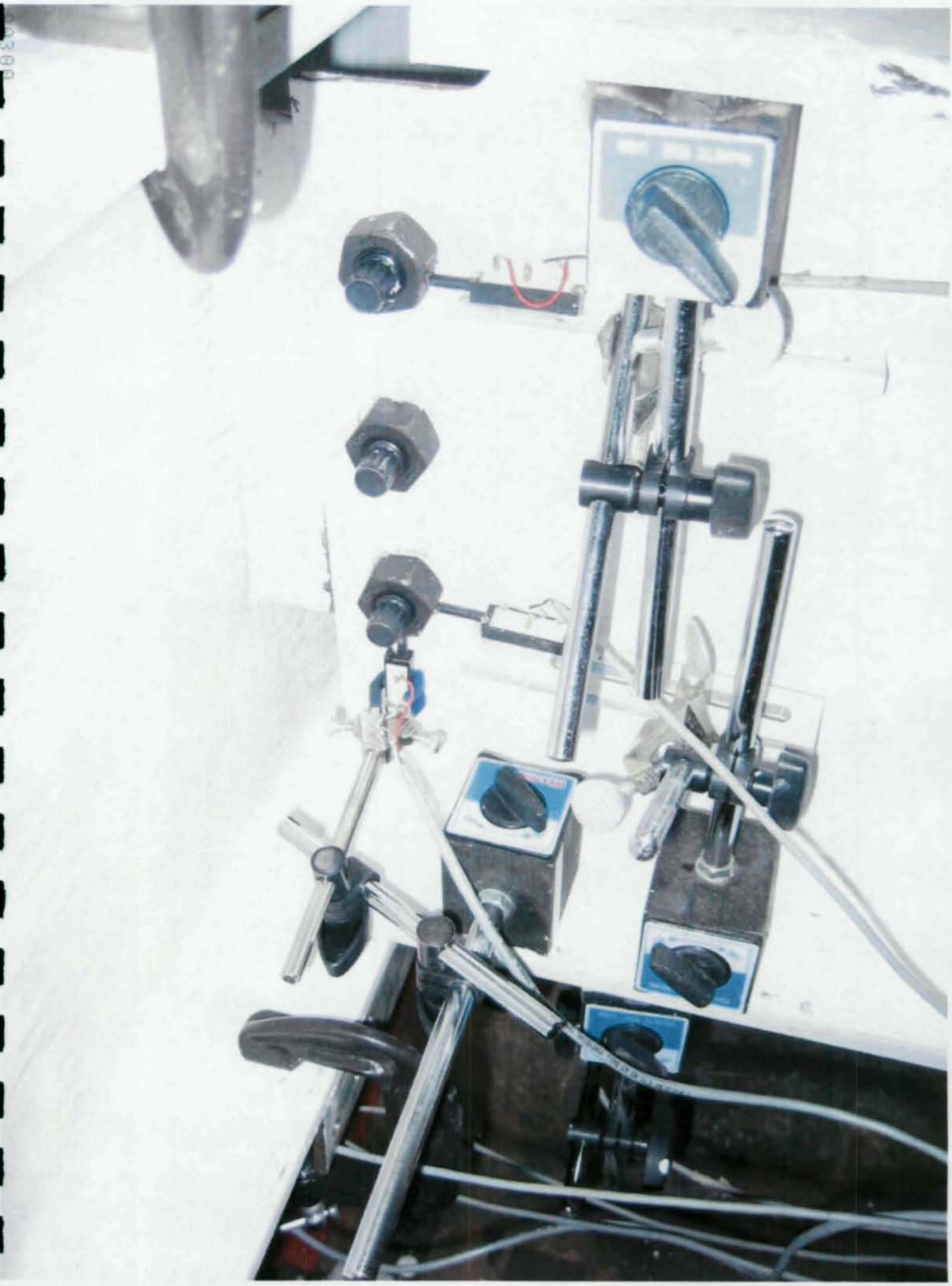
MAGNETIC BASE CHINA











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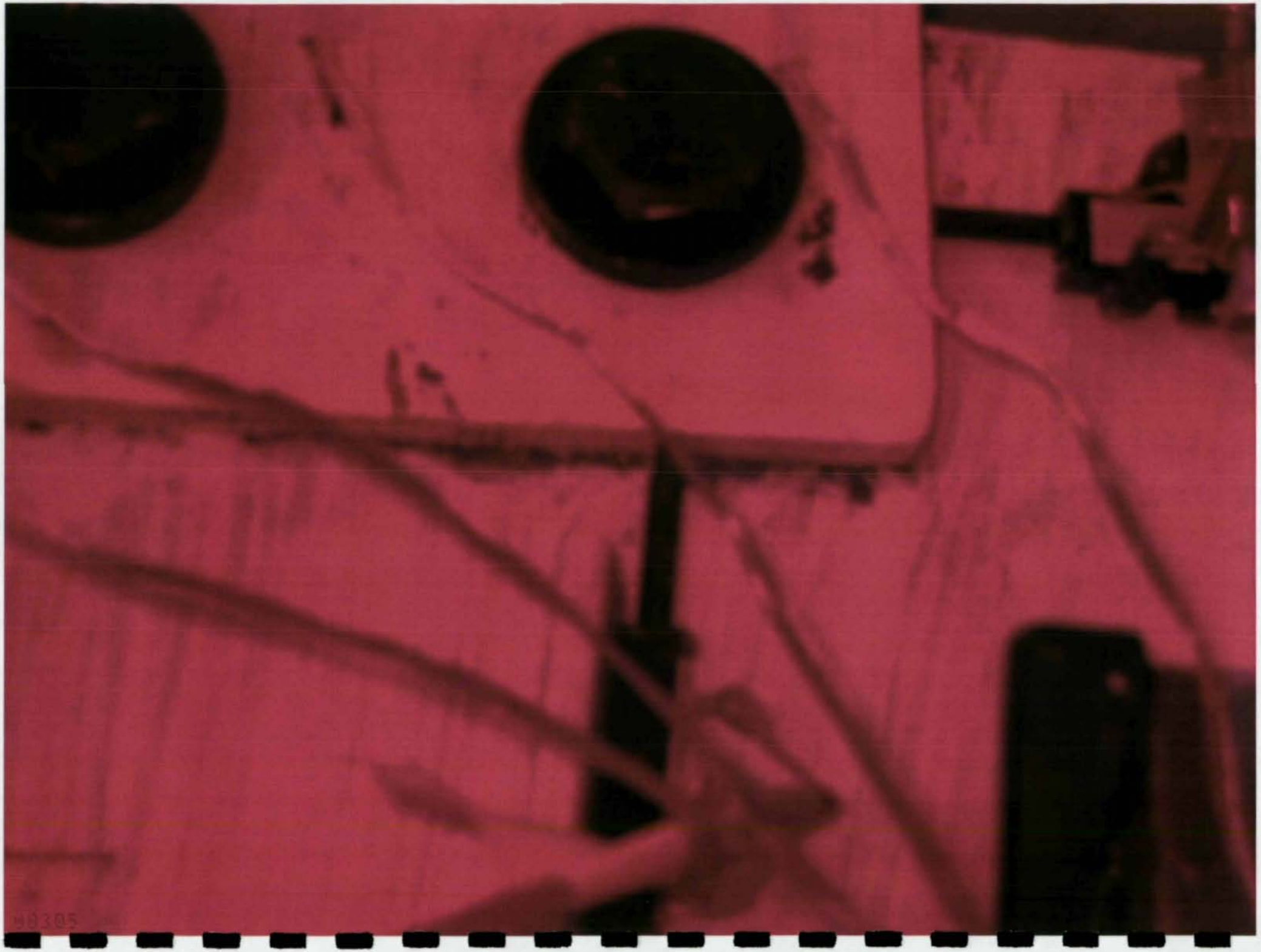

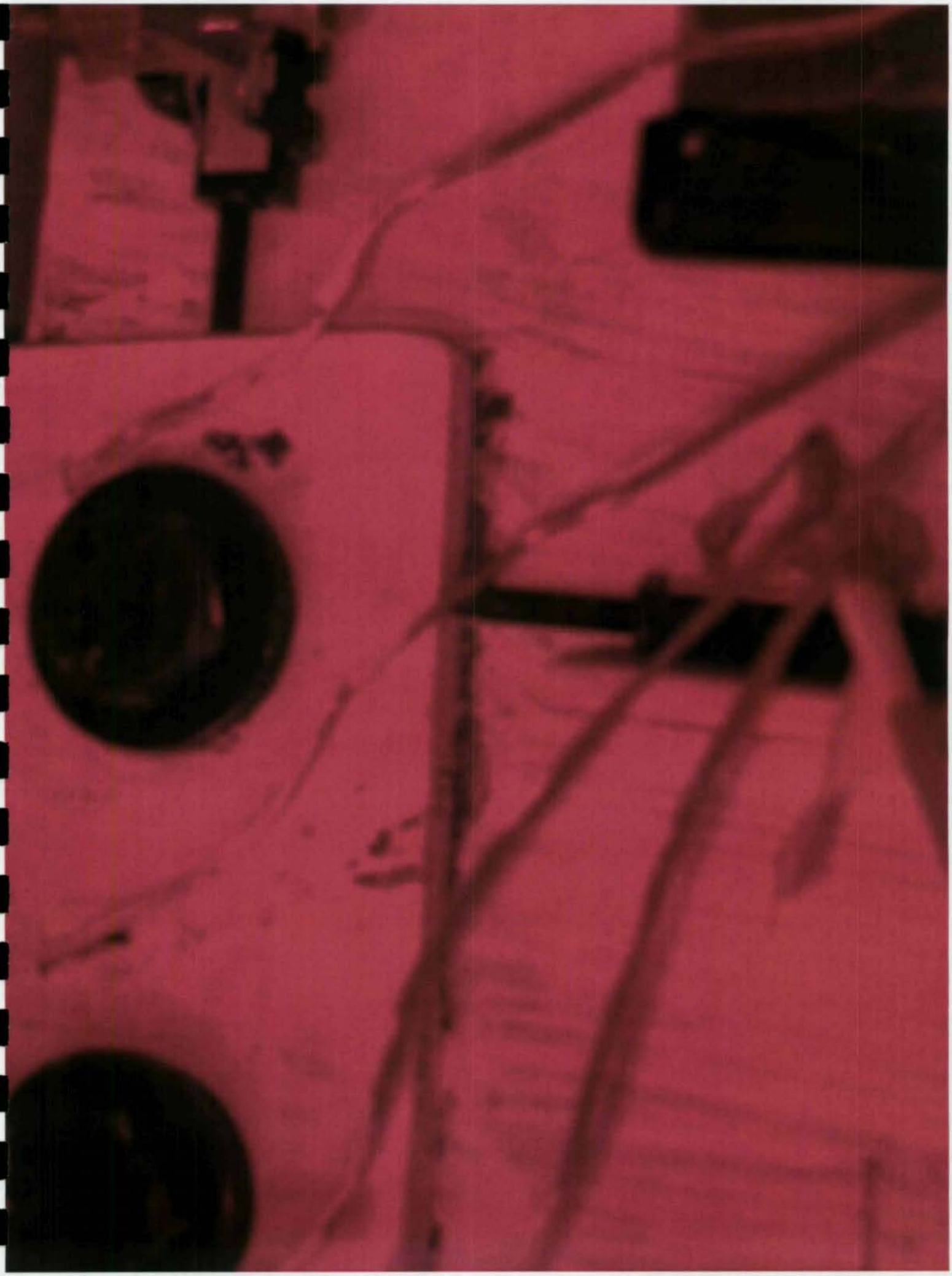

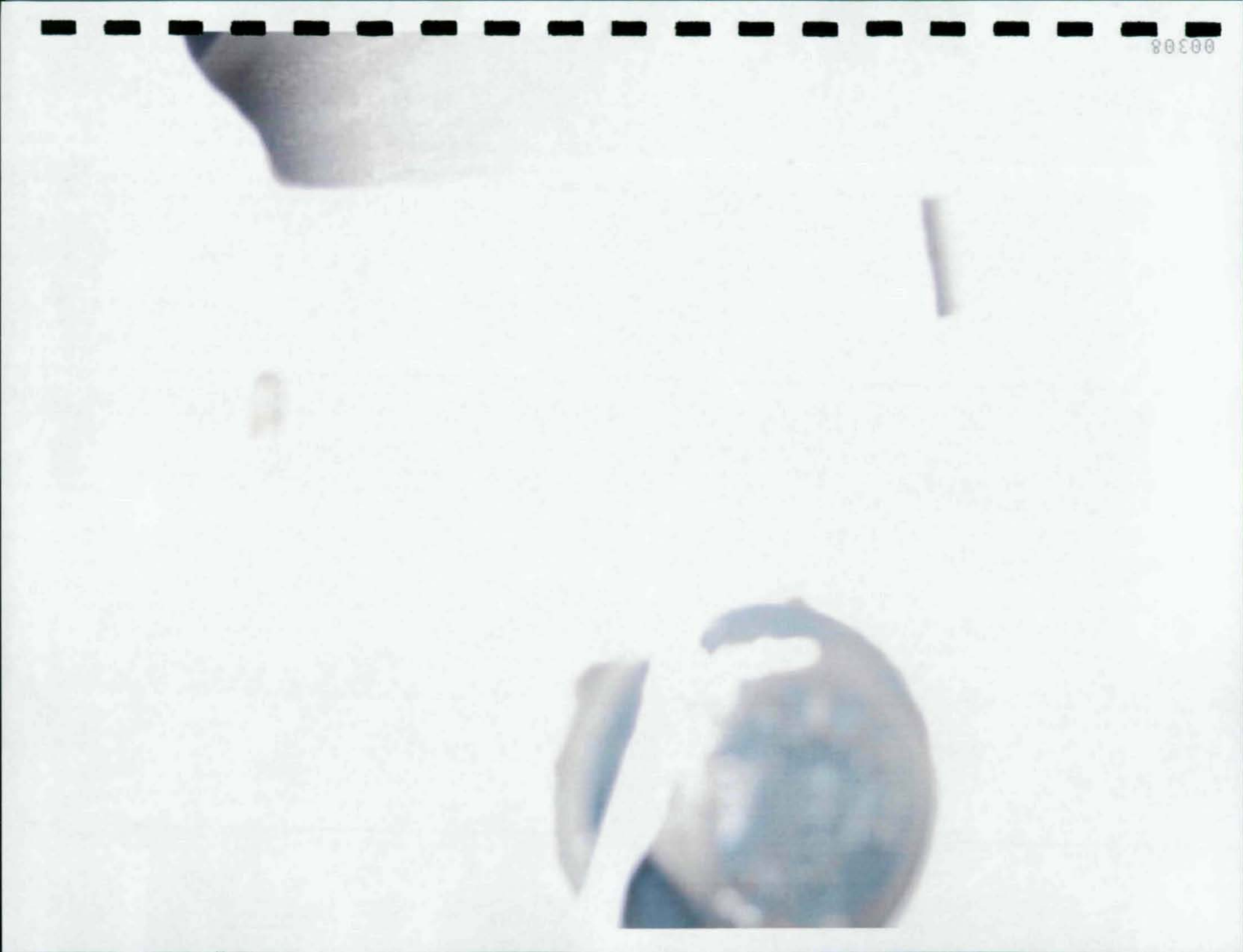

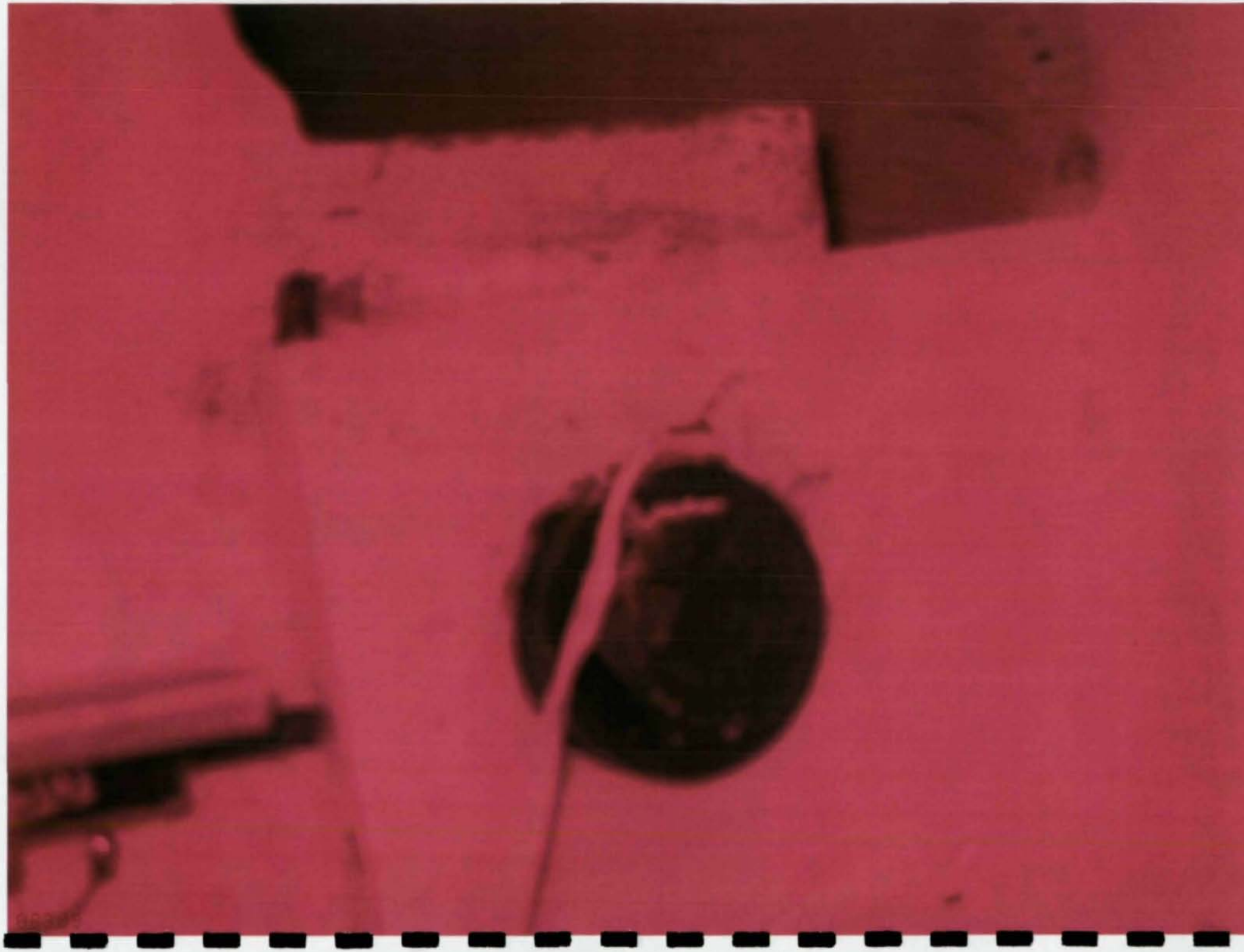

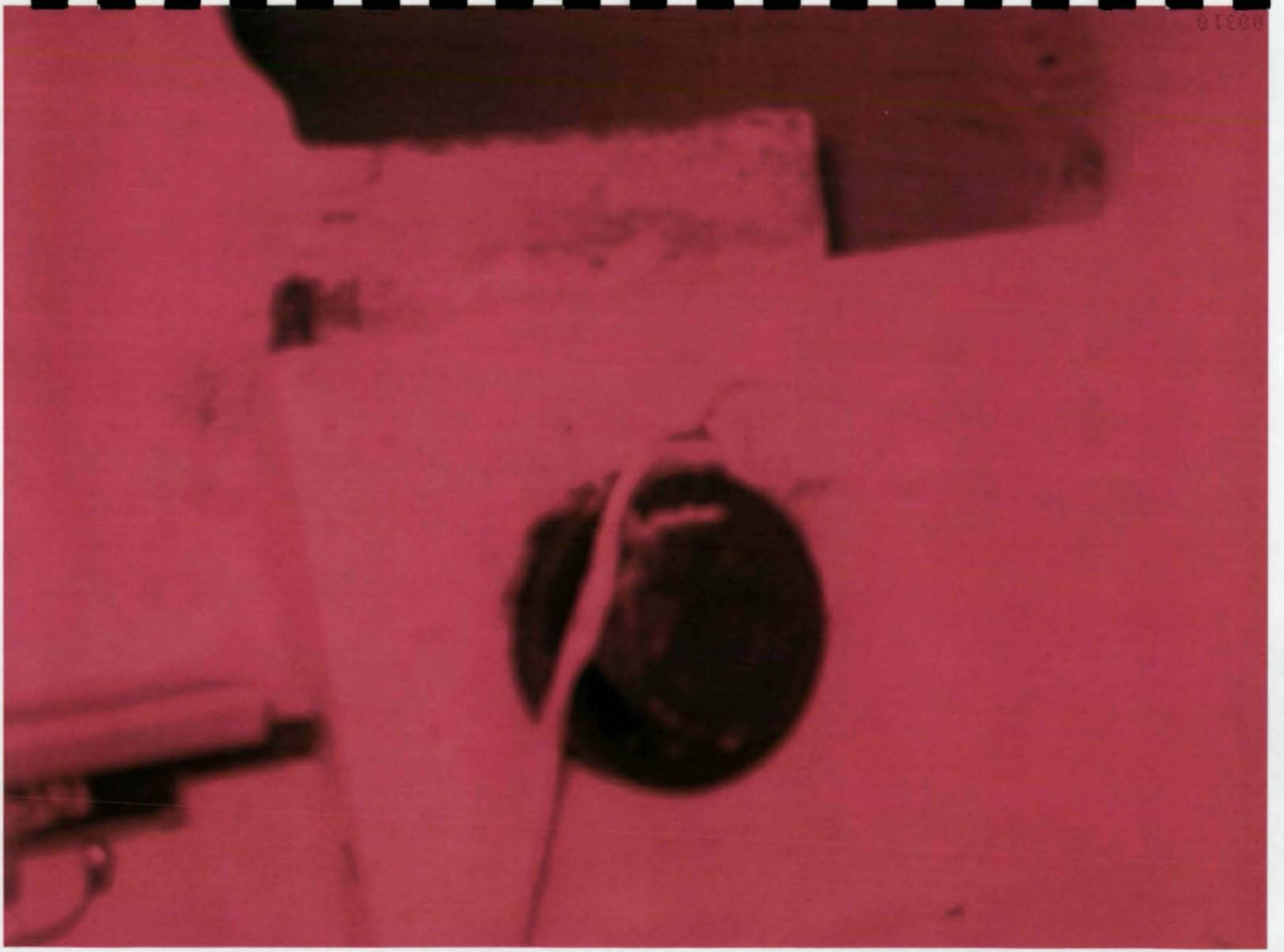

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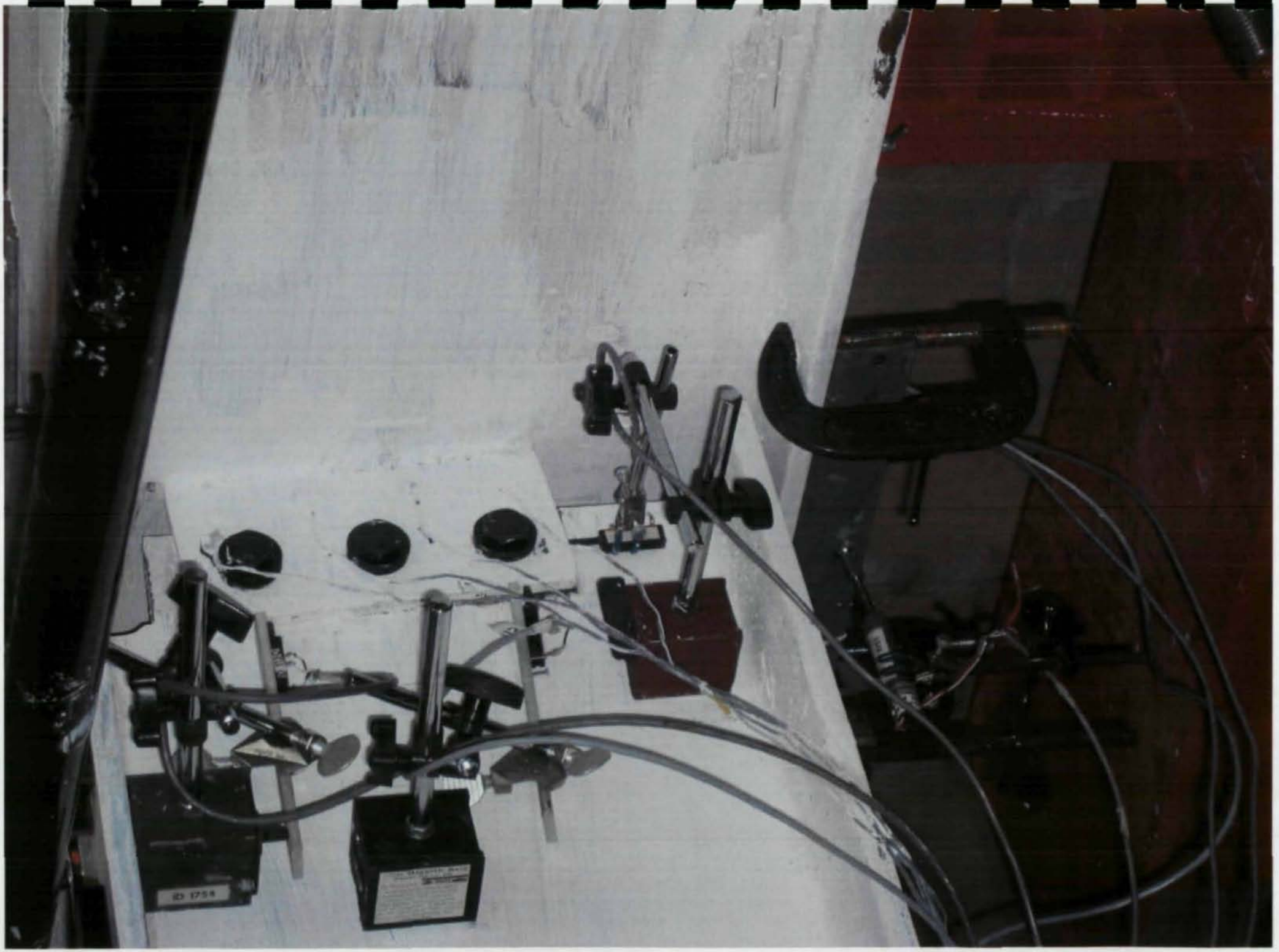

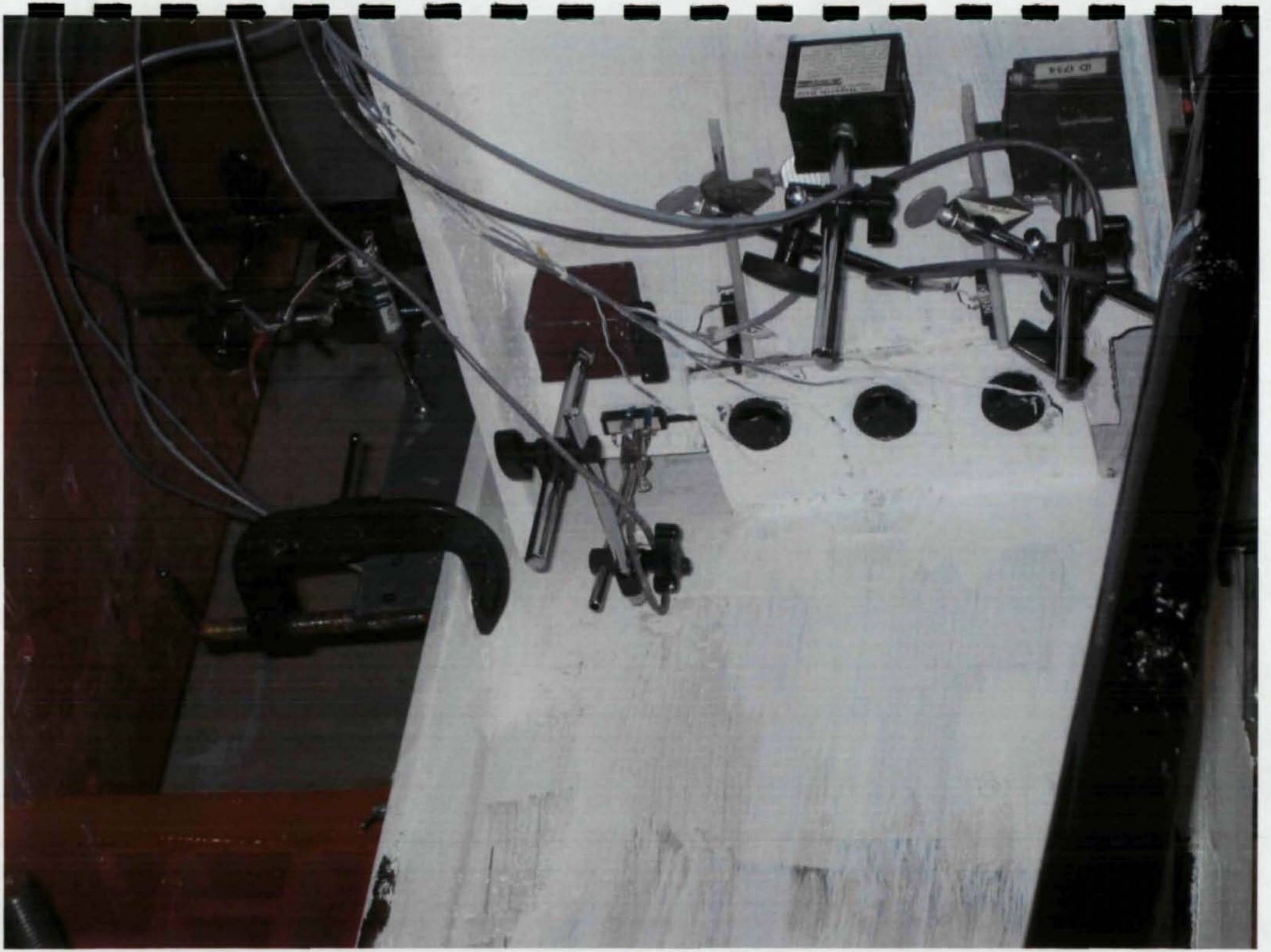

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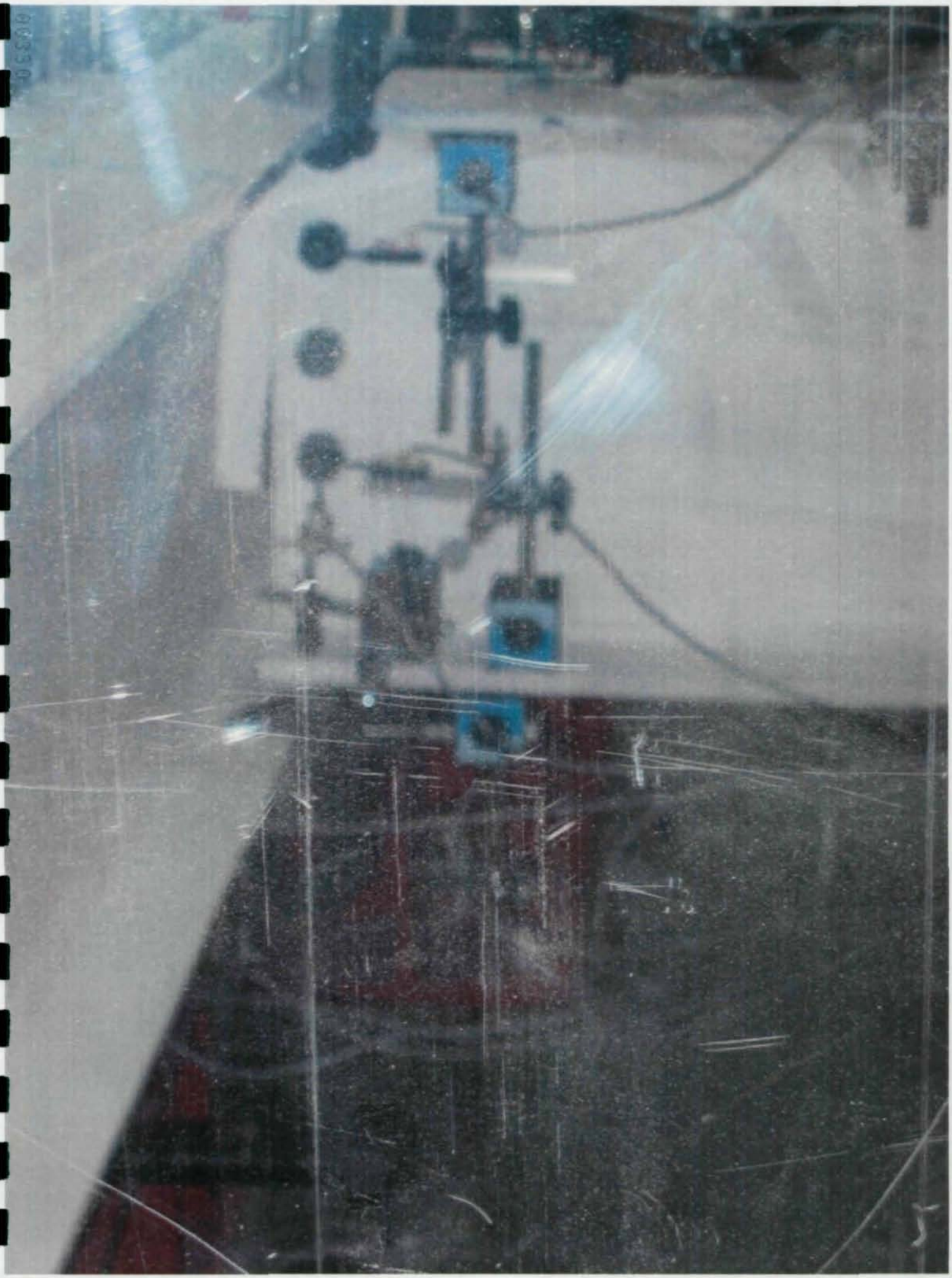

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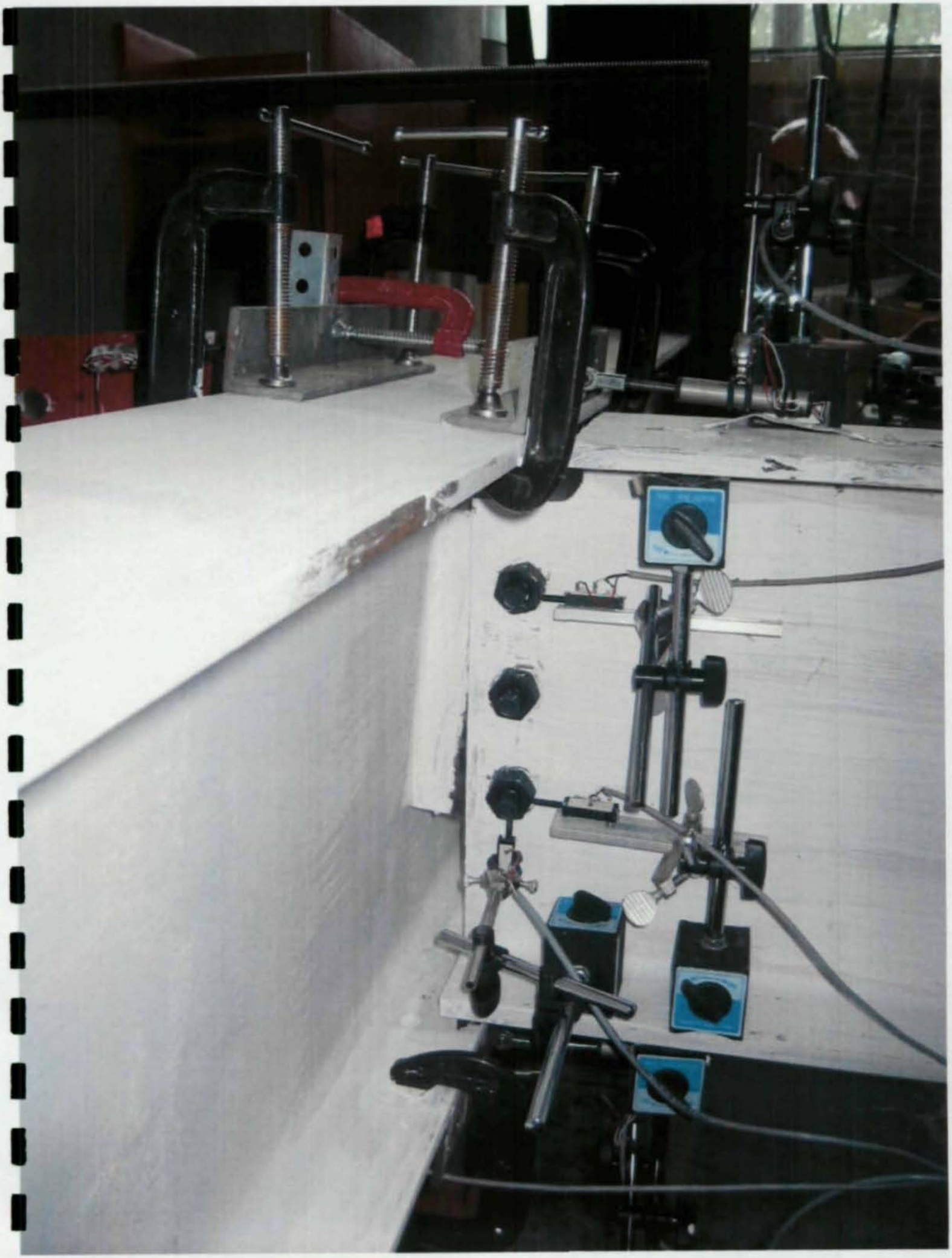

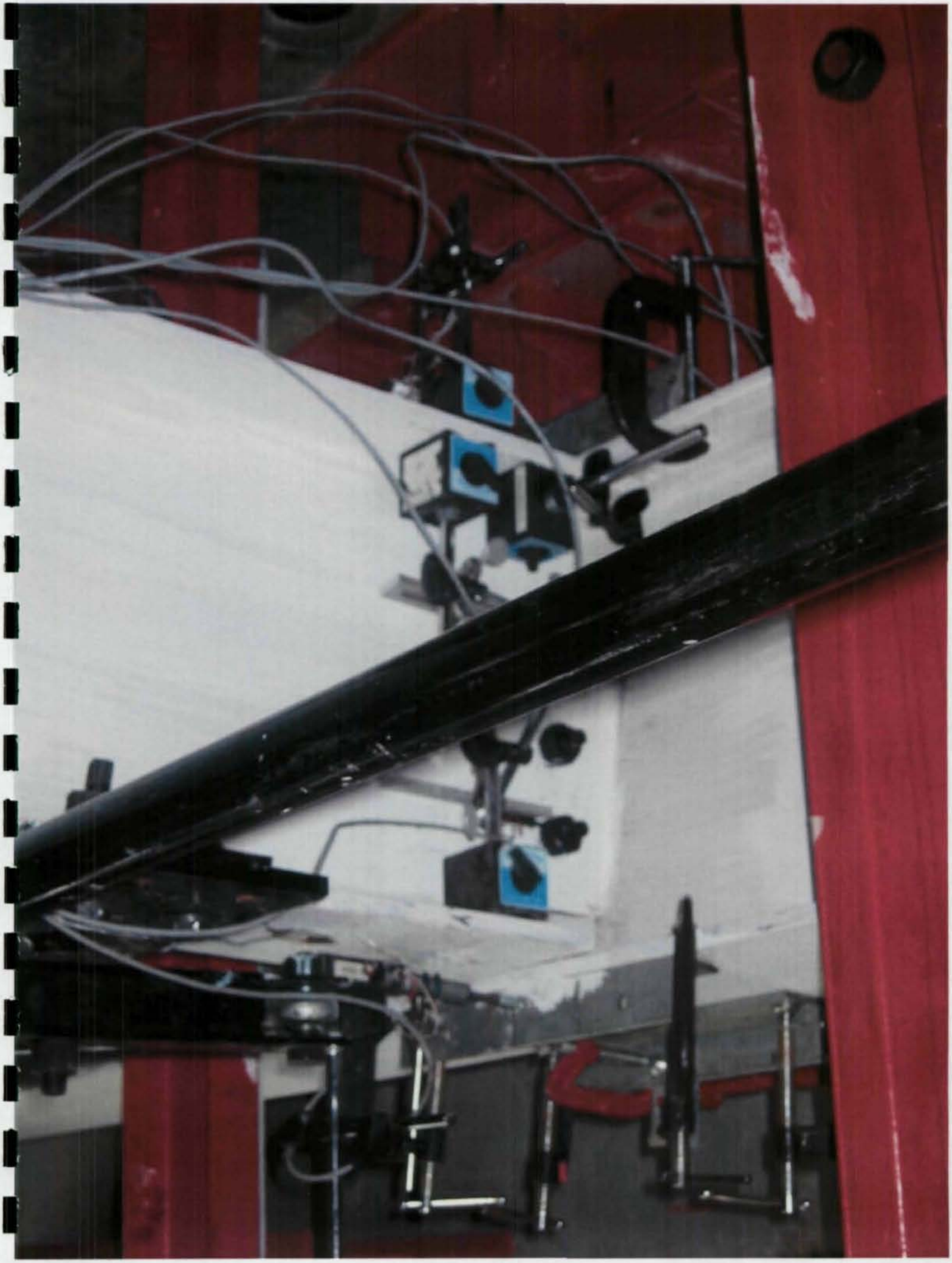

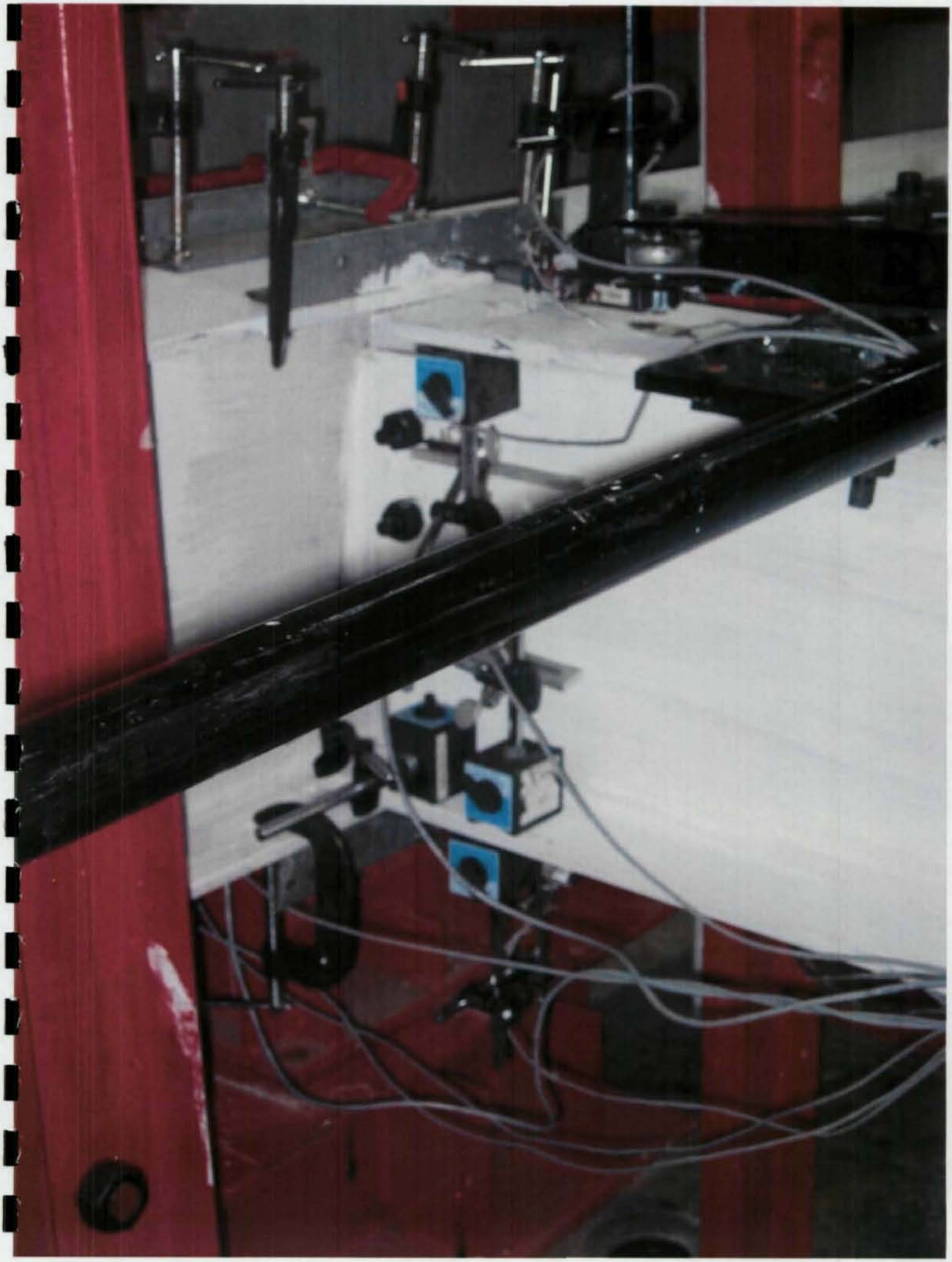

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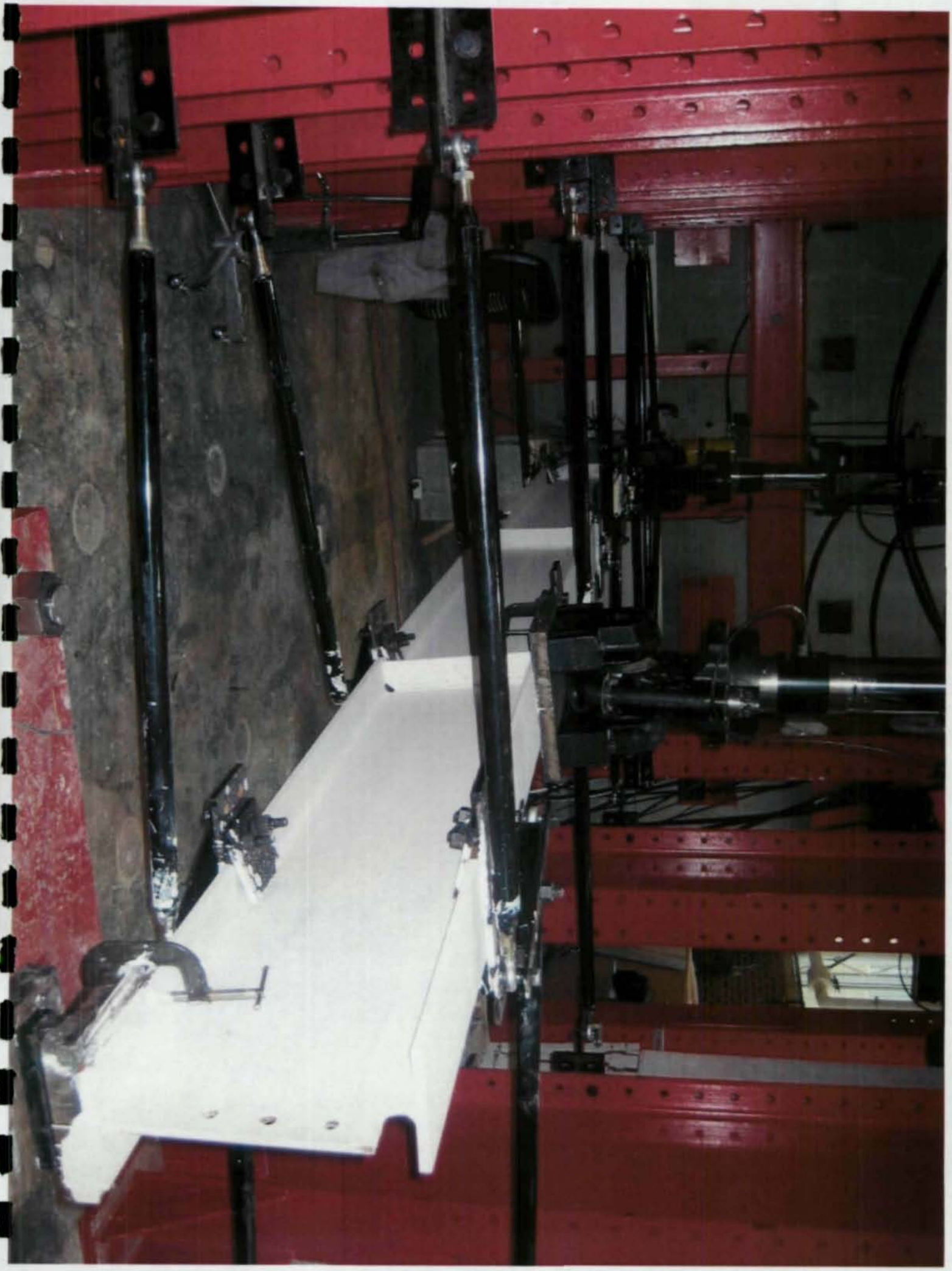

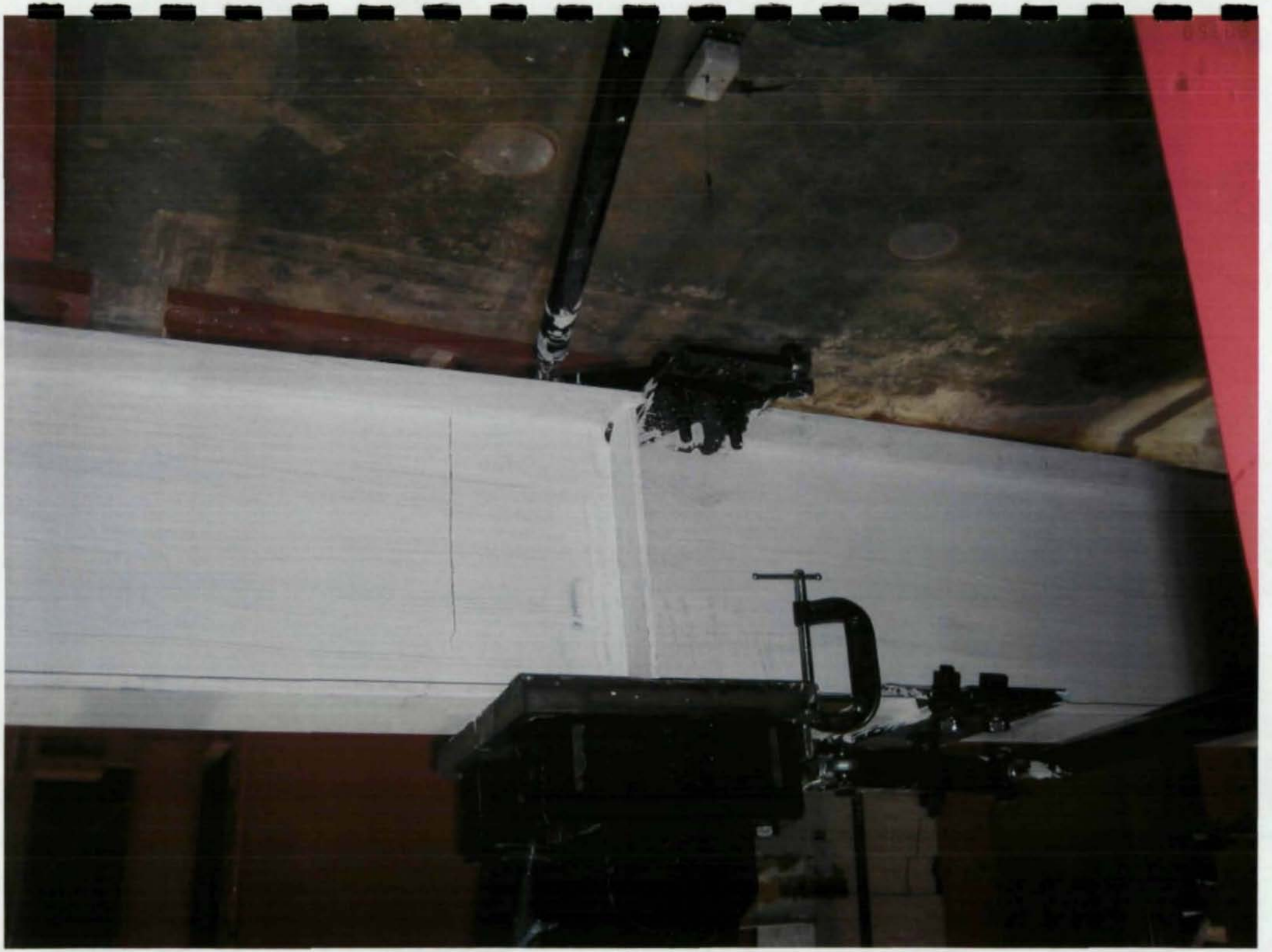

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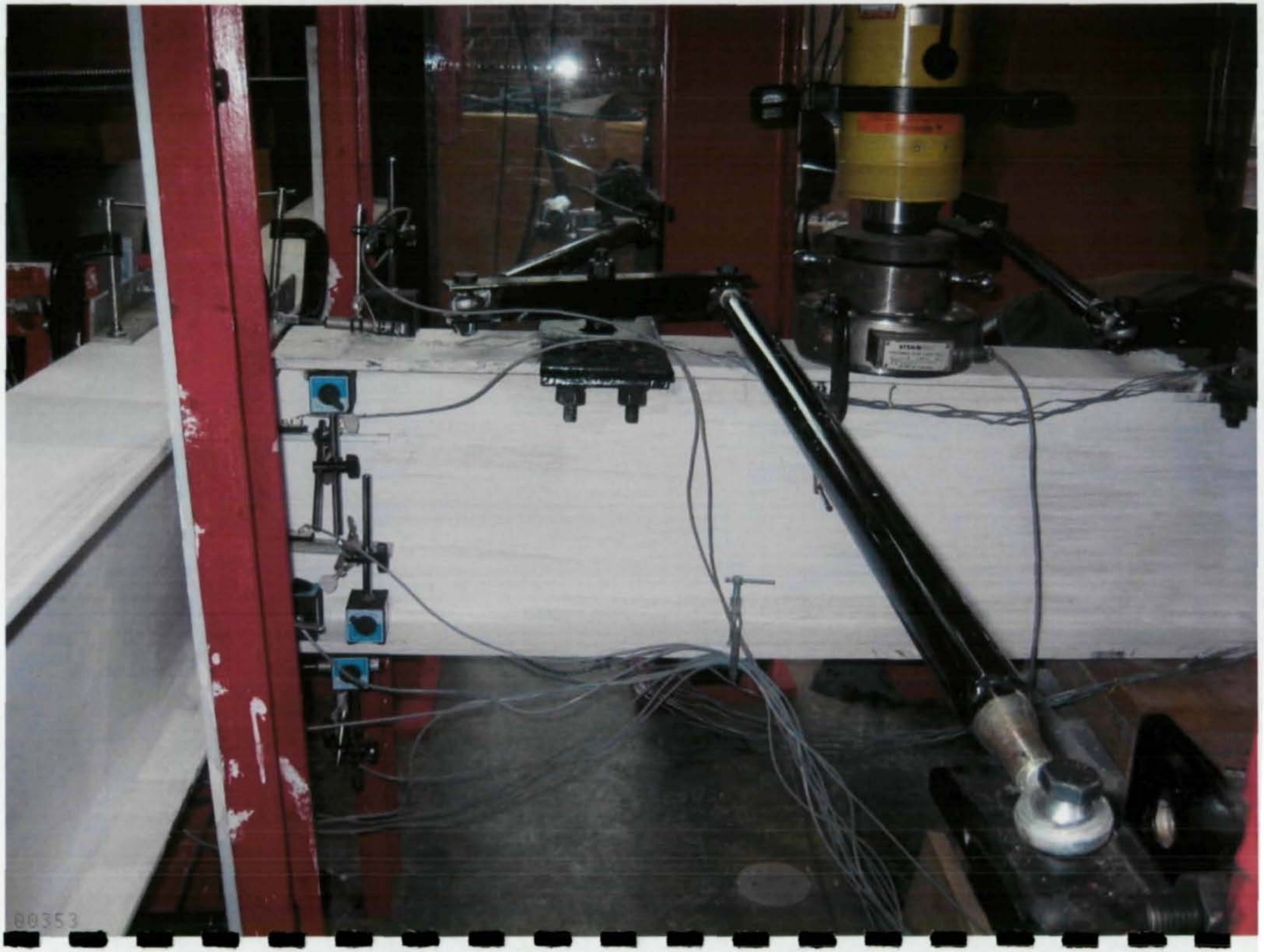
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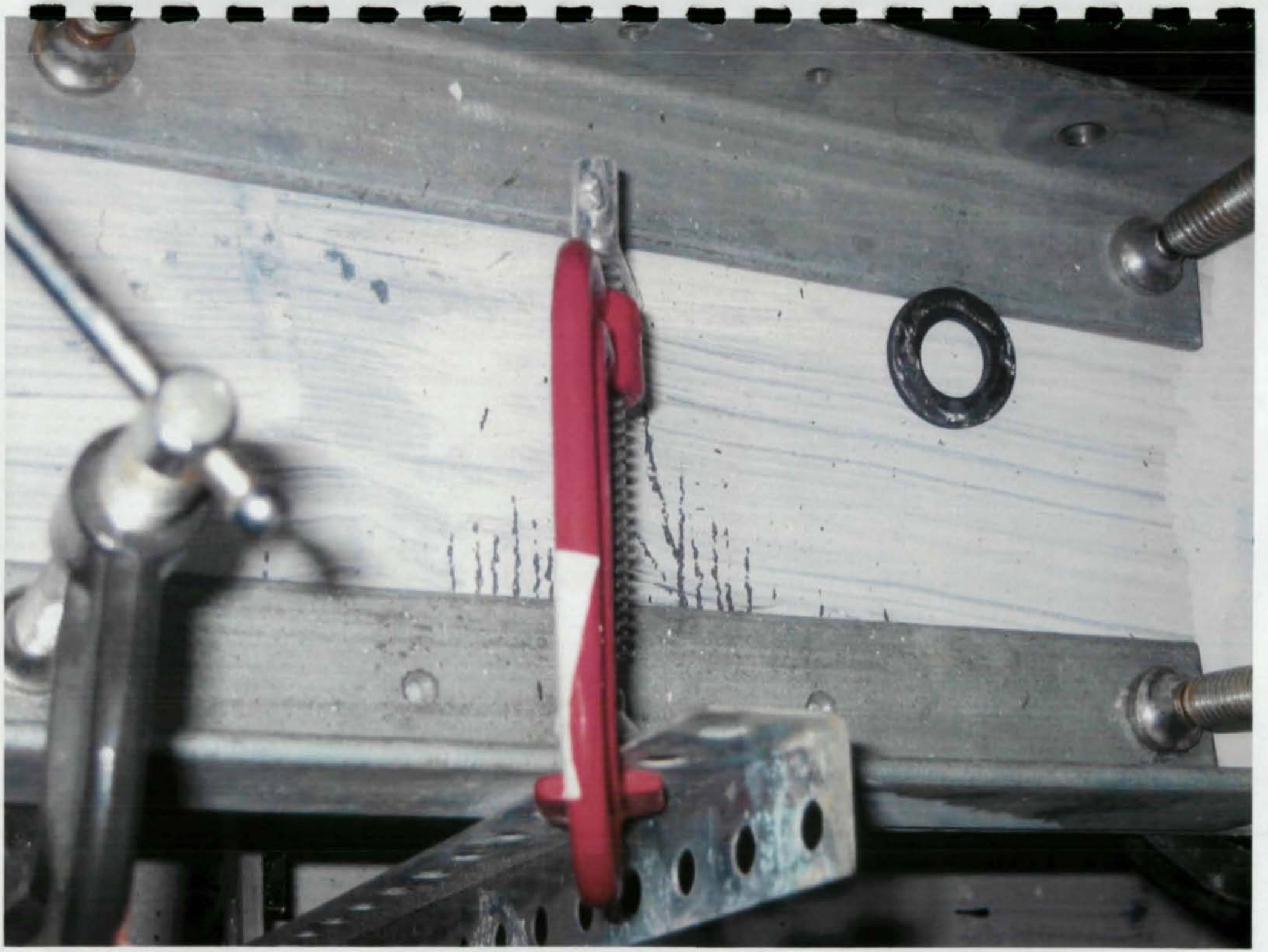

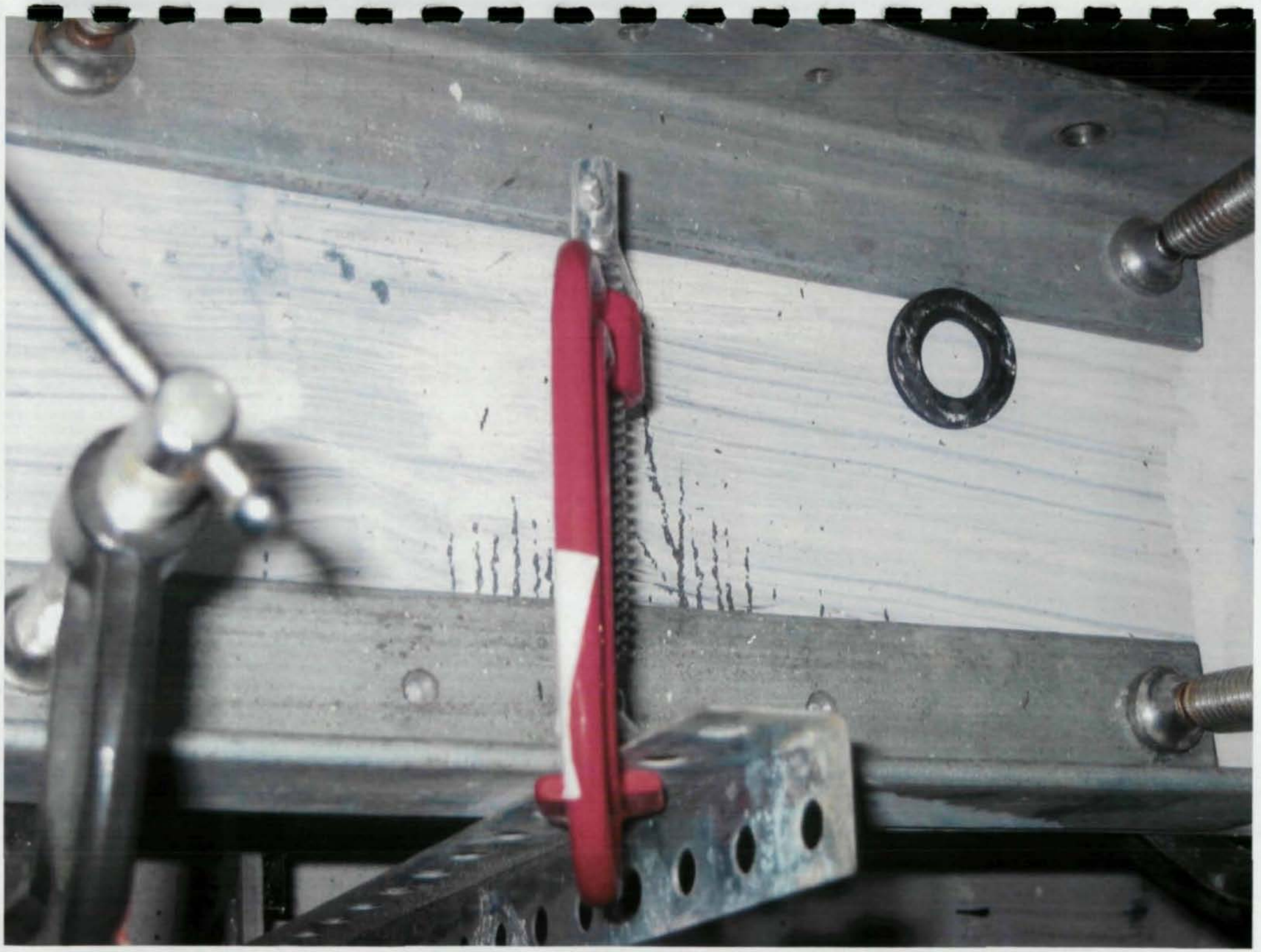

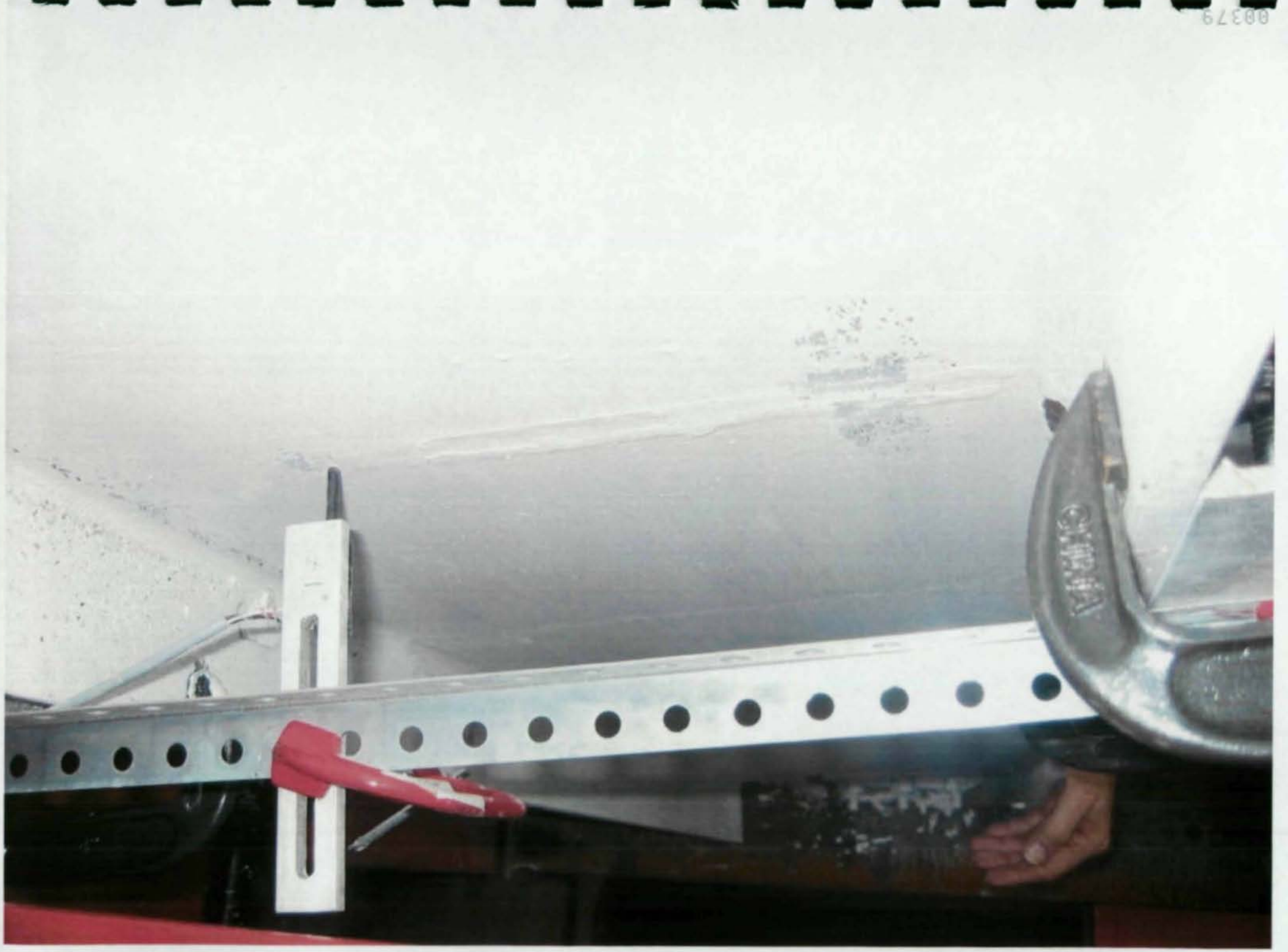

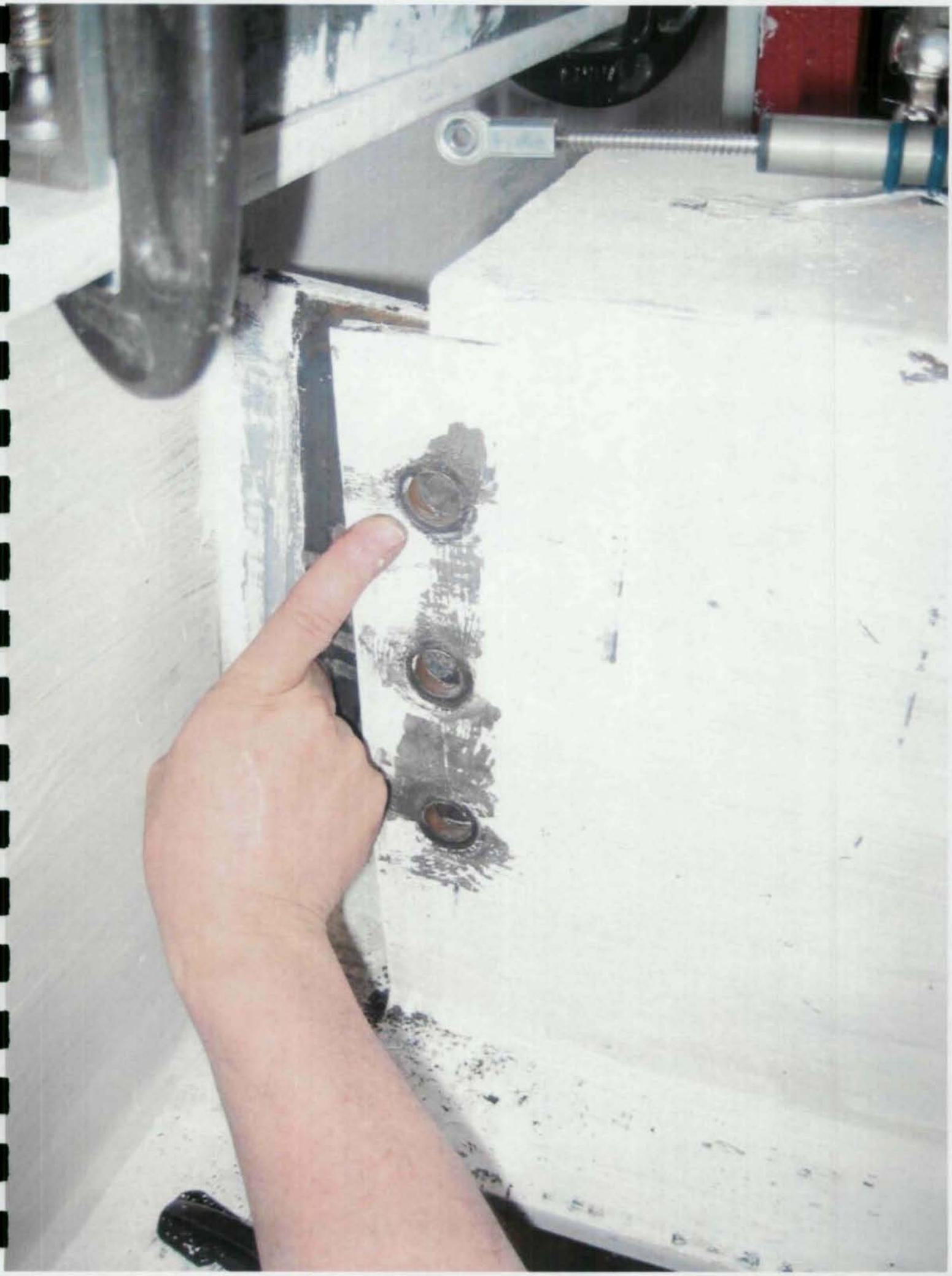


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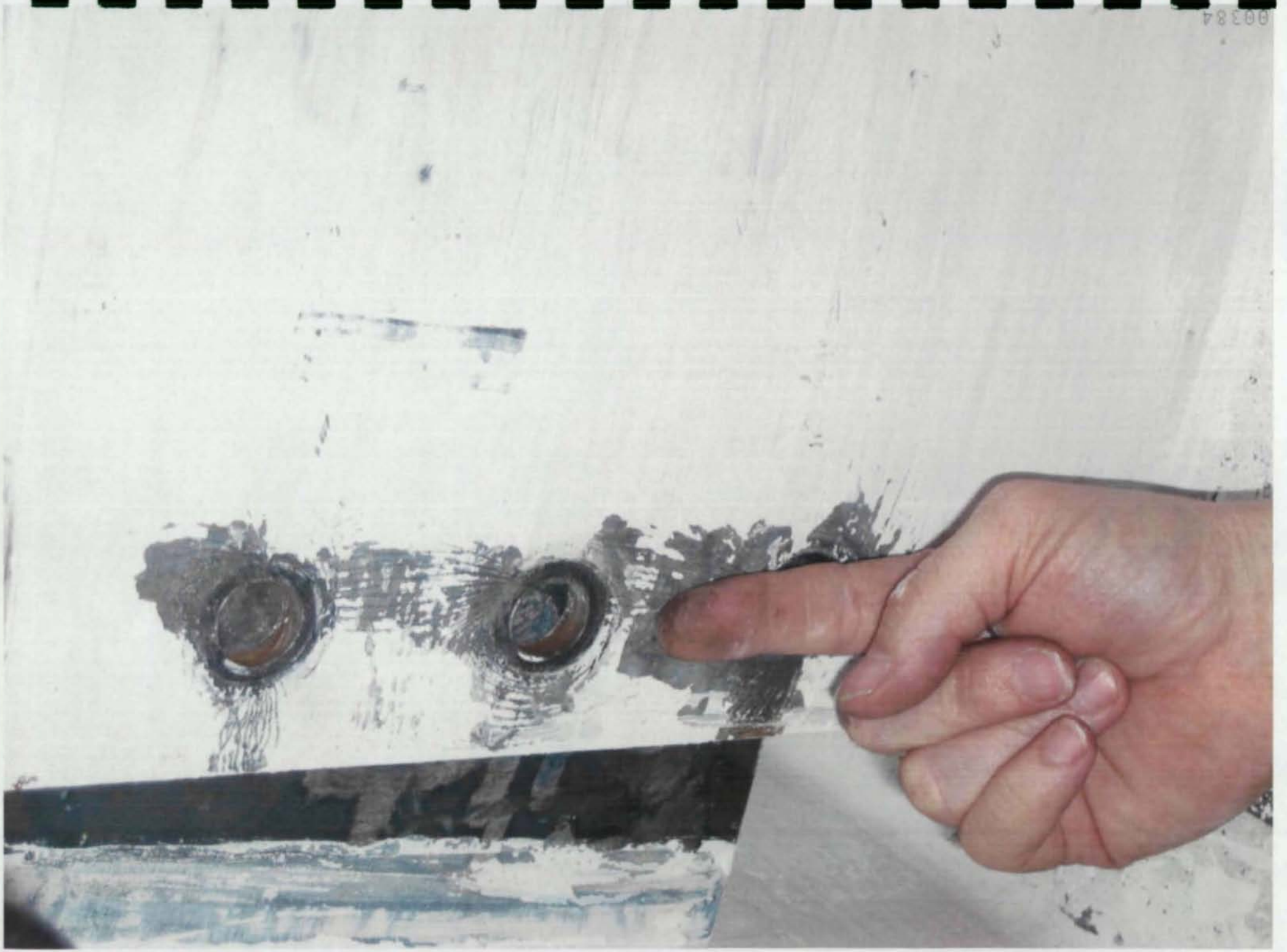

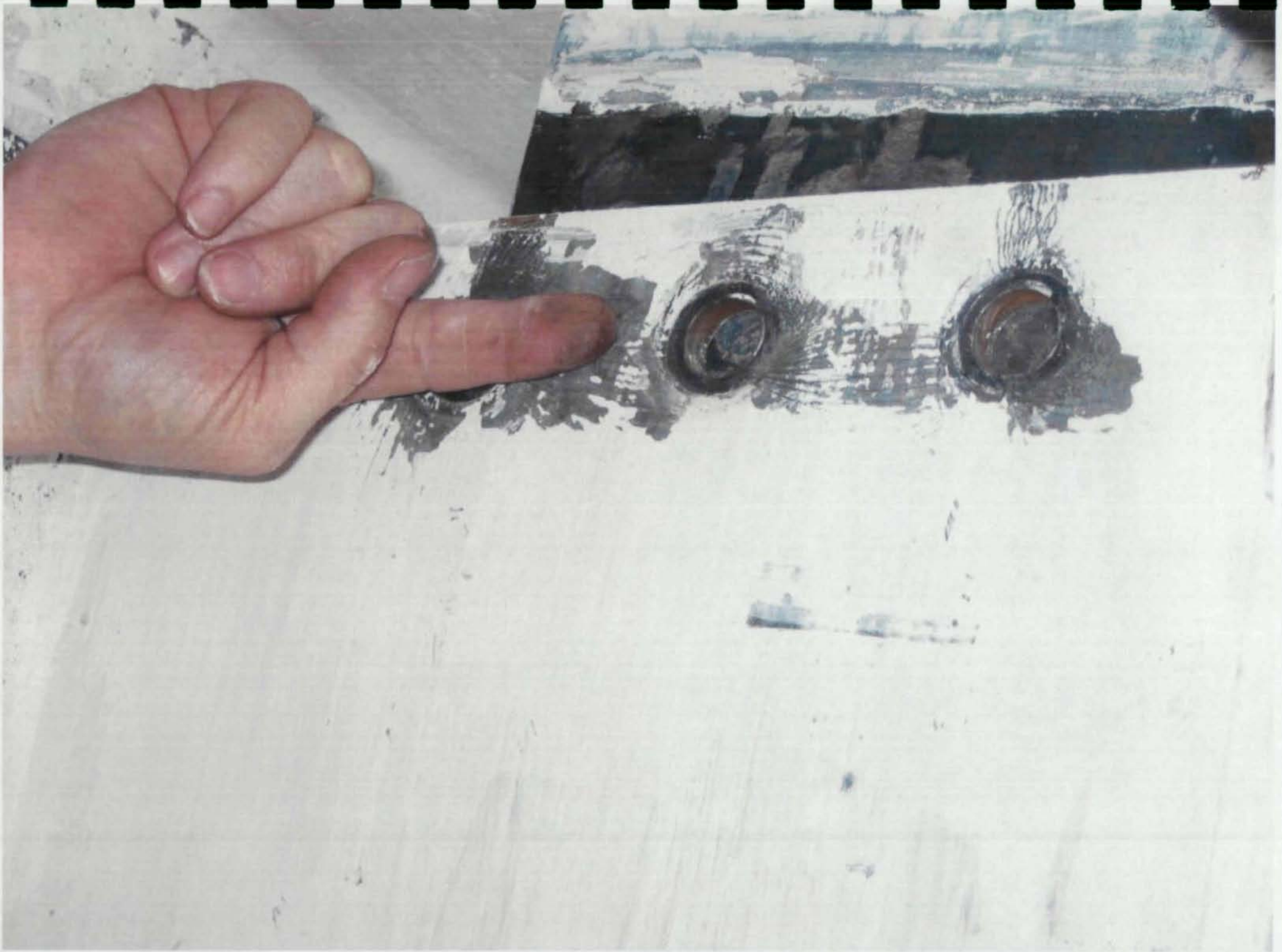

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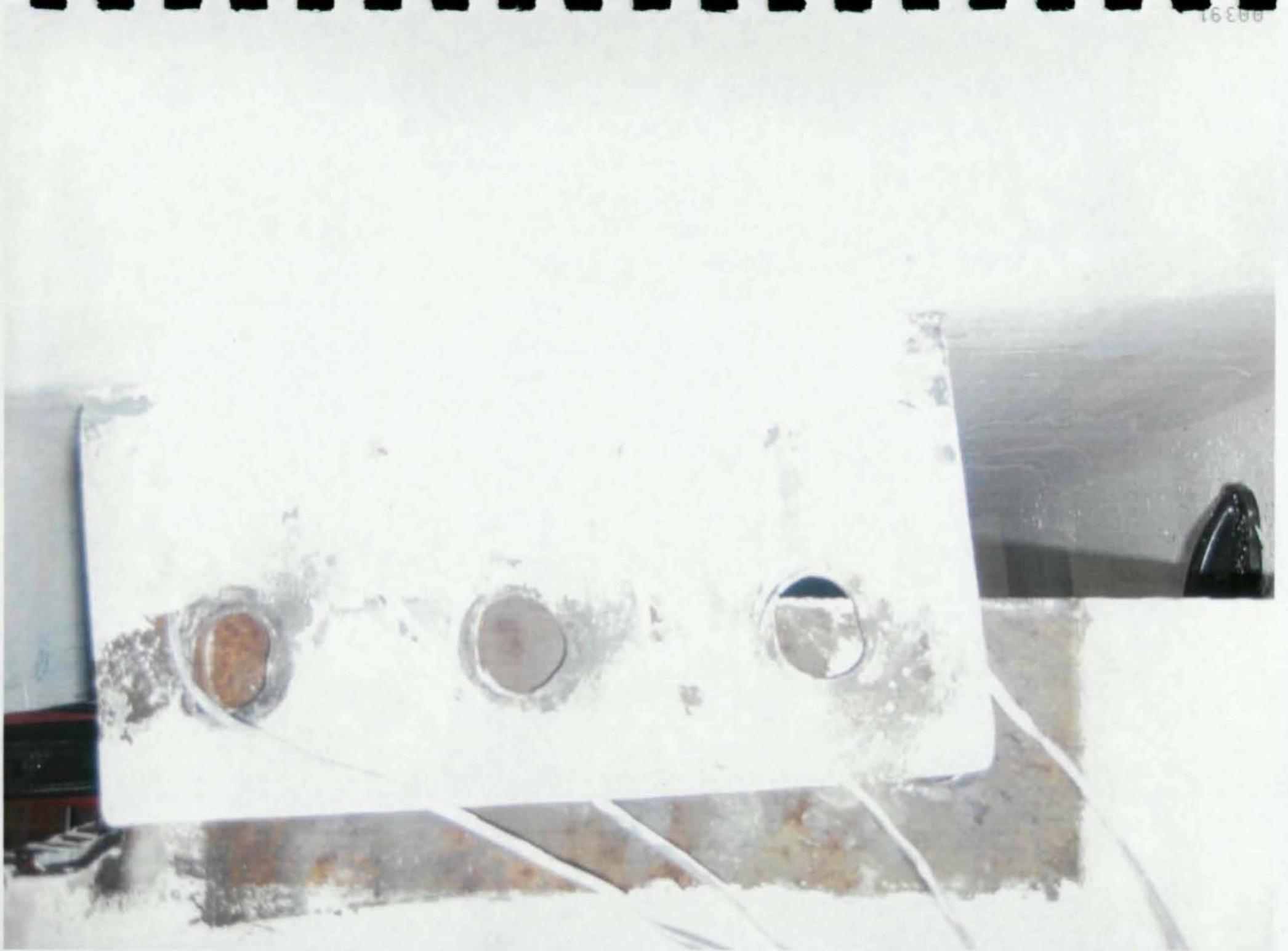

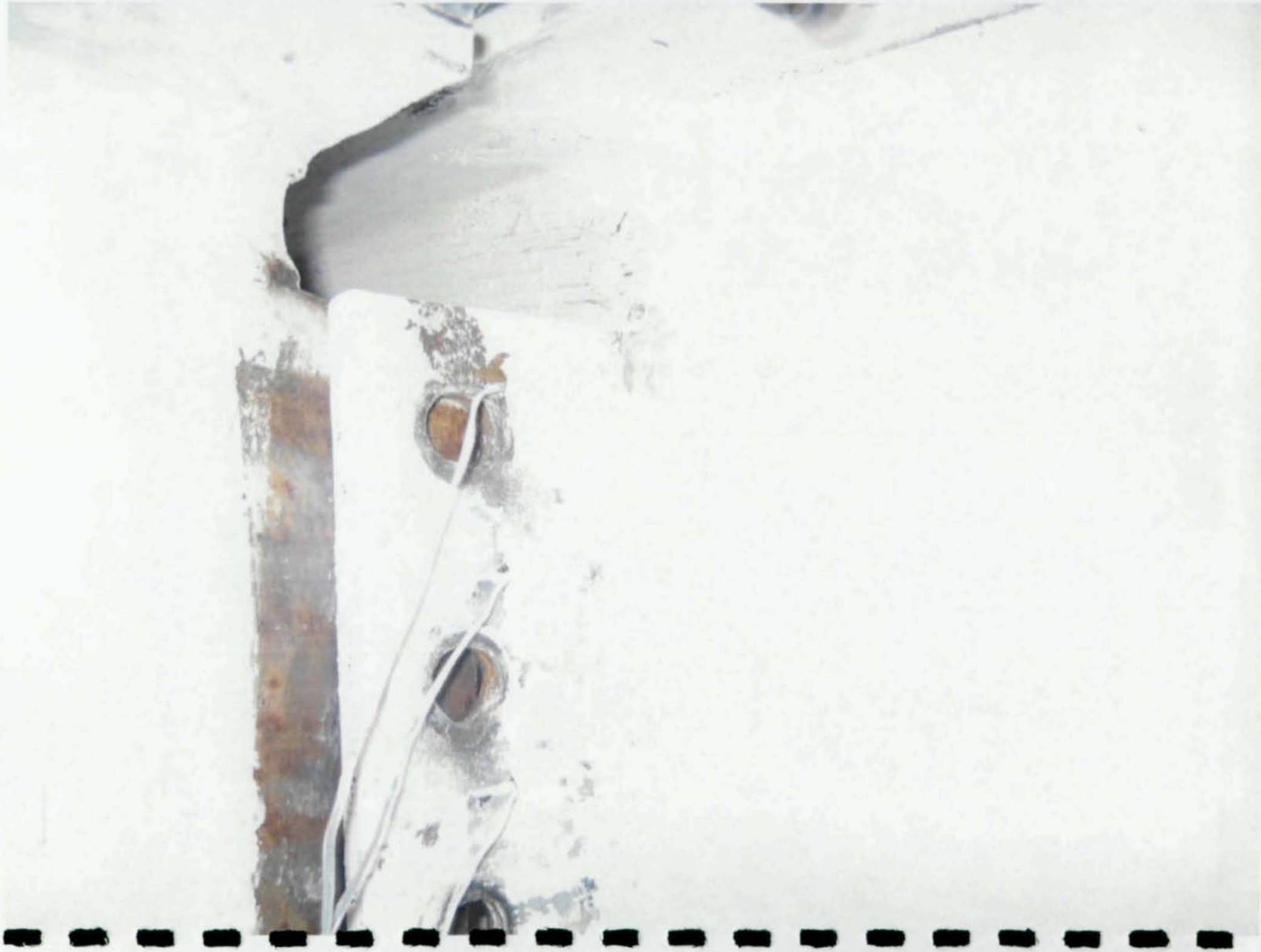


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