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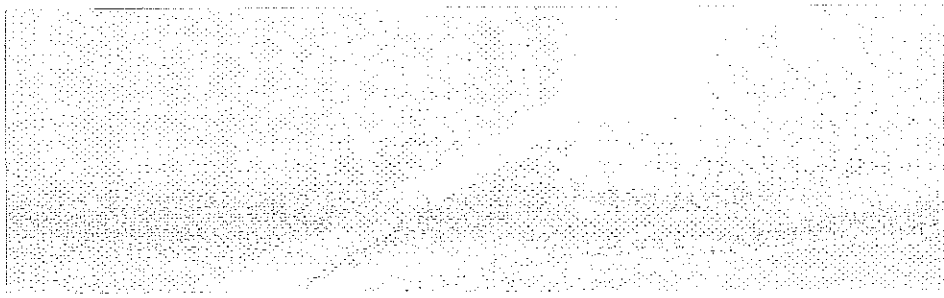
INVESTIGATION OF STEEL BEAM GUARDRAIL CHEMISTRIES

MICHIGAN DEPARTMENT OF TRANSPORTATION

MATERIALS and TECHNOLOGY DIVISION



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INVESTIGATION OF STEEL BEAM GUARDRAIL CHEMISTRIES

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This project was initiated by a request from the Traffic and Safety Division to investigate whether a length of guardrail, fractured in service, had the specified physical properties. The Structural Research Unit of the Research Laboratory conducted the investigation.

Investigation

The fractured section of steel beam guardrail, along with another damaged section of guardrail were brought to the M&T Laboratory for investigation. For comparison purposes, a section of new guardrail was obtained from the Aggregate and Materials Laboratory of M&T. The Aggregate and Materials Laboratory routinely tests sections of guardrail to determine if they meet Michigan Department of Transportation's Standard Specifications for Construction (Section 8.07.11 in the 1984 version). The guardrail section used for comparison had been tested previously and met the specified requirements. Specimens were removed from the fractured guardrail both in the damaged area and immediately adjacent to the damaged area. Testing involved determining chemical properties, yield strength, ultimate strength, subsized Charpies for impact properties and Rockwell hardness.

The fractured section of guardrail was a standard 13-ft length of rail which had been used in a retro-fit situation to fill a non-standard gap and, therefore, had extra holes in it. A normal section of guardrail has eight splice holes and one 2-1/2-in. center post slot at each end. Another 2-1/2-in. center post slot is located at the mid-section of the guardrail (Fig. 1). Because this section of guardrail was used to fill a 6-ft space, eight splice-bolt holes had been cut at the mid-section area with a welder's torch. The remaining guardrail section beyond the new splice holes was held behind the adjacent guardrail section with a single bolt through the center-post bolt hole of the guardrail end.

The fracture occurred through the four splice holes in the center of the replacement rail (Fig. 2). Temperature at the time of failure was reported to be quite low, probably about 10 F or less, which would tend to make steel with a high Rockwell hardness more brittle. Eight holes had been torch-cut through the guardrail in this area. The four holes where the fracture occurred were close to the end of the other section and were thus at a stress concentration point in the beam section.

Four tensile specimens were removed from both the fractured section and the damaged section of guardrail. The section obtained from the Aggregate and Materials Group had been tested previously for yield and ultimate strengths so only chemistry samples were removed from this section. The tensile samples from the fractured section were taken 13 in. from the fractured end. One set of eight Charpy impact test specimens was taken 24 in. from the fractured end, another set was removed 16 in. from the undamaged end. Eight Charpy specimens were removed from the damaged section of guardrail 26 in. from the mid-section hole.

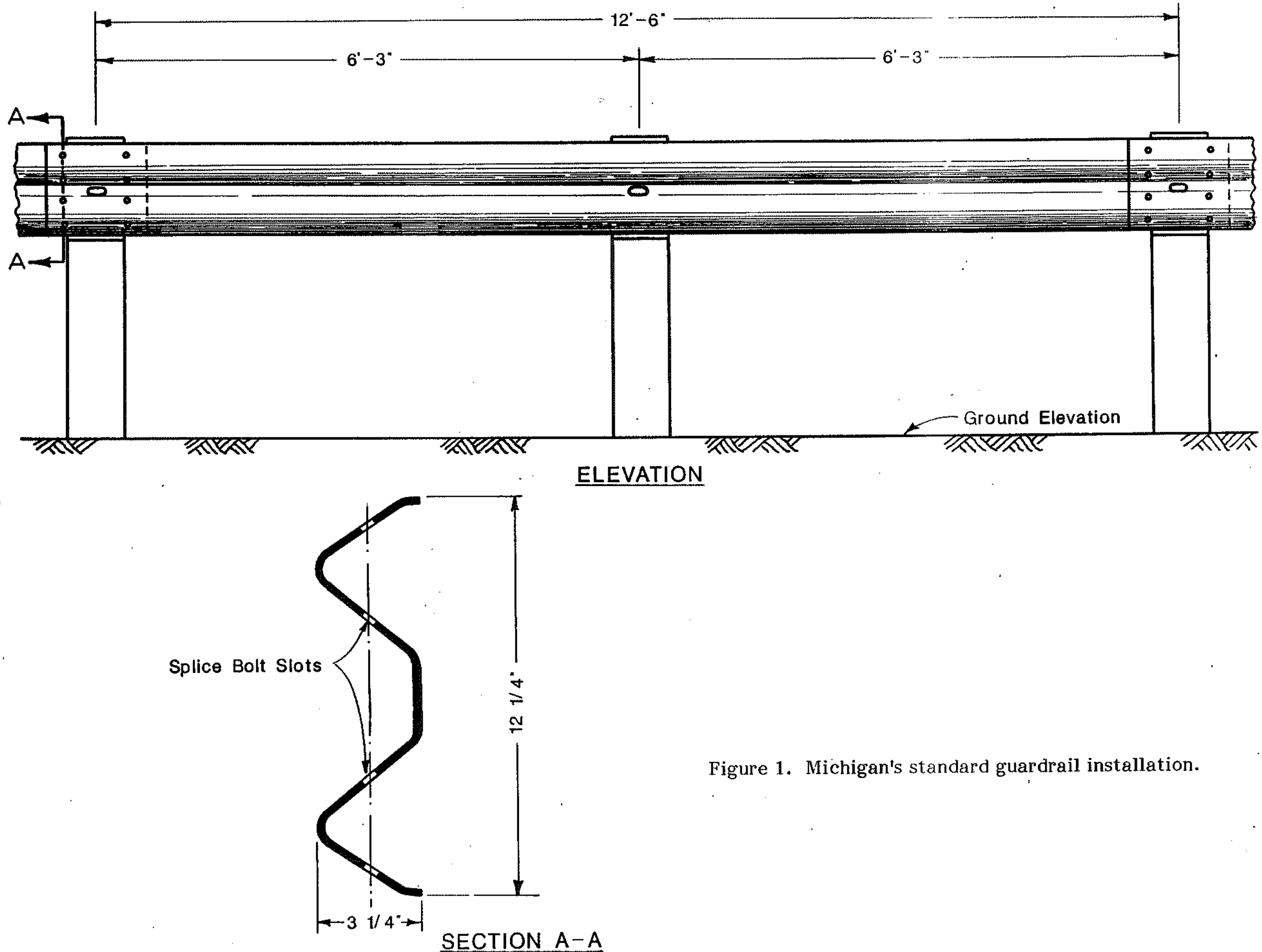

Figure 1. Michigan's standard guardrail installation.

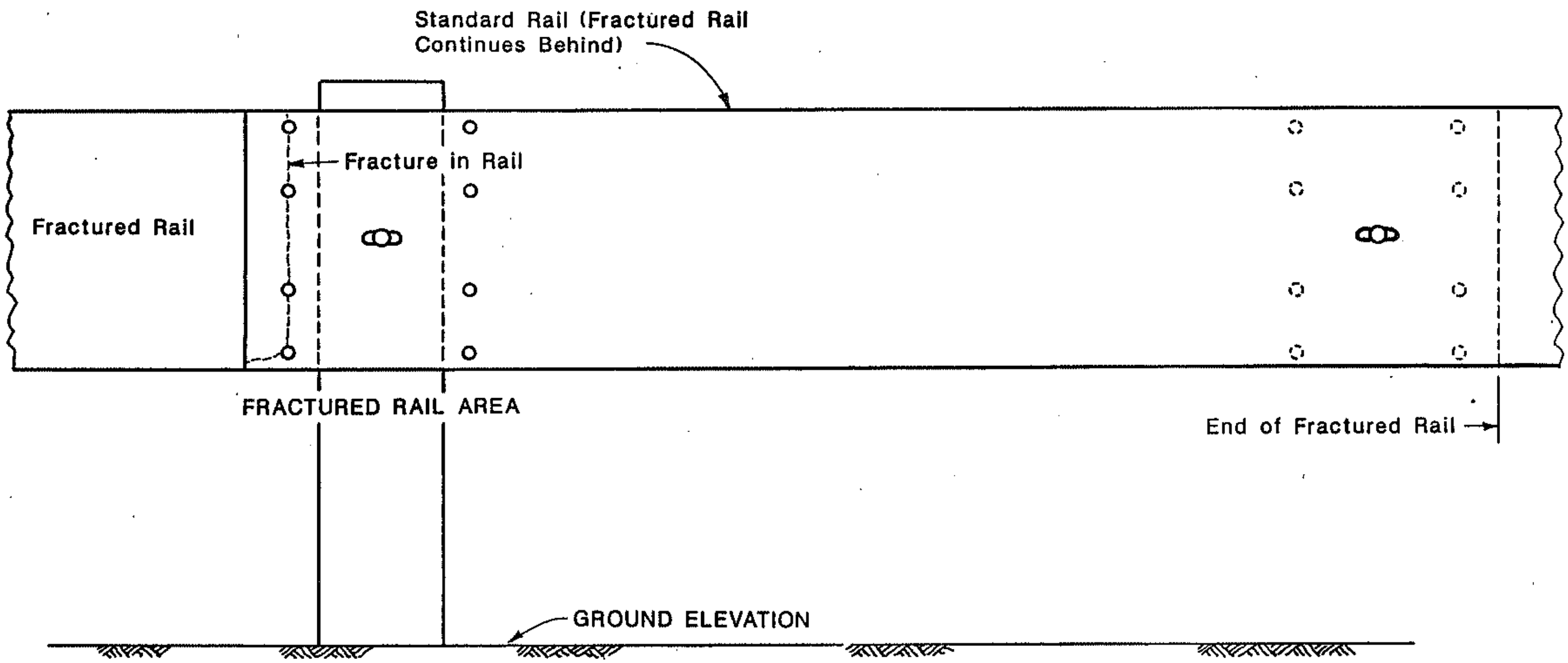

Figure 2. Retrofit installation and fracture location.

The tests were performed per ASTM procedures. The test results are as follows:

Test Results for Specimens Removed From Guardrails

Test	Fractured Straight	Damaged Straight	Test Sample from Lab	Specified Properties (AASHTO M-180)
Charpy (avg)	12 samples	12 samples	10 samples	
(Subsize @ 0 F)	6.7 ft-lb	8.9 ft-lb	16.1 ft-lb	(not required)
Yield (avg) PSI	69,100	51,900	61,000	50,000 min
Ultimate (avg) PSI	101,500	73,400	77,600	70,000 min
Red. of Area (avg)	64%	57%	61%	(not required)
Elongation (avg)	18%	23%	23%	12% min
Rockwell Hardness				
B Scale	95		86	(not required)
Carbon	0.47%	NA	0.23%	
Manganese	0.79%		0.92%	
Chromium	<0.01%		0.03%	
Nickel	<0.01%		0.02%	
Copper	<0.01%		0.05%	
Carbon Equivalency	0.67%		0.46%	

AASHTO's Standard Specification for Corrugated Sheet Steel Beams for Highway Guardrail (AASHTO Materials Specification M-180) requirements involve only strength and elongation. The chemical requirements are permitted to vary as long as the guardrail meets the specified strength and elongation requirements. Since all the criteria for strength and elongation were met by the failed section, additional evaluations were necessary to determine the cause of the fracture. Because the splice bolt holes were observed to have been torch-cut through the guardrail beam, hardness tests were run on the metal adjacent to the holes. It was found that the metal had been hardened.

Chemical analyses were done and the results used to determine the Carbon Equivalency (CE). The CE is used as a factor to determine weldability or hardenability of steel used in bridge beams, sign structures, etc.

The formula $CE = \%C + \frac{\%Mn}{4}$ is used for computing Carbon Equivalency, where CE is Carbon Equivalency, %C is percent carbon, and %Mn is percent manganese. Carbon content provides the greatest variable with manganese providing the next greatest in the type of steel used for guardrail. In Michigan, the maximum CE value allowed for welded members without special pre-heating precautions is 0.40 percent. Steels with sufficient carbon equivalent chemical content, therefore, are subject to the possibility of hardening in the heated area adjacent to a place where welding or cutting torch operations have been done.

Background Metallurgical Information

Hot-rolled or forged steel that has been slowly cooled from above a red heat consists structurally of pearlite with either free ferrite or free cementite, depending upon the carbon content. The steel is in a relatively soft and plastic state. If the carbon content (or CE) is high enough, the steel is said to be hardenable by heat treating. To increase the hardness of such steel, it is heated to a temperature in excess of 1350 F and then cooled quickly. The heating changes the normal and soft pearlitic structure to a solid solution structure called 'austenite.' If the steel is then quenched, or cooled quickly to a temperature of below 200 F, the austenite changes to a hard structure known as 'martensite,' which is the structure of fully hardened steel and is quite brittle unless toughened by subsequent heat treating or tempering. Special precautions such as preheating, etc., are required to prevent or diminish the probability of forming this brittle microstructure upon cooling. By using a cutting torch to cut holes for splicing in the subject guardrail section, the steel was heated enough to form the brittle martensitic microstructure upon cooling, thus making the steel in close proximity of the holes very brittle, initiating and contributing to the failure of the guardrail.

Statewide Investigation of Steel Beam Guardrail Chemistries

As a result of the chemical tests obtained during testing of the guardrail sections involved in the previous investigation, and the lack of chemical requirements by the American Association of State Highway and Transportation Officials specification, a study was undertaken to determine the chemical content of other existing guardrail installations in Michigan.

Even though the existing guardrail sections are not brittle until altered by heat from a cutting torch or welding, a survey was conducted to remove samples from random locations in the lower peninsula. Eighty samples were taken and submitted for chemical analysis performed by independent testing laboratories. A list of the locations is given in Table 1.

Routes were layed out in the office which would follow various trunkline highways. Because the actual locations of the guardrail and the lineal feet of guardrail per installation were not known, a final determination of exact specimen locations was made in the field.

After the chemical analysis results were received, the Carbon Equivalency formula was used to determine possible problems which could occur due to a high carbon or manganese content. Here again, the formula used was $CE = \%C + \frac{\%Mn}{4}$.

The highest CE recorded in this investigation was 0.78 percent, the lowest CE was 0.15 percent, the mean CE was 0.58 percent. Figure 3 shows a graphical representation of the results.

Recommendation

Because such a high percentage of the guardrail sections tested (82.4 percent) had a Carbon Equivalency greater than 0.40 percent, steel beam guardrail should not be altered by use of a cutting torch. Excessive amounts of heat may cause the localized microstructure of the guardrail to change

TABLE 1

Sample No.	Location Description	Carbon Percent	Sulphur Percent	Phosphorous Percent	Manganese Percent	Silicon Percent	Carbon Equivalency
1	Section 004 M 99 over I 94	0.41	0.027	0.015	0.67		0.58
2	Section 164 on ramp off EB I 94 to Grass Lake	0.24	0.014	0.005	0.76		0.43
3	Section 006 Temp I 69 EB west of Beard Rd south	0.15	0.027	0.006	0.58		0.30
4	NB old US 27 0.5 miles south of Mt. Hope Rd Eaton County	0.46	0.011	0.009	0.66		0.63
5	Section 078 I 496 EB at Aurelius Rd overpass	0.46	0.017	0.016	0.70		0.64
6	Section 011 NB US 127 at Wood Rd	0.46	0.013	0.008	0.73		0.64
7	WB I 69 ramp to WB I 96 under Francis Rd	0.19	0.012	0.008	0.80		0.39
8	M 100 SB near State Police Airport Section 002	0.21	0.026	0.009	0.70		0.39
9	Section 059 Cochran Rd SB over I 69	0.41	0.009	0.006	0.66	0.02	0.58
10	Section 005 SB M 50 just east of Eaton Rapids	0.44	0.011	0.019	1.00		0.69
11	Section 005 SB M 99 at south city limits of Eaton Rapids	0.42	0.025	0.007	0.68		0.59
12	Section 001 WB I 96 at Waverly Rd	0.24	0.012	0.007	0.79	0.12	0.47
13	Elephant trap over RR just west of Durand exit on I 69	0.38	0.015	0.022	0.57	0.10	0.55
14	Section 094 loop ramp to Miller Rd off EB I 69	0.44	0.024	0.010	0.70	0.02	0.62
15	Section 004 EB I 96 at Kent Lake	0.43	0.026	0.013	0.72	0.10	0.64
16	Section 033 EB I 96 at RR overpass just east of rest area	0.27	0.011	0.011	0.71	0.03	0.46
17	Section 107 SB US 27 south of south Clare Interchange	0.38	0.019	0.013	1.11	0.06	0.67
18	Ramp to US 27 SB from south Ithaca Interchange	0.22	0.013	0.022	0.75	0.02	0.41
19	SB US 27 1 mile north of M 61	0.21	0.017	0.009	0.69	0.03	0.39
20	Hartwick Pines Rd over I 75	0.42	0.010	0.010	0.65	0.02	0.59
21	SB I 75 at Meads Landing Rd Section 035	0.21	0.013	0.016	0.69	0.02	0.39
22	Sturgeon Valley Rd over I 75 Mile Pt. 289	0.39	0.027	0.022	1.12	0.05	0.68
23	US 24 in City of Taylor	0.20	0.013	0.010	0.69	0.03	0.38
24	M 50 at Sandlake Rd Lenawee County	0.42	0.018	0.023	0.89	0.04	0.65
25	On ramp from Portland to WB I 96 Section 110	0.09	0.022	0.093	0.78	0.30	0.36
26	Section 010 WB I 96 0.5 mile east of Morrison Lake Rd	0.49	0.017	0.010	0.66	0.03	0.66
27	WB I 96 at Hastings Rd	0.47	0.021	0.010	0.71	0.02	0.65

TABLE 1 (cont.)

Sample No.	Location Description	Carbon Percent	Sulphur Percent	Phosphorous Percent	Manganese Percent	Silicon Percent	Carbon Equivalency
28	Section 030 I 96 WB 0.4 mile east of Thornapple River	0.17	0.018	0.010	0.85	0.02	0.39
29	WB I 196 at Eastern Ave	0.40	0.031	0.009	0.68	0.16	0.61
30	SB US 131 0.25 mile north of Burton St	0.32	0.023	0.008	0.70	0.02	0.50
31	SB US 131 at 44th St	0.42	0.019	0.011	0.97	0.05	0.67
32	SB US 131 off ramp to Shelbyville Rd (old)	0.37	0.026	0.035	0.71	0.11	0.58
33	SB US 131 at M-89 overpass	0.28	0.023	0.022	0.69	0.03	0.46
34	I 94 EB just east of Westnedge Ave	0.21	0.012	0.011	0.72	0.02	0.39
35	I 94 EB at Mile Pt. 79	0.23	0.015	0.012	0.68	0.03	0.41
36	I 94 EB 0.4 mile west of 38th St	0.29	0.013	0.012	0.70	0.01	0.47
37	M 66 SB 0.2 mile south of T Dr North	0.35	0.013	0.011	0.72	0.02	0.53
38	M 66 NB 600 ft north of Baseline Rd	0.45	0.015	0.010	0.66	0.02	0.62
39	M 66 NB 0.4 mile south of Barry Rd Section 10	0.43	0.012	0.008	0.64	0.02	0.60
40	M 79 at M 66 small creek just east of M 66 Section 17 (old)	0.41	0.027	0.014	0.71	0.10	0.61
41	M 79 EB just west of Mason Rd (old)	0.40	0.015	0.016	0.79	0.12	0.63
42	Section 16 M 79 EB 0.9 mile west of Ainger Rd (old)	0.35	0.018	0.014	0.68	0.06	0.54
43	EB I 69 at Britton Rd North (old)	0.25	0.018	0.012	1.29	0.03	0.58
44	EB I 69 at Seymour Rd Thrie Beam (new)	0.18	0.012	0.011	0.65	0.01	0.35
45	EB I 69 1.2 miles west of Elba Rd	0.20	0.013	0.018	0.70	0.04	0.39
46	EB I 69 at M 24	0.23	0.013	0.011	0.76	0.02	0.43
47	EB I 69 at Newark Rd	0.48	0.027	0.017	0.71	0.03	0.66
48	M 53 NB 0.4 miles south of Muck Rd (old)	0.39	0.027	0.007	0.60	0.02	0.55
49	M 53 NB 500 ft south of Reside Rd (old)	0.33	0.030	0.014	0.65	0.10	0.52
50	M 90 WB 0.5 mile west of North Branch (old)	0.39	0.019	0.010	0.64	0.02	0.56
51	M 90 WB at Flint River Bridge	0.37	0.020	0.011	0.70	0.04	0.55
52	M 24 NB 100 ft north of Elmwwod Rd	0.44	0.019	0.011	0.66	0.02	0.61
53	M 24 NB RR crosing 1 mile south of Mayville	0.44	0.016	0.010	0.65	0.02	0.61
54	M 15 NB at Hack Rd	0.29	0.053	0.017	0.69	0.03	0.47
55	M 84 SB 100 ft north of Salzburg	0.37	0.027	0.012	0.61	0.01	0.53
56	I 75 SB just south of M 84	0.44	0.024	0.009	0.61	0.02	0.60
57	I 75 SB at Hess Rd	0.06	0.012	0.009	0.36	0.01	0.15

TABLE 1 (cont.)

Sample No.	Location Description	Carbon Percent	Sulphur Percent	Phosphorous Percent	Manganese Percent	Silicon Percent	Carbon Equivalency
58	M 57 WB 0.4 mile east of McKinley Rd	0.35	0.022	0.012	0.65	0.02	0.52
59	M 57 WB at west city limits of Chesaning	0.40	0.024	0.013	0.64	0.02	0.57
60	M 52 SB at south village limits of Oakly	0.33	0.022	0.009	0.45	0.03	0.45
61	I 96 WB Section 69 just west of Mile Pt. 24 Ottawa County	0.16	0.017	0.006	0.70	0.01	0.34
62	I 96 WB near exit 10 Ottawa County Section 9 (old 25' gr.)	0.38	0.030	0.017	1.22	0.09	0.71
63	M 120 NB at Wilson Beach Rd Section 8 Muskegon County (old 25 ft gr.)	0.39	0.026	0.018	1.14	0.11	0.70
64	M 120 NB village of Horton Section 24 Muskegon County	0.38	0.030	0.010	0.87	0.05	0.61
65	M 120 NB Section 3 Newaygo County	0.46	0.014	0.008	0.78	0.04	0.67
66	M 20 EB Section 11 Newaygo County	0.50	0.023	0.009	0.91	0.19	0.78
67	M 37 NB Section 35 Newaygo Co.*	0.36	0.027	0.017	1.12	0.07	0.66
68	US 10 EB at Baldwin River Lake County Section 10 (old 25 ft gr.)	0.37	0.022	0.028	0.98	0.06	0.63
69	US 10 EB 1.5 miles west of Chase Section 23	0.35	0.010	0.006	0.53	0.05	0.50
70	US 131 NB at 7 Mile Rd Osceola County (Thrie Beam)	0.23	0.020	0.033	0.85	0.01	0.45
71	US 131 NB at Mile Pt. 174 Section 10 Wexford County	0.35	0.027	0.008	0.72	0.09	0.55
72	M 115 SB at US 131 SB Section 6 Wexford County	0.44	0.018	0.017	0.90	0.03	0.67
73	M 115 SB 300 ft north of 100th Rd Section 20 Osceola County	0.44	0.020	0.013	0.90	0.01	0.67
74	M 66 SB Section 23 Osceola County 0.5 mile north of 13 Mile Rd (25 ft gr.)	0.40	0.038	0.011	0.70	0.07	0.59
75	M 66 SB Section 18A Osceola County 0.4 mile north of Sylvan Rd (25 ft gr.)	0.39	0.030	0.021	0.83	0.20	0.65
76	M 66 SB Section 39 Mecosta County 0.4 mile north of 22 Mile Rd	0.21	0.027	0.025	0.77	0.01	0.40
77	M 66 SB Section 31 Mecosta County 500 ft north of 18 Mile Rd	0.43	0.018	0.032	0.93	0.02	0.67
78	M 66 SB Section 2 Mecosta County 500 ft south of Alamo Rd	0.43	0.037	0.015	0.79	0.05	0.64
79	M 66 SB Montcalm County 300 ft north of Ruby Rd	0.13	0.015	0.018	1.10	0.03	0.41
80	M 57 EB Section 18 Montcalm County Carson City west limits	0.39	0.055	0.028	1.24	0.05	0.71

*Center slot has been torched

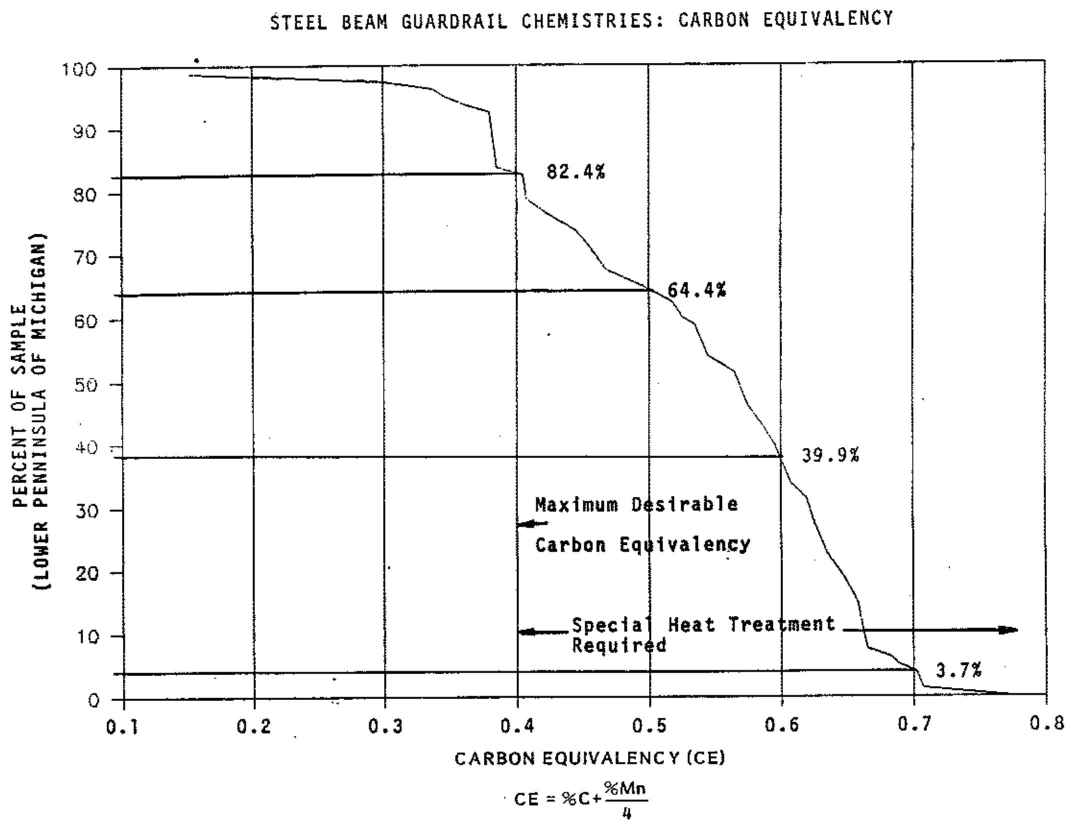

Figure 3. Carbon Equivalency results.

and become very brittle, thus preventing the guardrail from absorbing as much energy as it should under deformation. In the long-term, specification changes should be made to limit the Carbon Equivalency of materials for such rail.

Due to the results of this investigation, it appears that a more appropriate method for altering guardrail beams (adding holes, changing lengths) is to use a saw for changing the length of sections and to drill or punch all holes. We realize that any alterations done in the field using hand tools (drills, saws) are extremely difficult, so extra care should be taken when installing guardrail posts to ensure proper spacing. Another possible solution would be to design and build a portable punch that could be used in the field.