INVESTIGATION OF RIGID FUSE PLATES FOR USE ON BREAKAWAY SIGNS
(Progress Report)

MICHIGAN HIGHWAY RESEARCH LABORATORY DIVISION

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

INVESTIGATION OF RIGID FUSE PLATES FOR USE ON BREAKAWAY SIGNS
(Progress Report)

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ABSTRACT: The fused splice on a breakaway sign post is designed to separate and allow the post to swing up and away in a vehicle - sign collision. Fuse plates, rigidly connected at the splice, were investigated in order to develop a fused splice that will give dependable and predictable wind load resistance (10WF 21 posts were emphasized). The results of static load tests on rigid fuse plates verified that stress concentration resulting from various size and shape holes, used to reduce cross-sectional area, did not adversely affect the gross yielding or ultimate failure of the fuse. Impact tests performed on various small-scale fuse plates showed that fracture occurred at a dynamic load about equal to the ultimate static load. The recommended plate has three holes at the splice line to reduce the plate's cross section and is fabricated from galvanized ASTM A 441 steel. Vehicle impact tests are recommended before this type of fuse plate is used.

KEY WORDS: sign structures, hinged structures, fracturing, supports, splicing, impact tests, static tests.

INTRODUCTION

Recently there has been considerable national interest in developing safer roadside sign supports. Several approaches to the problem have been suggested, one of the more promising of these being the slip-base, or breakaway, design. This consists of a base connection that can resist forces induced by wind loadings, but shears free from the foundation when struck by a vehicle. A fused and hinged connection in the post near the bottom of the sign panel has been included as an additional safety measure.

The breakaway connection at the base of the sign post is the primary safety device for preventing lethal decelerations of the occupants of impacting vehicles. The fused-and-hinged connection higher up on the post performs a secondary function, allowing the lower post section to swing away from the windshield area of the impacting vehicle as it passes beneath the sign. If the fuse does not separate under impact, the upper and lower post sections will swing forward and upward as a unit. The post unit may or may not remain attached to the sign, depending upon the strength of the connection between the post and sign, and the rigidity and strength of the sign material.

Designing the fuse presents a dilemma, for it must be capable of withstanding the wind load imposed on the structure, yet fail readily when the post is impacted by a vehicle. If the fuse is designed to withstand reasonable wind forces, there will be some minimum vehicle impact speed below which the fuse will not separate. Obviously, the design must compromise the opposing demands.

Sign supports spliced with friction type, rather than fracture type, fuse plates have performed satisfactorily in vehicle crash tests. For example, on December 12, 1966 and January 4, 1967, crash tests were performed at the General Motors Proving Grounds on a sign utilizing 10WF 21 posts spliced with friction-type fuses. In these tests, the fuse parted readily when impacted by a full-size car at 60 mph, and somewhat hesitantly when impacted by a compact car at 40 mph.

The performance of friction type joints under static loading, however, has been shown to be unsatisfactory by tests performed in the Laboratory. In Research Report No. R-601 (September, 1966), it was noted that the friction fuses tested in uniaxial tension did not develop enough slip resistance to carry the design load specified by the AASHO Specifications for the Design and Construction of structural supports for Highway Signs. Further, the static slip resistance was found to be erratic. Additional static tests,

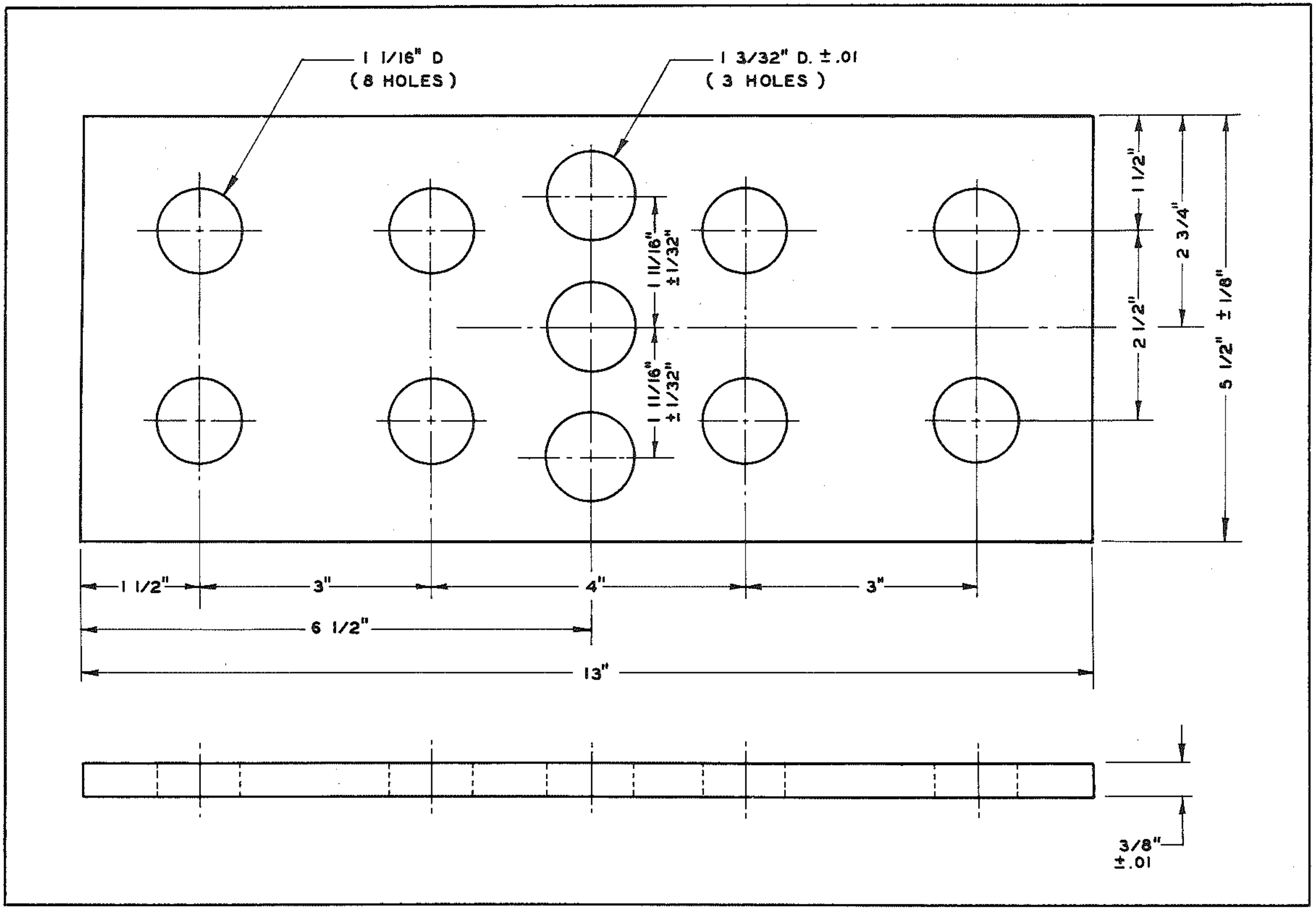

Figure 1. Proposed rigid fuse plate for use with 10WF 21 sign post.

requested by the Office of Design, were performed on breakaway sign components salvaged from the General Motors impact tests. These tests showed that the static load carrying capacity of the unmodified salvaged components was only about one-half the design wind load requirement (memorandum to W. W. McLaughlin, February 9, 1967). Later, tests were conducted as requested by the Office of Design on a rigid-type fuse plate, fastened with aluminum bolts that were designed to fail in shear. These tests, reported by memorandum on February 17, showed that although this type of fuse connection provided adequate ultimate static strength, it was not recommended for use as it slipped back and forth at very low loads thus damaging the aluminum bolts.

Further efforts to improve the static capacity of the friction joint involved increasing bolt sizes, (finally to a maximum of 1-1/2 in. dia), and the number of bolts used to clamp the fuse plates to the beam. Static tests showed it generally unfeasible to provide an adequate number of bolts of a large enough diameter to develop the required static slip resistance. Although the friction type fuse currently is being used on breakaway signs, it was felt that a better device might be developed.

The following report summarizes the developmental research performed thus far in attempting to design a safe, dependable, fuse connection. The approach taken to this problem has been to study the performance of post splices formed by rigidly connected fuse plates containing geometric stress raisers. Figure 1 shows this type of fuse splice designed to fail in tension under dynamic loading, rather than by slipping.

Michigan specifications require roadside sign supports to be fabricated from galvanized ASTM A 441 steel. The work reported here has been directed toward developing fuse plates of the same material as the posts. This presents a suitable appearance, prevents corrosion problems, and avoids the use of separate specifications for fuse and post materials.

RESEARCH PROCEDURE AND DISCUSSION OF RESULTS

Bolting Requirements

Prior to investigating stress concentration factors, it was necessary to determine the fastener requirements needed to insure a rigid connection between the galvanized fuse plate and sign support post. A rigid connection is required to prevent repeated slippage in the wind which would cause loosening and damage to the connecting bolts and plates. Several tests were performed on a spliced sign support post using various bolting arrangements. Table 1 summarizes the test information used in determining the bolting requirements. Based on the data given in Table 1 and the results of previous tests (Appendix), it is estimated that the effective coefficient of friction between the fuse and support is in the range 0.15 to 0.20 for galvanized ASTM A 441 steel. The actual value adopted for design of the bolted connection was 0.15. It was concluded that reasonable resistance to slippage can be provided by using eight 1-in. dia bolts (four bolts on each side of the splice) for the 10WF 21 sign post on which the research has been primarily concentrated. This provides a resistance against slip equal to 75 percent of the design tension load given in Column 3 of Table 2. To provide this resistance, it is necessary to torque the A 325 High Strength bolts to proof load to provide adequate clamping force.

TABLE 1
EFFECTIVE COEFFICIENT OF FRICTION
BETWEEN BEAM AND SINGLE FUSE PLATE

Sample Identification	Bolts Used	Bolt Torque, ft lbs	Bolt Lubricant	Slip Load,[1] lbs	Applied Tension,[2] lbs	Apparent Friction Coefficient[5]
3-10-1	4 ea 7/8 in. dia H.S.[4]	500	"Dri-Slide"	30,300	144,000	.210
3-15-1	4 ea 1 in. dia	300	"Dri-Slide"	23,800	-------[3]	----
3-15-2	4 ea 1 in. dia	400	"Dri-Slide"	32,500	-------[3]	----
3-15-3	4 ea 1 in. dia	500	"Dri-Slide"	43,300	-------[3]	----
3-20-1	4 ea 1-1/4 in. dia	550	"Dri-Slide"	30,300	-------[3]	----
3-20-2	4 ea 1-1/4 in. dia	550	Beeswax	36,100	-------[3]	----
3-27-1	4 ea 1 in. dia H.S.	500	Beeswax	36,700	189,000	.191
3-27-2	4 ea 1 in. dia H.S.	500	Beeswax	41,400	189,000	.219
4- 5-1	4 ea 1 in. dia H.S.	500	Beeswax	36,400	189,000	.187
3- 5-2	4 ea 1 in. dia H.S.	500	Beeswax	43,700	189,000	.231
3- 5-3	4 ea 1 in. dia H.S.	500	Beeswax	45,600	189,000	.242
4- 7-1	4 ea 1 in. dia H.S.	500	Beeswax	37,400	189,000	.198

[1]Slip load is defined as the load at which parallel slip between plates reached 0.01 in.
[2]Applied tension is approximately 4 times proof load of one bolt.
[3]Special bolts fabricated in laboratory machine shop. Applied tension unknown.
[4]H.S. denotes ASTM A 325 High Strength bolts.
[5]Apparent coefficient of friction equals slip load divided by applied tension.

Wind Load Design Criteria

Wind load requirements were discussed with Office of Design personnel and guidelines for the design of breakaway signs were obtained. The general philosophy adopted was to base the design on sign size experience. Accordingly, it was assumed that the sign will be at least twice as wide as it is high. For most of the sign sizes used on the large posts the actual wind loads determined are less than that which would be obtained using this assumed height to width ratio. The design information in Table 2 is based on this assumed minimum ratio of sign width to sign height. The wind load per sq ft of sign is based on an 80 mph wind reduced by 20 percent for signs less than 15 ft above ground, in accordance with AASHO Specifications.

Table 2 gives the anticipated design static bending load in the support at the fuse plate, the resulting fuse plate tension, required cross-section area of fuse plate, connecting bolts required, and recommended fuse plate size for five different sign posts.

TABLE 2
FUSE PLATE WIND LOAD DESIGN DATA

Post	Post Design Moment,[1] lb ft	Fuse Plate Design Tension, lbs	Required Net Cross-Section Area at Weakened Section, sq in.	High Strength Bolts Required	Fuse Plate Size (Thickness and width), in.
10 WF 21	34,500	41,400	.83	8 ea 1 in. dia[2]	3/8- by 5-1/2[3]
8 WF 17	24,600	37,000	.74	8 ea 1 in. dia	3/8- by 5-1/2
8 B 13	14,400	21,600	.43	8 ea 7/8 in. dia	1/4- by 4
6 B 8.5	7,480	15,000	.30	8 ea 7/8 in. dia	1/4- by 4
4 I 7.7	3,620	10,900	.22	4 ea 7/8 in. dia	1/4- by 2-3/4

[1] Assuming ratio of sign length to height ≥ 2, if ratio is less, special bolting modifications may be required and increased fuse plate cross sectional area may be needed.
[2] Total number of bolts given per plate, e.g., 8 bolts required indicates that 4 bolts should be used on each side of the splice.
[3] Figure 1 shows proposed fuse plate for 10 WF 21.

Stress Concentration Under Static Load

Using the information from the first three Columns of Table 2 as a design guide, the following fuse plates containing points of stress concentration were fabricated and statically tested in tension, to ultimate failure:

1. Three, 1 to 3.7 scale samples of the fuse plate designed for use on the 10WF 21 posts, were tested in uniaxial tension.

2. One pair of full size 10WF 21 post fuses were made and tested on a salvaged 10WF 21 post, that was subjected to a flexural loading.

3. Three full-size 10WF 21 fuse plates were tested in uniaxial tension.

4. Three full-size 8B 13 fuse plates were tested in uniaxial tension.

The results of these static tests (Table 3) verify that the ductility of the A 441 steel is sufficient to distribute the stresses over the reduced area before gross yielding and fracture occur. In other words, for the stress raiser arrangements used, it is feasible to design fuse plates statically on the basis of average yield strength and average ultimate strength over the reduced cross sectional area. The static design criterion adopted in this study has been to provide enough cross sectional area at the stress concentration section of the fuse plate to insure that guaranteed yield strength times the net area is equal to the maximum tensile load listed in Column 3 of Table 2. It should be noted that there is a practical safety factor involved in design based on guaranteed values of yield and ultimate strength since

TABLE 3

STATIC LOAD TESTS TO FAILURE

(Samples based on proposed 10WF 21 and 8 B 13 fuse plates.)

Sample Identification	Fuse Sample Dimensions		Stress Raiser Description	Minimum Cross-Sectional Area, sq in.	Results of Standard Tension Tests		Test Type[2]	Predicted Yield Load, lbs	Predicted Ultimate Load, lbs	Measured Yield Load, lbs (app.)	Measured Ultimate Load, lbs
	Thickness, in.	Width, in.			Yield Strength, psi	Ultimate Strength, psi					
4- 6-1	.137	1.47[1]	1-3/4 in. dia hole.	.099	59,200	81,400	a	5,850	8,050	between 5,000 and 6,000	8,000
5-12-1	.100	1.50[1]	3 ea 5/16 in. dia holes.	.056	59,200	81,400	a	3,320	4,560	3,500	4,500
5-12-2	.100	1.50[1]	1/16-in. V transverse notch	.056	59,200	81,400	a	3,320	4,560	3,500	4,600
4- 7-1	.343	5.56	3 ea 1-1/4-in. dia holes.	.603	59,200	81,400	b	35,600	49,000	42,000[3]	55,600
4-28-1	.343	5.56	3 ea 1.20-in. dia holes.	.672	59,200[4]	81,400[4]	a	39,800	54,700	not observed	52,000
4-28-2	.343	5.56	3 ea 1.27-in. dia holes.	.600	59,200[4]	81,400[4]	a	35,600	48,900	not observed	46,000
4-28-3	.343	5.56	3 ea 1.27-in. dia holes.	.600	59,200	81,400	a	35,600	48,900	33,000	45,000
5- 4-1	.250	4.00	3 ea 0.76-in. dia holes.	.430	43,800	66,600	a	18,800	28,600	between 20,000 and 25,000	29,200
5- 4-2	.250	4.00	3 ea 0.82-in. dia holes.	.383	43,800	66,600	a	16,800	25,500	19,600	26,200
5- 4-3	.250	4.00	3 ea 0.76-in. dia holes.	.430	43,800	66,600	a	18,800	28,600	not observed	28,400

[1]Small scale fuse samples scale = 1/3.7 of 3/8- by 5-1/2-in. fuse.

[2]Direct tension test in universal testing machine is denoted by "a". Beam bending test when fuse plate is in tension is denoted by "b".

[3]Observed stretching of plate around holes at this load.

[4]Assumed value. Standard tension test was not performed on plate used for sample.

the steel provided will usually have yield strength and ultimate strength in excess of that guaranteed. For example, standard uniaxial tension tests performed in the Laboratory indicate the yield and ultimate strength of the steel salvaged from the General Motors tests to be higher than guaranteed by 18 and 16 percent respectively.

Small Scale Dynamic Tests

After verifying that the stress concentration did not affect the static load carrying ability of the fuse plate, further research was directed towards finding a suitable stress raiser configuration under dynamic loading. A 1 to 3.7 scale, dynamic direct-tension test was devised utilizing the Riehle impact testing machine. A sketch of a sample is shown in Figure 2 and the testing apparatus in Figure 3. The samples tested were scale models of the fuse plates proposed for use on the 10WF 21 sign support posts. They were constructed of the same A 441 steel used in the static tests. Deceleration of the sample, and the impact hammer on which it was mounted, was measured at the time of impact with a 500g accelerometer. This measured peak deceleration was then used to calculate the force exerted on the plate sample. These tests, summarized in Table 4, showed that the dynamic failure load was about equivalent to the static failure load for A 441

TABLE 4
SMALL SCALE DYNAMIC LOAD TESTS

Sample Identification[1]	Peak Deceleration, g's	Estimated Static Load Ultimate Strength, lbs	Fracture Load, lbs	Energy Dissipated, ft lbs	Description of Stress Raiser Configuration
4- 6-1	N.O.[2]	5140	N.O.	128 (F. F.)[3]	1 in. dia hole, Net Area = .063 sq in.
4- 6-2	N.O.	5140	N.O.	67 (F. F.)	2 ea 1/2 in. dia holes, A = .063 sq in.
4- 6-3	N.O.	4310	N.O.	34	3 holes, ea 0.359 in. dia, Net A = .053 sq in.
4- 6-4	N.O.	5200	N.O.	124 (F. F.)	3 holes, ea 0.328 in. dia, Net A = .064 sq in.
4- 6-5	N.O.	4640	N.O.	88	3 holes, ea 0.348 in. dia, Net A = .057 sq in.
4-14-1[4]	78	4560	4660	49	3 ea 5/16 in. dia holes, Net A = .056 sq in.
4-14-2	N.O.	4560	N.O.	43	3 ea 5/16 in. dia holes, Net A = .056 sq in.
4-19-1	90	4560	5400	68	Slotted from ea edge, Net A = .056 sq in.
4-19-2	87	4560	5300	60	Circular Notch ea edge, A = .056 sq in.
4-19-3	80	4560	4790	34	V Notch ea edge, Net A = .056 sq in.
4-20-1	76	4560	4570	40	4 ea 15/64 in. dia holes, Net A = .056 sq in.
4-20-2	76	4560	4600	39	5 ea 3/16 in. dia holes, Net A = .056 sq in.
4-24-1	76	4560	4560	86	5/16 in. x 15/16 in. slotted hole, Net A = .056 sq in.
4-25-1	72	4560	4350	41	3 ea 5/16 in. dia holes, Net A = .056 sq in.
4-25-2	77	4560	4620	46	3 ea 5/16 in. dia holes, Net A = .056 sq in.
5-26-1	88	4560	5300	42	1/16 in deep V groove running transversely across sample A = .056 sq in.
5-26-2	83	4560	5000	45	3 ea 5/16 in. dia holes, Net A = .056 sq in.

[1]Figure 2 illustrates typical sample.
[2]Not observed
[3]Fastener failed
[4]All succeeding samples tested were constructed to 1/3.7 scale of a full size 3/8" x 5-1/2" fuse plate.

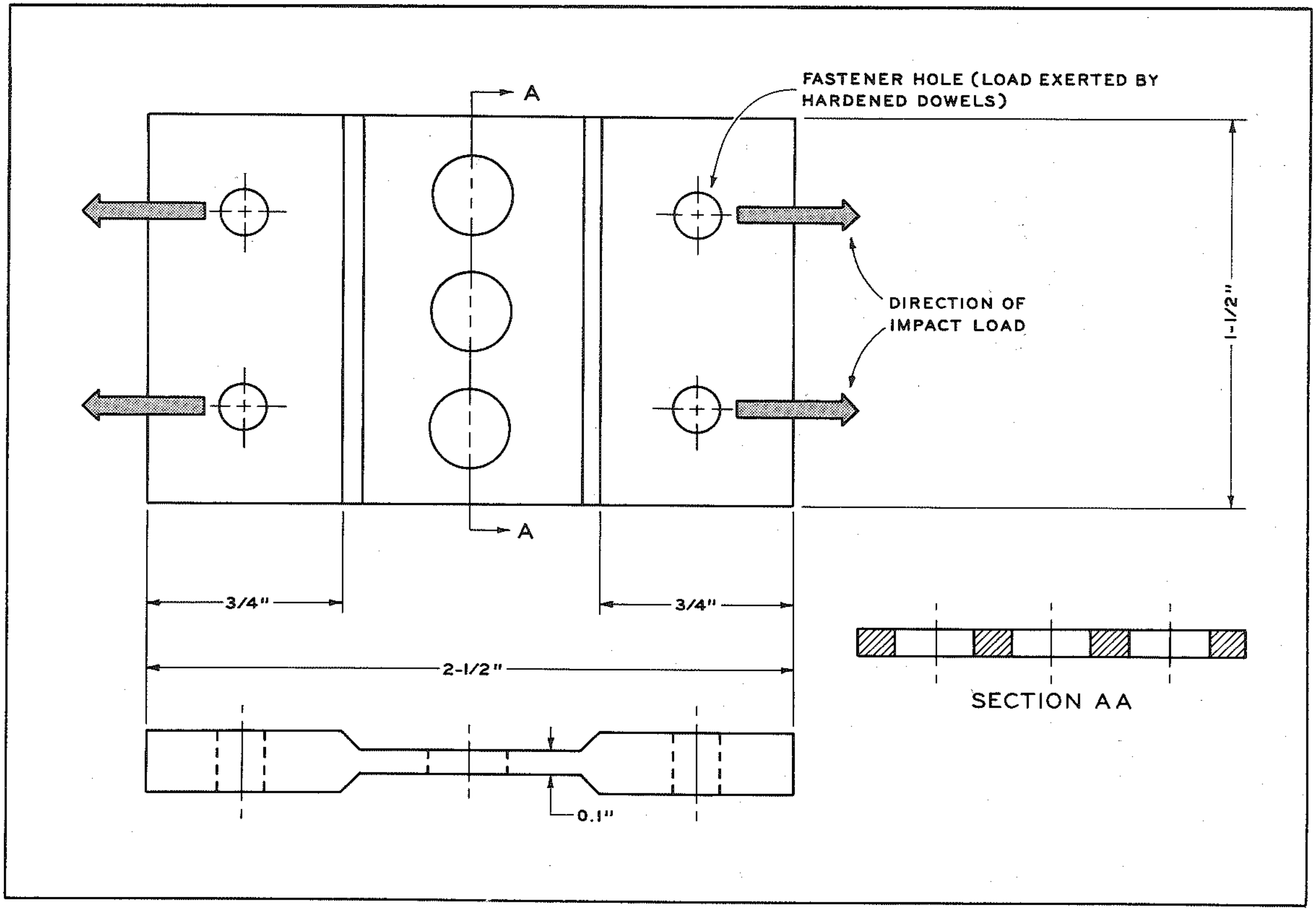

Figure 2. Typical small scale impact test sample.

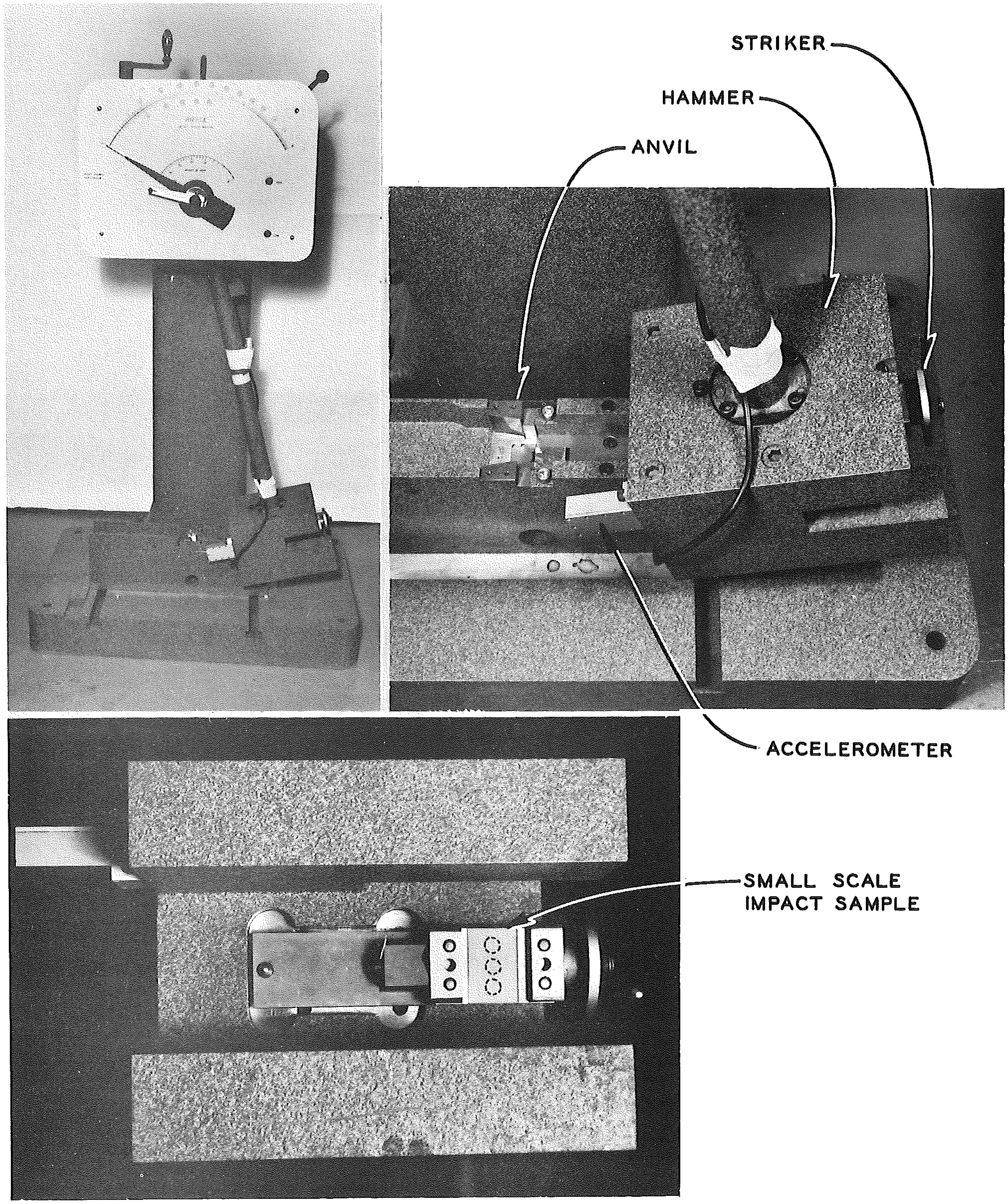

Figure 3. Small scale impact test apparatus.

steel with the stress concentrations tested. The tests also demonstrated that drilling three holes at the reduced cross-section would provide a fuse plate that fractures efficiently. The work done in fracturing the fuse is also an important factor and, therefore, the energy dissipated by the hammer in each test was recorded. The samples containing three holes also performed well in this respect. This type of fuse would be easier to fabricate than those containing more complicated stress raisers. For these reasons, the three-hole stress raiser configuration is proposed for use on the rigid fuse plates.

Full Scale Dynamic Problem

Whether the rigid fuse will break away when the sign post is hit by a car, can only be considered on the basis of the testing thus far performed. Olson, Rowan, and Edwards[(1)(2)] have reported the results of full scale crash tests in which friction type fuses and rigid cast iron fuses were utilized. Their tests were conducted at the Texas Transportation Institute, Texas A & M University. The authors determined from high speed photographs that the upper portion of post and the attached sign did not rotate or translate during the initial period of response to an impacting vehicle. This means that considerable resistance to movement of the sign support is provided initially by the inertia of the sign and support structure.

In crash test 40, at the Texas Transportation Institute, a peak acceleration of about 67g's was measured at about 9 milliseconds after impact by an accelerometer mounted perpendicular to the post, 6.5 ft below the rigid cast iron fuse. Assuming the impact tended to rotate the post and sign about the center of mass which was located approximately at the fuse splice line, the indicated linear acceleration 6.5 ft from the splice would result in an angular acceleration about the splice line of nearly 330 radians per sec per sec. If it is assumed that the upper portion of the 10WF 21 support assembly would be angularly accelerated a like amount in a similar crash test, and that the post will act as a rigid body, an inertial moment equal to the product of the angular acceleration and the effective mass moment of inertia of the upper part of the structure would resist the motion. The effective mass moment of inertia of the Michigan sign structure above the fuse is about 100 ft lb sec^2. Using this mass moment of inertia, and the acceleration value from the Texas Transportation Institute Test 40, the maximum resisting moment that would be developed is calculated to be about 33,000 lb ft. In transferring this moment at the splice, the proposed fuse plate would be subjected to a tensile load of approximately 40,000 lbs. The ultimate static tensile capacity of the proposed rigid fuse shown in Figure 1, based on the guaranteed ultimate strength of the metal, would be 58,000 lbs. This strength is greater than the estimated load which would be caused by the inertial moment. Therefore, the proposed fuse may not break if the assumptions made here are valid, and the impacting vehicle speed is equal to that used in the test.

It is of interest to note that the Texas Transportation Institute acceleration data were obtained from a 42 mph crash test, utilizing a full size car. At higher speed impacts, the acceleration of the post would be larger. This analysis does not assure that sufficient force will be generated in a 42 mph collision to cause the proposed fuse to break away. However, it seems that at higher impact speeds, sufficient force should certainly occur.

It is also important to compare the amount of energy dissipated in causing a friction fuse to slip free to that required to fracture a rigid-type fuse. In order to consider the friction fuse currently used in Michigan for reference, it is necessary to refer to the dynamic tests performed by the General Motors Corporation. In crash tests conducted there, utilizing signs with 10WF 21 posts and friction fuses fastened with bolts torqued to proof load, satisfactory breakaway occurred. Assuming an average effective coefficient of friction of 0.15 and a total fuse slip under load of 1 in., the energy dissipated in freeing the fuse in these tests is estimated to have been about 1800 ft lb. Based on this estimate, it can be seen that about 1800 ft lb of energy is required to separate a friction fuse comparable in size to the rigid fuse being studied.

Data from the static tests given in Table 3, and from the 1 to 3.7 scale dynamic tests given in Table 4, were used to estimate the energy required to cause impact failure of the full sized fuse plates. Table 5 summarizes the method used to estimate the energy that would be required to fracture the proposed fuse plate.

The assumptions required for the analysis shown in Table 5 are:

1. The energy dissipated in fracturing the various samples is proportional to the amount of plastic work done in permanently deforming the samples in the vicinity of their weakened cross-sections.

2. The plastic work done in permanently deforming the fuse plate samples is approximately equal to the product of the ultimate tension load and the permanent elongation of the samples.

3. The permanent elongation of the samples is equal to the measured elongation that occurred at the reduced cross-section of each sample.

4. The energy dissipated in deforming the plates statically is equivalent to that which would be dissipated in deforming them dynamically.

TABLE 5
ENERGY DISSIPATION COMPUTATIONS

Sample	Scale and Test Type	Hole Dia, in.	Elongation of Plate, in.	Failure Load, lb	Plastic Work,[1] ft lb	Total Energy Dissipated, ft lb
4-14-1	1/3.7, Dynamic	.31	.09	4660	35	49
4-14-2	1/3.7, Dynamic	.31	.08	Not observed		43
4-25-1	1/3.7, Dynamic	.31	.09	4350	33	41
4-25-2	1/3.7, Dynamic	.31	.08	4620	31	46
4-26-2	1/3.7, Dynamic	.31	.07	5000	29	45
Average	1/3.7, Dynamic	.31	.08	4660	32	45
5-12-1	1/3.7, Static	.31	.08	4500	30	---
						Estimated[2]
4- 7-1	Full, Static	1.25	.33	55,600	1530	2160
4-28-1	Full, Static	1.20	.34	52,000	1610	2070
4-28-2	Full, Static	1.27	.35	46,000	1340	1890
4-28-3	Full, Static	1.27	.33	45,000	1240	1750

[1] Plastic Work = (Failure Load) x (Elongation)
[2] Total Energy Dissipation is proportional to Plastic Work.

The following five-step procedure was used to obtain the energy estimates given in Table 5.

1. The average elongation, average failure load, and average energy dissipated in the small scale dynamic tests was determined from the data shown in lines one through five of the table and is shown in line six.

2. The average plastic work done on the small scale dynamic test samples was then computed.

3. The plastic work done on the static sample was calculated and compared with that obtained in Step 2 for the average dynamic sample. Comparison showed good agreement and tended to verify assumption 4 (See lines 6 and 7 of Column 6).

4. The elongation that occurred in each full scale static test was measured and the plastic work done on these samples computed.

5. The probable energy dissipation under dynamic load which would occur in fracturing the full-size fuses of the dimensions given in lines eight through eleven of the table was then computed. This computation consisted of multiplying the average energy dissipated in the small scale dynamic tests times the ratio of plastic work done in the full-scale static test to the average value obtained for the small scale dynamic tests.

For a fuse plate with the dimensions shown in Figure 1, it is estimated, based on the results of step five above, that 2000 ft lb of energy would be dissipated in fracturing the proposed fuse plate.

From this analysis it can be seen that the energy required to break away the rigid fuse appears to be approximately 1.1 times that required to free the friction fuse.

SUMMARY

In an attempt to develop a fuse splice that will give dependable and predictable resistance to static wind load and long term non-varying dynamic response characteristics, fuse plates rigidly connected at the splice have been investigated. These plates, fabricated from galvanized ASTM A 441 steel, contained a reduced cross section at the splice point sufficient to provide the minimum wind load strength requirements. Static load tests were performed on rigid fuse plates incorporating various methods of reducing cross sectional areas at the splice line. It was verified that the stress concentration resulting from holes and slots of various shapes established at the reduced cross section, did not adversely affect the gross yielding or ultimate failure of the fuse. Yielding and failure occurred as if the uniaxial tension in the plate was uniform over the cross section.

Actually, localized yielding did occur in the areas of stress concentration at a lower load. However, these areas of plastic deformation were confined by the surrounding region of elastically stressed material. This type of plastic yielding is referred to as confined plastic deformation, i.e., plastic deformation that is limited by the elastic deformation occurring in the remainder of the plate. It was therefore concluded that the design of the A 441 steel fuse for static loading could be based on average stress on the cross-section. Since large deformation occurred only at, or above, the average yield strength of the metal (which was higher than the guaranteed minimum yield strength), it was concluded that the fuse could safely be designed for an allowable stress equal to the guaranteed minimum yield stress at maximum design loading.

Having established a practical limit for static load design of the fuse that placed no restrictions on the geometry of the plate at the reduced cross section, impact tests were performed on small scale fuse plates with various stress raiser configurations. These tests showed that fracture occurred essentially at a dynamic load equal to the ultimate static load for the material and configurations tested. A reasonable plate configuration was found

to be a plate with three holes drilled at the splice line to reduce the plate section there. Figure 1 illustrates the plate configuration proposed for use on a 10WF 21 sign post.

A report by the Texas Transportation Institute was reviewed, describing full-scale vehicle crash tests in which friction fuses were used. An approximate analysis of the possible behavior of the 10WF 21 rigid fuse plate was made, on the basis of the detailed information given in that report. It was concluded from the analysis that sufficient force to break the fuse might not be developed by a vehicle impacting at 40 mph. Also, more energy would be dissipated in breaking the rigid fuse than was required to cause the friction fuse to slip free. The Institute has also written two computer programs depicting mathematical models of breakaway sign response. If possible, these programs will be utilized by the Research Laboratory to further evaluate the probable performance of the proposed rigid fuse under vehicle impact loading.

It was concluded that fuses can be fabricated of ASTM A 441 steel, that will exhibit reasonably predictable performance under static and dynamic conditions. Additional research will be necessary before a judgement can be made as to whether the rigid fuse will function satisfactorily under vehicle impacts. Specifically, it is thought that full-scale vehicle crash tests would be the only sure means of determining whether the rigid fuse plate will perform safely during a vehicle impact. Such tests might be done on contract by such agencies as the General Motors Corporation or the Texas Transportation Institute. Alternatively, crash testing could be conducted by the Research Laboratory if funds were made available. The contract procedure has the advantage of providing quicker results since the test site and foundations already exist.

RECOMMENDATIONS

1. Bolting Requirements - It is recommended that sufficient bolts be provided in the connection to ensure that enough frictional resistance will be developed to prevent any slippage between the beam and fuse plate until at least 75 percent of the design wind load tension is developed. In determining this frictional resistance it is recommended that the coefficient of friction between the two galvanized surfaces be taken as 0.15, and that the normal force applied by each bolt be assumed equal to the proof load of the bolt as specified in ASTM Specification A 325. Plans should specify that the bolts be lubricated and tightened to proof load.

2. Wind Load Design - For fuse plates constructed of ASTM A 441 steel, it is recommended that the design minimum cross-section of the fuse plate be based on a maximum allowable average stress equal to the guaranteed minimum yield stress of the metal. It is further recommended that tests be required for any metal substitutes for A 441 steel.

3. Weakened Cross-Section - It is recommended that the weakened section of the fuse plate be formed by drilling three holes of the appropriate diameter to provide the required reduction in area. The holes should be spaced so that four equal pieces of metal stock remain. An example of proper hole spacing is shown in Figure 1. A tolerance of lateral hole misplacement of $\pm$ 1/32 in. may be allowed. The hole size tolerance should be maintained at $\pm$ .010 in.

4. Embrittlement - Since there is some danger of embrittlement occurring in the fuse plate if the holes are drilled or sheared prior to galvanizing the plate, it is recommended that ASTM Specification A 143, "Recommended Practice for Safeguarding Against Embrittlement of Hot Galvanized Structural Steel Products and Procedure for Detecting Embrittlement," be followed in the fabrication and inspection of the fuse plates. Galvanizing the plate should be according to ASTM Specification A 153. Drilling is preferred to shearing or punching.

5. Vehicle Impact Tests - It is recommended that vehicle impact tests be performed on sign posts utilizing the proposed A 441 rigid fuse plate to insure that they will perform safely. It is also recommended that this type fuse plate not be put in service until the crash tests have been performed.

Because of the complexity of the collision response, it is thought that crash tests using cars should be performed rather than tests utilizing a large impact hammer or a swinging pendulum. A basic experiment that would determine whether the fuse fractures satisfactorily could be set up with relatively little expense utilizing used governmental vehicles that are disposed of periodically.

APPENDIX

EFFECTIVE COEFFICIENT OF FRICTION (PREVIOUS TESTS)

Previous uniaxial tests performed on breakaway fuse assemblies reported in Research Report No. R-601 indicated that the coefficient of friction, μ, is less than suggested here in Table 1. Consider, for example, the fuse tested for the 6B 8.5 post. It consisted of one galvanized plate attached to a galvanized beam flange with two, 3/4 in bolts in slotted holes. Comparing the applied torques recorded for these tests with the bolt torque tension tests shows that proof load was attained in the bolts in fastening samples 4, 6, 7, 8, and 12. Therefore, the apparent value of μ for these (R-601) tests may be estimated by dividing the slip load recorded at .01 in. slip by two times the proof load of a 3/4-in. dia bolt. From this computation the apparent values of μ are found to be 0.16, 0.13, 0.11, 0.15 and 0.16.

After considering both the recent tests reported in Table 1, and the previous tests of Report No. R-601, it was concluded that 0.15 is a reasonable value for the apparent coefficient of friction between the galvanized fuse plate and beam. It should be emphasized that this is not necessarily the actual coefficient of friction between two galvanized surfaces, but the apparent value based on the assumption that the normal force is equal to the proof load in the bolts that connect the fuse to the sign post.

REFERENCES

1. Olson, R. M., Rowen, N. J., and Edwards, T. C., "Break-away Sign Components Produce Safer Roadside Signs," Highway Research Record No. 174. pp. 1-29.

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