OFFICE MEMORANDUM

MICHIGAN
STATE HIGHWAY DEPARTMENT

September 19, 1966

To: W. W. McLaughlin
Testing and Research Engineer

From: E. A. Finney

Subject: Break-Away-Sign Supports.
Research Project 54 G-73. Research Report No. R-601.

The following is a report by C. J. Arnold concerning torque-tension tests on various combinations of coated A 325 high strength bolts and nuts, including elastic stop nuts for use in the fuse connection of break-away sign supports. Also included are the results of static tension tests on two galvanized fuse connections as per MDSH Plan S440.

Torque-Tension Tests

A description of the various coated bolt and nut combinations used in these tests is given in Table 1. Tables 2 and 3 show test results for the 3/4- and 7/8-in. diam bolts, respectively. Six bolts were tested for each torque value listed, and the mean and range of the resulting tensions are given for both initial torque and retorque fastening conditions.

The tests were made with a Skidmore-Wilhelm bolt tension indicator, and calibrated torque wrenches of 200 and 600 ft-lb capacity. Each bolt was tightened initially to a given torque and the tension recorded. The bolt was then loosened and retorqued to the same value and a second tension reading made. The average tension for each torque and retorque value was determined along with the range of values obtained. The range is an indication of how predictable the tension will be for a given torque on a given bolt-nut-coating combination. Coating thicknesses on representative bolts of each type were measured with the laboratory's Magne-Gage. Accumulated coatings on threads of bolts and nuts required retapping of the nuts in many cases. Taps were made 0.015-in. oversize, as suggested by the Lamson and Sessions Bolt Co., and this clearance was used for all cases where nut retapping was required.

Current specifications for steel sign support structures call for hot-dip galvanizing with a minimum zinc coating thickness of 1.8 oz per sq ft of surface, which is slightly greater than 3 mils. Hot-dip galvanizing of fastening hardware such as bolts and nuts requires a minimum zinc coating on bolts greater than 3/8 in. diam of 1 oz per sq ft (measured outside the thread area) or about 1.7 mils (ASTM A 153). The largest electrodeposited zinc coating class (Type GS, ASTM A 164) requires a minimum thickness of 1 mil measured outside the thread area. Most electrodeposited zinc coatings are usually 1/2 mil or less, and it is generally concluded that the hot-dip process will give considerably greater corrosion resistance on bolt threads than the electrodeposited material. Hot-dip galvanized bolts require a "spinning" operation after dipping to remove excess metal from the threads, and the use of oversized tapped nuts. The Lamson and Sessions Bolt Co. and the Screw and Bolt Co. of America can supply such fasteners. Lamson and Sessions furnished hot-dip galvanized high-strength bolts with nuts retapped oversize, for the Laboratory tests. Should a fabricator wish to supply high-strength bolts to be galvanized locally, he would have to find a galvanizing company equipped with a "spinner" to properly clear the bolt threads of molten zinc. Galvanizers Inc. in Detroit is equipped to do such work, and did so for the Laboratory tests. Oversized retapping of the nuts would then have to be done by the fabricator.

The beeswax lubricant used with some of the hot-dip galvanized bolts tested proved to be very effective. Nuts were prepared for beeswax coating by washing with trichloroethylene solvent after tapping, then dipped one at a time in melted beeswax, and set out to cool. The resultant coating was easy to apply, fairly uniform, and presented no handling problems.

Hot-dip galvanized and zinc-plated bolts without lubrication showed the expected galling tendency, making the torque-tension relationship extremely unpredictable. Application of beeswax to nuts used with the galvanized bolts effectively eliminated galling, and allowed tightening to well above proof load with the application of relatively small torques, as shown in Tables 2 and 3. The change in torque-tension characteristics of similar bolt-nut combinations, with and without beeswax, can be seen from a comparison of Types 1a and 3a. Cadmium-plated bolts exhibited the most uniform torque-tension relationship of the unlubricated combinations. This is because the cadmium tends to act as a lubricant to the steel bolt.

Zinc plus dichromate plating is reported to provide at least 50-percent more corrosion protection than zinc plating alone. The dichromate did seem to allow higher tensions for a given torque (Type 5) than were obtainable with zinc plating alone, probably because the galling tendency of the zinc is reduced somewhat by the dichromate treatment. The range of tension values was still quite wide, however.

Elastic stop nuts cannot be used with hot-dip galvanized bolts because of the resulting oversize bolt thread. ESNA stop nuts were used in the Laboratory tests, with electrodeposited cadmium- and zinc-plated bolts. Close tolerances were used in the manufacture of the stop nuts, so they fit quite tightly on plated bolts. The tight fit did not hinder the torque-tension relationship for the cadmium-plated bolts (Type 4), but the results with zinc-plated bolts were more erratic (Types 2 and 2a). The zinc plating caused galling in the threads, as previously noted. Standard coating thickness for plated elastic stop nuts runs about 0.2 mils, which is not sufficient to provide corrosion protection commensurate to the remainder of the sign structure. For this reason, elastic stop nuts are not recommended for use on steel sign support structures.

In summary, the results of these tests have affirmed the well-known fact that torque is at best a poor indication of bolt tension, especially where zinc coatings are involved.

They have also shown that sufficient tensile force can be developed with reasonable torques in hot-dip galvanized bolts, providing the nuts are retapped to provide sufficient clearance in the threads and beeswax lubricant is used. Electroplated bolts, nuts, and stopnuts are specifically not recommended for use with steel sign supports, because of the difficulty in obtaining sufficient corrosion protection for such fasteners. The best fastener combination from the standpoints of torque-tension uniformity and greatest corrosion resistance was the hot-dip galvanized bolt and nut with a 0.015-in. oversized tapped nut assembled with beeswax lubricant.

Fuse Connection Test

To check out load-slip characteristics of the galvanized contact surfaces, static tension tests were conducted on the galvanized plates, simulating the fuse connections for the 6B8.5 and 8WF17 post supports. Slots and holes in the plates were made as per Plan S440. High-strength, hot-dip galvanized bolts with beeswax lubricant were used to assemble the fuse connections. Test results are shown in Table 4. Failure load is defined as the maximum load achieved prior to a 0.2-in. slip. Coating thicknesses indicated are total zinc thicknesses between mating surfaces.

W. D. Bullen has indicated that the design tensile load requirements for the fuse connections are 16,900 lb for the 6B8.5 post and 42,800 lb for the 8WF17 post. Torque values for the first two tests (Samples 1 and 2) were determined by using a linear proportion of the proof load torque from the torque-tension tests, equal to the plan torque divided by the proof load torque given in Article 5.02.03e9 of the Standard Specifications for Road and Bridge Construction. The maximum tensile loads obtained for Samples 1 and 2 were very low when compared to design requirements. Samples 3 and 4 were then prepared in an attempt to double the torque used in the initial tests. Sample 4, with the 3/4-in. bolts, gave indications of plastic deformation prior to reaching the attempted value, and so a lesser torque was used. Results for both the 3/4- and 7/8-in. diam bolts were still far below the design requirements. Samples 5 and 6 were then prepared by tightening the nuts snug plus a half-turn, which should give some plastic deformation of the bolts. Application of such forces to the simulated 6B8.5 connection caused the slots to widen and distort, resulting in tensile values below those obtained in prior tests (Samples 1 and 4). The simulated 8WF17 connection showed no such visible damage, but the test results (Sample 6) were lower than for the previous tests (Samples 2 and 3).

The remaining specimens were prepared with torque values as shown in the table, and tested to determine variability of results when torque values were held constant. There was considerable variation in failure load, even though the bolts were assembled with beeswax, which gave the least variation in tension for a given torque in the preceding tests. Any assemblies without lubricant would probably show greater variation in tensile capacity.

The relatively low capacities of the friction fuse connections tested may be due in part to the slotted plate. Tests of high-strength bolted connections are usually run on specimens prepared with holes instead of slots. The slots tend to spread as the connections are pulled apart, especially those with the 3/4-in. diam bolts where no back plate is used. Also, the total zinc coating thickness of the connecting surface was quite thick. The iron-zinc alloy that forms at and near the interface is considerably harder than the pure zinc metal. It is possible that thinner zinc coatings would result in more interaction of the harder iron-zinc alloy on the mating surfaces of a bolted connection, and in higher coefficients of friction.

The results of these limited fuse plate connection tests indicate that even with bolt torques exceeding values which would develop bolt tensions equal to the proof load of the bolt, the resulting frictional resistance was insufficient to develop the desired tensile connection capacity. In view of this, we suggest that the sign supports incorporating this type of fuse connection, to be used in the impact tests that have been scheduled at the General Motors Proving Ground, be assembled to develop the greatest possible fuse connection resistance. For the two connections tested here, one might assume that torques of 200 and 300 ft-lb for the 3/4- and 7/8-in. diam bolts, respectively, would approach this condition.

We would also suggest that the impact tests include a break-away sign support without fuse connections, to ascertain the relative behavior and safety potential of this feature when used with aluminum sign panel extrusions.

OFFICE OF TESTING AND RESEARCH

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TABLE 1
DESCRIPTION OF BOLT TYPES

Bolt Type	Description
1	3/4-in. diam hot-dipped galvanized bolt and nut, with 0.015-in. oversize tapped nut. Average bolt shoulder zinc coating thickness = 2.6 mils.
1a	7/8-in. diam hot-dipped galvanized bolt and nut, with 0.015-in. oversize tapped nut. Average bolt shoulder zinc coating thickness = 2.6 mils.
2	3/4-in. diam zinc-plated bolt with ESNA zinc-plated nut. Average bolt shoulder zinc coating thickness = 0.4 mils.
2a	7/8-in. diam zinc-plated bolt with ESNA zinc-plated nut. Average bolt shoulder zinc coating thickness = 0.5 mils.
3	3/4-in. diam hot-dipped galvanized bolt and nut, with 0.015-in. oversize tapped nut and beeswax nut lubricant. Average bolt shoulder zinc coating thickness = 2.6 mils.
3a	7/8-in. diam hot-dipped galvanized bolt and nut, with 0.015-in. oversize tapped nut and beeswax nut lubricant. Average bolt shoulder zinc coating thickness = 2.6 mils.
3b	7/8-in. diam Lampson and Sessions hot-dipped galvanized bolt and nut, with 1/64-in. oversize tapped nut and beeswax lubricant. Average bolt shoulder zinc coating thickness = 2.6 mils.
4	3/4-in. diam cadmium-plated bolt with zinc-plated ESNA nut. Average bolt shoulder cadmium coating thickness = 0.8 mils.
5	3/4-in. diam zinc-plus-dichromate-plated bolt and nut, with 0.015-in. oversize tapped nut. Average bolt shoulder coating thickness = 0.9 mils.
6	7/8-in. diam cadmium-plus-dichromate-plated bolt and nut, with 0.015-in. oversize tapped nut. Average bolt shoulder coating thickness = 0.2 mils.

TABLE 2
TORQUE-TENSION TEST RESULTS FOR 3/4-IN. DIAM BOLTS

Bolt Type	Initial Torque, ft-lb	Initial Bolt Tension, lb		Retorque, ft-lb	Retorqued Bolt Tension, lb	
		Mean	Range		Mean	Range
1	200	22700	14750-27750	200	20100	15750-24750
	260	23000	19250-27750	260	28500	24750-30750
	310	29700	25500-34000	310	24000	21500-27750
2	200	12800	10750-13750	200	8700	7500-9000
	260	19700	15250-23000	260	13700	10750-16250
	310	22600	20000-24750	310	14600	10750-17750
3	50	8000	7500-8250	50	8000	7500-9000
	100	17600	16650-19250	100	17900	17000-19250
	150	37600	36250-39250	150	38460	37000-40000
4	100	21100	19250-23000	100	21000	19250-23000
	150	30200	25500-35500	150	29400	26250-34750
	200	38700	37000-42250	200	36400	33250-39250
5	150	22000	20000-23750	150	20300	16000-23000
	200	29900	27750-32500	200	26700	23000-33250
	250	35000	31000-39250	250	31200	22250-37000

TABLE 3

TORQUE-TENSION TEST RESULTS FOR 7/8-IN. DIAM BOLTS

Bolt Type	Initial Torque ft-lb	Initial Bolt Tension lb		Retorque ft-lb	Retorqued Bolt Tension lb	
		Mean	Range		Mean	Range
1a	370	9200	8250-10500	370	7100	6000-7500
	450	10300	9000-12250	450	7800	6750-9000
	530	13100	11250-14500	530	8900	6000-10500
2a	370	23400	19250-29250	370	17900	15250-21500
	450	23300	20000-26250	450	18900	16750-23000
	530	34400	30000-44500	530	27200	24750-32500
3a	100	20500	18500-22250	100	20500	18500-21500
	150	31500	27750-34000	150	31400	27750-33250
	200	41100	37000-44500	200	41800	38500-46000
3b	150	28700	26500-31750	150	28400	25500-31750
	200	38100	34000-41500	200	38700	34000-41500
6	200	18300	14500-21500	200	15100	11500-18500
	370	29700	24750-35500	370	27500	20000-31750
	450	38100	32500-41500	450	37900	35500-41500

TABLE 4
TENSION TEST RESULTS OF FUSE CONNECTIONS

Post Support Type(a)	Connection Sample No.	Bolt Torque, ft-lb	Load at Which First Slip Occurred, lb	Max. Load at 0.2-in. slip, lb	Ultimate Load, lb	Slip at Ultimate load, in.	Total Zinc Coating Thickness of Contacting Surfaces of Connection, mils
6B 8.5 post with 3/4-in. diam fuse connection bolts	1	120	5000	9300	*	--	10.5
	4	200	8400	12200	*	--	11
	6	250	5500	7800	*	--	9
	7	180	5400	8500	*	--	9.5
	8	180	8000	9700	*	--	9
	12	180	9300	10600	*	--	9
8WF 17 post with 7/8-in. diam fuse connection bolts	2	150	8000	9200	*	--	9 and 14
	3	300	20000	26000	31600	0.5	8 and 13
	5	350	17000	22300	26900	0.5	7 and 12.5
	9	300	--	15300	17000	0.5	6 and 9
	10	300	15400	17200	23200	0.4	5 and 8
	11	300	12200	13400	*	--	6.5 and 12

(a) As per MDSH Plan S440

* Ultimate load is the same as the maximum load at 0.2-in. slip.