NORTHRIDGE 20
SYMPOSIUM

Failure Analysis of Pre-Northridge Connections - Lessons Learned

by

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Figure 1. General view of specimenSP3.2. Top flange on left.

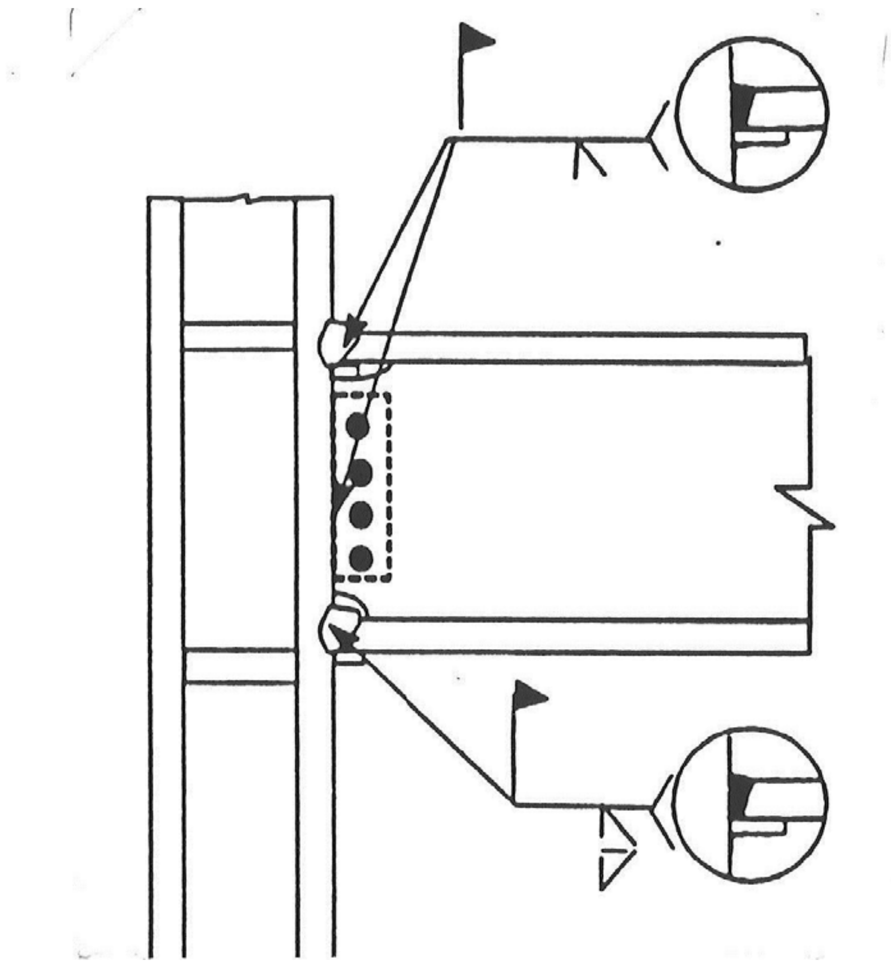


Figure 2. Schematic of Pre-Northridge Connection.

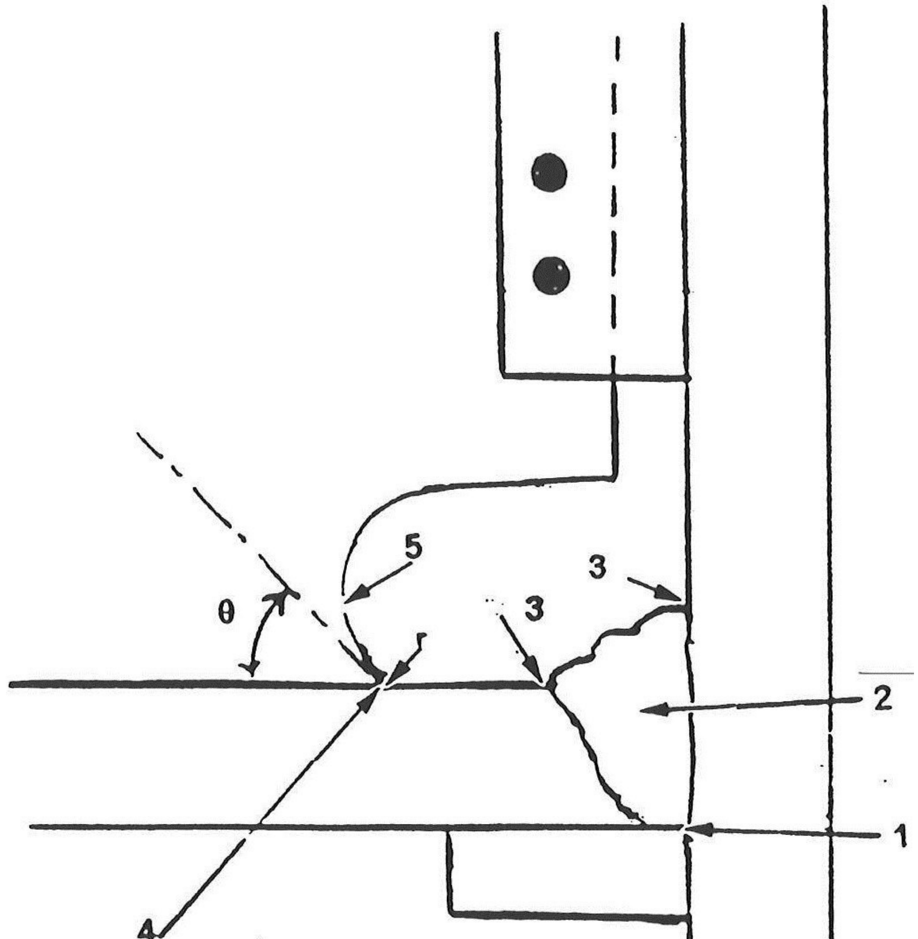
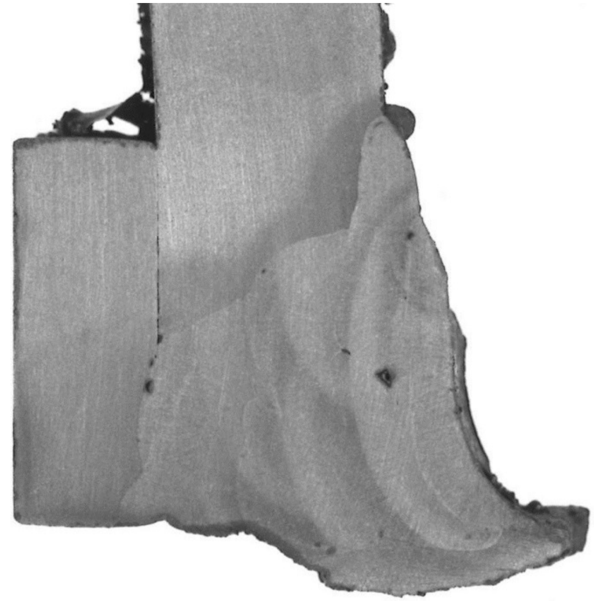
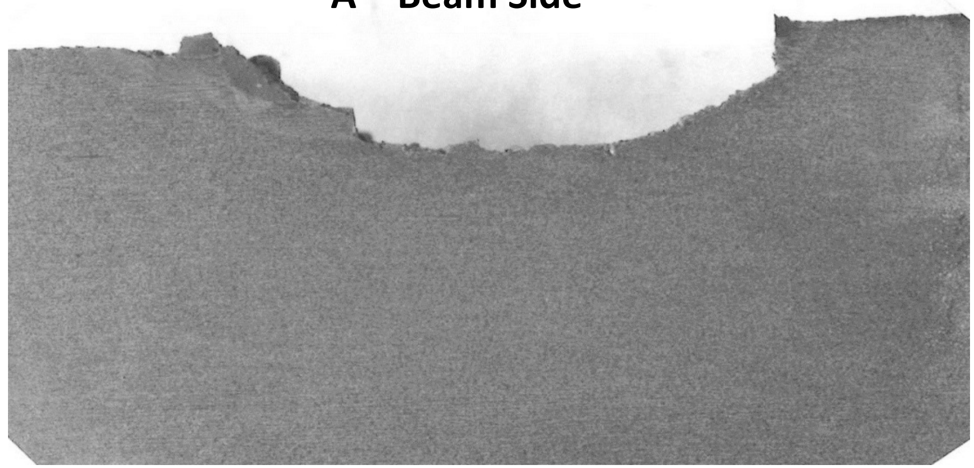


Figure 3. Schematic of Pre-Northridge Connection.

Figure 5. Divot type fracture of connection SP1.1.



A – Beam Side



B – Column Side

Figure 7. Cross sections of divot-type fractures at mid-width of the beam flange.

Figure 4. Bottom flange fracture of connection SP1.1 along the length of the backing plate.

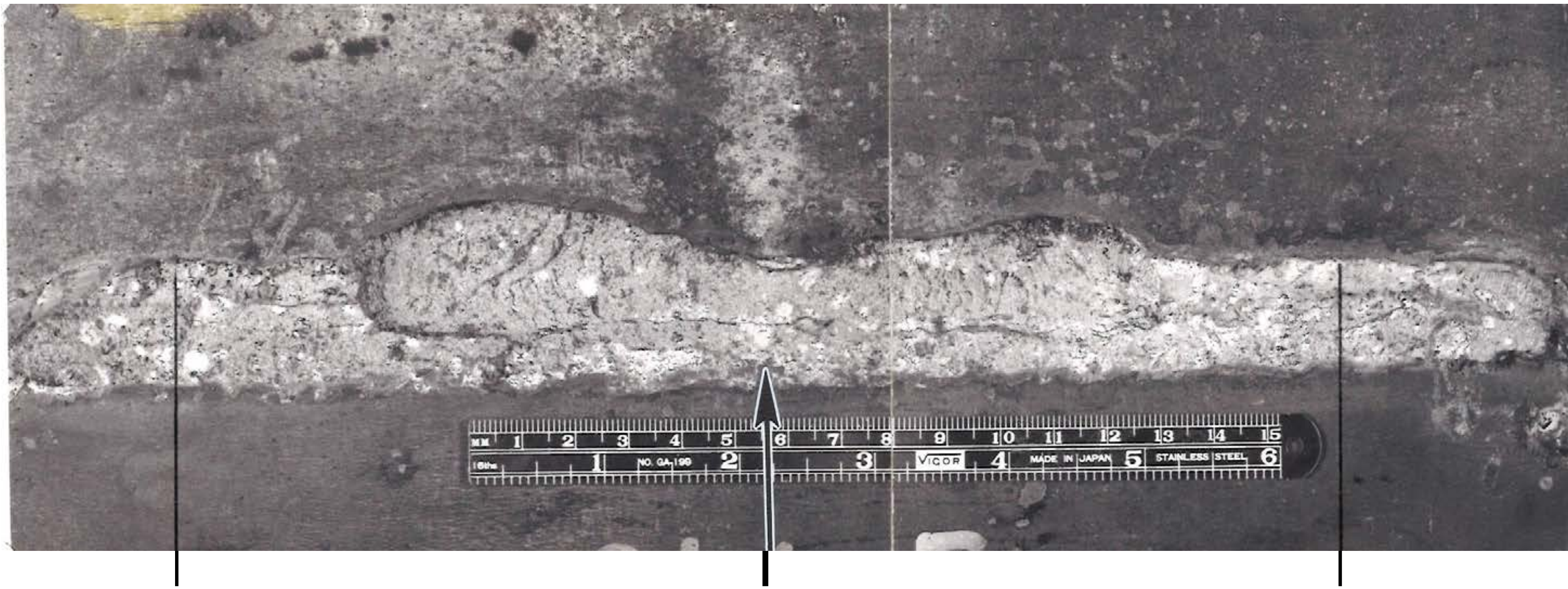


Figure 6. Surface of bottom beam-flange divot-type fracture.

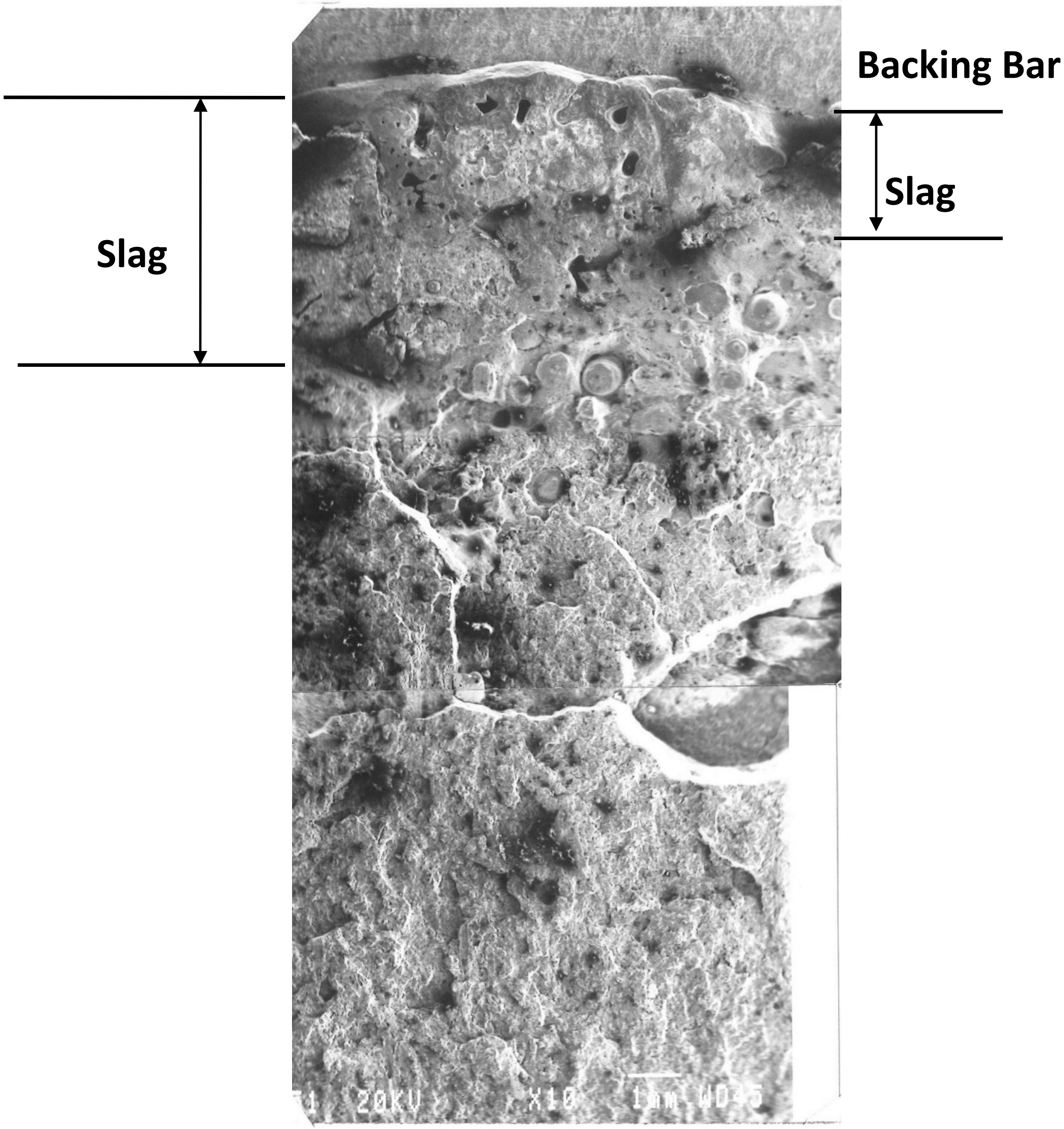


Figure 9. Scanning electron micrograph of the fracture origin on the beam side.

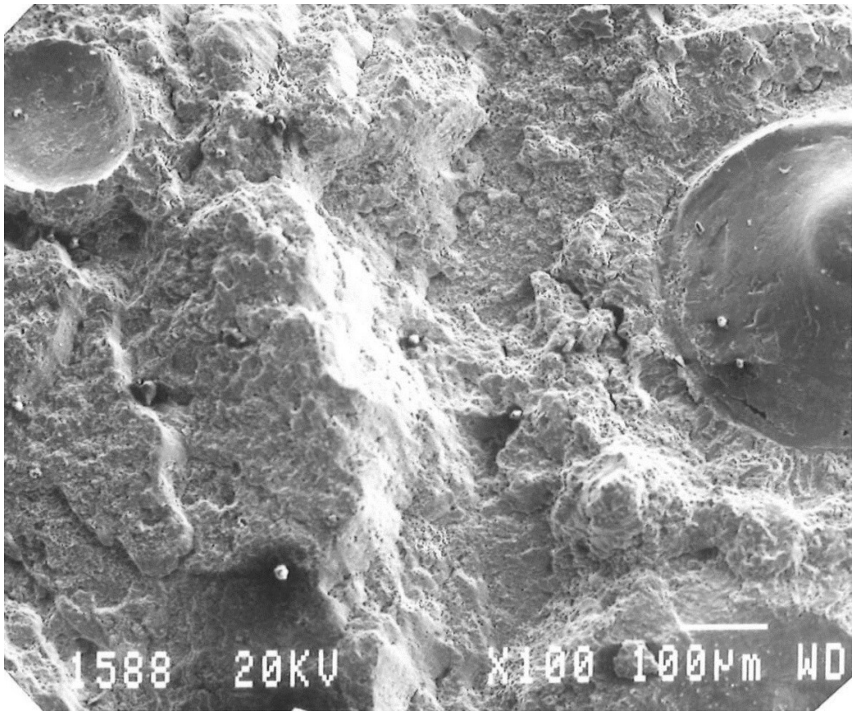


Figure 11.1. Ductile fracture of an area in the weld metal at the fracture origin.

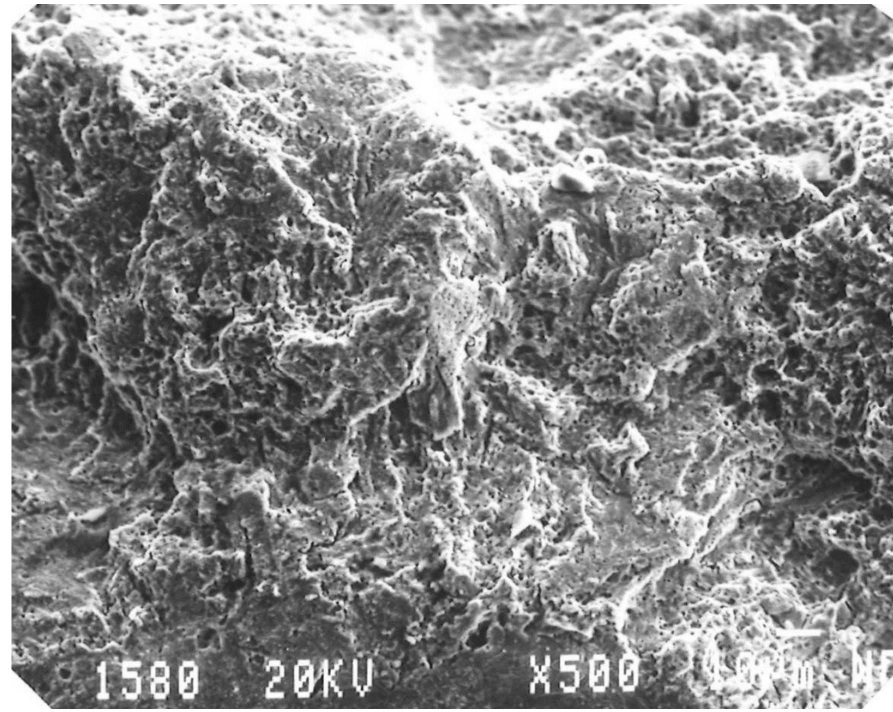


Figure 11.2. Higher magnification of ductile fracture area in the weld metal at the fracture origin.

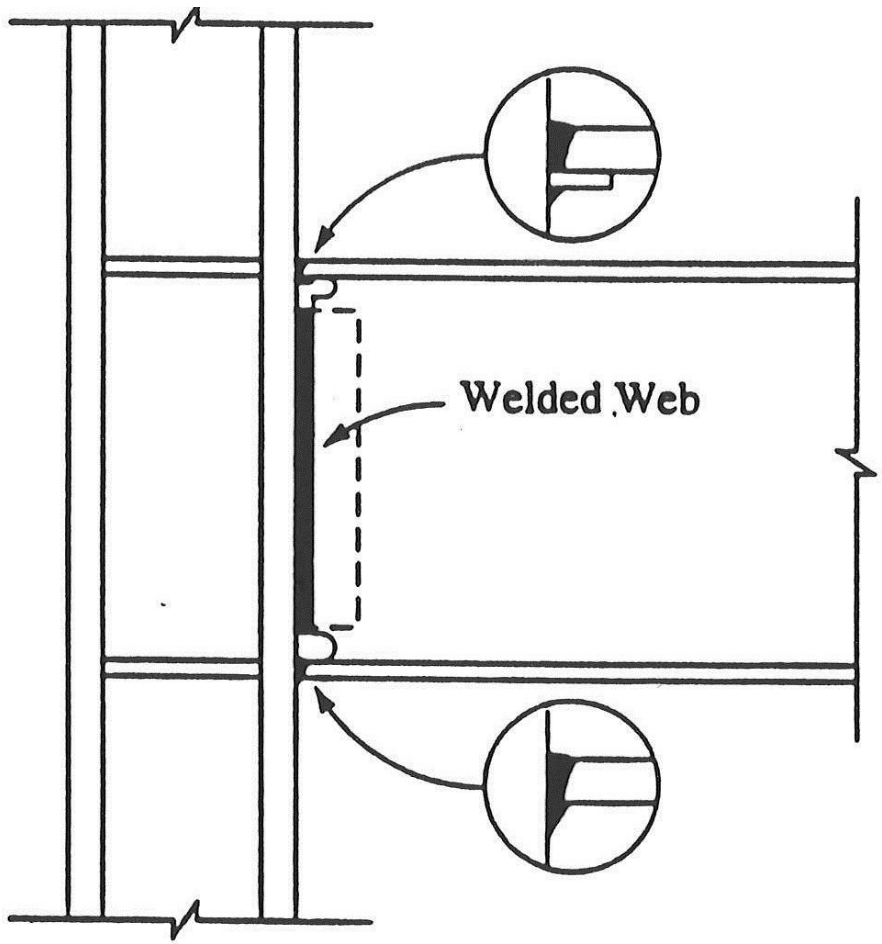


Figure 12. Schematic of Post-Northridge Connection.

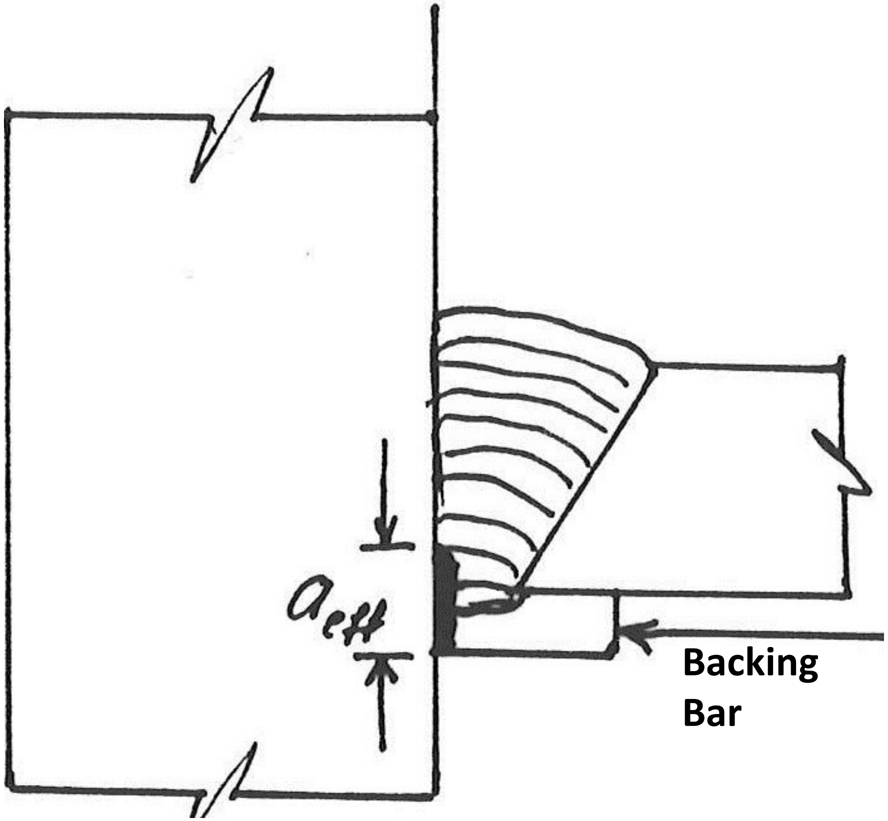


Figure 13.1. Effective flaw geometry.

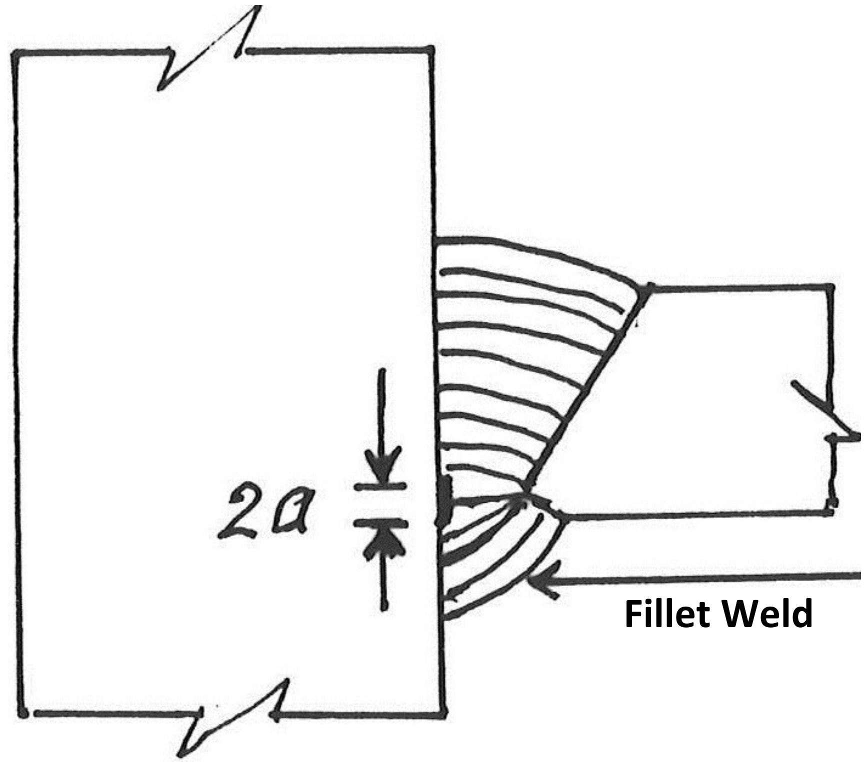


Figure 13.2. Buried flaw geometry.

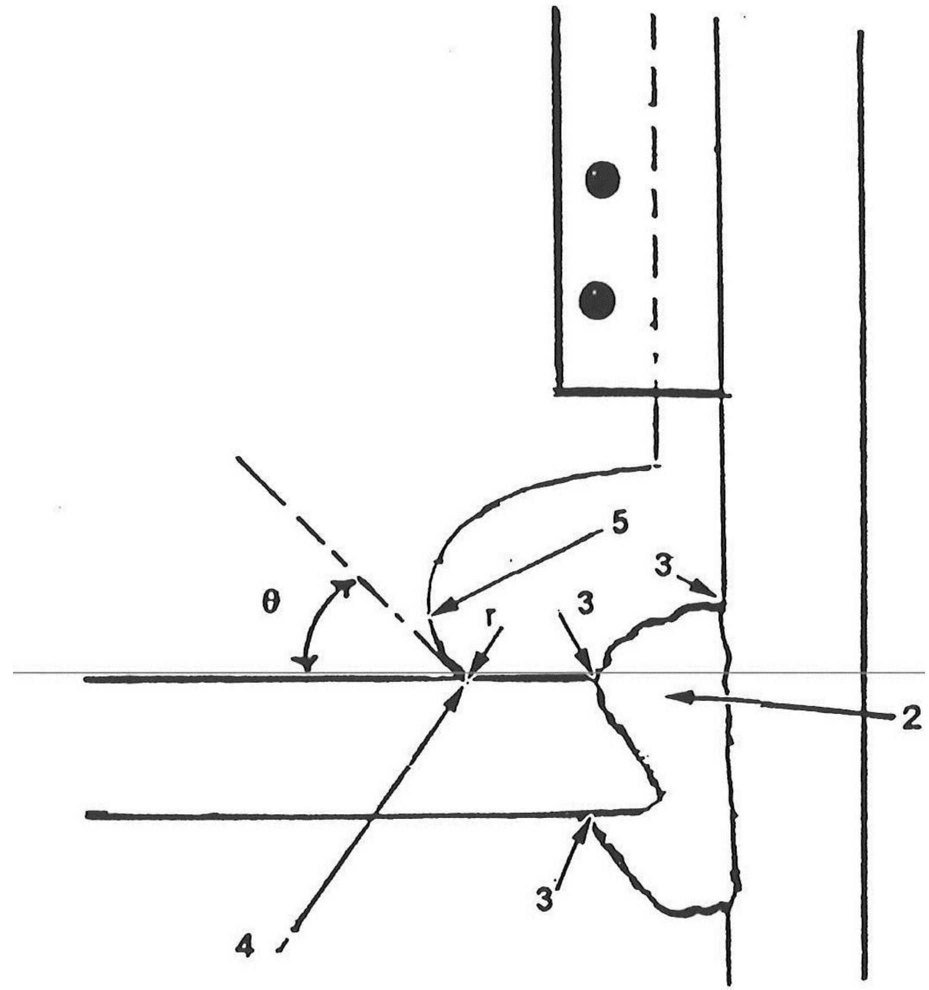
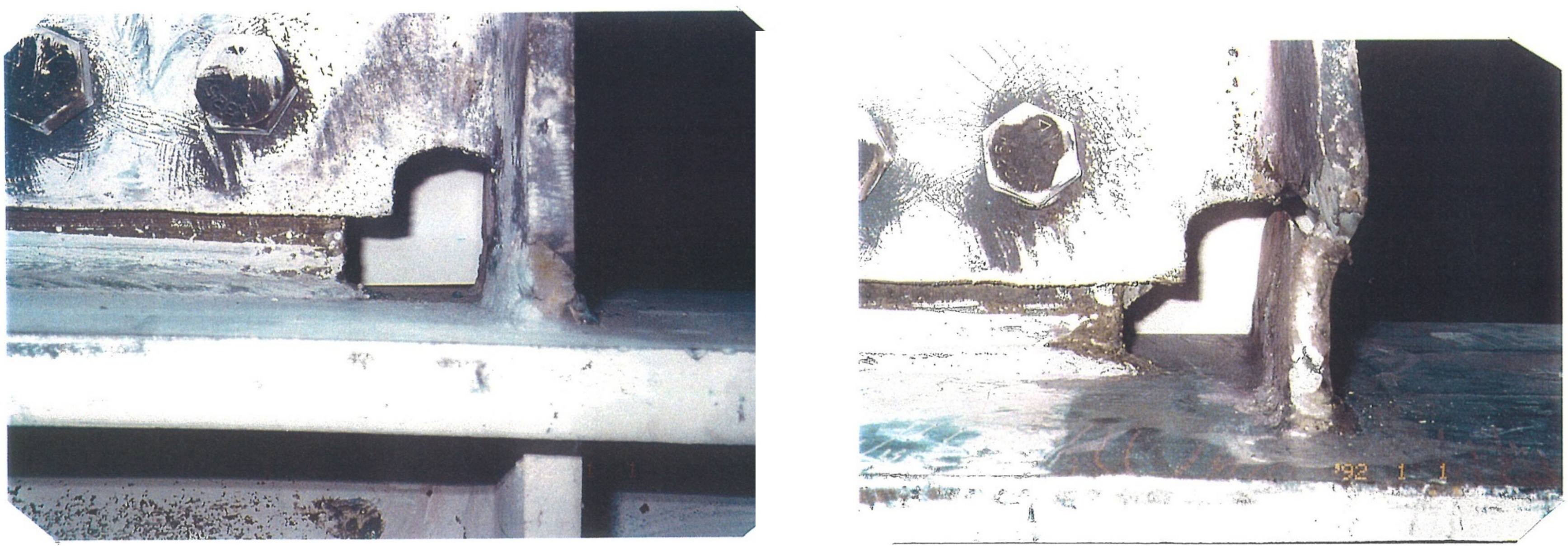


Figure 14. Schematic of Un-reinforced Post Northridge Connection.

specimen	total rotation (rad)	plastic rotation (rad)	beam component (rad)	column and panel zone component (rad)
1.1	0.010	0.000	0.000	0.000
1.2	0.010	0.000	0.000	0.000
3.1	0.030	0.017	0.010	0.007
3.2	0.030	0.017	0.013	0.004
4.1	0.030	0.019	0.006	0.013
4.2	0.030	0.019	0.008	0.011
5.1	0.039	0.026	0.013	0.013
5.2	0.020	0.010	0.007	0.003
6.1	0.020	0.009	0.009	0.000
6.2	0.015	0.006	0.006	0.000
7.1	0.020	0.010	0.007	0.003
7.2	0.030	0.018	0.012	0.006

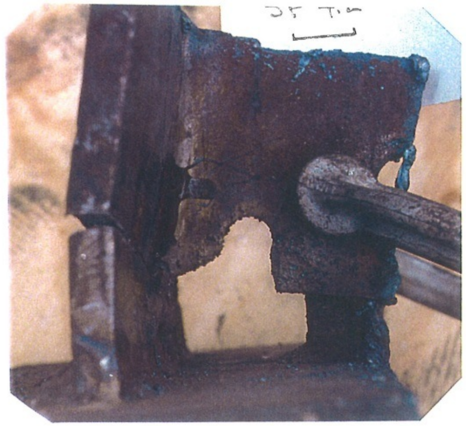
Table 2. Connection rotations measured at peak deformation points attained before failure – University of Michigan.

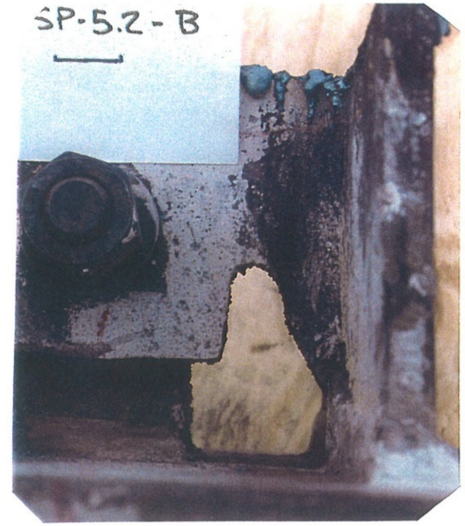


A. Specimen 3.1 (Bottom)

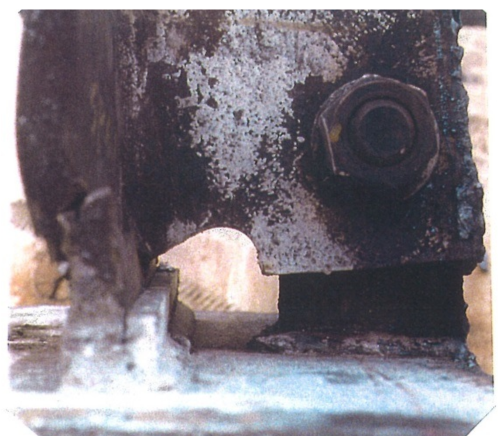
B. Specimen 3.2 (Bottom)

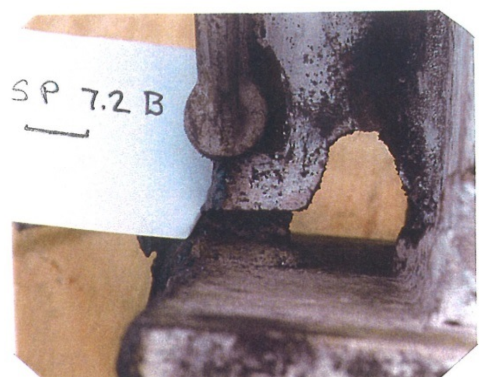
Figure 17. Examples of severe web-to-flange intersections at weld access hole.





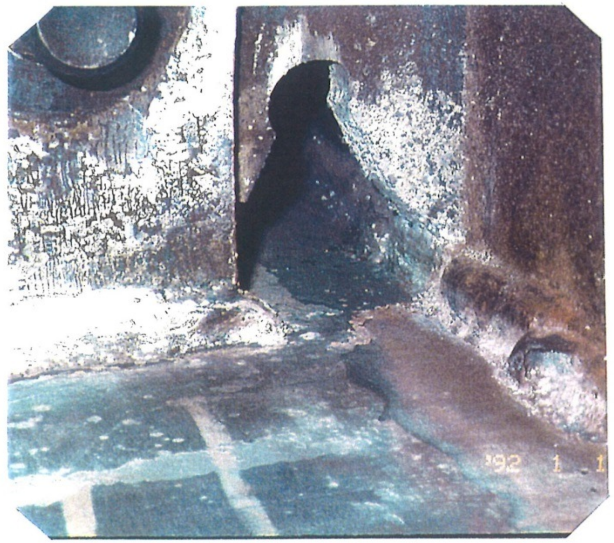
A. Specimen 4.2 (Bottom) B. Specimen 5.2 (Bottom)





C. Specimen 6.1 (Top) D. Specimen 7.2 (Bottom)

Figure 16.2. Various weld access hole geometries tested at University of Michigan.

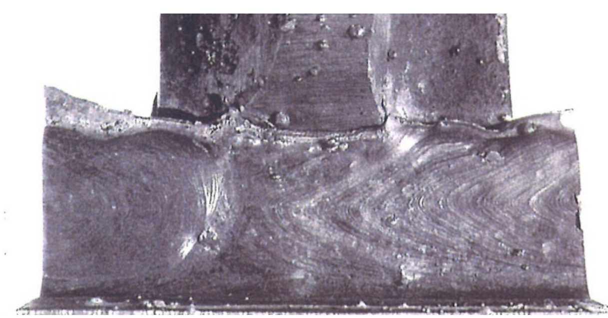


A.Web-to-flange intersection at the weld access hole coincident with weld toe.

Specimen 4.1

B. Close up of weld access hole and inside weld geometry.

Specimen 5.2 (Bottom)



C.Close up of fatigue crack at web-to-flange intersection of the weld access hole coincident with the weld toe.

Specimen 5.1 (Bottom)

Figure 18. Examples of stress and strain regions caused by the coincidence of the web-to-flange intersection at the weld access hole and the weld toe.

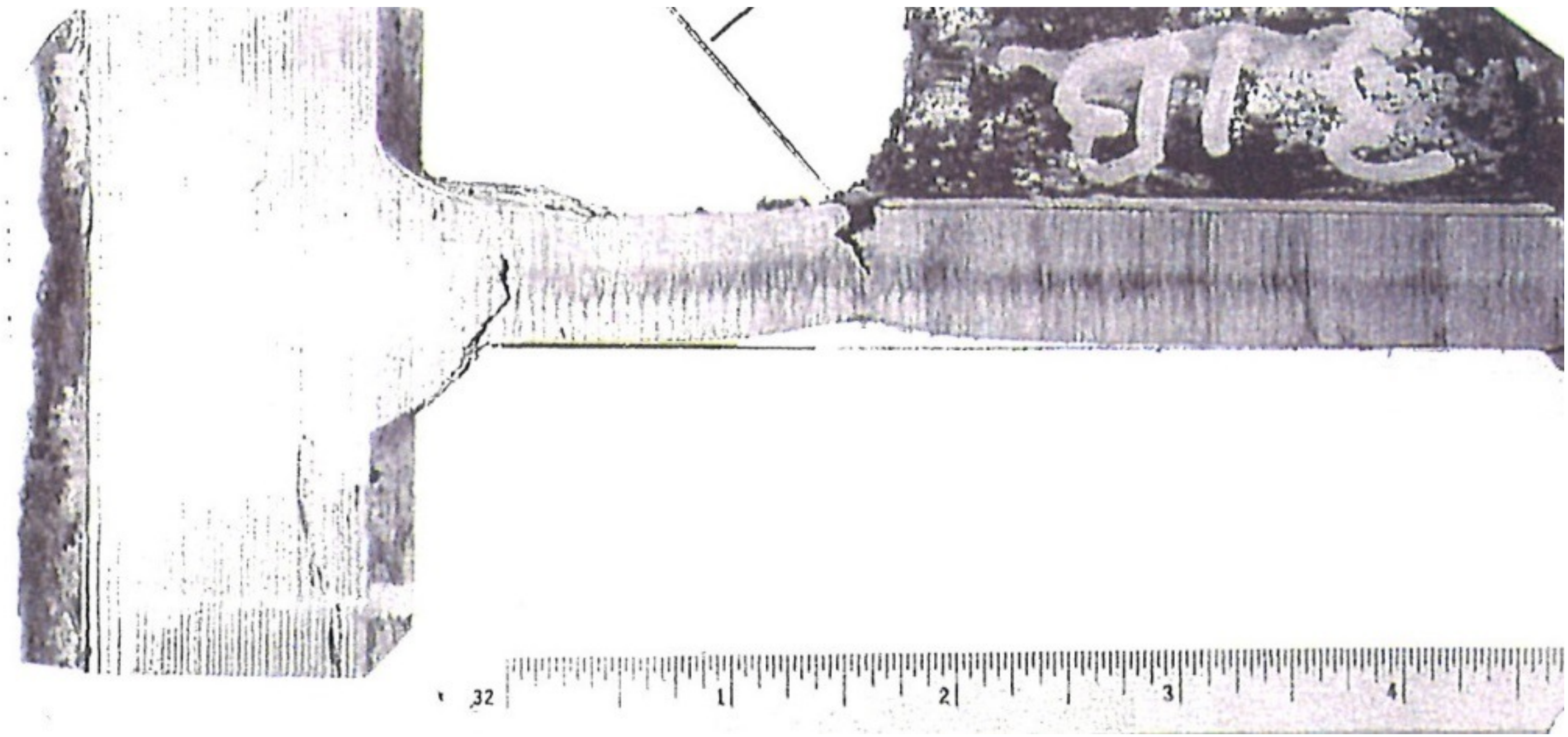
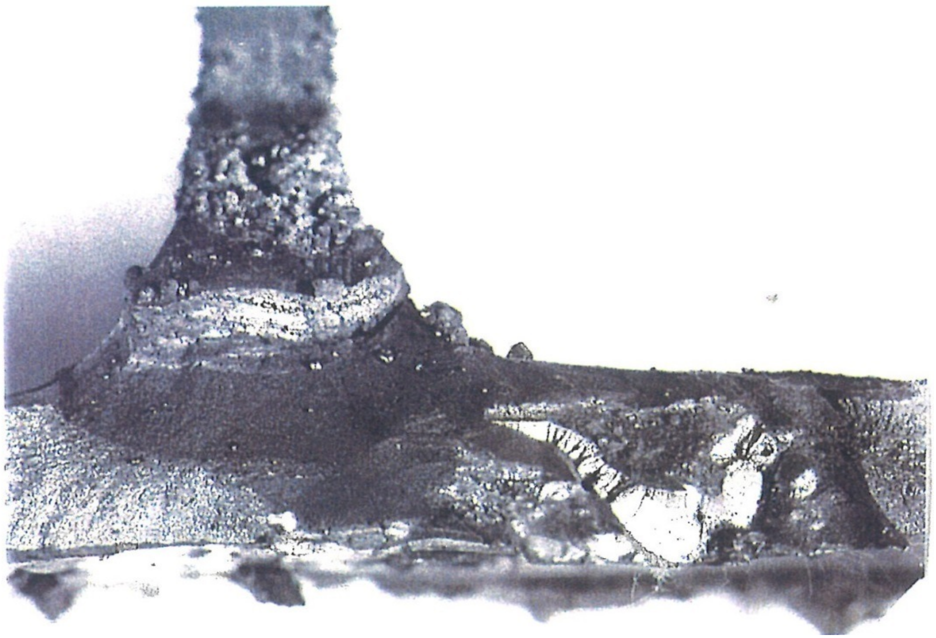


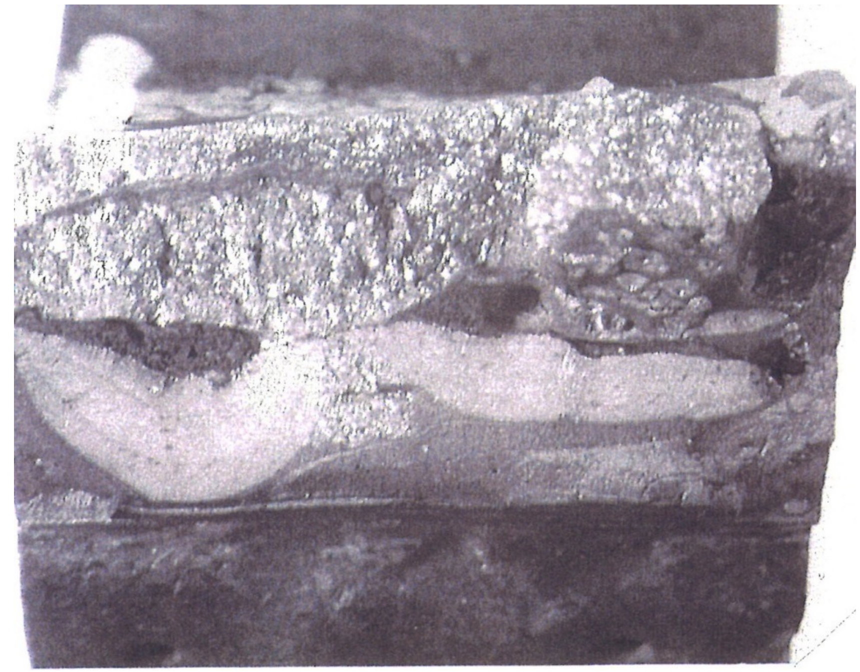
Figure 20. Fatigue cracks initiated at web-to-flange intersection at the weld access hole and at the weld toe in the bottom surface of the bottom flange.

Specimen 3.1 (Bottom)



A. Fracture surface showed the fracture was caused by two fatigue cracks. One within the weld metal from a lack-of-fusion and slag inclusions, the other from the web-to-flange intersections at the weld access hole.

Specimen 4.2 (Bottom)



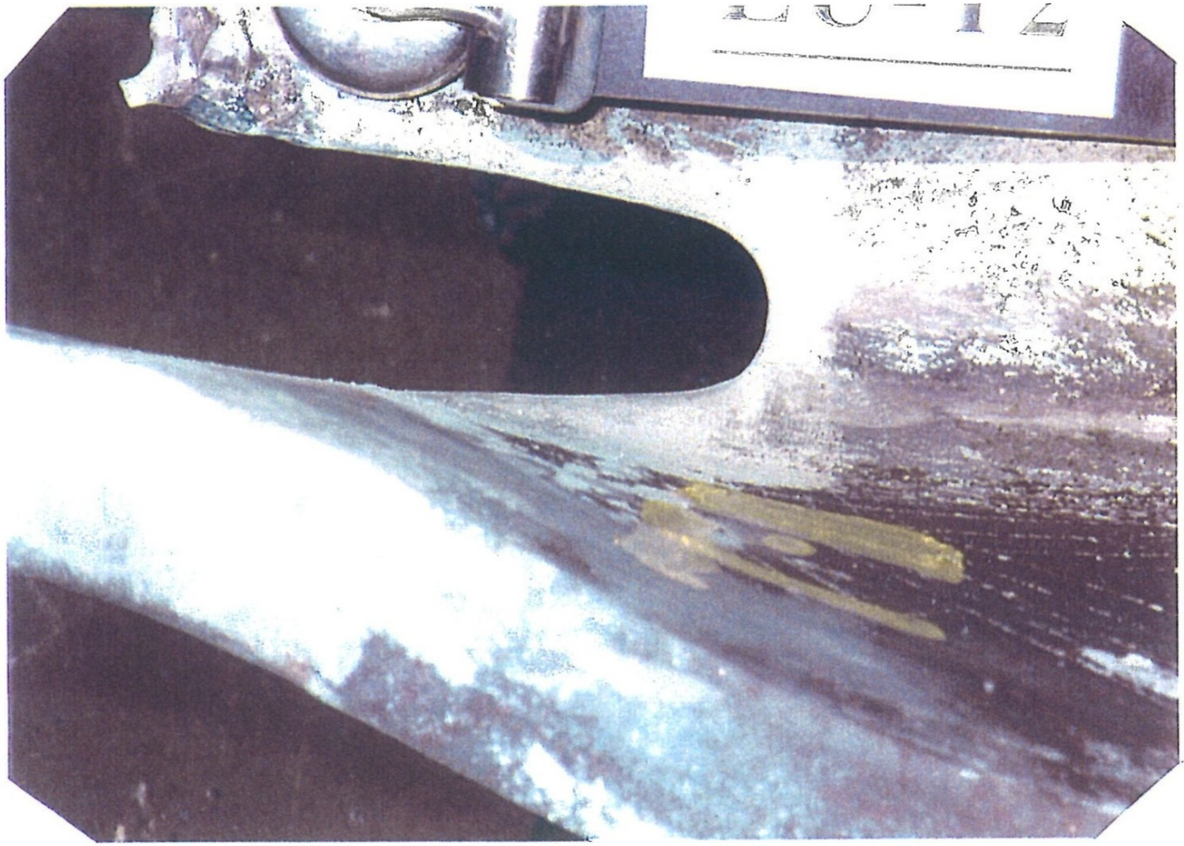
B. Multiple cracks initiated within the weld from lack-of-fusion and slag inclusions.

Specimen 3.1 (Bottom)

Figure 22. Fatigue crack initiated at lack-of-fusion imperfections.

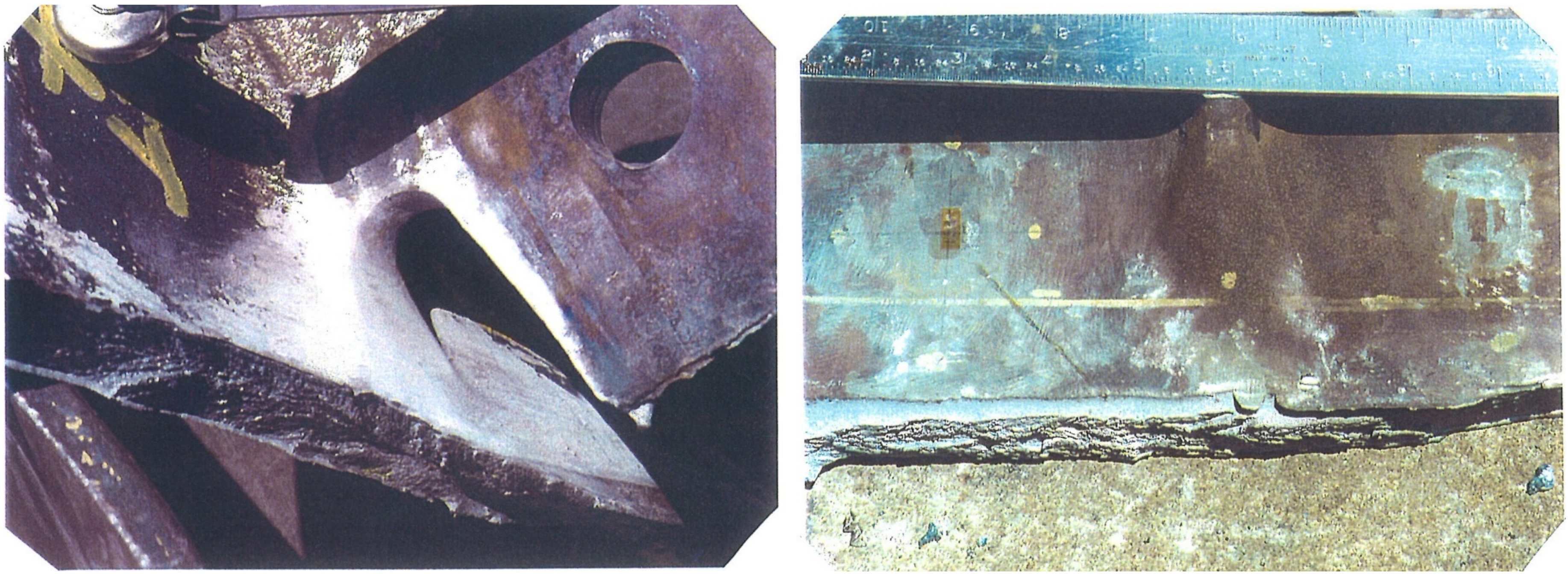
Specimen No.	WAHG[1]	WAHS[2]	WG[3]	WI[4]	
					[1] Weld access hole intersection geometry (WAHG)
3.1B[5]	X	X	X	X	[2] Weld access hole flame cut surface roughness(WAHS)
3.1T[6]	X				[3] Weld geometry (WG)
3.2B	X	X			[4] Weld imperfections (WI)
4.1[7]					[5] B denotes bottom flange
4.2B	X			X	[6.] T denotes top flange
4.2T	X				[7.] Column fracture due to undersized continuity plate fillet welds
5.1B	X		X		
5.1T	X	X			
5.2B	X		X		
5.2T	X		X		
6.1B			X		
6.1T	X				
6.2B	X		X		
6.2T	X				
7.1B	X		X	X	
7.1T	X		X		
7.2B			X	X	
7.2T	X				

Table 3. Distribution of cracks in WSMF Connections Tested at the University of Michigan.



Specimen LU-T2

Figure 30. Weld access hole geometry investigated by Lehigh University.



A.Specimen LU-T2 B. Specimen LU-T1

Figure 29. Weld access hole surface investigated by Lehigh University,

specimen	total drift θ - (% rad)	plastic rotation θρ - (% rad)	beam plastic rot. θρ, bm - (% rad)	panel zone plastic rotation θρ,ρz – (% rad.)
LU-T1	5.0	3.5	1.2	1.9
LU-T2	5.0	2.5	1.0	1.3
LU-T3	3.0	2.0	1.2	0.6
LU-T4	4.0	1.8	0.9	0.7
LU-C1	5.0	3.9	3.5	0.3
LU-C2	6.0	5.0	4.6	0.3
LU-C3	5.5	4.1	4.0	0.1
LU-C4	6.0	5.2	5.1	0.1
LU-C5	5.0	4.6	4.2	0.3

Table 5. Connection rotations measured at peak deformation points attained before failure- Lehigh University.

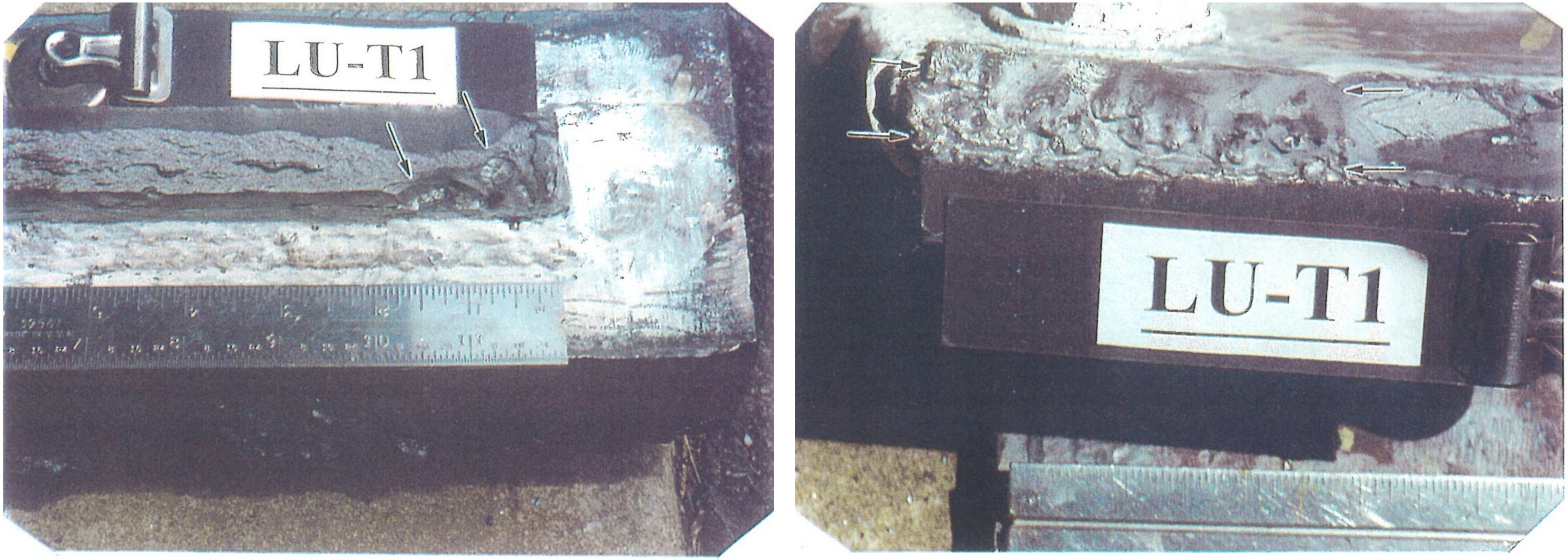


Figure 31.1. Examples of weld imperfections in Lehigh University connection LU-T1.

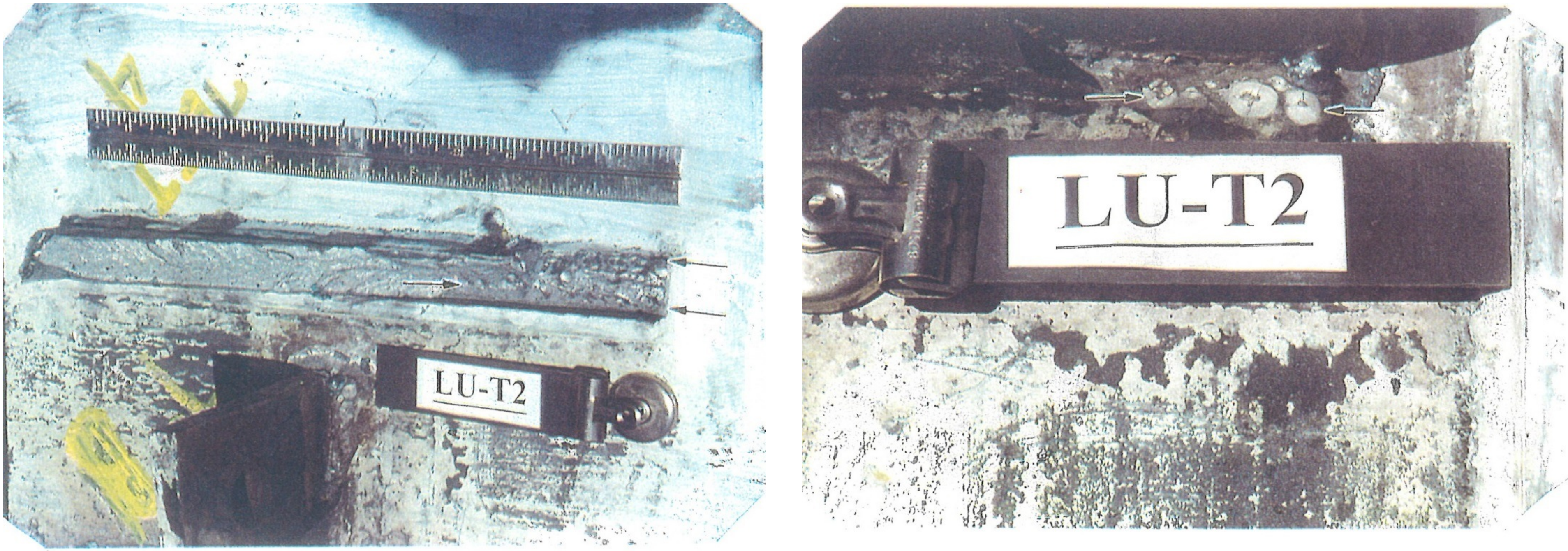
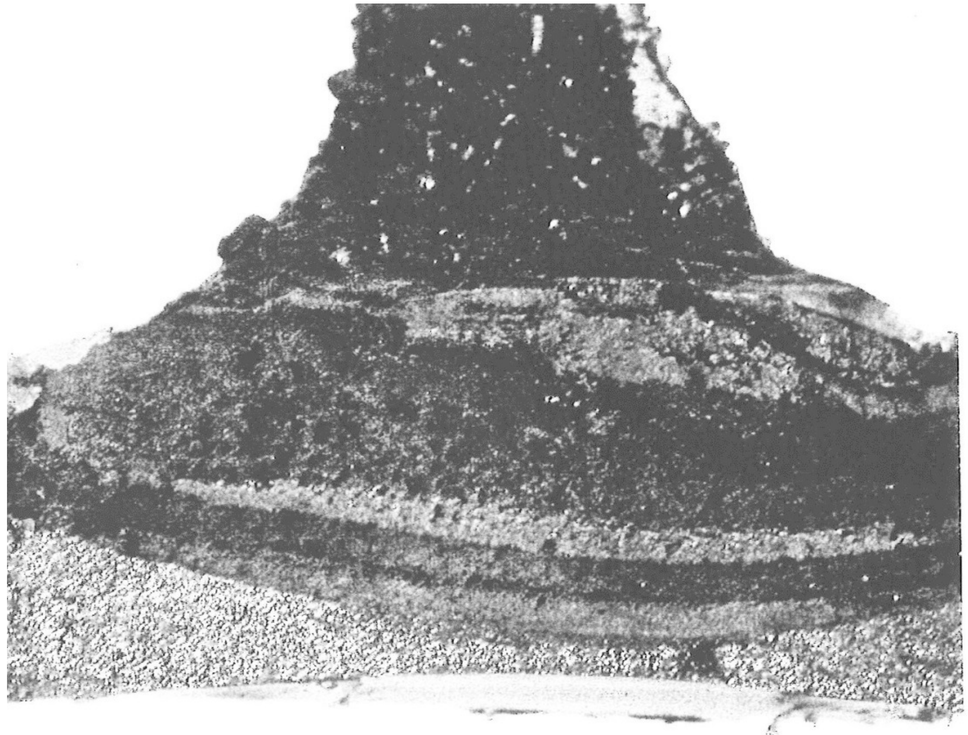


Figure 32. Examples of weld imperfections in Lehigh University connectionLU-T2.

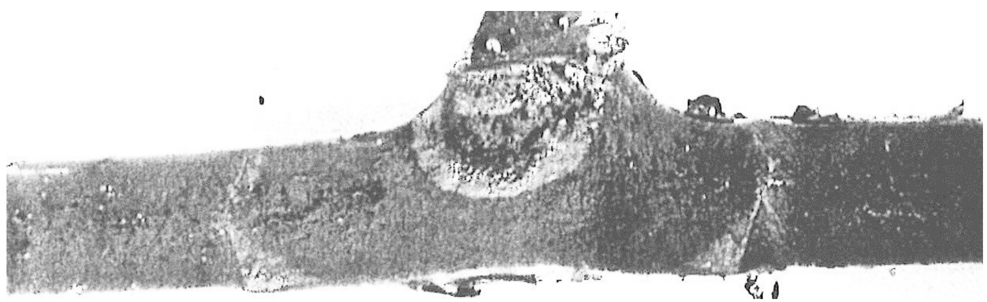
Figure 36. Multiple fatigue cracks along the fillet weld toe and the fusion line of the groove weld.

Specimen No.	WAHG[1]	WAHS[2]	WG[3]	WI[4]	
LU-T1B[5]			X	X	
LU-T1T[6]			X	X	[1] Weld access hole intersection geometry (WAHG)
LU-T1S[7]				X	[2] Weld access hole flame cut surface roughness(WAHS)
LU-T2B			X		[3] Weld geometry (i.e. weld toe) WG
LU-T2T			X	X	[4] Weld imperfections (i.e. lack of fusion) WI
LU-T2S				X	[5] Specimen LU-T1 bottom flange
LU-T3B			X	X	[6] Specimen LU-T1 top flange
LU-T3T			NA[10]	NA	[7]. Specimen LU-T1 shear tab
LU-T3S			NA	NA	[8]. Specimen LU-C2 east beam bottom flange
LU-T4B			NA	NA	[9]. Specimen LU-C2 west beam top flange
LU-T4T			X	X	[10]. Failure analysis could not be performed
LU-T4S			NA	NA	
LU-C2EB[8]				X	
LU-C2ET			X	X	
LU-C2ES				X	
LU-C2WB					
LU-C2WT[9]			X	X	
LU-C2WS				X	

Table 6. Distribution of cracks in WSMF Connections tested at Lehigh University.



A. Rapid fatigue crack propagation in specimen SP-3.1.



B. Rapid fatigue crack propagation in specimen SP3-2.

Figure 37. Rapid fatigue crack propagation through the thickness of beam flanges.

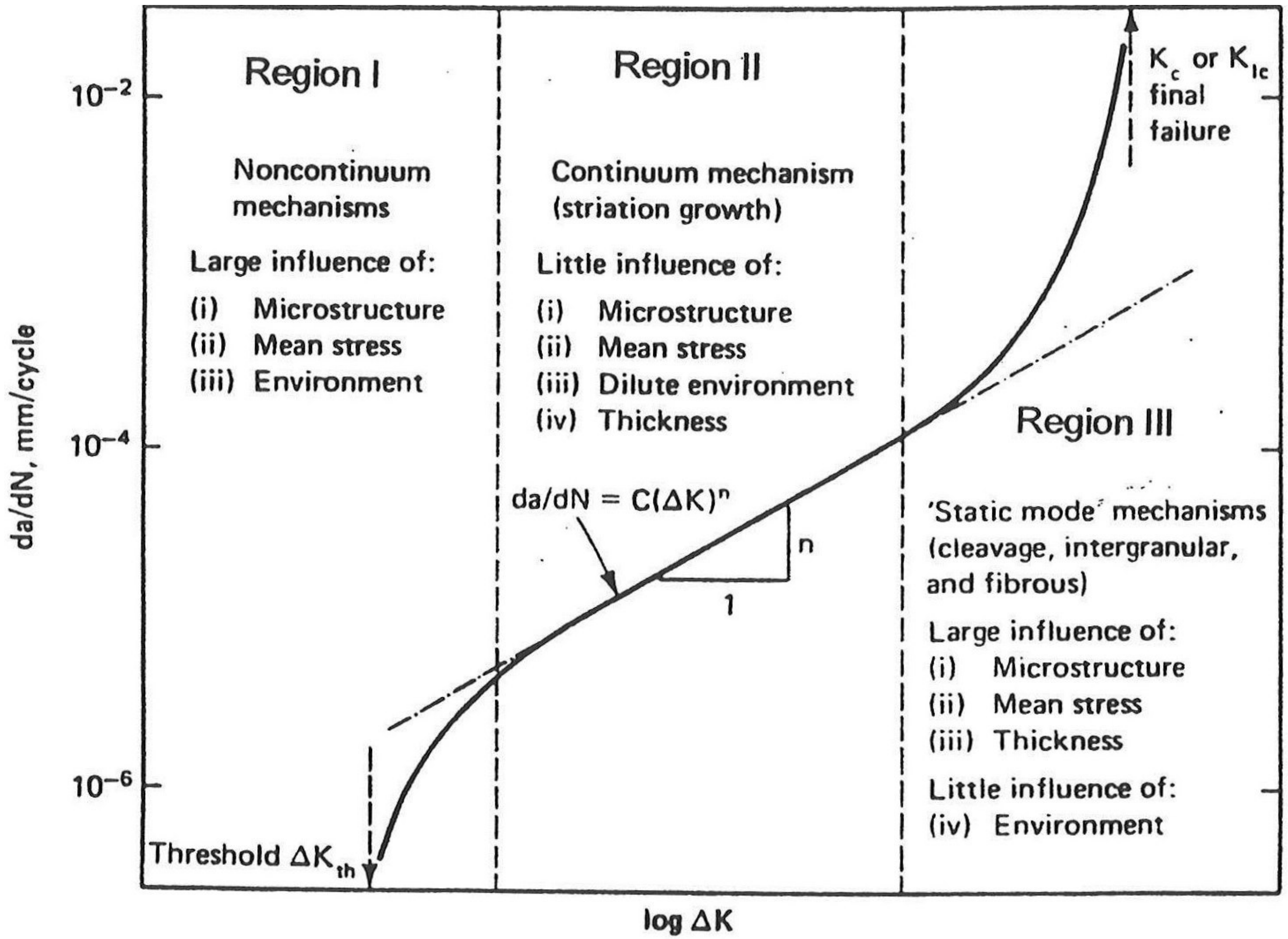


Figure 38. Schematic Representation of Fatigue Crack Growth Rate in Steels.

Figure 44. Fracture Toughness Requirements for Weld Metal in Seismic Applications.

40 ft-lb @ +70°F

20 ft-lb @ 0°F