INVESTIGATION OF TURN-OF-NUT METHOD FOR SLIP-CRITICAL JOINTS OF ALUMINUM USING A325 BOLTS

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1. INTRODUCTION

Slip-critical bolted joints will be used to join aluminum bridge deck sections by Reynolds Metals Company (RMC). To help ensure that a joint does not slip the proper bolt clamping force to achieve what is known as a friction connection must be determined. One method of achieving the proper clamping force is by "turn-of-nut" tightening. In this method a nut on a bolt clamping a joint together is rotated a specified amount, after first tightening the nut to a snug tight condition. The Specification for Structural Joints Using ASTM A325 or A490 Bolts describes the methodology and requirements for obtaining friction connections in steel and states that for bolts clamping steel plates together the nut must be turned 1/3 of a turn (120 degree rotation) past snug-tight to achieve the desired clamping force, for a bolt length up to and including 4 diameters. The specification states that the tolerance for rotation of the nut is ± 30 degrees. An Aluminum Association specification describing the methodology and requirements for obtaining friction connections in aluminum is currently underway. The ability to achieve a friction connection joint in aluminum was demonstrated by research paid for by RMC in 1995, but the research failed to determine the amount a nut on a bolt must be rotated to achieve this connection. In joining aluminum bridge decks this information would be very beneficial. Otherwise, obtaining these friction connections in field applications would be very cumbersome and difficult.

The specification for the turn-of-nut method in an aluminum joint needs to be determined. Tests must be done to see what effect the difference in stiffness between the aluminum and steel has on the rotation of the nut. To accomplish this task a test plan was developed to determine the difference between an aluminum joint and a steel joint. To determine the relationship between the clamping force in the bolt and the turn-of-nut two series of tests were planned. The first tests were done using a Skidmore-Wilhelm bolt tension calibrator to determine the relationship between the change in length and the clamping force in the bolts. After those results were determined the relationship between the clamping force and the turn-of-nut in an aluminum joint was found.

2. SKIDMORE-WILHELM BOLT TENSION CALIBRATOR TESTS

The tests to determine a relationship between the change in length and the clamping force were accomplished by using a device called a Skidmore-Wilhelm bolt tension calibrator. The Skidmore-Wilhelm bolt tension calibrator gives a direct dial pressure reading equivalent to the bolt clamping force. For these tests a 3/4 inch by 2 3/4 inch A325 bolt was inserted into the Skidmore-Wilhelm device along with 4 washers, which were included to give a grip length equivalent to the grip length of the aluminum joints. The change in length of the bolts was measured with a deep throat micrometer. The bolts, washers and nuts were mechanically galvanized and the nuts were lubricated at the factory.

To develop the relationship between the change in length and the clamping force, the bolt length was measured at several increments of clamping force. Test on five different A325 bolts were done to develop the relationship between the change in length and the clamping force. Figure 1 shows a curve fitted to data from the five Skidmore-Wilhelm tests. Length measurements were commenced at a preload of 3,000 lbs. This curve is linear up to about 25,000 lbs. At this point the curve becomes non-linear, which shows that the bolts are starting to yield. The Specification for Structural Joints Using ASTM A325 or A490 Bolts shows that for a slip-critical connection the minimum clamping force in a 3/4 inch A325 bolt is 28,000 lbs. From the curve in Fig. 1 it is found that to reach a clamping force of 28,000 lbs. the bolt must have a change in length of 0.0045 inches. This information is necessary to be able to determine the amount to rotate a nut in a bolted joint.

3. BOLTED JOINT TESTS

Using the data from the Skidmore-Wilhelm tests the clamping force in a bolted joint can be determined by measuring the change in length of a bolt as the nut is tightened. The next set of tests performed used this information to determine how far to rotate a nut past snug tight to achieve the desired clamping force in an aluminum joint. For these tests three plates were bolted together with a 3/4 inch by 2 3/4 inch long A325 bolt, with a hardened steel washer under both the bolt head and the nut. The three aluminum plates were ½ thick with the surface roughened to a 2 mil profile. The roughening of the aluminum surface is necessary to achieve the needed coefficient of friction for the friction joint. Figure 2 shows the dimensions of the plates. This test series included 3 sets of mill-finish hot rolled steel plates, used as the control case, and 5 sets of aluminum plates.

The procedure used in these tests involved tightening the nuts on the joints and then measuring the change in length of the bolts and the angle of rotation of the nut. The micrometer used in the Skidmore tests was used in these tests to measure the change in length of the bolts. The angle of rotation of the nut was determined by marking the nut and the zero location on the plates. The nut was first tightened on the joints to a snug tight condition. Snug tight was defined as about 25 ft-lbs of torque, which was the torque used on the bolts in the Skidmore test to obtain a 3,000 lb. clamping force in the bolts. This was specified as the zero length for the bolt and the zero angle of rotation. The bolt was then rotated and the angle of rotation and the change in length of the bolt were recorded. This was done at various increments until the nut had been rotated past 150 degrees.

The first tests done were the control case with the steel plates. These tests were done to confirm that the test data taken agreed with the data contained in the Specification for Structural Joints Using ASTM A325 or A490 Bolts. Table 1 shows the amount of clamping force related to the turn-of-nut, based on the results from the Skidmore-Wilhelm tests and the tests on the steel plates. The results of these tests can be seen in Fig. 3. A curve was fitted to the data taken from the 3 sets of steel plates. The graph in Fig. 3 shows that to achieve a change in length of the bolt of 0.0045 inches, which was the value determined in the Skidmore-Wilhelm tests to give a clamping force of 28,000 lbs., the nut must be rotated 95 degrees. This is about the value that would be expected from examining the Specification for Structural Joints Using ASTM A325 or A490 Bolts, which says the nut should be rotated to a minimum of 120 degrees ± 30 degrees.

After completing the control case with the steel plates the tests with the aluminum plates were done. For this test series, data from 5 sets of aluminum plates and A325 bolts was recorded. The relationship between the change in length measured in these tests and the clamping force determined in the Skidmore-Wilhelm tests is shown in Table 2. Figure 4 shows the measured change in length of the bolts versus the turn-of-nut. From these tests the amount of nut rotation to reach a clamping force on 28,000 lbs. was determined to be 81 degrees.

The initial expectations of these test were that since the aluminum is about 1/3 as stiff as the steel the nut rotation should be more in the aluminum than in the steel. The tests did not confirm this expectation. The explanation for this is in what is defined as snug tight. For both the steel and aluminum plates the nuts were initially tightened to what felt like the same torque force, but it is believed that this position is different in the two materials. From snug tight the first value of nut rotation and change in length of the bolts, for both the steel and aluminum plates, was measured after applying 50 ft-lb of torque with a torque wrench. Immediately a difference is seen between these results. For the steel plates the angle of rotation of the nut is about 40 degrees, but for the aluminum plates it is only about 20 degrees. What this means is that the irregularities in aluminum plates and the washers are more quickly being settled out and that the load is going more directly into the bolt. This can be seen by examining the clamping force at 20 degrees and 40 degrees in Tables 1 and 2. Since the steel has a higher value of stiffness it takes more torque to eliminate of the initial non-linearities in the joint and washers. Therefore the initial snug-tight is getting rid of more of these non-linearities in the aluminum joint than it is in the steel joint. The curves fitted to the test data from the aluminum and steel joints are plotted together in Fig. 5. Figure 5 shows that for the steel plates there is a definite non-linear region in the beginning of the curve which is not as apparent in the curve for the aluminum. This means that as the nut is tightened, the aluminum joint is more quickly being drawn together than the steel joint.

4. CONCLUSION

The results of these tests show that the same rules can be applied for tightening bolts in an aluminum joint as those applied in a steel joint. The fact that there is a 14 degree difference between the rotation to reach a 28,000 lb. clamping force in the aluminum plates and the steel plates does not mean that different rules should be applied. This amount is insignificant since the tolerance on the nut rotation is ± 30 degrees and the specifications state that the joint needs to be tightened to a minimum of this value. The fact that the aluminum joint achieves the minimum clamping force sooner than does the steel joint results in a conservatively larger clamping force in the aluminum. The nuts in the aluminum plates were rotated as much as 470 degrees without breaking a bolt. These tests have established that an aluminum joint clamped with an A325 bolt can use the same nut rotation criteria as those specified for a steel joint.

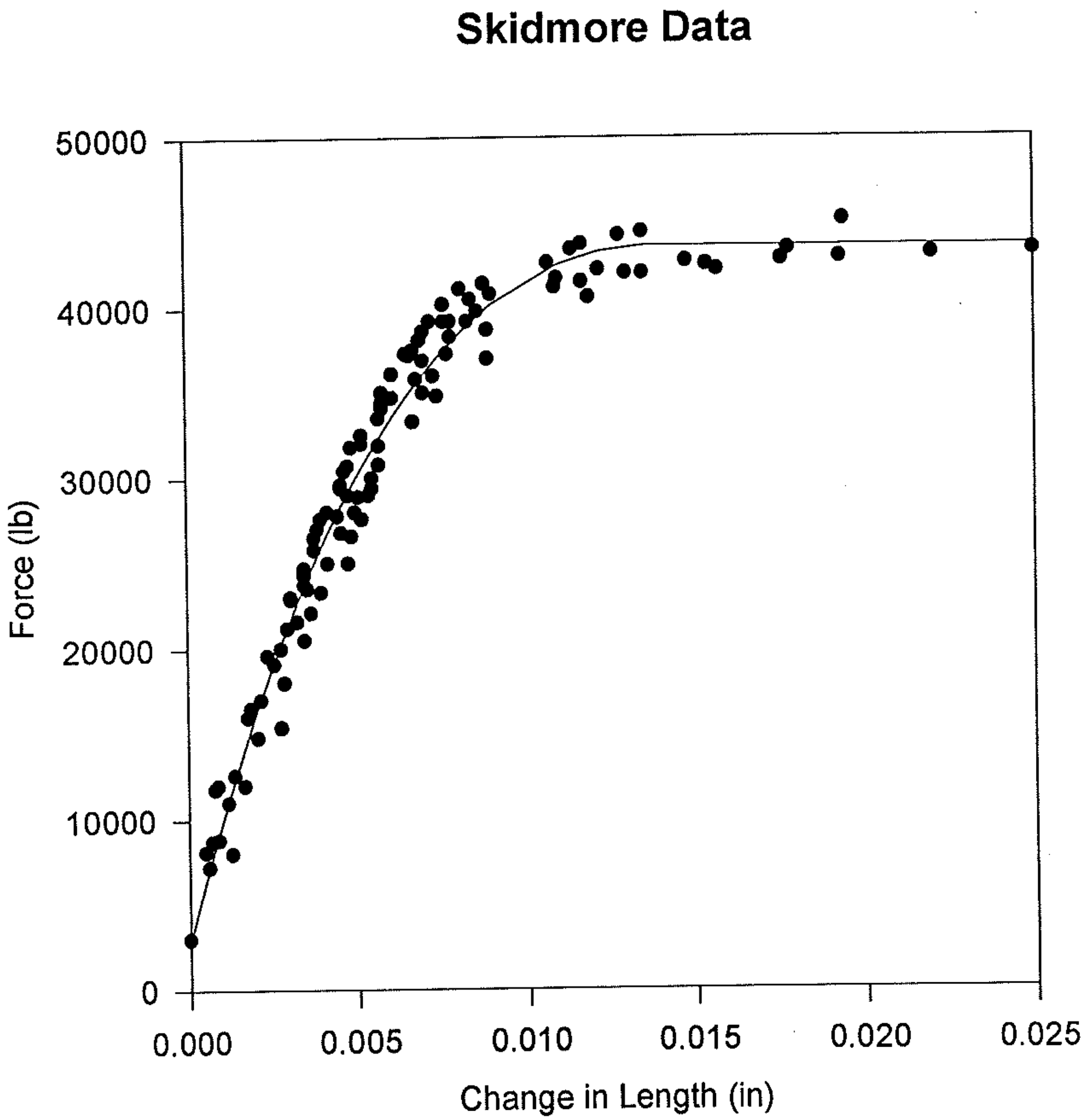

Figure 1. Skidmore-Wilhelm Device Test Data from Five A325 Bolts

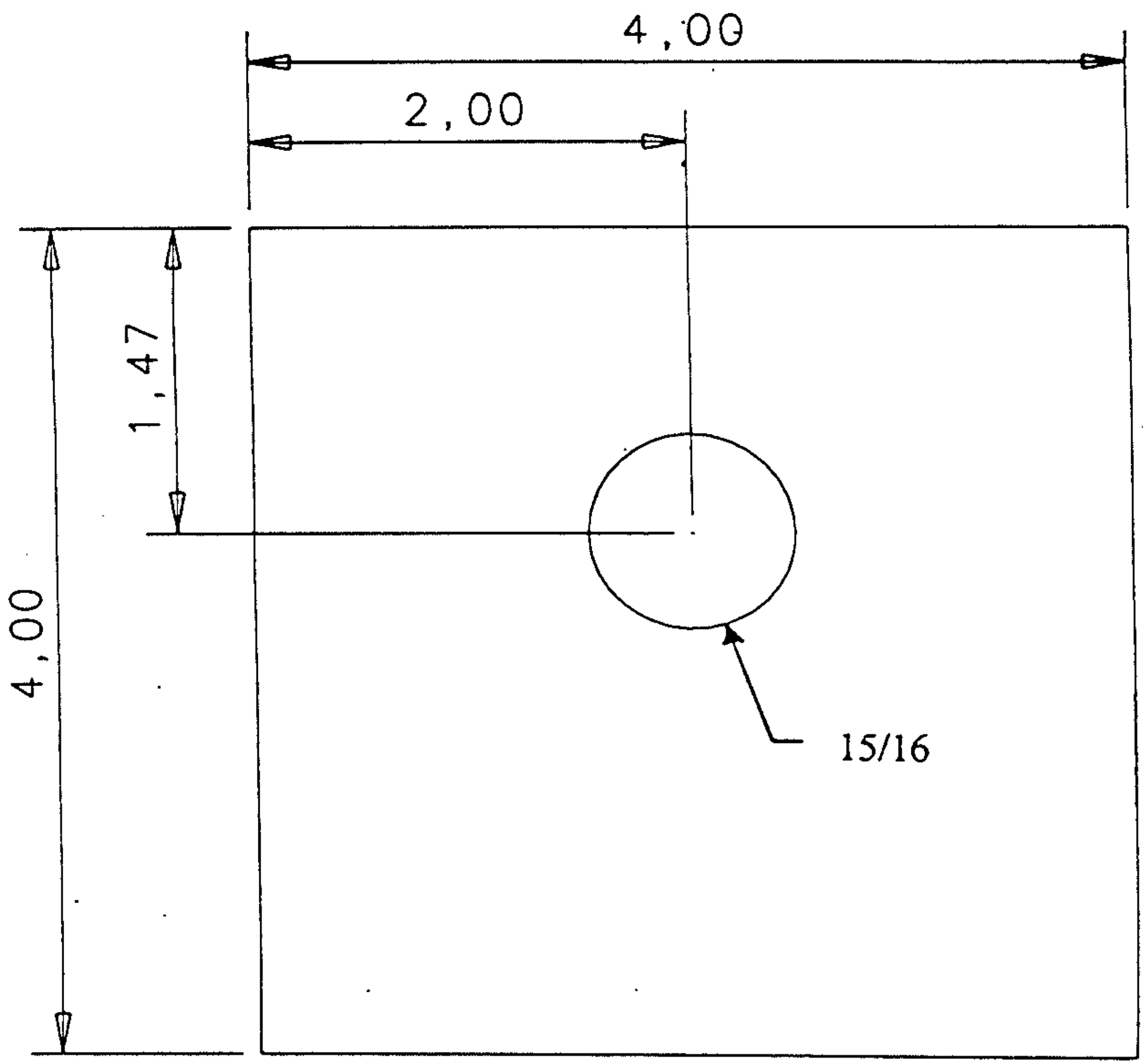

Figure 2. Plate Dimensions

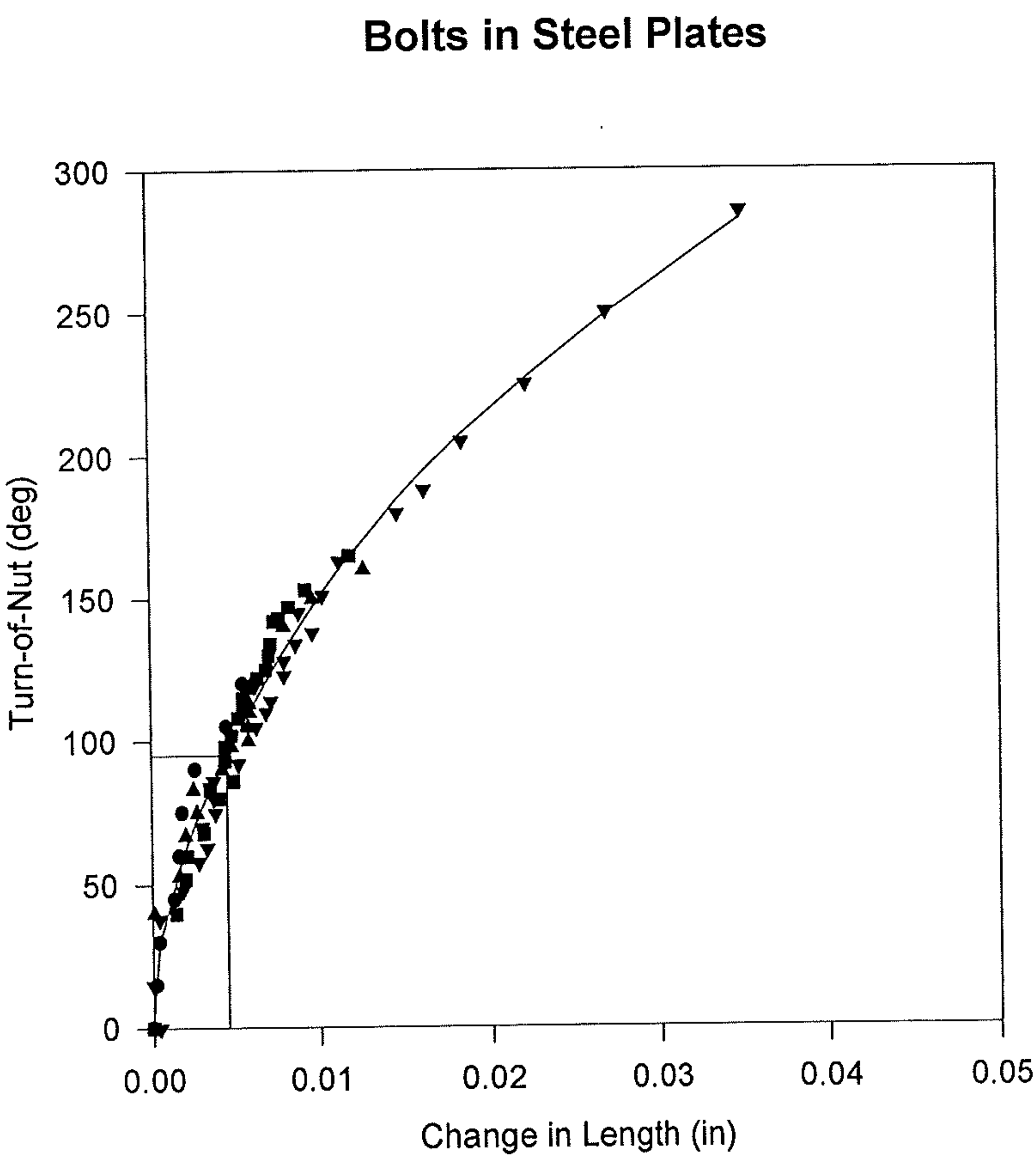

Figure 3. Steel Plate Test Data for Five A325 Bolts

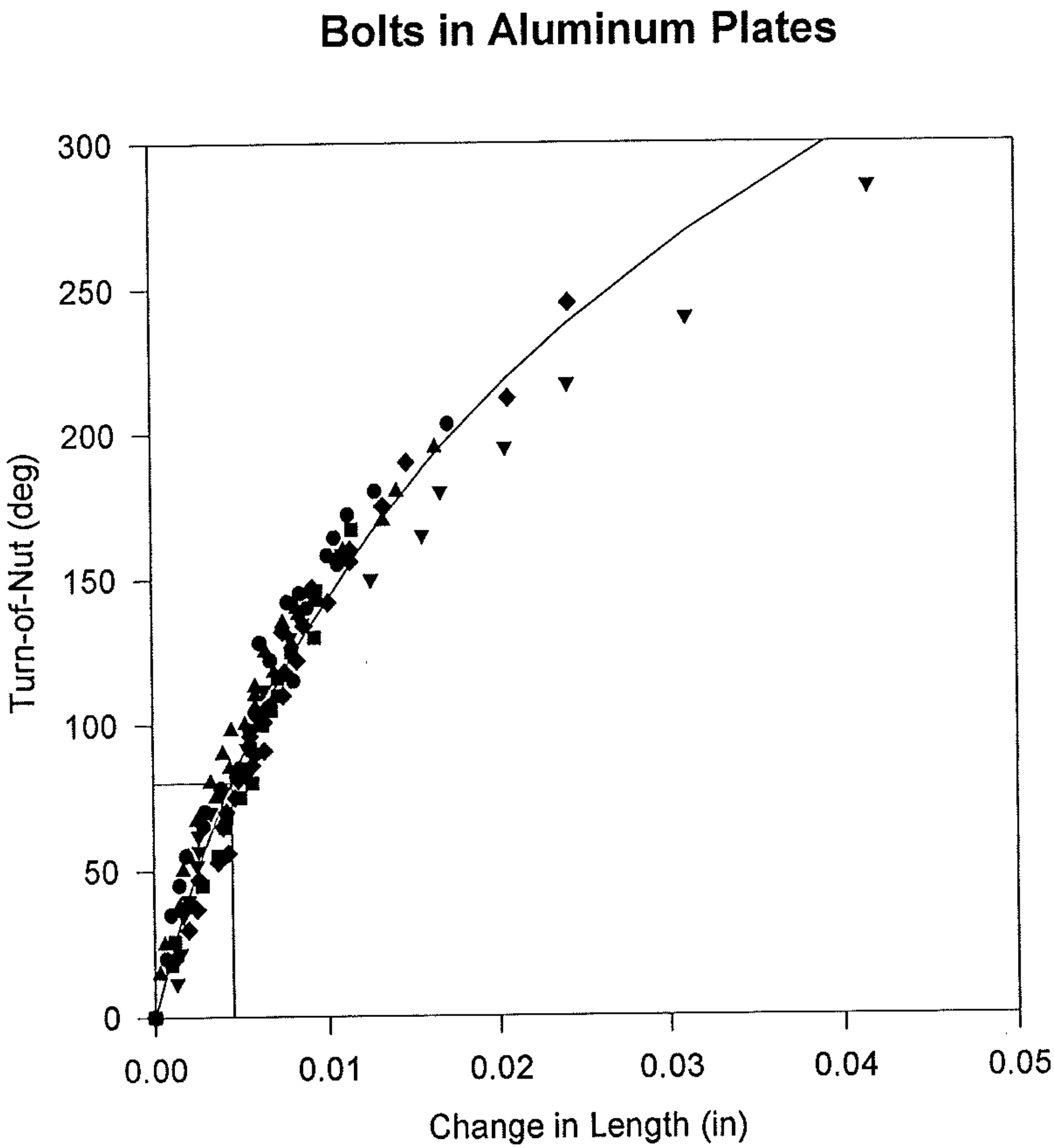

Figure 4. Aluminum Plate Test Data for Five A325 Bolts

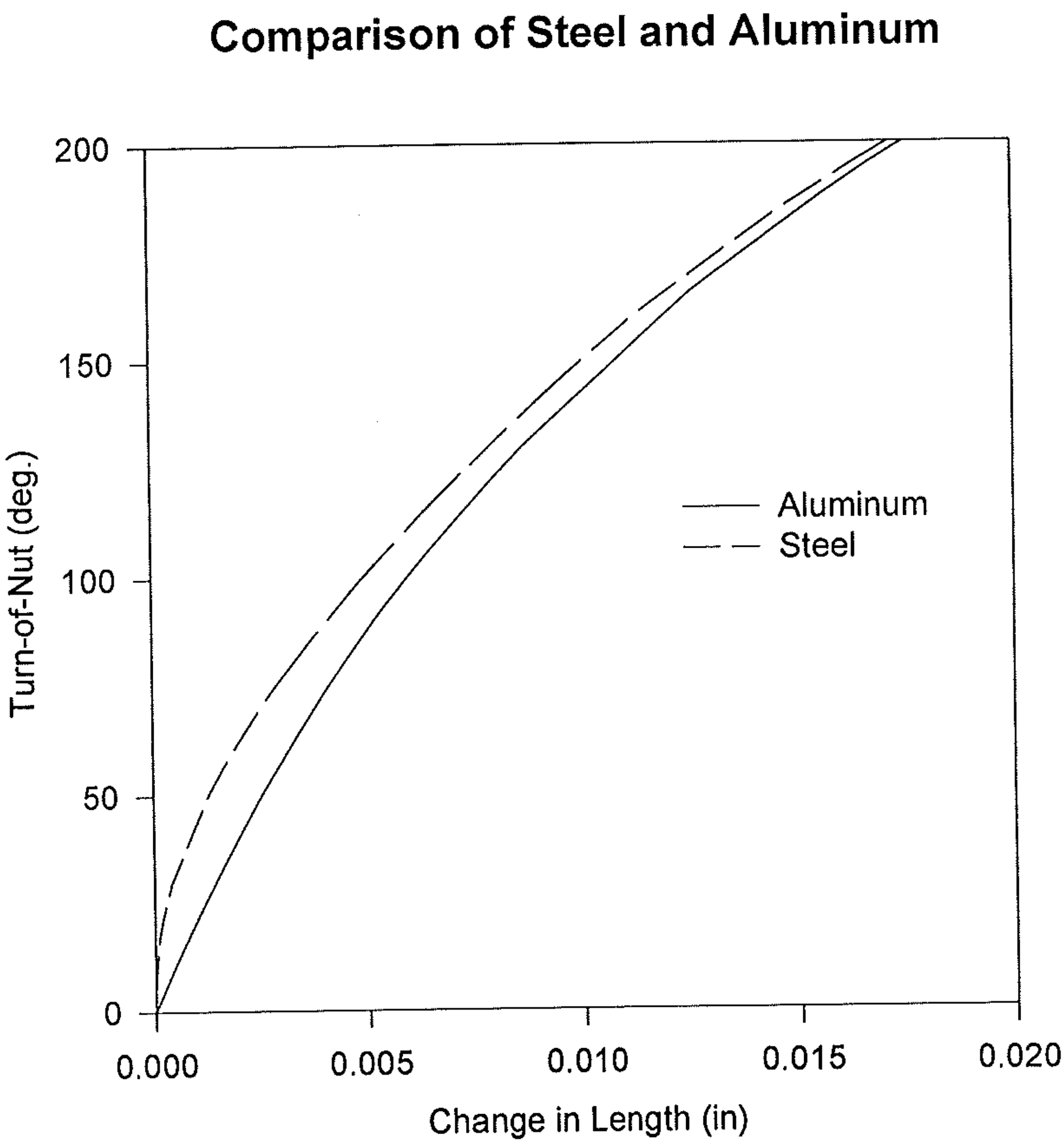

Figure 5. Comparison of Steel and Aluminum Plates

Table 1. **Comparison of Clamping Force to Turn-of-Nut for Steel Plates Clamped With 3/4 inch Diameter A325 Bolts.**

Turn-of-Nut	Average Change in Length (in)	Force from Skidmore (lb)
0°	0.0	3,000
20°	0.000157	4,100
40°	0.000792	8,500
75°	0.00288	20,700
80°	0.00326	22,600
81°	0.00334	23,000
90°	0.00407	26,300
95°	0.00450	28,000
100°	0.00494	29,700
120°	0.00682	35,700
150°	0.01002	41,600
180°	0.01392	43,600
200°	0.01709	43,600

Table 2. Comparison of Clamping Force to Turn-of-Nut for Aluminum Plates Clamped With 3/4 inch Diameter A325 Bolts.

Turn-of-Nut	Average Change in Length (in)	Force from Skidmore (lb)
0°	0.0	3,000
20°	0.000921	9,400
40°	0.00196	15,700
75°	0.00410	26,400
80°	0.00445	27,800
81°	0.00452	28,100
90°	0.00517	30,600
95°	0.00556	32,000
100°	0.00595	33,200
120°	0.00767	37,700
150°	0.01072	42,300
180°	0.01448	43,600
200°	0.01744	43,600

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