EVALUATION OF BREAKAWAY CABLE TERMINAL ENDINGS ON GUARDRAIL

B. W. Ness

Research Laboratory Section
Testing and Research Division
Research Project 82 TI-853
Research Report No. R-1221

Michigan Transportation Commission
William C. Marshall, Chairman;
Lawrence C. Patrick, Jr., Vice-Chairman;
Hannes Meyers, Jr., Carl V. Pellonpaa
Weston E. Vivian, Rodger D. Young
James P. Pitz, Director
Lansing, May 1983

Summary

Slack and disconnected cables in the BCT guardrail endings have been noted throughout the State. At first the problem was thought to be caused by either natural environmental action, such as expansion and contraction, or by vandalism. After conducting a field condition survey and a laboratory investigation, it appears the problem is due to improper installation and use of noncomplying parts rather than environmental causes, and the problem is not as widespread as was originally suspected. Recommendations for alleviating the problems are stated at the end of the report.

Introduction

The Breakaway Cable Terminal (BCT) ending was developed and tested by the Southwest Research Institute in 1972, after it was discovered that the existing terminal and transition details of longitudinal barriers needed improvement from a safety standpoint. The cable helps develop the ribbon strength necessary to ensure proper vehicle redirection after impact within the length-of-need section. The buffered end section minimizes the possibility of guardrail penetration into the vehicle passenger area when the end section is hit head on (1, 2). Michigan adopted and started to install this type of ending on its guardrail sections in the mid-1970's. Although some minor alterations have been made from time to time since then, the design of the BCT ending has always been similar to the one currently used and shown in Figure 1. For details of the BCT ending, refer to III-58F of the current Michigan Department of Transportation's "Standard Plans—Road Design and Bridge Design Plans" (3).

Slack and disconnected cables in the BCT endings have been noted at isolated locations throughout the State, and questions were raised as to Construction and Maintenance Division practices when installing the cable endings. The Department's Barrier Advisory Committee speculated that because this problem appeared to be so widespread, natural environmental action such as expansion and contraction of the guardrail or vandalism might be the cause of the problem, rather than the cable nuts not being properly tightened at installation. The Structural Research Unit was asked by the Committee to investigate and make recommendations which would alleviate any apparent problem.

The investigation was conducted in two phases. Phase I involved a field survey to determine the extent of, and possible causes for the slack or disconnected cables. Phase II was a laboratory evaluation in which a full-scale BCT ending was constructed and oscillated to simulate field expansion and contraction.

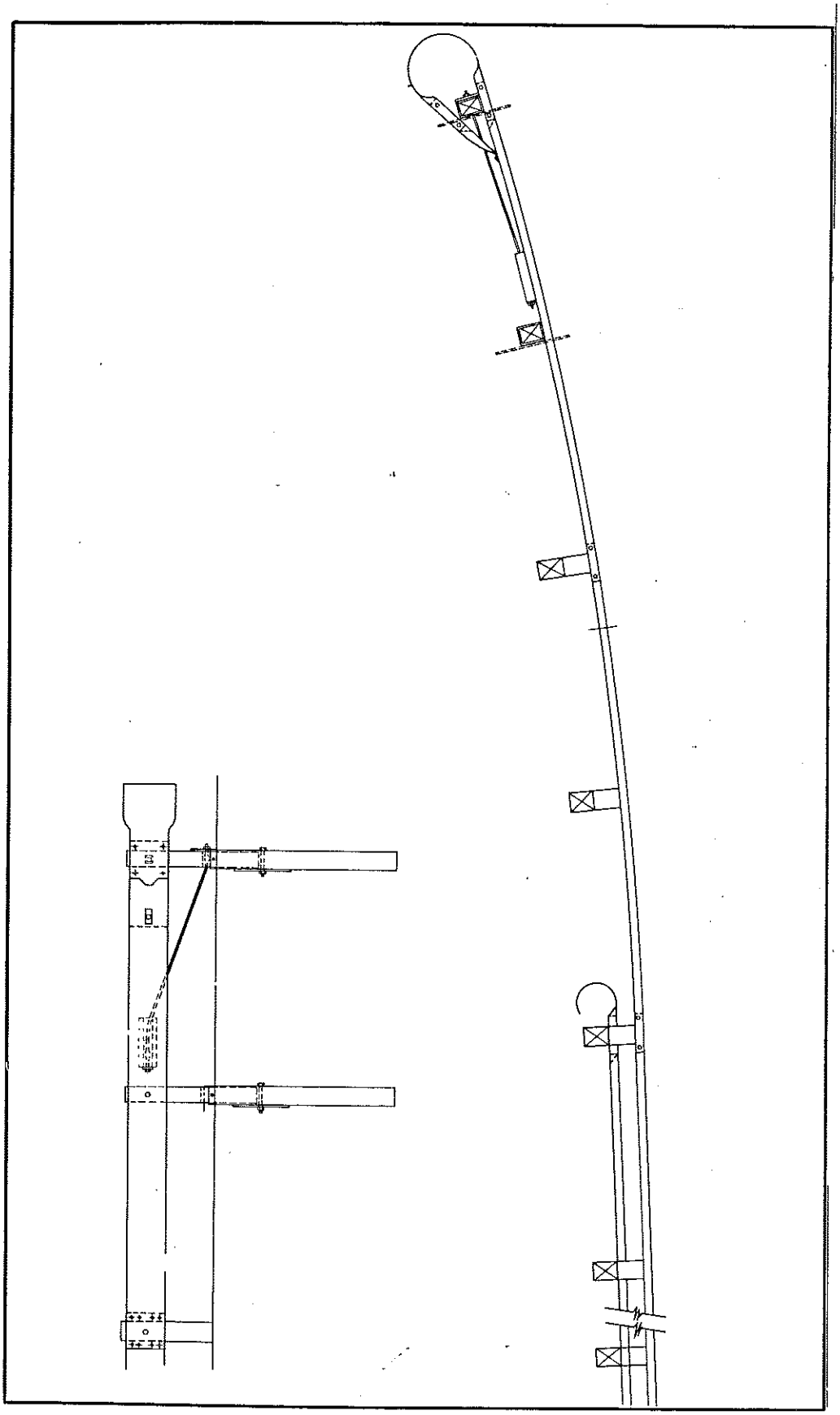


Figure 1. Design of the Michigan BCT ending.

Phase I - Field Survey

The field survey involved the evaluation of 344 BCT endings located in a nine-county area around Lansing. The survey was conducted in mid-February 1983 in overcast weather with daytime temperatures in the low 40's. Of the locations inspected, 153 were found to have tight cables, 174 of the cables were noticeably loose, eight cables were disconnected at either the guardrail anchor plate or at the post bearing plate, and nine locations had no cable, even though all the hardware for connecting the cable was assembled. Minor problems were encountered with the BCT ending not conforming to all of the requirements of the Michigan Standard Plan, because of missing sleeves, rotten or split posts, improper guardrail height, nonstandard bearing plates, and anchor plates with loose or missing bolts. A complete summary tabulating all the field survey data and noting conditions within the Districts (in which virtually all the BCT endings in each District were checked) is shown in Table 1. Detailed field data tabulated by control sections are shown in Tables A1 through A4 of the Appendix. The photographs (Figs. 2 through 9) help to further illustrate the minor deficiencies cited in this report and in the summary table.

The table shows no consistent pattern for deficiency conditions with respect to control sections. The percentage of tight and loose cables is relatively constant for the three control sections of District 5, whereas the number of loose cables in Jackson, Livingston, and Shiawassee Counties is extremely high. Nonstandard bearing plates involving problems such as plates being too thin or upside-down (which would probably not happen if care were taken to install the plates and tighten the nuts properly) as shown in Figures 2, 7, and 9, appear frequently in Control Section 76023 of Shiawassee County, with 83 percent in nonconformance as well as 39 percent of the 2-in. pipe sleeves missing in this control section. This might indicate a lack of understanding by the contractor or enforcement by the Department when these endings were installed. Also, Jackson County (Control Section 38131) is missing 26 percent of the 2-in. pipe sleeves and 26 percent of the cables have all the threads used up at the anchor plate. In Calhoun County, 22 percent of the cables are gouging into the second post as shown in Figure 6 on Control Section 13082 which raises a question as to the accuracy of the post placement in the BCT ending flare along this section. Improper guardrail height at the end section was noted at 29 percent of the locations as shown in Figure 3 in Shiawassee County (Control Section 76011).

At one location, the four upper bolts were missing where the anchor plate attaches to the guardrail, and at other locations these bolts were

TABLE 1

SUMMARY OF FIELD DATA FOR 16 CONTROL SECTIONS IN DISTRICTS 5, 6, 7, AND 8

		Subtotals								Total	
		District 5		District 6		District 7		District 8			
		Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Sample Surveyed	Approach endings	52	61.2	53	82.8	119	79.3	41	91.0	265	77.0
	Trial endings	33	38.8	11	17.2	31	20.7	4	9.0	79	23.0
Cable Condition Summary	Tight cables	23	27.1	5	7.8	118	78.7	7	15.6	153	44.5
	Loose cables	52	61.1	55	85.9	30	20.0	37	82.2	174	50.6
	Cable disconnected at anchor plate	4	4.7	--	--	1	0.7	1	2.2	6	1.7
	Cable disconnected at bearing plate	--	--	1	1.6	1	0.7	--	--	2	0.6
	No cable but has hardware	6	7.1	3	4.7	--	--	--	--	9	2.6
Summary of Noncompliance with Standard Plans or Specifications	2 in. sleeve missing	2	2.4	16	25.0	--	--	5	11.1	23	6.7
	Post rotted on top	2	2.4	--	--	--	--	--	--	2	0.6
	Guardrail installed too close or too high from the ground	2	2.4	5	7.8	4	2.7	2	4.4	13	3.8
	Bearing plate not standard	--	--	34	53.1	2	1.3	1	2.2	37	10.8
	Bearing plates or nut touching or under ground	2	2.4	3	4.7	--	--	2	4.4	7	2.0
	Post split but not hit	1	1.2	--	--	2	1.3	--	--	3	0.9
	Anchor plate loose or bolts missing	--	--	--	--	2	1.3	--	--	2	0.6
	Post split around 2 in. hole in post	2	2.4	--	--	1	0.7	--	--	3	0.9
Summary of Other Findings	Gravel washed away from post	--	--	--	--	1	0.7	2	4.4	3	0.9
	All threads used at anchor plate	2	2.4	--	--	1	0.7	5	11.1	8	2.3
	All threads used at bearing plate	--	--	--	--	--	--	1	2.2	1	0.3
	Cable touching or gouged into second post	--	--	--	--	11	7.3	--	--	11	3.2
	All threads used at both ends but cable loose	--	--	--	--	2	1.3	3	6.7	5	1.5
	Guardrail had been hit	--	--	--	--	1	0.7	1	2.2	2	0.6
	End shoe had been hit	2	2.4	4	6.2	7	4.7	2	4.4	15	4.4
	Buffered shoe with diaphragm	77	90.6	5	7.8	74	49.3	22	48.9	178	51.7

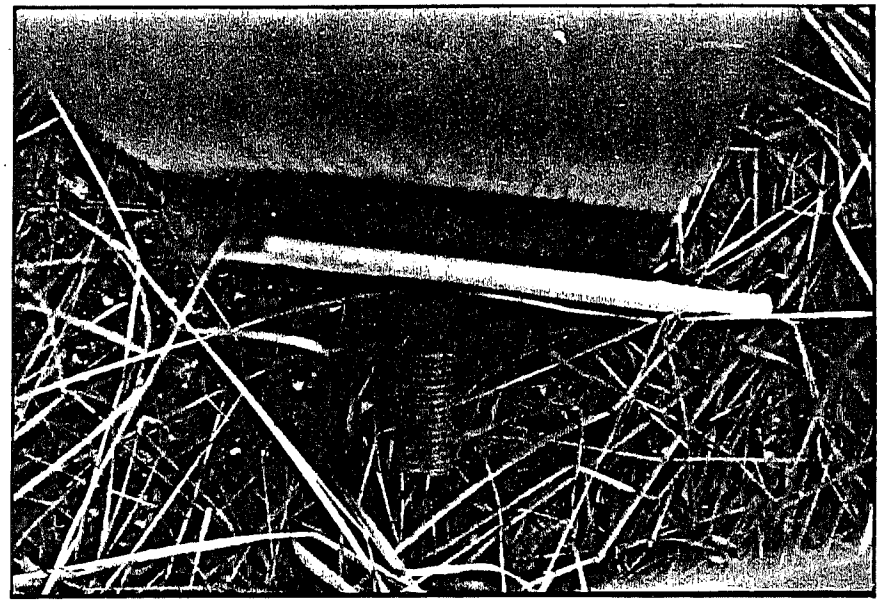


Figure 2. Bearing plate too thin and turned.

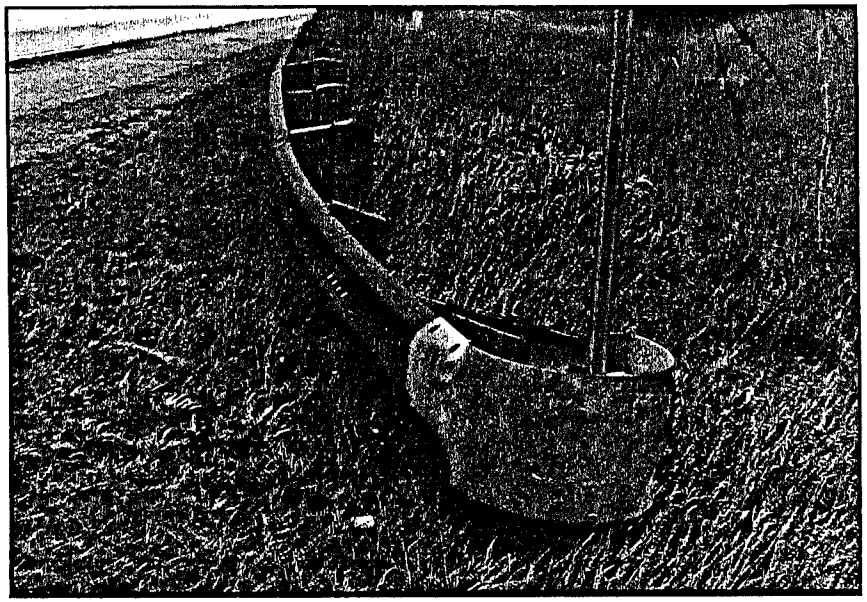


Figure 3. Shoe end installed too close to the ground.

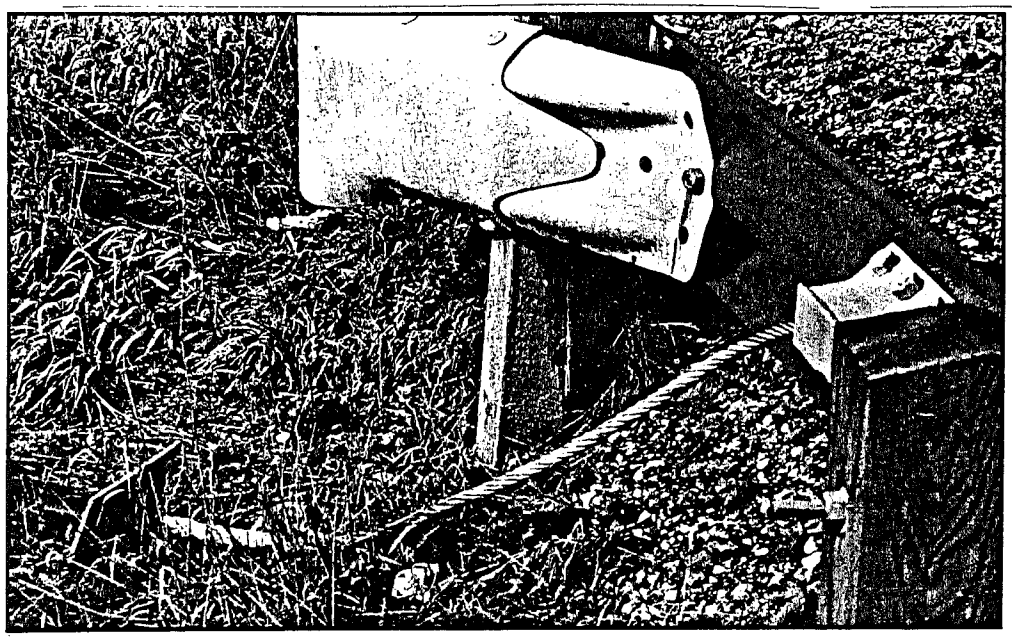


Figure 4. Hole in post is too small for cable.

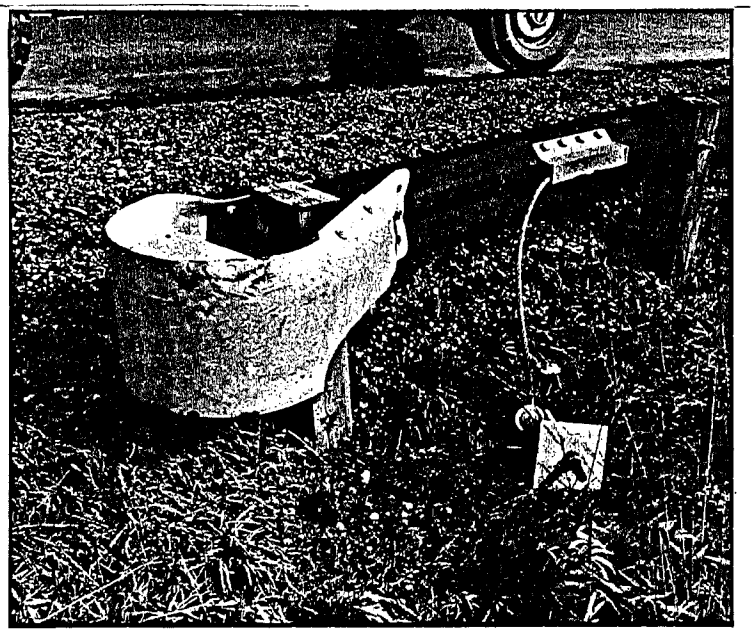


Figure 5. Cable laying on ground.

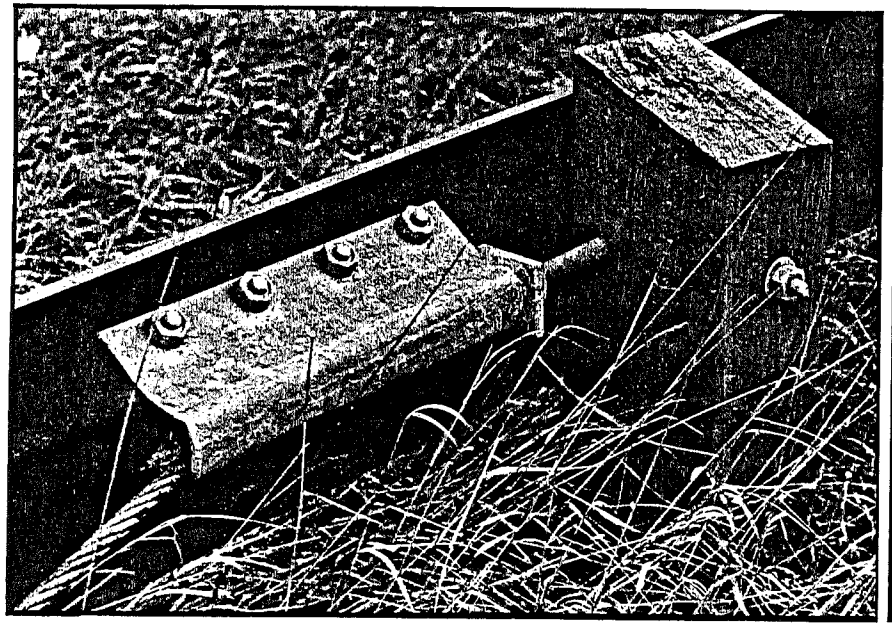


Figure 6. Cable gouged into second post.

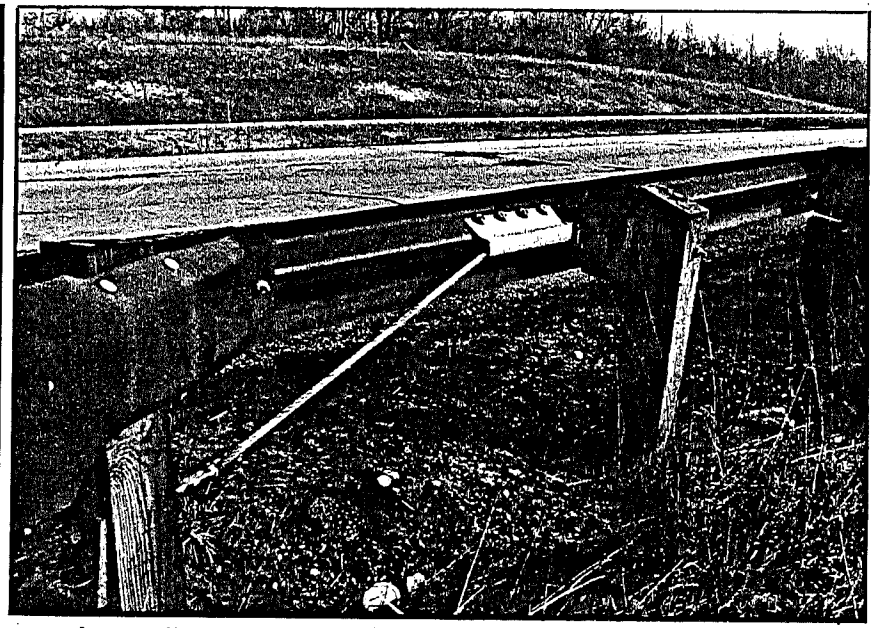


Figure 7. A588 guardrail; bearing plate upside down; second post blocked out.

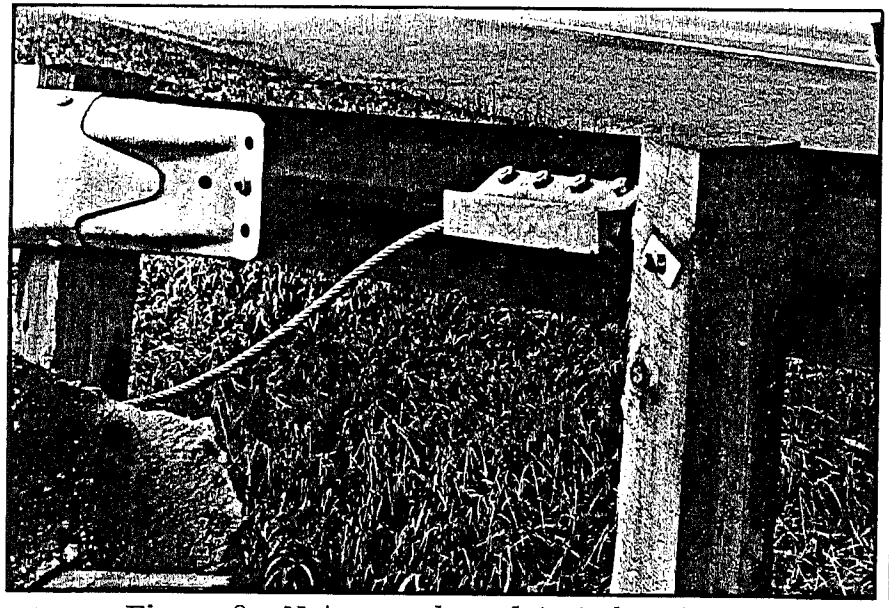


Figure 8. Nut on anchor plate is barely on.

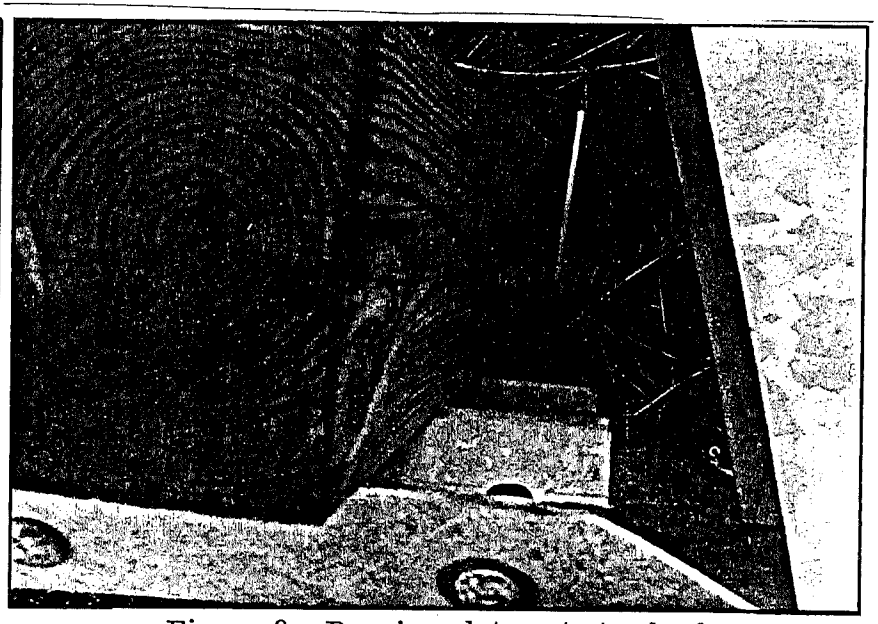


Figure 9. Bearing plate not standard.

found to be loose. In some cases where the cable was disconnected, the hole in the post was found to be too small for the cable to fit through, and the cable was left lying on the ground as shown in Figures 4 and 5.

Most other noncompliance problems occur less than 10 percent of the time. Problems found with nonconformance of the Standard Plans or Specifications may be the major concern for the Department at this time. It appears that the problems encountered with the slack or disconnected cables on the BCT endings are probably due to improper installation and the use of noncomplying parts rather than environmental causes. It has been concluded that the disconnected cable problem is not as widespread as was originally suspected.

Phase II - Laboratory Evaluation

A full-scale BCT ending was built in the Structures Laboratory as shown in Figures 10 through 13. The overall plan is shown in Figure 14. The rail was connected to the MTS electrohydraulic testing machine in such a manner that the BCT ending could be oscillated in a sinusoidal cycle simulating, at a much faster rate, the expansion and contraction cycles which occur in the field. Assuming no 'freeze-up' of the guardrail joints, movement caused by temperature change would affect 12 ft-6 in. of guardrail. The maximum temperature differential which could occur during the course of any given day should be 80 F, assuming a maximum temperature of 120 F during a hot summer day with the sun beating down on the rail and the temperature falling to a minimum of 40 F during the night. Using the thermal expansion coefficient for steel, 6×10^{-6}/deg F, the maximum movement of the guardrail, and consequently the BCT ending, would be 0.072 in.

Keeping in mind the maximum expansion and contraction which should occur, four sets of tests were chosen to simulate the natural movement with variations in the initial tightness of the cable nuts. Two sets of tests were run displacing the BCT ending 0.05 in., one at three cycles/second for 7,500 cycles and one at six cycles/second for 15,000 cycles. The other two sets of tests displaced the BCT ending 0.1 in., again at three cycles/second and six cycles/second at 7,500 and 15,000 cycles, respectively. After each test, the nut displacement was measured. All of these tests produced an oscillation of greater magnitude than normally would occur in the field. The results of these tests are shown in Tables 2 and 3. Details of individual tests are shown in Tables A5 through A8 of the Appendix.

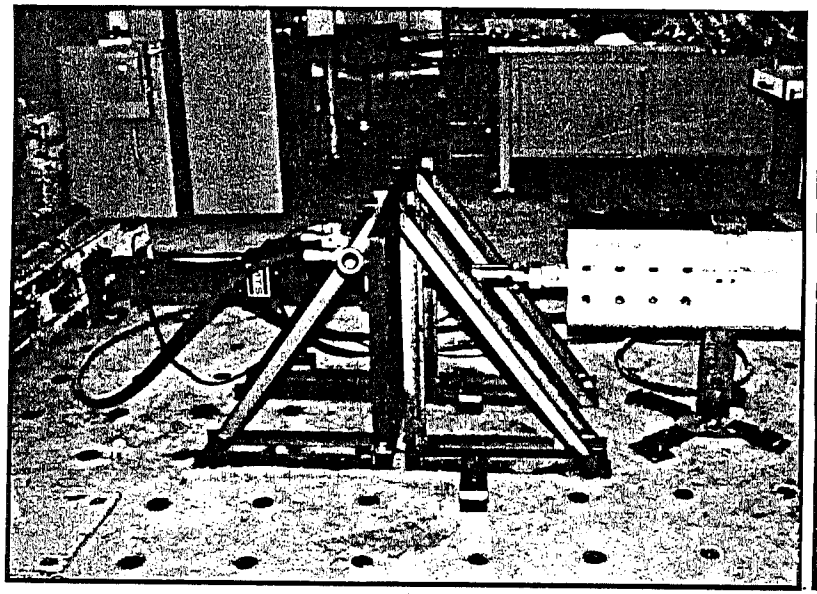


Figure 10. Fixture for holding MTS ram and BCT ending.

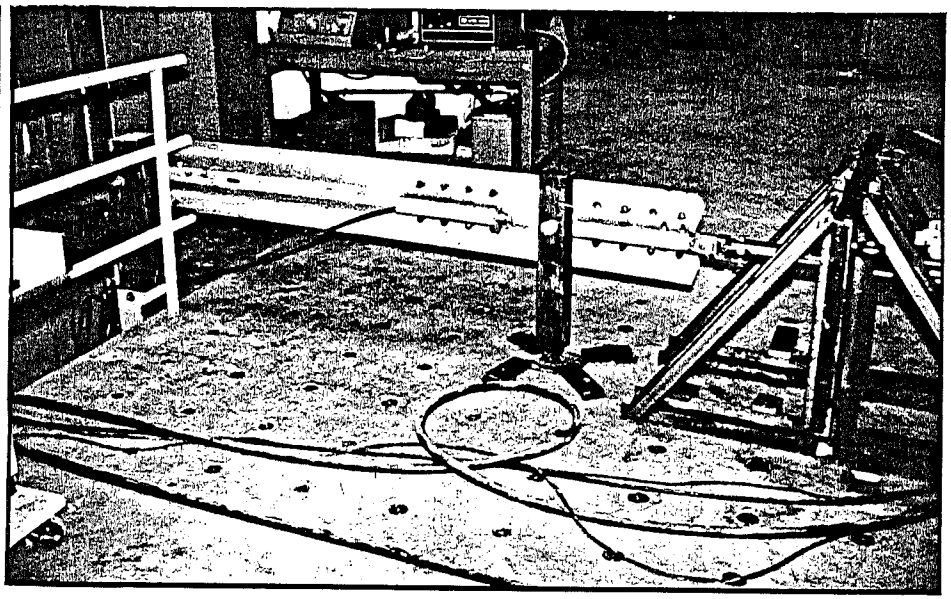


Figure 11. BCT ending fixture; back view.

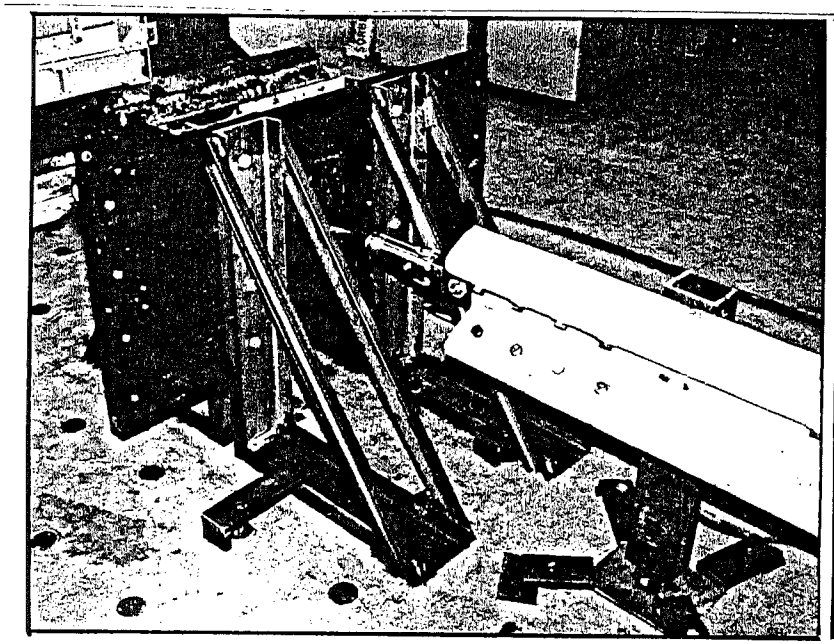


Figure 12. BCT ending hook-up to MTS ram.

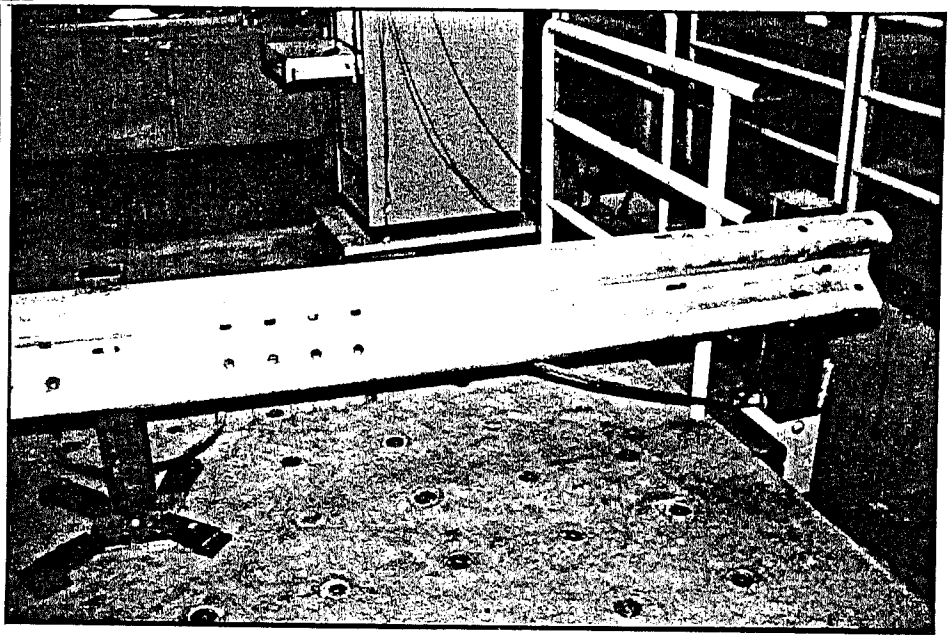


Figure 13. BCT ending fixture; front view.

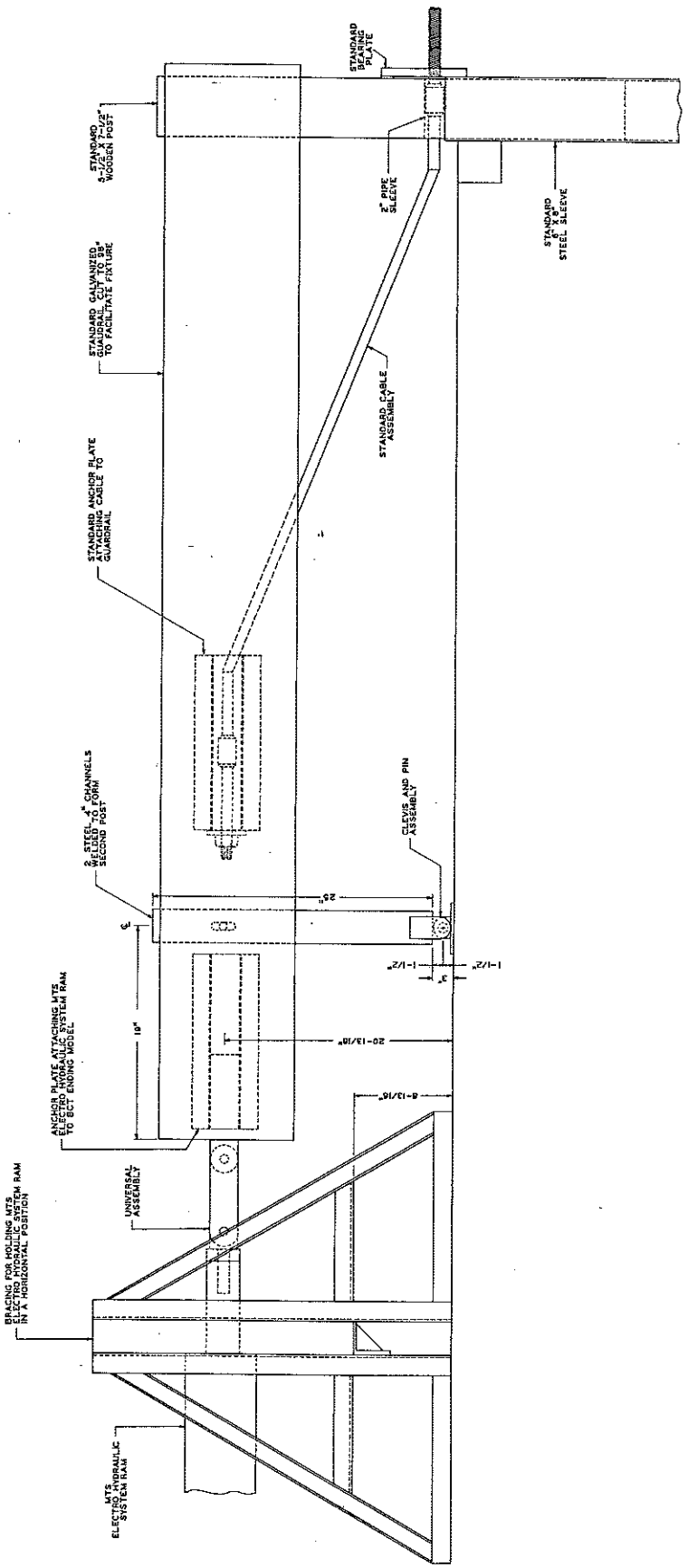


Figure 14. Plan of BCT ending model.

The tests show the nuts to remain unchanged for the most part (72.9 percent of the time) with the nuts loosening up for only 12.5 percent of the tests. The nuts actually tightened themselves up 14.6 percent of the time. The movement of the nut was relatively insignificant for any one test, with the maximum change being less than 1/8 in.

The laboratory evaluation indicated that environmental action would not be expected to cause the nuts to become fully displaced or for the cable to loosen significantly. With proper installation, the BCT ending should function as it was designed to.

TABLE 2
SUMMARY OF
LABORATORY EVALUATION
FOR INDIVIDUAL NUTS
(48 Measurements, 24 Tests)

	Number	Percent
Unchanged:		
Upper	15	31.2
Lower	20	41.7
Total	35	72.9
Tightened:		
Upper	4	8.3
Lower	3	6.3
Total	7	14.6
Loosened:		
Upper	5	10.4
Lower	1	2.1
Total	6	12.5

TABLE 3
SUMMARY OF OVERALL
MOVEMENT OF BOTH NUTS
(24 Tests)

	Number	Percent
Unchanged	13	54.2
Tightened	6	25.0
Loosened	5	20.8

Recommendations

It is recommended that the following action be taken with regard to the installation of future BCT endings:

1) All the parts used for the BCT ending must meet the guidelines set forth in Michigan's Standard Plans for Road and Bridge Design, both in regards to dimensions and the type of material which is used.

2) Stricter enforcement of installation by the Construction and Maintenance Divisions should be initiated immediately to ensure that the BCT endings are installed according to Standard Plans.

3) Spoiling the threads at both ends of the cable immediately after installation may prevent vandals from tampering with the nuts and removing the cable.

If these steps are taken and the BCT ending is installed properly, the nuts should not come off due to expansion and contraction in the field. To ensure a safer environment for the motoring public the BCT ending must be installed as it was designed.

REFERENCES

1. Bronstad, M. E. and Michie, J. D., "Breakaway Cable Terminals for Guardrails and Median Barriers," Transportation Research Board, NCHRP Research Results Digest No. 84, March 1976.

2. Bronstad, M. E. and Michie, J. D., "Guardrail Crash Test Evaluation: New Concepts and End Designs," Transportation Research Board, NCHRP Research Report No. 129, 1972.

3. "Standard Plans—Road Design Plans and Bridge Design Plans," Michigan Department of Transportation, 1982.

APPENDIX

TABLE A1
FIELD SURVEY DATA FOR THREE CONTROL SECTIONS IN DISTRICT 5

		Clinton County						Ionia County		Total	
		Control Section 19022		Control Section 19061		Subtotal		Control Section 34062			
		Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Sample Surveyed	Approach endings	19	100.0	12	48.0	31	70.5	21	51.2	52	61.2
	Trail endings	--	--	13	52.0	13	29.5	20	48.8	33	38.8
Cable Condition Summary	Tight cables	6	31.6	6	24.0	12	27.3	11	26.8	23	27.1
	Loose cables	13	68.4	13	52.0	26	59.1	26	63.4	52	61.1
	No cable but has all hardware	--	--	5	20.0	5	11.4	1	2.5	6	7.1
	Cable disconnected at anchor plate	--	--	1	40.0	1	2.3	3	7.3	4	4.7
Summary of Noncompliance with Standard Plans or Specifications	Guardrail installed too close or too high from ground	--	--	--	--	--	--	2	4.9	2	2.4
	Post rotted on top	--	--	--	--	--	--	2	4.9	2	2.4
	2 in. sleeve missing	--	--	1	4.0	1	2.3	--	--	2	2.4
	Post split but not hit	--	--	--	--	--	--	1	2.5	1	1.2
	Post split around 2 in. hole in post	--	--	2	8.0	2	4.5	--	--	2	2.4
	Bearing plate or nut touching or under ground	--	--	--	--	--	--	2	4.9	2	2.4
Summary of Other Findings	All threads used at anchor plate	2	10.5	--	--	2	4.5	--	--	2	2.4
	End shoe had been hit	--	--	--	--	--	--	2	4.9	2	2.4
	Buffered shoe with diaphragm	11	57.9	25	100.0	36	81.8	41	100.0	77	90.6

TABLE A2
FIELD SURVEY DATA FOR FOUR CONTROL SECTIONS IN DISTRICT 6

		Shiawassee County									
		Control Section 76061		Control Section 76023		Control Section 76041		Control Section 76011		Total	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Sample Surveyed	Approach endings	2	50.0	41	100.0	1	50.0	9	52.9	53	82.8
	Trial Endings	2	50.0	--	---	1	5.0	8	47.1	11	17.2
Cable Condition Summary	Tight cables	4	100.0	--	---	-	---	1	5.9	5	7.8
	Loose cables	-	---	39	95.1	2	100.0	14	82.3	55	85.9
	No cable but has all hardware	-	---	1	2.4	-	---	2	11.8	3	4.7
	Cable disconnected at bearing plate	-	---	1	2.4	-	---	--	--	1	1.6
Summary of Noncompliance with Standard Plans or Specifications	Guardrail installed too close or too high from the ground	-	---	--	---	-	---	5	29.4	5	7.8
	Bearing plate not standard	-	---	34	82.9	-	---	--	--	34	53.1
	2 in. sleeve missing	-	---	16	39.0	-	---	--	--	16	25.0
	Bearing plate or nut touching or under ground	-	---	--	---	-	---	3	17.6	3	4.7
Summary of Other Findings	End shoe had been hit	-	---	2	4.9	1	50.0	1	5.9	4	6.2
	Buffered shoe with diaphragm	-	---	3	7.3	-	---	2	11.8	5	7.8

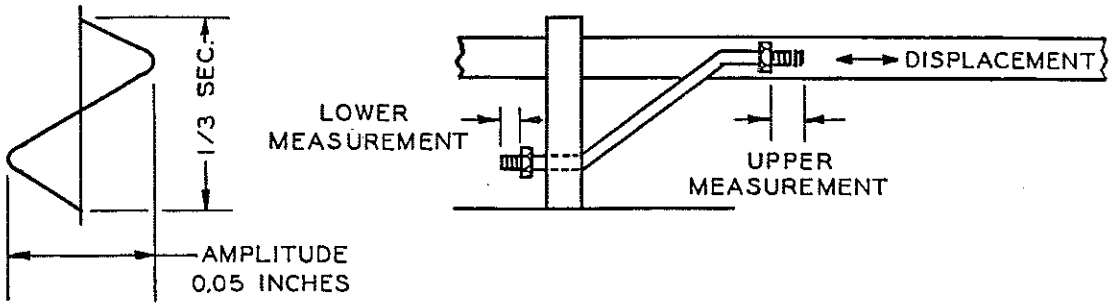
TABLE A3
FIELD SURVEY DATA FOR FIVE CONTROL SECTIONS IN DISTRICT 7

		Calhoun County								Berry County						Total	
		Control Section 13033		Control Section 13083		Control Section 13082		Subtotal		Control Section 08034		Control Section 08031		Subtotal			
		Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Sample Surveyed	Approach endings	13	100.0	30	100.0	36	100.0	79	100.0	28	51.9	12	70.6	40	56.3	119	79.3
	Trail endings	--	---	--	---	--	---	--	---	26	48.1	5	29.4	31	43.7	31	20.7
Cable Condition Summary	Tight cables	8	61.5	13	44.3	31	86.1	52	65.8	51	94.4	15	88.2	66	93.0	118	78.7
	Loose cables	5	38.5	15	50.0	5	13.9	25	31.6	3	5.6	2	11.8	5	7.0	30	20.0
	Cable disconnected at anchor plate	--	---	1	3.3	--	---	1	1.3	--	---	--	---	--	---	1	0.7
	Cable disconnected at bearing plate	--	---	1	3.3	--	---	1	1.3	--	---	--	---	--	---	1	0.7
Summary of Noncompliance with Standard Plans or Specifications	Guardrail installed too close or too high from the ground	1	7.7	--	---	3	8.3	4	5.1	--	---	--	---	--	---	4	2.7
	Bearing plate not standard	--	---	1	3.3	1	2.8	2	2.5	--	---	--	---	--	---	2	1.3
	Post split but not hit	--	---	--	---	2	5.6	2	2.5	--	---	--	---	--	---	2	1.3
	Anchor plate loose or bolts missing	--	---	1	3.3	1	2.8	2	2.5	--	---	--	---	--	---	2	1.3
	Post split around 2 in. hole in post	--	---	1	3.3	--	---	1	1.3	--	---	--	---	--	---	1	0.7
Summary of Other Findings	Gravel washed away from post	--	---	1	3.3	--	---	1	1.3	--	---	--	---	--	---	1	0.7
	Cable touching or gouged into second post	1	7.7	2	6.7	8	22.2	11	13.9	--	---	--	---	--	---	11	7.3
	All threads used at anchor plate	1	7.7	--	---	--	---	1	1.3	--	---	--	---	--	---	1	0.7
	All threads used at both ends, but cable loose	--	---	2	6.7	--	---	2	2.5	--	---	--	---	--	---	2	1.3
	Guardrail had been hit	1	7.7	--	---	--	---	1	1.3	--	---	--	---	--	---	1	0.7
	Post split but not hit	--	---	--	---	2	5.6	2	2.5	--	---	--	---	--	---	2	1.3
	End shoe had been hit	--	---	4	13.3	3	8.3	7	8.9	--	---	--	---	--	---	7	4.7
	Buffered shoe with diaphragm	12	92.3	26	86.7	36	100.0	74	93.7	--	---	--	---	--	---	74	49.3

TABLE A4
FIELD SURVEY DATA FOR FOUR CONTROL SECTIONS IN DISTRICT 8

		Jackson County		Livingston County		Ingham County		Eaton County		Total	
		Control Section 38131		Control Section 47082		Control Section 33085		Control Section 23152			
		Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Sample Surveyed	Approach endings	19	100.0	5	55.6	11	100.0	6	100.0	41	91.0
	Trial endings	--	---	4	44.4	--	---	-	---	4	9.0
Cable Condition Summary	Tight cables	--	---	-	---	4	36.4	3	50.0	7	15.6
	Loose cables	18	94.7	9	100.0	7	63.6	3	50.0	37	82.2
	Cable disconnected at anchor plate	1	5.3	-	---	--	---	-	---	1	2.2
Summary of Noncompliance with Standard Plans or Specifications	2 in. sleeve missing	5	26.3	-	---	--	---	-	---	5	11.1
	Guardrail installed too close or too high from the ground	--	---	1	11.1	--	---	1	16.7	2	4.4
	Bearing plate not standard	--	---	1	11.1	--	---	-	---	1	2.2
	Bearing plate or nut touching or under ground	--	---	2	22.2	--	---	-	---	2	4.4
Summary of Other Findings	Gravel washed away from post	2	10.5	-	---	--	---	-	---	2	4.4
	All threads used at anchor plate	5	26.3	-	---	--	---	-	---	5	11.1
	All threads used at bearing plate	1	5.3	-	---	--	---	-	---	1	2.2
	All threads used at both ends, cable loose	3	15.8	-	---	--	---	-	---	3	6.7
	Guardrail had been hit	1	5.3	-	---	--	---	-	---	1	2.2
	End shoe had been hit	2	10.5	-	---	--	---	-	---	2	4.4
	Buffered shoe with diaphragm	16	84.2	6	66.7	--	---	-	---	22	48.9

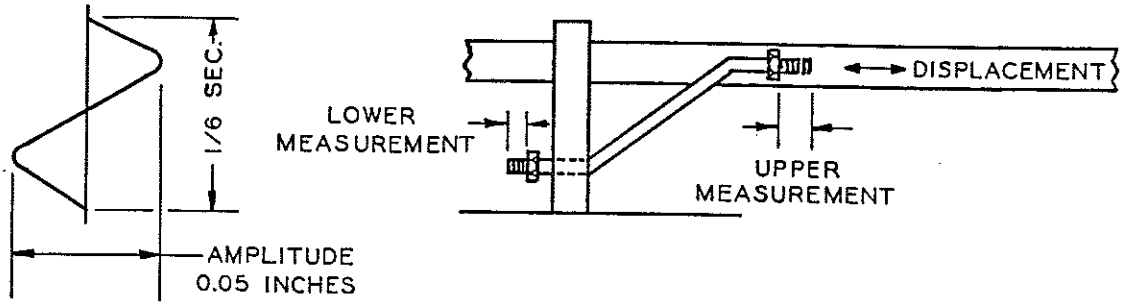
TABLE A5
NUT MOVEMENT FOR 0.05 in.
DISPLACEMENT AT THREE CYCLES/SECOND



	Number of Cycles	Time, min.	Lower Measurement Change*	Upper Measurement Change*	Total Measurement Change*
Maximum torque at both ends	7,500	42	0	0	0
Hand tight at both ends	7,500	42	0	0	0
Hand tight less one turn at top	7,500	42	0	0	0
Hand tight less one turn at top and one turn at bottom	7,500	42	0	-2/64	-2/64
Hand tight less two turns at top and two turns at bottom	7,500	42	-2/64	0	-2/64
Hand tight less four turns at top and four turns at bottom	7,500	42	0	0	0

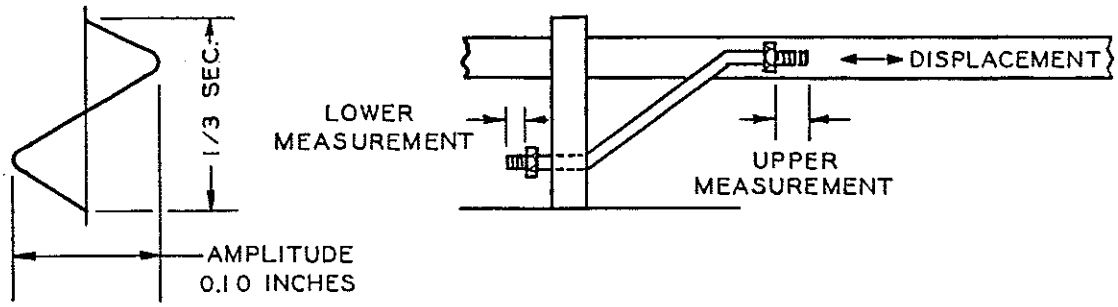
* minus sign indicates loosening

TABLE A6
NUT MOVEMENT FOR 0.05 in.
DISPLACEMENT AT SIX CYCLES/SECOND



	Number of Cycles	Time, min.	Lower Measurement Change	Upper Measurement Change	Total Measurement Change
Maximum torque at both ends	15,160	42	0	0	0
Hand tight at both ends	15,000	41	0	0	0
Hand tight less one turn at top	15,000	41	0	0	0
Hand tight less one turn at top and one turn at bottom	15,000	41	0	0	0
Hand tight less two turns at top and two turns at bottom	15,000	41	0	0	0
Hand tight less four turns at top and four turns at bottom	15,000	41	0	0	0

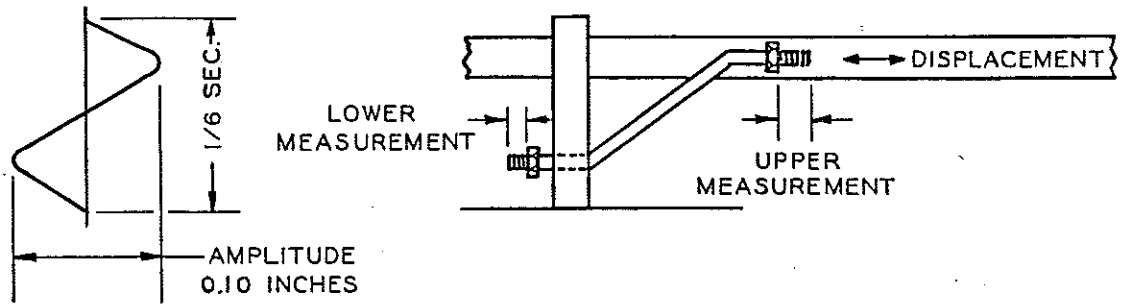
TABLE A7
NUT MOVEMENT FOR 0.1 in.
DISPLACEMENT AT THREE CYCLES/SECOND



	Number of Cycles	Time, min.	Lower Measurement Change	Upper Measurement Change*	Total Measurement Change*
Maximum torque at both ends	7,500	42	0	+2/64	+2/64
Hand tight at both ends	7,500	42	0	0	0
Hand tight less one turn at top	7,500	42	0	0	0
Hand tight less one turn at top and one turn at bottom	7,500	42	0	-2/64	-2/64
Hand tight less two turns at top and two turns at bottom	7,500	42	0	+1/64	+1/64
Hand tight less four turns at top and four turns at bottom	7,500	42	0	0	0

* plus sign indicates tightening, minus sign indicates loosening

TABLE A8
NUT MOVEMENT FOR 0.1 in.
DISPLACEMENT AT SIX CYCLES/SECOND



	Number of Cycles	Time, min.	Lower Measurement Change*	Upper Measurement Change*	Total Measurement Change*
Maximum torque at both ends	15,000	43	0	+5/64	+5/64
Hand tight at both ends	15,000	43	+1/64	+7/64	+8/64
Hand tight less one turn at top	15,000	43	+6/64	-2/64	+4/64
Hand tight less one turn at top and one turn at bottom	15,000	43	+4/64	0	+4/64
Hand tight less two turns at top and two turns at bottom	15,000	43	0	-5/64	-5/64
Hand tight less four turns at top and four turns at bottom	15,000	43	0	-6/64	-6/64

* plus sign indicates tightening, minus sign indicates loosening