Research Report

EFFECTS OF HEAD SIZE ON THE PERFORMANCE OF TWIST-OFF BOLTS

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EFFECTS OF HEAD SIZE ON THE PERFORMANCE OF TWIST-OFF BOLTS

1. PURPOSE

The head diameter of button-head type twist-off bolts necessary for adequate and reliable performance has been brought into question. Following the RCSC Specification, F436 washers are not required under the bolt head when the bolt head diameter equals or exceeds the diameter of a standard ASTM F436 washer, when used on oversized and slotted holes. The same is true for A490 strength bolts that are used with steels that have minimum specified yield strengths less than 40 ksi. The intent of this study was to determine if the RCSC Specification should be modified to allow for ASTM F1852 minimum diameter twist-off bolts.

Minimum head diameters that are smaller than an ASTM F436 washer are allowed under the ASTM F1852 specification. Some manufacturers produce twist-off bolts that have head diameters that are larger than that required by ASTM F1852, but are less than the ASTM F436 washer diameter. These diameters would be required to have a washer under the bolt head on oversized and slotted holes if the current RCSC Specification was followed.

The purpose of this research was to determine if bolts with ASTM F1852 minimum head diameters are comparable to those with a diameter equal to or larger than an ASTM F436 washer. Testing was done on bolt diameters ranging from 5/8 in. to 1-1/8 in., including both A325 and A490 strength bolts. Bolt heads having the minimum required diameter permitted by ASTM F1852 were tested against those having larger head diameters. Plates were used with various hole sizes including standard, oversized, excessively oversized and slotted holes.

2. PREVIOUS RESEARCH

Previous research dealing with twist-off bolts is very limited. Much of this work did not deal specifically with the effects of bolt-head size on pretension forces. However, some work is related to the findings contained in this report.

Research was conducted by Chesson and Munse in the early 1960's at the University of Illinois dealing with the effect of washers on the clamping force of 3/4 in. A325 bolts. Regular and heavy semi-finished hexagon head bolts were used along with finished, heavy, and flanged nuts. Hole sizes ranged from a standard 13/16 in. diameter hole to an oversized hole of 7/8 in. diameter. The majority of the bolts were tightened using turn-of-nut method. The tightening procedure involved snugging the bolt with an impact wrench to approximately 5,000 pounds, then turning the nut or bolt head an additional one-half turn. Bolts that were tightened with washers under the bolt head were compared to those tightened without washers.

Test results showed that the presence of a washer under the bolt head had no significant effect on the clamping or pretension force achieved in the bolts for all hole sizes. The type and hardness of the nut had a greater effect on the clamping force than the washers. The torque required to achieve the pretension forces measured was found to be higher for the bolts without washers due to the galling of the nut into the soft plate material. Hole size did not influence the achieved pretension by a significant amount. All clamping forces on oversized holes without washers were well above the required minimum, and comparable to the tests conducted on standard holes with washers. Long term relaxation of the bolts forces was also studied and found that the inclusion or exclusion of washers had no influence on relaxation. The major difference between the testing conducted by the University of Illinois and the testing contained in this report deals with the kind of bolts used and the method of tightening that was employed -- hexagon head bolts compared to twist-off bolts and turn-of-nut procedure versus twist-off torque control.

Allan and Fisher performed studies on oversized and slotted holes in the late 1960's. They were primarily concerned with holes having larger clearances, above the 1/16 in. and 1/8 in. tested by Chesson and Munse. Bolts of 1 in. diameter and A325 strength were

tested in hole sizes of 1/4 in. and 5/16 in. above the nominal bolt diameter and compared against the standard 1/16 in. clearance. The bolts were installed with and without washers using the turn-of-nut method. The results obtained were analyzed to observe the effects of oversized and slotted holes had on achieved bolt pretension, bolt relaxation, and joint slip resistance. The data was used to determine if washers should be required under the bolt head.

Bolts tested in the 1-1/16 in. standard hole without washers were able to attain pretensions well above the minimum, as shown in the previous tests by Chesson and Munse. Bolts tested in the 1-1/4 in. oversized hole without washers had the same average pretension as bolts tested with washers in the same hole size. These pretensions however were slightly lower than those obtained in the 1/16 in. hole size. The increased hole size increased galling around the hole in the test setups that did not include washers under the bolt head. The 5/16 in. oversized holes required washers under both the head and nut to attain the necessary pretension. The relaxation of the bolts was not affected by oversized and slotted holes. Allan and Fisher also concluded that the slip coefficient for the 1-1/4 in. holes were comparable to the standard holes, however the coefficient decreased for the 1-5/16 in. and slotted holes. Omitting washers from the 1-1/4 in. oversized hole did not affect bolt pretension greatly but they were suggested to be used to prevent plate galling.

Other research relating hole size and joint slip coefficients can be found in "Bolted Connections with Varied Hole Diameters" by Shoukry and Haisch. Their tests involved determining the effects oversized holes had on bolted connections. 3/4 in. and 7/8 in. A325 bolts were used in butt and lap joints and were tightened using the calibrated wrench and the turn-of-the-nut methods with washers only under the turned element. Hole clearances ranged from 1/16 in. up to 1/4 in. Testing concentrated on the initial slip of the joints which was needed for slip coefficient calculations. After this data was collected, the specimens were loaded until failure to find the ultimate shear load and shear stress of the joint. Results showed that the slip coefficients and ultimate shear strengths of the joints were not significantly affected by hole clearances up to 3/16 in. This is true for the 3/4 in. and 7/8 in. A325 bolts tested in the butt and lap joints.

More recent testing specifically with twist-off bolts was performed by Kulak and Undershute in the late 1990's, studying factors that affect the achievable pretension force in twist-off bolts. They stated that, "Factors that affect the preload of a tension control bolt are bolt material strength, thread conditions (such as lubrication, dirt, and thread damage), the diameter of the annular groove at the splined end, and friction conditions at the nut-washer interface." The main factors investigated included the effects of storage and aging conditions as well as friction conditions on the achieved pretension force in the bolt. Bolts of 3/4 in. diameter and A325 strength were received from seven different manufacturers. These bolts were of different ages upon receipt and were purposely subjected to different storage conditions prior to tightening. Some of these conditions included sealing the bolts in a container for up to 4 weeks, fully exposing others to the elements and subjecting additional bolts to humid environments. The friction tests involved testing bolts with different lubrication arrangements.

All of the bolts in the storage tests were able to attain the required pretension force. Sealing in containers and exposing to humidity had little effect on the ultimate pretension. Average values for these were 16% to 20% higher than required. Full exposure to weather, and weathered snugged bolts in a steel joint produced the lowest pretension values, around 5% to 10% above that required. The friction tests revealed how loss of lubrication on the assembly affects pretension values. These bolts were an average of 20% below the required preload force. On the high end, bolts and washers that were cleaned and relubricated resulted in a pretension 52% above required. The tests performed by Kulak and Undershute show how important storage conditions and proper lubrication is on the ultimate pretension force in twist-off bolts.

Research by Oswald, Dexter and Brauer dealt with large-diameter bolts and the effects of grip length on pretension forces. Their work found that many 1 in. and 1-1/8 in. bolts that had grip lengths longer than 7 in. were unable to attain the necessary preload required. Shorter length bolts had no problem attaining this value. Reasons for the low pretensions attained were stated as, "greater difficulty in snugging the plies in the connections with the longer bolts and the very high pretension forces that the large-diameter, high-strength bolts required to develop specified pretension stresses...".

suggested that "designers should consider alternatives to the use of large diameter A490 bolts in slip-critical joints, especially if the bolts have a long effective bolt length (greater than 178 mm or 7 in.) and are installed through more than one interface".

The research that is most related to this study is that performed by Chesson and Munse and by Allan and Fisher. Both tests looked at the need for washers under the bolt head in oversized holes. The main difference is the type of tightening procedure used and the type of bolts tested. The work by Allan and Fisher and Shoukry and Haisch added information on effects of hole size on pretension forces and slip coefficients.

Kulak and Undershute's analysis show how storage conditions and lubrication amounts alter the attainable ultimate preload. All bolts tested in this study were kept in closed lid boxes inside the laboratory and were received with proper lubrication prior to tightening. The study by Oswald, Dexter and Brauer demonstrated one more factor that can affect a bolt's pretension force. Although no bolts in this test had a grip of 7 in., it is still important to recognize the potential reduction of attained preload as bolt diameter, grip, and strength increase.

3. DESCRIPTION OF BOLTS

A single twist-off bolt manufacturer provided all of the bolts tested in the project. They supplied both ASTM F1852 minimum head diameter and their standard head diameter in both F1852/A325 and A490 strengths. Specifics for these bolts can be found in the bolt certificates that are provided in Appendix A.

The minimum head diameter bolts that were used during testing had to be manufactured on a special basis by the manufacturer. The bolts were machined from the manufacturer's standard head diameters down to the minimum ASTM F1852 diameter. Table 3.1 provides average measured head diameters for the minimum head diameter and the asmanufactured bolts, and the nominal F436 washer diameters. Figure 3.1 shows photos of minimum and standard head diameters, as supplied.

Bolt Diameter	Minimum Head Diameter (ASTM F1852)	Manufacturer's Standard Head Diameter	F436 Washer Diameter
5/8" (A325)	1.099"	1.166"	1.313"
3/4"	1.340"	1.394"	1.469"
7/8"	1.534"	1.578"	1.750"
1"	1.771"	1.846"	2.000"
1-1/8"	1.992"	2.178"	2.250"

Table 3.1: Average Head Diameters for Supplied F1852/A325 & A490Strength Bolts, and F436 Washer Diameters



Figure 3.1: Photo of Manufacturer's Standard and F1852 Minimum Diameter 1-1/8" Bolts

4. TEST SETUP AND PROCEDURE

The standard of comparison between the minimum ASTM F1852 and the manufacturer's standard head diameters was the achieved pretension force in the bolt after tightening. A Skidmore Wrench Calibrator, (Model ML), was used to measure the tension in the bolt. Bolts ranging from 5/8 in. to 1-1/8 in. were tested with plates having standard, oversized, grossly oversized, and slotted holes. These plates were steel of A36 minimum yield strength and measured 4 in. square by 1/4 in. thick. Plate holes ranged from 1/16 in. to 3/8 in. greater than the bolt diameter. Testing of specimens produced an average plate yield strength of 34.89 ksi and tensile strength of 51.27 ksi. All plate holes were measured prior to testing to ensure correct diameters.

The test setup involved placing the bolt head along with a plate on the front of the Skidmore with a flat bushing on the rear. A washer and nut was placed on the bolt and tightening was done from the back on the Skidmore. Figure 4.1 shows a typical setup from the front of the Skidmore. Additional pictures of the test setup can be found in Appendix E. Two different electrically powered Tone wrenches were used for tightening the bolts, Model S-60EZA for the 5/8 in. through 7/8 in. bolts, and Model S-110EZ for the 1 in. and 1-1/8 in. bolts.

Once the bolts were installed in the Skidmore, the wrench was used to snug the bolts against the plate. After waiting several seconds, the wrench was then used to tighten the bolts until the splined end sheared off. An initial measurement of bolt pretension was taken 5-10 seconds after tip twist-off. A second reading was taken 30-45 seconds later after most of the bolt relaxation had occurred. After the two readings were recorded, the bolt was then removed using an air impact wrench. All bolts and plates were visually inspected after testing for concerns such as plate embedment depths.

Tables 4.1 and 4.2 show the test plate matrix used for each bolt diameter. Bolt strengths of F1852/A325 and A490 were tested for bolt diameters ranging from 3/4 in. through 1-1/8 in. The 5/8 in. diameter bolts were tested with F1852/A325 strength only, due to the lack of availability of A490 strength twist-off bolts.

The first set of tests were conducted with the bolts centered in the middle of the hole. The holes in these plates were punched, which resulted in a slightly larger hole diameter on one side of the plate. All bolt diameters except the 7/8 in. were placed in the Skidmore with the larger diameter facing the bolt head. The plates used for the 7/8 in. bolts were reversed so that the smaller hole diameter was now facing the bolt head. This was done to determine if there would be any noticeable difference in performance.

After the first set of tests were finished, a second set of tests were conducted placing the bolt to one side of the hole diameters. This was done to determine if there were any deviations in performance compared to tests performed with the bolts centered in the holes. 3/4 in. through 1-1/8 in. bolts were used for these tests, as outlined in Table 4.2. The holes in these plates were punched in some as well as drilled or punched and flame-slotted in others. All plates were placed with the larger hole diameter facing the bolt head.

Bolt	Standard	3/16"	1/4"	5/16"	3/8"	Long-
Diameter	Holes	Oversized	Oversized	Oversized	Oversized	Slotted
5/8" (A325)	11/16"	13/16"	7/8"	15/16"		11/16" x 1-9/16"
3/4"	13/16"		1"	1-1/16"		13/16" x 1-7/8"
7/8"	15/16"		1-1/8"	1-3/16"		15/16" x 2-3/16"
1"	1-1/16"		1-1/4"	1-5/16"		1-1/16" x 2-1/2"
1-1/8"	1-3/16"			1-7/16"	1-1/2"	1-3/16" x 2-13/16"

Table 4.1: Test Matrix with Bolts Centered in Holes

As previously explained, the F1852 minimum and manufacturer's standard bolt heads were tested in standard, oversized, grossly oversized and long-slotted holes in centered and off-centered positions. With the change in hole size along with bolt position, comes a change in the bearing area between the plate and the underside of the bolt head. The influence of bearing area on the achievable pretension force in twist-off bolts will be discussed further in the coming sections.

Bolt Diameter	5/16" Oversized	3/8" Oversized	Short- Slotted
3/4"			1-1/16" x 1-5/16"
7/8"	1-3/16"		
1"			1-3/16" x 1-9/16"
1-1/8"		1-1/2"	

Table 4.2: Test Matrix with Bolts Placed to One Side of Hole

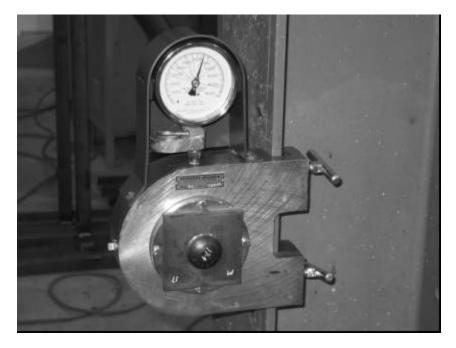


Figure 4.1: Typical Skidmore Setup with Test Sample

5. EXPERIMENTAL RESULTS

5.1 Overview

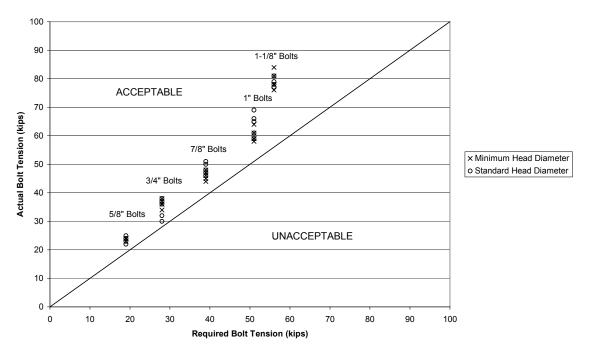
Results for the tests on the F1852/A325 and A490 strength bolts can be found in Appendices C and D, respectively. The data shows initial and relaxed bolt tension strengths that were read directly from the Skidmore. Usually a drop of one to two kips occurred between the initial and relaxed readings.

Graphs have also been included in Appendices C and D as well as below. Unacceptable and acceptable regions for all of the bolts are shown on the graphs.

5.2 Results for F1852/A325 Strength, Centered Bolts

In Figures 5.1 through 5.3, A325 strength, ASTM F1852 minimum head diameter bolts are compared against the manufacturer's standard bolts. The three figures are divided into standard, oversized, and long-slotted holes, with all of the bolts centered in the holes. Each of these figures clearly indicates that the F1852 minimum head diameter bolts are able to achieve the same pretension as the manufacturer's standard bolt. All of the F1852/A325 bolts, minimum and standard, were above the necessary required bolt pretension force. The minimum head diameter bolts are all within the reasonable scatter that is expected.

More significantly, the size of the hole in the plate showed no significant effect on the achieved bolt pretensions. The bolt forces developed in the standard, oversized, excessively oversized and long-slotted holes are all randomly distributed within the normal scatter for both minimum and standard bolt diameters. Figures C.1 and C.2 in Appendix C illustrate these results. A more in-depth look at the pretension forces for each bolt diameter is available in Figures C.3 through C.7 in Appendix C. Individual graphs for each F1852/A325 bolt diameter are provided which show the achieved pretension for each specific hole size. F1852 minimum and the manufacturer's standard bolt heads are compared against each other. Averages of the pretension force per bolt head and hole clearance are also shown.



All F1852/A325 Centered Bolts - F1852 Minimum & Manufacturer's Standard Head Diameters -Standard Holes

Figure 5.1: F1852/A325 Strength, Centered Bolts, Standard Holes

All F1852/A325 Centered Bolts - F1852 Minimum & Manufacturer's Standard Head Diameters - Oversized Holes

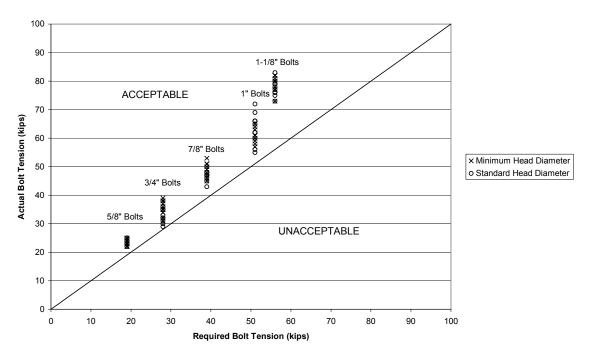
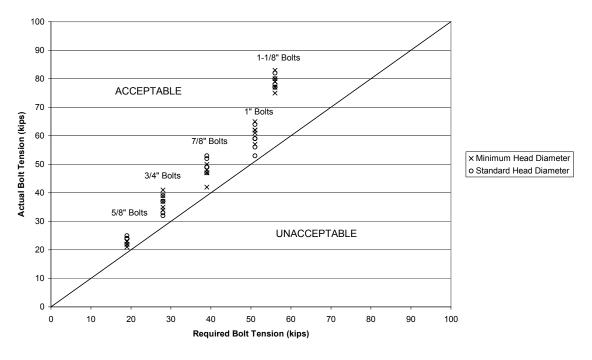


Figure 5.2: F1852/A325 Strength, Centered Bolts, Oversized Holes

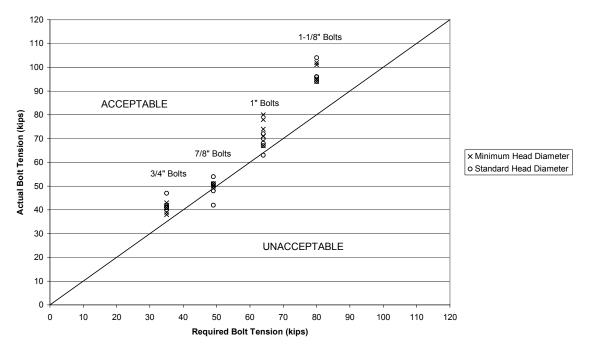


All F1852/A325 Centered Bolts - F1852 Minimum & Manufacturer's Standard Head Diameters - Long-Slotted Holes

Figure 5.3: F1852/A325 Strength, Centered Bolts, Long-Slotted Holes

5.3 Results for A490 Strength, Centered Bolts

In Figures 5.4 through 5.6, A490 strength bolts with the ASTM F1852 minimum head diameter are compared against the manufacturer's standard. The figures are divided by standard, oversized, and long-slotted holes with all of the bolts centered in the holes. All three plots are consistent with the results from the F1852/A325 tests. The minimum head diameter bolts show no indication that they are unable to achieve as much pretension as the manufacturer's standard head bolt. A single 7/8 in. bolt was found to have a relaxed pretension of 42 kips which is well below the required pretension of 49 kips. It is believed that this bolt was damaged in some way, and therefore it has been recorded but excluded from the averages. The 7/8 in. bolts were closest to the required pretension for both the minimum and manufacturer's standard bolt heads. The range of minimum and maximum pretension increased as the hole sizes increased from standard to oversized to long-slotted. This is most evident for the 1-1/8 in. bolts.



All A490 Centered Bolts - F1852 Minimum & Manufacturer's Standard Head Diameters - Standard Holes

Figure 5.4: A490 Strength, Centered Bolts, Standard Holes

All A490 Centered Bolts - F1852 Minimum & Manufacturer's Standard Head Diameters - Oversized Holes

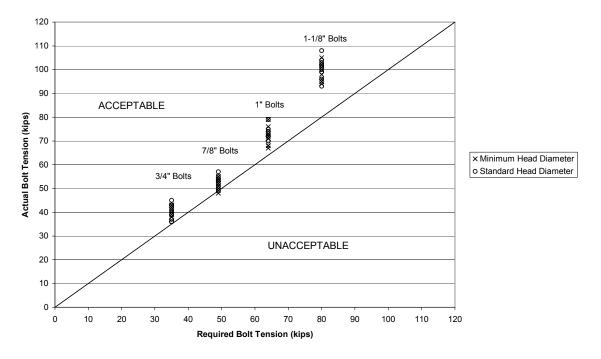
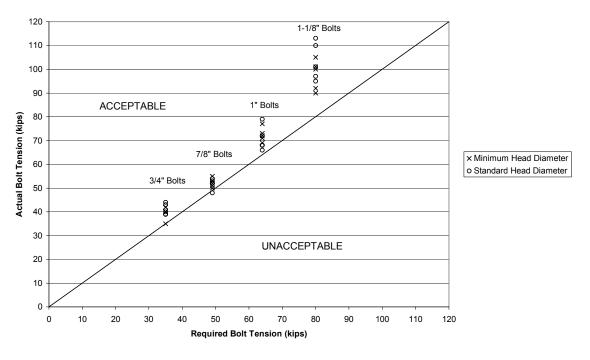


Figure 5.5: A490 Strength, Centered Bolts, Oversized Holes



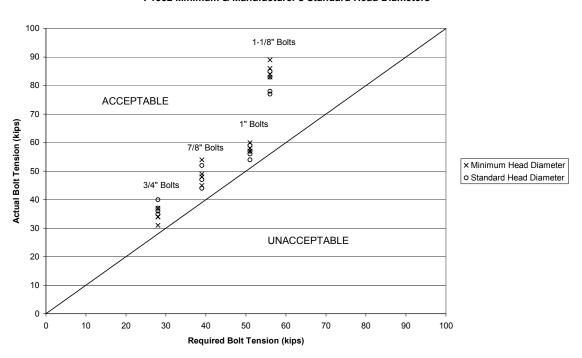
All A490 Centered Bolts - F1852 Minimum & Manufacturer's Standard Head Diameters - Long-Slotted Holes

Figure 5.6: A490 Strength, Centered Bolts, Long-Slotted Holes

More significantly, the effect of hole size on the A490 bolts can be seen in Figures D.1 and D.2 in Appendix D. The effect of standard, oversized, grossly oversized and long-slotted holes on pretension forces is minimal. The achieved pretensions for all four hole sizes are within the regular expected distribution, for both the minimum and standard head diameters. Additional graphs of pretension forces for each bolt diameter are available in Figures D.3 through D.6 in Appendix D. Individual graphs for each A490 bolt diameter are provided which show the achieved pretension for each specific hole size. F1852 minimum and the manufacturer's standard bolt heads are compared against each other. Averages of the pretension force per bolt head and hole clearance are also shown.

5.4 Results for F1852/A325 & A490 Strength, Off-Centered Bolts

After all of the testing was complete with the various bolts centered in the plate holes, a second set of tests was run with bolts set in off-centered positions. This was done with 3/4 in. through 1-1/8 in. bolts with the plate holes shown in Table 4.2. Results of these tests are in Appendix C and D as well as in Figures 5.7 and 5.8 below. The achieved pretensions for minimum and standard bolt diameters were not affected significantly by this alteration. All of the F1852/A325 strength bolts were well above the required pretension. A few of the A490 strength, 7/8 in. bolts were just below the required strength, which is consistent with the previous tests. The 3/4 in. and 1 in. bolts were not affected significantly by the short-slotted holes. Average pretensions for both of these were well within the expected scatter. Comparing Figures 5.7 and 5.8 with Figures C.1, C.2, D.1 and D.2 also shows the minor effects of off-centering the bolt.



All F1852/A325 Off-Centered Bolts F1852 Minimum & Manufacturer's Standard Head Diameters

Figure 5.7: F1852/A325 Strength, Off-Centered Bolts

All A490 Off-Centered Bolts F1852 Minimum & Manufacturer's Standard Head Diameters

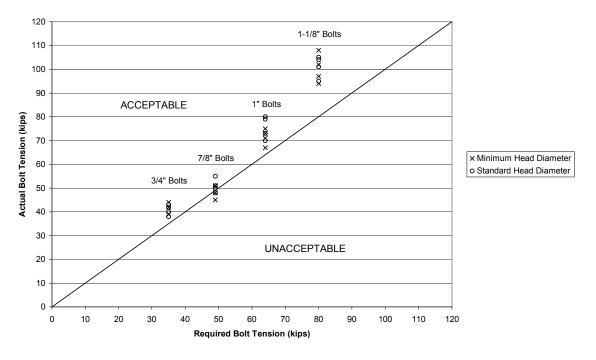


Figure 5.8: A490 Strength, Off-Centered Bolts

The tests conducted on the A325 and A490 centered bolts along with the tests on the A325 and A490 off-centered bolts demonstrates the lack of influence that hole diameter has on achieved pretension. The hole diameter, whether standard, oversized, grossly oversized or long-slotted relates directly to bearing area under the twist-off bolt head. Whether the bearing area is large or small, it will not affect the achieved pretension force in a twist-off bolt. This is due to the type of bolts used along with the method needed for tightening – torque control.

6. CONCLUSIONS

The purpose of this investigation was to determine if RCSC Specification should be modified to allow for smaller bolt heads on twist-off bolts. The current specification removes washer requirements for bolts with a head bearing diameter equal to that of an F436 washer. The ASTM F1852 specification allows for smaller bolt head diameters.

Testing was conducted on bolts with both minimum and a manufacturer's standard head diameter. The bolts ranged in size from 5/8 in. to 1-1/8 in., and included both F1852/A325 and A490 strength. These bolts were tested on various hole sizes in both centered and off-centered positions. A total of 434 bolts were tested, half with minimum head diameter, the other half with the manufacturer's standard head diameter. Of the 217 minimum head diameter bolts, only three were under the required pretension force and deemed unacceptable. Of those with the manufacturer's standard head diameter, five of the 217 bolts were found to be unacceptable. Overall, both head diameters performed well in all circumstances, regardless of hole size and type.

Final analysis of the data has shown that there is no significant difference in the achieved pretension force between the manufacturer's standard head and minimum bolt head diameter. The data clearly indicates that the minimum head diameter is able to attain the same pretension force as the manufacturer's standard head diameter.

More significantly to the issue of the RCSC Specification provisions regarding twist-off bolt head diameter, the size of the hole is also shown to not affect the pretension force in the bolt. The pretension expected to be achieved with a bolt with the minimum F1852 head diameter is the same as that of a bolt with a larger head diameter equal to the size of a F436 washer, if the hole size meets the RCSC Specification limitations on hole size.

This conclusion can be drawn from the fact that amount of bearing surface under the twist-off bolt head does not affect achieved bolt pretension. This was demonstrated by measuring bolt pretension in grossly oversized round holes, when used centered in long-slotted holes, and when off-centered in slotted holes, without the presence of a washer beneath the head as called for in the RCSC Specification. There was no significant reduction in achieved bolt pretension from that of a standard hole diameter, even with

minimum bolt head diameters, when these bolts were used in bolt holes that exceeded the oversized diameter permitted by the RCSC Specification. Similarly, the bolt bearing area was at a minimum when used centered in long-slotted holes, yet the achieved bolt pretension was virtually identical to that achieved in a standard hole.

Tests using A490 strength level twist-off bolts in very low-strength steel plate also demonstrated that the achieved pretension was not significantly reduced with either oversized or slotted holes, compared to standard holes.

Because the twist-off bolt uses torque control to establish the shearing of the bolt spline, it is not affected by the amount of embedment in the steel plate that occurs beneath the bolt head. There is a reduction in achieved pretension if turn-of-nut methods are used, as embedment depths increase, as demonstrated by prior University of Illinois tests. The amount of embedment of the steel beneath the bolt head increases with smaller bolt head size, with increasing bolt hole diameter, higher strength (A490 strength compared to F1852/A25 strength) bolts, and lower strength material, but there is no correlation with bolt pretension associated with the amount of embedment when the twist-off bolt method is used.

The RCSC Specification footnote (a) to Table 6.1 should be revised to reflect that washers are not required beneath the bolt head of a twist-off bolt provided that the bolt head diameter meets the minimum head diameter requirements of ASTM F1852, rather than provide a bearing circle equal to or greater than that of an F436 washer. Similarly, section 6.2.1 should be revised to state that a washer is not required beneath the head of an A490-strength twist-off bolt when used in steels with a specified minimum yield strength less than 40 ksi, provided the bolt head diameter meets the minimum head diameter requirements of ASTM F1852.

7. REFERENCES

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APPENDIX A

BOLT INSPECTION CERTIFICATES

ASTM F1852 Type 1 ASTM A563 Grade DH+00	Specification		_		Si	Size			Qua	Quantity		1	4		One	Unyti	One Unytite Drive	ive	
ASTM F436 Type 1	Type 1 Grade DH ype 1	+00		5/8-11	11 DNC	C X 3			7,92	7,920 pcs.		1		Peru, Illinois 61354 815-224-2221 — FAX # 815-224-3434	Peru, I-2221	- FA	Peru, Illinois 61354 1-2221 — FAX # 815-22	354	3434
Mechanical properties testing in a production of the second source in the second secon	ties tested	5 81 undance	to ASTM FEDEFEDEM, ASTM A370, ASTM E18	06/F606M	ASTM A	370, ASTA	A EI8				1	Date:	Aug.	. 26,'02	, 02				
	Mechai	Mechanical Property of Full Size Bolts	erty of Fu	I Size F	Solts	Heat 1	Heat Treatment		IDENTIFICATION	NO		0	Chemical Composition	al Con	posit	tion %			
	Tensile	Tensile Strength	RECF LOW	_	Hardness	-	F ('C)			0	15	Mu		5	Ce.	ž	Ŭ	Mo	-
	(tot)	Position of fracture	19200 lbf. (Length Method)		HRC	Quench	Temper		432	*	*		x 1000	× 1000	~		0	~	× 10,000
Spec	271'00	Part of Screw	Max. +/- 00005 in		25 - 34	1	Min. 800		Heat No.	8 2		Min.	Max.	Nax N	1	1	1	1	s 0
Average	34972	72 Part of Screw	ALL PASS		32.7	1580	860	-	7325902	2 30	0 25	82	11	14	-	10	80	2	18
	-	Hardness		Heat T	Heat Treatment		IDENTIFICATION	7		Chen	Chemical Composition	odmo	ition ?	0/ 0/			Thread	Thread Accuracy	¢,
Hardness			Proof Load	ł.			6		3	Wu		sodmo	C ION	ž	0	1	(Bolt	(Bolt & Nut)	
(HRC)	+	HRB	((1))	Quench	Temper		5	X 100	X 100	X 100	X 1000	X 1000	X 100	X 100	X 100	-			
		Min.	0		Min	1	6	8		Min.	Max	Max				T	Bolt	ASME B1.1 Class 2A	81.1
Spec. 24	24 - 38	HRB 89		+	850		Heat No.	55	1	99	40	50	2	Ĩ	4	-	Virt	ASME B1.1	1.18
Mean/Spcs. 21	26.9	-	ALL PASS	1562	106'	N	7309118	8 44	22	75	13	20	1	C4	-	φ		Class 28	88
WASHER LOT NO.	NO.	CYOD	1										Fastene	Fastener Tension	E	1			
		IDENTIFICATION	CATION			Chemi	Chemical Composition	mposi	tion %			L	Fasten	Fastener Tension	-		REN	REMARKS	
Hardness (HRC)	\$50	C	E	c x 100	\$1 x 100	Mn x 100	р в 1000	s * 1000	* 100	NI N 100	Cr x 100		Spec. (bit)	Min. 195	19950				
j	14.46	D					Max.	Max.				Mear	Mean / 5 sets.	22	22512	_			
Mean/5 Pcs.	39.6	208143	143	48	12	70	*	4	. '	. '	1	Str	Standard Deviation	6530	226	1			

Figure A.1: Bolt Certificate for 5/8", F1852/A325 Strength Bolts

Spe	Specification	ion			Si	Size		-	Quantity	tity			ſ		One	Unyti	One Unytite Drive	ve	
ASTM F1852 Type 1 ASTM A563 Grade DH ASTM F436 Type 1	Type 1 itade DF	-00 -00		3/4-1	10 UN	3/4-10 UNC X 3-1/4	-1/4		12,464 pcs.	pcs.		1		Peru, Illinois 61354 815-224-2221 — FAX # 815-224-3434	Peru, 4-2221	- FA	Peru, Illinois 61354 1-2221 — FAX # 815-22	54	3434
Mechanical properties tested in accordance to ASTM F606/F606M, ASTM A370, ASTM E18 BOLT LOT NO. 66201	es tested i	ted in accordance 662.01	to ASTM F60	36/F606M	I, ASTM A	370, ASTM	E18					Date:	NOV	Nov.15,'02	02				
	Mechan	Mechanical Property of Full Size Bolts	erty of Ful	I Size I	Bolts	Heat Tr	Heat Treatment	_	IDENTIFICATION	Z		0	hemic	Chemical Composition	nposit	ion %			
	Tensile	Tensile Strength	Proof Load Hardness	ad Har	rdness	*	7 (0)		0		3	Mu		*	3	Z	0	Ma	
	(Ibi)	Position of fracture	28400 bt. 0.evgh Method		HRC	Quench	Temper	432	150	* 100	×	-	× 1000 ×	x 1000	0	0	0	~	× 10,000
	Min.		-	-			Min		2C	2		Min.	Max.	Max.					5
Spec. 4	40100	40100 Part of Screw	4/ 0.0005 in	-	25 - 34	1	800	-	Heat No.	3	+	99	9	20	1	£	1	1	9
Average 4	18484	48484 Pan of Screw	ALL PASS		31.4	1580	906		7240470	30	25	82	11	13	н	m	80	N	14
NUT LOT NO.	08	08051																	
	F	Hardness		Heat T	Heat Treatment	_	IDENTIFICATION	L		Chemical Composition	cal Co	soduuc	ition %	%		-	Thread	Thread Accuracy	ey.
Hardness	-	After 24 hr	Proof Load	*	1 (0	6	6			Ma			ð	ž	0		floff	(Bolt & Nut)	
(HRC)		HEB	((164))	Quench	Quench Temper		1	X 100	×	X 100	X 1000	X 1000	X 100	×	×				
_		,um			Min	1	3	20		Min.	Max	Max.				1	Bolt	ASME B1.1 Class 3A	B1.1
Spec. 24 - 38	36	HR8 89	58450	r.	850	He	Heat No.	35	I.	9	40	50	Ŧ	1	3		Nut	ASME B1.1	81.1
Mean/Spcs. 28	28.7	1	ALL PASS	1562	1112		7242139	46	21	79	7	24	'n	10	11			Class 28	8
WASHER LOT NO.	NO.	J921	1								1		Fastene	Fastener Tension	uo				
		IDENTIFI	IDENTIFICATION		-	Chemia	Chemical Composition	nposi	tion %				Fasters	Fastener Tension	c		REN	REMARKS	
Hardness (HRC)	8	6	C	c C x 100	x 100	Mn x 100	x 1000	s x 1000	Cu x 100 x	N 100	Cr x 100		Spec. (bt)	Min. 29	29400	L			
Spee.	38 - 45) iest) v	1	I.	E	¥₩ 9	Max. 50		1	E	Mean	Mean / 5 sets.	37	37324				
Mean/5 Pcs.	42.2	125	495	33	18	78	14	s	t	'	1	20	Standard Deviation	-	1727				
Material used for the holt, nut and washer were melted & manufactured in the USA.	he holt a	ut and wash	WH WERE THE	thed & n	vanufactu	red in the	· USA.					041	O I O I	alles As	Third of Quality Assurance Section	a Sart	100		

Figure A.2: Bolt Certificate for 3/4", F1852/A325 Strength Bolts

ASTM A490 Type 1 -00 3/4-10 UNC X 3-1. ASTM A563 Grade DH -00 3/4-10 UNC X 3-1. ASTM A563 Grade DH -00 3/4-10 UNC X 3-1. Mechanical properties tested in accordance to ASTM F606F566M, ASTM AJ70, ASTM E18 Peat Treat BOLT LOT NO. 71821 * Y CC BOLT LOT NO. 71821 * Y CC Astronomical property of Full Size Bolts Heat Treat Proof Load Partness * Y CC Average 56,8000 * At of 2000 * At of 2000 Spec. 50,1000 * At of 2000 * At of 2000 Average 546.3600 * At of 2000 * At of 2000 Average 546.3600 * At of 2000 * At of 2000 Average 54.63.6 * At of 2000 * At of 2000 Average 54.63.6 * At of 2000 * At of 2000 Average 54.63.6 * At of 2000 * At of 2000 Average 24.38 * 1000° f * At of 2000 Average 24.38 * 1000 * 1000 Average 24.38 * 1000 * 1000 Average 24.38 3.3.5 1220 Average 28.2 - Att PAS 122 Average 2				Quantity	LA.	_	l	4		One	One Unvtite Drive	e Dr	ive
lies trented in accordance to ASTM F60taF60t6M, ASTM A Mechanical Property of Full Size Bolts Tensile Strength Proof Load Hardness Load Position of 40, 100-bt. HRC BDD Part of Screen ALP-90005 In HRC S0, 100 Part of Screen ALP-90005 In HRC S0, 100 Part of Screen ALP-90005 In HRC S0, 100 Part of Screen ALP-90005 In Max. 33.5 33.5 096.822 33.5 096.822 AL PASS 33.5 096.822 AL PASS 33.5 122 8.2 - AL PASS 136.2 122 NO. 392.6 NO. 392		3-1/4		300	300 pcs.		>		15-224	Peru,	Peru, Illinois 61354 815-224-2221 - FAX # 815-224-	5 613 1 81	5-224
71821 Mechanical Property of Full Size Bolts Tensile Strength Proof Load Hardness Load Prosition of 40,100.ot. HRC 001 fracture 40,100.ot. HRC 56,800 Part of Scene 410,100.ot. HRC 56,800 Part of Scene ALL PASS 3.3.5 02682 Alt PASS 3.3.5 03682 Alt PASS 3.3.5 1000* Proof Load Quench Treatment Alter 24 hs ALL PASS 132.2 8.2 ALL PASS 158.2 122 NO. J326 X100 X100	A A370, ASTM	1 618											
Mechanical Property of Full Size Bolts Tensile Strength Proof Load Hardness Load Position of Ibin Aux 40,100 bit S6,800 Pan of some 40,100 bit HRC S6,800 Pan of some Aux Head field S6,800 Pan of some ALL PASS 33.5 S4636 Pan of some ALL PASS 33.5 09682 All Proof Load Quench Freatment Mine 24 bit Proof Load Quench Mine 24 bit Proof Load Quench Mine S8450 - 8:0 Min. 58450 - 8:0 Mo. J326 - 122						â	Date:	Mar.		01, 03			
Tensile Strength Proof Load Hardness Load Position of (bb) Prosition of hacture 40, 100.0H Hardness S0, 100 Part of Screes 41-90005 h HRC S6, 800 Part of Screes 41-90005 h Alt. S6, 800 Part of Screes ALL PASS 33.5 S6, 800 Part of Screes ALL PASS 33.5 096.82 Alt. PASS 33.5 096.82 Alt. PASS 33.5 096.82 Alt. Past From Provided Part Treatment Alter 24 hr Proof Load Quench Tempe Min. HR8 89 584.5 850 B. 2 Alt. PASS 132.2 Mo. J92.6 Alt. 850		Heat Treatment	IDENTIFICATION	CATION			£	Chemical Composition	I Con	iposi	tion %		
Load Position of fracture 40,100 Length Method HRC 50,100 Part of Screw 41, PASS 33.5 56,800 Part of Screw ALL PASS 33.5 09682 ALL PASS 33.5 8.2 Alter 24 hr Proof Load Quench Treatment Alter 24 hr Proof Load Quench Treatment Min. 8.2 Alt PASS 158.2 122 8.3 JOS 584.50 584.50 53.5 00. JOS S158.2 122		7 CO	0	6				-	1	1	3	6	
S0, 100 56, 800 Part of Screeven Hardrock Max H- 00005 in ALL PASS Max 33.5 54636 Part of Screeven Hardrocks ALL PASS 33.5 09682 ALL PASS 33.5 Alter 24 hr Alter 24 hr Alte	Quench	Temper	A4	¥S,	8	× 100	0	x 1000 x	8	-	0	0	× 100
54636 Part of Screw ALL PASS 33.5 09682 Hardness Heat Treatment Alter 24 hr Proof Load Quench Treatment Alter 24 hr Alter 24 hr Alter 24 hr Alter 24 hr Alter 24 hr Alter 24 hr Min. 58450 - 8:0 B.2 - ALL PASS 1322 NO. J326 - 51	1	Min. 800	Heat No.	No.	30	:	Min.	Max.	Max. So		1	3	- 3
09682 Hardness After 24 hr After 24 hr Afte	5 1580	1031		7442286	40	24	93	8		~	9	102	22
After 24 hr Froot Load Tree reponsion x 1000° F Proof Load Quench Tempe Min. 5845.0 650 Min. Min. 5845.0 650 122 Justice ALL PASS 1562 122 J926 x 100 x 100 x 100		IDENTIFICATION		D	nemic	al Coi	Chemical Composition	ion %				Thread	Thread Accura
Min. Min. Min. Min. Min. Min. Min. Min.	P	6	-		W		~			5		(Boh	(Bolt & Nut)
HRB 89 58450 - 650 - ALL PASS 1562 122 J926 IDENTIFICATION C SI		2	-	X 100 X	_	x 1000	X 1000	X 100	X 100	× 100	-	Bolt	AGME
- ALL PASS 1962 122 J926 IDENTIFICATION C SI x 100 x 100		Heat No.	8 8	-	WW 99	40 Wax	Max. SO	1	:	t	2	Nut	Class 2 ASME
1926 IDENTIFICATION C SI C SI C 100		\$55542	45	21	71	11	28	25	6		14		Class 2
IDENTIFICATION C 51 x 100 x 100							-	Fastener Tension	r Tensi	5	1		
	Chemic	Chemical Composition %	position	% (i.			Fastene	Fastener Tension			REA	REMARKS
	Mn x 100	r 1000 x	s Cu x 1000 x 100	Cu Ni 100 x 100	0 × 100	- 8	Spec. (bbt.)	Spec. (bit)	Min. 36,750	20	- a a	THESE BOLTS HA BEEN MAGNETIC	OUTS H
Spec. 38 - 45 Heat No	. 1	*	Max. 50		_		Mean / 5 sets	5 sets.	41,200	8		IN ACCORDANC	RDAN
Mean/5 Pcs 41.4 221761 34 20	67 0	15	5	1	1	1	Standard Deviation	Standard Deviation	2,	2,200	20<	ACCUREMENTS OF SPECIFICATIO ASTM A490	PICATIC

Figure A.3: Bolt Certificate for 3/4", A490 Strength Bolts

ASTM F1852 Type 1 ASTM F1852 Type 1 ASTM F436 Type 1 ASTM F436 Type 1 ASTM F436 Type 1 ASTM F436 Type 1 Acchanical properties teglo grapportance to ASTM F606/F606/4, AST0 Acchanical property of Full Size Bolts teansile Strength REC/C 10/2 Hardness Access 55/4/5.0 Prov Act, PASS 32.9 Acchanical property of Full Size Bolts Access 55/4/5.0 Prov Act, PASS 32.9 Access 71.36.3 Part of Screw Act, PASS 32.9 Access 73.32.9 Access 71.36.3 Part of Screw Act, PASS 32.9 Access 73.32.9 Access 74.0 Past of Screw Act, PASS 32.9 Access 74.0 Past of Screw Act, PASS 32.9 Access 74.0 Past of Screw Act, PASS 32.9 Access 74.0 Past of Screw Act, PASS 156.2 12 Access 26.9 - Act, ALL PASS 156.2 12 Access 26.9 - Act, ALL PASS 156.2 12 Access 27.9 Access 26.9 - Act, ALL PASS 156.2 12 Access 27.9 Access 27.9 Acce	7/8-	Si	Size		L	Quantity	itity		ſ	4		One	Unyti	One Unytite Drive	ive	
al properties teglod g Agrordance to OT NO. OT NO. Tensile Strength et totad Prostene a bit francial Propert Tensile Strength et totad Prostene a bit franciste a totad Prostene a tot	606/16064	9 UNC	×	3-1/2		5,425	pcs.		2		Peru, Illinois 61354 815-224-2221 — FAX # 815-224-3434	Peru, t-2221	- FA	Peru, Illinois 61354 I-2221 — FAX # 815-22	354 5-224-	3434
Mechanical Proper Tensile Strength (hh) fracture ((hh) fracture ((hh) fracture (71363 fran of Screw 06151 Min. 24 hr After	I	A. ASTM A	370, A5TM	618				1	Date:	Aug.	08,'02	02				
Tensile Strength Load Position of fracture (i) 554750 Par of Screw 71363 Par of Screw 71363 Par of Screw 06451 Min. 138 Hardness Min. 1488 06451 Min. 138 Herdness 06451 No.	ull Size	Bolts	Heat Ti	Heat Treatment		IDENTIFICATION	z		Ċ	Chemical Composition	al Con	nposit	ion %			
Load Position of fracture Quillon of fracture Quillon of fracture 71363 Pan of Screw Minor 71363 Pan of Screw Minor 06153 Minor Minor - 38 Head Minor A 06153 Minor Minor - 39 Minor A	IRCUE ILOND Hardness	rdness	*	1 (70	1	17		7	Min	•		3	ž	0	Mo	
S\$\$"50 Part of Screen +1 71363 Part of Screen 1 06151 Part of Screen 1 After 24 hr After 2	o Ibr.	HRC	Quench	Temper	432	150	× 100	×	-	8	8		0	0	~	× 10,000
71.363 Part of Screw 061.51 061.51 Alter 24 hr Alter 24 hr Alter 24 hr Alter 24 hr 86.9 6.9 0.3910		25 - 34	1	Min. 800	Ť	Heat No.	8 2		Min. 60	Max. 40	Max. 50	1	1	,	1	5 00
06151 1 Hardness Anter 24 hr Atter 24 hr Atter 24 hr HR8 199 8 6.9AL	-	32.9	1580	869	72	7241885	32	23	79	9	8	æ	4	2	10	17
Mise 24 hr x 1000° F Pro Min 8 HRB 59 HRB 59 J910	Heat T	Heat Treatment	_	IDENTIFICATION			Chemical Composition	cal Co	mpos	tion %				Thread	Thread Accuracy	A
Min. 8 Min. 8 Min. 8 Min. 8 Min. 8 Min. 8 Min. 8 Min. 8 Min. 8 Min. 10 Min. 10		'r ('C)		HICKING	5		Chem	cal CC	sodue			L	Т	Threat	read Accura (Bolt & Nuch	č
Min. 8 1111 111 1111 1111111111111111111111	duench.	h Temper			x 100	x 100	x 100	X 1000	x 1000	x 100	x 100	X 100	_			
- VI	C	Min	J	B	20		Min.	Max	Max				T	Bolt	ASME B1.1	81.1
- 1910	1	850		Heat No.	55	1	09	40	50	3	9		_	Nut	ASME B1.1	81.1
۱Ľ	5 1562	1256		S52747	43	20	69	11	28	24	8	13	-		Class 2B	82
							2			Fastener Tension	r Tensi	E	1			
IDENTIFICATION		Ĩ	Chemic	Chemical Composition	positi	on %		Г		fastene	fastener Tension		_	REA	REMARKS	
Hardness (HRC)	С х 100	Si x 100	Mn x 100	r x 1000 x	s x 1000	Cu x 100	× 100 ×	Cr x 100	3.0	Spec. (Ibil)	Min. 405	40950				
			8		Max.		3	1	Mean	Mean / 5 sets.	548	54832	-			
Mean/5 Pcs. 30 - 40 - 7 123110	33	18	85	14	8 6	1	1	1	Sta	Standard Deviation	4(4082				

Figure A.4: Bolt Certificate for 7/8", F1852/A325 Strength Bolts

ASTM A490 Type 1 ASTM A563 Grade DI+00 ASTM F436 Type 1	Specification	100	_		Si	Size		_	Quai	Quantity		l	ľ		One	One Unvtite Drive	One Unvtite Drive	ve	
achanical amount	pe 1 rade DH	00-00-		7/8-	9 UNC	×	3-1/2		2,725	2,725 pcs.		2		315-22	Peru, 4-2221	- FA	Peru, Illinois 61354 815-224-2221 FAX# 815-224-3434	54	3434
BOLT LOT NO.	623	Mechanical properties lested in accordance to 62371. 62371.		6,1606M	L ASTM A	ASTM FE06(F606/N, ASTM A370, ASTM E18	A ETB				1	Date:	Sep.	Sep.20,'02	02				
	Mechar	Mechanical Property of Full Size Bolts	erty of Ful	I Size	Bolts	Heat T	Heat Treatment	-	IDENTIFICATION	Z		0	Chemical Composition	al Con	nposit	tion %			
	Tensile	Tensile Strength	ROOP LOND		Hardness	ŕ	7 (20)		6	-	0	-	•	-	3	1	4	-	
	(Ibi)	Position of fracture	55450 Ibf. (Length Method)	_	HRC	Quench	Temper	-	VS)	× 100	×	*	8	8	•	0	0	-	x 10,000
Spec. 7	09300	Part of Screw	Max. +/- 0:0005 in			1	Min. 800		Heat No.	8 2	1	WW 99	Max. 40	Max. 50	1	,	1	1	5 08
Average 7 8 pcs	75827	Part of Screw	ALL PASS	9	5.7	1580	1022	-	7440952	40	27	89	6	6	4	s	66	21	0
NUT LOT NO.	TECON	TE	1					1											
	-	Hardness		Heat I	Heat Treatment		IDENTIFICATION	7		Chem	Chemical Composition %	oduco	ition 9				Thread	Thread Accuracy	A.
Hardness	< *	After 24 hr x 1000° F	Proof Load		1 (C)	6	6	v	5	Wu	•	5	3	ž	0	_	(Bolt	(Bolt & Nut)	
(HRC)	+	HRB	(150	Quench	Temper		2	X 100	X 100	X 100	X 1000	X 1000	X 100	X 100	X 100	0			
-		Min.	80850		Min.	1)	2		Min	Max.	Max			1	T	Bolt	ASME B1.1	81.1
Spec. 24 - 38	_	HKB 89		x	850	ž	Heat No.	55	ı	99	40	20	1	t	1		Nut	ASME B1.1	81.1
ean/Spcs. 26	26.8	1	ALL PASS	1562	1049		299684	44	18	70	9	26	4	e	m			Class 28	28
WASHER LOT NO.	NO.	1.160											Fastener Tension	r Tensi		1			
		IDENTIFI	IDENTIFICATION			Chemi	Chemical Composition %	mposit	tion %		Γ	L	Fasten	Fastener Tension	e		REN	REMARKS	
Hardness (HRC)	8	C	Ē	с x 100	× 100	Mn x 100	× 1000	s × 1000	100 F	x 100	* 100		Spec. (Ibf.)	Min. 514	n. 51450		THESE BOUTS HAVE BEEN MAGNETIC	OUTS HU	JME.
		2	2				Max	Max.				Mean	Mean / 5 sets.	55	55090	T	PARTICLE INSPECTION IN ACCORDANCE WITH THE	RDANC	NOL H
Spec.	38-45	Heat N	Heat No.	1 2	1 0	1	\$	8 0		1				ì		-	REQUIREMENTS	MENTS	
Mean/5 Pcs.	0.04	199	****	t'	9		7	N				89-	Standard	N	2300		OF SPECIFICATION ASTM A490	FICATIK 90	z

Figure A.5: Bolt Certificate for 7/8", A490 Strength Bolts

Iteration Size 1 -00 1 = 8 UNC X 3-1/2 e DH=00 51500 UN 1 = 8 Frometry of Full Size Bolts Heat Treatment e Position of S1500 UN Aux 900 Part of Screen A Position of Screen Aux 900 Part of Screen Aut PASS 30 - 8 900 Part of Screen Aut PASS 30 - 8 1 = 900 from tripoint Nin. Aut PASS 30 - 8 1 = 900 from tripoint Nin. Aut PASS 130 - 8 1 = 900 from tripoint Nin. Aut PASS 1980						I NO	UNYILE. INC.	2	
1 -00 1 - 8 UNC X 3-1/2 1 - 7 Clarrical Property of Full Size Bolts - 7 (C) 1 - 7 (C) - 7 (C) - 7 (C) 1 - 7 (C) - 7 (C) - 7 (C) 1 - 7 (C) - 7 (C) - 7 (C) 1 - 7 (C) - 7 (C) - 7 (C) 1 - 7 (C) - 7 (C) - 7 (C) 1 - 7 (C) - 7 (C) - 7 (C) 1 - 7 (C) - 7 (C) - 7 (C) 1 - 7 (L) - 7 (L) - 600 1 - 7 (L) - 7 (L) - 600 1 - 7 (L) - 7 (L) - 7 (L) 1 - 7 (L) - 7 (L) - 7 (L) 1 - 7 (L) - 7 (L) - 7 (L) 1 - 7 (L) - 7 (L) - 7 (L) 1 - 7 (L) - 7 (L) - 7 (L) 1 - 7 (L) - 7 (L) - 7 (L) 1 - 7 (L) - 7 (L) - 7 (L) 1 - 7 (L) - 7 (L)	Qu	Quantity		ł		One Unvtite Drive	vite D	rive	
Inglighting of Full Size Bolts Heat Treatment Chamical Property of Full Size Bolts Heat Treatment Chamical Property of Full Size Bolts Heat Treatment Chamical Property of Full Size Bolts Heat Treatment Site Site Site Site Site Site Site Site	6,486	86 pcs.		>	815-22	Peru, Illinois 61354 815-224-2221 FAX # 815-224-3434	nois 61 FAX # 8	15-224	-3434
Mechanical Property of Full Size Bolts Heat Treatment Tensile Strength RECOF Hardness *r (*) Load Position of 51500 bt/ Hardness *r (*) Renge 90507 Part of Screen ALL <pass< td=""> 30.48 1996 Bit 90507 Part of Screen ALL<pass< td=""> 30.68 159.0 Min. Dof451 ALL PASS 30.8 159.0 B69 Min. Dof451 Min 10607 ALL PASS 30.8 159.0 B69 Alte Min 106007 ALL PASS 30.8 159.0 B69 Alte 24.38 Min 106000 Min. FCO Min. Min. Alte 26.5 ALL PASS 1088 298334 A Alter 26.5 ALL Min. Tentment E A Alter 106000 Alter 1088 298334 A A Alter</pass<></pass<>			1	Date: St	Sep.10,'02	02			
sile Strength IROCP LOW Hardness A Position of Science Landon HRC Pool Part of Science Adv. Pool Part of Science Adv. Pool Part of Science Adv. Part of Science Adv. Pool Part of Science Adv. Part of Science Adv. Pool Part of Science Adv. Pool Pool Pool Pool Pool Pool Pool Pool	t IDENTIFICATION	NOI		Chem	ical Cor	Chemical Composition	9% L		
d Position of fracture 51500 bit. Max HRC 900 Part of Screw +1- 0.0005 in Max 25 - 14 507 Part of Screw ALL PASS 30 - 8 607 Part of Screw ALL PASS 30 - 8 617 Part of Screw ALL PASS 30 - 8 617 Part of Screw ALL PASS 30 - 8 617 Part of Screw ALL PASS 30 - 8 615 Pool Load Quench Treatmen Min. 106 00 0 - 850 H8 B9 J106 00 0 - 850 J308 1562 108 J308 1562 108 IDIMITICATION x 100 510	0	-	-	Mn P		ž		-	
90 Part of Screw Max. 25 - 34 507 Part of Screw ALL PASS 30 - 8 607 Part of Screw ALL PASS 30 - 8 604551 ALL PASS 30 - 8 Atter 24 hr Proof Load Heat Treatmen Atter 24 hr Proof Load Quench Tempa Atter 34 hr Proof Load Quench Tempa Min. 106 00 d - 850 HR8 106 00 d - 850 - ALL PASS 156.2 108 Atter 24 hr Rectored - 850 Atter 24 hr Proof Load Quench Tempa Min. 106 00 d - 850 - ALL PASS 156.2 108 - ALL PASS 156.2 108 - ALL PASS 156.2 108	432	450	×	-	* 1000	*	×	x 100	×10,000
507 Parr of Science ALL PASS 30.8 06451 Hardness ALL PASS 30.8 Hardness Alter 24 hr Front Front Alter 24 hr Pixod Load Quench Temper Alter 24 hr 10600 f 8 Alter 24 hr Pixod Load Quench Temper Min. 106000 - 850 HRB 106000 - 850 J908 Alt PASS 1562 108 IDENTIFICATION C 51	Heat No.	83	,	Min, Max 60 40	Max. 50		,	1	s 05
06451 Hardness After 24 hs After 24 hs After 24 hs Httls Htt	9 7241018	m	1 23	19	6	-	m	1	19
After 24 hr x 1000° F Proof Load HRB T(Lbr) Min. 106000 - 850 - 350 J908 1562 108 (Lbr) 7 F(°C) Min. 106000 - 850 - 350 - 300 - 300		Chem	ical Co	Chemical Composition	2	[Three	Thread Accuracy	acy
x 1000° F Proof Load (Lbn) Quench Temperature Min. 106.000 - Min. H88.89 106.000 - 850 - ALL PASS 156.2 108				mucoding					
Min. 106000 - 850 HR8 69 106000 - 850 J908 1562 108 1908 1562 108 106MTHCATION C 51	C 51 X 100 X 100	Mn X 100	r 1000	5 Cu X 1000 X 100	00 X 100	Cr X 100	(84	(Bolt & Nut)	
HIE 69 - 850 - ALL PASS 1562 108 - 108 101011111CATION C 51 x 100 x 100	50	Min.	Max.	Max.			Bolt	ASME B1.1	1.18
UD08 UD08	55	60	40	50	ł	1	Nut	ASME 81.1	81.1
IDENTIFICATION C S x 100 x 100	43 18	8 68	ŝ	24	7 4	ŝ		Class 2B	28
IDENTIFICATION C 51 x 100 x 100			Î	Faste	Fastener Tension	uo			
C Si Mn F *100 ×100 ×100 ×100	nposition %			Fast	Fastener Tension		RE	REMARKS	5
	s Cu x 1000 x 100	× 100	* 100	Spec. (Ibi)	Min. 53	53550			
Spec 18 - 45 Heat No - 40 50	Max,			Mean / 5 sets		62090			
41.1 401N0764 37 22 70 17		1	1	Standard Deviation		3449			

Figure A.6: Bolt Certificate for 1", F1852/A325 Strength Bolts

															UN HILLING		ž	į	
~	Specification	tion			S	Size		-	Quantity	ntity	Г	l	4		One Unvtite Drive	Invtit	o Driv	; 9	
ASTM A490 Type 1 ASTM A563 Grade DH ASTM F436 Type 1	1 Type 1 Crade DH Type 1	-00		- 1	8	UNC X 3	3-1/2	-	2,005	pcs.		2		Peru, Illinois 61354 815-224-2221 - FAX # 815-224-3434	Peru, Illinois 61354 1-2221 – FAX # 815-22	llinoi	613	54	1434
Mechanical properties tested in accordance to BOLT LOT NO. 6.6.2.9.1	perties tested	sted in accordance 6.6.2.9.1	to ASTM FIG	06/16/06A	A, ASTM A	ASTM F606/F606M, ASTM A370, ASTM E18	813 V				1	Date:	net	CO' LC HEL	2				
	Mecha	Mechanical Propert	erty of Full Size Bolts	Il Size	Bolts	Heat T	Heat Treatment		IDENTIFICATION	N		0	Temica	Chemical Composition	positi	% uo			
	Tensile	Fensile Strength	Proof Load Hardness	ad Ha	rdness	*	(DJ) 4,	Ľ	6	-							H	F	
	(toad (tbf)	Position of fracture	1270 dbt.		нкс	Quench	Temper	1	VS.	x 100	× 100	* 100	x 1000 x	x 1000 x	100	* 100 ×	001.	× 100 ×	8 x 10,000
Spec	90,900	Part of Screw	Max. +/- 0.0005 in	4			Min.	1	Heat No.	2 3		Win	Wax.	Mar	-	-	-	-	-
Average 8 pcs	99703	Part of Screw			35.5	1580	1049	-	236620	41	24	89	0	11	1 00	, .	103		R
		7000		Heat 1	Heat Treatment	_	IDENTIFICATION			Chom	C Int		in the second			L	The second		
	•	Hardness After 24 hr		*	7 (1)		6			Cuem	Cnemical Composition %	soduc	tion %			-	Thread Accuracy	Accurac	
Hardness (HRC)		x 1000" F HRB	Proof Load (Lbf)	Quend	Quench Temper		\overline{C}	x 100	SI 100	Mn X 100	P X 1000	5 X 1000	x 100	x 100	x 100		(Boht a	(Bolt & Nut)	
	-	Min.			Min.	1)	20		Min.	Max.	Max				ă	Bolt A	ASME B1.1	1.1
Spec. 2	24 - 38	HR8 89	106000	1	930	ž	Heat No.	55	1	99	40	50	1	t		Nu		ASME B1.1	< 2
tean/spcs.	27.2	1	ALL PASS	1562	1256		S55540	43	21	70	12	26	23	6	18			Class 28	
WASHER LOT NO.	I NO.	J924	1										Fastene	Fastener Tension	F	1			
		IDENTIFI	IDENTIFICATION			Chemical Composition %	cal Col	mposit	ion %				Fastene	Fastener Tension			REMARKS	VRKS	
Hardness (HRC)	ues (C)		Ĉ	c C	si * 100	Mn x 100	* 1000	5 x 1000	× 100	× 100	Cr x 100	40	Spec. (Ibi)	Min. 67200	g	# 8 8	THESE BOUTS HAVE BEEN MAGNETIC	TS HAV	
Spec.	38 - 45	Heat No.	N ž	1	ţ	t	Max. 40	Wax So	1	1	1	Mean	Mean / 5 sets.	76130	30	S Z S I	MARTILLE INSPECTION IN ACCORDANCE WITH THE	ONNCE	5
Mean/5 Pcs. 39.9 40208	39.9	40208	08230	34	19	65	10	~	1	1		Des o	Standard Deviation	2240	40	202	OF SPECIFICATION ASTM A490	CATION	7

Figure A.7: Bolt Certificate for 1", A490 Strength Bolts

201 101 130															-			-	
S1	Specification	tion			S	Size			Qua	Quantity	Г		4		One	Unvti	One Unvtite Drive	ive i	
ASTM F1852 Type 1 ASTM A563 Grade DH ASTM F436 Type 1	32 Type 1 3 Grade DI 1 Type 1	н - 00 1 - 100		1-1/8"		7 X 5-1/2"	/2"		3,250			1		Peru, Illinois 61354 815-224-2221 — FAX # 815-224-3434	Peru, t-2221	- FA)	Peru, Illinois 61354 1-2221 — FAX # 815-22	354 5-224-	3434
Medunical properts BOLT LOT NO.	perties tested	Medunical properties treated in accordance to ASTM F606/F606M, ASTM A370, ASTM £18 SOLT LOT NO. 52201	to ASTM FC	506/F606A	A. ASTM /	U70, ASTA	4 (18				1	Date:	03-27-02	-02		2	COPY	>	
		Mechanical Property		of Full Size Bolts	Bolts	Heat T	Heat Treatment		IDENTIFICATION	NO		0	Chemical Composition %	al Con	nposit	ion %			
	Tensile	Tensile Strength	Proof Load Hardness	ad Ha	rdness	ŕ	QJ 4.		6	-	0		•			3	1	-	
	(lbf)	Position of fracture	56450 lbf. (Length Method)		HRC	Quench	Temper	1	432	*	×	<u> </u>	* 1000 ×	8	-	x 100		x 100 p	× 10,000
Spec.	Min. 80100	Part of Screw	Max. 4/- 00005 in		25 - 34	1	Min. 800		Heat No.	30	1	Min.	Max. 40	Max. 50	1				s 0
Average	102560	Part of Screw	VIT PASS		27.2	1580	923	-	7224455		25	81	-	12		~	-	-	
NUT LOT NO.	0. 01951	51																	
		Hardness		Heat	Heat Treatment	I IDENT	IDENTIFICATION	7		Chem	Chemical Composition	ompos	ition %			-	Thread	Thread Accuracy	A.
Hardness		After 24 hr x 1000° F	Proof Load	-	7 (C)	6	6	U	8	Mn	۵.	5	3	ž	Ö		(Bolt	(Bolt & Nut)	
(HRC)		HKB	((10))	Quenc	Quench Temper		5	X 100	X 100	X 100	X 1000	X 1000	X 100	X 100	×				
		Min.			Min.	/	3	2		Min.	ALAR.	Max.				-	Bolt	ASME B1.1	81.1
Spec.	24 - 38	HR8 89		1	650	Ŧ	Heat No.	55	r.	09	40	50	1	1	'	-	Nut	ASME B1.1	81.1
Mean/5pts.	28.9	I	ALL PASS	1562	1112		298007	43	18	74	23	24	10	47	2			Class 28	28
WASHER LOT NO.		3756	I										Fastener Tension	r Tensic	. u	1			
		IDENTIFICAT	CATION			Chemi	cal Co	Chemical Composition %	tion %				Fastene	Fastener Tension			REN	REMARKS	
Hardness (HRC)	ness (C)		C	c x 100	s x 100	Mn x 100	r 1000 x	5 × 1000	Cu x 100	x 100	Cr x 100	4.0	Spec. (Ibil)	Min. 58,800	00				
Spec	38 - 45		No	1))1	Max.	Ŵ 9				Mean	Mean / 5 sets.	80,300	000				
Mean/5 Pcs.	40.9	A82240		52	17	70	11					Des	Standard Deviation	2	2.200				

Figure A.8: Bolt Certificate for 1-1/8", F1852/A325 Strength Bolts

	Specification	tion			S	Size		-	Qua	Quantity	-	I	1		One	One Unvite Drive	One Unvtite Drive	ino	
ASTM A490 Type 1 ASTM A563 Grade ASTM F436 Type 1	ASTM A490 Type 1 ASTM A563 Grade DH ASTM F436 Type 1	-	+	1-1/8" -		7 X 5-1/2"			1,825	PIECES		-7		Peru, Illinois 61354 815-224-2221 - FAX # 815-224-3434	Peru,	- FA	Peru, Illinois 61354	354	3434
techanical pre	Mechanical properties tested in accordance to ASTM F606/F606M, ASTM A370, ASTM E18	in accordance	to ASTM F60	06/F606M	L ASTM A	370, ASTA	A ET8				1								
BOLT LOT NO.	NO. 56921	321	1					1			-	Date:	05-15-02	02					
	Mecha	Mechanical Property of Full Size Bolts	erty of Fu	I Size	Bolts	Heat T	Heat Treatment	-	IDENTIFICATION	z		0	Chemical Composition	al Con	nposit	tion %			
	Tensile	Fensile Strength	Proof Load Hardness	ad Ha	rdness	*	100		6	U	5	Mn			3	12	0	-	
	(Ibf)	Position of fracture	91,550 lbt. (Length Method)		HRC	Quench	Temper		VS,	×	×	* 100	8	8	-	× 100	* 100	-	x 10,000
Spec.	114,450 129,700	Part of Screw	Max. +/- 0.0005 h.	£		1	Min. 800		Heat No.	30	्र	Min.	Max.	Max. 50	1			1	s 0
Average 8 pcs	124,771	124,771 Part of Screw	ALL PASS		34.2	1580	1013	_	7440952	40	27	68	6	6	4	-0	66	21	
NUT LOT NO.		03651 Hardness		Heat T	Heat Treatment		IDENTIFICATION	-		Chem	Chemical Composition %	sodmo	ition 3			-	Thread	Thread Accuracy	4
Hardness		After 24 hr + 1000" f	Proof Load	٣	1 ('C)	P	6	0		Ma	-		3	ž	6	T	(Bol	(Bolt & Nut)	
(HEO)	-	HRB	((150)	Quench	£1.		3	X 100	×	X 100	X 1000	x 1000	×	×	×				
		WW		ł	ці.		-	8	1	Min	Max	Max.					Bolt	ASME B1.1 Class 2A	1.18
Spec.	24 - 38	HRB 89		1	920	*	Heat No.	8		99	40	30	1	1	1	-	Nut	ASME B1.1	81.1
Mean/Spcs.	29.2	I	VIL PASS	1562	1220		S52030	44	22	71	12	18	27	=	13			Class 28	28
WASHER LOT NO.		3890	1										Fastene	Fastener Tension	e o	1			
		IDENTIFI	IDENTIFICATION			Chemi	Chemical Composition %	mposi	tion %				Fasten	Fastener Tension	E	_	REA	REMARKS	
Han H	Hardness (HRC)		Ē	0 ⁰	* 100	Mn x 100	r 1000	s x 1000	x 100	2 00 ×	× 100		Spec. (bit.)	Min. 84,	n. 84,000		THESE BOUTS HAVE BEEN MAGNETIC	OUTS HA	WE
Spec.	38 - 45		Nº2		1	t	Max.	Max. 50	1	ĩ	1	Mean	Mean / 5 sets.	99,	99,100		PARTICLE INSPECTION IN ACCORDANCE WITH THE	REDANC FEDANC	NOL E
Mean/5 Pcs.	Mean/5 Pct. 41.8 B53602 54 18 81 14 2	B53602	02	54	18	81	14	2	1	1	1	89	Standard Deviation	2	2,800		OF SPECIFICATION ASTM A490	INCARC 190	z

Figure A.9: Bolt Certificate for 1-1/8", A490 Strength Bolts

APPENDIX B

GRAPHICS OF BOLT AND PLATE LAYOUTS

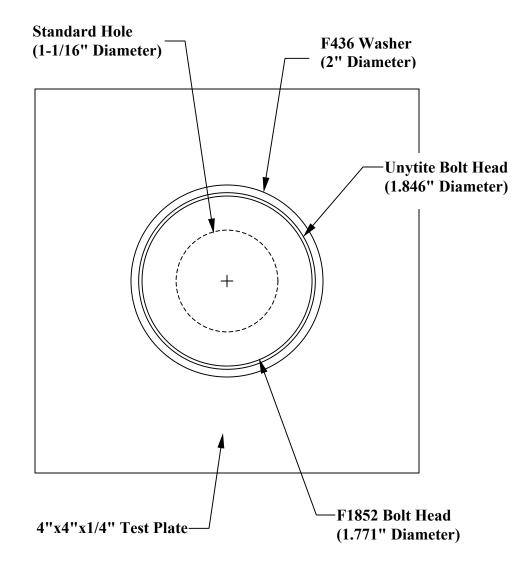


Figure B.1: Bolt and Plate Layout for 1" Bolt in Standard Hole (Drawn to Scale)

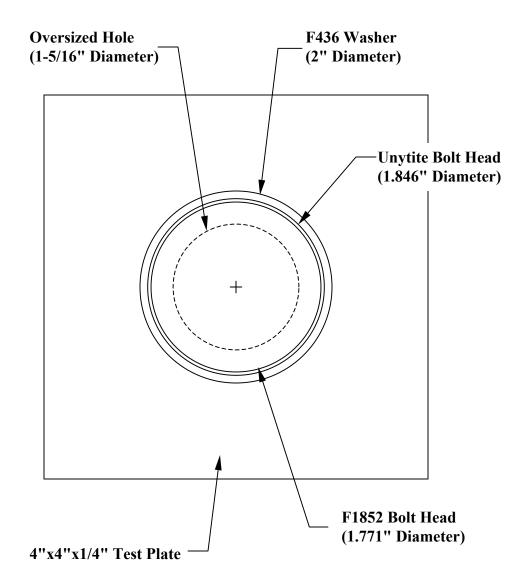


Figure B.2: Bolt and Plate Layout for 1" Bolt in Oversized Hole (Drawn to Scale)

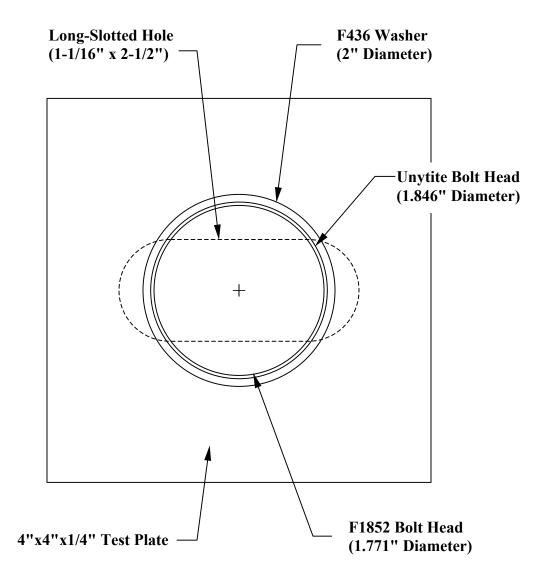
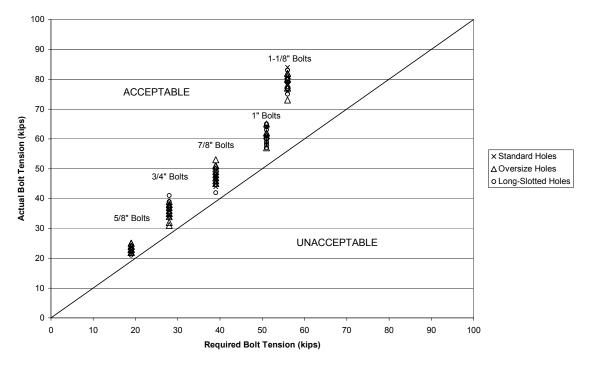


Figure B.3: Bolt and Plate Layout for 1" Bolt in Long-Slotted Hole (Drawn to Scale)

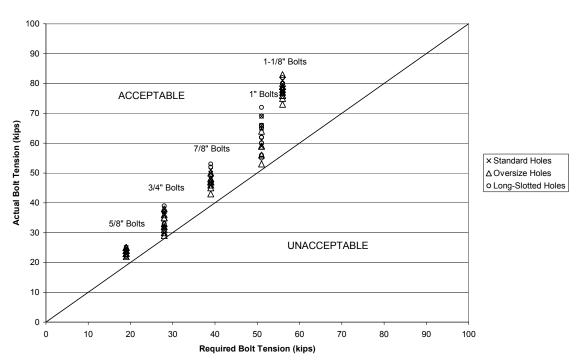
APPENDIX C

TEST RESULTS FOR F1852/A325 STRENGTH BOLTS



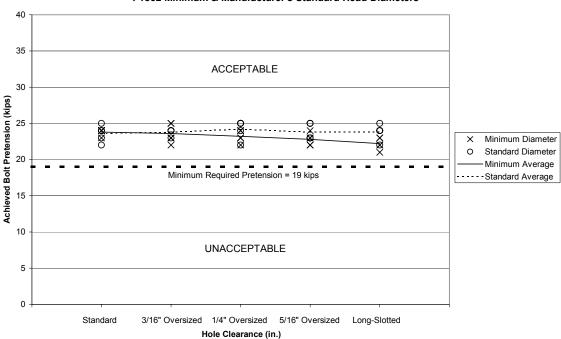
All F1852/A325 Centered Bolts - F1852 Minimum Head Diameter

Figure C.1: All F1852/A325 Strength, Centered Bolts, Minimum Head



All F1852/A325 Centered Bolts - Manufacturer's Standard Head Diameter

Figure C.2: All F1852/A325 Strength, Centered Bolts, Standard Head



All 5/8", F1852/A325 Centered Bolts F1852 Minimum & Manufacturer's Standard Head Diameters

Figure C.3: Results for 5/8" F1852/A325 Strength, Centered Bolts, Minimum & Standard Heads

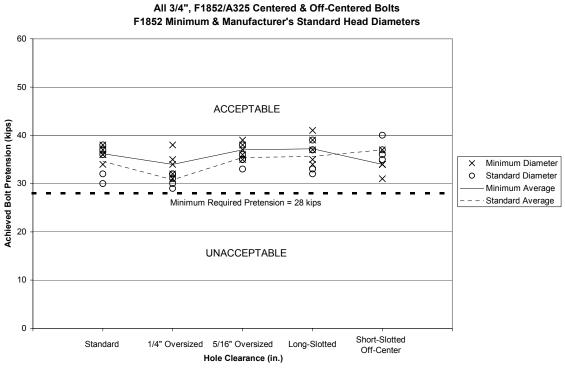
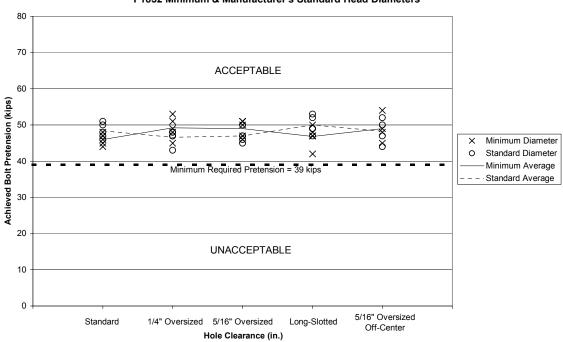


Figure C.4: Results for 3/4" F1852/A325 Strength, Centered & Off-Centered Bolts, Minimum & Standard Heads



All 7/8", F1852/A325 Centered & Off-Centered Bolts F1852 Minimum & Manufacturer's Standard Head Diameters

Figure C.5: Results for 7/8" F1852/A325 Strength, Centered & Off-Centered Bolts, Minimum & Standard Heads

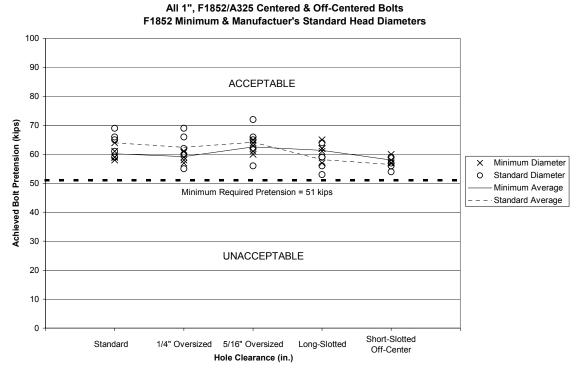
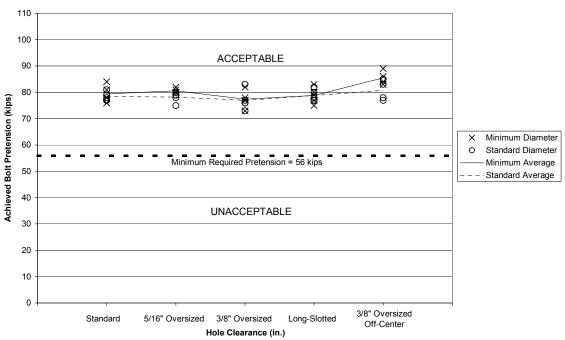


Figure C.6: Results for 1" F1852/A325 Strength, Centered & Off-Centered Bolts, Minimum & Standard Heads



All 1-1/8", F1852/A325 Centered & Off-Centered Bolts F1852 Minimum & Manufacturer's Standard Head Diameters

Figure C.7: Results for 1-1/8" F1852/A325 Strength, Centered & Off-Centered Bolts, Minimum & Standard Heads

	Hole Size in Plate						
Test #	11/16"	13/16"	7/8"	15/16"	11/16" x 1-9/16"		
1	24	24	24	25	23		
·	24	23	24	24	22		
2	24	25	23	23	22		
2	23	25	23	22	21		
3	24	25	24	22	23		
3	24	25	24	22	22		
4	24	23	22	24	23		
-	24	23	22	23	23		
5	25	23	23	23	24		
3	24	22	23	23	23		
Avg Initial	24.2	24.0	23.2	23.4	23.0		
Avg Relaxed	23.8	23.6	23.2	22.8	22.2		
Required Bolt	t Pretension =	19 kips					

Table C.1: Pretension Force in Kips for 5/8" Bolts(F1852/A325 Strength, F1852 Minimum Head Diameter)

Table C.2: Pretension Force in Kips for 5/8" Bolts(F1852/A325 Strength, Manufacturer's Standard Head Diameter)

		H	lole Size in Plat	e	
Test #	11/16"	13/16"	7/8"	15/16"	11/16" x 1-9/16"
1	25	24	25	23	25
·	25	24	25	23	25
2	23	24	24	25	24
2	23	24	24	25	24
3	22	24	25	25	24
3	22	24	25	25	24
4	24	24	22	23	24
-	24	24	22	23	24
5	24	23	25	23	22
5	24	23	25	23	22
Avg Initial	23.6	23.8	24.2	23.8	23.8
Avg Relaxed	23.6	23.8	24.2	23.8	23.8

Required Bolt Pretension = 19 kips

			Hole Size in	Plate	
Test #	13/16"	1"	1-1/16"	13/16" x 1-7/8"	1-1/16" x 1-5/16" OC
1	37	32	39	35	31
·	36	31	38	34	31
2	34	32	36	36	35
2	34	32	35	35	34
3	36	35	37	38	34
3	36	34	37	37	34
4	38	38	36	39	37
-	37	38	36	39	37
5	38	35	39	42	
3	38	35	39	41	
Avg Initial	36.6	34.4	37.4	38.0	34.3
Avg Relaxed	36.2	34.0	37.0	37.2	34.0

Table C.3: Pretension Force in Kips for 3/4" Bolts(F1852/A325 Strength, F1852 Minimum Head Diameter)

Required Bolt Pretension = 28 kips

Table C.4: Pretension Force in Kips for 3/4" Bolts(F1852/A325 Strength, Manufacturer's Standard Head Diameter)

			Hole Size in	Plate	
Test #	13/16"	1"	1-1/16"	13/16" x 1-7/8"	1-1/16" x 1-5/16" OC
1	36	31	34	33	36
•	36	30	33	32	36
2	38	32	37	39	40
2	37	32	36	39	40
3	38	32	39	37	35
3	38	31	38	37	35
4	32	30	35	38	38
-	32	29	35	37	37
5	31	33	36	33	
3	30	32	35	33	
Avg Initial	35.0	31.6	36.2	36.0	37.3
Avg Relaxed	34.6	30.8	35.4	35.6	37.0

Required Bolt Pretension = 28 kips

Table C.5: Pretension Force in Kips for 7/8" Bolts (F1852/A325 Strength, F1852 Minimum Head Diameter)

	Hole Size in Plate							
Test #	15/16"	1-1/8"	1-3/16"	15/16" x 2-3/16"	1-3/16" OC			
1	49	49	48	43	49			
•	48	49	47	42	48			
2	48	49	51	48	50			
2	47	48	51	47	49			
3	45	46	51	48	46			
3	44	45	50	47	45			
4	47	52	52	50	55			
-	46	51	51	50	54			
5	45	54	47	49				
5	45	53	46	48				
Avg Initial	46.8	50.0	49.8	47.6	50.0			
Avg Relaxed	46.0	49.2	49.0	46.8	49.0			
Required Bolt	Pretension =	39 kips						

Table C.6: Pretension Force in Kips for 7/8" Bolts

(F1852/A325 Strength, Manufacturer's Standard Head Diameter)

	Hole Size in Plate							
Test #	15/16"	1-1/8"	1-3/16"	15/16" x 2-3/16"	1-3/16" OC			
1	46	48	47	52	48			
·	46	47	47	52	47			
2	47	44	47	48	45			
2	47	43	46	47	44			
3	51	49	48	49	53			
3	50	48	47	49	52			
4	49	48	51	50	50			
-	48	47	50	49	50			
5	52	48	46	54				
J L	51	48	45	53				
Avg Initial	49.0	47.4	47.8	50.6	49.0			
Avg Relaxed	48.4	46.6	47.0	50.0	48.3			

Required Bolt Pretension = 39 kips

Table C.7: Pretension Force in Kips for 1" Bolts(F1852/A325 Strength, F1852 Minimum Head Diameter)

	Hole Size in Plate							
Test #	1-1/16"	1-1/4"	1-5/16"	1-1/16" x 2-1/2"	1-3/16" x 1-9/16" OC			
1	60	60	65	58	58			
	59	59	64	57	57			
2	66	62	64	63	59			
2	64	61	63	62	58			
3	59	58	62	62	58			
Ŭ	58	57	61	61	57			
4	62	62	61	66	61			
-	61	61	60	65	60			
5	60	59	66	63				
5	59	58	65	62				
Avg Initial	61.4	60.2	63.6	62.4	59.0			
Avg Relaxed	60.2	59.2	62.6	61.4	58.0			
Required Bolt	Pretension =	51 kips						

Table C.8: Pretension Force in Kips for 1" Bolts(F1852/A325 Strength, Manufacturer's Standard Head Diameter)

			Hole Size in	Plate	
Test #	1-1/16"	1-1/4"	1-5/16"	1-1/16" x 2-1/2"	1-3/16" x 1-9/16" OC
1	60	70	63	54	57
'	59	69	62	53	56
2	71	63	66	60	60
2	69	62	65	59	59
3	62	67	74	65	55
3	61	66	72	64	54
4	67	61	67	60	58
-	66	60	66	59	57
5	66	56	57	57	
3	65	55	56	56	
Avg Initial	65.2	63.4	65.4	59.2	57.5
Avg Relaxed	64.0	62.4	64.2	58.2	56.5

Required Bolt Pretension = 51 kips

Table C.9: Pretension Force in Kips for 1-1/8" Bolts (F1852/A325 Strength, F1852 Minimum Head Diameter)

	Hole Size in Plate							
Test #	1-3/16"	1-7/16"	1-1/2"	1-3/16" x 2-13/16"	1-1/2" OC			
1	85	84	78	81	87			
	84	82	77	80	86			
2	82	83	74	85	85			
2	81	81	73	83	84			
3	79	81	84	77	84			
3	78	80	82	75	83			
4	79	82	79	78	90			
7	78	80	78	77	89			
5	77	82	79	81				
5	76	80	77	79				
Avg Initial	80.4	82.4	78.8	80.4	86.5			
Avg Relaxed	79.4	80.6	77.4	78.8	85.5			
Required Bolt	Pretension =	56 kips						

 Table C.10: Pretension Force in Kips for 1-1/8" Bolts

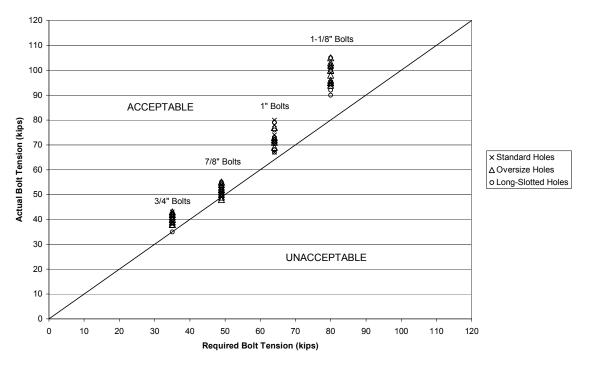
 (F1852/A325 Strength, Manufacturer's Standard Head Diameter)

	Hole Size in Plate							
Test #	1-3/16"	1-7/16"	1-1/2"	1-3/16" x 2-13/16"	1-1/2" OC			
1	79	80	77	79	78			
·	78	79	76	78	77			
2	80	81	85	78	84			
2	79	79	83	77	83			
3	82	76	77	81	79			
3	81	75	76	80	78			
4	78	81	75	83	86			
-	77	80	73	82	85			
5	78	79	78	79				
3	77	78	77	77				
Avg Initial	79.4	79.4	78.4	80.0	81.8			
Avg Relaxed	78.4	78.2	77.0	78.8	80.8			

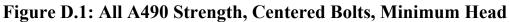
Required Bolt Pretension = 56 kips

APPENDIX D

TEST RESULTS FOR A490 STRENGTH BOLTS



All A490 Centered Bolts - F1852 Mimimum Head Diameter



All A490 Centered Bolts - Manufacturer's Standard Head Diameter

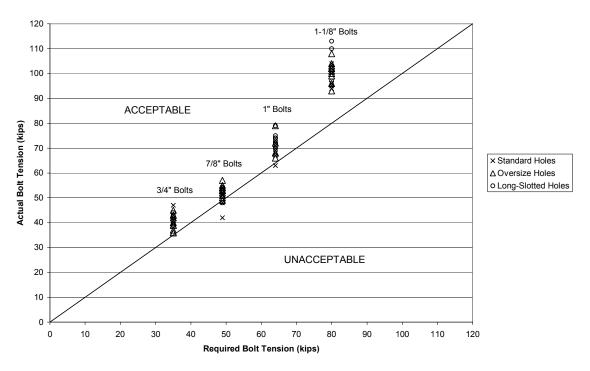
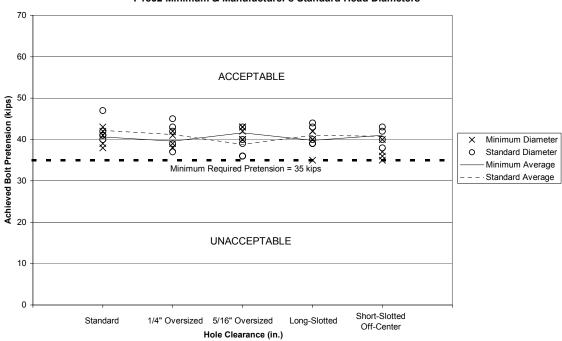


Figure D.2: All A490 Strength, Centered Bolts, Standard Head



All 3/4", A490 Centered & Off-Centered Bolts F1852 Minimum & Manufacturer's Standard Head Diameters

Figure D.3: Results for 3/4" A490 Strength, Centered & Off-Centered Bolts, Minimum & Standard Heads,

All 7/8", A490 Centered & Off-Centered Bolts F1852 Minimum & Manufacturer's Standard Head Diameters

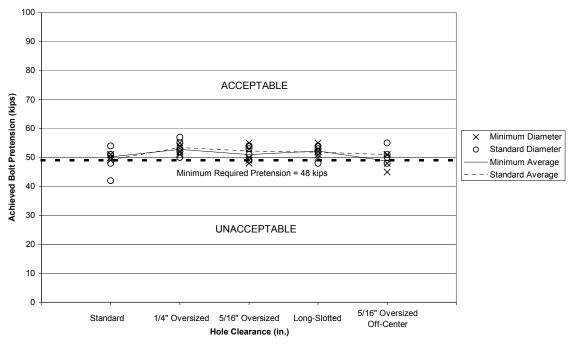
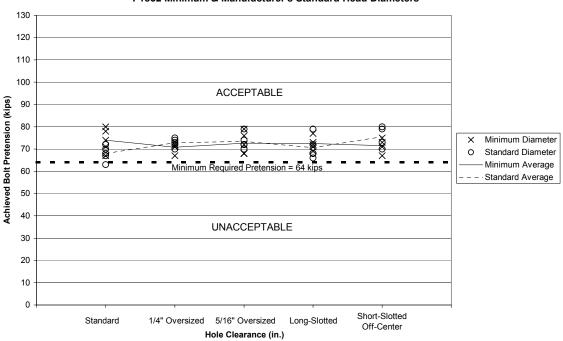


Figure D.4: Results for 7/8" A490 Strength, Centered & Off-Centered Bolts, Minimum & Standard Heads



All 1", A490 Centered & Off-Centered Bolts F1852 Minimum & Manufacturer's Standard Head Diameters

Figure D.5: Results for 1" A490 Strength, Centered & Off-Centered Bolts, Minimum & Standard Heads

All 1-1/8", A490 Centered & Off-Centered Bolts F1852 Minimum & Manufacturer's Standard Head Diameters

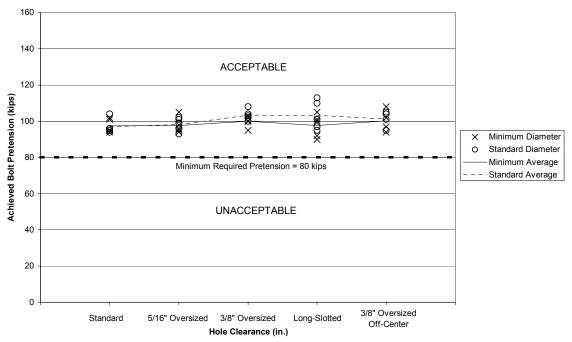


Figure D.6: Results for 1-1/8" A490 Strength, Centered & Off-Centered Bolts, Minimum & Standard Heads

			Hole Size in	Plate	
Test #	13/16"	1"	1-1/16"	13/16" x 1-7/8"	1-1/16" x 1-5/16" OC
1	39	39	40	35	44
·	39	38	40	35	44
2	42	38	44	42	40
2	42	38	43	42	39
3	44	42	41	41	42
3	43	42	40	40	42
4	39	41	42	42	40
4	38	41	42	42	39
5	42	39	44	41	
3	41	39	43	40	
Avg Initial	41.2	39.8	42.2	40.2	41.5
Avg Relaxed	40.6	39.6	41.6	39.8	41.0
Required Bolt	Pretension = 3	35 kips			

Table D.1: Pretension Force in Kips for 3/4" Bolts(A490 Strength, F1852 Minimum Head Diameter)

Table D.2: Pretension Force in Kips for 3/4" Bolts(A490 Strength, Manufacturer's Standard Head Diameter)

	Hole Size in Plate							
Test #	13/16"	1"	1-1/16"	13/16" x 1-7/8"	1-1/16" x 1-5/16" OC			
1	47	39	41	44	42			
•	47	39	40	43	42			
2	40	42	44	45	41			
2	40	42	43	44	40			
3	42	38	36	41	39			
3	42	37	36	40	38			
4	42	44	36	40	43			
-	41	43	36	39	43			
5	41	46	40	39				
3	41	45	39	39				
Avg Initial	42.4	41.8	39.4	41.8	41.3			
Avg Relaxed	42.2	41.2	38.8	41.0	40.8			

Required Bolt Pretension = 35 kips

	Hole Size in Plate					
Test #	15/16"	1-1/8"	1-3/16"	15/16" x 2-3/16"	1-3/16" OC	
1	52	53	50	55	46	
•	51	52	49	55	45	
2	50	52	54	52	52	
2	49	52	53	51	51	
3	52	52	50	51	49	
3	51	51	50	50	48	
4	51	55	49	54	51	
+	50	54	48	53	51	
5	51	56	56	53		
5	50	55	55	52		
Avg Initial	51.2	53.6	51.8	53.0	49.5	
Avg Relaxed	50.2	52.8	51.0	52.2	48.8	
Required Bolt	Pretension =	49 kips				

Table D.3: Pretension Force in Kips for 7/8" Bolts(A490 Strength, F1852 Minimum Head Diameter)

Table D.4: Pretension Force in Kips for 7/8" Bolts (A490 Strength, Manufacturer's Standard Head Diameter)

Test #	Hole Size in Plate					
	15/16"	1-1/8"	1-3/16"	15/16" x 2-3/16"	1-3/16" OC	
1	55	53	50	53	51	
•	54	52	49	52	51	
2	42 *	56	55	54	51	
2	42 *	55	54	53	50	
3	52	58	53	55	48	
	51	57	53	54	48	
4	51	54	51	49	56	
-	51	53	51	48	55	
5 -	49	51	54	53		
	48	50	54	52		
Avg Initial	51.8	54.4	52.6	52.8	51.5	
Avg Relaxed	51.0	53.4	52.2	51.8	51.0	

Required Bolt Pretension = 49 kips

*Excluded from Averages

			Hole Size in	Plate				
Test #	1-1/16"	1-1/4"	1-5/16"	1-1/16" x 2-1/2"	1-3/16" x 1-9/16" OC			
1	81	72	69	74	74			
•	80	71	68	73	73			
2	72	72	69	73	72			
2	71	71	68	72	71			
3 —	79	74	80	78	76			
	78	73	79	77	75			
4 –	75	68	77	72	68			
	74	67	76	71	67			
5 –	68	73	73	70				
	67	72	72	69				
Avg Initial	75.0	71.8	73.6	73.4	72.5			
Avg Relaxed	74.0	70.8	72.6	72.4	71.5			
Required Bolt	Pretension =	64 kips						

Table D.5: Pretension Force in Kips for 1" Bolts(A490 Strength, F1852 Minimum Head Diameter)

Table D.6: Pretension Force in Kips for 1" Bolts(A490 Strength, Manufacturer's Standard Head Diameter)

Test #	Hole Size in Plate						
	1-1/16"	1-1/4"	1-5/16"	1-1/16" x 2-1/2"	1-3/16" x 1-9/16" OC		
1	73	73	75	73	74		
•	72	72	74	72	73		
2	64	74	80	80	81		
2	63	73	79	79	80		
3 —	68	76	73	69	80		
	67	75	72	68	79		
4	69	75	73	67	71		
	68	74	72	66	70		
5 —	71	71	71	69			
	70	70	70	68			
Avg Initial	69.0	73.8	74.4	71.6	76.5		
Avg Relaxed	68.0	72.8	73.4	70.6	75.5		

Required Bolt Pretension = 64 kips

	Hole Size in Plate					
Test #	1-3/16"	1-7/16"	1-1/2"	1-3/16" x 2-13/16"	1-1/2" OC	
1	103	98	105	102	96	
	101	96	103	100	94	
2	96	96	102	107	104	
2	95	94	100	105	102	
3	96	97	104	103	110	
3	94	95	102	101	108	
4	103	107	102	92	99	
7	102	105	100	90	97	
5	96	100	97	94		
3	95	98	95	92		
Avg Initial	98.8	99.6	102.0	99.6	102.3	
Avg Relaxed	97.4	97.6	100.0	97.6	100.3	
Required Bolt	Pretension =	80 kips				

Table D.7: Pretension Force in Kips for 1-1/8" Bolts(A490 Strength, F1852 Minimum Head Diameter)

Table D.8: Pretension Force in Kips for 1-1/8" Bolts (A490 Strength, Manufacturer's Standard Head Diameter)

	Hole Size in Plate					
Test #	1-3/16"	1-7/16"	1-1/2"	1-3/16" x 2-13/16"	1-1/2" OC	
1	98	98	105	103	106	
•	96	96	104	101	105	
2	97	104	104	97	102	
2	96	102	102	95	101	
3 -	96	103	110	115	96	
	95	101	108	113	95	
4	96	100	104	112	105	
+	94	99	103	110	104	
5	106	95	102	99		
5	104	93	100	97		
Avg Initial	98.6	100.0	105.0	105.2	102.3	
Avg Relaxed	97.0	98.2	103.4	103.2	101.3	

Required Bolt Pretension = 80 kips

APPENDIX E

PHOTOS TAKEN DURING TESTING



Figure E.1: Rear View of Typical Skidmore Setup



Figure E.2: Manufacturer's Standard and F1852 Minimum Bolt Heads



Figure E.3: Tone Wrenches Used for Tightening



Figure E.4: Setup for 1" Bolt, A490 Strength, Off-Centered Test